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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)

October 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

The University of Costa Rica (UCR) didn't receive any additional payment from LSU after project completion. We faced problems with the UCR administration because of the no overhead charges condition placed on the extension of the project. UCR Co-PI´s are still working to sign up the Subaward Amendment received from LSU in July 26, 2012.

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, 4.37% of the IAI extension 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 6000 US dollars for the period May-October 2012.

3 Research Activities and Findings

Continuing with the previous initiatives of 2008-2011, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2011, 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. (see Amador *et al*. 2012).

4 Others Contributions of the Co-PIs Work and Collaborators

1) Hidalgo and Alfaro (2012) compared the relative magnitude of precipitation and temperature changes obtained from 21st-century climate change projections from general circulation models (GCMs) with the changes in a selection of socioeconomic indicators from countries in Central America. The objectives of the study are: (1) to determine the relative influence of climatic and socio-economic variables for different 21st-century scenarios; and (2) to compare the relative situation of each of the countries of Central America, considering climate and socio-economic variables during present and future scenarios. Each socio-economic variable along with the projected changes in precipitation and temperature are used to produce red-green-blue (RGB) composite maps during the historical, mid-century, and end-of-21st-century horizon scenarios. The most consistent result is that the current north–south socio-economic contrast between the countries (in which the southern countries of Panama and Costa Rica present better living conditions than the rest of the Central American countries), is not diminished in the future; and for some combination of scenarios this

contrast is exacerbated by future socio-economic differences and climate change impacts. Moreover, Panama and Costa Rica are the only countries that present improved living conditions at the end of the century when considering increases in gross domestic product (GDP) and the effects of climate change. It is worrisome that the north–south differences in the living standards will keep growing in the region, and attention should be given to socio-economic and physical aspects that may play a role in increasing these differences.

2) Bahía Culebra, at Gulf of Papagayo on the north Pacific coast of Costa Rica, is an area of seasonal upwelling where more intense cooling events may occur during some boreal winter weeks mainly. To study these extreme cool events, Alfaro and Cortes (2012) analyzed records of nine sea subsurface temperature stations from 1998 to 2010 were analyzed. Five events associated with extremely cool temperatures in this region were identified from these records and taken as study cases. Sea temperatures decreased about 8-9ºC during these events and occurred while cold fronts were present in the Caribbean, with strong trade wind conditions over Central America. These strong wind conditions may have favored the offshore displacement of the sea surface water. The axis of Bahía Culebra runs northeast-southwest, a condition that favors and triggers cool water events, mainly because the displaced water is replaced by water from deeper levels.
3) In relationship with the study previously cited and to determine the relationship of climate and the subsurface temperature variability at Bahía Culebra, Alfaro et al. (2012) analyzed nine records of sea subsurface temperature from the Bay, continuously recorded from 1998 to 2010. The analysis characterized the annual cycle and explored the influence of different climate variability sources on the subsurface sea temperature and air temperature recorded in Bahía Culebra. Data from an automatic meteorological station in the bay were studied, obtaining the annual and daily cycle for air surface temperature and wind speed. Sea surface temperature (SST) trend from 1854 to 2011 was calculated from reanalysis for the region that coverts 9-11°N, 85-87°W. Because of the positive SST trend identified in this region, results showed that annual and daily cycles in Bahía Culebra should be studied under a warming scenario since 1854, that is coherent with the global warming results and its

climate variability is influenced by El Niño-Southern Oscillation (ENSO) in the Equatorial Pacific and by atmospheric forcing triggered by climate variability with Atlantic Ocean origin, because warm (cold) events in Bahía Culebra tend to occur in concordance with positive & negative (negative & positive) anomalies in Niño 3.4 (NAO) index. Additionally, in order to evaluate metal enrichment in sediments , Lizano et al. (2012) proposed and tested a method in Bahia Culebra and the Golfo de Nicoya, Costa Rica through the normalization of the elements against aluminum, and by linear regression of the logarithm of the concentrations of different elements respect to aluminum. The distributions of the elements manganese, and strontium of Bahia Culebra did not satisfy the tests of normalization and linear regression, indicating a nonnatural distribution or enrichment of these elements in this region. In the Golfo de Nicoya the elements copper, zinc, rubidium and the strontium did not satisfy the test of normality or the linear regression with respect to aluminum, indicating a possible enrichment of these elements. The majority of the concentrations of the elements in two sample sites, with the exception of chromium, are within the natural ranges in rocks or clays of marine sediments, and within the concentration ranges of other studies done in these same regions. Chromium has average values beyond the natural concentrations, the values of some samples in the Golfo de Nicoya are up to 10 times greater than the concentration value of a typical bay with high contamination of this element.

5 Publications

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

Journal – Book Publications

- Amador, J. A., H. Hidalgo, E. J. Alfaro, B. Calderón , N. Mora & I. Rivera, 2012. Central America. In: State of the Climate in 2011, Special Supplement to the *Bull. Amer. Met. Soc*., 93(7), S169-170.

- Hidalgo, H. and E. Alfaro, 2012. Some Physical and Socio-economical Aspects of Climate Change in Central America. *Progress in Physical Geography. DOI: 10.1177/0309133312438906.* 36(3), 380 – 399.

- Alfaro, E., J. Cortés, J. Alvarado, C. Jiménez, C. Sánchez, J. Nivia, A. León & E. Ruiz, 2012. Clima y temperatura sub-superfical del mar en Bahía Culebra, Golfo de Papagayo, Costa Rica. *Revista de Biología Tropical*, 60(Supl. 2), 159-171.

- Alfaro, E. & J. Cortés, 2012. Atmospheric forcing of cool subsurface water events in Bahía Culebra, Gulf of Papagayo, Costa Rica. *Revista de Biología Tropical*, 60(Supl. 2), 173-186.

- Lizano, O., E. Alfaro & A. Salazar, 2012. Un método para evaluar el enriquecimiento de metales en sedimentos marinos en Costa Rica. *Rev. Biol. Trop.* 60(Supl. 2). 197-211.

