2A.6 EVOLUTION OF DRIZZLE CELLS IN SE PACIFIC STRATOCUMULUS

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1. INTRODUCTION

Marine stratocumulus (Sc) clouds cover 12 to 15% of earth's surface and contribute significantly to earth's global albedo (Randall et al. 1985). It has been estimated that a mere 4% change in the amount of marine Sc would offset the warming from a doubling of CO_2 concentration (Randall et al. 1984). Because Sc have such a large effect on the earth's radiation budget, it is necessary for climate prediction to be able to determine the mean albedo of a Sc region. Two of the key components needed to estimate the albedo are the mean cloud thickness and the horizontal variability of the Sc layer.

To obtain cloud thickness and extent, the structure and life cycle of individual Sc elements must be understood, including the temporal and spatial scales on which their evolution plays out. The diurnal cycle provides the key temporal forcing for cloud thickness and drizzle. Because drizzle affects the dynamics of the BL, it is important to understand how drizzle relates to the horizontal variability of Sc on their primary spatial scale, the mesoscale (10-100 km).

Horizontal variability within Sc sheets resembles the hexagonal "open cell" and "closed cell" mesoscale patterns that appear in regions with large heat fluxes (e.g. Agee 1984). These patterns are called mesoscale cellular convection (MCC). In Sc the cells are irregularly shaped and are on the order of 30 km in diameter. They are caused by cloud-top cooling instead of surface heating. Closed cells are cloudy regions surrounded by narrow areas of clearer, sinking air. Open cells contain narrow cloud-topped updrafts that surround broad areas of clear, subsiding air. There is often a relatively abrupt transition between the open and closed cells in Sc sheets.

The field campaign EPIC 2001 Sc (the Sc leg of the Eastern Pacific Investigation of Climate project; Bretherton et al. 2003) was designed to document the cloud and boundary layer (BL) structure in the SE Pacific and to examine the interactions among drizzle, BL dynamics, and cloud thickness. The EPIC cruise took place aboard the NOAA ship Ronald H. Brown (RHB) and spent six days at 85°W, 20°S. The RHB was equipped with a scanning C-band radar, a vertically-pointing millimeter-wavelength cloud radar (MMCR), and other instrumentation for measuring BL properties. Findings include a significant diurnal cycle of cloud thickness and precipitation, with substantial early-morning drizzle.

In this study, we use meteorological time series data to characterize the Sc BL and C-band radar and MMCR data to associate drizzle with enhanced mesoscale variability. We also identify and composite cellular features in the C-band radar data, and use these to determine the characteristics of drizzle cell structure and lifetime.

2. CHARACTERIZATION OF THE BL

The diurnal cycle is a key modulator of cloud thickness in Sc. In the SE Pacific, cloud thickness varies with cloud top height. During the night long-wave cooling is able to drive mixing throughout the BL, so the surface and cloud layers are coupled. This mixing increases the entrainment at cloud top and causes the cloud top to rise, thereby thickening the cloud, during the night. If the cloud is thick enough and large drops are present, these can fall through the cloud, collect smaller drops, and eventually fall out as drizzle. Drizzling periods occur most often during the early morning. During the day, short-wave absorption within the cloud layer offsets some of the long-wave cooling at the cloud top so mixing is inhibited between the surface layer and the layer above, and the BL becomes decoupled. This pattern of *coupled-drizzling-decoupled* is not entirely predictable because other dynamics are superimposed upon the diurnal cycle.

To further explore the mesoscale variability of Sc, we take a closer look at the dynamics involved in each of the three BL categories just mentioned: coupled, decoupled and drizzling. If the area-averaged reflectivity from the C-band radar is greater than -5 dBZ at any time, the BL is classified as drizzling. Otherwise, if the difference between that hour's cloud base height from the ceilometer (z_{CB}) and the lifting condensation level (LCL) is less

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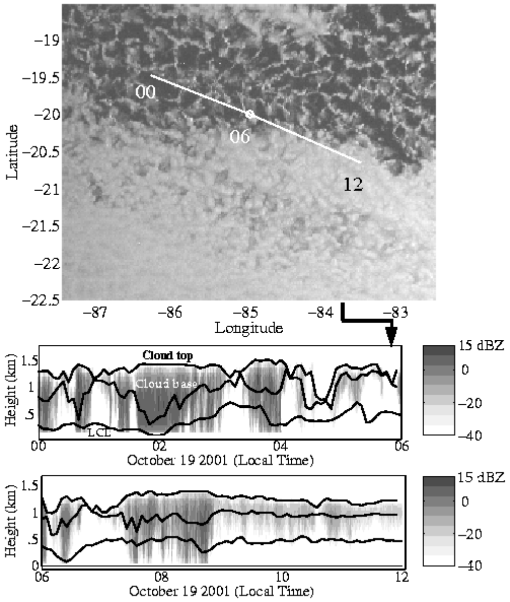

