Stratocumulus-to-Cumulus Transition: A Case-study from the MAGIC Field Campaign

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Motivation and Approach

Boundary layer stratocumulus (Sc) and cumulus (Cu) clouds cover vast areas of the Northern Pacific ocean. Sc clouds form in the East Pacific that is characterized by colder SSTs and strong boundary layer inversion. As these clouds get advected towards the trade-wind region that has warmer SSTs and weaker inversion, they decouple from the surface and transition to broken Cu clouds. Most of the Global Climate Models (GCM) used for predicting the future climate fail to accurately simulate this transition from Stratocumulus to Cumulus (Sc-to-Cu) cloud regimes. The cloud transition is thought to occur over a span of three days due to complex interplay of processes modulated by surface fluxes, radiative cooling, inversion strength and precipitation. The goal of this work is to understand the relative importance of different factors responsible for the Sc-to-Cu transition through budgets of energy, moisture, and mass.

Data collected during the MAGIC field campaign between 20-25 July 2013 form the basis of this work. The cloud and precipitation microphysical properties were retrieved by combining data from vertically pointing radar (KAZR), lidar (HSRL) and microwave radiometer (MWR).

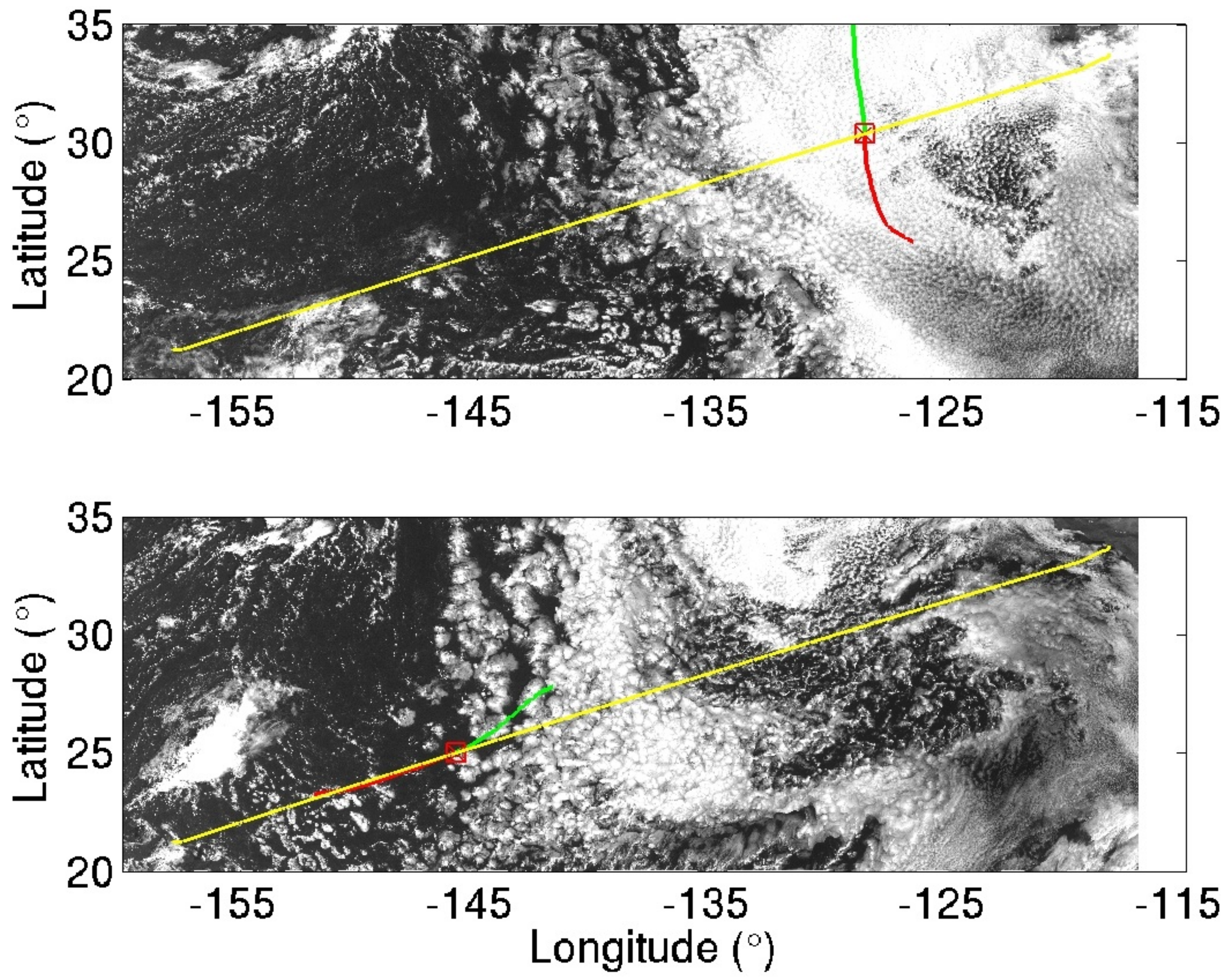

Figure 1: Longitude-latitude mapping of the shortwave albedo reported by the GOES-15 satellite at 1800 UTC on 21 July 2013 (top) and 23 July 2013 (bottom). The ship location during that time is shown in red square. The green lines show the location of an air parcel at 500 m during the past 24-hours, and the red lines denote the same for the next 24-hours. 1800 UTC corresponds to 10am local time at -115° longitude and 8am local time at -155° longitude. The ship-track for the entire period is shown in yellow.

