Abstract: A non-linear statistical retrieval operator for precipitation cell-top altitude using high spatial-resolution passive 118-GHz O_2 brightness spectra is demonstrated. The retrieval operator consists of a Karhunen-Loève (KL) transformation followed by a rank reduction, a linearization, and a linear minimum mean-square-error estimator. Information from the 118-GHz data on the ambient atmosphere temperature profile and the precipitation cell size is also incorporated into the linear stage of the retrieval operator. The RMS retrieval error is 1.5 km for cumulus-stage cells with tops ranging from 1.5 to 16 km. The sensitivity of nadiral 118-GHz spectra to the cell-top altitude is predominantly due to the scattering and absorption of radiation originating from low, warm atmospheric levels by colder liquid and frozen precipitation. This effect causes cold perturbations in the brightness spectrum, which typically become stronger with increasing cell-top altitude. The different peaking-altitudes of the clear-air 118-GHz weighting functions provide additional “altitude-slicing” sensitivity.

Key Words: precipitation, retrieval, statistical, non-linear.

1. Introduction

Satellite-based observations of precipitation provide a means for monitoring the global hydrologic cycle over inaccessible regions, as well as giving advanced warning of inclement weather near populated regions. Precipitation cell-top altitude retrievals have previously been demonstrated using passive measurements of the infrared radiance emitted at the cloud top [1]. However, due to Mie scattering and absorption of infrared radiation by sub-millimeter sized hydrometeors, passive IR observations cannot directly probe beneath non-precipitating cloud canopies. At microwave frequencies such small hydrometeors behave instead as Rayleigh scatterers and absorbers, and thus cause significantly less extinction. This feature suggests the possibility of using passive microwave observations to directly probe the larger precipitating particles (i.e., those of radius $\geq 200 \mu$m) located beneath non-precipitating canopies.

The statistical retrieval of cell-top altitude has been investigated using high-resolution passive 118-GHz multichannel precipitation cell imagery. The images were produced by the Millimeter-wave Temperature Sounder (MTS) instrument [2] aboard the NASA ER-2 high-altitude aircraft during GALE (February, 1986) [3] and COHMEX (June-July, 1986) [4]. Presented here are the results of a non-linear statistical 118-GHz cell-top altitude retrieval technique, illustrating a systematic method of parameter estimation from non-linearly dependent observables. The method is realized within a framework that allows straightforward incorporation of auxiliary information from both weakly dependent and strongly linearly dependent observables.

The embedding of cell-top altitude information in 118-GHz observations occurs via two mechanisms. First, a statistical dependence exists between the cell-top altitude and the brightness temperature of the cell top. In the case of cells with tops below the freezing level, higher cell-top altitudes are associated with increased precipitation, and hence increased absorption, which produces decreases in brightness for land backgrounds. In the case of cells extending above the freezing level increasing quantities of ice occur in the cell top. The presence of ice causes strong scattering of the cold cosmic background radiation, producing large negative perturbations in brightness temperature. Second, the altitude distribution of atmospheric water in the troposphere and lower stratosphere can be probed by virtue of the successively higher peaking altitudes of the 118-GHz clear-air temperature weighting functions [5]. The 118-GHz clear-air weighting functions peak at altitudes ranging from the surface, for transparent frequencies located $\sim 2.5$ GHz from the 118.750-GHz line center, to $\sim 35$ km (well above most clouds) for frequencies at the line center.

2. Precipitation Cell Brightness Spectra

In order to evaluate the precipitation cell parameter retrieval capability of 118-GHz observations, an ensemble of 279 independent near-nadiral spectra for precipitation cell cores was compiled, consisting of spectra from MTS observations during GALE and COHMEX. The observed precipitation cells were distributed throughout the southeastern United States, with most of the observations occurring during summer over the Huntsville, AL area.

The optical cell-top altitude $\alpha_i$ of each cell top was estimated by stereoscopy, using the MTS video images and the known altitude and speed of the aircraft. Generally, $\alpha_i$ is slightly higher than the corresponding microwave cell-top altitude due to coverage by optically-opaque cirrus shields which are nearly transparent to microwaves. A noise $\sigma_{\alpha}$ with an estimated RMS value of $\sim 1$ km is superimposed on $\alpha_i$ due to errors in the stereoscopic altitude estimation process. The size $s_i$ of each cell was taken to be the distance along the flight track of the aircraft over which the MTS transparent channel brightness perturbation decreased to half its maximum value. The optical cell-top altitudes ranged from 2 to 16 km and the sizes ranged from 1.5 km (the resolution of the 118-GHz scanning spectrometer) to 200 km. In addition to cell-top altitude and