The seasonal evolution of the diurnal variation of the low-level winds around the Gulf of California. Is there a link to vegetation green-up during the wet season?

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1. INTRODUCTION

Sea-land breeze circulations are ubiquitous along the Gulf of California (GoC). Sea breezes are well developed in response to the strong diurnal heating over the desertic regions along both sides of the Gulf. Different factors, however, alter the characteristics of these breezes including (1) the ample seasonal range of the sea surface temperature (SST), especially over the northern Gulf and (2) the rapid foliation of the seasonal dry forest found along the eastern side of the Gulf, which occurs after the onset of the summer rains. It was hypothesized that the sea-land breeze circulations might be modified by the rapid vegetation change and associated change in the land surface characteristics such as albedo and evapotranspiration. This in turn, might affect the diurnal evolution of rainfall over the region. Figure 1 shows the aforementioned changes in vegetation cover based on MODIS imagery obtained before and after the onset of the monsoon season of 2004.

The recently completed field phase of North American Monsoon Experiment (NAME) provided an opportunity to determine the possible seasonal variation of the sea-breeze and its relationship with the onset of the rainy season and vegetation cover changes. This presentation will describe the effort to measure the diurnal cycle of the winds and its seasonal variation. Some observational aspects will be highlighted in terms of the relationship with the regional evolution of the ocean-land temperature gradient and the precipitation.

This work is organized as follows: Section 2 presents a brief description of the data set and methodology used to explore them. Section 3 displays preliminary analyses and in section 4 some conclusions are discussed along with suggestions for future work.

a) June b) August

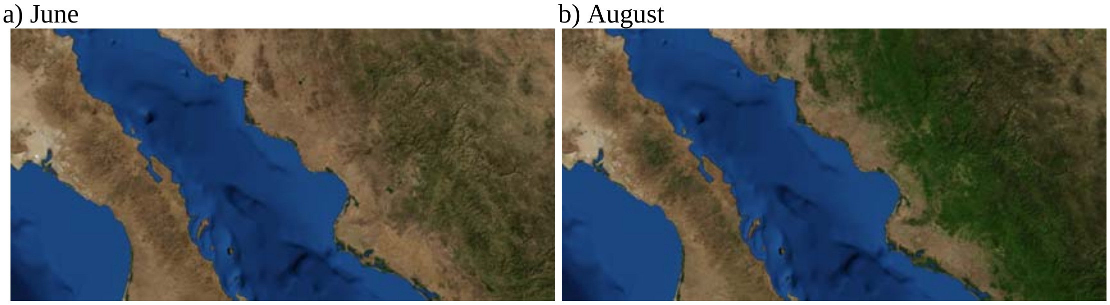

Figure 1 Monthly time scale vegetation maps for (a) June and (b) August, 2004. Vegetation composites obtained from http://mapus.jpl.nasa.gov/ (This is a MODIS product from the NASA's Earth Observatory). Notice the green-up of vegetation on the western slope of the Sierra Madre Oriental which occurs after the onset of the monsoon.

2. DATA AND METODOLOGY

A network of 7 pilot balloon stations made observations twice-daily for approximately four months, with two of these making more frequent observations during special periods. The stations were located along the Baja California Peninsula East coast (Loreto and Santa Rosalia), the Sonoran-Sinaloan coastal plain (Empalme, Huatabampo and Topolobampo) and inland along the foothills of the Sierra Madre Oriental (SMO) (Tesopaco and Choix), see Figure 2. Data on pilot balloon observations of the type used during name can be found at: http://www.nssl.noaa.gov/projects/pacs.

