ON THE EVOLUTION OF A CIRRUS ANVIL OBSERVED BY NASA SCANNING RAMAN LIDAR ON 19-20 JUNE 2002 DURING IHOP

Ruei-Fong Lin[1,2], David Starr[2], Belay Demoz[2], Zhien Wang[1,2] and David Whiteman[2]

[1]Goddard Earth Sciences and Technology Center, University of Maryland, Baltimore County, Baltimore, MD, USA
[2]Laboratory for Atmospheres, NASA/GSFC, Greenbelt, MD, USA

1. INTRODUCTION

A persistent cirrus anvil (more than 10 hours in time) was observed by the NASA Scanning Raman Lidar (located at Homestead, OK) on 19-20 June 2002 during the International H2O Project (Fig. 1). The cloud was initially (0100 UTC) about 12.5 km of altitude and 0.5 km of depth. It deepened to about 1.5 km of depth within 1.5 hr (not shown). The overall cloud height and depth did not change much afterward (Fig. 2). However, the optical and microphysical properties became two-layered. The top layer featured higher depolarization ratio, larger ice water content (IWC) and smaller ice crystals, while the lower layer featured the opposite. The retrieval schemes for IWC and effective size are described in Wang et al. (2004). The depth of the top layer decreased with time while that of the lower layer increased. Furthermore, from radiosonde measurements, the top layer seemed to correspond to a layer of neutral instability.

These concurrent features prompt the question if the layering was associated with a cirrus outflow layer (Lilly, 1988) which was decreasing its depth with time.

2. HYPOTHESIS

Cirrus anvil outflow may evolve into an elevated turbulent mixed layer driven by the differential radiative heating, which decreases quasi-linearly with height in the optically translucent and well-mixed cirrus layer of uniformly distributed particles directly over the warm surface without any low-level cloud in between (Lilly, 1988). To simplify the derivation, ice crystals are assumed to be small such that their fall speed is negligible and the slope (a measure of the strength of the destabilizing) of the differential radiative heating does not change with time. A mixed layer with increasing depth due to entrainment is deduced.

Corresponding author: Ruei-Fong Lin, NASA/GSFC, Mailstop 912, Greenbelt, MD, 20771. lin@agnes.gsfc.nasa.gov.

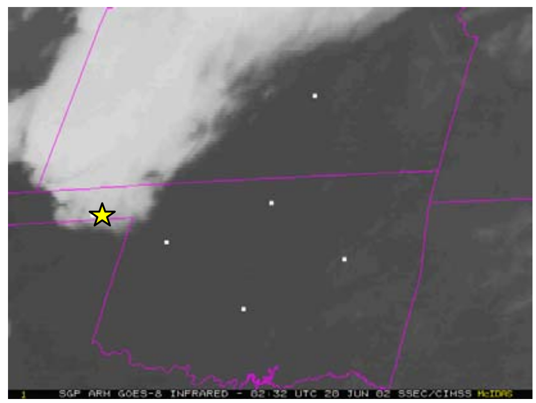

Figure 1. GOES infrared image at 0232UTC on 20 June 2002. Homestead, OK is indicated by the star.

The hypothesis is examined by Lin (1997) using a two-dimensional model with explicit bin micro-physics (the particle size distribution, PSD, is fully resolved in each grid box) and an interactive radiative transfer scheme. It is assumed that, in the early phase of cirrus outflow, ice particles are distributed uniformly entailing a linearly de-creasing radiative heating profile following Lilly's hypothesis. However, the study shows that the mean ice mixing ratio increases with height for a developed mixed layer. The cloud is translucent. Therefore, the redistribution of ice crystals results in an altered radiative heating profile, which becomes S shaped; that is, radiatively stabilizing the lower layer but destabilizing the upper layer. This microphysical feedback to thermo-dynamical forcing is not considered in the original work by Lilly (1988). As a result, the depth of the mixed layer decreases with time while a stable debris layer composed of particles with greater fall speed ejected from the mixed layer just below the mixed layer forms and deepens. The simulated scenario of cirrus outflow evolution is qualitatively similar to what has been observed by the NASA Raman lidar. It will be interesting to see if the model could simulate the IHOP case well to verify the modified hypothesis.

