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TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

Cloud occurrence on the Antarctic plateau: ground-based detection and satellite products

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Data analysis at Dome-C (Antarctic Plateau)

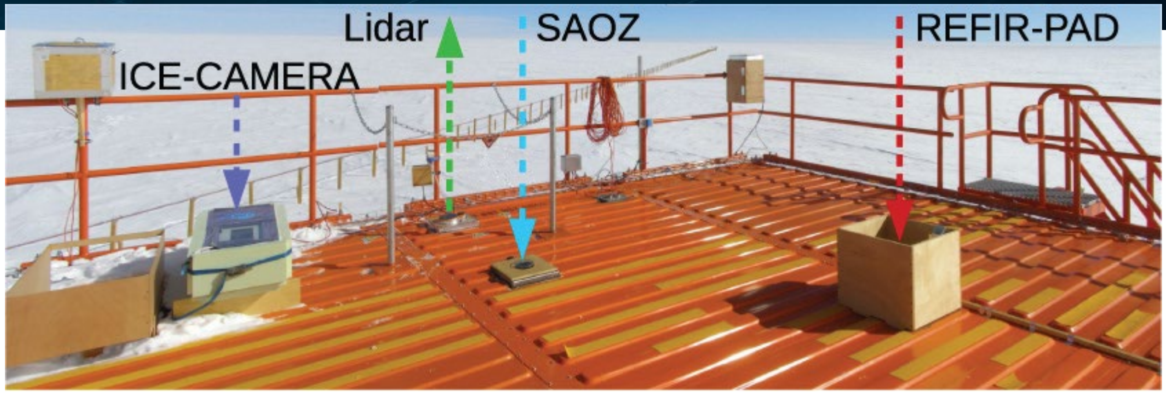
Within the PNRA project **FIRCLOUDS** (and **DOCTOR**) a remote ground-based station on the Antarctic Plateau is used to test our ability to observe and derive cloud properties by exploiting the far infrared (FIR, 100-600 cm^{-1}) and mid infrared spectral region.

The research aims at:

- Implementing **identification/classification** algorithms for high spectral resolution FIR-MIR satellite data (the 9th ESA Earth Explorer: FORUM)
- Providing a reference **statistic of cloud occurrence** at different timescales and investigate for possible correlations with atmospheric parameters
- Testing **reference databases** (cloud properties) and **characterizing the signal** in presence of clouds at FIR
- Applying **retrieval methods** to infer cloud properties from FIR-MIR data and estimate **cloud radiative forcing**
- Comparing results from ground-based measurements with **satellite L3 and L2 products**

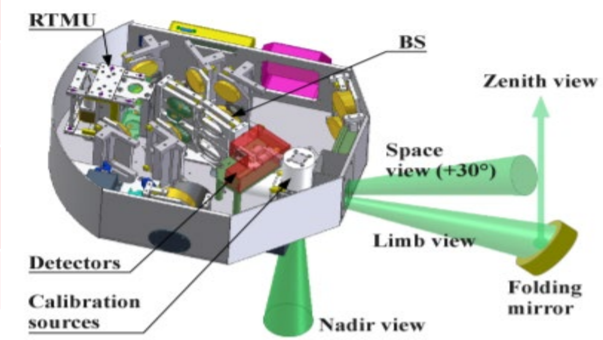
Concordia Station – Dome C (75.1°S, 123.3°E, 3233m)

esa



REFIR-PAD

Parameter	Values
Spectral bandwidth	**100–1500 cm^{-1}** (100–6.7 μm)
Spectral resolution	0.4 cm^{-1} (double-sided interferograms)
Optical throughput	0.01 cm^2 sr
Line of sight	Zenith looking with a field of view of about 100 mrad
Single-spectrum integration time	80 s
Measurement	∽ 5.5 min (average of four observations), Repetition rate ∽ **14 min** (sequence duration)
Measurement cycle	5-6 hours of measurements 1-3 hours of analysis
NESR	About 10^{-3} W/(m^2 sr cm^{-1}) at 400 cm^{-1}



Year	2012	2013	2014	2015	2012-2015
# Spectra	16177	19298	25089	27396	**87960**

LiDAR

Parameter	Values
Channels	Backscatter and depolarization channels
Wavelength	532 nm (linear polarization)
Measurement range	30–7000 m
Vertical resolution	7.5 m
Line of sight	Zenith looking through a window all weather
Telescope	10 cm diameter, f = 30 cm refractive optics
Filter	0.15-nm interference filter
Laser	Quantel (Brio)

CIC - Algorithm

A **machine learning algorithm** performs a **principal component analysis** (PCA) to classify the scene as clear or cloudy, and to identify the type of cloud – multi-class comparison.

- **TS spectra** of each class (CLEAR and CLOUD sky, for example) are assembled into matrixes

$$TS_X = TS_X(\nu, t)$$

- **Extended TS** (ETS) are created by **adding the observed spectrum to the TS** matrix

