A Far Infrared Radiative closure experiment for Antarctic Clouds

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www.ino.cnr.it
WHY CIRRUS CLOUDS ARE SO IMPORTANT?

- Cirrus clouds play a key role in the Earth radiation budget since they modulate the solar incoming radiation and the outgoing thermal emission.

More than 40% of the OLR and of the greenhouse effect comes from FIR where the pure rotational band of water vapour is present.
The best place to study the atmosphere: Concordia

“Physics” Shelter placed at about 500 m from the Concordia base hosts many different instruments for the study of the atmosphere.
Synergy of various instruments
Synergy of various instruments
Synergy of various instruments

INCO-CNR. BEFR-PAD spectrum
Measurement data: IPADm_20210618_004400 UTC

SPHERES group
Synergy of various instruments
Synergy of various instruments
Synergy of various instruments
REFIR-PAD spectroradiometer
**INSTRUMENT SPECIFICATIONS**

Mach-Zehnder interferometer

Spectral band = 100-1400 cm\(^{-1}\) (7-100 μm)

Spectral resol. = 0.25 – 0.5 cm\(^{-1}\) (now 0.4)

BT error ≈ 0.3K (@280K)

NESR ≈ 1 mW /m\(^2\)-sr-cm\(^{-1}\)
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Modeling of single scattering properties

Ping Yang et al. 2013, Jour. Atm. Sci.

\[ Q_{v}^{e,a} = Q_{v}^{e,a}(D_e) \]
\[ \omega_{v} = \omega_{v}(D_e) \]
\[ g_{v} = g_{v}(D_e) \]

Effective diameter

\[
D_e = \frac{3}{2} \frac{\int_{L_{\text{min}}}^{L_{\text{max}}} \left[ \sum_{i=1}^{N} f_i(L)V_i(L) \right] n(L) dL}{\int_{L_{\text{min}}}^{L_{\text{max}}} \left[ \sum_{i=1}^{N} f_i(L)A_i(L) \right] n(L) dL}
\]
## Retrieval of cloud properties

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measure</th>
<th>Exploited Spectral Band</th>
<th>Retrieved Parameters</th>
<th>Algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>REFIR-PAD</td>
<td>spectral radiance</td>
<td>200–980 cm$^{-1}$</td>
<td>$D_e$, OD$_V$, H$_2$O/T profiles</td>
<td>SACR</td>
</tr>
<tr>
<td>REFIR-PAD</td>
<td>spectral radiance</td>
<td>380–1000 cm$^{-1}$</td>
<td>phase (ice or liquid)</td>
<td>CIC</td>
</tr>
<tr>
<td>LiDAR</td>
<td>Backscatt./depolar. signal</td>
<td>532 nm</td>
<td>CBH, CTH</td>
<td>PT</td>
</tr>
</tbody>
</table>

**CIC**

(Cloud Identification & Classification

**SACR**

(Simultaneous Atmospheric and Cloud Retrieval
Di Natale et al. 2020,
doi: https://doi.org/10.1016/j.jqsrt.2020.106927)

**PT**

(Polar Threshold
Van Tricht et al. 2014,
doi: 10.5194/amd-7-1153-2014)

**Cloud phase**

**Spectral radiance**

$D_e = (34.2 \pm 0.2)$ μm

$OD = (0.678 \pm 0.004)$
Comparison with radar reflectivity

Selected case of precipitating ice cloud

Matching for aggregates of plates

No matching for single columns

\( Z_e = \frac{\lambda^4}{\pi^5 |K|^2} \int_{L_{\text{min}}}^{L_{\text{max}}} \sigma(L) \text{PSD}(L) dL \)

\((D_e, \text{OD}) \rightarrow (N_o, R_m) \rightarrow \text{PSD}\)

Particle size distribution

Intercept and modal radius
Cloud statistics: properties and forcing

Di Natale et al. 2020, doi:https://doi.org/10.3390/rs12213574

<table>
<thead>
<tr>
<th>$D_e$ (μm)</th>
<th>Crystals Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Columns</td>
</tr>
<tr>
<td>55</td>
<td>Plates</td>
</tr>
<tr>
<td>51</td>
<td>Bullet rosettes</td>
</tr>
<tr>
<td>35</td>
<td>Aggregates</td>
</tr>
</tbody>
</table>

Forcing (W/m²)

- 30 (ice clouds only)
- 46 (ice + water clouds)
Cloud statistics: phase and occurrence

Cossich et al. 2021, doi:https://doi.org/10.5194/amt-2021-104
(under revision on ACPD)

<table>
<thead>
<tr>
<th>CIC CLASSIFICATION</th>
<th>ENTIRE DATASET 2012 (%)</th>
<th>ENTIRE DATASET 2013 (%)</th>
<th>ENTIRE DATASET 2014 (%)</th>
<th>ENTIRE DATASET 2015 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAR SKY</td>
<td>72.3 ± 1.5</td>
<td>68.6 ± 1.4</td>
<td>75.1 ± 1.5</td>
<td>76.3 ± 1.5</td>
</tr>
<tr>
<td>ICE CLOUD</td>
<td>24.9 ± 0.3</td>
<td>25.4 ± 0.3</td>
<td>22.8 ± 0.3</td>
<td>21.1 ± 0.3</td>
</tr>
<tr>
<td>MIXED-PHASE CLOUD</td>
<td>2.7 ± 0.3</td>
<td>5.8 ± 0.6</td>
<td>2.0 ± 0.2</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td>UNCLASSIFIED</td>
<td>0.1 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>0.1 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
<tr>
<td>Mean T (°C)</td>
<td>-53.5</td>
<td>-49.6</td>
<td>-54.5</td>
<td>-53.4</td>
</tr>
<tr>
<td>Warm season Mean T (°C)</td>
<td>-40.2</td>
<td>-37.6</td>
<td>-41.0</td>
<td>-40.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># spectra</th>
<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>21209</td>
<td>21093</td>
<td>22395</td>
<td>23061</td>
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</table>

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<thead>
<tr>
<th>CIC CLASSIFICATION</th>
<th>DJF (%)</th>
<th>MAM (%)</th>
<th>JJA (%)</th>
<th>SON (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEAR SKY</td>
<td>71.1</td>
<td>75.1</td>
<td>66.8</td>
<td>76.1</td>
</tr>
<tr>
<td>ICE CLOUD</td>
<td>17.6</td>
<td>24.7</td>
<td>33.2</td>
<td>23.8</td>
</tr>
<tr>
<td>MIXED-PHASE CLOUD</td>
<td>10.9</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
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<tr>
<td>UNCLASSIFIED</td>
<td>0.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mean T (°C)</td>
<td>-34.9</td>
<td>-61.0</td>
<td>-65.0</td>
<td>-52.2</td>
</tr>
</tbody>
</table>
We know that more than 40% of the OLR comes from Far Infrared and cirrus clouds play a key role in the Earth Radiation Budget (ERB).

REFIR-PAD spectrometer is particularly suitable to this purpose covering the whole spectral emission band of the Earth and has been installed in Antarctica since 2012 in synergy with a lidar, an ice camera and micro rain radar.

An automatic routine based on CIC, PT and SACR codes is able to retrieve simultaneously the atmospheric profiles and cloud properties from the large database collected in 9 years of measurements at Dome-C.

The FIRCLOUDS antarctic project has the main goal a radiative closure experiment with the purpose to validate the current cirrus clouds models through intercomparison of instruments products.

Statistics about the cloud optical and microphysical properties, the thermodynamic phase and occurrence were performed and compared with previous studies.

Other works about the retrievability of crystal habits are ongoing.
Thank you for your attention!!