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ON THE POTENTIAL FOR OVERLAPPING CLOUD DETECTION IN HIGH SPECTRAL RESOLUTION INFRARED DATA

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1. INTRODUCTION

This study investigates the feasibility of using high spectral resolution infrared radiance measurements to discriminate between single-layered and multi-layered clouds. We confine our study to those cases where single-layer clouds are assumed to be either ice or water phase, and multi-layer cloud systems are composed of a thin ice cloud overlapping a lower-level water cloud. We perform radiative transfer modeling of water, ice, and multi-layered clouds for a set of 18 microwindows at wavelengths between 8 and 13 μm.

Ultimately, the feasibility of detecting multi-layered cloud systems will be inferred from comparision of modeled radiances to measured radiances. We plan on comparing our modeled radiances to measurements made by the University of Wisconsin High-resolution Interferometer Sounder (HIS) during the SUbsonic aircraft: Contrail & Cloud Effects Special Study (SUCCESS) field experiment of 1996.

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2. MODELS

To model cloud radiances it is beneficial to limit our focus to highly transmissive atmospheric regions. DeSlover et al. [1998] chose 18 microwindows between 8.5 and 13 μm to retrieve cirrus optical thickness using a combination of high-spectral resolution infrared and lidar measurements. The microwindows we have chosen are similar to those in the DeSlover et al. [1998] study and are shown in Table 1. Based on the variations of the indices of refraction of water and ice throughout this region, we expect to have high sensitivity to cloud thermodynamic phase. This sensitivity should aid in the detection of overlapping cloud layers.

We have developed models of ice and water cloud radiative properties for each of the 18 infrared microwindows. The cirrus cloud models are based on single scattering properties of discrete crystal sizes averaged over size distributions. The size distributions are based on recent models developed by Nasiri et. al. [2002] as well as from distributions described by Fu [1996]. The Nasiri et al. distributions were developed from in situ measurements of particle size and habit distributions from three mid-latitude field experiments: FIRE-1 in 1996, FIRE-II in 1991 (FIRE refers to the First ISCCP Regional Experiment; ISCCP refers to the International Satellite Cloud Climatology Project), and an ARM (Atmospheric Radiation Measurement) campaign in 2000. The water cloud models assume modified gamma droplet size distributions with effective radii of 4, 10, and 15 μm and an effective variance of 0.1

Ice cloud single scattering properties have been calculated using ray tracing, finite difference time domain and other approaches including the stretched scattering potential method at 12 wavelengths between 8 and 13 μm and 49 size bins with bin centers between 10 μm and 1 cm as described by Yang et al. [2001]. Results are presented here for solid hexagonal columns. Based on the slopes of the real and imaginary parts of the index of refraction of ice between these wavelengths, we use linear interpolation to determine properties for the 18 microwindows for each size bin. . The water cloud single scattering properties are derived using Mie theory.

A discrete ordinate radiative transfer model is used to calculate the microwindow radiances expected at aircraft altitude. We assume an atmosphere composed of a discrete number of adjacent homogeneous layers with temperature and water vapor mixing ratio profiles from a SUCCESS radiosonde and climatological ozone profiles. Correlated k-distribution routines for each microwindow are used to calculate gaseous optical thicknesses.

Figure 1 shows modeled brightness temperatures for a set of cloud overlap simulations. For this simulation we assume a lower level water cloud at 269 K with an effective radius of 4 μm and an upper level cirrus cloud with an effective radius of 40 μm at 243 K. The temperature and water vapor profile are from a 21 April, 1996 radiosonde launched from the Southern Great Plains ARM site at 17 UTC. There are seven curves on the plot. The uppermost curve is for a single-layer water cloud with an 11.1 μm optical thickness of 5 while the lowermost curve is for a single-layer ice cloud with an optical thickness of 15. The middle five curves are for cloud overlap situations where the lower level water cloud optical thickness is held at 5 while the upper level ice cloud optical thickness is increased from 0.4 to 5. Note that for the single-layer water cloud curve, the brightness temperatures of first 11 microwindows show a positive slope, while those of last 9 show a negative slope. As the optical thickness of the overlying ice cloud increases, these slopes decrease. In the limit where no radiation from the lower level water cloud reaches the instrument (as in the single-layer ice cloud case), both slopes go nearly to zero.

