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Natural Disasters

Edited by Sorin Cheval

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http://dx.doi.org/10.5772/1373
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First published in Croatia, 2012 by INTECH d.o.o.
eBook (PDF) Published by IN TECH d.o.o.
Place and year of publication of eBook (PDF): Rijeka, 2019.
IntechOpen is the global imprint of IN TECH d.o.o.
Printed in Croatia

Legal deposit, Croatia: National and University Library in Zagreb

Additional hard and PDF copies can be obtained from orders@intechopen.com

Natural Disasters
Edited by Sorin Cheval
p. cm.
ISBN 978-953-51-0188-8
eBook (PDF) ISBN 978-953-51-4968-2

Meet the editor

Dr Sorin Cheval, Ph. D., Senior Researcher, is the Scientific Director of the National Institute for Research and Development in Environmental Protection, Bucharest, Romania. Dr Sorin Cheval defended a Ph.D. thesis focused on natural hazards, elaborated within the Institute of Geography of the Romanian Academy (2004). He is a Fulbright Alumnus of the University of South Carolina (Hazard Research Lab).
Over 16 years of professional experience in the field of climatology and natural hazards, as well as publications in prestigious journals and books, contributions within international research projects tackling various geographical areas and diverse topics (extreme precipitations, urban heat islands, ecosystems vulnerability, climate change) and the evaluation activities for different international programmes and journals, advocate for his competencies in investigating very complex events like natural disasters.

Contents

Preface

The Earth environment derives from a unique combination of factors favouring the development of various landscapes and life forms. The activity of the meteorological, geophysical or hydrological factors is characterized by variations of different amplitudes and frequencies that can provoke severe disequilibrium to a given ecosystem. Disasters can arise anywhere at the crossroads between natural hazards and human society, as a combined result of the strength of extreme events and a fragile, unprepared community.

Natural disasters induce threats to well established, wealthy countries and emerging economies as well, even if with different damage costs and human tolls. The consequences depend on many-sided circumstances, including the characteristics of the phenomena and the capability of the environment and human society to cope with all phases of a disaster. Bearing in mind the complexity of problems as well as the obvious need for reducing the impact of natural disasters on communities and environment, the interest of the scientific world, authorities and administration, private stakeholders and large public has increased constantly in the last decades. Eventually, major natural disasters, such as the Indonesian tsunami (2004), the hurricane Katrina (2005) and the Haiti earthquake (2010), have contributed to raising the humankind awareness of the potential of natural hazards to impact dramatically our lives, assets and environment.

The book *Natural Disasters* compiles contributions approaching various facets of the natural disasters management, tackling diverse topics like regional policies and human rights, forecasting and mapping, in various geographical spots, and exploring different triggering hazards such as avalanches, tropical storms or hurricanes.

Claudio F. Szlafsztein depicts the natural disaster management in the states of Acre, Amazonas and Pará, a complex and sensitive Brazilian territory confronted with multi-hazards situations, both natural and technological. The considerations exposed in the chapter can be transferred to similar areas.

People with different disabilities are more exposed to the effects of a disaster. Janet Njelesani and her co-authors “introduce a human-rights based approach for meeting the needs of persons with disabilities in disaster management initiatives”, exposing further a case-study focused on the January 2010 earthquake in Haiti.

Hurricanes represent one of the most disaster-triggering hazards on the Earth, and therefore they have been studied intensively. Georgy Sergeyevich Golitsyn exposes a well-documented review of the physics of hurricanes, very useful for those interested in the profound understanding of the processes taking place inside a hurricane.

Two chapters of the book refer to tropical storms. The leading authors (Worachat Wannawong and Thomas Dekarski) cover case-studies from Thailand and Mexico, but they are far from being of local interest only. The complexity of situations presented and proposed perspectives pledge for a much more extended utility of the studies.

In close connection with tropical storms, coastal floods are described in a manner of interest for practitioners and for people interested in theory or techniques used in hazard investigations. Dean B. Gesch approaches a precise topic, namely the role of elevation in assessing the coastal inundations, reflected by circumstances from the U.S. Atlantic Coast. An interesting connection with the IPCC Sea-Level Rise Scenarios completes the chapter.

Peter Höller presents a well-documented chronology of hazard awareness, with examples from the Alps and North America, emphasizing the disaster prospective and the significance of keeping a vigilant awareness.

Obviously, a book will never cover in-depth and comprehensively the aspects related to natural disasters. There are many other hazards potentially triggering disasters, and there are multiple facets that should be considered, including the genesis and the behaviour of the phenomena, its contact with society, the forecast and the management of consequences, the social and economic context. While wording these lines, a very harsh winter is under deploying in Europe, and demonstrates again the limits of our societies to natural threats. Hopefully, the book will be beneficial to those who invest their efforts in building communities resilient to natural disasters.

15 February 2012

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1

Natural Disaster Management in the Brazilian Amazon: An Analysis of the States of Acre, Amazonas and Pará

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1. Introduction

For many years, the Amazon region of Brazil has been considered to be territory immune from the threat of serious natural disasters. However, in recent years, extreme natural events, increasingly more recurrent and intense, have manifested both in rural and urban areas in the region. Consequently, this territory has been exposed to the impacts of several technological and natural hazards, mostly associated with droughts, floods, and fires and soil, fluvial, and coastal erosion.

A disaster is associated with natural hazardous frequency, recurrence, and magnitude with regard to the exposed population and infrastructures' vulnerability. In the Brazilian Amazon, these disasters negatively impact a region whose development already presents many unresolved problems, with particular regard to the economic and environmental activities of the most vulnerable people (e.g., the poor in urban areas and subsistence farming communities). It is expected that the situation will worsen, considering the forecasted scenarios of more prevalent and more intense use of the forests and the increasing occupation of the cities, as well as the intensification of climate change in the Amazon region. In this sense, a big challenge corresponding to the response to these scenarios is to develop and implement risk management policies, strategies, and measures that can address the regional peculiarities.

In Brazil, most of the natural disaster historical record, the academic researches, and the risk management strategies and measures are focused on the most densely populated and developed regions of the country – the Northeast, the South, and the Southeast. The scarce studies associated with this issue in the Amazon region are neither integrated nor systematic and are poorly disseminated within and outside of Brazil (Marcelino et al., 2006; Leal and Souza, 2011). Brown et al. (2001) describe and analyze the unique case study of governmental responses to natural disasters (drought and forest fires) in the Amazon region, in particular with the set up of a "situation room" in order to facilitate the flow of information and coordinate among government institutions on the extreme events of 2005 and 2010 (Lewis et al., 2011; Marengo et al., 2011; Brown et al., 2006).

This book chapter aims to describe and analyze the particularities of risk management in the Amazon region, principally in the states of Acre, Amazon, and Pará. In this way, considering the possibility of understanding to what the natural risk management really integrates the governmental policies, this research seeks answers to the following key questions: What are the rules that drive risk management in Brazil and particularly in the Amazon region? Who is responsible for executing the projects and programs and for implementing and enforcing the laws that drive risk management in the Amazon region? What financial resources are available for risk management in the Amazon region of Brazil?

2. Some initial considerations

Considering the different variables that correspond to the risk management issues in the Amazon region, some initial reflections should be established in order to develop better studies and analyses.

The Brazilian Amazon region is a heterogeneous territory divided into 6 states and 310 municipalities. According to the Brazilian Institute of Geography and Census (IBGE, 2011), the Amazon region occupies an area of 3.575.951 km², representing approximately 40% of Brazil and, its population of 14.481.009 inhabitants an 8% of the total population of the country. Although the intense activities natural resources exploration, yet 62% of the area maintain its forest original cover, and around 20% is already impacted. Many of the forests and traditional villages are protected by conservation units (around 390) and indigenous

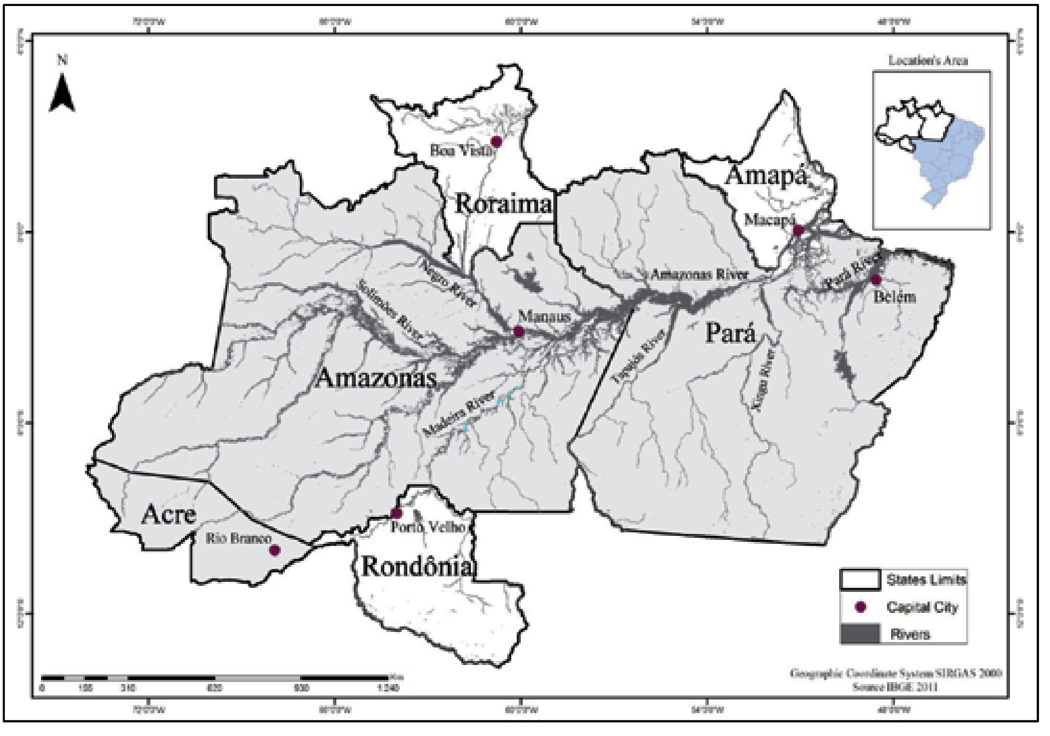

Fig. 1. The Amazon region of Brazil. The study area is concentrated in the states of Acre, Amazonas and Pará (highlighted).

reservations covering almost 30% of the territory of the region. Along with its forests and biodiversity, the region concentrates enormous mineral resources and it has become, since the 1980s, in the latest agricultural frontier of Brazil (figure 1).

The main risks in the Amazon region are caused by natural and social hazards, with the technological hazards in a few urban areas (e.g., Barcarena, Belém and Manaus). Among the first, floods and drought of the main rivers are described with recurrent consequences in urban areas (e.g., Rio Branco, Manaus), in the Western region of the State of Acre and small towns at the margins of the Amazonas, Tocantins and Xingu Rivers. To a lesser extent, strong whirlwind, localized processes of fluvial erosion, and seismicity reflection of Andean tectonic conditions also could be depicted. Social risks are mainly related to the extensive and intense process of deforestation. Natural or social forests burning risk shows the simultaneous loss of biodiversity and infrastructure in areas of close proximity to road systems (Szlafsztein, 2003; Eger and Aquino, 2006; Maia et al., 2008) (figure 2).

Fig. 2. Population living in natural risk prone areas in urban areas of the Amazon region. Left - Mass movement in Novo Repartimento (state of Pará), and right – Flood in Parauapebas (state of Pará).

Since the time of colonialism, the Amazon region has been a territory where both government-incentivized and spontaneous migrations have been justified mainly by geopolitical theories of "territorial occupation" as well as by mining of the region's natural resources (e.g., forests and minerals) (Rodrigues et al., 2009). This exploit has supported much of the growth of the different regions of Brazil, leaving a series of issues still unresolved with regard to the Amazon region development and, as a consequence, a growing social vulnerability to natural hazards.

This is very evident in certain areas of the Amazon region. The existence of large "demographic empty spaces" (e.g., population density in Amazonas State is 2 inhab./km^2) concentrates the majority of natural disaster records in regional metropolitan areas (e.g., Belem and Manaus), which are home to around 70% of the State's total population (IBGE, 2011). This population, looking for a better life condition, migrates from rural areas and quickly and disorderly occupies marginal areas that lack basic urban services (e.g., sanitation) and are naturally hazard prone (Padoch et al., 2008).

Some socioeconomic characteristics can be used as indicators of the difficult living conditions that intensify population vulnerability in urban areas of the Amazon region. More than 80% of the municipalities present a life expectancy and a rent per capita underneath the national average, and near 50% of the states have more than 65% of its municipalities showing an alphabetization index greater than the Brazilian average. In the Amazon region predominates the inexistence of collecting nets of sanitary sewers, and when collected, they are poorly treated. The variables of house quality in the region also indicate many problems, considering its constructive precariousness, the absence of bathrooms, the density of inhabitants per residence, and the access to electric energy (PNUD, IDHS/PUC minas, UFPA 2007; Freitas and Giatti, 2009).

Risk management, from the point of view of academic and governmental action, has been focused in the Southeast (where mass movements and urban floods are common) and Northeast regions (where chronic drought is an issue). In the Amazon region, the described causes of extreme natural events as well as the disaster response strategies and measures are clearly influenced by cultural and religious aspects.

Finally, a clear legal definition of the government's responsibilities (Federal, State and Municipal) and the trend of the strengthening of the local powers were established in the Federal Constitution of 1988 (Lobo, 1988). However, there are enormous difficulties associated with plainly separating the policies and actions of the various levels of government in the Amazon region.

3. The risk management legal framework in the Amazon region

Brazilian environmental legislation is profuse and detailed, showing a constant evolution since the 1980s. In the Brazilian legal system, the supreme norm since 1988 has been the Federal Constitution. However, the states and municipalities have authority, albeit limited, to organize and govern themselves by their own constitutions and laws (Bastos and Martins, 1997). Often, in order to complement the risk management legal framework at the state level, it is necessary to observe some of the main legislative acts at the federal level.

Issue	STATES		
	ACRE	AMAZONAS	PARA
Sustainable Development	Law 1117/94 - Environmental Policy	Law 2985/05 - State Council of Environment	Law 6213/99 - Executive Secretary of Urban and regional Development
	Decree 2027/00 – State council forsustainable rural development		Law 6345/00 - Fund for the sustainable development of the State
	Law 1460/02 - Traditional and small agricultures communities support program		Law 5887/95, 6671/04, 6745/05 - Environmental State Policy
	Law 1478/03 - Institute for Forest Protection		Law 7026/07 – Organization of the State Secretary of Science, Technology and Environment
	Law 1492/03 - Indigenous state council, Fund for indigenous development		
	Law 1693/05 - Agro forestry center program		
Territorial Zoning	Decree 265/93 - Agro ecologic and Economic – Zoning Program	Law Mai 2007 - State System of Conservation Units	Law 6506/02 – Methodology for the Ecologic and Economic Zoning
	Decree 503/99; 1904/07 - State Program of Ecologic and Economic Zoning		
	Law 1373/01 - State Institute of Land		Law 6745/05 - Ecologic and Economic Macro-zoning of the State
	Law 1426/01 and 1548/04 - State System of Conservation Units, State Forest Council and Fund		
Risk Management	Decree 507/98 - Committee to Combat and Prevent the Forest Fires		Law 5731/92 – Organize the Firefighters Corps Decree 3036/98 - Create the Committee to Combat and Prevent the Forest Fires
Climate Change	Law 2808 /10 – State System of Environmental Services (SISA)	*Law 3135/07 – State Policy of Climate Change, Environmental Conservation and Sustainable Development*	
Water Resources	Law 1500/03; 1596/04 - State Policy of water resources and create the State System of Water Resources Management	Law 2712/01; 2940/04 - State System of Water Resources Management	Law 5630/90 – Norms for the preservation of the water resources
			Law 6381/01 – State Policy of water resources and create the State System of Water Resources Management

Table 1. Main regulatory instruments at the State of Acre, Amazonas and Pará related with Sustainable Development, Territorial Zoning, Risk Management, Climate Change and Water Resources issues. Source: http://www4.planalto.gov.br/legislacao

The constitutions establish that the three levels have joint competence, among other things, regarding environment protection and preservation, in harmony with sustainable development. Only the constitutions specifically refer to the actions and responsibilities in the case of calamities; other legal instruments do not or only poorly consider risk management as a key element in the contexts of land use and water resources regulation, sustainable development, and climate change. Noteworthy is the wide range of legal instruments, which indirectly assist to mitigate the current risk impacts and/or prevent the potential ones, reducing vulnerability factors (table 1).

The Federal Constitution guarantees, as one of the so-called “social rights,” the protection of life and patrimony, in the face of the possibility of natural disasters. Also it determines that is competence of the federal government to "plan and to promote permanent defense against the public calamities, especially droughts and floods," and to “legislate on territorial defense, aerospace defense, marine defense, *civil defense* and national mobilization" (Brasil, 1991).

The State has the responsibility of providing public security and social protection in order to, among other things, supply relief and assistance to the population in case of calamities. The police and the military firefighter’s corps are the institutions that share the following tasks: the preservation and restoration of public order; forest fire prevention and fighting; and the planning, coordination and implementation of civil defense activities.

The declaration of calamity situations allows the government to hire works, provide services, and make purchases and disposals without the due bidding process, opening extraordinary loans to meet urgent and unforeseeable expenses, to occupy and to use temporarily public/private goods and services and, in a particular case, transfer the capital city of Acre.

In cases of imminent and serious risk to human life or important infrastructures, the government is authorized to determine whether emergency measures and activities may be reduced or restricted in the affected areas during a critical period. In Pará, it prohibited the installation of energy power units and human settlements in tectonically active and ecologically fragile regions, mass movement or flood-prone areas, and landfill areas with material harmful to public health.

It should be noted that many legal aspects, not analyzed here, integrate a range of legal instruments which, although not acting directly on risk management, assist to reduce the current and/or potential risks, mainly the vulnerability factors.

Territory planning policies are established as instruments of vulnerabilities reduction. The state’s systems of conservation units are implemented in order to contribute to the maintenance, restoration, and protection of biodiversity and hydrological processes; sustainable development promotion; the improvement of the local population’s quality of life; environmental services assessment; and GHG storage. On the other hand, the states establish the Ecological Economic Zoning (EEZ). The EEZ is a strategic instrument of territorial planning and management, whose procedure and criteria consider physical, biotic and socio-economic potential and limitations of the landscape and guide public policies focused on sustainable socio-economic development and the promotion of the population’s well being.

The water resources policy in the three States aims to ensure the water resources availability through integrated and rational exploitation and the reforestation and protection of the river basins. In particular, it has the purpose of promoting the prevention of and providing protection against extreme hydrological events, defining flood prone areas, as well as creating and operating hydro-meteorological monitoring and early warning systems. It stands out in this policy that in critical situations of drought and flood, the priority is water consumption by human and domestic animals, and to that effect, it is possible to definitively or temporarily suspend, restrict or revoke the right of groundwater use.

Policies on climate change exist only in the states of Acre and Amazonas. They aim to identify and inventory GHG emissions; stimulate regional models of sustainable development; promote and regulate clean development mechanisms and environmental education; establish certification seals; mitigate the adverse effects of climate change; establish new conservation units, and particularly, set up indicators that identify areas of high vulnerability to climate change.

4. The risk management institutional framework in the Amazon region

Successful risk management depends on the integrated action of various governmental institutions and society (Raschky, 2008). The Federative Republic of Brazil is formed by the indissoluble union of States, Municipalities and the Federal District, and the government is divided into independent but complementary legislature, judiciary, and executive powers.

Considering the remarkable breadth of emergency response to natural disasters, the preservation or prompt re-establishment of public order or social peace threatened by major natural disasters is described as one of the several responsibilities of the Executive power. However, it is possible to act in anticipation, to avoid a generation of new vulnerabilities or hazards (preventive measures) and to reduce the existing ones (mitigation measures).

The description and analysis of the institutional framework concentrate on the direct administration ministries and secretariats in Brazil, particularly in the states of the Amazon region.

At the federal level, most of the programs linked to risk management are implemented by the following ministries: Science and Technology (Inter-ministerial Commission of Global Climate Change); Agriculture (Agricultural Zoning for Climate Risk); Agrarian Development, National Integration (prevention, preparedness and response to emergencies and disasters); Cities (municipal master plans); Environment, Water Resources, and Amazonia (protected conservation units) and the institutions that comprise the National System of Civil Defense (SINDEC).

The SINDEC (Federal Decrees 97274/88, 895/93, 5375/05, 7257/10) is regulated through a multi-level structure, in which each level has its own objectives and activities. The SINDEC has to plan and promote the permanent defense against natural or man-made disasters, to act in disaster situation, to prevent or minimize damages, to help and to attend to affected populations and to recover areas. Actions after a disaster at SINDEC begin following governmental approval and declaration of Emergency Situation (the legal recognition of the existence of an abnormal condition caused by a disaster with tolerable damage to the community) or a State of Public Calamity (declared when the disaster has caused serious damage to the community, affecting the safety and life of the population) (Cerri Neto, 2007).

Figure 3 describes the complex schema established by the SINDEC that allows the recognition of an "Emergency Situation" or a "Public Calamity State" at different governmental levels. At the local level, the Municipal Commission of Civil Defense (COMDEC) or in its absence, the population, after a field recognition in the affected areas sends the "Disasters Notification - Preliminary Report" (NOPRED) to the Municipal Prefect's knowledge. After studying the severity of the region, the prefect can decree an "Emergency Situation" or a "Public Calamity State" in the region. This municipal decree only has significance if the Governor of the state homologates it. In order for this to happen, the affected municipality should send the governor, within 12 hours, the NOPRED and the

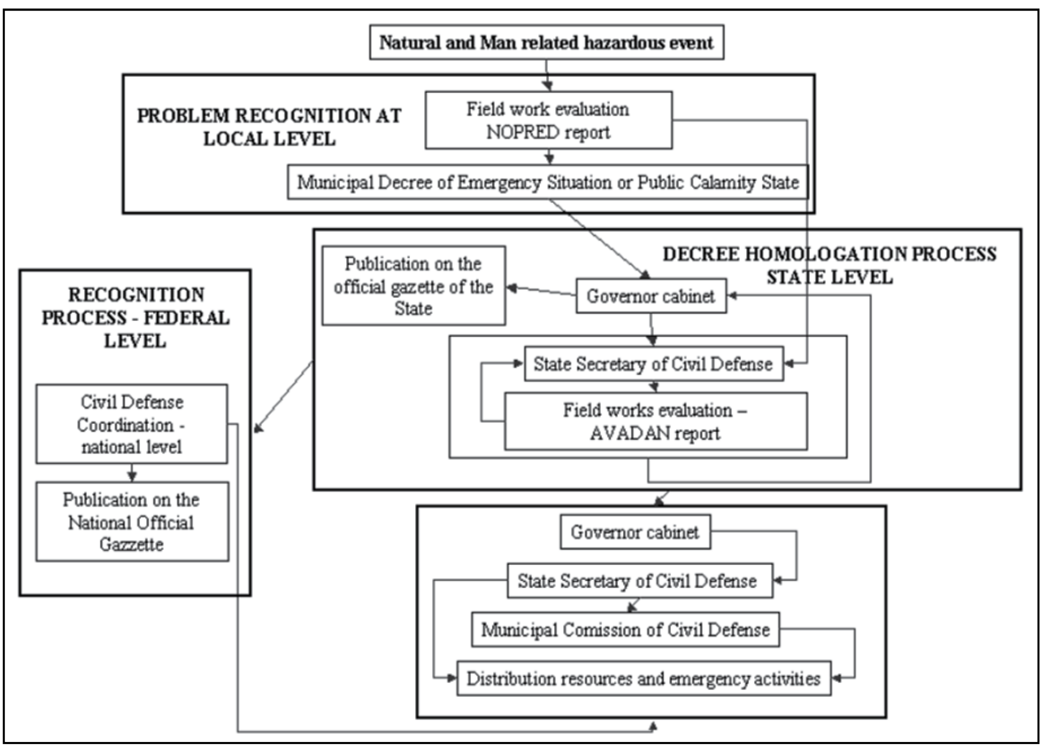

Fig. 3. Schematic diagram indicating the proceeding form of SINDEC once a natural or man-made disaster happens (modified from Szlafsztein, 2003).

"Emergency Situation" or the "Public Calamity State" decrees. The Governor then instructs the Civil Defense Coordination of the State (CEDEC) to check the damages described in the municipal ordinance. Within five days, the "Impact Assessment Report" (AVADAN) has to indicate the severity of the situation and to advise the Governor on the issue of homologation. Given the severity, the ordinance is published in the Official Gazette of the State (Szlafsztein, 2003).

The States' Civil Defense Systems have similar structures to those described with regard to SINDEC. As a result, many of the institutional goals and responsibilities at the federal level can be relatively easily assigned to similar institutions at the state and municipal levels.

This paper considers that the institutional structure for risk management encompasses all agencies or institutions related to the prevention, mitigation and response, applied research and risk monitoring. In Brazil, these functions are dispersed among various institutions. In this sense, the institutional structures of the states governments are classified according to the type of relationship to risk management (thematic, temporal, skills and activities) (table 2). The information presented is the result of a comparison with the structure of SINDEC, data obtained during visits to some of the institutions, and the interviews.

Type of Relation	Class	Description
Thematic	Direct	The objectives of the programs, projects and institutional actions have a direct and/or explicit link with risk management
	Non-Direct	The objectives of the programs, projects and institutional actions do not have a direct and/or explicit link with risk management
	Non-Existent	Non-existent: no clear relationship with risk management
Temporal	Before the Disaster	Prevention, Mitigation
	After the Disaster	Emergency response and rehabilitation
Capabilities and Activities	Survey of Basic Information and Diagnostic	Survey of environmental, historical disaster, natural hazards, and vulnerability information
	Formulation and Approval	Develop, propose and approve the plans, policies, and risk management strategies
	Implementation and Control	Implement and ensure the effectiveness of proposed actions

Table 2. Proposed classification of the state's institutional structure according to the type of risk management relationship.

A simple analysis of the type/degree of the relationship of the various components of the institutional State's structures (41 Acre, 35 Amazonas, 66 Pará) indicate that most of them have some relationship with risk management. In particular, there is a large proportion of institutions that have or say they have, a direct relationship in the States of Amazonas and Acre (Figure 4). Considering the temporal relationship with respect to the occurrence of a hazardous event (Figure 5), the predominance of activities performed after the occurrence of the disaster (sometimes the same institution has, or says to have activities before and after the event) stands out. The government institutions have been classified according to their

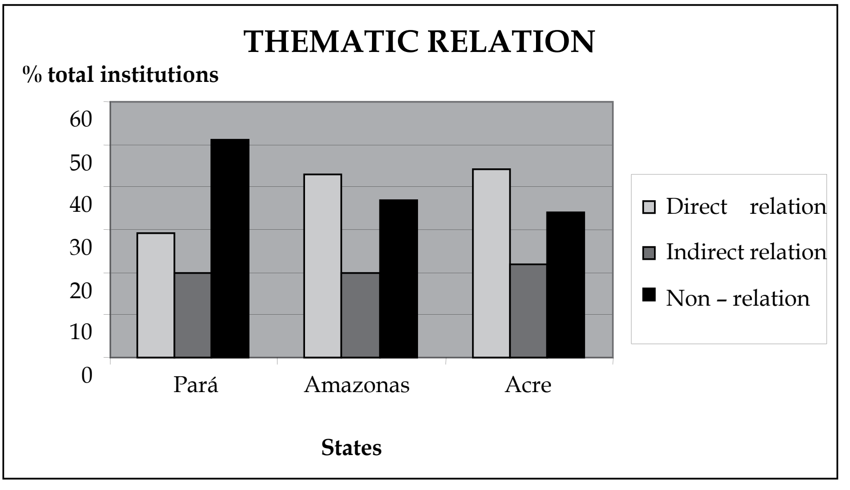

Fig. 4. Classification of government institutions in the States of Amazonas, Acre and Pará according to their relation with the risk management process.

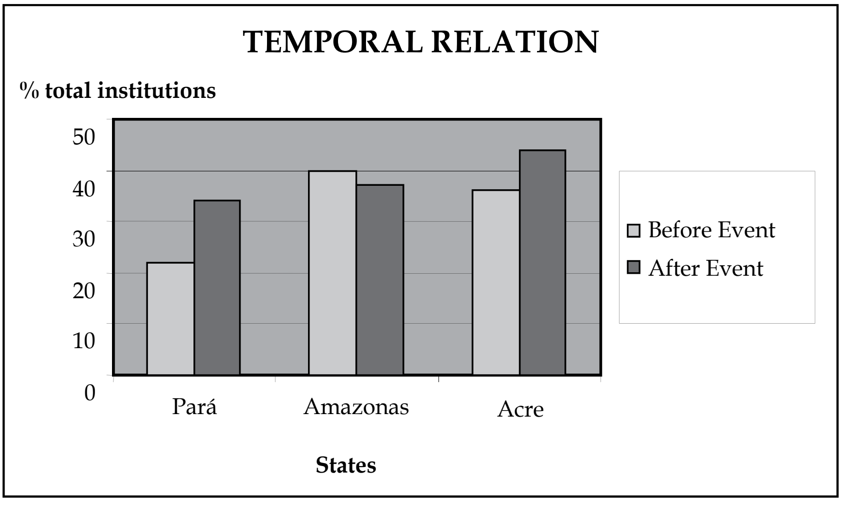

Fig. 5. Classification of government institutions in the States of Amazonas, Acre, and Pará according to their temporal relation to the occurrence of the disaster in the risk management process.

competences and activities in the risk management process (sometimes the same institution has, or claims to have more than one activity in the risk management process). *Surveys of basic information and diagnostic* are the activities less mentioned and the *implementation and control of policies and strategies* the most pointed out (Figure 6).

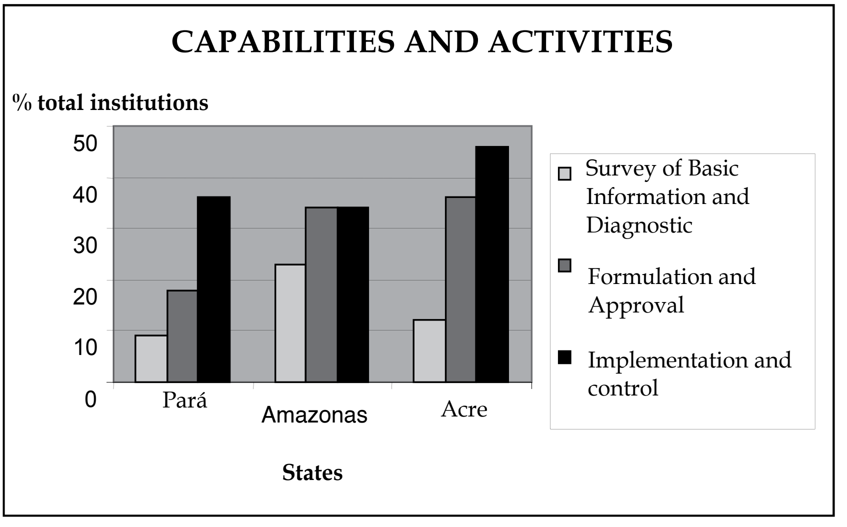

Fig. 6. Classification of government institutions in the States of Amazonas, Acre and Pará according to their capabilities and activities in the risk management process.

5. The risk management financial framework in the Amazon region

The review of the financial framework in order to know the financial capacity of the institutions in charge of risk management actions describes and analyzes the proportion of resources, their availability, and the mechanism procedures for the execution of prevention, mitigation emergency response activities (Ghesquiere and Mahul, 2010).

Government funding, particularly of the Union, in the case of emergency and disaster situations has been highlighted in all of the constitutions, since the 1891 Constitution of Brazil.

Since 1969, a Special Fund for Public Disasters (FUNCAP) has existed at the federal level in order to support reconstruction actions in areas affected by the disaster. The States set up special environmental funds for the implementation of their environmental policy. Amazonas established (a) *The climate change, environmental conservation and sustainable development fund* for combating poverty and encouraging the reduction of deforestation; the management of public forests and conservation units; reforestation and recovery of degraded areas; climate change and environmental research, education and technical training and support for sustainable production chains; and (b) *The water resources fund* to finance state water resources policies through, among other means, the implementation of programs concerning protection against dangerous and critical events and by supporting the operation and expansion of a hydro-meteorological network and water quality monitoring. The *Housing fund* in Acre was established to ensure the implementation of programs regarding the construction and improvement of low-income population housing and the removal of residents from risk prone areas.

The scarce or nonexistent monetary resources in the funds require the concentration of the financing for the implementation of governmental risk management policies, strategies and measures in ordinary and extraordinary budgets at the federal and state levels. The ordinary budgets of the Environment secretary and the fire department do not exceed 1% of the general state budgets, and typically do not use more than 70% of this value (Brasil, 2011). An extraordinary budget is created only to meet urgent and unforeseeable expenses, such as those arising from public calamity.

However, these resources are not sufficient to achieve of their goals. Consequently, it is frequently necessary to find other funding sources to complement the risk management activities. Among these additional sources are those that: (1) seek to decrease the possibility of a public calamity; (2) share the costs among affected people through insurance contracts, and finally, (3) allow the delegation of emergency assistance tasks to non-governmental organizations and other institutions.

With regard to the first group, a detailed analysis of the state budget shows the allocation of financial resources for the structural measures of risk management (e.g., actions against drought through irrigation works and water storage or the construction of flood control measures) and the non-structural measures (e.g., development in space and atmosphere science and in data collection satellites, the deployment of state groups and the modernization of the systems for monitoring climate and hydrology, and the impacts of climate change and vulnerability).

Concerning the second group, private insurance has been revealed as a valid financial alternative, which may be appropriate and effective for the treatment of natural risk, limiting the support of assistance and recovery actions to the people affected and insurance institutions. In Brazil, the National System of Private Insurance (Decree Law 73/66) is composed of several types of coverage. One of them is the protection against the impacts arising from natural dangerous events called “Multirisk.” This is a special coverage that already includes different and, sometimes, new types of insurance, such as the protection of buildings and their contents against "external" source damages (e.g., natural floods hazards, earthquakes and seismicity, high winds and storms) (Funenseg, 1998).

Concerning third group, the emergency assistance from national and international non-governmental organizations, focuses (i) on the collection of funds in cash and supplies, as well as (ii) on emergency assistance for affected populations (Strömberg, 2007). Many of these institutions, even those of foreign origin, have shown outstanding performance in the country and receive financial assistance from uni/multilateral cooperation agencies (e.g., United States of America – USAID, UN Office for the Coordination of Humanitarian Affairs – OCHA; United Nations Disaster Assessment and Coordination - UNDAC) and religious organizations (e.g., Red Cross).

Table 3 summarizes the various aspects of financing risk management policies and actions in Brazil and in the Amazonian states and an analysis of the beneficial and limiting factors of these mechanisms, considering the legal and institutional framework.

Framework	Mechanisms for financing risk management	Beneficial factors	Limiting factors
Legal	Reserve funds (emergency resources)	Incipient spreading at the state and municipal levels. Quick availability of resources	Having no financial resources. Unknown among risk managers
	Ordinary budgets for disaster prevention and attention	The constitutional requirement for supporting the Civil Defense System	Scarce budgetary resources and non-application of the resources
	Extraordinary budgets for disaster prevention and attention	The constitutional requirement for emergency response in case of a public calamity	High dependence on external factors, such as economic and political context
	Insurance, Reinsurance	Form of social distribution for the response and rehabilitation costs	Lack of major market broadcast. Little culture of forecasting and prevention. Low local population socioeconomic development
	Aid (local, national, international)	Affected population quickly accessesthe financial and material resources for relief	High dependence on external factors, such as economic and political environment
Institutional	Federal Government	The largest ordinary and extraordinary budgets for risk management	Available only with the approval of a great rating of the emergency and calamity states
	State Government	Moderate ordinary and extraordinary budgets for risk management	Available only with the approval of at least a moderate rating of the emergency and calamity states
	Municipal Government	Proximity to the areas and populations affected	Few or no budgetary risk management resources
	Countries and multilateral organizations	Available resources and their own mechanisms for risk management financing	Complex administrative procedures for the receipt of aid
	NGOs		Complex processes for the receipt of aid. Social and political distrust

Table 3. Beneficial and limiting factors of the existing mechanisms for financing risk management at the state level in the Amazon region.

6. Decision making suggestions

Managers and qualified technical staff from the various secretaries and institutions at the state level (Table 4) were interviewed. They were asked the following main questions: What is your institution's participation in the risk management activities, with particular considerations to the prevention, response, and mitigation steps? What are the main challenges (e.g., institutional, technical, budgetary, and regulatory) facing the state and preventing a better risk management performance? What importance do you assign to the territorial planning, water resources management, and climate change aspects in the risk management of natural disasters? How are they implemented by your institution?

<table>
<tr><th rowspan="2">ISSUE</th><th colspan="3">STATE'S INSTITUTIONS</th></tr>
<tr><th>ACRE</th><th>AMAZONAS</th><th>PARÁ</th></tr>
<tr><td>Environment</td><td>Environment Institute of Acre (IMAC); State Secretary of Environment (SEMA)</td><td>Environment Protection Institute (IPAAM); State Secretary of Environment and Sustainable Development (SDS)</td><td>State Secretary of Environment (SEMA)</td></tr>
<tr><td>Civil Protection</td><td colspan="3">State Civil Defense Coordination</td></tr>
<tr><td>Development Planning</td><td rowspan="2">State Secretary of Economic Sustainable Planning and Development (SEPLANDS)</td><td>Sustainable Development Agency of Amazonas (ADS)</td><td>State Secretary of Strategic Projects (SEPE)</td></tr>
<tr><td>Economy</td><td>State Secretary of Economic Planning and Development (SEPLAN)</td><td>State Secretary of Planning and Budget (SEPOF)</td></tr>
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Table 4. The institutions visited in order to interview managers and technical staff.

The answers given by the managers of the institutions of the state governments were classified into the following two groups: *problems faced* and *solutions implemented in risk management*.

The challenges and obstacles of the risk management in the states of the Amazon region include the following:

a. *Lack of natural risk perception:* Risks have always been considered to be elements of natural origin, and society was regarded to have no influence on their causes or in the mitigation of their impacts. State governments clearly still do not understand that it is an important cross-cutting issue across policies and actions, nor do they comprehend its direct influence on the regional sustainable development.
b. *The diminutive importance of the global climate change issue:* Global climate change is still not considered to be a priority issue on the government's agendas. When considered, its role as a potential generator of opportunities (e.g., carbon market) is highlighted and not the impacts and consequences of these changes, nor its function as a key element in the present and future development models.
c. *New territorial management projects*: Territorial management, on the various levels, is extremely new yet already has quantifiable results and an easy interpretation and use by government and society. Also, it generally does not incorporate the theme of natural hazards in its conception nor its methodology.

d. *The importance of Civil Defense in risk management coordination:* Risk management currently presents a significant lack of inter-institutional coordination within the government and with NGOs. The role of the Civil Defense is considered to be a priority when risk management instigates actions as part of an emergency response after a disaster. However, this institution does not actively participate in the coordination, elaboration and implementation of prevention actions related to environmental management and spatial organization.
e. *Scarce resources:* The state's budget allocations both directly and indirectly regarding risk management are scarce; furthermore most of the programs and actions depend on financing by international cooperation and from federal government transfers. This situation creates remarkable degree of risk management vulnerability as seen in the threat of temporal discontinuity, the states' acceptance of strategies and activities not adapted to a local reality, few and/or not well functioning structures, and disinterested or uninformed administrators and staff.
f. *Lack of risk data and information:* The state does not have systematic or available information, including representative maps (in both quantity and quality), with respect to risks issues (hazard and vulnerability).
g. *Institutional problems:* A deficient number or poorly structured government institutions related to environment and civil defense issues have been installed outside the capital cities causing (i) the increased oversight of local activities by central bodies, (ii) the concentration of risk management activities and the responsibility of these bodies being based in metropolitan regions and (iii) mitigation activities being made a greater priority than planning and prevention.

The following are among the currently implemented solutions in risk management in the states of the Amazon region:

a. *On the development model:* Since 2000, the states of the region have intended to gradually transform the natural resource extractive practices and income concentration into a still incipient policy of prioritizing natural resources processing and greater income distribution. This change is one of the best ways to decrease the vulnerability of the population.
b. *On the state policy on climate change:* The states of the Amazon region were some of the first in Brazil to established a law addressing climate change issues, introducing, among other things, financial mechanisms (e.g., State climate fund, environmental conservation, sustainable development and forest grant programs), educational programs on climate and environmental monitoring and protection, as well as research centers and discussion (State climate change center).
c. *On institutional structure:* In the Secretaries of the Environment, some changes are related to the establishment of new departments overseeing climate change issues have been seen, as well as an increase in the number of planning issues activities (prevention and preparation), and the delegation of the responsibilities of fiscalization, monitoring, and licensing in other institutions.
d. *On the partnerships:* The Civil Defense department has begun the process of establishing and strengthening partnerships (Geological Service, Universities, Remote sensing research institutes, etc.) that are considered strategic, mainly in order to increase the availability of information and the implementation of the capacity building process.

7. Final considerations

The Amazon region presents a new frontier for natural disaster issues. Larger and more frequent hazards (natural, technological, and social), better record, the dissemination of journalistic information and more in-depth scientific studies are occurring simultaneously alongside a rapid population increase, demographic concentrations in a few metropolitan areas, the occupation of risk-prone areas, unwise land use practices, low socioeconomic development indices, and the uncertainties of the effects of global climate change in the region.

Given the results, the final considerations are presented and discussed here, along with the main challenges to be faced by risk management offices in the coming years in the Amazon region.

One of the main challenges is to keep the natural risks issue on the agendas of both mainstream society and the governments independent of the occurrence of a major natural disaster. When large magnitude events do occur, they permeate formal and informal communication channels that could be used also in "normal" situations.

On the other hand, it is essential to strengthen the strategies and activities to be undertaken before the occurrence of a disaster in the Amazon. There is a general recognition of the importance of the prevention and the preparation processes for risk management. However, in practice, most actions focus on the so-called "response" to the disaster. The climate policy of the State of Amazonas (law 07/3135) is the only one to refer to the principles of Prevention (adoption of measures that help to prevent climate change) and Precautionary (procedures that, even in the absence of scientific certainty, predict damage, as a guarantee against potential risks).

Transforming issues from emergency and security policies to include prevention is not an easy task, especially in the Amazon region, where:

a. The broad risk management concept is not yet fully understood by all public managers, with a great discrepancy of ideas between the states and the secretariats of each of those states;
b. The risk management issue is not considered by the governments to be a priority in the creation of social and economic development policies, possibly on the basis of considering the greater "visibility" of other governmental policies and measures, the unpredictability of disaster occurrence, the poor prevention culture existing in society, and the non-existence of success indicators for evaluation and presentation of risk management strategies and actions;
c. Civil defense public employees do not feel motivated to be proactive due to their low salaries and, sometimes, precarious working conditions (e.g., few employees, overseeing of several activities), limiting the response to demands received;
d. There is not "pressure" for carrying out prevention activities because the society recognizes disasters as cultural and religious events and, at a high frequency, turns them into landscape "chronic" issues. In many opportunities, society is adapted or resigned to the impacts. On the other hand, the outage or delays in socioeconomic development of large rural areas of the Amazon region because of the occurrence of disasters, particularly in riverside communities of flood-prone areas, do not have a

large impact on (macro) state development indices or are translated into social pressure (NGOs, journalism, etc.); and

e. In large urban areas, the risk issue is of greater visibility. However, its complexity lies in the many and various stakeholders and the absence of a public authority in certain (dangerous) regions making the implementation, monitoring and enforcement of the law difficult.

The state constitutions specifically refer to actions and responsibilities in case of calamities. However, the states' environmental legislation does not or only poorly considers the various types of risks and their management as decisive factors in the classification and organization of land use and water resources. Moreover, most of the state laws have not been regulated, despite having been adopted long ago. Regulated or not, there is also an enormous difficulty of implementing them, possibly due to a lack of coordination between government agencies, a lack of resources (financial and human) and infrastructure, political and economic pressures, and a cultural norm of people only accepting the rules when they agree with them or benefit from them.

The risk management institutional framework in states of the Amazon region shows no characteristics unique from other governance processes (e.g., reduced budgets, scarce qualified personnel, the overlay or "gaps" of responsibilities and tasks, programs lacking continuity). In particular, risk management seeks an institutional structure of high technical level, including multidisciplinary approaches and working methods, and with administrative flexibility and autonomy for decision-making.

However in the Amazon region another institutional framework is observed. Several institutions express enthusiastic interest with respect to risk issues and recognize different degrees of relationship to them. But supported by the power delegation established in the State and Federal constitutions, they associate the responsibility of risk management within the governmental structure to the civil defense coordination. In this sense, improving and strengthening the existing structures of civil defense and other government bodies to actually incorporate in risk management is believed necessary.

To strengthen the governmental structures of civil defense, the following are proposed:

a. Train employees on issues related to the consequences of climate change and the planning of prevention, mitigation and adaptation measures.
b. Encourage the understanding of the risks with regard to climate change scenarios through the production of knowledge in several themes and in particular geographic regions that are still not very well known.
c. Redefine the relationship of subordination of the State Civil Defense departments to the Military Firefighters Corps. This relationship enables a binding budget dependency, the existence of rigid structures and institutional regulations, a common association made by society concerning the goals of civil and the purpose of the Fire Department, limitations on the employment of "civil" technical staff in the corps, and non-participation in environmental and territorial planning projects.

The States have the legal autonomy to determine their territorial planning and their own security. However, up to the present time, the federal Government becomes a key element, considering the lack of resources and information at State level and the numerous exclusive federal. Currently, risk management in the states cannot be made without coordination on the federal scale.

There is no need to devise new mechanism in order to implement risk management at municipal level: they already exist. On the one hand, the Civil Defense system already has created numerous municipal departments but not yet in all municipalities, since its creation and maintenance depend largely on political desire and the municipal financial resources. What is seen in those that are already created is that few are structured and many lack staff and/or equipment, are temporary, and only develop emergency responses at the time of the disaster. On the other hand, the municipal government needs to strengthen its institutions and take on the responsibilities of elaborating and implementing territorial zoning in order, for example, to have the capacity to supervise and monitor of land occupation.

As the liaison with the federal level, a municipal risk management must be considered. The large territory, the temporary or permanent difficulties accessing some distant regions from large urban centers, and the lack of financial resources and qualified personnel have become major obstacles to the states' successful risk management.

The knowledge of the environment (physical, biological, socioeconomic, political, etc.) is one of the most important inputs for the management of the environment, the territory and the risk. However, in the Amazon region, primary data gathering, systemization, and dissemination provision are still very incipient. Much has been advanced in recent years on spatial low-resolution scales, but huge territories and themes still have not been analyzed either by the Academy, governmental bodies or NGOs. In this sense, in order to generate knowledge to support decision-making, the following are proposed: (a) encourage and strengthen the institutional partnerships of the civil defense agencies with others organizations that can collaborate with information, data processing, personnel and technical infrastructure, and (b) create a scientific research institute to look into risk management issues in the Amazon region, as referenced in the Center for Disasters Studies and Research (Federal University of Santa Catarina) in Florianopolis (SC) and the National Institute of Spatial Research (INPE) in Santa Maria (RS), both in the southern region of Brazil.