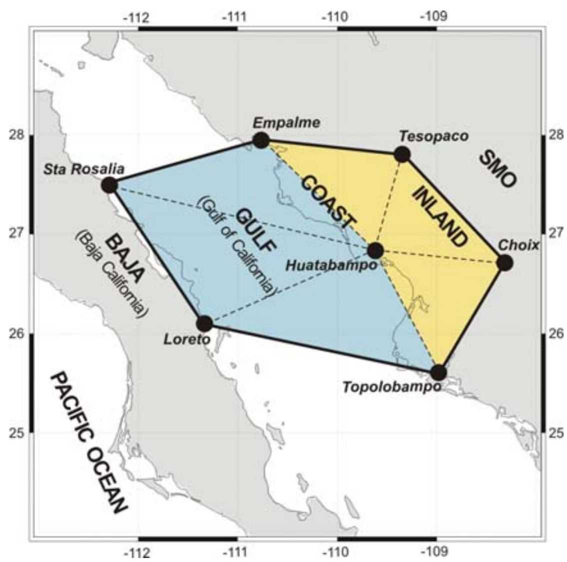

Figure 2 Pilot balloon network selected for the circulation analyses. Divergence was computed over the polygons indicated, assuming a linear wind field between the stations. See details in the text.

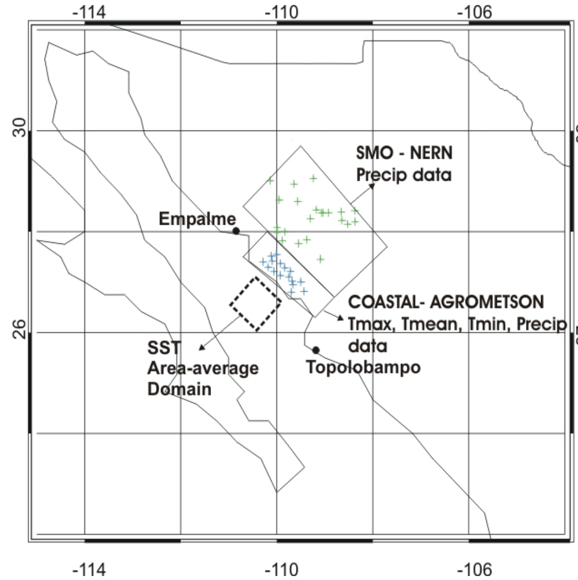

Figure 3. Spatial distribution of AGROMETSON surface stations (which provide the daily mean, minimum and maximum temperature, and daily precipitation for the coastal region), and NERN raingauges (which provides the daily precipitation data for the SMO region). SST's were averaged over the dashed area over the GoC.

Surface observations from automated surface stations were available from the Southern Sonora (Mexico) Agrometeorological network (AGROMETSON: http://www.pieaes.org.mx/datos.htm). This data set provides observations over the coastal plain (Figure 3) of mean, minimum and maximum surface temperatures and hourly temperature and precipitation amounts. The NAME Event-Based Raingauge Network (NERN) have been used for precipitation composites over the SMO (Gochis et al., 2003) in order to observed the contrast with respect to the coastal plain precipitation sites mentioned above. Pentad-averages were calculated and average over each of the domains.

Sea Surface Temperature (SST) data are used to quantify the land-sea day-to-day temperature gradient and its seasonal evolution. The SST's are derived from data collected by the Advanced Very High Resolution Radiometer (NOAA-17 AVHRR). A spatial -average was performed in a 40×40 km^2 region offshore Huatabampo. Only cloud-free days were taken into account to avoid cloud contamination in the estimation of the SST's.

Circulation analyses

The area-average circulation analyses were constructed extracting wind information from the seven stations of the NAME temporary pilot balloon network database (Figure 2).

For a description of the onshore and offshore breezes, the across-Gulf winds were extracted by rotating the reference frame 35° counter-clockwise. This aligned the north-south (meridional) direction along the axis of the GoC. The zonal-rotated winds represent the flow perpendicular to the coasts and therefore are used to describe the strength of the breezes.

Divergence calculations were constructed using the non-rotated winds by assuming a linear wind field between sites and applying Cramer's Rule over the polygons of stations shown in Figure 2. The computations made over the three easternmost triangles were averaged to represent the divergence over land and the average over the three westernmost triangles represents the divergence over the GoC.

