15A.5 DAILY HURRICANE VARIABILITY INFERRED FROM GOES INFRARED IMAGERY

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1. INTRODUCTION

As a typical tropical storm develops, vigorous convection near the vortex center penetrates vertically to the tropopause and spreads radially outward to form a cirriform canopy. A number of previous studies using geostationary IR satellite imagery have considered the temporal evolution of tropical cyclone cloudiness in various ocean basins, and have revealed a strong diurnal (24 h period) cycle in the horizontal areal extent of the canopies above the storms. The interpretation of the diurnal oscillation of tropical cyclone cirrus canopies has conventionally rested on the assumption that it is predominantly forced by a diurnal oscillation in deep convection near the storm center. This interpretation has prompted studies to determine the causal mechanism for diurnal forcing of deep eyewall convection.

The present work challenges the idea that the diurnal oscillation of the hurricane canopy is mechanistically linked to a diurnal oscillation in the central convection. Using a large IR data set and best track information regarding storm center, it is found that a diurnal oscillation dominates the variability of the brightness temperature (T_{BB}) field in a region beyond around 200 km from the storm center. However, inside of 200 km (i.e., closer to the central convective region), the diurnal oscillation usually becomes insignificant. Inside of 100 km, only two storms, within a 21 storm sample, exhibited a significant diurnal oscillation in cloudiness.

While diurnal oscillations are typically absent near the storm center, T_{BB} variability inside of 100 km is often dominated by a highly significant semidiurnal (12 h period) oscillation. The phase of the semidiurnal oscillation in the central convective region remains relatively fixed during the lifetime of each storm and doesn't vary from storm to storm. This fixed phase strongly insinuates a mechanistic link between hurricane central convection and the semidiurnal atmospheric solar tide (S_2).

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The results of this study suggest the need for revised hypotheses to explain the mechanisms responsible for the daily variability of hurricane cloudiness. Two hypotheses are constructed. The first is offered to explain the diurnal oscillation of the canopy in the absence of a diurnal oscillation of the convective regions. The hypothesized mechanism is based on the radial variation of nighttime net radiational cooling and subsidence. The second hypothesis is offered to explain the semidiurnal oscillation near the central convective region, and is based on the possible presence of a semidiurnal oscillation of local lapse rates associated with S_2.

2. RESULTS

Combining infrared (IR) satellite imagery from the NESDIS/CIRA archive with best track center fix information, the evolution of azimuthally averaged T_{BB} can be displayed (Fig. 1) in the form of

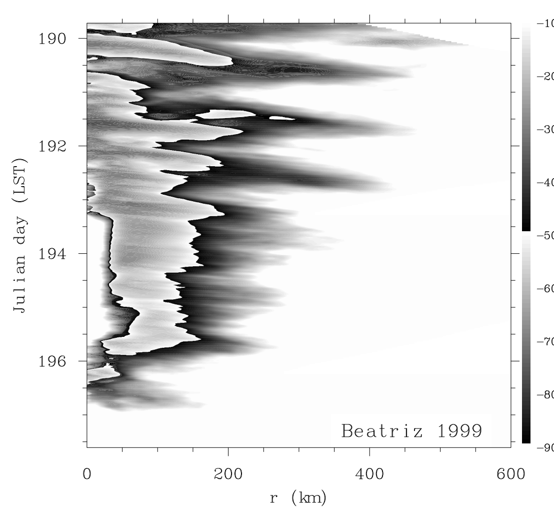

Figure 1: Radius versus LST diagram of azimuthally averaged T_{BB} (°C) in eastern Pacific hurricane Beatriz. Averages are with respect to interpolated best track center. Note the diurnal oscillation of T_{BB} in the region of the cirrus canopy ($r > \sim 200$ km).

a radius versus Local Mean Solar Time (LST) plot. Fig. 1 comprises 150 T_{BB} time series in 4 km increments from 0 to 600 km. Similar diagrams were created for the 21 Atlantic and Eastern Pacific storms that occurred in 1999, and spectral analyses of the resulting 3150 time series were performed.

