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CONSIGLIO NAZIONALE DELLE RICERCHE

Study of the retrieval of ice crystal habits from the far infrared spectral radiance to be measured by the FORUM sounder

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Luca Palchetti

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Ice clouds: a mixture of crystals

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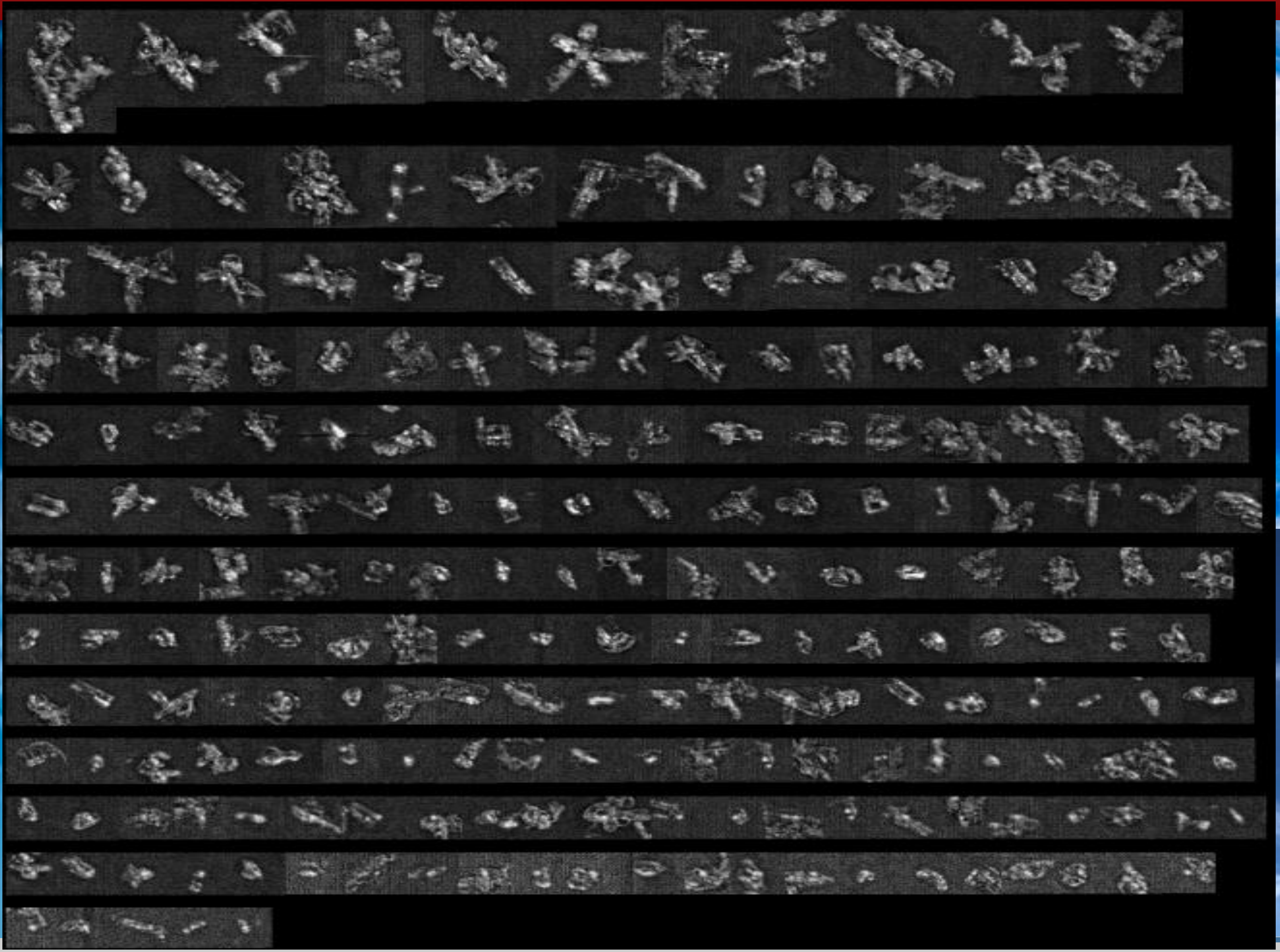