3. RESULTS

From observations is has been noted that the heaviest rainfall associated with the NAMS undergoes an apparent migration from the high terrain over the SMO early in the monsoon season towards the coastal regions later during the season. The 2004 monsoon season (Figure 4) clearly shows this behavior. The July maximum over the SMO region is clearly distinctive from the July rainfall over the coastal plains but the opposite, a distinctive higher pick in the coastal regions in August/September, is not so evident due to the effect of tropical cyclones. The indirect influence of hurricane Howard (Aug 30th -Sept 5th) and Javier (Sept 10th-17th) (National Weather Service, Mexico) contributed to relatively large rainfall amounts measured by the coastal raingauges, and to distinctive but smaller picks observed in the SMO region.

The temperature trend associated with the gradient between the surface temperatures and the GoC SST's for this particular season figure 5) may offer some partial explanations to the migration of the precipitation maximum towards the coastal region.

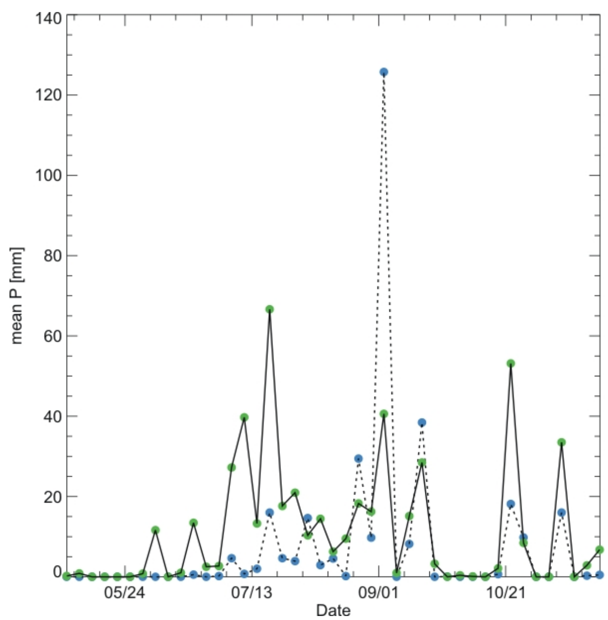

Figure 4 Pentad-mean precipitation averaged in the coastal (solid lines) domain and the SMO domain (dashed lines). Data obtained from AGROMETSON and NERN (Gochis et al. 2003), respectively.

The magnitude of the difference between the mean land temperature and the SST's increases gradually becoming larger and negative by late August and September (i.e. SST's > Tmean). Transient events (e.g.

monsoon bursts and breaks, cold-moisture surges, tropical waves, hurricanes, etc.), however, alter the direction and intensity of this gradient during short periods of time. The temperature range over the coast (figure 5 central panel) shows large day-to-day variability (12-25°C), but stabilizes (9-15°C) after the first rains (mid July). This suggests that an increase in soil moisture may be playing a role; however, more data is needed to support this hypothesis.

From figure 5, it can be also noted that the temperature difference between the maximum temperatures over land and the SST's also decreases slightly along the season, being the smallest in the month of September.

After the start of the wet season, the interior cools due to a combination of factors, the most important of which may be a combination of the following: (1) the increased soil moisture, (2) larger values of evapotranspiration from the leafing-out dry forest, and increased cloud cover. These, together with increasing SST's, result in a weaker sea-breeze circulation. Likewise, the very warm SST's late in the wet season may contribute to relatively strong land-breeze early morning. Thus, these factors may change the preferred convective development toward the coastal and offshore water.