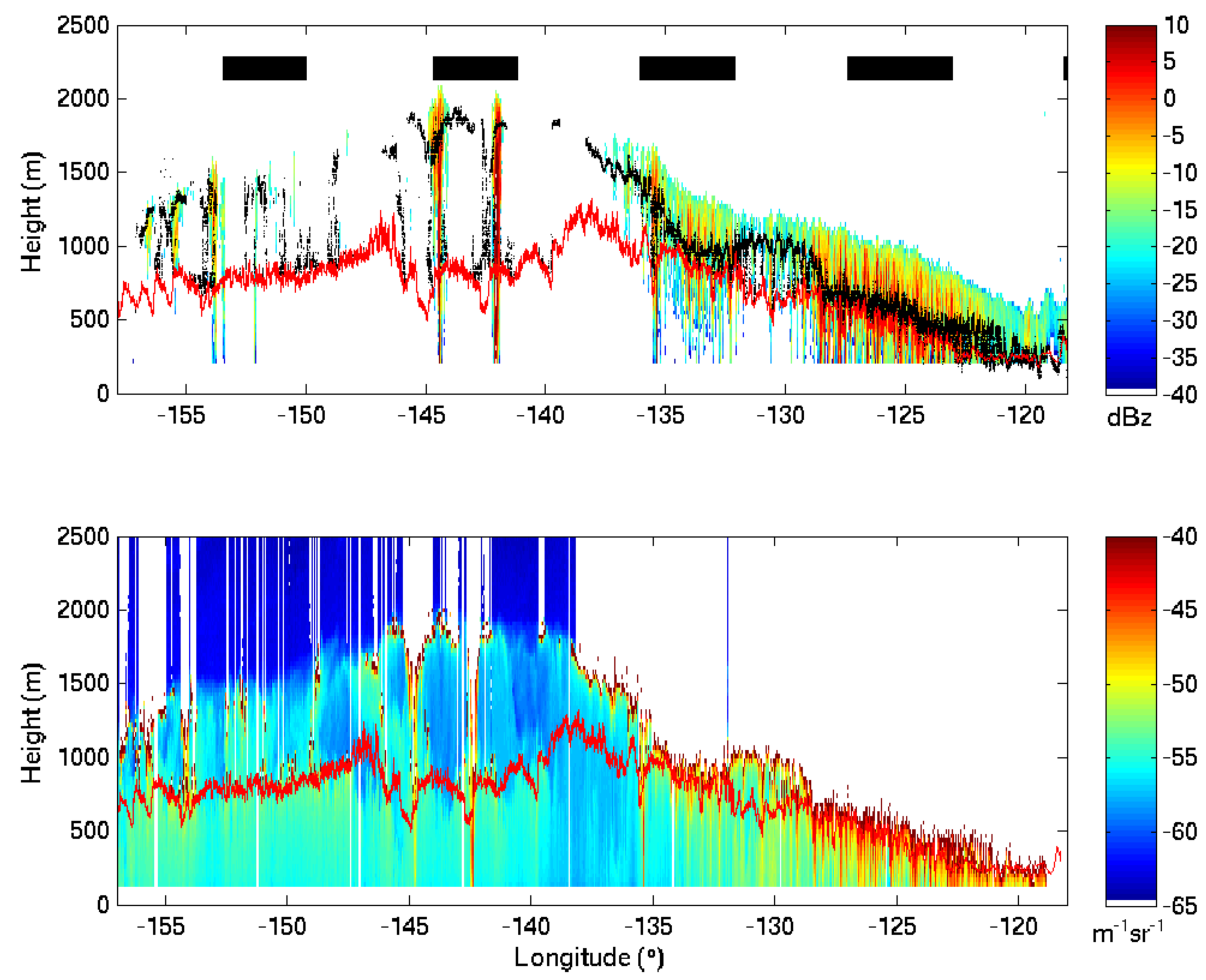

Figure 2: Longitude-height mapping of the KAZR reported reflectivity (top) and the HSRL reported backscatter (bottom). The ceilometer reported first cloud base height (black) is shown in the top panel, while the LCL (red) is show in both panels. The black horizontal bars in the top panel show nighttime period. Completely overcast boundary layer east of -140° is primary focus of this work. Daytime decoupling of the boundary layer can be seen around -130°.