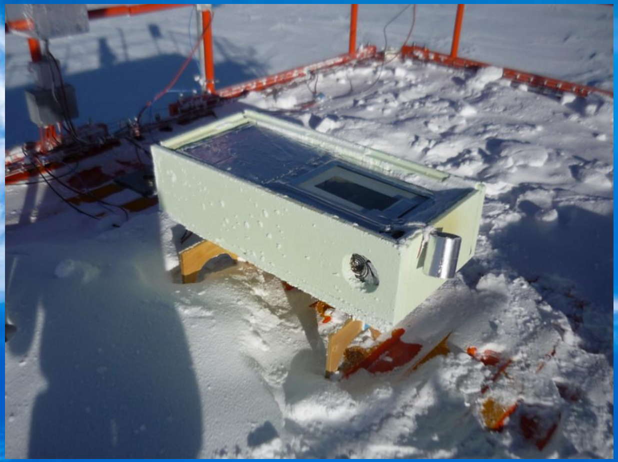

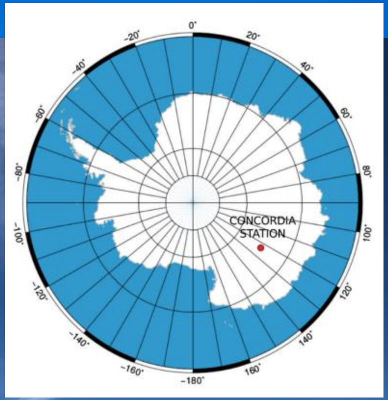

provided by Dr. Massimo Del Guasta

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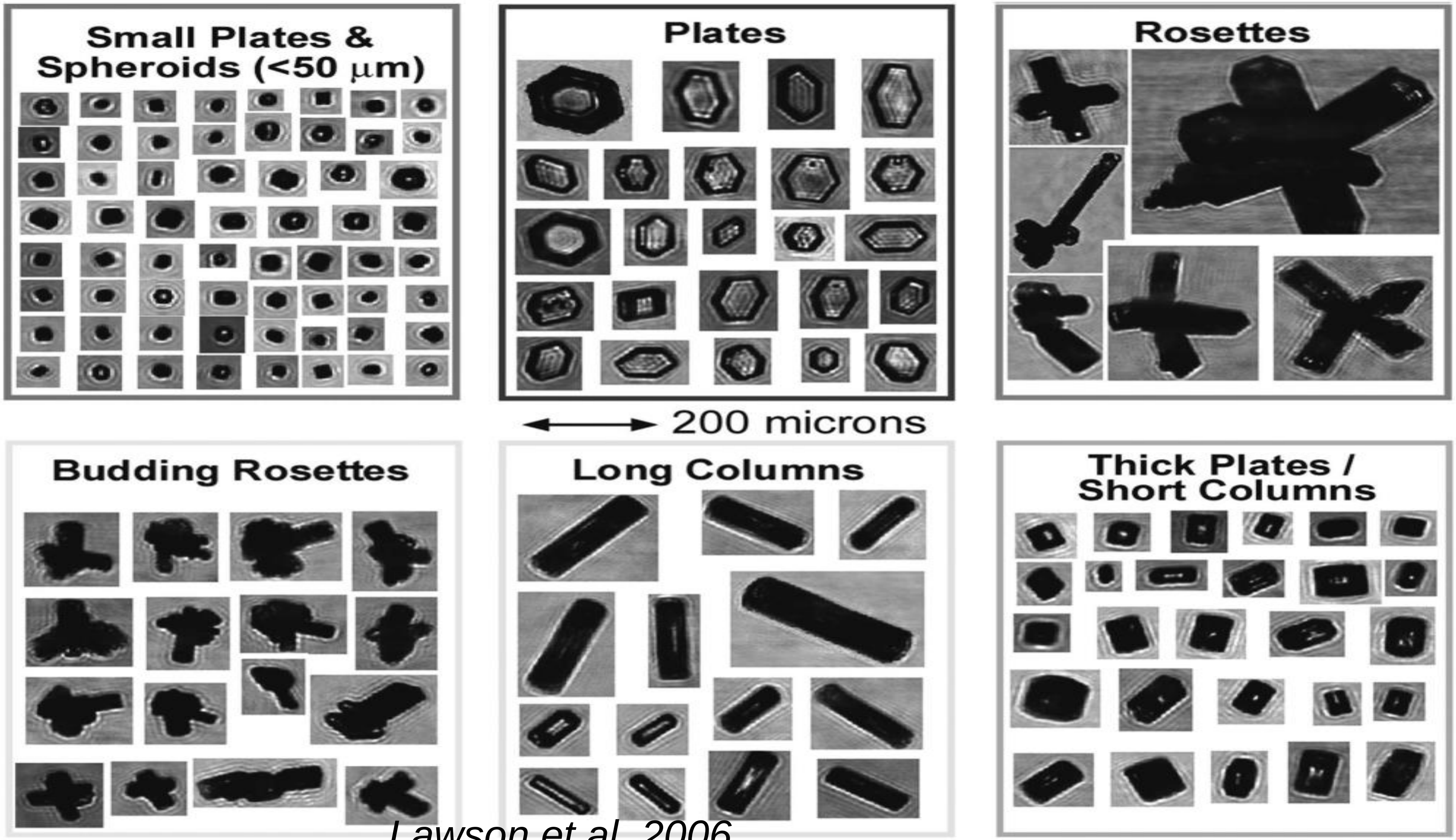
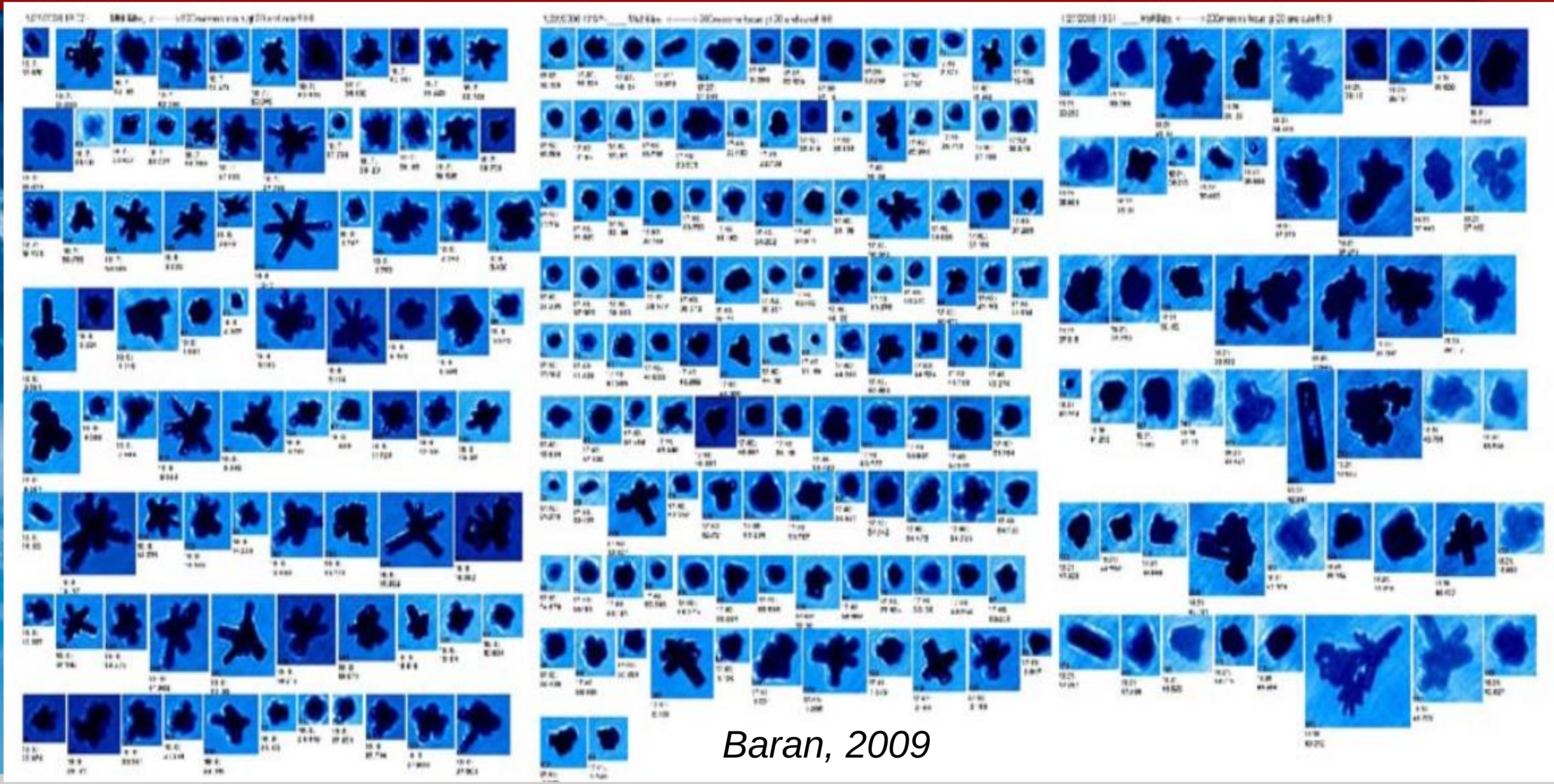


