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SCALAR FLUX-PROFILE RELATIONS OVER THE OPEN OCEAN

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1. INTRODUCTION

The flux-profile relationships for velocity, temperature, and humidity over the ocean are usually assumed to be those obtained from over-land experiments, such as from Kansas (Businger, et al., 1971). (Note that humidity profiles and humidity fluxes were not measured in the 1968 AFCRL Kansas experiment.) The well-known Kansas experiment showed that the flux-profiles for velocity and temperature followed Monin-Obuhkov similarity theory, although there is still debate about the rather low value obtained for the Von Karman “constant” of 0.35 (see Andreas et al., 2002). Similar measurements over the ocean are fewer due to the difficulty of replicating the usual over-land instrumented tower in a stable configuration over the ocean. Badgley et al. (1968) obtained profiles measurements from a mast on a raft in rather calm conditions in the Indian Ocean, but direct flux measurements were not obtained. Dunckel et al. (1974) deployed a gyro-stabilized mast on a buoy in the open ocean tethered to a mother ship. Paulson et al. (1972) mounted a profiling system on a boom on the stable platform R/P FLIP in BOMEX. These pioneering measurements were fraught with complications due to salt contamination of temperature sensors used to obtain the required sensible heat flux (Schmitt et al., 1978), limited sensor levels in the vertical, use of wet-bulb thermometers for humidity, and possible flow distortion. The result is that definitive profile forms have not been obtained for the important open-ocean environment.

This paper presents the results of the attempts to measure the profiles of temperature and humidity in trade-wind conditions from R/P FLIP as a part of the Rough Evaporation Duct (RED) experiment. Part of the focus of RED was the determination of the scalar flux-profile relations, as these affect electromagnetic propagation.

2. EXPERIMENT

R/P FLIP is a 100-meter long stable manned platform that was moored off of Oahu, HI for 30 days in the RED experiment. A 16-meter vertical mast was deployed at the end of the 20-meter port boom, as shown in Figure 1. FLIP was oriented so that the aerodynamically shaped hull was pointed into the prevailing trade winds. Flow distortion at the end of the boom is believed to be small, as judged from a simple potential flow model calculation. (The model did show some possible flow distortion near the boom itself.)

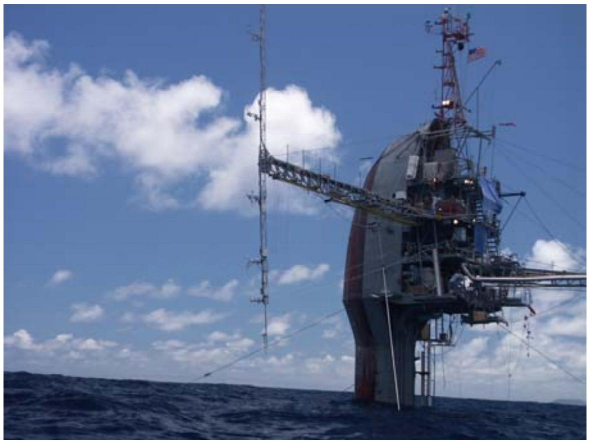

Figure 1: R/P FLIP with 5 levels of temperature and humidity sensors on the 18m mast.

The instrumentation consisted of 5 levels of solar radiation aspirated shields (EG&G 110SM) with Hart Scientific thermistor and EdgeTech chilled mirror dew point sensors between 5.1 and 16.8 m above the mean sea surface. Six sonic anemometers were also mounted along the mast. The serial temperature data were recorded at 1 Hz; the analog data at 50 Hz. Data were recorded essentially continuously for 12 days in August-September 2001. The time series of the conditions are shown in Figure 2.

