Impact of global climate change and desertification on the environment and society in Southern Centre of Vietnam (a case study in Binh Thuan province) Climate today and tomorrow: state of play and perception.

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The Province of Binh Thuan is the driest area of Vietnam. It is felt as being affected by desertification processes that are mainly resulting from the ongoing 'climate change', especially shortening rainfall. But has climate, and especially precipitations, really changed in recent years? Or is the recent increase of agricultural activities with higher water needs may explain such perception of a changing climate?

In the collection of four papers presented hereafter, we try to answer to these questions.

Yet, the first paper investigates recent trends in precipitation and temperatures using daily data from the weather station of Phan Thiet. It appears that the area did not experience any significant precipitation decrease (rainfall have, at the contrary, globally increased) but a very significant increase in temperature.

The second paper focuses on future climate projections (that is 2046-2065 and 2081-2100 compared to historical data 1970-1999). It shows that the Province of Binh Thuan will face an increase of mean temperature of about 1.6°C (over 2046-2065) and 2.5°C (over 2081-2100) and an increase of extreme temperatures and extreme rainfall events. However, no significant changes about the evolution of the annual amount of precipitation were found. It also indicates that the dry season is likely to be longer in 2046-2065 owing to a delay in the onset of the rainy season (up to 15 days) accompanied by an earlier end of the rainy season (up to 30 days).

The third paper explores recent land use and land cover changes in the Province of Binh Thuan. Comparisons of the land cover maps reveal that a steady growth in population has caused extensive changes of land cover throughout the area. The maps also indicate that the loss of woody land (forest) and the extension of irrigated area, combined with built-up encroachment, remains one of the most serious environmental problems today. Yet, results showed over the 12-year span, approximately 115,120 ha of forests were converted respectively to brush, irrigated area, cropland and built-up. This is an overall average decrease of approximately 9,594 ha of forested area per year. Based on the identified causes of these changes, we made policy recommendations for better management of land use and land cover. Such results show that water needs are always increasing due to the extension of irrigated areas.

The last paper concludes with a case study of a fishing village disappearing as a result of shoreline erosion. It shows that the term "climate change" is misused probably because it is easier to blame a global issue rather than the local mismanagement of natural resources, the lack of land use planning and the nonexistence of policies focused on natural hazard management in the uncontrolled construction the seaside resort of Mui Ne.

This reflexion about the wrong perception of climate change which may cause several economic problems could be extended to water availability which may not be sufficient to support recent developments of irrigated agriculture. Understanding current problems may help developing adaptation strategies in the next decades. Further research is needed to understand such perception of climate change, especially when knowing that future climate may be really affected by an increase of extreme rainfall events and an extended dry season.

Recent trends and perceptions of 'climate change' in the Binh Thuan Province, Vietnam (1978-2007)

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Abstract— *The Province of Binh Thuan is the driest area of Vietnam. It is felt as being affected by desertification processes that are mainly resulting from the ongoing 'climate change', especially shortening rainfall. But has climate, and especially precipitations, really changed in recent years? Or is the recent increase of agricultural activities with higher water needs may explain such perception of a changing climate?*

This paper investigates recent trends in precipitation and temperatures using daily data from the weather station of Phan Thiet. It appears that the area did not experience any significant precipitation decrease but a very significant increase in temperature. Further research is needed to understand such perception of climate change, especially when knowing that future climate may be really affected by an increase of extreme rainfall events and an extended dry season.

Keywords: climate change, precipitation, temperature, climate extremes, Binh Thuan, Vietnam

I. INTRODUCTION

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, it is globally predicted that a *virtually certain* (that is a probability of occurrence of over 99%) augmentation in warmer nights and hot days, and a *very likely* (that is a probability of occurrence of over 90%) increase in warm spells, heat waves and heavy precipitation should occur by the mid- to late 21st century [1].

Vietnam's exposure to weather-related events and disasters ranks among the highest among all developing countries [2-3]. Storms and floods (occasionally resulting from tropical cyclones) have caused extensive and repeated damages to buildings and infrastructure, significant losses to the agriculture and fisheries sectors, and resulted in a large number of fatalities. In the course of the 20th century, approximately 25,000 lives have been lost in Vietnam as a direct result of climate related events. Between 1991 and 2000 more than 8,000 people were killed by natural disasters (storms, floods, flash floods, landslides). In addition, an estimated 6 million houses were destroyed. The total economic value of losses for this period alone was estimated at USD 2.8 billion [4]. This is the reason why water resources management has become a major concern at the national scale.

The Binh Thuan Province (Fig. 1) knows a recent increase of agricultural activities in order to contribute to reduce poverty although the technical efficiency of Binh Thuan is still very low [5-7]. Within this framework of higher dependency of the local economy on the agricultural sector, there is growing evidence that changes in climate extremes are increasing exposure of currently vulnerable rural populations.

Within the framework of the project entitled "Impact of global climate change and desertification on the environment and society in Southern Central Vietnam - Case study in Binh Thuan Province", this paper aims to assess recent evolutions of rainfall and temperatures measured at the weather station of Phan Thiet while the future climate of the province of Binh Thuan has been analyzed elsewhere [8]. Yet, the global feeling of farmers and agents of the provincial People's Committees met during a fieldtrip realized in March 2011 is that the Binh Thuan Province is affected by desertification processes that are mainly resulting from the ongoing climate change, especially shortening rainfall. Such recent trends in rainfall is seen as a threatening factor impacting agriculture by reducing yields due to lack of rainfall; and damaging crops consequently to heavy precipitations.

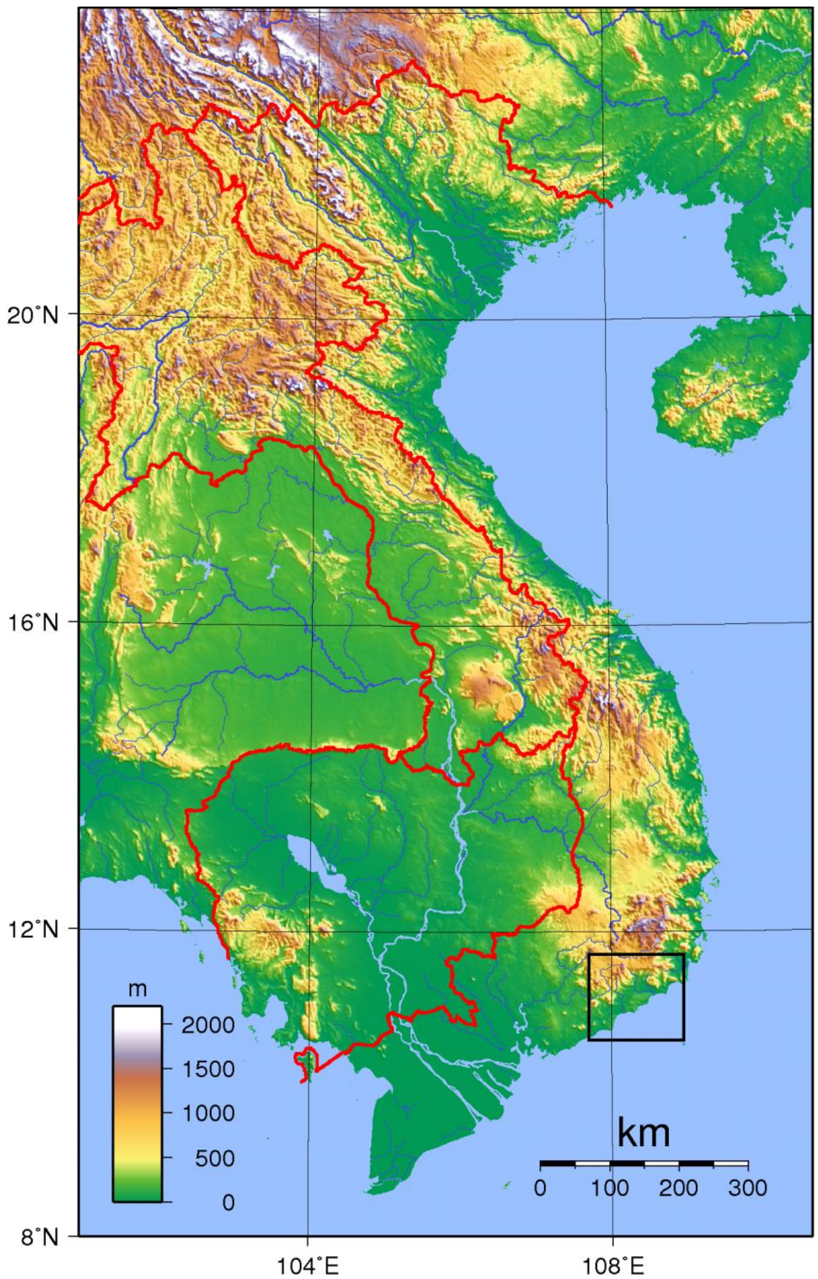

Figure 1. Vietnam topography with the region of interest in the black rectangle (source: http://fr.wikipedia.org/wiki/Việt_Nam).

II. DATA AND METHODS

Data used in this work were collected from the weather station of Phan Thiet. They cover the 1978-2007 period for daily rainfall and the 1979-2007 period for what regards daily minimum, maximum and mean temperatures.

A. Precipitation and temperature indices

In order to assess recent changes in rainfall, several indices were calculated and analyzed: annual total precipitation, monthly total precipitation, number of wet days, annual number of very heavy and extremely heavy precipitation days and annual maximum 1-day precipitation amount. For what regards minimum, maximum and mean temperatures, only annual and monthly averages were analyzed (Tab. I).

TABLE I. PRECIPITATION AND TEMPERATURE INDICES WITH THEIR DEFINITIONS AND UNITS, BASED ON [9;10].

Index	Indicator name	Definition	Unit
PRCPTOT	annual total precipitation	annual total precipitation	mm
PRCP[Jan-Dec]	monthly total precipitation	monthly total precipitation from January to December	mm
WDAY	number of wet days	annual count of days with precipitation >= 1mm)	days
RX1d	max 1-day precipitation amount	annual maximum 1-day precipitation	mm
R20mm	number of very heavy precipitation days	annual count of days when precipitation >= 20mm	days
R50mm	number of extremely heavy precipitation days	annual count of days when precipitation >= 50mm	days
ATN	average annual Tmin	annual average value of daily minimum temperature	°C
ATX	average annual Tmax	annual average value of daily maximum temperature	°C
ATM	average annual Tmean	annual average value of daily mean temperature	°C
ATN[Jan-Dec]	average monthly Tmin	monthly average value of daily minimum temperature from January to December	°C
ATX[Jan-Dec]	average monthly Tmax	monthly average value of daily maximum temperature from January to December	°C
ATM[Jan-Dec]	average monthly Tmean	monthly average value of daily mean temperature from January to December	°C

A much more detailed analysis of precipitation and temperature extremes could have been performed based on percentile but the relatively short period of available data made it impossible since at least 30 years of data are needed to do so.

B. Trend analysis

For each indices, trends from 1978 (1979) through 2007 were estimated by linear regression with time (years) as independent variable. The regression slopes were recorded either for the rainfall or for temperatures indices and were qualified in five classes indicating highly statistically significant or statistically significant positive or negative and stable trends. The regression procedure supplies a Student t-test and its resulting significance p-level to analyze the hypothesis that the slope is equal to 0. This p-level was used as a criterion to define the class boundaries. The trends for the parameters were labeled as 'highly statistically significant' if the p-level exceeded 0.01 for the one-tailed t-test, 'statistically significant' if the p-level is ranged between 0.01 and 0.05 and otherwise 'stable' if the p-level is up to 0.05.

III. RESULTS

A. Precipitation indices

Trends were performed for all precipitation indices over the 1978-2007 period. Results are presented in Table II with average data, absolute trends and percentage changes. It appears that annual total precipitation have increased by 10.8%, a change that is however statistically insignificant although it represents an absolute augmentation of 117.6 mm over the 30-year period. The dataset presents four years of drought (that is >= 1 standard deviation below average) with the latest occurring in 1997 (Fig. 2). Monthly precipitations during the rainy season (May to November) show different trends (Fig. 3): declining during June and October, increasing during the months of May, July, August, September and November. Only May presents a statistically significant trend in precipitations. For other indices: number of wet days, annual number of very heavy and extremely heavy precipitation days and annual maximum 1-day precipitation amount; no particular change are noticed.

TABLE II. TRENDS OF PRECIPITATION INDICES (* = STATISTICALLY SIGNIFICANT; NA = NO APPLICATION).

Index	Average [1978-2007]	Absolute trend [1978-2007]	Trend % [1978-2007]
PRCPTOT	1150,9	+117,6	+10,8
PRCP-Jan	0,2	+0,5	NA
PRCP-Feb	0,2	+0,2	NA
PRCP-Mar	7,8	-18,2	NA
PRCP-Apr	26,1	+3,5	NA
PRCP-May	159,9	+94,4	+86,3 *
PRCP-Jun	156,6	-61,5	-32,4
PRCP-Jul	181,6	+43,1	+27,2
PRCP-Aug	181,8	+35,8	+22,0
PRCP-Sep	193,1	+23,6	+13,1
PRCP-Oct	157,4	-92,1	-44,6
PRCP-Nov	66,9	+58,2	+162,7
PRCP-Dec	19,2	+30,1	NA
WDAY	86,7	+1,6	+1,9
RX1d	87,4	-2,1	-2,3
R20mm	17,6	+1,0	+5,6
R50mm	3,0	+0,8	+31,6

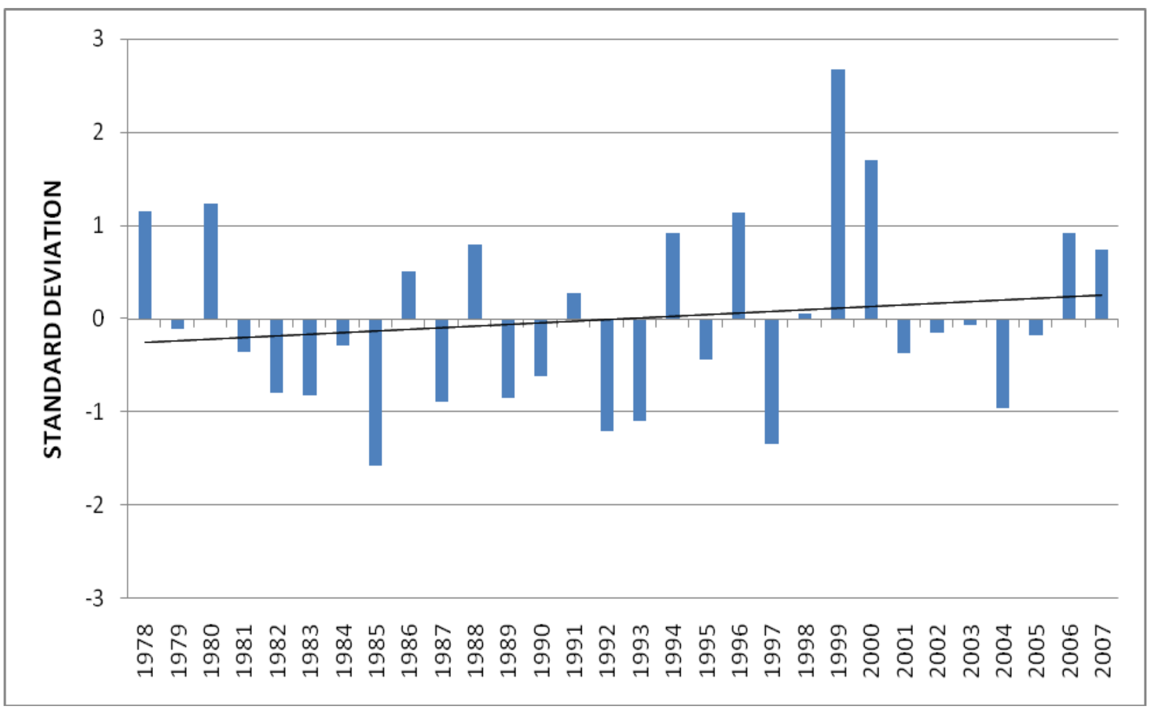

Figure 2: Standard deviation of annual precipitations in Phan Thiet from 1978 to 2007

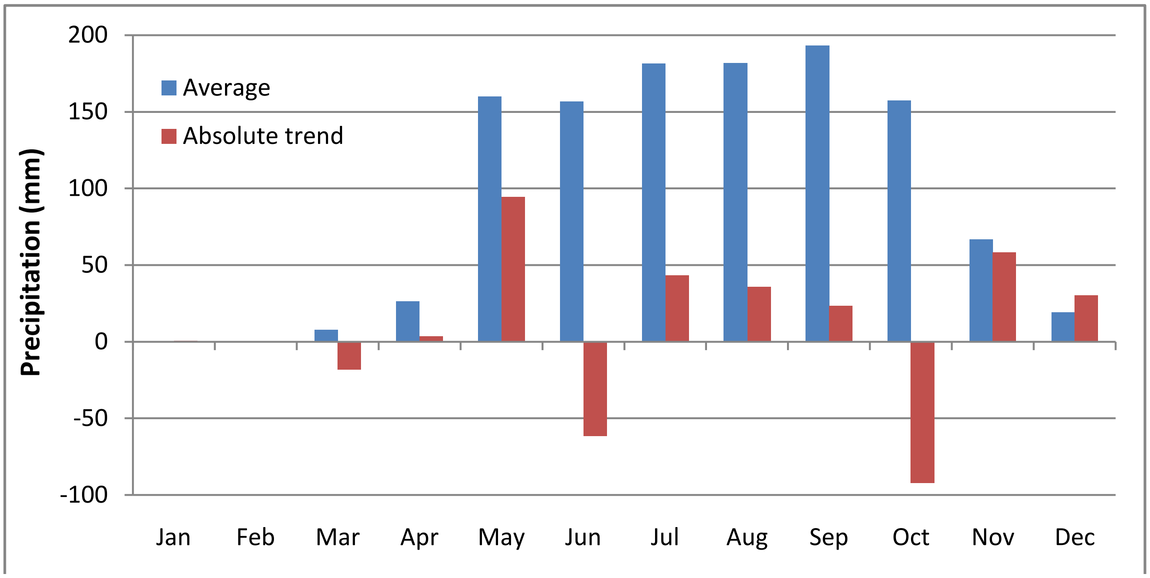

Figure 3: Average monthly precipitations in Phan Thiet and absolute trends (mm) from 1978 to 2007

B. Temperature indices

Minimum, maximum and mean temperatures trends were analyzed at both annual and monthly scales. Unsurprisingly, annual Tmin, Tmax and Tmean all increased at a rate of +0.30, +0.15 and +0.22°C per decade, respectively, with annual Tmin and Tmean trends being highly statistically significant and Tmax being statistically significant (Fig. 4 and Tab. III).

