First Annual Report
1 July 2006 - 30 June 2007

1. Project Information

Project Title: "Tropical cyclones: current characteristics and potential changes under a warmer climate"
Project Number: CRN II -048
Principal Investigator: Graciela Binimelis de Raga
Key Words: tropical cyclones, East Pacific basin, climatology, intensification

2. Project Funding

No complementary funds were received for this project

3. Research Activities and Findings

As an introductory remark, it should be noted that the agreement between UNAM and IAI was finalized towards the end of 2006, so the individual agreements between UNAM and the other participating institutions (both in Mexico and abroad) have not been signed yet (June 2007). Nevertheless, there have been a few developments to report in this brief period, detailed below.

The objectives listed in original proposal were:

a) To better understand the factors and processes that influence the intensification of tropical cyclones, through observations and model simulations.

b) To evaluate which of those factors could be more important under global warming scenario.

c) To evaluate the impact of coastal waves induced by tropical cyclones under global warming scenario.

The original work plan for the first 12 months of the project was primarily geared towards objective a). The timeline proposed was the following:

i) Climatological study from satellite data over the East Pacific (EPAC) Ocean
ii) Climatological study using NCEP-R2 and ECMWF data
iii) Operational modeling with MM5 during the cyclone season
iv) Data analysis from field projects with aircraft (TCSP/IFEX and EPIC)

Due to the delays in signing the formal agreements, there have only been advances in topics i) and iv) which are reported below. Topics ii) and iii) will be addressed in the second year of the project. Note that it has already been decided to use the Hurricane Weather Research and Forecasting (H-WRF) model, rather than the older MM5 (which has originally proposed), because of the improvements introduced in the code (in terms of physical parameterizations) and also because the National Hurricane Center (US) made the decision to use this version operationally.

i) Climatological study from satellite data over the East Pacific (EPAC) Ocean

A new collaboration was established with Dr. O. Sanchez, working at an institute (CICATA) in the city of Altamira (Tamaulipas), which is part of the research network of the Instituto Politécnico Nacional (IPN) in Mexico. This collaboration was *not* originally included in the project, but Drs. Zavala and Binimelis de Raga considered appropriate to incorporate Dr. Sanchez as a collaborator. A formal research agreement is currently being evaluated by the legal departments at UNAM and CICATA-IPN, so that Dr. Sanchez can visit UNAM for 7-10 days every 2 months for face-to-face discussions and to report on his progress. He has already visited UNAM during March and June 2007. We report briefly on the developments of the analysis of oceanic satellite data that Dr. Sanchez is carrying out and that was part of the original work plan of this project.

The data analyzed in this project was extracted from the global multi-mission altimeter database: Jason-1, TOPEX/Poseidon, ENVISAT, GFO, ERS1/2 and GEOSAT. The database is generated using common processing facilities for global and regional applications, by providing a consistent and homogeneous catalogue of products, both for near real time applications and offline studies and it ensures that upgrades are consistently applied on all products to better serve the altimetry user community. Altimeter data from TOPEX/Poseidon, ERS-2, ENVISAT, Jason-1, and GEOSAT Follow-On have been merged together in order to analyze the sea level anomaly for the period from 1993 to 2003. This merged database provides gridded ($1/3^0 \times 1/3^0$) information with a temporal resolution of a data point every 7 days. The region of interest for this study is located in the Tropical East Pacific, from the Equator to 30°N in latitude and from the Pacific coast of Central America to 140° W. As an example of the analysis we present the monthly mean sea surface height (SSH) anomaly in **Figure 1**. This SSH anomaly has been calculated as the difference from the 11-year average (1993-2003). Note that the SSH anomaly pattern changes dramatically throughout the year in this region. The anomalies are elongated in the zonal direction; early in the year a negative anomaly is observed closer to the Equator with a positive observed immediately north. This zonal pattern reverses, with a high anomaly closer to the Equator found in September. In the region limited by 90 and 110 W in longitude and 10-15N in latitude, the high anomaly starts to develop in February and reaches its maximum positive value during May. Note how this high anomaly continues to propagate westward and is then replaced by a generalized low SSH anomaly. This low anomaly seems to also originate near the coastline, but then separates from the coast and develops in amplitude reaching a minimum value in November. These anomalies in the SSH are related to the depth of the thermocline, and are likely related with the oceanic circulations in the Equatorial Pacific (Kessler et al., 2006).

Close to the coastline, near the Isthmus of Tehuantepec, we observe high SSH anomalies starting in May. In June, there is an interesting pattern in the SSH anomaly that appears located westward of the main gaps in the mountains that span Southern Mexico and Central America: Tehuantepec, Papagallo and Panama. A strong negative SSH anomaly starts to develop in Tehuantepec in December. Later in the winter, the negative anomalies are evident near these three coastal regions, with the area near Panama reaching the lowest values. Note that these high and low anomalies are relative to the 11-year average, so their amplitude cannot be considered absolute.