One of the most important obstacles to risks management is the lack of mechanisms for receiving and spending financial resources in situations of *imminent* risk. Establishing action, strategies and measures (and the associated resources costs) with respect to an event that may or may not happen is very difficult for the government. For this reason, the government must establish subsidies that allow for decision-making, with should include, among other things, a better definition (conceptual and temporal) of the risk situations of imminent hazard and high levels of vulnerability of a population or infrastructure concerning a particular threat, and the peculiarities of regional diversity.

The mechanisms to financing risk management activities, at all levels, prove the status quo for the release of financial resources after the occurrence of the disaster, particularly to assist the relief efforts of the affected communities. Scarce resources lead to numerous strategies and measures that depend on numerous factors to be employed (e.g., economic and political circumstances at the national and international levels, the goodwill of donors, the subjective assessment of disaster severity and other existing priorities). Extraordinary credits clearly represent a lack of foresight by the authority's complacency with the inevitable economic and administrative benefits of the approval of emergency situations and Public Calamity States. As a result, it is believed to be necessary to create mechanisms that would definitely strengthen and modify already existing funds (e.g., new sources of money, such as the lottery), as well as create new ones (e.g., states' and municipal funds). All these proposals seek to "break a vicious circle" (Calamity – "desperate" demand of resources for emergency assistance – lack of resources and the consequent deficiency in prevention activities – new calamity).

After analyzing this risk management scenario in the Amazon, it is believed that many of the changes and propositions can possibly be applied in so far as a clear tendency to strengthen the process of popular participation and instrument of social control over the projects and their actions can be seen in the region.

8. Acknowledgement

This document is originated as part of a project of the German International Cooperation GIZ in Brazil. Financial support is gratefully acknowledged.

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2

Using a Human Rights-Based Approach to Disability in Disaster Management Initiatives

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1. Introduction

1.1 Prevalence and incidence of disability

Worldwide, 15% of the global population, an estimated 1 billion people are living with a disability (World Health Organization (WHO), 2011). While the prevalence of disability is higher in high-income countries, due to increased survival and longevity, the incidence of disability is higher in low and middle-income countries. Therefore, the majority of the world's people with disabilities live in low and middle-income countries (WHO, 2011).

1.2 Defining disability

In congruence with the United Nations (UN) Convention on the Rights of Persons with Disabilities (CRPD), within this chapter disability will refer to "long-term physical, mental, intellectual or sensory impairments, which in interaction with various barriers may hinder people's full and effective participation in society on an equal basis with others" (CRPD, 2006). This broad definition appeals to a social model of disability that emerged in the 1980s as an alternative to earlier charity-based and medical models that conceptualized disability as an individual problem. The social model, and the World Health Organization's bio-psychosocial model of disability (demonstrated in Figure 1) reflect how people are disabled through stigmatizing social interactions, environmental barriers and other social phenomena.

The bio-psychosocial model of disability demonstrates how it is a combination of physical, environmental and personal factors that can affect participation. This means that people with different impairments (sensory, physical, intellectual, cognitive, etc.) will experience varying degrees of disability based on their social and environmental contexts. Therefore, what is considered a disability can vary across different geographic and cultural contexts. For example, in East Africa people with albinism face extreme cultural prejudices and due to this social alienation their organizations belong to the disability movement in countries such as Tanzania. Whereas in Canada people with albinism may not consider themselves disabled unless they acquire a visual impairment.

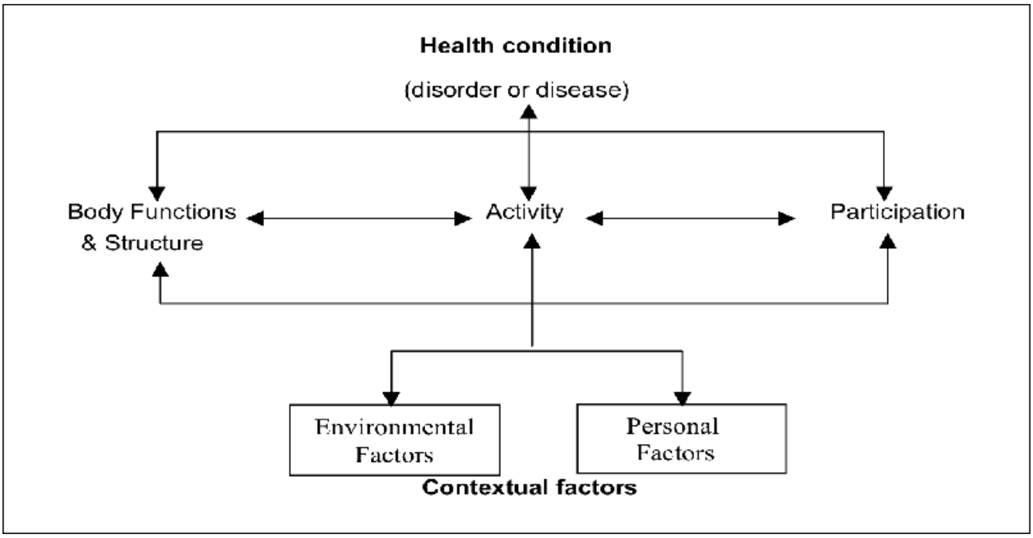

Fig. 1. The bio-psychosocial model of disability (WHO, 2001)

1.3 Disability in the context of natural disasters

Disability issues need to be considered in all natural disasters, not only because of the global prevalence of disability but also because of the effects of natural disasters on individuals, families and communities.

1.3.1 Different groups of people with disabilities arise in disaster situations

People with newly acquired injuries and impairments. If a person's injuries are not treated properly they can develop into impairments, such as bone fractures that are not followed up. Disasters (particularly earthquakes) also often result in many people acquiring permanent impairments, such as amputations and spinal cord injuries, as seen in Haiti where approximately 200 000 people are expected to live with disabilities as a result of their injuries from the earthquake in 2010 (United Nations Enable, n.d). This group of people are often the first to be targeted and treated post-disaster.

People with pre-existing disabilities. During natural disasters persons with disabilities not only suffer the same impact of the disaster as the general population but also are less able to cope with the deterioration of their environment as a result of socio-economic conditions, empowerment and access to resources (United Nations Enable, n.d). Additionally, persons with disabilities suffer particularly high rates of mortality and morbidity in disasters partially as a result of being less able to flee or find protection, or from being left behind or abandoned during evacuation. These instances result due to a lack of prevention and planning, and inaccessible services and transportation (United Nations Enable, n.d). Persons with disabilities also experience greater loss of autonomy following disasters. For example, people with mobility impairments who are able to flee may subsequently become more dependent because mobility aids were left behind.

People with pre-existing impairments. People with certain impairments may have not found their condition to be particularly disabling prior to a disaster; but, if infrastructure is destroyed or mobility or communication aids lost (or destroyed) during the disaster, then a previously relatively benign impairment may become severely disabling. Similarly, people with chronic diseases (such as diabetes, epilepsy and HIV) conditions can deteriorate if their access to medication is interrupted.

> "Persons with disabilities are doubly vulnerable to disasters, both on account of impairments and poverty; yet they are often ignored or excluded at all levels of disaster preparedness, mitigation and intervention." (International Federation of Red Cross and Red Crescent Societies [IFRC], 2007)

1.4 Considering human rights in addressing disability in disaster management initiatives

1.4.1 Human rights approach to disability

Where persons with disabilities have been poorly supported in the past, during times of disaster existing unequal power distributions, discrimination and inequality are exacerbated (SPHERE, 2011) putting persons with disabilities at greater risk of being denied their basic rights. Failure to recognize the rights of persons with disabilities and the barriers they face in gaining access to disaster management initiatives can result in further marginalization and denial of vital assistance. For example, persons with disabilities tend to be invisible to emergency registration systems. They are frequently left unregistered, which means that they fail to receive their basic entitlements to food, water and clothing. Furthermore, the assumption cannot be made that provisions made to the public will reach persons with disabilities, or that people will automatically have equitable access to whatever is made available. There are many reasons why people fail to receive their entitlements including: they may be hidden by their families; they may not know about services because they cannot attend community meetings due to physical inaccessibility; they cannot hear radio announcements; or they may not be able to access services due to poor terrain or lack of mobility aids. Despite that many of the services that persons with disabilities need in emergencies are no different from other peoples' needs, it is important to recognize that persons with disabilities may have some specific needs. For example, it can be harder for people with physical impairments to keep warm due to lack of movement and poor circulation, so they may have an increased need for warmer clothing or blankets.

The human rights approach to disability reflects a paradigm shift in attitudes and approaches to persons with disabilities, in the direction of the social model of disability described above. It is a shift in focus from a person's limitations arising from impairments, to the barriers within society that prevent the person from having access to basic social services and from enjoying her or his rights. The human rights approach to disability moves from the treatment of persons with disabilities as objects of charity, medical treatment and social protection, towards viewing persons with disabilities as people with rights who are capable of claiming those rights and making decisions for their lives based on their free and informed consent, as well as being active members of society. This moving away from equating inclusion as a charitable act, drives the approach to be inspired by the promotion of human rights that benefits the entire population of a country and provides a clear statement of a government's commitment to all its citizens and to the principles of good governance. In the context of disaster management, looking from this perspective has the benefit of not only improving access to quality services, but also increasing participation in decision making and creating public awareness and demand.

Disability is a human rights issue because:

- People with disabilities experience inequalities – for example, when they are denied equal access to health care, employment, education, or political participation because of their disability.
- People with disabilities are subject to violations of dignity – for example, when they are subjected to violence, abuse, prejudice, or disrespect because of their disability.
- Some people with disability are denied autonomy – for example, when they are subjected to involuntary sterilization, or when they are confined in institutions against their will, or when they are regarded as legally incompetent because of their disability.

(WHO World Report on Disability, 2011, pp. 9)

1.4.2 Recognition of persons with disabilities rights in disaster management initiatives

While disability equality issues have historically been marginalized they are increasingly referenced in disaster evaluation and practice development (SPHERE, 2011). Following the 2004 tsunami in Asia, major relief organizations and international non-governmental organizations (NGOs) commissioned disability audits in their post-tsunami evaluations resulting in recognition of the rights of persons with disabilities in natural disasters by the international community. Disability specific working groups have since been incorporated into the United Nations cluster coordination system and disability issues were included in the 2011 edition of the SPHERE guidelines. The SPHERE guidelines set out what people affected by disasters have a right to expect from humanitarian assistance. They are based on the principles and provisions of international humanitarian, human rights and refugee law and point out that disability is an important crosscutting issue that needs to be addressed by all those involved. They include minimum standards for non-discrimination and specific reference to strategies for persons with disabilities in each chapter (SPHERE, 2011).

1.4.3 The Convention on the Rights of Persons with Disabilities

The Convention on the Rights of Persons with Disabilities is a human rights instrument with an explicit social development dimension. It adopts a broad categorization of persons with disabilities and reaffirms that all persons with all types of disabilities must enjoy all human rights and fundamental freedoms. It clarifies and describes how all categories of rights apply to persons with disabilities and identifies areas where adaptations have to be made for persons with disabilities to effectively exercise their rights and areas where the protection of their rights must be reinforced. By the end of 2011, 108 countries have ratified the CRPD, but the inclusion of persons with disabilities during natural disaster management initiatives remains highly inadequate. This is demonstrated by the fact that the response to the specific rights of persons with disabilities is often postponed or disregarded as most agencies fail to adequately plan for or include persons with disabilities in their disaster preparedness or response plans. The lack of inclusion causes severe inequities in access to services for people who had a disability prior to the disaster and also those who acquire a disability as a result of the disaster.

In order for the rights of persons with disabilities to be meet in disaster management initiatives, it is necessary to propose direct and practical solutions. These solutions must include persons with disabilities, their families and communities as well as Disabled Persons' Organisations at every stage. Human rights-based approaches are often considered to be approaches that only lawyers are capable of as they may appear to be too obscure for people without human rights training to actually engage with; however, the CRPD offers a framework for addressing the rights of persons with disabilities that can be broken down into practical tips for putting a rights-based approach into action. Therefore, the aim of this chapter is to introduce a human rights-based approach for meeting the needs of persons with disabilities in disaster management initiatives and to present practical strategies for operationalizing this approach. Following this introduction, part 2 of this chapter introduces a human rights-based approach to disability. Part 3 uses the cases of the January 2010 earthquake in Haiti and Hurricane Katrina in the United States in 2005 to illustrate how the dimensions of a human rights-based approach play out in real-world situations. Finally, in part 4, practical strategies for addressing the rights of persons with disabilities in disaster management initiatives are presented.

2. Using a human rights-based approach to promote the inclusion of persons with disabilities in disaster management initiatives

A human rights based approach includes explicitly including human rights into programs. Using a rights-based approach focuses on the way initiatives are undertaken and also the outcomes (Klasing, Moses & Satterthwaite, 2011). "A rights-based approach is set apart from others in that it draws on the existing legal framework of human rights, which codifies relationships between rights-holders—those individuals and groups with valid claims and legal entitlements— and duty-bearers, those with correlative obligations to those claims or legal entitlements" (Klasing, Moses & Satterthwaite, 2011, pp. 11). The overall role of a rights based approach is to strengthen the opportunities for rights-holders to claim their rights and the capacity of duty-bearers to respond to such claims and fulfill rights.

There are nine core international human rights treaties (see Figure 2), which can guide the way disaster management initiatives are undertaken. These human rights instruments all reinforce the rights of persons with disabilities, because the principle of non-discrimination is a fundamental part of all international human rights instruments, thus guaranteeing their relevance to persons with disabilities.

Despite the inclusion of persons with disabilities in all of the treaties and the fact that the CRPD contains neither new human rights nor new disability rights, the CRPD was chosen as the focus of this chapter as it is the only disability specific convention and as such shapes the existing set of general human rights to the specific situation of people with disabilities and also because it provides disability specific references.

1. International Convention on the Elimination of All Forms of Racial Discrimination (in force January 4, 1969)
2. International Covenant on Civil and Political Rights (in force March 23, 1976)
3. International Covenant on Economic, Social and Cultural Rights (in force January 3, 1976)
4. Convention on the Elimination of All Forms of Discrimination against Women (in force September 3, 1981)
5. Convention against Torture and Other Cruel, Inhuman or Degrading Treatment or Punishment (in force June 26, 1987)
6. Convention on the Rights of the Child (in force September 2, 1990)
7. International Convention on the Protection of the Rights of All Migrant Workers and Members of Their Families (in force July 1, 2003)
8. Convention on the Rights of Persons with Disabilities (in force May 3, 2008)
9. International Convention for the Protection of All Persons from Enforced Disappearance (in force December 23, 2010)

Fig. 2. The nine core international human rights treaties

The Convention on the Rights of Persons with Disabilities is a universal, legally binding standard that was adopted in 2006 and entered into force in international law in 2008. The purpose of the Convention on the Rights of Persons with Disabilities is "to promote, protect and ensure the full and equal enjoyment of all human rights and fundamental freedoms by all persons with disabilities, and to promote respect for their inherent dignity" (CRPD, 2006). Member States that have signed the Convention agree to promote, protect and ensure the full and equal enjoyment of the human rights of persons with disabilities and prompt respect for their inherent dignity. The Convention provides a moral compass for state actors, as the primary guarantors of rights; however, in some circumstance including the weakening of a state following a natural disaster, non-state actors (e.g., NGOs) may respond and take on some of the state's obligations. Non-state actors may take on these obligations in efforts to ensure the provision of services and to prevent further suffering caused by the disaster (Klasing, Moses & Satterthwaite, 2011). The Convention also explicitly underpins disability work for United Nations organizations (e.g., World Health Organization, UNICEF) and many international organizations (e.g., CBM International, Handicap International [HI]). The Convention covers a number of key areas such as accessibility, personal mobility, health, education, employment, habilitation and rehabilitation, participation in political life, and equality and non-discrimination. Specifically to natural disasters, Article 11 of the CRPD embeds, into international law, the need for measures for the "protection and safety of persons with disabilities in situations of risk, including situations of armed conflict, humanitarian emergencies and the occurrence of natural disasters".

There are eight guiding principles that underlie the CRPD (see Figure 3). These are articulated in the text of the Convention in order to guide the interpretation and implementation of the rights enshrined by the Convention. The principles offer a rationale and clarity to why and how the CRPD should and can be used. They provide a guide for stakeholders to consciously include the rights of persons with disabilities in disaster management initiatives and as such are identified and discussed below and also underlie the strategies identified in section 4.0 of this chapter.

1. Respect for inherent dignity, individual autonomy including the freedom to make one's own choices, and independence of persons
2. Non-discrimination
3. Full and effective participation and inclusion in society
4. Respect for difference and acceptance of persons with disabilities as part of human diversity and humanity
5. Equality of opportunity
6. Accessibility
7. Equality between men and women
8. Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities

Fig. 3. Guiding principles that underlie the CRPD (CRPD, 2006)

2.1 Respect for inherent dignity, individual autonomy including the freedom to make one's own choices, and independence of persons

The first principle recognizes the rights and agency of persons with disabilities. It emphasizes that rather than simply seeing people with disabilities as passive victims of assistance, people have the right and thus need to be involved. When applied to natural disasters, this principle emphasizes the involvement of persons with disabilities and disabled peoples organizations in disaster management initiatives. When persons with disabilities are included in leadership roles not only are disaster management initiatives improved in the short-term, but their involvement also helps to avoid rights violations in future occurring disasters.

2.2 Non-discrimination

Non-discrimination means treating people fairly without prejudice. The principle of non-discrimination is fundamental to all human rights instruments and includes acts of both direct and indirect discrimination. Persons with disabilities must not be denied access to emergency evacuation, shelter, food aid, non-food items, health care and other services integral to the disaster response. It is also important to take steps to ensure equity within groups of persons with disabilities: that persons with disabilities are not discriminated against on the basis of race, gender, religion, impairment, or other classifications. Too often persons with disabilities are portrayed as a homogenous group, which obscures the diversity between people with disabilities. This phenomenon has been noticed within other marginalized groups, as is evident in the quote from Amartya Sen, below.

The most common example of ways in which discrimination can occur in disability-focused interventions is that, in trying to reach persons with disabilities, project implementers may fail to recognize the gendered dimensions of service uptake and although men with disabilities may receive the services they need, women with disabilities due to gendered dimensions of resource distribution may not receive the necessary services (see Guiding Principle 2.7).

> "A small peasant and a landless laborer may both be poor, but their fortunes are not tied together. In understanding the proneness to starvation of either we have to view them not as members of the huge army of the 'poor', but as members of particular classes, belonging to particular occupational groups, having different endowments, being governed by rather different entitlement relations. The category of the poor is not merely inadequate for evaluative exercises and a nuisance for causal analysis, it can also have distorting effects on policy matters" (Sen, 1981, pp.3).

2.3 Full and effective participation and inclusion in society

Full and effective participation and inclusion in society is recognized in the Convention as a general principle (Article 3), a general obligation (Article 4) and a right (Articles 29 and 30). Participation is important to correctly identify specific needs as decisions made about persons with disabilities are better informed and more likely to produce positive outcomes if they are involved in the process. Participation and inclusion also empowers individuals, as persons with disabilities with no voice are vulnerable to abuse, violence and exploitation, since they have no means of challenging this oppression. Through participation the needs and concerns of persons with disabilities become clearer, and persons with disabilities have the opportunity to raise issues and hold decision makers accountable. Through inclusion, persons with disabilities become more visible and persons without disabilities have the opportunity to learn and change from the experience of persons with disabilities – and vice-versa.

2.4 Respect for difference and acceptance of persons with disabilities as part of human diversity and humanity

Disability is an intrinsic part of life and impairments do not always need to or should be "fixed" or rehabilitated. Programs must meet people where they are, through designing programs to accommodate varying abilities, rather than expecting people (and their bodies) to conform to a certain norm. Often this norm is attainable to few people beyond young, non-disabled men. Programs that address the rights of persons with disabilities will benefit a range of people beyond those labeled as disabled, such as pregnant women, young children and the elderly.

2.5 Equality of opportunity

Even though people with certain disabilities may not be able to conduct certain tasks as a result of their physical or intellectual impairments, they should still be afforded with every opportunity to participate in society. Accommodations should be made to ensure that they have opportunities to go to school or attend informal educational opportunities, to participate in daily social life and practice the religion of their choice.

2.6 Accessibility

Accessibility appears both as a general principle (Article 3) as well as a stand-alone article (Article 9). Accessibility is essential to enable persons with disabilities to live independently and participate fully in life – it is therefore an outcome as well as a means to the realization of rights. Within the CRPD accessibility includes not only the accessibility of the physical environment but also accessibility to transport, communication and information in urban and rural areas.

2.7 Equality between men and women

"Women living in post-disaster situations are at daily risk of physical, emotional, economic and social harm in ways that have no direct parallels for their male counterparts" (Davis & Bookey, 2011, pp. 2). While disability correlates with disadvantage, not all people with disabilities are equally disadvantaged. Women with disabilities experience the combined disadvantages associated with gender as well as disability (WHO, 2011). Evidence suggests that women are more likely than men to become disabled during their lives due to access to fewer resources, receiving less medical attention when ill and getting less preventative care and immunizations. Data compiled in the World Report on Disability demonstrates the larger of burden of disability amongst women as compared to men in both low and high-income countries, although the difference is even greater in low-income countries (WHO, 2011).

2.8 Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities

Children with disabilities are especially vulnerable following natural disasters. They are often the first to be abandoned by families and the last to receive relief and support (UNICEF, 2007). Several factors that increase the vulnerability of children following natural disasters include the collapse of social infrastructure, inequitable access to social services, absence of law and order, and loss of autonomy resulting in dependence on others due to disruption of communities and families.

3. Using a human rights-based approach to examine disaster management initiatives: The cases of Haiti and the United States

3.1 Haiti earthquake of 2010

On January 12, 2010 at 4:45 pm (local time) an earthquake measuring 7 on the Richter scale hit Haiti. The epicenter of the most violent earthquake in 200 years in Haiti was located 14 kilometers from the capital city of Port-au-Prince. This disaster drew attention to the rights of persons with disabilities in disaster response efforts, especially due to the number of new amputations and injuries. Before the earthquake, it was estimated that between 500 000 to 800 000 Haitians were living with a disability (PAHO, 2010). It is estimated that as a result of the earthquake there were 300 000 new injuries, with approximately 1500 people with amputations, hundreds of thousands with fractures and close to 200 people with spinal cord injuries (O'Connell et al., 2010). In addition to physical injuries, post quake, there was a high incidence of post-traumatic stress disorder, psychosis and hysterical paralysis (Phillips, 2011). The earthquake caused the destruction and damage of over 300 00 homes, the majority of government and ministerial buildings and a large number of hospitals and health centers (Government of the Republic of Haiti, 2010).

In 2009, Haiti signed and ratified the CRPD. Other initiatives supporting the rights of persons with disabilities that were in place prior to the earthquake included the Secretariat of State for the Integration of Persons with Disabilities in Haiti (SEIPH) under the Ministry

Fig. 4. The earthquake in Haiti caused significant damage to buildings in Port-au-Prince (UN, 2010)

of Social Affairs and Labor, which advocated for the rights of persons with disabilities and inclusive programming. Nonetheless, the pre-existing challenges of implementing rights-based approaches in Haiti (Klasing, Moses, & Satterthwaite, 2011) and the further weakening of the state following the earthquake and its resultant of loss of personnel and infrastructure created a situation where the government alone was not equipped to address all of the rights for persons with disabilities in Haiti. Despite the numerous challenges, there are also many examples of success of how the rights of persons with disabilities were met following the 2010 earthquake in a place where resources were limited and in which logistical and security constraints placed severe limitations on what could be achieved. Opportunities also arose out of the disaster, as the devastation of infrastructure in Haiti created an opportunity through the reconstruction process for the rights of persons with disabilities to be met. Not only did reconstruction offer an opportunity for the building of accessible communities but also an opportunity to facilitate social and economic integration.

3.2 Hurricane Katrina 2005

Hurricane Katrina of the 2005 Atlantic hurricane season was one of the five deadliest hurricanes in the history of the United States (Knabb, Rhome & Brown, 2006). Destruction from the hurricane occurred all over the Gulf Coast, but the most significant number of deaths occurred in Louisiana, as eighty percent of the city was submerged (United States Congress, 2006). When the hurricane arrived in Louisiana, over 350,000 families were living with a member with a disability (US Census Bureau, 2000). While there are no concrete estimates of how many people with disabilities died as a result of Hurricane Katrina, 71 percent of the 1,330 victims were older than 60, suggesting people living with disabilities suffered disproportionately (White House, 2006). Furthermore, as indicated in the report that assessed the impact of Hurricane Katrina on persons with disabilities by White et. al (2007), "every person interviewed lost their residence and household belongings, while over half lost items that significantly affected their independence for weeks or even months after the storm. These included such things as vehicles, durable medical equipment, or accessible housing. Many also lost the family or social networks that sustained them" (p. 12). Despite the United States having the Americans with Disabilities Act (ADA), which requires emergency preparedness and response programs to be accessible to people with disabilities and the fact that most of the states had emergency shelters and designated transportation providers allocated throughout, the losses occurred because the services were not significantly coordinated to maximize evacuation of residents with disabilities (White et al, 2007) and many local emergency management offices did not have appropriate plans in place to account for the needs of person with disabilities.

Fig. 5. The potential needs of people using mobility devices in times of disasters were not significantly considered (USA TechGuide, 2011).

Examining the disaster management initiatives of the 2010 Haiti earthquake and the 2005 Hurricane Katrina through the lens of a human rights-based approach, using the principles of the CRPD as a guide, reveals lessons that can be applied to future disaster management initiatives.

3.3 Respect for inherent dignity, individual autonomy including the freedom to make one's own choices, and independence of persons

3.3.1 Disabled persons organizations possess knowledge and expertise that is vital to the inclusion of persons with disabilities in disaster response. Following both disasters, there existed not only a lack of coordination between disaster response organizations and disabled persons organizations but also a lack of involvement of persons living with disabilities. The participation of persons with disabilities and disabled persons organizations is not only crucial but is also an obligation as cited in Article 4 of the CRPD, "decision-making processes concerning issues relating to persons with disabilities, States Parties shall closely consult with and actively involve persons with disabilities, … through their representative organizations" (CRPD, 2006).

3.4 Non-discrimination

3.4.1 The needs of people with different disabilities should have been more widely considered. For example, many people will experience emotional and behavioral reactions following a natural disaster and disasters can also exacerbate pre-exiting vulnerabilities (Eustache et al., 2010). Despite the high incidence of post-traumatic stress disorder, psychosis and hysterical paralysis following the earthquake in Haiti, fewer services existed for people with psychological health conditions than those for people with physical impairments as government mental health services in Haiti were limited to two mental hospitals located in the West Department and the Ministry of Health and Population did not have any mental health units at general hospitals (PAHO, 2010). Furthermore, the specific needs of people with cognitive conditions and who were dependent on their caregivers but were separated from their caregivers as in the case in the United States or their caregivers were injured or killed as was commonly seen in Haiti were not widely addressed.

3.4.2 In regards to access to services, Haiti had few rehabilitation professionals of its own prior to the earthquake with disability and rehabilitation knowledge to address rights of persons with disabilities. Rehabilitation professionals are regarded as [one of the types of] professionals who are well equipped to help persons with disabilities and access to rehabilitation is considered a right according to Article 26 of the CRPD. The lack of rehabilitation providers was due to many factors including the absence of any rehabilitation professional training programs in higher education institutions and the lack of a nation-wide system for rehabilitative care. Of the Haitian rehabilitation providers that were working in country, training in disaster response was limited. From international rehabilitation actors, over 27 organizations provided specialized services for people with disabilities following the earthquake during the period from January through November 2010. Assistive device distribution to persons with disabilities included over 1 800 artificial limbs, 2 000 braces, 4 500 wheelchairs and nearly 10 000 walking aids. Over 23 000 people received physical therapy and nearly 37 000 received counseling (Eitel, 2011).

3.4.3 The evacuation plans for Hurricane Katrina often required a person being able to walk, drive, see or hear, and therefore many plans were not appropriate for people living with disabilities. For example, most evacuation buses did not have wheelchair lifts. Furthermore, when evacuated, persons with disabilities were often evacuated without their medicine, medical equipment, wheelchairs or guide animals. Most people in the United States received emergency information about the storm from the television; therefore, effective communication may not have been available to people with sensory disabilities. “Without closed captioning or sign language interpretations of the televised emergency information, people with hearing disabilities often remained unaware of the scope or nature of the emergency. Moreover, effective communication was troublesome for people with visual impairments because television broadcasts typically did not provide audio descriptions of visual displays of critical information, such as maps or lists of affected areas” (Emergency Management, 2006, p. 4-5).

3.4.4 Persons with disabilities were not entirely included in mainstream rescue and evacuation services, relief access, safe location/ adequate shelter, water, and sanitation services in either Haiti or following Hurricane Katarina due to the inconsistent awareness of the rights of persons with disabilities among mainstream relief groups and the thought that including persons with disabilities may require highly specialized expertise, costly facilities or complex programs.

3.5 Full and effective participation and inclusion in society

3.5.1 Persons with disabilities and representatives of Disabled Peoples Organizations were not consistently invited to attend disaster planning meetings, camp coordination meetings and cluster coordination meetings in Haiti. Not including persons with disabilities or representatives of Disabled Peoples Organizations resulted in the absence of recognition of the broad spectrum of rights persons with disabilities. Where persons with disabilities were involved, including in the “Inclusion Working Group”, that was situated under the health cluster, there remained a divide between them and the organizations providing services, as non-governmental organizations had a separate “Injury, Rehabilitation and Disability Working Group” which rarely included a person with a disability. It was not until over one year post-disaster (May 2011) that these two groups merged through the recognition that collaboration was essential to both the appropriateness and the sustainability of services.

3.5.2 A National Plan for People Living with Disabilities in Haiti led by SEIPH, was developed and guided by the CRPD principles, which considered the needs of the range of stakeholders and the rights of persons with disabilities. The Plan was created through consulting various Disabled Peoples Organizations in order to identify specific needs. Consensus was gained from Disabled Peoples Organizations by having representatives attend planning workshops and final validation was also gained through having representatives review the Plan’s final objectives and actions.

3.5.3 Despite having plans in place for persons with disabilities prior to the Hurricane in the United States, the plans failed because service organizations did not sufficiently involve persons with disabilities in the planning processes. One example of a plan failure is when during the Katrina evacuation, many people with disabilities could not evacuate because to do so would require them to abandon support services and personnel. The need for some people to receive support from personnel in order to evacuate had not been sufficiently considered by all disaster response organizations.

3.6 Respect for difference and acceptance of persons with disabilities as part of human diversity and humanity

3.6.1 As a range of international organizations largely provided the disaster response services in Haiti there appeared to be an unrealistic sense of the local resources available. This was seen when people were fitted with medical equipment that could not be maintained with existing technology or human resources in Haiti, resulting in a poorer fit on the individual and more equipment breakdowns.

3.6.2 Following Hurricane Katrina, many shelters refused to admit persons with disabilities or inappropriately referred them to special needs shelters. "American Red Cross implemented a policy to refuse shelter access for people with obvious disabilities. Sometimes, people with disabilities were referred to special needs shelters. Families were sometimes split up when Red Cross officials refused to allow family members with disabilities to access the general shelters. In other instances, people with disabilities were admitted to the general shelters but segregated from the general population by physical barriers" (Emergency Management, 2006, p. 12).

3.7 Equality of opportunity

3.7.1 One example of creating equality in opportunities in post-disaster responses is interim employment initiatives. One such cash-for-work project in Haiti included a segment devoted and made explicitly to securing positions for people with amputations, inherently improving the inclusivity of the entire program towards persons with disabilities. However, there were too few of such opportunities created for persons with disabilities as in Haiti the majority of cash for work opportunities emphasized physical labor and thus were in line with the strengths of persons without disabilities than those with – thereby creating an inequality of opportunity.

3.7.2 After meeting the essential short-term needs of evacuees in the United States, such as housing and food, government turned toward employment concerns. Government worked to provide employment opportunities for persons with disabilities affected by the hurricane. In 2005, President Bush signed into law the "Assistance for Individuals with Disabilities Affected by Hurricanes Katrina and Rita Act of 2005," providing $25.9 million in vocational rehabilitation funds for hurricane survivors (U.S. Department of Education, 2005).

3.8 Accessibility

3.8.1 The physical accessibility of services in Haiti was a barrier as persons with disabilities were particularly affected by changes in terrain and the amount of rubble resulting from the earthquake. For example, people who used wheelchairs could not roll over the mounds of rubble. To address the barrier of accessing services, several international organizations have partnered with local organizations in order to deliver services to persons with disabilities in their homes through a community based rehabilitation model.

3.8.2 Following Hurricane Katrina, many evacuation sites were not equipped for people with disabilities. According to the National Organization on Disability (2009), "Over 80 percent of the shelters did not have access to TTY; 60 percent of the shelters did not have captioning TV capabilities. Less than 30 percent had access to sign language interpreters (pp. 14)." These lack of services resulted in people who were deaf not being able to use phones to contact family members or arrange for housing and people with visual impairments not being able to access information only handed out in flyers. Recognizing that the rights of persons with disabilities were not being met, non-profit organizations, such as Centers for Independent Living (CILs), provided persons with disabilities in shelters with the resources that the shelters lacked, such as teletypewriters, wheelchairs, walkers and oxygen.

3.8.3 In Article 2 of the CRPD, universal design "means the design of products, environments, programs and services to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design". Building with a universal design benefits everyone; however, universal designs (e.g., ramps, handrails) were not followed in the construction of the majority of the formal displaced persons camps throughout Haiti due in part because the camps were planned with people who were not familiar with universal design. With over 1.3 million people living in camps (IOM, 2010), camp design features such as large ditches running through the camps without bridges being built across, made the camp not accessible not only to persons with physical disabilities but also made it difficult for older adults and small children to walk around (see Figure 6). Accessible toilet facilities were also not widely available in most camps. Making a toilet accessible includes building a toilet with a ramp, wide door, and handrails outside and inside the toilet stall. This design could have increased the accessibility and safety of toilets not only for people with mobility impairments but also for the elderly, pregnant women and parents needing to accompany their children to the toilet. The barriers to accessibility were even greater in the informal camps (e.g., Camp Canaan), where no planning occurred at all as people moved in and the camp grew larger.

3.8.4 Following the Hurricane, the most common forms of short-term housing for disaster survivors were apartments and trailers; however, persons with disabilities were not being supplied with accessible trailers and often had difficulties securing accessible apartments. When trailers were deemed to be accessible because they had ramps at the entrances; they often did not meet the needs of persons with mobility impairments due to their lack of space to turn a wheelchair and inaccessibility of bathrooms and kitchens.

3.8.5 It is estimated that more than 500 000 people left areas affected by the earthquake in Haiti to either return to rural homes or live with extended family or hosts (IOM, 2010). Despite the majority of people living in rural areas the geographical accessibility of services, both disability specific and not, were limited to the capital city of Port-au-Prince, creating a barrier for all Haitians living in rural areas. However, this barrier created by the geographic concentration of services was more severe for persons with disabilities, as a person with a physical disability would have had more difficulty hiking down the hillside, jumping on a camion and being able to pay the fare.

3.8.6 Information was not widely distributed in multiple formats about disaster response services available. Haiti is a country where oral communication strategies are culturally entrenched, so when communication strategies for individuals with hearing impairments were not used (e.g., visual communication), messages, warnings and other forms of communication did not reach them.

Fig. 6. Large ditch to be crossed when using the footpath within the camp (Camp Corail, Croix-des-Mission, Haiti)

3.9 Equality between men and women

3.9.1 In a culture that prioritizes men, following the earthquake in Haiti, men were seen as the priority for the receipt of food and non-food items and assistance; therefore, steps should have been taken to ensure that aid destined for women with disabilities actually reached them.

3.9.2 In both Haiti and the United States the relative lack of status, power, and resources put many women with disabilities at risk of being sexually assaulted in shelters and camps. In many cases, after an assault occurred there was no one for the victim to report the incident. In a number of instances in the United States when an assault was reported to a police officer, an official statement was not taken because of other life-threatening priorities (Thornton & Voigt, 2007).

3.10 Respect for the evolving capacities of children with disabilities and respect for the right of children with disabilities to preserve their identities

3.10.1 It is estimated that up to 80% of schools within Port-au-Prince, Haiti were damaged or destroyed as a result of the disaster (CBM, 2011). Education initiatives set up post-disaster did not consistently take an inclusive education approach and therefore some of the schools constructed after the earthquake by agencies such as UNICEF were built with physical accessibility in mind, but so far efforts have been piecemeal (see Figure 7).

Fig. 7. New classroom buildings with ramps (Camp Corail, Croix-des-Mission, Haiti).

3.10.2 Over 200,000 school age children became homeless because of Hurricanes Katrina and some estimates indicate that 12 percent of the displaced students had disabilities (Council of Parent Attorneys and Advocates, 2005). Some student-evacuees with disabilities were unable to register for school because they had not secured housing in the evacuation area and therefore could not provide documentation. This issue was addressed when the McKinney-Vento Homeless Assistance Act came into effect and allowed students to attend school despite the lack of formal documentation. Despite the Act coming into effect some schools still denied students their rights to necessary educational services because many student-evacuees with disabilities did not bring documentation about the nature of their disability when they fled from the hurricane (Council of Parent Attorneys and Advocates, 2005).

4. How to begin: A four-point plan for how disaster management initiatives can take a rights-based approach to disability

The review of the 2010 Haitian earthquake and the 2005 Hurricane in the United States demonstrates how persons with disabilities were not included in disaster response, despite the fact that there is a human rights imperative do so. Reviews of the inclusion of disability into the responses of other disasters have demonstrated similar findings (IFRC, 2007). The proposed explanations for this repeated discrimination in the face of international conventions and laws include the perspective that a) disability is a specialized field and b) that accommodating for disability implies increased expense and time (IFRC, 2007; Handicap International, 2010).

Seeing as a sizeable proportion of the population is disabled (WHO & World Bank, 2011), disability should be seen as an issue of importance to all actors along the continuum (preparedness, prevention, response and rehabilitation) of disaster management initiatives. Disability occurs in every continent, amongst people of every nationality, race and religion. The consideration of disability rights by all disaster management initiatives, as opposed to the focused contributions of a precious “specialized” few, will improve the probability that persons with disabilities rights are met. Furthermore, with good planning and foresight these considerations need not be expensive or onerous. The building of accessible physical structures serves as an example of this principle: building to ensure accessibility is of a similar cost as compared to building an inaccessible environment. Furthermore, to do so is far more effective and efficient than trying to adapt and retrofit built environments once local expectations or legislation require such accessibility. Through this example we can see how foresight in a disaster management initiative can lead to an overall cost savings while yielding a result that meets human rights.

The strategies presented here are intended to be the starting point of a good planning process to allow “mainstream” (i.e., non-disability focused) disaster management initiatives to meet their obligation to address the rights of persons with disabilities. These strategies are applicable along the continuum of disaster management initiatives and practical but allow for flexibility of application. Individual initiatives are free to determine the precise way in which they will address disability as part of their disaster intervention (HI, 2005), but it is now well established that the longstanding tactic doing nothing (Wisner, 2002) is no longer acceptable.

In order to respect the human rights principles surrounding the inclusion of persons with disabilities, every disaster management initiative should include:

- making a commitment to persons with disabilities, review this commitment regularly and incorporate it into the idea of success;
- involving persons with disabilities in positions of leadership and decision-making processes;
- training staff on issues that persons with disabilities face; and
- building as much as possible using universal design principles.

4.1 Make a commitment to persons with disabilities, review this commitment regularly and incorporate it into the idea of success

Effectively including persons with disabilities as part of a disaster response begins with a conscious decision. When this decision is made it can become second nature to incorporate the rights of persons with disabilities and identify the gaps as they arise. Current practice in all fields of disaster response includes a review of activities to ensure that they have successfully met their objectives and a review of these objectives to ensure that they are appropriate for the situation. The intertwining of disability into this framework can have a significant impact upon how the objectives are framed and subsequently how activities are oriented.

For example, let us imagine an intervention that is designed to accommodate 90% of a given population that is affected by a disaster, which could be a realistic and reasonable target in a challenging situation. If the implementation and evaluation of this intervention do not account for disability there is a high probability that the intervention could effectively be considered successful by remaining completely inaccessible to the 10% of the population that is disabled. In this case, the design of the intervention would be ignorant towards meeting the rights of persons with disabilities and the evaluation would likely remain uncritical towards this ignorance, especially in light of the success of the intervention according to its own objectives. By contrast, let us consider an intervention where the objective was to reach 90% of a given population including 90% of persons with disabilities. This intervention would need to incorporate specific considerations to allow it to be accessible to persons with disabilities from the outset. If during the evaluation phase it was found that 95% of persons without disabilities but only 50% of persons with disabilities were able to access the service there would likely be a critical analysis of the barriers that persons with disabilities faced that would stimulate reflections, learning and improvements for subsequent interventions.

The preceding example is intentionally simplistic in order to clearly represent the influence that a conscious incorporation of disability can have on programming. The same principle applies to the more complex planning and implementation that are used in the many aspects of disaster response; the key is that the decision must be made to include disability. Furthermore, it is really only with the acceptance of this first step that the additional strategies proposed here can be utilized to their full effectiveness.

4.2 Involve persons with disabilities in positions of leadership and decision-making processes

People are the true experts of their situation and therefore are in the ideal position to give recommendations about how to best include disability into a disaster response (HI, 2005). Those involved in disaster management should therefore seek out persons with disabilities and include them in the leadership and decision-making process (IFRC, 2007). Beyond the principle of "full and effective participation and inclusion" being an underlying principle of the CRPD (CRPD, 2006), there is empirical evidence to support that including persons with disabilities the leadership of disaster management activities reduces their vulnerability and improves the effectiveness of the initiatives (United Nations Enable, n.d.). It must be noted that the inclusion of persons with disabilities in disaster management leadership is best done at as early a stage as is possible; and far easier in the disaster prevention or preparedness stages than it is in the disaster response stage when there is less available time and communications are hampered (IFRC, 2007).

To facilitate the operationalization of this principle, the National Organization on Disability in the USA has identified types of disability organizations (see Figure 8) and recommended strategies that disaster management initiatives can use to approach them (National Organization on Disability, 2009). Although the organizations and the strategies are contextually oriented to the situation in the USA, they provide a framework and methodical structure that could be adapted and emulated according to the structures available in other jurisdictions.

The category "advocacy organizations" merits special mention. This type of organization generally consists of persons with disabilities who have organized themselves into disabled persons' organizations. Collaboration with disabled persons' organizations allows the benefits of improving the probability that the persons with disabilities involved with the disaster management activities will arrive with more leadership experience and systematically including persons with disabilities who are members of that association through the organization's representatives. Nonetheless, it must be known that the inclusion of representatives from a disabled persons' organization does not constitute the perspectives of all persons with disabilities: just as persons with disabilities constitute a heterogeneous group, so are disabled persons' organizations diverse in nature. A given disabled persons' organization could be focused on a given community (i.e., city or town) or embedded within an institution (e.g., a university or a union). Furthermore, a disabled persons' organization could link members with a single type of disability or characteristic (i.e., a given gender or age category) or be more broadly focused upon people from all walks of life with all types of disabilities. It is thus important to remember this variety when reaching out to disabled persons' organizations (and persons with disabilities more generally) in order to recognize the strengths and potential gaps in perspective.

A final point to consider when incorporating persons with disabilities into the leadership of disaster management activities is that of true participation: as members of a generally disadvantaged and often neglected group, persons with disabilities are often on the weak side of an imbalanced power dynamic. Disaster management activities must therefore be aware of the possibility of this dynamic to limit participation and seek ways to encourage true and equitable participation.

Government Organizations

Usually, the best place to start in selecting and involving disability representatives is the disability agency or task force within the Governor's office, the Mayor's office, or the state or county government. Typically, officials in these organizations can assist in identifying a cross-section of disability representatives within a locality. Other government entities that may be helpful include:

- Department of Health and/or Mental Health
- Department of Aging
- Department of Veterans Affairs
- The local Americans with Disabilities Act (ADA) Coordinator

Institutional Participants

Examples of institutional partners are:

- Representatives from the home-based care industry, such as the local Visiting Nurse Service and the Home Health Aides Association
- Residential healthcare facilities, such as nursing homes, skilled care homes, and assisted living facilities
- Hospital associations
- The local end stage renal disease (ESRD) network (a.k.a. local dialysis network)
- The ambulette and private accessible transportation industry

Advocacy Groups

It is important to include representatives from advocacy groups in the disability community, such as:

- The local Independent Living Center
- Local groups serving specific and general disability populations (e.g., people who are blind, deaf, or have limited mobility or cognitive disabilities)
- Individuals with disabilities who, though not affiliated with a group, are known to emergency professionals and who are willing to participate in the planning efforts

Fig. 8. Examples of organizations to approach in order to incorporate the perspective of persons with disabilities in disaster management activities (National Organization Disability, 2009, pp. 25-26).

4.3 Train staff on issues that persons with disabilities face

Inclusion efforts will not be successful if they lack broad support in an organization, especially at the level of the front-line staff. Literature on this subject cites specific situations where the accessibility of a disaster response towards persons with disabilities was directly influenced by the awareness of frontline staff. Clear examples from the 2007 World Disaster Report (IFRC, 2007) include instances of persons with disabilities being turned away from shelters where the staff thought that they would not be able to meet their needs, interpreted the presentation of their disabilities as intoxication or sent them to hospitals on the mistaken belief that they were sick or injured. The examples above demonstrate situations where the decisions and subsequent actions of staff created a barrier to a service for persons with disabilities. Training that increases awareness of the issues that persons with disabilities face in disasters can prevent the occurrence of such instances and can therefore improve the accessibility of services (IFRC, 2007).

Beyond the mitigation of unnecessary barriers to access, a staff that is more sensitive to issues of disability can provide an important positive contribution that can make services more accommodating for persons with disabilities (HI, 2005). Possibilities include frontline workers becoming more helpful towards persons with disabilities and their contribution to adaptations and creative solutions. Furthermore, frontline workers are in a key position to identify existing barriers and challenges and feed this information into a perspective of the disaster response. The improved sensitivity towards disability as stimulated by training can thus have an enormous impact upon how an organization addresses disability.

Handicap International (HI, 2005) recommends various training options that range from sensitization through the visits of persons with disabilities to the inclusion of disability specialists on an organization's staff. The ultimate choice in staff training will depend upon a given disaster management initiative's specific situation, which can be determined through the goals that it has related to disability and the input of the persons with disabilities as part of its leadership.

4.4 Build as much as possible using universal design principles

The benefits of universal design to persons with disabilities in disaster management are tremendous: in the event of an emergency it can be far more feasible for a person with a disability to evacuate from such an area, creating a direct and immediate effect upon the probability of survival. After the occurrence of a disaster the physical environment of emergency shelters or camps, of sanitation and hygiene facilities and of health care installations will all impact the well-being of persons with disabilities. The reconstruction phase of a disaster is an opportunity to design the built environment in order to allow the participation of persons with disabilities in society. Finally, holding disaster management planning sessions and meetings in locations that are physically inaccessible creates a barrier to participation in these activities by persons with disabilities that can in turn weaken the entire disaster management initiative's ability to incorporate a disability perspective.

Ramps are generally the best option to facilitate passage between areas of different elevations. Although ramps are not only of benefit to wheelchair users, it is their needs that often drive the design. Ramps should therefore be sufficiently wide to allow the passage of a wheelchair, have a handrail on each side and be of a grade that permits a wheelchair user to push him or herself up the ramp and have a landing that is large enough for a wheelchair user to turn around.

