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Statistical assessment of the offshore wind and temperature profiles at the North of the Yucatan Peninsula - Mexico

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ABSTRACT

Using a telecommunication tower installed on a pier approximately 7km from the coastline, a set of ultrasonic sensors were installed at 10m and 25m height. Sea Surface Temperature (SST) values were also derived from Geostationary Satellite Imagers with a spatial resolution of approximately 6km and hourly data sets. Then, the SST hourly data from the GEOS satellite was synchronized in space and time with the onsite measured data from the offshore tower. The evaluation process showed the persistent of a shallow stable boundary layer conditioned by a highly directional wind patterns which blow almost parallel to the coastline.

1 Introduction

Among the principal factors influencing the atmospheric stability of the offshore boundary layer, the differences between the air and sea temperatures and the distance from the sea-land interface plays a crucial role. Another important effect of the offshore environment is reflected by the turbulent mixing and momentum transfer which face important variations as a result of the changes in roughness, availability of heat and moisture encountered by the wind flows over a costal discontinuity [1].

Preliminary studies of the temporal, spatial and vertical wind characteristics have been reported for sites located inland and onshore of the Yucatán Peninsula [2,3]. These studies reveal highly directional wind patterns dominated by the atmospheric conditions of the surrounding seas: the Gulf of Mexico and the Caribbean Sea. On the other hand, initial analysis for the coastal region of the North-East of the Yucatán Peninsula [4,5] revealed unexpectedly high wind shear that was not well represented by Monin-Obukhov similarity theory.

This paper objective is to analyse the vertical wind and thermal profiles to study the stability conditions of the atmosphere offshore of the North coast of the Yucatán Peninsula. In this regard, a set of measurements were recorded at 10m and 25m height on a communication tower installed close to the end of a long pier located almost perpendicular to the shoreline. Additionally, sea surface temperatures derived from satellite thermal maps were integrated to analysis different stability measures. The results show offshore patterns of wind driven by oscillating cycles of land and sea breezes with a high influence of the Coriolis force.

1.1 Measurement site

The North coast of the Yucatán Peninsula is located at the South-East of the Gulf of México close to the tropic of Cancer covering almost 400km of coast approximately parallel to the tropic line. Its sea depth is very shallow increasing around 1m every 1km in the majority of the regions while the onshore terrain is almost flat reaching just 7m above the sea mean level at around 30km inland. The vegetation grows up to an average of 3m height.

The offshore study site is located at the end of the "Progreso" pier which extends 6.65km into the Gulf of México from the Northwest shore of the Yucatán Peninsula with geographical coordinates: 21°20'45.18"N, 89°40'17.32"W. The mast used to this study

will be referred to as the API tower. Figure 1 below shows the locations of the study site and the position of the sensors installed on the measurement tower.

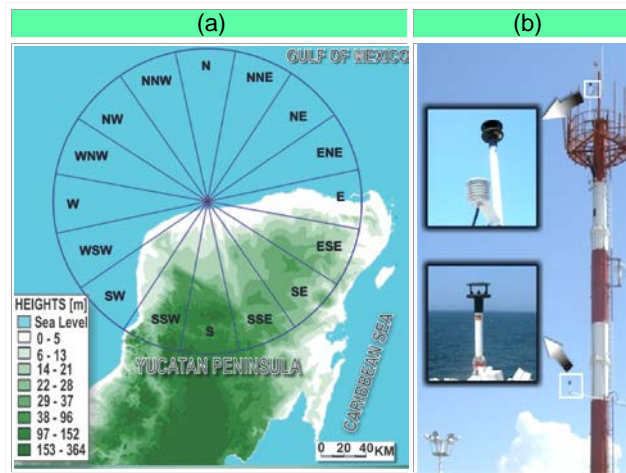


Figure 1. Locations of the study site on the Northwest of the Yucatan Peninsula (a) and Position of the sensors on the measurement tower (b)

Wind and ambient temperature were monitored every one second to compute and record the ten minute averages and their standard deviation. The measurements were taken during 23 continuous months starting in August 2007. A total of 87470 ten minute averages of onsite parameters were available for this study.