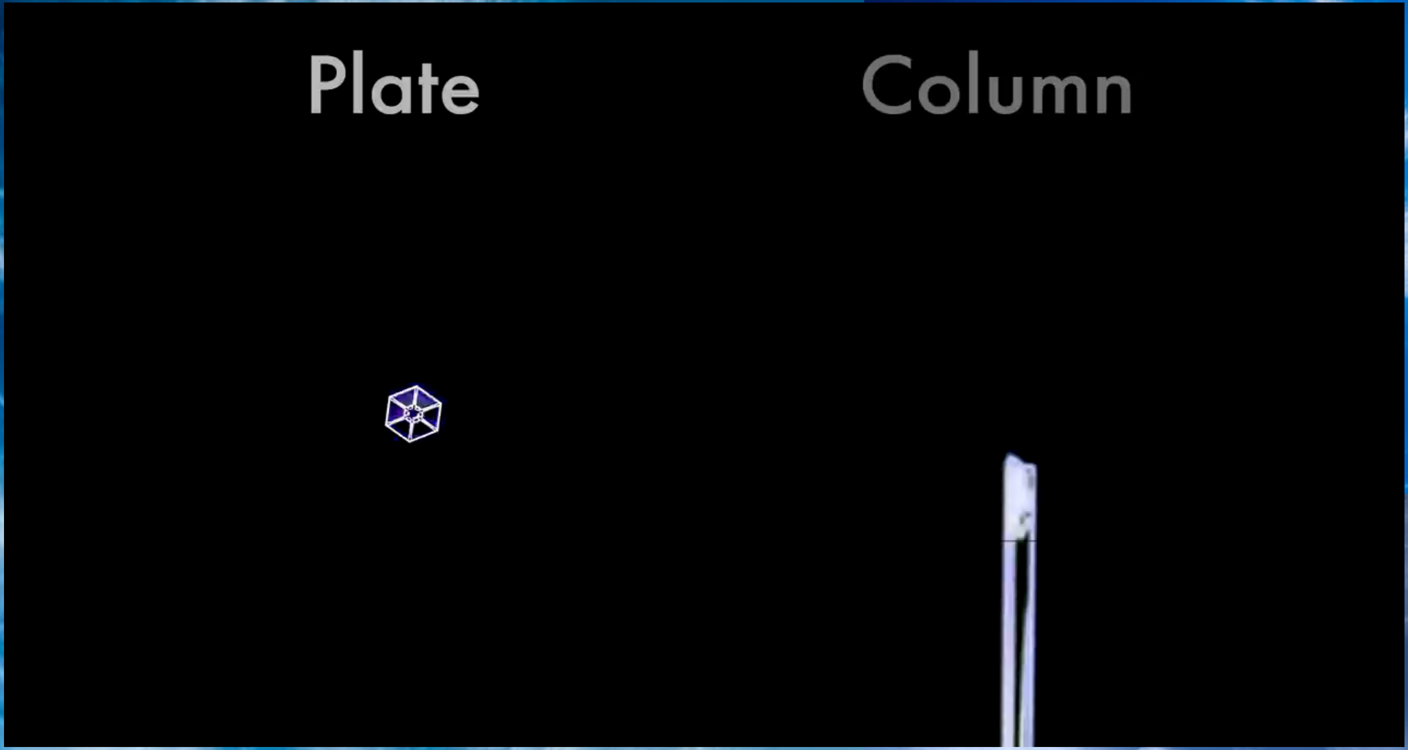
Lawson et al. 2006

Ice clouds: a mixture of crystals



Baran, 2009

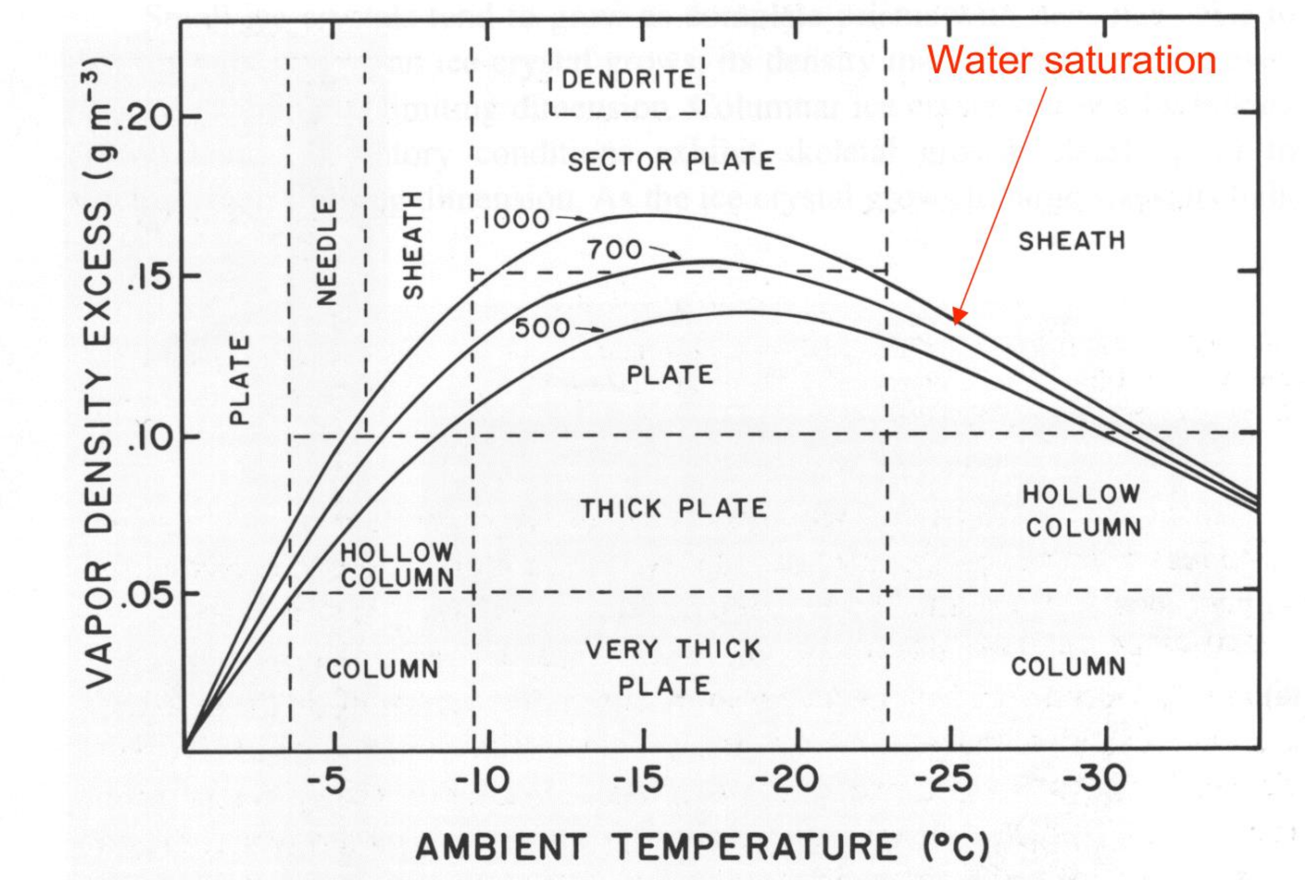
Ice crystals basic structure



Growth depends on the local supersaturation and temperature

From "Why are snowflakes like this?" Veritasium, interview to Prof. Kenneth Libbrecht

Crystal shape dependence on environmental conditions



NAKAYA
DIAGRAM

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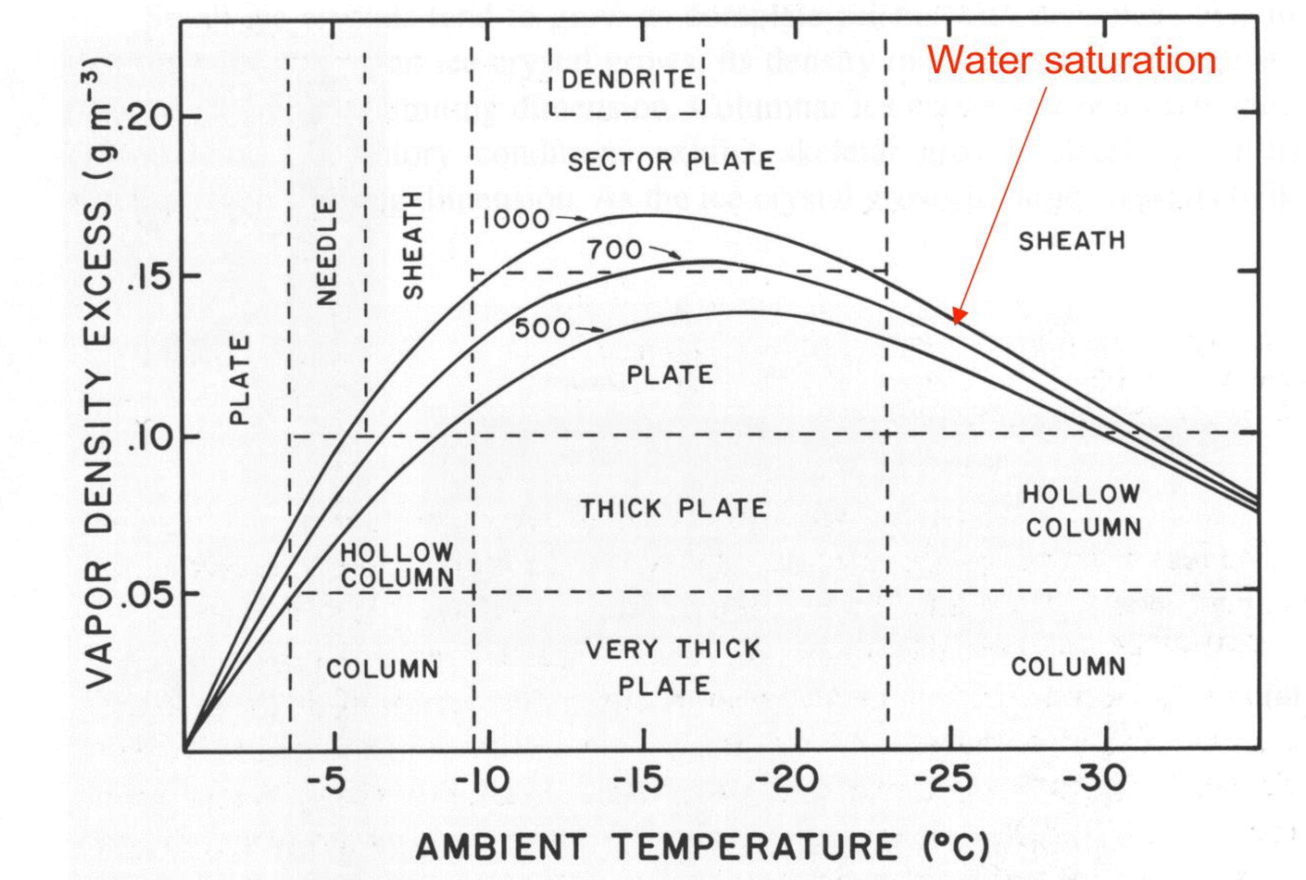
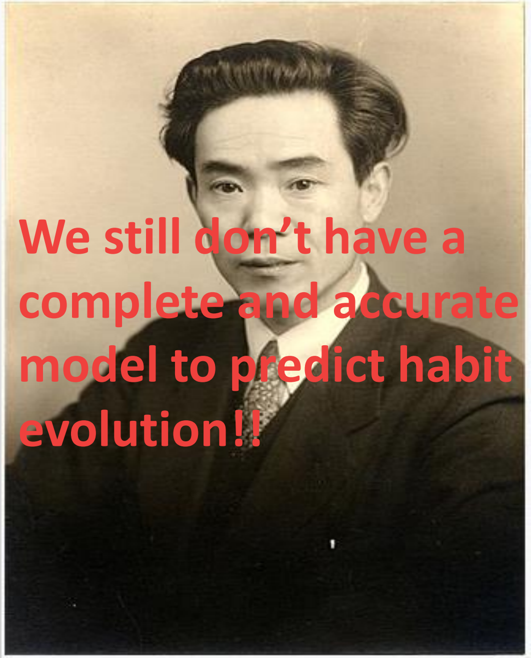