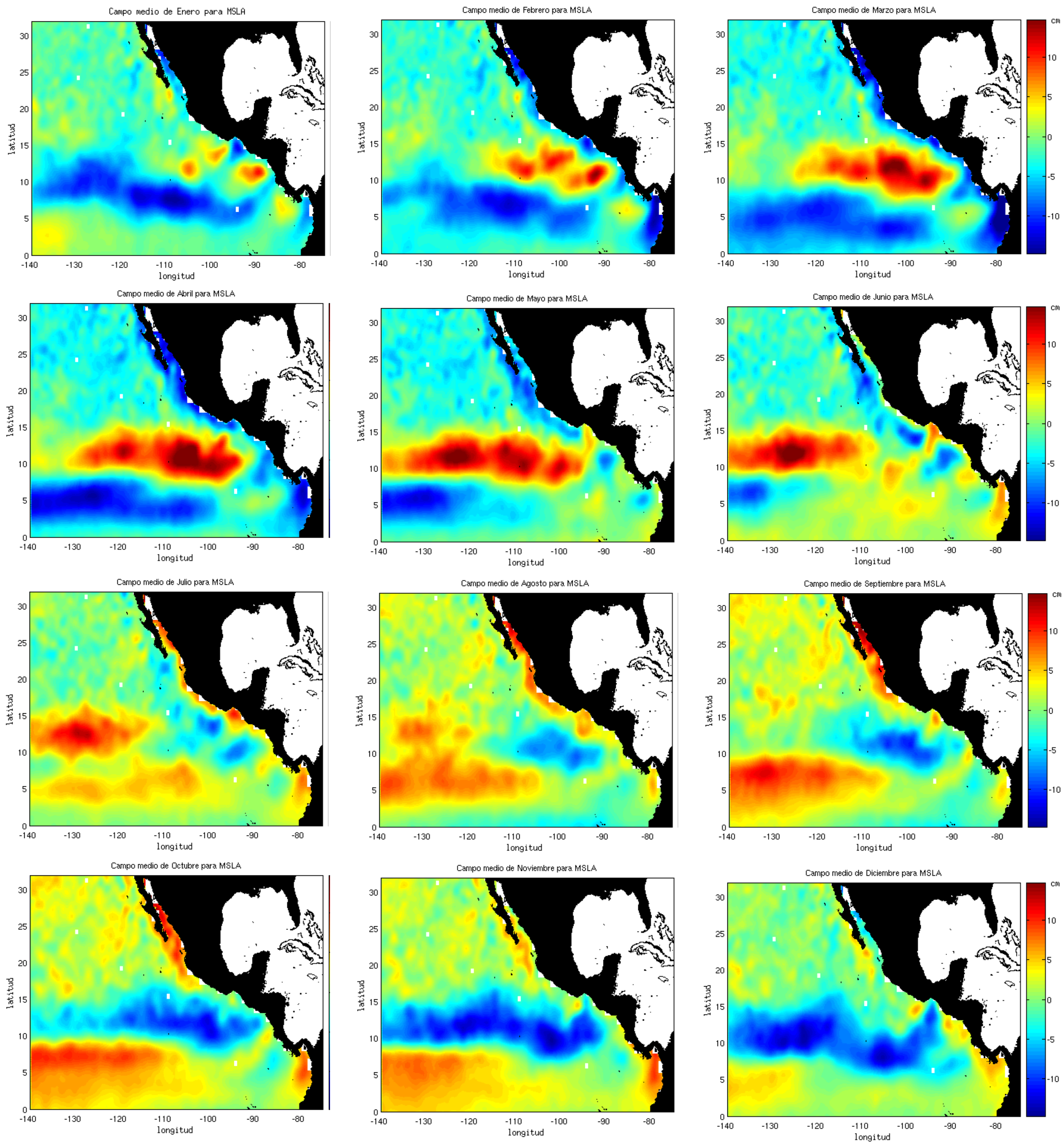

Figure 1. Monthly mean SSH anomaly in the Tropical East Pacific with respect to the 11-year average (1993-2003)

Romero-Centeno et al (1007) studied the wind circulations in the region and observed enhanced wind speed ("jets") during mid-summer through these mountain gaps. The oceanic response to these jets can be observed as dipoles close to the coastline, with an area of high SSH anomaly to the right of the axis in the exit region of the jet.

The reversal in the sign of the SSH anomaly appears to be related to the propagation of Kelvin coastal waves northward from the Equator that become unstable in the region of the Gulf of Tehuantepec, as described by Zamudio et al. (2006), from results of ocean modeling. This instability results in eddies that propagate westward from the coast, which are particularly frequent during the winter. However, they are also observed during the summer months, at least during the simulated period. Note the presence of high and low SSH anomalies near the coast, as discussed in the previous paragraph.

The period of SSH anomalies analyzed here includes the very strong El Niño event of 1997-98. Large year-to-year variability is observed in the region. As an example, **Figure 2** shows the yearly average SSH anomaly maps for a neutral (2001) and an El Niño year (1997). Note how the overwhelming El Niño signal of high SSH anomaly that developed in the region late in 1997 dominates the yearly average. A neutral year shows moderate positive and negative SSH anomalies in the EPAC.

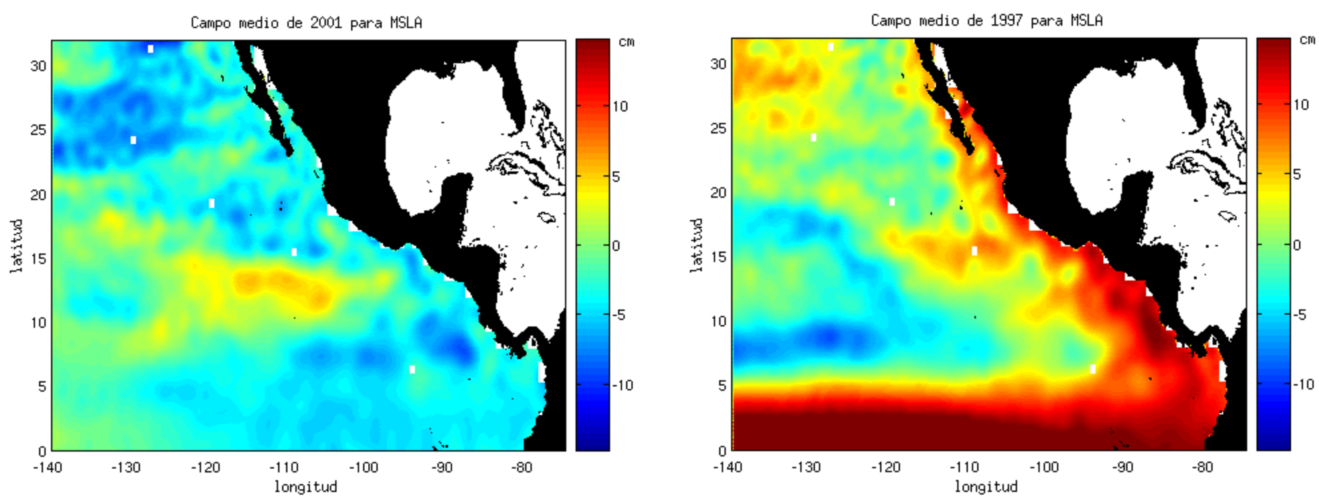

Figure 2. SSH anomaly for the years 2001 and 1997, with respect to the 11-year average (1993-2003)

The database has also been divided into 2 categories, to discriminate whether the presence of a tropical cyclone in the region leaves a signal in the SSH anomaly data. The goal is to produce the corresponding climatological patterns observed in the ocean prior and after the development of a cyclone. The presence of high SSH anomalies in the trajectory of a cyclone, may lead to intensification, as has been observed in the Gulf of Mexico for Katrina (Scharroo et al, 2005) and the Western Tropical Pacific for super-typhoon Maemi (Lin et al, 2005).

A tropical cyclone extracts heat from the oceanic mixed layer in order to intensify. Depending on the vertical stratification in the ocean and the bathymetry, the passage of a cyclone can leave a signal in the sea surface temperature, as was seen after the passage of Katrina in the Gulf of Mexico (Sun et al, 2005). However, in some regions, such as in the EPAC the sea surface temperature (SST) is so high that there is no noticeable wake in SST after the passage of a cyclone. The altimeter data can be used to identify the oceanic regions that have been affected by the passage of tropical cyclones. As an example, **Figure 3** shows a map of the difference between the SSH anomalies the week prior and the week after the passage of category 4 Hurricane Adolph in May-June 2001. Note the “wake” region (in shades of blue) which indicates that the storm has left behind a concentrated region of negative anomaly, reaching up to -20cm. This information can be related to the heat content extracted by the storm from the ocean, which will be part of the future work. The climatological SSHA data is currently being written up as a manuscript, to be submitted by September. Another short note is planned, discussing the “wake” left by a few selected cyclones near the Mexican coast.

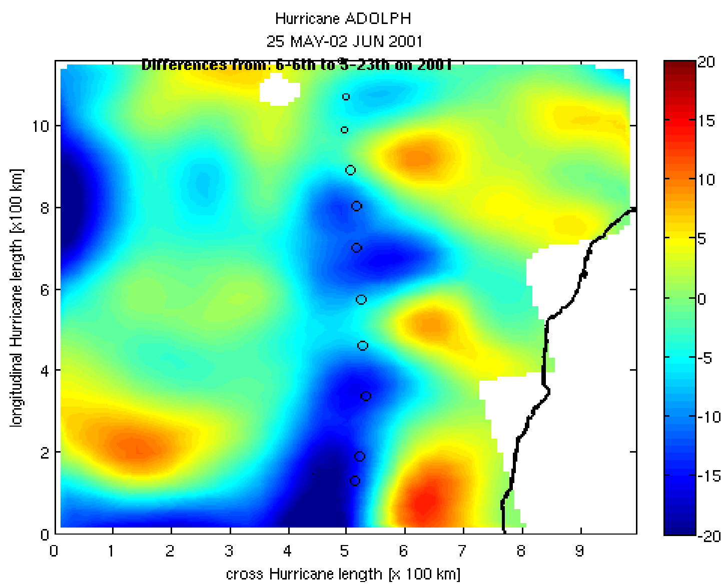

Figure 3. Difference between SSH anomalies prior and after the passage of Hurricane Adolph in the Tropical East Pacific. The circles indicate the trajectory of Hurricane Adolph, which reached category 4.