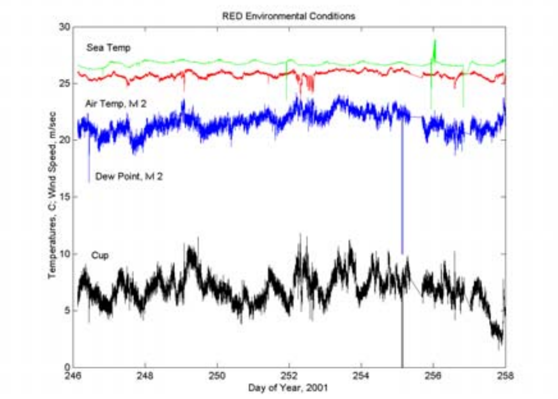

Figure 2: Environmental Conditions for RED 2001 from R/P FLIP.

The conditions for RED were typical of the trade winds, with moderate wind speeds and slightly unstable surface-layer buoyancy forcing. There were a few periods of rain showers around day 252. The buoyancy flux was obtained through the quasi-virtual temperature from the sonic anemometers. Humidity flux was obtained from a H2O/CO2 sensor and sonic anemometer mounted on a side boom on the opposite side of FLIP from the main meteorological mast as Lyman-alpha humidiometers on the mast were intermittent. Momentum flux was obtained from the sonic anemometers with the exception of one suspended below the mast that suffered wave damage. The aspiration of Level 3 failed so this level was not included in the analysis. As a precaution, the dew point temperature from this level was also not included, although there was no evidence that it was affected. In this analysis, 30-min block averages were used to calculate the mean values of the temperatures and dew points and the covariances for the fluxes. The sonic anemometer wind components were rotated into a local wind coordinate system for each 30-min block. The small motion of the mast was measured, but not applied for the analysis presented here.

Accurate measurements of the small vertical gradients of potential temperature and humidity are a challenge. The temperature probes were tested in a water bath before and after the experiment, and retained relative accuracy to one probe of <0.006C. Relative accuracy of the chilled mirror dew pointers was not determined as the control system may reach a new state every time they are turned on and off. Factory accuracy is stated to be +/- 0.2C. We remark that salt spray was not observed on the chilled "mirrors" after the continuous use on R/P FLIP. The contorted airflow path in the aspirated shields presumably inertially separated out the salt aerosols. Salt aerosol loading was not that large in RED. Salt aerosol deposited on temperature probes does not affect the *mean* temperature (Friehe, unpublished), although none was observed. Potential temperatures were calculated from the measured mean temperatures with the dry adiabatic lapse rate.

3. RESULTS

A sample of potential temperature and specific humidity profiles is shown in Figure 3 in a semi-log presentation. There is overall adherence to the semi-log form for potential temperature. The 5.1 m level of specific humidity is low.

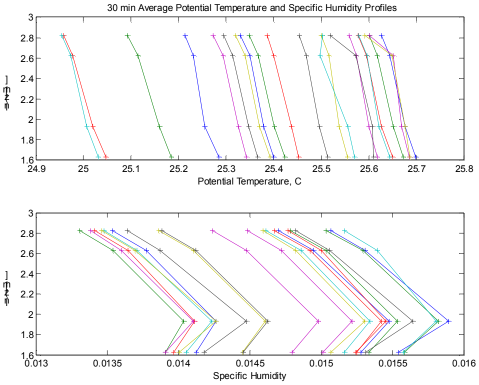

Figure 3: Sample 30 min averaged profiles of potential temperature and specific humidity versus ln of height.

Slopes of the semi-log temperature and specific humidity profiles for each 30-min segment were calculated from a least-squares fit. Corresponding Reynolds stresses and buoyancy fluxes were calculated from the sonic anemometer data. The profile similarity-normalized slopes (phi_h and phi_q) were calculated from their definitions (Busch, 197X) using a Von Karman constant of 0.4. The "phi" functions are shown in Figure 4 versus z/L.