NAKAYA DIAGRAM



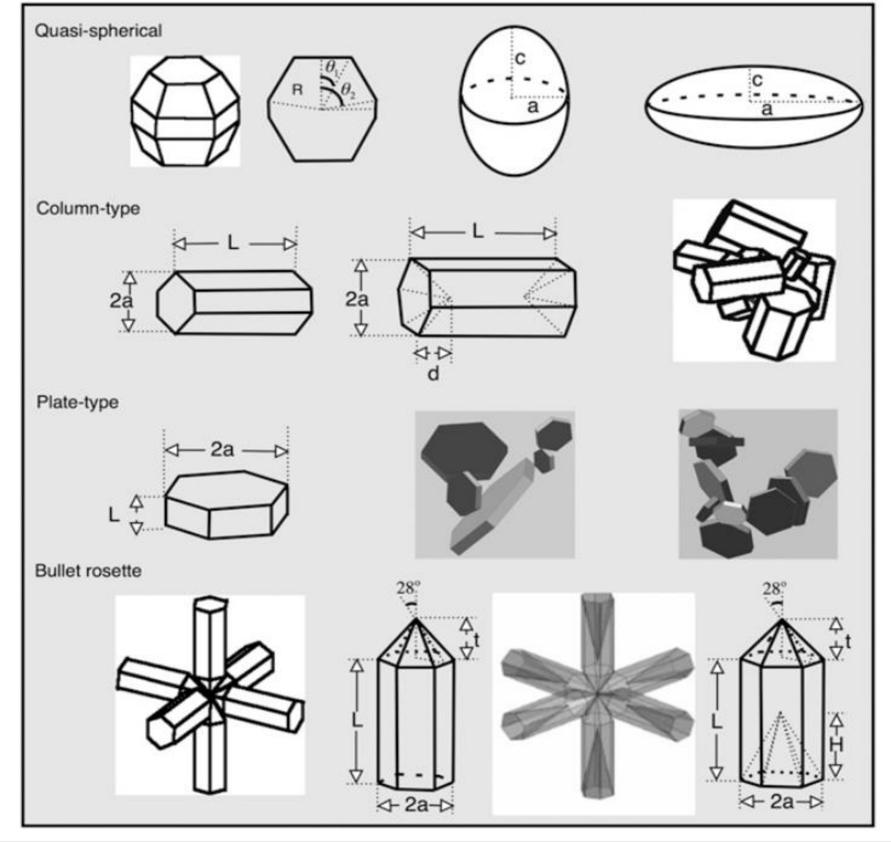
We still don't have a complete and accurate model to predict habit evolution!!

Why study cirrus clouds?

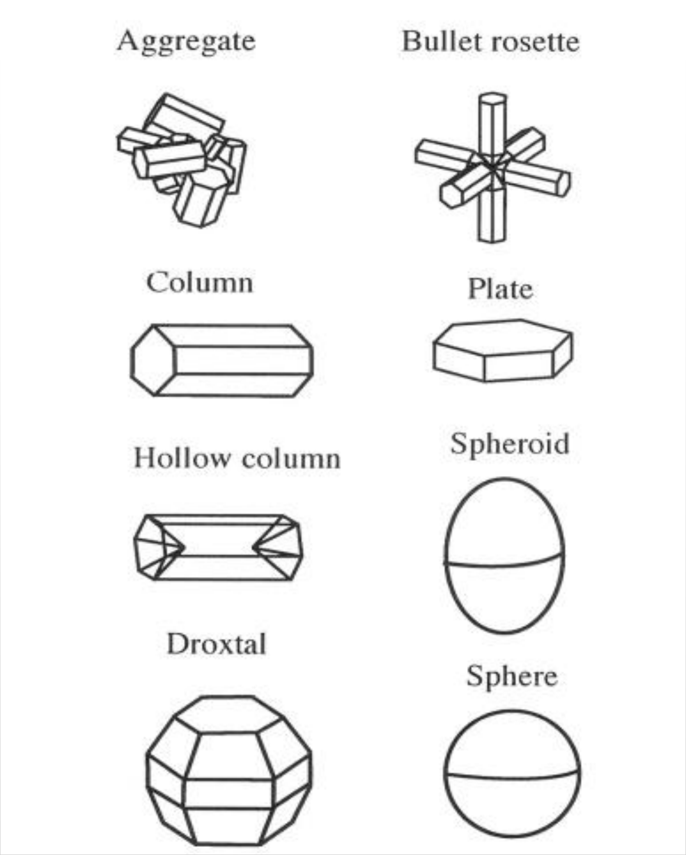


\\Ice clouds are extremely important to determine the Earth’s Radiation Budget and they have a strong impact on climate

Single scattering properties of ice crystals



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



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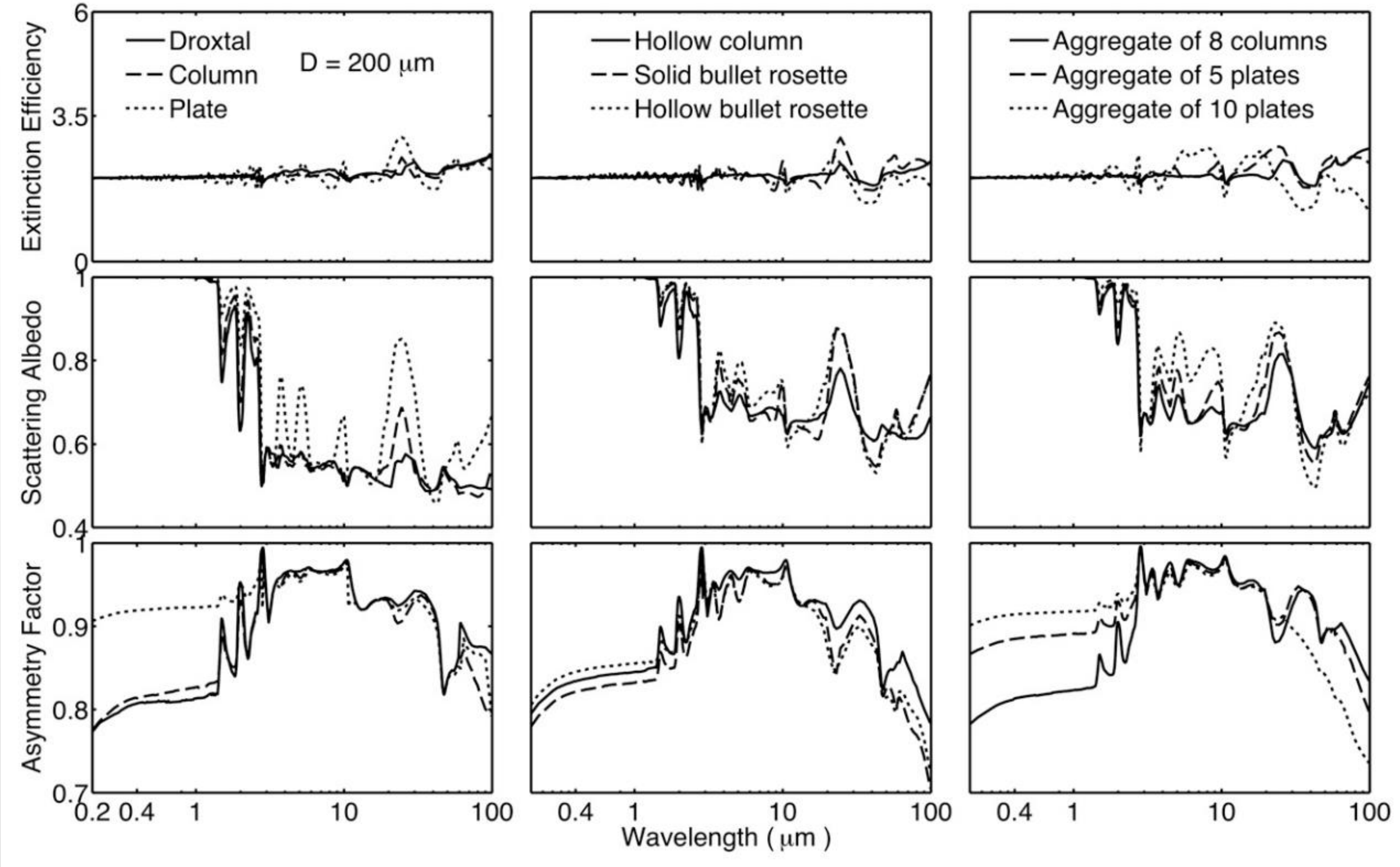