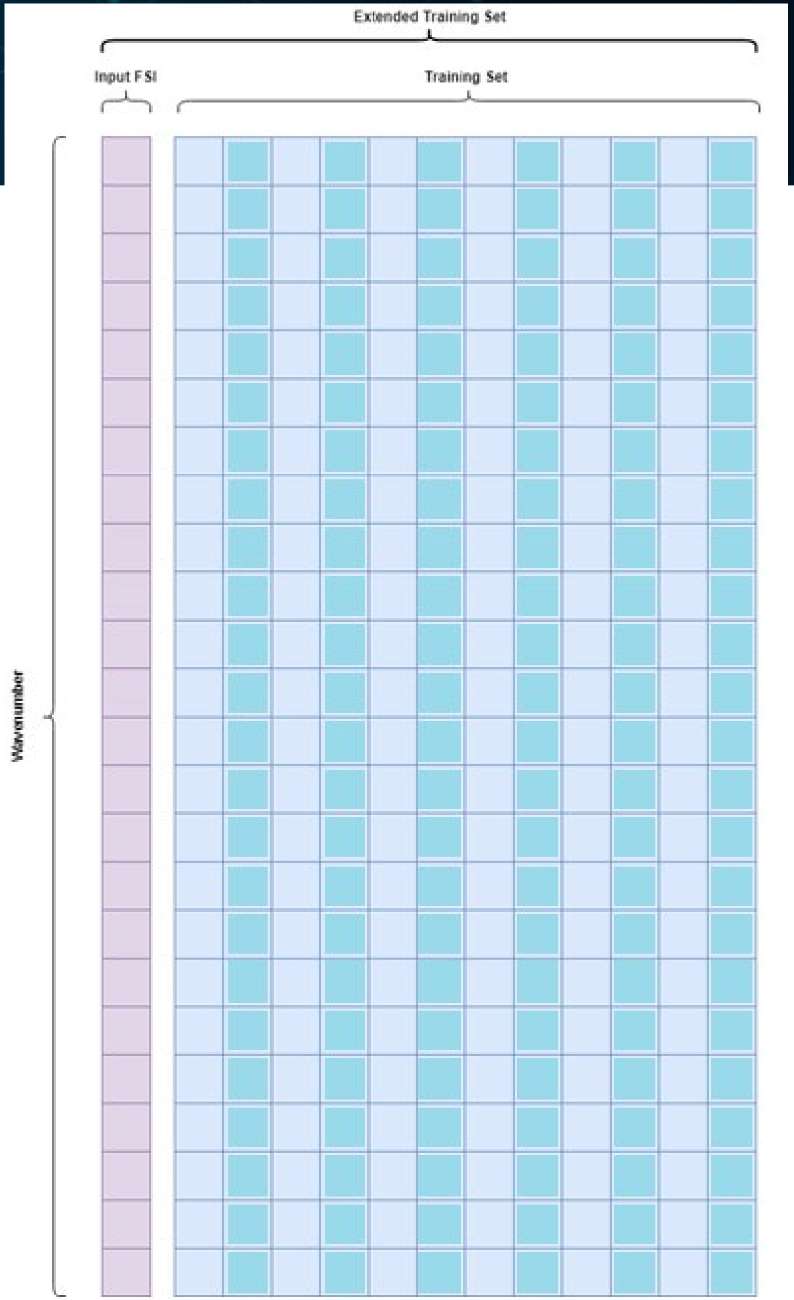
$$ETS_X = [TS_X(\nu, t), obs(\nu)]$$

- **Eigenvectors matrixes** are computed for TS and ETS

$$(E)TSEM_X(\nu, p) = eig\left(cov\left((E)TS_X(\nu, t)\right)\right)$$

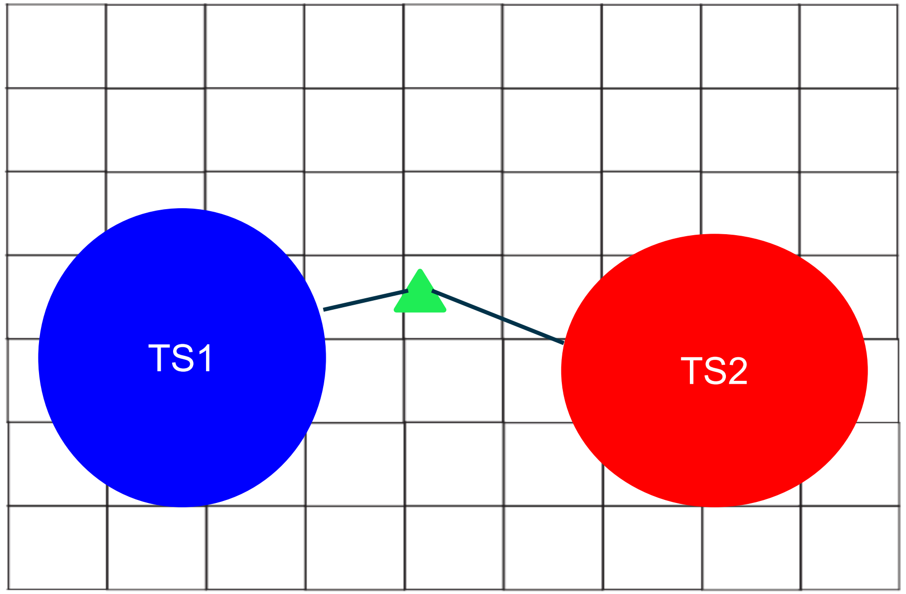
- **A similarity index (SI)** is defined as the comparison of the significant eigenvalues of TS and ETS **for each class**

$$SI_X = 1 - \frac{1}{2P_0} \sum_{p=1}^{P_0} \sum_{\nu=1}^{\nu_{tot}} \left| ETSEM_X(\nu, p)^2 - TSEM_X(\nu, p)^2 \right|$$

