P5.11 AEROSOL AND CLOUD DROPLET MEASUREMENTS IN THE UNITED ARAB EMIRATES

Daniel Breed*, Roelof Bruintjes, Tara Jensen, Vidal Salazar,
National Center for Atmospheric Research, Boulder, Colorado, USA
and Stuart Piketh
University of Witswatersrand, Johannesburg, Republic of South Africa

1. INTRODUCTION

As part of a feasibility study to assess the potential for rainfall enhancement via cloud seeding, two field campaigns – winter and summer seasons in 2001 - were conducted in the United Arab Emirates (UAE) during which data were collected on aerosol and cloud physics characteristics in the region. The UAE is located on the Arabian Peninsula at the south end of the Persian Gulf (known regionally as the Arabian Gulf and referred to here as simply the Gulf). A variety of observational systems were employed in the study, including airborne trace gas instruments and a sun photometer whose data are not discussed here but can be viewed on a link from our project Website: www.rap.ucar.edu/projects/UAE. Airborne measurements of condensation nuclei (CN), cloud condensation nuclei (CCN), aerosol sizes and concentrations (PCASP), and cloud droplet spectra (modified FSSP) are presented which briefly summarize the natural and anthropogenic background characteristics of aerosols and their potential effect on cloud microphysics in a region of historically sparse *in situ* observations.

2. SYNOPTIC BACKGROUND

The winter 2001 field project period, from 1 January to 31 March, was chosen to coincide with the climatological peak rainfall period at most recording stations in the UAE. During this season, the country is under the influence of upper level westerly (mid-latitude) flow and rainfall is associated with westerly troughs and frontal systems passing through the region, generally with enough instability to cause convection. However, most of the time, a prevailing anticyclonic circulation dominates the region with subsidence causing a strong boundary layer inversion and often multiple stable layers aloft. During the summer months (sampled during 2001 from 15 June to 15 September), rainfall is mostly confined to the mountainous regions in eastern UAE and Oman. During this period, the region is under the influence of upper level easterly (tropical) flow that provides moisture from the Arabian Sea and Indian Ocean. However, the flow at low-levels is often from the west to northwest during the daytime due to the sea (Gulf) breeze and/or mountain-valley circulations, and convection can initiate over the eastern mountains depending on the moisture and stability profiles. Subsidence due to anticyclonic conditions is still prevalent in the summer, but the boundary layer is often more deeply mixed. During all months at nearly all stations, the standard deviation of precipitation exceeds the mean, reflecting the relatively low annual rainfall amounts and the extreme year-to-year variability.

**Corresponding author address:* Daniel Breed, NCAR/RAP, P.O. Box 3000, Boulder, CO 80307-3000
email: breed@ucar.edu

3. INSTRUMENTATION AND SAMPLING STRATEGY

The airborne platform used was a twin turboprop aircraft (Piper Cheyenne II) with the capability for mounting four PMS-type probes during winter conditions and two probes during the extreme heat of the summer. Relevant instrumentation to this paper, besides state parameters, consisted of a TSI-type CN counter (the 3760A used in the winter and a 3010 model used in the summer), a University of Wyoming CCNC-100 (CCN counter), a PMS PCASP, and a DMT-modified FSSP (sometimes referred to as an SPP probe).

The sampling strategy for mapping missions was to fly over the entire UAE and nearby Gulf region to obtain spatial and vertical distributions of trace gases and aerosols, concentrating on identifiable source plumes. Vertical distributions of parameters were determined by either flying in a spiral pattern above a particular site or flying vertical profiles along a flight transect. Soundings were typically flown to 6 km, but the majority of the sampling occurred within the boundary layer (below 2 km). For the cloud droplet data, passes through clouds just above cloud base altitude are summarized, although the altitudes and the "activity" of the clouds varied considerably. During the summer, the types of clouds were more convective but were sampled over a wider range of conditions as well (from active updrafts to passive cloud remnants).

4. RESULTS

4.1 *Aerosol Measurements*

Aerosol particles are injected into the atmosphere from either natural or anthropogenic sources, and also form in the atmosphere through gas-to-particle conversion. Dry aerosol particles can be classified into three size categories: nucleation or Aitken mode particles (radii < 0.1 μm), large or accumulation mode particles (0.1 < radii < 1.0 μm) and giant particles (radii > 1.0 μm). The CN counter measures the number of particles that fall within the nucleation and accumulation modes, and the PCASP measures primarily accumulation mode particles. For example, emissions of

SO_2 result in the production of aerosols through oxidation. These aerosols are formed in the nucleation mode and subsequently grow into the accumulation mode. Highest concentrations of these particles are likely to occur in the vicinity of the highest emissions of SO_2 in the UAE region.