Different behavior of the optical coefficien

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

Simulation of the radiance in presence of a mixture

PARTICLE SIZE DISTRIBUTION (PSD)

$$n(L, L_m) = N_0 L^{\mu} e^{-(\mu+3)\frac{L}{L_m}}$$

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habit fractions

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EXTINCTION EFFICIENCY

$$\langle Q_e \rangle_\nu = \frac{\sum_h p_h \int_{L_{min}}^{L_{max}} Q_{e,h\nu}(L) A_h(L) n(L, L_m) dL}{\sum_h p_h \int_{L_{min}}^{L_{max}} A_h(L) n(L, L_m) dL}$$

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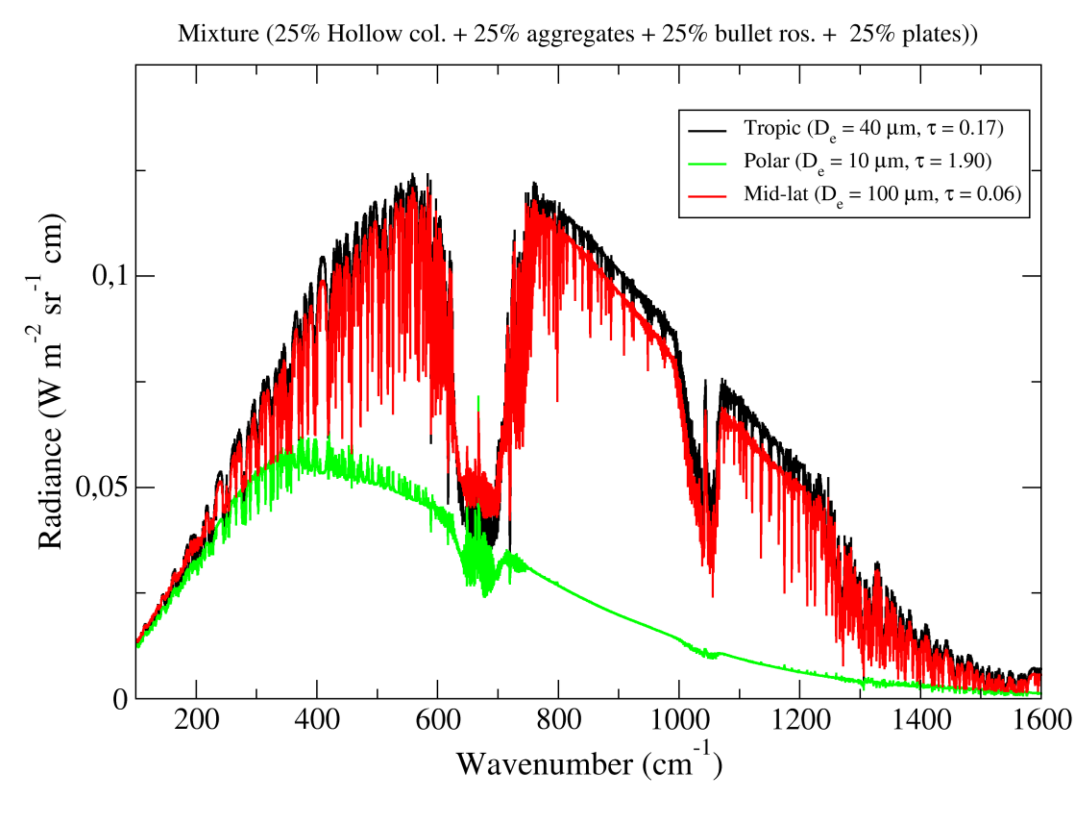
ASYMMETRY FACTOR

$$\langle g \rangle_\nu = \frac{\sum_h p_h \int_{L_{min}}^{L_{max}} g_h(L) Q_{s,h\nu}(L) A_h(L) n(L, L_m) dL}{\sum_h p_h \int_{L_{min}}^{L_{max}} Q_{s,h\nu}(L) A_h(L) n(L, L_m) dL}$$

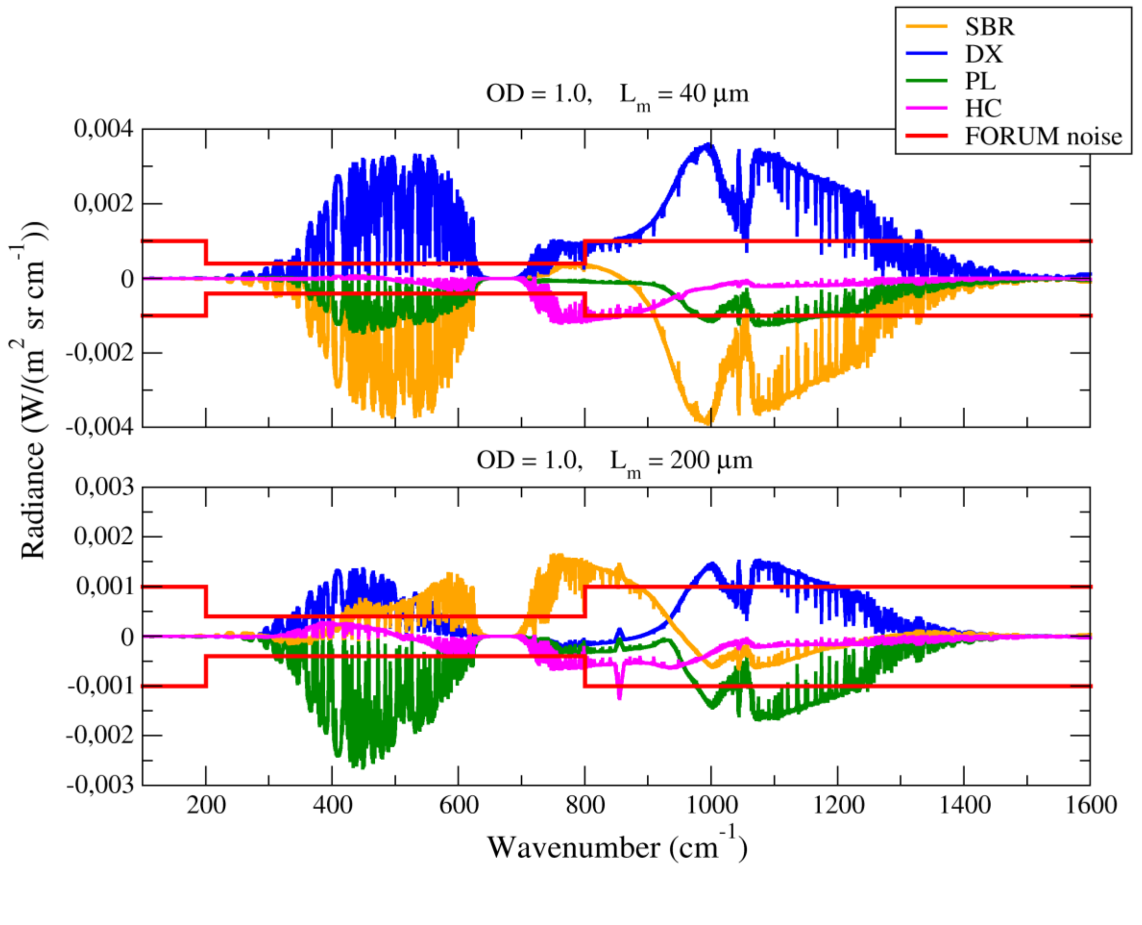
Sensitivity to the habits



Let's fix an ice cloud between 8 km and 10 km and simulate FORUM observations obtained for different latitudes and different ice clouds assuming an homogeneous habit distribution

The SACR code (*Di Natale et al. 2020, JQSRT*) **is used to simulated the radiative trasfer in the presence of ice clouds**