Sites should have at least one or a reasonable percentage of accessible **toilets or latrines.** That is to say that they have an approach that allows a person in a wheelchair to reach the entrance and an entrance that is wide enough to allow the passage of a wheelchair. Once inside the toilet area there must be sufficient space to allow a wheelchair to turn and handrails to allow someone to move from the wheelchair to the toileting surface. The toilet should include or be sufficiently close to an accessible facility for washing and hygiene activities.

Fig. 9. Examples of universal design features (HI, 2005; Smith, 1996)

To demonstrate examples of the practical aspects of universal design Figure 9 presents some features that are common to allow for improved accessibility, especially among people with mobility impairments. Those seeking an introductory text on universal design principles should consult "The Universal Design File" made available by the Center for Universal Design in the USA (Story et al., 1998). Nonetheless, the effective and extensive application of universal design requires more discussion of the technical aspects than what is possible here. Where possible it is advisable for the leaders of disaster management initiatives to only contract to designers who are well versed in universal design or at least willing to learn. In situations where this is not possible those responsible for designing facilities should use the resources above as a starting point. Regardless of the designers' experience or interest in universal design, responsiveness to the feedback and perspectives of the persons with disabilities using the facilities remains a critical aspect of this strategy.

5. Conclusion

Due to the exclusion of persons with disabilities in disaster management initiatives, their rights are often unmet resulting in unnecessarily high rates of mortality and morbidity, deterioration of health conditions and loss of autonomy. The exclusion of persons with disabilities from disaster management initiatives can be reversed through using a rights-based approach to disaster management initiatives that are based on the guiding principles of the CRPD. The strategies presented above are intended to be complementary and interrelated: accessible physical environments and communications are precursors to allow the inclusion of persons with disabilities in planning and review activities. In turn, the inclusion of persons with disabilities in these activities will serve as a constant reminder of the necessity of accessible physical environments and communications. These processes must not be limited to merely the domain of disability specialists but rather embraced and incorporated into the modus operandi of all disaster management initiatives, and to do so is now necessary according to international convention. When inclusion is practiced effectively the rights of persons with disabilities are given equal weight to other considerations. Inclusion thus transforms the philosophy towards meeting the rights of persons with disabilities from one of peripheral concern to one of unconscious operating.

6. Acknowledgements

The authors would like to thank all of the organizations that supported their work in the field of disaster management and to also thank most of all, the people who shared their stories and time with us.

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3

Hurricanes: Catastrophic Effects and Their Physical Nature

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1. Introduction

Hurricanes are one of the most formidable and threatening phenomena on Earth. They are forming over the warm water under combination of specific conditions. Therefore, they are not so often as one could expect: about 80 per annum with noticeable interannual variability. North-West Pacific is their most common place where they are called typhoons. The next place in numbers is North Atlantics, then Indian Ocean with few hurricanes per year.

Meteorological term is tropical cyclones, TC, for short because they are formed in latitude belts 5-25° North or South of equator. To be called hurricanes or typhoons they must have winds U over $33\,{}^{m}\!/_{s}$. For $U > 20\,{}^{m}\!/_{s}$ the term is tropical storms.

Very few TC are observed in the Southern Hemisphere and mostly in the Indian Ocean. The are never near equator which suggests importance of the Coriolis force, i.e. the rotation of the planet. TC_s are seasonal phenomena, their season is from July to November in the Northern Hemisphere, mostly beginning of the autumn. Their tracks have pronounced pole ward component and coming to moderate latitudes they transform into ordinary cyclones. The description of TC from the synoptical point of view is presented well in the classical book by E.Palmen and C.W.Newton “Atmospheric Circulation Systems” [1]. TCs are important elements of the General Circulation of our Atmosphere bringing substantial amount of moisture and angular momentum into the middle latitudes.

TCs are destructive for humans: many ships sink when they happened to be under their action. At their landfall, they destroy much of the property and many people and life perish in general from high winds and massive precipitation often causing floods. Coastal areas are devastated by giant ocean waves. The single TC Katrine in August 2005 devastated New Orleans and many smaller towns in Louisiana, Mississippi and Alabama with overall damage of hundreds billions of US dollars. TC cause most of the damage of hydro meteorological extreme events and the price is increasing during last decades. Now the damage is several times larger than that from earthquakes, volcanoes and other geophysical phenomena. Only one historical TC in Bangladesh in 1975 took about half a million human lives. To diminish the damage the building construction codes have been developed, and should be observed and the warning systems must be in use for population on approaching TC. If similar systems would be in 1975 in Bangladesh the life toll there could be lesser by many times.

But they also bring large amounts of precipitation, and many Chinese collegues were telling this author that this precipitation is vital for the agriculture in PRC, so the overall effects of TCs into China is positive. Forecast of their formation and evolution is of great importante for many countries, especially for USA, PRC, Japan, Central American states, India, Australia. But to forecast a phenomenon one should understand and model it sufficiently well. However, our understanding is incomplete, especially of the formation stage. TCs are formed in a day or even half day[1].

For the orientation in the physics of a TC one should look wide around onto our atmosphere for something similar. Satellite images of the Earth surface are giving us detailed information about what is going on in the atmosphere. We present on Figs 1, 2 and 3 examples of intense atmospheric vortices, IAV. On Fig.1 we see a typical TC near Florida. Fig.2 gives us a view of a polar hurricane, polar mesocyclone, of much smaller size than a TC, so it is called polar low, PL, and Fig.3 presents a quasitropical cyclone QTC, over Black Sea. At the fall season such QTCs are occasionally formed over Mediterranean Sea, and very rare over the Black Sea. We need to understand size, energy or winds and conditions for their development.

Fig. 1. Typical TC, hurricane Andrew near Florida, 23 August 1992.(*The figure captions for paper Hurricanes, by G.S. Golitsyn)*

Here we consider conditions for forming intense atmospheric vortices hurricanes and typhoon, polar lows, their physical nature, scales for their winds and sizes, their parameterizations in terms of thermodynamic disequilibrium between ocean and atmosphere. This would allow us to formulate some quantitative necessary conditions for their generation.

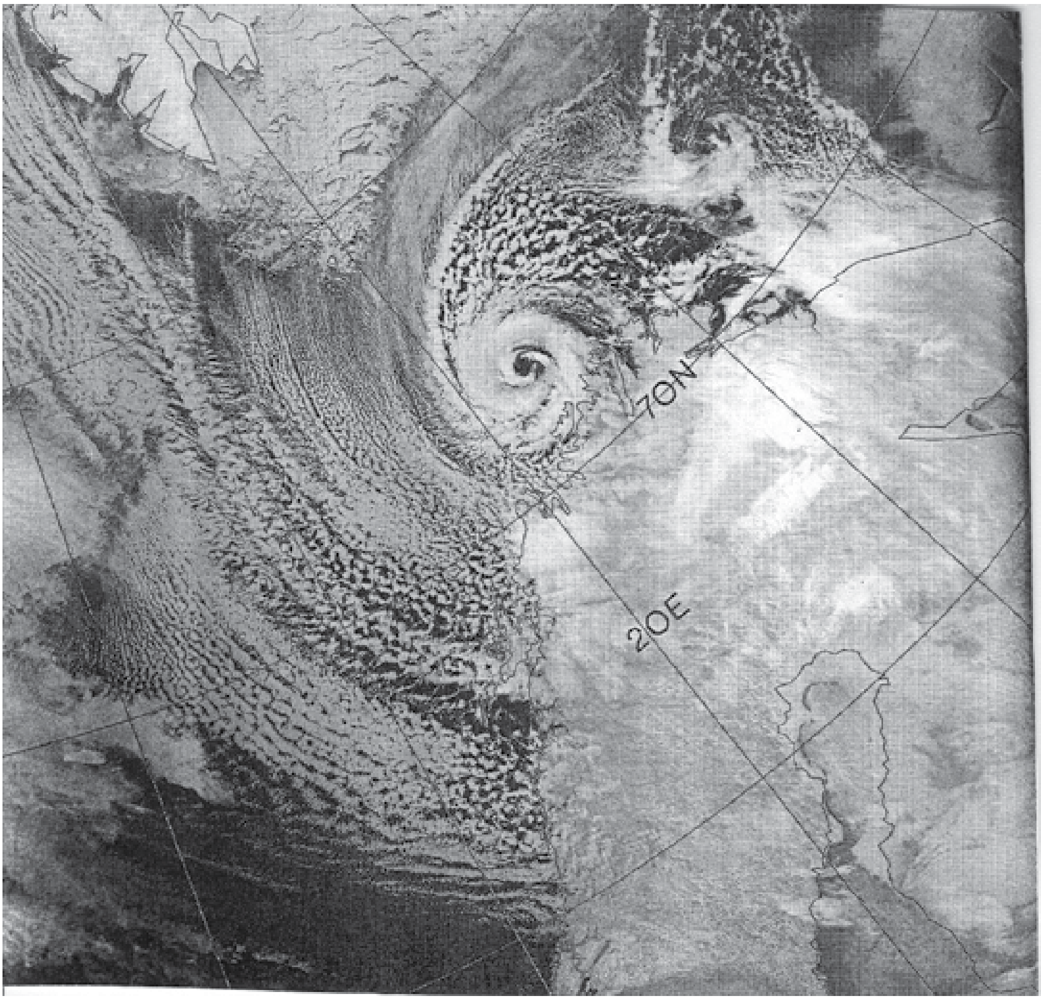


Fig. 2. Polar low, polar mesocyclone to the North of Scandinavia, February 1987. (*The figure captions for paper Hurricanes, by G.S. Golitsyn*)

Hurricane winds are of 33 m/s or larger, vortices with winds between 20 and 33 m/s are called tropical storms, and lesser winds are typical for tropical, depressions, de crease in the pressure, or geopotential fields with pressure drops of about $\delta p \sim 10\text{hPa}$. Initial stage of a TC is a depression but only of order 10% of such depressions evolve to a TC.

The base for a TC development is a substantial thermodynamic disequilibrium between the ocean surface water and the atmosphere as was visit clearly stated by Riehl [2] in 1950, and Kleinschmidt [3] in 1951.This means that the water must be warmer than the atmospheric air. This is observed during the colder seasons and explains the seasonality of a TC cycle. The very first quantitative condition was found in 1948 by Eric Palmen [4] and it was stating that the temperature of the water must be warmer than $T_s \geq 26^{\circ}C$.

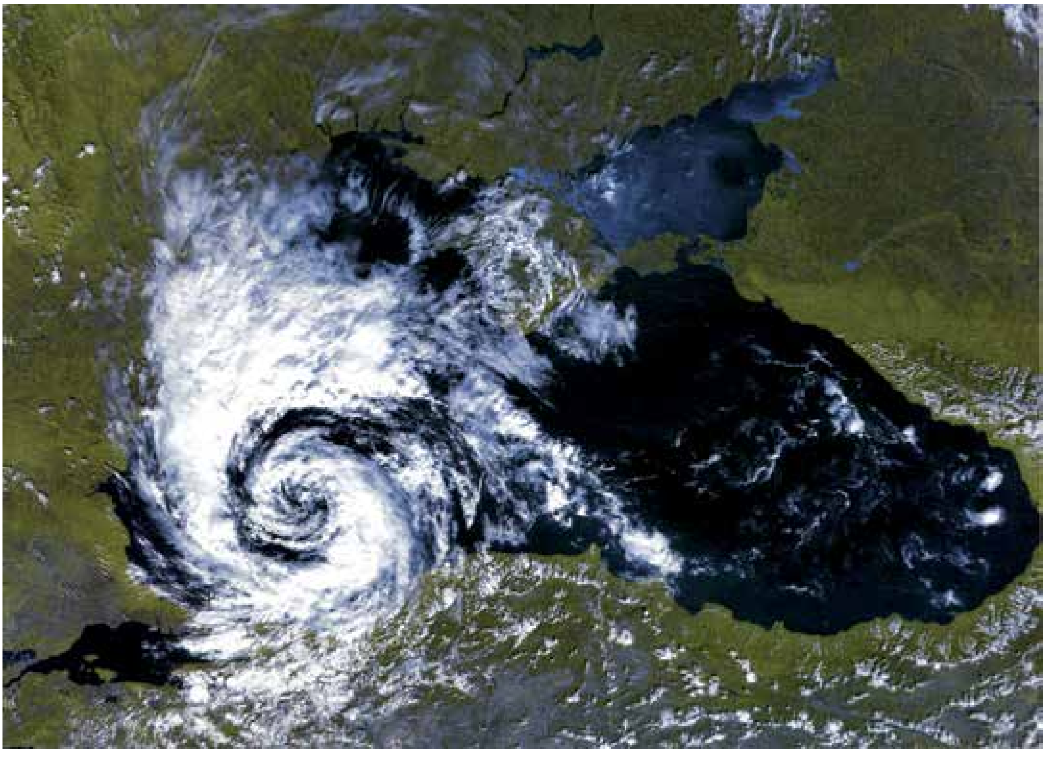


Fig. 3. Quasi-tropical cyclone over the western part of Black Sea, 25 September, 2005. (*The figure captions for paper Hurricanes, by G.S. Golitsyn)*

The other conditions for such a development were first described by William Gray [5]. They are:

i. The static stability of the atmosphere must be small, i.e. the vertical temperature gradient should be close to the wet adiabatic one;
ii. The tropospheric air about the planetary boundary layer should have enough moisture, otherwise the ascending air being entrained by dry air from above would not condense and the heat of condensation is the main fuel for TCs;
iii. The vertical wind shear should be small, otherwise the hurricane column would be destroyed;
iv. The surface waters should be warmer than the air of lower few meters (usually, the reference height is 10m);
v. The upper mixed layer of the ocean (usually it is about 50-100 m) should be thick enough to supply the sufficient energy for a TC;
vi. Ocean temperature, i.e. of UML, should not have large horizontal variation in order to supply the moving TC with necessary fuel.

These conditions should be quantified and that would be a content of the next Sections.

2. Physics of the hurricanes and other IAVs

2.1 Fluxes between ocean and air

The main physical process to resolve the thermodynamic disequilibrium in fluids under the gravity field is convection. Convection is an ascent of lighter fluid into a denser one. If the air is windy, as it is always the case, then the air extracts from the water surface the sensible heat and the latent heat as the water vapor and the ocean is losing its heat content or enthalpy. The vapor is condensed at some height because the air temperature is decreasing with height. The heat of condensation is the main source of the energy supply for a TCs. The ascending air causes a drop of pressure at its base and the continuity equation of fluid causes the convergence of adjacent air. Because the Earth is a rotating planet the converging air brings in the convection column its angular momentum, the sum of absolute momentum due to the Earth's rotation and what is of relative vortical motion in the environmental flow. Concentration of the momentum in the ascending convective column enhances the azimuthal velocity in the column. The increased wind causes more evaporation and the sensible heat flux from the water surface which in its turn enhance the wind, etc. The complicated balance between convection strength, winds and energy dissipation, mostly within the boundary layer over water, determines the energy of a TC. Its vertical extent is up to tropopause, i.e. 15-18 km in the tropics. TC_s do not propagate further up because of the very strong static stability of the stratosphere. The acquired angular momentum is dispersed at the top of a TC in the form of anticyclonic spirals so well seen by satellites.

This qualitative picture was quantisized to some extent by Kerry Emanuel and was called by him as WISHE (**W**ind **I**ntensification by **S**ensible **H**eat and **E**vaporation). The detailed description of this one can find in his two review papers [6, 7]. At the end of the latest review he concludes that the origin of TCs was still unclear and that it might be not just one way for their origin. To resolve the problem one needs more observations and their detailed analysis and numerical experiments with a kilometer resolution, not available in the early 2000s for the domains of a few thousand kilometers.

Let us consider hurricanes, TC and PL, as convection vortices in rotating fluids. The theory and extensive experimentation can be found in the book [8] and research papers [9-12]. The first results are for the scales of velocity and area [9-14] were obtained from dimensional analysis. For convection the main governing parameter is the buoyancy flux, which in a steady state is equal to the rate of the kinetic energy dissipation [15] it the Boussinesq approximation:

$$b = \varepsilon = -\frac{g}{\rho} < \rho' w' > = -\frac{g}{pT} < w'T' > -0.622 < w'g' > \qquad (1)$$

where g is the gravity acceleration, ρ the gas density, w prime signs mean fluctuations relative to mean state the vertical velocity component, T the gas temperature, g the water vapour mixing ratio, angular brackets mean statistical averaging

The moist gas thermodynamics is assumed [6, 7] here when the density of an air parcel is here equal to the sum of air and vapour densities:

$$\rho = \rho_a + \rho_w = \frac{p_a}{R_a T} + \frac{e_s}{R_w T} = \frac{p_a}{R_a T}\left(1 + \frac{\mu_w}{\mu_a}\cdot\frac{e_s}{p_a}\right) \cong \frac{p_a}{R_a T}\left(1 + 0.622\frac{e_s}{\rho_a}\right), \tag{2}$$

where the ideal gas equation of state is assumed, $R_a = R/\mu_a$, $R_w = R/\mu_w$, constants for a gas with molecular weight μ, e_s is the saturation water vapour pressure whose dependence on the temperature is described by the Clapeiron-Clausius equation. The mixing ratio is related to the specific humidity *e(T)* as

$$q = \frac{\mu_w}{\mu_a}\frac{e}{p} = 0.622\frac{e}{p} , \tag{3}$$

where μ_w=18.015 and μ_a=28.97 are corresponding molecular weights for water vapour and air, *p* is the atmospheric pressure. The decrease of the air density, as compared with the dry air at the same pressure, is equal to

$$\Delta\rho = -\frac{0.622}{R_a T} p\Delta q = -\frac{0.378}{R_a T}, \quad 0.378 = \frac{\mu_a - \mu_w}{\mu_a} , \tag{4}$$

The thermodynamic disequilibrium between the ocean and the atmosphere is resolved in the process of the two media interaction by means of the momentum, heat and moisture fluxes. The study of these fluxes, especially at high winds, is still one of the main goals of the physical oceanography, complications are due to presence of the waves at the water surface.

The fluxes of the momentum, sensible and latent heat are described by the so-called bulk formulae [16-19]:

$$\tau = \rho\langle w'u'\rangle = c_D \rho U^2 = \rho u_*^2 , \tag{5}$$

$$F_{SH} = \rho c_p \langle w'T'\rangle = c_T c_p \rho U \Delta T , \tag{6}$$

$$F_{LH} = \rho\langle g'w'\rangle = c_E \rho U \Delta q , \tag{7}$$

where U is the wind velocity at the reference level 10m, $c_{D,}\ c_T, c_E$ are the drag coefficients for the momentum, sensible heat and moisture, $\Delta T = T_s - T_a$ is the temperature difference between sea surface and the air at 10m, Δq is the difference between the mixing ratios of the water vapour at the sea surface where $T = T_s$, and the relative humidity is 100%, and the one at T(10m). According to ocean climatology [20] the relative air humidity $r = q(T)/q_s(T)$ over all oceans at all latitudes in all seasons is close to 80%, i.e. $r \approx 0.8$. It decreases to 0.7 only occasionally. Emanuel [6] in his review used $r \approx 0.75$. In this case the Bowen number the ratio of the sensible and latent heat fluxes, would be smaller by a factor $(1-r_2)/(1-r_1) = 0.25/0.20 = 1.25$.

The formulae (4)-(6) follow from similarity considerations and are obtained by the analogy with a technical problem of a plate cooled by a colder air flow with velocity U. The coefficient c_T in such a problem is known as the Stanton number [15]. It should be noted that under the modern instrumental precision [19] $c_T \approx c_E$ in (5) and (6), i.e. these coefficients are assumed further to be equal.

2.2 Buoyancy flux

The buoyancy flux is described by eq.(1). Using the bulk formulae for sensible and latent heat, eqs. (5) and (6), we obtain from eq.(1).

$$b = -c_T \frac{\Delta T}{T} gU \left(1 + 0.622 \frac{c_E}{c_T} T \frac{\Delta q}{\Delta T} \right). \tag{8}$$

Remembering that $c_T = c_E$, according to [17-19], and taking into account eqs.(3) and (4) we re-write eq.(8) as

$$b = -g'U, \quad g' = c_T \frac{\Delta T}{T} g \left(1 + 0.378 \frac{\Delta e}{p\Delta T} \right), \quad \Delta e = e_s(T_s) - re_s(T_a) \ , \tag{9}$$

where g' may be called the reduced gravity acceleration. Following [20] the saturated water vapour pressure as a function of temperature can be conveniently presented (in Pa units) as

$$e_s(T) = \exp[23.7812 - 4157(T - 33.91)^{-1}], \tag{10}$$

$$e_a(T) = \exp[23.8014 - 4157(T - 33.91)^{-1}]. \tag{11}$$

These expressions were obtained from the integration of the Clapeyron-Clausius equation by some approximations and are valid with the accuracy of a few hundredths of a percent in all practical ranges of atmospheric temperatures. One can find other formulae for the air humidity, but we use these ones in the calculations below. The difference in the first term in the square brackets in eqs.(10) and (11) is related to the fact that for water with salinity 34‰ the pressure of the saturated water vapour is 98% of the pressure over distilled water [18].

The first formula (9) shows that the buoyancy flux is the product of the reduced gravity acceleration and the wind velocity. It has the dimension of power per unit mass. In statistically stationary conditions, i.e. in a steady state, this flux is, evidently, equal to the rate of generation and dissipation of the convective kinetic energy also per unit mass. This follows with the convective energy balance equation [15]. This does not hold in non-stationary conditions, e.g. the buoyancy flux in penetrative convection (see below section 4) decreases linearly with height, expending its energy to the lift and warm the air [21-23].

Equation [9] determines the buoyancy flux over the water surface in the absence of condensation. Observations show that for TC, as well as for PL, the condensation starts forming clouds at levels of a few hundred meters (300-400 m) above the ocean surface. In TC the clouds rise up to the tropical tropopause of 15-18 km. In PL the cloud tops reach 5-6 km [24]. In this case there should not be a substantial error if we neglect the relatively thin subcloud layer and assume that the latent heat of condensation starts to be felt right at the water surface. In any case, the enthalpy flux leaving the water is just the sum of sensible and latent heats fluxes in the air. We can now rewrite eqs.(9) as

$$b = -c_T \frac{\Delta T}{T} g\left(1 + \mathrm{Bo}^{-1}\right) = g'U,\; g' = c_T \frac{\Delta T}{T} g\left(1 + \mathrm{Bo}^{-1}\right)\;. \tag{12}$$

We introduce here the Bowen number, $\mathrm{B_O}$ the ratio of the sensible and latent heat fluxes. Its inverse ratio is equal to

$$\mathrm{Bo}^{-1} = \frac{\mu_w}{\mu_a} \frac{L\Delta e}{pc_p\Delta T} = 0.610 L_1 \frac{\Delta e}{\Delta T} \tag{13}$$

where $L = 10^6 L_1$, is the latent heat of evaporation, $p = p_s = 1.013 \cdot 10^5\,\mathrm{Pa}$ is the globally mean air pressure at the sea level. According to [20] the latent heat in SI units is a function of the absolute temperature in the following form

$$L = 1.91846 \cdot 10^6 [T(T - 33.91)^{-1}]^2\,. \tag{14}$$

In the observed range of temperatures of the ocean's open surface from -2°C to +31°C the value of $L_1 = 10^{-6} L$ changes from 2.506 to 2.430 or by 3%. This should be taken into account in exact computations.

Note that eqs.(8) and (9) show that buoyancy flux exists even at $\Delta T = 0$, i.e. when both temperatures of air and water are equal. The flux then is only due to the lighter water vapour as compared to the unsaturated air. The last flux vanishes when the air is warmer than the water, as it follows from eq.(9) by

$$\Delta T = T_a - T_s = 0.378 \frac{\Delta e}{p}\,, \tag{15}$$

where from in the tropics at T=300K, or 27°C, and $\frac{\Delta e}{p} \approx 10^{-2}$, we get $\Delta T \approx 1K$.

The fluxes of the sensible and latent heat, and therefore the buoyancy flux, depend on the wind speed U, see the bulk formulae and eqs.(9) and (12).

The convective vortices are processing the ambient air by rising it up. These processes create high winds by concentrating the ambient angular momentum, which intensifies the convective vortices increasing the fluxes in its turn. The process is stabilized when the dissipation of the kinetic energy proportional to the cube of the wind and occurring mainly in the boundary layer [24] becomes equal to the rate of the energy generation [13, 14, 24]. These are highly non-linear processes but fortunately the situation can be described by invoking parameterizations depending on fluxes in consideration.

3. Scaling for steady vortices

3.1 Convection in rotating fluids

The average lifetime of TC is about a week, though one such vortex is known to exists for a month [25, 26]. A PL lives of order a day or even less [27]. The theory of convection for rotating fluids assumes the steady state and constant fluxes [8-10]. Therefore the theory gives the right scales for the winds and size at a steady state but even for the development stage it should not be much in error.

The main parameters determining the convection should be the buoyancy flux *b* with $[b]=L^2T^{-3}$, where after J.C.Maxwell square bracket mean the dimension, L and T are dimensions of length and time, and the Coriolis parameter

$$l_c = 2\omega \sin \Theta \, , \tag{16}$$

where ω is the rotation rate and Θ is the latitude. Also an external length scale is present, e.g. the planetary radius R. From these three parameters determine a non-dimensional similarity criterium [9] which we take in the form

$$\mathrm{Ro} \;= b^{1/2} l_c^{-3/2} R^{-1} \, , \tag{17}$$

which happened to be the Rossby number [9] as we would see just in few lines. When $\mathrm{Ro} \ll 1$ the rotation is felt strongly. Now we suppose that the characteristic vortex sizes *d* are much less than R. From the two remaining parameters, *b* and l_c, we construct the scales of length *d*, say, diameter of a TC, and velocity:

$$d = c_1 b^{1/2} l_c^{-3/2} \tag{18}$$

$$U = c_2 b^{1/2} l_c^{-1/2} \tag{19}$$

where c_1 and c_2 are numerical constants determined experimentally [10-12]. It was found that $c_1 \approx 10$ and $c_2 = 1.7 \pm 0.1$ so $c_2^2 \approx 3$ which we shall us later.

After combining eqs.(12) and (19) we obtain a relationship between the velocity and reduced gravity:

$$U \approx 3 g' l_c^{-1} \tag{20}$$

and the reduced gravity g' is determined by the second eqs.(12). The relationship (20) expresses the wind velocity in a hurricane through the parameters of the thermodynamic disequilibrium between the atmosphere and ocean.

3.2 Differences between TCs and PLs

The eqs.(18) explains why a PL is typically three times smaller than a TC [27]: at Θ=20° we have the Coriolis parameter (16) equal to $0.5 \cdot 10^{-4} s^{-1}$, but for Θ=70°, as on Fig.2, $l_c = 1.37 \cdot 10^{-4} s^{-1}$.According to (18), if the other conditions equal the diameters should be different by $\left[{l_c(70^\circ)} \Big/ {l_s(20^\circ)} \right]^{\frac{3}{2}} = \left(1.37/0.5\right)^{\frac{3}{2}} = 4.5$ times. As we will see later the reduced gravity at high latitudes is about twice of that in the tropics due to much higher static stability of the polar atmosphere than in the tropics and much lower Bowen ratio. Therefore to reach the hurricane winds of 33 m/s the reduced gravity is about twice or more than in the tropics. This reduces the size difference for TC and PL to about three times as it is in reality.

The enthalpy fluxes from the ocean to the atmosphere are of order 700Wm^{-2} or more at hurricane winds of TC, and for PL they may reach 1.5-2kWm^{-2} or even more. Such high fluxes were measured in winter near Newfoundland and east of Japan (private communications by Yu.A.Volkov and S.S.Lappo, early 1990s).In [13,14] one can find special tables for both tropical and polar conditions for the reduced gravity, Bowen ratio, enthalpy fluxes and corresponding velocities $U \geq 33 \, m/s$ or higher at the ranges of polar temperatures at the sea surface of 0 to 8^{o}C, ΔT=20K, and for tropical range T_s from 24 to 30° C, ΔT=2K and 1K. As we noted above the air relative humidity plays important role, especially in the tropics. If we decrease there r from 80% to 70° the Bowen ratio would increase in 1.5 times. Such an increase may happen in Easterly waves in Atlantics bringing dry air from Sahara [1].

The high IAV winds not only take away the heat content from the upper mixed layer, UML, of the ocean but stir it additionally. If UML is H=50m deep with the (flux) out of it F=1kWm^{-2} during one day, t_1, it would cool by 0.43 K.

Quite often few degree of cooling of UML is observed after a TC passage which means that this layer is mixed down to the thermocline by high surface waves breaking bringing up colder deep waters. This means that good TC, and PL, prediction models must have a deep enough block for the ocean description and also for the wind surface a waves. The colder surface waters would decrease ΔT , the surface air temperature difference, diminish the enthalpy fluxes and weaken the vital feedback for IAVs.

4. Atmospheric stratification and penetrative convection

From the point of view by Gray [4] the most important condition for a TC origin is the static stability of the atmosphere. It is determined by the vertical air density gradient

$$\Gamma = \left(\frac{d\rho}{dz}\right)_a - \frac{d\rho}{dz}, \; \left(\frac{d\rho}{dz}\right)_a = \Gamma_a = -\frac{\rho g}{c_a^2}, \; c_a^2 = \chi R_a T \; , \tag{21}$$

where c_a is the adiabatic sound velocity in an ideal gas, $\chi = \frac{c_p}{c_v}$ is the adiabatic exponent. The hydrostatic equation $dp = -\rho g dz$ is used here. A convenient measure of the density gradient is the square of the Brunt-Väisälä frequency $N^2 = -\left(\frac{g}{\rho}\right)\Gamma$. In the Boussinesq approximation, it is equal to

$$N^2 = -\frac{g}{T}\left(\frac{dT}{dz} - \gamma_a\right), \quad \gamma_a = -\frac{g}{c_p} = -9.8\frac{\text{K}}{\text{km}} \tag{22}$$

When a source of buoyancy at the lower boundary of a stably stratified fluid layer starts to act, then a convective boundary layer develops. Its height increases with time *t* as [21-23]:

$$h(t) = (2bt)^{\frac{1}{2}} N^{-1} \tag{23}$$

This expression should also take into account the entrainment from above of the ambient air which would increase r.h.s. of eq.(23) by some 20% [22,23]. The typical values of $\Gamma = \frac{dT}{dZ}$ is about $-6\,{}^{\text{K}}\!/_{\text{km}}$. It is about $-6.5\,{}^{\text{K}}\!/_{\text{km}}$ at low latitudes and $-5.5\,{}^{\text{K}}\!/_{\text{km}}$ at high latitudes [28]. In the first case $N \approx 1\cdot 10^{-2}\text{s}^{-1}$, and in the second $N = 1.24\cdot 10^{-2}\text{s}^{-1}$. Higher internal wave frequency means that penetration of convective patterns at high latitudes is some 25% slower than at low latitudes.

We know time of development for both TC and PL. The height of these IAV_s is correspondingly 15÷18 km and 5÷6 km. Accepting these two conditions we may estimate what kind of thermodynamic disequilibrium is necessary to reach the observed tops of the vortices in the prescribed time, using (23):

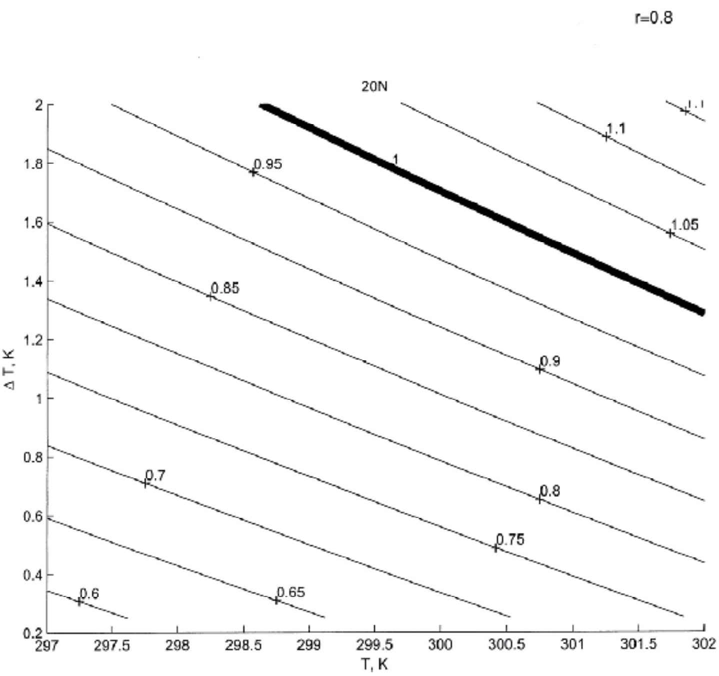
$$b = \frac{N^2 h^2(t)}{2t}, \tag{24}$$

with the buoyancy flux expressed by eq.(12) and the wind speed by eq.(20). From the eqs.(24), or (23), we have

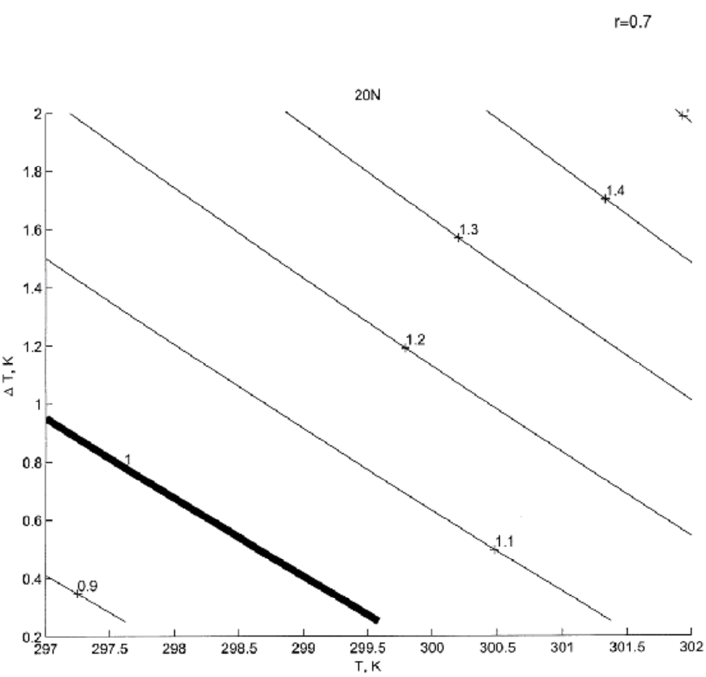
$$\frac{c_T g}{hN}\left(\frac{2t}{l_c}\right)^{\frac{1}{2}} \frac{\Delta T}{T}\left(1 + \text{Bo}^{-1}\right) = A\frac{\Delta T}{T}\left(1 + \text{Bo}^{-1}\right), \quad A = \frac{c_T g}{hN}\left(\frac{2t}{l_c}\right)^{\frac{1}{2}} \tag{25}$$

where A does not depend on the disequilibrium conditions.

If we take $N \approx 1\cdot 10^{-2}\text{s}^{-1}$ and typical value $b = 0.03\text{m}^2\text{s}^{-3}$, then the time of reaching 18 km by convection would be several days. This clearly illustrates the importance of the small static stability. We assume $N = 3\cdot 10^{-3}\text{s}^{-1}$ which corresponds to the difference of only about $0.3\,{}^{\text{K}}\!/_{\text{km}}$ between the actual and the dry adiabatic temperature gradient while normally the difference is $(9.8-6.5) = 3.3\,{}^{\text{K}}\!/_{\text{km}}$. Fig.4a,b presents the non-dimensional criterion (25) on the plane $(\Delta T, T_s)$. The curves with number larger or equal to 1 (thick curve for the last case cover the area of the parameter space with a possibility of a TC development at 20°N in 11 hours or $4\cdot 10^4\text{s}$. Due to the independence of the multiplier A in (25) on either ΔT or T_s this graph has a wide interpretation. E.g. the curve labeled 0.8 can become the thick curve labeled 1 if we enlarge A by a factor 1.25 by increasing time by 1.25^2=1.5625, or decreasing N by a factor 1.25.



a)



b)

Fig. 4. Diagram for tropical cyclone, TC origin conditions depending on sea surface temperature T_s and the difference $\Delta T = T_s - T_a$, where T_a is the atmospheric temperature at

At $z = 10$ m reference height z=10m. a) For relative humidity r=0.8 and b) for r=0.7. The thick line 1 is the critical curve where development of a TC becomes possible in the parameter space to the right above this curve. (*The figure captions for paper Hurricanes, by G.S. Golitsyn*)

Figs.4a and 4b differ only by the values of the relative humidity *r* of the atmosphere. Changing *r* at Fig.4a from 0.8 to *r*=0.7 at Fig.4b increases the Bowen ration by a factor of 1.5. Only this replacement decreases the necessary temperature difference ΔT to a fraction of a degree, still presenting a possibility for TC formation at high SST.

At Fig.5 we present similar results for polar lows or PL_s, at $\Theta = 70^\circ N$ and $\Theta = 70^\circ N$, $N = 1 \cdot 10^{-2} s^{-1}$ $t = 2 \cdot 10^4 s = 5.5h$. Here the necessary temperature difference is about 25K, or larger. This is an agreement with results of simulation of PL s[27] requiring $\Delta T > 20\text{K}$ in order to form such vortices. The same kind of reinterpretation, as for TC case, can be made here with curves labeled with different numbers around 1. One should also note that similar conditions might be also applicable to VHT, vertical hot tower formation.

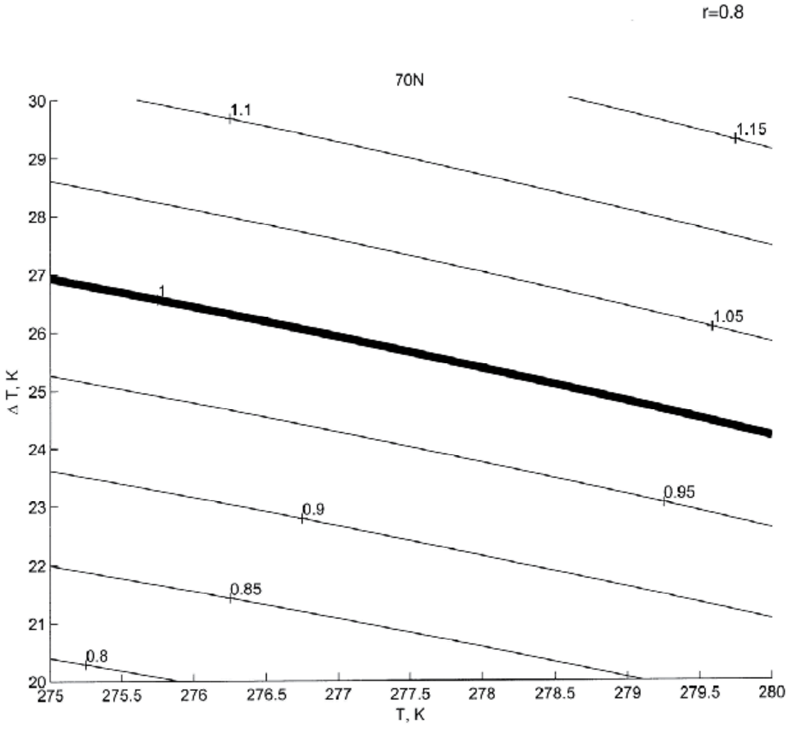


Fig. 5. Same as at Fig.4.but for the origin of a polar low, PL, at r=0.8 (*The figure captions for paper Hurricanes, by G.S. Golitsyn)*

In [13,14] there are also velocity, estimates for IAVs using the boundary layer energy balance [24] which is independent from Coriolis parameter. These estimates for conditions used for construction of our Fig.4 and 5 give results within 20% of the presented above on these figures. However, the last estimates require more *ad hoc* parameters and therefore suffer more uncertainties.

5. Problems associated with IAVs origin

The potential area should be large enough or at least greater than the scale of a generated vortex *d* presented by eq.(18). The necessary homogeneity of the water surface temperature leads to a condition

$$\left(dT_s / dx \right) d << \Delta T = T_s - T_a \ , \tag{26}$$

where *x* is the horizontal coordinate.

The condition of the small vertical wind shear [4, 5] can be written as

$$t_{dvp} \Delta U << d \ , \tag{27}$$

where t_{dvp} is the time of the vortex development and $\Delta U = \left(dU / dz \right) h$ is the ambient wind velocity difference between the lower and upper parts of the developing vortex. These two conditions are enough for the energy supply to feed the development of the vortex, which should not be sheared apart.

Emanuel [7] noted in his review that there could be several mechanisms for the origin of a TC. The observations show that TC is always originating from a tropical depression, TD. But only a small part, about one tenth, of them may develop a hurricane. TD_s are accompanied by developing vortical hot towers, VHT, reaching the tropopause and 20 to 30 km in diameters.

The analysis of satellite images of TD_s preceding the formation of a TC, shows that normally there are about 20-30 VHT in a TD. But to develop a TC there should be more VHTs, about 30÷40 as revealed the analysis in 1980s at the Colorado State University. In the extensive series of computations [30-32] it was demonstrated how VHTs develop, acquire initial vorticity, and merge by bringing in this way the planetary angular momentum of the ambient air from thousands of kilometers away. In [14] one can find an analysis of vorticity balance at merging 40 VHTs with their initial azimuthal velocities of only 0.5 m/s may produce a TC with the maximum velocity of 40 m/s at the distance of 50 km from the center of the TC. There is a review [14] of theoretical works in hydrodynamics on the process of merging vortices of the same sign.

The presence of an initial vortex [4, 5], or forming it at an initial stage of a TC generation is a very important condition. For instance the cyclone over Black Sea (Fig.2) at the end of September 2005, successfully modeled in [34] by a MM5 model, could not be formed without such a vortex brought in by Balkan cold air. Such a necessity was also clearly demonstrated by a series of the 3D high resolution computations initiated by Montgomery (see [32] and references therein). It was shown there that the full extent of the wind-induced surface heat exchange follows the stage of the initial vortex formation which could start even at the nominal trade wind velocities of order 10 m/s. This vortex is intensified by locally buoyant VHTs and near surface convergence induced by them within the boundary layer.

A number of numerical studies [33-35] reveal that a TC may be formed from a random convection patterns without systematic initial winds if the integration is long enough, 5÷15 days. Most of these computations assume initial temperatures and its and humidity profiles from [36] where T_s=28°C. It is due to cooperative interaction between large-scale moisture in the troposphere, locally enhanced sea-surface fluxes leading to aggregation of convection [33], in other words merging of VHTs.

There is a hope that during nearest year's extensive high-resolution computations together with specially organized field campaigns would clarify the ways for TCs formation, possibly not just one way.

We see that TCs may be formed at temperature difference of a fraction of a degree and small static stability of the atmosphere, for which we should know rather precisely the temperature and humidity profiles in the boundary lager. All these is unattainable with the present satellite instrumentation and data retrieval techniques. This suggests that operational forecast of place and time of a TC origin is a matter of a distant future, if possible at all. What present weather forecasting operational models can perform that to follow the track and intensity evolution of a TC. The precision of the performance is improving but its further improvement is highly desirable. With PL_s the situation is better: when cold polar air masses intrude over open water and temperature difference between air and water surface is 20-40K the disequilibrium is striking and forecasts are easier.

Importante question is what would happen to TCs in a warmer climate. This is one of the most important areas for IPCC kind of studies. There is a large number of papers already, starting with [37] analyzing empirical evidence. It is concluded that if the number of TC_s may not increase but their destructiveness proportional to U^3 is increased during the last 30 years when signs of global warning became obvious. There are several modeling studies, e.g. [38, 39] but model result are still inconclusive for a global number of TCs, especially for various basins: Atlantics, Pacific, etc. Though the areas with $T_3 \geq 26^{\circ}C$ are greatly increasing the other conditions essential for a TC formation may change. At the moment a general result of [37] may be valid but one should wait for more conclusive results in the 5th IPCC Report in 2014.

6. Conclusions

The intense atmospheric vortices considered here evolve from the thermodynamic disequilibrium between ocean and atmosphere, therefore their global monitoring could be done by satellites. The sizes of these vortices decrease in general to higher latitudes due to the earth rotation.

The static stability of the atmosphere also plays a role, increasing with latitudes. Some necessary conditions for their generation are described here revealing that the present remote sensing systems are not able to present necessary precision for determining the time a place for formation, especially for a TC. Therefore the observation of construction codes and warning systems must be in operation to reduce greatly the damage.

Global warning poses an important question on the evolution and behavior of these vortices in future: would their number increase together with their destructiveness? The present understanding, before the IPCC5 report in 2014, is that the number might still be under one hundred but the winds in them could be higher. Therefore the numerical modeling with higher than 1 km resolution is required. At present the improvement is urgent of weather prediction operational models in following the trajectories and evolution of these vortices.

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4

Tropical Cyclone Wind-Wave, Storm Surge and Current in Meteorological Prediction

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1. Introduction

Several researches in the earth system prediction have studied a delicate balance among ocean, land, ice, and atmosphere. The researchers have classified the scales in the meteorological prediction; the global, regional, coastal, synoptic, meso and other scales (Wittmann & Farrar, 1997). These discoveries raise new questions that now define the course of research for the coming three decades. From this scientific foundation, Earth System Science (ESS) cluster, The Joint Graduate School of Energy and Environment (JGSEE) must carefully formulate plans for requisite missions. The resultant next phase of research will extend our understanding of how ocean ecosystems, coastal sediment and erosion, coastal habitats, and hazards influence Earth's ecosystem health and services, human health, welfare, recreation, and commerce. ESS's Research Program will also enable the formulation of effective strategies for assessing, adapting to, and managing climate change through observations and improved Earth System modeling capabilities.

In this chapter, the recent events have illustrated the devastation and loss of human life, property, and commerce from environmental hazards that have impacted coastal zones (Fig. 1).

Fig. 1. Super Typhoon Durian on December 3, 2006 from the earth observatory using data provided courtesy of the MODIS Rapid Response Team and NASA Goddard Space Flight Center by Jesse Allen (2006), Hundreds of people in Viet Nam are homeless and the families search through hundreds of destroyed villages for loved ones by Live Science (2006).

Supporting over one quarter of the Thai population, coastal regions are increasingly vulnerable to both chronic and acute hazards. Coastal zone hazards include coastline sediment and erosion (Ekphisutsuntorn et al., 2010), flooding of low-lying areas, sea level rise, and plumes of noxious algae, toxins, pollutants, pathogens, and suspended matter. How can we best forecast, assess, and respond to the environmental hazards that shape our coasts and sustain the marine and human life dependent upon coastal resources?

To date, environmental hazard monitoring in the ESS cluster, JGSEE at King Mongkut's University of Technology Thonburi, Thailand has primarily focused on Atmosphere-Ocean-Coastal-based hazards, such as coastal erosive reduction, sediment transport, morphological evolution, flood, tropical cyclone wind-wave, storm surge, strong current, heavy rainfall and their impacts on the local countries. The environmental hazards, however, have tremendous impacts on the world's oceans, the communities residing along coastlines and the economies they support. Recent years have witnessed record-breaking natural hazards impacting coastal zones. Worldwide, the number of intense Category 4 and 5 hurricanes has nearly doubled since the 1970s.

