Errors in Cloud Detection over the Arctic

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Introduction and Overview

The trend in Arctic sea ice extent has been negative and decreasing in every month in the last thirty years, and this trend is expected to continue. Changes in sea ice extent impact cloud cover, and cloud amount influences the surface radiative fluxes, which in turn affects the surface temperature.

Satellites provide the best means of determining cloud amount over the Arctic. The dependence of cloud detection on surface type may influence our understanding of feedback mechanisms, such as the ice-albedo feedback. To explore this dependence we compare cloud amount from MODIS with the cloud products of CloudSat and CALIPSO.

Our primary focuses are:

- Comparing active vs passive cloud detection in the arctic
- Determining influences of biases in the passive cloud detection on other physical parameters

Cloud Amount and Trend Analysis

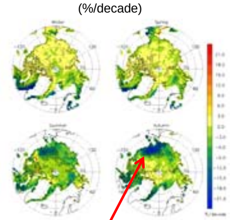
Changes in sea ice concentration from 1982 to 2004 are different in four seasons, in terms of sign, magnitude, and spatial distribution, shown in the top figure to the right. For example over the Chukchi Sea we see small positve ice trend in the Winter and Spring and a larger negative trend in the Summer and Autumn months.

These changes in sea ice concentration will cause an errant cloud amount trend, associated with better satellite cloud detection capabilities over open water than over sea ice. Less sea ice means more easily seen , not necessarily more clouds.

The middle figure to the right shows the cloud amount trend error associated with the sea ice concentration changes, due to better cloud detection capabilities over open water than over sea ice. This is calculated from the sea ice relationship to cloud fraction difference between MODIS and CloudSat and CALIPSO and applying it to the entire AVHRR time record.

The bottom figure shows the anomalous cloud amount forcing trend due to erroneously increasing cloud detection. Using cloud forcing terms from Schweiger and Key (1994) and the anomalous cloud amount trend in the middle figure we can obtain an anomalous cloud forcing term. Wang and Key (2004) estimated the decadal net cloud forcing from 1982 to 1999 to be -3.17 Wm^{-2}. This study suggests that the cooling feedback of Arctic cloud on the surface temperature would be stronger by about 10%, or -0.27 Wm^{-2}.

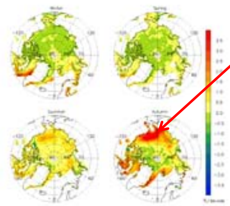
Sea ice concentration (%/decade)



Sea ice concentration decadal trends in winter, spring, summer, and autumn from 1982 to 2004.

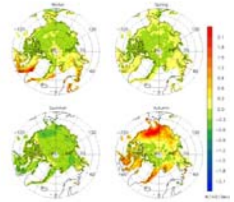
Less sea ice = More cloud???

Anomalous Cloud Amount (%/decade)



Anomalous cloud amount decadal trends caused by ice concentration changes, leading to changes in satellite detection capabilities. The decadal trends are for winter, spring, summer, and autumn from 1982 to 2004.

Anomalous Cloud Forcing (W/m²/decade)



Anomalous cloud radiative forcing decadal trend caused by "false cloud amount" associated with trends in SIC, that lead to errors in cloud detection capabilities. The decadal trends are for winter, spring, summer, and autumn from 1982 to 2004.

MODIS Cloud Fraction Data

Two cloud fraction datasets are currently provided in MODIS at the Level-3 resolution. The one used for this study is:

$$CF = \frac{\#\text{ of cloudy pixels}}{\text{sum(all pixels)}}$$

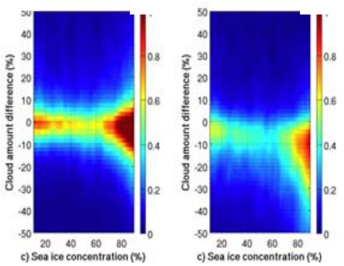
The other cloud fraction which has been used to characterize the cloud cover over the Arctic during the record minimums sea ice extent in 2007 (Kay et al. 2007):

$$Rcf = \frac{\#\text{ of successful retrievals}}{\#\text{ of possible retrievals}}$$

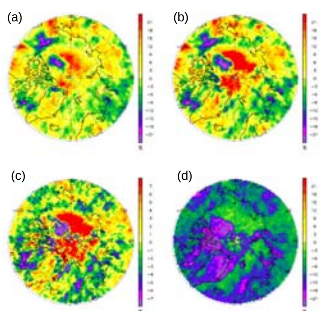
The top figure to the right shows the cloud fraction(CF) vs the retrieval cloud fraction(Rcf) minus CloudSat cloud fraction vs the sea ice concentration in 10° longitude by 3° latitude regions over the arctic.