Sensitivity to the habits



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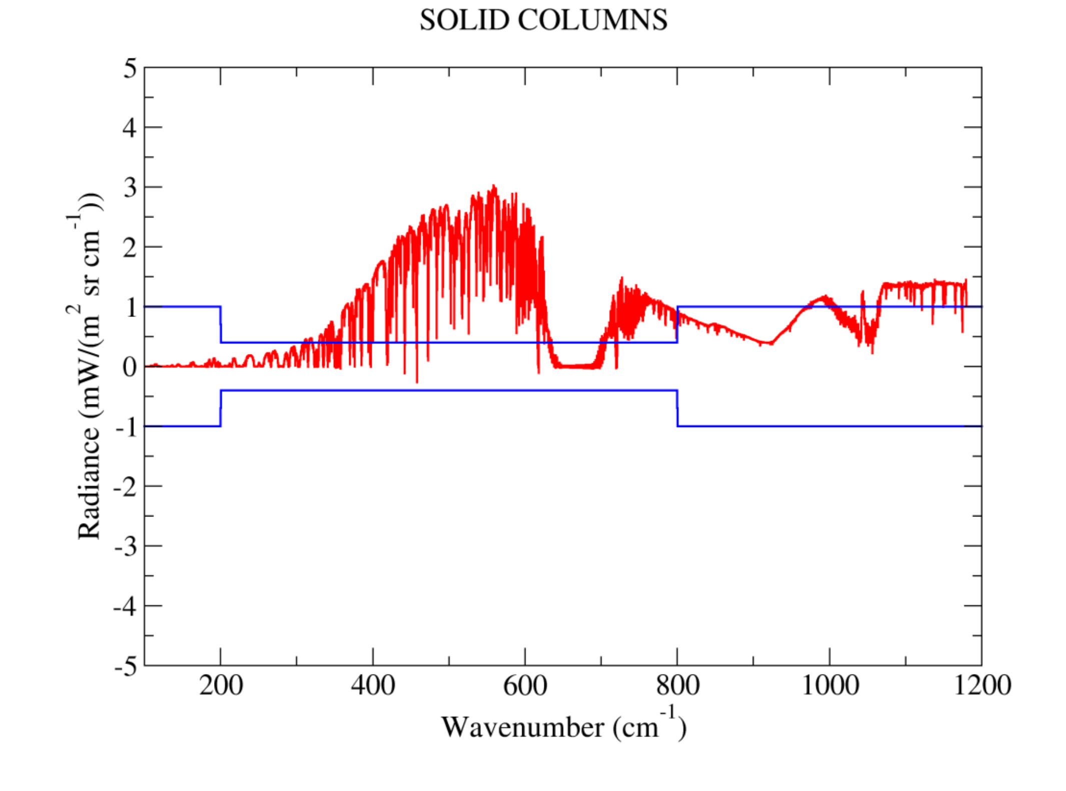

Far InfraRed spectrum represents the perfect candidate for ice crystal habits retrieval !

Towards the retrieval of the habit distribution

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$$\mathbf{q} = (q_1, \ldots, q_N) \rightarrow \boldsymbol{p}(\boldsymbol{q}) = (p_1(\boldsymbol{q}), \ldots, p_N(\boldsymbol{q}))$$

$$q_1, \ldots, q_N \in [\mathbf{0{,}1}]$$

Change of Variables !

Towards the retrieval of the habit distribution

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Change of Variables !

$$\begin{cases} p_1(\mathbf{q}) = q_1 \\ p_2(\mathbf{q}) = q_2(1 - p_1(\mathbf{q})) = q_2(1 - q_1) \\ p_3(\mathbf{q}) = q_3(1 - p_1(\mathbf{q}) - p_2(\mathbf{q})) = q_3(1 - q_1 - q_2(1 - q_1)) \\ \vdots \\ p_{N-1}(\mathbf{q}) = q_{N-1}(1 - p_1(\mathbf{q}) - \ldots - p_{N-2}(\mathbf{q})) = q_{N-1}(1 - \sum_{h=1}^{N-2} p_h(\mathbf{q})) \end{cases}$$

$$p_N(\boldsymbol{q}) = 1 - \sum_{h=1}^{N-1} p_h(\boldsymbol{q})$$

From Di Natale and Palchetti, 2022, JQSRT

The algorithm is integrated in the SACR code

Scenarios

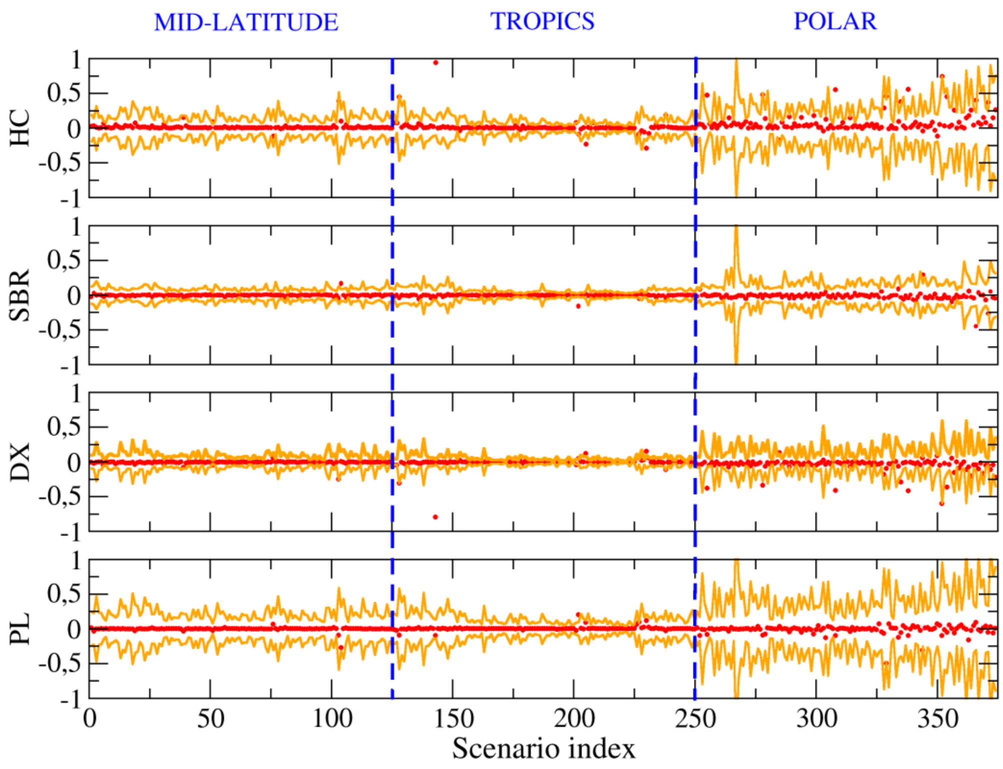
Tropics
Mid-latitude
Polar

OD	L_m (µm)
0.1	40
0.5	100
1.0	200
2.0	300
4.0	400

375 synthetic scenarios

	p_1 (HC)	p_2 (SBR)	p_3 (DX)	p_4 (PL)	p_1 (HC)	p_2 (SBR)	p_3 (DX)	p_4 (PL)	p_1 (HC)	p_2 (SBR)	p_3 (DX)	p_4 (PL)
	Mid-latitude				Tropics				Polar			
a)	0.80	0.10	0.05	0.05	0.80	0.10	0.05	0.05	0.80	0.10	0.05	0.05
b)	0.10	0.80	0.05	0.05	0.10	0.80	0.05	0.05	0.05	0.80	0.05	0.10
c)	0.05	0.10	0.80	0.05	0.05	0.05	0.80	0.10	0.05	0.05	0.80	0.10
d)	0.05	0.05	0.10	0.80	0.10	0.05	0.05	0.80	0.05	0.05	0.10	0.80
e)	0.20	0.30	0.30	0.20	0.30	0.25	0.25	0.20	0.40	0.10	0.40	0.10

Results

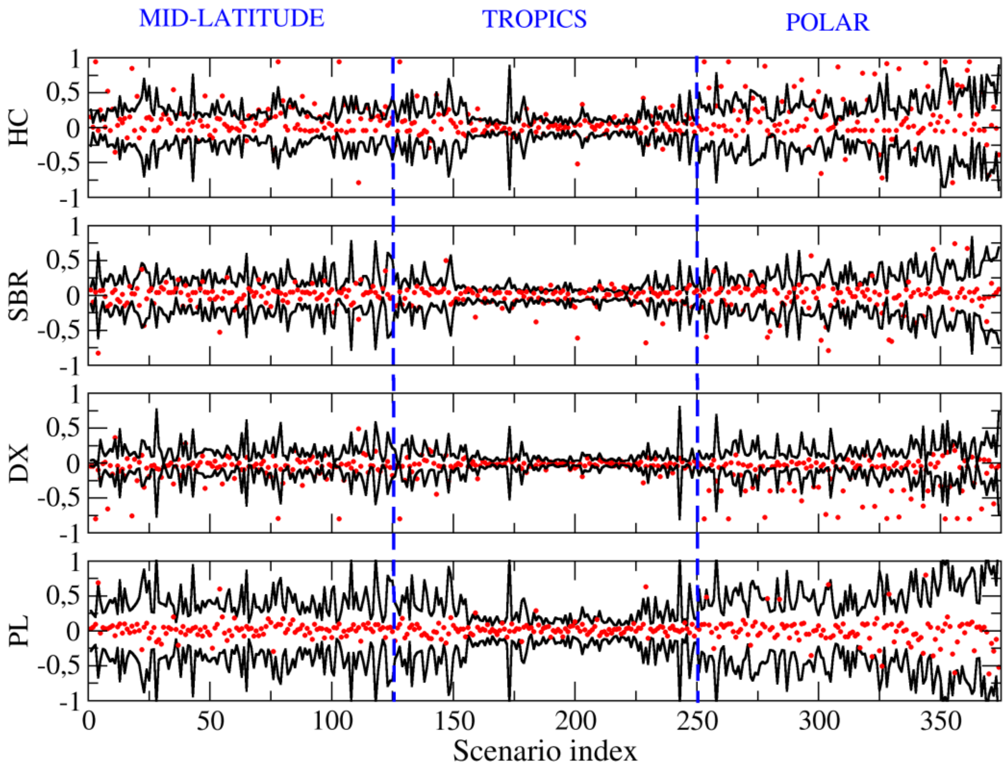


Let's start with a self consinstency study of the algorithm by using free noise simulated observations

Optimal estimation approach with 100% a priori error for habit fractions

Di Natale et al. 2023, Atm. Meas. and Techniq.

