Cloud Overlap Detection from HIRS and AVHRR

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Abstract

An algorithm for detecting multi-layered cloud systems with satellite data is presented. The algorithm was designed to be applicable to data in the 0.63 μm, 10.8 μm, and 12 μm regions of the spectrum that are available on the Advanced Very High Resolution Radiometer (AVHRR). The cloud overlap algorithm has been validated and is currently used operationally in the Extended Clouds from AVHRR (CLAVR-x) processing system. In this study, the unmodified AVHRR cloud overlap detection scheme is applied to the 0.69 μm, 11.11 μm, and 12.47 μm channels on the High Resolution Infrared Radiation Sounder (HIRS). The results from 60°N to 60°S were compared with results from the AVHRR. It was found that the AVHRR algorithm could be effective at detecting cloud overlap with HIRS. Regions of cloud overlap were compared to the HIRS operational CO_2 slicing-based cloud top pressure product. The results indicate that the retrieved cloud top pressure is generally consistent with the location of the top cloud layer.

Introduction

Surface observations have shown that multi-layered cloud systems occur in most parts of the world (Warren et al., 1985). Such systems are especially common in the tropics where anvils associated with convective systems can spread out over large horizontal distances and with mid-latitude cyclones (Hahn et al., 1982, 1984: Tian and Curry, 1989). In addition, satellite cloud property retrievals are generally performed under the assumption that only a single cloud layer is present in a given pixel. Because of this assumption, the quality of cloud optical depth, particle size, and cloud height retrievals may suffer when more than one cloud layer is actually present.

Detecting multi-layered cloud systems from space is often difficult since the higher clouds may be optically thick and obscure the presence of a lower cloud layer. Conversely, higher level clouds may be too thin to be detected in the presence of a thicker lower cloud from current passive remote sensing observations. Two cloud layers may also have an insufficient vertical separation, making it difficult to distinguish the multi-layer cloud system from a single layer cloud using thermal emission signatures. Nevertheless, a technique for detecting cloud overlap is presented. This technique is partially based on the work of Ou et al. (1996) and was designed to work on data from the Advanced Very High Resolution Radiometer (AVHRR) which is on board the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites. This algorithm is used operationally in the Extended Clouds from AVHRR (CLAVR-x) processing system The utility of this method will be demonstrated with AVHRR data and the algorithm will then be applied to data from the High Resolution Infrared Radiation Sounder (HIRS), which is also on the NOAA polar orbiting satellites. The results will be compared to results using AVHRR data and the HIRS cloud top pressure product will be qualitatively analyzed in regions where cloud overlap is indicated by the AVHRR cloud overlap algorithm.

Cloud Overlap Algorithm Description

The AVHRR algorithm utilizes 0.63 μm reflectance and brightness temperatures from the infrared window region of the spectrum (10.8 μm and 12 μm). The premise of the algorithm is that for a single layer cloud, the 0.63 μm reflectance and the 10.8 - 12 μm brightness temperature difference (split window brightness temperature difference) should behave as predicted by plane-parallel radiative transfer simulations. In general, as a single layer cloud becomes optically thick, its reflectance increases and its split window brightness temperature decreases (Inoue, 1985). In the case of a semi-transparent cirrus cloud overlying a lower water cloud, the vertical separation has little effect on its reflectance but a large effect on the split window brightness temperature difference. Given a sufficient temperature difference between the cirrus and the lower water cloud, the difference in transmission through the cirrus cloud at 10.8 μm and 12 μm will generally result in a split window brightness temperature difference that is much larger than that predicted by plane parallel theory for a single-layer cloud with a similar reflectance. A radiative transfer model was used to perform single-layer (water and ice) simulations and simulations with an ice cloud overlapping a water cloud with the optical depth of both clouds and the atmospheric profiles being varied. Thresholds of 10.8 - 12 μm brightness temperature difference were determined as a function of 0.63 μm reflectance for various viewing and solar zenith angles. When the actual 10.8 - 12 μm brightness temperature difference exceeds the threshold value and the 10.8 μm brightness temperature is less than 270 K and the 0.63 μm reflectance is greater than 30%, cloud overlap is said to be present. For additional details concerning this algorithm refer to Pavolonis and Heidinger (2003).