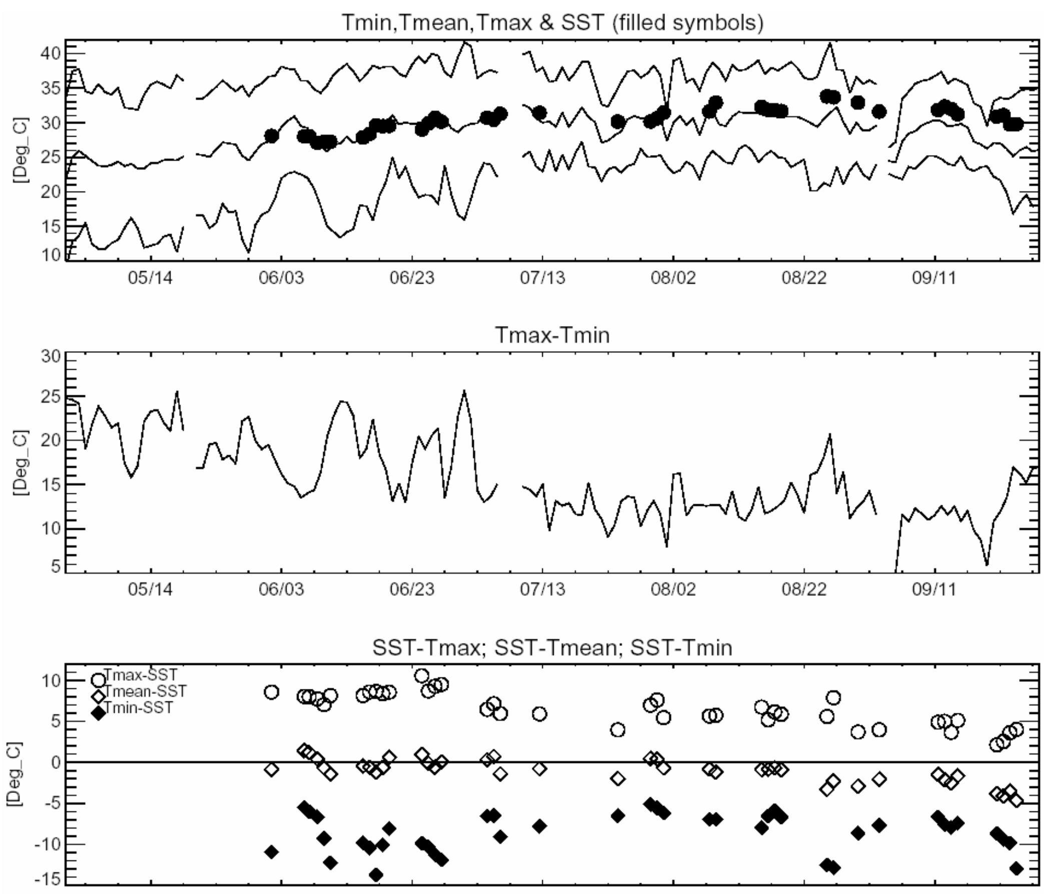

Figure 5 Daily time series of Tmean, Tmin, and Tmax surface temperature (solid lines), and SST (filled symbols) during NAME (upper-panel), Tmax-Tmin (middle-panel), and Tmax-SST, Tmean-SST, and Tmin-SST (lower-panel).

Circulation analyses

Seasonal changes on the morning and afternoon breeze circulations are apparent on the 15-day averaged rotated winds presented in Figure 6. They suggest that the intensity of the afternoon breezes observed inland decreases as the monsoon develops and starts to increase in the month of September, after the rainfall events decrease on frequency and intensity in the region.

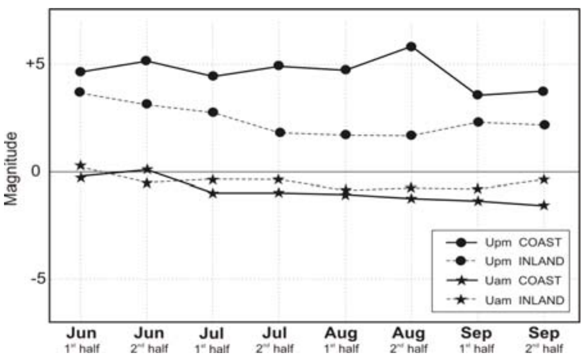

Figure 6 Seasonal variations of the rotated zonal winds inland (dashed) and over the coastal plain (solid) for the morning (stars) and afternoon (circles).

Over the coast, however, the seasonal cycle of the onshore flow remains almost constant through mid-August, but increases slightly during the second half of the month, which coincides with an extended period of low rainfall both in the coast and inland (Figure 4). This extended period of dry conditions was also evident on the coastal surface temperature plots (**Figure 5**), where an increase in the diurnal variations of the temperatures is observed. In contrast, the intensity of the breezes decreases and remains low during the entire month of September, after the heavy coastal rainfall events associated to hurricane Howard.