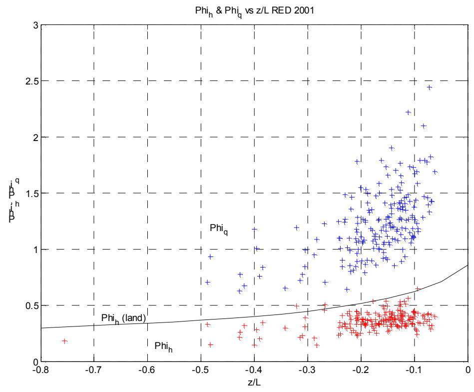

Figure 4: Phi functions for potential temperature and humidity versus z/L. The phi function for temperature from Oncley et al. (1998) is also shown (---) for comparison.

It is clear that the present Phi_h function for temperature is different from that over land; the slope of the profile is less. Conversely, the Phi_q function for specific humidity is different from that for temperature over the sea, and also different from that for temperature over land. However, the dependencies on z/L follow similar trends to those of temperature over land.

The small biases (maximum +0.006 C) among the temperature probes were accounted for and made only a small difference in the results, as shown in Figure 5.

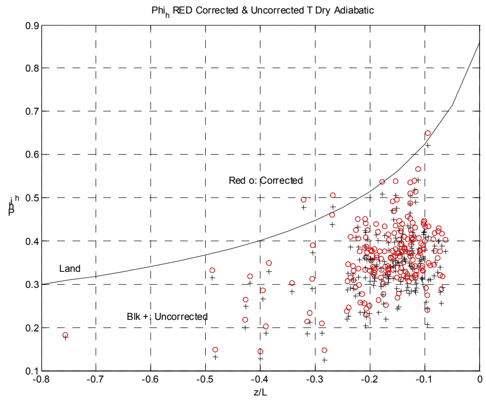

Figure 5: Effect of temperature probe biases on Phi_h. Red o: Corrected; Black +: Uncorrected.

Similarly, the use of an adiabatic lapse rate for moist air of dew point temperature 20C did not materially affect the results for Phi_h.

Another possible source of error in the FLIP measurements is the accuracy of the exact height of the sensor mast above the mean water surface. To evaluate this, we varied the absolute heights by +/- 1 meter, which is larger than the estimated uncertainty in the distance to the mean sea. The results on the phi functions are shown in Figure 6.

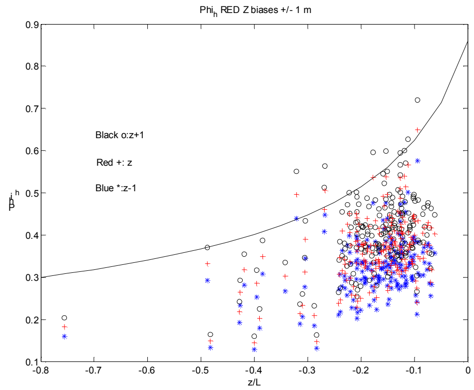

Figure 6: Effect of biases in absolute height of temperature sensors on Phi_h.

The sensitivity of a 1 m bias in z is about 0.02 units of Phi_h.

4. DISCUSSION

The preliminary analysis of flux-profile relations for temperature and humidity from an experiment over the open ocean from the stable platform FLIP show substantial differences from the overland result for temperature. The possible sources of error for the temperature profile results (biases in mean temperature and heights) do not seem to explain the differences. Further analysis will focus on correcting the virtual temperature flux for humidity, which will affect the scaling heat flux for the temperature profile slope. Also, it was observed that the water vapor flux from the H2O/CO2-sonic system on the starboard side of FLIP was lower than the water vapor fluxes on the mast when a Lyman-alpha humidiometer was operational. Assuming, however, that the present measurements are approximately correct, the reason for the differences must lie in the boundary conditions between the land and ocean surfaces. The reason for the difference between the temperature and humidity profiles is more puzzling, since, they are scalars with approximately the identical Prandtl and Schmidt numbers (0.71 and 0.58).

5. ACKNOWLEDGEMENTS

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