It is interesting to compare the annual cycle of SSH anomaly with the sea surface temperatures (SST) in the EPAC. **Figure 4** shows the SST, where it is obvious that the EPAC meets the requirement of 28.5C minimum SST for the development of mayor cyclones. However, the monthly mean SSH anomaly maps (**Figure 1**) indicate the presence of a wide spread negative SSH anomaly in the primary region of cyclogenesis of the EPAC. High anomalies in SSH are associated with a deeper (warmer) oceanic mixed layer. This would suggest that the cyclones that develop in the EPAC do so over a relatively shallow oceanic mixed layer from where to extract the heat needed for intensification.

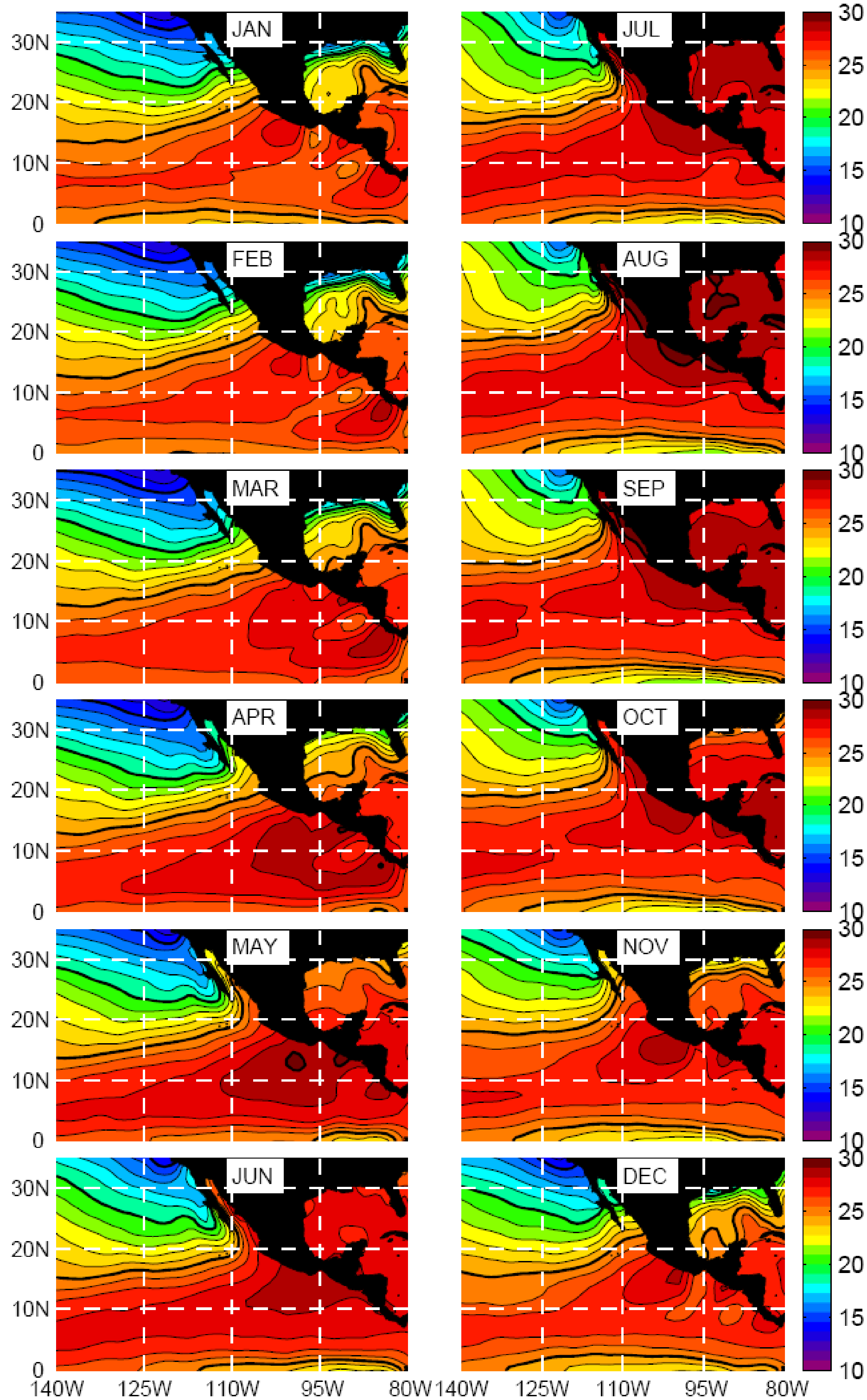

Figure 4. Monthly mean sea surface temperature (SST) in the Eastern Pacific region.

It is well known that the EPAC is the region that develops more cyclones per unit area than anywhere in the globe. **Figure 5** shows the time series of named storms from 1966 to 2006 (satellite record), from the database provided by the National Hurricane Center, which average 16 per year (with a standard deviation of 4). Nevertheless, few cyclones reach strong hurricane status (defined as category 3 and larger), as can be seen in **Figure 6.** The ratio of strong to total number of hurricanes in the EPAC basin from 1966 averages 0.44 with a standard deviation of 0.20. There are some years with a much larger fraction, notably 1991-92 and 1997-98, linked to strong El Niño events. Only 1 out of 4 named storms develop in the EPAC will reach category 3 or larger and 1 out of 6 will make landfall in Mexico, most as tropical storms or category 1 hurricanes Only 11 category 5 cyclones have been recorded since 1966 in this basin, and most all of them developed far away from the Mexican coast.

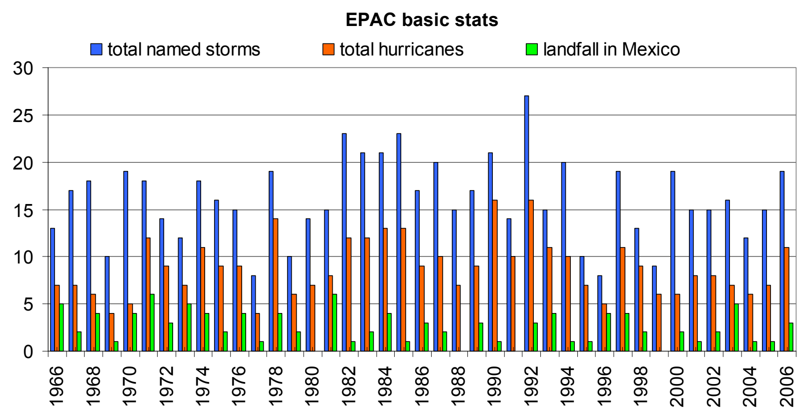

Figure 5. Time series of the total number of named storms (in blue), the number of hurricanes in the EPAC basin (in orange) and the number that make landfall in Mexico (in green), from database at the National Hurricane Center, NOAA.