- Solano, F. J., R. Díaz, and J. A. Amador, 2012. La Institucionalización de la meteorología en Costa Rica (1860-1910). Editorial Nuevas Perspectivas. Serie Estudios Sociales de la Ciencia, la Técnica y el Medio Ambiente. (In press) [In Spanish]

Project results were also divulgated in national and regional conferences like:

1- Participación en el Taller "Perspectivas interdisciplinarias: riesgo y vulnerabilidad ante fenómenos naturales". Programas: Agua, tierra, aire, bosques: Historia y Ambiente en Costa Rica (siglos XIX y XX) y Desarrollo y Sustentabilidad en Perspectiva Histórica (2011-2015). **Trabajo presentado**: Análisis de impactos climáticos en Costa Rica, América Central, de acuerdo a algunas fuentes de información histórica locales (**E. Alfaro**). Inter, multi y transdisciplinariedad en los estudios del clima, la variabilidad y el cambio climático (**J. Amador**) 11 de octubre, 2012, Sala de Exrectores, Biblioteca Joaquín García Monge, Campus Omar Dengo, Universidad Nacional. Heredia, Costa Rica.

2- Participación en el FORO INSTITUCIONAL 2012, "CAMBIO CLIMATICO Y ESTRATEGIAS DE DESARROLLO". Durante la primera sesión "Cambio climático: un escenario a considerar en las estrategias de desarrollo", en la primera mesa redonda "Cambio climático: fundamento científico". **Trabajo presentado**: "Introducción a algunos fundamentos científicos relacionados con el cambio climático global" (**E. Alfaro**). **"**Cambio climático: Mecanismos fundamentales y análisis de evidencias a nivel global, regional y local" (**J. Amador**).03 de octubre de 2012. Auditorio del CTT, LANAMME / Ciudad de la Investigación, Universidad de Costa Rica.

6- Participación en REUNIÓN DE CIERRE DEL PROGRAMA DE DESARROLLO DE CAPACIDADES DE INVESTIGACIÓN PARA LA PREVENCIÓN Y MITIGACIÓN DE DESASTRES EN AMÉRICA CENTRAL –DIPREDCA-, 9-11 DE MAYO, 2012. Ciudad de Guatemala, Guatemala. Como miembro del comité de tesis doctoral del B.Sc. Tito Maldonado quién presentó el trabajo *Comparison and Verification of Cumulus Parameterization Schemes in tropical regions using the Weather Forecast and Research Model: The Central America case,* y como co-autor de las presentaciones de los **Dres. Jorge Amador** y Hugo Hidalgo, quienes presentaron los trabajos, *The UCR Meteorology Hub in the DIPREDCA program* y *Modeling the impacts of climate change on water resources,* respectivamente.

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, last visit Jun. 17Th, 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/), 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.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 section 1-5 for the student involved in the project activities.

8 Regional Collaboration/Networking

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 finished by June 2012 but was extended during the PhD studies development of B.Sc. Tito Maldonado and Beatriz Quesada in University of Uppsala, Sweden.

Several associated projects, all registered at the UCR Vice-Presidency for Research contributed, both logistically and financially, to achieve many of the project objectives. The associated projects are listed below.

805-A8-606 Desarrollo de un sistema de modelado dinámico para la predicción de la variabilidad climática estacional y del cambio climático", PI. Dr. Jorge Amador.

805-B0-065 El ciclo diurno del viento sobre Costa Rica (Diurnal cycle of wind over Costa Rica), PI. Dr. Jorge Amador.

805-A9-224 Simulaciones del ciclo hidrológico terrestre usando el modelo hidrológico distribuido de capacidad de infiltración variable, PI, Dr. Hugo Hidalgo.

805-B0-402 Clima, variabilidad y cambio climático en la vertiente Caribe de Costa Rica: un estudio básico para la actividad bananera. PI, Dr. Jorge A. Amador.

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

9 Media Coverage and Prizes

The local component of the project was chosen to represent the UCR in the Biannual Recognition to the Research Excellency done in the Central America and Dominican Republic public universities. The activity was organized by the Central American Council of Public Universities (CSUCA in Spanish) in San Salvador, El Salvador, October 26-27, 2012.

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

The CRN2050 project extension allowed the possibility of consolidating several data bases at local and regional scales. A good progress had been achieved in the project in

the understanding of the CLLJ´s role in precipitation distribution in Central America. So far some new ideas are being developed to include regional moisture sources at different scales in time and space. Preliminary statistical analysis of ITCZ, position and intensity of moisture fluxes, and CLLJ variability indexes are being estimated with the aim to propose a conceptual model of the interaction of these mechanisms in the production of regional rainfall. Based on the results of some of the publications mentioned above, regional climate change and its effects on regional physical mechanisms are also being studied using ERA-Interim data.

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

- Amador J. A., E. Alfaro, E. Rivera & B. Calderón, 2010. Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas. En 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.
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- Compo GP,Whitaker JS, Sardeshmukh PD, Matsui N, Allan RJ, Yin X, Gleason Jr BE, Vose RS, Rutledge G, Bessemoulin P, Br¨onnimann 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.

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2 Project Funding

The University of Costa Rica (UCR) has received the second extension payment in September 2013 from LSU. We faced problems initially with the UCR administration because of the no overhead charges condition placed on the extension of the project. This situation was resolved and FUNDEVI signed up the Subaward Amendment received from LSU on July 26, 2012.

The local component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The name of the local 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 2013 this project received from the University of Costa Rica 403 876.65 Costa Rican colones (about 796 US dollars, 3.79% of the IAI extension funding); for student support only 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., those from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone, basic

computer cluster use and maintenance, local administrative support and student support. The undergraduate meteorology student Alejandro Meza (UCR ID number A63609) is also working in the project supported by these funds, basically helping with information processing, digitalization and data base building. The total local contribution is estimated in 7000 US dollars for the year 2013.

3 Research Activities and Findings

Continuing with the previous initiatives of 2008-2012, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2012, 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, including the discussion of tropical cyclone impacts in the region (see Amador *et al*. 2013).

4 Others Contributions of the Co-PIs Work and Collaborators

1) Farfán et al. (2013) evaluated impacts from tropical cyclone (TC) landfalls on populated areas located along the Pacific Ocean coast of Mexico. The period of interest was from 1970 through 2010 and an international disaster database was used to identify the impact from the landfalling TCs. More than 30 landfall events occurred during the period; the authors examined the top 25 TCs based on rainfall accumulation, as well as the top 10 TC-related disasters based on the affected population. Each event resulted in affected population from 20 000 to more than 800 000. Strong winds and heavy rainfall, during periods of one to three days, were associated with property damage and loss of lives. Their results indicated that excessive rainfall accumulations and daily rates, over highly populated areas, are important elements associated with the occurrence of disasters. Six of the top 10 TC-related disasters occurred during El Niño and three during neutral conditions; however, looking at the top 25 events, 10 occurred during El Niño and 10 during neutral conditions. Three case studies that occurred during El Niño events (Liza in 1976, Pauline in 1997, and Lane in 2006) are documented in more detail as they affected

areas with different population densities in the southern and northwestern coasts of Mexico.

