Analysis of day- and night-time Arctic clouds by means of hyperspectral infrared and ground-based observations

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Satellite cloud detection in polar regions is difficult because of:

- extremely cold surface temperatures
- little infrared and visible contrast with snow/ice surface
- strong temperature inversions
- usually low and thin clouds

During polar nights, cloud detection is even more difficult:

- poor or no solar contribution
- reflectance tests are unusable (e.g. 1.6 μm test)
Current MODIS and AIRS IR spectral tests are based on climatological mean temperature, water/ice spectral absorption, water vapor continuum, temperature inversion strength.
Nighttime Polar Cloud Detection Tests

1) $\text{BT}(800)-\text{BT}(1100) = \text{BT}12.5-\text{BT}9.1 < \text{Tr}1$
2) $\text{BT}(800)-\text{BT}(1100) = \text{BT}12.5-\text{BT}9.1 > \text{Tr}2$  cloudy tests
3) $\text{BT}(960)-\text{BT}(1100) = \text{BT}10.4-\text{BT}9.1 > \text{Tr}3$
4) $\max(\text{BT}(6.7-8.3\text{mm}))-\text{BT}(10\text{mm}) > \text{Th}4$  clear test

Based on Holtz and Ackerman, Proc. AMS, 2005

Ackerman et al., Discriminating clear-sky from clouds with MODIS, J. Geo. Res., 1998


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Surface polar regions are a combination of ice, snow, and seawater.

IR spectral emissivities differ significantly and it can play a crucial role in cloud detection due to the spectral features in the 700-1200 cm\(^{-1}\) range.

from MODIS UCSB Emissivity Library (PI: Zhengming Wan)
AIRS Tb spectra are simulated in clear sky using RTTOV (Eyre, J.R., 1991)
AIRS Tb spectra are simulated in cloudy sky using RTX

The numerical model RTX [Rizzi et al., 2001; Amorati and Rizzi, 2002, Maestri et al., 2005], solves the radiative transfer equation with the adding and doubling method taking into account the multiple scattering by randomly-oriented particles with a plane of symmetry. Polarized radiation is considered in term of Stokes parameters under the hypothesis of a plane-parallel and vertically inhomogeneous atmosphere including both thermal and solar sources.

Spectral properties of atmospheric gases are computed with the RTTOV model while the extinction and scattering coefficients, the single scattering albedo and the Lagrange coefficients to expand the scattering matrix are computed for a gamma-modified size distribution of spherical cloud particles (water and ice) using a Mie code (Wiscombe 1979).
Cloud parameters for cloud spectra simulation

- T and RH profiles
- Cloud top 2.2, 2.7, 3.2, 3.7, 5.1, 5.5 km
- Cloud phase: liquid, ice, mixed phase
- Effective radius: 5, 15, 25, 30, 50, 70 μm
- Ice or water liquid content: 0.001 0.005 0.01 0.03 0.05 0.07
Surface emissivity ($\varepsilon$): sea water, ice, snow plus $\varepsilon = 1$
Clear and cloud spectra using ice emissivity

Water clouds

Ice clouds
Clear and cloud spectra using snow emissivity.
Clear and cloud spectra using water emissivity.
Clear and cloud spectra using constant emissivity ($\varepsilon = 1$)

**Water clouds**

**Ice clouds**
## Test Results

<table>
<thead>
<tr>
<th></th>
<th>Percentage of “cloud-detected-clear”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td>22 %</td>
</tr>
<tr>
<td>Snow</td>
<td>29 %</td>
</tr>
<tr>
<td>Water</td>
<td>30 %</td>
</tr>
<tr>
<td>Emissivity=1.</td>
<td>30 %</td>
</tr>
</tbody>
</table>

140*4 spectra

Clear spectra are correctly detected for water and constant emissivity only
AIRS Tb spectra are simulated in clear sky using RTTOV for 305 artic profiles

Test Results

<table>
<thead>
<tr>
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<th>Percentage of “clear-detected -cloud”</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>100 %</td>
</tr>
<tr>
<td>SNOW</td>
<td>100 %</td>
</tr>
<tr>
<td>WATER</td>
<td>15 %</td>
</tr>
<tr>
<td>ε=1.</td>
<td>12%</td>
</tr>
</tbody>
</table>

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Windows slopw
Spectra for different geometry

Standard Deviation for simulated spectra

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Window Slope test

<table>
<thead>
<tr>
<th></th>
<th>Percentage “cloud-detected-clear”</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>1%</td>
</tr>
<tr>
<td>SNOW</td>
<td>8%</td>
</tr>
<tr>
<td>WATER</td>
<td>5%</td>
</tr>
<tr>
<td>$\varepsilon=1.$</td>
<td>2%</td>
</tr>
</tbody>
</table>

Clear spectra are detected correctly

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Test based on window slope, estimated in clear condition at different time/day.

MODIS or AVHRR channel at 1.6 $\mu$m for clear identification.
Radiosonde data are from WVIOP2004 (PI: Ed Westwater).

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31 March 2004

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Conclusion and Future work

Using currently available polar nighttime cloud detection algorithms for AIRS:

- clear-sky spectra with $\varepsilon=1$ are detected correctly
- clear-sky spectra with $\varepsilon$ for water are not always detected correctly
- clear-sky spectra with $\varepsilon$ for ice/snow are always misidentified as cloudy
- Information on clear window slope spectra can improve current tests.

- Analysis of the tests will be extend to a large measured data set.

For further results on MODIS and IASI see poster A24 by D. Cimini