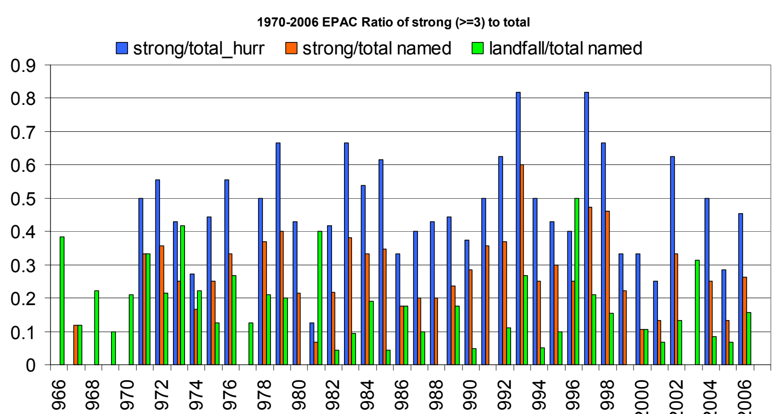

Figure 6. Time series of the ratio of strong (category 3 and larger) to total number of hurricanes (in blue), to the total number of named storms (in red)and the ratio of landfalling to total number of named storms (in green), in the EPAC basin (from database at the National Hurricane Center, NOAA)

Only 1 category 5 hurricane made landfall in Mexico since 1966, Hurricane Kenna in 2002. This small number of very intense hurricanes in the EPAC region may be related to the fact that cyclones develop mostly over a shallow oceanic mixed layer. Similarly, we can hypothesize that the presence of warm eddies generated during the cyclonic season may have an impact on the intensification of certain storms. This will be investigated further in the near future.

In future work the altimeter data will be correlated with other variables (e.g. sea surface temperature and horizontal winds from the QuickScat database) to estimate the air-sea heat fluxes in the region of interest. Not only the climatological study will be produced, but also we envision a couple of case studies including atmospheric modeling (with WRF).

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iv) Data analysis from field projects with aircraft (TCSP/IFEX and EPIC)

Two PhD students (J. Cisneros from Costa Rica, a registered student at New Mexico Institute of Mining and Technology supervised by Dr. Raymond) and (J. Marín from Cuba, a registered student at UNAM supervised by Dr. Binimelis de Raga) are currently doing research on topics very much related to the objectives of this project. They have been working on different aspects of tropical cyclogenesis using the data from past projects (TSCP/IFEX in 2005 and EPIC in 2001), to identify key parameters in the development (or not) of organized convection. We present here some results of the research of J. Marin.

It is known that uncertainties still remain about the mechanisms that control the development and organization of deep convection over the East Pacific tropical ocean, that in turn result in poor numerical weather predictions in the region. The East Pacific Investigation of Climate (EPIC2001) was carried out during September and October, 2001 (Raymond et al. 2004, Bretherton et al. 2004), to understand, among other topics, the location, intensity and variability of deep convection in the East Pacific (EPAC) region. The wind fields, especially at the surface, appear to be an important factor in convective development and intensification (Raymond et al. 2003; McGauley et al. 2004) and require a correct representation in numerical models. The wind fields from observational data during EPIC2001 and from the Final Global Data Assimilation System (FNL), were compared and the relative good agreement between them, encouraged us to use these analyses to evaluate the intensification of tropical cyclones in the EPAC.

Dropsondes were launched from the two research aircraft during EPIC2001, which followed to types of flight patterns: i) in a 4º x 4º domain centered at (10N, 95W) (hereafter named EPIC domain) and ii) along the 95W meridian. The other dataset used is the FNL, run operationally by the National Centers for Environmental Prediction on a 1º x 1º grid, four times a day. Winds speed and direction as well as thermodynamic parameters are obtained from the dropsondes along the 95W meridian and were compared against the FNL gridded data (distributed in 26 vertical pressure levels from 1000hPa to 10hPa).

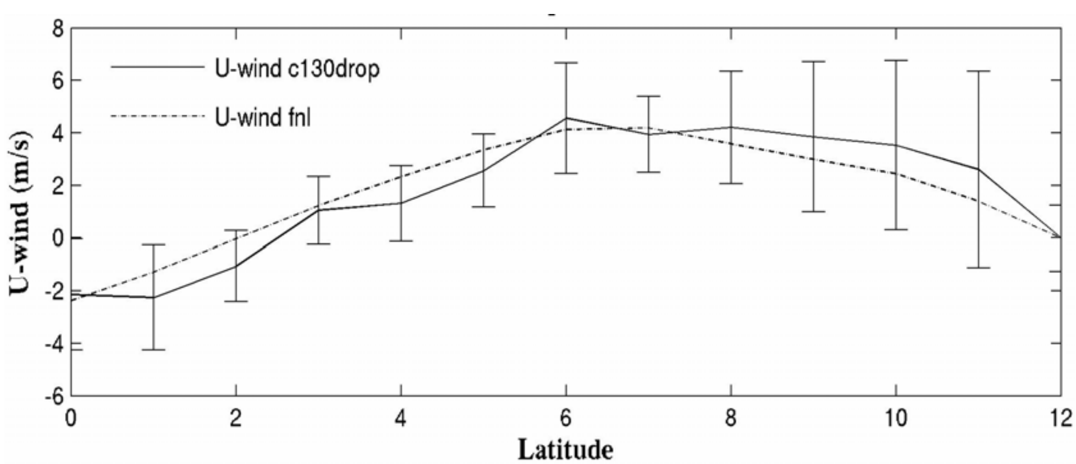

Figure 7. Zonal wind (u) at the surface averaged over the eight flights, from dropsonde (solid line) data and FNL (dashed line) data. Error bars represent the standard deviation in the dropsonde measurements.

Figures 7 and **8** show the comparison of the *u* and *v*-component of the wind at the surface from the dropsondes and the FNL data, averaged over the eight flights along the 95W longitude. There is a very good correspondence in both wind components at the surface. The largest variability in the zonal wind is observed in the convective region between 8 and 12N. The vertical-meridional root mean square (rms) error of the zonal wind indicates that the best agreement is found between 900 and 1000hPa, deteriorating between 6-12N due to the larger variability observed in this region. The rms error is larger above 900hPa between 0-6N and in the convective region 8-12N.

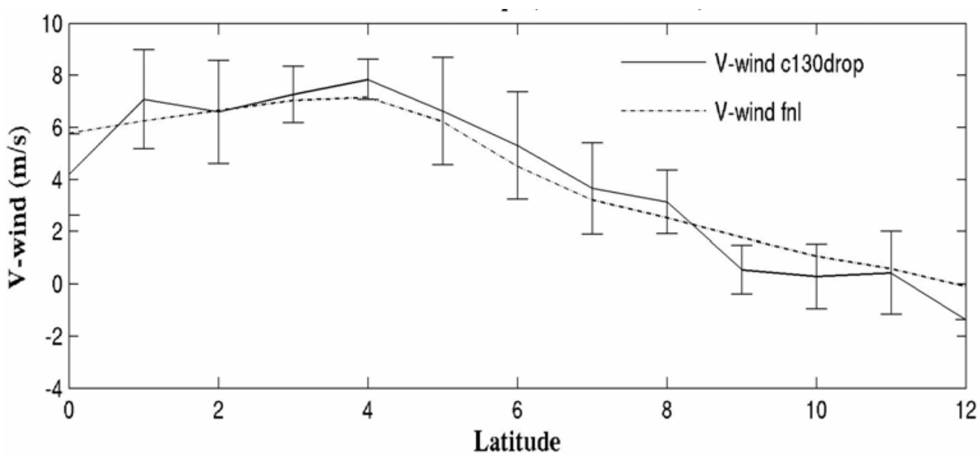

Figure 8. Same as Fig.7, but for the meridional wind at the surface

Figure 9 shows the time evolution of the zonal wind at 850hPa from the dropsonde and the FNL data, averaged over the EPIC domain. The variations in the zonal wind observed during the experiment, from westerlies to easterlies and vice versa, are associated with the passage of easterly waves, which later developed into tropical cyclones. Their names are indicated in the figure, located at the date of the wave passage. The FNL data seem to capture the observed variations in the zonal wind, although it tends to overestimate its magnitude during the wave episodes. This indication of easterly wave passage can also be observed at the surface (**Fig. 10**). The FNL data compares well with observations but overestimates the magnitude the zonal wind in both phases (westerlies and easterlies). Similarly, the FNL data overestimates the meridional wind at the surface.

