

Universidad de Costa Rica  
Vicerrectoría de Investigación  
Centro de Investigaciones Geofísicas  
Tels. (506) 2207 5096 / 2207 5320  
Fax. (506) 2234 2703  
Email: [cigefi@cigefi.ucr.ac.cr](mailto:cigefi@cigefi.ucr.ac.cr)



## **Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity**

**PI: Dr. Kam-biu Liu (Louisiana State University)**

**Co-PIs Technical Report**

**Dr. Eric J. Alfaro**

**Dr. Jorge A. Amador**

**Prime Award: CRNII 2050 (NSF Grant No. GEO-0452325)**

**Sub-award: University of Costa Rica (No. 11805)**

**July 2008**

**\*1 Project Title, Project Number, Principal Investigator, Key Words\***

Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity

CRN-2050

**PI:** Kam-biu Liu (Louisiana State University)

**Key words:** paleotempestology, Caribbean, hurricanes, climate change, vulnerability, social impact, extreme events

**\*2 Project Funding\***

The University of Costa Rica (UCR) received from LSU the first project payment the second week of July, 2008. The amount received was 5885 US dollars for each researcher (Co-PIs Alfaro and Amador, see column “Ingreso” in the financial report given by the UCR Foundation, FUNDEVI). Because of the delay in receiving this money, we are still following the University of Costa Rica procedures to use this money for the project activities.

The national component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The title of this component is “Estudio y comparación histórica del impacto de ciclones tropicales en Centroamérica y el Caribe”, PI Dr. Eric J. Alfaro and Co-PI Dr. Jorge A. Amador. The grant number is V.I. 805-A7-002. During 2007 we received from the University of Costa Rica 264912 Costa Rican colones (about 475.94 US dollars, 1.98% when it is compared with the IAI annual requested funding), 2.26% for office supplies, 22.65% for computation supplies and 75.09% for students support. In 2008 we received from the University of Costa Rica 345532 Costa Rican colones (about 620.78 US dollars, 2.59% when it is compared with the IAI annual requested funding), 8.68% for printing expenses, 2.89% for office supplies, 17.36% for computation supplies and 71.06% for students support. The undergraduate meteorology student Natalie Mora is working in the project with these funds, basically helping with information processing, digitalization and data base building. Other UCR

contributions come from infrastructure, electricity, and telephone use, basic computer maintenance, and local administrative support. This contribution is estimated in 3000,00 US dollars for the period January 2007-June 2008. Support from other research programs (VI-FEEI-2008) has allowed Erick Rivera from the Center for Geophysical Research to collaborate, under Dr. Amador's supervision, on the development of the atmospheric model system to perform simulations and predictions on regional scales for future use in the project. This contribution is estimated in 2000,00 US dollars during the period January-June 2008.

### **\*3 Research Activities and Findings\***

Variability in the annual number of Tropical Cyclones for the Atlantic was studied by Alfaro (2007a) as a function of the interannual and decadal variability of Sea Surface Temperature (SST). Given a scenario below normal, neutral and above normal in some selected SST indices for 1944-2004 (61 years), contingency table analysis was used to calculate the conditional probabilities for scenarios below normal, neutral and above normal for different annual time series of tropical cyclone activity in the Atlantic basin. This annual activity was conditioned on the difference between the normalized SST of the tropical North Atlantic and the Equatorial Eastern Pacific. Lower than average activity years were observed with cooler (warmer) than average temperatures in the Tropical North Atlantic (Eastern Equatorial Pacific), greater wind shear over the Tropical North Atlantic but smaller over the Eastern Tropical Pacific, near Central America; and higher (lower) sea level pressure in the Tropical North Atlantic (Eastern Equatorial Pacific). Higher than average activity years were observed in general terms with opposite anomaly patterns in the regions described previously.

To help in the understanding how the Pacific and Atlantic variability influence the circulation of the overlaying atmosphere, key factor that is related with the hurricane formation, a shallow water model was used by Alfaro et al. (2007) to simulate the anomalous circulation over the Intra American Seas (IAS), due to heat forcing functions located at the Tropical North Atlantic and the Eastern Equatorial Pacific Oceans,

respectively. Despite of its simplicity, the shallow water model represented the main features of the anomalous circulation over the IAS due to the heat forcing functions described previously. The main anomaly patterns were observed when heat sources have opposite signs across the IAS, e.g. Tropical North Atlantic cool (warm) and Eastern Equatorial Pacific warn (cool). Results imply an increase (a decrease) in the vertical wind shear over the IAS for a cool (warm) Tropical North Atlantic and a warm (cool) Eastern Equatorial Pacific. These patterns could be associated with a larger (smaller) vertical wind shear over the IAS.

Additionally, climate variability, diagnostic and predictability, of the precipitation field were studied by Alfaro (2007b). This study helps in the understanding and comparison of impacts during the hurricane occurrence. For this, a statistical model based on Canonical Correlation Analysis was used to explore the predictability of early May, June, July (MJJ) and late August, September, October (ASO) rainfall seasons in Central America. Explanatory variables are seasonal Atlantic and Pacific Ocean SST for the region inside  $112.5^{\circ}\text{E}$ - $7.5^{\circ}\text{W}$  and  $7.5^{\circ}\text{S}$ - $62.5^{\circ}\text{N}$  during 1958-1998. For the early rainfall season, MJJ, positive (negative) Tropical Atlantic SST anomalies were associated with positive (negative) rainfall anomalies over a broad area located at the north of the studied region. For the late season, ASO, opposite sign anomalies in the Atlantic and Pacific oceans that surround Central America were associated with a strong rainfall signal, in which positive & negative (negative & positive) SST anomalies in the Pacific & Atlantic Tropical oceans, tend to be associated with lobes of negative (positive) rainfall anomalies mainly at Central American Pacific slope. The model results were cross validated, showing significant skill values over an important portion of the studied region.

In order to gain some insight into data sources, and socio-economic impacts of tropical cyclones in the Centro America region, two initial activities were identified as crucial. One has to do with the lack of a “common scientific language” between physicists, meteorologists and social scientists, and the second one with availability of historical, religious, official documentation and digital data to start a database to achieving project objectives. To bridging the gap between physicists dealing with the

structure and dynamics of phenomena and social scientists working on impact information, a detailed but yet simple update of the scientific genesis of hurricanes and its different stages of development was prepared (Amador y Bonilla, 2008). A brief historical account of hurricanes hitting the region, the likely origin of hurricanes, as a tropical traveling wave from western Africa or as a tropical disturbance associated with the Inter-tropical Convergence Zone (ITCZ), and tropical cyclone relationship with El Niño-Southern Oscillation (ENSO) warm and cold phases are also discussed. To start developing the proper configuration of the MM5 model for future simulations and data base development, the work of Amador y Bonilla (2008) also presents, as a case study, the analysis of Hurricane Mitch (October-November 1998) both, by use of the dynamic downscaling technique and by the impact it produced in some economic sectors such as housing, health, infrastructure, energy, and the number of human loses attributed to Mitch.

As may be expected, data sources for impact studies differ greatly depending on the impact scale of the disturbances or phenomena. For the case of Mitch discussed above that caused a great regional impact, information is usually available from international funding agencies or Government Ministers, International Red Cross, Non-Governmental Organizations, etc. However, this information may have underestimated the actual losses, simple and purely, due to the laborious and economic burden to gather impact data over a relatively large and topographically complex region as Centro America. To show that in some cases, “local” weather impacts can be very important affecting, not only local but country scale economy and welfare, another case study was prepared (Bonilla y Amador, 2008). A typical “temporal” (Amador et al. 2003) lasting several days, associated firstly with the intensification of the trades in the Caribbean and later with a cold surge from mid-latitudes, occurred over northern Costa Rica during 5-20 January 2000. This disturbance had a profound impact, especially during the first days, on the water level of the Lake Arenal, one of the main reservoirs for electricity generation in Costa Rica, and on the dam’s security levels (Amador et al. 2003). The temporal affected with intense and long lasting rains, an area dedicated to bean production. At first, impact data was difficult to get at a local scale to estimate loses, however, agriculturalists and affected people were somehow eager to provide information since they saw an opportunity to get help form the

government. This work estimated that at least 5 million US dollars were lost during the temporal that also affected at a country scale the consumption of beans.

To support the works of Amador y Bonilla (2008) and Bonilla y Amador (2008) and to develop the local capacity for future simulations and predictions, the ability of two general circulation models (ECHAM4.5 and CCM3.6) to simulate key climate features of Central America was investigated by the evaluation of both precipitation and low-level wind fields for the period 1990-1999. According to the evaluation, ECHAM4.5 exhibits a more realistic representation of the regional climate. Therefore, its output can be used, in principle, to provide the initial and boundary conditions necessary to perform a dynamical downscaling using the regional model MM5v3 (Rivera y Amador, 2008).

#### **\*4 Contributions of Co-PIs\***

##### **University of Costa Rica (co-PIs: Amador and Alfaro)**

The general project goal of the Costa Rican co-PIs is to develop a historical hurricane database for the Caribbean and Central America region and to conduct climate analysis of tropical cyclone activity for the Caribbean and other regions. In spite of the lack of money availability, the following progress has been made with the limited budget.

- 1) The geography graduate student, BSc. Adolfo Quesada, is working in the project building the data base for hurricanes in the Intra Americas Seas, Caribbean and Gulf of Mexico; he is also collaborating in the collection of data from the Mesoamerican disasters database “DesInventar” related with the hurricanes and extreme event disasters.
- 2) The Geographer, Lic. Adriana Bonilla is collaborating with the project in the collection and analysis of the information collected from the “DesInvertar” database. She is also gathering and analyzing different socio-economic indices related with the hurricanes and extreme event disasters. See also the Publications section below.

- 3) The Historian, Lic. Flora Solano, is collaborating with the project in reviewing the Costa Rican archives related with hurricanes and extreme event disasters.
  - 4) The Physicist, BSc. Rodrigo Castillo, is helping with the project in building and maintaining a MySQL database under Linux environment.
  - 5) The atmospheric sciences graduate student, BSc. Tito Maldonado, has contributed in the preliminary scenarios analysis using the information described above.
  - 6) Erick Rivera, a Ph.D. student at the University of Costa Rica has been working with Dr. Amador in developing the atmospheric model system to perform simulations and predictions using dynamical downscaling. See the Publications section below.
- 7)

**\*5 Publications \***

**Journal Publications**

**Alfaro, E.**, 2007a. Escenarios climáticos para temporadas con alto y bajo número de huracanes en el Atlántico (Climate scenarios for years with high and low number of Hurricanes in the Atlantic basin). Revista de Climatología, 7, 1-13. (Available at: <http://webs.ono.com/reclim/>, last visit 25/07/2008)

**Alfaro, E.**, D. Hernández y A. Bezanilla, 2007: Uso de un modelo de aguas someras para analizar la influencia del Atlántico Tropical Norte y del Pacífico Ecuatorial del Este sobre la circulación atmosférica en los mares Intra-Americanos (Use of a shallow water model to analize the influence of the Tropical North Atlantic and the Eastern Tropical Pacific on the Intra Americas Seas atmospheric circulation). Revista de Climatología, 7, 15-26. (Available at: <http://webs.ono.com/reclim/>, last visit 25/07/2008)

**Alfaro, E.**, 2007b. Uso del análisis de correlación canónica para la predicción de la precipitación pluvial en Centroamérica (Use of CCA for the Central American rainfall prediction). Revista Ingeniería y Competitividad, **9** (2), 33-48. (Available at: <http://revistaingenieria.univalle.edu.co/>, last visit 25/07/2008)

**Amador, J. A.** y A. Bonilla 2008. Ciclones tropicales y sociedad: Una aproximación al enfoque científico de estos fenómenos atmosféricos como referente para la investigación social en desastres. En: Concepciones y representaciones de la naturaleza y la ciencia en América Latina, Programa de Estudios Sociales de la ciencia, la Técnica y el Medio Ambiente. Editorial Universidad de Costa Rica. En prensa.

Bonilla, A. y **J. A. Amador**, 2008. El temporal de enero 2000: sus características e impactos socio-económicos sobre las comunidades próximas a la cuenca de la Laguna de Arenal y de la región Huetar Norte. En: Concepciones y representaciones de la naturaleza y la ciencia en América Latina, Programa de Estudios Sociales de la ciencia, la Técnica y el Medio Ambiente. Editorial Universidad de Costa Rica. En prensa.

Rivera, E. y **J. A. Amador**, 2008. Predicción Estacional del Clima en Centroamérica mediante la reducción de escala dinámica. Parte I: Evaluación de los Modelos de Circulación General CCM3.6 y ECHAM4.5. Revista de Matemática: Teoría y Aplicaciones, 15(2), 131-173.

#### \*6 Data\*

At this point we have used only public databases like Costa Rican History Archives, HURDAT (<http://www.aoml.noaa.gov/hrd/hurdat/>, last visit 25/07/2008), and DesInventar (<http://www.desinventar.org/desinventar.html>, last visit 25/07/2008). Standard grid data such as NCEP/NCAR (Kalnay et al 1996), ECHAM4.5 and CCM3 digital data were used to performed regional analysis and model simulations.

**\*7 Capacity Building\***

See section 4, items 1, 5 and 6 for the students involved in the project activities.

**\*8 Regional Collaboration/Networking\***

In the Intra-Americas Seas CLImate Program (IASCLIP) framework, proposed for 2009-2014, as a new component of CLIVAR VAMOS, Dr. Alfaro is actually the chair of the Working Group D (Applications and Capacity Building). Also, Dr. Amador is the regional Focal Point for the meteorology component in the project Desarrollo de Capacidades de Investigación para la Prevención y Mitigación de Desastres en Centroamerica (Capacity Building and Development for Disasters Prevention/Mitigation in Central America), supported by the Central American Council for Higher Education and the Swedish Agency for International Development Cooperation. We expect that these initiatives will produce a positive feedback in the project activities during the coming years.

**\*9 Media Coverage and Prizes\***

None.

**\*10 Policy Relevance\***

Nothing to report yet.

**\*11 Main Conclusions\***

1. The start of this project locally has been seriously delayed due to complications arising from contract and subcontract negotiations. Essentially the Year 1 and 2 budgets for the co-PIs have not been spent as a result of the delay in setting up the sub-awards and the delays in the way that the money was transfer to UCR (ordinary mail). These project delays have affected the overall goals and objectives of our group project.

2. Despite these delays certain project activities have been conducted using small local funds (see sections 3 and 4). We will expect to carry over the Year 1&2 budget to

the budget of the coming years, so that some of these project-related activities can be properly funded. See next section for explanation.

### **\*12 Work Plan for Next Year with Associated Costs\***

We will continue on the Database development and case studies, collecting socio-economic, historical, and climatic data from regional libraries and archives to develop a database for hurricane impacts in the Caribbean region. Specific cases of historical hurricane disaster will be selected for detailed study, and information gathered will be input into the GIS for display and analysis. To achieve the above, we plan to incorporate more students and researches into the process.

Also some simulations using the Center for Geophysical Research, University of Costa Rica, atmospheric model system will be perform using dynamical downscaling [ECHAM4.5, GFS, MM5] in order to understand the applicability (limitations and advantages) of regional numerical products and its relationship with social impacts in the past depending on data availability to initialize the models. Co-PI Amador is planning to update current knowledge on the dynamics and role of the Intra-Americas Low-Level Jet (IALLJ) on weather and climate in the region, and to model IALLJ boundary layer processes using a mesoscale model such as the MM5. In this respect, an effort will be made to incorporate more research associates to the project activities and spend the July 2008-June 2009 corresponding budget along with some funds from the previous non-used budget (see main conclusions above). Visits to Centro America Archives such as those in Guatemala, Dominican Republic, and Colombia are also being considered for the coming year.

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## **\*1 Project Title, Project Number, Principal Investigator, Key Words\***

**Project Title:** Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity

**Project Number:** IAI-CRN-2050

**Principal Investigator:** Kam-biu Liu (Louisiana State University)

**Key words:** paleotempestology, Caribbean low-level jet, hurricanes, climate change, vulnerability, social impact, extreme events

## **\*2 Project Funding\***

The University of Costa Rica (UCR) received from LSU the first project payment the second week of July, 2008. The amount received was 5885 US dollars for each of the researchers (Co-PIs Alfaro and Amador, see column “Ingreso” in the financial report given by the UCR Foundation for Research, FUNDEVI). The second project payment was received the second week of October, 2008. Dr. Amador and Dr. Alfaro received 21091 and 24727 US dollars, respectively.

