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Continuous Profiles of Cloud Microphysical Properties for the Fixed Atmospheric Radiation Measurement Sites

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1. Background

The Atmospheric Radiation Measurement (ARM) Program defined a specific metric for the third quarter of Fiscal Year 2006 to produce and refine a one-year continuous time series of cloud microphysical properties based on cloud radar measurements for each of the fixed ARM sites. To accomplish this metric, we used a combination of recently developed algorithms that interpret radar reflectivity profiles, lidar backscatter profiles, and microwave brightness temperatures into the context of the underlying cloud microphysical structure. Because mapping functions used to convert raw information from the remote and passive sensors to geophysically meaningful quantities are typically under-constrained, procedures using assumptions for site location and cloud type have been developed to produce a continuous time series of the microphysical profile. The product of this analysis, the continuous baseline microphysical retrieval (microbase) includes vertical profiles of the liquid/ice water content, liquid/ice cloud particle effective radius and cloud fraction, at twenty minute time intervals and over 230 vertical levels. We have produced the microbase value-added product (VAP) for the ARM Climate Research Facility (ACRF) Southern Great Plains (SGP) site for March 2000 – February 2001, the ACRF North Slope of Alaska (NSA) locale for January 2004 – December 2004 and the ACRF Tropical Western Pacific (TWP) site at Manus Island for November 2003 – October 2004. This product is an important step in the calculation of broadband radiative heating rates.

2. Scientific Relevance

Clouds play a critical role in the earth's energy cycle through direct interactions with electromagnetic radiation and impacts through the hydrological cycle. Through these interactions, clouds provide a dominant feedback on the climate system that we must be able to define if we are to predict future climate states. Clouds may transmit, scatter or absorb radiant energy that impinges upon them. For a given cloud, the synergy of these processes depends on both cloud macrophysical (cloud height, cloud fraction, cloud thickness) and microphysical (phase, size and number density of cloud particles) properties. Therefore, to perform accurate calculations of the transfer of electromagnetic radiation through the atmosphere and to quantify the role clouds play in the earth's climate and climate change, vertical profiles of liquid and ice water, and the number and sizes of the cloud particles that contribute to this total water are needed.

3. Results

The microbase VAP uses a combination of observations from the millimeter cloud radar (MMCR), the ceilometer, the micropulse lidar (MPL), the microwave radiometer (MWR) and balloon-borne sounding profiles to determine the profiles of liquid/ice water content (L/IWC), liquid/ice cloud particle effective radius (r_e) and cloud fraction. The L/IWC is determined from the radar reflectivity values in the Active Remote Sensing of Clouds (ARSCL) VAP (Clothiaux et al. 2000). For liquid cloud layers (T > 0°C) we use the relationship derived by Liao and Sassen (1994),

$$LWC = \left(\frac{N_0 Z}{3.6} \right)^{1/1.8},$$

to produce the initial estimate of LWC where N_0 is a reference cloud particle number concentration, which we assume to be equal to 100 cm^{-3}, and Z is the radar reflectivity in mm^6m^{-3}. This quantity is vertically integrated to provide a liquid water path (LWP), which is then linearly scaled to match the LWP observed by the MWR. Liquid cloud particle effective radii are computed assuming a log-normal droplet distribution with a width of σ = 0.35 and a mode radius given by

$$r_m = \left(\frac{3LWC}{4\pi\rho_w N_d \exp(9\sigma^2)} \right)^{\frac{1}{3}},$$

where N_d is the cloud particle number concentration, which we assume to be equal to 200 cm^{-3}, and ρ_w is the density of water (Frisch et al. 1995). This mode radius is converted to the cloud particle effective radius assuming and log-normal size distribution such that

$$r_e = 1.358 r_m$$

For ice cloud layers (T ≤ -16°C), the water content is determined using the Z-IWC relationship from Liu and Illingworth (2000),

$$IWC = 0.097 Z^{0.59},$$

while the cloud particle effective radius is determined as a function of temperature from the relationship of Ivanova et al. (2001)

$$r_{ei} = \frac{(75.3 + 0.5895T)}{2},$$

where T is the temperature in degrees Celsius. For the mixed-phase region of the cloud (-16°C < T < 0°C) we assume a linear fractionation of ice/liquid where the ice fraction is equal to -T[°C]/16.

This algorithm is used to provide the profiles of cloud microphysical properties at the ACRF SGP and NSA sites. For the ACRF TWP site at Manus Island the algorithm is altered in accordance with the work by Mather et al. (2006). Here we use a number concentration of 100 cm^{-3} rather than 200 cm^{-3}. The scaling of the LWP by MWR observations is only done when the MWR LWP is less than the radar-derived LWP and a stochastic method based on the probability distributions of liquid/ice content by Korolev et al. (2003) is used to assign the presence of liquid at temperatures below 0°C.