2 Directional distribution of wind measurements

Figure 2 presents an array of plots describing how the wind is distributed for each hour of the diurnal cycle over the main directional sectors from North (N) to South (S) in clockwise direction considering the whole study period. Row (1) in Figure 2 show the pattern between mid-night and mid-day while row (2) between mid-day and mid-night. Column (a) shows the land (a.1) and sea (a.2) breezes, see Figure 1 above with the directional positions of the sea and the land on the North of the Yucatán Peninsula. On the other hand, the transition periods with mixed contribution of sea and land wind is presented in column (b). The study site is located around the 21 degrees of latitude North within the region influenced by the Hadley cell. Thus, the trade winds which blow to the Intertropical convergence zone from subtropical high-pressure zone are deflected toward the west by the effect of the Coriolis force [6,7]. This effect is overlapped with the diurnal cycles of breezes producing the winds patterns observed in Figure 2 around the East direction.

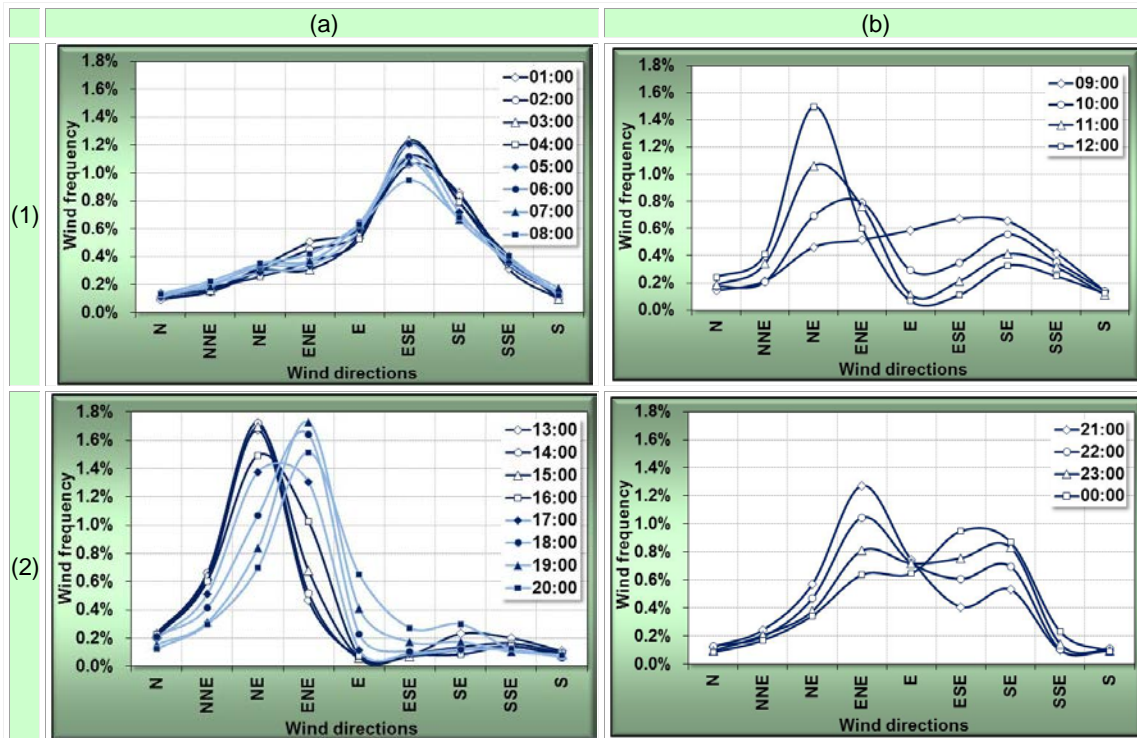
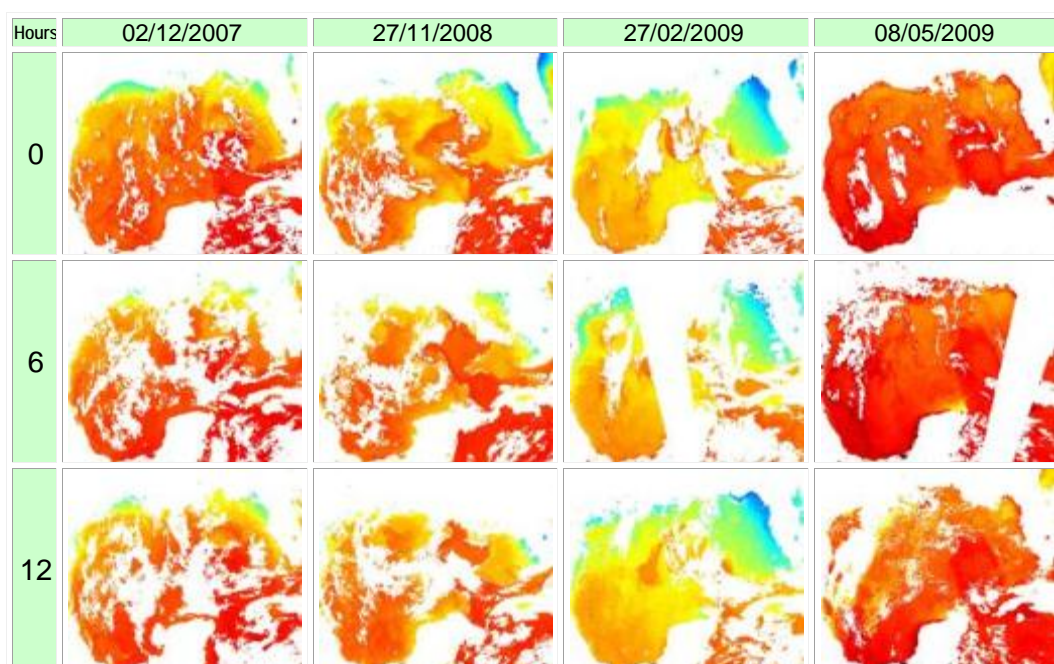