Results

To qualitatively illustrate the effectiveness of the AVHRR cloud overlap detection scheme, an AVHRR scene is analyzed. Fig. 1a shows a Red Green Blue (RGB) multi-spectral AVHRR Global Area Coverage (GAC) image from July 2, 2001 over the Eastern Pacific Ocean. AVHRR channel 1 (0.63 μm) reflectance, channel 3a (1.65 μm) reflectance, and channel 4 (10.8 μm) brightness temperature are displayed on the red, green, and blue color guns respectively. In this image, ice clouds will have a pink hue, low water clouds will appear yellow, and mid-level cloud will appear to be white/off-white. From Fig. 1a, it is clear that there are regions in this scene where cloud overlap is present. Fig. 1b shows the results of the AVHRR cloud overlap algorithm. The results from the complete AVHRR cloud typing algorithm used in CLAVR-x are also shown in Fig. 1b. It is evident that the algorithm is able to correctly identify regions where cloud overlap is present, more specifically, on the left and top sides of the image. The AVHRR cloud overlap algorithm has also been validated against cloud radar data. The validation technique and results are detailed in (Pavolonis and Heidinger, 2003).

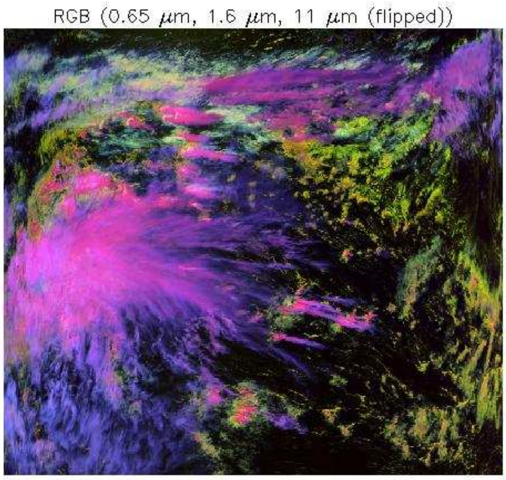

Fig. 1a: An RGB (0.63 μm, 1.65 μm, 10.8 μm) image of an AVHRR GAC scene over the Eastern Pacific Ocean on July 2, 2001.

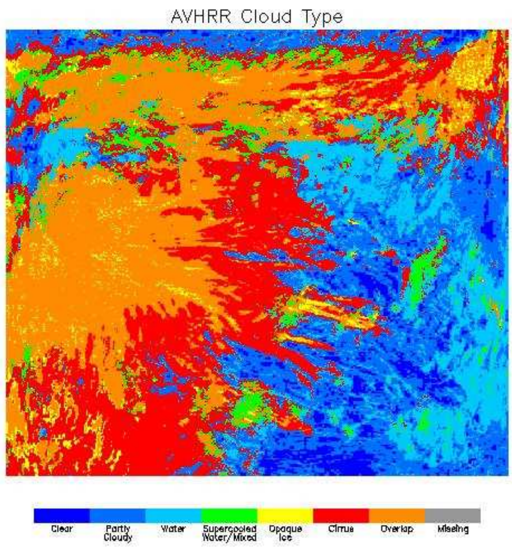

Fig. 1b: AVHRR cloud typing results for the scene shown in Fig. 1a.

The complete AVHRR cloud typing algorithm was applied to AVHRR data for the ascending node of NOAA-16 on October 13, 2003. Fig. 2 shows the dominant cloud type within 0.5 degree equal area grid cells from 60°S to 60°N. The regions where cloud overlap is dominant are displayed in orange. As would be expected, most of the cloud overlap is present in the tropics and the mid-latitude storm tracks. The AVHRR cloud overlap algorithm was applied to HIRS channel 20 (0.69 μm), channel 8 (11.11 μm), and channel 7 (12.47 μm) cloudy field-of-views (FOVS). No adjustments were made to the algorithm. A cloud overlap mask for the HIRS data is shown in Fig. 3. These preliminary results indicate that the AVHRR cloud overlap scheme can be effective on HIRS data, which has a much courser spatial resolution (~19 km compared to ~4 km) and the channels used have slightly different spectral characteristics compared to AVHRR GAC data. Many areas of cloud overlap indicated by the AVHRR data are present in the HIRS analysis, although some clear differences exist, especially in the tropics. However, the AVHRR algorithm was not modified, it is likely that some modification is needed to optimize the algorithm to be used with HIRS data. Thus the results presented here can likely be improved, assuming the AVHRR results are accurate.