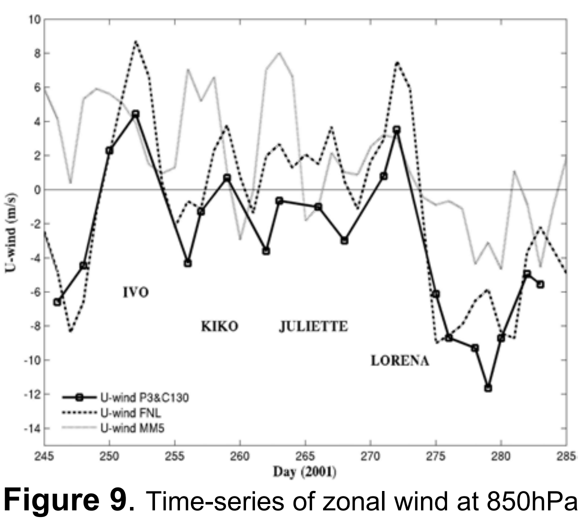

Figure 9. Time-series of zonal wind at 850hPa averaged over the EPIC domain, from dropsonde (solid line) and FNL (dashed line) data. The names correspond to the tropical storms that developed during this period from easterly waves**.**

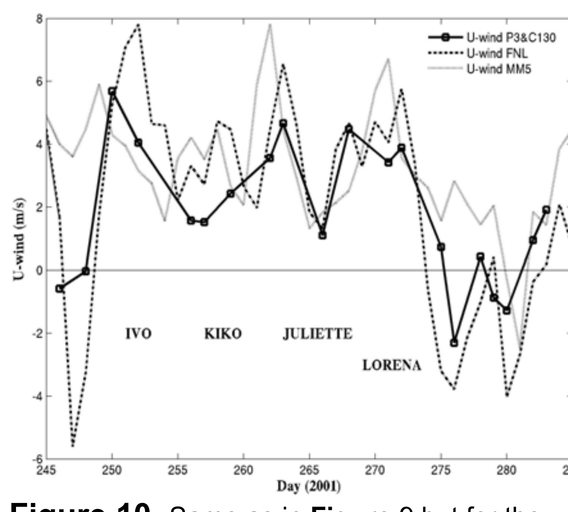

Figure 10. Same as in **Figure** 9 but for the zonal wind component at the surface.

In summary, given the small overestimates observed, the FNL data is considered acceptable for studies of the large-scale characteristics in the EPAC region and will be used further to estimate intensification of convection into tropical cyclones.

Tropical cyclogenesis can be described as a rapid increase of low-level cyclonic vorticity within a region of enhanced convective activity. Studies that have tried to understand the role that dynamics plays in tropical cyclogenesis include Montgomery and Enagonio (1998), Raymond et al (1998), Enagonio and Montgomery (2001), Davis and Bosart (2001) and Reasor (2005). Raymond et al (1998, hereafter R98) analyzed several case-studies of easterly waves that developed into tropical cyclones in the EPAC during TEXMEX, using a dynamical framework based on the vorticity equation. Here we extend the ideas of R98 to analyze several tropical cyclones that developed in the EPAC using FNL data. The results from the Global Forecast System (GFS) are also used for the analysis, for systems that developed in June and July 2005 during TCSP/IFEX.

The vorticity equation in pressure coordinates can be written as:

$$\partial \zeta_a / \partial t + \partial Z_x / \partial x + \partial Z_y / \partial y = 0 \qquad (1)$$

where Z_x and Z_y are:

$$Z_x = u \zeta_a + \omega \partial v / \partial p - F_y$$
$$Z_y = v \zeta_a + \omega \partial u / \partial p + F_x$$

and ω is the pressure vertical velocity, p is the pressure, ζ_a is the absolute vorticity and F_y and F_x are the horizontal components of the turbulent frictional force per unit mass. We can integrate (1) over some area A* that encompasses the area of the storm A(z) at all levels (**Figure 11**) to obtain an expression for the absolute circulation (Γ_a).

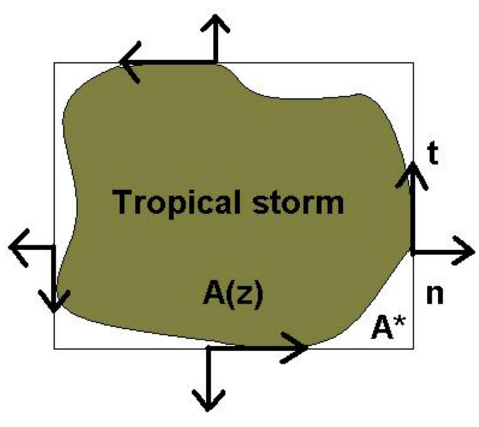

Figure 11. Schematic showing the area A* and vectors tangential (t) and normal (t) to the periphery of A*.

If the periphery of A* is in clear air, then ω in (1) is likely to be very small there, and can be ignored. Thus, applying the divergence and Stokes theorems we obtain:

$$d\,\Gamma_a^* / d\,t = -\zeta_a \cdot \Delta^* + \tau^* \qquad (2)$$

which relates the rate of spin-up of a storm to the convergence of absolute vorticity into the system at each level, and the spin-down tendency due to frictional forces.

The frictional term (τ^*) that represents the eddy transfer of momentum to the surface, can be estimated as the residual from Eq. (2), since the other two terms can be calculated from the FNL dataset. Alternatively, the frictional term can be calculated as:

$$\tau^* = \int \delta A^* \, \mathbf{F} \cdot \mathbf{t} \, ds \qquad (3)$$

where **F** is the drag force. Since the vertical distribution of **F** is not known, the vertically averaged **F** per unit mass due to surface friction can be approximated with the bulk formula: $\mathbf{F} = -Cd\,|\mathbf{u}|\,\mathbf{u} / D$, where D corresponds to the depth of the averaging layer.

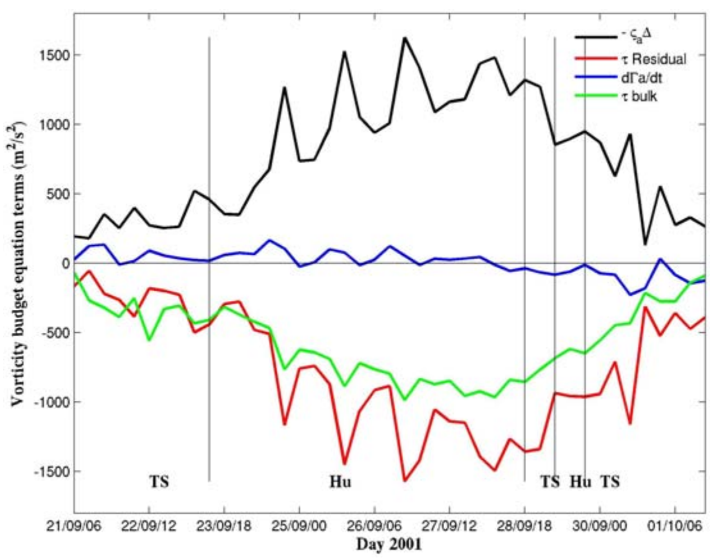

Figure 12. Terms in Equation (2) for hurricane Juliette. The time rate of change of the absolute circulation (blue) and the convergence of absolute vorticity (black) are obtained from FNL data. The friction term calculated as a residual from Eqn (2) is shown in red and calculated from the bulk formula is shown in green. The vertical lines show the different stages in the lifetime of the storm (TS: tropical storm; Hu: hurricane).

