Cirrus Clouds Retrieved from IASI and AIRS Observations: Diurnal Variation and Microphysical Properties

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Abstract

Cirrus clouds cover about 30% of the globe and play an important role in the climate system, affecting the heating of the upper troposphere and preventing escape of the Earth's infrared (IR) radiation to space.
Satellite observations provide a continuous survey of clouds over the whole globe and IR sounders have been observing our planet since 1979. These instruments are sensitive to cirrus clouds both day and night that makes them an ideal tool for studying this type of clouds.
The CIRS-LMD cloud property retrieval approach is based on a weighted $\chi 2$ method and uses the channels around the 15 μm CO2 absorption band, providing cloud pressure and emissivity of a single cloud layer (which is the uppermost one in the case of multi-layer clouds). We applied it to cloud retrievals from IASI and AIRS (Atmospheric InfraRed Sounder) observations. The retrieval quality was estimated using the information from active sounders: the AIRS instrument is a part of the NASA Afternoon Constellation (A-Train) mission, which includes a two-wavelength polarization-sensitive nadir viewing lidar, providing high-resolution vertical profiles of aerosols and clouds.
Once the cloud physical properties (cloud pressure and IR emissivity) are known, cirrus bulk microphysical properties (De and IWP) are determined from spectral emissivity differences between 8 and 12 µm.
In this work, we present cloud pressure and cover and bulk microphysical properties retrieved from IASI and AIRS observations (9:30 AM and 9:30 PM and 1:30 AM and 1:30 PM local time, respectively) and discuss their diurnal variation.

Cloud retrieval from infrared observations - basics

The approach makes use of spectrally resolved infrared radiance measured by satellite instruments (HIRS, AIRS, IASI). The spectral channels should carry the information about different layers of the atmosphere, from the ground to tropopause (corresponding contribution functions should overlap and peak at different heights.)

Necessary formulae

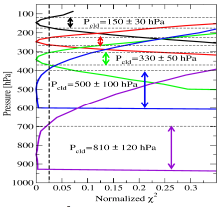
$$\varepsilon_{cld} = \frac{I_{clear} - I_{meas}}{I_{clear} - I_{opaque}(p_{cld})} \quad \text{cloud emissivity}$$

$$I_{\mu\nu}^{clear} = I_{\mu\nu}(0)\cdot\Psi_{\mu\nu}(0) + \int_0^{Z_{sat}} \frac{\partial\Psi_{\mu\nu}}{\partial z}\eta(z,\nu)dz$$

$$I_{\mu\nu}(0) = (1-\delta_\nu)\cdot I_{\mu\nu}^{\downarrow} + \delta_\nu \cdot I_{\mu\nu}^{\uparrow} \quad \text{lower boundary}$$

$$I_{\mu\nu}^{opaque}(z_{cld}) = B(T(z_{cld}),\nu)\cdot\Psi_{\mu\nu}(z_{cld}) +$$

opaque cloud radiance: $$+\int_{z_{cld}}^{Z_{sat}} \frac{\partial\Psi_{\mu\nu}}{\partial z}\eta(z,\nu)dz$$

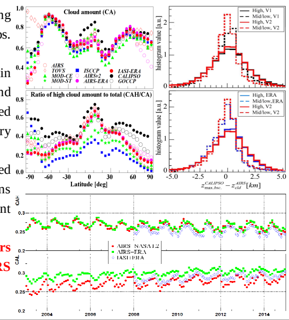


χ^2 minimization approach

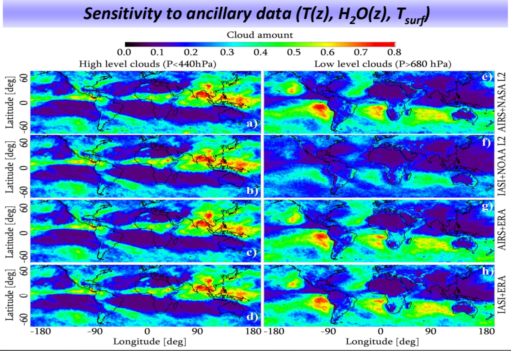
$$\chi^2(p_k) = \sum_i \frac{\left[\left(I_{opaque}(p_k,\nu_i) - I_{clear}(\nu_i)\right)\cdot\varepsilon(p_k) - \left(I_{meas}(\nu_i) - I_{clear}(\nu_i)\right)\right]^2}{\sigma^2(\nu_i)} W^2(p_k,\nu_i)$$