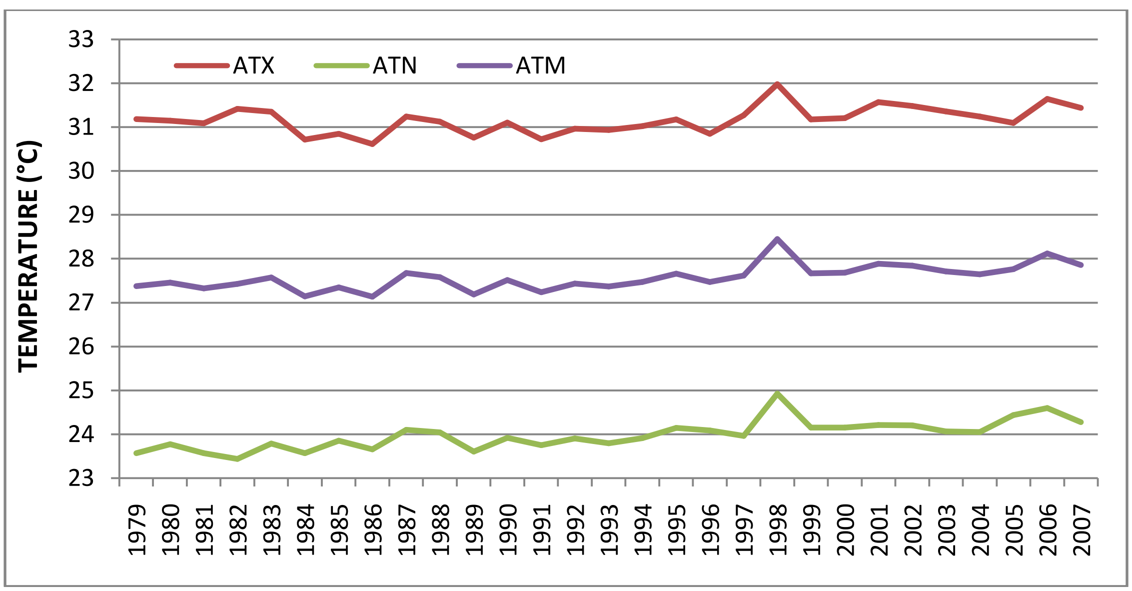

Figure 4: Evolution of annual Tmin, Tmax and Tmean in Phan Thiet from 1979 to 2007

At the monthly scale, all Tmin, Tmax and Tmean present increasing trends over the 1979-2007 period with the exception of Tmax for the months of July and August which present an insignificant decrease of 0.04 and 0.02°C per decade (Tab. III). The largest increases that are highly statistically significant are observed in January and December for Tmin with over +0.7°C per decade.

TABLE III. TRENDS IN TEMPERATURE INDICES (* & ** = STATISTICALLY & HIGHLY STATISTICALLY SIGNIFICANT).

Index	Average [1979-2007]	Trend (°C per 10 years)	Index	Average [1979-2007]	Trend (°C per 10 years)
ATN	24,0	+0,30 **	**ATX**	31,2	+0,15 *
ATN-Jan	21,4	+0,72 **	**ATX-Jan**	29,4	+0,22
ATN-Feb	22,1	+0,38 *	**ATX-Feb**	29,8	+0,17
ATN-Mar	23,7	+0,47 **	**ATX-Mar**	30,8	+0,15
ATN-Apr	25,5	+0,15 *	**ATX-Apr**	32,2	+0,22
ATN-May	25,8	+0,04	**ATX-May**	32,9	+0,13
ATN-Jun	25,3	+0,15	**ATX-Jun**	32,3	+0,24
ATN-Jul	24,7	+0,10	**ATX-Jul**	31,6	-0,04
ATN-Aug	24,7	+0,03	**ATX-Aug**	31,5	-0,02
ATN-Sep	24,6	+0,20 **	**ATX-Sep**	31,5	+0,23
ATN-Oct	24,3	+0,18 *	**ATX-Oct**	31,1	+0,22 *
ATN-Nov	23,4	+0,23	**ATX-Nov**	30,9	+0,03
ATN-Dec	22,0	+0,73 **	**ATX-Dec**	30,0	+0,29 *

IV. DISCUSSION AND CONCLUSION

Although most people met in the Province of Binh Thuan are saying that the area is affected by desertification processes mainly resulting from the ongoing climate change, especially shortening rainfall, the analysis of recent trends in precipitation shows that there is no declining rainfall since the late 1970s. Yet, all precipitation indices used in this study indicate a relative stability over the past three decades. We detected no lack of rainfall neither any statistically significant increase in annual maximum 1-day precipitation (RX1d that slightly declines). Only the number of extremely heavy precipitation days (R50mm) has increased by 31.6% but the trend remains not statistically significant.

It can be argued that the Phan Thiet meteorological station is not representative of the Bhin Thuan Province and that the dataset ends in 2007. But our results are in accordance with Endo et al. [10] who also found that annual total precipitation and R50mm tend to increase in southern Vietnam.

For what regards annual Tmin, Tmax and Tmean, the statistically significant increase at a rate of +0.30, +0.15 and +0.22°C per decade, respectively, is online with recent studies in southeast Asia [11].

As expected at the global scale, future climate in the Province of Binh Thuan should be characterized by higher temperature of about 1.6°C (over 2046-2065) and 2.5°C (over 2081-2100) and an increase of extreme temperatures and extreme rainfall events. But the current perception of climate change inducing declining rainfall is wrong probably because it is influenced by other drivers such as the increasing water needs to support expending agriculture. Yet, a survey made in March 2011 realized amongst farmers, water resources planners, and the agriculture administration pointed out that water needs were currently not met.

REFERENCES

[1] Core Writing Team, R. K. Pachauri, and A. Reisinger, Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 2007.

[2] T. Pham Anh and K. Shannon, “Urbanization and climate change in Vietnam: a case study of Hanoi,” In: M. De Dapper, D. Swinne, and P. Ozer, Eds. *Developing countries facing global warming: a post-Kyoto assessment*, Académie royale des Sciences d’Outre-Mer, Brussels, Belgium, 2010, pp. 203-220.

[3] Y. Biot, “Towards a strengthened climate deal. A brief scientific and historical context of the global policy response to climate change,” In: M. De Dapper, D. Swinne, and P. Ozer, Eds. *Developing countries facing global warming: a post-Kyoto assessment*, Académie royale des Sciences d’Outre-Mer, Brussels, Belgium, 2010, pp. 295-325.

[4] World Bank, The economics of adaptation to climate change. The World Bank Group, Washington DC, 2010.

[5] C.V. Nguyen, "Poverty projection using a small area estimation method: Evidence from Vietnam," Journal of Comparative Economics, in press, doi:10.1016/j.jce.2011.04.004

[6] V.H. Linh, "Vietnam's agricultural productivity: a Malmquist index approach," Vietnam Development Forum, Working Paper 0903, May 2009. http://www.vdf.org.vn/workingpapers/vdfwp0903

[7] Y.C. Hountondji, F. de Longueville, P. Ozer (2012) "Land Cover Dynamics (1990-2002) in Binh Thuan Province, Southern Central Vietnam", *International Journal of Asian Social Science*, Vol.2, No.3, pp. 336-349.

[8] S. Doutreloup, M. Erpicum, X. Fettweis, and P. Ozer (2011) "Analysis of the past (1970-1999) and future (2046-2065 and 2081-2100) evolutions of precipitation and temperature, in the Province of Binh Thuan, South East Vietnam, based on IPCC models", Proceedings of the 1st International Conference on Energy, Environment and Climate Changes, Ho Chi Minh City, Vietnam, 27th and 28th August, 2011. Available at http://hdl.handle.net/2268/96759

[9] E. Aguilar, et al. (2005) "Changes in precipitation and temperature extremes in Central America and northern South America, 1961– 2003", *J. Geophys. Res*., 110, D23107, doi:10.1029/2005JD006119.

[10] N. Endo, J. Matsumoto, T. Lwin (2009) "Trends in precipitation extremes over southeast Asia", *SOLA*, Vol.5, pp. 168-171.

[11] Y. Zhou, G. Ren (2011) "Change in extreme temperature event frequency over mainland China, 1961−2008", *Climate Research*, Vol.50, pp. 125-139.

Analysis of the past (1970-1999) and future (2046-2065 and 2081-2100) evolutions of precipitation and temperature, in the Province of Binh Thuan, South East Vietnam, based on IPCC models [1]

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Abstract— *Natural resource-dependent societies in developing countries are facing increased pressures linked to global climate change. The Province of Binh Thuan, in South East Vietnam, where rainfall is on average 500 to 700 mm but can drop as low as 350 mm in some years, knows a recent increase of agricultural activities in order to contribute to reduce poverty although the technical efficiency of Binh Thuan is still very low. Within this framework of higher dependency of the local economy on the agricultural sector, there is growing evidence that changes in climate extremes are increasing exposure of currently vulnerable rural populations.*

In order to assess the future climate of the province of Binh Thuan, only three models able to simulate the current climate in the study area were used out of the 24 selected by the IPCC: CCCMA-T47, INGV and IPSL.

The future climate projections (that is 2046-2065 and 2081-2100 compared to historical data 1970-1999) were focused on two targets: [i] assessing changes in climate statistics, and [ii] analysing the beginning and the end of the rainy season.

[i] The first analysis indicates an increase of mean temperature of about 1.6°C (over 2046-2065) and 2.5°C (over 2081-2100) and an increase of extreme temperatures and extreme rainfall events. However, no significant changes about the evolution of the annual amount of precipitation were found.

[ii] The second analysis indicates that the dry season is likely to be longer in 2046-2065 owing to a delay in the onset of the rainy season (up to 15 days) accompanied by an earlier end of the rainy season (up to 30 days).

Although it must be kept in mind that precipitations are the most difficult climate variable to predict, it is likely that increasing water needs to support expending agriculture within the context of climate change in the Province of Binh Thuan will be a challenge. Indeed, extreme rainfall events are likely to increase and unchanged yearly amounts of precipitation should be concentrated in time.

Keywords: climate change, precipitation, temperature, climate extremes, Binh Thuan, Vietnam

[1] Paper published in the *Proceedings of the 1st International Conference on Energy, Environment and Climate Change, August 26-27 2011, Ho Chi Minh City, Vietnam*. Available at http://hdl.handle.net/2268/96759

I. INTRODUCTION

Extreme weather and climate events have received increased attention in the last few years in the context of global climate change. Yet, the latest Intergovernmental Panel on Climate Change (IPCC) report predicts, by the mid- to late 21st century, a *virtually certain* (that is a probability of occurrence of over 99%) augmentation in warmer nights and hot days, and a *very likely* (that is a probability of occurrence of over 90%) increase in warm spells, heat waves and heavy precipitation [1]. Without taking into account any changes or developments in adaptive capacity, the major projected impacts of these changes in warm regions are:

- Agriculture, forestry and ecosystems: reduced yields in warmer regions due to heat stress; damage to crops and soil erosion consequently to heavy precipitations; inability to cultivate land due to waterlogging of soils;
- Water resources: increased water demand consequently to warming; adverse effects on quality of surface and groundwater; contamination of water supply;
- Human health: increased risk of heat-related mortality (especially for the elderly, chronically sick, very young and socially isolated); increased risk of deaths, injuries and infectious and skin diseases due to heavy precipitations and consecutive flooding;
- Industry, settlement and society: increased energy demand for cooling; reduction in quality of life for people in warm areas without appropriate housing; disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property [1].

Vietnam‘s exposure to weather-related events and disasters ranks among the highest among all developing countries [2-3]. Storms and floods (occasionally resulting from tropical cyclones) have caused extensive and repeated damages to buildings and infrastructure, significant losses to the agriculture and fisheries sectors, and resulted in a large number of fatalities. In the course of the 20th century, approximately 25,000 lives have been lost in Vietnam as a direct result of climate related events. Between 1991 and 2000 more than 8,000 people were killed by natural disasters (storms, floods, flash floods, landslides). In addition, an estimated 6 million houses were destroyed. The total economic value of losses for this period alone was estimated at USD 2.8 billion [4]. This is the reason why water resources management has become a major concern at the national scale.

The Province of Binh Thuan, in South East Vietnam (Fig. 1), where rainfall is on average 500 to 700 mm but can drop as low as 350 mm in some years [5], is characterised by a monsoon [6].

There are two distinct periods; a dry period and a wet period. The dry period begins approximately in November through April and the wet period from May through October. The wet season is characterised by two maximum of precipitations. The first one is in May-June and the second one is in September-October. These maximum of precipitations are due to the round-trip of the monsoon. The first maximum occurs when the Inter-Tropical Convergence Zone (ITCZ) goes to the North. During this passage, the air masses are saturated in humidity thanks to all Indonesian water mass. And the second maximum occurs when the ITCZ goes to the South. During this passage, the air mass is also saturated in humidity thanks to the South China Sea. The evolution of temperature is relatively constant through the year. The monthly mean temperatures oscillate between 25°C and 30°C.

The Province knows a recent increase of agricultural activities in order to contribute to reduce poverty although the technical efficiency of Binh Thuan is still very low [7-9]. Within this framework of higher dependency of the local economy on the agricultural sector, there is growing evidence that changes in climate extremes are increasing exposure of currently vulnerable rural populations.

This present study is realized within the framework of the project entitled “Impact of global climate change and desertification on the environment and society in Southern Central Vietnam - Case study in Binh Thuan Province” and aims to assess the future climate of the province of Binh Thuan.

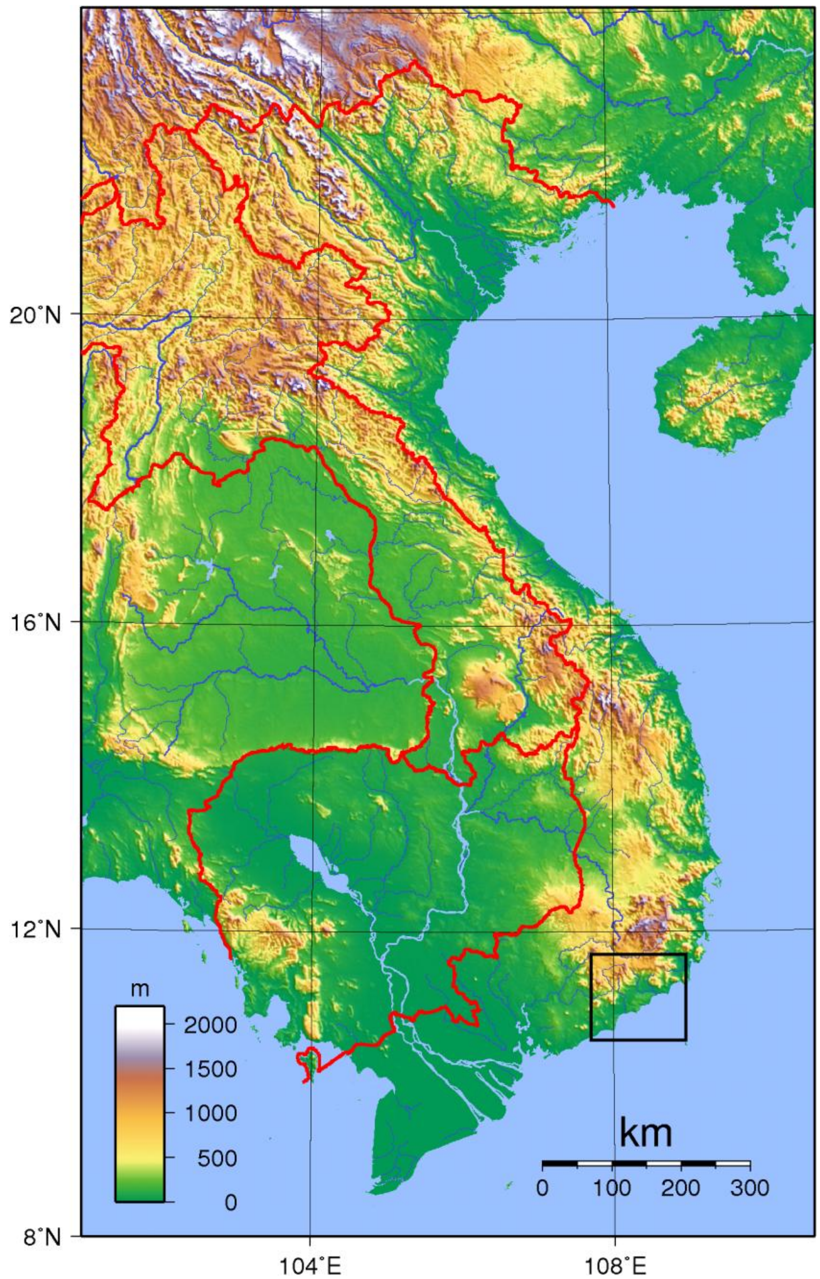

Figure 1. Vietnam topography with the region of interest in the black rectangle (source: http://fr.wikipedia.org/wiki/Viêt_Nam).

