Detection of Thin Cirrus in Cirrus/Aerosol Atmospheres

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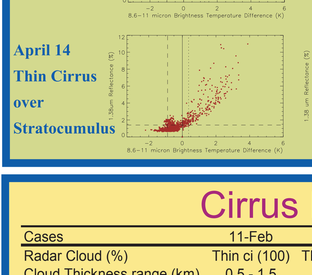
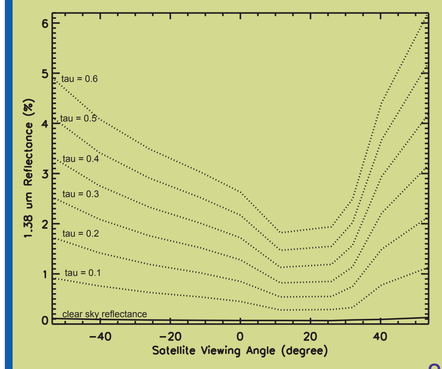
SCIENTIFIC OBJECTIVES

- Develop a new cirrus cloud detection scheme that utilizes the MODIS 1.38-micron band in a series of reflectance thresholds along with 8.6-11 micron brightness temperature difference as the two parameters for identifying cirrus cloud.
- Validate results by comparison with other existing cloud detection schemes, MODIS cloud phase products, and ground based sensors.
- Discover accurate 1.38-micron reflectance thresholds that detect very thin cirrus cloud with low optical thickness and exclude reflectance off lower cloud layers.



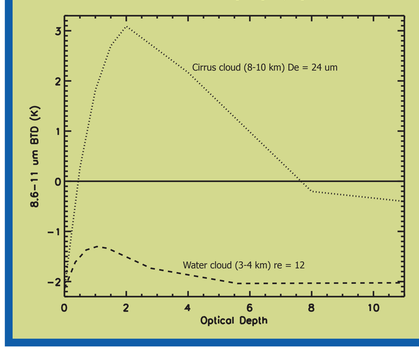
Three Clear Sky Probabilities (CSP) according to the MODIS MOD35 Cloud Mask on October 15, 2000 (1725 UTC)are plotted:
CLEAR: Solid Purple: CSP > 95%
UNCERTAIN: Dotted Red: 95% > CSP > 66%
CLOUDY: Dashed Orange: CSP < 66%
1.38-micron reflectance hints that thin cirrus may be responsible for the second peak in the UNCERTAIN plot and the CLEAR curves tail.

Radiative Transfer Calculations



1.38-micron reflection

Theoretical 1.38-micron reflectance for clear sky (solid curve) and cirrus clouds (dashed curves) with optical depths (tau) between 0.1 and 0.6. The solar zenith angle was 32 degrees while a relative azimuthal angle of 5 degrees was used for positive satellite viewing angles and 175 degrees used for negative angles. Calculations were made using 0.5% surface reflectance, continental aerosol size distribution with optical depth of 0.32 and a cirrus cloud 2.3 km thick with cloud top of 10 km using the cold cirrus size distribution from Heymsfield and Platt (1984) and Takano and Liou (1989) with effective particle size of 24 microns.



8.6-11 micron Brightness Temperature Difference

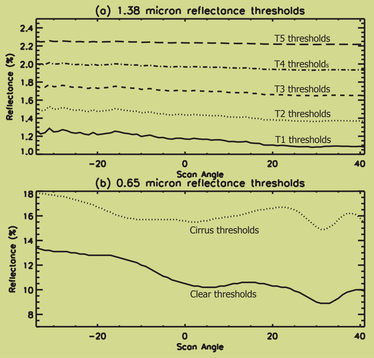
Theoretical 8.6 - 11 micron brightness temperature difference (BTD) measured in Kelvin plotted against cloud optical depth for an ice cloud (dotted curve) and water cloud (dashed curve). The simulated ice cloud is 2 km thick with cloud top at 10 km and particle size distribution described by of Heymsfield and Platt (1984) and Takano and Liou (1989) with effective size parameter of 24-microns, while the water cloud is 1 km thick and located between 3-4 km with effective particle radius of 12-microns.

