Use of active and passive satellite remote sensing from the NASA A-Train to investigate the relationship between cloud structure and hurricane intensification

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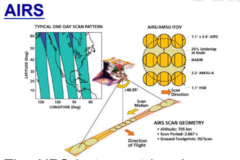
Abstract

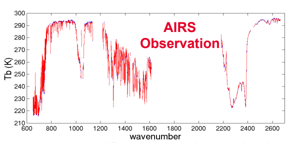
Hurricane intensity forecast accuracy is extremely important in order to take necessary precautions for landfall events. Good intensity forecasts require a solid understanding of the underlying dynamics that cause a hurricane to strengthen or weaken. The causes of change in intensification of tropical storms and hurricanes have been widely studied, yet some aspects are still not well understood. Compared to the technical difficulty, cost, and danger associated with taking in situ measurements of these events, the use of satellite observation to study hurricanes presents a good way to attain timely data even in remote regions of the Earth. The EOS A-Train constellation of spacecraft provides unique insight into cloud geometric structure and atmospheric thermodynamic state from both active and passive sensors.

The purpose of this study is to investigate the relationship between hurricane intensity and the temporal changes in cloud structure and water vapor distribution of the storm and its environment. The passive and active remote sensing instruments and their derived products will be used to examine the 3-D cloud structure, temperature profiles, and water vapor profiles of Hurricane/Super Typhoon Ioke at various points in its life cycle. The sensitivity of hyperspectral IR sounders is shown to provide unique insight into tropical cyclones.

Data Sources

AIRS





The AIRS instrument is a hyperspectral, scanning IR sounder aboard the A-train satellite Aqua. It measures 2378 IR spectral channels over the range of 3.7 – 15.4 μm with a spatial resolution of 13.5 km at nadir, as well as 4 Vis/NIR spectral channels with a spatial resolution of approximately 2.3 km. AIRS attains complete global coverage daily using cross-track scanning, divided into granules of 6 minutes of calibrated radiance data containing 135 scan lines of 90 cross-track fields of view between ±49.5°.

The UW-Madison CAVP algorithm uses both spatial and spectral filtering of AIRS radiances to detect cloud amount from the top of the atmosphere to the surface using 25 discrete layers. The threshold value of 0.05 is used to determine cloud presence.

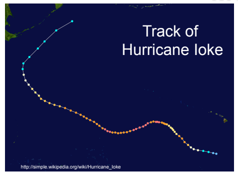
MODIS

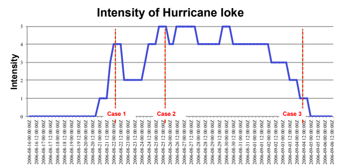
The MODIS (Moderate Resolution Imaging Spectroradiometer) instrument is also found on Aqua as well as the Terra satellite. It measures 36 spectral bands ranging from 0.4 μm to 14.4 μm in wavelength with high radiometric sensitivity. Two bands are imaged at a resolution of 250 m at nadir, five bands at 500 m, and the remaining 29 bands at 1 km. MODIS attains complete global coverage daily using cross-track scanning, divided into granules of 5 minutes of calibrated radiance data containing 406 scan lines of 270 cross-track fields of view between ±55°.

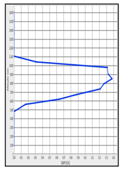
CALIPSO

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite is also part of the A-train constellation of satellites, following a few minutes behind Aqua and allowing for coordinated observations. It combines an active lidar instrument with passive IR and visible imagers to obtain the vertical structure and properties of thin clouds and aerosols. CALIPSO is a joint U.S. and French mission that has been in operation since April, 2006.

Methodology

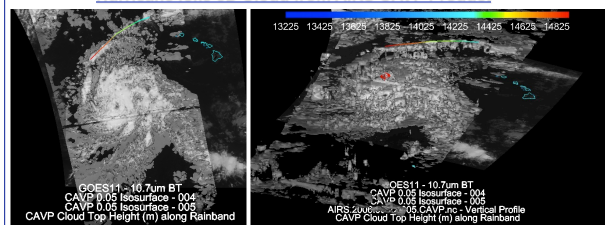






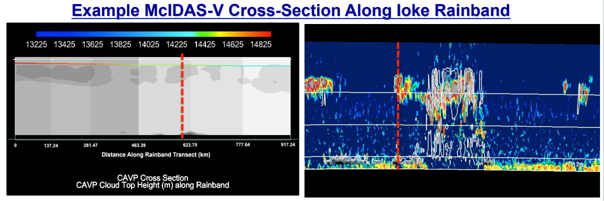
Stemming from a history of using satellite observations to investigate hurricanes, this method investigates the downward slope of cloud top height along a rainband and its possible relationship to the intensity of the hurricane. In McIDAS-V, the Vertical Profile Probe was used to determine cloud top height along a rainband, with the cloud top defined as the highest point at which the CAVP profile (example at left) crosses the 0.05 threshold. These points were then used to calculate the slope. Transects begin closest to the eye and spiral outward, resulting in a negative slope (given in m/km).