II. DATA

In this section, we present all the data used in this work and briefly explain how they were created, where we can find them, and what are their advantages and disadvantages.

A. ECMWF and NCEP-NCAR Reanalysis

The reanalysis models in general are global models which calculate the past climate with a forcing of the meteorological observations including radiosondes, balloons, aircraft, buoyes, satellites, scatterometers. We can consider the reanalysis as the best representations of the past climates. In this study, we used the 30-year period extending from January 1970 through December 1999.

The ECMWF reanalysis [10] is one of the reanalysis model used in climatology over the period from September 1957 through August 2002 while the NCEP-NCAR Reanalysis-1 [11] is another reanalysis model used in climatology over the period from January 1948 through present.

The advantage of using such datasets is that the entire world is covered by at least one set of meteorological data. The disadvantage is that data over one region are interpolated compared with the real observation data in a meteorological station. The interpolation is proportional to the spatial resolution of the model (see Table 1). A second advantage can be found in the nature of these data. Yet, those are calculated by a model. This fact implies that we compare two models among them and not local observations with a global model. The local observations represent the climate of one site and are very difficult to apply to an entire region because the site of measurements has specific characteristics that may not be similar to an entire surrounding area.

B. Models selected by the IPCC

The IPCC [12] has selected 24 models in its last report (Table I). These models are forced by none observational data. All of these models have initial conditions, which are created randomly and the models run from these initial conditions until they reach equilibrium conditions. According to their internal configurations, the models are different. Thus, some models may not be consistent with the real climate.

All models have a different spatial resolution (Table I). Some models have a relatively precise spatial resolution like the INGV model with 1.1° latitude and 1.1° longitude whereas other models have a coarse spatial resolution like the GISS–EH model with 5.0° latitude and 4.0° longitude. This fact implies that the interpolation of data over one region is bigger when the spatial resolution is coarse.

The IPCC models have different time periods. Firstly, the IPCC models have a scenario called 20C3M which calculates past climate over the 1961-2000 period. As mentioned above, we used this scenario over the 1970-1999 period in the two sorting to compare with the reanalysis models.

Secondly, the IPCC models forecast different time periods in the future using different scenarios. In this work, we used the 20-year periods 2046-2065 and 2081-2100 for three different scenarios: B1, A1B, A2 [12]. So we eliminated two intermediate scenarios (B1 and A1T) as well as the worst case scenario (A1FI) [1] although recent trends in global GHG emissions show that the latter scenario is far from being unlikely [14].

- The B1 scenario believes that the world will be more integrated and more ecologically friendly. It is characterized by: a rapid economic growth but with rapid changes towards a service and information economy; a population rising to 9 billion in 2050 and then declining; reductions in material intensity and the introduction of clean and resource efficient technologies; and an emphasis on global solutions to economic, social and environmental stability. With this scenario which is the most optimistic about the future behaviour of our societies and presumably the less probable given the weak global policy response to climate change [15], best global temperature change estimate between 1980-1999 and 2090-2099 is +1.8°C, with a likely range of +1.1°C to 2.9°C.
- The A1B scenario bets on a more integrated world and is characterized by: a rapid economic growth; a global population that reaches 9 billion in 2050 and then gradually declines; the quick spread of new and efficient technologies; a convergent world income and way of life converge between regions; extensive social and cultural interactions worldwide; and a balanced emphasis on all energy sources. With this scenario, best global temperature change estimate between 1980-1999 and 2090-2099 is +2.8°C, with a likely range of +1.7°C to 4.4°C.
- The A2 scenario imagines a more divided world. It is characterized by: a world of independently operating, self-reliant nations, a continuously increasing population, a regionally oriented economic development, a slower and more fragmented technological changes and improvements to per capita income. With this scenario, best global temperature change estimate between 1980-1999 and 2090-2099 is +3.4°C, with a likely range of +2.0°C to 5.4°C.

TABLE I. MODELS AND REANALYSES USED IN THIS STUDY WITH THEIR SHORT NAME AND SPATIAL RESOLUTION. THE AOGCMS SHORT NAMES ARE BASED ON THE WORK OF LELOUP ET AL. [13]. †

Data name	Short name	Spatial resolution
BCCR–BCM2.0	BCCR	2.8° × 2.8°
CCCMA–CGCM3.1(T47)	CCCMA–T47	3.7° × 3.7°
CCCMA–CGCM3.1(T63)	CCCMA–T63	2.8° × 2.8°
CNRM–CM3	CNRM	2.8° × 2.8°
CSIRO–Mk3.0	CSIRO–0	1.9° × 1.9°
CSIRO–Mk3.5	CSIRO–5	1.9° × 1.9°
GFDL–CM2.0	GFDL–0	2.6° × 2.0°
GFDL–CM2.1	GFDL–1	2.6° × 2.0°
GISS–AOM	GISS–AOM	4.0° × 3.0°
GISS–EH	GISS–EH	5.0° × 4.0°
GISS–ER	GISS–ER	5.0° × 4.0°
IAP–FGOALS–g1.0	IAP	2.8° × 2.8°
INGV–SXG	INGV	1.1° × 1.1°
INM–CM3.0	INMCM	5.0° × 4.0°
IPSL–CM4	IPSL	3.8° × 2.5°
MIROC3.2 (hires)	MIROC–HR	1.1° × 1.1°
MIROC3.2 (medres)	MIROC–MR	2.8° × 2.8°
MIUBECHO-G	MIUB	3.7° × 3.7°
ECHAM5/MPI–OM	MPI	1.9° × 1.9°
MRI–CGCM2.3.2	MRI	2.8° × 2.8°
NCAR–CCSM3	CCSM3	1.4° × 1.4°
NCAR–PCM1	PCM1	2.8° × 2.8°
UKMO–HadCM3	HADCM3	3.8° × 2.5°
UKMO–HadGEM1	HADGEM1	1.9° × 1.2°
ECMWF 40 Year Reanalysis	ERA–40	1.1° × 1.1°
NCEP/NCAR Reanalysis 1	NCEP1	2.5° × 2.5°

† Data source: the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3).

III. METHODOLOGY

In order to predict future temperatures and precipitations in South-Eastern Vietnam during the 21st century, future projections models selected by the IPCC were used. The first step was to test the ability of each model to simulate the past climate (1970-1999) in South-Eastern Vietnam in order to select the best models. The second step was to use the future projections of these selected models to obtain future trends of temperatures and precipitations.

Tests were performed on the 24 different models available. From the beginning, we rejected the BCCR, INMCM, HADCM3 and HADGEM1 models because all required data for this study were not available. All models are not suitable to analyse the future projections. So, the first step was to sort them and select the models which best simulate past climate in the Province of Binh Thuan. For this aim, we compared the

IPCC models with the ECMWF and NCEP-NCAR reanalysis. We sorted the models two successive steps. The first sorting was performed to eliminate the worst models and the second sorting was done to keep the best models and obtain some models from which we used the projections of future climatic parameters and their evolutions.

For the first sorting, we used daily data of the IPCC models, the ECMWF and NCEP-NCAR reanalysis during the 1970-1999 period. For each IPCC models, we calculated the monthly mean temperature at 2 meter-height and the monthly sum of precipitations. We also calculated the monthly standard error (σ) of temperatures and precipitations for the reanalysis models. Then we plotted the IPCC models data on a climograph with superimposed ±2σ results of each reanalysis model.

The method to eliminate the less appropriated IPCC models for the region of interest was based on 2 criteria:

- The curves of temperatures and precipitations had to respect the best the behaviour of the curves of the reanalysis models. Especially, the curves of temperatures and precipitations had to respect at best the dry and wet seasons;
- The curves of temperatures and precipitations had to be included at best into the range of ±2σ. The aim of this sorting consisted in selecting the models for which the curve was included (or very near) into the range determined by the ±2σ limits of the reanalysis. Thus we kept only the models which best represented reality given by the reanalysis.

After these two sortings, we considered that all selected models best represented reality given by the reanalysis models and thus were the models which best represented future projections.

The future climate projections (that is 2046-2065 and 2081-2100 compared to historical data 1970-1999) were focused on two targets:

- Assessing changes in climate statistics (annual mean temperature, annual amount of precipitation, standard deviation of temperature and precipitation, maximum and minimum of temperature and precipitation);
- Analysing the beginning and the end of the rainy season.

IV. RESULTS

A. Selection of the IPCC models

All criteria mentioned above were applied to the IPCC models. All detailed climographs can be retrieved from Doutreloup *et al*. [16]. Although they may seem quite different, three models were selected: CCCMA-T47, IPSL and INGV (Fig. 2).

B. Changes in climate statistics

Future projected changes in climate statistics for periods 2046-2065 and 2081-2100 compared to past records (1970-1999) were performed for the three selected IPCC models using scenarios A1B, A2 and B1. Results are given in Tables II-IV. They show a systematic increase of mean temperatures close to what is expected at the global scale and an unclear rainfall evolution. However, all models under different scenarios agree that extreme maximum temperature and rainfalls (99th percentile) will increase in the Province of Binh Thuan.

C. Length of the rainy season

The analysis of the length of the rainy season indicates that the dry season is likely to be longer in 2046-2065 owing to a delay in the onset of the rainy season (up to 15 days) accompanied by an earlier end of the rainy season (up to 30 days) (Table V). The annual rainfall total will probably remain stable but the seasonal distribution of rainfall will change. Yet, if evolutions remain unclear in spring, precipitation recorded in the late summer summit is likely to increase. The same conclusions can be drawn for the 2081-2100 period. The future climate of the Province of Binh Thuan will therefore be characterized by a longer dry season and concentrated rainfall in the summer with an increase in extreme rainfall events.

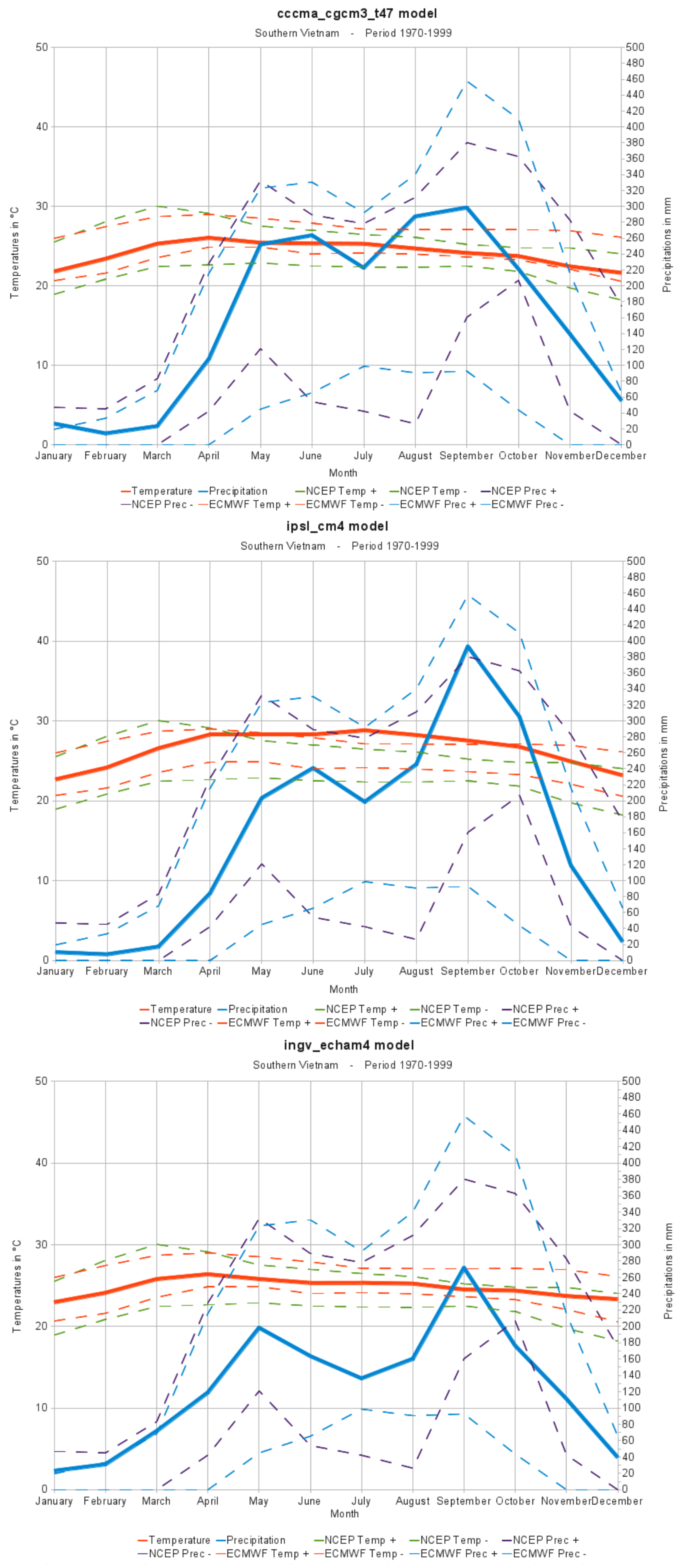

Figure 2. Climographs of the 3 selected IPCC models with the reanalysis models error curve of ±2σ. The continuous blue and red curves represent monthly precipitations and temperatures of the models. The discontinuous blue and violet curves represent the ±2σ monthly precipitations in the ECMWF and the NCEP-NCAR reanalysis models. The discontinuous red and green curves represent the ±2σ monthly temperatures in the ECMWF and the NCEP-NCAR reanalysis models [*].

TABLE II. PAST (1970-1999) AND FUTURE (2046-2065, 2081-2100) CLIMATE VALUES AND STATISTICS USING THE CCCMA-T47 MODEL WITH THREE DIFFERENT SCENARIOS (A1B, A2 AND B1).

CCCMA-T47 model	**Past**	**Scenario A1B**		**Scenario A2**		**Scenario B1**	
Variables	1970-1999	2046-2065	2081-2100	2046-2065	2081-2100	2046-2065	2081-2100
Mean Temperature (C)	24,1	25,7	26,6	25,9	27,3	25,5	25,8
Sum Precipitation (mm/year)	1912	1990	1955	2020	2186	1880	1976
Standard-Error Temperature (C)	3,6	4,2	4,2	4,1	4,2	4,1	4,1
Standard-Error Precipiation (mm)	9,6	10,3	10,6	11,0	13,2	8,7	10,2
Centile 50 of the Temperature (C)	24,3	25,9	26,6	26,0	27,4	25,6	25,9
Centile 50 of the Precipitation (mm)	2,3	2,1	2,0	2,1	2,0	2,1	2,2
Centile 99 of the Temperature (C)	28,4	30,2	31,4	30,6	32,2	29,8	30,5
Centile 99 of the Precipitation (mm)	49,1	52,6	53,8	54,5	71,1	45,8	54,7

TABLE III. SAME AS TABLE II FOR THE IPSL MODEL.

IPSL model	**Past**	**Scenario A1B**		**Scenario A2**		**Scenario B1**	
Variables	1970-1999	2046-2065	2081-2100	2046-2065	2081-2100	2046-2065	2081-2100
Mean Temperature (C)	26,5	28,5	28,6	28,3	30,2	28,0	28,6
Sum Precipitation (mm/year)	1782	1753	1860	1762	1714	1779	1694
Standard-Error Temperature (C)	3,9	4,5	4,5	4,5	4,6	4,5	4,5
Standard-Error Precipiation (mm)	7,0	8,8	12,2	8,6	9,3	8,0	7,4
Centile 50 of the Temperature (C)	27,4	29,3	29,5	29,1	31,0	28,9	29,5
Centile 50 of the Precipitation (mm)	3,3	2,3	1,8	2,4	1,8	2,7	2,1
Centile 99 of the Temperature (C)	29,8	33,8	33,8	32,3	35,4	32,3	33,8
Centile 99 of the Precipitation (mm)	29,6	32,3	44,6	34,6	35,2	34,3	31,7

TABLE IV. SAME AS TABLE II FOR THE INGV MODEL.

INGV model	**Past**	**Scenario A1B**		**Scenario A2**	
Variables	1970-1999	2046-2065	2081-2100	2046-2065	2081-2100
Mean Temperature (C)	24,7	26,3	27,0	26,1	27,4
Sum Precipitation (mm/year)	1459	1438	1478	1540	1465
Standard-Error Temperature (C)	3,4	4,0	4,0	3,9	4,1
Standard-Error Precipiation (mm)	7,1	7,5	8,2	3,9	8,3
Centile 50 of the Temperature (C)	24,7	26,3	26,9	26,1	27,3
Centile 50 of the Precipitation (mm)	1,0	0,8	0,7	1,0	0,7
Centile 99 of the Temperature (C)	28,3	30,3	31,4	30,2	32,1
Centile 99 of the Precipitation (mm)	28,0	33,0	35,0	35,2	34,7

TABLE V. SUMMARY TABLE OF THE ANALYSIS OF THE CLIMOGRAPHS OF THE THREE MODELS ON THE PERIOD 2046-2065. #

2046-2065	CCCMA-T47	INGV	IPSL
Beginning of the wet season (days)	↗ [0 : +10]	↗ [0 : +10]	↑ [+10 : +15]
Ending of the wet season (days)	↓ [−30 : −10]	↘ [−30 : 0]	↘ [−10 : 0]
Late spring summit of precipitation (%)	↑ [+5 : +20]	↓ [−11 : −4]	↘ [−4 : 0]
Late summer summit of precipitation (%)	↑ [+15 : +33]	∅ [−2 : +10]	↑ [+5 : +14]
Annual sum of precipitation (%)	∅ [−2 : +6]	∅ [−4 : +3]	↓ [−5 : −4]
Annual mean of temperatures (^{o}C)	↑ [+1.3 : +1.8]	↑ [+1.4 : +1.6]	↑ [+1.5 : +2.1]

The evolution is represented by the arrows and refers to the past climate. The range shows the minimum and maximum value of the scenarios. ↑ : the evolution is strictly positive; ↗ : the evolution is positive or equal to zero; → : the evolution is equal to zero; ↘ : the evolution is negative or equal to zero; ↓ : the evolution is strictly negative; ø : the evolution has no general trend.