The results of the spectral analyses are summarized in Fig. 2. It is clear that most of the 21 storms

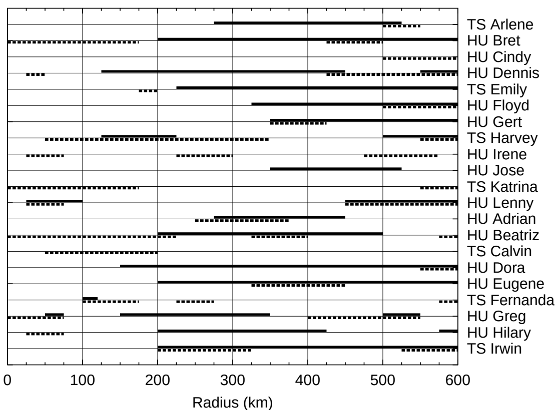

Figure 2: Results of time series analyses at all radii in the 21 Atlantic and Eastern Pacific storms of 1999. The thick solid (dashed) lines span all radii where the diurnal (semidiurnal) harmonics were significant at confidence levels greater than 99.99%.

exhibit a highly significant diurnal oscillation within some annulus between 0 and 600 km. The only exceptions are Hurricanes Cindy and Irene, and Tropical Storms Katrina and Calvin. The significant diurnal oscillations are more often found beyond $r = 300$ km. For example, 16 of the 21 storms have significant diurnal oscillations in some annulus beyond $r = 300$ km. This is the region where the T_{BB} field is dominated by the cirrus canopy. However, within annuli that are closer to the convective region near the storm center ($0 \leq r \leq 200$ km), most storms (15 out of 21) do not exhibit a significant diurnal oscillation in T_{BB}. Within the innermost 100 km annulus, only 2 of the storms exhibited diurnal T_{BB} oscillations. In contrast, 10 of the storms exhibited highly significant semidiurnal oscillations within this annulus. The semidiurnal range of T_{BB} within this annulus is typically $\sim 10°$C, and the phase of the semidiurnal harmonics is consistently around 1000 LST regardless of distance from storm center. Thus, T_{BB} is typically coldest at 0400 and 1600 LST, at the times of minimum pressure perturbation associated with S_2. This result strongly suggests a physical connection between T_{BB} (and possibly central convection) and the amplitude of the S_2 pressure perturbation.

3. DISCUSSION

The diurnal cycle of the hurricane cirrus canopy has conventionally been thought to be forced by a diurnal cycle in hurricane convection, but Fig. 2 demonstrates that the diurnal oscillation is generally insignificant near the central convective region. An alternative mechanism is hypothesized here: Over a hurricane, upper level outflow carries convective cloud particles outwards as glaciation occurs, creating the cirrus canopy. After sunset, local net radiative cooling occurs and the atmospheric response to this net cooling is manifested as an increase in local subsidence. This subsidence is expected to be greater in warm T_{BB} versus cold T_{BB} regions. Since T_{BB} of the canopy increases with radius, radiatively driven subsidence may increase with radius. The radial dependence of the warming of the subsiding air would manifest as an apparent "shrinking" of the areal extent of the canopy. Based on this mechanism, the shrinking would be expected to begin near local sunset and end near local sunrise, in agreement with the results of this study. Note that this hypothesis relies on convection to create and maintain the canopy, but the diurnal oscillation of the canopy is dissociated from the convection.

The fairly common presence of a significant semidiurnal T_{BB} oscillation in the central convective regions of hurricanes poses the question of what might be causing it. This semidiurnal oscillation is consistently in phase with the solar semidiurnal atmospheric tide S_2. A mechanism linking the *vertical structure* of S_2 and local cloudiness, is hypothesized here: The local temperature response to the S_2 pressure perturbation might be expected to exhibit vertical structure since local atmospheric density is not vertically uniform. If local temperature perturbations associated with S_2 have vertical structure, then local lapse rates should oscillate semidiurnally. Such a lapse rate oscillation can be constructed from results of previous studies, and although the effects are small, the maximum destabilization is found to occur at 0400 and 1600 LST, and is thus physically consistent with the results of this study that suggest a local increase in cloud heights around 0400 and 1600 LST.

4. REFERENCES

All references (and acknowledgements) are found in

Kossin, J. P., 2002: Daily hurricane variability inferred from GOES infrared imagery. *Mon. Wea. Rev.*, conditionally accepted. Manuscript currently available at http://euler.atmos.colostate.edu/∼kossin