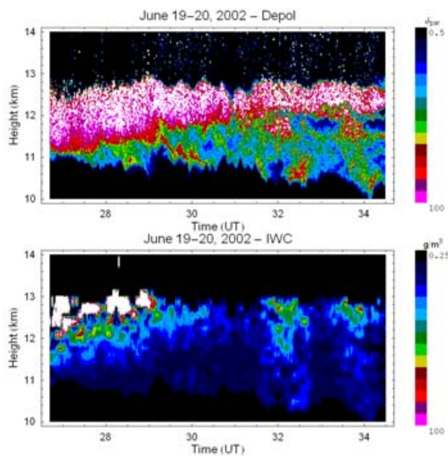

Figure 2. Top panel: Particle depolarization ratio using a linear-scale color bar. Fully depolarized signal is 100%. Lower panel: Lidar derived IWC using a linear-scale color bar.

We plan to compare the profiles of model derived IWC, effective diameter, as well as the depolarization ratio, with the observed. IWC and effective diameter can be easily calculated from the model generated profiles of PSDs, while the calculation of the backscattering depolarization ratio is not as straightforward. The depolarization ratio depends on particle shape. In general, the ratio is zero for spherical particles, and it is higher for columns than for plates. The ratio also depends on the effective size parameter and the particle aspect ratio (Mishchenko and Sassen, 1998). The 2D model has been modified to treat different shapes of ice particles simultaneously for the current study.

3. PRELIMINARY RESULTS

A test run is performed assuming the initial cirrus outflow is composed of 50% (mass) of hexagonal columns and 50% of plates. The total IWC of the two particle species, uniform within the prescribed initial cloud layer, is about 45 mg m^{-3}, a number loosely based on the lidar retrieval. Both species are assumed to be log-normally distributed with respect to the effective diameter. The initial mean size of the columnar particles is smaller than that of the plates, as inferred by the particle depolarization ratio. The simulation is initialized with small perturbation temperature in the cirrus outflow layer. Nighttime radiation condition is adopted.

The IWC profile for each of the particle species at simulation time t = 60 min is shown in Fig. 3. The cloud layer above 11.5 km is turbulent resulting in an increase of IWC with height. This feature of increasing IWC in the upper layer is also evident in the lidar derived IWC profiles. The cloud layer below 11.5 km gradually stabilizes. Particle sorting caused by the difference in the net outgoing particle mass fluxes from the turbulent layer between these two species is also evident. As a result of the particle sorting, more columns are in the upper layer, while more plates are in the lower layer. The test run suggests that our hypothesis is feasible, at least qualitatively. Comparison of the time evolution of the model derived IWC profiles with the observations is underway and more sensitivity tests on the initial PSDs will be conducted in the future.

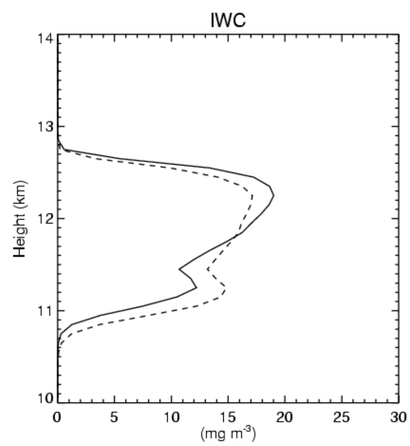

Figure 3. Simulated IWC profiles at simulation time t = 60 min. Solid: columns; dashed: plates.

4. FUTURE PLANS

A question immediately arises when comparing a ground-based lidar observation (Eulerian framework) to a model simulation which assumes the model domain is advecting with the mean horizontal flow (Lagrangian framework): the time series of the observed cloud profiles is not the time series of the evolution of the cirrus outflow in a Lagrangian sense. Thus, we need to evaluate the distance between the ground-based measurement site and the convective core along the cirrus outflow trajectory as a function of observation time. This may be achieved by the backward trajectory calculation using a fine-meshed mesoscale simulation of the convective system. We also plan to develop a scheme to calculate the particle depolarization ratio profiles from model generated PSDs.

5. REFERENCE

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