TABLE VI. SAME AS TABLE V FOR THE PERIOD 2081-2100.

2081-2100	CCCMA-T47	INGV	IPSL
Beginning of the wet season (days)	↑ [+10 : +15]	↑ [+30]	↑ [+15]
Ending of the wet season (days)	↘ [−10 : 0]	→ [0]	↘ [−10 : 0]
Late spring summit of precipitation (%)	↑ [0 : +27]	↘ [−14 : −11]	↓ [−18 : −1]
Late summer summit of precipitation (%)	↑ [+24 : +56]	↑ [+8 : +13]	∅ [−3 : +50]
Annual sum of precipitation (%)	↑ [+2 : +14]	↓ [−2]	∅ [−8 : +1]
Annual mean of temperatures (^{o}C)	↑ [+1.7 : +3.2]	↑ [+2.2 : +2.6]	↑ [+2.1 : +3.7]

V. DISCUSSION AND CONCLUSION

As expected at the global scale, future climate in the Province of Binh Thuan should be characterized by higher temperature of about 1.6°C (over 2046-2065) and 2.5°C (over 2081-2100) and an increase of extreme temperatures and extreme rainfall events.

Although it must be kept in mind that precipitations are the most difficult climate variable to predict, it is likely that increasing water needs to support expending agriculture within the context of climate change in the Province of Binh Thuan will be a challenge. Yet, extreme rainfall events are likely to increase and unchanged yearly amounts of precipitation should be concentrated in time. A recent survey (March 2011) realized amongst farmers, water resources planners, and the agriculture administration points out that water needs are currently not met. What will happen in the next decades if the dry season extends and that the agriculture switches towards more intensive and irrigated crops? Our results may help future land use planning.

In the meantime, since the area of concern is already highly prone to flood hazard, water management should become a top priority of local authorities in order to reduce future exposure and vulnerability of the population.

REFERENCES

[1] Core Writing Team, R. K. Pachauri, and A. Reisinger, Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 2007.

[2] T. Pham Anh and K. Shannon, "Urbanization and climate change in Vietnam: a case study of Hanoi," In: M. De Dapper, D. Swinne, and P. Ozer, Eds. *Developing countries facing global warming: a post-Kyoto assessment*, Académie royale des Sciences d'Outre-Mer, Brussels, Belgium, 2010, pp. 203-220.

[3] Y. Biot, "Towards a strengthened climate deal. A brief scientific and historical context of the global policy response to climate change," In: M. De Dapper, D. Swinne, and P. Ozer, Eds. *Developing countries facing global warming: a post-Kyoto assessment*, Académie royale des Sciences d'Outre-Mer, Brussels, Belgium, 2010, pp. 295-325.

[4] World Bank, The economics of adaptation to climate change. The World Bank Group, Washington DC, 2010.

[5] P. Chaudhry and G. Ruysschaert, "Climate change and human development in Vietnam," Human Development Report Office, Occasional Paper 2007/46.

[6] S. Nieuwolt, "The climates of continental Southeast Asia," In: K. Takahashi and H. Arakawa, Eds., *Climates of Southern and Western Asia*, Elsevier, Amsterdam, Netherlands, 1981, pp. 1-66.

[7] C.V. Nguyen, "Poverty projection using a small area estimation method: Evidence from Vietnam," Journal of Comparative Economics, in press, doi:10.1016/j.jce.2011.04.004

[8] V.H. Linh, "Vietnam's agricultural productivity: a Malmquist index approach," Vietnam Development Forum, Working Paper 0903, May 2009. http://www.vdf.org.vn/workingpapers/vdfwp0903

[9] Y. C. Hountondji and P. Ozer, "Land cover change analysis 1990-2002 in Binh Thuan Province, south central Vietnam," paper presented at the 1st International Conference on Energy, Environment and Climate Changes, Ho Chi Minh City, Vietnam, 27th and 28th August, 2011. Available at http://hdl.handle.net/2268/97731

[10] ECWMF: European Centre for Medium-range Weather Forecast. http://www.ecmwf.int/

[11] NCEP-NCAR: National Centre for Environmental Prediction - National Centre for Atmospheric Research http://www.cpc.ncep.noaa.gov/

[12] S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, et al., Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007.

[13] J. Leloup, M. Lengaigne, and J. P. Boulanger, "Twentieth Century ENSO characteristics in the IPCC database," Clim. Dyn., vol. 30, pp. 277-291, 2008, doi:10.1007/s00382-007-0284-3

[14] Global Carbon Project, "Carbon Budget 2009," http://www.globalcarbonproject.org/, 20 January 2011.

[15] M. De Dapper, D. Swinne, and P. Ozer, Developing countries facing global warming: a post-Kyoto assessment. Académie royale des Sciences d'Outre-Mer, Brussels, Belgium, 2010.

[16] S. Doutreloup, X. Fettweis, P. Ozer, "Analysis of the evolution of the climate parameters, especially precipitations and temperatures, in the province of Binh Thuan in Southern Vietnam based on IPCC models," Scientific Report. 30 p. URL: http://hdl.handle.net/2268/92711.

[*] Higher resolution format of Fig. 2 is available from: http://hdl.handle.net/2268/96759

Land use and land cover change analysis 1990-2002 in Binh Thuan Province, south central Vietnam[*,1]

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Abstract *- Describing the nature and extent of land resources and changes over time has become increasingly important, especially in developing countries. In this study, two Landsat satellite image scenes were examined to identify land use and land cover changes in Binh Thuan province (Vietnam) between 1990 and 2002. Classification accuracies were based upon ground truth data obtained by global positioning system and field collection. A post-classification comparison analysis was used to identify areas that have experienced conversions in land use and land cover. Comparisons of the land cover maps reveal that a steady growth in population has caused extensive changes of land cover throughout the area. The maps also indicate that the loss of woody land (forest) and the extension of wetlands (irrigate area), combined with built-up encroachment, remains one of the most serious environmental problems facing the Binh Thuan Province today. The post-classification change detection analysis showed that critical habitats accounted for nearly 38.5% of the total intensive study area between 1990 and 2002 while 61.5% remained stable. Results also showed over the 12-year span, approximately 1151.2 km² (115.120 ha) forest were converted respectively to brush, irrigated area (wetlands), cropland and built-up. This is an overall average decrease of approximately 9594 hectares of forested area per year. Throughout the study area, districts most affected by forest conversion to another land cover are: Bac Bihn (2798 ha/year), Than Linh (2717 ha/year), Ham Thuan Nam (1601 ha/year) and Ham Thuan Bac (1524 ha/year). Based on the identified causes of these changes, we made policy recommendations for better management of land use and land cover.*

Keywords: Land cover, Change detection, Landsat, Binh Thuan, Vietnam

I. INTRODUCTION

The research on the land use/cover change is one of the frontiers and the hot spots in the global change research. The urban growths, deforestation, extension of the cultivated lands are the main talks in the current scenario of rapid changes in the climate. The change of the land cover of a specific area over a time period can provide us information on how sustainable the land has been used. While standard ground survey methods for undertaking such measurements are imperfect or expensive it has been demonstrated that satellite-based and airborne remote sensing (RS) systems offer a considerable potential. This capacity for quantitative land-surface monitoring over large areas makes RS well-suited for a very wide range of disciplines, including land-use planning and providing spatial information needed for local or regional-scale analyses of the relationships between climate change, land degradation and desertification processes [1]. Therefore, studying the change detection by remotely sensed data's of different date's remains a challenge because of factors such as the complexity of the

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[1] Paper presented at the *1st International Conference on Energy, Environment and Climate Change, August 26-27 2011, Ho Chi Minh City, Vietnam*. Available at http://hdl.handle.net/2268/97731 and published as follows: Hountondji Y.C., De Longueville F., Ozer P. (2012) "Land Cover Dynamics (1990-2002) in Binh Thuan Province, Southern Central Vietnam", *International Journal of Asian Social Science* Vol.2, No.3, pp. 336-349. Available at http://www.aessweb.com/abstract.php?m=March2012&id=5007&aid=1207

landscape in a study area selected remotely sensed data. Change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times [2]. This technical issue is useful in many applications related to land use and land cover (LULC) changes, such as shifting cultivation and landscape changes [3], land degradation and desertification ([4]; [5]), urban sprawl [6], deforestation ([7]; [8]), landscape and habitat fragmentation and other cumulative changes [9]. Continual, historical, and precise information about the LULC changes of the Earth's surface is extremely important for any kind of sustainable development program, in which LULC serves as one of the major input criteria. Satellite remote sensing is the most common data source for detection, quantification, and mapping of LULC patterns and changes because of its repetitive data acquisition, digital format suitable for computer processing, and accurate georeferencing procedures ([10]; [11]). The successful use of satellite remote sensing for LULC change detection depends upon an adequate understanding of landscape features, imaging systems, and methodology employed in relation to the aim of analysis [12]. Many change detection techniques have been developed and used for monitoring changes in LULC from remotely sensed data, such as post-classification comparison (PCC), image differencing, principle components analysis, and vegetation index differencing [13]. The PCC method, which is recognized as the most accurate change detection technique, detects land cover changes by comparing independently produced classifications of images from different dates. Using the PCC method thus minimizes the problems associated with multi-temporal images recorded under different atmospheric and environmental conditions. Data from different dates are separately classified, and hence, reflectance data from multi-dates do not require adjustment for direct comparability ([14]; [15]). There are currently numerous satellite programs in operation. For change detection studies, the Landsat program is unique because it provides an historical and continuous record of imagery. Landsat images can be processed to represent land cover over large areas and over long time spans, which is unique and absolutely indispensable for monitoring, mapping, and management of LULC [16].

This paper aims to investigate spatial and temporal land cover changes in Binh Thuan province in the southern central Vietnam and understand the possible causes of the changes. To do this, we applied land classification schemes to classify the land cover types using Landsat data focus on six districts included in Binh Thuan province. Based on the previously developed methodology such as maximum-likelihood classification and change detection techniques, we assessed the accuracy of the land classification techniques by comparison with supervised classification based on numerous ground truth data. Land cover changes between 1990 and 2002 were quantitatively presented with the results of accuracy assessments. We also suggested recommendations regarding towards better management of LULC.

II. DATA AND METHODS

A. Study area

Locate between 107°24' – 108°50'E and 10°33'– 11°33'N (Fig. 1), Binh Thuan is a sea coast province of south of central Vietnam, having north-east border with Ninh Thuan province, north-west border with Lam Dong province; west border with Dong Nai province; south-west border with Ba Ria - Vung Tau province; east and south-east border with the South China Sea. Total land area is 7830.4 km² [17] and the province has 8 districts, 1 city and 125 towns, communes.

This region is the driest and hottest region of Vietnam. The area faces the Pacific Ocean to the east with a coastline of about 192 km and is characterized by a combination of tropical monsoon and dry and windy weather. The Binh Thuan Province can be divided into 4 main landscapes: Sand dunes along the coast - alluvial plains - hilly areas – and the Truong Son mountain range. The mean annual temperature is 27°C, with average minimum 20.8°C in the coldest months (December, January), and an average maximum of 32.3°C in the hottest months (May and June). Rainfall in this area is limited and irregular. Annual average precipitation is 1024 mm, while evaporation in some years is equivalent to precipitation. At some locations annual rainfall can be as low as 550 mm. The dry season is from November to April, with 60 days of January and February having almost no rain. The rainy season is from May to October with heavy rains concentrated in a short periods with up to 200 mm/day. The total population of the province in 2004 is around 1.140.429 so urban conditions have improved in recent years through the extension of water supply networks and road upgrading.

B. *Data acquisition and processing*

A pair of cloud-free Landsat images was selected to classify the study area: December 30, 1990 (Landsat-5 TM) and January 05, 2002 (Landsat-7 ETM+). These time series of Landsat images are freely available from the Landsat archive from the United States Geological Survey (USGS) [18]. All visible and infrared bands (except for the thermal infrared band) were included in the analysis. Only the intersected area (province boundary and image subset) has been taken into account for spatial statistics. Six of the nine districts of Binh Thuan province were contained within Landsat path 124, rows 52. All images were rectified to UTM zone 48N, GRS 1984, using at least 35 well distributed ground control points. The root mean square errors were less than 0.25 pixel (7.125 m) for each of the two images.

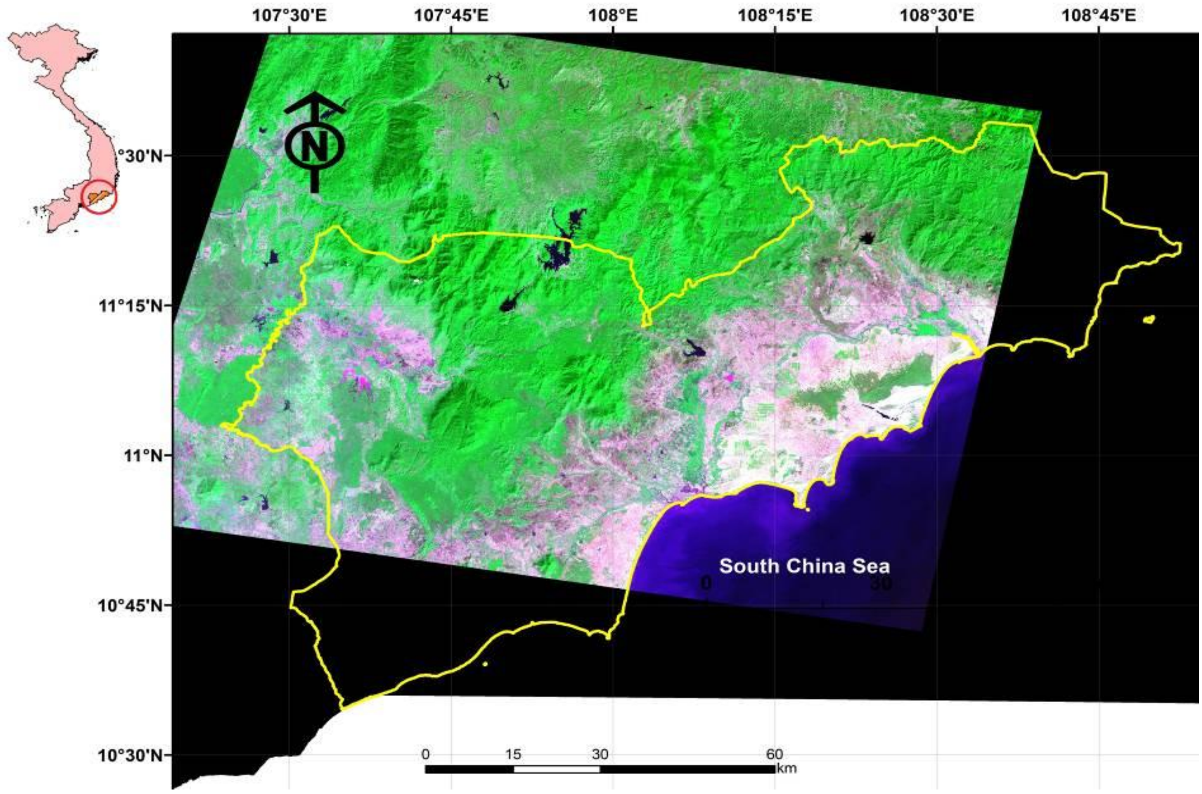

Fig. 1: Location of Binh Thuan province and area covered by Landsat ETM+ image subset (05.01.2002) False color (RGB: TM3, TM 4, TM 2)

We used the Environment for Visual Imaging software (ENVI version 4.4) [19] developed by Research System Incorporated (RSI) for digital image processing of the subsets of chosen Landsat images described above. Image processing included images calibration to reflectance, enhancement, rectification, and sub-setting. The accuracy of the classification was determined based upon ground truth region of interest (ROI). Each class included a different number of ROI's, depending upon the albedo and contrast of class types. Training samples were selected for each of the predetermined LULC types by delimiting polygons around representative sites. Using the pixels enclosed by these polygons, we derived spectral signatures for the respective land cover types recorded by the satellite images. A spectral signature is considered to be satisfactory when 'confusion among the land covers to be mapped is minimal [20]. Once the spectral signature was deemed satisfactory, we entered it into the classification process. Ground truth ROI's were divided into two groups. The first group is for classification procedure and the second group is for accuracy assessment. Two LULC maps were produced (for 1990 and 2002). Our classification scheme, with seven classes (Table I), was based on the land cover and land use classification system developed [21] for interpretation of remote sensor data at various scales and resolutions.

TABLE I: LAND COVER CLASSIFICATION SCHEME

Land cover class	Acronym	Description
Built-up	BUP	Urban or rural build-up - industrial – transportation – cities – towns -villages
Forest-Plantation	FPO	Natural forest - reforested land - mixed forest – orchards - groves
Dunes and sandbank	DSB	Dune roving - sandbank
Crop land	CLD	All arable land (not limited to land under crops) – rain-fed crop fields and bare fields
Highland and Bush	HIB	High lands or hills with vegetation – wild lands with spare vegetation – unused land
Water bodies	WAT	Permanent open water – lakes – reservoirs – streams - bays and estuaries
Lowland	WET	Irrigated cropland - paddy field - water ponds - flooded lands.