A moving tropical cyclone is an intense source of surface wind stress and sea level pressure that causes many significant changes in ocean wind-wave, storm surge and current (WSC) characteristics (Wannawong et al. 2010d). These features have been well identified in open oceans in the western Atlantic/eastern Pacific regional seas, for example, the Hurricane Region (HR). A hurricane with an intense and fast-varying wind produces a severe and complex ocean wave field that can propagate for thousands of kilometers away from the storm center, resulting in dramatic variation of the wave field in space and time (Barber & Ursell, 1948). To investigate the wave characteristics, the directional spectra of hurricane generated waves were measured using various instruments. For example, the fetch effect was detected in the Celtic Sea using the high-frequency radar. The wave characteristics of the northeast Pacific during the passage of a storm were investigated by using the synthetic aperture radar image from the ERS-1 satellite (Holt et al., 1998). The spatial wave variation of hurricane directional wave spectra were identified for both open ocean and landfall cases using the NASA scanning radar altimeter (Wright et al., 2001; Walsh et al., 1989). The directional wave spectra from the ocean surface topography were computed by Hwang and Wang (2001). The ocean wave response identified in the HR has a significant right forward quadrant bias in the significant wave height (Hs). During the passage of Hurricane Bonnie (1998) in the Atlantic Ocean, both observational and modeling studies showed that the Hs reached 14 m in the open ocean (Wright et al., 2001; Moon et al., 2003). The maximum Hs appeared in the right forward quadrant of the hurricane center and propagated in the same direction as the hurricane. Moon et al. (2003) simulated the wave characteristics successfully using the wave model such as the WAVEWATCH-III (WW3) (Tolman, 1991) and found that the hurricane-generated wave field was mostly determined by two factors: the distance from the hurricane center or radius of maximum winds (represented by Rmax) and the hurricane translation speed. For the case of a hurricane with low translation speed, the dominant wave direction is mainly determined by the distance from the hurricane center.

However, most of the observational and modeling studies on ocean waves generated by tropical cyclones were focused in the HR. A few observational and/or modeling studies have been conducted in the Typhoon Region (TR), especially in the South China Sea (SCS) and the Gulf of Thailand (GoT). The topographical information of the SCS and GoT is shown in Fig. 2. Also due to its semi–enclosed nature, the SCS and GoT are subjected to high spatial and temporal variability from external forcing factors. One significant source of the SCS and GoT variability is the tropical cyclones that routinely affect the TR. The WW3 has been implemented and verified for the SCS using the TOPEX/POSEIDON satellite data (Chu et al., 2004). For the storm surge, an abnormal high sea level phenomenon is generated by very low pressure accompanied with very strong wind (tropical cyclone). Naturally, water can flow freely in the open sea in duration of the occurring of tropical cyclone, but not on land. Therefore, the water is piled–up at the shore and spilled over lands. This causes serious hazards to coastal regions, such as flooding, coastal erosion, etc., and devastating the residential properties in those areas. In the GoT, the tropical cyclones affecting Thailand usually take a course from the Western North Pacific Ocean or the South China Sea (SCS). The extreme of tropical cyclones is typically characterized by wind speed and a pressure drop at the eye of the storm. The GoT is subjected to the monsoon system which influences the surface currents clockwise during the southwest monsoon and counterclockwise during the northeast monsoon. The GoT is affected by tropical cyclones because of its location farther inland. However, WSC characteristics have not been well identified in the GoT. There were seven severe typhoons that previously passed through the GoT (Typhoon Vae in 1952, Tropical Storm Harriet in 1962, Typhoon Gay in 1989, Typhoon Becky in 1990, Typhoon Fred in 1991, Typhoon Forrest in 1992 and Typhoon Linda in 1997). The occurring

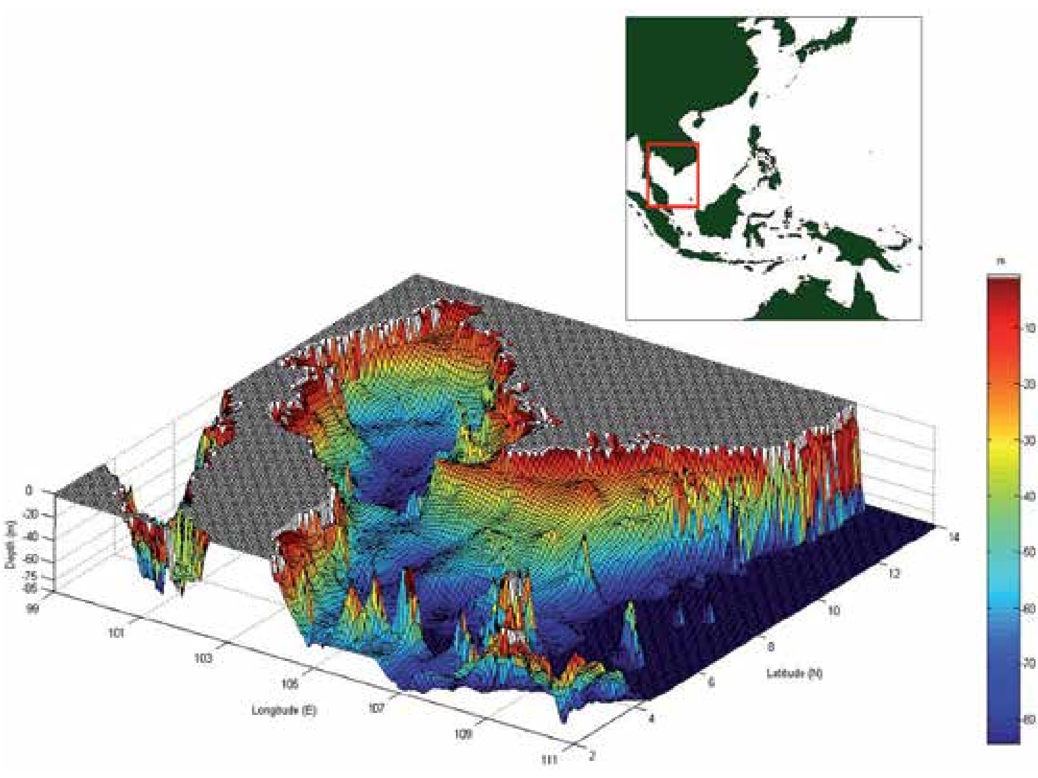

Fig. 2. Bathymetry in a three dimensional perspective with depth (in meters)

frequency of the tropical cyclone is approximately once in every two years and some can cause severe damage to lives and properties in the coastal area. For example, in 1962, Tropical storm Harriet hit Leam Talumpuk, NakornSriThammarat province and caused severe damages to the area including more than 900 casualties. In 1989, Typhoon Gay hit Chumporn province causing serious disaster, such as destroying the agricultural lands (about 183,000 hectare (ha) or 1.83×10^9 m^2), killing over 400 people, and directly affecting 154,000 people. In 1997, Typhoon Linda striked at Thupsake, PrachuapKirikhan province, resulting in 30 people death, 102 people missing, and more than 400,000 Rai (6.4×10^8 m^2) of agricultural land destroyed. Therefore, the warning WSC system is needed for people who live in risking regional and coastal areas. At present, there is no such the favorable warning of WSC system for the regional and coastal regions in Thailand. This chapter was to examine how WSC affects the regional and coastal areas in the SCS and GoT, and to modify the meteorological models to predict the WSC characterized by tropical cyclones in the SCS and GoT. In this chapter, Typhoon Linda in 1997 was firstly studied to serve as inputs in the meteorological model predictions and useful in the test cases of Typhoon Muifa in 2004 and Typhoon Durian in 2006 respectively.

2. Methodology

The methods and steps to study the cyclone WSC characteristics in the SCS were described in this section. The cyclones generated and entering the study domain (Fig. 2) were chosen according to the statistical data obtained from the Joint Typhoon Warning Center (JTWC) and the Thai Meteorological Department (TMD). The meteorological prediction models were applied to simulate WSC as considered under the statistical data which presented in Section 2.1. The histories of three typhoons were given in Section 2.2. The model description was described in Section 2.3. Finally, the model setting and implementation were explained in Section 2.4.

2.1 Statistical data of tropical cyclone

The yearly statistical data in 1951 to 2009 of the TMD were reported that there were only 3 severe tropical cyclones generated in the GoT: Typhoon Vae in 1952, Super Typhoon Gay in 1989 and Typhoon Linda in 1997. Typhoon Gay was classified as the category 1 in the GoT. It then made landfall in the southern part of Thailand and upgraded to the categories 2 and 3. It began to weaken slightly (category 1) as it moved out of Thailand. It upgraded back to the category 5 as it approached land in India. Typhoon Linda behaved as the category 1 in the GoT. It was influenced by Super Typhoon Keith (category 5) entering the Pacific Ocean nearby the Philippine Islands and also the local wind. In term of numbers of tropical cyclone, 18 tropical cyclones were the maximum number reported in 1964 to 1965. They were classified as 17 tropical depressions and 1 tropical storm. According to the statistical data, it was found that the numbers of tropical cyclone decreased since 1965 to 2009 as shown in Fig. 3.

The yearly statistical data in 1951 to 2009 considered as monthly data were found that the tropical cyclone was not found during January to March. The maximum number of tropical cyclone was reported in October with totally 51 tropical cyclones. They were classified as 47 tropical depressions, 3 tropical storms and 1 severe tropical cyclone which were Typhoon Vae in October 1952. In November, 2 severe tropical cyclones which were Super Typhoon

Gay in 1989 and Typhoon Linda in 1997 were reported as presented in Fig. 4. The third highest numbers of tropical storm were found in September, October and November with the percentages of 26, 28 and 16% respectively. Thus, the data suggest that the severe tropical cyclones in Thailand generally found as the winter storm (Fig. 5). From the statistical data, the characterizations of three severe winter storms: Typhoon Muifa 2004 (category 4), Super Typhoon Durian 2006 (category 5) as well as Typhoon Linda in 1997 (category 1) entering our study domain were studied as illustrated in Fig. 6.

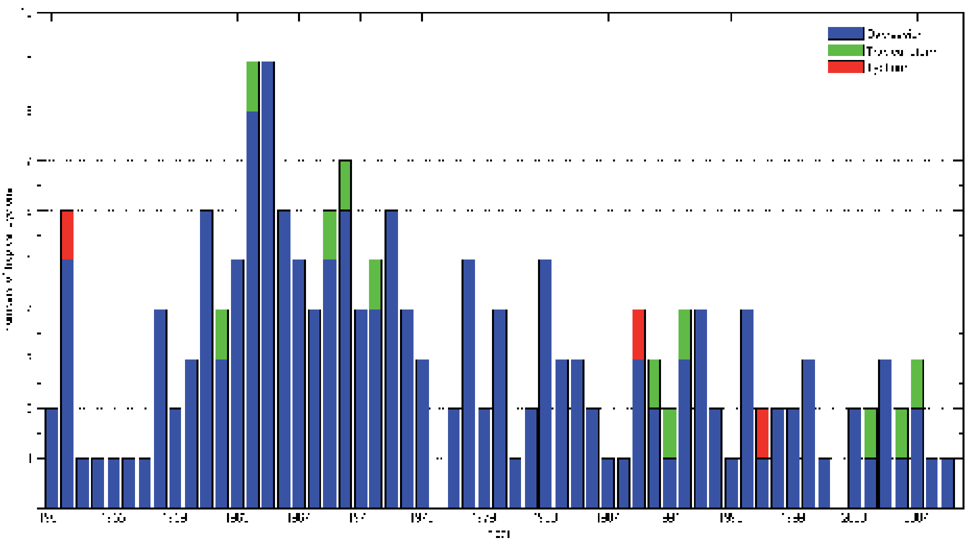

Fig. 3. Numbers of tropical cyclone passing the SCS, Thailand and entering the study domain in 1951–2009

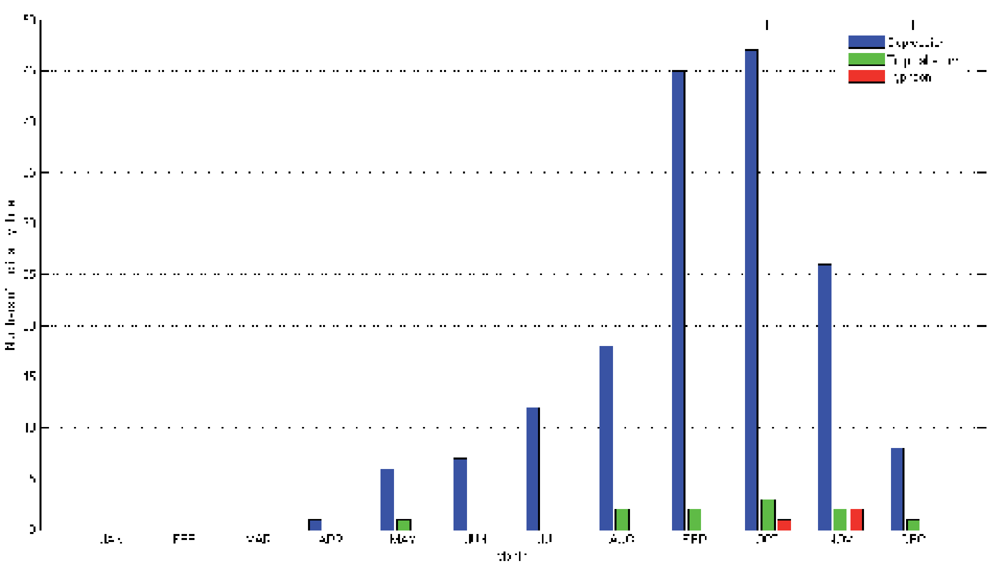

Fig. 4. Numbers of tropical cyclone passing the SCS, Thailand and entering the study domain during January–December in 1951–2009

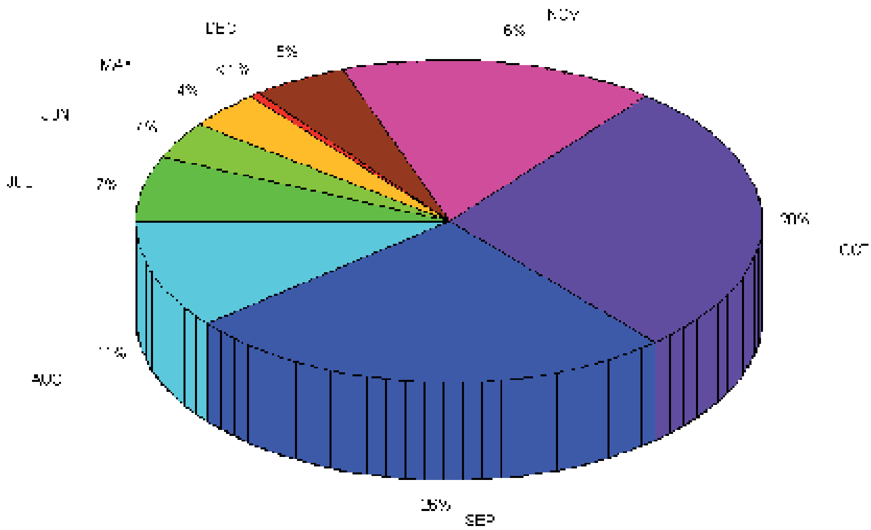

Fig. 5. Percentages of numbers of the tropical cyclone passing the SCS, Thailand and Entering the study domain during January-December in 1951 -2009

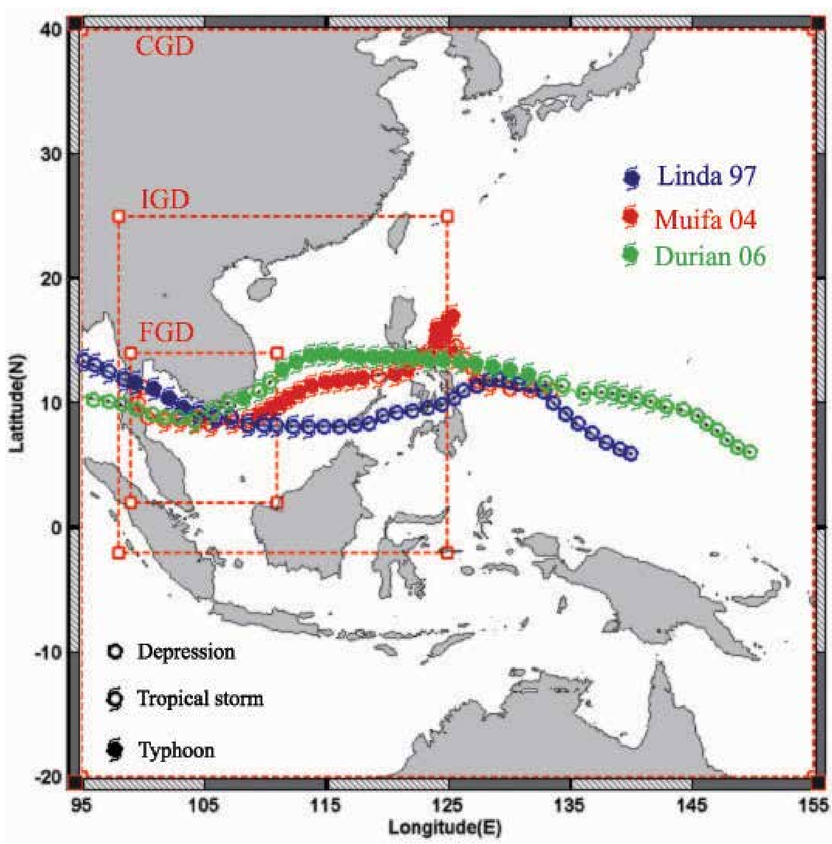

Fig. 6. Three steps of the standard one–way nested grid with Typhoon tracks

2.2 History of tropical cyclone

Typhoon Linda formed as the tropical disturbance on October 26, 1997 within an area of convection east of the Philippine Islands which is near 130°E in longitude and 10°N in latitude. It then moved westward under the subtropical ridge to the north. When entering the SCS, Typhoon Linda transformed into a tropical storm and moved westward to the southern tip of Cape Camau of Vietnam at 0900 UTC on 2 November with the intensity of 55 knots (28 m s^{-1}). After that, it approached the GoT around 00.30 UTC on 3 November with typhoon intensity in a range of 64-82 knots (approximately 33-42 m s^{-1}) (Fig. 7) and turned northwestward following steering from the subtropical ridge. Its strength weakened as it encountered mountains in Prachaubkirekhun province, Thailand. After crossing over the Andaman Sea, it reconsolidated and became typhoon once again at 00.00 UTC on 6 November.

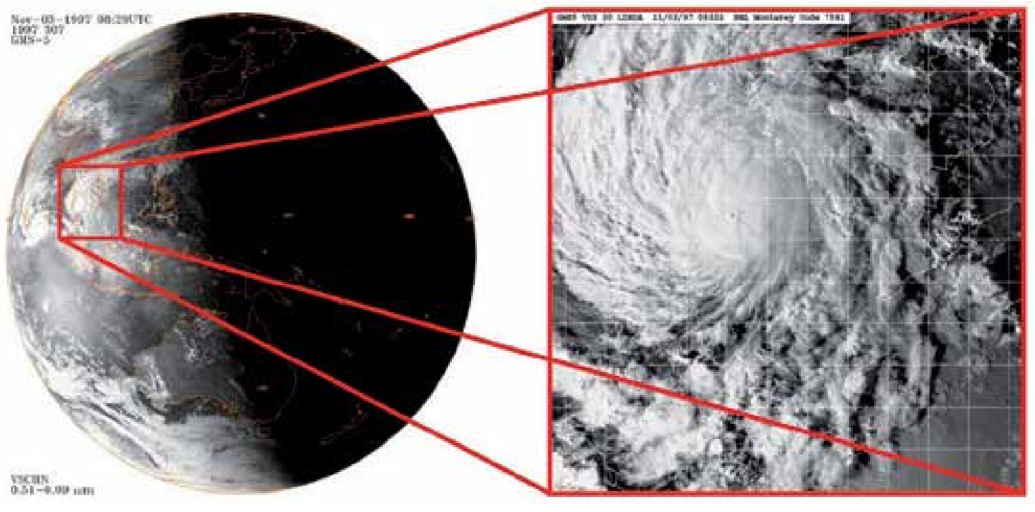

Fig. 7. GMS-5 visible images of Typhoon Linda at 08.29 UTC and 09.32 UTC on November 3, 1997 when it located at center of the GoT.

Typhoon Muifa generated as a tropical depression on 11 November 2004 in the Western North Pacific Ocean. It moved steadily northwestward through north of Palau before entering the Philippine Sea. It was firstly mentioned by the JTWC at 16.00 UTC on 13 November, approximately 400 km north of Palau. It became a tropical storm on 14 November and was named as Muifa by the Japan Meteorological Agency (JMA). On 18 November, the intensity of Typhoon Muifa was peaked at 115 knots (54 m s^{-1}). It went west-southwestwards across the SCS and its intensity reached the second peak of 90 knots (46.3 m s^{-1}) at 18.00UTC, approximately 800 km east of Vietnam. Typhoon Muifa entered Vietnam on 22-23 November and weakened again. The maximum velocity was further decreased to 45 knots (23.2 m s^{-1}) at 12.00 UTC on 24 November. Typhoon Muifa continuously weakened to 30 knots (15.4 m s^{-1}) and downgraded to tropical depression at 12.00 UTC on 25 November. At 00.00UTC on 26 November, its final position was 250 km south-southwest of Bangkok, Thailand.

Typhoon Durian was designated as a tropical depression on 25 November. It then was upgraded to a tropical storm at 06.00UTC on 26 November. It intensified slowly and moved west to west-northwestward with the intensity of 35 knots (18 m s^{-1}). Then it was intensified to 50 knots (25.7 m s^{-1}) on 27 November and became a severe tropical storm. On November 28, it continued to track towards the Philippines. Rapid intensification occurred on November 29, causing the JMA to upgrade the storm to 100 knots (51.4 m s^{-1}) in wind intensity. It began to weaken slightly as it approached land but quickly regained peak strength. It made landfall on 30 November over southern Catanduanes. It then made another landfall after crossing the Lagonoy Gulf in northeastern Camarines Sur. It finally moved to the SCS and made landfall in Ben Tre Province, Vietnam on 5 December with the decreased intensities from 55 to 25 knots (28.3 to 12.9 m s^{-1}). It rapidly weakened over land, and it was downgraded to a tropical storm by JMA.

(a) (b)

Fig. 8. MODIS-Aqua 250 m imagery of Typhoon Muifa (a) and Super Typhoon Durian (b) at 04.55 UTC on November 17, 2004 and at 05.00 UTC on November 30, 2006, respectively.

2.3 Model description

The wind-wave model is based on the WAve Model Cycle 4 (WAMC4) to simulate the surface wave (WAMDI Group, 1988; Komen et al., 1994) and the hydrodynamic model is based on the POM model including the storm surge and current modeling components to simulate the storm surges and current fields (Blumberg and Mellor, 1987). Both models were used to simulate the impacts of Typhoon Linda 1997, Typhoon Muifa 2004 and Super Typhoon Durian 2006 in the meteorological prediction. This section briefly described the information of WSC models.

2.3.1 Wind-wave model

In the absence of diffraction and currents, the spectral energy balance equation which is the basic equation of spectral wave model in Cartesian coordinates, is (e.g., Komen et al., 1994)

$$\frac{\partial E}{\partial t}+\frac{\partial (c_x E)}{\partial x}+\frac{\partial (c_y E)}{\partial y}+\frac{\partial (c_\theta E)}{\partial \theta}=S_{tot} \quad (1)$$

where $E(t, \boldsymbol{x}, f, \theta)$ is the energy density of wave, t is the time, $\boldsymbol{x}$ is the Cartesian coordinates that are geographical space (x, y), f is the frequency, θ is the wave direction measured clockwise from the true north, c_x and c_y are the propagation velocities of the group velocity c_g in geographical space and c_θ is the propagation velocity in spectral space (directional space). These propagation speeds are taken from the linear theory of surface gravity waves without the effects of diffraction. The governing equation for the WAMC4 model (Eq. 1) in the spherical coordinates reads (WAMDI Group, 1988),

$$\frac{\partial E}{\partial t}+\frac{\partial (c_\lambda E)}{\partial \lambda}+(\cos\phi)^{-1}\frac{\partial (c_\phi \cos\phi E)}{\partial \phi}+\frac{\partial (c_\theta E)}{\partial \theta}=S_{tot} \quad (2)$$

where $E(t, \boldsymbol{x}, f, \theta)$ is the energy density of waves, $\boldsymbol{x}$ is the spherical coordinates that are geographical space (λ, ϕ), c_λ and c_ϕ are the propagation velocities of the group velocity c_g in the geographical space and c_θ is the propagation velocity in the spectral space. The left–hand side of Eqs. (1)-(2) is the regional scale (e.g. GoT). It represents the local rate of change of wave energy density in time, propagation in geographical space, and shifting of frequency and refraction due to the spatial variation of the depth and current. The right–hand side of both equations (S_{tot}) shows all effects of generation and dissipation of the waves in deep water including wind input (S_{in}), white capping in dissipation (S_{ds}) and non–linear quadruplet wave–wave interactions (S_{nl}) in deep water. These equations, however, ignored the current interactions in this study. In shallow water, both equations need to be extended to include an additional source function (S_{bf}) representing the energy loss due to bottom friction and percolation. The bottom friction dissipation term (S_{bf}) represented the formulation proposed during JONSWAP (Hasselmann et al., 1973),

$$S_{bf}=-\frac{\Gamma}{g^2}\frac{\omega^2}{\sinh^2 kD}E \quad (3)$$

with Γ = 0.038, ω is the angular frequency ($\omega^2 = gk\tanh kD$), g is the gravitational acceleration, k is the wave number and D is the finite depth dispersion relation.

2.3.2 Storm surge and current model

The Princeton Ocean Model (POM) is based on the hydrodynamic model which is a three–dimensional, nonlinear, primitive equation with the finite difference ocean model (Blumberg and Mellor, 1987). The POM model uses a mode–splitting technique that solves the barotropic mode (2D) for the free surface and vertically averaged horizontal currents, and the baroclinic mode (3D) for the fully three–dimensional temperature, turbulence, and current structure. The equations are written in the sigma vertical coordinate system and include a turbulence closure parameterization with an implicit time scheme for vertical mixing. These are the vertically integrated nonlinear continuity and horizontal momentum equations, which solve the water level and the horizontal components of velocity (*u, v*). In the present work, these equations were modified by the storm surge applications to simulate the storm surges and currents in the 2D and 3D modes respectively. At the sea surface boundary, the model was forced by wind stress and atmospheric pressure of Typhoon Linda, whereas tidal forcing, current and river outflow at the lateral boundary conditions were not considered. The typhoon pressure field and surface wind velocity created by the pressure gradient were modeled following the Bowden (1983) and Pugh (1987) relationships:

$$\frac{\partial p_a}{\partial \eta} = -\rho g, \tag{4}$$

$$\frac{\partial \eta}{\partial x} = \frac{\rho_a C_d V_c^2}{\rho g d}, \tag{5}$$

where p_a is the atmospheric pressure, η is the sea surface elevation from the reference level of undisturbed surface, ρ is the density of sea water, g is the gravitational acceleration of Earth, x is the coordinate in the east–west direction, ρ_a is the density of air, C_d is the drag coefficient, V_c is the wind profile that results from the typhoon pressure gradient and d is the depth of sea water. According to Eq. (4), the pressure decreasing for 1 mb corresponds to about a 1 cm rise in sea level. The water depth (d) has inversely affected the sea surface elevation (η), whereas the wind speed at the specific height (10 m) directly affects the sea surface elevation.

The wind stress is computed through the following bulk formula:

$$\tau = \rho_a C_d \left|\overline{V}_w\right| \overline{V}_w, \tag{6}$$

where V_w is wind speed at height of 10 m, ρ_a is the density of air, and the drag coefficient, C_d, is assumed to vary with wind speed as:

$$10^3 C_d = \begin{cases} 2.5 & \text{if } \left|\overline{V}_w\right| > 22 \text{ m s}^{-1} \\ 0.49 + 0.065\left|\overline{V}_w\right| & \text{if } 8 \le \left|\overline{V}_w\right| \le 22 \text{ m s}^{-1} \\ 1.2 & \text{if } 4 \le \left|\overline{V}_w\right| < 8 \text{ m s}^{-1} \\ 1.1 & \text{if } 1 \le \left|\overline{V}_w\right| < 4 \text{ m s}^{-1} \\ 2.6 & \text{if } \left|\overline{V}_w\right| < 1 \text{ m s}^{-1} \\ 0.63 + 0.066\left|\overline{V}_w\right| & \text{for all } \left|\overline{V}_w\right| \\ 0.63 + \left(0.066\left|\overline{V}_w\right|^2\right)^{1/2} & \text{for all } \left|\overline{V}_w\right|. \end{cases}$$

This C_d formula follows Large and Pond (1981) when the wind speed is less than 22 m s^{-1}, otherwise, it is assumed as a constant as indicated in Powell et al. (2003). In the present study, the last condition was selected. The horizontal momentum equations consist of local time derivative and horizontal advection terms, Coriolis deflection, sea level pressure gradient, tangential wind stress on the sea surface, and quadratic bottom friction. The system of equations is written in flux form and solved using a finite differencing scheme that is centered in time and space on the Arakawa C grid.

2.4 Model setting and Implementation

The operational WSC model system contained three domains, which covered the Pacific Ocean, SCS and GoT (Fig. 6), in order to study the impacts of strong WSC generated by Typhoon Linda, Typhoon Muifa and Super Typhoon Durian.

The wind-wave (WAMC4) model required the topographical data and input wind fields to be specified for each grid cell in each grid domain. The topographical data was obtained from ETOPO5, ETOPO1 and Royal Thai Navy (Amante and Eakins 2008; Edwards 1989; Wannawong et al. 2010a). The ETOPO5 was updated in June 2005 for deep water conditions and it was applied in the CGD in this study. The ETOPO1 (Bedrock version) was applied in both IGD and FGD. The bathymetry data obtained from the Royal Thai Navy was only applied to the FGD which is shown in Fig. 9. The merging of the Royal Thai Navy data, ETOPO1 and ETOPO5 data, and the nested grid method were described in the previous studies (Wannawong et al. 2010a; Wannawong et al. 2010b; Wannawong et al. 2010c; Wannawong et al. 2010d; Wannawong et al. 2011b). The wind fields at 10-meter height were obtained from the U.S. Navy Global Atmospheric Prediction System (NOGAPS) model with 1×1 degree data resolution. Linear interpolation was used to generate the wind data to the grid points (Hogan and Rosmond 1991). The CGD covering the Pacific Ocean with the closed boundary condition was applied with a resolution of 0.5 degrees. The domain covered the area of storm generation from 95°E to 155°E in longitude and from 20°S to 40°N in latitude, which gives 121×121 grid points for both latitude and longitude. The IGD covering the SCS with the open sea condition has a resolution of 0.375 degrees. It covers from 98°E to 125°E in longitude and from 2°S to 25°N in latitude, which gives 109×109 grid points for both latitude and longitude. Finally, the FGD with open sea condition in the GoT was set to 0.25 degrees resolution. The FGD covers from 99°E to 111°E in longitude and from 2°N to 14°N in latitude, which gives 49×49 grid points for both latitude and longitude. Both propagation and source time steps of CGD, FGD and IGD were set to 1800, 1200 and 600 s, respectively (Wannawong et al. 2011c).

The storm surge and current (POM) model required the input bathymetry data, atmospheric forcing (wind and pressure fields), temperature and salinity at each grid point (Wannawong et al. 2008). The bathymetry data was taken by merging of the Royal Thai Navy data, ETOPO1 and ETOPO5 data. The wind and pressure fields were obtained from NOGAPS with 1×1 degree data resolution (Hogan and Rosmond, 1991; Harr et al., 1992). The temperature and salinity with 1×1 degree data resolution provided by Levitus94 (Levitus and Boyer, 1994; Levitus et al., 1994) were indicated by the climatological monthly mean fields in the model. The domain covered from 99°E to 111°E and 2°N to 14°N with high resolution of 0.1×0.1 degree spatial grid size which gave 121×121 points by using the bilinear interpolation of these data in the horizontal coordinate. In the vertical coodinate, 21 sigma levels were employed for adequacy and computational efficiency. The nested grids were not included in this model version. The model integration was divided into spinup and simulation phases. The model was integrated with all three components of velocity initially set to zero in the spinup phase of the model run. The model time steps were 20 s and 1200 s (20 min) for the external and internal time steps respectively (Wannawong et al. 2010d; Wannawong et al. 2010e; Wannawong et al. 2011a, Wannawong et al. 2011c). Finally, the results of both models were presented in every hour of Typhoon Linda, Typhoon Muifa and Super Typhoon Durian passing through the GoT. The simulation was started at 00UTC on October 20 and ended at 00UTC on November 10, 1997 for Typhoon Linda. In Typhoon Muifa, the simulation was performed from 00UTC on November 10 to 00UTC on November 28, 2004. Finally, the simulation was started at 00UTC on November 21 and ended at 00UTC on December 9, 2006 for Super Typhoon Durian. The results of the both models were stored every hour for the duration of the simulation. The stability of both models was computed according to the Courant–Friedrichs–Lewy (CFL) stability condition.

Fig. 9. Bathymetry data (annotated excerpt from the Royal Thai Navy).

3. Meteorological prediction results

The meteorological predictions of wind–wave and coordinate propagation with the flag condition of the WAMC4 model, and the storm surge and current of the POM model in the barotropic and baroclinic modes were analyzed. The meteorological predictions of the WSC generated by Typhoon Linda were firstly considered. The Hs, storm surge and current related with the wind field and sea level pressure during the passage of Typhoon Linda in each domain is shown in Figs. (11)–(12). In the CGD, Super Typhoon Keith 1997 was also found in the Pacific Ocean while Typhoon Linda was in the SCS (Fig. 11). Along the best track (Fig. 6), the FGD presented the wind field, wind stress and pressure drop related with the Hs, sea surface elevation and current (Figs. (11)–(12)). The meteorological predictions did not only present the Hs, peak surge and current but also showed the coastal water level drop and the energy loss of waves due to the bottom friction and percolation in the coastal zone (Figs. (11)–(12)). The effects of the extreme Hs, sea surface elevation and current, and the difference between the maximum Hs, sea surface elevation and current computed by the WAMC4 and POM models at four locations of buoy (B1-B4) and ten locations of tide gauges station (S1- S10) in the GoT region (Fig 10) were calculated. The results of the WAMC4 model showed that the Hs at B1, B2 and B3 were similarly different while at the station B4 showed a markedly different (Hs). The results of the POM model showed that the maximum storm surge and current at each station presented the similar values and also showed the similar trends with the observational data, except those of the stations S5, S6 and S8.

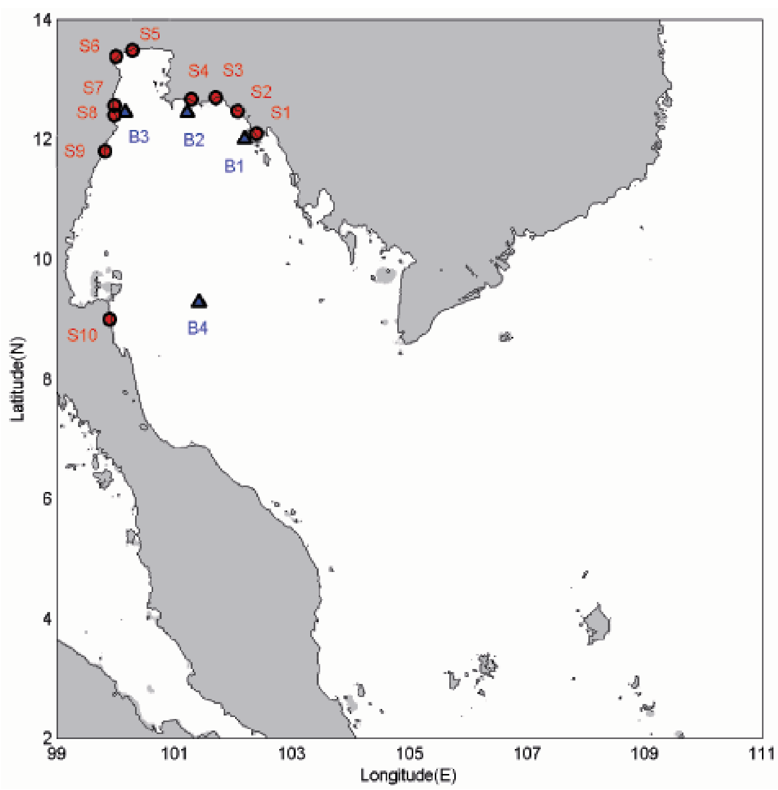

Fig. 10. Position of the observational data at each station inside the FGD

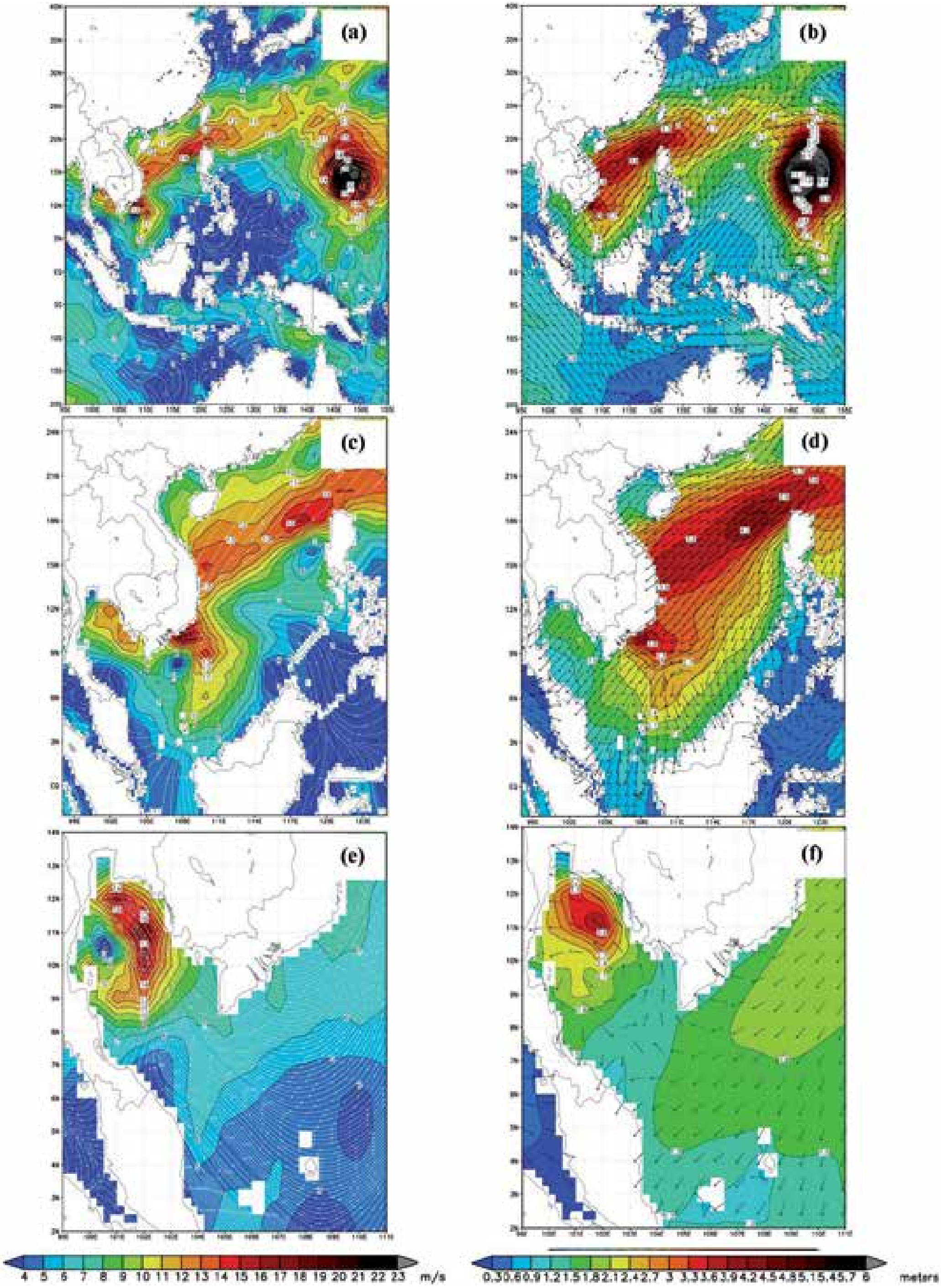

Fig. 11. Three pathway nested grids of wind streamline and speed (m s^{-1}), Hs (m) and its direction at (a) 23UTC01NOV1997, (b) 23UTC01NOV1997 and (c) 12UTC03NOV1997 in the CGD, IGD and FGD

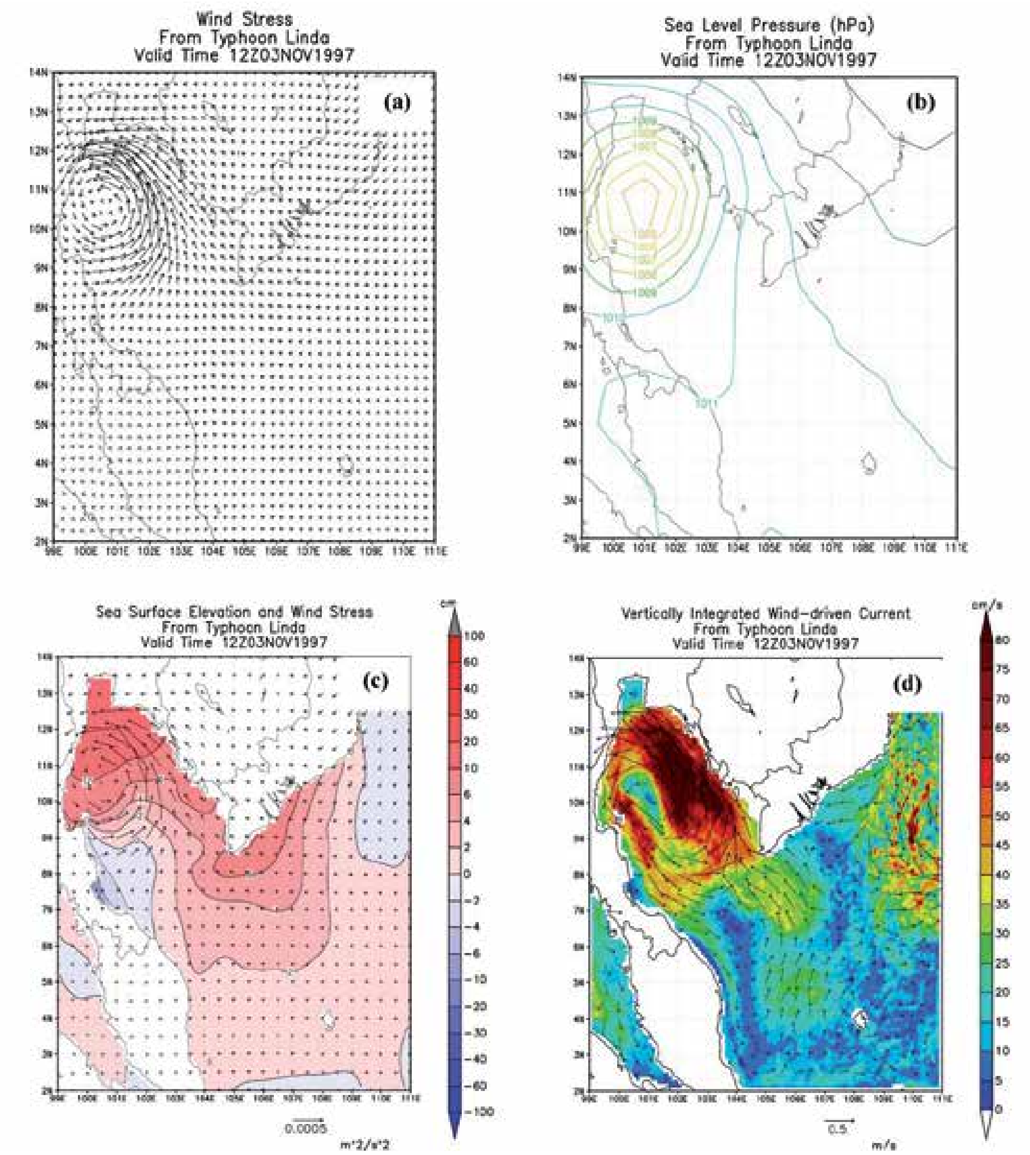

Fig. 12. (a) Wind stress (m^2s^{-2}), (b) Sea level pressure (hPa), (c) Sea surface elevation (cm) and wind stress (m^2s^{-2}) , (d) current (cm s^{-1}) and its directions at 12UTC03NOV1997 in the FGD

The Hs, storm surge and current related with the wind field and sea level pressure during the passage of Typhoon Muifa and Super Typhoon Durian only in FGD domain is shown in Figs. (13)–(18). Along the best track (Fig. 6), the FGD presented the wind field, wind stress and pressure drop related with the Hs, sea surface elevation and current (Figs. (13)–(18)). The meteorological predictions also present the Hs, peak surge and current with the coastal water level drop and the energy loss of waves due to the bottom friction and percolation in the coastal zone (Figs. (13)–(18)).

