Aerosol-Cloud Interactions and the Role of Clouds in Modifying Atmospheric Composition during INTEX-NA

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Summary

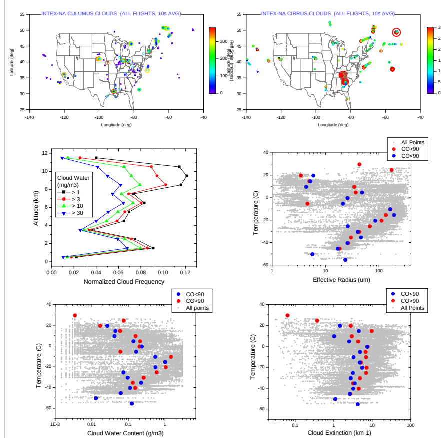
The 2004, NASA Intercontinental Transport and Chemical Evolution Experiment from North America (INTEX-NA) was conducted during summer, the time of year when eastward transport of dust and pollution from the United States reaches a maximum. From bases of operation in St. Louis Missouri and Portsmouth New Hampshire, extensive measurements of trace species concentrations and characteristics were made from aboard the NASA DC-8 aircraft as it flew sampling missions within air masses over the North American continent at varying distances off the U.S. east and west coasts and at altitudes ranging from near surface to over 12 km. Clouds were often encountered along the flight paths, as wet convection was quite active thoughout the study area. To examine the impact of clouds upon trace gas distributions and chemistry as well as to search for links between aerosols and cloud properties (indirect effects), aerosol data recorded aboard the DC-8 were used to derive a number of important cloud microphysical parameters were including cloud water content, extinction, effective radius, particle mean volume and number diameters, and particle number densities. These has been separated into data sets for warm, cumulus-type clouds and high, cirrus clouds as described in the text at left. The UV-Dial instrument flown aboard the aircraft also provided unique cloud observations which have been used to calculate cirrus cloud frequency, optical depth, wavelength dependencies, and depolarization ratios. The images and text below explores the spatial distribution of clouds within the INTEX study area, provides mean statistical descriptions of the clouds a as function of temperature, and examines the linkages between clouds and chemistry in both water and ice clouds. Preliminary results indicate that both cumulus and cirrus cloud microphysics are sensitive to ambient concentrations of submicron particles in the 0.3 to 2 um size range. Ambient aerosols appear to have a particularly significant effect on cumulus cloud extinction and effective radius as show in the figures to the far right.

Multi-Layer clouds observed over the ocean during INTEX

Cirrus clouds and contrails overlying Portsmouth at the end of a DC-8 science flight.

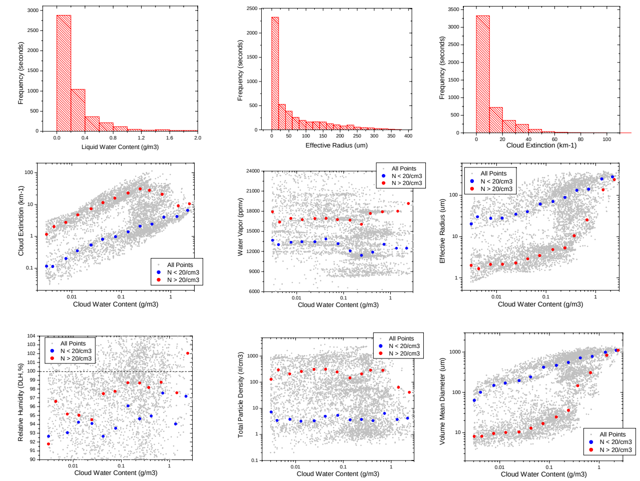
Wingtip probe used to measure aerosol and cloud particle size distributions and cloud liquid water content.

Cloud Spatial Distributions and Microphysical Properties



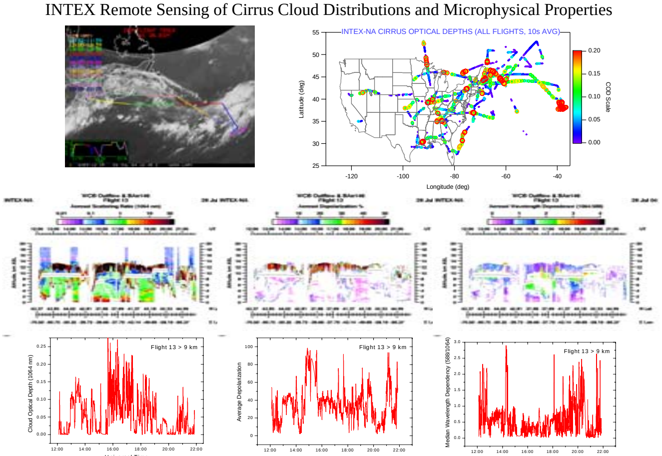
The maps at top show regions where cumulus (left) and cirrus clouds (right) were encountered along the flight route. For INTEX, we define cumulus as clouds that reside below 2 km altitude, are warmer than 5ºC, and contain at least 0.003 g/m3 liquid water. Cirrus were defined as clouds residing at temperatures below –35ºC, containing particles > 2 um in size, and exhibiting ice water contents >0.001 g/m3. The frequency of various levels of cloud water content are shown in the middle-left plot and indicate that, depending on how a cloud is defined, the aircraft was sampling within clouds somewhere between 5 and 10% of the time at most flight levels. The rest of the plot collectively indicate that the largest cloud particles, highest cloud water concentartions, and greatest average extinctions were found at temperatures between –20 and 0oC. This is the region where mixed phase particles exist and also were precipitation is most likely to form. An examination of the Microphysical parameters as a function of CO concentration suggests that cloud formation processes are sensitive to pollution.