A supervised training approach was used with maximum likelihood classification [22]. Since several research have produce different land classes ([23], [24], [25]) than those of our Landsat classification, data from both sources were aggregated into seven categories. Class histograms were checked for normality and small classes were deleted. Post-classification refinements were applied to reduce classification errors caused by the similarities in spectral responses of certain classes such as bare fields and urban and some crop fields and wetlands. An independent sample of an average of 40 polygons, with up to 100 pixels for each selected polygon, was randomly selected from each classification to assess classification accuracies. Error matrices as cross-tabulations of the mapped class vs. the reference class were used to assess classification accuracy [26]. Overall accuracy, user's and producer's accuracies, and the Kappa statistic were then derived from the error matrices. The Kappa statistic incorporates the off diagonal elements of the error matrices (i.e., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. Finally, a 3x3 majority filter was applied to each classification to recode isolated pixels classified differently than the majority class of the window.

C. Change detection

Following the classification of imagery from the individual years, a post-classification comparison change detection algorithm was used to determine changes in land cover in 1990–2002 intervals. This is the most common approach to change detection [27] and has been successfully used to monitor land use changes in previous studies ([28]; [13]; [14]; [15]). Post-classification comparison (PCC) was employed to detect the differences between each pair of LULC maps (1990 and 2002). The PCC approach provides ''from–to'' change information and the kind of landscape transformations that have occurred can be easily calculated and mapped. A change detection map with 49 combinations of ''from–to'' change information was derived for each of the two seven-class maps and then, a change map was compiled to display the specific nature of the changes between the classified images.

III. RESULTS

Results presented in the following sections are restricted to the area of Binh Thuan province for which the chosen Landsat scenes intersected with provincial boundaries. This overlapped area covers 6070 km² representing 78.9% of the total area of the province.

A. Classification maps accuracies and statistics

Before using the classification results for change detection, we assessed their validity by testing the results against ground truth data. Error matrices were used to assess classification accuracy and results are summarized for the two years in Table II.

The overall accuracies for 1990 and 2002 were, respectively, 98.05% and 91.41%, with Kappa statistics of 96.61% and 87.98%. User's and producer's accuracies of individual classes were consistently high, ranging from 99% to 76%. FPO, WAT and HIB classes were all characterized by the highest classification accuracy. This is because the integration of the results of visual interpretation and supervised classification, which allowed us to correct the misclassified pixels.

The data presented in Fig. 2 and Table III represent respectively the rate and the total area of each LULC class for 1990 and 2002. In 1990, HIB was the largest class, representing 2407 km² of the total LULC categories assigned, occupying 39.7% of the study area. In 2002, this class amount had increased significantly, resulting chiefly in the reduction of forest and plantation class (from 30% in 1990 to 20.7% in 2002). With the exception of the Lowland class (WET: 4.9%) and the dune roving (DSB:

2.3%) in 1990, built-up (BUP) and free-water bodies classes (WAT) accounted for the lowest percentages of the total LULC categories in all study years.

TABLE II: SUMMARY OF LANDSAT SUBSET CLASSIFICATION ACCURACIES (%) FOR 1990 AND 2002

Land cover class	Acronym	1990		2002	
		Producer's	User's	Producer's	User's
Built-up	BUP	97.59	87.22	80.04	76.66
Forest-Plantation	FPO	99.47	77.58	98.48	85.75
Dunes - sandbank	DSB	98.13	99.58	88.66	99.63
Crop land	CLD	94.82	98.05	95.85	94.39
Highland and Bush	HIB	98.80	99.95	91.25	99.96
Water bodies	WAT	99.18	99.98	99.96	98.17
Lowland	WET	97.89	78.58	95.26	86.51
Overall accuracy (%)		98.05		91.41	
Kappa statistic(%)		96.61		87.98	

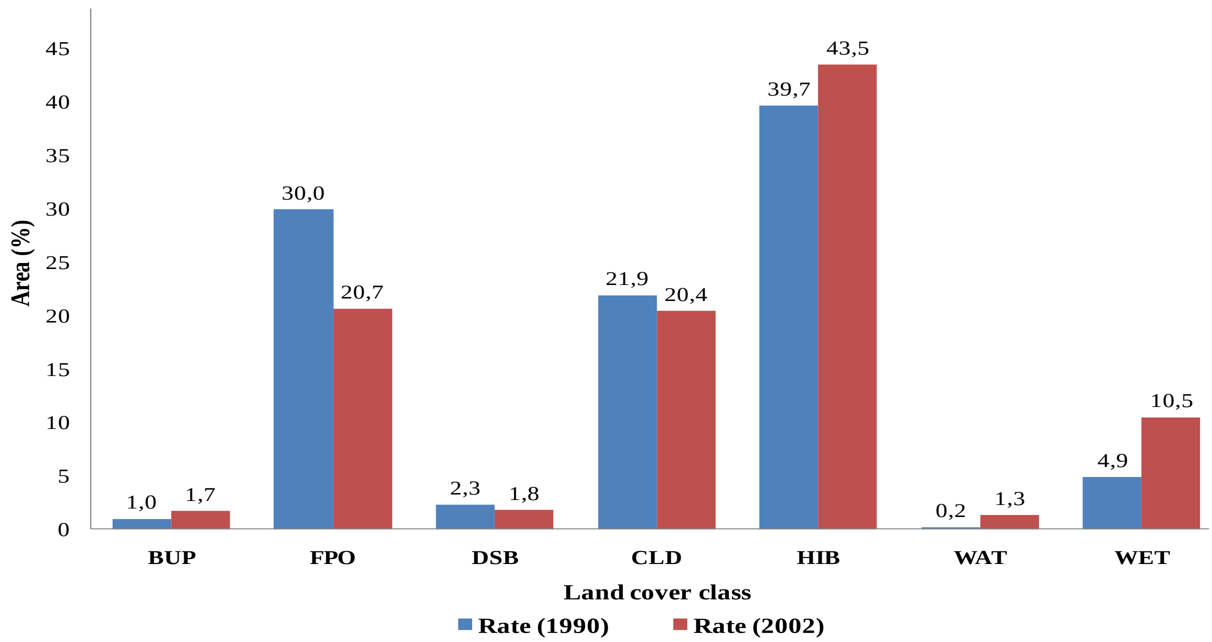

Fig. 2: Area percentage of each land cover class resulting from the classified images (6070 km²) for 1990 and 2002.

The major changes during 1990-2002 periods were found in FPO class (natural forests including planted forest), WET class (irrigated land, paddy fields) and HIB class (vegetation re-growth, shrubs, hill's vegetation). The areas of water bodies and built-up (urban or rural settlements) also increased significantly. Thus, from 1990 to 2002, BUP, HIB, WAT and WET area increased respectively 0.7% (44.3 km²), 3.8% (233.6 km²), 1.1% (67.1 km²) and 5.6% (341.2 km²) while FPO, DSB and CLD decreased 9.3% (562 km²), 0.5% (31.5 km²) and 1.5% (92.2 km²). Although the extent of wetlands may change from year to year due to varying precipitation and temperature, the variation in wetland area is also likely due to classification errors. However, the fluctuations in Lowlands classification errors are believed to be related to varying sol humidity levels given the high classification (producer's accuracy about to 97.89% in 1990). The spatial distribution of the assigned categories for each year is shown in Fig. 3.

TABLE III: AREA OF EACH LAND COVER CLASS RESULTING FROM THE CLASSIFIED IMAGES.

Land cover class	Acronym	1990		2002	
		Area (km²)	Rate (%)	Area (km²)	Rate (%)
Built-up	BUP	60.8	1.0	105.1	1.7
Forest-Plantation	FPO	1818.1	30.0	1255.4	20.7
Dunes - sandbank	DSB	141.9	2.3	110.4	1.8
Crop land	CLD	1332.2	21.9	1240.0	20.4
Highland and Bush	HIB	2407.0	39.7	2640.6	43.5
Water bodies	WAT	13.4	0.2	80.5	1.3
Lowland	WET	296.6	4.9	637.8	10.5
Total		6070	100	6076	100

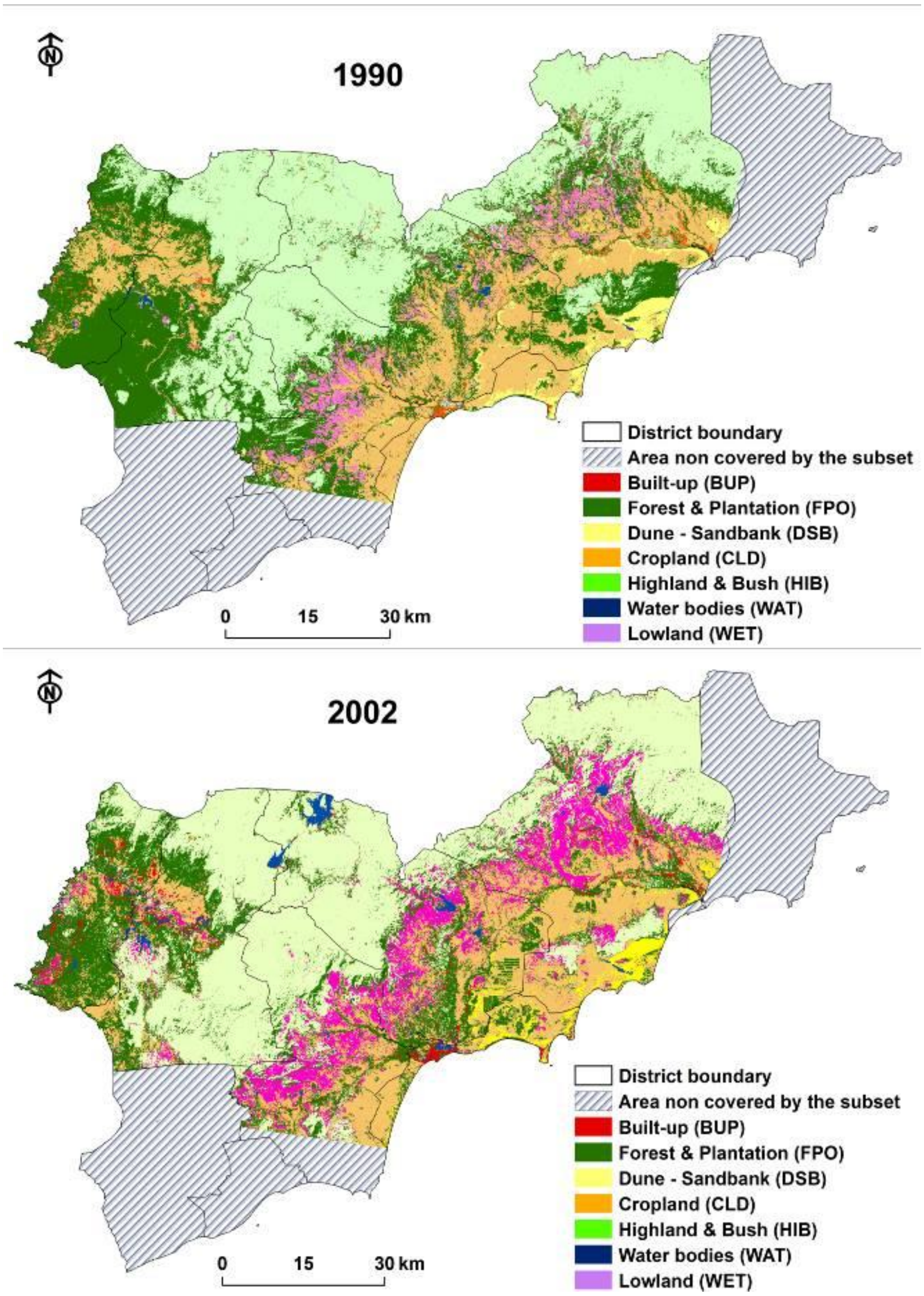

Fig. 3: Land use and land cover maps (1990 and 2002) resulting from the integration of supervised classification and visual interpretation

B. Analysis of change patterns

By constructing a change detection map, the advantages of satellite remote sensing in spatially disaggregating the change statistics can be more fully appreciated. Our results showed over the 12-year span, 3735.5 km² (61.5% of the studied area) were unchanged while changes occurred elsewhere (38.5%) (Table IV). These unchanged areas were mainly composed by HIB (34%), CLD (12.7%) FPO (11%) and WET class (2.2%). In order to examine more specifically areas where changes affected more than 5 km², a table showing combinations of ''*from–to*'' change has been gathered (Table V). The selected results represented 99% of the major changes that occurred during the studied period and the spatial distribution of the resulting conversion classes is shown in Fig. 4.

TABLE IV: AREA AND PERCENTAGE OF CHANGE IN EACH LULC CLASS AND ANNUAL RATE OF CHANGE BETWEEN THE DIFFERENT DATES

LULC class	Districts included						Total change (km²)	Rate (1990-2002)
	Bac Binh	Duc Linh	Ham Thuan Bac	Ham Thuan Nam	Phan Thiet	Tanh Linh		
BUP	17.7	29.1	13.5	6.3	6.2	17.0	89.9	1.5
FPO	149.2	78.1	162.8	77.3	37.6	83.6	588.6	9.7
DSB	14.2	0.1	9.4	0.5	10.5	0.3	35.1	0.6
CLD	187.7	36.6	92.7	68.9	18.4	65.4	469.6	7.7
HIB	108.8	54.6	64.0	94.8	1.2	252.5	575.9	9.5
WAT	10.9	7.9	27.0	2.2	3.6	18.0	69.6	1.1
WET	204.2	16.2	130.3	118.5	3.4	33.1	505.7	8.3
Changed area (km²)	692.7	222.8	499.7	368.5	80.8	469.9	2334.4	38.5
Unchanged area (km²)	1169,0	323,3	845,2	536,1	130,9	731,0	3735,5	61,5
District area (km²)	1861.7	546.1	1344.9	904.6	211.7	1200.9		100

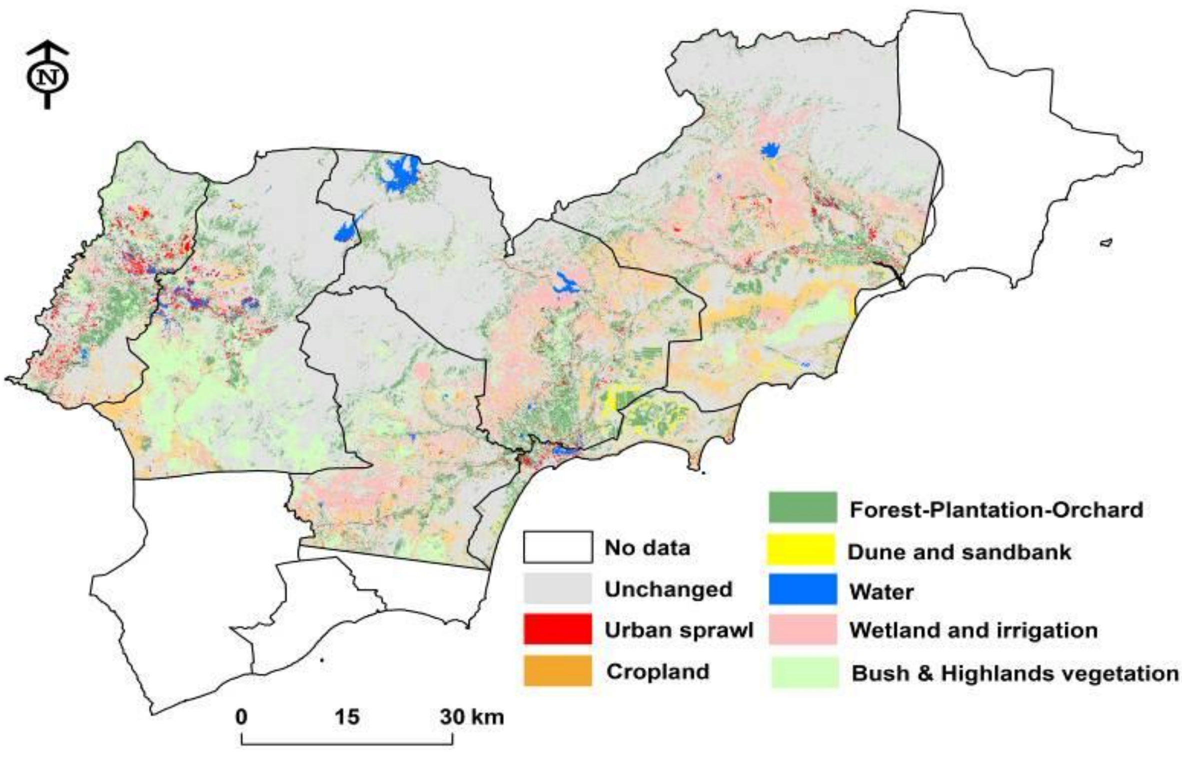

Fig. 4: Change detection map for the studied area (spatial extends of converted classes are highlighted).