As expected, convergent low-level flow was found during the afternoon over land contrasting with divergent flow over the GoC (Figure 7). During the morning, the divergence was close to zero for both the GoC and the land, being more negative over the GoC. The observed afternoon convergence over land was expected since the afternoon breezes near the coast were found to be stronger than those inland as discussed above (Figure 6).

Seasonal changes of the divergence were observed both over the GoC and inland. Even though intraseasonal fluctuations (such as the dry period during late August, synoptic fluctuations and higher frequency oscillations evident in the wind data) complicated the analysis, the divergence seasonal tendencies were still palpable. Afternoon convergence over land observed in a persistent manner during the early stages of the monsoon (mid-July to late-August) decreases but remains convergent towards the month of September. Simultaneously, morning and afternoon divergence over the Gulf, roughly constant during July and August, decrease during the month of September leading to persistent convergent flow over the Gulf.

Figure 8 (top panel) shows an overall migration of the perpendicular component of the wind from towards the continent to towards Baja California. This suggests the influence of the seasonal evolution of the SST's.

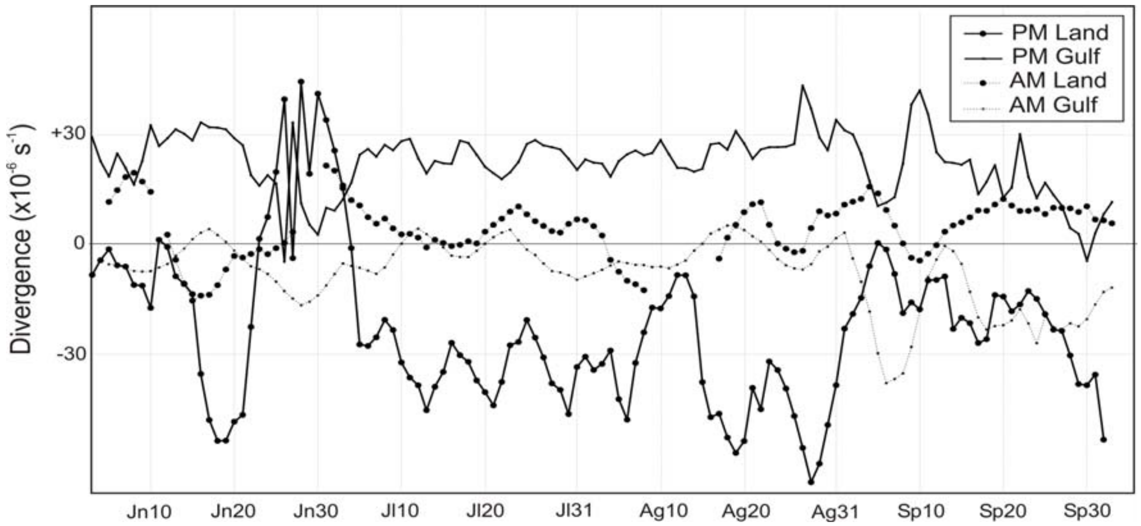

Figure 7 Early morning (dashed line) and afternoon (solid line) divergence averaged over the GoC (asterisks) and interior (circles). A 5-day centered mean has been applied.