The national component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The title of the national component is: “Estudio y comparación histórica del impacto de ciclones tropicales en Centroamérica y el Caribe”, PI Dr. Eric J. Alfaro and Co-PI Dr. Jorge A. Amador. The grant number is V.I. 805-A7-002. During 2008 this project received from the University of Costa Rica 345532 Costa Rican colones (about 620.78 US dollars, 2.59% of the IAI Costa Rican annual funding); 8.68% for printing expenses, 2.89% for office supplies, 17.36% for computer supplies, and 71.06% for student support. The UCR budget for this component was 283752 Costa Rican colones (about 490 US dollars, 2.04% IAI Costa Rican annual

funding), all for student support. The undergraduate meteorology student Natalie Mora (UCR ID number A53709) is working in the project supported by these funds, basically helping with information processing, digitalization and data base building. Other UCR contributions (i.e., that from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone use, basic computer maintenance, and local administrative support. This contribution is estimated in 3000 US dollars for the period January 2008-June 2009. Support from other research programs (VI-FEEI-2008, UCR number 805-A8-606) has allowed Erick Rivera from CIGEFI to collaborate, under Dr. Amador's supervision, on the development of the atmospheric model system to perform simulations and predictions on regional scales for future use of the project. This contribution is estimated in 2000 US dollars during the period January-June 2009.

### **\*3 Research Activities and Findings\***

In late 2008, Co-PI Amador was invited to contribute, as author, to the State of the Climate in 2008, with focus in Central America, a Special Supplement to the Bulletin of the American Meteorological Society. This invitation derived in a short paper contribution to that issue that is to see the light in or about July 2009 (Amador et al. 2009a). As part of the above collaboration this team of researchers prepared additional data and analysis for Central America and the Caribbean for 2008, material that was presented in poster session at the **2<sup>nd</sup> Summit on Hurricanes and Climate Change**, May 31-June 5, 2009, in Corfu, Greece. Currently this material is being considered as the basis for a future contribution to the Summit Memories (Amador et al. 2009b).

Amador et al. (2009b) state that climate of the Intra Americas Seas (IAS), consisting of the Gulf of Mexico, Southern Mexico, Central America, the eastern Pacific, the Caribbean, and northern South America, is determined by a wide range of atmospheric signals, both, in space and time, however, some of them are particularly important and are observed to dominate the regional circulations. These unique climate features, such as the Mid Summer Drought (MSD) or "veranillo", a phenomenon rarely observed in the tropics (Magaña et al. 1999); the Caribbean low-level jet during summer

and its winter counterpart, the only mostly zonal low-level jet in the Americas; the IAS warm pools and associated cyclogenetic regions; and the strong convective activity of the ITCZ (Intertropical Convergence Zone), are some of the phenomena that heavily imprint the economy and human well-being of a region of more than one hundred million people living in relatively small countries, some of which are among the poorest in the Americas and the world. Two papers mentioned in the 2008 report: “Cyclones tropicales y sociedad: Una aproximación al enfoque científico de estos fenómenos atmosféricos como referente para la investigación social en desastres” (Amador and Bonilla 2009) and “El temporal de enero 2000: sus características e impactos socio-económicos sobre las comunidades próximas a la cuenca de la Laguna de Arenal y de la región Huetar Norte” (Bonilla and Amador 2009), are currently at the stage of production “proof corrections” at the UCR Press. The objectives of these papers are to show the importance of impact estimation under two intense meteorological phenomena at different regional spatial scales (Hurricane Mitch and a cold outbreak in January 2000) in order to bring the attention of policy makers about planning and risk management to avoid life loses and to ameliorate the socioeconomic stress during and after the impact.

According to Alfaro and Quesada (2009), the study of the tropical cyclones activity, and their historic characterization in the Central American region, is a basic element to mitigate their impact over different regions of the isthmus. As part of the project, years with high and low tropical cyclone impacts in Costa Rica were defined, considering variables like trajectory, maximum wind velocity and the annual occurrence of cyclones in the basin, according with the HURDAT data base. Additionally, Costa Rica has a good natural disaster data base, related with events that affected specific locations and several socioeconomic sectors like agriculture, energy and transport. This data base, called DesInventar, allowed the study of disasters in Costa Rica related with tropical cyclones during the last four decades. The analysis showed a trend in the annual number of impacts associated with hydrometeorology causes that cannot be explained by climate trends only. This means that socioeconomic variables should also be included in the analysis in order to understand climate impacts.

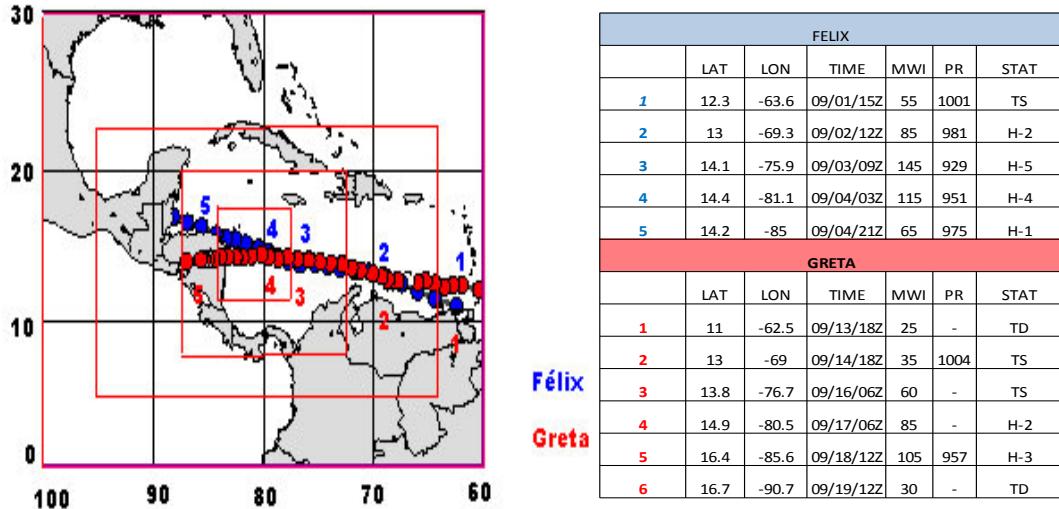
To deal with gaps in the meteorological information analyzed, Alfaro and Soley (2009) studied two methods to filling missing data in geophysical time series. The first one is based on the principal component decomposition of the correlation matrix built for close spatial stations with common time series records of the same variable. This multivariate method allows the incorporation in the estimated values, of large scale features based on the information shared by the stations (Tabony, 1983). The second method could be used when there are no nearby stations and the missing data must be calculated from the same station historical information. This method adjusts an auto-regressive model to the time series, which is then used, to estimate the missing data. Two algorithms were used to calculate the auto-regressive coefficients: the Burg estimator (Ulrych & Bishop, 1975) and the one proposed by Ulrych and Clayton (Ulrych & Clayton, 1976). The first one is appropriate for stochastic processes and the second for deterministic series. The two methodologies described in Alfaro and Soley (2009) are recursive: a first estimation of the missing data is done running the algorithms but ignoring or using a crude approximation at the beginning. Then, the algorithm runs again with the new estimated data, replacing the previous run missing data estimations. The run stops when the maximum difference between two successive estimations is smaller than a certain value specified by the user. Filled data conserves the mean and standard deviation of the original time series. These algorithms have been adapted and modified for its use in SCILAB using also Graphic User Interfaces. Scilab is an open source platform, similar to MATLAB, and runs indistinctively in Windows or Linux.

In regards to the comparative case studies of tropical cyclones, three pairs of systems were identified, Felix 2007-Greta 1978, César 1996-Joan 1988, and Dean 2007-Fifi 1974. One of the criteria to select these cases is that each pair has similar trajectories (see Figure 1 for Felix-Greta) but produced very different social impacts in Central America. Blanca Calderón (UCR ID number 990724), an undergraduate meteorology student started, under the guidance of Dr. Amador, preliminary cyclone simulations to study precipitation and wind distributions at a regional scale using the Nonhydrostatic fifth-generation Pennsylvania State University National Center for Atmospheric Research Mesoscale Model (MM5v3, Grell et al. 1994). The MM5v3 model for the preliminary

hurricane simulations used only a 2-domain grid configuration of 75, and 25 km horizontal resolutions (50x63, 88x133 points respectively) with 35 vertical model layers. The model was initialized using both the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS) data and the National Center for Environmental Prediction (NCEP) / National Center for Atmospheric Research (NCAR) Reanalysis data as initial and lateral boundary conditions every six hours with two way nesting dynamics. No data assimilations were applied. The following model physics were used : 1) simple ice scheme for microphysics; 2) cloud radiation cooling of the atmosphere; 3) MRF scheme for planetary boundary layer (PBL); 4) Grell cumulus parameterization scheme (CPS) was applied on the 75, and 25 km grids; 5) no shallow convection was used. Figure 2 presents cross sections of the x-p plane (left panel) and y-p plane (right panel) showing the vertical structure of the wind (m/s) for the case of hurricane Greta at 00Z for 18 September 1978. The white boxes at the bottom of the panels are a coarse representation of the topography in the 75 km grid size domain. Since, one of the objectives of the study is to better understand the interaction of wind flow with topography in the region, it is clear that a higher resolution is needed in the cyclone simulations. To do this, the MM5v3 model is being configured to increase the number of domains to at least three, with the innermost domain with a grid size in the order of a few km (i.e., 8-5 km or less, depending on the computational facilities available at CIGEFI). Besides the above improvement, output data at 1-2 hours intervals is intended to study the temporal evolution of the systems along with the intense periods of interaction of the wind flow and the regional topographical features.

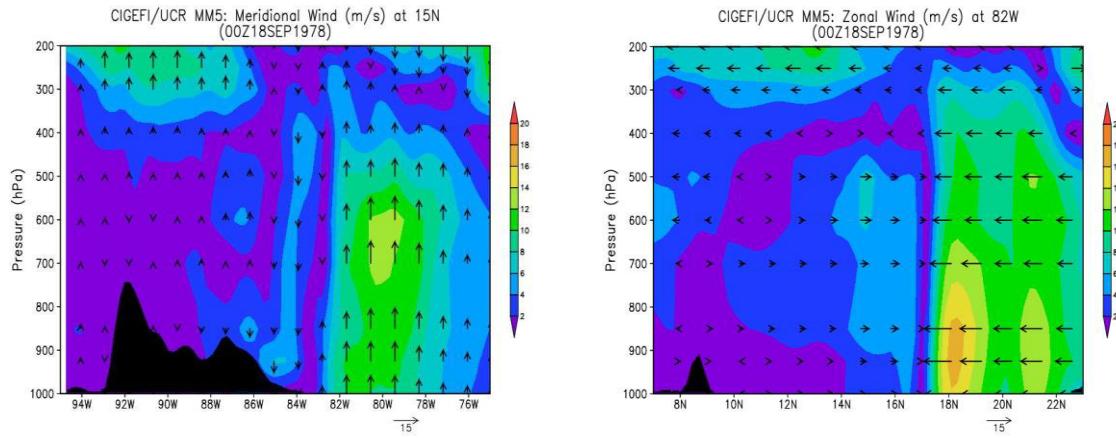
### Proposed simulation period

**Félix: 2007/09/01 \_15Z to 2007/09/04 \_21Z**  
**Greta: 1978/09/13 \_18Z to 1978/09/19 \_12Z**

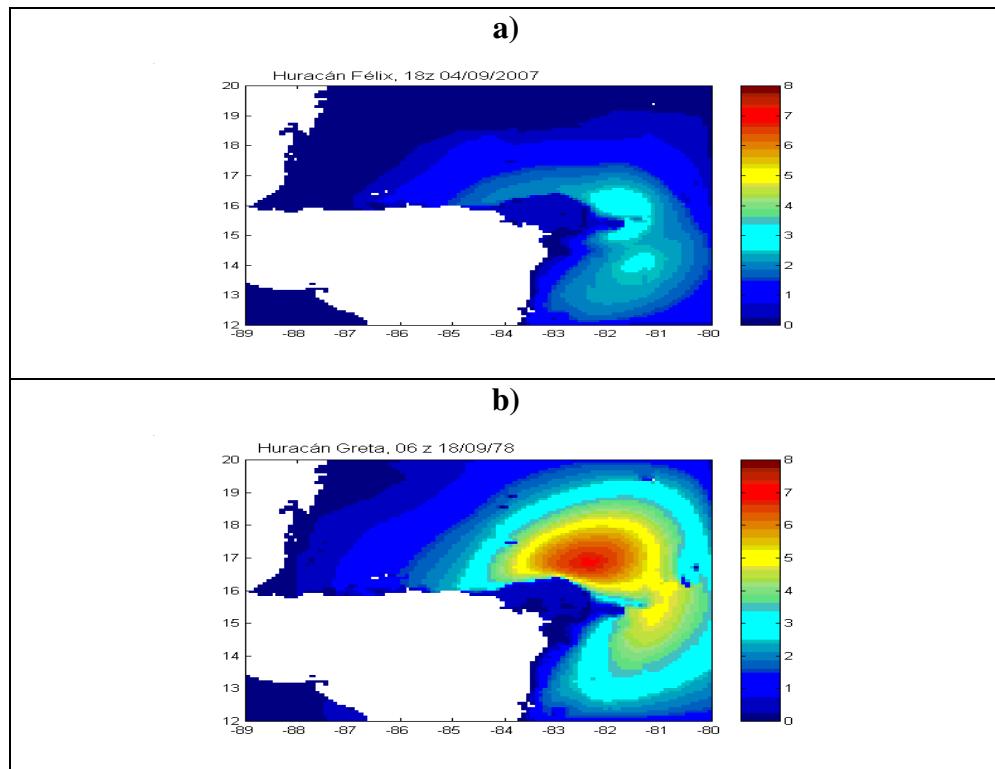


**Figure 1.** Trajectories for tropical cyclones Félix (2007) in blue, and Greta (1978) in red (left panel), and the corresponding latitude-longitude positions (lat, lon, respectively) at Time (month/day/time), maximum observed winds (MWI) near the cyclone eye, center pressure (PR), and system status according to standard intensity categories (right table). The upper title reflects the proposed simulation period for both storms.

For the selected study cases, Dr. Omar Lizano (CIGEFI\_CIMAR-UCR) has been collaborating with this research initiative. Dr. Lizano is running the SWAN wave model to compare wave heights for the tropical cyclone pairs Félix 2007-Greta 1978, César 1996-Joan 1988, and Dean 2007-Fifi 1974. Figure 3 presents the wave height model estimates for the pair Félix-Greta, at 18Z on 4 September 2007 (Figure 3a) and at 06Z on 18 September 1978 (Figure 3b), respectively. At those dates, Félix was H-3 cyclone at 14°N, 84°W, whereas Greta was a H-3 cyclone at 15°N, 84°W, approximately. Note the difference in wave height between these two tropical cyclones, a condition that cannot be inferred solely by hurricane intensity and relative position in the Caribbean warm pool.



**Figure 2.** Cross sections in the x-p plane (left panel) and y-p plane (right panel) showing the vertical structure of the wind (m/s) for the case of hurricane Greta at 00Z for 18 September 1978 using the model MM5v3. At the bottom of the panels are a course representation of the topography in the 75 km grid size domain.



**Figure 3.** Wave height (m) for Tropical Cyclone a) Felix (2007) and b) Greta (1978), using the SWAN wave model. See text for discussions.

Other proposed activities of the project were, the study of the Intra-Americas or Caribbean Low-Level and the numerical modeling of its structure and interactions with the underlying ocean. In this respect, Amador (2008) studied this relevant climate feature of the Intra-Americas Sea (IAS), the low-level jet (IALLJ) dominating the IAS circulation, both in summer and winter; and yet it is practically unknown with regard to its nature, structure, interactions with mid-latitude and tropical phenomena, and its role in regional weather and climate. This paper updates IALLJ current knowledge and its contribution to IAS circulation–precipitation patterns and presents recent findings about the IALLJ based on first in situ observations during Phase 3 of the Experimento Climático en las Albercas de Agua Cálida (ECAC), an international field campaign to study IALLJ dynamics during July 2001. MM5v3 simulations were compared with observations and reanalysis. Large-scale circulation patterns of the IALLJ northern hemisphere summer and winter components suggest that trades, and so the IALLJ, are responding to land–ocean thermal contrasts during the summer season of each continent. The IALLJ is a natural component of the American monsoons as a result of the continent’s approximate north–south land distribution. During warm (cold) El Niño–Southern Oscillation phases, winds associated with the IALLJ core (IALLJC) are stronger (weaker) than normal, so precipitation anomalies are positive (negative) in the western Caribbean near Central America and negative (positive) in the central IAS. During the ECAC Phase 3, strong surface winds associated with the IALLJ induced upwelling, cooling down the sea surface temperature by 1–2 °C. The atmospheric mixed layer height reached 1 km near the surface wind maximum below the IALLJC. Observations indicate that primary water vapor advection takes place in a shallow layer between the IALLJC and the ocean surface. Latent heat flux peaked below the IALLJC. Neither the reanalysis nor MM5v3 captured the observed thermodynamic and kinematic IALLJ structure. So far, IALLJ knowledge is based on either dynamically initialized data or simulations of global (regional) models, which implies that a more systematic and scientific approach is needed to improve it. The Intra-Americas Study of Climate Processes is a great regional opportunity to address trough field work, modeling, and process studies, many of the IALLJ unknown features.