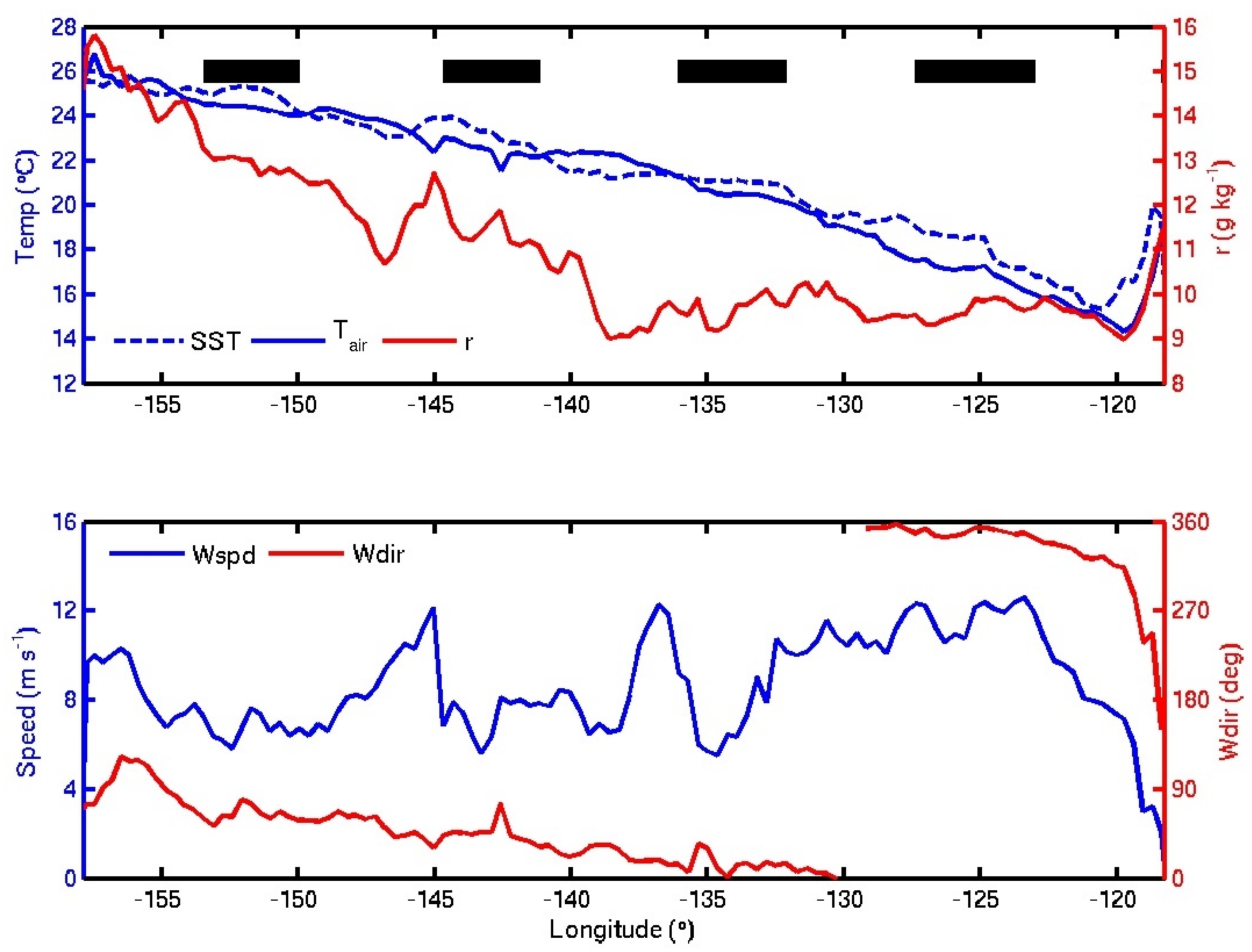

Figure 3: Longitudinal evolution of the (top panel) sea surface temperature (SST), surface air temperature (Tair), and mixing ratio (r), and (bottom panel) that of surface winds. Temperatures and mixing ratio decreased east of -120°, and the winds were from the Northeast east of -130° suggesting coastal and mesoscale effects. The gradient in GOES cloud top heights were also high east of -130°.