The vorticity balance described by Eqn. (2) was analyzed in several tropical cyclones that developed in the EPAC in order to study the relative importance of each term, at the different stages in the lifetime of the storms. As an example, **Figure 12** shows the balance for tropical cyclone Juliette (21/09/2001-1/10/2001), calculated averaging the layer 1000-900hPa. The convergence of absolute vorticity (black line) increases significantly from the tropical storm to the hurricane stage, resulting in a small but positive tendency of the absolute circulation. As the cyclone matures, the convergence of absolute vorticity decreases and the friction term becomes more important, leading to a slow-down of the circulation.

The good agreement between the friction terms calculated by the two different ways described above (see in **Figure 12**, green and red lines), suggests that the balance in this storm is valid when a relatively shallow layer (approx. 1km) is considered. This is more clearly seen during the early stages of cyclone development. As time progresses, the two estimates of the friction term start to diverge. One of the reasons for this may be related to the assumption of a fixed depth for the averaging layer independent of cyclone lifetime. As cyclones evolve, there may be a need to consider a different layer over which the vorticity balance would be valid. Therefore, an optimum value of this depth was calculated, by minimizing the difference between the two ways of estimating the friction term. The results (**Figure 13**) suggest that the balance is more frequently valid in the layer 0-4000 m, for all the storms irrespective of their developmental stages. When only cases where cyclones are tropical depressions (TD) are considered, over 50% of the heights are larger than 2500 m, with a few quite a few cases of very deep layers found. In the tropical storm (TS) stage, the frequency at which the balance is observed at heights above 5000 m decreases notably from the previous stage. In the hurricane (Hu) stage, the balance is observed only in the layer 0-2000 m. Note that if the transfer of turbulent momentum is concentrated in the lower layers of the atmosphere it would suggest that no deep convection is likely to occur. The results suggest that when tropical cyclones intensify, the balance seems to be frequently concentrated in a deeper layer. This layer becomes shallower as the cyclone evolves.

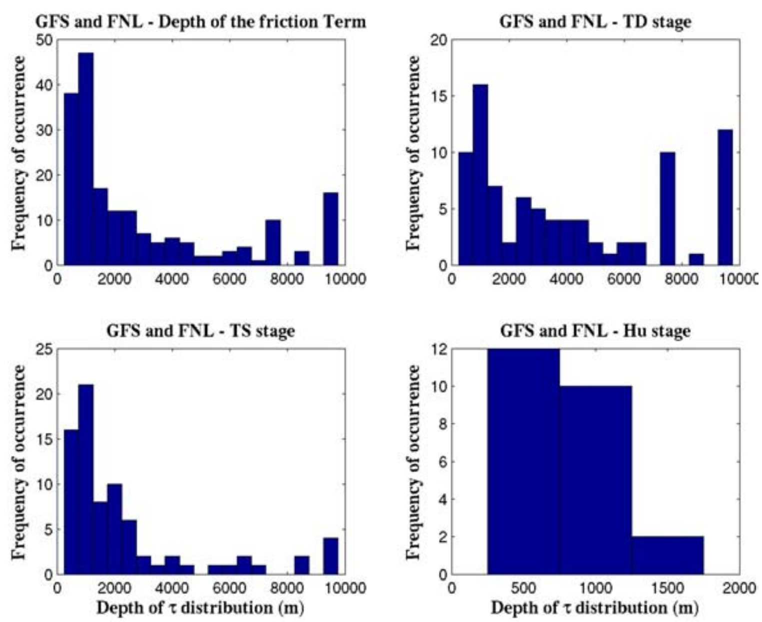

Figure 13. Histograms of the depth (D) over which the balance of Eqn (2) is valid (see text for details). Upper left panel: All cyclones included. Upper right: TD stage. Lower left: TS stage. Lower right: Hu stage.

Finally, it is of interest to consider the vertical profiles of the horizontal mass convergence, vertical mass flux and absolute circulation (as a measure of the intensity of the cyclones), for different stages in the lifecycle of the cyclones. We again present the case of tropical cyclone Juliette as an example of the analysis, in **Figure 14.** The results show that there is mass convergence in al deep layer, during the stages when the cyclone is intensifying. The height at which the horizontal mass convergence becomes very close to or zero changes as the cyclone evolves (**Fig. 14** lower left panel). And similarly, the profile of the vertical mass flux within the cyclone also changes, with maxima moving higher up as the cyclone intensifies. The results shown in **Figure 12**, considered only a fixed depth D, over which the vorticity balance was valid, but the evidence of changes in the depth (from **Fig. 14**) suggests that the calculation with a variable depth may be more appropriate. Just such calculations are now being performed, as part of the on-going research.

It is interesting to note that the vertical wind shear (**Fig. 14**, upper left panel) indicates very low values during several days for Juliette, while evolving from tropical depression to hurricane. Low values are a favorable environmental factor for cyclone intensification. The shear then becomes larger, coinciding with the decaying stage of the cyclone.

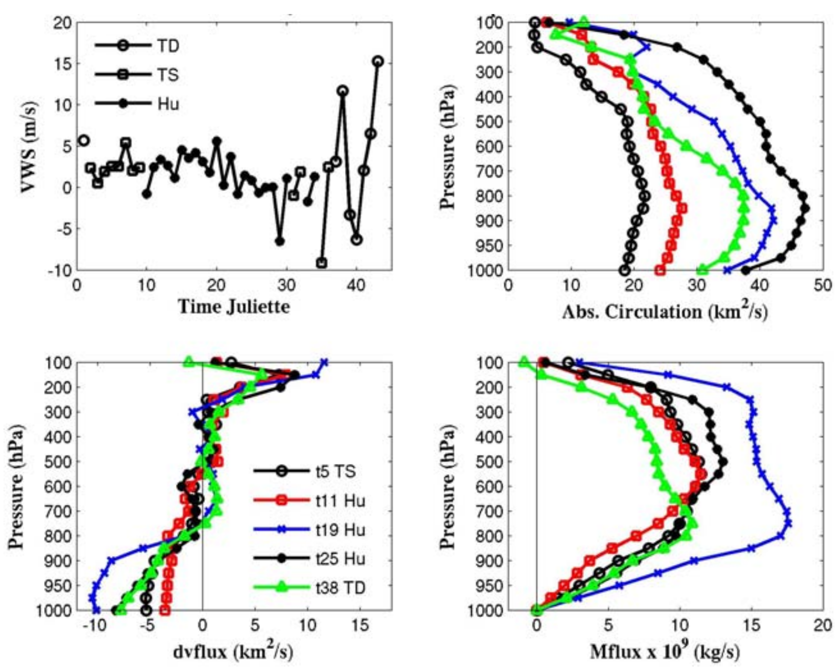

Figure 14. Upper left panel: Time evolution of the vertical wind shear (VWS) calculated for the 850-200 hPa layer. Upper right: Vertical profile of absolute circulation. Lower left: Vertical profile of horizontal convergence of mass. Lower right: Vertical profile of vertical mass flux at different times (t5, t11, t19, t35 and t38), which correspond to different stages in the lifecycle of tropical cyclone Juliette.

In summary, the results from this study using data from global models agree with previous results from R98: tropical cyclones only develop when the vorticity balance (as given by Eqn. 2) is valid in a deep layer of the troposphere. The results also indicate that as the tropical cyclones start to intensify, the convergence of absolute vorticity dominates in the vorticity balance, resulting in the increase of the absolute circulation, i.e., storm spin-up. Once the storm reaches a mature stage, the friction term dominates in the balance producing a decrease in the storm circulation and its final decay. A manuscript is in preparation based on these results and will be submitted for publication before December 2007.