Reflectance and Other Thresholds

Threshold Value	SGP	TWP
$R_{1.38\ T1}$	1.16	1.13
$R_{1.38\ T2}$	1.42	1.41
$R_{1.38\ T3}$	1.69	1.68
$R_{1.38\ T4}$	1.96	1.96
$R_{1.38\ T5}$	2.23	2.23
$R_{0.65\ Tclr}$	11.2	4.2
$R_{0.65\ Tcir}$	17.7	15.6
$BTD_{8.6\text{-}11\ Tclr}$	-0.9	-0.57
$BTD_{8.6\text{-}11\ Tlow}$	0.76	0.85

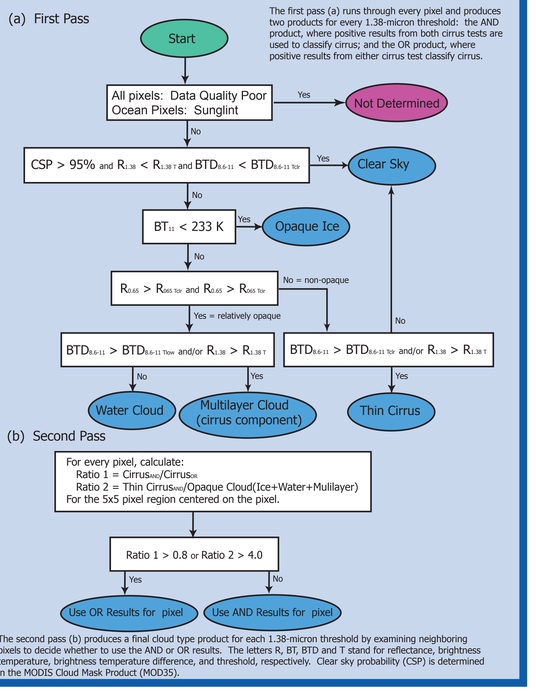
Average threshold values for the seven Southern Great Plain (SGP) cases and the three Tropical Western pacific (TWP) cases.

R: represents reflectance in percent. BTD: represents brightness temperature difference in K. Clear, cirrus, and low cloud thresholds are indicated by clr, cir, and low, respectively.



The five 1.38-micron reflectance thresholds are plotted versus satellite scan angle for an SGP scene (March 22, 2001) in (a) and the two 0.65-micron reflectance thresholds are shown in (b). For this scene, the average solar angle and solar azimuthal angle were 35.9 and 154.6 degrees respectively. A total of 317,552 pixels were examined. Negative scan angles are defined as those to the right of the satellite path, while positive angles are to the left.

New Cloud Type Detction Scheme



The first pass (a) runs through every pixel and produces two products for every 1.38-micron threshold: the AND product, where positive results from both cirrus tests are used to classify cirrus; and the OR product, where positive results from either cirrus test classify cirrus.

The second pass (b) produces a final cloud type product for each 1.38-micron threshold by examining neighboring pixels to decide whether to use the AND or OR results. The letters R, BT, BTD and T stand for reflectance, brightness temperature, brightness temperature difference, and threshold, respectively. Clear sky probability (CSP) is determined in the MODIS Cloud Mask Product (MOD35).

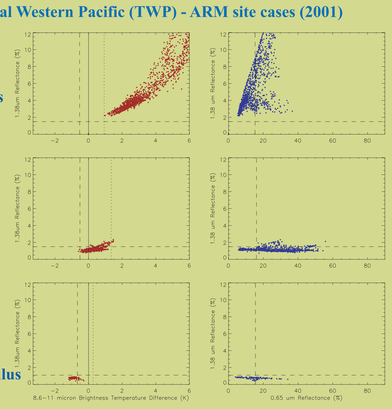
1.38-micron reflectance vs $BTD_{8.6\text{-}11}$ and 0.65-micron reflectance

Tropical Western Pacific (TWP) - ARM site cases (2001)