The bottom figure to the right compares the two cloud fractions for September 2007: (a) Sept. 2007 CF cloud amount anomaly, (b) Sept. 2007 Rcf anomaly, (c) RCF anomaly minus CF anomaly for Sept. 2007, and (d) the mean RCF minus the mean CF.

MODIS CF vs CloudSat vs Sea Ice



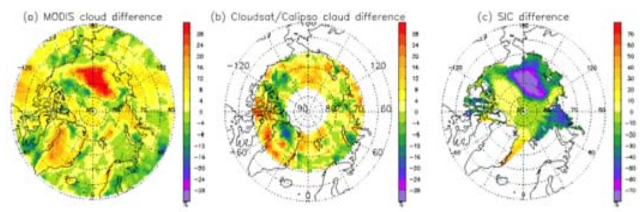
September 2007 CF Comparison



Cloud Amount and the Record Minimum Sea Ice Extent

An unprecedented decrease in sea ice extent in 2007 was observed. This record minimum sea ice extent was reached in September 2007, together with the strong positive cloud fraction anomaly over the same region. The figure below shows the MODIS cloud fraction anomaly (a) for the September 2007 mean minus the 2006 mean, (b)the corresponding CloudSat/Calipso CF anomaly and (c) the sea ice concentration decrease relative to the 2002-2007 mean. Most of the difference between the CloudSat/CALIPSO and MODIS cloud fraction anomalies can be explained by the better MODIS cloud detection over water than over sea ice.

Anomalous September 2007: Record Minimum Sea Ice Extent

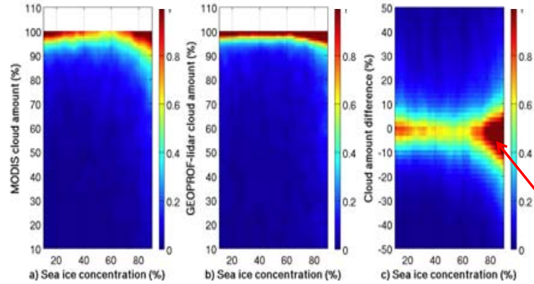


The difference between 2007 and 2006 September to October (a) mean cloud fraction from MODIS, (b) CloudSat/CALIPSO, and (c) AMSR-E SIC anomalies for 2007 versus the 2002-2007 mean. White areas for CloudSat/CALIPSO signify an insufficient number of observations, with less than 1800 observations.

Cloud Amount: Passive vs Active

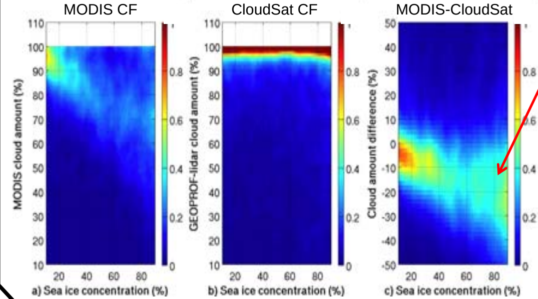
As sea ice extent decreases more surface area in the Arctic becomes open water. Cloud detection over open water is far less complicated than over sea ice for passive instruments like MODIS. The figures below demonstrate the decreasing ability of MODIS to detect cloud over sea ice coverage increases. This is especially true for nighttime scenes (bottom figure).

Daytime Cloud Fraction



Increasingly negative CF difference at night compared day between MODIS and CloudSat over Ice

Nighttime Cloud Fraction



The figures above show the cloud frequency distributions of the (a) MODIS daily mean cloud amount (%), (b) GEOPROF-lidar daily mean cloud amount (%), and (c) daily mean cloud amount difference between MODIS and GEOPROF-liar (%) with AMSR-E SIC (%). These are calculated over regions that are 10° longitude by 3° latitude over the arctic. Only regions with a sea ice concentration between 10 and 90% are included. The top figure is daytime only pixels and the bottom is night time only pixels.

The night time cloud fraction difference between MODIS and CloudSat show increasingly larger differences with high sea ice concentrations. This would indicate that MODIS has less skill at discriminating cloud from clear sky over ice covered surfaces (bottom)

Data Source Acknowledgement:
The 2B-GEOPROF-LIDAR product from CloudSat data processing center.

The MODIS Level -2 cloud mask is from NASA GSFC LAADS web.

The AMSR-E is from NSIDC.

References:

Kay, J. E., T. L'Ecuyer, A. Gettelman, G. Stephens, and C. O'Dell, 2008: The contribution of cloud and radiation anomalies to the 2007 Arctic sea ice extent minimum. *Geophys. Res. Lett.*, **35**, L08503.

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