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Surface Diurnal Cycle over Venezuela

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With 3 Figures

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Summary

The surface thermodynamic diurnal cycle over Venezuela is compared with that over Kansas grassland and the Canadian boreal forest, illustrating the greater upward transport of water vapor out of the subcloud layer by shallow cumulus clouds in the tropics, which limits the daytime rise of θ_E.

1. Introduction

The second Venezuela International Meteorological and Hydrological Experiment (VIMHEX) took place in the summer of 1972 with a central site at Carrizal, Venezuela (9°22.8′ N, 66° 55.0′ W). It was planned and organized by Professor Herbert Riehl, and the present author was the field meteorologist. An extensively modified M-33 radar with a 2° beam-width scanning antenna tracked precipitating convective cells within a raingauge network of diameter 120 km. Radiosondes were launched each morning at 1000 local time and in rapid sequence (every 75–90 minutes) to give cross-sections through convective mesosystems, once these were observed on radar. Routine surface observations were also made. Several papers have been written on the main objectives of VIMHEX-1972, the study of deep convection over land (Betts, 1976a; Betts et al., 1976; Miller and Betts, 1977) and the convective boundary layer (Betts, 1976b). However, the diurnal cycle shown by the surface data has never been published, and it is the interest for its contrast with high latitude studies, as it shows the more important role of shallow cumulus clouds in the upward transport of water vapor in the tropics.

2. Data

The surface thermodynamic measurements were primitive by current standards. A recording hygrothermograph and barograph were installed in a Stevenson's screen in a mowed grass enclosure near the edge of the (unused) airfield. The surrounding vegetation was mixed shrubs and woodland. A horizontal square thatch screen (roughly 3×3 m) was placed at a height of about 2.5 m over the Stevenson's shelter as an additional shading device and partial protection from rainfall. Professor Riehl's experience in the tropics had shown him that routine surface thermodynamic observations were unreliable, if the Stevenson's shelter got wet, and was then exposed to full sun. These data were subsequently digitized at hourly time resolution. The humidity measurements were converted to mixing ratio, q.

3. Surface Diurnal Cycle over Venezuela

Figure 1 shows two composites on a conserved variable plot of mixing ratio, q, and potential temperature, θ, plotted hourly from 0600 to 1700 local time, from sunrise through the daytime

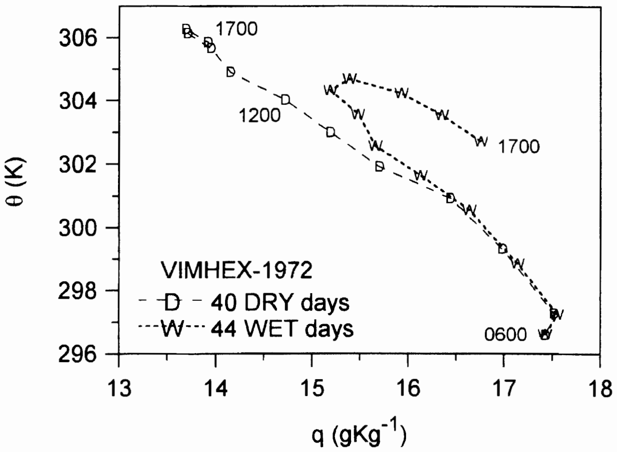

Fig. 1. Surface diurnal cycle for dry and wet day VIMHEX composites from 0600–1700 local time on a (θ, q) diagram

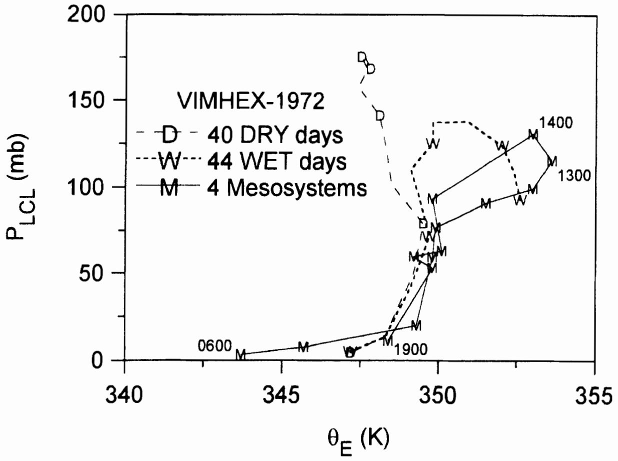

Fig. 2. A (θ_E, P_{LCL}) plot of Fig. 1; with the addition of an average for four mesosystem days from 0600–1900 local time