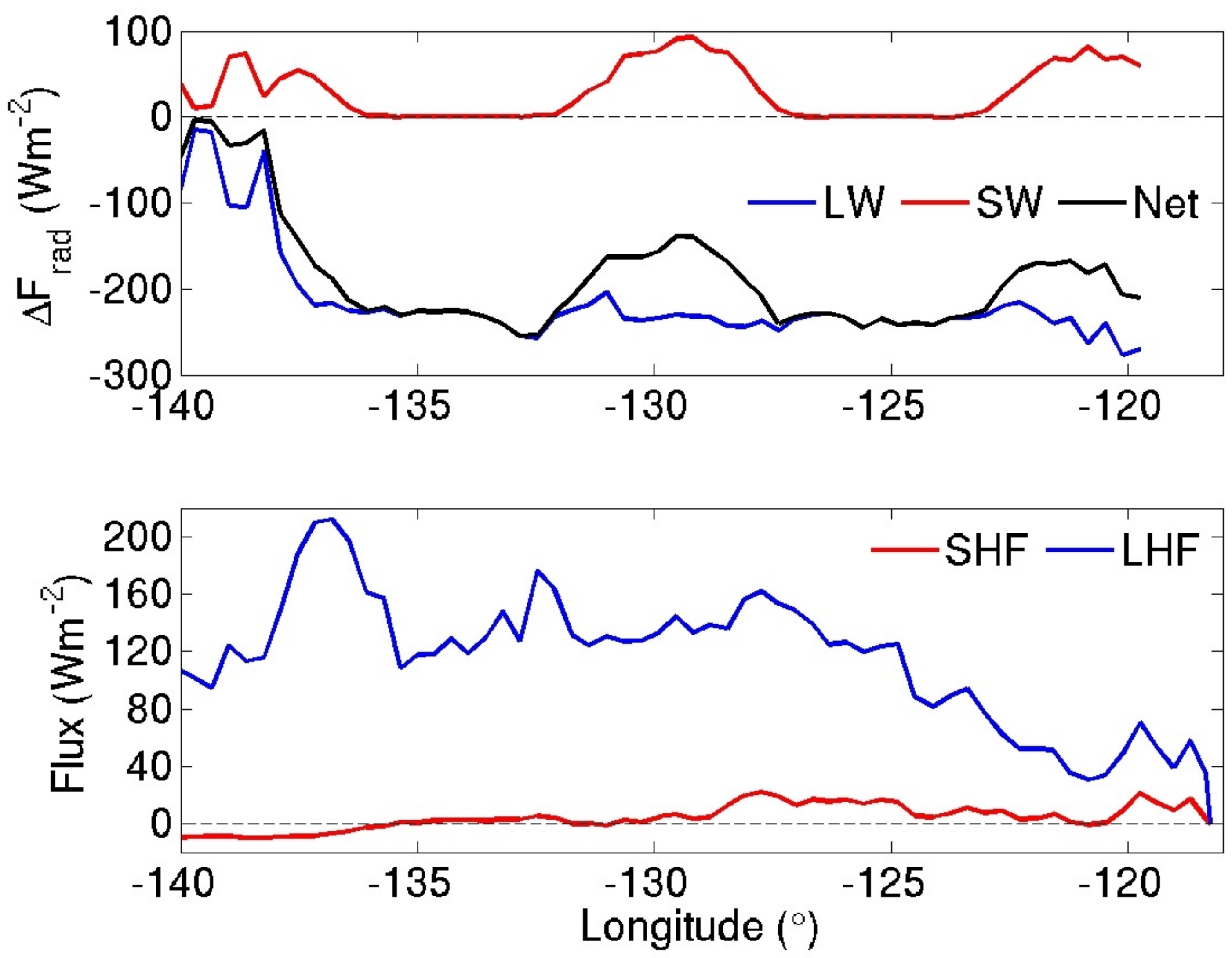

Figure 4: Longitudinal evolution of the radiative flux divergence across the cloud layer (top panel) and the surface fluxes (bottom panel). The radiative fluxes were simulated using the Rapid Radiative Transfer Model (RRTM), and the surface fluxes were calculated using bulk algorithm. During the nighttime, the radiative cooling was twice the LHF, while during the daytime they were comparable. The precipitation heating was less than 20 Wm^{-2} during the entire period.