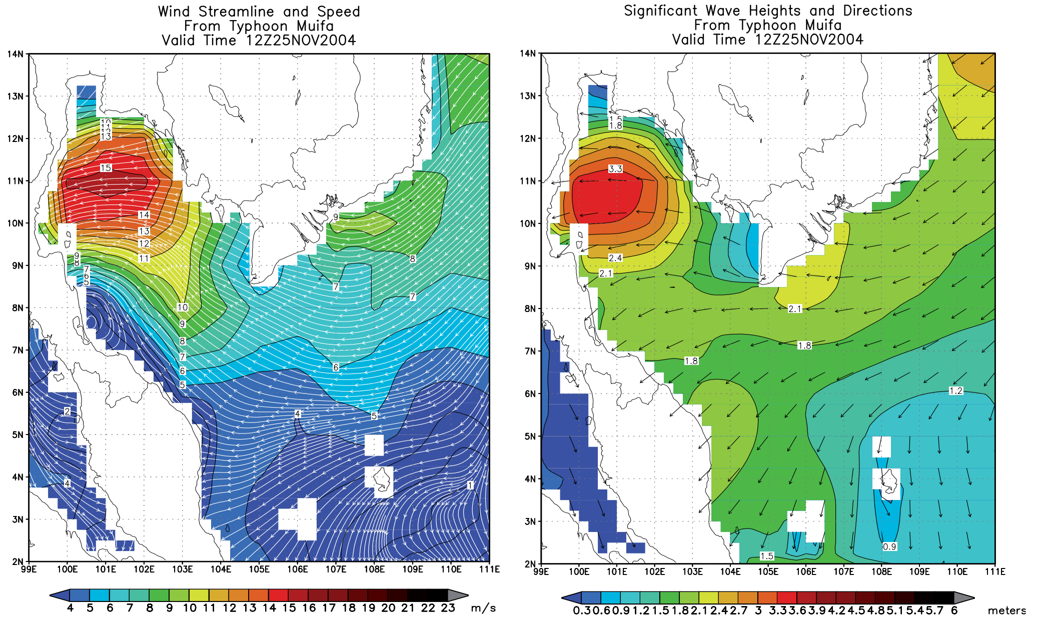

Fig. 13. (a) Wind streamline and speed (m s^{-1}) and (b) Hs (m) and its direction at 12UTC25NOV2004 in the FGD

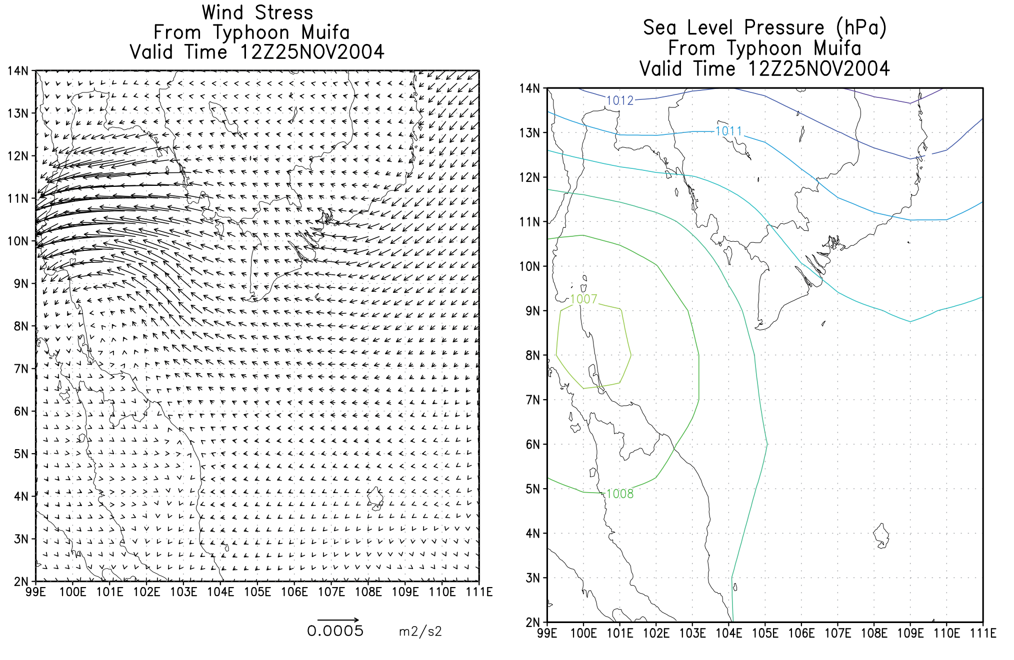

Fig. 14. (a) Wind stress (m^2 s^{-2}) and (b) Sea level pressure (hPa) at 12UTC25NOV2004 in the FGD

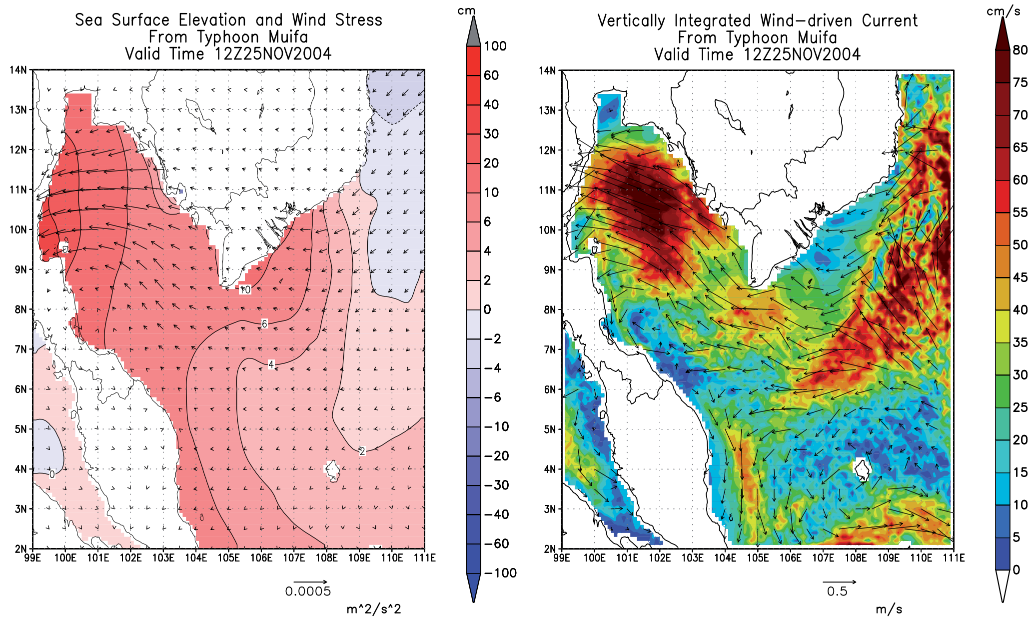

Fig. 15. (a) Sea surface elevation (cm) and wind stress ($m^2 s^{-2}$) ; (b) current ($cm s^{-1}$) and its directions at 12UTC25NOV2004 in the FGD

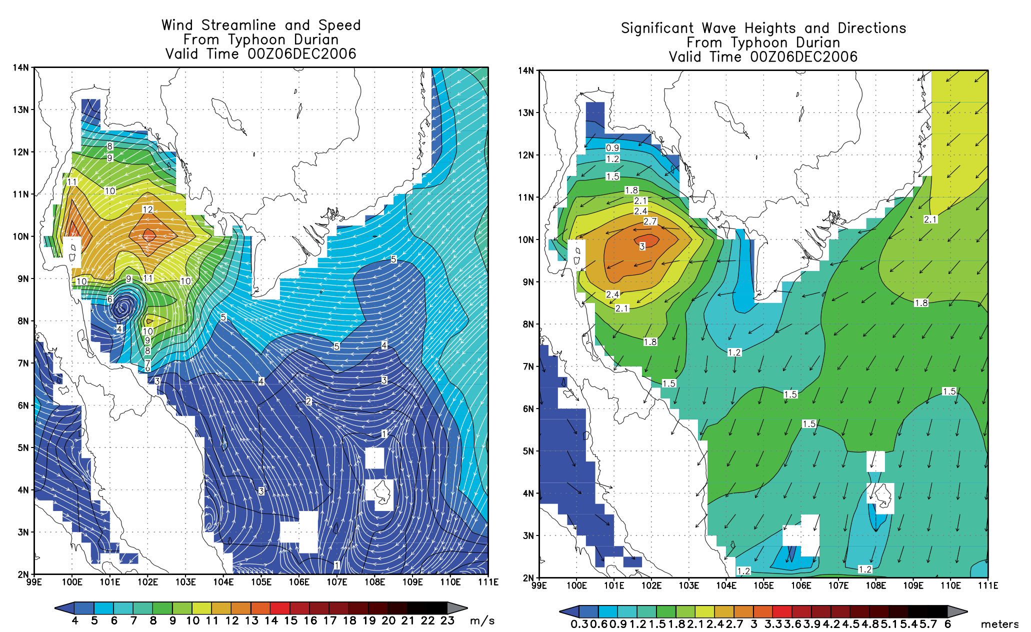

Fig. 16. (a) Wind streamline and speed ($m s^{-1}$) and (b) Hs (m) and its direction at 00UTC06DEC2006 in the FGD

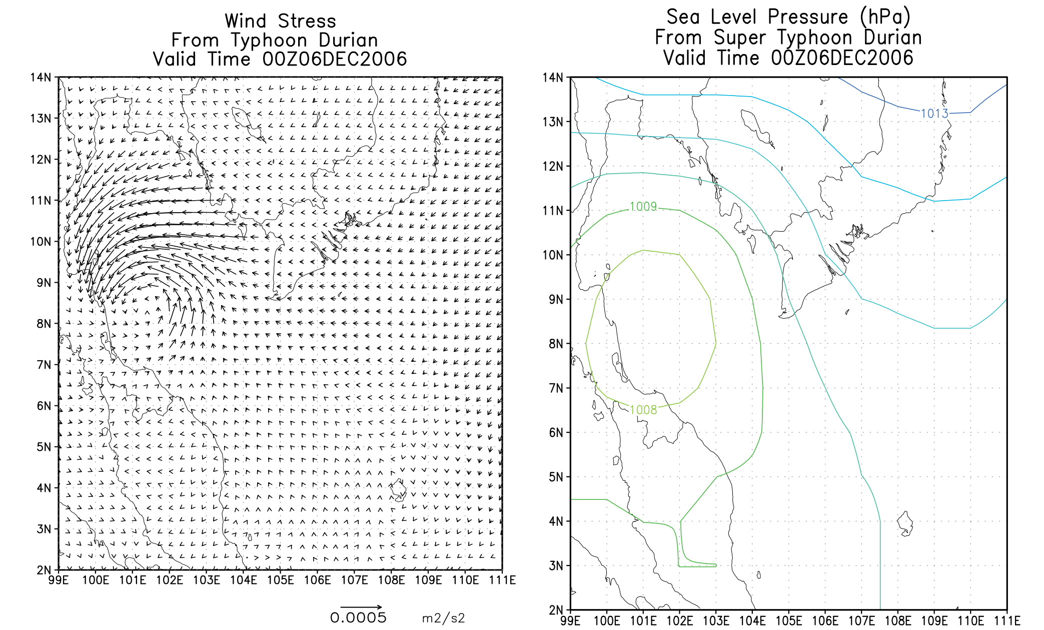

Fig. 17. (a) Wind stress ($m^2 s^{-2}$) and (b) Sea level pressure (hPa) at 00UTC06DEC2006 in the FGD

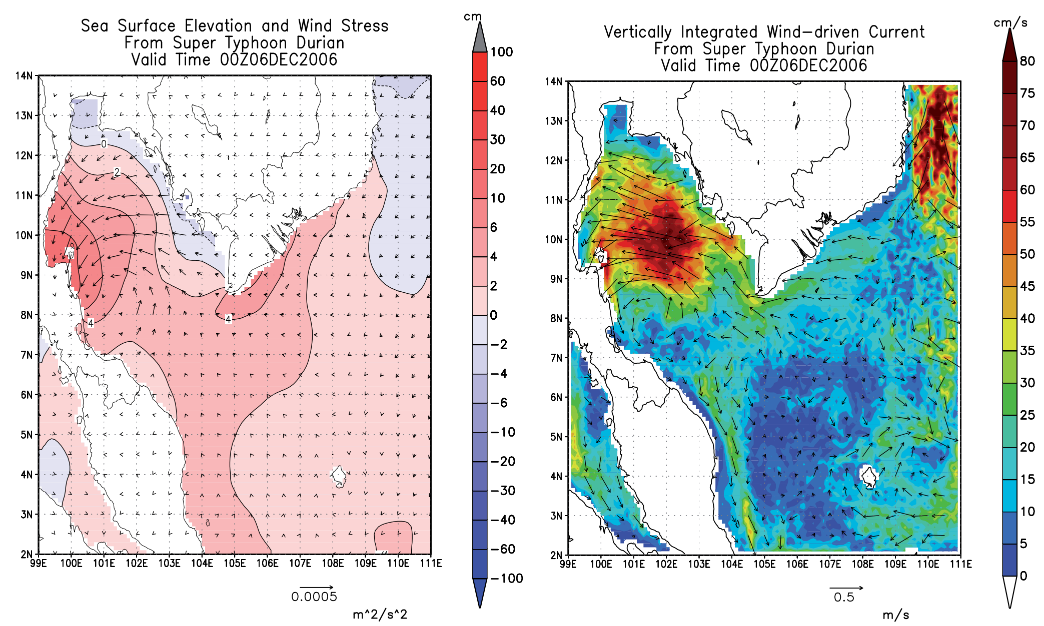

Fig. 18. (a) Sea surface elevation (cm) and wind stress ($m^2 s^{-2}$); (b) current ($cm\ s^{-1}$) and its directions at 00UTC06DEC2006 in the FGD

4. Discussion and conclusion

The results of both models are presented the incorporated Hs in the regional zone affects into the coastal storm surge zone. Specifically, the results are indicated that the WSC generally under the approximation is not only the peak surge but also the coastal water level drop which can also cause substantial impact on the coastal environment. The wind and sea level pressure fields induced the storm surge and current can significantly improve storm surge and current in the meteorological prediction. The both model system can be particularly useful to study wind-induced the WSC. The WSC in this study demonstrate the impact of severe storms in the GoT. The results indicate that Typhoon Linda was the most severe storm in 21 years according to data collected by the Joint Typhoon Warning Center (JTWC) and the Thai Meteorological Department (TMD). It can be explained that the passage of Super Typhoon Keith (1997) into the SCS led to the upgrading of Typhoon Linda from tropical storm to a category 1 typhoon. On the other hand, Typhoon Muifa and Super Typhoon Durian weakened when they approached the GoT and they were downgraded to tropical storms. Their wind intensities continuously decreased leading to decreasing the WSC. This is because the southern part of Vietnam is abundant in forests which act as natural walls to protect Thailand from storms and heat supplied from the warm sea. In addition, the steepness of topography also resulted in decreasing wave heights due to loss of energy as described in the results and discussion section. Finally, the results of impacts of the WSC obtained from this work will provide necessary data to study the coastal erosion caused by waves, and also the sediment transport and morphological evolution in the future.

5. Acknowledgements

The author would like to acknowledge the Earth System Science (ESS) Cluster, The Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi for kindly providing 2011 research fund to Dr. Worachat Wannawong. The author is thankful to Cdr. Wiriya Lueangaram for providing the numerical oceanic model codes and datasets. Finally, the author is greatly indebted to Mr. Michael Willing and Dr. Donlaporn Saetae for their English proofreading of my book chapter.

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5

Tropical Storms as Triggers for Intensified Flooding and Erosion Processes in Southernmost Mexico

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1. Introduction

Risks and disasters in Middle America

The Sierra Madre de Chiapas and the south-westwards adjacent coastal plain of the Soconusco at the southernmost tip of Mexico as well as the neighbouring south-western part of Guatemala must be considered as one of Middle America's most vulnerable regions to natural disasters. Among the regions of Middle America only Haiti suffered more from national catastrophes during the last century. Earthquakes are by far the most deadly events in Middle America with the great Haiti-seism in Jan. 2010 (223.000 casualties) and Guatemala-seism in Feb. 1976 (23.000 casualties). Furthermore, large parts of the region are prone to frequent summer storms, especially to cyclones, causing vast floods and destructive mass movement events. Among them, an innominated hurricane devastated the

Fig. 1. Main nature risks and population density in Middle America (Richter & Adler 2007, modified) including the position of the study area

Yucatan Peninsula, Honduras and, above all Guatemala, which led to more than 40.000 fatalities in Oct. 1949, while Mitch as the second deadly one resulted in a death toll of more than 19.000 in Sept. 1998, hitting Honduras, Nicaragua and Guatemala most seriously.

Of course, the number of killed people does not depend only on the disaster type, frequency and magnitude but also on the population density of the affected area. Thus, a map of the vulnerability to nature catastrophes must combine the latter phenomenon and different risk exposures as given by fig. 1. It indicates a regional concentration of increased susceptibility to hazards around Mexico City, in southern Mexico, in Guatemala, in El Salvador, and in the western part of Hispaniola. While most of the tropical part of the Pacific coast side is exposed to inundation risks including a certain danger of tsunami intrusions, the adjacent mountain escarpments towards the Sierra Madre in Chiapas and Guatemala as well as the slopes of the Central American solitaire volcanoes suffer from frequent mass movement events during the rainy season. Both phenomena, i.e. downpours and consequent mass movements, result from storm activity. However, against the obvious assumption, a lesser degree triggered by Pacific storms but by tracks following alongside the Caribbean and Gulf Coast towards west or northwest. For example, fig. 2 makes clear that the driving forces for the exuberant rainfalls on the western escarpment during hurricane Stan were situated over the Gulf of Mexico with humid air masses drifting northwards through the isthmus of Tehuantepec and swelling them concurrently from the Pacific against the slopes of the Sierra Madre.

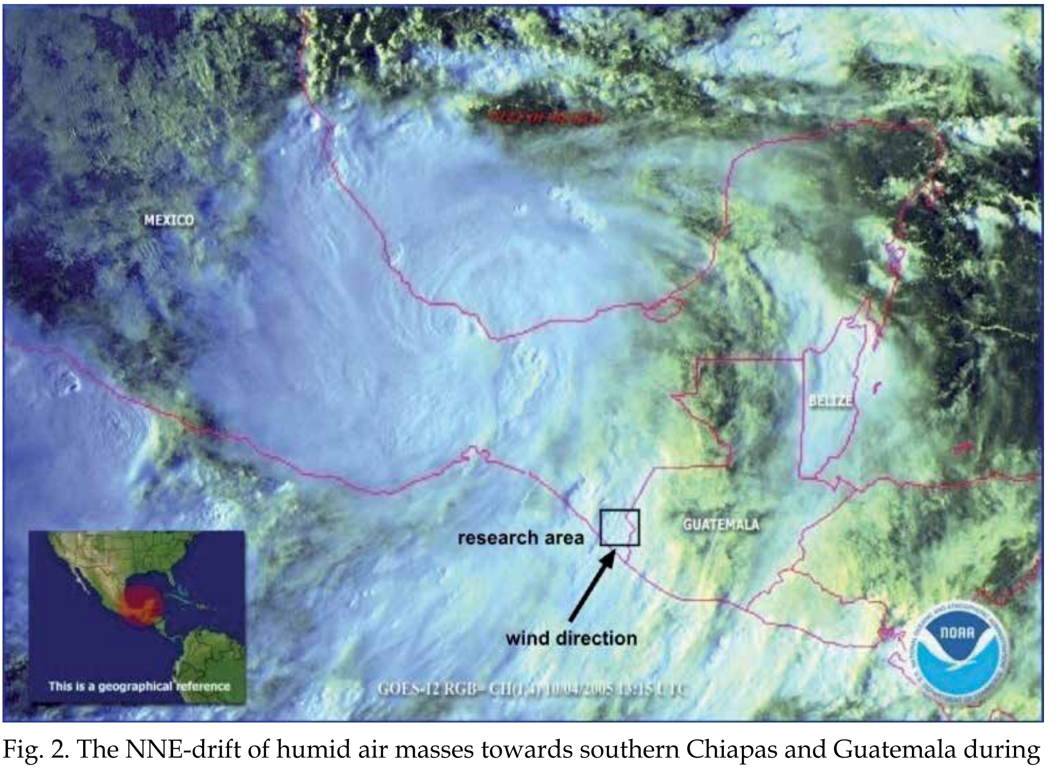


Fig. 2. The NNE-drift of humid air masses towards southern Chiapas and Guatemala during hurricane Stan ; supplemented source: http://www.osei.noaa.gov

The purpose of this paper is to take the southern part of Chiapas as a prominent example for a disturbed “highland-lowland interaction system”, which is typical for many mountainous areas and their forelands in Middle America (Richter 2000). Apart from the description of single catastrophes with high impact the study also focuses on aspects such as the frequency and distribution of ongoing processes as well as a short projection on possible future trends. Moreover government regulators focus on technical damage prevention instead of an application of geo-ecological measures, which ought to be discussed here presenting some alternatives. It will be highlighted that although structured by a similar petrography basement mainly containing metamorphic rocks such as granites, diorites and few andesitic outcrops differences in weathering intensities and climate presettings as well as in vegetation covers and land use practices govern the risk potential of a tropical mountain chain and its forelands. Many Latin American regions suffer from similar problems.

2. Taking the southern part of the Sierra Madre de Chiapas as case study

Summarized in tab. 1, the southern tip of Chiapas is differentiated into five prominent landscape-types between the Pacific Ocean and Volcano Tacaná, i.e. the highest point culminating in 4064 m a.s.l. (fig. 3). The coastal plain of Soconusco as well as the gently

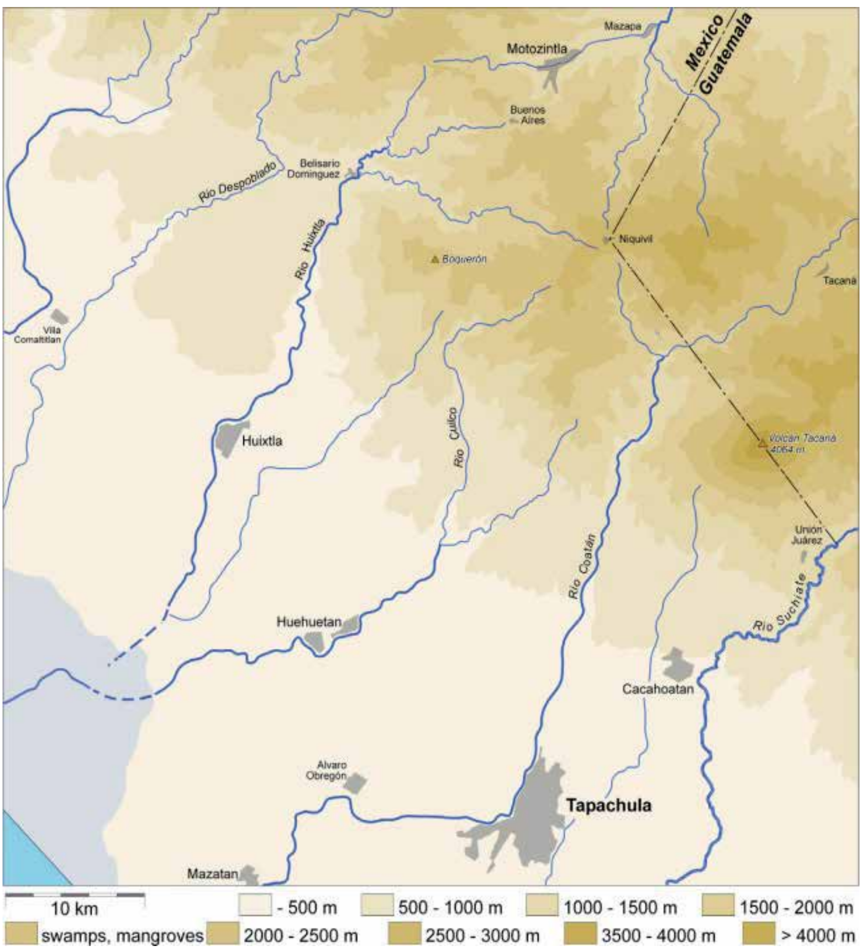


Fig. 3. Overview map of the research area in southernmost Chiapas (position s. fig. 1)

inclining contiguous foothills of the Sierra Madre form rather uniform ecoregions characterized by a semi humid climate of with up to seven relatively dry months and approximately 1500 up to 5000 mm of annual rainfall amounts. Former semi-deciduous forests are meanwhile converted into dry-farming fields (soya, sesame, corn) or fruit tree plantations (mango, banana, papaya) and farmland within a landscape belt of occasional inundations and lateral erosion by overflowing rivers.

Comparatively, the western escarpment shows a much higher landscape heterogeneity affected by unequal precipitation inputs ranging from rather dry valley sections of only six humid months per annum to south western exposed slopes with up to ten wet months. The latter areas contain vast coffee plantations with fragments of seasonal tropical rainforests, while dry deciduous and mixed coniferous forests dominate the drier valley areas. These are for example the upper parts of the Rio Huixtla and Rio Coatán both of them protected by secondary ridges such as the Boquerón and volcanoes such as the Tacaná Volcanic Complex against south western monsoonal wet air streams from SSW. In these cases, primitive corn cultivation in a field rotation system (milpa) on steep slopes is the prevailing land use form of hazardous consequences.

landscape type	coastal plain	foothills	SW escarpment	crest line	NE escarpment	valley
region	Soconusco			Sierra Madre		Motozintla
altitude m a.s.l.	- ca. 100 m	100 - 250 m	250 - 2200 m	> 2200 m	2200 - 1400 m	< 1400 m
geology	sediments (partly compacted)		granite, andesite, gneiss and few schist			sediments, gneiss
annual rainfall	- ca. 2500 mm	2000 - 3500 mm	2500 - 5000 mm	2000 - 3000 mm	1200 - 3000 mm	< 1200 mm
soils	fluvisols, alisols		andosols, cambisols			fluvisols, lithosols
landforms	alluvial plain	incised fans	V-shaped valleys	slopes, ridges	V-shaped valleys	riverbed, fans
vegetation	semideciduous forest	seasonal rainforest	coniferous forests		mixed forest	dry forest
land use	cash crops	cocoa, cattle	coffee	milpa, sheep		(orchards)
settlements	towns, villages		villages	isolated farms (villages)		towns
ethnic groups	mestizos	mestizos, caucasian		indigenous		mestizos
main risks	inundation	lateral erosion	sheet erosion	gullying, landslides		flashfloods

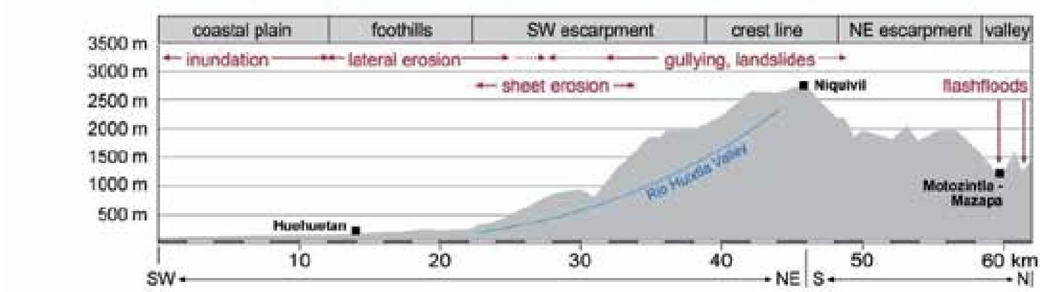


Table 1. Landscape subdivision along a profile from the Pacific coastal plain towards NE and N through the Sierra Madre de Chiapas, including an approximate overview of the extensions of most prominent geographical features (erosional and denudative processes marked by reddish terms)

The same applies for the complete northern escarpment of the Sierra Madre de Chiapas towards the Valley of Motozintla, where hundreds of landslide and gully processes threaten the population in an even higher degree. Once again these activities are a matter of a climate with an extended dry season and are intensified by a meanwhile sparse vegetation cover. Even more environmentally degraded is the valley ground itself, serving from ancient times as an area for extensive cattle farming and milpa cultivation without any remnant forest cover and thus prone to accumulations of deposits by ongoing mudflows and numerous small slides as well as to flash floods.

Instead, the crest area of the Sierra Madre along the line between Niquivil and Boquerón turns out to be relatively stable and less hazardous because dense coniferous mixed forests of pines and oaks prevail. The lesser impact results also from a sparse settlement on isolated ranches, from the moderately inclined upper slopes, and from more gentle steady rains instead of heavy downpours. However, in overexploited land use areas such as the surroundings of the nearby small towns Las Nubes, Tacaná and Sibinal on the Guatemalan part of the Sierra Madre turf exfoliation by sheep overgrazing leads to an extension of bare grounds. Hence, these ongoing processes have long range effects on the drainage basins of the rivers Coatán and Suchiate by depositing sediments along the same rivers entering also the coastal plains of Chiapas.

3. Aims of the study and methods

Although encompassing only a small part of Middle America, the risk conditions and nature disaster types in the Sierra Madre de Chiapas can be used as a model example for hazardous processes caused by recent environmental problems within a tropical highland-lowland interactive system (Richter 2000). Following on years of political turmoil, this ecological crisis has become a new "Central American Dilemma". This term, derived from the so-called "Himalayan Dilemma", describes ecological and socioeconomic interactions within a highland–lowland interactive system (Ives & Messerli 1989). Richter (2000, p. 332) mentioned that "1998 may be recorded in the recent history of Mexico and Central America as the "year of the floods"". However, meanwhile comparable disasters comprising sliding and inundations recurred twice within the research area and adjacent areas in southern Mexico and Central America, raising the question whether the region suffers from a speed-up of catastrophic mass movement effects. Since neither Waibel (1933) nor Helbig (1964) did report on rainfall induced disasters during the 1920s or 1950s, respectively, and Richter (1986) recognized only initial stages of rare mass movement processes it must be concluded that a new phase of climatic and further environmental changes started some few decades before.

Thus rainfall incidents generating mass movements and a possible acceleration of such effects are a first issue of this paper (i). Consequently in a first step diurnal rainfall data available from long-standing weather stations using data collections from various sources (CONAGUA, Servicio Meteorológico Nacional, and records from private long-term rainfall stations at coffee plantations) are presented. In a second step the recurrent intervals based on magnitude frequency analyses where calculated for the homogenised weather stations. Based on that source the cases of extraordinary high inputs over larger areas (i.e., regional precipitation ≥150 mm/day over more than 1000 km^2) were analysed. Among them, two cases of disastrous impacts serve as exemplary incidents and are presented in detail; the simultaneous storms of Javier and Frances in Sept. 1998 and hurricane Stan in Oct. 2005. In these cases, spatial data of surface-near wind streams and pressure fields derived from the NCEP/NCAR Reanalysis model help to understand the development of such downpour phenomena.

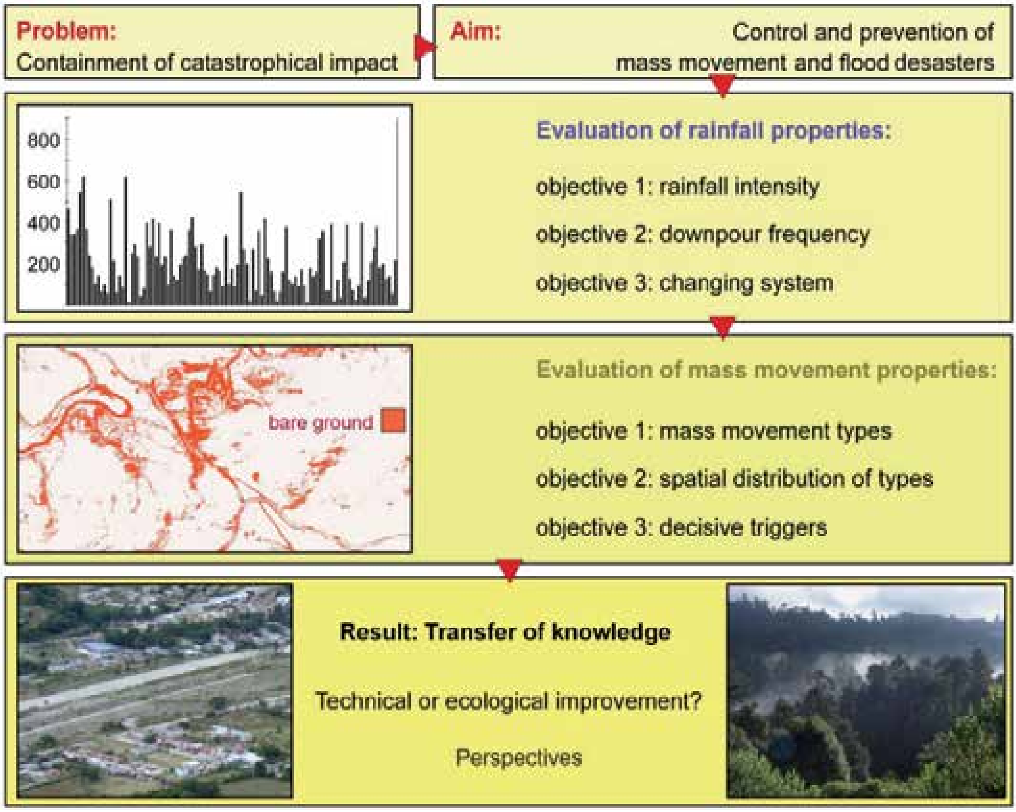


Fig. 4. Concept of the methodological approach

Types and events of vast destructive denudation processes and their spatial proliferation are described in the second part (ii). Number and size of mass movement incidents increased considerably throughout certain areas within the Sierra Madre and contributed to vast sedimentation in the foreland. However, since subregions are affected differently questions on possible triggers for the varying dimensions of the catastrophic events arise. In this context, types of the general mesoclimatic precondition, the specific magnitude and action of a disastrous downpour, the consistence of parent material, and the rural as well as urban land use practices must be challenged. Interpretations of repeated pictures taken by the last author, aerial photography and satellite images (QuickBird scenes and high resolution imagery provided by Google Maps) of various times during the last 30 years allow georeferenced mappings and the control of the advance or stabilisation of particular erosion forms. They help to detect areas of increased risk.

4. Disaster types: Triggers and consequences

The study area is characterised by spatially and temporally diverse rainfall inputs. Different regimes of precipitation reach from just 5 up to 10 humid months projected on a distance of not more than 30 km (fig. 5). The rainfall amounts start with annual means of 845 mm/a in the dry valley of Rio Xelajú Grande at Motozintla and exceed 5000 mm/a at Finca La Lucha on approximately 600 m a.s.l. in the coffee zone between Rio Cuilco and Rio Huixtla (catchment of Rio Tepuzapa). This means that the Sierra Madre serves as a decisive weather- and watershed between the wet Pacific escarpment and the much drier basins of the upper Rio Grijalva system, which leads far away into the Gulf of Mexico. But also on the Pacific flank itself rainfall inputs vary significantly. Here, humidity can enter without difficulty into valleys with openings facing south while those turning into a latitudinal direction, such as the upper Huixtla Valley and the upper Coatán Valley, are protected against southern or south-western airflows by monsoonal effects or moist valley breezes from the sea. Curiously enough, these dry parts in the upper valleys are most harmed through mass movement effects as demonstrated in the following.

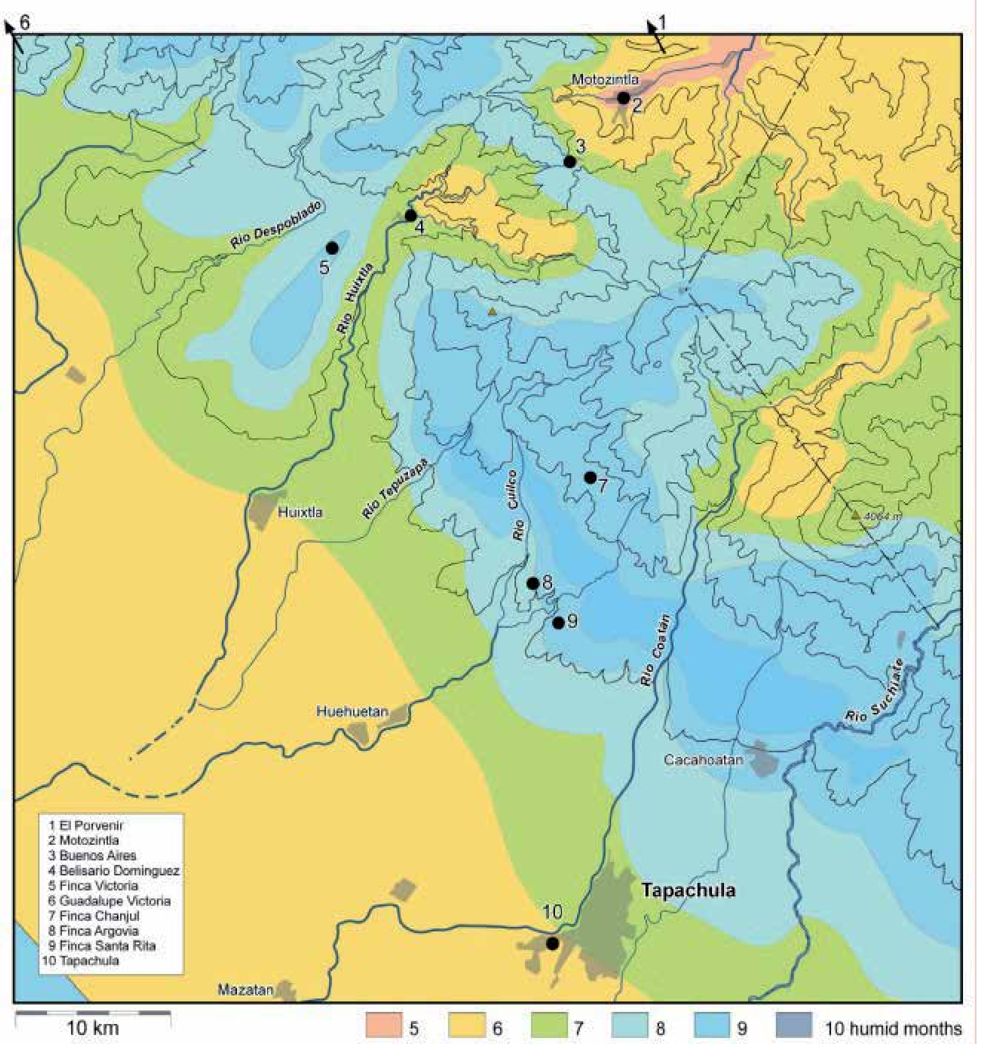


Fig. 5. Mean amount of humid months per annum documenting the Sierra´s general role as decisive rain barrier, while less prominent side crests like those of Tacaná and Boquerón (s. triangles) can pose as secondary rain barrier on the windward side. Rain stations documented in fig. 7 and 8 (lower part) are indicated by numbers

4.1 The annual rainfall pattern and the influence of tropical storms

The research area is a tropical storm prone region, influenced by heavy downpours, which provide high precipitation amounts (of up to 550 mm rainfall within one day during hurricane Stan!) presented by various diagrams. The wet season (May – October) starts in the research area with a rapid onset of monsoon rains at the end of May. The highest monthly totals are measured during June and September, while the precipitation usually decreases during the ‘canicula’, a dryer period between mid-July and early August. Hence most of the precipitation fell in the hurricane season when heavy rainfall events are common.

4.1.1 Torrential rain

Although the atmospheric conditions for the development of tropical storms in the eastern Pacific Ocean have been less favourable since 1995, the frequency of torrential rain has risen in southern Mexico (Peralta-Hernández et al. 2009). This traces back to the fact that the majority of extreme downpour events in Middle America are related to the higher sea-surface temperatures (SST) in the tropical Atlantic waters (Meehl et al. 2007). One more key factor for the genesis of prolonged downpours along the western escarpment of the Sierra Madre de Chiapas is the cyclonic activity in the Bay of Campeche which also depends on SSTs. Consequently, a connection between the above average temperatures in the southern bight of the Gulf of Mexico on the one hand and torrential rain phenomena in the southernmost tip of Mexico on the other hand is obvious (NOAA 2011).

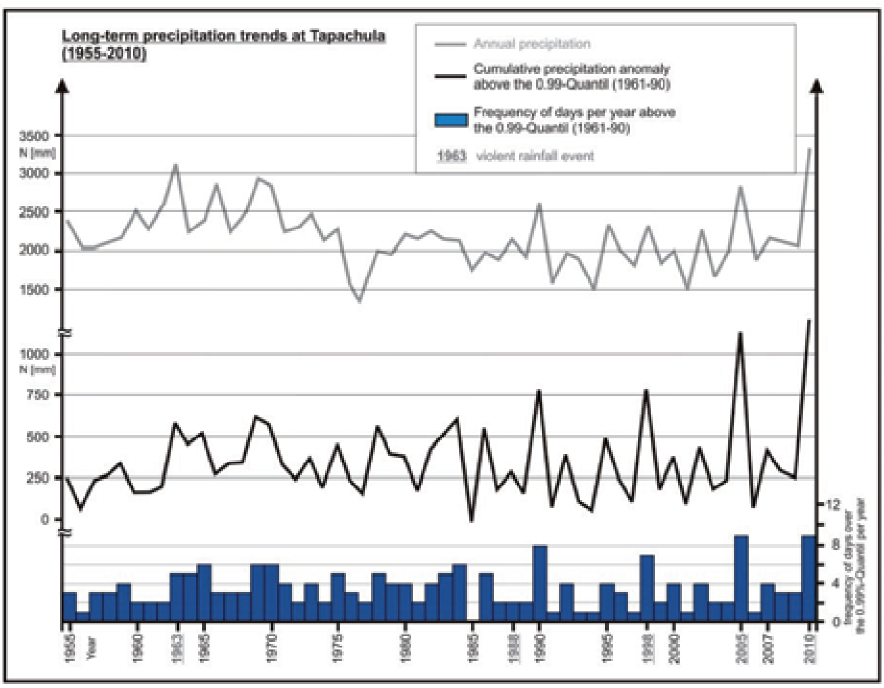


Fig. 6. Rainfall characteristics (annual amounts, anomalies, frequencies) during the last 57 years at Tapachula (179 m a.s.l.)

For this study a discrete threshold was calculated for each station based on an interval of 30 years (1961-90) from daily rainfall data, using the 0.99 percentile value to separate a normal rainfall pattern from extreme situations. The results for the thresholds differ between 22 mm/day in the relatively dry intramontane valley of Motozintla and above 100 mm/day at the windward stations of the western escarpment. The average return period for an occurrence above this threshold is up to four times per year (fig. 6). During the wet season convective showers of up to 150mm day are widespread in the coffee zone on the Pacific slopes of the cordillera. But they occur only locally and are caused by atmospheric disturbances. Moreover, such rainfall amounts per day are a possible trigger for sliding processes on slopes of the drier intermontane basins in the Sierra.

The major rainfall events, defined as diurnal rains >150 mm at ten or more stations sites in the study area, were determined and analysed separately. The ministry of civil defence from Chiapas considers such rainfall amounts per day as common threshold for torrential rains. The examination of station data reveals that nearly 50 percent of the potentially catastrophic situations occur in September, a month which is likely to be particularly vulnerable for heavy downpours. Most of them are coupled with a tropical disturbance in the Bay of Campeche. In the research area, in six of 57 years the precipitation amount exceeded 300 mm/48h. Such short-term amounts are considered as initiating events for vast sliding in the Sierra Madre de Chiapas. Murcia et al. (2009) mention prolonged rainfall events also for 1933 as well as 1944, which may have been triggers for former extensive denudation processes in the study area.

Although the western escarpment of the Sierra is well known as a tropical storm prone region the rainfall pattern seems to differ slightly in the course of the last 25 years. The rainfall amounts of two major events (1988, 1998) exceeded the 50-year recurrence interval in parts of the research area. But even more devastating was the torrential rain during hurricane Stan for large parts in Central America (fig. 8). Most of the Pacific escarpment of the Sierra Madre de Chiapas and the Volcanic Cordillera in Guatemala was exposed to two days of excessive rainfall >300 mm/day. For several stations in the dryer part of the mountain the recurrence period for such an event is up to 500 years. A further reason for the effects of the three major catastrophic incidents was the duration of the downpours lasting, which at several stations was up to six continuous days with totals above the 0.99%-Quantile in the case of Stan.

Concerning the rainfall intensity (mm/h), at Tapachula the most intensive shower activity during the prevailing monsoonal regime has been 81 mm/h in 2010, i.e. a magnitude which the local storm water system could barely cope with. The classified violent rainfall rates (>50 mm/h) are more likely to occur during downpours within a monsoonal trough. Again the analyses of the hourly data from the Tapachula weather station points out that the September has the highest number of heavy rainfall events (>25 mm/h). The conditions for such events are favourable in the end of the wet season, because the SST is high enough for significant moisture transports into the atmosphere, which already starts to cool down. In addition to the monthly rainfall amounts, statistical studies revealed that the ITCZ shifts northward until its northernmost position in September (Hasenrath 2001). Therefore, the maximum occurrence of "Temporales" and the precipitation totals on the Pacific side of Southern Mexico are connected with the annual cycle variations of the intertropical convergence zone.

Broadly speaking, there are two principle types of potentially catastrophic weather situations: One is the highly productive spells of intensified shower activity embedded within the prevailing monsoonal regime. The other is prolonged rainfall during a cyclonic activity in the Bay of Campeche.

4.1.2 The influence of tropical storms

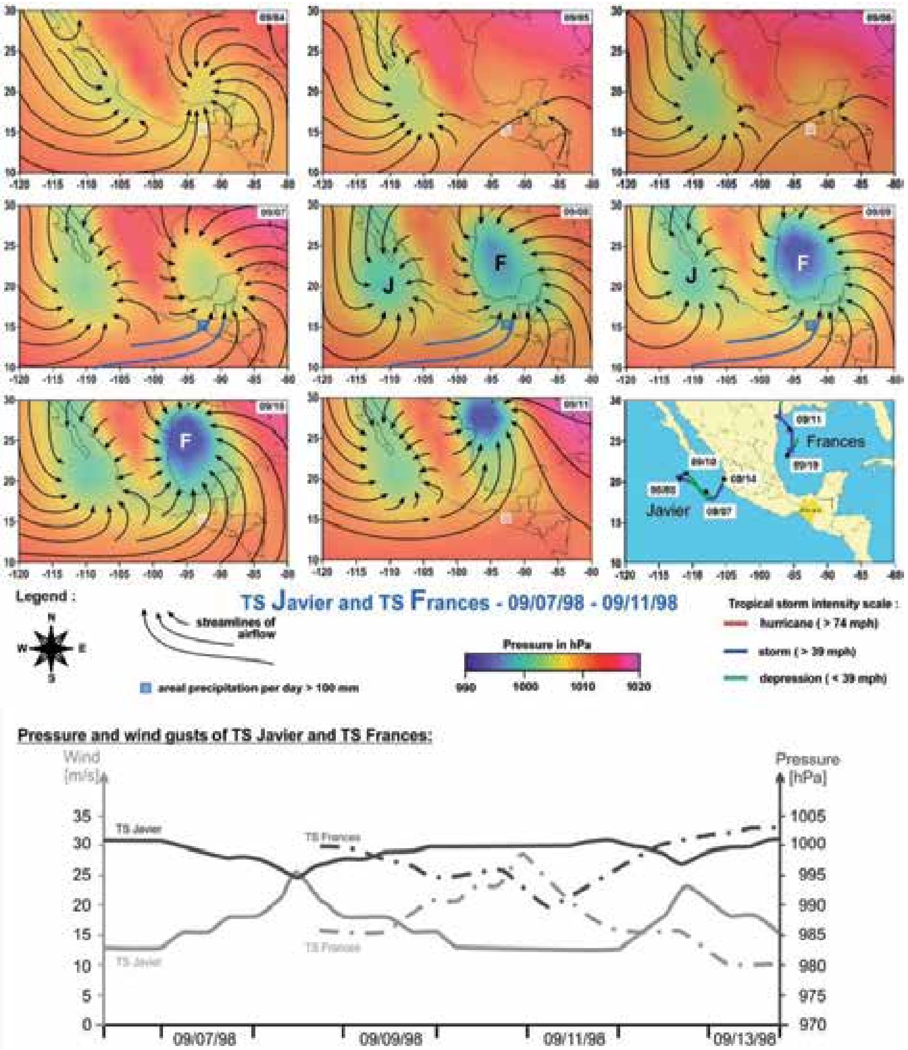
The last three prolonged heavy rainfall events which caused catastrophic flooding in the coastal plains and led to slope failures in the Sierra Madre occurred within 17 years which is definitely an abnormal short recurrence interval for such calamities. The calculation for the recurrence periods is based on magnitude frequency analyses for the observed meteorological stations. It shows that the 1988 and 1998 disasters had a recurrence factor up to 50 years in the drier valleys of the Sierra Madre de Chiapas (Caballero et al. 2006). The disastrous Hurricane Stan in 2005 had an even higher recurrence interval of up to 500 years for the drier valleys of the mountain region.

The two catastrophic examples in 1998 and 2005 developed during a period of above-average SSTs in the surrounding tropical sea. Both disasters were caused by cyclonic activities in the Bay of Campeche as well as by an intensified shower activity originating from the monsoonal regime. The combination which triggered the prolonged torrential rain events resulted from abnormal wind confluence towards NE over the land bridge, followed by deep moist convection and buoyancy.

The orographic lift of the moist saturated air finally led to deep convective showers in the mountainous region and above in its dry valleys. The transfer of the moist saturated air is represented by blue stream lines in the map sequence of fig. 7 and 8. Furthermore, the same maps indicate that the atmospheric flows during these events were characterized by winds eventually diverted by topographic barriers and then pulled trough the Isthmus of Tehuantepeque towards the Gulf depression.

