Mixed Phase Detection and Cloud Property Retrievals during NPOESS

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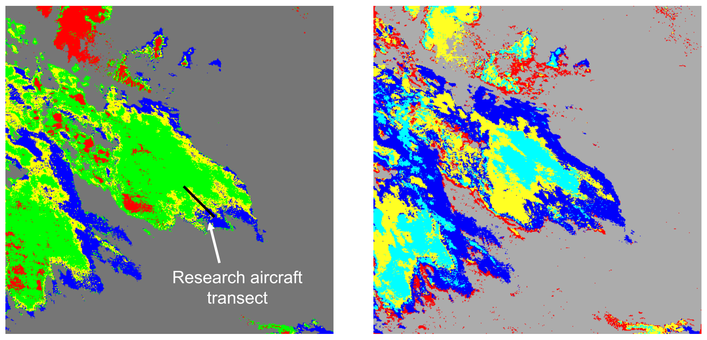
Introduction

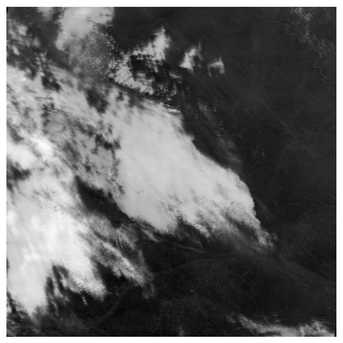
Abstract: An ability to detect mixed phase conditions and retrieve cloud properties is important for civil and military aircraft operations. This detection can help improve weather model predictions of cloud dynamics. Cloud phase is determined by the NPOESS Visible Infrared Imaging Radiometer Suite (VIIRS) cloud mask. The VIIRS algorithm was designed to differentiate between a mixed phase condition and thin ice cloud overlapping water cloud. Different algorithms are used to retrieve properties of either water cloud or ice cloud. Hence all VIIRS cloud products depend on cloud phase determination. This poster describes the current process for detecting mixed phase clouds by the VIIRS cloud mask, some verification of the algorithm performance, and recommendations for combining observations from current satellite sensors to improve phase detection and cloud property retrievals for future versions of the VIIRS algorithm.

Background: Midlevel, mixed phase clouds particularly altocumulus and altostratus represent a large fraction of clouds globally (20-30%). Such clouds contain a mixture of liquid and ice particles that may coexist in clouds down to -40°C. These clouds are often characterized by super-cooled liquid water at or near the cloud tops over ice particles falling as virga beneath. Similar structure has been reported for Arctic nimbostratus. Altostratus and altocumulus clouds, also known as moderate temperature clouds, are typically mistyped from satellite observations as either water or ice clouds. The NPOESS Visible Infrared Imaging Radiometer Suite (VIIRS) with 8.5 µm, 11 µm and near IR reflectance channels has the capability to detect mixed phase clouds, but the accuracy of the detection has not been demonstrated. In addition, there are currently no formulae for retrievals of mixed phase cloud properties for remote sensing applications although work is in development (Niu et al., 2006). VIIRS cloud algorithms currently retrieve cloud properties for ice and water clouds but not mixed phase.

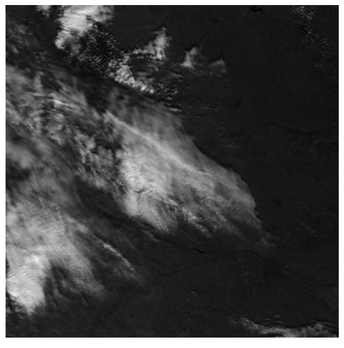
Mixed Phase Detection in MODIS Proxy Data



Cloud mask type for MODIS (left color map) and VIIRS (right color map, based on MODIS proxy data) for October 14, 2001. Clear (gray), uncertain (green), water cloud (red), supercooled water or mixed phase cloud (yellow), opaque ice cloud (magenta), cirrus (non-opaque) ice cloud (blue), cloud overlap (cyan). Aircraft flight track marked by black line.



MODIS visible imagery of North Platte, Nebraska for October 14, 2001.



MODIS TOA 11 µm brightness temperatures of North Platte, Nebraska for October 14, 2001.

