Joint Airborne IASI Validation Experiment (JAIVEx) Cirrus Cloud Property Intercomparison

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Abstract

The study of cirrus clouds using high spectral resolution infrared measurements provides the spectral detail to independently determine a number of cirrus cloud optical properties, including optical depth, number density, and bulk ice crystal effective radius. We will compare results from various methods designed to retrieve cirrus optical properties from the infrared atmospheric emission signature. Emphasis will be placed on the Joint Airborne IASI Validation Experiment (JAIVEx), which occurred in April 2007; and was the first coordinated validation campaign for the Infrared Atmospheric Sounding Interferometer (IASI). A pair of aircraft were coordinated to support this mission: the NASA WB-57, carrying the NPOESS Airborne Sounder Testbed (Interferometer and Microwave, NAST-I and NAST-M, respectively) and Scanning High-resolution Interferometer Sounder (S-HIS); and the Facility for Airborne Atmospheric Measurements (FAAM) BAe 146-301 aircraft, capable of providing a full suite of cloud physics instrumentation for in-situ measurements of aerosols, liquid water and ice particles.
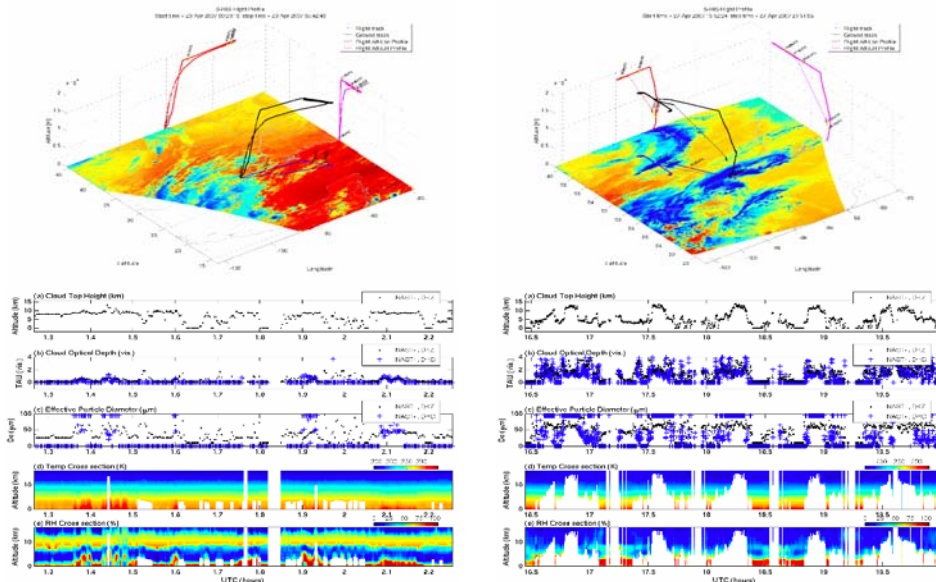
The two figures to the left (top) are three-dimensional WB57 aircraft profiles for both 20 April 2007 (left) and 27 April 2007 (right). The aircraft profiles are also provided as altitude-longitude, altitude-latitude, and surface projections; where the surface projection is shown as an overlay to the IASI imager data for the targeted IASI overpass on each respective date. This gives an indication of aircraft transit over cirrus cloud cover, which is represented by the cooler (blue) color scale. Conditions on 20 April 2007 varied between clear sky and thin cirrus for a flight over the Gulf of Mexico; while the 27 April case consisted of multilayer clouds (both water and ice) that varied from optically thick to opaque, with a focus over the DOE Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility (located at N36 36.30' W97 29.10').