#### **\*4 Others Contributions of the Co-PIs Work and Collaborators\***

The general project goal of the Costa Rican Co-PIs was also to develop a historical hurricane database for the Caribbean and Central America and to conduct climate analysis of tropical cyclone activity for the Caribbean and other adjacent regions. The following progress has been made along these lines.

- 1) The geography graduate student, B.Sc. Adolfo Quesada, is working in the project building the data base for hurricanes in the Intra Americas Seas, Caribbean and Gulf of Mexico. He is collaborating in the collection of data from the Mesoamerican disaster database “DesInventar” mostly related with the impact of hurricanes and extreme event disasters. Mr. Quesada is also analyzing the disaster data base elaborated during the project “Impact and Adaptation to Climate Change and Extreme Events in Central America” (AIACC-LA06-UCR), a regional project funded by (Assessments of Impacts and Adaptations to Climate Change, <http://www.aiaccproject.org/>). This data base has information since 1950. He has also been collaborating in the analysis of social indices like the Social Development Index (SDI) for communities that are usually impacted by tropical cyclones.
- 2) The historian, Lic. Flora Solano, has been participating in the project by reviewing the Costa Rican historical archives at different institutions related with hurricanes and extreme event disasters. Because 1969 (year identified as an active year for tropical cyclones in Central America) didn't have records in DesInventar data base, Lic. Solano is collecting information associated with this year from different archives and historical sources. Information related with tropical cyclones Camille, Francelia, Jenny, Laurie and Martha is currently being analyzed.

Additionally, using the available budget, it is being planned that Lic. Solano and B.Sc. Quesada visit a regional historical archive to collect information associated with

impacts in Central America of tropical cyclones that occurred during the second and first part of XIX and XX centuries. Lic. Solano has already collected information from Costa Rican archives for this purpose, but it is necessary to extend this activity to other regional archives.

- 3) The atmospheric sciences graduate student, BSc. Tito Maldonado, has contributed in the preliminary scenarios analysis using the information described above and is currently working at CIGEFI-UCR. B.Sc. Maldonado, UCR ID number A22905, was supported by the project IAI-CRN2048 to participate in the Second Spring Course on Tropical Cyclones and in the Symposium Human Dimensions of Tropical Cyclones, March, 9-13<sup>th</sup>, 2009, Acapulco, México.
- 4) Erick Rivera, a Ph.D. student at the University of Costa Rica, and also a staff member of CIGEFI, has been working with Dr. Amador in developing the atmospheric model system to perform simulations and predictions using dynamical downscaling. For this purpose MM5v3 and Weather Research and Forecasting Model (WRFv3, Skamarock et al. 2008) are being implemented to run under parallel Linux platforms. See the Publications section below.

## **\*5 Publications\***

**(The Project CRN2050 is mentioned in the acknowledgements. The pdf version of the published papers are included)**

### **Journal – Book Publications**

- **Alfaro, E. y J. Soley, 2009.** Descripción de dos métodos de relleno de datos ausentes en series de tiempo meteorológicas (Description of two methodologies for filling gaps in meteorological time series). Revista de Matemáticas: Teoría y Aplicaciones. 16(1), 59-74. (Available at <http://revista.emate.ucr.ac.cr/index.php/revista>, last visit 29/06/2009) (X)

- **Amador** J. A., E. **Alfaro**, E. Rivera y B. Calderón, 2009a. Central America. In State of the Climate in 2008, Special Supplement to the Bulletin of the American Meteorological Society Vol. 90, No. 7, July 2009. (\*)
- **Amador** J. A., E. **Alfaro**, E. Rivera y B. Calderón, 2009b. Central America. State of the Climate in 2008. Considered as the basis for a future contribution to the 2<sup>nd</sup> Summit on Hurricanes and Climate Change Memories. (\*)
- **Amador, J. A. y E. J. Alfaro**, 2009. Métodos dinámicos y estadísticos de reducción de escala: Aplicaciones al tiempo, clima, variabilidad climática y cambio climático. Revista Iberoamericana de Economía Ecológica. In Press (October 2009).
- **Amador, J. A.**, y A. Bonilla, 2009. Ciclones tropicales y sociedad: Una aproximación al enfoque científico de estos fenómenos atmosféricos como referente para la investigación social en desastres. En Concepciones y Representaciones de la Naturaleza y la Ciencia en América Latina, 165-188. Editorial de la Universidad de Costa Rica. **In press**.
- **Amador, J. A.**, 2008. The Intra-Americas Sea Low-Level Jet (IALLJ): Overview and Future Research, Trends and Directions in Climate Research, Annals of the New York Academy of Sciences, 1146: 153–188. (\*)
- Bonilla A. y J. A. **Amador**, 2009. El temporal de enero 2000: sus características e impactos socio-económicos sobre las comunidades próximas a la cuenca de la Laguna de Arenal y de la región Huetar Norte. En Concepciones y Representaciones de la Naturaleza y la Ciencia en América Latina, 249-260. Editorial de la Universidad de Costa Rica. In press.
- Rivera, E. y J. A. **Amador**, 2008. Predicción Estacional del Clima en Centroamérica mediante la reducción de escala dinámica. Parte I: Evaluación de los Modelos de Circulación General CCM3.6 y ECHAM4.5. Revista de Matemática: Teoría y Aplicaciones, 15(2), 131-173.
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## Congress Extended abstracts

- **Alfaro, E.** and A. Quesada, 2009. Análisis del impacto del paso de los Ciclones Tropicales en el Mar Caribe sobre Costa Rica en las últimas décadas (Caribbean sea tropical cyclone occurrences in the last four decades and their impacts in Central America). Memories of IV Congress of Latin American and Caribbean Association of Environmental and Natural Resource Economists. E-document, available in CD. Universidad Nacional, Costa Rica. March 19th-21st, 2009. (\*), (+)

(X) oral presentation of this paper was presented during the **Ibero-American Workshop on Climate Prediction**. October 22-23th, 2008. Guayaquil, Ecuador.

(\*) papers presented as posters at the **2<sup>nd</sup> Summit on Hurricanes and Climate Change**. May 31-June 5, 2009. Corfu, Greece.

(+) paper presented as poster at the **7TH International Convention on Environment and Development - I International Congress on Climate Change**. July 6-10<sup>th</sup>, Havana, Cuba.

Project results were also divulgated in national conferences. The Co-PI's and most collaborators participated in the University of Costa Rica, Center for Geophysical Research XXVIII, XXIX and XXX Mini-Congresses, celebrated in April-2008, November-2008 and April-2009, respectively. Also, in the conference organized by the University of Costa Rica, Geography School, the Day of the Earth, April 22, 2009.

## \*6 Data\*

At this point the project has used only public databases like Costa Rican History Archives; HURDAT (<http://www.aoml.noaa.gov/hrd/hurdat/>, last visit 25/07/2008), and DesInventar (<http://www.desinventar.org/desinventar.html>, last visit 25/07/2008). The disaster data base elaborated during the project "Impact and Adaptation to Climate Change and Extreme Events in Central America" (AIACC-LA06-UCR), the Social Development Index (available at <http://www.mideplan.go.cr/sides/social/indx10.htm>) and

the Gross National Product (Costa Rica Central Bank, <http://www.bccr.fi.cr>). Standard grid data such as NCEP/NCAR (Kalnay et al. 1996), ECHAM4.5 (Roeckner et al. 1996) and CCM3.6 (Kiehl et al. 1996) output data were used to performed regional analysis and model simulations.

## **\*7 Capacity Building\***

See sections 2 and 4 (items 1, 3, and 4) for the students involved in the project activities.

## **\*8 Regional Collaboration/Networking\***

In the Intra-Americas Seas CLImate Program (IASCLIP) framework, proposed for 2009-2014, as a new component of Climate Variability and Predictability (CLIVAR) Variability of the American Monsoon Systems (VAMOS), Dr. Alfaro is currently the Chair of the Working Group: Applications and Capacity Building (more information is available

at

[ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP\\_S&Iplan\\_spr08\\_v2.pdf](ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP_S&Iplan_spr08_v2.pdf).

Also, Dr. Amador is the regional Focal Point for the meteorology component in the project Desarrollo de Capacidades de Investigación para la Prevención y Mitigación de Desastres en Centroamerica (Capacity Building and Development for Disasters Prevention/Mitigation in Central America), supported by the Central American Council for Higher Education and the Swedish Agency for International Development Cooperation (see <http://dipredca.csuca.org/> for more information). Both Co-PI's expect that these initiatives will produce a positive feedback in the project activities during the coming years.

## **\*9 Media Coverage and Prizes\***

Dr. Alfaro and other colleagues had an interview in Radio Nacional, “Visión Crítica” Program (National Radio, 101.5FM) about the project results. The interview was broadcasted from 7 to 8pm, Costa Rican local time, March, 13<sup>th</sup>, 2009.

Dr. Amador received the Costa Rican 2008 Science National Award “Clodomiro Picado Twilight” for his work related with the The Intra-Americas Sea Low-level Jet, presented in Amador (2008). It was also communicated in national newspapers (see for example [http://www.nacion.com/ln\\_ee/2009/febrero/03/aldea1862046.html](http://www.nacion.com/ln_ee/2009/febrero/03/aldea1862046.html)).

## **\*10 Policy Relevance\***

Nothing definitive to report yet, however, some of the publications could be used to strengthen the views of policy makers in regards to the relevance of weather and climate impacts on society.

## **\*11 Main Conclusions\***

**1.** The start of this project, at a local level, has been seriously delayed due to complications arising from contract and subcontract negotiations. Essentially the Year 1 and 2 budgets for the Co-PIs have not been spent as a result of the delay in setting up the sub-awards and the delays in the way that the money was transferred to UCR (ordinary mail). These project delays have affected the overall goals, objectives, and the progress of the project.

**2.** Despite the delays certain project activities have been conducted using small local funds (see sections 3 and 4). Co-Pi's expect to carry over the Year 1&2 budgets to

the budget of the coming years, so that some of these project-related activities can be properly funded and executed. See section 12 for explanation.

**3.** A great deal of data has been analyzed and archived, making this a valuable contribution to the scientific community interested in tropical cyclones and low-level jets at low-latitudes.

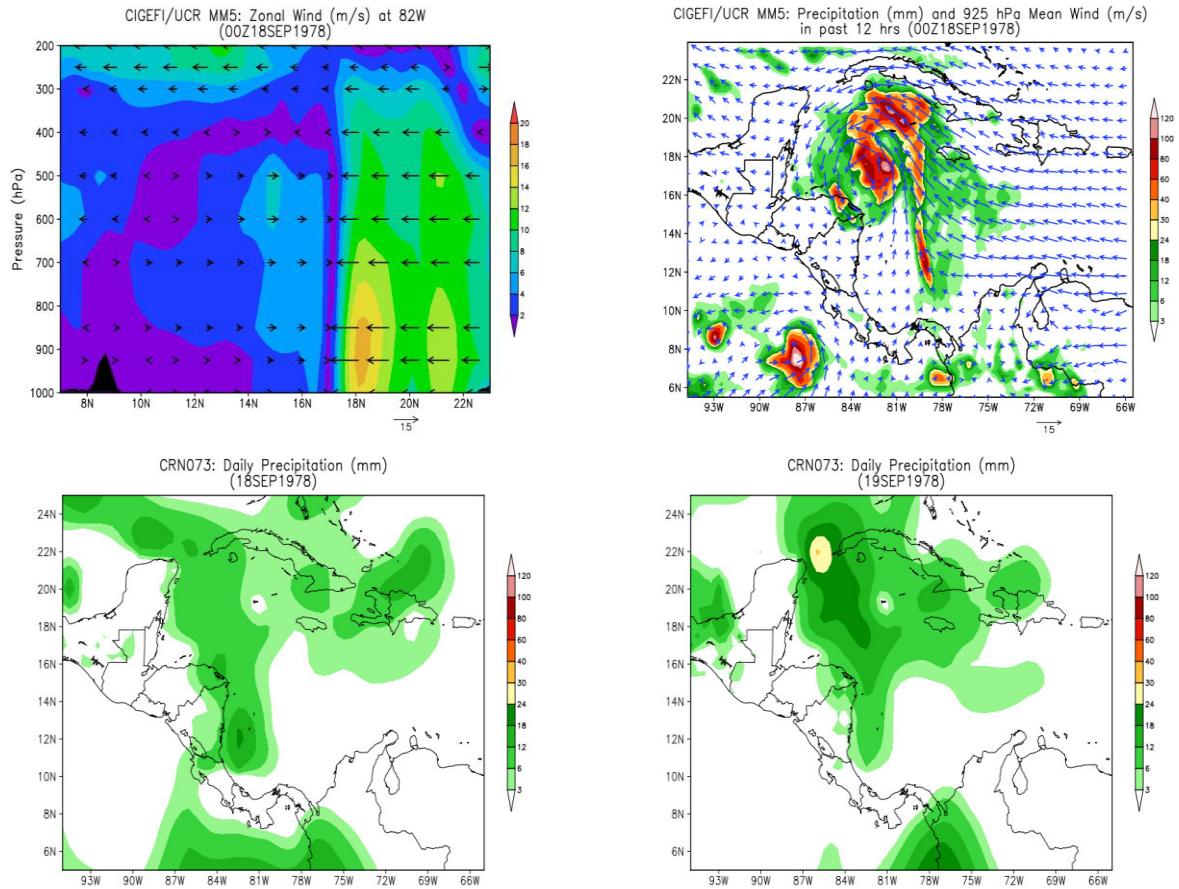
**4.** A considerable number of undergraduate and graduate students, both at the UCR and other institutions abroad, have benefited from the project, by means of discussions, available facilities and materials, statistical and numerical model development and scientific publications.

**5.** The published papers and poster presentations speak of reasonable scientific achievements related to the project objectives and provide new research opportunities with other scientific groups interested in the region.

6. The funding provided by the IAI has been very important to promote research in tropical meteorology in the region, especially in those scientific topics that are associated with atmospheric systems that impact the region leaving large amounts of material and human loses in an already very vulnerable regional society.

#### **\*12 Work Plan for Next Year with Associated Costs\***

The Co-PI's will continue with the Database improvement and the case studies, collecting socio-economic, historical, and climatic data from regional libraries and archives to develop a database for hurricane impacts in the Caribbean region. Specific cases of historical hurricane disasters will be selected for detailed study, and information gathered will be fed into the GIS for display and analysis. To achieve the above, it is planned to incorporate more students and researchers into the process.



**Figure 4.** MM5v3 model simulations of hurricane Greta on 18 September 1978 at 00 Z showing a cross section of the zonal wind at 82° W (upper left panel), the precipitation distribution and mean wind (both from last 12 hours from 00 Z) at 925 hPa (upper right panel). For comparison purposes, daily precipitation distributions for Greta on 18 September 1978 (lower left panel) and 19 September 1978 (lower right panel) using data from the project IAI-CRN073

(<http://iridl.ideo.columbia.edu/SOURCES/.UNAM/.gridded/.monthly/.v0602/>)

Also, some simulations using the Center for Geophysical Research, University of Costa Rica, atmospheric model system will be perform using dynamical downscaling techniques [ECHAM4.5, GFS, MM5v3, WRFv3] in order to understand the applicability (limitations and advantages) of regional numerical products and its relationship with social impacts in the past.

Plans include an increase in the spatial resolution of the dynamical models to scales, depending on computer resources, such that a better understanding of the ocean-atmosphere-land interactions processes can be achieved. The success of the simulations may depend, of course at some point, on data availability to initialize the models.

Figure 4 presents an example of an improved topographical representation of the Central America topography in order to study air flow-topography interactions and associated precipitation distribution during cases where hurricanes are close to the Central America coastline in the Caribbean. This is the case of hurricane Greta in September 1978. Figure 4 illustrates MM5v3 model simulations of hurricane Greta on 18 September 1978 at 00 Z showing a cross section of the zonal wind at  $82^{\circ}$  W (upper left panel), and the precipitation distribution and mean wind (both from last 12 hours from 00 Z) at 925 hPa (upper right panel). For comparison purposes, daily precipitation distributions for Greta on 18 September 1978 (lower left panel) and 19 September 1978 (lower right panel) using data from the project IAI-CRN073. As observed from the cross section in Figure 4, there is a strong convergence at all levels below 500 hPa in the zonal wind component near  $17^{\circ}$  N consistent with the model precipitation distribution in Figure 4 upper right panel. The “observed precipitation” for 18, 19 September, using IAI-CRN073 data, shows good agreement with corresponding model output, especially over land, which is indicative of model skill to capture basic ocean-atmosphere-land interactions.