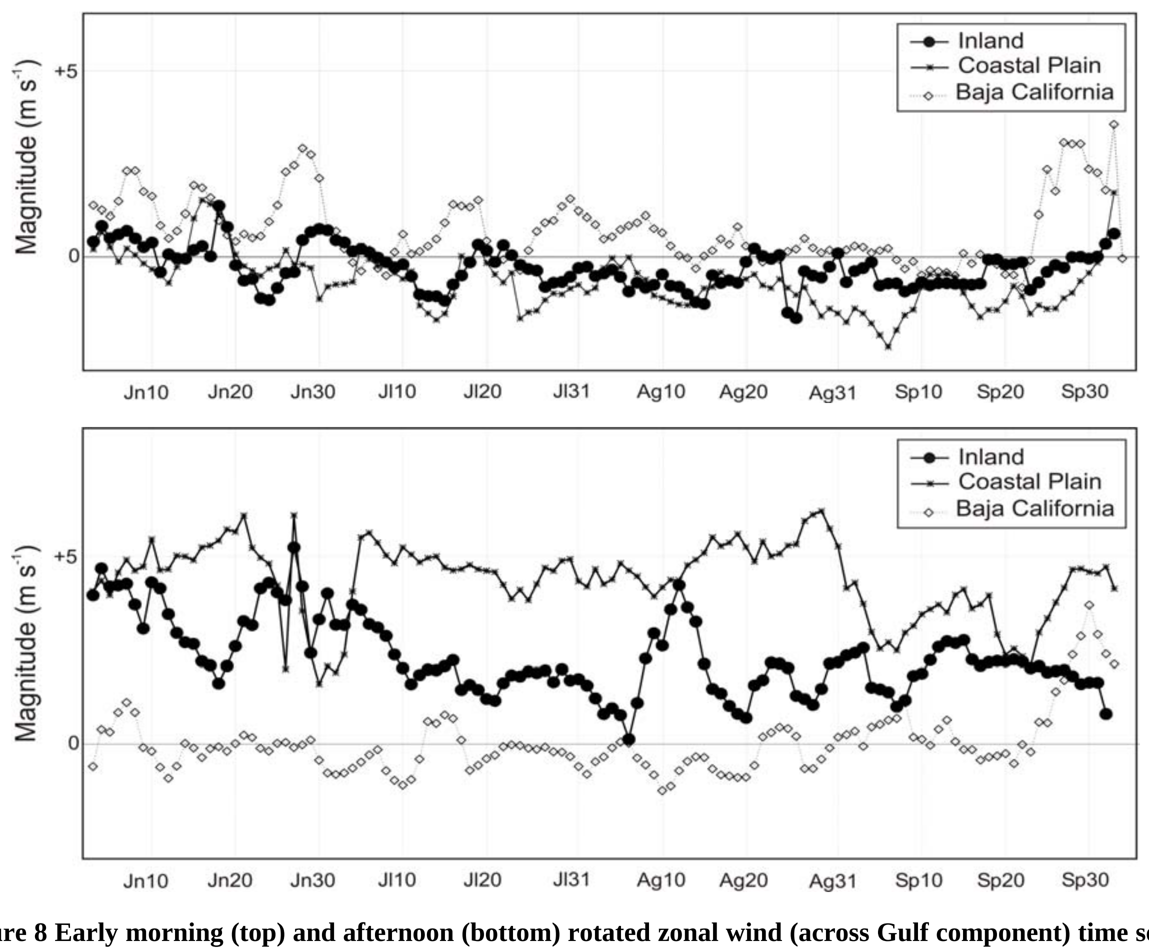

Figure 8 Early morning (top) and afternoon (bottom) rotated zonal wind (across Gulf component) time series for three regions: Inland (Tesopaco and Choix), the coastal plain (Empalme, Huatabampo and Topolobampo), and the Baja California coast (Loreto and Santa Rosalia). The curves are smoothed with a 5-day centered mean.