Cloud property and atmospheric state retrievals as time series from these two cases are shown in the lower figures to the left. The top panel shows cloud top height determined by the physical retrieval (DKZ, Zhou et al.), a coincident lidar was not present on the WB57 for this campaign; the second panel compares visible cloud optical (OD) depth as determined independently from the physical retrieval (DKZ) and the RTE inversion method (DHD, DeSlover et al.) [see green panel for discussion on methodologies]; the third panel is bulk cloud particle effective diameter (DKZ and DHD); atmospheric temperature profile cross-section (DKZ) is given in the fourth panel; and the bottom panel shows atmospheric relative humidity cross sections (DKZ).
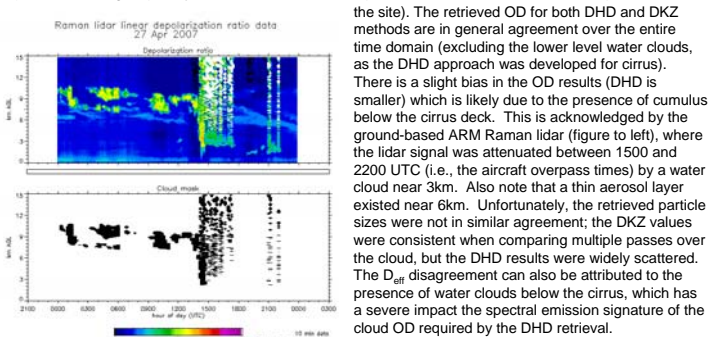
20 April 2007

For data acquired on 20 April, the retrievals show very thin subvisible cirrus, with good agreement in OD (notably the regions around 1.4 and 2.1 UTC where the OD increased to 1). These are the same regions where the two techniques produce good agreement in retrieved particle size (D_{eff}). The DHD approach fails to obtain values of D_{eff} when the OD is roughly 0.6 and smaller. This is because the algorithm determines the by looking at the spectral variation in retrieved OD; such that, for small OD, the uncertainty in retrieved OD is of the same magnitude as the retrieved value. This does not occur for the DKZ approach as all values are retrieved simultaneously: cloud height, OD, D_{eff}, surface emissivity, and profiles of T and RH. It should also be noted that the temperature and relative humidity profiles show little variation despite a range in cloud OD (at least down to the planetary boundary layer where cumulus may have contaminated the observations).

27 April 2007

Shifting focus to the 27 April case, where there were several WB57 passes over the DOE ARM site (note that the high, optically thick cloud features are repeated as the aircraft makes several passes over

the site). The retrieved OD for both DHD and DKZ methods are in general agreement over the entire time domain (excluding the lower level water clouds, as the DHD approach was developed for cirrus). There is a slight bias in the OD results (DHD is smaller) which is likely due to the presence of cumulus below the cirrus deck. This is acknowledged by the ground-based ARM Raman lidar (figure to left), where the lidar signal was attenuated between 1500 and 2200 UTC (i.e., the aircraft overpass times) by a water cloud near 3km. Also note that a thin aerosol layer existed near 6km. Unfortunately, the retrieved particle sizes were not in similar agreement; the DKZ values were consistent when comparing multiple passes over the cloud, but the DHD results were widely scattered. The D_{eff} disagreement can also be attributed to the presence of water clouds below the cirrus, which has a severe impact the spectral emission signature of the cloud OD required by the DHD retrieval.

## Methodology: Physical Retrieval (DKZ)

A physical inversion scheme has been developed dealing with cloudy as well as cloud-free radiance observed with ultraspectral infrared sounders to simultaneously retrieve surface, atmospheric thermodynamic, and cloud microphysical parameters. A fast radiative transfer model, which applies to the clouded atmosphere, is used for atmospheric profile and cloud parameter retrieval. A one-dimensional (1D) variational multivariable inversion solution is used to improve an iterative background state defined by an eigenvector-regression retrieval. The solution is iterated in order to account for nonlinearity in the 1D variational solution. It has been shown that relatively accurate temperature and moisture retrievals can be achieved below optically thin clouds. For optically thick clouds, accurate temperature and moisture profiles down to cloud-top level are obtained. For both optically thin and thick cloud situations, the cloud-top height can be retrieved with relatively high accuracy (i.e., error 1 km). This work was motivated by the need to obtain solutions for atmospheric soundings from infrared radiances observed for every individual field of view, regardless of cloud cover, from future ultraspectral geostationary satellite sounding instruments, such as the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS). However, this retrieval approach can also be applied to the ultraspectral sounding instruments to fly on polar satellites, such as the Infrared Atmospheric Sounding Interferometer (IASI) on the European MetOp satellite, the Cross-track Infrared Sounder (CrIS) on the NPOESS Preparatory Project, and the follow-on NPOESS series of satellites. Cloud retrieval results shown have been limited to observations within 8 degrees of nadir for comparison with the DHD approach.