Figure 2. Distributions of wind for the main directional sector during each hour of the diurnal cycle. Column (a) shows hours of land (1) and sea (2) contributions while column (b) shows the transition from land breeze to sea breeze (1) and from sea breeze to land breeze (2).

3 Satellite SST data for the study period

A time period between 25/07/2007 and 26/06/2009 was selected covering the period of measurements previously recorded on the API mast (703 days). A total of 6500 hourly average of SST values concurrent with the onsite mast measurements were successfully extracted from the GEOS satellite thermal images [8] to integrate a new dataset. Figure 3 below presents a set of samples of satellite images for four different dates every six hours from mid-night.



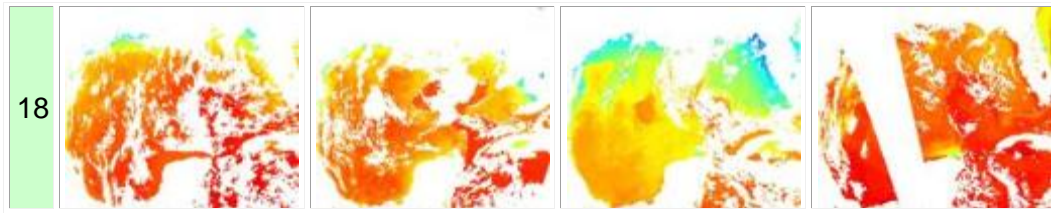


Figure 3. Samples of GEOS Satellite images for selected dates and times

A time period between 25/07/2007 and 26/06/2009 was selected covering the period of measurements recorded on the API mast (703 days). A total of 38.5% SST values concurrent with the mast measurements was successfully extracted from the GEOS satellite thermal images corresponding to 6500 hourly values. Figure 4 below shows the distribution of SST data available binned by hour of the day and averaged over the entire study period.

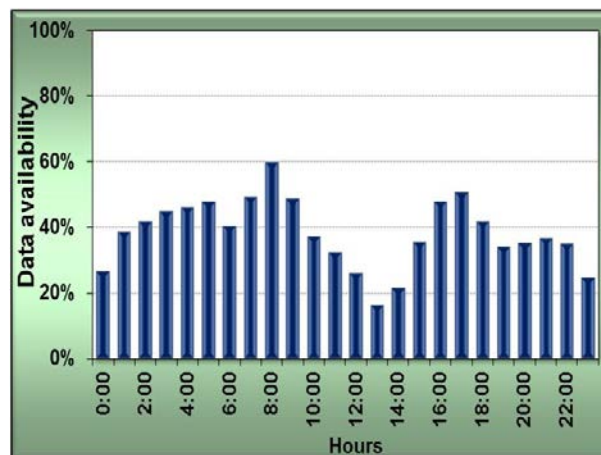


Figure 4. SST data available from GEOS Satellite during the day averaged over the entire study period between 25/07/2007 and 26/06/2009.