August 16 Thin Cirrus

August 17 Cumulus

August 25 Clear sky + Stratocumulus



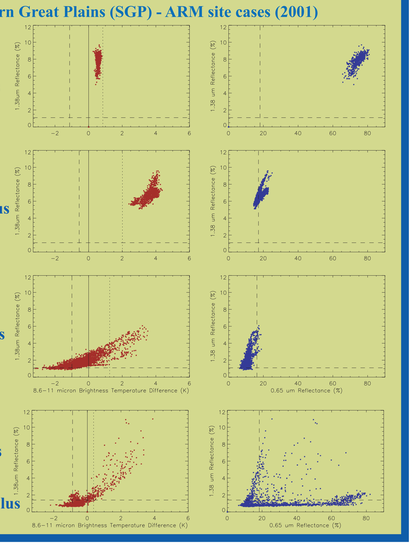
Southern Great Plains (SGP) - ARM site cases (2001)

April 16 Altostratus

March 6 Thick Cirrus

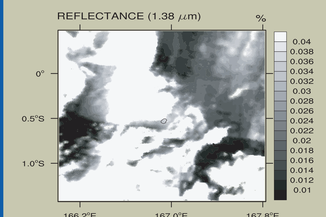
March 22 Thin Cirrus

April 14 Thin Cirrus over Stratocumulus

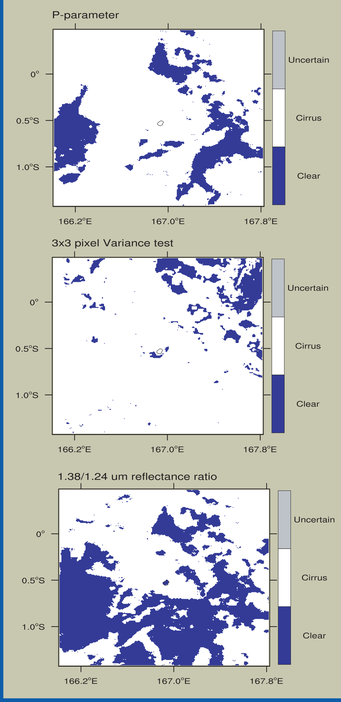


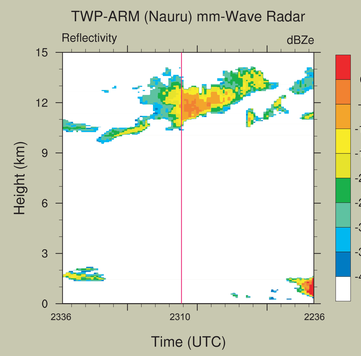
TWP ARM Site August 16, 2001

Cirrus Clouds

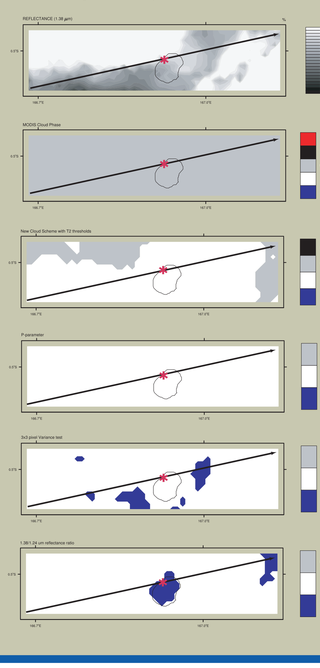


Cirrus clouds are seen throughout the 1 hour mm-wave time series below. Cloud optical depths were calculated to be less than 0.7. The time series is shown in reverse order so that the clouds advected by the cirrus level wind match better with the spatial plots that lie directly below. It can be seen that the New cloud type detection scheme bests identifies the cirrus. Mixed phase, or multilayer, clouds are taken to be two-layer with one ice phase and another water. The plots to the left include a greater region and indicate that the cirrus detection parameter, P, does the best job at screening for high cloud.