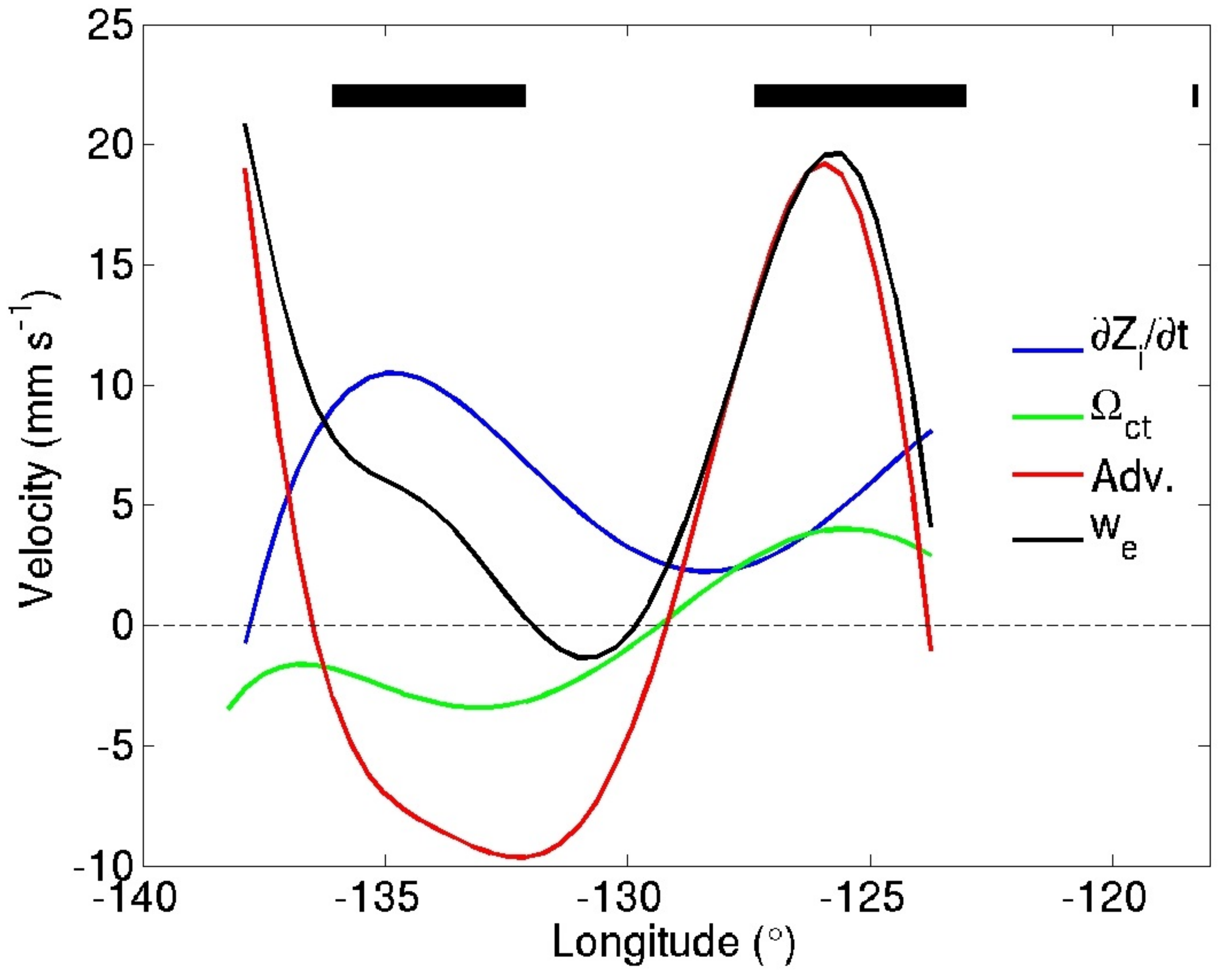

Figure 5: Longitudinal evolution of the terms in boundary layer mass budget equation that was used to calculate the entrainment rates (W_e). The KAZR reported cloud top heights, ECMWF-reported largescale vertical velocity, and GOES-reported cloud top heights in pixels adjacent to the ship were used. W_e is heavily dependent on the advection term east of -130°, while the local tendency term becomes important west of it.

Preliminary Conclusions and Future Work:

- Daytime decoupling of the boundary layer is primarily due to reduction in the cloud top radiative cooling, while nighttime decoupling is due to drizzle evaporative cooling in the sub-cloud layer.
- Entrainment rates were higher during the nighttime and during periods when cloud thinning led to complete dissipation.
- Future work will focus on characterizing the uncertainty in the entrainment rates and calculating the energy and moisture budgets for the transition.

References:

Caldwell, P., C. Bretherton, and R. Wood, 2005: Mixed-Layer Budget Analysis of the Diurnal Cycle of Entrainment in Southeast Pacific Stratocumulus. *J. Atmos. Sci.*, **62**, 3775–3791.

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