Figure 5 below shows the diurnal thermal patterns for this new concurrent dataset. Though the SST varies relative little during the day, on average there is evidence of a diurnal cycle with temperatures lower than the air temperature during the daylight hours. In general, the air temperatures and SST patterns follow a similar pattern.

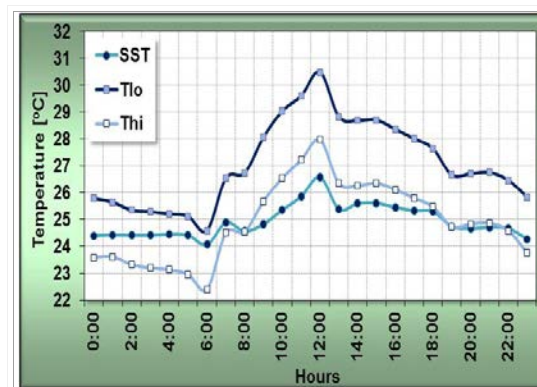


Figure 5. Diurnal pattern of air temperature and SST over the whole study period using concurrent data from the onsite and Satellite measurements

4 Integrated vertical temperature profile

Averages of the measured temperature as a function of height have been plotted in Figure 6 for the whole study period over the diurnal cycle every three hours. Vertical temperature trends over the day at all heights display a diurnal cycle with the highest temperature at noon and the lowest just around sunrise, e.g. 06:00. However, the ranges of temperatures differ: there is range of around 6 degrees Celsius at 10m and 25m height, but the range at the sea surface is less than 2 degrees Celsius. This is as one would expect due to the high thermal mass of the water. What is interesting to note is the lapse rate between 0m and 10m and that between 10m and 25m height. The temperatures at 10m and 25m would suggest very unstable conditions throughout the day, whereas those between 0m and 10m would suggest stable or close to neutral conditions with the most stable conditions at midday and the least stable (closer to neutral) at sunrise (06:00).

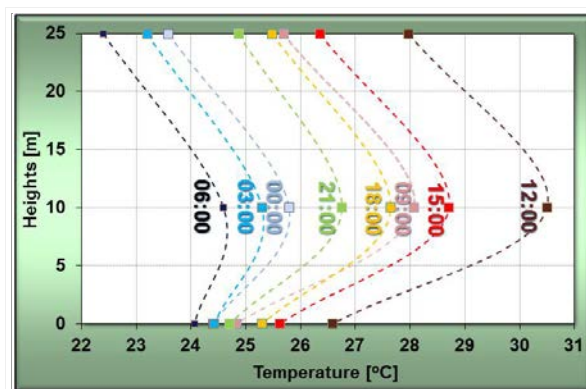


Figure 6. Vertical temperature profiles every three hours of the diurnal cycle using measurements from the GEOS Satellite for SST (0m) and from the API mast at “lo” (10m) and “hi” (25m) heights

Figure 7(a) integrates the wind distributions of the directional sectors that conforms the sea and land breezes to make evident their contribution for each hour of the diurnal cycle. The contribution of the land wind coming from terrains, located from the East to the South of the API site, between sunrise and midday proved to be not negligible.

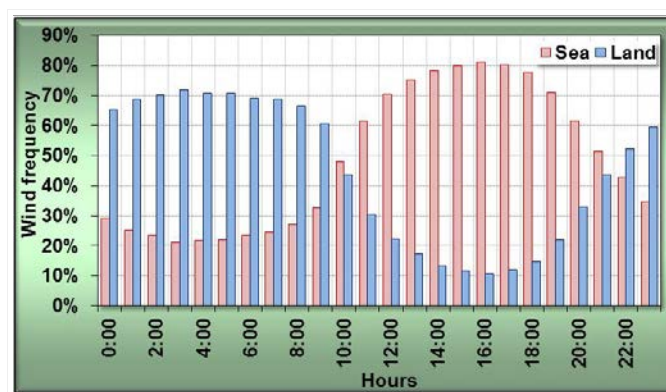


Figure 7. Diurnal patterns, contribution of the sea and land breeze at the API site

It is also relevant to mention that, the almost East-West orientation of the North coast of the Yucatan peninsula and its wind patterns blowing almost parallel to the coastline could be producing some coastal upwelling effect that might play a role in the cooler temperatures observed in Figure 5 for the Sea surface at the API site. Although this situation requires additional research to be confirmed, this effect has been studied for

tropical coastal zones with similar characteristics around the same geographical region [9, 10].