* Location of the mm wave radar on Nauru. Black vector represents the average 10-14 km wind throughout the 1 hour period from 2240 to 2340 UTC



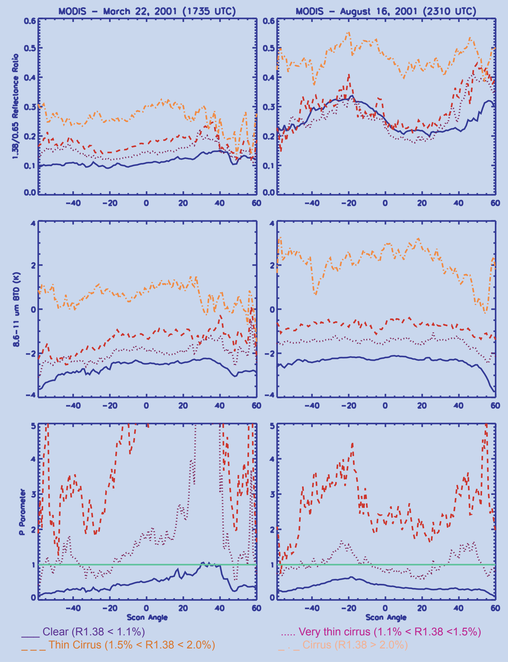
Cirrus Detection Parameter

$$P = \exp[(1.38/0.65)*x + BTD_{8.6\text{-}11}]$$

x = 14 (Land) or 5 (Ocean)

P > 1 for high cloud

P < 1 for clear or low cloud



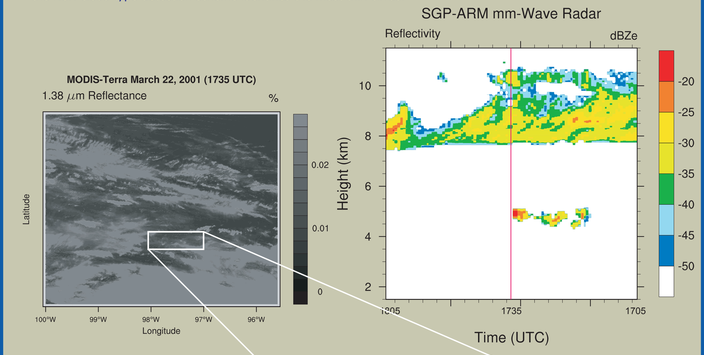
SUMMARY

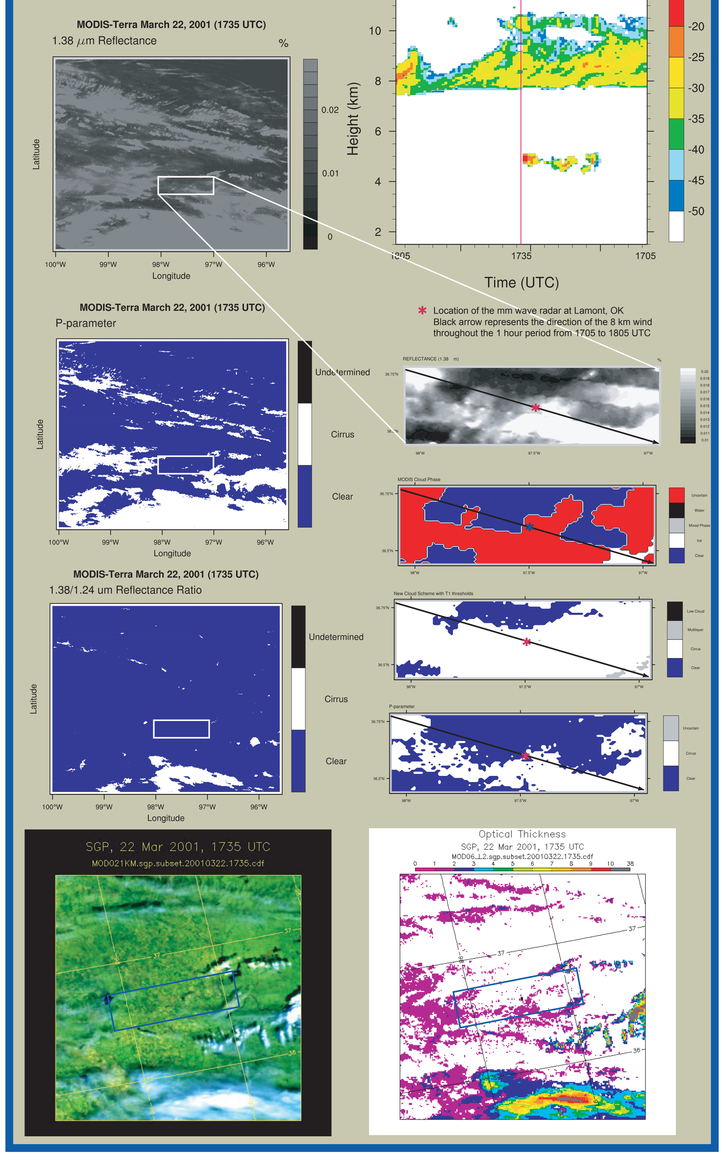
- The new 1.38-micron/8.6-11 micron BTD based cloud type detection scheme is able to identify a greater amount of thin cirrus clouds than other schemes in cases involving single-layer cirrus only. Best results were found using the lowest (T1) 1.38-micron reflectance threshold.
- Higher 1.38-micron cirrus thresholds (T3-T4) were needed to exclude reflection off low clouds when present. Mid-level clouds above 4 km reflect too much 1.38-micron energy to distinguish them from thin cirrus and are separated from mid-level clouds by using 8.6-11 micron BTD thresholds.
- The Cirrus detection parameter (P), shows potential in separating high cloud, including thin cirrus, from clear sky and low cloud.