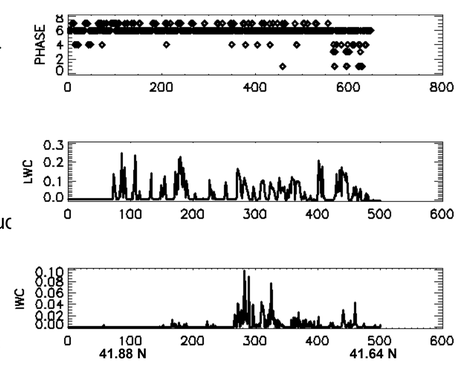
➢ Phase types retrieved by MODIS cloud mask compared to the VIIRS cloud mask (applied to MODIS observations) for October 14, 2001 over Nebraska show significant differences between the algorithms:

- Over broad region VIIRS cloud mask identifies mixed phase and cloud overlap regions marked mostly uncertain by MODIS cloud mask
- More water cloud detection near cloud edges from VIIRS algorithm
- Along aircraft transect (see description below), VIIRS algorithm retrieves mixed phase through holes in cirrus classified mainly uncertain by MODIS algorithm

VIIRS Algorithm Verification from Aircraft Observations

➢ Satellite data for October 14, 2001 show detection of mixed phase in regions where ice particles and water droplets were measured by aircraft sensors

- Cloud Layer Experiment (CLEX), series of aircraft measurements to sample mixed-phase non-precipitating clouds in the middle troposphere
- CLEX-9 took place over North Platte, Nebraska, October to November 2001
- University of Wyoming King Air research aircraft sampled ~5300 m near cloud top heights
- Aircraft observations closely coincide with the Terra satellite overpass
- Ice particle in-situ measurements made by Particle Measuring System 2-DC and 2-DP probes
- Liquid water content and droplet size distribution made by Forward Scattering Spectrometer Probe, Droplet Measurement Technology model LWC-100, Rosemount 871FA icing detector and Gerber PVM-100A



Upper panel: phase type determined by VIIRS algorithm (1 - clear; 2 – partly cloudy; 3 – water cloud; 4 – mixed phase, 5 – opaque ice cloud ; 6 – cirrus non-opaque ice cloud; 7 – cloud overlap); middle panel: cloud water content (gm^{-3}); lower panel: ice water content (gm^{-3}).

Detection of Mixed Phase in the VIIRS Cloud Mask

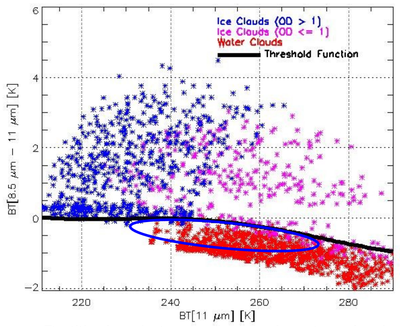
➢ VIIRS cloud phase algorithm determines five separate categories:

- Water: Single cloud layer composed completely of water droplet.
- Mixed Phase: Single cloud layer composed of a mixture of water and ice particles or of supercooled water.
- Opaque Ice: Optically thick cloud with cloud top composed of ice crystals
- Cirrus: Non-opaque, single-layer ice cloud.
- Overlap: At least two distinctive cloud layers defined as ice cloud above cloud predominantly water phase.

➢ Criteria for phase selection include:

- 11 µm brightness temperatures ranging between 233 and 273 K
- Differences between the 8.5 µm and 11 µm bands (eg BTD[8.5, 11])
  - BTD larger when mainly ice is present at cloud top;
  - For same cloud temperature, BTD larger for an ice cloud than water cloud
- NIR/visible reflectance and IR brightness temperature thresholds
  - NIR reflectance at 1.65 µm greater than 25% over water/snow/ice;
  - Greater than 32% over all other surfaces

➢ Uncertainty in phase selection depends on accuracy of model calculations and satellite data (AVHRR and MODIS) to adjust thresholds