Figure 1 represents an attempt to summarize all of the winter aerosol flights onto a regional map. The peak CN concentrations at any height were composited and interpolated onto the horizontal projection of Fig. 1. Although height and daily variabilities are masked in Fig. 1, the map generally represents low-level conditions since the aerosol peak consistently resided in the boundary layer (BL). The highest CN concentrations (>12000 cm^{-3}) are found near and downwind of identifiable SO_2 sources (oil production and processing facilities, and power plants). Relatively high CN concentrations (>4000 cm^{-3}) cover a majority of the sampled area.

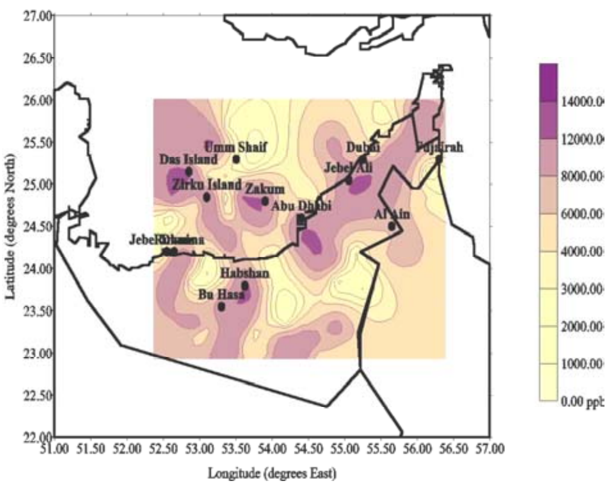

Figure 1. CN concentrations (number per cm^3) over the UAE and Gulf region for January through March 2001.

Although peak concentrations are found in the BL (usually providing a clear demarcation of the top), vertical profiles of aerosol-related measurements from individual flights often show elevated layers of enhanced concentrations and complicated structures. Figure 2, a scatter plot of CN concentration and PCASP concentration versus altitude, is an example of a sounding made during the winter season (16 Feb 2001). Aerosol concentrations decrease rapidly in the BL, which extends to about 800 m and is dominated by nucleation mode aerosols. A layer of enhanced concentrations is evident between 900 m and 1400 m, apparently the result of remnants of earlier BL's. Another layer exists between 3600 m and 4200 m, and like the lower layer, has proportionally more accumulation mode aerosols than the fresh source region of the BL. The extreme minima in concentrations at the top of these layers were common and visually quite remarkable, appearing as "clear slots". An example profile from the summer (14 July 2001) is plotted in Fig. 3. It has similar features, with a BL top at about 1200 m, an elevated layer directly above the BL (peak at about 2000 m), and decreasing concentrations aloft. The vertical structure of CN-measured particles in the BL is not evident because of the extreme values that peaked beyond the range of the recording system (10000 cm^{-3}). PCASP concentrations were somewhat less than in the 16 February example, but were well mixed throughout the BL. The increase in PCASP concentrations and hence the ratio of CN to PCASP concentrations are marked in the layer around 2000 m, reflecting aging of the aerosol population.

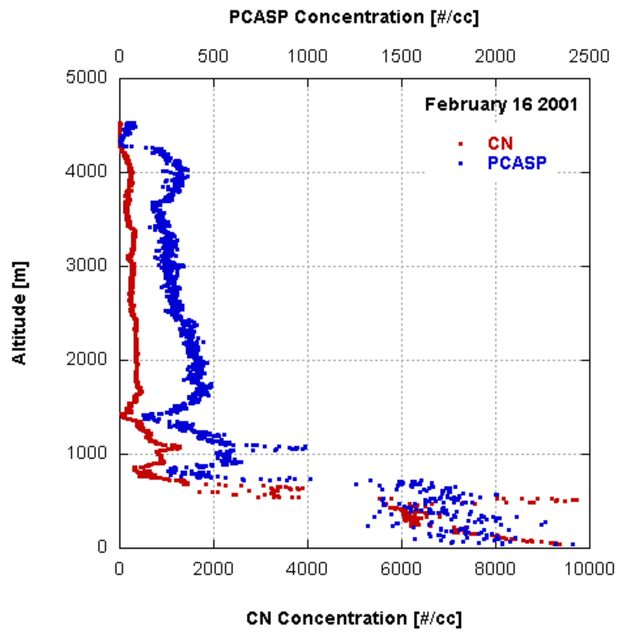

Figure 2. Scatter plot of CN concentration (red points, scaled on the bottom) and PCASP concentration (blue points, scaled on the top) versus altitude for a sounding made on 16 February 2001.