Co-PI Amador is planning to update current knowledge on the dynamics and role of the Intra-Americas Low-Level Jet (IALLJ) on moisture transport in weather and climate in the region, and to model IALLJ boundary layer processes using a mesoscale model such as the MM5v3. In this respect, an effort will be made to incorporate more research associates to the project activities and spend the July 2008-June 2009 corresponding budget along with some funds from the previous non-used budget (see main conclusions above) to support these activities. Visits to Meso-America and Caribbean Historical Archives such as those in Guatemala, Dominican Republic, and Colombia are also being considered for the coming year.

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**Universidad de Costa Rica**  
**Vicerrectoría de Investigación**  
**Centro de Investigaciones Geofísicas**  
Tels. (506) 2511 6388 / 2511 5320  
Fax. (506) 2234 2703  
Email: [cigefi@cigefi.ucr.ac.cr](mailto:cigefi@cigefi.ucr.ac.cr)



## **Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity**

**PI: Dr. Kam-biu Liu (Louisiana State University)**

### **Co-PIs Technical Report**

**Dr. Eric J. Alfaro**

**Dr. Jorge A. Amador**

**Prime Award: CRNII 2050 (NSF Grant No. GEO-0452325)**

**Sub-award: University of Costa Rica (No. 11805)**

**June 2010**

## **\*1 Project Title, Project Number, Principal Investigator, Key Words\***

**Project Title:** Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity

**Project Number:** IAI-CRN-2050

**Principal Investigator:** Kam-biu Liu (Louisiana State University)

**Key words:** paleotempestology, Caribbean low-level jet, hurricanes, climate change, vulnerability, social impact, extreme events

## **\*2 Project Funding\***

The University of Costa Rica (UCR) received from LSU the third project payment was received the second week of November, 2009. Dr. Amador and Dr. Alfaro received 16096.8 and 19732.8 US dollars, respectively (see lines in section “Mas: Ingreso” in the financial report given by the UCR Foundation for Research, FUNDEVI).

The national component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The title of the national component is: “Estudio y comparación histórica del impacto de ciclones tropicales en Centroamérica y el Caribe”, PI Dr. Eric J. Alfaro and Co-PI Dr. Jorge A. Amador. The grant number is V.I. 805-A7-002. During 2009 this project received from the University of Costa Rica 283 752 Costa Rican colones (about 525.95 US dollars, 2.19% of the IAI Costa Rican annual funding); all for student support. The undergraduate meteorology student Natalie Mora (UCR ID number A53709) is working in the project supported by these funds, basically helping with information processing, digitalization and data base building. Other UCR contributions (i.e., that from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone use, basic computer maintenance, and local

administrative support. This contribution is estimated in 3000 US dollars for the period January 2009-June 2010. Support from other research programs (VI-FEEI-2008, UCR number 805-A8-606) has allowed Erick Rivera from CIGEFI to collaborate, under Dr. Amador's supervision, on the development of the atmospheric model system to perform simulations and predictions on regional scales for future use of the project. This contribution is estimated in 2000 US dollars during the period January-June 2010.

### **\*3 Research Activities and Findings\***

As in 2008, in late 2009, Co-PI Amador was invited to contribute, as author, to the State of the Climate in 2009, with focus in Central America, a Special Supplement to the Bulletin of the American Meteorological Society (see Amador et al. 2009). This invitation derived in a short paper contribution to that issue that is to see the light in or about July 2010. As part of the above collaboration this team of researchers prepared additional data and analysis for Central America and the Caribbean for 2009. The paper prepared is:

**Amador J. A., E. Alfaro, H. Hidalgo, E. Rivera & B. Calderón, 2010. Central America.**  
In: State of the Climate in 2009, Special Supplement to the Bulletin of the American Meteorological Society, submitted.

Part of the material that was presented in poster session at the **2<sup>nd</sup> Summit on Hurricanes and Climate Change**. May 31-June 5, 2009. in Corfu, Greece, is being considered as the basis for a contribution to the Summit Memories book, the paper prepared is:

**Amador J. A., E. Alfaro, E. Rivera & B. Calderón, 2010. Some atmospheric and oceanic indexes and their relationship with tropical cyclones over the Caribbean,**  
submitted.

The other poster was used as the base of the paper:

**Alfaro, E., A. Quesada & F. Solano, 2010:** Análisis del impacto en Costa Rica de los ciclones tropicales ocurridos en el Mar Caribe desde 1968 al 2007 (Impact analysis in Costa Rica of the Caribbean Sea tropical cyclones occurrences from 1968 to 2007, submitted to Diálogos Journal, <http://historia.fcs.ucr.ac.cr/>). In Spanish.

Previous paper was presented also by Dr. Alfaro during the XXVIII Central America Climate Outlook Forum in Guatemala City, July 2009 and in the Symposium on Aquatic Sciences in the University of Costa Rica, November 2009.

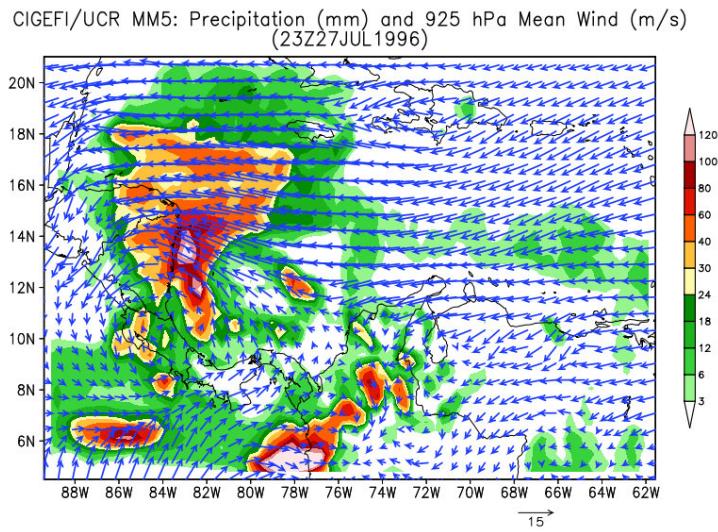
Two papers mentioned in detail in the 2009 report as Amador and Bonilla (2009) and Bonilla and Amador (2009), were already printed. The proper citation are:

**Amador, J. A., & A. Bonilla, 2009:** Ciclones tropicales y sociedad: Una aproximación al enfoque científico de estos fenómenos atmosféricos como referente para la investigación social en desastres. En: Concepciones y Representaciones de la Naturaleza y la Ciencia en América Latina (R. Viales, J. Amador y F. Solano eds.), 159-179. Editorial de la Universidad de Costa Rica.

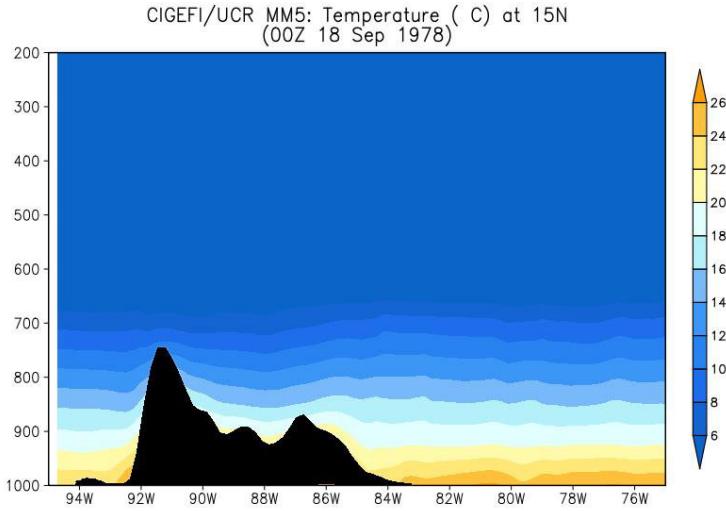
Bonilla, A., & **J. A. Amador, 2009:** El temporal de enero 2000: sus características e impactos socio-económicos sobre las comunidades próximas a la cuenca de la Laguna de Arenal y de la región Huetar Norte. En: Concepciones y Representaciones de la Naturaleza y la Ciencia en América Latina (R. Viales, J. Amador y F. Solano eds.), 243-253. Editorial de la Universidad de Costa Rica.

In regards to the comparative case studies of tropical cyclones, developed mainly by the undergraduate meteorology student Blanca Calderón (UCR ID number 990724), under the guidance of Dr. Amador. The work continued increasing the meridional and zonal extension of the profiles and introducing better topography to interpret the wind-topography processes and the precipitation at different space scales. The rainfall

comparison was for the tropical cyclone pairs Félix (2007) - Greta (1978), Cesar (1996) – Joan (1988) and Dean (2007) – Fifi (1974), using the MM5 model and observed gauge data. The research is focus in explain the physical causes for the differences and the similarities. The evidence showed for example, more (less) precipitation generated by Félix (Greta), Dean (Fifi) in Costa Rica. The short system life for hurricanes Cesar and Joan (5-6 days), their maximum category and similar paths, among the generous rainfall generated, were the criteria used to select these cyclones (see for example Fig. 1). Additionally, meridional and zonal profiles for wind and temperature were generated for hurricanes Félix y Greta (see for example Fig. 2). Work is done actually in specific humidity, divergence and humidity flux divergence for the selected cases.



**Figure 1.** Precipitation and 925 hPa wind outputs from MM5 model run for hurricane case Cesar.



**Figure 2.** Temperature zonal profile ( $15^{\circ}\text{N}$ ) for the hurricane case Greta.

Additionally, observations from PACS-SONET (2001-2006), radiosondes (2007), surface meteorological stations and NCEPNCAR were used to analyze and document the structure and time-space variability of the low-level jet over the Venezuelan Llanos in northern South America by Torrealba and Amador (2010). This current, relatively less studied than others in the region, shows mean values of about 11 m/s during the austral summer (November-March) near 925 hPa (750 m.a.s.l., approximately), with vertical wind shears near 1 m/s per 100 m in the first km, and absolute maxima greater than 14 m/s in February. Above 925 hPa the jet decreases rapidly to 6m/s about 700 hPa. The low-level jet presents a marked diurnal cycle with maxima at 12:00 UTC and relatively weak winds at 21:00 UTC, showing strong changes in the vertical wind shear during January-March for the period analyzed. The low-level jet intraseasonal variability is very strong, with periods of up to several days where winds associated with this current are very weak. In a few days winds can vary from 25 m/s to near 5 m/s. With the information used in this work, the physical mechanisms responsible for these changes are not clear, however, variations in wind intensity show a good relationship with observed changes in surface temperature. The analyzed stations show maximum values of the vertical wind shear during the dry season with minima during the wet season, indicating the importance of this index for convective activity. The low-level jet over this region is also

characterized by a marked interannual variability. In regards to its zonal and meridional extents, data suggest values of 1500 km and 500 km, respectively.

In order to justify the downscaling processes used in the project activities, Amador and Alfaro (2009) stated that coupled Atmosphere-Ocean General Circulation Models demonstrate good skill in simulating large scale circulations. However this output is not very useful to study local impacts, as its spatial resolution is courser than the scale of local impacts. It is very important to consider this issue when studying, for instance, climate impacts on human activities, coastal-marine biodiversity and tropical coral reefs. In general terms, there have been two different approaches to deal with this scale and information difference: the dynamic and the statistic downscaling methods. In that work, the basic climate elements are presented and the possible physical causes of atmospheric changes are discussed. Also, a summary of the main physical concepts that define the climate system as well as the climate and climate variability of a region with respect to the mean atmospheric state and the general aspects of the problem of climate change with emphasis on regional scales, is presented. In addition, the study describes the methodological schemes of the downscaling process and presents a discussion of downscaling advantages and disadvantages, while providing applications for regional weather and climate as well as for socio-economic benefits in coastal, agricultural and tourism activities, among others.

#### **\*4 Others Contributions of the Co-PIs Work and Collaborators\***

The general project goal of the Costa Rican Co-PIs was also to develop a historical hurricane database for the Caribbean and Central America and to conduct climate analysis of tropical cyclone activity for the Caribbean and other adjacent regions. The following progress has been made along these lines.

- 1) Lic. Flora Solano and Bach. Adolfo Quesada revised different newspapers from XIX and XX centuries in the Universidad Nacional Autónoma de México

(UNAM), library. Years were selected according to the tropical cyclone impact in the region, using for example the system path in the Intra-American Seas. The search were focus on years 1870, 1873, 1878, 1885, 1900, 1901, 1904, 1906, 1922, 1924, 1933 and 1940. Some of the newspapers used are Siglo Diez y Nueve, el Monitor Republicano, la Voz de México, el Universal, el Excelsior y el Imparcial. Other sources consulted include the “Anuario del Observatorio Astronómico de Tacubaya”, the “Boletines de Estadística”, the Yucatan official newspaper, the “Boletines de la Sociedad de Geografía” from the UNAM Geography Institute, the book “*Los Ciclones Tropicales de México*”, 2001 edition and the father Benito Víñes' book “Investigaciones relativas a la Circulación y *Traslación Ciclónica de los Huracanes de las Antillas*”, 1895 edition. The visit was done from Sep. 27<sup>th</sup> to Oct. 5<sup>Th</sup>, 2009.

- 2) The graduate student, B.Sc. Tito Maldonado, UCR ID A22905, from the Atmospheric Sciences program participated in the workshop on the use of the risk and hazard probabilistic model, Feb. 22-24<sup>th</sup>, 2010 in the UCR. This student is collaborating in the vector and scalar fields analysis and works actually in the Center for Geophysical Research, UCR. This workshop was the continuation of another one celebrated in Bogota, Colombia, from Nov. 18<sup>th</sup> to 20<sup>th</sup>, 2009, in which the graduate geography student B.Sc. Adolfo Quesada participated. Both activities are part of the Central America Probabilistic Risk Assessment (CAPRA) initiative, supported by the World Bank. Additionally, Drs. Alfaro and Amador presented the work Information associated with past hurricanes: some ideas for the CAPRA implementation in Costa Rica, during the Panel 2: Discussion on Risk Assessment and the Central America Probabilistic Risk Assessment Programme (CAPRA) and Global Risk identification programme (GRIP), Session 3: Regional Initiatives in Disaster Risk Reduction and Early Warning Systems  
of the WMO - Training Workshop on Multi-Hazard Early Warning Systems with focus on Institutional Partnership and Coordination . March 22-25, 2010. San Jose, Costa Rica (

[http://www.wmo.int/pages/prog/drr/events/MHEWSCostaRica/index\\_en.html](http://www.wmo.int/pages/prog/drr/events/MHEWSCostaRica/index_en.html), last visit Jun. 6<sup>Th</sup>, 2010).

- 3) The geography graduate student, B.Sc. Adolfo Quesada, continue working in the project building the data base for hurricanes in the Intra Americas Seas, Caribbean and Gulf of Mexico. He is collaborating in the collection of data from the Mesoamerican disaster database as “DesInventar” mostly related with the impact of hurricanes and extreme event disasters. Mr. Quesada is also analyzing the disaster data base EM-DAT (<http://www.emdat.be/>, last visit Jun. 6<sup>Th</sup>, 2010) and the one based in newspapers information and elaborated during the project “Impact and Adaptation to Climate Change and Extreme Events in Central America” (AIACC-LA06-UCR), a regional project funded by (Assessments of Impacts and Adaptations to Climate Change, <http://www.aiaccproject.org/>). Both data bases have information since early 1950s. He has also been collaborating in the analysis of social indices like the Social Development Index (SDI) for communities that are usually impacted by tropical cyclones.
- 4) The historian, Lic. Flora Solano, also continue participating in the project by reviewing the Costa Rican historical archives at different institutions related with hurricanes and extreme event disasters. Because 1968 and 1969 (year identified as an active year for tropical cyclones in Central America) didn't have records in DesInventar data base, Lic. Solano is collecting information associated with this year from different archives and historical sources. Information related with tropical cyclones Camille, Francelia, Jenny, Laurie and Martha is currently being analyzed and also the is actually preparing the work:

Solano, F., **E. Alfaro**, & A. Quesada, 2010: Impacto de los Ciclones Tropicales del Atlántico en Centroamérica, Temporadas de 1968 y 1969 (Impact of the Atlantic Tropical cyclones in Central America. 1968 and 1969 seasons). To be submitted to Diálogos Journal, see: <http://historia.fcs.ucr.ac.cr/>, last visit Jun. 6<sup>Th</sup>, 2010. In Spanish.