Results



Vector of not retrieved parameters:

$$\mathbf{b} = (\mathbf{WV}, \mathbf{T}, \varepsilon_s, T_s, \mathrm{CBH}, \mathrm{CTH})$$

... and the associated variance-covariance matrix (VCM) $\mathbf{S}_b$ used to derive the final radiance VCM:

$$\mathbf{S}_f = \mathbf{K}_b \mathbf{S}_b \mathbf{K}_b^T$$

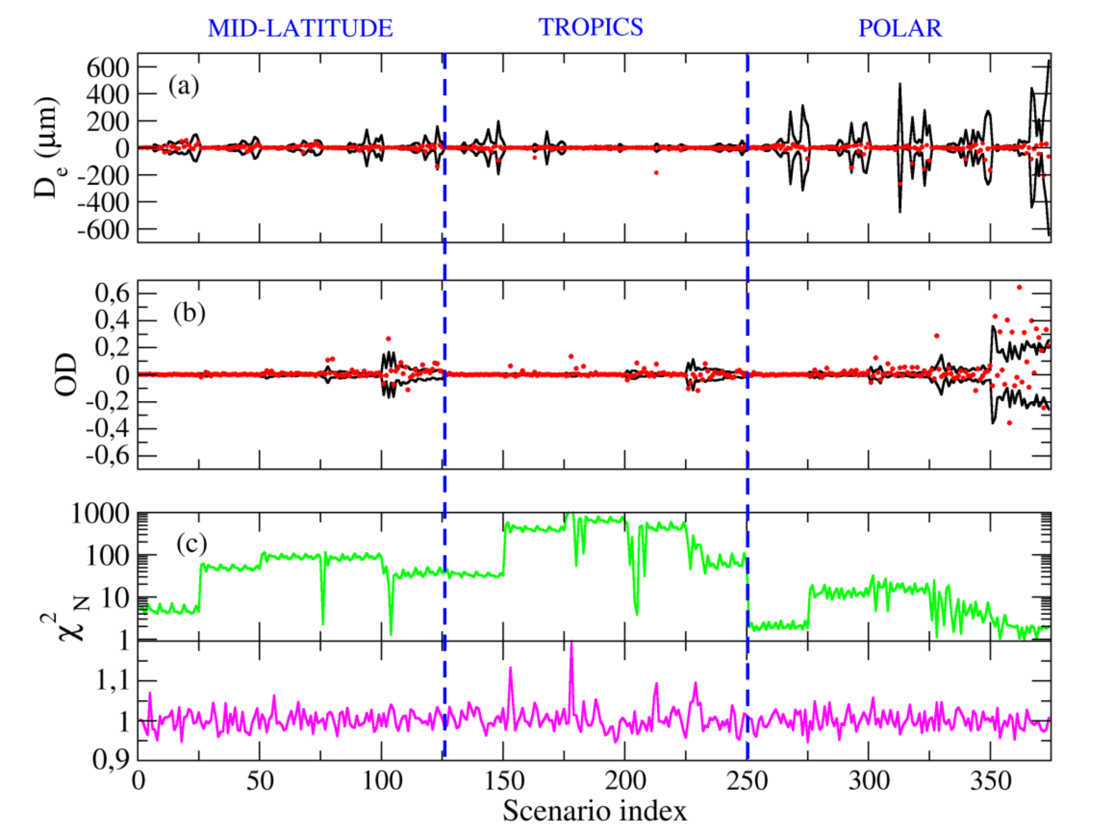
... and the final measurement VCM $\mathbf{S}_y'$:

$$\mathbf{S}_y' = \mathbf{S}_y + \mathbf{S}_f$$

... and the VCM on the retrieved **p**:

$$\mathbf{S}_p = \mathbf{K}_{pq}^T (\mathbf{K}_q^T \mathbf{S}_y^{-1} \mathbf{K}_q + \mathbf{S}_{aq}^{-1}) \mathbf{K}_{pq}$$

Results

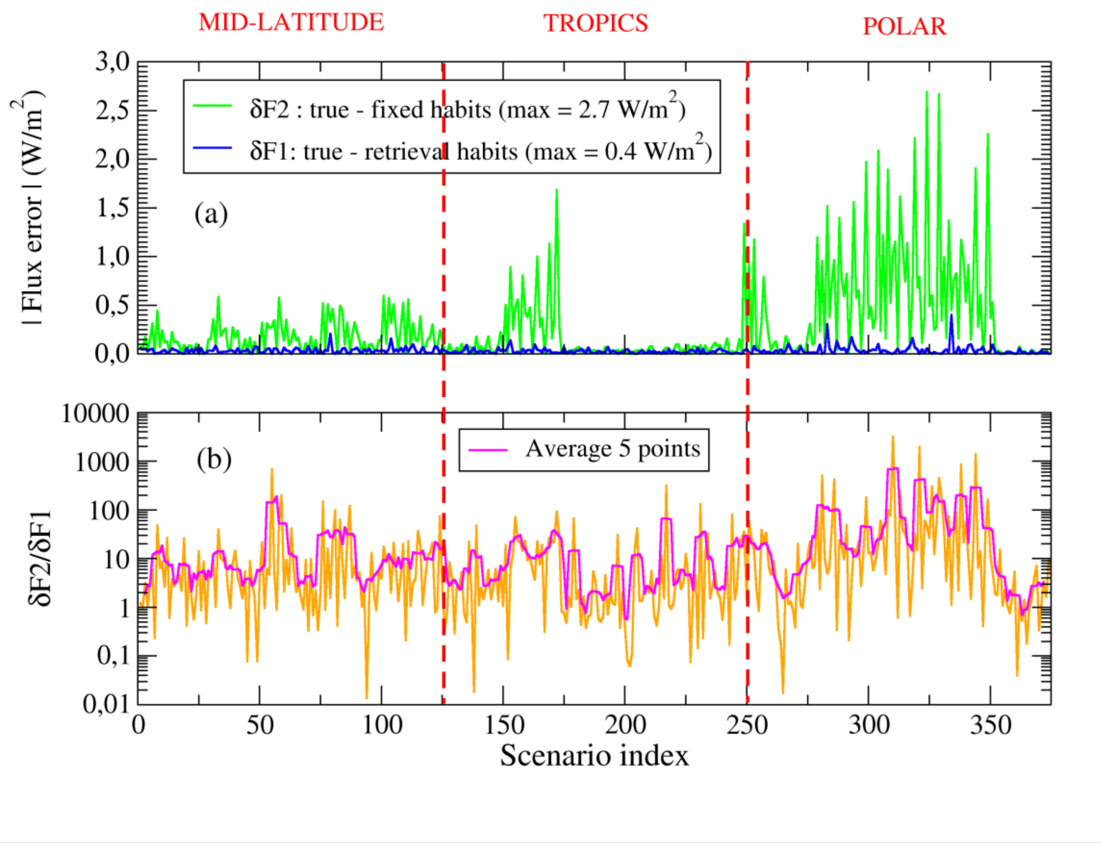


Regarding the effective diameters and optical depths

Overall, normalized χ^2_N lower than 1.1 are found

Di Natale et al. 2023, in discussion on Atm. Meas. and Techniq.