Figure 1: GOES 8 visible image at 0545 local time on 19 October 2001, with estimated advection for the previous and following six hours indicated by lines. The circle is the 0600 position of ship. Corresponding MMCR time-height sections are below for the previous and following six-hour time segments, with overlayed lines of hourly cloud top (from the MMCR), hourly cloud base (from the ceilometer) and hourly LCL (calculated from surface measurements). Local time is used in this figure.

than 300 m, the BL is coupled. If the difference is greater than 300 m the BL is decoupled. Each time series (temperature, water vapor mixing ratio, wind speed, cloud base, top and thickness, LCL and LW radiation) was band-pass filtered. The filter was designed to keep frequencies between 25 min and about 6 hours, corresponding to horizontal wavelengths of 10-100 km advecting past the ship at a typical wind speed of 7 m/s. This was done to isolate the mesoscale and to remove the effects of the diurnal cycle.

Computing the variances for the band-passed series in each category, we find that the drizzling BL has the highest variance for each examined parameter. The drizzling BL is therefore the most horizontally inhomogeneous on the mesoscale. The coupled BL is the most horizontally homogeneous, and the decoupled BL falls in between.

Figure 1 shows a visible satellite image taken at 0545 local time on 19 October 2001. The circle in the center shows the ship location at 0600. The lines extending to the NW and SE indicate the approximate advection during the previous and following six hours. The two MMCR time-height sections also correspond to the previous and following six hours, respectively. Between midnight and 0900 local time, the BL cloud field appears very patchy and variable in both the horizontal and vertical images. There is also a significant amount of drizzle during these hours. After 0900, the cloudiness smoothes out and drizzle ceases, although mesoscale features are still visible. We can clearly see the association between mesoscale variability and drizzle in this example, although we do not know if the drizzle enhanced the horizontal variability or vice versa.

The C-band data from this time period (not shown) also indicates a transition from high reflectivity drizzle cells in open-cell type patterns to a smoother field of low reflectivity. Note that ”drizzle cell” refers to the drizzling portion of either the closed cell or open cell cloud formation. When using C-band radar data, we refer simply to the precipitating region because this radar does not detect clouds.

3. STRUCTURE AND LIFE CYCLE OF Sc

The high-resolution C-band data set enables us to observe the evolution of drizzle cells as they pass by the ship. Some drizzle cells were observed to form, while others dissipated. Within the 1.5-2 hours it takes to advect through the C-band field of view, no sizable drizzle cell was observed to go through an entire life cycle, from development through dissipation. Therefore drizzle cell lifetimes are estimated to be somewhat longer than two hours. Drizzle cells were found to range in size up to 100 km^2 in area. Some of the cells split and others merged.

An example of the evolution of a drizzle cell is shown in Figure 2. The drizzle cell that is boxed in the top panel has been identified and ”cut out” of each (five minute) C-band image throughout its lifetime in the C-band field of view. Five of these individual snapshots are displayed at the bottom of the figure. This cell starts to split and to fade during the hour shown. The entire set of these drizzle-cell cutouts was composited. The mean e-folding distance in reflectivity (dBZ) for this cell, and for two other examples, was about 2.5 km. This indicates the rapid drop-off of reflectivity within a drizzle cell, as well as the degree of patchiness of the drizzle signal. This result supports the observation that drizzle is associated with more variable conditions.

4. CONCLUSIONS

We have found a loosely diurnal pattern of coupled, decoupled and drizzling conditions in the Sc BL in the SE Pacific. Drizzle often appears in distinct cellular structures, and it is associated with enhanced

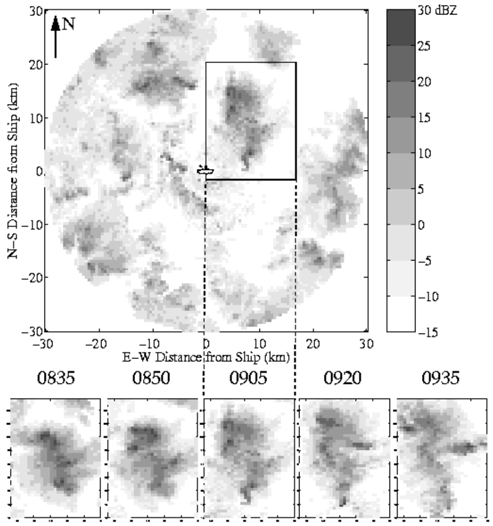

Figure 2: C-band image at 0905 UTC (0305 local time) on 21 October 2001 and evolution of boxed drizzle cell between 0835 and 0935 UTC. The 2-D reflectivity map shown has been averaged through the cloud layer.

mesoscale variability. Future modeling studies will be necessary to fully explore the cause-and-effect relationship between drizzle and enhanced variability, but these models will need to be constrained with analyses based on observations.

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