3.. INSTRUMENTS AND MEASUREMENTS

We compare our modeled microwindow radiances to measurements from the High-resolution Interferometer Sounder (HIS) during the SUCCESS experiment. HIS is a Fourier transform spectrometer that flew on the the NASA ER-2 during field experiments from 1986 to 1998. It has three spectral bands which cover the regions from 600-1070, 1040-1800, 2100-2700 cm^{-1} with band spectral resolutions of 0.3, 0.6, and 1.0 cm^{-1}, respectively (unapodized),. The HIS is a nadir viewing instrument with a spatial field of view of 2 km from ER-2 altitude.

Data from SUCCESS were chosen for the comparison because of multi-layered cloud observations, as well as for the combination of data from the HIS, an imager - the MODIS Airborne Simulator (MAS), and a cloud lidar - the Cloud Lidar System (CLS). Using a combination of MAS images at 0.65, 1.6, 1.9, and 11 μm, and CLS backscatter and cloud boundary data, we choose flights and times for HIS/model intercomparisons. Based on these data, we focus our study on data from 21 April, 1996, and 07 May, 1996.

Four HIS spectra are shown in Figure 2. The top spectra from 20:24:17 UTC is of the surface observed through a cloud free atmosphere. The second spectrum from 20:27:16 UTC is of an optically thick water phase cloud. A scene with cirrus overlying a water cloud is shown in the third spectrum. The fourth spectrum from 20:10:56 is of a cirrus cloud. These scenes were identified and classified by examination of MAS imagery at 0.65, 1.6, 2.1, and 11 μm.

Further work will include modeling the scene in Figure 2 more closely and comparing the measured radiances averaged over the microwindows to modeled radiances. By understanding how well we are able to model the overlap scence, we hope to begin to be able to establish the limits of cloud overlap detectibility using only IR microwindows.

Microwindow Number	Minimum Wavenumber (cm^{-1})	Maximum Wavenumber (cm^{-1})	Center Wavelength (μm)
1	785.8	790.8	12.686
2	809.0	813.0	12.330
3	815.4	824.4	12.197
4	828.5	834.5	12.026
5	843.0	848.0	11.827
6	860.0	864.0	11.601
7	872.5	877.5	11.429
8	891.9	895.9	11.187
9	898.4	905.4	11.088
10	929.7	939.7	10.699
11	960.1	964.1	10.394
12	985.0	998.0	10.086
13	1076.7	1084.7	9.253
14	1092.0	1099.0	9.128
15	1113.5	1116.5	8.969
16	1124.5	1132.5	8.861
17	1142.1	1148.1	8.733
18	1155.3	1163.3	8.626

Table 1: Infrared microwindows.