maximum temperature. A few symbols are marked with the hours for clarity. The averages are simply labeled "D" for 40 DRY days with very little rainfall, and "W" for 44 WET days with significant precipitation (mean daily rainfall >1 mm, as determined by the raingauge network). The diurnal thermodynamic paths start together, cool and moist at sunrise. After 0700 local time, q falls as θ rises. For the "DRY" composite, this continues to a peak temperature and minimum mixing ratio at 1600. This strong fall of q during the daytime cycle is different from what is seen over northern hemisphere grassland and forests, where q often changes little during the daytime. It reflects the more vigorous and deeper shallow cumulus convection in the tropics, which pumps water out of the subcloud layer to greater depths, often 600–700 mb over land. Betts (1976b) showed a convective boundary layer budget for a subset of 20 dry days, which showed this large upward transport of water through cloud-base. They estimated the surface Bowen Ratio to be 0.93±0.14. In contrast for the "WET" day composite, the diurnal cycle starts the same, but the minimum q and maximum θ is reached sooner (1300–1400 local time), when the first precipitation often occurs. The diurnal cycle then shows a cooling and moistening, presumably associated with evaporation of falling precipitation, or more evaporation from the wet surface.

Figure 2 shows the same data on a (θ_E, P_{LCL}) plot, where θ_E is equivalent potential temperature, and P_{LCL} is the pressure height to the lifting condensation level. A few hours after sunrise in Venezuela, this is a good measure of the pressure height of cloud-base. The patterns are similar to that shown in Fig. 1, but they give a different perspective. At 0600, close to sunrise, both composites are close to saturation with $\theta_E = 347$ K. During the day cloudbase rises to $P_{LCL} = 175$ mb for the DRY composite, while θ_E reaches a peak of 349.5 K at 0900 and falls slightly during the rest of the day back to 347.5 K. During the entire daytime diurnal cycle, θ_E changes by less than 3 K. This is because the tropical atmosphere has a structure which is weakly unstable to the moist adiabat (Riehl, 1954), so near-surface and the sub-cloud θ_E is strongly constrained by shallow cumulus convection. If θ_E rises, more clouds develop, transporting moisture upwards and reducing θ_E. This occurs for shallow non-precipitating convection as well as for deep convection, which also control θ_E through unsaturated downdrafts, which bring down low θ_E air into the subcloud layer. (This is essence of the Boundary Layer Quasi Equilibrium approach to parameterizing convection, discussed recently in Raymond, 1997). For the WET day composite, the weak afternoon fall of θ_E is not seen and after 1300, θ_E increases and P_{LCL} falls, as the near surface air is brought closer to saturation by evaporative processes. The increase of θ_E in this composite (reaching 352.5 K by late afternoon) presumably comes from the continued addition of some energy at the surface, perhaps trapped in a shallower cooled surface layer. (However, the surface data is questionable after rain, despite the precautions taken).

Can convective downdrafts, which bring down low θ_E air from above cloudbase (Betts, 1976a; Miller and Betts, 1977) be seen at the surface? On most days they cannot be seen in this hourly surface data, in contrast to the surface change seen with high time resolution mesonet data beneath severe storms (e.g., Betts, 1984). The third curve labeled M is an average of four days (July 24, August 7, 11 and September 4, 1972), where strong mesoscale systems brought low θ_E air down to the surface, during the afternoon between 1500 and 1900 local time. For this composite, the morning rise of θ_E, and P_{LCL} occurs till 1000 local time, and then θ_E rises sharply to a 1300 maximum ahead of the rain systems. Then after 1400, θ_E and P_{LCL} fall sharply with the arrival of downdraft air, falling to near saturation at nearly constant $\theta_E = 349\,\mathrm{K}$ by 1900 local time. On days with late afternoon or evening rain, this near-saturation of the surface air by sunset is typical.