Many of the common features discussed above for the two cases are summarized in Figure 4. This is a composite vertical profile of aerosols in winter over a region surrounding Dubai on the northeast coast of the UAE. The top of the BL is smoothed by averaging but is generally located around 1500 m, and concentrations of all aerosols decreased rapidly above the BL. The large difference between the CN and PCASP concentrations below 1500 m indicates that the BL is a major source of nucleation mode aerosols. This is true for all source regions within the UAE. It also appears that above the BL, nucleation mode aerosols are an important source of CCN.

The data presented above indicate that background levels of aerosols and hence CCN are enhanced due to local pollution sources in the region and should result in higher droplet concentrations in clouds making them more continental in nature. Still unknown are details of the role of mineral dust particles and their potential for sulfate coating, which in turn affects their role as CCN. They could either have a positive effect (large particles) or a negative effect (small particles) on precipitation formation via coalescence. The current project is addressing this unknown by collecting filters for detailed chemical analyses of the aerosols.

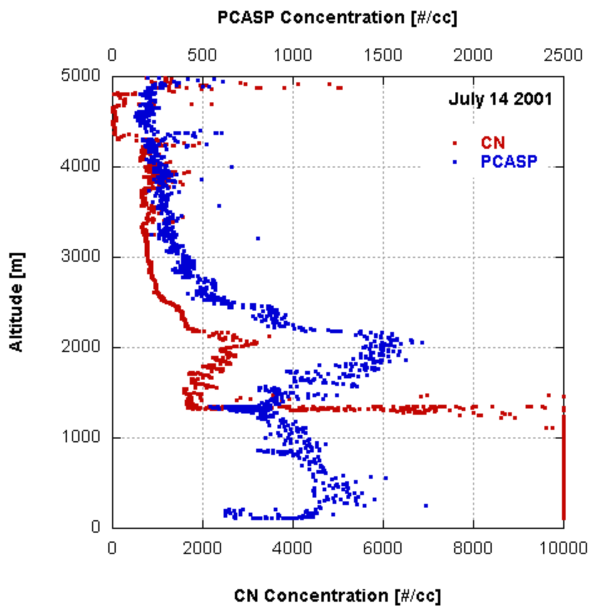

Figure 3. Same as Fig. 2 except for 14 July 2001.

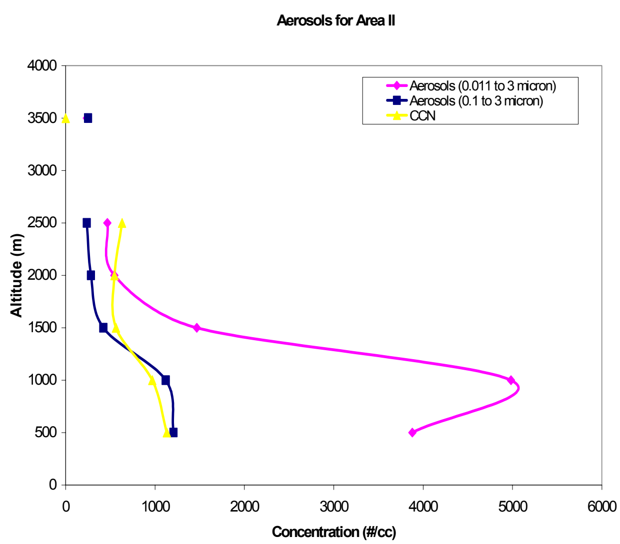

Figure 4. Average vertical profile of CN concentrations (pink line), PCASP concentrations (blue line) and CCN concentrations at 0.3% SS (yellow line) for the Dubai region sampled during January through March 2001.