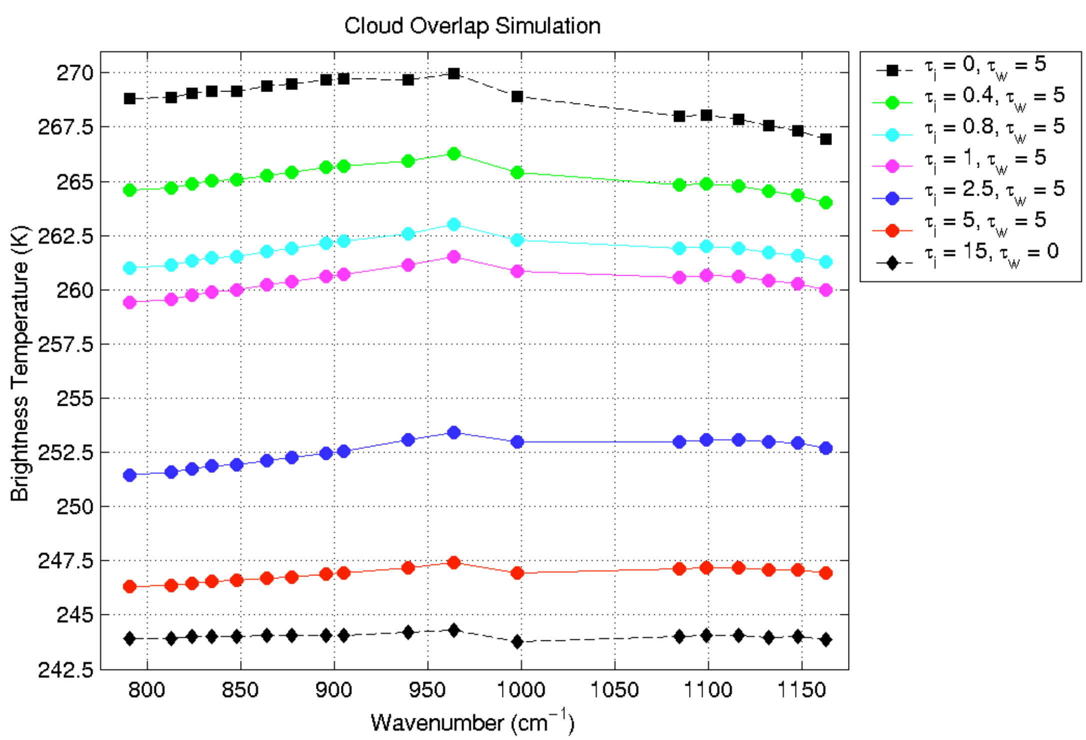

Figure 1: Simulation of cloud overlap. The water cloud effective radius is 4 μm and the ice cloud effective radius is 40 μm. The ice cloud level temperature is 243 K and the water cloud level temperature is 269 K. □ refers to the 11.1 μm ice cloud optical thickness, while □$_w$ refers to the 11.1 μm water cloud optical thickness. The first curve is for a single-layer water cloud and the last curve is for a single-layer ice cloud.

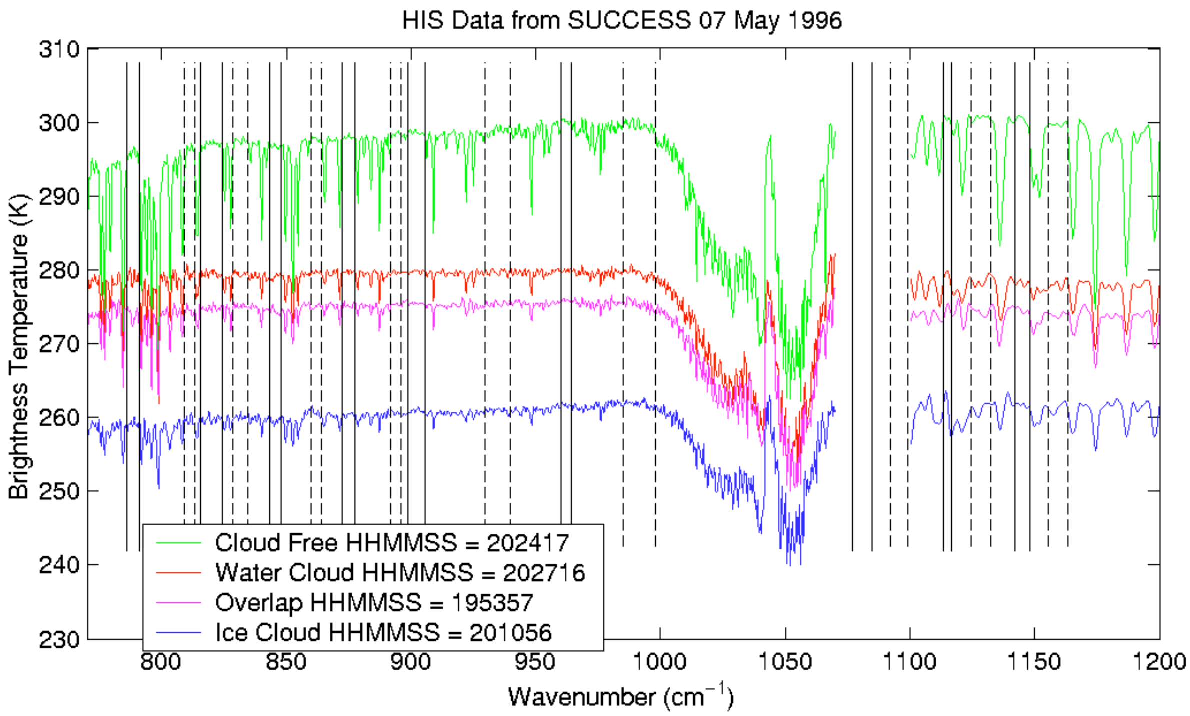

Figure 2: HIS spectra from SUCCESS on 07 May, 1996. Spectra from a clear scene, a scene with cumulus clouds, a scene with cirrus, and a scene with cirrus overlapping cumulus are shown, as well as the flight times for each. HIS microwindows are overplotted. Odd numbered microwindows are demarcated by solid lines and even-numbered microwindows are demarcated by dashed lines.

4.. REFERENCES

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5. ACKOWLEDGEMENTS

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