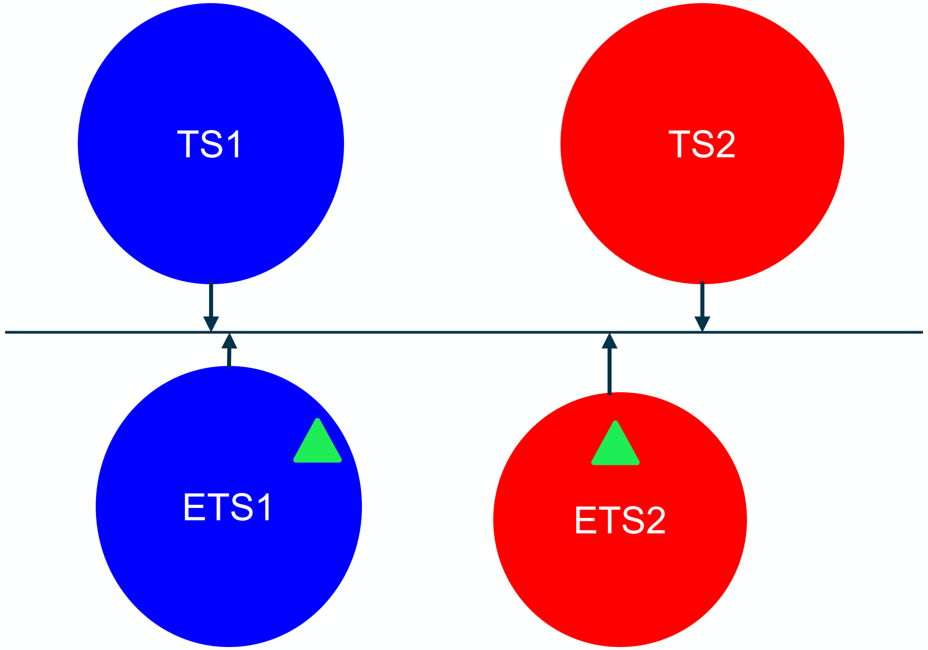


Machine Learning: The CIC metrics

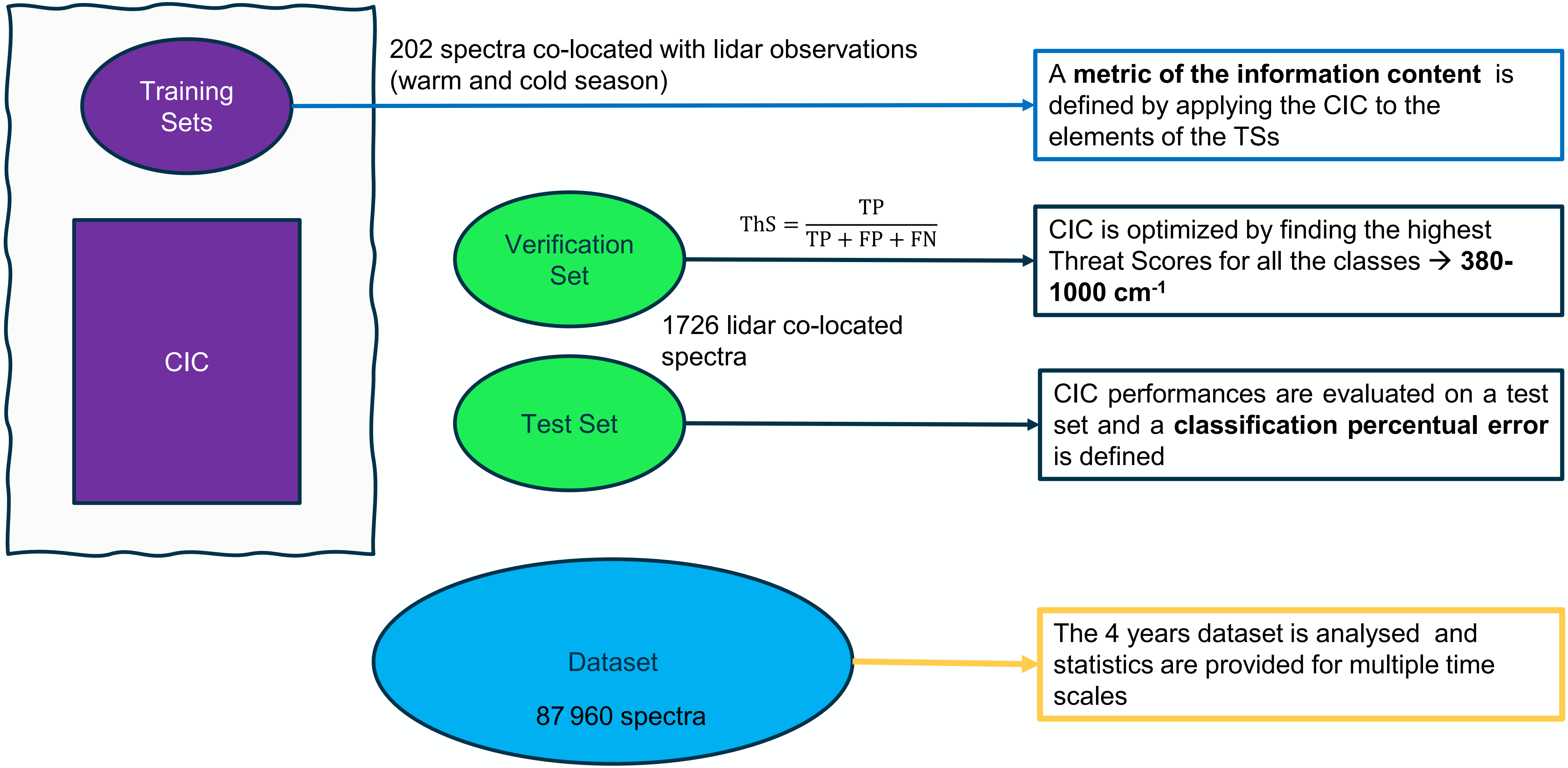
Support Vector Machine with linear kernel analyses the key features of two classes (defined by a linear discriminant analysis)
A supervised learning algorithm defines the features of 2 reference training sets and a metric to establish the distance between the analyzed element and the TSs



CIC exploits the PCA analysis to extract the information content of 2 reference TSs and their change after the addition of the analyzed element. This allow to rely on small TSs and an easy to implement algorithm



CIC: optimization and error definition



Results: total mean and interannual variability

Dataset spans over 4 years of data comprising 87758 spectra classified

CIC CLASSIFICATION	ENTIRE DATASET (%)	2012 (%)	2013 (%)	2014 (%)	2015 (%)
CLEAR SKY	**72.3 ± 1.5**	68.6 ± 1.4	75.1 ± 1.5	76.3 ± 1.5	68.8 ± 1.4
ICE CLOUD	**24.9 ± 0.3**	25.4 ± 0.3	22.8 ± 0.3	21.1 ± 0.3	29.6 ± 0.4
MIXED-PHASE CLOUD	**2.7 ± 0.3**	5.8 ± 0.6	2.0 ± 0.2	2.5 ± 0.2	1.5 ± 0.2
UNCLASSIFIED	**0.1 ± 0.1**	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1
Mean T (°C)	-53.5	-49.6	-54.5	-53.4	-55.0
Warm season Mean T (°C)	-40.2	-37.6	-41.0	-40.7	-41.1

- Inter-annual variability of total cloud occurrence on Dome-C: the sum of ice and mixed-phase clouds, spans between about 23 and 31%.
- Cloud occurrence is in accordance with Adhikari et al. (2012), who analysed data from CloudSat and CALIPSO between 2006 and 2010
- Positive correlation between mean air temperatures in the warm macro-season and the occurrence of mixed-phase clouds

Seasonal Means: cloud occurrence and surface air T

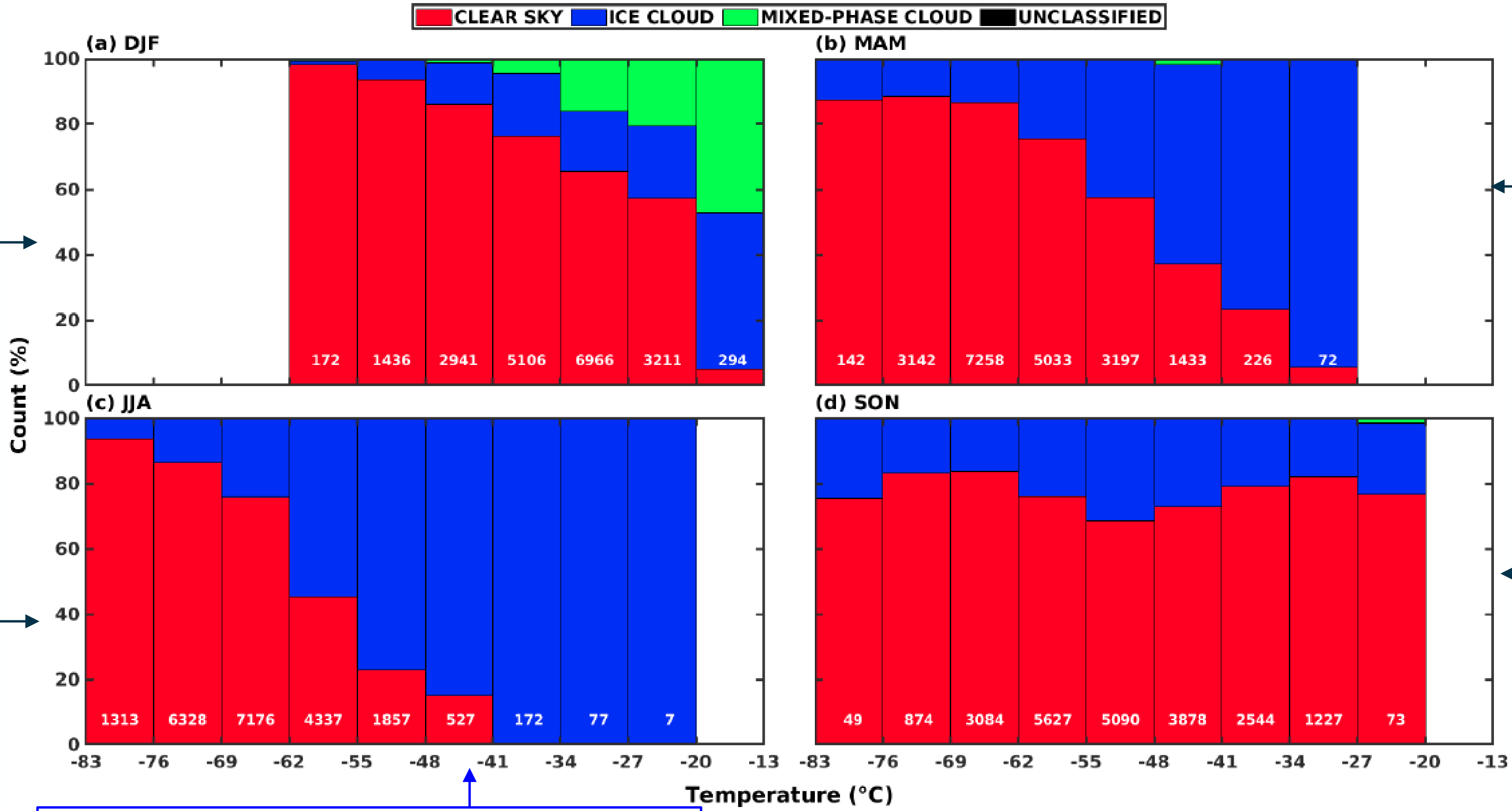
The detected cloudy sky occurrence increases (clear skies decrease) as surface air temperature increases (except that for the spring -SON)