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Other activities related to the project: Special sessions and workshops by participants

1st Summit on Hurricanes and Climate Change

Participation in this event had not been planned when the proposal was first submitted, since the event was announced late in 2006. Therefore, Dr. Binimelis de Raga requested permission to attend, which was granted by Dr. Breuleman. The participation resulted in vey successful interactions with several of the participants, particularly Dr. Emanuel (MIT) and Dr. I-I Lin (Taiwan University), which suggested helpful ideas for the ongoing research on the sea surface height anomalies. Also, links were established with Dr. Bye in Australia (University of Melbourne), to use his methodology in the East Pacific region and Dr. Scoccimarro in Italy (Istituto Nazionale di Geofisica e Vulcanologia), to study the ocean response in the East Pacific, since the coupled atmosphere-ocean model is not able to reproduce the climatology of tropical cyclones in the region.

AGU Spring meeting, 21-24 May, Acapulco

Drs. Raymond, Shay, Zavala-Hidalgo and Binimelis de Raga organized the special session: “The Tropical East Pacific: A natural laboratory for coupled ocean-atmosphere research”, held on 21 and 22 May with a total of 22 papers on the topic.

Another related special session was organized by R. Romero-Centeno and S. Curtis: “Mid-summer drought: Causes and implications”, held on 24 May, in which 13 presentations were scheduled.

Another special session named “Earth and Space Science Informatics” was organized by Drs. Luis Farfan (CICESE/Mexico) Tom Yoksas (UCAR) Elen Cutrim (Western Michigan Univ.), Glen Rutledge (NOAA) and Waldenio de Almeida (CPTEC/Brazil). It consisted of 22 oral presentations and 22 posters.

An informal meeting was held in Acapulco during the AGU Spring meeting, where Co-PIs and PhD students from the project discussed results and planed following research activities.

The participation of L. Farfan, J. Marin and R. Romero-Centeno at the AGU Spring meeting was partially funded by this project. The poster presentations of Marin et al. (MarinEtAl_AGU2007.pdf), Farfan and Cosio (Farfan&Cosio_AGU2007.pdf) and Romero et al. (RomeroEtAl_AGU2007.pdf) at the AGU Spring meeting are attached to this report.

4. Contributions of Co-PIs

Since the agreements between the UNAM and the other research institutions have not been formally finalized (no funds have yet been transferred), then it is not feasible to require individual co-PIs to carry out the proposed research. Therefore, we report here about the activities of some of the investigators who have already started.

Costa Rica:

O. Lizano (CIGEFI) will implement the coastal wave model using current an future hurricane climate scenarios for the Eastern Tropical Pacific coast. In particular, the detailed bathymetry is needed for some of the bays and ports on the West coast, to assess the potential risk to coastal cities.

Cuba:

D. Martínez and I. Mitrani (INSMET) will be responsible for numerical simulations with MM5 in forecast mode during the hurricane 2007 season. Also the hindsight simulations will be carried out by the group at INSMET.

Mexico:

J. Zavala-Hidalgo and GB Raga (CCA-Mexico), together with O. Sanchez (CICATA-Mexico) have started the analysis of the sea surface height anomaly (from satellite data Topex/Poseidon), which are the first phase towards the generation of the proposed regional maps of heat content of the oceanic mixed layer in the EPAC region. A manuscript will be submitted for publication in September 2007.

GB Raga and her PhD student J. Marin (CCA-Mexico) have started the analysis of the FNL data and the results from modeling work using the global forecasting system (GFS), that was carried out at NCEP. The preliminary results were presented in a poster during the recent Spring Annual Meeting of the AGU and another manuscript is in preparation in collaboration with Dr. Raymond.

L. Farfán (CICESE-Mexico) will participate in the application of mesoscale models (WRF and MM5) to simulate the development of tropical cyclones in a near real-time basis. He will also be working on a climatological study of storm tracks which has an impact over the west coast of Mexico (1976-2006).

R. Prieto (IMTA-Mexico) will be partially responsible for the climatological study using gridded data for the current climate conditions.

United States of America:

D. Raymond (NMT-USA) together with his PhD student J. Cisneros have already started the analysis of the airborne Doppler radar and dropsonde data from the TCSP/IFEX project. The preliminary results were presented in a poster during the recent Spring Annual Meeting of the AGU and a manuscript is currently in preparation in collaboration with J. Marin.

5. Publications

No formal publications are yet available. Three poster presentations at the Spring Meeting of the AGU relate to the topics of this project:

1. Marin, J., D. Raymond and G.B. Raga: Vorticity balance in East Pacific tropical cyclones. (MarinEtAl_AGU2007.pdf)
2. Romero-Centeno, Rosario, Jorge Zavala-Hidalgo, and G. B. Raga: Midsummer Drought in Mexico and Central America and its Relationship with the Eastern Pacific Gap Winds. (RomeroEtAl_AGU2007.pdf)
3. Farfan, L. and M. Cosio: Relationships between Eastern Pacific tropical cyclones and convective rainfall in Baja California. (Farfan&Cosio_AGU2007.pdf)

6. Data

No new data has yet been generated in this project.

7. Capacity building

Two PhD students are currently are currently doing research on topics very much related to the objectives of this project:

- Jorge Cisneros from Costa Rica, a registered student at New Mexico Institute of Mining and Technology under the supervision Dr. Raymond
- Julio Marín from Cuba, a registered student at UNAM supervised by Dr. Binimelis de Raga

A new PhD student has been admitted to the graduate program in Earth Sciences at UNAM, and will start his research next fall. His research topic involves regional ocean modeling of the EPAC, validation with in situ data (from ocean probes during EPIC2001 and the Argo network) and identification of the role of oceanic warm eddies in the explosive intensification of tropical cyclones in the EPAC.

- Fernando Oropeza from Mexico, a newly registered student at UNAM supervised by Dr. Binimelis de Raga

Early last year, an advertisement was published in EOS to request applications to fill the postdoctoral positions associated with the project. Even though there were several candidates that met the requirements solicited, when the positions were offered to the top 4 candidates from countries other than the participating ones, all of them unfortunately declined to take the postdoctoral positions. The decision was made not to advertise again widely to the outside community and go through another selection process. Instead, one of the positions will be awarded to an upcoming PhD graduate from UNAM, who has been working on a related topic for her thesis. R. Romero is expected to graduate in August 2007 and take up the postdoctoral position during the next fall.

Since our project involves training graduate level students, but not many have recently applied, some direct actions need to be taken to publicize the project and recruit students. Dr. Luis Farfan visited the Department of Atmospheric Sciences at the Universidad Veracruzana in May, performing the following activities: a) meeting with faculty members to identify potential areas of technical collaboration, b) seminar to students on tropical cyclone development during the season of 2006 in the EPAC region and c) meetings with students who are interested in participating in activities associated with this project.

Another activity to report is the upcoming 75 hour-long course on tropical meteorology with emphasis on tropical cyclones that will be offered at the Atmospheric and Ocean Sciences Department at the Universidad of Buenos Aires (UBA). The course will take place during July and August 2007 and Dr. Binimelis de Raga has already been formally appointed as a Visiting Professor for this course. The course is divided into 30 hours of theory and 45 hours of "hands-on" work on different databases of tropical cyclones. In particular, satellite data (temperatures, winds and precipitation) will be analyzed for 3 hurricanes that developed in the EPAC during the 2006 season (category-4 John, category-2 Lane and category-3 Paul). Results from modeling of those cases using WRF will also be provided to the students. Dr. L. Farfan will also participate as an instructor in this course for 1 week, presenting observational case studies from the EPAC region. Dr. J. Zavala will also participate in the course and will teach 3 lectures on ocean dynamics and oceanic response to tropical cyclones. It is hoped that the post-doc in this project (R. Romero), will help with the practical aspects of the course, where students will be asked to work on real cases of tropical cyclones observed in the EPAC. It is foreseen that this course will serve as a dual purpose activity:

- it will increase the knowledge of tropical phenomena in the undergraduate student base in Latin America which could in the future become interested in continuing research in the topic (as graduate students) and can be considered an activity of outreach within this CRNII project.