CIRS–LMD: a universal cloud retrieval package

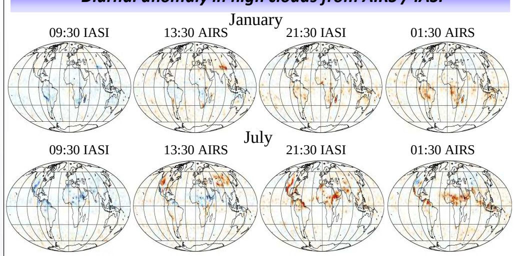
- Based on a weighted χ^2 method using channels around the 15µm CO_2 abs. band (Stubenrauch et al. 1999).
- Recently updated: radiative transfer in the lower atm. layers, latitudinal and seasonal CO_2 variation, normalized solution, various sources of ancillary data (T, H_2O, surface emissivity).
- Retrieved cloud parameters validated using CALIPSO/GEOPROF colocations and GEWEX Cloud Assessment Products (Stubenrauch et al., 2013)
- **Applied to 13 years of AIRS, 8 years of IASI, and 30+ years of HIRS observations.**
- Portable to other infrared sounders.



Sensitivity to ancillary data (T(z), H_2O(z), T_{surf})

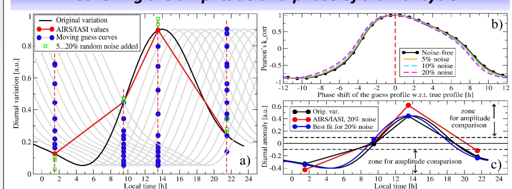


Diurnal anomaly in high clouds from AIRS / IASI

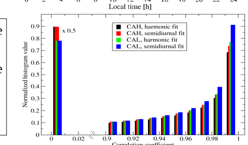


- Certain areas demonstrate diurnal patterns like: (−/0/+/+) or (−/+/+/−)
- These patterns are stronger in the summer hemisphere
- Variation, which follows the detectable diurnal pattern, is stronger over land

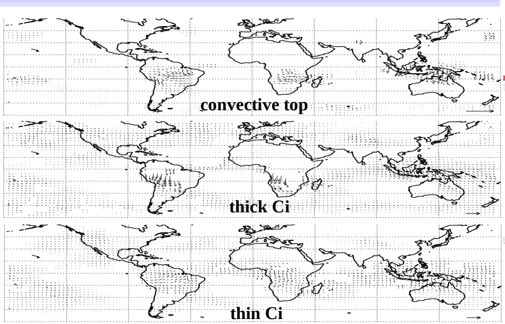
Retrieving the amplitude and phase of diurnal cycle



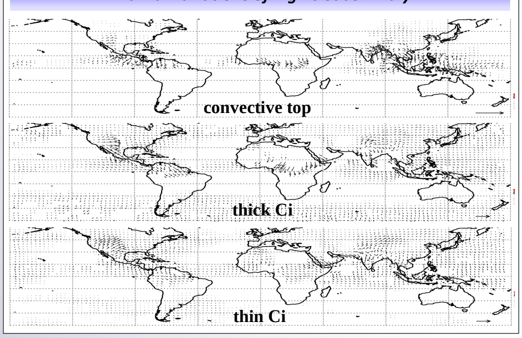
- Four measurements per day are just on the edge for the detection of diurnal cycle
- Using the advantage of knowing the shape of the variation (Cairns, 1995)
- Maximal correlation coefficient gives φ
- In the second step, amplitude is estimated



Diurnal variations of high clouds in January



Diurnal variations of high clouds in July



Bulk microphysical properties of clouds

$$D_e = 2\frac{\int \frac{3V}{4p} n(r)\,dr}{\int \frac{P}{p} n(r)\,dr} = \frac{3}{2}\frac{IWC}{\rho_i P}$$