2) Studying the very active 2010 tropical cyclone season, Maldonado et al. (2013) explained that high mountains divide Costa Rica, Central America, into two main climate regions, the Pacific and Caribbean slopes, which are lee and windward, respectively, according to the North Atlantic trade winds – the dominant wind regime. The rain over the Pacific slope has a bimodal annual cycle, having two maxima, one in May–June and the other in August-September-October (ASO), separated by the midsummer drought in July. A first maximum of deep convection activity, and hence a first maximum of precipitation, is reached when sea surface temperature (SST) exceeds 29 °C (around May). Then, the SST decreases around 1 °C from the above value due to diminished downward solar radiation and stronger easterly winds (during July and August), resulting in a decrease in deep convective activity. Such a reduction in deep convection allows an increase in solar radiation and a slight increase in SST (about 28.5 °C) by the end of August and early September, resulting once again in an enhanced deep convection, and, consequently, in a second maximum of precipitation.
3) Most of the extreme events are found during ASO. Central American National Meteorological and Hydrological Services (NMHS) have periodic Regional Climate Outlook Fora (RCOF) to elaborate seasonal predictions. Recently, meetings after RCOF with different socioeconomic stakeholders took place to translate the probable climate impacts from predictions. From the feedback processes of these meetings has emerged that extreme event and rainy days seasonal predictions are necessary for different sectors. As is shown in the above work, these predictions can be tailored using Canonical Correlation Analysis for rain during ASO, showing that extreme events and rainy days in Central America are influenced by interannual variability related to El Niño-Southern Oscillation and decadal variability associated mainly with Atlantic Multidecadal Oscillation. Analyzing the geographical distribution of the ASO-2010 disaster reports, the authors noticed that they did not necessarily agree with the geographical extreme precipitation event distribution, meaning that social variables, like population vulnerability, should be included in the extreme events impact analysis.

4) Fallas and Alfaro (2012a, b) used statistical techniques to produce predictive schemes associated with rainfall in Central America including the tropical cyclone season. Useful predictive schemes were found for practically all the relationships studied, noticing that most of the Central America climate variability could be explained by the El Niño (La Niña) (e.g. interanual variability) and the Atlantic (AMO, mainly, e.g. multidecadal variability) indices.

5 Publications

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

Journal – Book Publications

- Amador, J. A., E. J. Alfaro, B. Calderón, A. M. Durán-Quesada, H. G. Hidalgo and I. L. Rivera, 2013. Central America. In: State of the Climate in 2012, Special Supplement to the *Bull. Amer. Met. Soc*., **94**(8), S232-234.

- Farfán, L., E. Alfaro and T. Cavazos, 2013: Characteristics of tropical cyclones making landfall on the Pacific coast of Mexico: 1970-2010. *Atmósfera*, **26**(2), 163-182.

- Maldonado, T., E. Alfaro, B. Fallas and L. Alvarado, 2013. Seasonal prediction of extreme precipitation events and frequency of rainy days over Costa Rica, Central America, using Canonical Correlation Analysis. *Advances in Geosciences,* **33**, 41-52.

- Fallas-López B, Alfaro E (2012a): Uso de herramientas estadísticas para la predicción estacional del campo de precipitación en América Central como apoyo a los Foros Climáticos Regionales. 1: Análisis de tablas de contingencia. *Revista de Climatología*, **12**, 61-79.

- Fallas-López B, Alfaro E (2012b): Uso de herramientas estadísticas para la predicción estacional del campo de precipitación en América Central como apoyo a los Foros Climáticos Regionales. 2: Análisis de Correlación Canónica. *Revista de Climatología*, **12**, 93-105.

Project results were also divulgated in national and regional conferences like:

1- AGU-MEETING OF THE AMERICAS, 2013. Posters presented: "Characterization of the Mid Summer Drought in the Central Valley of Costa Rica, Central America" (E. Alfaro), "Diurnal cycle on the Caribbean slope of Costa Rica: An observational

study" (J. A. Amador & F. Saenz), "Connections between the Intertropical Convergence Zone and other climatic features in Central America" (H. Hidalgo, A. M. Durán-Quesada, J. A. Amador & E. J. Alfaro), "The role of the Caribbean Low Level Jet in the modulation of the regional moisture transport" (A. Durán- Quesada, J. Amador & L. Gimeno) and, "Connections between the Intertropical Convergence Zone and other climatic features in Central America" (H. Hidalgo, A. M. Durán-Quesada, J. A. Amador & E. J. Alfaro). Oral: "Lagrangian analysis of moisture sources associ- ated with precipitation in Central America" (A. Durán-Quesada, L. Gimeno & J. Amador). Cancun, Mexico, May 13-17, 2013. The first two of them were also presented during the Science Faculty Research Forum at the University of Costa Rica. Aug. 6-7, 2013.

2- E. Alfaro participated in the Workshop on the impacts of climate change on species distribution, ecosystems and ecosystem services in Central America, a component of the project - Ecosystem-based Adaptation for Smallholder Subsistence and Coffee Farming Communities in Central America. CATIE, Turrialba, Costa Rica, Jan. 29-31, 2013.

3- Alfaro, E. J.: "Analysis of climate impacts in Costa Rica, Central America, from local historical information sources" and Amador, J. A.: "An analysis of climate indexes and tropical cyclones in the Intra-Americas Seas". 8th EGU Alexander von Humboldt International Conference on Natural Disasters, Global Change, and the Preservation of World Heritage Sites, Universidad Nacional de San Antonio Abab del Cusco (UNSAAC), Facultad de Ingeniería Civil, Scientific Committee for Disaster Prevention and Mitigation and the European Geosciences Union (EGU), Cuzco, Perú, November 12th - 16th, 2012.

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), EMDAT (http://www.emdat.be/, last visit 11/09/2013) 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, last visit Jun. 17Th, 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/), 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.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 section 1-5 for the student involved in the project activities.

8 Regional Collaboration/Networking

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 finished by June 2012 but a component of it, related to PhD studies

of M. Sc. Tito Maldonado and M. Sc. Beatriz Quesada at the University of Uppsala, Sweden, is still in progress.

Several associated projects, all registered at the UCR Vice-Presidency for Research contributed, both logistically and financially, to achieve many of the project objectives. The associated projects are listed below.

805-A8-606 Desarrollo de un sistema de modelado dinámico para la predicción de la variabilidad climática estacional y del cambio climático", PI. Dr. Jorge Amador.