Summer: Total CF

<Ts_clear> = -36.4°C
<Ts_cloud> = -31.9°C

Winter: LW CF

<Ts_clear> = -67.9°C
<Ts_cloud> = -59.0°C



Autumn

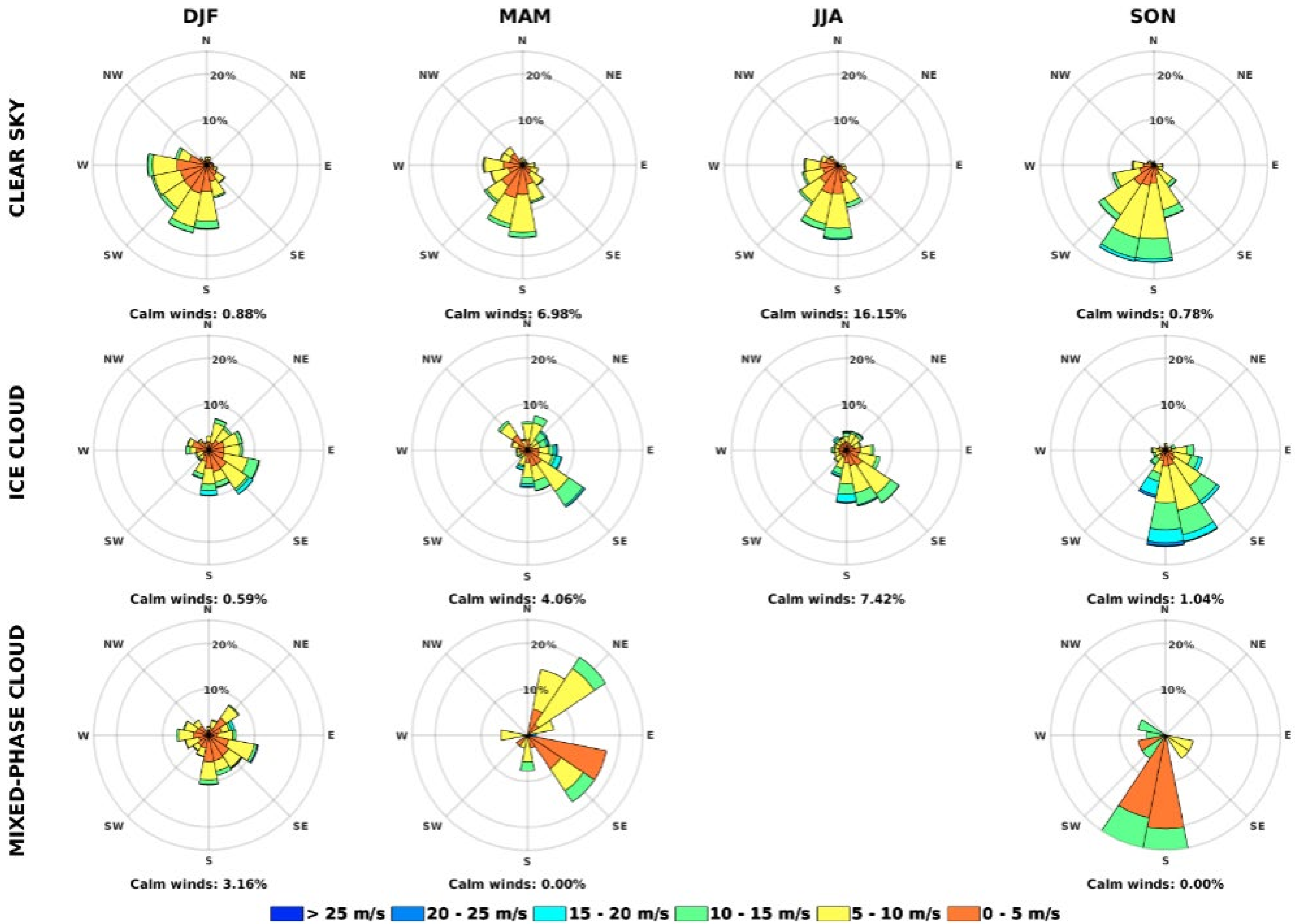
<Ts_clear> = -62.7°C
<Ts_cloud> = -55.4°C

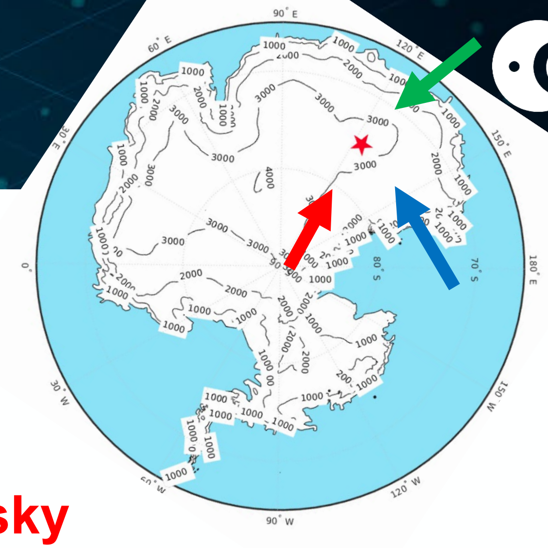
Spring: CF?