Tropical storm Frances was formed out of a broad area of low pressure and widespread showers in the southern Gulf of Mexico and the western Caribbean. The existence of three poorly-defined tropical waves in the area may have contributed to the formation of a tropical depression on 8th September. In addition, the close interaction between larger systems of rainstorms (Javier) developed over the Pacific. The rain fell in torrents for at least three days until the tropical system moved slowly northward and the humidity transfer into the mountainous region of the Sierra ended. At the windward station of Guadelupe Victoria concentrated deep convective showers account for the stations breakdown (fig. 7, table). The influence of tropical storm Javier on the prolonged rainfall in the Sierra was only marginal. But it contributed to a broader area of disturbed weather that persisted over the tropical eastern Pacific. Note that the dark blue colour of Frances hints to lower pressures than in case of Stan. Nevertheless, the potential of 2005 was never reached because the constellation was different (extension of the whole complex as well as vigorousness of the storm centre; compare diagrams in fig. 7 and 8).

Instead of three tropical waves promoting the development of Frances, only one tropical wave was probably the precursor to Stan. The tropical system first developed on October 1 near the eastern coast of Yucatan. After the traverse of the peninsula the system regained a rapid intensification over the open water of the Gulf before its final landfall at the coast of



Rainfall amount per day:

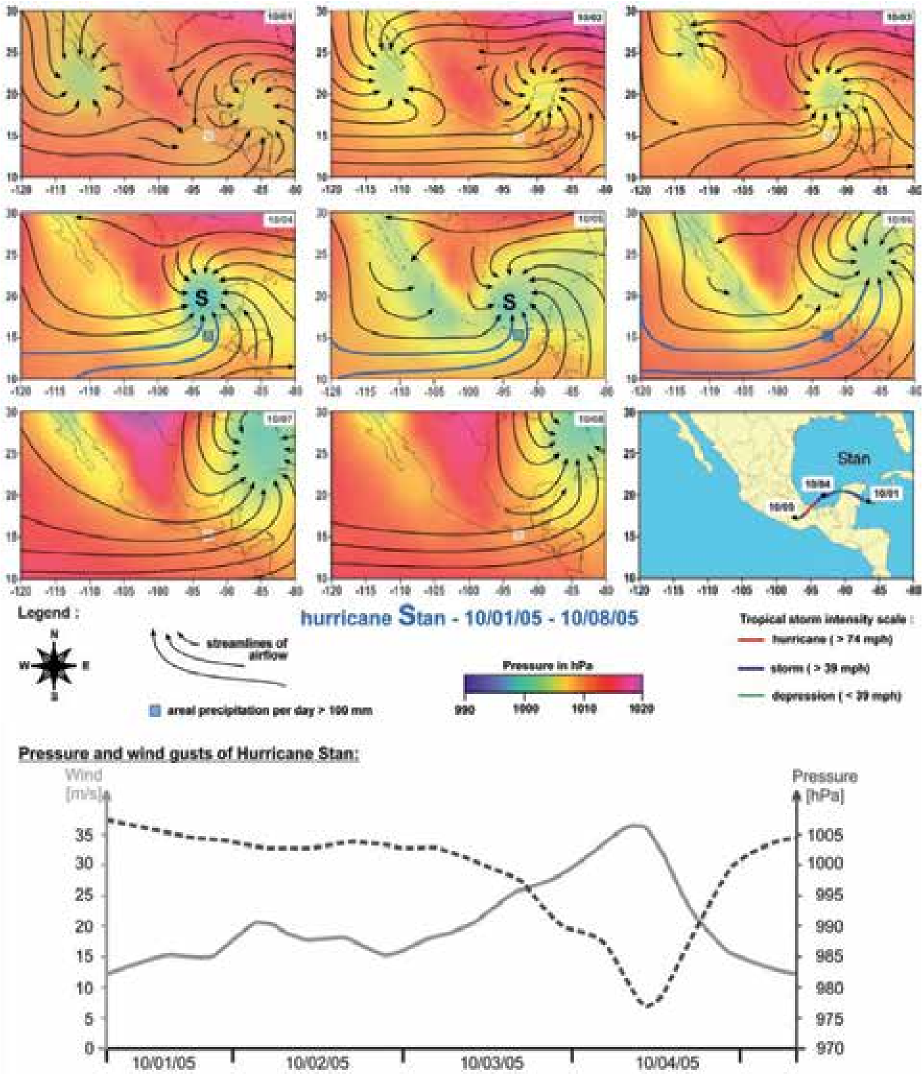
Weather Station	Altitude (a.s.l.)	LTMAP*	9/1/98	9/2/98	9/3/98	9/4/98	9/5/98	9/6/98	9/7/98	9/8/98	9/9/98	9/10/98	9/11/98	9/12/98
Motozintla	1210m	845	11	0	2	6	5	18	175	130	27	10.1	0	0
Buenos Aires	1720m	1141	0	0.5	10	0.4	80	270	30	20	40	35	40	45
Belisario Dominguez	680m	1964	92	1	0	15	25	117	298	280	150	0	0	8
Finca Chanjul	1250m	4138	22	0	2	50	29	115	316	210	130	20	0	0
Finca Victoria	980m	2474	8	0	5	75	24	40	315	255	232	38	0	8
Santa Rita	680m	4228	30	110	0	18	34	40	234	170	124	14	6	2
Finca Argovia	620m	4160	23	94	1	10	27.5	30	163	177.5	106	11	3.5	4
Guadalupe Victoria	130m	2580	40	100	175	195	180	401	Station breakdown					
Tapachula	170m	2837	5.6	0.4	0	27.5	20.7	92.7	145.5	140.2	92.1	0.5	0	0

* Long-term mean of annual precipitation

Rainfall intensity:

(>60mm/d) strong (>150mm/d) very strong (>250mm/d) violent

Fig. 7. Coloured maps: Pressure development and air flows during tropical storm activity of Javier and Frances from Sept. 4th to 11th 1998; blue stream lines indicate the direction of main humidity transfer during wet days (derived from NCEP/NCAR Reanalysis data). Black and white diagrams: Wind speeds and pressure (NOAA) as well as rainfall amounts from several stations during the 12-day period (CONAGUA, and private stations). Note the double effect by the traverse of two storms



Rainfall amount per day:

Weather Station	Altitude (a.s.l.)	LTMAP*	9/29/05	9/30/05	10/1/05	10/2/05	10/3/05	10/4/05	10/5/05	10/6/05	10/7/05	10/8/05	10/9/05	10/10/05
El Porvenir	2730m	1813	14	15	28	29.5	375	348	165	124	37.5	33	21	12
Motozintla	1210m	845	11	9	0	0	100	43	320	55	4	1	0	0
Buenos Aires	1720m	1141	0	18	0	0	95	186.7	160	105	75	0	13.5	0
Finca Chanjul	1266m	4138	68	10	15	30	130	400	380	150	25	0	15	10
Finca Victoria	989m	2474	32	2	0	9	146	409	340	150	0	0	14	23
Santa Rita	680m	4228	30	15	115	33	110	434	416	164	5	50	15	15
Finca Argovia	620m	4160	22	15	84	21	74	373	320	109	4	48	6	12
Guadalupe Victoria	130m	2580	15	0	19.6	111	170	415	552	236	125	148	66	1
Tapachula	170m	2037	6.6	10.9	36	0	133.6	145.2	155.5	119.4	12.8	15.2	11.1	0.6

* Long-term mean of annual precipitation

Rainfall intensity: (>60mm/d) strong; (>150mm/d) very strong; (>250mm/d) violent

Fig. 8. Coloured maps: Pressure development and air flows during passage of hurricane Stan from Oct. 1st to 8th 2005; blue stream lines indicate the direction of main humidity transfer during wet days (derived from NCEP/NCAR Reanalysis data). Black and white diagrams: Wind speeds and pressure (NOAA) as well as rainfall amounts from several stations during the 12-day period (CONAGUA, and private stations)

Veracruz, when the hurricane achieved its lowest barometric pressure of 977 hPa. The track into the southwest caused an interaction with a broad, deep-layer cyclonic circulation in eastern Mexico. The diagram in fig. 8 shows that on October 3 the prolonged heavy rainfall began on the western escarpment, in the dry valleys and in the mountains around El Porvenir. This northernmost area served as a barrier and stopped the overflow of the convective showers and on October 4 most of the study area was exposed to excessive rain. Next day the remnants of hurricane Stan contributed to the highest daily amounts and led to the catastrophic outcome of the abnormal weather situation (Vasquez 2008).

The wind constellation brought the moist convective air into the valley of Motozintla and the adiabatic uplift on the slopes lead to excessive showers. Although the orographic lift of rain clouds on the Pacific side of the Sierra ceased after October 5 the residual atmospheric disturbance produced one more day of torrential rain throughout the coffee-zone of the Sierra (Cruz Bello et al. 2010).

Results of DeMaria and Kaplan (1993) showed that the majority of Atlantic storms reach their maximum intensity off the Gulf coast, where the conditions is favourable for tropical cyclone intensification. The combination of wet air and warm water increases the deep convection process. This means the slow-moving hurricane Stan could gather strength off the Gulf coast, contributing to the heavy rainfall onshore. So the biggest risks for rain-triggered landslides are given by the slow moving systems (Philpott et al. 2008). The remnants of Stan remained for another three days over parts of the Sierra (in total 1757 mm during seven days at Guadalupe Victoria, s. fig. 8 below), dropping torrential rain that contributes to sliding and flash floods (Vasquez 2008).

4.2 Mass movement and erosion in the mountains

Additionally, landslide and erosion processes cause extensive land losses and threaten cultivated land and infrastructure on the pacific slope of the Sierra Madre as shown in fig. 9. The study area along the upper Valley of the Huixtla River includes parts of the pacific slope from the town of Belisario Dominguez towards the north-east over the natural watershed at Las Cruces into the rain shadow flank around Motozintla. From this region three separate zones are presented here. The first is located along a crest north of Belisario Dominguez. The second zone is situated in front of the watershed nearby the federal road between Huixtla and Motozintla. The third area is a mountain escarpment south of Motozintla around the hamlet of Rivera Morelos. All examples represent different important features of common mass movement processes in the Sierra and offer different climate, land-use and geology aspects. The parent municipality of all three areas is Motozintla.

In terms of geology nearly the entire western escarpment of the Sierra is characterized by the same petrography. The massif is formed by an ancient batholith, i.e. the so called Chiapas Granite Massif, and consists of various granites and diorites. Because of its position between the Cocos, Caribbean and North-American tectonic plate the mountain chain is stressed by faults following primarily the coastline to the north-west. The town of Motozintla lies within the Polochic Fault, one of the main faults in the region. Instead, the Huixtla River follows the El Retiro Fault from Belisario Dominguez down to the coast. Recent and ancient volcanic complexes like Tacaná and Boquerón are also linked to the active tectonic zone. Frequent temblors are probably a factor for weakening the heavily weathered stone, which facilitates sliding processes (Philpott et al. 2008).

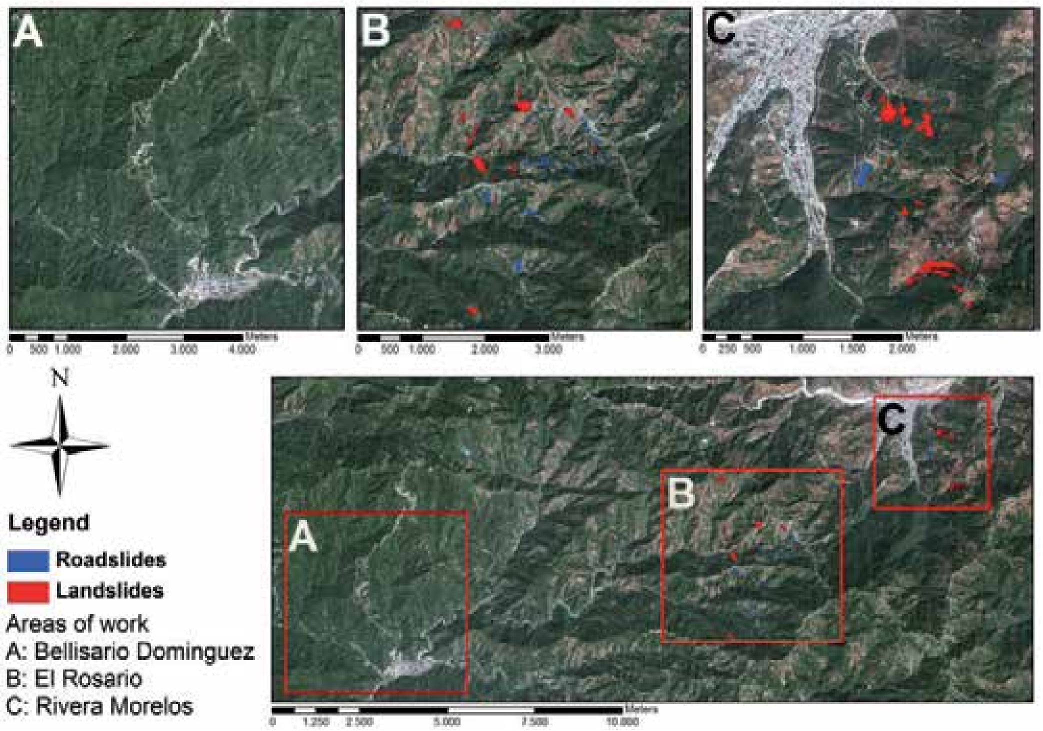


Fig. 9. Overview and detail of the research areas with road- and landslides derived from satellite images presented by GoogleMaps (recording date 12/19/2010)

Ranging from around 600 m a.s.l. to 1300 m a.s.l., Belisario Dominguez is not only the lowest of the three areas but also differs considerably by the natural vegetation and the land-use. Due to the course of the Huixtla Valley the mountain slope above town owns a windward position towards monsoonal rainfalls and thus is predestined for sliding impacts. Here, the number and size of landslides predominantly depend on the land-use and vegetation type. Fig. 10 documents a large number of small and shallow translational slides, flows and complex slide-flows. Today, six years after the heavy rainfalls of hurricane Stan, many of the landslides can hardly be discovered anymore in satellite imaginary or in the field, so in fig. 9, where only few road slides are recognizable. The recuperation rate seems to be very high in this area, possibly due to a fast secondary plant succession by dense assemblages of tall grasses, pioneer shrubs and trees stabilising even steep slopes and absorbing much of the precipitation. In many cultivations of shade-coffee under tree canopies the coverage by trees is rather high. Thus, the vegetation prevents ongoing sliding through a fast up growth of vegetation, better soil stability and adapted land-use measures. However, indications of slight slope movements become obvious by curved tree trunks, which document soil creep all over the study area.

The situation in the El Rosario research area is less stable than in Belisario Dominguez. The overall appearance changes from small and shallow landslides to a mixture of many different forms from small slides with less than 100m² to slides extending to around 35,000m², as shown in table 4 and easily recognizable on the satellite image in fig. 9 B. The relatively dry leeward valley is oriented towards north-north-east beyond the volcano ruin of

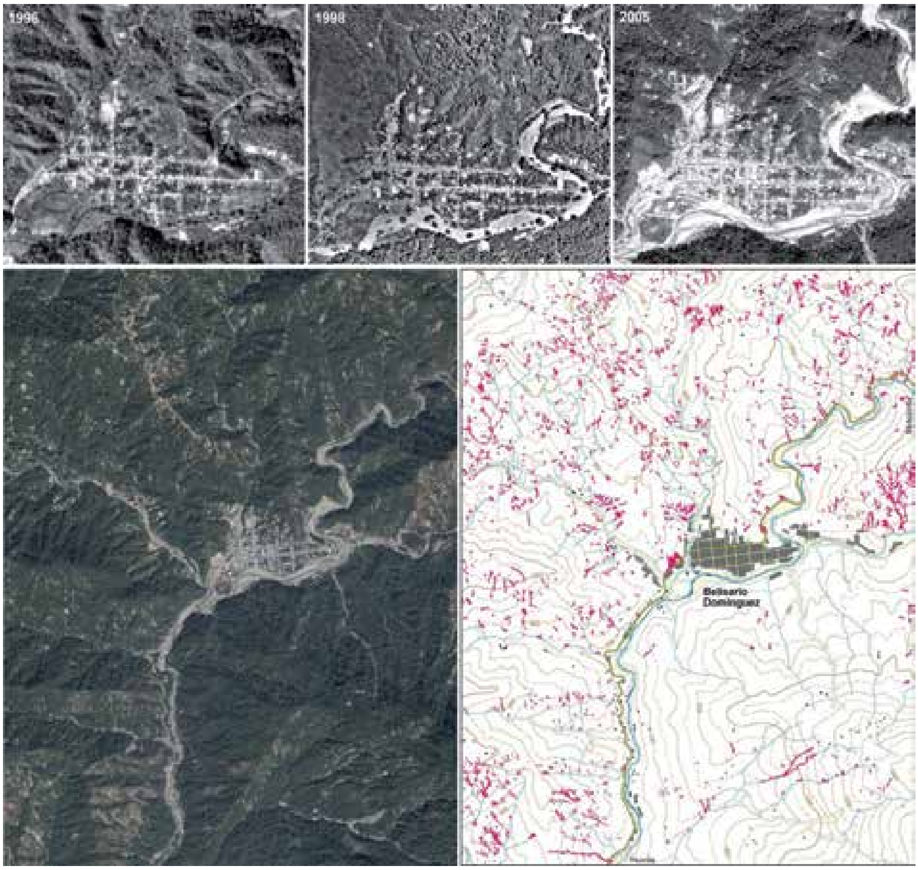


Fig. 10. Top: Aerial pictures of Belisario Dominguez in 1996, 1998, 2005 from INEGI. Below: The surroundings of the same town affected by small and shallow landslides after hurricane Stan 2005 (Quickbird image from DigitalGlobe, recording date 15/12/2005)

Boquéron in the south. In contrast to Belisario Dominguez, the landslides are less covered by pioneer vegetation, although some slides are older than 2005. This indicates either a climatic reason or progressive sliding. During the rainy season occasional downpours cause changings of the landslide surfaces by forms of water induced erosion such as rills and gullies, from where the debris and sediments are removed towards the next riverbed. Since the end of the rainy season often suffer from highest precipitation rates a potential pioneer vegetation cannot start growing immediately thereafter due to the onset of the dry season. The high solar radiation around this longitude is backing the fast drying up of the bare deposits. This different land forming processes makes it difficult to determine the type of mass movement and hence, the resulting complex forms cannot be grouped without doubt into existing landslide classes. Likewise, it is not possible to differentiate between debris flows and translational or rotational slides, because their aspect has changed since 2005. These processes assure annual sediment overloads in the rivers and the described outflows into the coastal plain.

Many of the larger slides were not triggered by the events in 1998 and 2005 but can be decades older and are modified in a subtle way. A convincing example is the compound landslide in fig. 11 located only few meters in front of the watershed at Buenos Aires within a vast pasture area. The complex slides within an arroyo (dry creek) of slow retrograde erosion exist for more than three decades and some of its sections are slowly altering their aspect. A comparison of the two photos of 1983 and 2011 indicates, for example, that the rotated blocks below the uppermost scarp are meanwhile more dissected, slightly slipped off and covering only half of their former size. Additionally, few side scarps within the arroyo hardly expanded during the three decades. However, on the other hand the two pictures point to a surprisingly stable situation which contrasts completely to a nearby form, that is developing further.

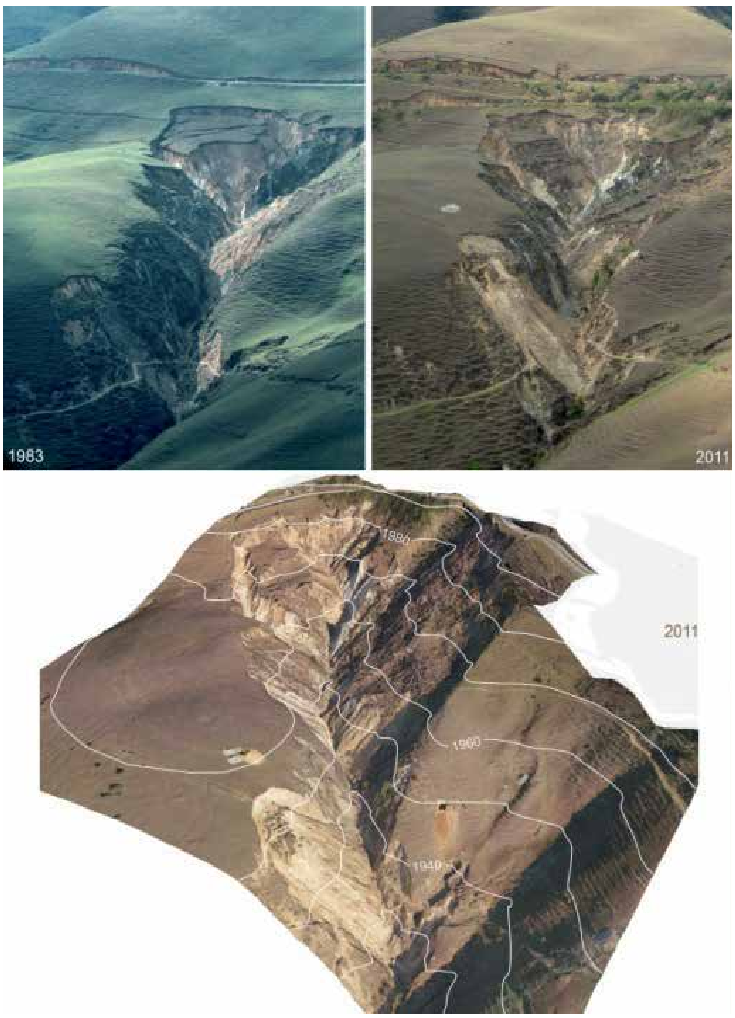


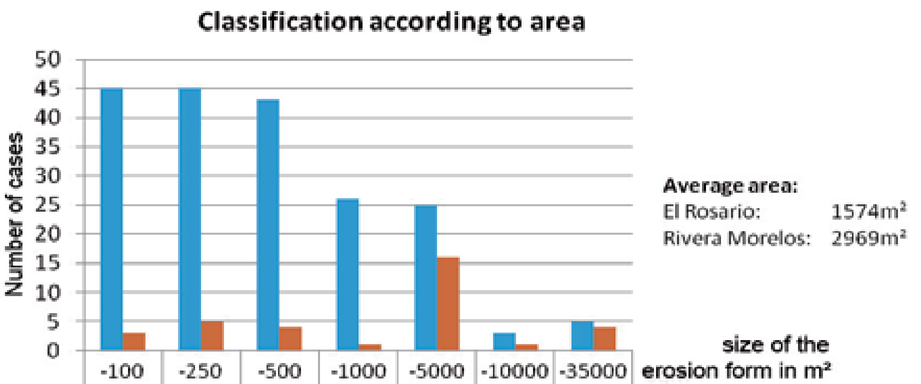
Fig. 11. Development of a landslide near the watershed at Las Cruces. 3D-image derived from aerial images taken by an octocopter; contour lines derived from GPS-measurements on site

This is the study area of Rivera Morelos beyond the watershed, where small devastations are nearly absent and large denudation forms of more than 10,000m² are characteristic. The height above sea level of 1300 to 1900 m a.s.l. is almost the same as in El Rosario, but the annual precipitation is less. Here, gully erosion is the dominant mass movement process. Situated in the north east of the study area (fig. 9 C) the old gully form in fig. 12 (upper left) is developing towards an enormous valley in the lower right of the sequence of the same site. The specific characteristic of this area is an ongoing and vivid development of mass movement forms. Only three vaster erosion scars, e.g. the gully in fig. 12, existed before hurricane Stan. Until today their number rapidly increased, their outlines expanded and the baselines deepened. In contrast to the other study areas fresh mass movements occurred during the rainy season in 2010 when heavy rainfalls intruded by the tropical depression 11-E. Most of the processes were once again gullying, in some cases accompanied by rotational sliding and toppling through undercutting. The anthropogenic influences combined with a micro-climatically enforced physical weathering of meta-granodiorites as parent rock, which leads to coarse-grained substrate, are reasons for a growing instability in this region and can explain the meanwhile huge gullies as a dominant mass movement form. It is no surprise that the deforested pine forest area is the main new hazard source. The growing problem here is the development from gullies towards valleys, which means a lot of land will be lost and a stabilisation by reforestation measures on the slopes of the completely bare and deeply dissected new V-shaped arroyos becomes an illusion.

Fig. 12. From gully towards valley – ongoing erosion effects near Morelos above Motozintla through 30 years (photographs by M. Richter)

Alongside the great number of mass movements, two different mayor developments become obvious: On one hand these are the older large landslides, which arose in their present formation over years. The younger second development is linked to gully erosion accompanied with various denudation processes on the edges of the fresh landforms. For the future development the younger forms are more dangerous, because they will be less stable as the older bigger forms.

Ibadango et al. (2005) mentioned for the Loja basin in Ecuador, that the high density of landslides is a result of the regional geology, stream down cutting causing the over-steeping of slopes, moderate seismicity, high precipitation, and anthropogenic influence. This is surely true for the research areas. In total the three research areas can be divided in three classes. The first class around Belisario Dominguez shows the highest recuperation rate. The second type lies in the drier region of El Rosario and shows advancing landslides, but in most cases once again small slides (tab. 3) through the annual rainy season. In the case of extreme events new landslides will emerge and nearly no recuperation can be detected. The third and driest part is the Rivera Morelos area and features much fewer small slides but a similar amount of huge active denudation forms (tab. 3), which cause widespread destructions and endanger the town of Motozintla by massive sediment loads (see 6.1). Here, in spite of the reputed lesser degree of outgoing erosion material the risk is highest, given by the immediate neighborhood of the town and the elsewhere rare form of spacious and highly active gullies, which show already first signs of rapid valley building. No recuperation signs can be found and the ongoing deforestation seems to destabilize the system more and more. The total number of recent mass movements is not as high as in El Rosario. Overall the current changes in landslide activity seem to be mostly influenced by anthropogenic influence, like Restrepo et al. (2009) mentioned for many mountain landscapes of the world.



	-100	-250	-500	-1000	-5000	-10000	-35000
El Rosario	45	45	43	26	25	3	5
Rivera Morelos	3	5	4	1	16	1	4

Table 3. Landslide classification according to size and number at two study sites

4.3 Flooding in the valleys and plains

The export crop focused economy as well as the primitive milpa regime in southern Chiapas play a huge role in the generation of large flood events. Over the last century and especially the last four decades land-use systems in the plains were changed to intensify the output of cash crops, while the Sierra suffers from increasing land seizure. The deforestation has spread to the top of the Sierra Madre even in areas with steepest slopes and thus a higher probability of land losses through different forms of erosion and mass movement is given. According to experts, about 80% of the forest coverage in Chiapas is degraded (Castillo Santiago 2010). Steep slopes with exposed soil surfaces in many upper parts of the rivers enhance the outflow towards the coastal line significantly, especially in the dry valley areas. The increasing susceptibility to erosion in the mountainous region provokes an even more vulnerable coastal plain. The heavy rainfalls during the described tropical storms reinforced the erosion problem further and led to a higher load of sediment, debris and boulders in the rivers (fig. 13).This provoked large devastations in infrastructure, housing and a huge loss of agricultural land, as shown in table 4.

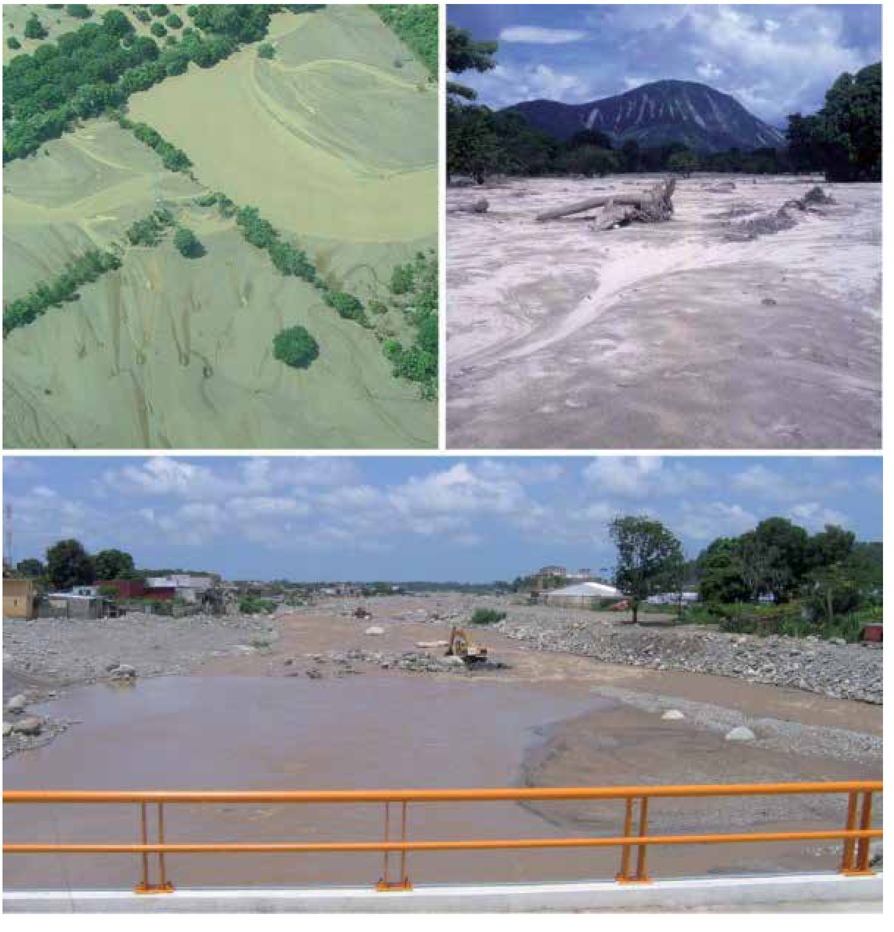


Fig. 13. Inundation and sedimentation in the surroundings of Rio Coatán near Tapachula caused by hurricane Stan (2005, left) and of Rio Novillero near Mapastepeque after tropical storm Frances (1998, right). View from the Rio Huixtla bridge after the Stan floods (below)

Damage	Tropical storm Frances 1998	Hurricane Stan 2005
Casualities	229	82
Bridges damaged or destroyed	40	253
Housing	16,000	45,166
Agricultural area	51,159 ha	307,000 ha
Cost	63,000,000 USD	1,149,000,000 USD

Table 4. Damages caused mainly by floods during and after the tropical storm Frances and hurricane Stan in Chiapas (Mundo Molina 2010)

4.3.1 The case of Motozintla municipality

The vast community land of Motozintla (782,5 km²) includes the three research areas and several small towns such as Belisario Dominguez or Niquivil, many hamlets such as Beriozabal, Boquerón, Buenos Aires, and Rivera Morelos, as well as even some of the remote but ample coffee plantations on the Pacific escarpment of the Sierra Madre such as the Fincas Chanjul, Bremen and Lubeca, or La Victoria. The centre is located at 1260 m a.s.l. in the valley ground of Rio Mazapa (syn. Rio Xelajú Grande), which during the 1902 eruption of Volcano Santa María, Guatemala, disappeared in its river load (Williams and Self, 1983). The total community area extends from little below 400 m a.s.l. between Huixtla and Belisario Dominguez on the Pacific escarpment up to nearly 2.700 m a.s.l at Niquivil. Of the around 65.000 inhabitants little less than a third lives in the municipal seat.

Parts of the town itself were flooded and overwhelmed by sediments during a storm in Oct. 1949, severely derogated by flash floods during Frances and Javier in Sept. 1998 as well as by Stan in Oct. 2005, while in Oct. 2010 lower extensions of the urban part were affected by mud flows. These events affected also remote urban areas, since the town spreads into some narrow V-shaped tributary valleys. Caballero et al. (2006) reported in detail the causes and impacts of the 1998 hazard in Motozintla, which in the Soconusco plain led to further devastations in the surroundings of Acapetahua, Mapastepec, Pijijiapán and Tapachula. In Motozintla the rainfalls of 305 mm in two days and the consequent debris- as well as mudflows in the rivers leading to the town caused a flood, which destroyed 600 houses and required 30 casualties. 30.000 people were evacuated or otherwise affected. Similar is true for the Valleys of Rio Coatán and in special for the town of Belisario Dominguez. In total Chiapas, almost every third inhabitant was affected by the floods following the depressions of Frances and Javier as well as the precursory storm Earl, with Motozintla and Pijijiapán the most severely impacted.

In Motozintla, governmental and municipal aid and prevention measures were intensive but not all of them reasonable since the authorities trust more in technical than in environmental solutions - as is rampant in several Latin American countries (problems of corruption and nepotism are not addressed in this paper). Post-catastrophe damage mitigation measures were aligned on dams, channels, retention basins etc., while reconstruction plans ignore relief dangers even today. New houses for resettlement were and are located on alluvial fans (fig. 14, yellow arrow), where at the base of steep slopes and the entrances of small but actively incised valleys the debris surfaces undergo active erosion and sedimentation. Thus, it was foreseeable that the October 2005 floods destroyed even several of those new dwellings, where inhabitants were relocated after the 1998 disaster.

Nevertheless the death toll during the 2005 event was a little less (28 fatalities) although the rainfall amounts were higher yet and the floods larger than in 1998 (375 mm in two days and more than half of the average annual input during four days, i.e. 518 mm versus 845 mm). The slightly lower impact is partly due to the dammed tributary creek shown in fig. 14, which did not yet exist before 1998 and was still too small before 2005. Many of the casualties in 1998 were attributed to overflows and debris accumulations along the meanwhile channelled tributary (fig. 14, left and right upper part), where the solid reinforcement protects the lower parts of town from massive flooding. But as channel stabilization was performed with only the 1998 flood as the design event, a strong 2010 storm (tropical depression 11-E, Sept. 4 and 5, rainfall data not yet available at date of submission) banked up heavy debris loads alongside and beyond the concreted creek wall.

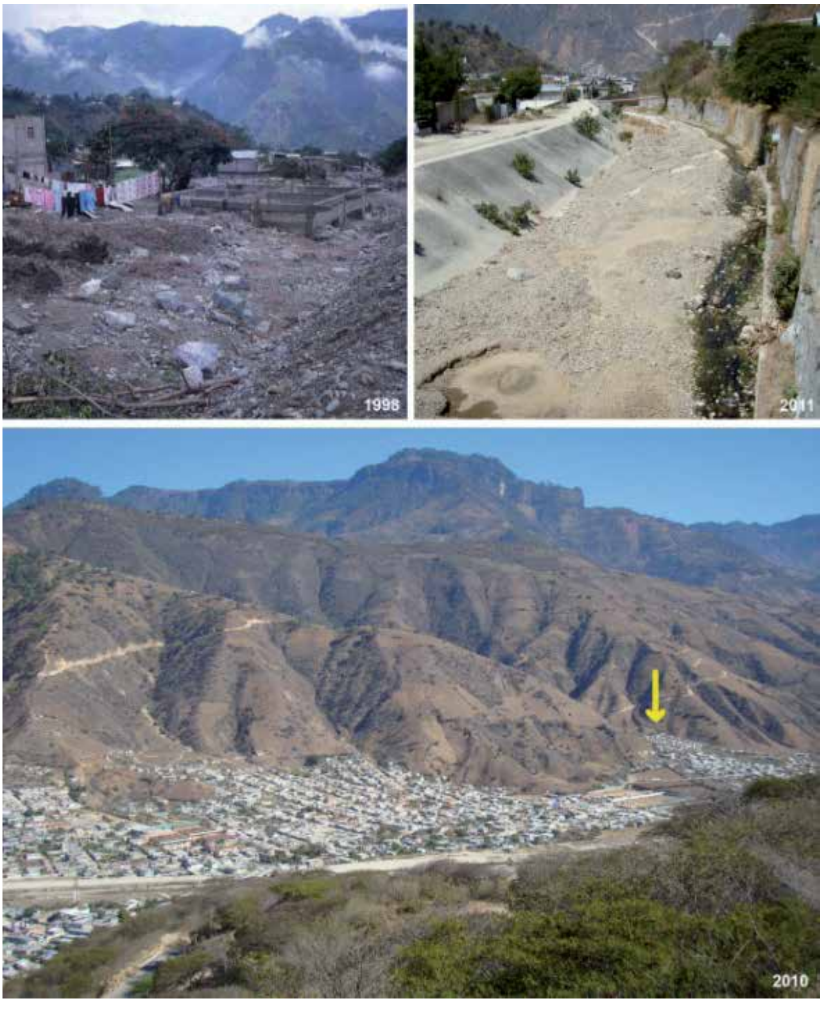


Fig. 14. A mostly dry channel of a tributary creek passing through Motozintla (upper left after the disaster in Sept. 1998, upper right in Feb. 2011 after channelling) and overview on those suburbs of the town which were installed mainly after the 1998 event; the yellow arrow marks a recently established quarter highly endangered by flash floods

Also the hamlets and smaller towns of the municipality as well as the countryside of the upper Huixtla and Coatán Valley have been battered severely during downpours spanning several days. For example, Buenos Aires, located around 500 meters above Motozintla received 540 mm during the four day event in 2005 or even 615 mm in five days. After such incidences road interruptions last up to several weeks just as was in 1998. In these cases technical prevention normally consists of safeguarding techniques such as the integration of stone filled baskets, so called welded mesh gabions. Under the existent runoff forces and pressures by slide masses they form only a provisory shelter, however a useful tool to protect and enhance the establishment of trees planted as intermediary soil-fixing media. This is also valid for welded mesh mattresses on gully flanks if combined with treelets planting at the same time.

4.3.2 Flooding in the plain of Tapachula

In Tapachula, for instance the rising water level of the Coatán River triggered by the intense rainfalls during hurricane Stan, hit the town hard as shown by the following interview (Alscher & Faist 2010):

"The torrential river took away my entire house. This here, from my mother, was buried by mud. The house of my brother was also taken away by the river; mine has disappeared completely. [..] Everything has been demolished. We were rescued with a rope. Thereafter everything was covered by mud, buried. [..] In this quarter, four streets were washed away – before the storm here were houses – up to there. We used to live in the fourthstreet – now we live in the first street." (Maria, 62 years, Tapachula)

The 2005 event was probably the worst disaster that ever hit the city. Four bridges and the railway were carried away cutting the town into two parts. The photo sequence in Fig. 15 proves that main parts of the city were isolated from major transport links to the north of the country. 10 barrios were heavily damaged and 12 were flooded with mud deposits. More than 2,000 homes were destroyed and nearly 100,000 people affected (Murcia & Macías 2009). The figure shows also the fast recuperation in the river bed, where many areas are inhabited by plants once again although the short distance between the high mountain range and the lowland favors the flood danger. In the upper parts of the Rio Coatán for example about 8653 ha are partly or totally deforested. This leads to an erosion rate up to 9t/ha higher than mountain slopes with endemic forests (Mundo Molina 2010). In the case of Tapachula the 4064 m a.s.l. high Tacaná Volcanic Complex in the backcountry enlarges the sediment load.

The catchment area of the Rio Cuilco was reforested during a project of the CONAGUA (National Water Commission, see also Baumann 2006) and therefore the impacts on the lower parts of the river and the municipality of Huehuetan were not as disastrous as in Tapachula. A similar project in most parts of the Rio Coatán would have been desirable. Especially the longitudinal section above the town strongly tends to mass movement during torrential rain. Generally, the damage caused by the 2005 flood can be divided in three different subtypes depending on the type of erosion or accumulation:

- Destruction through raising water level, higher flow velocity and rock and sediment load on the alluvial plain
- Kerning of higher riversides at the undercut slope and producing its collapse
- Accumulation of mud sediments on the slip-off slope

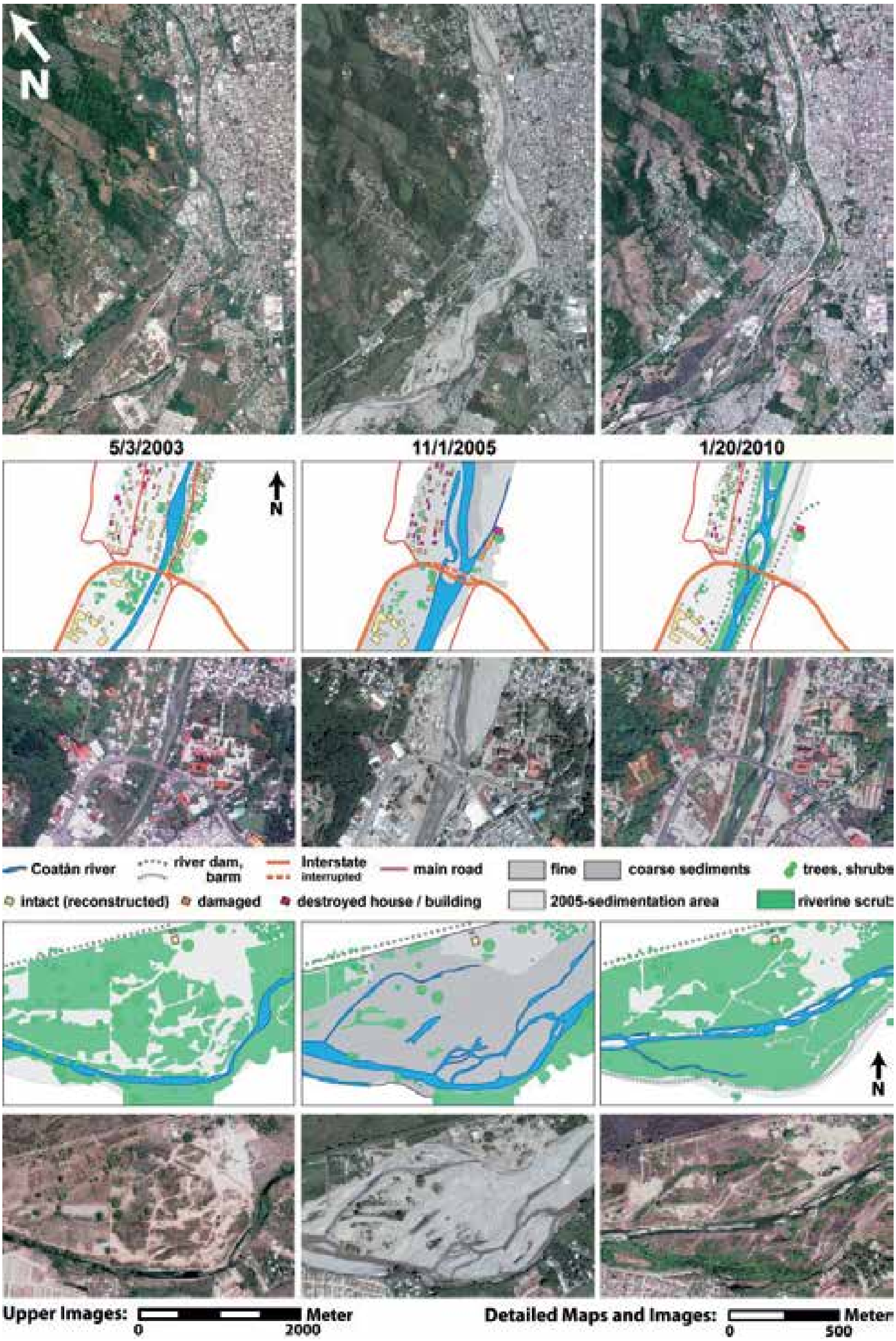


Fig. 15. Effects of the floods along the Rio Coatán at Tapachula in consequence of the hurricane Stan event in Oct. 2005 presented by satellite images before (left row), three months after (middle) and 40 months after the event (right)

The impacts of natural disasters are nowadays higher than in the historical past, especially in terms of economic and social effects. This development is substantially influenced by population growth. The population density has risen rapidly from 36.7 inhabitants per km^2 in 1970 to 79.9 in 2000 in the Soconusco (Sanchez-Crispin & Propin-Frejomil 2002).

This growth, the economic change towards crop export and supply of services forced the people to occupy new land and to enlarge the urban area. The natural birth growth was enhanced by immigration from Central American countries and by an intra-regional migration within rural-areas and towards the towns of the plain. Especially the expansion and founding of settlements on the lower river terraces increased the risk of flooding impact. The lack of state-build water and sewage supply, lack of infrastructure and the unsupervised growing and building of settlements are problems that are going hand in hand. The recurring time of large inundations demonstrates that these events are not unusual, but before the year 1998 the social, infrastructural and economic impact was not as serious as is today.

The character of the 2005 inundation was rather erosive than accumulative. Many old deposits were exposed and now it is possible to identify at least ten flood events in the past 680 years of the Rio Coatán terraces near Tapachula, among which seven are not older than 105 years (Murcia & Macías 2009). The authors use the terms of "hyper-concentrated" and "sediment-loaden" flow to describe the type and the composition of flood deposits. The main type is the sediment-loaden flow with a weight of less than 40% sediment. The hyper-concentrated flow has a sediment weight of 40 to 80%. The latter form the higher stratigraphic deposits containing glass, plastic and other human legacies as residual waste products of the last 60 years. Some of the floodplains were even settled since decades, what explains many of abandoned houses in Tapachula as fig. 15 demonstrates by examples in the left row.

The river terraces of the last 680 years indicate that the Rio Coatán does not change its own riverbed actually. Consequently further destructive inundations seem to be realistic. Today, the Tapachula section of the Rio Coatán is confined by dykes along most of its length passing through the city. The dams follow an imaginary line between intact residences only flooded with mud and the zone of destructive rock and debris deposits. The establishment of the dam was the only one initiated by the government, thus it seems questionable if it meets a reliable and stable function to safeguard the inhabitants.

5. Increasing vulnerability

5.1 Deforestation

An outline of the historical course of land reclamation and degradation explains the increasing destabilisation of the geomorphological and geoecological resilience. The coastal plains of the Soconusco are the only subregion settled since ancient times with evidences of pre-Columbian influences starting as early as 1500 BC by the forefathers of Olmec and later followed by the pre-classic period of the Mayan civilisation, as well as influenced by the Aztec empire. Up to 1400 m a.s.l. land reclamation on the above following lower escarpment of the Sierra Madre started as late as in the second half of the 19th century by converting the seasonal and evergreen rainforests into shade coffee plantations with traditional methods of soil conservation. The practice of tree shadow and weed tolerance was ecologically extremely important for this inclined section since denudation effects were still limited. This changed again in the late 1970ies when many land owners started to eliminate the shade trees and to apply herbicides. Several coffee fincas suffered from creeping effects of soil erosion by splash (Hagedorn 1996) and consequent surface runoff. Meanwhile, most proprietors are conscious of the protecting effect of dense plantations and returned to traditional systems or successfully converted their grounds into shaded cultivations of ornamental plants. Hence, in spite of the enormous rainfall amounts in this area of maximum downpour intensity the small scale denudation effects form a hidden aspect while great dimensions of slides and gullies are relatively rare. Therefore, interestingly, although situated in the belt of highest rain intensities, the coffee belt with its subtle soil erosion must be considered of lesser peril to human life and hazardous effects. Nevertheless, researching the effects caused by hurricane Stan on coffee fincas of the region, Philpott et al. (2008) revealed that a reduction of the complexity of the shade canopy increases the surface area affected by landslides as well as the number of roadside landslides.

Likewise, the similarly humid sections of the uppermost reaches of the Sierra are relatively stable against catastrophic mass movements as long as they are forested, which in most cases is valid due to the lower population density in steep environments. Only the crest line nearby Niquivil and around Boquerón is more densely settled since the late 1880ies, when the former carrying capacity in the highlands of Guatemala was exceeded and therefore many Mam Indians were forced to invade into the Mexican border zone. Here, denudation processes are once again characterized by subtle but continuous landform activities like turf exfoliation initiated by trampling of livestock with progressive surface runoff and sheet wash on abandoned fields.