4.2 *Cloud Droplet Measurements*

4.2.1 Winter conditions

Cloud droplet measurements were conducted on 19 days during the winter months when clouds occurred over the UAE. Peak FSSP concentrations near cloud base versus cloud base altitude for clouds sampled during January through March 2001 are shown in Figure 5. Cloud bases varied between about 1000 m and 5000 m MSL while the droplet concentrations varied from ~100 cm^{-3} to ~600 cm^{-3}. There is a clear grouping of cloud base altitudes between low bases and high bases, which generally reflects the types of clouds sampled (layered versus convective). There were nine days when cloud bases were lower than 3000 m. These days occurred primarily in January and March, with all of the cloudy days in February having elevated cloud bases. Higher (lower) droplet concentrations generally occur when cloud bases are lower (higher). However, the range of convective strength in the sampled clouds with lower bases generates a larger range of concentrations than found in the higher and generally more layered clouds. The grouping in Fig. 5 is consistent with Fig. 4, where aerosol concentrations and CCN also showed a decrease with altitude. The lower-based clouds are more likely to form in air originating in the BL while the higher-based clouds form in relatively clean air.

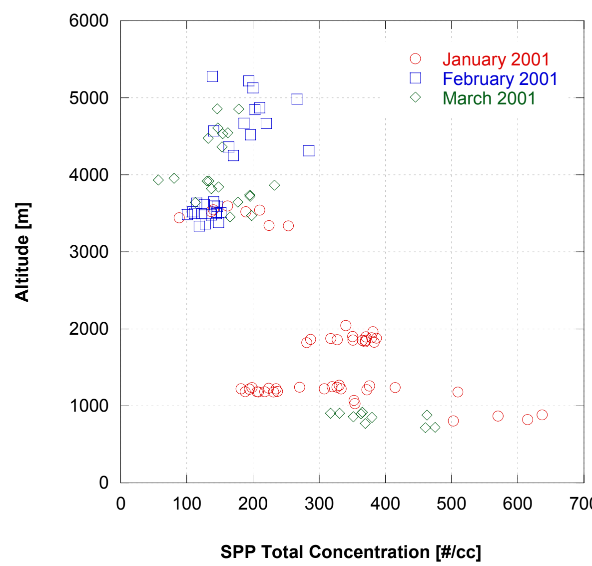

Figure 5. Peak FSSP concentrations versus cloud base altitude, January through March 2001.

In general, when cloud droplet concentrations at the same cloud base level decrease, the effective radius (ER) of the droplets increases. Once a threshold value of 14 μm ER is exceeded, it is generally assumed that the coalescence process will be active in the cloud and that rain will form. However, if the droplets stay below this threshold value, collisions between droplets will occur infrequently and the cloud will have to grow to colder levels where ice can form before precipitation develops. Figure 6 displays the ER of the cloud droplets as a function of concentration for near cloud-base passes from January through March 2001.

No relationship is evident between ER and droplet concentration, but the variability of cloud base altitudes and sampled cloud conditions complicates any comparison. However, it is clear from Fig. 6 that all the measurements collected in the UAE show an ER of less than 10 µm in diameter. This indication of colloidal stability is likely a result of the high aerosol content prevalent in the region.

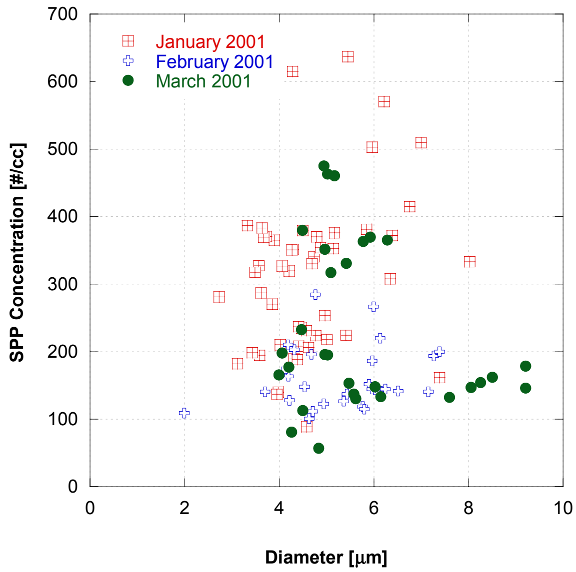

Figure 6. Effective radius (labeled Diameter) versus peak FSSP concentration for near cloud-base passes in January through March 2001.