<Ts_clear> = -62.7°C
<Ts_cloud> = -55.4°C

For T > -43.3°C only ice clouds are detected

Cloud occurrence and surface winds





Clear sky

Dominant surface winds from **South-West**

Ice clouds

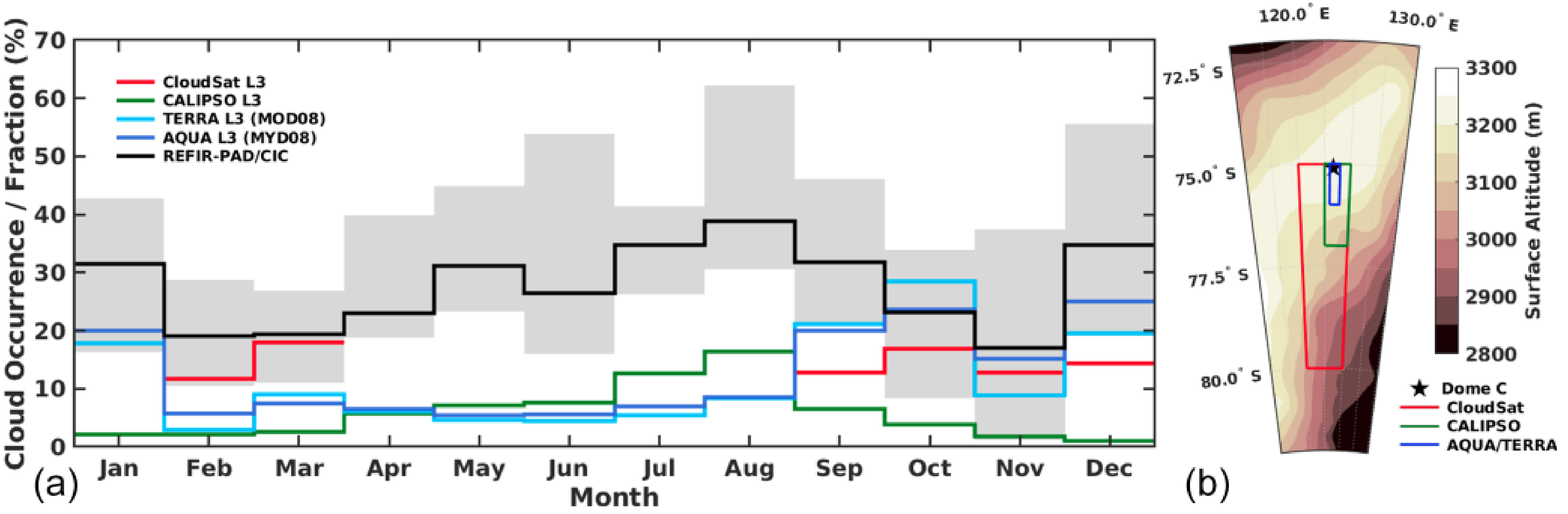
Dominant surface wind direction is from the **South-East**, and the wind intensity is larger than in clear sky conditions on average (7.7 m/s versus 6.1 m/s).

Mixed-phase

Dominant component: **South-East**

North-East winds are observed only when mixed-phase clouds are detected.

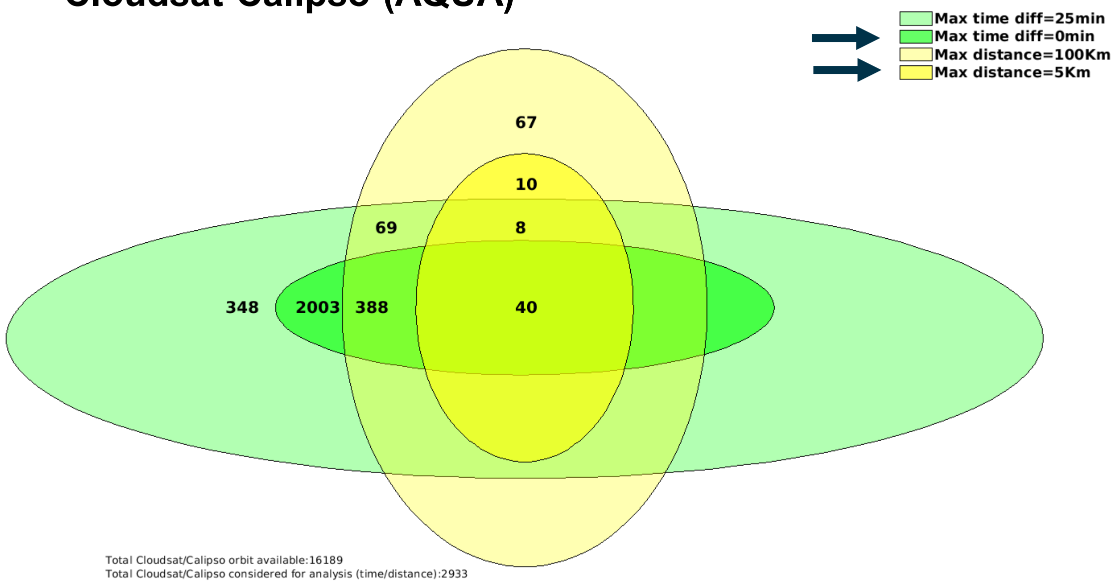
Monthly means: comparison with L3 satellite products



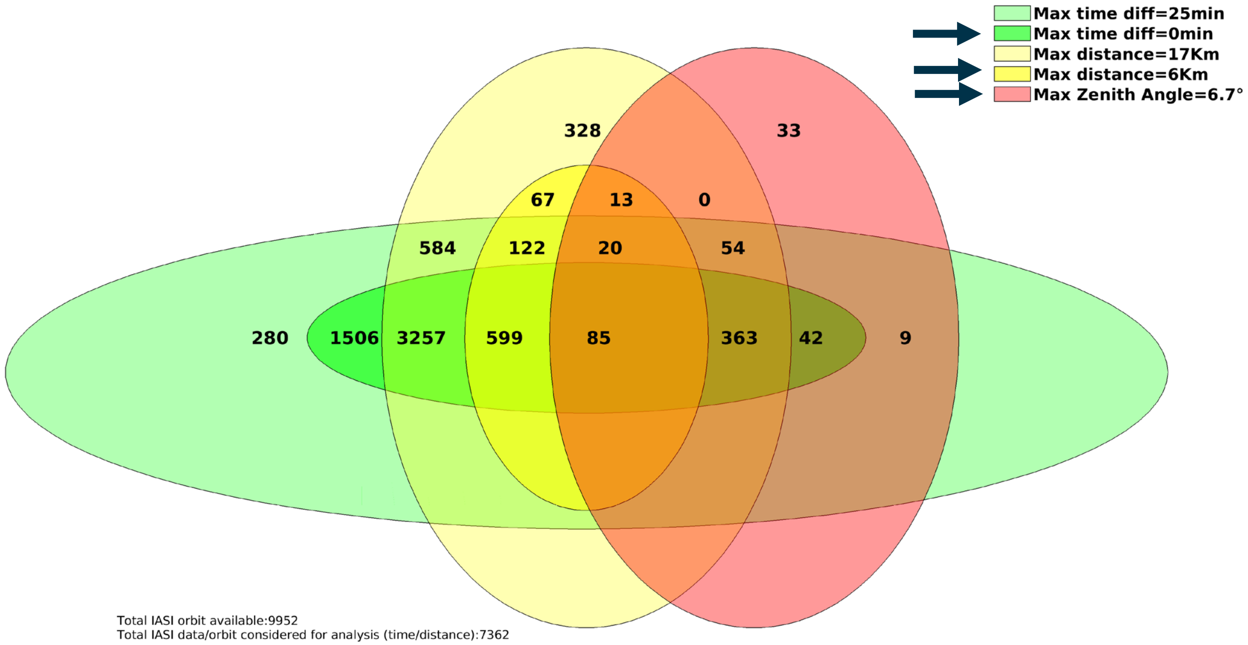
Sensor	Product (area)	Notes
MODIS	Cloud fraction (3 000 km^2)	Low efficiency at IR – Dependent on solar zenith angle
CALIOP	Vol. cloud occurrence (15 000 km^2)	Low efficiency to detect thin clouds close to the ice surface
CLOUDSAT	Vol. cloud occurrence (75 000 km^2)	Unable to detect thin cirrus (vertical res 500 m)

Co-location with satellite L2 products

Cloudsat-Calipso-(AQUA)



IASI



Satellite	Overpass Time (UTC)
AQUA (~1 km res.)	7.45-8.15 // 15.15-15.45
Cloudsat-Calipso (~5 km res.)	"

Satellite	Overpass Time (UTC)
METOP-A (~12km res.)	15.30-16.00 // 22.30-23.00
METOP-B (~12km res.)	15.00-15.30 // 23.00-23-30