Hurricane Ioke 3D Cloud from AIRS CAVP Product



Hurricane Ioke at 0030Z on 22 August 2006
Left: Top view of UW-CAVP 0.05 isosurface over GOES-11 10.7um brightness temperature satellite imagery. A rainband cross-section transect is colored by cloud top height, as determined by CAVP vertical profiles.
Right: Same as left, but shown in 3-D from the southeast.

Example McIDAS-V Cross-Section Along Ioke Rainband



Distant rainband from Hurricane Ioke at 0030Z on 22 August 2006
Left: Cross section of CAVP along rainband transect overlain with cloud top height along transect.
Right: CALIPSO 532nm total attenuated backscatter overlain with CAVP contours.
Red dashed lines are used to indicate intersections of CAVP cross-section and CALIPSO path.

References

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• Houze, Robert A., 2010: Clouds in Tropical Cyclones. Mon. Wea. Rev., 138, 293–344. doi: http://dx.doi.org/10.1175/2009MWR2989.1
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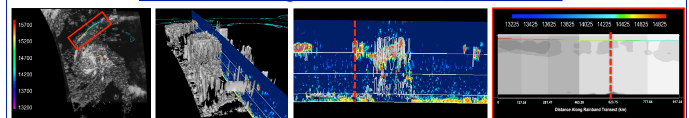
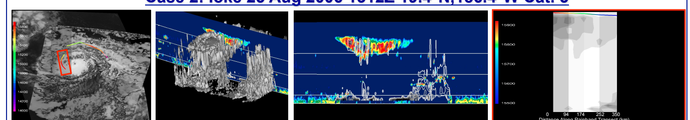
Results

The path of Hurricane Ioke across the Central Pacific in October 2006 was intersected by overpasses of the NASA Aqua satellite with the MODIS and AIRS sensors. Several cases of varying storm intensity were selected along the track to investigate the relation of remotely sensed cloud geometry to intensity. The CAVP product was compared with CALIPSO passes to check for consistency in cloud top heights of rainbands, when possible.

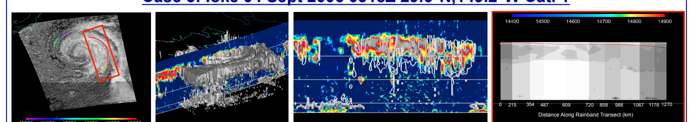
Case 1: Ioke 22 Aug 2006 0030Z 13.6°N,192.9°W Cat. 4



Case 2: Ioke 25 Aug 2006 1312Z 19.4°N,186.4°W Cat. 5



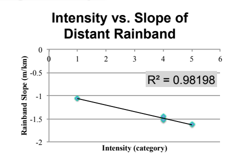
Case 3: Ioke 04 Sept 2006 0318Z 29.6°N,149.2°W Cat. 1



First column: Top view of UW-CAVP 0.05 isosurface over satellite imagery. Rainband cross-section tracks are colored by cloud top height, as determined by CAVP vertical profiles. **Second column:** CALIPSO 532nm total attenuated backscatter (TAB) running through CAVP granule. **Third column:** CALIPSO 532nm TAB overlaid with CAVP contours. **Fourth column:** Cross section of CAVP along rainband transect indicated by a red box in column one, overlaid with cloud top height along transect. Red dashed lines are used to indicate intersections of CAVP cross-section and CALIPSO path.

Table 1: Ioke Latitude/Longitude/Date/Time/Intensity/RB Slope

DATE	TIME	LAT	LON	CAT	RAINBAND SLOPE (m/km)	RAINBAND TYPE*
22 Aug 06	0030Z	13.6	192.9	4	-1.68	Secondary
					-1.53	Distant
25 Aug 06	1312Z	19.4	186.4	5	-1.21	Secondary
					-1.62	Distant
28 Aug 06	1200Z	16.6	177.2	4	-1.45	Distant
04 Sep 06	0318Z	29.6	149.2	1	-1.18	Secondary
					-1.06	Distant



* Rainband type based on figure from Houze 2010, p. 384.

Conclusions

•McIDAS-V was used to determine the slope of the cloud top along hurricane rainbands.
•The slope of the cloud top along the spiral arm of a secondary or distant rainband was found to have a characteristic value between -1 m/km and -2 m/km.
•The variation of this value with time is hypothesized to correlate with cyclone intensity. The distant rainband slope shows the best correlation in cases thus far.
• The CAVP product is more consistent with CALIPSO TAB cloud tops in rainband regions than near the eye of the storm. Therefore, measurements of distant rainbands using CAVP have less inherent error than measurements of primary and secondary rainbands (which occur closer to the eye).
•Further work includes using alternate methods of determining slope, additional case studies, and investigation of rainband and environmental water vapor distribution.

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