POLARIZATION LIDAR STUDIES OF ALASKAN FOREST FIRE SMOKE, AND INDIRECT EFFECTS ON CLOUDS

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ABSTRACT

Reported are polarization lidar studies of forest and tundra fire smoke in the interior of Alaska. Although fresh smoke aerosol generates near-zero depolarization, somewhat higher depolarization is sometimes noted in aged smoke. Moreover, there is evidence from the lidar and cloud microphysical model findings that the smoke has the ability to nucleate ice crystals below water saturation at temperatures colder than ~-15°C, presumably as the organic-solution haze particles are diluted in updrafts to enable embedded ice nuclei to become active.

DESCRIPTION

Perhaps attributable to the effects of global warming, which are likely to be particularly evident in Arctic regions, recent forest fire seasons in the wooded interior of Alaska have been historically extreme. Regular polarization lidar measurements from the Arctic Facility for Atmospheric Remote Sensing (AFARS) in the interior of Alaska have captured numerous boundary layer and deeper smoke layers from local and regional forest and tundra fires. Normally the laser depolarization produces near-zero linear depolarization ratios. This is consistent with the backscattering properties of spherical droplets composed of aqueous organic solutions released by the combustion, and also likely embedded mineral particles (Pruppacher and Klett 1997). Forest fire smoke has been observed to contain about 10% mineral particles.

It has been known for many years that smoke from at least some types of combustion, like forest and sugar cane fires, also liberates generous amounts of ice nuclei (IN) that are capable of freezing mildly supercooled cloud droplets (Pruppacher and Klett 1997). Several organic substances and mineral particles are both seen as the likely IN source. However, heterogeneous ice nucleation is affected by the molality of the solute in the aqueous solution, which in effect can be viewed as increasingly the effective droplet temperature with increasing relative solution strength. This situation is commonly considered to dominate the formation process of cirrus cloud ice crystals from the homogeneous freezing of haze particles (e.g., Khvorostyanov and Sassen 1998).

Interestingly, we have observed supercooled liquid altocumulus clouds in contact with the top of smoke layers to behave unusually at temperatures of –15°C and colder. The supercooled water clouds are observed somewhat after the ice crystal virga is first observed, as is shown in the ruby (0.694 um) Cloud Polarization Lidar CPL) displays in Figure 1. A smoke layer (with near-zero lidar depolarization extends to a height of ~5.0 km, which is well below the cirrus cloud but corresponds to the location of a supercooled (–16°C) altocumulus cloud. The corresponding MODIS image in Figure 2 depicts the approaching cirrus and cellular altocumulus clouds approaching the AFARS site in Fairbanks, Alaska (see arrow), as well as the smoke-filled surrounding valleys. The ice virga below the thin water cloud is in this case composed of horizontally-oriented ice plates, which produce near-zero depolarization as a result of simple specular reflections. Nonetheless, as shown by the cloud microphysical results in Figure 3 tailored for these conditions, ice virga should appear in the sub-water saturated region just below the water cloud base if IN are becoming activated in growing haze particles. This and other examples will be described in detail.

REFERENCES

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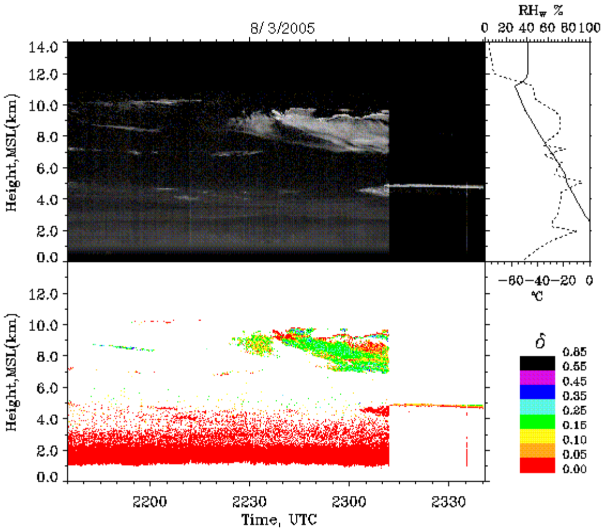

Figure 1. CPL returned power and linear depolarization displays of upper tropospheric cirrus clouds and a supercooled altocumulus cloud (with horizontally-oriented ice crystal virga) located at ~5.0 km at the top of a non-depolarizing smoke layer. Virga is present throughout the period, but is difficult to see in this display.

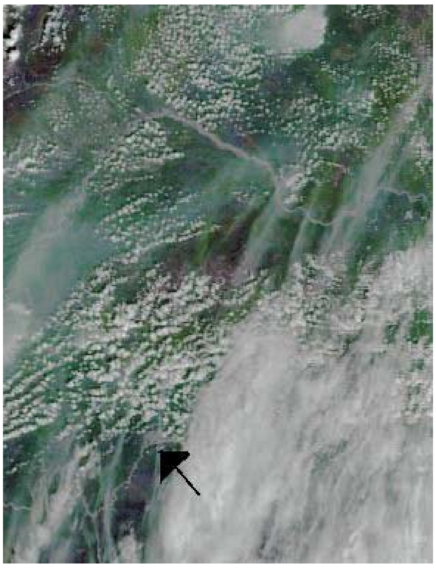

Figure 2. The corresponding Aqua satellite MODIS image collected at 2210 UTC. Shown are invading cirrus clouds (bottom right), developing cellular altocumulus clouds, and smoke plumes surrounding the Fairbanks AFARS site (arrow).

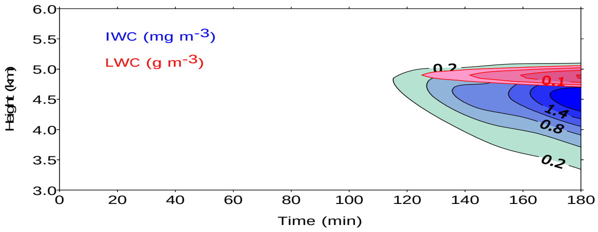

Figure 3. 2D cloud microphysical model results for ice (IWC) and liquid (LWC) water contents versus run time based on the atmospheric conditions in Fig. 1, assuming a ice nucleation contact parameter of m = 0.5 and an updraft velocity of 10 cm/s. Ice crystals appear slightly in advance of the supercooled liquid layer because of heterogeneous ice nucleation in smoke droplets that become diluted in updrafts.