- 5) Dr. Alfaro was part of the Committee in the Meteorology Licentiate Thesis:

Zambrano, R., 2008: Características y efectos de los ciclones tropicales que atravesaron o se formaron en las zonas cercanas a la República Bolivariana de Venezuela durante el período 1986-2005 (Characteristics and effects of the tropical cyclones that landed or were formed near Venezuela, 1986-2005). School of Physics, University of Costa Rica, San Jose, Costa Rica. (Dr. **Jorge Gutierrez**, Director).

- 6) Dr. Alfaro directed the Meteorology Licentiate Thesis:

Fallas, B., 2009: Predicción Estacional de los campos de precipitación y temperatura en Centroamérica usando herramientas estadísticas (Seasonal rainfall and temperature prediction using statistical tools). School of Physics, University of Costa Rica, San Jose, Costa Rica.

## \*5 Publications\*

**(The Project CRN2050 is mentioned in the acknowledgements. The pdf version of the published papers are included)**

### Journal – Book Publications

Torrebalba, E., y **J. Amador**, 2010. La corriente en chorro de bajo nivel sobre los Llanos Venezolanos de Sur América. Revista de Climatología, **10**, 1-20. (Available at <http://webs.ono.com/reclim/>, last visit Jun. 6<sup>Th</sup>, 2010) (1)

**Amador, J. y E. Alfaro**, 2009. Métodos de reducción de escala: Aplicaciones al clima, variabilidad y cambio climático. Revista REVIBEC, **11**, 39-52. (Available at <http://www.redibec.org/>, last visit Jun. 6<sup>Th</sup>, 2010) (2)

**Amador J. A., E. Alfaro**, E. Rivera y B. Calderón, 2009. Central America. In: State of the Climate in 2008, Special Supplement to the Bulletin of the American Meteorological Society, 90(8), S130.(Available at <http://journals.ametsoc.org/doi/abs/10.1175/BAMS-90-8-StateoftheClimate>, last visit Jun. 6<sup>Th</sup>, 2010)

- (1) Based on the Meteorology Licentiate Thesis:

Torrealba, E., 2008: La corriente en chorro de bajo nivel al norte de Suramérica. School of Physics, University of Costa Rica, San Jose, Costa Rica. (Dr. **E. Alfaro**, Committee Member, Dr. **Jorge Amador**, Director).

- (2) Paper presented at the “III Ibero American Congress on Development and Environment”. Nov. 5 – 9<sup>th</sup>, 2007. National University, Heredia, Costa Rica.

Project results were also divulged in national conferences. The Co-PI’s and most collaborators participated actively in the University of Costa Rica, Center for Geophysical Research XXXI, and XXXII Mini-Congresses, celebrated in November-2009 and April-2010, respectively.

## \*6 Data\*

At this point the project has used only public databases like Costa Rican History Archives; HURDAT (<http://www.aoml.noaa.gov/hrd/hurdat/>, last visit 25/07/2008), and DesInventar (<http://www.desinventar.org/desinventar.html>, last visit 25/07/2008). The disaster data base elaborated during the project “Impact and Adaptation to Climate Change and Extreme Events in Central America” (AIACC-LA06-UCR), the Social Development Index (available at <http://www.mideplan.go.cr/sides/social/indx10.htm>), the disaster data base EM-DAT (<http://www.emdat.be/>, as a collaboration from the WFP) and the Gross National Product (Costa Rica Central Bank, <http://www.bccr.fi.cr>). Standard grid data such as NCEP/NCAR (Kalnay et al. 1996), ECHAM4.5 (Roeckner et al. 1996) and CCM3.6 (Kiehl et al. 1996) output data were used to performed regional analysis and model simulations.

## \*7 Capacity Building\*

See sections 2 - 5 for the students involved in the project activities.

## **\*8 Regional Collaboration/Networking\***

In the Intra-Americas Seas CLImate Program (IASCLIP) framework, proposed for 2009-2014, as a new component of Climate Variability and Predictability (CLIVAR) Variability of the American Monsoon Systems (VAMOS), Dr. Alfaro is currently the Chair of the Working Group: Applications and Capacity Building (more information is available at [ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP\\_S&Iplan\\_spr08\\_v2.pdf](ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP_S&Iplan_spr08_v2.pdf)). Also, Dr. Amador is the regional Focal Point for the meteorology component in the project Desarrollo de Capacidades de Investigación para la Prevención y Mitigación de Desastres en Centroamerica (Capacity Building and Development for Disasters Prevention/Mitigation in Central America), supported by the Central American Council for Higher Education and the Swedish Agency for International Development Cooperation (see <http://dipredca.csuca.org/> for more information). Both Co-PI's expect that these initiatives will produce a positive feedback in the project activities during the coming years.

## **\*9 Media Coverage and Prizes\***

Dr. Alfaro had an interview in UCR TV Channel 15, "Espectros" Program about his work done at UCR and some project results were explained among other things. The interview was broadcasted June 1<sup>st</sup> and 7<sup>th</sup> at 20:30 and 2<sup>nd</sup> and 8<sup>th</sup> at 12:30pm, Costa Rican local time, 2009.

Drs. Amador and Alfaro working jointly with their colleague Dr. Hugo Hidalgo won in 2009 the Excellency award given by the Florida Ice & Farm Co. The work presented is: Desarrollo y aplicación de un sistema acoplado de modelado atmosférico-hidrológico para la investigación de la variabilidad climática estacional y del cambio climático regional (Development and implementation of a couple atmosphere-hydrology model for the seasonal regional climate variability and change, see [http://www.florida.co.cr/info\\_corp\\_es/ganadores\\_aportes.php](http://www.florida.co.cr/info_corp_es/ganadores_aportes.php), last visit Jun. 6<sup>Th</sup>, 2010).

## **\*10 Policy Relevance\***

Nothing definitive to report yet, however, some of the publications could be used to strengthen the views of policy makers in regards to the relevance of weather and climate impacts on society.

## **\*11 Main Conclusions\***

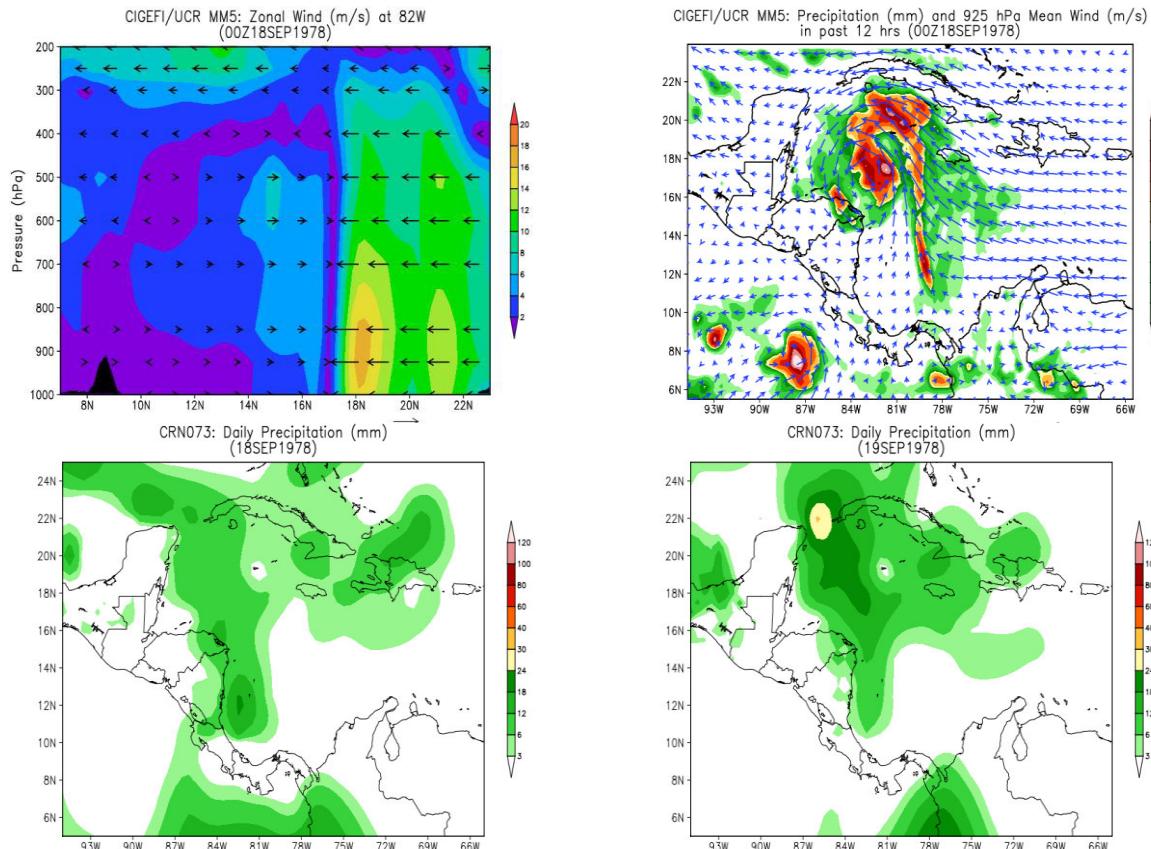
- 1.** The start of this project, at a local level, has been seriously delayed due to complications arising from contract and subcontract negotiations. Essentially the Year 1 and 2 budgets for the Co-PIs have not been spent as a result of the delay in setting up the sub-awards and the delays in the way that the money was transferred to UCR (ordinary mail). These project delays have affected the overall goals, objectives, and the progress of the project.
- 2.** Despite the delays certain project activities have been conducted using small local funds (see sections 3 and 4). Co-Pi's expect to carry over the Year 1&2 budgets to the budget of the coming years, so that some of these project-related activities can be properly funded and executed. See section 12 for explanation.
- 3.** A great deal of data has been analyzed and archived, making this a valuable contribution to the scientific community interested in tropical cyclones and low-level jets at low-latitudes.
- 4.** A considerable number of undergraduate and graduate students, both at the UCR and other institutions abroad, have benefited from the project, by means of discussions, available facilities and materials, statistical and numerical model development and scientific publications.

**5.** The published papers and poster presentations speak of reasonable scientific achievements related to the project objectives and provide new research opportunities with other scientific groups interested in the region.

**6.** The funding provided by the IAI has been very important to promote research in tropical meteorology in the region, especially in those scientific topics that are associated with atmospheric systems that impact the region leaving large amounts of material and human loses in an already very vulnerable regional society.

## \*12 Work Plan for Next Year with Associated Costs\*

The Co-PI's will continue with the Database improvement and the case studies, collecting socio-economic, historical, and climatic data from regional libraries and archives to develop a database for hurricane impacts in the Caribbean region. Specific cases of historical hurricane disasters will be selected for detailed study, and information gathered will be fed into the GIS for display and analysis. To achieve the above, it is planned to incorporate more students and researchers into the process.



**Figure 4.** MM5v3 model simulations of hurricane Greta on 18 September 1978 at 00 Z showing a cross section of the zonal wind at 82° W (upper left panel), the precipitation distribution and mean wind (both from last 12 hours from 00 Z) at 925 hPa (upper right panel). For comparison purposes, daily precipitation distributions for Greta on 18 September 1978 (lower left panel) and 19 September 1978 (lower right panel) using data from the project IAI-CRN073

(<http://iridl.ldeo.columbia.edu/SOURCES/.UNAM/.gridded/.monthly/.v0602/>)

Also, some simulations using the Center for Geophysical Research, University of Costa Rica, atmospheric model system will be perform using dynamical downscaling techniques [ECHAM4.5, GFS, MM5v3, WRFv3] in order to understand the applicability (limitations and advantages) of regional numerical products and its relationship with social impacts in the past.

Plans include an increase in the spatial resolution of the dynamical models to scales, depending on computer resources, such that a better understanding of the ocean-atmosphere-land interactions processes can be achieved. The success of the simulations may depend, of course at some point, on data availability to initialize the models.

Figure 4 presents an example of an improved topographical representation of the Central America topography in order to study air flow-topography interactions and associated precipitation distribution during cases where hurricanes are close to the Central America coastline in the Caribbean. This is the case of hurricane Greta in September 1978. Figure 4 illustrates MM5v3 model simulations of hurricane Greta on 18 September 1978 at 00 Z showing a cross section of the zonal wind at 82° W (upper left panel), and the precipitation distribution and mean wind (both from last 12 hours from 00

Z) at 925 hPa (upper right panel). For comparison purposes, daily precipitation distributions for Greta on 18 September 1978 (lower left panel) and 19 September 1978 (lower right panel) using data from the project IAI-CRN073. As observed from the cross section in Figure 4, there is a strong convergence at all levels below 500 hPa in the zonal wind component near 17° N consistent with the model precipitation distribution in Figure 4 upper right panel. The “observed precipitation” for 18, 19 September, using IAI-CRN073 data, shows good agreement with corresponding model output, especially over land, which is indicative of model skill to capture basic ocean-atmosphere-land interactions.

Co-PI Amador is planning to update current knowledge on the dynamics and role of the Intra-Americas Low-Level Jet (IALLJ) on moisture transport in weather and climate in the region, and to model IALLJ boundary layer processes using a mesoscale model such as the MM5v3. In this respect, an effort will be made to incorporate more research associates to the project activities and spend the July 2008-June 2009 corresponding budget along with some funds from the previous non-used budget (see main conclusions above) to support these activities. Visits to Meso-America and Caribbean Historical Archives such as those in Guatemala, Dominican Republic, and Colombia are also being considered for the coming year.

### **\*13 References not included in Section 5 Publications\***

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**Universidad de Costa Rica**  
**Vicerrectoría de Investigación**  
**Centro de Investigaciones Geofísicas**  
Tels. (506) 2511 6388 / 2511 5320  
Fax. (506) 2234 2703  
Email: [cigefi@cigefi.ucr.ac.cr](mailto:cigefi@cigefi.ucr.ac.cr)



## **Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity**

**PI: Dr. Kam-biu Liu (Louisiana State University)**

**Co-PIs Technical Report**

**Dr. Eric J. Alfaro**

**Dr. Jorge A. Amador**

**Prime Award: CRNII 2050 (NSF Grant No. GEO-0452325)**

**Sub-award: University of Costa Rica (No. 11805)**

**April 2011**

## **\*1 Project Title, Project Number, Principal Investigator, Key Words\***

**Project Title:** Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity

**Project Number:** IAI-CRN-2050

**Principal Investigator:** Kam-biu Liu (Louisiana State University)

**Key words:** paleotempestology, Caribbean low-level jet, hurricanes, climate change, vulnerability, social impact, extreme events

## **\*2 Project Funding\***

The University of Costa Rica (UCR) received from LSU the fourth project payment. It was received the second week of April, 2011. Dr. Amador and Dr. Alfaro received 11199.60 and 13200.8 US dollars, respectively (see lines in section “Mas: Ingreso” in the financial report given by the UCR Foundation for Research, FUNDEVI).

The national component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The title of the national component is: “Estudio y comparación histórica del impacto de ciclones tropicales en Centroamérica y el Caribe”, PI Dr. Eric J. Alfaro and Co-PI Dr. Jorge A. Amador. The grant number is V.I. 805-A7-002. During 2010 this project received from the University of Costa Rica 332 363 Costa Rican colones (about 665 US dollars, 2.80% of the IAI annual funding); all for student support. The undergraduate meteorology student Natalie Mora (UCR ID number A53709) working in the project supported by these funds, basically helping with information processing, digitalization and data base building. Other UCR contributions (i.e., that from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone, basic

computer cluster maintenance and use, and local administrative support. This contribution is estimated in 10000 US dollars for the period January 2010-April 2011.

### **\*3 Research Activities and Findings\***

Part of the material that was presented in poster session at the **2<sup>nd</sup> Summit on Hurricanes and Climate Change**. May 31-June 5, 2009. in Corfu, Greece, was considered as the basis for a contribution to the Summit Memories book, the paper published is:

**Amador J. A., E. Alfaro, E. Rivera and B. Calderón, 2010. Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas. In J.B. Elsner et al. (eds.), Hurricanes and Climate Change: Volume 2, DOI 10.1007/978-90-481-9510-7 9 (pp. 149-173). New York: Springer.**

In this book chapter, Amador et al. (2010) used indexes of the Intra-Americas or Caribbean Low-Level Jet (IALLJ or CLLJ, respectively), Niño 3, Tropical North Atlantic (NATL), Atlantic Multidecadal Oscillation (AMO), and Outgoing Long Wave Radiation (OLR) are quantified for the period 1950–2007, to study their relationship with tropical cyclone (TC) frequency for summer–autumn of the Northern Hemisphere. A remarkable inverse relationship is found between both, the strength of the wind speed at 925 hPa and the vertical wind shear at low levels, and the monthly relative frequency of TCs for two selected areas in the Caribbean. The July peak in wind speed and low-level vertical wind shear are associated with a minimum in the monthly relative frequency of TCs. On the contrary, a decrease in the wind speed and vertical shears are associated with a maximum value of the relative frequency of TCs. Stronger (weaker) than normal IALLJ summer winds (July–August) during warm (cold) ENSO events imply a stronger (weaker) than normal vertical wind shear at low-levels in the Caribbean. This condition may inhibit (allow) deep convection, disfavoring (favoring) TC development during these months. Correlation values of the monthly mean CLLJ core winds and the monthly normalized values of NATL – Niño 3 index for 1950–2007 showed statistical significance greater than 99% during July–August.