805-B0-065 El ciclo diurno del viento sobre Costa Rica (Diurnal cycle of wind over Costa Rica), PI. Dr. Jorge Amador.

805-A9-224 Simulaciones del ciclo hidrológico terrestre usando el modelo hidrológico distribuido de capacidad de infiltración variable, PI, Dr. Hugo Hidalgo.

805-B0-402 Clima, variabilidad y cambio climático en la vertiente Caribe de Costa Rica: un estudio básico para la actividad bananera. PI, Dr. Jorge A. Amador.

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

9 Media Coverage and Prizes

The Co-PIs Alfaro and Amador were invited to talk about several climate subjects related with Climate Change, including those related with this project at Radio Universidad de Costa Rica (http://radiosucr.com/, last visit 12/09/2013). The program was recorded in December 2012 and was broadcasted in January 2013.

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

The CRN2050 project extension allowed the possibility of consolidating several data bases at local and regional scales. A good progress had been achieved in the project in the understanding of the CLLJ´s role in precipitation distribution in Central America. So far some new ideas are being developed to include regional moisture sources at different scales in time and space. Preliminary statistical analysis of ITCZ, position and intensity of moisture fluxes, and CLLJ variability indexes are being estimated with the aim to propose a conceptual model of the interaction of these mechanisms in the production of regional rainfall. Based on the results of some of the publications mentioned above, regional climate change and its effects on regional physical mechanisms are also being studied using ERA-Interim data.

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).

13 References not included in Section 5 Publications

- Amador J. A., E. Alfaro, E. Rivera & B. Calderón, 2010. Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas. En 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.
- Compo GP,Whitaker JS, Sardeshmukh PD, Matsui N, Allan RJ, Yin X, Gleason Jr BE, Vose RS, Rutledge G, Bessemoulin P, Br¨onnimann 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.

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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)

September 2014

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 the third extension payment in February 2014 from LSU.

The local component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The name of the local 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 2014 this project received from the University of Costa Rica 529 408.00 Costa Rican colones (about 971 US dollars, 4.62% of the IAI extension funding); for student support only. The undergraduate students Aaron Vega and Elsie Troyo (UCR ID numbers A96690 and A86413, respectively) are working in the project supported by these funds, basically helping with information processing, digitalization and data base building. Other UCR contributions (i.e., those from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone, basic computer cluster use and maintenance, local administrative support and student support. The undergraduate meteorology student Alejandro Meza (UCR ID number A63609) is also working in the project supported by UCR funds, basically helping

with information processing, digitalization and data base building. The total local contribution is estimated in 7000 US dollars for the year 2014.

3 Research Activities and Findings

Continuing with the previous initiatives of 2008-2013, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2013, 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, including the discussion of tropical cyclone impacts in the region (see Amador *et al*. 2014).

4 Others Contributions of the Co-PIs Work and Collaborators

1) Amador and Alfaro (2014) states that the Central America region hosts a valuable amount of World Heritage Sites (WHS), many of them located in areas of floods, landslides, drought, high winds, intense precipitations, and earthquakes. The effective management of WHS requires the understanding of this type of environmental phenomena and their potential impacts on these sites. The objective of that work was twofold. To make an analysis of some of the atmospheric systems (easterly waves, cold fronts and tropical cyclones [TCs]) hitting Central America, to estimate their effects on socio-economic activities and potential impacts on WHS during the period 2002–2012. The second objective was to identify, for a case study, the potential effects of hydro-meteorological events associated with a tropical storm on the Diquis Delta region in southern Costa Rica. This site, an important unique archeological site of stone spheres, has been proposed by this country as a WHS. To achieve both, public data bases like HURDAT (North Atlantic Hurricane Database), and information from regional newspapers and National Emergency Committees, among other sources, were used for the study of socio-economic impacts caused by these natural hazards. To accomplish the latter, course resolution NCEP/NCAR (National Center for Environmental Prediction/National Center for Atmospheric Research) Reanalysis atmospheric data served to initialize version 5 of a numerical atmospheric mesoscale model (MM5). This

approach permitted to obtain higher resolution gridded data for a set of atmospheric variables for a case study associated with the formation of tropical storm Alma upon the Pacific basin. The MM5 resulted winds and precipitation, among other variables, were then used to evaluate potential impacts on the WHS region. Among the systems analyzed for Central America, TCs were the ones that most severely impacted regional social life and worsened the already weak regional economies. During the period analyzed, TCs affected regions where WHS are very relevant to cultural life and touristic income. The MM5 derived data shows its potential for providing detailed spacetime atmospheric data to help quantify and anticipate impacts for WHS protection and management. The overall results are expected to bring the attention of organizations and governments about the importance of socio-economic and cultural losses associated with the impacts caused by natural hazards near WHS in the region.

2) Serra et al. (2014) mentioned that Tropical intraseasonal variability (TISV) of the atmosphere describes the coherent variability in basic state variables, including pressure, wind, temperature, and humidity, as well as in the physical phenomena associated with the covariability of these parameters, such as rainfall and cloudiness, over synoptic (~1,000 km,~1–10 days) to planetary (~10,000 km,~10–100 days) scales. In the past, the characteristics of individual TISV modes were studied separately, and much has been learned from this approach. More recent studies have increasingly focused on the multiscale nature of these modes, leading to exciting new developments in our understanding of tropical meteorology. That article reviews the most recent observations of TISV and its associated impacts on regional weather, short-term climate patterns, and atmospheric chemical transports, as well as the ability of numerical models to capture these interacting modes of variability. They also suggest where the field might focus its efforts in the future.
3) Locally, Alfaro and Pérez-Briceño (2014) reviewed historical local information sources like bulletins produced by the National Weather Service, to account for relevant climate events and their associated impacts in Costa Rica. Cold fronts or outbreaks, easterly waves and tropical cyclones are the weather phenomenon that were considered as study objects from 1977 to 2012, originated in the surrounded seas of Central America. Impacts associated with cold fronts (tropical cyclones) were located mainly in the Costa Rican

Caribbean (Pacific) slope while those associated with easterly waves have a more even spatial distribution through the country. Additionally, Fallas-López and Alfaro (2014) studied the statistical technique of contingency table analysis and canonical correlation analysis to produce predictive schemes associated with maximum and minimum temperatures in Central America. As a first step, principal component analysis was used to produce indices using 146 daily station records. One index was obtained for both, maximum and minimum temperatures. Keeping in mind that one of the work objectives is to support the Regional Climate Outlook Forums process, the predictive schemes used the trimesters of May-June-July, August-September-October and the four month period of December-January-February-March as targets for predictions of maximum and minimum temperatures. Different climate indices like Niño 3 and NAO were used as predictors, associated with several climate variability sources that influence the climate patterns in Central America, using one or two bimester previous to the predicted season. Linear combination of climate indices was also used to create new ones. Useful predictive schemes were found for practically all the relationships mentioned previously, noticing that most of the Central America climate variability could be explained by the El Niño (La Niña) (e.g. interannual variability) and the Atlantic (AMO, mainly, e.g. multidecadal variability) indices.