HIRS-derived cloud top pressures for the same orbits shown in Figs. 2 and 3 were mapped to 0.5 degree equal area grid and are shown in Fig. 4. The HIRS cloud top pressures were obtained from an Advanced TIROS (Television Infrared Observation Satellites) Operational Vertical Sounder (ATOVS) rotating 1T file and were retrieved using a CO_2 slicing technique. In regions where cloud overlap is present, the retrieved cloud top pressures are predominantly consistent with the presence of high clouds. Most of the overlap retrieved with the AVHRR algorithm is characterized by high ice clouds that overlap lower clouds. Thus, the CO_2 slicing technique seems to be largely insensitive to lower cloud layers when multiple cloud layers are present.

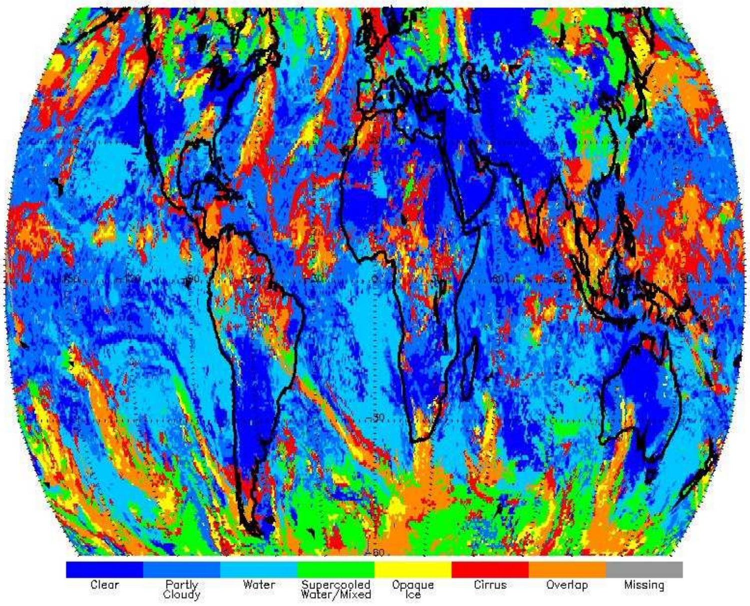

Fig. 2: AVHRR cloud typing results for the ascending node of NOAA-16 on October 13, 2003. The dominant cloud type within a 0.5 degree equal area grid cells is shown.

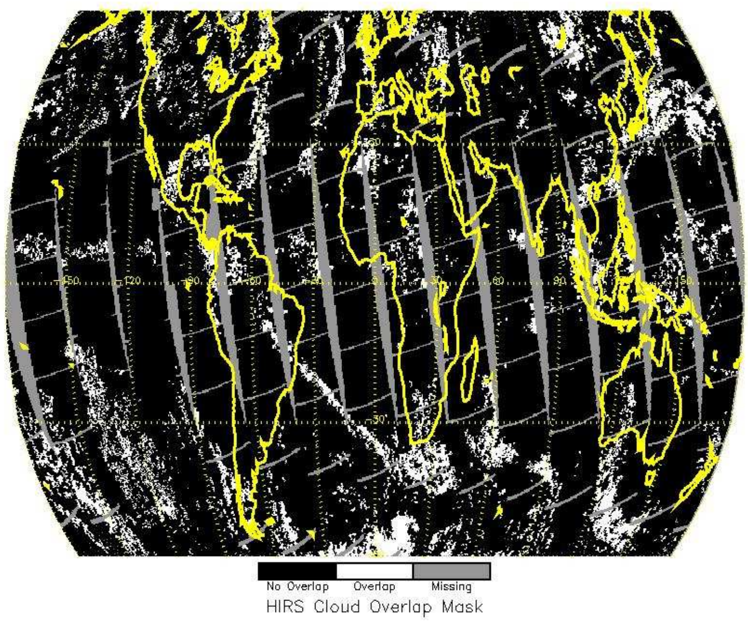

Fig. 3: Results from the AVHRR cloud overlap algorithm when applied to HIRS data for the scene shown in Fig. 2.