L2 cloud occurrence

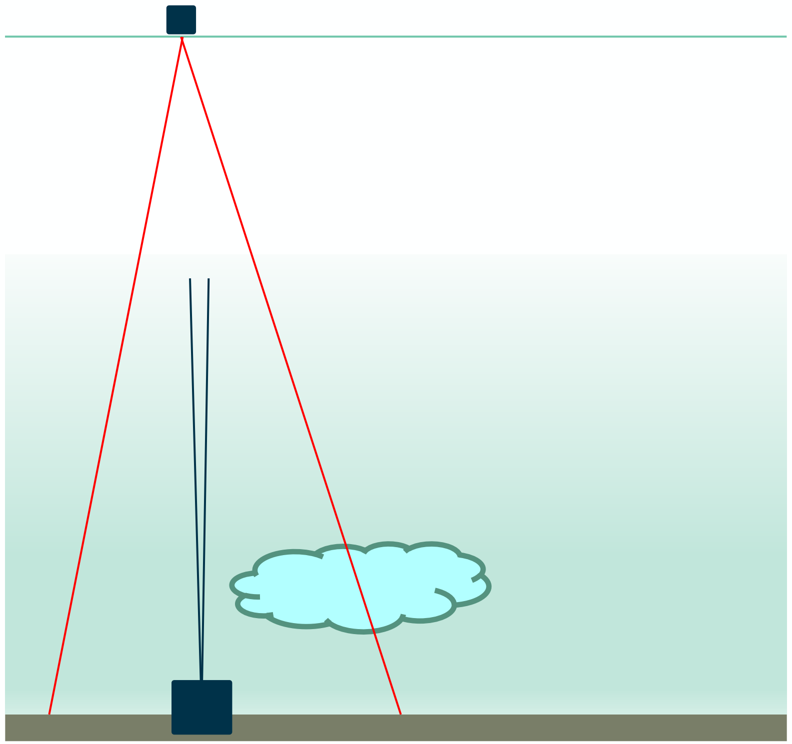
Total		CLEAR	ICE CLOUD	MIXED PHASE	UNCLASS.
85	CIC	62 (73%)	20 (23.5%)	3 (3.5%)	-
	IASI	8 (9.4%)	75 (88.2%)	2 (2.4%)	-

Total		CLEAR	ICE CLOUD	MIXED PHASE	UNCLASS.
40	CIC	28 (70%)	9 (22.5%)	3 (7.5%)	-
	CLOUDSAT-CALIPSO	38 (95%)	0 (0%)	2 (5%)	-
	MODIS AQUA	35 (87.5%)	4 (10%)	0	1 (2.5%)

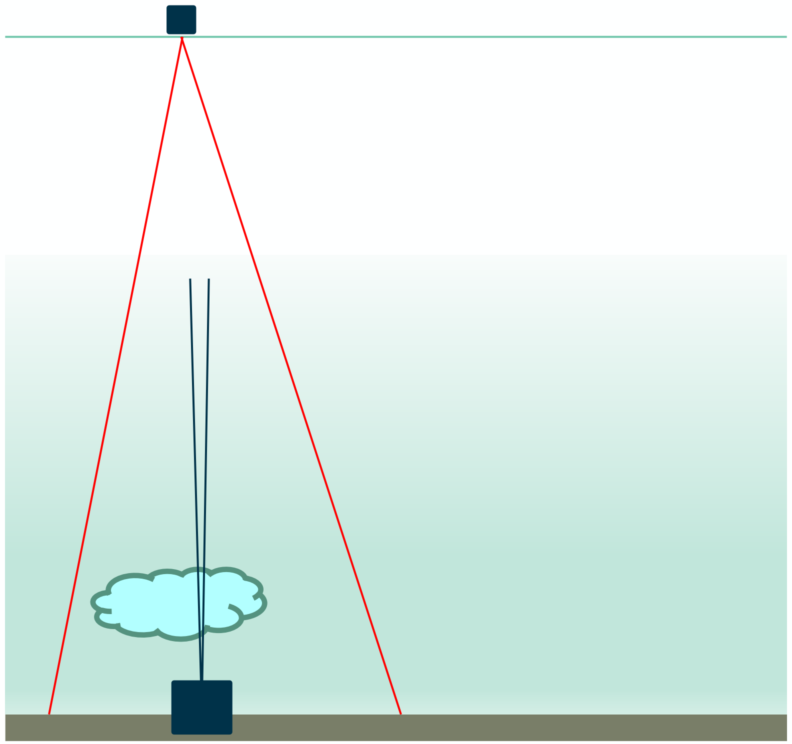
Is the satellite footprint size the cause for the different cloud occurrence statistic?

Comments about comparison

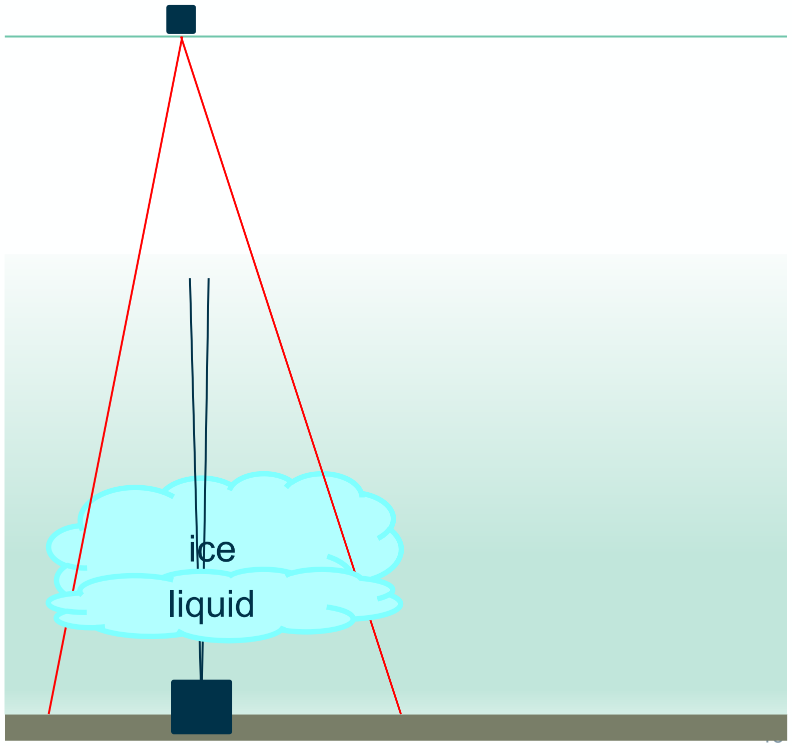
Clear from ground does not mean clear from satellite



Cloudy from ground should mean (at least partially) cloudy from satellite



Cloud properties (i.e. phase) from ground are different from cloud properties from sat



L2 cloud occurrence

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	MODIS AQUA	35 (87.5%)	4 (10%)	0	1 (2.5%)
	MODIS AQUA 12KM (CF>0)	31 (77.5%)	8 (20%)	0	1 (2.5%)