TABLE V: AREA AND PERCENTAGE OF CHANGE IN EACH LULC CLASS AND ANNUAL RATE OF CHANGE BETWEEN 1990 AND 2002

Change class		Districts and city affected by changes						Total area (km²)	Change rate (%)	
From	To	Bac Binh	Duc Linh	Ham Thuan Bac	Ham Thuan Nam	Phan Thiet	Tanh Linh			
FPO	HIB	91.3	46.6	40.6	76.4	0.5	237.5	492.8	21.1	
	WET	136.2	8.1	75.6	82.7	2.0	20.1	324.6	13.9	
	CLD	98.3	34.8	57.7	30.3	2.4	58.4	282.0	12.1	49.1
	BUP	4.5	15.6	3.6	2.0	1.5	6.1	33.4	1.4	
	WAT	2.3	2.7	4.6	0.8	0.2	3.9	14.4	0.6	
CLD	FPO	57.6	55.9	89.7	36.4	30.5	35.1	305.2	13.1	
	WET	36.3	7.5	36.1	29.7	1.3	9.6	120.5	5.2	
	HIB	9.7	7.1	16.1	5.0	0.6	8.3	46.8	2.0	24.1
	BUP	9.2	12.6	7.2	2.6	2.7	9.4	43.7	1.9	
	DSB	9.7	0	8.4	0.3	10.3	0.0	28.7	1.2	
	WAT	2.3	3.0	3.7	0.5	1.2	6.2	17.0	0.7	
HIB	FPO	70.2	11.7	55.3	27.1	2.0	44.0	210.3	9.0	
	WET	30.9	0.1	18.0	5.4	0	3.2	57.7	2.5	14.4
	CLD	25.0	0.3	5.9	1.3	1.1	4.1	37.7	1.6	
	WAT	3.4	1.4	16.7	0.3	1.5	6.7	30.0	1.3	
WET	CLD	30.4	0.6	19.2	33.7	0.9	1.3	86.1	3.7	
	FPO	8.9	2.8	8.5	10.2	0.2	2.8	33.5	1.4	
	HIB	6.9	0.4	6.5	13.2	0.1	6.2	33.3	1.4	7.0
	BUP	2.5	0.5	0.9	1.4	0.1	0.4	5.8	0.2	
	WAT	1.9	0.7	1.6	0.6	0.2	0.4	5.5	0.2	
DSB	CLD	29.7	0.2	5.8	1.7	13.2	0.2	50.7	2.2	
	FPO	4.7	0.8	2.4	0.5	3.6	0.4	12.4	0.5	2.7
BUP	FPO	7.8	6.4	6.7	3.2	1.2	1.1	26.4	1.1	
	CLD	4.2	0.7	3.5	2.0	0.8	1.3	12.5	0.5	1.7
Total (km²)		683.9	220.5	494.5	367.0	78.1	466.8	2310.9	99.0	99.0

In 21.1% of the cases the change was ‘‘Forest to wild-land with spare vegetation” and approximately 14% was “forest to irrigated agriculture’’ change. Table 5 also reveals that residential uses comprise over half the cases that changed to urban. Relatively rare and unlikely types of conversions, such as agriculture to forest, and then to urban uses and forest to agriculture, and then to urban, totaling 5%, are assumed to largely be classification errors. The spatial interpretation of these results indicates that urban increases (BUP) mainly came from conversion of FPO, CLD and WET classes (representing 80.2% of the change rate). Overall, 82.8 km² of built-up was converted from forests and agricultural land (rainfed: CLD and irrigated: WET), while at the same time, 39 km² of urban or rural settlement land was converted to forest and cropland. These changes may seem to be classification errors, but forested areas are among some of the most sought after areas for developing new settlements. Streets, roads and rural tracks were generally classified as urban, but when urban tree canopies along the streets grow and expand, the associated pixels may be classified as forest. Also, the results of image interpretation and classification together with an access to archives on agricultural policies indicated that an intensive development programs have been implemented in the study area during the last two decades [29]. These programs included land reclamation and the expansion of irrigated culture areas, as well as the establishment of rural village communities into foothills of mountains previously considered as wild-lands or unused lands. Further GIS analysis revealed a strong relationship between new development and proximity to roads. Almost half (49%) of the Built-up development detected in our classifications occurred within 2 km of main roads and rural tracks, and 35% was between 2 and 4 km. Duc Linh, Tanh Linh, Bac Binh and Ham Thuan Bac are the districts where this urban sprawl is the most remarkable during the studied (1990–2002). All of these (bio)

physical changes within the setting of the region's ecosystems reflect the dynamics of human impacts on the study area.

Cropland (CLD) area declined from 1332.2 km² in 1990 to 1240 km² in 2002. This class was mainly changed into planted vegetation (FPO), irrigated land (WET), Brush (HIB) and Built-up accounting for almost 22% of the total occurred changes. Ham Thuan Bac, Bac Binh and Duc Linh are the districts mainly affected by this kind of conversion.

The area of water bodies plays an important role in development of aquaculture for the study area. During the studied period, water body increased by about 6.5 times of the original area. Water occupied 13.2 km² (0.2% of total studied area) in 1990 and finally reached 80.5 km² (1.3%) in 2002. This was converted mainly from natural forest, planted vegetation (FPO), cropland (CLD), bush (HIB), lowland and paddy fields (WET). The most plausible explanation of this conversion into water bodies was mainly due to hydroelectric dam constructions (Bac Binh, Ham Thuan Bac Tanh Linh districts) and also probably to expansion of small reservoirs for irrigation.

Lowland with irrigated agriculture fields (WET) also showed increasing trends in size from 1990 to 2002. The area of paddy fields was only 296 km² (4.9% of total area) in 1990, increased to 637 km² (10.5%) in 2002. This class extends on the foothill of the mountain chains and chiefly into hilly valleys following geographical orientation of the alluvial basins. This was converted mainly from natural forests (FPO), cropland (CLD) and HIB class vegetation and some from water bodies and mixed orchard.

Even though many hectares of natural forests were converted into planted vegetation and other agricultural land from 1990 to 2002, there was also conversion from barren lands to cropland and forests. This change occurred on dune and sandbak (DSB) class where decrease occurred from 141.9 km² to 110.4 km². These areas are used primarily for horticultural activity, with only very small areas of rain-fed rice grown in low-lying areas. Another explanation of this reverse trend is that there was a wide application of vetiver grass (*Vetiveria zizanioides*) planting that has real impact on land stabilization / reclamation. Although the concept of using vetiver for various applications has only been introduced into Vietnam in 1999 [17] vetiver has become widely known throughout the country with numerous successful applications for natural disaster mitigation and environmental protection. Typical examples include road batter stability enhancement, erosion / flood control of embankments, dykes, riverbanks, sand dune fixation. However, we can unfortunately notice a persistence of sandbank and dune roving, resulting probably of land degradation in Bac Binh (9.7 km²), Ham Thuan Bac (8.4 km²) districts and Phan Thiet (10.3 km²).

IV. DISCUSSION

Within a few years, Vietnam was not only producing enough food for domestic consumption but became one of the world's leading rice exporters [29]. Unfortunately, in some regions, farmers profited much less from the reforms than others. There is wide disparity in regional development trends following land reforms partly because the reforms were not implemented homogeneously throughout the country and also because of the tremendous diversity of natural and human environments they were applied to. This resulted in different ways of interpreting local success or failure of the land policy to lift marginal farmers out of poverty or reverse land degradation trends [30]. Land use in the study area has undergone dramatic change and was impacted by human resource development. Our findings from the satellite-image interpretation suggest a decrease in closed canopy forest due to conversion into rain-fed and irrigated agricultural land. Open canopy forest cover (including bush and fallows) increased during the 1990s approximately by 4%, mainly due to the natural regeneration of mixed grassland. Followed fields formerly used for shifting cultivation may be largely abandoned during the last decade and regenerated to become open canopy secondary forest. Overall, rain-fed mixed agriculture decreased slightly in the 1990s, as the reduction in shifting cultivation was compensated by an expansion of irrigate cropping area. Water bodies also showed increasing areas from 1990 to 2002, but the overall change was not large for these types. Increases in irrigated fields and water bodies represent the possibility of increasing aquaculture or increasing the suitability of the study area for future aquaculture. It has been demonstrated that in terms of economic returns, aquaculture often gives higher returns than rice culture [31]. However, the decision to convert paddy fields to fish ponds is often related to food security and social aspects. In order to maintain a balance between social and economic aspects, integrated rice-fish culture systems should be promoted [32]. Outreach and extension services to local farmers should be enhanced, and extension information should be produced. Over time, agricultural production became more locally concentrated. These changes in land use suggested that shifting cultivation as the traditional farming system practiced by the population in the research area almost entirely disappeared in its traditional form during the last decade. On the other hand, provincial and district authorities generally lack of manpower, resources, capacity and experience to put into practice consistent and participative land-use policy. They should be allocated more resources and more time to implement a policy that would satisfy the different objectives expressed at different hierarchical levels. Experience has shown that promoting the links between land allocation and subsequent extension activities is indispensable for close interaction with farmers and when directing research to development activities that are relevant and acceptable to local people. In a broader context, some studies are summarizing the general factors that promote a successful transition towards sustainable management of natural resources [33]. Three broad groups of factors that have been identified: information regarding the state of the resources and their degradation, motivations to search for solutions, and capacity to implement effective solutions. Environmental degradation of places with which people maintain an emotional connection can lead these people to adopt a more ecological worldview and to reassess their involvement in conservation activities ([34]; [35]). The perception of the capacity to predict and improve the state of the environment also mediates behavior [36].

Overall, natural forests declined in area, while the most dramatic increase was for irrigated fields. During the 12-years span, we can observe a pathway of land expansion into previously uncultivated areas. At the same time, due to market development, agricultural intensification is concentrated in the most suitable regions. Large areas of land marginally suitable for agriculture are therefore abandoned and left to forest regeneration. In this forest scarcity path, political and economic changes will arise as a response to the growing scarcity of forest products and decrease in the provision of ecosystem services following. We think it is possible that intensification of agriculture combined with the (enforced) protection of forested areas can reduce the pressure on forested land, and slow down or even halt the expansion of agricultural land if coupled with the right policy instruments.

Concerning the undesirable changes in land use and the need for more sustainable development in the region, we propose that the government should reconsider the policies applied to the region of the study area, as well as the policies of the surrounding regions that may directly or indirectly affect the development of the study area. For instance, the modeling power of GIS to evaluate land suitability for development of agricultural activities chiefly in the basins and watershed ponds must be developed. It is known that sustainable agricultural systems are based on managing soils according to their capabilities and environmental constraints. According to this, GIS information could allow the landholder to move from regional or district land suitability recommendations and land management practices to soil-specific management, thus improving productivity, profitability and sustainability. An economic component should be incorporated into GIS applications to determine economic suitability in addition to physical suitability. This would reduce the cost of the rehabilitation of degraded and barren areas and, consequently, facilitate the adoption of more ecological worldview and less vulnerable of land conservation activities. In addition, to lessen the degree of degradation, the free water areas should be reduced, or at least consolidated. This could be achieved through the improvement of the drainage network system in the waterlogged areas and by preventing drainage water from overflowing into lowlands. These actions could protect cropland areas from soil salinization and, consequently, increase agricultural production, especially in order to adapt to future impacts of climate change [37].

V. CONCLUSION

The results demonstrate that Landsat classifications can be used to produce accurate landscape change maps and statistics. General patterns and trends of land use change in Binh Thuan Province were evaluated by: (1) classifying the amount of land in six districts area that was converted from forest, agricultural, and wetland use to urban use during three periods from 1990 to 2002; (2) comparing the results of Landsat-derived statistics; (3) quantitatively assessing the accuracy of change detection maps; and (4) analyzing the major land use change patterns. In addition to the generation of information tied to geographic coordinates (i.e., maps), statistics quantifying the magnitude of change, and ‘‘from–to’’ information can be readily derived from the classifications. The results quantify the land cover change patterns in Binh Thuan Province and demonstrate the potential of multitemporal Landsat data to provide an accurate, economical means to map and analyze changes in land cover over time that can be used as inputs to land management and policy decisions. While it is a site specific comparison, it is also useful to compare the Landsat classification estimates to another, independent inventory such as the Natural Resources Inventory. Perfect agreement would not be expected due to the differences in the dates of data collection, as well as differences in classes between the two surveys.

ACKNOWLEDGEMENT

The research is funded by BELSPO (Belgian Science Policy Office) and executed in the framework of a research project entitled “Impact of Global Climate Change and Desertification on the Environment and Society in Southern Central Vietnam-Case Study in Binh Thuan Province”.

REFERENCES

[1] A. Singh, Digital change detection techniques using remotely sensed data. International Journal of Remote Sensing, 10(6), 1989, pp. 989– 1003.

[2] J. Imbernon, Changes in agricultural practice and landscape over a 60-year period in North Lampung, Sumatra. Agriculture, Ecosystems and Environment, 76 (1), 1999, pp. 61-66.

[3] P. Serra, X.Pons and D.Saurí, Land-cover and land-use change in a Mediterranean landscape: a spatial analysis of driving forces integrating biophysical and human factors. Applied Geography, 28(3), 2008, pp. 189-209.

[4] S. B.Adamo and K. A. Crews-Meyer, Aridity and desertification: exploring environmental hazards in Jáchal, Argentina. Applied Geography, 26(1), 2006, pp. 61-85.

[5] J. Gao and Y. Liu, Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. International Journal of Applied Earth Observation and Geoinformation, 12(1), 2010, pp. 9-16.

[6] F.Yuan, K. E. Sawaya, B.Loeffelholz, and M. E. Bauer, Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multitemporal Landsat remote sensing. Remote Sensing of Environment, 98 (2-3), 2005, 317-328.

[7] J.J. Schulz, L.Cayuela, C.Echeverria, J. Salas, and J. M. Rey Benayas, Monitoring land cover change of the dryland forest landscape of Central Chile (1975-2008). Applied Geography, 30(3), 2010, pp. 436-447.

[8] M. S.Wyman and T. V. Stein, Modeling social and land-use/land-cover change data to assess drivers of smallholder deforestation in Belize. Applied Geography, 30(3), 2010, pp.329-342.

[9] H. Nagendra, S. Pareeth, and R. Ghate, People within parks-forest villages, land-cover change and landscape fragmentation in the Tadoba Andhari Tiger Reserve, India. Applied Geography, 26(2), 2006, pp.96-112

[10] D. Lu, Mausel, P. E. Brondizio and E.Moran, Change detection techniques. International Journal of Remote Sensing, 25(12), 2004, pp. 2365-2407.

[11] X. Chen, L. Vierling and D. Deering, A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. Remote Sensing of Environment, 98(1), 2005, pp. 63-79.

[12] X.Yang and C. Lo, Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. International Journal of Remote Sensing, 23(9), 2002, pp.1775-1798.

[13] D.Lu, P. Mausel, E. Brondizio and & E.Moran, Change detection techniques. International Journal of Remote Sensing, 25(12), 2004, pp. 2365-2407.

[14] P. Coppin, I. Jonckheere, K.Nackaerts, B. Muys, and E. Lambin, Digital change detection methods in ecosystem monitoring: a review. International Journal of Remote Sensing, 25(9), 2004, pp. 1565-1596.

[15] W. Zhou, A. Troy, and M. Grove, Object-based land cover classification and change analysis in the Baltimore metropolitan area using multitemporal high resolution remote sensing data. Sensors, 8(3), 2008, pp. 1613-1636.

[16] M. A. Wulder, J. C. White, S. N. Goward, J. G. Masek, J. R. Irons, and M. Herold, Landsat continuity: Issues and opportunities for land cover monitoring. Remote Sensing of Environment, 112(3), 2008, pp. 955-969.

[17] Socialist Republic of Vietnam (SRV) General Statistical Office (GSO), Viet Nam Catalogue of the Administrative Divisions, Statistical Publishing House, 1994, Hanoi.

[18] http://glovis.usgs.gov

[19] The ENVI software package is described on the web site: http://www.ittvis.com/ [20] J.Gao and Y. Liu, Determination of land degradation causes in Tongyu County, Northeast China via land cover change detection. International Journal of Applied Earth Observation and Geoinformation, 12(1), 2010, pp. 9-16.

[21] J. R.Anderson, E. E. Hardy, J. T. Roach and W. E Witmer, A land use and land cover classification system for use with remote sensing data. Reston, Virginia’ U.S. Geological Survey, USGS professional paper 964, 1976, pp. 138– 145.

[22] M. E Bauer, C. A. Sersland, and S. J. Steinberg, Land cover classification of the Twin Cities metropolitan area with Landsat TM data. Proceedings, Pecora 13 symposium. August 20–22, Sioux Falls, South Dakota, 1996, pp. 138– 145.

[23] K.T. Le, T. H. Nguyen, D. D. Nguyen, A. Konda, K. Kajiwara, and Y. Honda, Automated Classification for Vegetation of Ninh Thuan, Binh Thuan and Lam Dong Provinces in Vietnam by Simulated GLI Data from Landsat TM. Journal of the Japan Society of Photogrammetry and Remote Sensing, 41 (6), 2002, pp. 4-13.

[24] Tran Thị An and Vu Anh Tuan, Application of Remote Sensing in Land Use Change Pattern in Da Nang City, Vietnam. Proceedings of the International Conference on GeoInformatics for Spatial-Infrastructure Development in Earth & Allied Sciences (GIS-IDEAS), Hanoi, Vietnam, 9-11 December 2010.

[25] Ding Yan, Christopher D. Elvidge and Ross S. Lunetta, "Survey of Multispectral Methods for Land Cover Change Analysis." Remote Sensing Change Detection Environmental Monitoring Methods and Applications 2, 1998, pp. 22-23

[26] G. M. Foody, Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80(1), 2002, pp. 185-201.

[27] J. R. Jensen, Digital change detection. Introductory digital image processing: A remote sensing perspective, New Jersey' Prentice-Hall, 2004, pp. 467– 494.

[28] P. Coppin, I. Jonckheere, K.Nackaerts, B. Muys & E.Lambin, Digital change detection methods in ecosystem monitoring: a review. International Journal of Remote Sensing, 25(9), 2004, pp.. 1565-1596.

[29] World Bank (WB), Asian Development Bank (ADB), Food and Agriculture Organisation (FAO), United Nations. Development Program (UNDP), NGO Water Resources Group, Institute of Water Resources Planning, Vietnam Water Resources Sector Review, Main Report, 1996., World Bank, Washington D.C

[30] O. Ducourtieux, and J.-C. Castella, 2006. Land reforms and impact on land use in the uplands of Vietnam and Laos: Environmental protection or poverty alleviation? Colloque international "Les frontières de la question foncière – At the frontier of land issues", Montpellier, 2006. 22 p.