During El Niño years, low-level wind increases at the jet core strengthening the low level convergence near Central America at the jet exit and the low-level divergence in the central Caribbean at the jet entrance. The descending motion associated with the latter acts as an inhibiting factor for convection and TC development. TC activity in the Caribbean is not only sensitive to ENSO influences, but to the strength of the CLLJ vertical wind shear, to barotropic energy conversions induced by the lateral wind shear, to the intensity of the regional scale descending motion associated with the jet entrance, and to the SST cooling generated by the CLLJ at the sea surface. Climatology of a group of General Circulation Models used in the 2007 report of the IPCC were tested to study their ability to capture the low-level wind annual cycle over the Caribbean and the known CLLJ structure. Some models do not capture basic characteristics of the jet. A discussion of cyclone potential over the Caribbean, based on the relationships developed using the models climatology, is presented for the period 2010–2050. As a study case, the findings were contrasted with the observed 2008 climate over the IAS region. Rainy season for 2008 in Central America evolved in a way consistent with the presence of La Niña event and the meridional migration of the ITCZ. Wind anomalies associated with the IALLJ were larger (smaller) than normal during February (July) 2008, in agreement with earlier findings in regards to the relationship of the IALLJ and ENSO phases. The year of 2008 was very active for tropical storm formation in the Caribbean basin ( $10\text{--}22.5^\circ \text{ N}$ ,  $60\text{--}82.5^\circ \text{ W}$ ). From 16 named storms observed in the Atlantic, 10 entered the Caribbean basin. Eight (five) Atlantic cyclones were hurricanes (strong hurricanes) and from the five hurricanes crossing the Caribbean basin, four were strong.

Based on the above work, Dr. Amador made a poster presentation during the European Geosciences Union General Assembly 2011, Vienna, Austria, Apr. 03rd – 08<sup>th</sup>, during the Tropical-Tropical Teleconnections and Variability session (ref. EGU2011-7551). See Appendix 1 for a description of the poster scientific contents.

The other poster presented at the 2009 Corfu Summit was used as the base of the paper:

**Alfaro, E., A. Quesada y F. Solano, 2010. Análisis del impacto en Costa Rica de los ciclones tropicales ocurridos en el Mar Caribe desde 1968 al 2007 (Analysis of Caribbean Sea tropical**

cyclones occurrences from 1968 to 2007 and their impact in Costa Rica, Revista Diálogos, <http://historia.fcs.ucr.ac.cr/>). Revista Diálogos, **11**(2), 22-38. In Spanish.

In this work, Alfaro et al. (2010) pointed out that the study of tropical cyclones activity in the Caribbean and their historic characterization in the Central American region is a basic element to mitigate their impact over different regions of the isthmus. Years with high and low tropical cyclone impacts in Central America were defined, considering variables like track, residence time near the isthmus and the annual occurrence of cyclones in the basin. The analysis showed that tropical cyclones are more likely to occur near Central America during August-September-October. Also, positive sea surface temperature and relative humidity at 700hPa and negative sea level pressure anomalies at the Tropical North Atlantic were observed for the years that showed high occurrences of tropical cyclones near Central America. Additionally, Costa Rica has a good natural disasters data base, related with events that affected specific locations and several socioeconomic sectors like agriculture, energy and transport. This data base, allowed the study of disasters in Costa Rica related with tropical cyclones during the last four decades. The analysis showed a trend in the annual number of impacts related with hydro-meteorology causes that cannot be explained by climate trends only. That means that other variables like those related with socioeconomic aspects should be included in the analysis to explain this variability and their associated impacts.

Dr. Alfaro made a presentation based partially on the above paper during the XXXI Central America Climate Outlook Forum in San Salvador, El Salvador, July 2010 and in the American Geophysical Union (AGU), 2010 The Meeting of the Americas. Foz do Iguaçu, Brazil, Aug. 8 – 12th, 2010. The works presented during this AGU meeting were: Retrospective analysis of extreme meteorological events in Central and North America from 1972 to 2001 (H.G. Hidalgo; **E.J. Alfaro**; T. Cavazos; A. Gershunov, oral) and Caribbean Sea Tropical Cyclone occurrences in the last six decades and their impacts in Central America and the Caribbean Islands (**E.J. Alfaro**, poster available at <http://kerwa.ucr.ac.cr/handle/10669/417>, last visit Apr. 26<sup>th</sup>, 2011).

Continuing with the previous initiative of 2008 and 2009, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2010, with focus in Central America, a Special Supplement to the Bulletin of the American Meteorological Society. This invitation derived in a short paper contribution to that issue that will be published by the middle of 2011. As part of the above collaboration this team of researchers prepared additional data and analysis for Central America and the Caribbean for 2010. The paper submitted is:

**Amador, J. A., E. J. Alfaro, H. Hidalgo & B. Calderon, 2011.** Central America. In: State of the Climate in 2010, Special Supplement to the Bull. Amer. Met. Soc., 92(8), Sxx., in press.

The 2011 special issue of BAMS on State of climate 2010 will also contain a “blue box” with information relative to the impacts of meteorological phenomena and tropical cyclones in Central America.

**Amador, J. A., 2011.** Socio-economic impacts associated with meteorological systems and tropical cyclones in Central America in 2010 [In State of the Climate 2011], Bull. Amer. Met. Soc., 92(8), Sxx., in press.

#### **\*4 Others Contributions of the Co-PIs Work and Collaborators\***

The Center for Geophysical Research, University of Costa Rica, hosted in its facilities the CRN2050 Workshop in February 17-18th, 2011. The agenda and the list of participants are included in the Appendix 2 at the end of this report. Between the objectives of the workshop were to present the project results, integrate and synthesize the main findings, and discuss future collaborations. All the co-PIs were invited to attend, and the participation of several students was supported too.

The general project goal of the Costa Rican Co-PIs was also to develop a historical hurricane database for the Caribbean and Central America and to conduct climate analysis of tropical cyclone activity for the Caribbean and other adjacent regions. The following progress has been made along these lines.

- 1) The graduate student, B.Sc. Blanca Calderón, UCR ID 990724, from the Postgraduate Program in Atmospheric Sciences. Continue the research related with the comparative case study of several tropical cyclones. Under the guidance of Dr. Amador, the work has continued focusing on: experiments with different parameterization schemes, in order to optimize results, the analysis of vertical sections for the wind field of and temperature and the comparison of specific humidity, divergence and moisture flux divergence of selected case studies.

The B.Sc. Calderon contributed also for the 1891 Cartago Floods in Costa Rica. This work was part of the Seminar I of the Master of Atmospheric Sciences, which has been studying extreme weather events occurred in Cartago, Costa Rica, 26 and 27 October, 1891. To study this phenomenon were be used historical databases CHUAN-The Comprehensive Historical Upper-Air Network-(Stickler et al. 2010) and Reanalysis Version 2 (Compo et al. 2010), and information from newspapers, books , etc. from the late nineteenth century. It is intended not only to study the phenomenon from the standpoint of weather and social impacts, but also to assess the historical data bases, in regard to the great importance of they have to do research in climate.

- 2) The graduate student, B.Sc. Tito Maldonado, UCR ID A22905, from the Postgraduate Program in Atmospheric Sciences submitted the work:

Maldonado, T., **E. Alfaro**, B. Fallas and L. Alvarado, 2011. Seasonal prediction of extreme precipitation events and frequency of rainy days over Costa Rica, Central America, using Canonical Correlation Analysis. Submitted to Advances in Science and Research.

The paper mentioned above was presented by this student at the XXXI Central America Climate Outlook Forum in San Salvador, El Salvador, July 2010. This work was also presented by Dr. Alfaro during the International Workshop on ENSO, Decadal Variability and Climate Change in South America '*Trends, Teleconnections and Potential Impacts*'. CIIFEN, Guayaquil, Ecuador, Oct. 12 – 14, 2010, under the title: "Decadal and interannual SST influences on Central American precipitation: tailoring the seasonal climate predictions" (**E. Alfaro** y T. Maldonado), session: "The 2009-2010 El Niño: regional analyses, forecasts, impacts, and climate service applications".

B.Sc. Maldonado collaborated additionally in the vector and scalar field analysis and works in the Center for Geophysical Research, UCR. He started his PhD studies at University of Uppsala, Sweden in April, 2011.

- 3) The historian Lic. Flora Solano, is currently leading the already accepted work:

Solano, F., **E. Alfaro**, & A. Quesada, 2010: Impacto de los Ciclones Tropicales del Atlántico en Centroamérica, Temporadas de 1968 y 1969 (Impact of the Atlantic Tropical cyclones in Central America. 1968 and 1969 seasons). Accepted for publication at Revista Diálogos, see: <http://historia.fcs.ucr.ac.cr/>, last visit Jun. 6<sup>Th</sup>, 2010. In Spanish.

She will continue her research into the nineteenth century and other periods, using several data sets and using different archives from Libraries and governmental institutions of Central America. She is also collaborating in the preparation of manuscripts for submission.

## \*5 Publications\*

(The Project CRN2050 is mentioned in the acknowledgements. The pdf versions of the published papers are included)

## **Journal – Book Publications**

**Alfaro, E.**, A. Quesada and F. Solano, 2010. Análisis del impacto en Costa Rica de los ciclones tropicales ocurridos en el Mar Caribe desde 1968 al 2007 (Analysis of Caribbean Sea tropical cyclones occurrences from 1968 to 2007 and their impact in Costa Rica, Revista Diálogos, available at: <http://historia.fcs.ucr.ac.cr/>). Revista Diálogos, **11**(2), 22-38. In Spanish.

**Amador J. A., E. Alfaro**, H. Hidalgo, E. Rivera and B. Calderon, 2010. Central America. In: State of the Climate in 2009, Special Supplement to the Bulletin of the American Meteorological Society, **91**(7), S143-144. (available at <http://globalfundexchange.com/press/wp-content/uploads/2010/07/climate-assessment-2009-lo-rez.pdf>, last visit Apr. 26<sup>th</sup>, 2011)

**Amador J. A., E. Alfaro**, E. Rivera and B. Calderon, 2010. Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas. In J.B. Elsner et al. (eds.), Hurricanes and Climate Change: Volume 2, DOI 10.1007/978-90-481-9510-7\_9 (pp. 149-173). New York: Springer.

Project results were also divulgated in national conferences. The Co-PI's and most collaborators participated actively in the University of Costa Rica, Center for Geophysical Research XXXIII, and XXXIV Mini-Congresses, celebrated in December-2010 and April-2011, respectively.

## **\*6 Data\***

At this point the project has used only public databases like Costa Rican History Archives; HURDAT (<http://www.aoml.noaa.gov/hrd/hurdat/>, last visit 25/07/2008), and DesInventar (<http://www.desinventar.org/desinventar.html>, last visit 25/07/2008). The disaster data base elaborated during the project “Impact and Adaptation to Climate Change and Extreme Events in Central America” (AIACC-LA06-UCR,

[http://www.aiaccproject.org/aiacc\\_studies/aiacc\\_studies.html](http://www.aiaccproject.org/aiacc_studies/aiacc_studies.html), last visit Jun. 17<sup>Th</sup>, 2010), the Social Development Index (available at <http://www.mideplan.go.cr/sides/social/indx10.htm>), the disaster data base EM-DAT (<http://www.emdat.be/>, as a collaboration from the WFP) and the Gross National Product (Costa Rica Central Bank, <http://www.bccr.fi.cr>). Standard grid data such as NCEP/NCAR (Kalnay et al. 1996), ECHAM4.5 (Roeckner et al. 1996) and CCM3.6 (Kiehl et al. 1996) output data were used to performed regional analysis and model simulations.

New data bases used include those described in Compo et al. (2010) and Stickler et al. (2010). Other data bases used include, Precipitation - Xie & Arkin ver(1,2) ([http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.Merged\\_Analysis/](http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.Merged_Analysis/)), SST - Smith & Reynolds (<http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.ERSST/.version3b/>), Wind - Quikscat ([http://www.remss.com/qscat/qscat\\_description.html](http://www.remss.com/qscat/qscat_description.html), <http://www.ifremer.fr/cersat/en/data/overview/gridded/mwfqscat.htm>) and Precipitation - TRMM (<http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=TRMM&dataGroup=Gridded>).

## \*7 Capacity Building\*

See sections 2 - 5 for the students involved in the project activities.

## \*8 Regional Collaboration/Networking\*

The ANUIES-CSUCA project Evaluación de impactos hidrometeorológicos extremos en Centroamérica y Norteamérica relacionados con los huracanes (Assessment of the extreme hydrometeorological event impacts in Central – North America related with hurricanes), P.I.s Drs. Tereza Cavazos, CICESE and Eric Alfaro, UCR, was developed during 2010. It was supported by the Mexico and Central America Public University Unions (ANUIES &

CSUCA, respectively). Co-PIs were: Drs. Hugo Hidalgo, UCR and Luis Farfan, CICESE & IAI-CRN2048. A collaboration workshop was developed in CICESE, Ensenada, Mexico, December 6-10, 2010, including the participation of Dr. Jorge Amador, UCR & IAI-CRN2050 and B.Sc. Tito Maldonado.

In the Intra-Americas Seas CLImate Program (IASCLIP) framework, proposed for 2009-2014, as a new component of Climate Variability and Predictability (CLIVAR) Variability of the American Monsoon Systems (VAMOS), Dr. Alfaro is currently the Chair of the Working Group: Applications and Capacity Building (more information is available at [ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP\\_S&Iplan\\_spr08\\_v2.pdf](ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP_S&Iplan_spr08_v2.pdf)).

Dr. Amador is the regional Focal Point for the meteorology component in the project Desarrollo de Capacidades de Investigación para la Prevención y Mitigación de Desastres en Centroamerica (Capacity Building and Development for Disasters Prevention/Mitigation in Central America), supported by the Central American Council for Higher Education and the Swedish Agency for International Development Cooperation (see <http://dipredca.csuca.org/> for more information). Both Co-PI's expect that these initiatives will produce a positive feedback in the project activities during the coming years.

## \*9 Media Coverage and Prizes\*

Drs. Amador and Alfaro are working jointly with their colleague Dr. Hugo Hidalgo in the second year of the 2009 Excellency Award granted by the Florida Ice & Farm Co. The work funded was: Desarrollo y aplicación de un sistema acoplado de modelado atmosférico-hidrológico para la investigación de la variabilidad climática estacional y del cambio climático regional (Development and implementation of a coupled atmosphere-hydrological model for seasonal regional climate variability and climate change research, see [http://www.florida.co.cr/info\\_corp\\_es/ganadores\\_aportes.php](http://www.florida.co.cr/info_corp_es/ganadores_aportes.php), last visit Jun. 6<sup>th</sup>, 2010).

## **\*10 Policy Relevance\***

Nothing definitive to report yet, however, some of the publications could be used to strengthen the views of policy makers in regards to the relevance of weather and climate impacts on society.

## **\*11 Main Conclusions\***

1. The project developed according to proposed objectives and activities, and provided the primary input to the investigators to prepare other research initiatives such as the one that won the 2009 Excellency Award.
2. A great deal of data was analyzed, archived and relevant results were published or are in the process to be published, making this a valuable contribution to the scientific community interested in tropical cyclones and low-level jets at low-latitudes.
3. A considerable number of undergraduate and graduate students, both at the UCR and other institutions abroad, have benefited from the project, by means of discussions, for a and local workshops, available facilities and materials, statistical and numerical model development and scientific publications.
4. The published papers (and those to appear in the next months), and poster presentations tell of relevant scientific achievements related to the project objectives and provide new research opportunities for local students and other scientific groups interested in the region.
5. The funding provided by the IAI has been very important to promote research in tropical meteorology in the region, especially in those scientific topics that are associated with atmospheric systems that impact the region leaving large amounts of material and human loses, in an already very vulnerable regional society.

## **\*12 Work Plan for Next Year with Associated Costs\***

The Co-PI's will continue with the Database improvement and the case studies, collecting socio-economic, historical, and climatic data from regional libraries and archives to develop a database for hurricane impacts in the Caribbean region. Specific cases of historical hurricane disasters will continue for a more detailed study, and information gathered will be fed into a GIS for display and analysis. Following our work on climate indexes and tropical cyclone activity (as in the paper published by our group, Amador et al. 2010), we suggest to extend the estimation of these indexes back to 1871 using the information provided in the paper by Compo et al. 2010 and perhaps using additional data from Sticker et al. 2010. An important part of the work planned for last year is to resume and integrate results, considering also the elaboration of papers to be submitted in peer review journals.