5 Publications

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

Journal – Book Publications

- Serra, Y., Jiang, X., Tian, B., **Amador, J.**, Maloney, E., & Kiladis, G. (2014). Tropical Intraseasonal Modes of the Atmosphere. Annual Review of Environment and Resources. 39 (5), 5-27. Doi: 10.1146/annurev-environ-020413-134219

- Fallas-López B, **Alfaro E** (2014): Predicción estacional de las temperaturas máximas y mínimas en América Central. Tópicos Meteorológicos y Oceanográficos, 13(1), 5-26.

- **Amador, J. A., E. J. Alfaro**, H. G. Hidalgo, A. M. Durán-Quesada, B. Calderón, I. L. Rivera and C. Vega, 2014. Central America. In: State of the Climate in 2013, Special Supplement to the *Bull. Amer. Met. Soc*., 95(7), S164-166.

- **Alfaro, E.** y P. M. Pérez-Briceño, 2014. Análisis del impacto de fenómenos meteorológicos en Costa Rica, América Central, originados en los mares circundantes. *Revista de Climatología*, 14, 1-11.

- **Amador, J. and E. Alfaro**, 2014. Weather and climate socio-economic impacts in Central America for the management and protection of world heritage sites and the Diquis Delta culture in Costa Rica (a case study). *Advances in Geosciences,* 35, 157–167.

Project results were also divulgated in national, regional and international conferences like:

1- **Alfaro, E**., 2014. The necessity for tailoring seasonal climate forecast in Central America for urban and coastal areas, including physics and human dimensions. Memories of the World Climate Research Programme (WCRP) Conference for Latin America and the Caribbean, Developing, Linking, and Applying Climate Knowledge. Montevideo, Uruguay, 17-21 March, 2014. (http://www.cima.fcen.uba.ar/WCRP/, visited 20/04/2014). This participation produced also the following collaboration:

- Simionato, C. G., **E. Alfaro** and R. Martinez, 2014. Summary community-based position paper on "Coastal environments", on the outcomes of the World Climate Research Programme (WCRP) Conference for Latin America and the Caribbean, Developing, Linking, and Applying Climate Knowledge. Montevideo, Uruguay, 17-21 March, 2014.

2- Participation in the VII Congress of the Latin American Network of Environmental Sciences. Works presented: “Climate Classification for the Costa Rican's Caribbean side” (P. Pérez, **J. Amador** and **E. Alfaro,** http://kerwa.ucr.ac.cr/handle/10669/11114) and Seasonal prediction of the mid summer drought in two Pacific slope river basins of Costa Rica, Central America (**E. Alfaro,** http://kerwa.ucr.ac.cr/handle/10669/8923). Instituto Tecnológico de Costa Rica, San Carlos, Costa Rica. Nov. 11-15, 2013.

3- - Cid, L., S. Ramírez, **E. Alfaro** & D. Enfield, 2013. Discrete analysis for the America west coast rainfall predictability using El Niño/Southern Oscillation relationships. Memories of the 3rd Congress in Physical Oceanography, Meteorology and Climate in the South West Pacific (poster VC.P3). Santiago, Chile. Oct. 16-18, 2013. http://kerwa.ucr.ac.cr/handle/10669/1411

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), EMDAT (http://www.emdat.be/, last visit 11/09/2013) 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, last visit Jun. 17Th, 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.

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7 Capacity Building

See section 1-5 for the student involved in the project activities.

8 Regional Collaboration/Networking

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 finished by June 2012 but a component of it, related to PhD studies of M. Sc. Tito Maldonado and M. Sc. Beatriz Quesada at the University of Uppsala, Sweden, is still in progress.

Several associated projects, all registered at the UCR Vice-Presidency for Research contributed, both logistically and financially, to achieve many of the project objectives. The associated projects are listed below.

805-A8-606 Desarrollo de un sistema de modelado dinámico para la predicción de la variabilidad climática estacional y del cambio climático", P.I. Dr. Jorge Amador.
805-B0-065 El ciclo diurno del viento sobre Costa Rica (Diurnal cycle of wind over Costa Rica), PI. Dr. Jorge Amador.
805-A9-224 Simulaciones del ciclo hidrológico terrestre usando el modelo hidrológico distribuido de capacidad de infiltración variable, P.I., Dr. Hugo Hidalgo.
805-B0-402 Clima, variabilidad y cambio climático en la vertiente Caribe de Costa Rica: un estudio básico para la actividad bananera. P.I., Dr. Jorge A. Amador.
805-B3-413 Proyecciones de alta resolución de Cambio Climático en Centroamérica usando modelos CMIP5. P.I. Dr. Hugo Hidalgo.
805-B3-600 Caracterización del ciclo hidrológico de los bosques tropicales: transporte de humedad, distribución de precipitación y respuesta a la variabilidad climática. P.I. Dr. Ana María Durán.
805-B4-227 Estudio de los sistemas de circulación meso-escalares en los mares intra-americanos. P.I. Dr. Gabriela Mora.

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

Dr. Alfaro was also a Contributing Author in Magrin et al., 2014. Chapter 27. Central and South America. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Working Group II contribution to the Fifth Assessment Report (WGII, AR5). Intergovernmental Panel on Climate Change (IPCC).

9 Media Coverage and Prizes

Results obtained and activities developed by Co-PIs Alfaro and Amador were used to collaborate with several divulgation newspaper and bulletin notes like:

- "Ciclones tropicales amenazan protección de esferas de piedra" Suplemento Crisol, Semanario Universidad, Reporter: Patricia Blanco Picado. 25/07/2014.

(http://www.semanariouniversidad.ucr.cr/suplementos/crisol/13567-ciclones-tropicales-amenazan-proteccion-de-esferas-de-piedra-.html, last visit 11/09/2014)

- "Foro del Clima de América Central en Guatemala" Boletín Informativo del Programa Regional de Cambio Climático, USAID, 1(1), May 2014. Reporter: Shirley Orozco.