[31] M.A. Salam, L.G. Ross, and C.M.M. Beveridge, A comparison of development opportunities for crab and shrimp aquaculture in southern Bangladesh, using GIS modelling. Aquaculture, 220, 2003, pp. 477–494.

[32] Gregory, G. and H. Guttman, Developing appropriate interventions for rice-fish cultures. In: P. Edwards, D.C. Little, and H. Demaine (Editors), Rural Aquaculture. CABI Publishing, Wallingford, United Kingdom, 2002, pp. 15–28.

[33] P. Raquez and E.F. Lambin, Conditions for a sustainable land use: case study evidence. Journal of Land Use Science, 1(2-4), 2007, pp. 109–125.

[34] B.K. Marshall, J.S Picou and C.A. Bevc, Ecological disaster as contextual transformation. Environmental values in a Renewable Resource Community. Environment and Behavior, 37 (5), 2005, pp.706-728.

[35] R. Rogan, M. O'Connor and P. Horwitz, Nowhere to hide: Awareness and perceptions of environmental change, and their influences on relationships with place. Journal of Environmental Psychology, 25, 2005, pp.147-158.

[36] E. Ostrom, Self-Governance and Forest Resources. Technical report, CIFOR Occasional Paper N.20, Bogor, 1999.

[37] S. Doutreloup, M. Erpicum, X. Fettweis, and P. Ozer, "Analysis of the past (1970-1999) and future (2046-2065 and 2081-2100) evolutions of precipitation and temperature, in the Province of Binh Thuan, South East Vietnam, based on IPCC models", paper presented at the 1st International Conference on Energy, Environment and Climate Changes, Ho Chi Minh City, Vietnam, 27th and 28th August, 2011. Available at http://hdl.handle.net/2268/96759

Is the fishing village of Phan Thiet victim of climate change? Reflexions on the perception of the impacts of 'global warming'.[1]

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Abstract— *Warming of the climate system is unequivocal, as it is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gases concentrations. In this framework, sea level rise is virtually certain. This will impact ecosystems, coastal areas, human health, and economies.*

Since current (2000-2010) CO_2 *emissions are well above the worst Intergovernmental Panel on Climate Change (IPCC) scenario (A1FI) projecting a global average surface warming of 2.4 to 6.4°C and a sea level rise of 26 to 59 cm at 2090-2099 relative to 1990-1999, Vietnam could be one of the most affected countries with its 3,200 km of shorelines.*

In January 2009, international broadcast news have relayed the information that 27 houses located on the southern coast of Vietnam, in the fishing village of Phan Thiet 200 kilometers east of Ho Chi Minh City, have collapsed and that another hundred buildings were also threatened of destruction. According to experts, this event was definitely one of the consequences of global warming.

This article shows, using the multi dates in Google Earth, that this assumption is not correct and highlights the real causes of this rapid and inevitable retreat of the coastline in this village, namely the mismanagement of natural resources, the lack of land use planning and the nonexistence of policies focused on natural hazard management in the uncontrolled construction the seaside resort of Mui Ne, a few kilometers east.

Keywords: climate change, perception, beach erosion, tourism, Binh Thuan, Vietnam

I. INTRODUCTION

We live in a constantly changing world characterized by an improved knowledge of past, current and future trends of several indicators. We now have a better understanding of how these global numbers will interact and what will be their impacts on environment, economy, trade, international stability, food security, etc.

In recent years, the world population has dramatically increased, rising from 3.7 billion in 1971 to 7.0 billion currently (2011) and is projected to reach 9.1 billion by 2050. Forty years ago, 64% of the population was living in rural areas. This proportion fell to 50% today and will decline to 30% by 2050 [1]. So the structure of the population changes, not only in absolute number but also in its way of life. In the same time, energy needs intensify in a globalising world. Yet, from 5,500 million tonnes of oil equivalent (Mtoe) in 1971, the world primary energy demand increased up to 12,300 Mtoe in 2008, which represents a 26% increase in energy demand per capita in near four decades. With a major problem: fossil fuels (oil, coal and gas) are the dominant energy sources (82%) and their proportion in the global energy offer should

[1] Paper presented at the *Colloque Géomatique et gestion des risques naturels, 6-8 mars 2012, Oujda, Maroc.*

remain unchanged by 2035 [2-4]. Although this allows an unprecedented human development in history, the question is to know if this development is sustainable with regards to the erosion of biodiversity, forests resources decline, advancing desertification or climate change. The past decade has seen an impressive rise in public awareness of the importance of climate change [5-7] which has become a major issue in corporate, national and global policies. Year after year, large scientific conferences and political negotiations take place all over the world. If the recent scientific understanding of climate change has improved remarkably [8], a spectacular shift in the political process is still awaited [9-10].

The radiative forcing of the climate system is dominated by the long-lived major greenhouse gases (GHGs). Global GHG emissions due to human activities have grown since pre-industrial times. Global atmospheric concentrations of CO_2, CH_4 and N_2O (the three major GHGs) have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years [8]. The atmospheric concentrations of CO_2 (390 ppm in 2010) [11-12] exceed by far the natural range over the last 800,000 years [10,13]. Global increases in CO_2 concentrations are due primarily to fossil fuel (coal, oil and gas) use, with land-use change (deforestation, decay of biomass, etc) providing another significant but smaller contribution. CO_2 represents 76.7% of the anthropogenic GHG, out of which 59.4% are due to fossil fuel combustion and 17.3% due to land-use change. The analysis of the recent anthropogenic global carbon dioxide budget is extremely interesting.

Recent increase in atmospheric CO_2 is driven by fossil fuel burning since 9.1 GtC were emitted in 2010, compared to the 7.7 GtC/y during the 2000-2009 period and to the 6.4 GtC/y recorded during the 1990s. This increase is extremely important: +49% from 1990 to 2010. In addition, land-use change contributed to 0.9 GtC/y in 2010. These 10.0 GtC released in 2010 are largely sufficient to exceed the balancing effect of natural sinks: land (2.6 GtC) and oceans (2.4 GtC). As a result, 50% of the CO_2 released currently remains into the atmosphere, far more than the 39% in the 1990s [11,14].

There is very high confidence that the global average net effect of human activities since 1750 has been a warming. Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is extremely unlikely that global climate change of the past 50 years can be explained without external forcing and very likely that it is not due to known natural causes alone. During this period, the sum of solar and volcanic forcings would likely have produced cooling, not warming [8].

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

Fig. 1 shows the time series of the combined global land and marine surface temperature record from 1850 to 2010. According to the method of calculation used by the Climate Research Unit of the University of East Anglia [15], the year 2010 was the equal third warmest on record (with 2003), exceeded by 1998 and 2005. The years 2003, 2005 and 2010 are only distinguishable in the third decimal place. The period 2001-2010 (0.44°C above 1961-90 mean) was 0.20°C warmer than the 1991-2000 decade (0.24°C above 1961-90 mean). The warmest year of the entire series has been 1998, with a temperature of 0.55°C above the 1961-90 mean. After 1998, the next nine warmest years in the series are all in the decade 2001-2010. During this decade, only 2008 is not in the ten warmest years. Even though 2008 was the coldest year of the 21st century it was still the 12th warmest year of the whole record.

Increases in sea level are consistent with warming. Global average sea level rose at an average rate of 1.3 mm/y since 1870, then of 1.8 mm/y over 1961 to 2003 and of about 3.4 mm/y from 1993 to 2008 [8,16]. Since 1993, approximately 30% of the rate of sea level rise is due to ocean thermal expansion in response to ocean warming. Mass loss in mountain glaciers and ice sheets accounts for approximately another 55% [16].

Observed decreases in snow and ice extent are also consistent with warming. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7% per decade, with larger decreases in summer of 7.4% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15% [8].

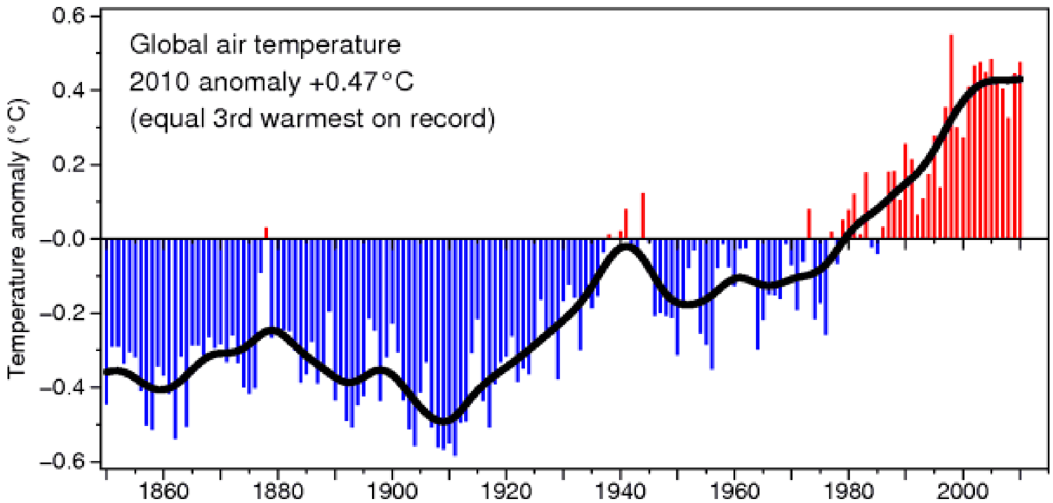


Figure 1. Global air temperature from 1850 to 2010 [15].

At continental, regional and ocean basin scales, numerous long term changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has likely increased since the 1970s [8].

Some extreme weather events have changed in frequency and/or intensity over the last 50 years. Yet, it is very likely that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. It is also likely that heat waves have become more frequent over most land areas, that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas, and that the incidence of extreme high sea level has increased at a broad range of sites worldwide since 1975 [8].

II. FUTURE IMPACTS OF CLIMATE CHANGE

Since we know that climate change is linked to GHG emissions, six scenarios to predict future GHG emissions [8] have been created by the Intergovernmental Panel on Climate Change (IPCC) based on population and economic growth, types of technologies, energy demand, etc. (Fig. 2):

- The B1 scenario believes that the world will be more integrated and more ecologically friendly. It is characterized by: a rapid economic growth but with rapid changes towards a service and information economy; a population rising to 9 billion in 2050 and then declining; reductions in material intensity and the introduction of clean and resource efficient technologies; and an emphasis on global solutions to economic, social and environmental stability. With this scenario which is the most optimistic about the future behaviour of our societies, best global temperature change estimate between 1980-1999 and 2090-2099 is +1.8°C, with a likely range of +1.1°C to 2.9°C.
- The B2 scenario expects a world more divided but more ecologically friendly. It is characterized by a continuously increasing population (but at a slower rate than in A2); an emphasis on local rather than global solutions to economic, environmental and social stability; intermediate levels of economic development; and a less rapid and more fragmented technological change than in A1 and B1. This scenario would lead to a temperature change of +2.4 [1.4 to 3.8]°C between 1980-1999 and 2090-2099.
- The A1 scenarios bet on a more integrated world and is characterized by: a rapid economic growth; a global population that reaches 9 billion in 2050 and then gradually declines; the quick spread of new and efficient technologies; a convergent world income and way of life converge between regions; and extensive social and cultural interactions worldwide. Three sub scenarios can be

distinguished based on their technological emphasis: A1T with a prominence of non-fossil energy sources; A1B with a balanced weight of all energy sources; and A1FI that would be fossil intensive (the worst case scenario). With these scenarios, best global temperature change estimate between 1980-1999 and 2090-2099 are +2.4 [1.4 to 3.8]°C, +2.8 [1.7 to 4.4]°C, and +4.0 [2.4 to 6.4]°C, respectively.

- The A2 scenario imagines a more divided world. It is characterized by: a world of independently operating, self-reliant nations, a regionally oriented economic development, a continuously increasing population, a slower and more fragmented technological changes and improvements to per capita income. With this scenario, best global temperature change estimate between 1980-1999 and 2090-2099 is +3.4 [2.0 to 5.4]°C.

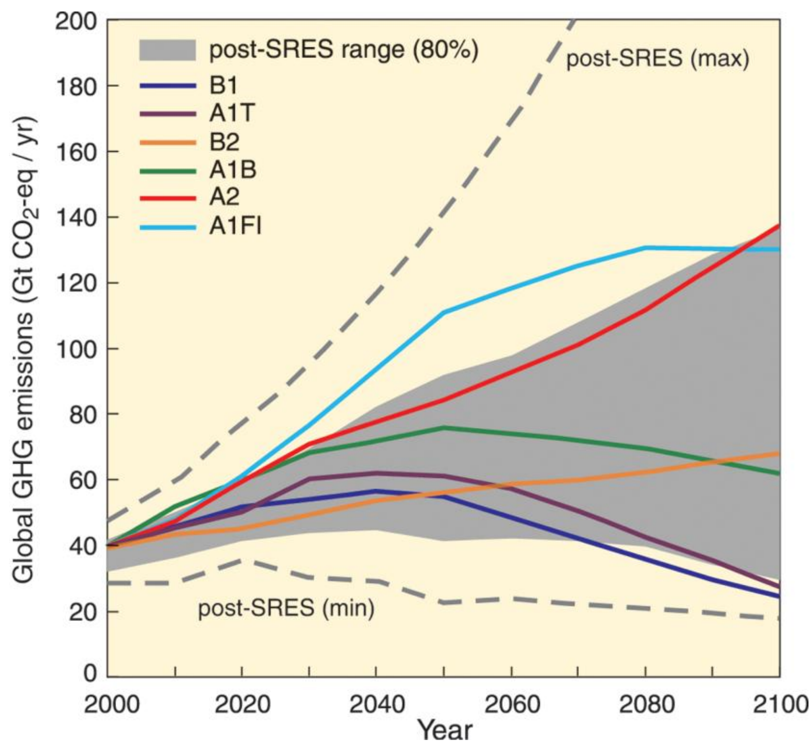


Figure 2. Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative scenarios (coloured lines). The emissions include CO_2, CH_4, N_2O and F-gases. See [8] for additional details.

For the next two decades a warming of about 0.2°C per decade is projected for a range of IPCC emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios. Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century.

The latest IPCC report predicts, by the mid- to late 21st century, a virtually certain sea-level rise, decrease of cold nights and increase in hot days and nights; a very likely increase in warm spells, heat waves and heavy precipitation; and a likely increase in intense tropical cyclone activity and in areas affected by droughts. Without taking into account any changes or developments in adaptive capacity, the major projected impacts of these changes are [8]:

- Agriculture, forestry and ecosystems: damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils; etc.

- Water resources: adverse effects on quality of surface and groundwater; contamination of water supply; and water stress;
- Human health: increased risk of malnutrition, deaths, injuries and infectious, respiratory and skin diseases; and migration-related health effects;
- Industry, settlement and society: disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property; and population migration [8].

But many uncertainties remain about the impact of the future climate. For example, the latest IPCC report projected a global sea level rise of 18 to 59 cm from 1990 to the 2090s, plus an unspecified amount that could come from changes in the large ice sheets covering Greenland and Antarctica [8]. But since 1993, sea level has risen about 80 per cent faster, at 3.4 mm/y, than the average IPCC model projection of 1.9 mm/y [16]. IPCC's projections seem therefore obsolete. Yet, as presented in Fig. 3, a number of recent studies taking the semi-empirical approach have predicted much higher sea level rise for the 21st century than the IPCC, exceeding one meter if greenhouse gas emissions continue to escalate [17-18].

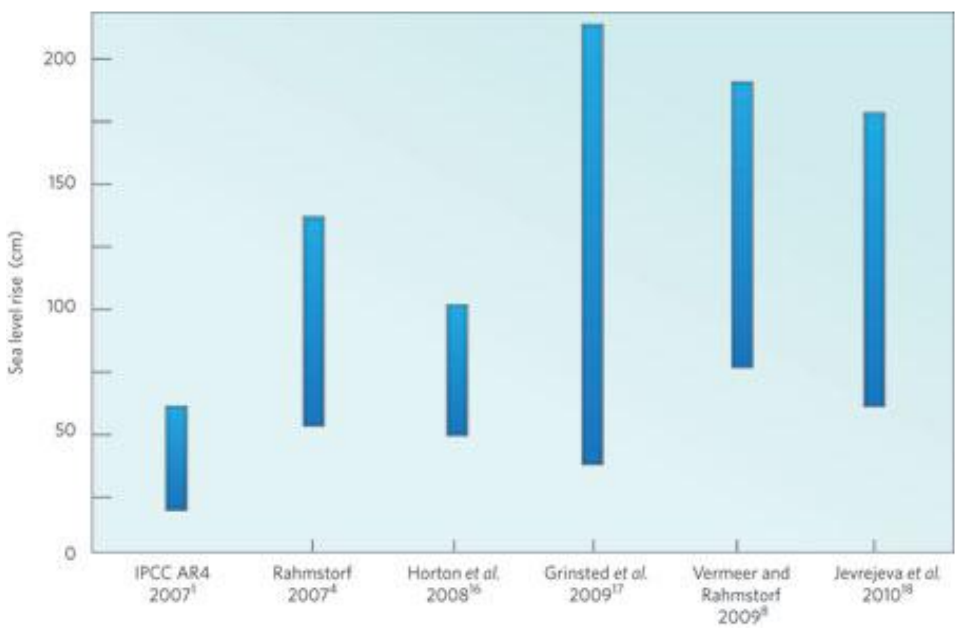


Figure 3. Estimates for 21st century sea level rise from semi-empirical models as compared to the IPCC Fourth Assessment Report [8]. For exact definitions of the time periods and emissions scenarios considered, see [17].