Main conclusions and future measurements

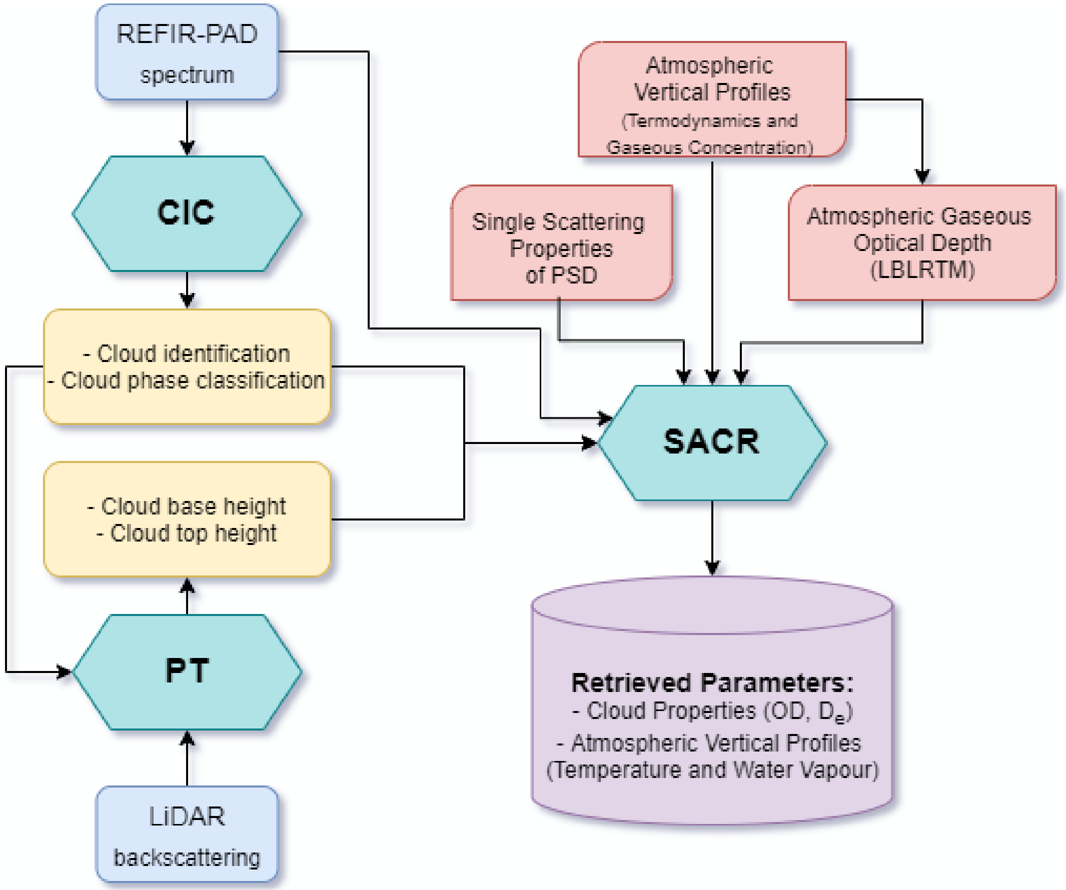
- By adapting the cloud classificator of the FORUM E2ES a solid statistic on cloud occurrence and phase is build from ground-based interferometric data at FIR and MIR wavelengths

- L3 products are representative of grid areas. Monthly means cloud occurrence (fraction) show significant differences with respect to ground-based data mainly due to large size of the grid and to detection performances (seasonal dependent)

- Long records from ground based measurements are required to test L2 satellite products when strict co-location constrains are set. Significant differences are found among multiple satellite sensors performances

- New sensors have been recently deployed at Concordia station such as micro rain radar (MRR) operating at 24 GHz, an Halo camera and an Ice Camera to retrieve size distribution of falling crystals.

Instrument	Measure	Exploited Spectral Band	Retrieved Parameters	Algorithm
REFIR-PAD	spectral radiance	200–980 cm^{-1}	D_e, OD_v, H_2O/T profiles	SACR
REFIR-PAD	spectral radiance	380–1000 cm^{-1}	phase (ice or liquid)	CIC
LiDAR	Backscatt./depolar. signal	532 nm	CBH, CTH	PT



Documentation

Main References

Cossich, W., Maestri, T., Magurno, D., Martinazzo, M., Di Natale, G., Palchetti, L., Bianchini, G., and Del Guasta, M.: Ice and Mixed-Phase Cloud Statistics on Antarctic Plateau, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2021-97, in review, 2021.

Di Natale, G.; Bianchini, G.; Del Guasta, M.; Ridolfi, M.; Maestri, T.; Cossich, W.; Magurno, D.; Palchetti, L. Characterization of the Far Infrared Properties and Radiative Forcing of Antarctic Ice and Water Clouds Exploiting the Spectrometer-LiDAR Synergy. *Remote Sens.* 2020, *12 (21)*, 3574. https://doi.org/10.3390/rs12213574

Maestri, T., Arosio, C., Rizzi, R., Palchetti, L., Bianchini, G., & Del Guasta, M. (2019). Antarctic ice cloud identification and properties using downwelling spectral radiance from 100 to 1400 cm^{-1}. Journal of Geophysical Research: Atmospheres, 124. https://doi.org/10.1029/2018JD029205

Data Documentation (L2)

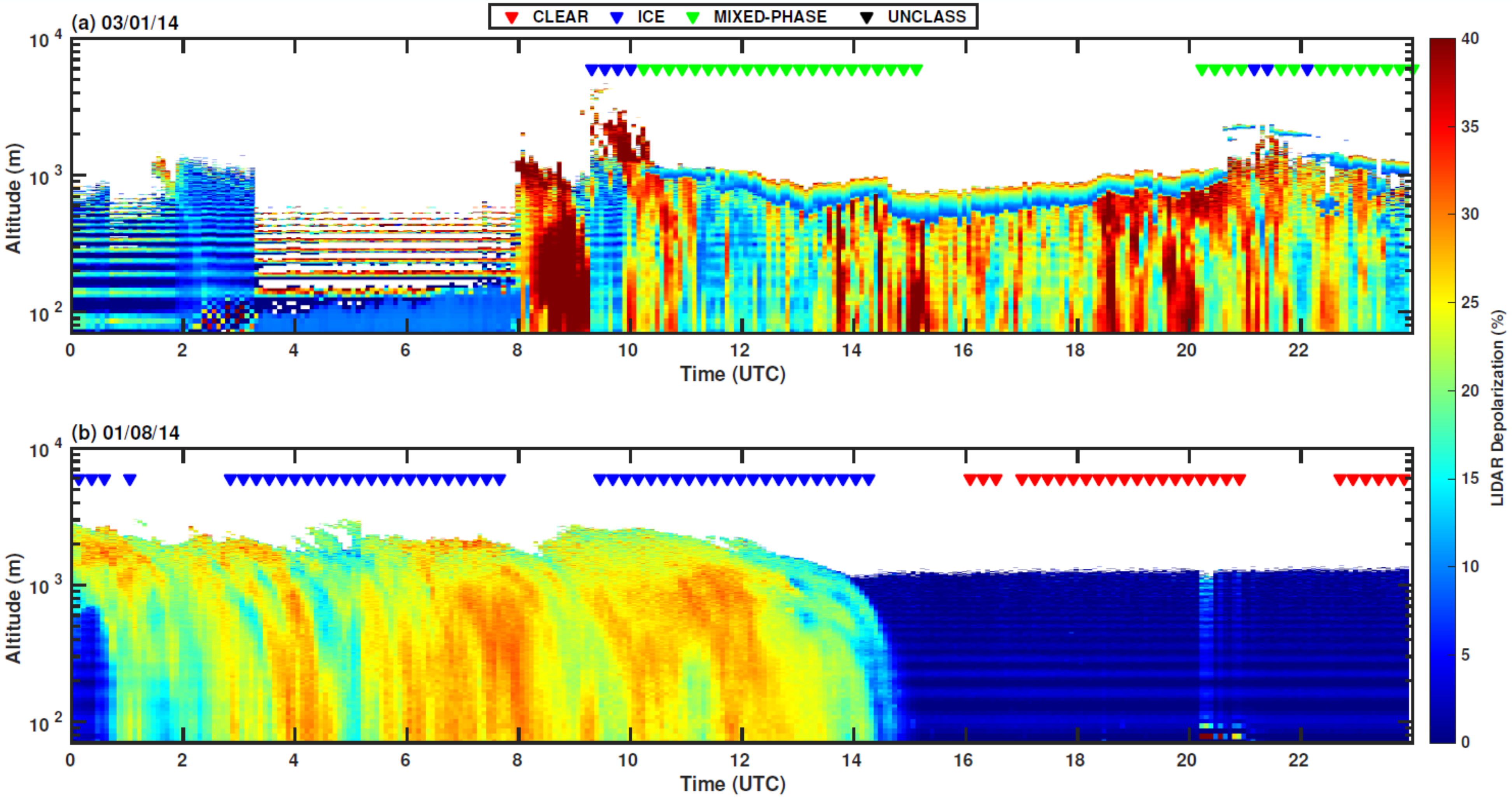
MODIS: https://atmosphere-imager.gsfc.nasa.gov/sites/default/files/ModAtmo/MOD06-ATBD_2015_05_01_2.pdf