(http://catie.ac.cr/programa-regional-cambio-climatico/boletin/1/files/assets/downloads/publication.pdf, last visit 15/05/2014)

- "Climate change, coral reefs, deforestation and dengue" The Tico Times, Reporter: Corey Kane. 07/04/2014. (http://www.ticotimes.net/2014/04/07/climate-change-coral-reefs-deforestation-and-dengue, last visit 20/04/2014)

- "América Central será más seca y caliente en 2050" Suplemento Crisol, Semanario Universidad, Reporter: Patricia Blanco Picado. 21/01/2014.

(http://www.semanariouniversidad.ucr.cr/component/content/article/4340-Crisol/12176-america-central-sera-mas-seca-y-caliente-en-2050.html, last visit 13/02/2014)

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.

Both Co-Pi's participated in the REGIONAL WORKSHOP ON CLIMATE SERVICES AT THE NATIONAL LEVEL FOR LATIN AMERICA, San José, Costa Rica, 28 -30 July 2014. The event addressed the following topics. Provision and Application of climate services at regional level: opportunities and challenges; Capabilities for the provision of climate services at national level; Discussion Groups on needs for climate services, current interfacing; Developing Climate Services at the National Level and communication of climate services to users Opportunities for partnerships in the region.

Dr. Amador attended the World Weather Open Science Conference (WWOSC 2014), Montreal, Canada, 16-21 August 2014. The program included two main topics, the Weather Science (WS), and User, Application and Social Science programs (UASS). The scope of the WS was the discussion of: Seamless Prediction of the Earth System: from minutes to months. The scientific program was organized around five science themes: Data Assimilation and Observations; Predictability and Dynamical/Physical/Chemical Processes; Interactions between sub-systems; Prediction of the Earth system: putting it all together; Impacts of weather and climate events, besides two special sessions on THORPEX legacy projects: Polar Prediction Project and Sub-seasonal to Seasonal Prediction Project. The UASS was aimed at providing an open forum where the experiences and perspectives of a variety of information providers and users will be combined with the latest applications and methodological advances in social science to: Demonstrate and document recent progress, highlighting and sharing lessons from both successful and 'less successful' projects and

applications; Identify and deliberate areas of practice, social science research methods, and training and education requiring new or continued attention; Expand and connect the interdisciplinary weather and society community; and Develop conference positions and recommendations regarding the state and advancement of knowledge and practice. Dr. Amador presented advances of an ongoing study about the Carta (Costa Rica) floods based on documentary sources and 20CR data.

Additionally, Dr. Alfaro participated in two workshops: Managing Climate Risk to agriculture in Central America Turrialba, Costa Rica, Apr. 28-May 2, 2014 and Managing Climate Risk to biodiversity and ecosystems in Central America, San Jose, Costa Rica, Sep. 9-11, 2014. The main purpose of this participation was to explore future collaboration with important projects that are working in the region like the Regional Program in Climate Change trough the activities developed locally in the CRN.

11 Main Conclusions

The CRN2050 project extension allowed the possibility of consolidating several data bases at local and regional scales. A good progress had been achieved in the project in the understanding of the CLLJ´s role in precipitation distribution in Central America. So far some new ideas are being developed to include regional moisture sources at different scales in time and space. Preliminary statistical analysis of ITCZ, position and intensity of moisture fluxes, and CLLJ variability indexes are being estimated with the aim to propose a conceptual model of the interaction of these mechanisms in the production of regional rainfall. Based on the results of some of the publications mentioned above, regional climate change and its effects on regional physical mechanisms are also being studied using ERA-Interim data.

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. Next core activities proposed are:

1. Analyses and discussion of the last results obtained to elaborate the last project papers and divulgation activities.

2. To participate in the wrap up CRN2050 project meeting, presenting and summarizing the results obtained and the activities developed.

3. To elaborate the local and IAI final technical and financial report.

13 References not included in Section 5 Publications

- Amador J. A., E. Alfaro, E. Rivera & B. Calderón, 2010. Climatic Features and Their Relationship with Tropical Cyclones Over the Intra-Americas Seas. En 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.
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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 Final 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)

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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-SPG-CRA-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) did not receive any payment after February 2014 from LSU. This budget was totally executed according to the contract.

The local component of this project is registered in the Vice Presidency for Research at the University of Costa Rica. The name of the local 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 2015 this project received from the University of Costa Rica 536 760.00 Costa Rican colones (about 990 US dollars, 4.71% of the IAI extension funding); for student support only. The undergraduate 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., those from the Center for Geophysical Research, CIGEFI) come from infrastructure, electricity, telephone, basic computer cluster use and maintenance, local administrative support and student support. The total local contribution is estimated in 4000 US dollars for the year 2015.

3 Research Activities and Findings

Continuing with the previous initiatives of 2008-2014, Co-PI Amador was invited to contribute, as leading author, to the State of the Climate in 2014, 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, including the discussion of tropical cyclone impacts in the region. It is expected that this issue will be published during boreal 2015 summer. Dr. Amador was also invited by Dr. Rosario Romero-Centeno from the Centre for Atmospheric Sciences, National Autonomous University of Mexico, to contribute to the Chapter 13 of the 2015 Mexican Communication on Climate Change about "Climate phenomena and its role on future climate change". The document is still in the preparation phase.

4 Others Contributions of the Co-PIs Work and Collaborators

1) Hidalgo et al. (2015) used data from the Global Precipitation Climatology Project covering Central America, the Caribbean Sea, the eastern tropical Pacific and northern South America are used to compute four indexes that describe characteristics of the Inter-Tropical Convergence Zone: the latitudinal center of mass of precipitation, the longitudinal center of mass of precipitation, the average precipitation in a region bounded by 10° S–25° N and 100° W–55° W, and the spread of the precipitation patterns. A very strong correlation is found between summer latitudinal center of mass and a summer index of the Caribbean Low-Level Jet suggesting connections between Pacific and Caribbean climatic processes. The sign of the correlation implies that when the jet is stronger (weaker) there is a lower (higher) latitudinal center of mass and at the same time less (more) precipitation in the Pacific slope of Central America. The connection between the Caribbean and Pacific climate is not only related to high-level wind convergence, but it is proposed here that local convection and the establishment of a zonal circulation may be playing a role in the process. The circulation seems to be consistent during years when latitudinal center of mass is lower than normal, apparently

reinforcing the jet, and presents weaker strength during years of high latitudinal center of mass. The proposed mechanism is explained in some detail.