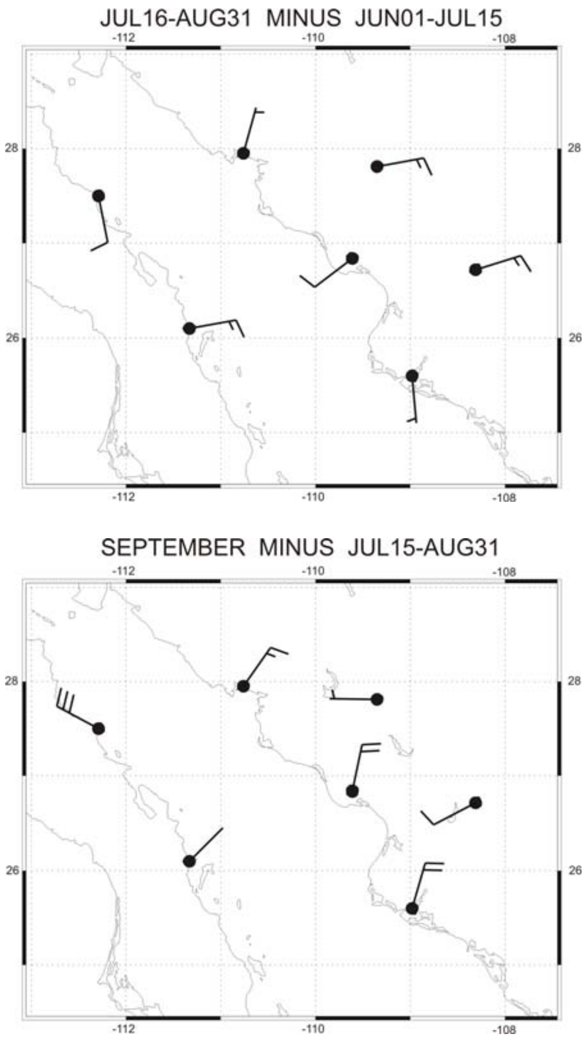

Figure 9 Difference between the low-level winds observed during the first stages of the early monsoon minus the pre-monsoon (top), and late-monsoon minus the early-monsoon. The barbs represent the winds in 10*ms^{-1}.

The seasonal changes of the wind field were also explored by displaying the difference between the winds measured during the early monsoon (July 16 through August 31) and the pre-monsoon (June 1 through July 15) and between the late monsoon (September) and the early monsoon. These results are displayed in Figure 9. They suggest, again, a migration of the convergence away from the foothills and towards the Gulf as the season progresses.

4. CONCLUSIONS

This study has begun to explore the hypothesis that the seasonal evolution of the sea-land breeze circulations along the Gulf of California is affected by both the changes in the land surface properties during the onset of the summer rains and the seasonal evolution of the temperature of the Gulf of California. Much of the work reported here is preliminary and exploratory. Although some of the results seem to suggest that the land breeze increases as the season progresses, other results find little change in the intensity of the afternoon sea breeze. Unfortunately, two tropical storms introduced considerable “noise” in to the observed trends, making a clear interpretation difficult.

Rainfall does increase towards the coastal areas as the summer progresses, and the calculated divergences over polygonal areas weakly support such a tendency. The changes in the winds from pre- through post-onset do seem to show a decrease in the low-level convergence over the foothills as the summer progresses.

Future work

Although diagnosis of the observations from the NAME-2004 has barely begun, it appears that it will be a challenge to identify the seasonal evolution of the diurnal cycle from observations alone. One season may be insufficient to obtain an adequate signal to noise ratio, given the size of the observed synoptic variability. At least two approaches may be necessary to evaluate the extent to the vegetation feedback on the diurnal cycle of the winds. One will involve modeling the mesoscale circulations with fine-resolution models where the land surface and SST characteristics can be varied. These sensitivity studies need to be compared with the observations from NAME and from multi-year observations of key aspects of the boundary layer over the region. Before embarking on such an observational effort modeling efforts should be carried out to determine the probable magnitude of the expected effects due to vegetation and SST changes, so an appropriate observational program can be designed. It might be noted that satellite based SST estimates over the central Gulf of California showed some variability that might complicate the interpretation of the mean land – Gulf temperature gradient. We have not yet evaluated the potential magnitude of this variability.

Inspection of the MODIS-based vegetation images revealed that there are large agricultural areas along the coastal plain between Empalme and Topolobampo that are dry during the summer season. That is, they are not green during the summer, but during the late winter, due to irrigation. This was unexpected and may have a complicating effect on the sea-breeze intensity. Modeling of this effect would seem to be in order.

If large-scale agriculture is indeed complicating the detection of a vegetation-atmosphere feedback over northwestern Mexico it might be necessary to make measurements where there are fewer such complications. There are other areas farther south in Mexico, where both the annual cycle of the SST is less, where the onset of the summer rains is abrupt, and where the vegetation near the coast is in a more natural state. One such area, Chamela, is near the Mexican radiosonde station of Manzanillo. Evaluation of those historical observations is underway.

Acknowledgments

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References

Gochis, D.G., J.-C. Leal, W.J. Shuttleworth, C. Watts, and J. Garatuza-Payan, 2003: Preliminary Diagnostics from a New Event-Based Precipitation Monitoring System in Support of NAME (North American Monsoon Experiment). J. Hydrometeorology, 4, 974-981.