SGP ARM Site March 22, 2001

Cirrus Clouds

Very thin cirrus covered the site as can be seen in the very bottom MODIS images that show, for the area determined by the cirrus level winds within 30 minutes of the Terra overpass (blue rectangle), cirrus was mostly sub-visible with optical depth below 2. The plots on the left show results from an area nearly the same size as the SGP site and indicate that the cirrus detection parameter, P, does a good job at identifying cirrus, except for very thin cloud. The radar time series ,below, shows high cloud throughout the period and is given in reverse order to better match the spatial plots of the various cloud type detection schemes lying directly below. It can be seen that the New cloud type detection scheme identifies the most thin cirrus.





* Location of the mm wave radar at Lamont, OK Black arrow represents the direction of the 8 km wind throughout the 1 hour period from 1705 to 1805 UTC

Cirrus Detection Results

Cases	11-Feb	6-Mar	22-Mar	14-Apr	16-Aug
Radar Cloud (%)	Thin ci (100)	Thick ci(100)	Thin ci(100)	ci(20), st(80)	Thin ci(100)
Cloud Thickness range (km)	0.5 - 1.5	3.9 - 5.0	0.7 - 2.8	ci(0.1-0.5),st(1-2.3)	0.5 - 3.4
Maximum Cloud Top (km)	10.7	10.5	10.6	ci(8.7), st(2.7)	14.1
Cirrus Optical Depth range	0.1 - 0.5	0.8 - 1.5	0.15 - 0.9	0.02 - 0.2	0.02 - 0.7
NS1[1]	100	100	92	72	100
NS2[2]	100	100	79	59	100
NS3[3]	100	100	74	57	100
NS4[4]	100	100	73	56	100
NS5[5]	100	100	73	54	100
M6[6]	0	100	19	0	41
VAR[7]	NA	100	NA	NA	94
RAT[8]	0	100	0	NA	81
P[9]	51	100	56	NA	99

Results from comparisons of cirrus detected by the individual cloud type detection schemes to that of observed cirrus by the millimeter-wave radar. Numerical values are listed in percent with the exception of the radar cloud thickness range and radar maximum cloud top height, which are given in km, and the range of cirrus cloud optical depth. Empirical optical depths were calculated using theoretical extinction coefficients produced for ice crystals with effective sizes of 10 and 42 microns (Liou 2002).

1: New Scheme with T1 (lowest) thresholds, 2: New Scheme with T2 thresholds, 3: New Scheme with T3 thresholds, 4: New Scheme with T4 thresholds, 5: New Scheme with T5 thresholds, 6: MODIS (MOD06) Cloud Phase Product, 7: MODIS 3x3 pixel Variance cloud detection algorithm (Martins el al., 2002), 8: MODIS 1.38um/1.24um reflectance ratio cloud detection algorithm (Gao et al., 2002), 9: Cirrus detection parameter (P).