2) Alfaro (2014) states that the Eastern Tropical Pacific region is characterized by climate features rarely observed in tropical regions, one of them is the Mid-Summer Drought (MSD), "veranillo" or "canícula" in Spanish. This is a period in which tropical cyclones occurrences decrease in the Caribbean Sea. On the Pacific slope of Central America, the annual precipitation cycle is characterized by two rainfall maxima in June and September-October, an extended dry season from November to May, and a shorter reduced precipitation period during July–August (MSD), during July, the magnitude of the trade winds increases and this is associated also with the Caribbean Low Level Jet (CLLJ), but characterization of these features using monthly data is difficult. In this work, seven daily gauge stations records, located at two important river basins of Costa Rica, Tarcoles and Tempisque, were studied to characterize the MSD from 1937 to 2012. Among the aspects considered are the MSD Start, Timing, End, Duration, Intensity and Magnitude. The modulation and seasonal predictability of these aspects by climate variability sources as Equatorial Eastern Pacific was lately explored, showing that warmer (cooler) conditions in Niño 3.4 tend to be associated to drier (wetter) MSD events.

3) Cid et al. (2015) determined the probability of occurrence of wet or dry season events, including Atlantic and Pacific hurricane seasons, by means of estimating latitudinal profiles for the association between El Niño – Southern Oscillation phenomenon and the rainfall along the west coast of Central and South America. The analysis was performed using multinomial linear regression and multinomial logit regression models. They used monthly time series of the Pacific equatorial sea surface temperature (SST) index Niño 3.4, a sea level pressure index (SOI) and rainfall anomalies over a 2.5x2.5 o grid along the west coast of Central and South America, for latitudes starting at 25 N, through 45 S, since 1951 to 2011 and defined an ENSO index (NSO) as predictor and rainfall as response. Data was grouped into seasons and then categorized into terciles to construct 3x3 non symmetrical three way contingency tables. As results, they generated latitudinal profiles of the predictability (association), of rainfall for the West Coast of Central and South America, using the ENSO phases as predictor.

4) Using data from September 2005 to November 2007, Morales et al. (2015) studied the meteorological typologies and the physical, chemical and zooplankton oceanography of Golfo Dulce, a unique aquatic ecosystem in the South Pacific of Costa Rica, a region that is normally affected by Caribbean Sea Tropical Cyclones occurrences. The water circulation pattern in Golfo Dulce is typical of fjord-type estuaries, with flux stratification within the water column. Surface water currents reached speeds near 18cm/s in the vicinity of the sill and diminished inward to the northwest at around 5cm/s. The east-west flux was predominant, whereas near Puerto Jiménez the speed was a moderated 5.4cm/s with a south direction. Higher speeds were found near the sill (17.8cm/s) and at the bottom (2.0cm/s to 4.8cm/s). One station was visited once, five were visited five times each. Dissolved oxygen was not absent in deep waters (70m to 140m), but concentrations were low (0.25mg/L to 1.10mg/L). Nutrient concentrations and distribution had the usual horizontal estuarine patterns and for the vertical level phosphate and silicate concentrations increased with depth. Decomposition of organic matter was evident because nitrate concentrations were higher in deep waters. Surface nutrient concentrations indicated the gulf has good environmental quality that sustains a variety of life. Copepods dominated zooplankton (44%-83.6%). The strongest equatorial westerlies were detected between September and October, coincident with higher wave heights. The trade winds blowing from December to April reduced the energy of entering waves and therefore the mean wave height. The annual rainfall cycle was the typical bimodal pattern from the Central America Pacific, with maxima in May and October, except for the midsummer interruption, and minimum rain was on February. Golfo Dulce is a unique environment in the Eastern Tropical Pacific, shows healthy environmental conditions, and is threatened; therefore we urge the establishment of zoning policy for human activities, and to improve protection under the principles of sustainable use.

5 Publications

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

Journal – Book Publications

- **Amador, J. A., E. J. Alfaro,** H. G. Hidalgo, Ana M. Durán, B. Calderón, I. L. Rivera, and C. Vega, 2015. Central America. [In State of the Climate 2014], Bull. Amer. Met. Soc.; 96(7), S. *In Press*.

- **Amador, J**. & Muñoz, G. (2015). Moduladores climáticos de baja frecuencia y las plagas de langostas en Mesoamérica. In Peraldo, G. (Ed.). *Plagas de langostas en América Latina. Una perspectiva multidisciplinaria*. San José, Costa Rica: Editorial Nuevas Perspectivas. 57-97pp.

- Morales-Ramírez, A., O. Lizano, J. Acuña, **E. Alfaro** y E. Gómez, 2015. Rasgos oceanográficos en el Golfo Dulce, Pacífico de Costa Rica: una revisión para la toma de decisiones en conservación marina (Oceanographic features of Golfo Dulce, Costa Rican Pacific: a review for decision-making in marine conservation). Revista de Biología Tropical, 63 (Supl. 1): 131-160. *Spanish*.

- Hidalgo, H.G., Durán-Quesada, A.M., **Amador J.A.** and **Alfaro, E.J**., 2015. The Caribbean Low-Level Jet, the Inter-Tropical Convergence Zona and the precipitation patterns in the Intra-Americas Sea: A proposed dynamical mechanism. *Geografiska Annaler, Series A: Physical Geography*. 97, 41–59. doi:10.1111/geoa.12085

- Cid, L., S. Ramírez, **E.J. Alfaro**, D. Enfield, 2015. Analysis for the American west coast rainfall predictability using an ENSO index. *Revista Atmósfera. In Press*.

- **Alfaro, E.,** 2014. Caracterización del "veranillo" en dos cuencas de la vertiente del Pacífico de Costa Rica, América Central (Characterization of the Mid Summer Drought in two Pacific slope river basins of Costa Rica, Central America). Revista de Biología Tropical, 62 (Supl. 4): 1-15. *Spanish*.

Project results were also divulgated in national, regional and international conferences like:

1- Participation in the III International Conference on ENSO. Bridging the gaps between Global ENSO Science and regional processes, extremes and impacts. Guayaquil, Ecuador, November 12-14, 2014. **Work presented**: Characterization and prediction of the Mid Summer Drought in the Tempisque river basin, North of Costa Rica, Central America, using ENSO and AMO relationships (**E. Alfaro,** http://kerwa.ucr.ac.cr/handle/10669/11194, visited 04/06/2015).

2- Participation in the Science Summit: Ecosystems, Climate Change and Smallholder Farmers in Central America. May 12 – 14, 2015, Punta Leona, Puntarenas, Costa

Rica. **Work presented**: Mapping the vulnerability to hydro meteorological hazards across Central America (**E. Alfaro**).