## **\*13 References not included in Section 5 Publications\***

- Compo GP, Whitaker JS, Sardeshmukh PD, Matsui N, Allan RJ, Yin X, Gleason Jr BE, Vose RS, Rutledge G, Bessemoulin P, Brönnimann S, Brunet M, Crouthamel RI, Grant AN, Groisman PY, Jones PD, Kruk MC, Kruger AC, Marshall GJ, Maugeri M, Mok HY, Nordli Ø, Ross TF, Trigo RM, Wang XL, Woodruff SD, Worley SJ. 2011. The Twentieth Century Reanalysis Project. *Q. J. R. Meteorol. Soc.* 137: 1–28. DOI:10.1002/qj.776
- Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R., Joseph, D., 1996. The NCEP/NCAR Reanalysis 40-year Project. *Bulletin of the American Meteorological Society* 77, 437–471.
- Kiehl, J. T., J. J. Hack, G. B. Bonan, B. A. Boville, B. P. Briegleb, D. L. Williamson and P. J. Rasch., 1996. Description of the NCAR Community Climate Model (CCM3). NCAR/TN-420+STR.

- Roeckner, E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, 1996. The atmospheric general circulation model ECHAM4: Model description and simulation of present-day climate. Max Planck Institut für Meteorologie, Report No. 218, Hamburg, Germany, 90 pp.
- Stickler, A; Grant, A N; Ewen, T; Ross, T F; Vose, R S; Comeaux, J; Bessemoulin, P; Jylhä, K; Adam, W K; Jeannet, P; Nagurny, A; Sterin, A M; Allan, R; Compo, G P; Griesser, T; Brönnimann, S (2010). The comprehensive historical upper-air network. *Bulletin of the American Meteorological Society*, 91(6):741 -751.

# Appendix 1.

Poster presented at the European Geosciences Union General Assembly 2011,  
Austria Vienna Center, Austria, 3-8 April 2011.

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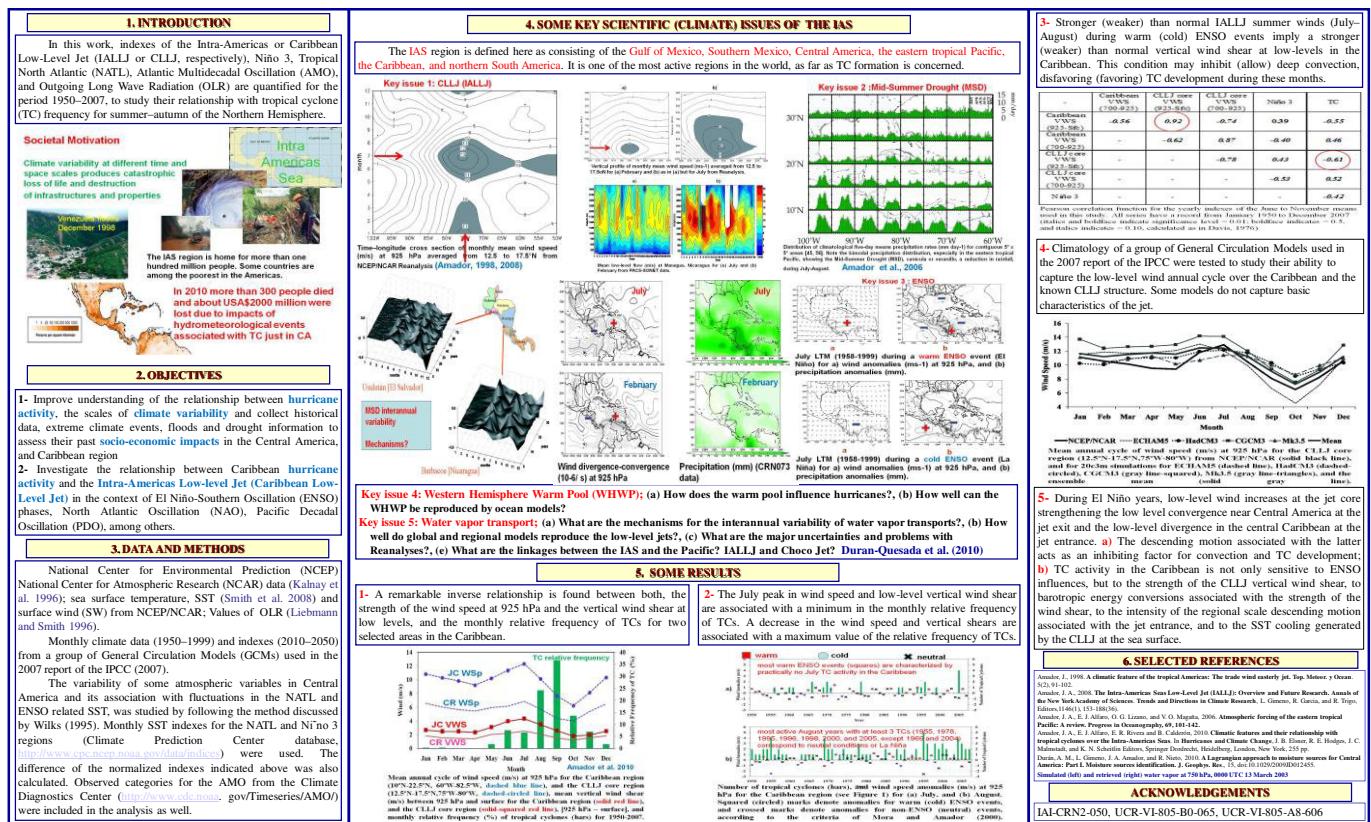


## Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas (IAS)

Jorge A. Amador<sup>1,2</sup>, Eric J. Alfaro<sup>1,2</sup>, Erick R. Rivera<sup>1</sup>, and Blanca Calderón<sup>1</sup>

<sup>1</sup>: Center for Geophysical Research; <sup>2</sup>: School of Physics,  
University of Costa Rica, San José 11501-2060, Costa Rica

Corresponding Author Email : jorge.amador@ucr.ac.cr



## **Appendix 2**

**CRN2050 Workshop**  
**Paleotempestology and Hurricane Climate Variability of the Caribbean**  
**Region**  
**February 17-18, 2011**  
**University of Costa Rica, San Jose, Costa Rica**

**Feb 17 (Thursday)**

9:00-9:15 a.m.	Welcome & Introduction
9:15-10:30 a.m.	Kam-biu Liu: “Sedimentary proxy records of past hurricane activity from the Caribbean and Central America”. Dana MacDonald: “Seismic Sub-bottom Profiling and Coring: Pelican Cayes, Belize”.
10:30-10:45 a.m.	Coffee break
10:45-12:00 a.m.	Kathryn Denommee & Sam Bentley: “High-resolution record of paleo-hurricane strikes from the Blue Hole, Belize”. Matt Peros: “Progress report on Cuba research”.
12:00-12:30 p.m.	Discussion
12:30-2:00 p.m.	Lunch
2:00-3:15 p.m.	Amy Frappier: “New approaches to speleothem paleotempestology: A 2300-year stratigraphic record of seasonal flooding events and hurricane frequency in Yucatan, Mexico”. Claudia Mora: “Progress report on dendro-paleotempestology”.
3:15-3:30 p.m.	Coffee break
3:30-4:30 p.m.	Terry McCloskey: “Caribbean paleotempestology: Findings and implications”. Tom Bianchette: “Paleohurricane proxy records from the Pacific coast of Mexico: A progress report”. Flora Solano: “Historical Impacts of Tropical Cyclone in Central America and the Caribbean (Costa Rica).”
4:30-5:00 p.m.	Discussion

6:30 p.m. Dinner

**Feb 18 (Friday)**

9:15-10:30 a.m. climate years."	Jorge Sanchez-Sesma: "Atlantic tropical cyclones, ENSO, and oscillations (linear and non-linear) during last 2000 years."
Inter-	Jorge Amador: "Tropical cyclone dynamics and meteorology in the American Seas"
10:30-10:45 a.m.	Coffee break
10:45-12:00 a.m.	Eric Alfaro: "Caribbean TC activity: Trends, historical records, and societal impacts in Central America". Nina Lam: "Vulnerability Assessment for Caribbean Countries".
12:00-12:30 p.m.	Discussion
12:30-2:00 p.m.	Lunch
2:00-3:30 p.m. IAI	Helbert Arenas: "Communicating Results Using Web-based GIS and Data and Information System"  Tito Maldonado & Eric Alfaro: - "Seasonal prediction of extreme precipitation events and frequency of rainy days over Costa Rica, Central America, using Canonical Correlation Analysis."  Rodrigo Castillo: Analysis of meteorological data during TC4.
	Blanca Calderon & Jorge Amador: - Numerical Simulations of Tropical Cyclones (Preliminary Results). - The 1891 Cartago Floods.
	Rodney Mora & Jorge A. Amador: ENSO and tropical cyclone frequency in the first half of the Twentieth Century
3:30-3:45 p.m.	Coffee break
3:45-5:30 p.m.	Discussion and conclusion
6:30 p.m.	Dinner

## **List of Participants**

### **Name, Affiliation, Address**

- 1) Kam-biu Liu, Louisiana State University, Department of Oceanography & Coastal Sciences
- 2) Nina Lam, Louisiana State University, Department of Environmental Sciences
- 3) Samuel Bentley, Louisiana State University, Department of Geology & Geophysics
- 4) Matthew Peros, University of Ottawa, Department of Geography
- 5) Claudia Mora, Los Alamos National Laboratory, Earth & Environmental Sciences Division
- 6) Amy Frappier, Skidmore College, Department of Geosciences
- 7) Jorge Sanchez-Sesma, IMTA, Mexico
- 8) Jorge Amador, University of Costa Rica, CIGEFI
- 9) Eric Alfaro, University of Costa Rica, CIGEFI
- 10) Dana MacDonald, Brown University, Department of Geological Sciences
- 11) Kathryn Denommee, Memorial University of Newfoundland, Department of Earth Sciences
- 12) Thomas Bianchette, Louisiana State University, Department of Oceanography & Coastal Sciences
- 13) Terry McCloskey, Louisiana State University, Department of Oceanography & Coastal Sciences
- 14) Helbert Arenas, Louisiana State University, Department of Environmental Sciences
- 15) Flora Solano, University of Costa Rica, CIGEFI
- 16) Tito Maldonado, University of Costa Rica, CIGEFI
- 17) Rodrigo Castillo, University of Costa Rica, CIGEFI
- 18) Blanca Calderon, University of Costa Rica, CIGEFI





Universidad de Costa Rica  
Vicerrectoría de Investigación  
Centro de Investigaciones Geofísicas  
Tels. (506) 2511 6388 / 2511 5320  
Fax. (506) 2234 2703  
Email: [cigefi@cigefi.ucr.ac.cr](mailto:cigefi@cigefi.ucr.ac.cr)



## **Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity**

**PI: Dr. Kam-biu Liu (Louisiana State University)**

**Final Co-PIs Technical Report**

**Dr. Eric J. Alfaro**

**Dr. Jorge A. Amador**

**Prime Award: CRNII 2050 (NSF Grant No. GEO-0452325)**

**Sub-award: University of Costa Rica (No. 11805)**

**May 2012**

## **\*1 Project Title, Project Number, Principal Investigator, Key Words\***

**Project Title:** Paleotempestology of the Caribbean Region: A Multi-proxy, Multi-site Study of the Spatial and Temporal Variability of Caribbean Hurricane Activity

**Project Number:** IAI-CRN-2050

**Principal Investigator:** Kam-biu Liu (Louisiana State University)

**Key words:** paleotempestology, Caribbean low-level jet, hurricanes, climate change, vulnerability, social impact, extreme events

## **\*2 Project Funding\***

After the fourth project payment, described in the last report and received the second week of April 2011, the University of Costa Rica (UCR) didn't receive any additional payment from LSU. These funds were executed until February 2012, according to the PI instructions.

The national component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The title of the national component is: "Estudio y comparación histórica del impacto de ciclones tropicales en Centroamérica y el Caribe", PI Dr. Eric J. Alfaro and Co-PI Dr. Jorge A. Amador. The grant number is V.I. 805-A7-002. During 2011 this project received from the University of Costa Rica 466 744 Costa Rican colones (about 918 US dollars, 3.83% of the IAI annual funding); for student support, printing, paper and computing materials. The undergraduate meteorology student Aaron Vega (UCR ID number A96690) is working in the project supported by these funds, basically helping with information processing, digitalization and data base building. Other UCR contributions (i.e., that from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone, basic computer cluster maintenance and use, and local

administrative support. This contribution is estimated in 10000 US dollars for the period January 2011-April 2012.

### **\*3 Research Activities and Findings\***

Some of the Co-PIs activities were related with finishing works that were in progress in past reports (see also section 4). For example, Alfaro and Quesada (2010) continued and extended the work of Alfaro et al. (2010). They defined years with high and low tropical cyclone impacts in Costa Rica related to tropical cyclone occurrences in the Caribbean Sea during 1948-2007. The analysis showed a trend in the annual number of impacts related with hydrometeorological causes that cannot be explained by climate trends only. It means that other variables like those related with socioeconomic aspects should be included in the analysis to explain this variability and their associated impacts.

Continuing with the previous initiative of 2008, 2009 and 2010, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2010, with focus in Central America, a Special Supplement to the Bulletin of the American Meteorological Society. This invitation derived in a short paper contribution to that issue. As part of the above collaboration this team of researchers prepared additional data and analysis for Central America and the Caribbean for 2010. The 2011 special issue of BAMS on State of Climate 2010 contained also a “blue box” with information relative to the impacts of meteorological phenomena and tropical cyclones in Central America. The works are listed in section 5 (see Amador et al. 2011 and Amador 2011, respectively).

### **\*4 Others Contributions of the Co-PIs Work and Collaborators\***

The general project goal of the Costa Rican Co-PIs was also to develop a historical hurricane database for the Caribbean and Central America and to conduct climate analysis of tropical cyclone activity for the Caribbean and other adjacent regions. The following progress has been made along these lines.

- 1) The graduate student, B.Sc. Blanca Calderón, UCR ID 990724, from the Postgraduate Program in Atmospheric Sciences, continue the research related with the comparative case study of several tropical cyclones. Under the guidance of Dr. Amador, the work has continued focusing on: experiments with different parameterization schemes, in order to optimize results, the analysis of vertical sections for the wind field of and temperature and the comparison of specific humidity, divergence and moisture flux divergence of selected case studies. The evidence for more (less) precipitation generated by Felix (Greta), Dean (Fifi) in Costa Rica, their short life cycle for both (5-6 days), the maximum category reach, the similarity in their tracks and the abundant precipitation generated by hurricanes Cesar and Joan, are the criteria used for the study case selection.

Meridional and longitudinal wind and temperature profiles for hurricanes Felix and Greta were analyzed. A comparison of specific humidity, divergence and humidity flux divergence fields for the study cases were made (Figs. 1 and 2).

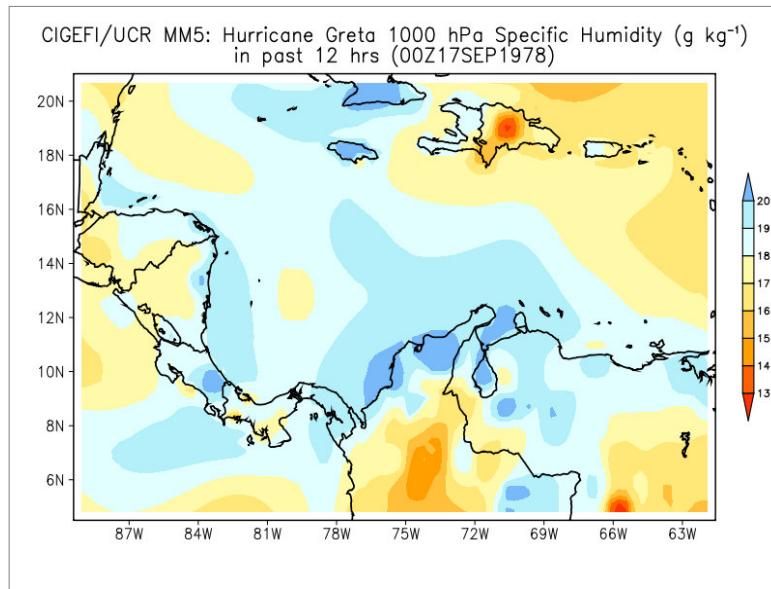


Figure 1: Twelve hours surface specific humidity (g/kg) accumulates, simulated with the MM5v3 regional model for hurricane Greta (17/09/1978).