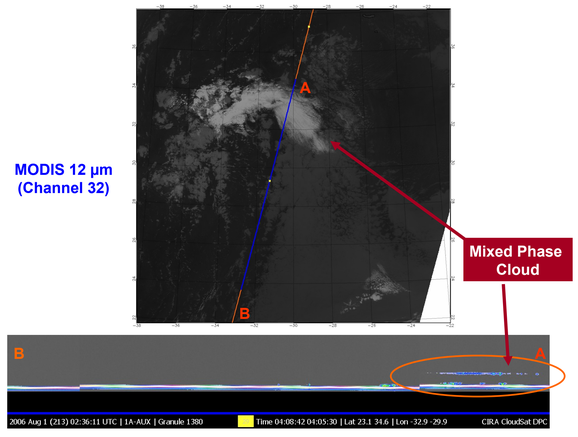
Partitioning between ice and water clouds based on bi-spectral testing. Region of possible mixed phase detected by the VIIRS algorithm bounded by the blue circle (from Pavolonis et al. 2004). OD refers to optical depth.

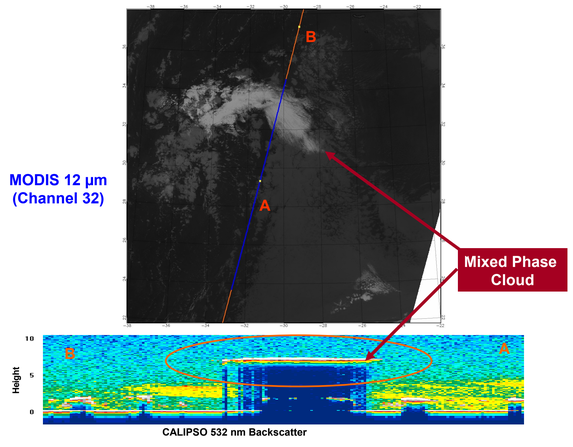
References:

M. Pavolonis, A. Heidinger and T. Uttal, Daytime global cloud typing from AVHRR and VIIRS: Algorithm, J. Appl. Met, 2004.

J. Niu, L. Carey, P. Yang, A. Kankiewicz and T. Vonder Haar, A common microphysical structure for midlevel mixed-phase cloud in the mid-latitudes: results from the Cloud Layer Experiment (CLEX-9), 2nd AMS Radar Conf., 4 pp., 2006.

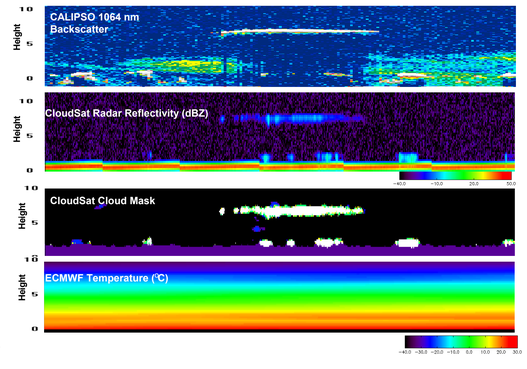
Mixed Phase Detection from CloudSat/Calipso/MODIS





➢ Cloud profiling systems used to interpret infrared measurements of mixed phase cloud:

- CloudSat: a 94-GHz nadir-looking radar which measures the power backscattered by clouds
- Calipso (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation): an active lidar instrument with passive infrared and visible imagers
- CloudSat/Calipso fly in close proximity on Earth Science System Pathfinder spacecraft, as part of NASA A-train
- Images acquired over the eastern United States at nighttime on August 1, 2006



Summary

The VIIRS retrievals of mixed phase conditions in altocumulus through holes of overlying thin cirrus are in relatively good agreement with the CLEX-9 aircraft measurements. The detection of cloud overlap occurred under conditions where water droplets were detected but not ice in regions of transparent cirrus. These are very encouraging results since the NGST/UCLA algorithm was designed to distinguish between ice cloud over water cloud (eg the expected cloud cover situation) and the mixed phase condition of liquid water over ice.

More validation studies are needed to verify the robustness and accuracy of the detection, and to accumulate more information that can be applied toward retrieving cloud properties in mixed phase. Studies of CloudSat/Calipso observations in conjunction with MODIS data are underway to provide an improved understanding of the vertical structure of mixed phase clouds that may be detected by infrared technique. New libraries that contain the bulk cloud optical properties of mixed phase clouds can improve RTA calculations for improved future versions of the VIIRS VCM.