3- Participation in the "*7o Curso de Primavera sobre Ciclones Tropicales: Dinámica y Paleotempestología*". May 21-25, 2015. Mérida, Yucatan. Joint collaboration of IAI-SPG-CRA-2050 and 2048. **Lectures listed in the agenda**: *Registro histórico e impacto en la sociedad en Centroamérica* (**E. Alfaro**) and *Consideraciones oceanográficas y climatología de CT en el Caribe y Atlántico Norte* (**J. Amador**).

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), EMDAT (http://www.emdat.be/, last visit 11/09/2013) 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, last visit Jun. 17Th, 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/), 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.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 section 1-5 for the student involved in the project activities.

8 Regional Collaboration/Networking

During their participation in the "*7o Curso de Primavera sobre Ciclones Tropicales: Dinámica y Paleotempestología*" in Mérida, Yucatan, May 21-25, 2015, Drs. Alfaro and Amador participated also during this event in the final synthesis meeting for the IAI-SPG-CRA-2050 project, in which key personnel of the project discussed ideas for further collaboration.

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 finished by June 2012 but a component of it, related to PhD studies of M. Sc. Tito Maldonado and M. Sc. Beatriz Quesada at the University of Uppsala, Sweden, is still in progress.

Dr. Amador is the local focal point on education and training of the National Meteorological Institute and the World Meteorological Organization.

Several associated projects, all registered at the UCR Vice-Presidency for Research contributed, both logistically and financially, to achieve many of the project objectives. The associated projects are listed below.

805-A8-606 Desarrollo de un sistema de modelado dinámico para la predicción de la variabilidad climática estacional y del cambio climático", P.I. Dr. Jorge Amador.

805-B0-065 El ciclo diurno del viento sobre Costa Rica (Diurnal cycle of wind over Costa Rica), PI. Dr. Jorge Amador.

805-A9-224 Simulaciones del ciclo hidrológico terrestre usando el modelo hidrológico distribuido de capacidad de infiltración variable, P.I., Dr. Hugo Hidalgo.

805-B0-402 Clima, variabilidad y cambio climático en la vertiente Caribe de Costa Rica: un estudio básico para la actividad bananera. P.I., Dr. Jorge A. Amador.

805-B3-413 Proyecciones de alta resolución de Cambio Climático en Centroamérica usando modelos CMIP5. P.I. Dr. Hugo Hidalgo.

805-B3-600 Caracterización del ciclo hidrológico de los bosques tropicales: transporte de humedad, distribución de precipitación y respuesta a la variabilidad climática. P.I. Dr. Ana María Durán.

805-B4-227 Estudio de los sistemas de circulación meso-escalares en los mares intra-americanos. P.I. Dr. Gabriela Mora.

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

9 Media Coverage and Prizes

Results obtained and activities developed by Co-PIs Alfaro and Amador were used to collaborate with several divulgation newspaper and bulletin notes like:

- "América Central será más seca y caliente en 2050" Suplemento Crisol, Semanario Universidad, Reporter: Patricia Blanco Picado. (http://latinclima.org/articulos/america-central-sera-mas-seca-y-caliente-en-2050, visited Jun 04, 2015)

- Radio program "*Comuidad 870*" on ENSO phenomena and Climate Change, including Tropical Cylone ocurrences (**E. Alfaro**), Radio Universidad de Costa Rica, Reporter Giselle García. Broadcasted on Tuesday, Oct. 28, 2014.

Dr. Amador was incorporated to the *Costa Rican Academy of Sciences* in December 2014. The academic work done in the IAI-CRN2050, was an item considered in this decision (http://anc.cr/noticias/noticia.html?tx_ttnews[tt_news]=437&cHash=89b1d904df9e32762993e2cdbb163381).

Dr. Alfaro received in October 2014 an UCR recognition for his contributions to the university academic repository called Kerwa, see:

http://www.ucr.ac.cr/noticias/2015/01/21/repositorio-institucional-kerwa-recopila-documentos.html

Material include the academic work developed during the CRN2050 that is possible to share in an open way (http://www.kerwa.ucr.ac.cr/browse?value=Alfaro+Mart%C3%ADnez%2C+Eric+J.&type=author).

10 Policy Relevance

The publications generated have been divulgated in different web pages as http://ucr.academia.edu/EricAlfaro/Papers, https://www.researchgate.net/profile/Eric_Alfaro/contributions and http://www.kerwa.ucr.ac.cr/browse?value=Alfaro+Mart%C3%ADnez%2C+Eric+J.&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. Additionally, the activities of the project were divulgated at the UCR Open House Activity, called EXPO-UCR-2015, from April 10 to 12, 2015 (http://www.expo.ucr.ac.cr/expo/).

Additionally, Dr. Alfaro participated in two important regional meetings: *Workshop on the design of a Climate Information Platform for Central America and Dominican Republic*, San Jose, Costa Rica, March 19, 2015 and the *XLV Central America Regional Climate Outlook Forum*, Panama City, Panama, November 18-19, 2014. The main purpose of this participation

was to explore future collaboration with important projects that are working in the region like the Regional Program in Climate Change trough the activities developed locally in the CRN and to divulgate the academic activities developed in the CRN.

11 Main Conclusions

The CRN2050 project extension allowed the possibility of consolidating several data bases at local and regional scales. A good progress had been achieved in the project in the understanding of the CLLJ´s role in precipitation distribution in Central America. So far some new ideas are being developed to include regional moisture sources at different scales in time and space. Preliminary statistical analysis of ITCZ, position and intensity of moisture fluxes, and CLLJ variability indexes are being estimated with the aim to propose a conceptual model of the interaction of these mechanisms in the production of regional rainfall. Based on the results of some of the publications mentioned above, regional climate change and its effects on regional physical mechanisms are also being studied using ERA-Interim data.

The CRN050 also allowed investigators to improve local research facilities and data bases, so, they can engaged in other types of collaboration (e.g., with the marine biology community). Two papers about climate and climate variability in the Eastern Tropical Pacific, as contributions to a local project on the Cocos Island biodiversity, were submitted to the International Journal on Tropical Biology and Conservation (IJTBC, http://www.biologiatropical.ucr.ac.cr/), three months ago. The paper on climate is back from reviewers and some changes were recommended to clarify some concepts and figures. After corrections, this manuscript is ready to be sent to the IJTBC Editor again. The second paper is still under review process.

12 References not included in Section 5 Publications

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