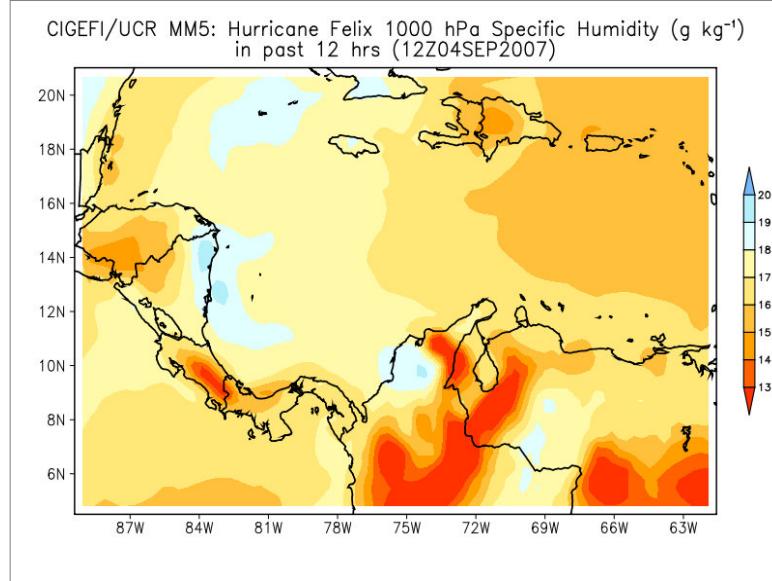


Figure 2: Twelve hours surface specific humidity (g/kg) accumulates, simulated with the MM5v3 regional model for hurricane Felix (04/09/2007).

- 2) The graduate student, B.Sc. Tito Maldonado, UCR ID A22905, from the Postgraduate Program in Atmospheric Sciences is actually doing he's PhD studies in the University of Uppsala, Sweden, as mentioned in the last report and he collaborated with the following works:

Maldonado, T., **E. Alfaro**, B. Fallas and L. Alvarado, 2012. Seasonal prediction of extreme precipitation events and frequency of rainy days over Costa Rica, Central America, using Canonical Correlation Analysis. Submitted to Advances in Science and Research.

The paper mentioned above was actually per reviewed and we expect to be published by middle 2012. Additionally, Maldonado and Alfaro (2011; 2010) generated models based on Canonical Correlation Analysis for prediction of extreme precipitation events during August-September-October (ASO), using as predictor the Sea Surface Temperature (SST) due to the hydrological response of the SST anomalies over the isthmus, and as predictant, the accumulated monthly rainfall, days with precipitation, the percentage of days exceeding the 80th percentile (extreme wet) and the percentage of days that do not exceed the 10th percentile (dry extreme). It was found that using the July SST

properly relate ENOS and AMO events with the prediction of precipitation extremes for ASO.

- 3) The historian Lic. Flora Solano, died last March 2012. She was working on:

**Alfaro, E.,** and Solano, F., 2011: Impacto de los Ciclones Tropicales del Atlántico en Centroamérica, Temporadas de 1906, 1922, 1924, 1934 y 1953 (Impact of the Atlantic Tropical cyclones in Central America. 1906, 1922, 1924, 1934 and 1953 seasons). In revision process.

Actually the archives that she left are under revision by the historian Lic. Ronald Diaz, to continue she's work. Additionally, Solano et al. (2011) worked with the years of 1968 and 1969 and studied these hurricane seasons that were very active near the Caribbean coast of Costa Rica. Actually; there are not impact studies by these systems over the different socioeconomic sector affected for those years. For that reason, that paper analyzed the presence and impact of these phenomena, in the years of 1968 and 1969, over some Caribbean Islands, Mexico and the United States, emphasizing Costa Rican territory. For 1968, the study and analysis focus in hurricane Gladys (October 16-21) and during 1969 season in tropical cyclones Camille (August 14-16), Francelia (August 29 – September 4), Jenny (October 1-2) and Martha (November 21-25).

In relationship with historical studies, Vargas et al. (2011) studied the probable hurricane occurrence or presence that could affected the Christopher Columbus fourth voyage and commented also on the ships used, navigation at the beginning of the XVI century, the river that they found on the Caribbean coast of Costa Rica, the climate, and the flora of the Uvita islet. They cite descriptions of the port of Limón at different times, and make some hypotheses on the conditions of the coastline prior to the impact of earthquakes and other processes that have uplifted the coast. They also discuss recent wind patterns and their possible similarity to those of 1502.

## \*5 Publications\*

**(The Project CRN2050 is mentioned in the acknowledgements. The pdf version of the published papers are included)**

#### **Journal – Book Publications**

**Alfaro, E.** y A. Quesada, 2010. Ocurrencia de ciclones tropicales en el Mar Caribe y sus impactos sobre Centroamérica (Tropical cyclone occurrences in the caribbean sea and their impact on Central America). Revista Intersedes, **11**(22), 136-153. (<http://www.intersedes.ucr.ac.cr/ojs/index.php/intersedes/issue/archive>) In Spanish.

**Amador, J. A., E. J. Alfaro**, H. Hidalgo & B. Calderon, 2011. Central America. In: State of the Climate in 2010, Special Supplement to the Bull. Amer. Met. Soc., **92**(6), S182-183.

**Amador, J. A.**, 2011. Socio-economic impacts associated with meteorological systems and tropical cyclones in Central América in 2010. In: State of the Climate in 2010, Special Supplement to the Bull. Amer. Met. Soc., **92**(6), S184.

Maldonado, T. y **E. Alfaro**, 2011. Predicción estacional para ASO de eventos extremos y días con precipitación sobre las vertientes Pacífico y Caribe de América Central, utilizando análisis de correlación canónica (Seasonal prediction of extreme precipitation events, and frequency of rainy days for ASO over the Pacific and Caribbean slopes of Central America using Canonical Correlation Analysis). Revista Intersedes. **13** (24), 78-108. (<http://www.intersedes.ucr.ac.cr/ojs/index.php/intersedes/issue/archive>) In Spanish.

Maldonado, T. y **E. Alfaro**, 2010. Propuesta metodológica para la predicción climática estacional de eventos extremos y días con precipitación. Estudio de caso: Sur de América Central (Seasonal climate prediction of extreme precipitation events and frequency of rainy days in the South of Central America as a study case. A methodological proposal). Revista Intersedes, **11**(21), 182-214. (<http://www.intersedes.ucr.ac.cr/ojs/index.php/intersedes/issue/archive>) In Spanish.

Solano, F., **E. Alfaro**, & A. Quesada, 2011: Impacto de los Ciclones Tropicales del Atlántico en Centroamérica, Temporadas de 1968 y 1969 (Impact of the Atlantic Tropical cyclones in Central America. 1968 and 1969 seasons). Revista Diálogos, **12**(1), 78-100. (<http://historia.fcs.ucr.ac.cr/>). In Spanish.

Vargas, J., **E. Alfaro** y J. Gómez, 2011. Tres Colón en Cariay (1502): reflexiones sobre marinos, el mar y la flora (Three Columbus in Cariay (1502): Reflections on the fleet, the sea, the land, and the flora). Revista Reflexiones, **90**(1), 105-120. (<http://reflexiones.fcs.ucr.ac.cr/index.php/ediciones-anteriores/127-edicion-90-1-2011>). In Spanish.

Project results were also divulgated in national conferences. The Co-PI's and most collaborators participated actively in the University of Costa Rica, Center for Geophysical Research XXXV, and XXXVI Mini-Congresses, celebrated in December-2011 and April-2012, respectively.

## \*6 Data\*

At this point the project has used only public databases like Costa Rican History Archives; HURDAT (<http://www.aoml.noaa.gov/hrd/hurdat/>, last visit 25/07/2008), and DesInventar (<http://www.desinventar.org/desinventar.html>, last visit 25/07/2008). The disaster data base elaborated during the project “Impact and Adaptation to Climate Change and Extreme Events in Central America” (AIACC-LA06-UCR, [http://www.aiaccproject.org/aiacc\\_studies/aiacc\\_studies.html](http://www.aiaccproject.org/aiacc_studies/aiacc_studies.html), last visit Jun. 17<sup>th</sup>, 2010), the Social Development Index (available at <http://www.mideplan.go.cr/sides/social/indx10.htm>), the disaster data base EM-DAT (<http://www.emdat.be/>, as a collaboration from the WFP) and the Gross National Product (Costa Rica Central Bank, <http://www.bccr.fi.cr>). Standard grid data such as NCEP/NCAR (Kalnay et al. 1996), ECHAM4.5 (Roeckner et al. 1996) and CCM3.6 (Kiehl et al. 1996) output data were used to performed regional analysis and model simulations.

Also include those described in Compo et al. (2010) and Stickler et al. (2010). Other data bases used include, Precipitation - Xie & Arkin ver(1,2) ([http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.Merged\\_Analysis/](http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.CPC/.Merged_Analysis/)), SST - Smith & Reynolds (<http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.ERSST/.version3b/>), Wind - Quikscat ([http://www.remss.com/qscat/qscat\\_description.html](http://www.remss.com/qscat/qscat_description.html), <http://www.ifremer.fr/cersat/en/data/overview/gridded/mwfqscat.htm>) and Precipitation - TRMM (<http://mirador.gsfc.nasa.gov/cgi-bin/mirador/presentNavigation.pl?tree=project&project=TRMM&dataGroup=Gridded>).

## \*7 Capacity Building\*

See sections 2 - 5 for the students involved in the project activities.

## \*8 Regional Collaboration/Networking\*

The ANUIES-CSUCA project Evaluación de impactos hidrometeorológicos extremos en Centroamérica y Norteamérica relacionados con los huracanes (Assessment of the extreme hydrometeorological event impacts in Central – North America related with hurricanes), P.I.s Drs. Tereza Cavazos, CICESE and Eric Alfaro, UCR, was developed during 2010. During 2011 was written the paper:

Farfán, L., E. Alfaro and T. Cavazos, 2011: Tropical cyclone impact over the population in western Mexico: 1970-2010. Submitted to Atmósfera.

The project was supported by the Mexico and Central America Public University Unions (ANUIES & CSUCA, respectively). Co-PIs were: Drs. Hugo Hidalgo, UCR and Luis Farfan, CICESE & IAI-CRN2048. A collaboration workshop was developed in CICESE, Ensenada, Mexico, December 6-10, 2010, including the participation of Dr. Jorge Amador, UCR & IAI-CRN2050 and B.Sc. Tito Maldonado. Related also with this collaboration, Dr.

Alfaro participated in the Marine Sciences Latino American Congress (XIV COLACMAR), Camboriu, Santa Catarina, Brazil. Oct. 30 – Nov. 04, 2011 and presented the work: Some aspects related with the climate variability and the tropical cyclones in the Eastern Tropical Pacific.

In the Intra-Americas Seas CLImate Program (IASCLIP) framework, proposed for 2009-2014, as a new component of Climate Variability and Predictability (CLIVAR) Variability of the American Monsoon Systems (VAMOS), until mid 2011, Dr. Alfaro was the Chair of the Working Group: Applications and Capacity Building (more information is available at [ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP\\_S&Iplan\\_spr08\\_v2.pdf](ftp://ftp.aoml.noaa.gov/phod/pub/enfield/IASCLIP/IASCLIP_S&Iplan_spr08_v2.pdf)).

Dr. Amador is the regional Focal Point for the meteorology component in the project Desarrollo de Capacidades de Investigación para la Prevención y Mitigación de Desastres en Centroamerica (Capacity Building and Development for Disasters Prevention/Mitigation in Central America, UCR code 805-A9-532), supported by the Central American Council for Higher Education and the Swedish Agency for International Development Cooperation (see <http://dipredca.csuca.org/> for more information). Core activities of this initiative will finish by June 2012 but will be extended during the PhD studies development of B.Sc. Tito Maldonado and Beatriz Quesada in University of Uppsala, Sweden.

Dr. Alfaro collaborated with Dr. Luis Cid from Bio-Bio University, Concepcion, Chile and visited him last October 2011 to work on seasonal prediction. Dr. Cid presented the paper:

Cid, L., S. Ramírez, **E. Alfaro** & D. Enfield, 2011. Latitudinal Profiles of Seasonal Rainfall-Enso Association along the Coast of Central and South America, Using Contingency Tables. Proceedings of the 2011 Joint Statistical Meetings, American Statistical Association. Miami Beach, Florida, July 30 - August 4, 2011.

This collaboration is maintained today including also M.Sc. Sandra Ramirez from Pontificia Universidad Javeriana, Cali, Colombia, and a small grant research project was presented to the Pan American Institute for Geography and History (PAIGH). During that visit, Dr. Alfaro participate in the Second Pacific Congress on Climatology, Meteorology and Physical Oceanography, Coquimbo, Chile, Oct. 5 – 7, 2011 and presented a work related with winter storms effects in Central America titled “Atmospheric forcing of cool subsurface water events in Bahía Culebra, Gulf of Papagayo, Costa Rica” (**E.J. Alfaro & J. Cortés**).

Both Co-PI’s evaluated that these initiatives produced a positive feedback in the project activities during its development.

## **\*9 Media Coverage and Prizes\***

Drs. Amador and Alfaro are working jointly with their colleague Dr. Hugo Hidalgo in the second year of the 2009 Excellency Award granted by the Florida Ice & Farm Co. The work funded was: Desarrollo y aplicación de un sistema acoplado de modelado atmosférico-hidrológico para la investigación de la variabilidad climática estacional y del cambio climático regional (Development and implementation of a coupled atmosphere-hydrological model for seasonal regional climate variability and climate change research, see [http://www.florida.co.cr/info\\_corp\\_es/ganadores\\_aportes.php](http://www.florida.co.cr/info_corp_es/ganadores_aportes.php), last visit Jun. 6<sup>Th</sup>, 2010, UCR code 805-A8-606). Core activities of this initiative will finish by June 2012 and produced a positive feedback in the project activities during its development.

During the second semester, 2011, Dr. Alfaro won a research award given by the UCR Vice Presidency for Research. This consisted in replace the assigned teaching duties with research activities related with CRN2050 (UCR code 805-A7-002) project.

## **\*10 Policy Relevance\***

The publications generated have been divulgated in different web pages as <http://ucr.academia.edu/EricAlfaro/Papers> and <http://www.kerwa.ucr.ac.cr/browse?value=Alfaro+Mart%C3%ADnez%2C+Eric&type=author>, they could be used to strengthen the views of policy makers in regards to the relevance of weather and climate impacts on society in Central America.

## **\*11 Main Conclusions\***

1. The project developed according to proposed objectives and activities, and provided the primary input to the investigators to prepare other research initiatives such as the one that won the 2009 Excellency Award and the research award mentioned.
2. A great deal of data was analyzed, archived and relevant results were published or are in the process to be published, making this a valuable contribution to the scientific community interested in tropical cyclones and low-level jets at low-latitudes.
3. A considerable number of undergraduate and graduate students, both at the UCR and other institutions abroad, have benefited from the project, by means of discussions, for a and local workshops, available facilities and materials, statistical and numerical model development and scientific publications.
4. The published papers (and those to appear in the next months), and poster presentations tell of relevant scientific achievements related to the project objectives and provide new research opportunities for local students and other scientific groups interested in the region.
5. The funding provided by the IAI has been very important to promote research in tropical meteorology in the region, especially in those scientific topics that are associated with atmospheric systems that impact the region leaving large amounts of material and human loses, in an already very vulnerable regional society.
6. An important quantity of interdisciplinary work has been developed.

7. This project has promoted the contact with other national and regional initiatives that share some common objectives, strengthening the results achieved and promoting also future work.

## **\*12 Work Plan for Next Year with Associated Costs\***

The Co-PI's will continue working in the project basically according to the Letter of Intent presented in response to IAI new funding opportunity for 3-year extension of CRN2 projects. Core activities proposed are:

1. Based on their research on IALLJ and ENSO, they will continue their work on developing quantifiable indices of tropical cyclone activity and contemporary climate conditions (as in the paper published by their group, Amador et al., 2010), and integrate these indices with paleotempestology results and socio-economic variables to improve their vulnerability assessment for the Caribbean region. They will extend the estimation of these indices back to 1871 using the information provided in the paper by Compo et al. (2010) and perhaps using additional data from Sticker et al. (2010).
2. They will participate in the training workshop being planned for 2013 that targets students and young professionals from Caribbean and Latin American countries. This training course will teach topics on hurricane climatology, paleotempestology, and geospatial techniques in social science research (focusing on human dimensions of hurricane science).
3. They will participate in the CRN2050 project meeting being planned for 2013 to discuss research results and data integration.

## **\*13 References not included in Section 5 Publications\***

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