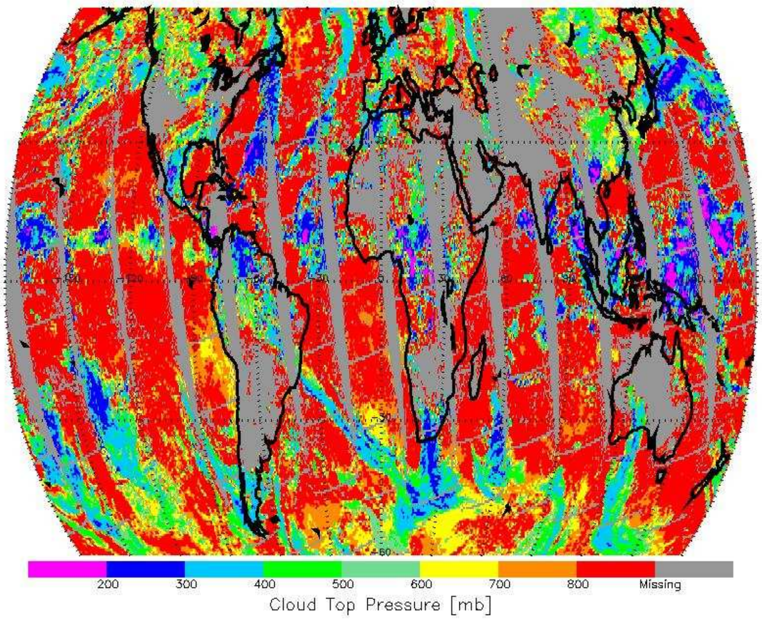

Fig. 4: HIRS-derived cloud top pressures (mb) mapped to a 0.5 degree equal area grid for the same orbits shown in Fig. 2.

Conclusions

Multi-layered cloud systems are commonly observed in many regions of the world. In this work, a multi-spectral algorithm was presented for identifying cloud overlap. The algorithm was designed to be applicable to AVHRR data and utilizes information from the 0.63 μm, 10.8 μm, and 12 μm regions of the spectrum. The AVHRR cloud overlap detection scheme has been validated and is currently used operationally in the Extended Clouds from AVHRR (CLAVR-x) processing system. Further, the utility of the algorithm was demonstrated through a qualitative analysis 4 km AVHRR data.

The AVHRR cloud overlap algorithm was applied to HIRS channel 20 (0.69 μm), channel 8 (11.11 μm), and channel 7 (12.47 μm) cloudy field-of-views (FOVS), with no adjustments. Comparisons with results using AVHRR data show that the algorithm has the potential to be effective with HIRS data. Regions of cloud overlap were then compared to the HIRS operational CO_2 slicing-based cloud top pressure product. The results indicate that the retrieved cloud top pressure is generally consistent with the location of the top cloud layer.

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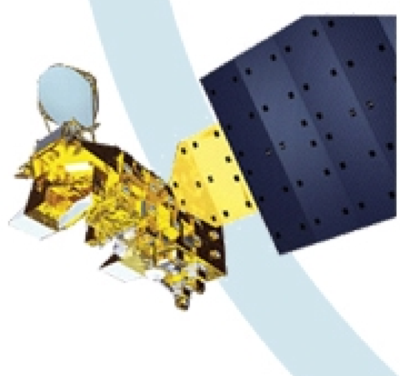
Proceedings of the Thirteenth International TOVS Study Conference



Sainte-Adèle, Québec, Canada
29 October – 4 November 2003