Methodology: RTE Approach (DHD)

For the results which are derived by direct inversion of the radiative transfer equation (RTE), we focus our study in regions located between gaseous absorption lines within the 8-10 μm infrared atmospheric window. This provides a number of spectral measurements in the cleanest portion of the measured spectrum. The measured radiance represents the upwelling column clear sky (molecular) radiance and any contribution from aerosol (e.g., cloud) and surface emission.

The measured upwelling radiance was broken up into layers: clear sky below cloud (including surface), cloud layer, and clear sky above cloud. Line-by-line radiative transfer model (LBLRTM) calculations--using ECMWF model forecasts in place of radiosonde atmospheric state measurements--as input, were used to determine the atmospheric clear sky transmittance. Cloud reflectance was parameterized based on a two-stream model, to account for reflected upwelling terrestrial and atmospheric radiation. The remaining unknown, cloud transmittance, was inverted from the radiative transfer equation to yield the cloud absorption optical depth. Surface emission was determined using the UW Seeman-Borbas (SEEBOR) database. LBLRTM transmittance profiles were calculated based on a 20-minute time grid where the subsequent temperature and LBLRTM transmittance profiles were then interpolated to derive clear sky column radiance for each infrared measurement.

Spectral variation in measured absorption optical depth were used to infer effective radius of ice particles within the cirrus. The top figure to the right shows variation in absorption optical depth for various effective radii assuming hexagonal column ice crystals; where each curve is normalized to an absorption optical depth of 1.0 at 900 cm^{-1}. Note that the sensitivity decreases with increased particle size; such that the retrieval capability diminishes at an effective radius of about 30 to 40 μm. An example is given (bottom right) for ground-based AERI measurements on 29 November 2002. The upper panel shows microwindow calculations for 5, 15, and 50 μm effective radii (open symbols) and a sample AERI measurement (asterisks). The bottom panel illustrates a best fit to the measurement using both Mie ice spheres and hexagonal column crystals. Both ice spheres and hexagonal columns yield a similar spectral fit, however, the derived effective radius is roughly 20 percent larger when assuming spheres.
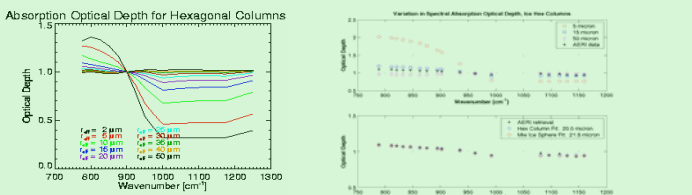
Conclusion

A comparison of two retrieval techniques were applied to high spectral resolution infrared radiances to determine cloud properties from aircraft based measurements on 20 and 27 April 2007 during the Joint Airborne IASI Validation Experiment (JAIVEx). Results were based upon a physical retrieval (DKZ), where all atmospheric variables are simultaneously determined, and a dedicated cirrus cloud retrieval algorithm (DHD) which also uses atmospheric state and lidar (a lack of coincident lidar likely impaired the DHD approach) to provide ancillary information to invert the cloud optical depth from the infrared radiative transfer equation.

The 20 April case was thin cirrus and results were in good agreement with the exception of the DHD size retrieval (expected for OD < 0.6). The 27 April case consisted of a complex, multi-layered cloud which varied from optically thick to opaque (including liquid, aerosol and ice clouds). Results were mixed for opaque conditions: the dedicated, DHD, retrieval was consistent with lidar measurements for OD, but unable to determine an effective particle size; which was likely biased by the presence lower altitude water clouds. It was useful to apply these algorithms to this multi-layer case to demonstrate the strength of the DKZ physical retrieval method. It showed its ability in deriving T and RH profiles below thin cirrus. A coincident lidar would have been a welcome tool to validate the retrieved OD.

References and Additional Information

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S-HIS, NAST-I, and AERI information can be found on the CIMSS web page: http://cimss.ssec.wisc.edu

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