5 Directional distribution of stability classes

Figure 10 reveals a decrease in stable states and an increase in unstable states when the wind approach the ESE direction which represents the higher contribution of the wind coming from the land, see map in Figure 1(a). Looking back at Figure 2(a.1), the wind will tend to come from the ESE direction sector mainly during the night which would be when cooler wind would be more frequently reducing the temperature gradient with the SST, see Figure 5 and Figure 6, and consequently making the atmosphere less stable.

On the other hand, the number of stable states increase to a maximum around the NE direction which occurs most frequently after midday, see Figure 2(a.2), when the highest temperature gradient between the air temperature and the SST is reached and the sea breeze dominates decreasing the number of stables states as temperatures drops over the afternoon, see Figure 5 and Figure 7, especially for the air layer between the sea surface and 10m height.

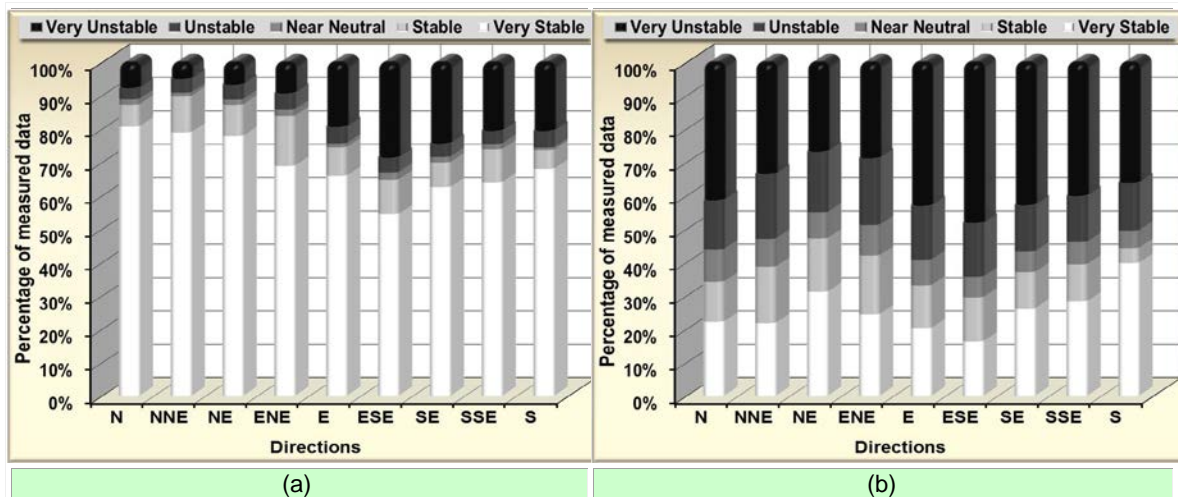


Figure 8. Stability classes for each directional sector using stability measures derived from: (a) air temperature at 10m height and SST and (b) air temperature at 25m height and SST.

6 Diurnal behaviour of stability classes

The diurnal cycle described by the stability classes is shown in Figure 11. In this case, clear diurnal patterns are seen for the fraction of stable and unstable states which is consistence with the preliminary analysis of temperatures shown in Figure 6. It can be seen that the fraction of stable states decreases to a minimum at sunrise (close to 06:00) when the air temperature is least and the wind is coming over the land mainly from the ESE direction, see Figure 2(a.1). Then, the fraction of stable states increases to a maximum at midday (around 12:00) when the air temperature is highest. During the rest of the afternoon, the sea breeze completely dominates with wind patterns concentrated mainly around the NE and ENE directions; see Figure 2(a.2) and Figure 7(a). This is also consistence with the results presented above in Figure 10 for the directional patterns of the stability classes.