Cumulus Cloud Properties and Their Dependence upon Background Aerosols



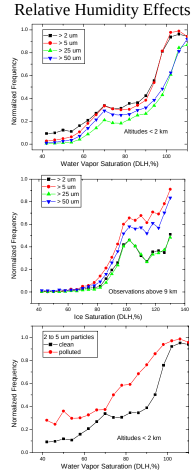
The above plots provide statistics for cumulus clouds and examine the relationship between cloud microphysical properties and the abundance of precursor aerosols. Because INTEX was primarily a fair-weather mission and great effort was typically expended in avoiding cloud systems, most of the cumulus that we sampled contained liquid water content (< 0.2 g/m3), had relatively small particles (<10 um), and exhibited low light extinction (<10 km-1). Many cloud penetrations occurred at the top of the planetary boundary layer, where convective overshoot had produced high levels of water vapor saturation. Assuming these clouds grew in parcels that contained roughly the same aerosol particle concentrations as the air just below cloud base, we investigated the relationship between submicron particle densities and cloud microphysical properties. The graphs in the second and third rows above indicate that at any particular cloud water content, there are significant differences in median cloud extinction, effective radius, volume mean diameter, and total particle concentrations between the "clean" and "polluted" cases.

INTEX Remote Sensing of Cirrus Cloud Distributions and Microphysical Properties



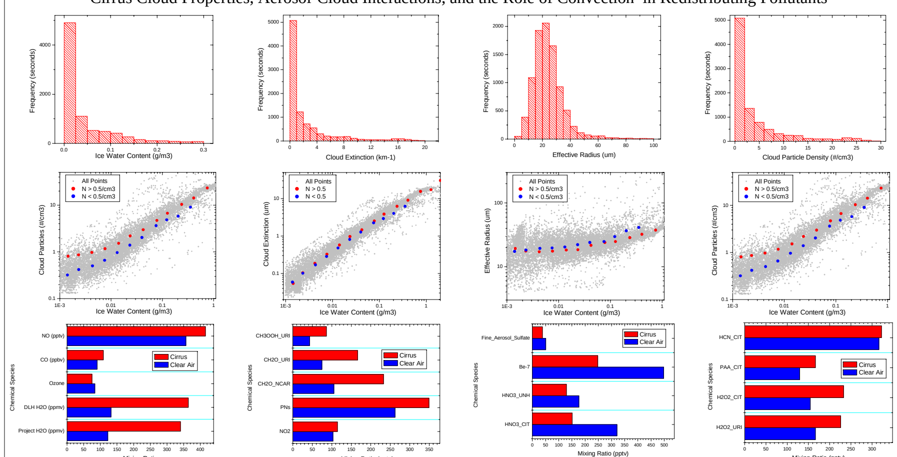
The DC-8 payload included a multi-wavelength lidar system capable of recording polarized backscattering ratios in both the zenith and nadir derections. Cirrus clouds encountered during INTEX were typically optically thin (see satellite image), which allowed the lidar to completely penetrate their depths (see figure in far left of middle row). Assuming cirrus particles yield an extinction to backscatter ratio of 25, we have calculated cloud optical depths for altitudes above 9 km. Values were usually < 0.25, as plotted on the map in the upper right-hand corner. The middle and bottom row graphs explore the layer of persistent cirrus that was observed above 8 km during most of flight 13. This layer was highly depolarized and exhibited low wavelength dependencies indicating that it was composed of fairly large, asymmetric particles.

Relative Humidity Effects



The above graphs show how particle concentrations in various size ranges vary as a function of humidity for warm and cold clouds. There are some indications that the frequencies may vary as a function of pollution for cirrus.

Cirrus Cloud Properties, Aerosol-Cloud Interactions, and the Role of Convection in Redistributing Pollutants



Thin cirrus clouds were often encountered at high altitudes during INTEX. Many of these were anvils from thunderstorms that had formed upwind of our sampling location, although some were associated with frontal systems that were propagating southeastwardly from more northerly latitudes. Many of the cirrus were widespread (see frame to left that discusses UV-Dial observations) but quite thin vertically. The majority of cirrus sampled in situ contained <0.01 g/m3 of particles that were, on average ~20 um in diameter. Calculated extinctions for these clouds were usually < 1 km-1, which corresponds to "sub-visual" clouds. If the observations are split according to their levels of interstitial submicron particles, the clouds that contain low levels of ambient aerosols are more likely to exhibit lower extinctions and larger particle sizes for a given amount of cloud water. The graphs in the bottom row above indicate that higher levels of pollutants are typically found in the vicinity of cirrus; nitric acid is the only measured species that appears to be lost to ice particle surfaces.