Applying this algorithm we determine the profiles of LWC, IWC, re and r_{ei} every ten seconds and then average over a 20-minute time period. Figure 1 (a-d) shows an example of the output from the microbase VAP for the ACRF SGP site on 03 March 2000.

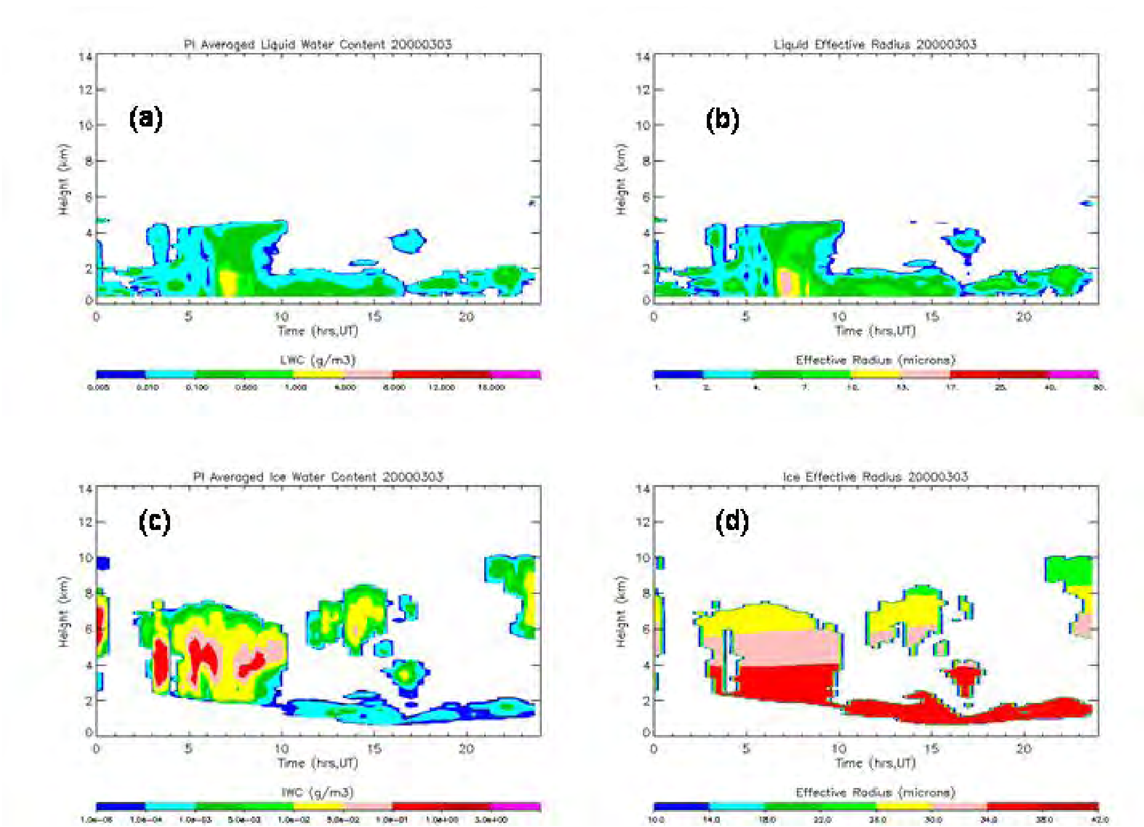

Figure 1. Continuous baseline microphysical retrieval (Microbase) results for the ACRF SGP site on 03 March 2000 (a) LWC [gm^{-3}], (b) liquid r_e[μm], (c) IWC [gm^{-3}] and (d) ice r_e[μm].

The uncertainties in the microphysical quantities computed as part of the microbase VAP may be evaluated using the method of surface radiative flux closure. This method entails providing cloud locations and microphysical composition to an advanced radiation code along with profiles of the temperature and humidity. The radiation code is used to model the downwelling surface broadband short- and longwave fluxes. These modeled fluxes are subtracted from measurements by upward-looking radiometers at the ACRF sites creating a residual. At present, a one-year closure test has been performed using data from the ACRF SGP. The residuals from this test show that for overcast conditions , liquid-only cases have mean residuals (measured minus modeled) of 17.1 Wm^{-2} with a standard deviation is 16.6 Wm^{-2}. Mixed-phase cases have a mean residual of 18.8 Wm^{-2} and a standard deviation of 68.4 Wm^{-2}, while ice phase cases, -16.2 Wm^{-2} and 73 Wm^{-2}, respectively. These uncertainties are based on analyses from the SGP, so the uncertainties at the other sites may be significantly different.

The above files and the rest of the data sets may be retrieved from the Data Archive at http://www.archive.arm.gov/microbase.

4. Contacts

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