A completely different situation is given on the slopes beyond side crests such as in the upper parts of the valleys of Rio Coatán and Rio Huixtla, located in the rain shadow of volcano Tacaná and Boquerón, respectively. Some lower parts of these dry valleys and especially the surroundings of Rio Xelajú Grande near Motozintla were populated in a moderate way during ancient times, but in the meantime they are subjected to a very strong land requirement by peasants. Here, sliding and gullying form very active processes and create correspondent landforms, which seem to contradict the semiarid climate conditions given. On the other hand, there exist several items that explain the high vulnerability of the relatively dry valleys to severe erosion damages:

- As the rain shadow valley sites never were occupied by exuberant and fast growing tropical vegetation types (mostly pine forests instead of broadleaved tropical rainforests and moderate succession speed on fallow land instead on fast weed and shrub recuperation) they were and are considered as preferred colonisation terrain for small farmers and hence, suffered from intensive deforestation.
- The same population never received advices and guidance in sustainable and variable land-use systems, such as in some communities of neighbouring departments in Guatemala (Totonicapan, Quetzaltenango, Sololá) and thus forever remained stuck in the primitive milpa system.

- The latter was rather acceptable as long as the "guatal", i.e., the fallow period used for soil recovery within the prevalent field rotation system lasted for at least ten years. But during the last decades natural population growth speeded up so fast that, apart from a recent trend of temporary migration to the US, more and more land owners were forced to accelerate the rotation cycle. Soil recovery and especially a useful re-humification were no longer sufficiently ensured.
- Additionally, the prevalent dry climate results in a higher rate of physical instead of chemical weathering, i.e., the prevalent coarse-grained substrate is less stable against heavy rainfalls due to its limited shearing resistance compared to the loamy soils of the tropical humid climate of the vicinity.

Open milpa fields and overgrazed fallow land on strongly weathered granitic saprolite predominate on the steep slopes an intense gully incision is present throughout the area around Motozintla and in upper Huixtla and Coatán Valley. Here, the most intense recent deforestation is also attributed to an immense expansion of public infrastructure including poorly planned roads passing through unsettled, steep terrain towards remote mountain areas. During the last four decades, they opened unexploited territories along the roadside for further immigration and thus an increasing demand of agricultural land.

5.2 Roadside slides

During the last decades, a booming investment in road access to remote and vulnerable highland areas provoked large devastations and land losses along the routes. Two classes of road slides can be differentiated. The primary describes the direct effect of material actively dozed down a slope during the construction process. The accumulation of waste material produces considerable stability problems to the road debris slopes (Caballero et al. 2006). The secondary class follows after excavation of the uphill slope. The resulting road cuts force continuous maintenance work to remove the rock and soil accumulated on the road, which is a frequent phenomenon during or after protracted heavy rainfalls as given by slowly passing storms. They are more dangerous as rapidly passing cyclones and lead to traffic interruptions of undefined periods caused by large damages. In most cases, dump material of primary road slides cannot be rated as hazardous sites, since it becomes settled by secondary pioneer vegetation and thus stabilised after construction. However, the resulting scars form an ugly aspect. Instead, unsecured uphill acclivities often cause a risk because of their potential of ongoing falls and slides as obvious disturbance factor in many of the tropical mountain landscapes worldwide.

Same as off-road landslides, the hot spots of road slides concentrate on drier sections of the Sierra Madre. In some cases they even exceed the number of out-of-the-way slides as interpretable by the red-blue patchwork in Fig. 9 (extract b). The slope failures depicted in Fig. 16 exist since several years, are quasi-permanently active, and some of them can be divided in a lower dump section and an upper excavation part. In the first case the forest sites below the road are dissected by lamellar debris (e.g., between the creek and the unpaved road in the middle of fig. 16, right). In case that a slide is located just in the uppermost part of a catchment of a stream like in the upper right half of fig. 16 (left), dump deposits are removed during rainy phases and hence, accumulation succeeds alongside the ditch. The just mentioned example in the picture forms a rotational slide which is well recognisable by multiple slide blocks due to a disruption of the initial and principle scar. Here, fault scarps and fractures create a continuous slope instability causing frequent slip and toppling failures leading to extended roadblocks during the last two decades.

Fig. 16. Roadside slides above Buenos Aires (left; locality Las Flores Buenavista, road towards Porvenir) and below Niquivil (right; locality Tuxchamén, dirt road towards Pavencul). Blue quadrates = houses and sheds, blue line = creek with arrow of flow, red-yellow lines = roads (source Google maps, date taken November 2010)

In contrast, the example on the right (fig. 16) stands for an enormous translation slide with a height of approximately 100 m and an extension of about 300 m, which gradually develops since the early 2000s and deepens stepwise by repeated gully erosion processes. Here, solely road construction is responsible for the sliding process, since before the intervention the environment was governed by a dense mountain forest. Same as in the Buenavista example, the Tuxchamén sliding resulted from an artificial excavation of the underlying stratum without the establishment of a firm fundament. In consequent, close-by home- and farmsteads become endangered like several premises below or also above the road slides, respectively, marked by blue rectangles in both aerial pictures in fig. 16. Spillage and fall risks of roads and houses in the Sierra are not only given by heavy rainfalls but also by relatively frequent earthquakes of a maximum magnitude between 3 and 5 or by a combination of waterlogged substratum and temblors.

5.3 Alteration of rainfall input, acceleration of erosion and flooding processes

In 2011 the highest annual rainfall amount during the wet season was measured in vast areas of the study area. The annual rate in Tapachula was the highest since 1933 and the most intense rainfall per hour was recorded. But 81mm/h in June 24 not only caused a flooded city. During September 2-5 the tropical depression 11-E brought torrential rain embedded in a widespread monsoonal flow from the Pacific into the southern parts of Mexico and Guatemala. The novelty was the crossing of the Isthmus of Tehuantepec and the regeneration of a tropical storm over the open water of the Gulf of Campeche. This was the fourth time in the year 2010 that a prolonged heavy rainfall was registered in southernmost region of Mexico.

Over all, the total precipitation during the wet season seems to have appreciably changed in the last years. Both, the monthly and the annual precipitation amounts appear to be more volatile. Moreover, in years of above-average rainfall amounts, a substantial increase of heavy rain has been measured (fig. 6). Furthermore, studies like those of Pavia et al. 2006 and Peralta-Hernández et al. 2009 show that extreme events tend to occur more frequently during La Niña periods and negative phases of the Pacific Decadal Oscillation (PDO). Therefore the multiple occurrences of torrential rains in the research area in 2010 seem to be a result from a teleconnection of the La Niña situation in the southern Pacific and the La Vieja regime in the northeast Pacific. In recent years the higher sea surface temperatures (SST) in the tropical Atlantic waters raised and led to increased rainfall intensities over Central America (Meehl et al. 2007). Moreover the hurricanes which affected the Pacific coast of Mexico show a marked augmentation (Jáuregui 2003). However, only the landfall of the tropical storm Barbara (2007) directly touched the study area and did not affect the region with torrential rains. Hence the major rainfall events are caused by remnants of tropical storms from the Atlantic in combination with a monsoonal flow of moist, convective air transport from the Pacific open waters. Consequently the occurrence of prolonged heavy rainfall events in southern Mexico depends on the atmospheric pressure situation in the Gulf of Campeche. The occurrence of torrential rain seems to intensify in the region although fig. 6 illustrates that downpours form a prominent part of the regional climate for a long time.

The extremely vulnerable mountain region in the municipality of Motozintla could be exposed to expanding dangers in the future. The last 25 years proved that impacts of heavy rainfall events as well as the change in social and economic terms led to a new dimension of environmental hazards in the Soconusco and the adjacent pacific mountain range. The anthropogenic influence acting with a rainfall pattern that seems to differ slightly could change the frequency and magnitude of sliding and furthermore flooding in valleys and the coastal plain. Especially the inappropriate land-use and the growing population pressure leading to deforestation, conquering of steep mountainous regions, boosted road construction and the end of traditional crop cultivation are forming a dangerous mixture. The ensemble of these natural and anthropogenic phenomena contributes largely to an acceleration of hazardous effects. The resident population is definitely even more aware of the impacts of inadequate land-use and exploitation measures than their caretakers. Both tend to define the problems down very soon, because they are lacking other economic stimulations or opportunities and are not familiar to more sustainable agricultural techniques as described in chapter 6. Therefore it is most evident that the magnitude and frequency of destructive denudation processes as well as of extreme flooding disasters will advance due to climatic incalculabilities and the ecological ignorance or perplexity of responsible administrators and actors.

6. Conclusion: Ecological versus technical prevention

Frequency analyses of historical records of daily rainfall in the study area of Motozintla indicate that extreme events like those described above have a high recurrence period (Caballero et al. 2006), which speeds up to more frequent torrential storms in the Sierra and inundations in the plains. This perspective goes along with social and economic problems. Notwithstanding a lowered population pressure by falling birth-rates during the last thirty years, remigration by many Mexican low-skilled farm-workers from the economically battered United States just started to flood the fragile region, as is also true for most of the neighbouring Central American mountain areas. As parts of towns and villages are constructed on sediment-loaden flow deposits or above and below slopes endangered by mass movements, great parts of the Sierra and its forelands remain areas of high risk. Therefore, hazard maps based on the type, course, magnitude, and frequency of all known disastrous events are urgently needed.

Technical prevention by devices like those mentioned before is only useful to a certain extend but not at all a convenient measure for an avoidance of sedimentation and spillage disasters or their reduction since the source of those events might be located far way and is given by disregard of an agro-ecological mismanagement. The main problem lies in the unwillingness of the authorities to recognize the danger given by open and at the same time low yielding corn fields on extremely steep slopes. They are widespread in the immediate vicinity above Motozintla and prone to active gully and sliding processes, as shown before by the example of Morelos in fig.12. Extensive sheep pasturing leads to comparable results (fig. 11). Both phenomena are the main trigger for the erosion and removal of sediment loads, which are transported over long distances into lower levels of lesser inclination. In the case of Motozintla, the recent deposits of the 1998 and 2005 flood followed over 3.5 km along the Arroyo Allende into town and result from a vast corn field area located around 400 m above the town. One more tributary catchment, which enters the town further west, i.e. of Arroyo La Mina, provokes similar debris fills due to the same causes.

Meanwhile, in the contiguous parts of Motozintla the subsistence system is no longer characterized by the former field rotation of cornfields with 2-year cycles and 10–15-year fallow periods for soil recovery. Instead, in most farmlands the guatál-period is cancelled due to the rapid rise in demand for land resulting from the great increase in the Indian population. Simultaneously, the descendants are forced to migrate into the steepest areas and cut the remaining forests. While both effects must be considered as an outcome of demographic pressure, permanent corn production combined with pastured fallow (fig. 17, above left) does not at all match the environmental conditions and is by far not the only survival option for the struggling rural population. Following the advices of Philpott et al. (2008) for the coffee area, in high-risk areas of the milpa zones in dry valleys farmers should be obliged to reduce the high susceptibility to heavy rainfall damage (e.g. landslides, gullies) by increasing on-farm vegetation complexity. So, fig 17 presents one of many alternatives integrated in an agro-foresting system (above right).

Among the plentiful feasible ways towards a sustainable land-use, which at the same time leads to hydrological and geomorphological preservation agro-ecological farming and agro-silviculture are the most promising ones. The first technique bases on crop-rotation

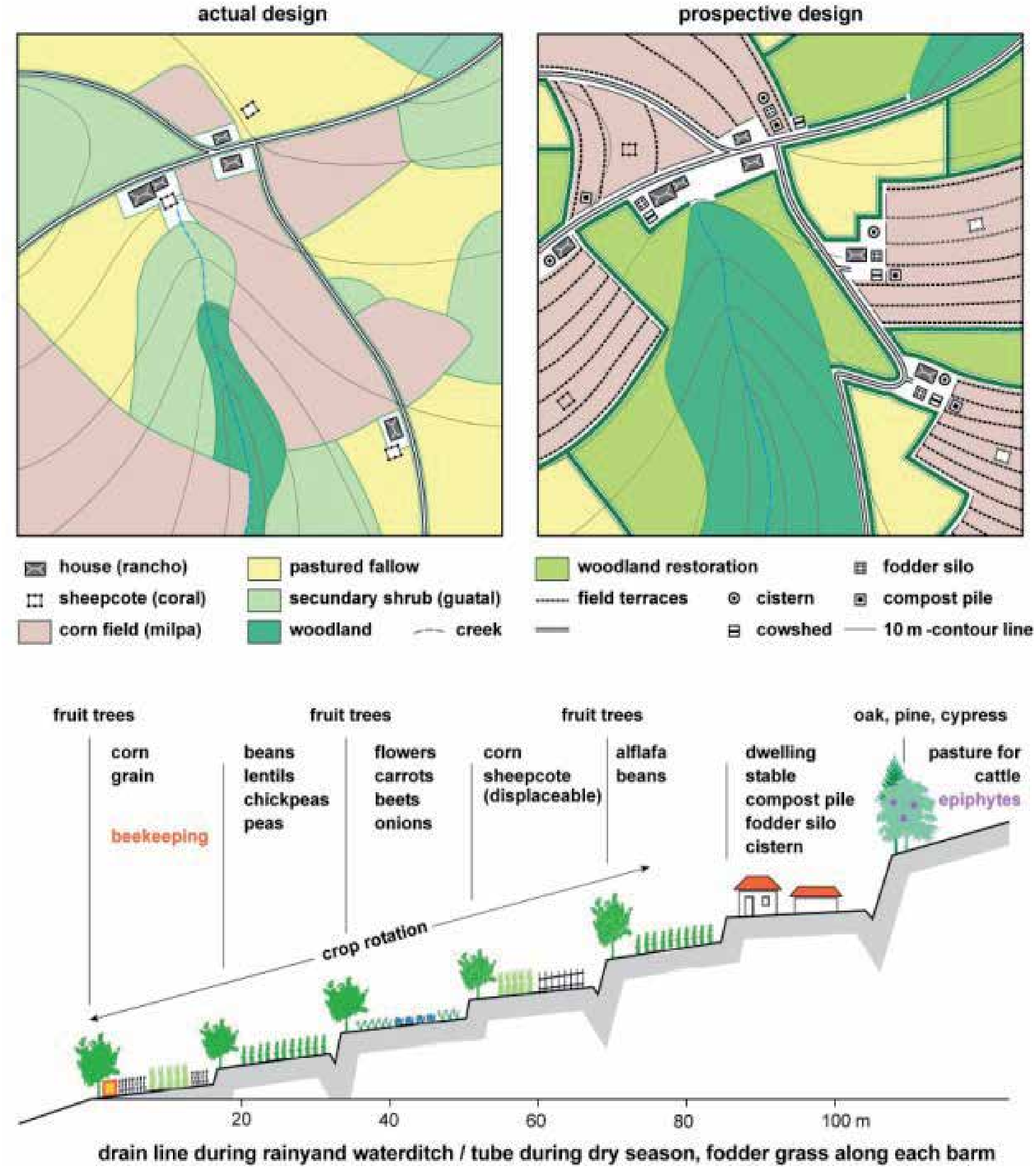


Fig. 17. Current situation of primitive subsistence agriculture (upper left) and target situation of land use management in the milpa zone (upper right) including a scheme of a sustainable crop rotation system for a same hillside environment (below)

instead of field-rotation to reduce mass movement risks as much as possible and to prevent land consumption by yield increases and minimisation of farmland. This advisement bases on ecological and economical experience in several nearby Guatemaltecan valleys of a relatively expanded dry period as given around Totonicapan or in places around Huehuetenango and Quetzaltenango. Here, the markets offer a larger food supply than in the semihumid and semiarid regions on the Mexican part of the Sierra Madre and the farmland is characterised by a multiple variety of products for growing consumer requests.

Additionally, an even more important task relies on the attempt to convert leached and steep unproductive fields into productive woodland. Secondary pine-alder forests respond to abandonment rather fast and create a favourable germination bed for following oak growth. Mature forests consist of many oak and pine species, which apart from firewood and timber harbour plenty of additional benefits like leaf litter supply, lopping of leaves for fodder, collecting of (partly huge) acorns for pigs, resin tapping of pines for chemical use, and much more. An auspicious approach for sideline income is breeding of ornamental epiphytes on gnarly branches densely covered by lichens and further up by mosses, first and foremost of bromeliads and orchids for home decoration in countries of the first world. Inventory studies in the neighbouring highlands of Chiapas by Wolf and Konings (2001) point to attractive and resistant species of high population density and even distribution in the lower stratum of forests as well as to little effects on their reproductive capacity when the harvest system follows a strict management plan.

Owing to their relatively small diameter and reduced height, trees in dry forests were and are considered of low value as well as less attractive for sustainable logging and hence, underwent slash-and-burn practices to gain farmland in the direct neighbourhood of Motozintla and in the well tapped dry valleys above Huixtla and Tapachula. Likewise, drastic erosion and sedimentation effects, respectively, occur along river margins and thus protection and restoration of meanwhile rare riverine forests in dry valleys as well as in the coastal plain of Soconusco must receive highest priority.

While the semiarid to semihumid areas of the Sierra Madre de Chiapas and the adjacent Cordillera Volcanica in Guatemala continue to suffer from dramatic land degradation due to insufficient agricultural maintenance and danger awareness the question arises why despite detailed scientific knowledge mismanagement problems advance without any control by advisers.

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6

Elevation Uncertainty in Coastal Inundation Hazard Assessments

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1. Introduction

Coastal inundation has been identified as an important natural hazard that affects densely populated and built-up areas (Subcommittee on Disaster Reduction, 2008). Inundation, or coastal flooding, can result from various physical processes, including storm surges, tsunamis, intense precipitation events, and extreme high tides. Such events cause quickly rising water levels. When rapidly rising water levels overwhelm flood defenses, especially in heavily populated areas, the potential of the hazard is realized and a natural disaster results. Two noteworthy recent examples of such natural disasters resulting from coastal inundation are the Hurricane Katrina storm surge in 2005 along the Gulf of Mexico coast in the United States, and the tsunami in northern Japan in 2011. Longer term, slowly varying processes such as land subsidence (Committee on Floodplain Mapping Technologies, 2007) and sea-level rise also can result in coastal inundation, although such conditions do not have the rapid water level rise associated with other flooding events.

Geospatial data are a critical resource for conducting assessments of the potential impacts of coastal inundation, and geospatial representations of the topography in the form of elevation measurements are a primary source of information for identifying the natural and human components of the landscape that are at risk. Recently, the quantity and quality of elevation data available for the coastal zone have increased markedly, and this availability facilitates more detailed and comprehensive hazard impact assessments.

1.1 Elevation-based inundation hazard assessments

Elevation is one of the most important parameters that determine the vulnerability of coastal lands to inundation from flooding events and sea-level rise (Gesch et al., 2009). In many coastal inundation impact assessments conducted at various scales, elevation is a primary variable that is analyzed to determine vulnerability to adverse effects of rising water levels. These assessments require use of topographic maps or digital elevation models (DEMs) to identify low-lying lands with low or no slope that are at risk (Committee on Floodplain Mapping Technologies, 2007). Numerous studies over the last three decades have used elevation data in various forms to map areas and tabulate statistics of lands that would be affected by a given water level increase, oftentimes due to sea-level rise and/or storm surges (Dasgupta et al., 2009; Dasgupta et al., 2011; Demirkesen et al., 2007; Ericson et al., 2006; Kleinosky et al., 2007; Li et al., 2009; McGranahan et al., 2007; Najjar et al., 2000; Neumann et al., 2010; Rowley et al., 2007; Schneider and Chen, 1980; Small and Nicholls, 2003; Titus and Richman, 2001; Titus et al., 1991; Weiss et al., 2011; Wu et al., 2002; Wu et al., 2009).

The accuracy and resolution with which coastal elevations have been mapped directly affect the reliability and usefulness of coastal inundation impact assessments. To many, it may seem straightforward to simply "raise the water level" on a coastal DEM to map and assess the vulnerability of land and its corresponding resources to inundation. However, recent research (Gesch, 2009; Gesch et al., 2009; National Ocean Service, 2010) has demonstrated that the qualities of the underlying geospatial data, especially the DEM, must be well understood to properly model potential inundation for reliable hazard assessment findings.

1.2 Elevation data accuracy

Because elevation data are such a critical component in coastal hazard assessments, the qualities of the data, especially vertical accuracy, exert a strong influence on the reliability of the results. As such, the vertical accuracy must be well characterized and well understood so that the data are applied properly. Absolute vertical accuracy is an expression of the overall quality of the elevations contained in a DEM compared to the true ground elevations at corresponding locations. The root mean square error ($RMSE_z$), as described by Maune et al. (2007), is a widely accepted metric to describe the absolute vertical accuracy of elevation data:

$$RMSE_z = \mathrm{sqrt}[\sum(z_{\mathrm{data}\ I} - z_{\mathrm{check}\ I})^2/n] \quad (1)$$

where $z_{\mathrm{data}\ I}$ is the vertical coordinate of the I^{th} check point in the elevation dataset, $z_{\mathrm{check}\ I}$ is the vertical coordinate of the I^{th} check point in the reference dataset, n is the number of points being checked, and I is an integer from 1 to n. Another common metric for expressing the vertical accuracy of elevation data is the "linear error at 95% confidence" (LE95). LE95 may be calculated directly from the measured $RMSE_z$ (Maune et al., 2007):

$$LE95 = 1.96 * RMSE_z \quad (2)$$

As described below, the absolute vertical accuracy is useful for determining the minimum increment of inundation that can be reliably modeled, and, in the case of sea-level rise, the minimum time period over which sea-level change can be effectively modeled.

1.3 Uncertainty in inundation assessments and maps

Uncertainty should be an important consideration in any modeling exercise. For flood inundation mapping, there are several sources of uncertainty, but they are often not quantified due to lack of awareness of the sources or lack of suitable data to quantify them (Bales and Wagner, 2009). These sources of uncertainty include water level, or hydrologic, data (Brown et al., 2007; Chu-Agor et al., 2011; Purvis et al., 2008), the hydrologic or hydraulic model itself (Bales and Wagner, 2009; Gallien et al., 2011), input parameters to the flooding model (Brown et al., 2007; Cowell and Zeng, 2003), and input topographic (elevation) data (Colby and Dobson, 2010; Wilson and Atkinson, 2005; Wechsler, 2007).

The input elevation information is a primary contributor to the uncertainty associated with inundation hazard assessments. In a study conducted for the Federal Emergency Management Agency (FEMA), the agency responsible for mapping flood hazards across the United States, the primary finding was that "topographic data are the most important factor in determining water surface elevations, base flood elevation, and the extent of flooding and, thus, the accuracy of flood maps" (Committee on FEMA Flood Maps, 2009). The study also recommends that flood map accuracy should be quantified and communicated by thorough documentation of the data and mapping and modeling methods used to develop the products. The resolution and accuracy of elevation data are especially critical for modeling inundation risks in low-relief, low-slope coastal settings (Coveney et al., 2010; Coveney and Fotheringham, 2011; Gesch, 2009). Gesch et al. (2009) and Lichter et al. (2011) review existing large-area sea-level rise vulnerability studies that employ elevation data and note that in many cases uncertainty is not considered. Gesch et al. (2009) also make suggestions on accounting for elevation uncertainty in future sea-level rise assessments.

Maps that depict areas vulnerable to potential inundation are useful to planners and land managers who are responsible for communicating and mitigating risks. Often, these maps are accompanied with corresponding statistical summaries of population, infrastructure, property value, economic activity, or other variables within the mapped impact zone. In many cases, the studies that have produced these maps and statistical summaries have not considered the uncertainty (inherent vertical error) of the underlying elevation data. There has been some recognition that hazard studies should include and report uncertainty in project results; for example, Merwade et al. (2008) have demonstrated that a modeled inundation area has uncertainty associated with it by depicting a buffer around the flood boundary. Smemoe et al. (2007) and Bales and Wagner (2009) have suggested adding probabilities to flood hazard maps as a way to communicate the uncertainty associated with modeled inundation areas, a concept which has been successfully demonstrated by Leedal et al. (2010). The use of probabilities (expressed as confidence levels) to communicate uncertainty should also be extended to the statistical summaries of impacted land area, population, and other socioeconomic variables (Gesch et al., 2009). Merwade et al. (2008) have also recommended such an approach for floodplain mapping, stating that the flood inundation extent should be reported as being "in the range from x units to y units with a z% confidence level."

2. Methods

Because the vertical accuracy of the input elevation data in coastal inundation hazard assessments is such a critical parameter that significantly affects the veracity of the modeling results, it must be described fully according to standards and accepted best practices. In many cases, the elevation data producer provides accuracy information, but overall dataset statistics may not be adequate to fully characterize the performance of the elevation model in extreme low-relief settings, which are often the target of inundation assessment studies (Coveney et al., 2010). If a suitable accuracy statement is not available for an elevation dataset, then the user must conduct an accuracy assessment; several standards and guidelines describe the best practices for doing so (Maune et al., 2007).

2.1 Elevation accuracy assessment

As described above, the RMSE is a common method of testing and reporting the vertical accuracy of elevation datasets. However, there are other methods used in the literature, and it is important to understand how the different metrics are related. Also mentioned above is LE95, or the use of the 95% confidence level. This convention follows the U.S. National Standard for Spatial Data Accuracy (NSSDA), which states that the "reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical location of the point falls within +/- of that linear uncertainty value 95-percent of the time" (Federal Geographic Data Committee, 1998).

Some data producers and studies report absolute vertical accuracy as "linear error at 90% confidence" (LE90), which derives from the older U.S. National Map Accuracy Standards (NMAS) issued in 1947, long before the age of digital elevation data. The NMAS state that "vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval" (U.S. Geological Survey, 1999). An alternative way to state the NMAS vertical accuracy standard is that elevations obtained from the topographic map will be accurate to within one-half of the contour interval 90% of the time. Even though the NMAS were developed for hardcopy topographic maps, the terminology is sometimes still applied in reference to digital elevation data, such as specifying accuracy for an elevation data acquisition that meets "2-foot contour accuracy." In this case, digital elevation data that supports a 2-foot contour interval would exhibit an RMSE of 18.5 centimeters. Maune et al. (2007) provide a useful comparison of NMAS equivalent contour interval, LE90, RMSE, and LE95 vertical accuracy metrics.

When testing and reporting the vertical accuracy of elevation data, if the measured errors have a mean of zero and are normally distributed, then the RMSE is the equivalent of the statistical standard deviation of the errors. Simple conversion factors can be applied to convert among the various vertical accuracy measures (Greenwalt and Shultz, 1962; Maune et al., 2007). Whichever accuracy metric is used, it must be identified. Too often, an accuracy number is cited for a DEM but no metric is identified, so the accuracy statement is meaningless.

In some cases, elevation data errors do not follow a normal distribution, so an alternative method is used to report the 95% error metric (Maune et al., 2007). Elevation data derived from lidar (light detection and ranging) remote sensing are often used in coastal areas because of their high vertical accuracy and high spatial resolution (Brock et al., 2002; Sallenger et al., 2003; Stockdon et al., 2007), but lidar measurements are sensitive to ground cover so in some cover types the lidar sensor may not detect ground level. This can lead to measured errors in an accuracy assessment that do not follow a normal distribution, thus the need for an alternative 95% confidence error metric. The U.S. National Digital Elevation Program (NDEP) has developed guidelines, or best practices, for testing and reporting the vertical accuracy of such datasets (National Digital Elevation Program, 2004), particularly lidar data.

2.2 Application of uncertainty information

Elevation accuracy testing supplies the knowledge of the inherent vertical error needed to account for uncertainty in inundation hazard assessment. This knowledge of uncertainty of the foundational elevation layer should be integrated into maps, statistical summaries, and any other final products of the impact assessment (Gesch et al., 2009). However, consideration of the vertical uncertainty of the base geospatial data should also be incorporated into the inundation parameters that are analyzed in the study, specifically the minimum increment of inundation used for modeling, and, for sea-level rise studies, the minimum planning timeline. These concepts are described below.

2.2.1 Minimum increment of inundation

Inundation modeling is most often a simple process in which the water level along the shoreline on a coastal DEM is raised by selecting a land elevation above the current water level elevation and then delineating all areas at or below that elevation, thus placing them into the inundation zone. This approach has been commonly referred to as the "bathtub" method, or the "equilibrium" method (Gallien et al., 2011), and it has been improved in later studies by accounting for hydrologic connectivity (Poulter and Halpin, 2007; Poulter et al., 2008). Such a procedure is essentially a contouring process. Hunter and Goodchild (1995) recognized that vertical error in an elevation dataset contributes uncertainty to delineation of a contour line from interpolation of the DEM values. The vertical accuracy of the DEM must be taken into account to determine the contour interval that is supported. An elevation dataset can be contoured at a fine interval, but doing so does not mean that the contours automatically meet published accuracy standards. Similarly, inundation assessments can use small intervals of water level change, but the underlying DEM must have the requisite vertical accuracy to truly support those intervals. The intervals must not be so small that they are within the bounds of the statistical uncertainty of the elevation data.

It has been shown that at the 95% confidence level elevation data to be used for inundation modeling should be at least as twice as accurate as the increment of water level change (Gesch et al., 2009). Recall that the 95% confidence level (LE95) can be calculated from the RMSE (Equation 2). Therefore, in the case of sea-level rise, the minimum increment for sea-level rise modeling, $SLRI_{min}$, is

$$SLRI_{min} = LE95 * 2 \tag{3}$$

Stated in terms of the RMSE, which is commonly the error metric that is calculated and reported, the $SLRI_{min}$ is

$$SLRI_{min} = (RMSE_z * 1.96) * 2 \tag{4}$$

or more simply

$$SLRI_{min} = RMSE_z * 3.92 \tag{5}$$

Given an elevation model with a reported absolute vertical accuracy (or determined through testing) expressed as an RMSE, Equation 5 can be used to determine the smallest increment of sea-level rise that should be considered in a study using that DEM. Using an increment smaller than $SLRI_{min}$ will give questionable results as the increment will be within the bounds of statistical uncertainty of the elevation data. Table 1 lists some common sources of elevation data, the associated absolute vertical accuracies, and the derived minimum increments for inundation modeling.

Elevation dataset	Vertical accuracy: RMSE	Vertical accuracy: LE95	Minimum increment for inundation modeling
Topographic map with 1-foot contour interval	9.3 cm	18.2 cm	36.3 cm
Industry standard lidar	15.0 cm	29.4 cm	58.8 cm
Topographic map with 2-foot contour interval	18.5 cm	36.3 cm	72.6 cm
Topographic map with 1-meter contour interval	30.4 cm	59.6 cm	1.19 m
Topographic map with 5-foot contour interval	46.3 cm	90.8 cm	1.82 m
Topographic map with 10-foot contour interval	92.6 cm	1.82 m	3.63 m
Topographic map with 5-meter contour interval	1.52 m	2.98 m	5.96 m

Table 1. Minimum inundation modeling increments supported by elevation datasets with different vertical accuracies. For the topographic maps, the assumption is that the maps meet U.S. National Map Accuracy Standards for vertical accuracy at the specified contour interval.

Equation 5 can be rearranged to answer, for example, the question, "what RMSE is required for elevation data to effectively model 1 meter of sea-level rise?"

$$RMSE_z = SLRI_{min} / 3.92 \quad (6)$$

Using Equation 6, the answer to the example question is that elevation data with a vertical RMSE of 25.5 cm (or better) is required to reliably model a sea-level rise of 1 meter.

Numerous sea-level rise assessment studies have used scenarios with sea-level rise increments of 1 meter or smaller. The example above demonstrates that highly accurate elevation data must be used to properly consider vertical uncertainty and to produce reliable maps and statistical summaries of impacted areas and resources. Such data, with an RMSE of 25 cm or better, are usually derived from lidar collections, large-scale photogrammetric mapping, or ground surveys. Thus, a challenge in assessing vulnerability to sea-level rise on the order of a meter over broad (global or regional) areas is that the required high-accuracy elevation data are generally not available for the entire study area. Global DEMs do exist, but none of them have the vertical accuracy to support modeling of a 1-meter increment of sea-level rise, which calls into question the reliability of the results of studies (Dasgupta et al., 2009; Li et al., 2009; Rowley et al., 2007) that have used such DEMs for inundation assessment. A 1-meter increment of sea-level rise is well within the bounds of statistical uncertainty of the currently available global elevation datasets (Gesch, 2009).

The discussion here uses sea-level rise as the inundation process, but the application is the same for other types of coastal inundation, such as storm surge. Considering Table 1 and Equation 6, the inundation zone from a 2-meter storm surge should not be mapped using a topographic map with a 5-meter contour interval. However, the impact zone for that same 2-meter storm surge could be reliably mapped based on a topographic map with a 1-meter contour interval.

Some studies combine the effects of climate change, through increased eustatic sea level, and storm surge to model potential future inundation scenarios (Dasgupta et al., 2011; Kleinosky et al., 2007). The concept of minimum inundation increment is applicable in both cases, to the sea-level rise increments and to the storm surge heights used in the study. Neither of them should be smaller than the vertical increment that is supported by the inherent accuracy of the base elevation dataset used in the modeling.

2.2.2 Minimum planning timeline

The time period for many coastal inundation events is measured in terms of minutes (for tsunamis), hours (for storm surges and tidal flooding), or occasionally days (extreme precipitation). However, sea-level rise is a much slower, long-term process that is usually assessed over years, centuries, and millennia. A common timeframe for assessing potential sea-level rise impacts is about 100 years, or from the present to the year 2100, as this timeframe was the general framework for the most recent Intergovernmental Panel on Climate Change (IPCC) analysis and report (Meehl et al., 2007). As with the minimum inundation increment described above, the minimum planning timeline for sea-level rise assessments is also controlled by the inherent accuracy of the foundational elevation data.

Sea-level rise impact assessments assume a given sea-level rise rate, usually a linear one. For instance, the latest IPCC report (Meehl et al., 2007) cites a maximum eustatic sea-level rise of 0.59 meters by the end of the 21st century, or an annual rate of 5.9 mm/yr. Given an annual sea-level rise (SLR) rate and the minimum sea-level rise increment, the minimum planning timeline can be calculated:

$$\text{Timeline}_{min} = \text{SLRI}_{min} \,/\, \text{annual SLR rate} \qquad (7)$$

In terms of the vertical RMSE of a given elevation dataset, the minimum planning timeline can be expressed as

$$\text{Timeline}_{min} = (\text{RMSE}_z * 3.92) \,/\, \text{annual SLR rate} \qquad (8)$$

As an illustration, assume the annual rate of sea-level rise for a study is 5.9 mm/yr, or the maximum rate from the most recent IPCC report. Also assume the elevation data to be used for modeling have a vertical RMSE of 9.25 cm, which would be the equivalent of a 1-foot contour interval topographic map that meets NMAS (Maune et al., 2007). Applying Equation 8, the minimum planning timeline is approximately 61 years. In other words, given the sea-level rise rate, it will take more than 61 years to reach the minimum sea-level rise increment afforded by the elevation data. In this example, mapping the potential sea-level rise impact zone 40 years hence would give unreliable results as the cumulative rise in sea-level would represent an increment smaller than the allowable minimum inundation increment.

If the accuracy of the input elevation model is held constant so that the minimum sea-level rise increment remains the same, the minimum planning timeline will decrease if a higher rate of sea-level rise is used. Conversely, if a lower rate of sea-level rise is used, the minimum planning time will be extended (it will take more years to reach the minimum inundation increment). Further illustrations using the IPCC sea-level rise rates are presented and discussed below.

3. Results

The following examples illustrate the application of elevation uncertainty information to coastal inundation hazard assessments. Sea-level rise is the subject of these example results, but the concepts and approach of accounting for elevation uncertainty would be the same for other higher frequency, higher magnitude types of coastal inundation.

3.1 North Carolina case study

The following case study (Gesch, 2009) illustrates the advantages of using high-resolution, high-accuracy elevation data for coastal inundation hazard assessment. In this case, lidar remote sensing is the source of the elevation data, a primary input data resource for coastal hazard impact assessments.

North Carolina on the mid-Atlantic coast along the eastern United States has a broad expanse of low lying land, so it is a good site for a mapping comparison for a sea-level rise (or inundation) application. Lidar data at 1/9-arc-second (about 3-meter) grid spacing were analyzed and compared to 1-arc-second (about 30-meter) DEMs derived from 1:24,000-scale topographic maps. The potential inundation zone from a 1-meter sea-level rise was mapped from both elevation datasets, and the corresponding areas were compared. The analysis produced maps and statistics in which the elevation uncertainty was considered. Each elevation dataset was "flooded" by identifying the grid cells that have an elevation at or below 1 meter and are connected hydrologically to the ocean through a continuous path of adjacent inundated grid cells. For each dataset, additional areas were delineated to show a spatial representation of the uncertainty of the projected inundation area. This was accomplished by adding the LE95 value to the 1-meter sea-level increase and extracting the area at or below that elevation using the same flooding algorithm. The lidar data exhibited a ±0.27 meter error (LE95) based on accuracy reports from the data producer, while the map-derived DEMs had a ±2.21 meter error (LE95) based on an accuracy assessment with high quality geodetic control points.

Figure 1 and Table 2 show the results of the comparison. In Figure 1 the darker blue tint represents the area at or below 1 meter in elevation, and the lighter blue tint represents the additional area in the vulnerable zone given the vertical uncertainty of the input elevation datasets. By adding the LE95 value to the projected 1-meter sea-level rise, more area is added to the inundation zone delineation, and this additional area is a spatial representation of the uncertainty. The additional area is interpreted as the region in which the 1-meter elevation may actually fall, given the statistical uncertainty of the original elevation measurements. Note how use of the more accurate lidar data for delineation of the vulnerable area results in a more certain delineation; in other words, the zone of uncertainty is small.

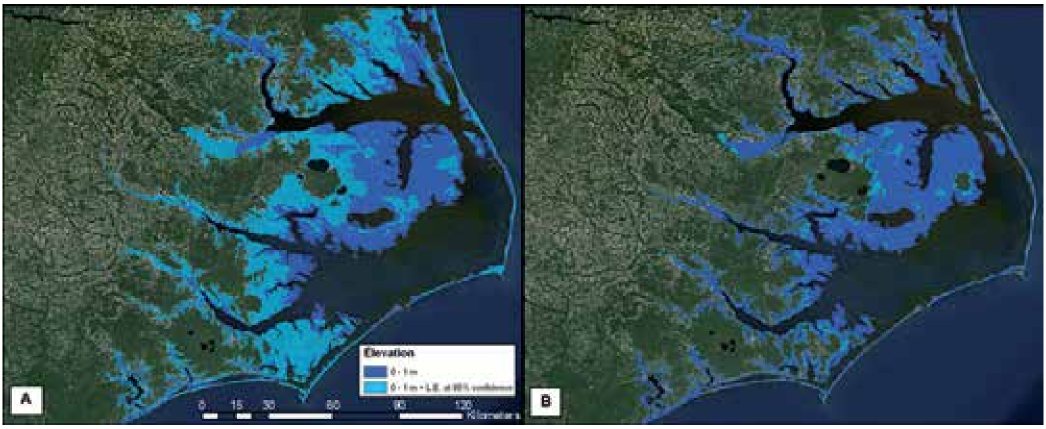

Fig. 1. Lands vulnerable to a 1-meter sea-level rise, developed from topographic map-derived DEMs (A) and lidar elevation data (B). The darker blue tint represents the area at or below 1 meter in elevation, and the lighter blue tint represents the additional area in the vulnerable zone given the vertical uncertainty of the input elevation datasets. The background is a true color orthoimage.

Elevation dataset	Area ≤ 1 meter in elevation (sq. km)	Area ≤ 1 meter in elevation at 95% confidence (sq. km)	Percent increase in maximum vulnerable area when elevation uncertainty is included
1-arc-second (30-meter) DEMs derived from 1:24,000-scale topographic maps	4,014	8,578	114%
1/9-arc-second (3-meter) lidar elevation grid	4,195	4,783	14%

Table 2. The maximum area of land vulnerable to a 1-meter sea-level rise as calculated from two elevation datasets (see Figure 1), as well as the area of vulnerability when the uncertainty of the elevation data is considered.

Table 2 compares the vulnerable areas as delineated from the two elevation datasets. The delineation from the topographic map-derived DEMs more than doubles in area when the elevation uncertainty is considered, which calls into question the reliability of any conclusions drawn from the delineation. It is apparent that for this site the map-derived DEMs do not have the vertical accuracy required to reliably delineate a 1-meter sea-level rise inundation zone. Lidar-derived elevation data are the appropriate data for finding out how much land in the study site is vulnerable to a 1-meter sea-level rise (3,548 to 4,783 square kilometers at a 95% confidence level). This range accounts for the LE95 of ±0.27 meters applied to the 1-meter sea-level rise increment, whereas Table 2 shows only the maximum potential inundation area given the elevation data uncertainty (1 m + 0.27 m for a total of 4,783 sq. km).

This case study emphasizes why a range of values should be given when reporting the size of the inundation zone (and the amount of resources within it) for a given sea-level rise scenario, especially for areas where high-accuracy lidar data are not available. Without such a range being reported, users of an assessment report may not understand the amount of uncertainty associated with area delineations from less accurate data and the implications for any subsequent decisions based on the reported statistics.

3.2 Assateague Island case study

Assateague Island is a 60-kilometer long barrier island located in the states of Maryland and Virginia on the mid-Atlantic coast along the eastern United States. Figure 2 shows a portion of the island and a graphical portrayal of the results of an accuracy assessment of a lidar elevation dataset covering the island. In this case, the elevation data are 1-meter EAARL (Experimental Advanced Airborne Research Lidar) data (Nayegandhi et al., 2006) collected in 2008. The lidar elevation data exhibit a vertical RMSE of 0.23 meters when tested against a set of high-accuracy survey benchmarks on the island. Following Equation 2, the LE95 value

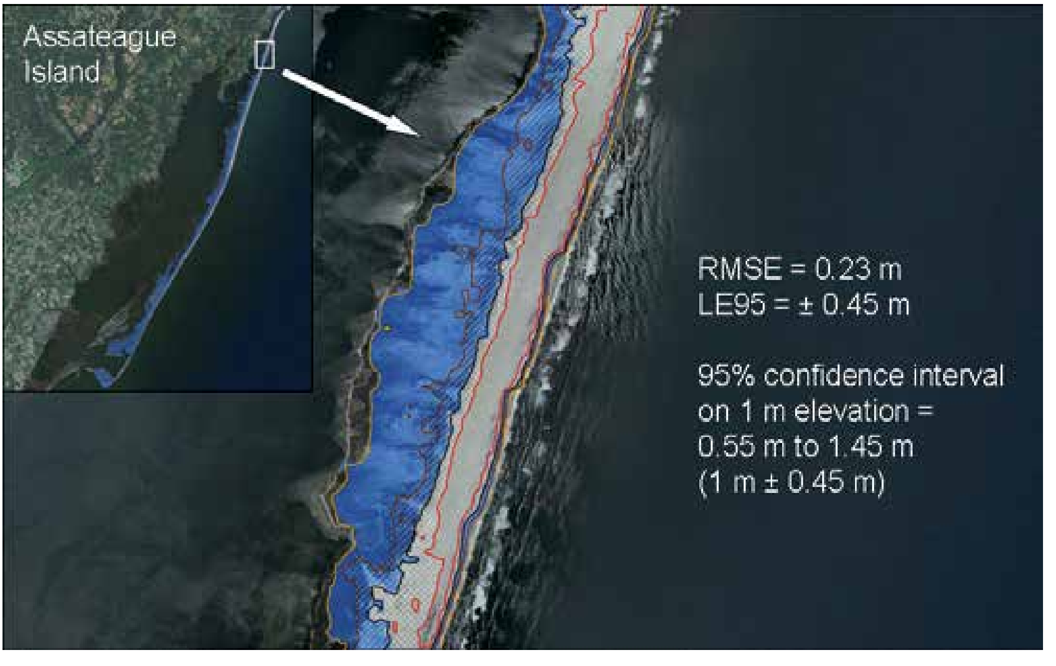

Fig. 2. Results of an accuracy assessment of lidar elevation data over a portion of Assateague Island. The orange line is the mean high water (MHW) shoreline. The black line is the 1-meter contour (above MHW), and the brown lines and cross-hatch patterns delineate a buffer around the 1-meter elevation. This buffer represents a spatial projection of the area of uncertainty associated with the 1-meter elevation (the 95% confidence interval, or 1 m ± 0.45 m). The blue tint covers the area between the MHW shoreline and the 1-meter elevation. The background is an orthoimage.

is ±0.45 meters. To model a 1-meter sea level rise, the LE95 value is applied (added and subtracted) to delineate the high and low extents of the zone of uncertainty. Applying Equation 5, the minimum sea-level rise increment that should be modeled is 0.90 meters, so this lidar elevation dataset is acceptable for assessing the potential effects of a 1-meter sea-level rise.

In Figure 2, the orange line is the mean high water (MHW) shoreline. The black line is the 1-meter contour (above MHW), and the brown lines and cross-hatch patterns delineate a buffer around the 1-meter elevation. This buffer represents a spatial projection of the area of uncertainty associated with the 1-meter elevation (the 95% confidence interval, or 1 m ± 0.45 m). The blue tint covers the area between the MHW shoreline and the 1-meter elevation. Note how the area of 1-meter or less in elevation is relatively broad on the back-barrier side of the island where marsh land cover is prevalent, but on the ocean side of the island the area between the MHW shoreline and 1-meter elevation is thin on the relatively steep beach face. To calculate the land area subject to a 1-meter increase in sea-level, the lower end of the range would be the area between the MHW shoreline and the 0.55 m contour (1 m – 0.45 m), and the upper end of the range would be the area between the MHW shoreline and the 1.45 m contour (1 m + 0.45 m). This range accounts for the vertical uncertainty in the elevation data, and the reported areas are expressed with a 95% confidence level.

Assateague Island provides a useful example of a site where simple inundation might not be the primary response to a rising sea-level. The response of a coastal region to sea-level rise can be characterized by one or more physical processes, including land loss by inundation, land loss due to erosion, wetland accretion and migration, conversion of wetland to open water, and saltwater intrusion (FitzGerald et al., 2008; Leatherman, 2001; Valiela, 2006). Barrier islands, in particular, may migrate or break up in response to sea-level rise. The specific response of a stretch of the coast to sea-level rise can be dependent on the collective influence of a number of local factors such as framework geology, sediment supply, and wave energy (Gutierrez et al., 2007). Elevation-based sea-level rise impact assessments generally delineate vulnerable areas that occur below a specified elevation, but because of the complexity of coastal processes it cannot be assumed that all of the delineated areas will simply become flooded or inundated. The challenge remains to better characterize the specific response to sea-level rise that will be exhibited in specific coastal settings (Gesch et al., 2009). Nonetheless, elevation-based assessments are useful for inventorying the amount of land and other resources that are potentially impacted by sea-level rise, whether it is in the form of simple inundation or another physical process.