CLOUDSAT-CALIPSO: CloudSat 2B-CLDCLASS-LIDAR Product Process Description and Interface Control Document (2019)

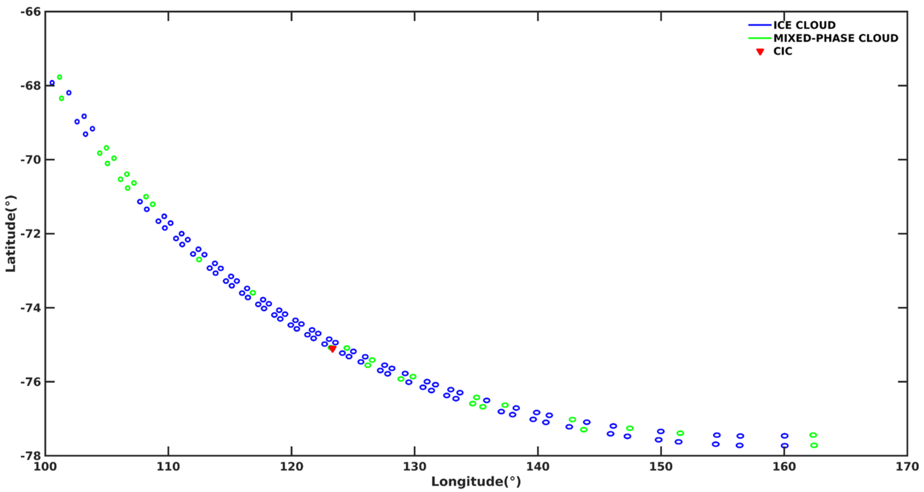
IASI: IASI Level 2: Product Generation Specification, EPS.SYS.SPE.990013 v8E e-signed (2017)

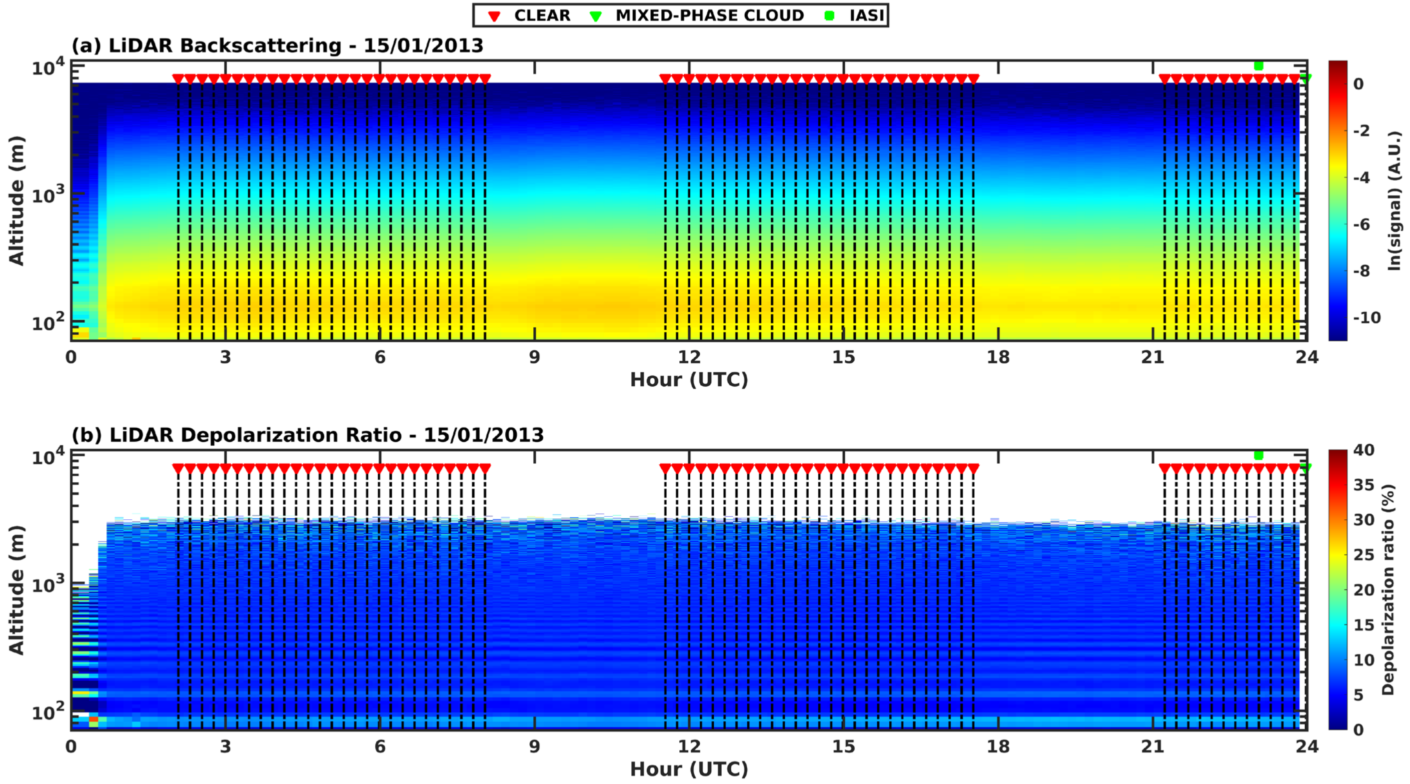
Classification results

Examples of classification on test set



CIC versus IASI





CIC versus MODIS and Caliop-CPR