4.2.2 Summer conditions

Cloud measurements were conducted on 24 days during the summer months when clouds occurred over the UAE. Although the summer project occurred between 15 June and 15 September, no clouds were sampled in September. Figures 7 and 8 present data in the same format as for the winter cloud conditions (Figs. 5 and 6). As mentioned previously, the clouds sampled in the summer were primarily convective but included a wide range of activity. This is reflected in the range of FSSP concentrations (<100 cm^{-3} to >1000 cm^{-3}), although in general droplet concentrations are higher than in the winter. Cloud base altitude (Fig. 7) also varies, but without the clear grouping as in winter. However, cloud bases were generally higher than in winter (most above 3000 m), reflecting the deeper BL and the mountain-generated clouds that were sampled.

The ER plot (Fig. 8) shows roughly the same scatter as Fig. 6, with no correlation between FSSP concentration and ER. The majority of ER values fall between 4 and 6 µm, as in Fig. 6, with only a few values greater than 10 µm. Therefore, the clouds sampled in the summer have similar colloidal stability as those in the winter, likely due to the enhanced aerosol population during the summer in the UAE.

5. DISCUSSION

Airborne measurements of aerosols and cloud droplets in the UAE and the adjacent Gulf region have been presented for winter and summer (2001) conditions. CN, CCN, and PCASP concentrations are almost always elevated above background values (sampled in remote areas but not shown here) throughout the region. The primary source of the aerosols in the BL is almost certainly local given the multiple source regions for pollutants such as SO_2. Enhanced aerosol concentrations aloft, which were shown to be significant, are probably local or regional, but further study is needed to determine the potential role of advection of trace gases and aerosols from distant sources.

Further analyses of the cloud droplet measurements need to account for the variability of growth (activity) stages of the sampled clouds. Nonetheless, the ER results and concentrations typically >300 cm^{-3} suggest that UAE clouds are colloidally stable, probably due to the enhanced aerosol concentrations, and therefore inhibiting the coalescence precipitation process. The role of giant aerosols has not been addressed and may overwhelm the colloidal stability issue argued here.

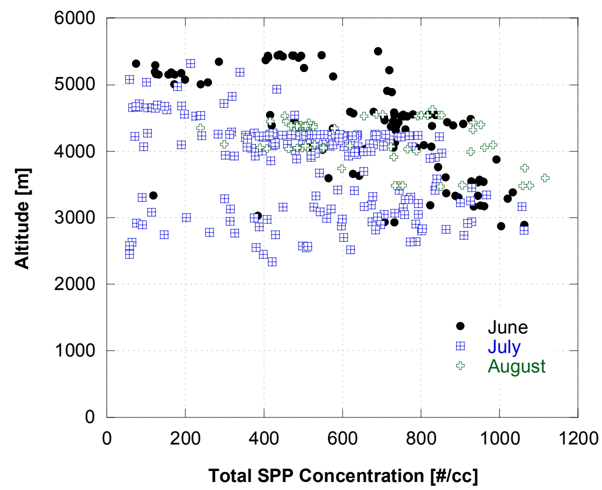

Figure 7. Same as Fig. 5 except for June-August 2001.

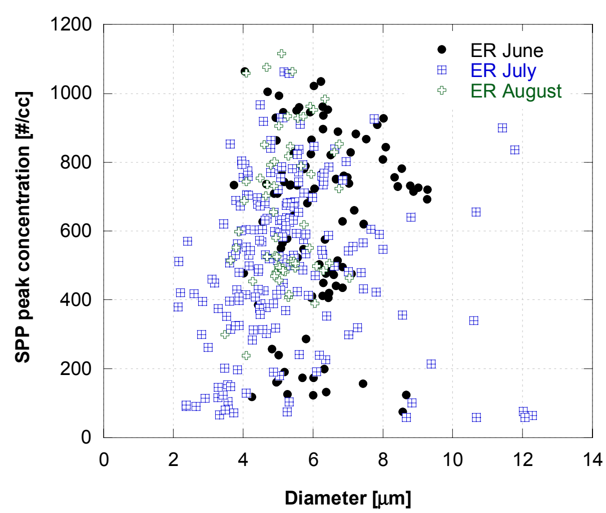

Figure 8. Same as Fig. 6 except for June-August 2001.