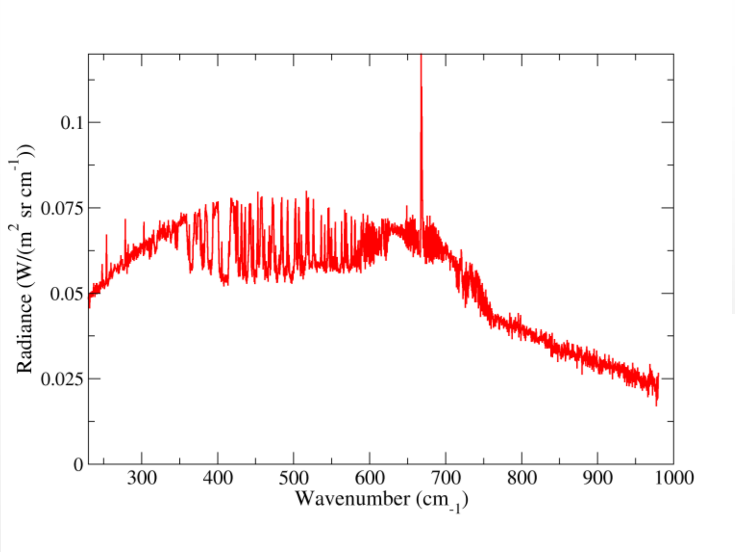
Results (fluxes)

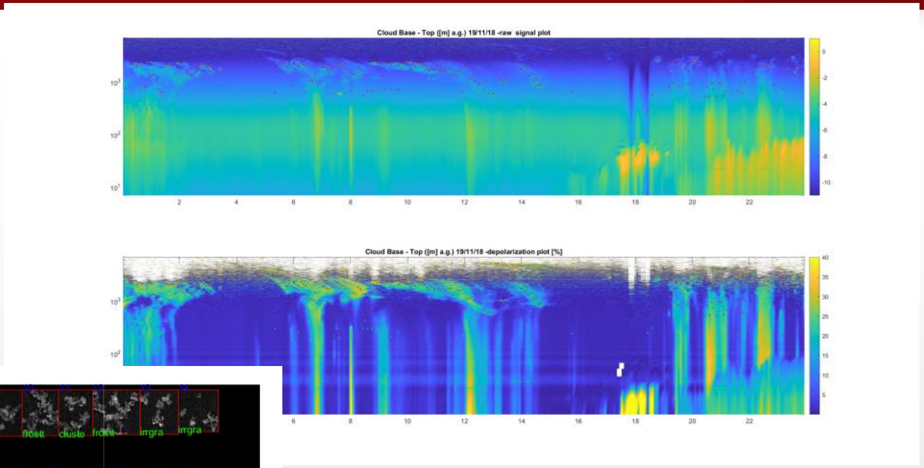


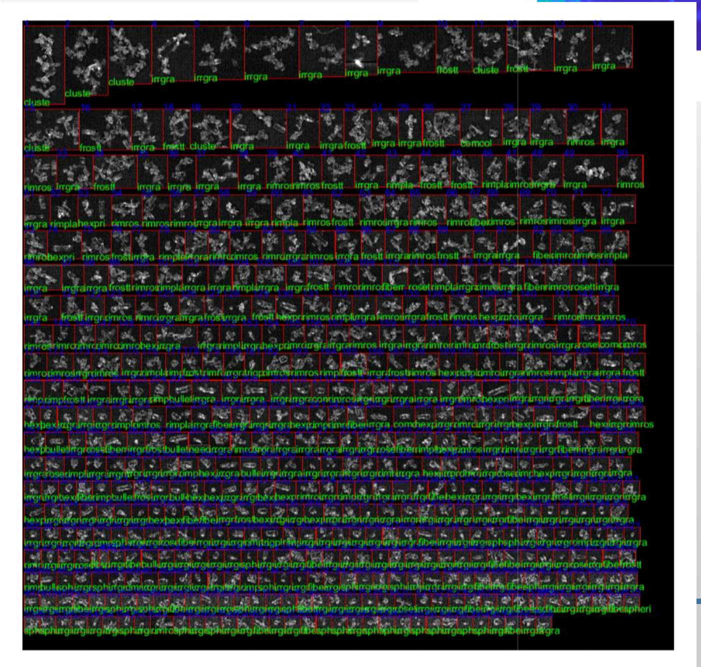
Impact of the habit assumption on the fluxes calculation at TOA

Di Natale et al. 2023, in discussion on Atm. Meas. and Techniq.

Antarctic dataset for validation







Summary

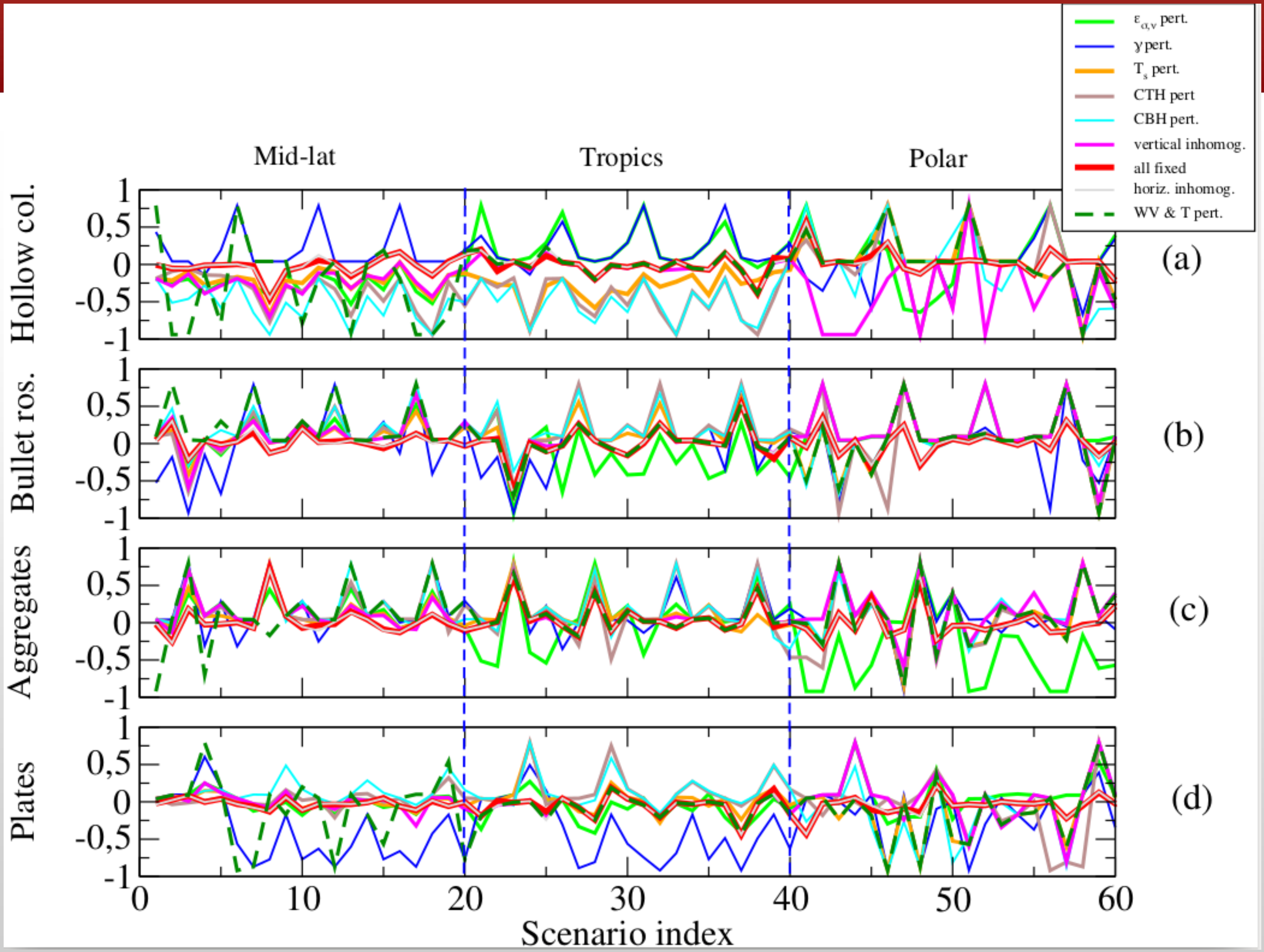
- Cirrus clouds are composed of a myriad of crystal habits which affect radiance spectrum.

- A new approach to retrieve crystal habits developed for FORUM observations

- Results on the syntethic spectra are very promising !

- We need to validate the method for instance by using spectra provided by the REFIR-PAD spectroradiometer in Antarctica

- Thank you!!



εσ,v pert.
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vertical inhomog.
all fixed
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WV & T pert.
Mid-lat
Tropics
Polar
Hollow col.
Bullet ros.
Aggregates
Plates
(a)
(b)
(c)
(d)
Scenario index