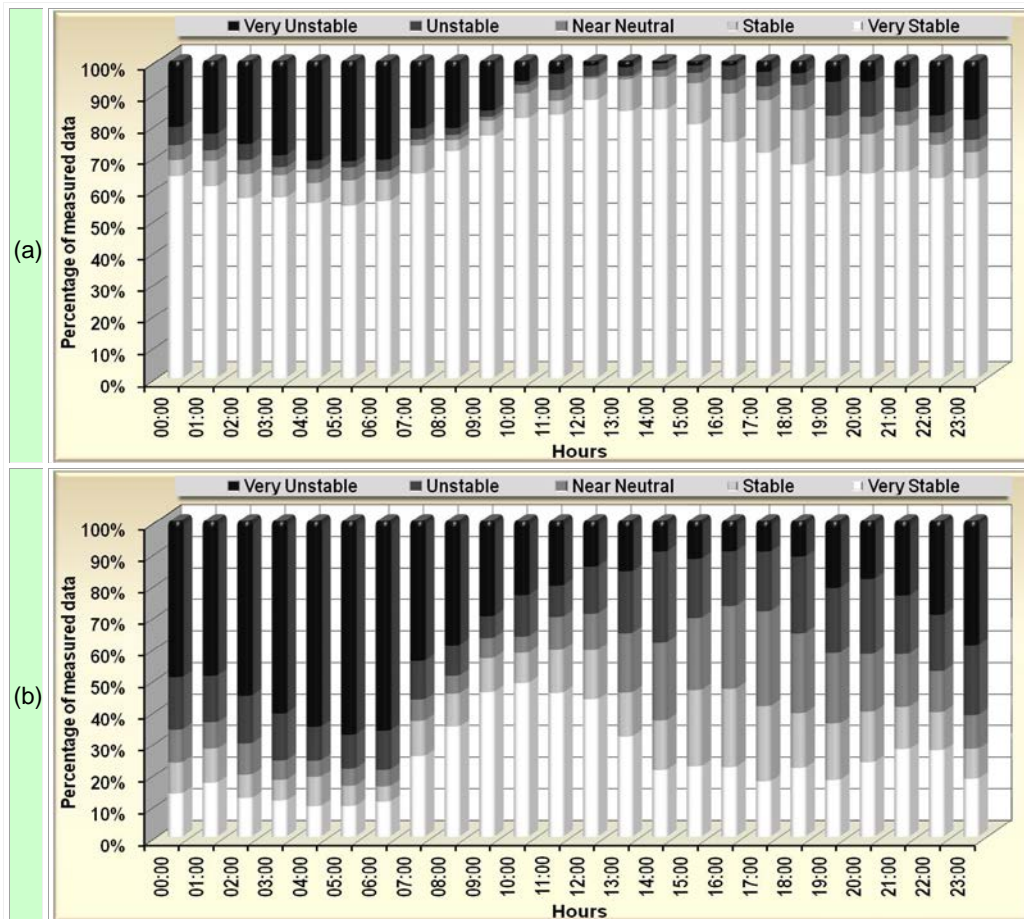


Figure 9. Diurnal distribution of stability classes using stability measures derived from: (a) air temperature at 10m height and SST and (b) air temperature at 25m height and SST.

The results presented so far would suggest that initially, after sunrise, the wind blows off the land over the sea. This results in a layer of warm air advecting over a cold sea and the development of a thin Stable Internal Boundary Layer (SIBL). As the morning develops, this SIBL builds up with the increasing air temperature of the land breeze up to midday when the offshore breeze begins to dominate with cooler air. This situation diminished the SIBL with the development of more convective atmospheric states when the air temperature drops during the afternoon. Then, as the air temperature continues dropping after the sunset up to before the sunrise, the rate of decrease of the SIBL becomes slower when the wind veers back parallel to the coastline to establish the land breeze during the whole night-time. This slower rate of decrease avoids that the SIBL completely decay by the sunset time when the cycle is repeated again. In the next section, a preliminary analysis to quantify the height of this potential SIBL has been introduced.

7 Conclusions

A study of the offshore wind properties was made on a tower at 6.65km from the North coast of the Yucatán Peninsula for around two years using onsite and satellite measurements. The wind speed and direction measured in offshore conditions at the API site follow the expected pattern of a diurnal cycle produced by the difference in the heating rates between the land and the sea which drive alternating pressure gradients. There is also a significant influence of the Coriolis force which causes the sea breeze

to blow in a direction more parallel to the shoreline of the North of the Yucatán Peninsula.

The analysis of the offshore data has revealed a non-uniform surface boundary layer and it is clear that more detailed profile measurements are required to gain greater insight into the atmospheric boundary layer offshore.

8 References

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