Such uncertainty on future sea level rise is extremely important since its immediate effect is submergence and increased flooding of coastal land, as well as saltwater intrusion of surface waters. Longer-term effects also occur as the coast adjusts to the new conditions, including increased erosion and saltwater intrusion into groundwater. Coastal wetlands such as saltmarshes and mangroves will also decline unless they have a sufficient sediment supply to keep pace with sea level rise, which is rarely the case. These physical impacts in turn have both direct and indirect socioeconomic impacts, which appear to be devastatingly negative. These impacts will even be worst in areas already affected by subsidence such as the Mekong and Red River deltas in Vietnam [18].

Flooding of coastal land and increasing shoreline erosion will very likely cause massive population displacements, as frequently forecasted as one of the most dramatic possible consequences of climate change. Yet, numerous deltas and shorelines have been studied in order to assess impact of sea level rise on agriculture, economy and people potentially affected.

Migrations as an adaptation strategy of the poor will not be restricted to sea level rise impacts but will also be driven by several climate modifications and related environmental degradation such drought, floods, extreme climate events, desertification, etc. In 2008, 20 million persons have been displaced by extreme weather events and this figure is very likely to increase in the next decades. Most widely cited estimates of the so-called climate refugees vary from 200 million to 1 billion people displaced by 2050 because of climate change impacts [19-21]. Three major factors will drive these forced migrations in the future: [i] the increase of climate deregulation affecting [ii] unprepared poor areas with no adaptation strategy to change [iii] in regions characterised by an important demographic growth.

III. WHO IS RESPONSIBLE FOR CLIMATE CHANGE

CO_2 emissions from the burning of fossil fuels are the primary cause of global warming. The early 2000's have known an unexpected rapid economic growth in a globalizing world. Global CO_2 emissions from the burning of fossil fuels have increased at an unpredicted rate [11]. Indeed, Fig. 4 shows that fossil fuel CO_2 emissions during the past decade have been more important than any scenario elaborated from 2000 onwards. Recent emissions are higher than the worst case scenario (A1FI) which is fossil intensive and which would lead to a best global temperature change estimate between 1980-1999 and 2090-2099 of +4.0 [2.4 to 6.4]°C.

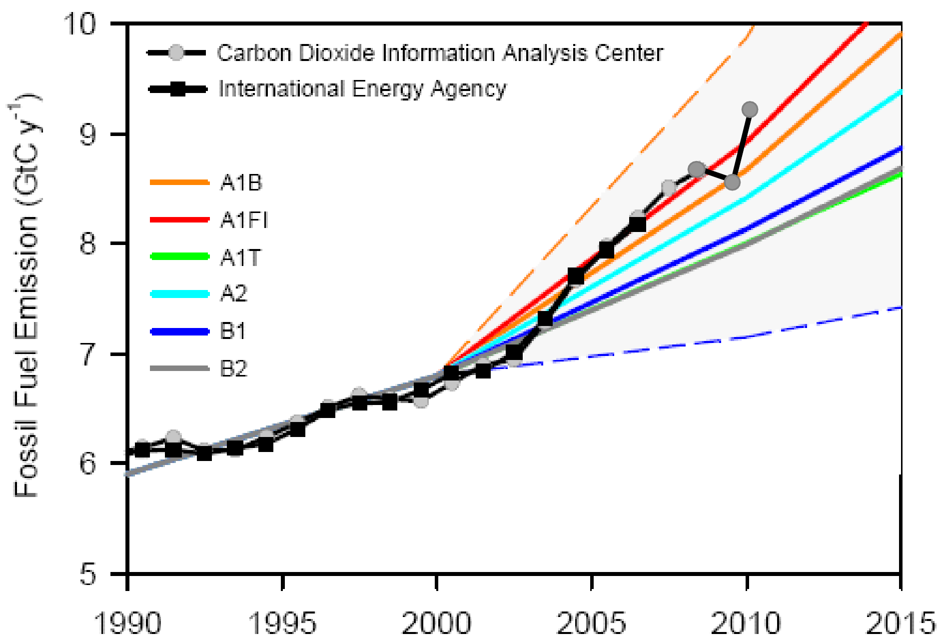
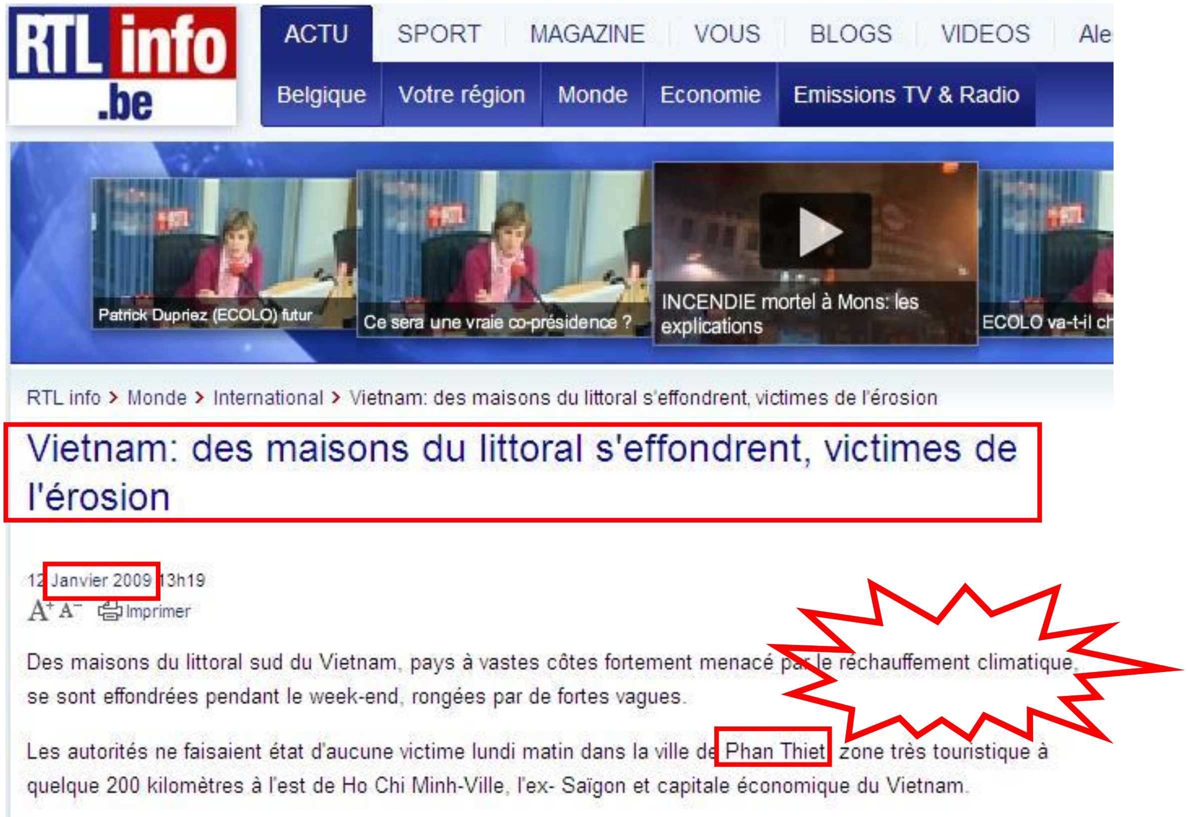


Figure 4. Fossil fuel CO_2 emissions (GtC per year) since 1990 compared with the six IPCC scenarios; adapted from [22].

IV. THE CASE STUDY: A FISHING VILLAGE VICTIM OF CLIMATE CHANGE

During our fieldtrip in the Binh Thuan Province, several people told us that the area was already affected by climate change because of the destruction of a fishing village on the western side of the Phan Thiet city. Searching on the web, it indeed appeared that in January 2009, 27 houses located on the southern coast of Vietnam, in the city of Phan Thiet tourist area 200 kilometers east of Ho Chi Minh City, have collapsed. A hundred other buildings were also threatened of destruction. The international media relayed the following information "hundreds of soldiers, coastguards and volunteers were mobilized to raise sandbags on site and try to limit the damage. Involved: coastal erosion, eroded by strong waves. According to experts, Vietnam and more than 3,200 kilometers of coastline are among the areas most vulnerable to the effects of global warming, whether rising sea levels or increase the frequency of typhoons and floods" [23]. So this is definitely one of the consequences of global warming (Fig. 5).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Vietnam: des maisons du littoral s'effondrent, victimes de l'érosion

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Imprimer

Des maisons du littoral sud du Vietnam, pays à vastes côtes fortement menacé par le réchauffement climatique, se sont effondrées pendant le week-end, rongées par de fortes vagues.

Les autorités ne faisaient état d'aucune victime lundi matin dans la ville de Phan Thiet, zone très touristique à quelque 200 kilomètres à l'est de Ho Chi Minh-Ville, l'ex- Saïgon et capitale économique du Vietnam.

Figure 5. Example of how the international media relayed the information about the destruction – because of 'global warming' – of 27 houses located on the southern coast of Vietnam in a fishing village, east of Phan Thiet [23].

V. WHAT HAPPENNED IN THE FISHING VILLAGE VICTIM OF CLIMATE CHANGE?

In order to understand what really happened to the fishing village located eastern of Phan Thiet, we used multi dates from remote sensing data in Google Earth. Figure 6 presents the global area and Figure 7 shows the littoral sea drift. It appears that the fishing village has suffered from very fast shoreline erosion since the beach totally disappeared in a few years (Fig. 8) and is now roughly protected by large rocks (Fig. 9).

But when having a look a few kilometers on the eastern side, we can notice that many luxury resorts and highly standardized hotels have been being erected along the coastline. The first hotel was built in 1994 (Coco Beach) and since then, all the coastline has been built with direct access to the beach. Mui Ne has modified its space to accommodate Western tourists. Thus, coconut plantations have been felled to make way for coconut trees are no longer part of that office decor on the beach, the bindweed sands were torn to repel sand fleas, sand has been leveled and the hotel facilities have covered the dunes to be in direct contact with the beach. Thus any decor "exotic" that is created to be conform with the representations of Western tourists [24].

The result was known in advance: the fragile coastline equilibrium is broken and sediment balance becomes negative. Between 2006 and 2009, the thirty meters beach has totally disappeared. But since the beach is the rationale of this place, it should be preserved at all costs. Thus, developers have used the construction of groynes of over 100 meters long to recreate long beaches, artificially, that interrupt the longshore sediment as shown in Figures 10 to 12 in front of the of the White Sands Resort (2009) then in front the Romana Resort & Spa (2010). The beach recess in the tourist area is therefore controlled by those groynes and jetties but it results of a displacement of the erosion spots to somewhere further down drift of the shore and causes the disappearance of beaches provoking the collapse of fishermen houses.

Figure 6. Presentation of the study area with the city of Phan Thiet on the western part and three areas of special interest: the fishing village, the Phu Hai Resort area, and the limit of the Western tourist zone.

Figure 7. Main direction of the littoral sea drift.

27 March 2006

10 May 2009

Figure 8. The fishing village, east of Phan Thiet in 2006 and 2009.

Figure 9. The fishing village in 2011 with rocks for protection against erosion.

Figure 10. Evolution of the beach erosion and consecutive construction of jetties for protection, first in front of the White Sands Resort (2009) then in front the Romana Resort & Spa (2010).

Figure 11. Construction of jetties for beach protection, first in front of the White Sands Resort.

Figure 12. View on the jetty for protection in front the Romana Resort & Spa (from its web site: http://www.romanaresort.com.vn).

The main reason of the beach erosion in the area is not likely linked directly to climate change and consequent sea-level rise but is due to mismanagement of natural resources, the lack of land use planning and the nonexistence of policies focused on natural hazard management in the uncontrolled construction the seaside resort of Mui Ne [25;26]. Now, unprotected areas are facing erosion processes as shown in Figures 13 and 14, and beaches are artificially refilled on a daily basis (Fig. 15).

Figure 13. Beach erosion at the limit of the Western resorts.

Figure 14. Seawalls destroyed by erosion processes at the limit of the Western resorts.

Figure 15. Artificial refill of beaches. Sand comes by truck (large arrow on left) then distributed on the beach on a daily basis in order to slow erosion.

VI. CONCLUSION

Current CO_2 emissions are well above the worst Intergovernmental Panel on Climate Change (IPCC) scenario (A1FI) projecting a global average surface warming of 2.4 to 6.4°C and a sea level rise of 26 to 59 cm at 2090-2099 relative to 1990-1999. Therefore, a sea level rise of well above one meter is not unlikely anymore. Vietnam could be one of the most affected countries with its 3,200 km of shorelines. But what we showed in this paper is that the term "climate change" is misused probably because it is easier to blame that than the mismanagement of natural resources, the lack of land use planning and the nonexistence of policies focused on natural hazard management in the uncontrolled construction the seaside resort of Mui Ne. This reflexion about the wrong perception of climate change which may cause several economic problems could be extended to water availability which may not be sufficient to support recent developments of irrigated agriculture. Understanding current problems may help developing adaptation strategies in the next decades.

REFERENCES

[1] FAO, "FaoStats," 2011, http://faostat.fao.org/.

[2] International Energy Agency, World Energy Outlook 2004. OECD/IEA, Paris, France, 2004.

[3] International Energy Agency, World Energy Outlook 2009. OECD/IEA, Paris, France, 2009.

[4] International Energy Agency, World Energy Outlook 2010. OECD/IEA, Paris, France, 2010.

[5] J. Lyytimaki, "Mainstreaming climate policy: The role of media coverage in Finland," Mitig. Adapt. Strateg. Glob. Change, vol. 16, pp. 649-661, 2011, doi: 10.1007/s11027-011-9286-x

[6] Y. Sampei and M. Aoyagi-Usui, "Mass-media coverage, its influence on public awareness of climate-change issues, and implications for Japan's national campaign to reduce greenhouse gas emissions." Glob. Environ. Change, vol. 19, pp. 203-212, 2009, doi:10.1016/j.gloenvcha.2008.10.005

[7] S. Billett, "Dividing climate Change: global warming in the Indian mass media," Climatic Change, vol. 99, pp.1-16, 2010, doi: 10.1007/s10584-009-9605-3

[8] Core Writing Team, R. K. Pachauri, and A. Reisinger, Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 2007.

[9] M. Cozier, "Restoring confidence at the Cancun Climate Change Conference," Greenhouse Gas Sci. Technol., vol. 1, pp. 8–10, 2011, doi: 10.1002/ghg3.010

[10] P. Ozer, "Vague de froid sur la Conférence de Cancun?," La Libre Belgique, Bruxelles, Belgium, pp. 52-53, 2010. http://hdl.handle.net/2268/76872

[11] P. Friedlingstein, R. A. Houghton, G. Marland, J. Hackler, T. A. Boden, et al., "Update on CO_2 emissions," Nature Geosci., vol. 3, pp. 811-812, 2010.

[12] T. Conway and P. Tans, "Trends in atmospheric carbon dioxide", NOAA/ESRL, 2011, www.esrl.noaa.gov/gmd/ccgg/trends/

[13] D. Lüthi, M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, et al., "High-resolution carbon dioxide concentration record 650,000–800,000 years before present," Nature, vol. 453, pp. 379-382, 2008, doi:10.1038/nature06949

[14] Global Carbon Project, "Carbon Budget 2009," 20 January 2011, http://www.globalcarbonproject.org/.

[15] P. Jones, "Global temperature record," January 2011, http://www.cru.uea.ac.uk/cru/info/warming/.

[16] A. Cazenave and W. Llovel, "Contemporary sea level rise," Annu. Rev. Mar. Sci., vol. 2, pp. 145-73, 2010, doi: 10.1146/annurev-marine-120308-081105

[17] S. Rahmstorf, "A new view on sea level rise," Nature Reports Climate Change, vol. 4, pp. 44-45, 2010, doi: doi:10.1038/climate.2010.29

[18] R. J. Nicholls and A. Cazenave, "Sea-level rise and its impact on coastal zones," Science, vol. 328, pp. 1517-1520, 2010, doi: 10.1126/science.1185782.

[19] F. Laczko and C. Aghazarm, Migration, environment and climate change: assessing the evidence. International Organisation for Migration, Geneva, Switzerland, 2009.

[20] Christian Aid, Human tide: The real migration crisis. Christian Aid Report, London, UK, 2007.

[21] N. Myers, “Environmental refugees: a growing phenomenon of the 21st century,” Phil. Trans. R. Soc. Lond. B, vol. 357, pp. 609-613, 2002, doi:10.1098/rstb.2001.0953

[22] C. Le Quéré, M. R. Raupach, J. G. Canadell, G. Marland, L. Bopp, et al., “Trends in the sources and sinks of carbon dioxide,” Nature Geosci., vol. 2, pp. 831-836, 2009.

[23] Vietnam: des maisons du littoral s'effondrent, victimes de l'érosion ». http://www.rtl.be/info/monde/international/209845/vietnam-des-maisons-du-littoral-s-effondrent-victimes-de-l-erosion

[24] Peyvel E., 2008. Mui Ne (Vietnam) : deux approches différenciées de la plage par les touristes occidentaux et domestiques. *Géographie et cultures*, 67 : 79-92.

[25] T.T. Tung, M.J.F. Stive, J. van de Graaff, 2008. Stabilization of tidal inlets along the central coast of vietnam. COPEDEC VII, 2008, Dubai, UAE. Paper N°190.

[26] D. Van To, 2008. The equilibrium stages of headland-bay beaches in the coastal provinces of Vietnam. Proceedings of the fifth anniversary workshop of the marine and coastal engineering faculty, pp. 95-102. http://coastal.wru.edu.vn/papers/2008-11/pdf/11E-Equilibrium%20headland-bay-Dang%20Van%20To.pdf