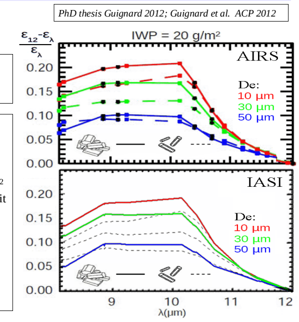
PhD thesis Guignard 2012; Guignard et al. ACP 2012

Bimodal size distribution assumed
Spectral emissivity difference increases with decreasing De

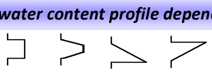
for semi-transparent cirrus :
- P_{cld} < 440 hPa
- 0.20 < ε_{cld} < 0.85

- sensitivity: D_e < 90mm, IWP < 120gm^{-2}
- indication of most probable crystal habit

Sensitivity to assumptions:
- like in (*Rädel et al. JGR 2003*):
- small on cloud parameters (z, Δz, T)
- horizontal heterogeneity : 3%
- partial cloudy pixels: up to 10%
- small on crystal habit (5%)



Ice water content profile dependence on ice water path



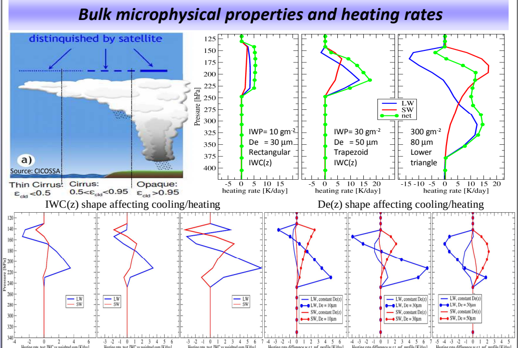
Feofilov et al., Atm.Chem.Phys, 2015

IWP [g m^{-2}]	Rectangular	Isosceles trapezoid	Lower triangle	Upper triangle	Relative occurrence
0–10	42	32	12 (+4)	14 (−3)	18
10–30	28	51	14 (+3)	7	21
30–100	25	55	16 (+4)	3	23
100–300	18	59	21 (+9)	2	17
300–1000	13	53	33 (+11)	1	12
> 1000	13	37	50	0	8

IWP [g m^{-2}]	Rectangular	Isosceles trapezoid	Lower triangle	Upper triangle	Relative occurrence
0–10	39	31	11	19	22
10–30	29	47	14	10	29
30–100	27	51	16 (+3)	6	27
100–300	21	56	20 (+10)	3	13
300–1000	19	52	27 (+9)	2	6
> 1000	19	41	40	1	2

- Clouds with the same IWP can have different IWC(z) vertical profile
- The IWC(z) affects the radiative transfer → energetic properties and remote sensing
- colocated AIRS / CALIPSO / GEOPROF / DARDAR
- 4 representative shapes
- statistical parameterization based on single variable: **IWP**
- independent on location / season
- constant and trapezoid: 80%
- upper triangle: IWP < 30g/m²
- lower triangle: increases with IWP from 11 to 33%

Bulk microphysical properties and heating rates



Conclusions and outlook

- Climate modeling and understanding the energy balance of the Earth's atmosphere need a reliable estimate of cloud radiative properties.
- Infrared instruments are sensitive to cirrus clouds, both day and night.
- CIRS-LMD modular cloud retrieval algorithm helps estimating cloud parameters from multispectral spatial observations in the infrared: AIRS, IASI, HIRS and can be applied to other instruments of this kind. The reliability of the retrieval has been confirmed through comparisons with active instruments (CALIPSO / CloudSat) and with other cloud climatologies from the GEWEX Cloud Assessment (Stubenrauch et al. 2013).
- Cloud parameters have been retrieved for AIRS (2003-2015), IASI (2007-2015).
- An approach to estimate the phase and amplitude of diurnal variation from four measurements per day (AIRS - IASI synergy) has been developed.
- Diurnal variations of high clouds are consistent with existing estimates and models.
- Bulk microphysical properties of high ice clouds have been analyzed from the synergy of active and passive instruments, leading to a parameterization of the vertical IWC shape in dependence of IWP (Feofilov et al., 2015).
- Future work will be focused on estimating, analyzing, and parameterizing radiative fluxes and heating rates for high-altitude clouds and cloud systems of different emissivity.