3.3 IPCC sea-level rise scenarios

Examination of the concepts of minimum inundation increment and minimum planning timeline using IPCC sea-level rise scenarios helps demonstrate application of the knowledge about the uncertainty inherent in the foundational elevation data used in inundation hazard assessments. The eustatic sea-level rise projected for the end of this century ranges from 0.18 meters to 0.59 meters across the six IPCC scenarios. Applying Equation 6 to determine the vertical RMSE required to reliably map those increments of sea-level rise results in an RMSE of 0.046 meters for the 0.18-meter sea-level rise scenario, and an RMSE of 0.15 meters for the 0.59-meter scenario. Collected under industry standard current best practices, lidar-derived elevation data routinely achieve vertical accuracies on the order of 15 centimeters (RMSE), thus mapping of the upper end of IPCC sea-level rise projections is quite attainable. However, elevation data with better than a 5-centimeter RMSE would be very difficult to produce cost effectively with current remote sensing approaches, so reliable mapping of the low end of IPCC sea-level rise projections would not be possible with any routinely available elevation sources.

Figure 3 and Table 3 show the 21st century minimum planning timelines associated with three eustatic sea-level rise rates and three qualities of elevation data. The sea-level rise scenarios include the IPCC minimum projected rate (1.8 mm/yr), the IPCC maximum rate (5.9 mm/yr), and for comparison purposes, a rate of twice the IPCC maximum (11.8 mm/yr). This third rate (11.8 mm/yr) would result in nearly 1.2 meters of sea-level rise by the year 2100, a number that is well within the range of eustatic sea-level rise projections published after the most recent IPCC report (Jevrejeva et al., 2010; Pfeffer et al., 2008; Rahmstorf, 2007; Vermeer and Rahmstorf, 2009).

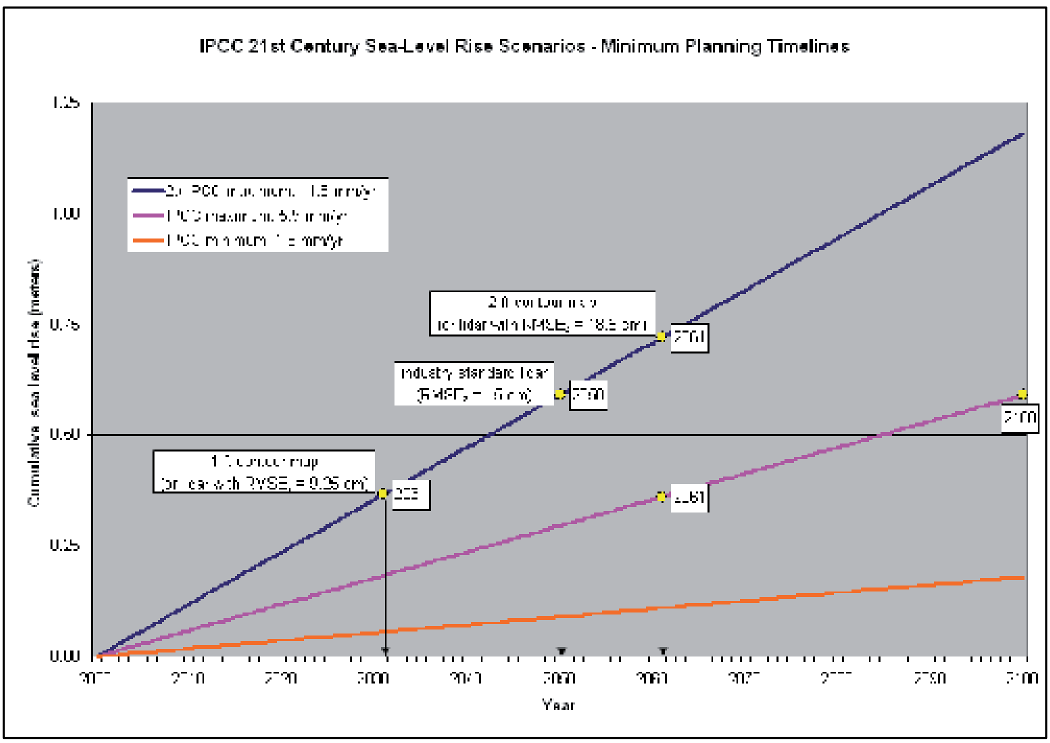

Fig. 3. Sea-level rise rates and the calculated minimum planning timelines given different types of elevation data (and their associated vertical accuracies). The minimum planning timeline is reached when the cumulative sea-level rise matches the minimum sea-level rise increment afforded by the vertical accuracy of the elevation data.

21st century sea-level rise scenario	Elevation data source for sea-level rise assessment		
	1-ft contour map (9.25 cm RMSE lidar)	15 cm RMSE lidar	2-ft contour map (18.5 cm RMSE lidar)
1.8 mm/yr	-	-	-
5.9 mm/yr	61 yrs.	100 yrs.	-
11.8 mm/yr	31 yrs.	50 yrs.	61 yrs.

Table 3. Minimum planning timelines derived from combinations of sea-level rise scenarios and accuracies of elevation datasets used for inundation modeling. Some combinations of sea-level rise rates and elevation data accuracies do not support planning timelines less than or equal to 100 years (indicated by the dashes); in other words, the cumulative sea-level rise does not reach the minimum increment for inundation modeling until after 100 years.

For a given sea-level rise rate, the minimum planning timeline is reached when the cumulative sea-level rise matches the minimum sea-level rise increment afforded by the vertical accuracy of the elevation data. For example, given an annual sea-level rise rate of 11.8 mm/yr and an elevation dataset with a vertical RMSE of 15 centimeters, the cumulative sea-level rise matches the minimum sea-level rise increment of 58.8 centimeters in 50 years, which represents the minimum timeline that should be used in the assessment. Note that when the same elevation data are applied in a study that uses a lower sea-level rise rate of 5.9 mm/yr, the minimum planning timeline extends to 100 years. In other words, in a study making use of 15-centimeter RMSE elevation data and the maximum IPCC sea-level rise scenario, no results should be presented for time slices less than 100 years. This constraint is also noted in Table 3 where planning timelines less than or equal to 100 years are not supported by some of the combinations of sea-level rise rates and elevation data accuracies. This does not imply that a specific type of elevation data should not be used in an analysis with lower sea-level rise rates but cautions that the supported timeline may be longer than the time interval of interest to planners.

4. Discussion

As has been demonstrated, the vertical uncertainty contributed by the foundational elevation data in elevation-based hazard assessments should be accounted for and documented quantitatively to improve the reliability of maps, statistical summaries, and other project findings. Although a primary source of uncertainty in inundation hazard assessments, elevation data are not the only source of error. For coastal inundation studies, especially sea-level rise assessments, uncertainty is also associated with the water level data (from long-term tide gages), the mathematically modeled tidal datums to which water levels are referenced vertically, and sea-level trends or projections (which often result from coupled climate models). For a complete picture of the total error budget, the uncertainty contributed by these other sources (besides the elevation data) should also be considered (National Ocean Service, 2010).

There are several options for accounting for elevation uncertainty in inundation assessments. The first, which has unfortunately been the case with many studies, is to ignore it. Some studies mention uncertainty in a very general way but don't quantify it. A second option, discussed at length in this paper, is to apply a global error estimate (RMSE or LE95) as a reflection of the vertical uncertainty. This approach tends toward a worse case scenario as it assumes the full magnitude of errors can occur throughout the study site. A third option is to model the spatial distribution of error and then perform error propagation through simulation (Wechsler and Kroll, 2006). The advantage of such an approach is that it can account for spatial autocorrelation in the errors. Application of spatial error modeling to elevation-based hazard assessments is viewed as a fruitful area for further research.

The concepts of minimum sea-level rise (or inundation) increment and minimum planning timeline have relevance for management use by planners and other land and resource managers. These methods can be used to answer questions posed by managers:

- "To model potential impacts of x cm of sea-level rise, what vertical accuracy (RMSE) do I need from the elevation data?" A common use of such a question might be when a municipality has modeled predictions of storm surge magnitudes and extents and managers want to know how those predictions will change if a storm surge is superimposed on top of future sea-level rise.
- "I have elevation data with an accuracy (RMSE) of x cm. What sea-level rise increment can I correctly model?"
- "I need to plan for x cm of sea-level rise by the year 2*xxx*. What accuracy (RMSE) do I need for elevation data to map the potential impact zone at 95% confidence?"
- "The harbor master for our city port facilities is interested in finding out what infrastructure might be at risk if local mean sea level rises by 50 centimeters over the next 30 years. The city is contracting for acquisition of new elevation data to support this study. What accuracy level should I include in the contract specification?"

The methods described here will allow each of these questions to be answered with proper consideration of elevation uncertainty, which will in turn lead to more reliable and defensible project results.

5. Conclusion

Elevation-based coastal inundation assessments should account for the vertical uncertainty of the base elevation data. The use of elevation data for inundation impact assessments is commonplace, but most published studies have not accounted for vertical uncertainty in a quantitative manner. Maps of potential impact zones, and statistical summaries of natural and anthropogenic resources within the impact zone, should carry an obvious expression of the uncertainties associated with the findings. For maps, this can take the form of symbology on the map itself that spatially portrays the areal uncertainty associated with a delineation, or a caveat in the map margin. For statistical summaries, ranges of variables should be reported along with a specific confidence level for the estimates. The choice of parameters for the study, especially the increment(s) of inundation to be modeled and the time interval for analysis, should be guided by knowledge of the inherent vertical uncertainty of the base elevation layer used in the study.

Most of the examples discussed in this paper have involved sea-level rise as the coastal inundation process. The shoreline will evolve in response to rising sea-level and will change relatively slowly in comparison with other water-level hazards. Accounting for elevation uncertainty, including delineating areas of uncertainty for potential inundation zones, may be even more important for other types of inundation that happen much faster than sea-level rise, such as tsunami run-up, storm surge, and extreme high tides. A certain level of detail is needed in a DEM that is used to model tsunami and storm surge propagation, but a better level of topographic detail is needed to model the impacts of inundation on the land surface. Increased topographic information content usually brings reduced vertical uncertainty with it, but in any case the uncertainty must be accounted for quantitatively in modeling results.

Assessment of additional types of inundation hazards that can occur away from the coast, including flash floods from extreme precipitation events, debris flows, and lahars, could also benefit from rigorous treatment of elevation uncertainty. A line delineating the edge of a hazard zone – whether from sea-level rise, flooding, tsunami, storm surge, lahar, or any other topographically controlled process – is often portrayed on a map as a definite feature. In reality, the line has a degree of "fuzziness" associated with it, which is a reflection of the inherent vertical uncertainty in the data used to make the delineation. A probability, or corresponding confidence level, can be associated with a location based on how far away from the line it is (Hunter and Goodchild, 1995). Such portrayal of uncertainty adds significantly to the value of the mapped hazard information.

Increasingly, coastal inundation hazard studies are adding consideration of the uncertainty inherent in the input datasets. Future studies will benefit as best practices (National Ocean Service, 2010) are documented and published. Further advances in hazard assessment will be realized as progress is made on improving the physical models (Gallien et al., 2011) used to characterize inundation vulnerability.

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7

About the Practical Knowledge to Understand Snow Avalanches – A Chronology

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1. Introduction

At all times settlements and infrastructures in mountainous regions were endangered by avalanches. The following table gives an overview on major avalanche disasters in residential areas.

Year	Venue	Fatalities
1518	Leukerbad/Wallis/Switzerland	60
1598	Graubünden/Switzerland	100
1689	Montafon/Voralberg/Austria	120
1689	Tyrol/Austria	122
1689	Prätigau/Switzerland	57
1718	Leukerbad/Wallis/Switzerland	55
1720	Vorderrhein/Graubünden/Switzerland	100
1888	Tyrol/Austria	53
1916	Front-line between Italy and Austria	some thousand
1951	Graubünden/Switzerland	54
1951	Tyrol/Austria	54
1954	Vorarlberg/Austria	122

Table 1. Selected avalanche disasters in the European Alps (Flaig, 1941; Flaig, 1955; Haid, 2007; Schott, 2005).

However, the development of alpine skiing at the end of the 19th century implicated that an increased number of humans encountered avalanche terrain in the backcountry. Thus many important findings on avalanches were generated by mountaineers and practitioners such as Zdarsky (1916, 1929), Lunn (1926) and Bilgeri (1934); further outstanding contributions were provided by scientists like Welzenbach (1930) and Paulcke (1938). Their findings had huge practical relevance and formed the basis for decision- making in mountaineering and backcountry skiing.

The basic findings from the 1920s and 1930s are still valid; they are certainly still used today and serve as an important tool in avalanche education.

However, the following decades provided a strong increase of knowledge, especially in snow classification and snow stability; the implementation of the stratetic methods at the end of the 1990s intensified the discussion of avalanche education.

This paper describes the most relevant practical findings in the field of snow and avalanches and reviews them in terms of their application for mountaineers and backcountry skiers.

2. Chronology

Although there were some books on avalanches published prior to 1900 (Coaz, 1881 etc.), the chronology of this paper starts with the time when alpine skiing became accepted in Central Europe. The founder of alpine skiing was Mathias Zdarsky who published his 'Lilienfelder Skilauf-Technik' in 1897. Since that time skiing became more and more popular and consequently the information on avalanche danger was an important topic too.

The chronology of this paper therefore starts with Zdarsky's 'Elements of Avalanche Awareness' published in 1916. The chronology is divided into four periods: 1900 to the 1930s, 1940 to the 1960s, 1970 to the 1980s and 1990 up to the present. Table 2 gives an overview including a commentary why just these four periods were prefered.

Period	Findings
1900 – 1930s	basics: influence of topography (slope angle...), meteorology (wind, new snow..) and snowpack on avalanche formation
1940 – 1960s	scientific findings: snow classification, classification of snow hardness
1970 – 1980s	snowpack stability: development of stability tests basic types of ram profiles
1990 up to present	strategic methods

Table 2. Chronology of the developments in the field of snow and avalanches

2.1 The period from 1900 to the 1930s

This is the period when basic findings on snow and avalanches were arrived at. Zdarsky (1916) identified four parameters for avalanche formation: the slope angle, the friction coefficient, the strength of snow and the weight of snow.

According to Zdarsky (1916), avalanches have to be expected when the slope angle is more than 22°. He indicated that the friction coefficient is lowest on unmown meadows. Zdarsky also found that deposited snow is not homogenous and that several layers may exist in an alpine snowpack; he stated that owing to evaporation snow acquires increasing void pockets, and indicated that kind of snow as *dröhnender Schnee* [rumbling snow]. The fourth parameter for avalanche formation is the weight of snow. This is dependent on the kind of snow and the intensity of the snowfall; however, Zdarsky also recognised the wind as another important factor.

In order to get an overview of the internal strength Zdarsky suggested scanning the snow with a pole. He concluded that great avalanche danger exists if the snow can be penetrated easily.

In 1926 Lunn published a book on alpine skiing, including a basic chapter on avalanches. He divided avalanches into four classes (dry powder avalanches, wet new snow avalanches, snow slabs or wind slabs and wet old snow avalanches). With powder avalanches Lunn stated that after a heavy snowfall the danger may last for a day or two, or even more. He also indicated that wind-driven powder may be covered by a fresh snowfall which makes it very difficult to assess the avalanche risk.

A still valid rule from Lunn (cited in Daffern (1992)) is to mistrust all steep slopes after a fresh fall until the pine trees are free from snow.

In 1929 Zdarsky published a more detailed book on avalanches which starts with the very well-known sentence ‘Der Wind ist der Baumeister der meisten Lawinen’ (‘the wind is the architect of most avalanches’).

Welzenbach (1930) reported on investigations at the Kaindlgrat (Wiesbachhorn) and the Eigergletscher which he carried out in cooperation with Paulcke; they found a previously not observed kind of snow and called it ‘Schwimmschnee’ (the term was later designated as depth hoar (Paulcke, 1938)). It was assumed that this kind of snow is able to cause avalanches.

Bilgeri (1934) mentioned the six most important points which have to be considered when travelling through avalanche terrain (angle of the slope, terrain, ground, depth of the snow, consistency of the snow and anchorage of the snow). He indicated that uniform slopes are more dangerous than ridged slopes, and that trees hold the snow better than bare ground. Bilgeri (1934) also recognised the depth of the snow as an other fundamental factor, and noted that the deeper the snow the more dangerous the situation. Furthermore he refers to the consistency of the snow (the more feathery or the wetter the snow, the more dangerous) and the anchorage of the snow (unanchored snow is more dangerous).

Flaig (1935) indicated the steepness of a slope (already mentioned by Zdarsky (1916) and Bilgeri (1934)) as an important influencing value; he gives even 14° as the lowest limit for avalanche release. Flaig (1935) noted that the prevailing conditions are the crucial factor for avalanches and not the terrain; according to Flaig there exist no specific avalanche areas in mountainous regions, only deadly snow and weather situations. Flaig’s point of view finds support by several statistical findings; almost every winter the greater part of avalanches are concentrated in a few - short - periods. Fig. 1 shows the distribution of avalanches in Austria in 2009/10. About more than a quarter of all avalanches occurred in just one week (3 to 8 Feb. 2010). In the same period 15 persons were killed by avalanches which is about 50% of all fatalities of an average winter in Austria (Höller and Bilek, 2010).

Flaig (1935) also identified that layering is an important factor, and proposed that skiers should consider the structure of the snowpack when assessing the avalanche risk.

Seligman (1936) specified the most meaningful records which should be available when travelling through avalanche terrain: maps, knowledge of past meteorological conditions, weather forecasts, snow depth, wind direction and snow sections. With reference to snow sections, Seligman (1936) noted that the investigations of snow sections is the best method of ascertaining the facts, more accurate and satisfactory than any consultation of weather records; this finding is more than 70 years old and remains important to the present day.

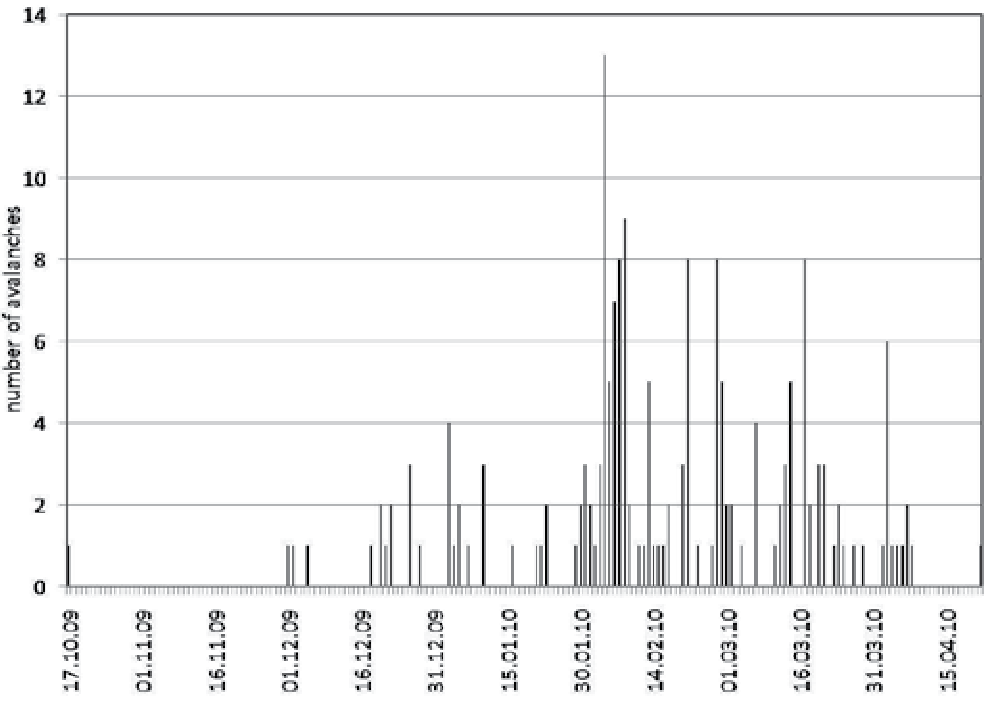

Fig. 1. Distribution of avalanches in Austria in 2009/2010 (Höller and Bilek, 2010).

Paulcke (1938) identified several influencing values that make snow slides more easily: the smoother and steeper the slope, the looser the snow, the wetter the snow, the more massive the depth hoar layers and the higher the loading; on the other hand snow slides less the more it is bonded with the base and the more it is metamorphosed into firn.

Paulcke (1938) pointed out that windward slopes are generally safer than lee sides, and that long periods with cold weather lead to distinctive depth hoar layers. In order to assess avalanche risk backcountry skiers primarily require the following data: total snow depth, the position of crust layers, new snow, depth hoar layers and the depth of these layers (Paulcke, 1938).

Following Seligman's example (1936), Paulcke (1938) also indicated that the basis for the accurate assessment of a prevailing situation is the evaluation of snow profiles (Fig. 2).

Bader et al. (1939) proposed to investigate the relative strength of snow layers by means of a simple test. They introduced the concept of ram resistance, which was measured with the Swiss *Rammsonde*. According to Bader et al. (1939), ram profiles can be used to identify layers in the snowpack and to assess the avalanche danger; snow profiles consisted of investigations of factors like temperature, density, air permeability and layering.

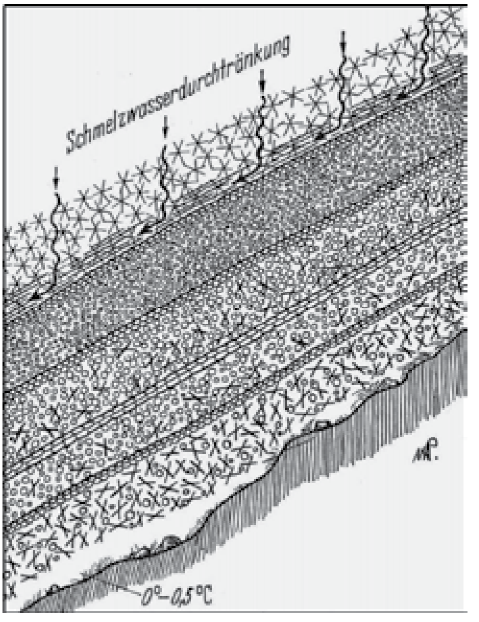

Fig. 2. Snow profile (Paulcke, 1938)

2.2 The period from 1940 to the 1960s

In this period, snow and avalanche science became an important area of research. Backcountry skiers in particular benefited from the snow classification and the classification of snow hardness. The beginning of avalanche warning and the implementation of safety equipment (e.g. avalanche beacon) was another very important subject in that period.

After World War II the first warning services were initiated. In Switzerland the SLF (Swiss Institute for Snow and Avalanche Research) took over the avalanche warning from the Swiss Army. The first avalanche warning center in Austria was established in 1953 in the federal state of Vorarlberg (Längle, 1977).

A simple snow classification was given by Bucher (1948). He divided snow crystals into fragmented particles, small rounded particles and large rounded particles. Bucher (1948) also introduced a degree of safety (the ratio of shear strength and shear stress).

De Quervain (1950) improved the previously used scale of hardness and proposed a simple handtest with five hardness levels.

After 10 years of snow measurements at the Weissfluhjoch (Davos), five different types of profiles were identified (EISLF, 1951): loose; loose base and strengthening in the remaining profile, but some intermediate layers; loose base with strengthening in the remaining profile; strengthening of the profile with the exception of some intermediate layers; strengthened snowpack).

Eugster (1952) introduced the terms destructive metamorphism (the transition to rounded grains) and constructive metamorphism (the transition to depth hoar). Snow profiles were complemented by further parameters: along with temperature, density and layering, profiles should also include grain size and grain shape (in each layer the grain shapes were given in quantiles of tenths) as well as hardness and water content.

In 1954 the first international snow classification was published (Schaefer et al., 1954). Fraser (1968) divided the release factors into two categories: spontaneous release due to gradual influence, and triggering due to a sudden effect. Spontaneous avalanches will be triggered as the result of a decrease in shear strength (increase of temperature, rain) or an increase in shear stress (snowfall, rain). Sudden effects are generated by external effects (skier, climber, deer) or as resulting from the failure of a lateral anchorage.

At the end of the 1960s the first avalanche beacon (SKADI) was applied in America; some years later the PIEPS was developed in Europe (Gayl, 1979; Neubauer, 1979).

In 1969 the 'Field Guide to Snow Crystals' was published by LaChapelle (1969). The book shows dozens of excellent photographs and can also be used by practitioners to identify snow crystals.

Sommerfeld and LaChapelle (1970) proposed a classification of snow metamorphism based on a genetic point of view; they introduced the terms equi-temperature metamorphism (instead of destructive metamorphism) and temperature-gradient metamorphism (instead of constructive metamorphism).

2.3 The period from 1970 to the 1980s

Basically this period was characterised by the development of the stability tests and new safety equipment (e.g. Avalanche airbag...) and the findings by Conway et al. (1984, 1988).

Already in the 1970s Hohenester (1979) reported on a balloon to retain a person on the surface of an avalanche. The device was later improved by Aschauer and is now well-known as avalanche balloon system (ABS).

In 1974 Nils Faarlund und Walter Kellermann (Kellermann, 1990) worked on a simple test to investigate the snowpack; they called it '*Norwegermethode*'. The test determines the force which is necessary to draw off a defined snow trapezoid (front side 0.6m, backside 0.2m) on a weak layer; the result is a measure for the stability of snow. Although the test only uses three levels (weak: 0 - 100 N, medium: 100 – 200 N, stable: > 200 N) to evaluate stability, the '*Norwegermethode*' agreed well with the previously developed *Rutschblock* test. A slightly modified form of the '*Norwegermethode*' is the shovel shear test. An evaluation of the shovel shear test can be found in Schaerer (1988). He noted that the shovel shear test is appropriate for identifying weak layers but requires many tests to get reliable results.

In addition to the shovel shear test the compression test has been applied in Canada since the 1970s (Clarkson, 1993; Jamieson, 1999). The test is done on an isolated snow column of 0.3 x 0.3 m. The shovel blade is placed on top of the column and the applied load is gradually increased: at 'easy' level, a failure occurs before 10 light taps, using fingertips only. 'Moderate' means that a failure occurs before 10 moderate taps with the elbow. A failure due to a higher load (10 firm taps with the whole arm) is classified as 'hard'.

The *Rutschblock* (Fig. 3) which was used in the Swiss Army to demonstrate weak layers in the snowpack was quantified by Föhn (1987). According to Föhn (1987) it is a useful tool for the evaluation of slope stability, but should be used only by experienced persons with an intuitive feel for the slope stability distribution.

The *Rutschblock* is the most sophisticated test, but it needs more time to complete a *Rutschblock*, as seven load levels are used. Levels 1 to 3 indicate that such slopes are unstable for skiers, the levels 4 and 5 indicate that such slopes should be considered as suspicious, the risk of triggering slabs on such slopes can be taken to be low when levels 6 and 7 are found.

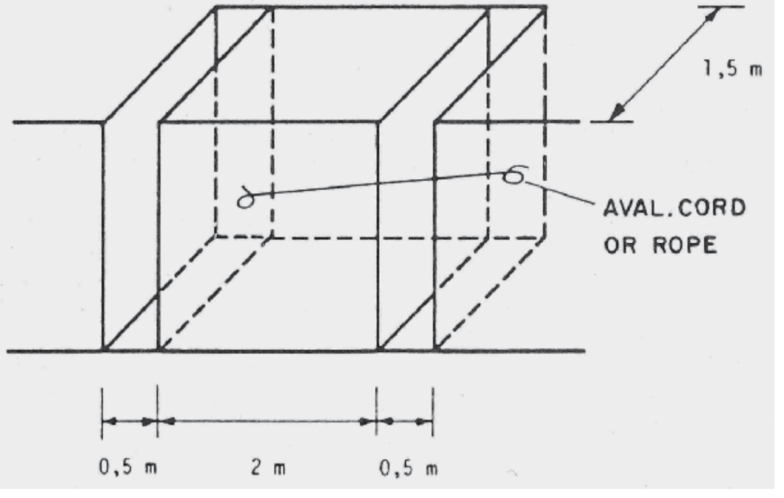

Fig. 3. Rutschblock (Föhn, 1987)

De Quervain and Meister (1987) found six different ram profile types (from very stable - with increasing hardness at the bottom -A in Fig 4 - to very weak - with 'belly-like' shape and very low hardness values at the bottom - F in Fig. 4).

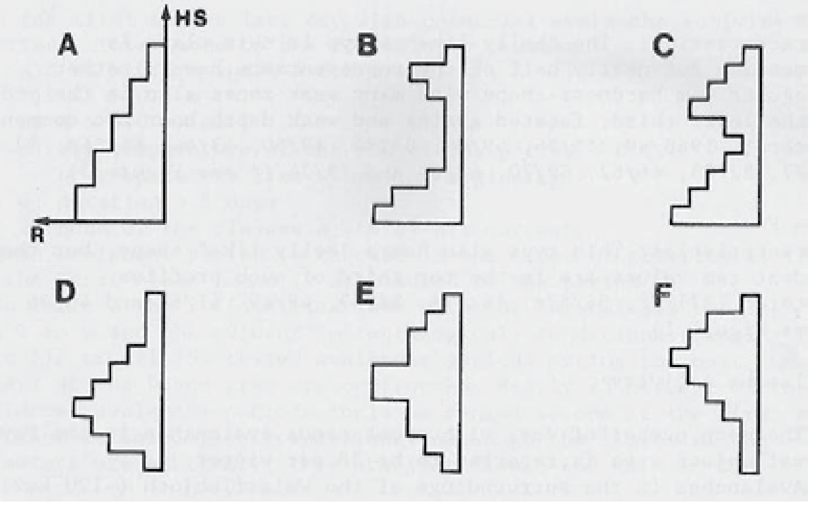

Fig. 4. Basic types of ram profiles (de Quervain and Meister, 1987)

Conway and Abrahamson (1984) measured shear indices on the crown walls of eight avalanched slopes. They found strong variations of stability (between 1 and 3) within short distances. The probability of coming upon an area where an avalanche may be released (shear stability < 1) is about 33%.

Salm (1986) illustrated these findings in a plain figure (Fig. 5), and concluded that on a typical slope areas with a low shear stability alternate with stable areas. Salm (1986) indicated the instability areas (where the shear stability is < 1) as 'Taschen' [hot spots] with a size of less than 3 m.

Föhn (1988) did not detect small 'deficit areas' (S < 1) as defined by Conway and Abrahamson (1984, 1988) on various slopes. However, a few "deficit areas" (S' < 1) and many weak zones (1 ≤ S' ≤ 2) have been found on all slopes. He concluded that either many small 'deficit areas' or a few large 'deficit zones' are needed for avalanche formation.

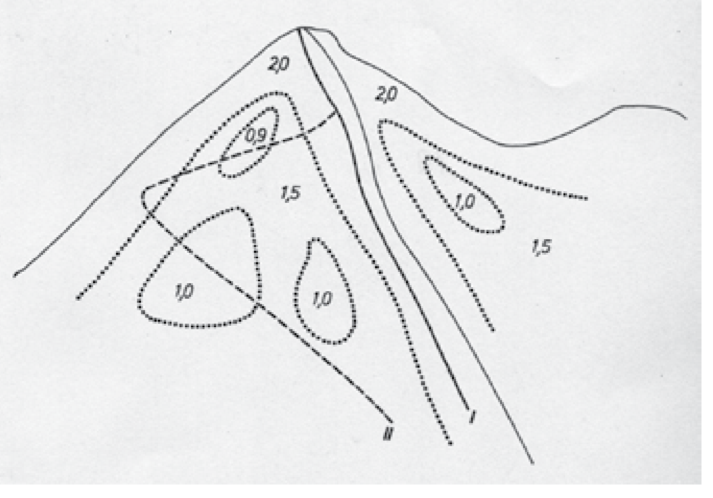

Fig. 5. Possible distribution of stability on a slope (Salm, 1986)

2.4 The period from 1990 up to the present

These two decades were characterised by the improvement of the stability tests and safety equipment (digital transceivers...) as well as by the implementation of a standardised avalanche danger scale and the introduction of strategic methods.

The new snow classification was issued in 1990 (Colbeck et al., 1990).

Föhn (1992) investigated the characteristics of weak snow layers or interfaces and found that - if a weak layer exists - it consists in 80% of all cases either of surface hoar, of faceted particles or of depth hoar; a sliding test (e.g. *Rutschblock*) proves to be the only fast and reasonable method for demonstrating the occurrence of such fragile interfaces.

The new European Danger Scale (Meister, 1994) became effective in the winter season 1993/1994. The scale which is now valid in many alpine countries is characterised by 5 levels (from 1 – low to 5 - very high) and makes it easier to compare the avalanche bulletins of the different countries.

At the end of the 1990s the first digital beacons (Edgerly and Hereford, 1998) were introduced. The advantage over the former transceivers was an optical display where indicators show the direction of a buried person.

Kronholm et al. (2002) studied the spatial variability of snow stability on small slopes. According to Kronholm et al. (2002), slopes with a weak layer with low average stability and low variability are more critical than if either average stability or stability variation is high.

In the 1990s different stability test methods were developed such as the loaded column test (McClung and Schaerer, 1993), the stuffblock test in 1993 (Birkeland and Johnson, 1999) and the quantified loaded column stability test by Landry et al. (2001).

The loaded column is done by loading a snow column (0.3 x 0.3 m) with blocks of snow until failure occurs (McClung and Schaerer, 1993).

The stuffblock test also is carried out on an isolated snow column of 0.3 x 0.3 m. In the first step the stuff sack (a nylon sack packed with snow, weighing 4.5 kg) is gently placed on the shovel blade which is put on the top of the isolated column. A failure of the weak layer at this point indicates a stuffblock drop height of zero. Then the column is loaded dynamically by dropping the stuff sack from 0.10 m, and increasing that height by 0.10 m increments until shear failure in the weak layer occurs (Birkeland and Johnson, 1999).

The extended column test (Simenhois and Birkeland, 2006) and the propagation saw test (Gauthier, 2007 – see Fig. 6) can also be used to evaluate the fracture propagation propensity of slab and weak layer combinations.

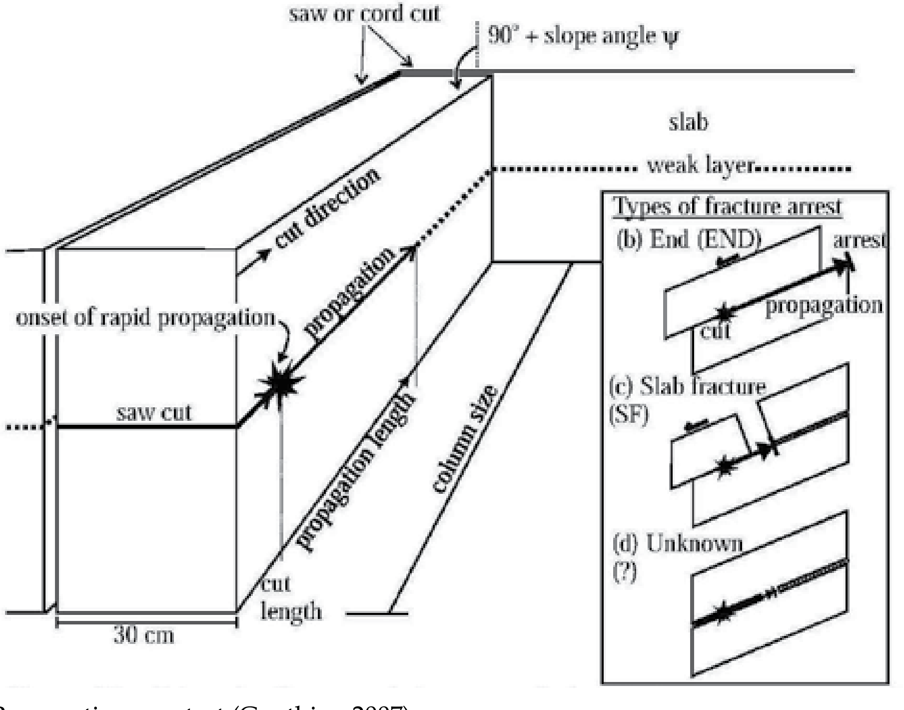

Fig. 6. Propagation saw test (Gauthier, 2007)

The extended column test (ECT) uses a column of 0.9 m cross the slope and 0.3 m upslope. The load (same loading steps as in the compression test) is applied at one end of the column. The following results are possible: (i) a fracture propagates across the full column during isolation, (ii) a fracture propagates across the full column on the same or one additional tap as initiation, (iii) a fracture initiates but does not propagate across the full column, (iv) no fractures are initiated. Propagation is predicted to be likely only when the fracture propagates to the end of the column on the same or one additional tap as initiation (Simenhois and Birkeland, 2007).

The propagation saw test (PST) is accomplished on a column of 0.3 m cross slope and 1.0 m upslope (Fig. 6). After identifying the relevant weak layer the blunt edge of a saw is draged upslope along through this layer at 10-20 cm/s until the fracture jumps ahead of the saw. The point where the fracture began to propagate ahead of the saw is noted. The propagating fracture will either reach the end of column, stop at a slab fracture, or selfarrest within the layer. Propagation is predicted to be likely only when the fracture propagates to the end and less than half the column has been cut (Gauthier et al., 2008).

Schweizer and Wiesinger (2001) and Schweizer and Lütschg (2001) extended the ram profile classification used by de Quervain and Meister (1987), the new classification now consisting of 10 types.

Another method to assess the danger of avalanches is the *Nietentest* (Schweizer, 2006) which is not a stability test but can help mountaineers to get a overview of the structure of the snowpack; the test uses six so-called *Nieten*: large grains (≥ 1 mm), hardness (level 1 - fist), faceted crystals (depth hoar), great difference in grain size between two layers, two levels of difference in hand hardness between two layers, critical layer less than 1 m below snow surface. Five or six discovered *Nieten* indicate that a critical weak layer within the snowpack is very likely; if three or four *Nieten* have been identified a critical weak layer is possible; one or two *Nieten*) suggest that there is no distinct weak layer.

Mair and Nairz (2010) introduced ten avalanche patterns; these patterns are mainly based on meteorological parameters. Mair and Nairz (2010) pointed out the following patterns: the second snowfall, gliding snow, rain, great temperature difference during snowfall, prevailing cold period, new snow and wind, areas with less snow, surface hoar, graupel, spring conditions. These patterns may be a useful tool for those backcountry skiers who are not able to estimate the avalanche danger on the basis of the available meteorological data.

The strategic methods which became popular at the end of the 1990s intensified the discussion of avalanche education.

The accepted risk according to Munter (1997) is the ratio of hazard potential and reduction factor and should be less than one; the hazard potential is defined as 2^L (L is the current hazard level of the avalanche bulletin); the reduction factor is dependent on the slope angle and slope aspect.

Larcher (1999) developed the ‚Stop or Go' method which is similar to Munter's system; however he supplemented the method with the addition of five direct observations (wind deposited snow, new snow, recent avalanches, moist snow, whumpf sounds).

The SnowCard which was developed by Engler and Mersch (2000) is based on the slope angle as well as on the hazard level and shows the risk in different colours (red - high risk, yellow - attention, keep away, green - low risk).

The NivoTest (Bolognesi, 2000) consists of 25 questions (mainly on meteorology and on visible signs (avalanches, visibility, wet snow, weak layers etc.); each question is related to a certain number of scores. If the total number of scores is less than eight the avalanche danger is low, if it is greater than 23 the situation can be described as critical.

The Avaluator (Haegeli et al. 2006) is a rule-based avalanche decision support tool developed in Canada (Fig. 7). The chart on the front of the Avaluator card provides guidance for trip planning by combining the hazard level (vertical axis) with the terrain of the intended backcountry trip (horizontal axis). The back side of the Avaluator card presents a list of seven obvious clues to facilitate slope decisions. 'Normal Caution' is recommended for slopes with two or fewer clues. Backcountry travel is 'Not Recommended' on slopes with five or more clues (Haegeli et al. 2006).

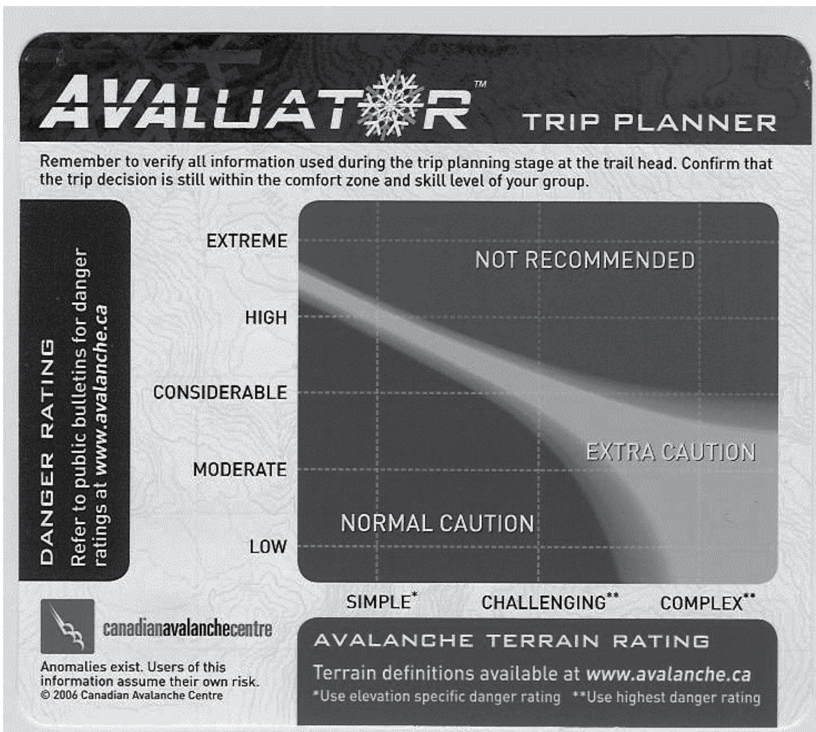

Fig. 7. Avaluator Card. The frontside provides guidance for trip planning by combining hazard level (vertical axis) with the terrain of the intended backcountry trip (horizontal axis). (Haegeli et al. 2006).

3. Discussion and conclusions

The basic principles on snow and avalanches (with regard to the practical application for mountaineers and backcountry skiers) were already set up in the 1920s and 1930s.

Snow classification and the classification of the snow hardness (both developed in the following decades) were also used by many mountaineers and backcountry skiers, and these classifications still play an essential part in evaluating the prevailing avalanche situation (see for example Schweizer 2006 – The '*Nietentest*'). The snow classification standardised snow profile investigations; the hardness classification is an important tool for the assessment of the varying layers in the snowpack. However, hardness measurements with the Swiss *Rammsonde* cannot be applied by backcountry skiers.

The classifications help to get a better overview of the structure of the snowpack and to estimate the current avalanche danger, although snow profiles do not give any information about the bonding of the different layers.

The 1970s and 1980s brought the stability tests which of course had great relevance for practitioners and skiers. However, the validity of these tests is more or less restricted to that location where the test was carried out; backcountry skiers need great experience to interpret the results of these tests.

The investigations from Conway et al. (1980...) indicated that snow stability may be subject to strong variations within short distances. These findings were highly significant; however, in practice it is not possible to identify these areas of instability.

The same is also true for the findings of Föhn (1988) which are of course of great scientific value but cannot be directly applied by mountaineers; skiers cannot locate either a small deficit area or a large deficit zone.

The *Nietentest* is more practicable for mountaineers than other stability tests. Here the diffculty of interpretation of the stability tests does not apply; the user just has to be familiar with the identification of snow crystals, hardness of snow and layering. Strictly speaking the results are valid only for that site where the test was performed; however, as some *Nieten* (e.g. depth hoar layers) normally exist over a greater area it seems to be possible to extrapolate the results from point-measurements.

The avalanche patterns described by Mair and Nairz (2010) may be a helpful tool for backcountry skiers, but cannot compensate for a lack of basic knowledge of snow and avalanche properties. These patterns are based on previous knowledge (in particular the influence of meteorological parameters on avalanche formation), nevertheless they are illustrated in a new style which makes it easier for mountaineers to better interpret the various influencing factors.

The strategic methods which became popular at the end of the 1990s use the fundamental knowledge available. As Höller (2004) mentioned, these methods do not provide any novel results; the only difference is a new design. Nevertheless the scheme can be used as a checklist so that mountaineers cannot forget any important influencing factor. Although the strategic methods will be propagated for less experienced people, these methods cannot be recommended for beginners (Höller, 2004).

The understanding on avalanche formation definitely increased in the last decades; however, with regard to the practical relevance for mountaineers and backcountry skiers the improvements are limited. Backcountry skiers have also to rely on findings which were already available 80 years ago.

Taking into account that the number of backcountry skiers has increased dramatically in the last decades (according to Würtl backcountry skiers in Austria have doubled from the end of the 1990s till today from about 250.000 to 500.000), the number of fatalities almost did not change. As shown in Fig. 8 the total of avalanche fatalities is subject to certain variations, but no significant trend becomes apparent.

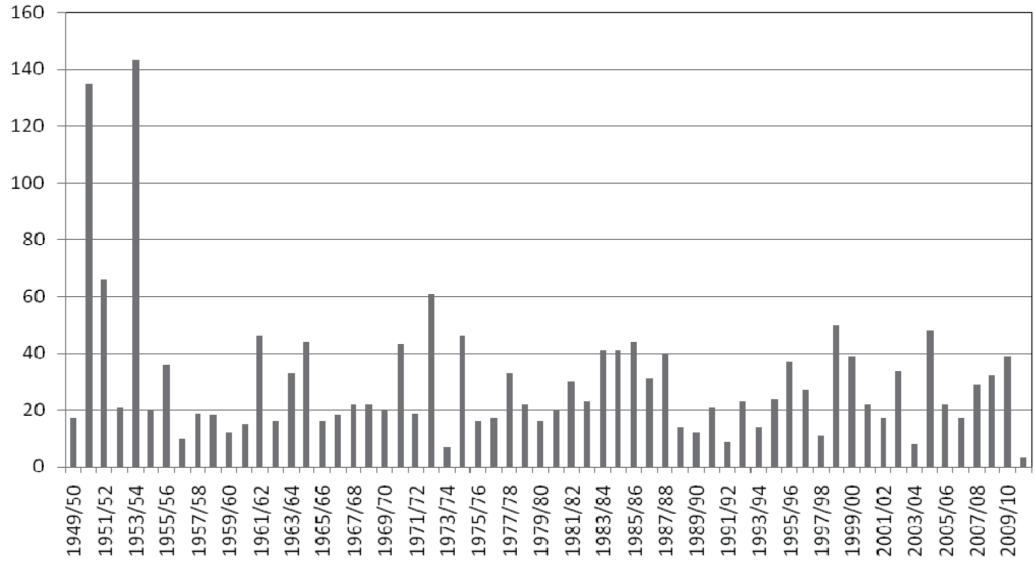

Fig. 8. Avalanche fatalities in Austria (Land Tirol 2000, H. Bilek, personal communication).

The improvement of the safety equipment (avalanche beacons, avalanche balloon,….), the great number of avalanche courses (including many informative brochures, folders and fliers) and the excellent work of the avalanche warning services (including the standardised danger scale) have contributed to the fact that the number of avalanche fatalities were not increasing to the same degree as the number of backcountry skiers.

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Edited by Sorin Cheval

The crossroads between a more and more populated human communities and their changing environment pose different challenges than ever before. Therefore, any attempt to identify and deliver possible solutions is more than welcome. The book Natural Disasters addresses the needs of various users, interested in a better understanding of hazards and their more efficient management. It is a scientific enterprise tackling a variety of natural hazards potentially deriving into disasters, i.e. tropical storms, avalanches, coastal floods. The case studies presented cover different geographical areas, and they comprise mechanisms for being transferred to other spots and circumstances. Hopefully, the book will be beneficial to those who invest their efforts in building communities resilient to natural disasters.

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