- it will constitute a “rehearsal” of the spring course planned for the second and third years of the project in Mexico, where the Co-PIs will serve as instructors and where students from several countries are expected to participate.

Full details of students and events in which Co-PIs have participated are given in the Excel file provided: CapacityBuilding_forms_CRNII_048.xls

8. Regional collaboration/Networking

For a week during January 2007 Dr. Raymond visited UNAM to continue the research collaboration and to attend the PhC exam of J. Marin, since both Drs. Raymond and Prieto are part of his advisory committee. During this week, a small seminar was organized where students and Drs. J. Zavala, Raymond, Prieto and Binimelis de Raga discussed results relevant to the project.

Prior to attending the AGU Spring meeting in May, Dr. Raymond and his PhD student J. Cisneros visited CCA-UNAM for a week, to increase collaboration between the 2 PhD students participating in the project. Their visit to Mexico was partially funded through this project.

9. Media coverage and Prizes

Not applicable

10. Policy Relevance

The results obtained thus far are too preliminary to be considered relevant to policymakers.

11. Main conclusions

From the preliminary analysis carried out so far, we can draw the following conclusions.

i) The analysis of the SSH anomaly in the EPAC has revealed a very interesting annual cycle, with anomalies totally reversing in sign (maximum positive in April-May to minimum negative in October-November). This temporal pattern seems to be linked to the ocean eddies shed near the coastline in the region of the Gulf of Tehuantepec.

ii) The differences between SSH anomalies prior and after the passage of a tropical cyclone reveal in many cases, a low anomaly “wake” behind the cyclones. Nevertheless, for some cyclones this wake is not as obvious. In a few cases there are “wave-like” oscillations in the SSH anomalies, which need to be further investigated with the aid of numerical modeling.

iii) The comparison between gridded data for the EPAC region and in situ data from EPIC2001 leads to the conclusion that the FNL data is considered acceptable for studies of the large-scale characteristics in the EPAC region and will be used further to estimate intensification of convection into tropical cyclones.

iv) Several cases of tropical cyclones that developed during EPIC20001 and during TSCP/IFEX (2005) were analyzed, following the methodology of R98 to evaluate the dynamical factors leading to intensification.

v) As the tropical cyclones start to intensify, the convergence of absolute vorticity dominates in the vorticity balance, resulting in the increase of the absolute circulation, leading to the spin-up of the cyclone.

vi) Once the cyclone reaches a mature stage, the friction term dominates in the vorticity balance, resulting in a decrease in the absolute circulation and the final decay of the system.

vii) The results indicate that tropical cyclones only develop when the vorticity balance is valid in a deep layer of the troposphere.

12 Work plan for next year with associated costs

The work plan proposed for Year 2 (1 July 2007 -30 June 2008) can be divided into 4 categories, as follows:

i) Data analysis:
-Continue climatological study from satellite data over oceans (O. Sanchez CICATA-Mexico, GB Raga and J. Zavala-Hidalgo, CCA-Mexico)
- Begin climatological study using NCEP-R2 and ECMWF data (R. Romero-Centeno, CCA-Mexico; R. Prieto, IMTA-Mexico)
-Continue with data analysis from TCSP/IFEX (J Marin and GB Raga, CCA-Mexico; J. Cisneros and D. Raymond, NMT-USA)

ii) Modeling:
-Operational modeling with WRF during the cyclone season (L. Farfan CICESE-Mexico; D. Pozo and GB Raga, CCA-Mexico, D. Martínez, INSMET)
-Ocean modeling for the EPAC region (F. Oropeza and GB Raga, CCA-Mexico)
-Analysis of results from coupled ocean-atmosphere global climate models runs (R. Romero-Centeno and GB Raga, CCA-Mexico.
-Coastal wave modelling (O. Lizano, CIGEFI)

iii) Capacity building:
- Preparations for spring school: invitation to speakers, open call for participants (October2007), logistical aspects (computers, internet access), preparation of material (handout notes for students)
- Spring school (2 weeks, most likely during early March 2008, in Baja California Sur, likely location: Los Cabos)
- First workshop for participants (following spring school)

iv) Publications:
- Presentations at the 28th Conference on Hurricanes and Tropical Meteorology,

29 April – 2 May, 2008 in Orlando, with extended abstracts.

- Manuscript for publication on climatology of SSH anomaly in the EPAC and selected case studies of tropical cyclones, by O. Sanchez, J. Zavala-Hidalgo, GB Raga.
- Manuscript for publication on the comparison of airborne Doppler radar, dropsonde and GFS modeling results for selected tropical cyclones during IFEX, by D. Raymond, J. Cisneros and J. Marin.
- Annual report to IAI

Detailed cost estimates for planned activities (Note: The financial report presents totals per categories and per institution in the table provided):

Expenditures for Spring School and CO-PI Workshop	Cost (usd)
Travel for 3 invited speakers (other than IAI participants)@ 800 usd x 3	3000
Per diem costs for 3 invited speakers: 7 days@210 usd per day x 3	4100
Travel for 15 participants from Mexico and Central America@ 800 usd x 15	12000
Living costs for 15 participants: 15 days@ 100usd x 15	22500
Travel for Co-PIs from Mexico @ 500 usd x 7	3500
Travel for Co-PIs from other countries @ 800 usd x 6	4800
Per diem costs for Co-PIs: 15 days@210 usd per day x 13	40950
Printing of school handouts	5000
Secretarial help (before and during school: 4 weeks)	2000
Mailings to participants and misc. materials	500
Rental of space for workshop (may vary, depending on location)	2000
Rental of microphones, PC projector, internet access, poster boards, etc	1000
Outreach activities: seminars open to general public on upcoming tropical cyclone season, seminar to civil defense authorities and hotel personnel in charge of evacuation plans. Visit to local high schools	500
Handout brochures and posters for outreach activities	500
Total (from UNAM's budget)	**102350**

Other activities, to be charged to separate budgets

Other expenditures @ UNAM	Cost (usd)
1 Post-doc and 1 research assistant @ 1500 usd per month x 2 x 12 (UNAM)	36000
Publication costs @ 1500 usd (UNAM)	1500
Travel to 28th Conf. on Hurricanes and Tropical Meteorology in USA @ 800 usd x 3 people (UNAM)	2400
Per diem @ 210 usd per day x 6 x 3 (UNAM)	3780
Registration fees @ 400 usd x 3 (UNAM)	1200
Total	**44880**

Other expenditures @ IMTA	Cost (usd)
Student scholarships	6000
Travel	1500
Total	**7500**

Other expenditures @ CICESE	Cost (usd)
Student scholarships	5700
Travel/workshops	3000
Total	**10700**

Other expenditures @ INSMET	Cost (usd)
Research expenses (Cluster)	8000
Travel	2000
Total	**10000**

Other expenditures @ NMT	Cost (usd)
Research Associate	13000
Travel	4500
Total	**17500**

Other expenditures @ CIGEFI	Cost (usd)
Student scholarships	6000
Research expenses	1500
Total	**7500**