4. Comparison with FIFE and BOREAS

Figure 3 shows comparison diurnal cycle curves of hourly data from 1100–2300 UTC (starting near sunrise) from the FIFE (First ISLSCP (International Land Surface Climatology Project) Field Experiment) and BOREAS (Boreal Ecosystem-Atmosphere Study) measurement programs, near Manhattan, Kansas (Sellers and Hall, 1992) and Prince Albert, Saskatchewan (Sellers et al., 1996). The BOREAS data is an average of 23 dry days (with no daytime rain) in August, 1994. In mid-summer, over the cooler Canadian boreal forest, as P_{LCL} rises, θ_E also rises rapidly until local noon and then more slowly. Two curves are shown for the FIFE data (adapted from Betts and Ball, 1998): one, labelled "w", is the diurnal cycle in mid-summer over wet soils (29.9% soil moisture (SM) by volume in the first 10 cm) and the other, labelled "d", is, over dry soils (14.7%). Over wet soils, the rise of P_{LCL} is reduced, but θ_E increases all day to mid-afternoon; while over dry soils, the increase of θ_E stops earlier around 1100 local time, while P_{LCL} reaches nearly 250 mb in mid-afternoon. In all the curves in Fig. 3, θ_E increases during the day by 10–15 K, much more than is seen in Venezuela. The constraint on low level θ_E by cumulus convection is much weaker. Over Kansas for example, the cumulus convection is often rather shallow, and mixing ratio typically changes rather little during the daytime diurnal cycle as temperature rises (Betts and Ball, 1995), unlike the pattern of falling q, shown in Fig. 1. The surface Bowen ratio near noon for both the BOREAS August mean (≈0.8, see Barr and Betts, 1997) and the dry soil moisture FIFE composite (≈0.8), are close to that estimated by Betts (1976b) for the VIMHEX data.

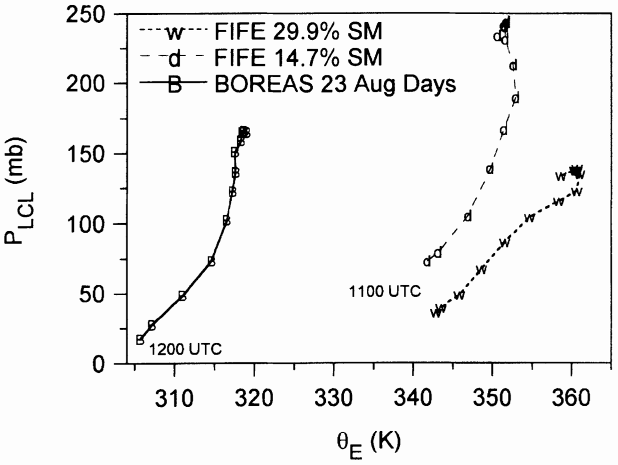

Fig. 3. As Fig. 2 for BOREAS composite from 1200–2300 UTC (23 dry days in August, 1994), and two FIFE composites for the daytime diurnal cycle over dry and wet soils from 1100–2300 UTC. Local noon is near 1830 UTC

5. Discussion

This diurnal cycle at higher latitudes differs from that over Venezuela (at 9° N) in two ways. Because relative humidities are lower, the surface cooling at night is much larger, and is followed by a large morning rise of θ_E of order 10 K. The upper atmosphere is more stable in mid-latitudes, and the cumulus convection is typically shallower. Over Venezuela, saturation is quickly reached at night at the wet-bulb temperature ≈22.5 °C (corresponding to $\theta_E \approx 347\,\mathrm{K}$), either by radiative cooling of the moist layer, or by the evaporation of rainfall. During the daytime in the tropics over land, P_{LCL} (and with it cloud base) lifts very much the same as in higher latitudes, but more vigorous shallow cumulus convection transports water vapor upward, and restricts the rise of θ_E near the surface and in the subcloud layer. Consequently, near-surface θ_E changes rather little over Venezuela during the daytime diurnal cycle, as temperature rises, mixing ratio falls, and cloud-base rises. In terms of BL structure this was illustrated in Betts (1976b); here we have shown the impact on the surface thermodynamic cycle.

Acknowledgments

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