A Methodology for Simultaneous Retrieval of Ice and Liquid Water Cloud Properties

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General Context

- It is imperative nowadays to **reduce** or at least **constrain the uncertainties** attached to our retrievals of cloud properties. Especially true in the case of **ice clouds**, where large uncertainties still remain.

- Numerous retrieval algorithms currently prove to be very efficient at retrieving ice or liquid cloud properties, but very few attempt **simultaneous retrievals** of their properties (*e.g.* Chang and Li, 2005; Watts et al, 2011).

- The occurrence of liquid/ice cloud multi-layer cases is **not negligible** (*e.g.* Wind et al., 2010), and the omission of one of these layers can **strongly impact the accuracy** of the retrievals (*e.g.* Davis et al., 2009; Sourdeval et al., 2013).

- Simultaneous retrievals also have the advantage of providing a **better coherence** between the diverse retrieved properties and their respective attached uncertainties.

➡ Development of a methodology that allows retrieving simultaneously the properties of ice and liquid clouds, along with precise uncertainties.

General Context

➡ Presentation of the retrieval methodology.

➡ Main results of a theoretical information content analysis.

➡ Results and comparisons with A-Train operational products.

Retrieval methodology (Sourdeval *et al,* QJRMS, submitted)

- A **variational scheme** based on the optimal estimation method (Rodgers 2000) is used in order to obtain retrievals along with **rigorous uncertainties**.

- Possibility of retrieval of **one ice** cloud and **up to two liquid** cloud layers. Their position must still be provided by CALIOP (research/evaluation stage).

- A set of **five passive measurement channels** from A-Train instruments is used for retrieving **integrated properties**.

State vector:

$$x = \begin{pmatrix} IWP \\ \tau^{low} \\ r_{eff}^{low} \\ \tau^{mid} \\ r_{eff}^{mid} \end{pmatrix}$$

- IWP: Ice cloud layer
- τ^{low}, r_{eff}^{low}: Low-altitude liquid water cloud layer
- τ^{mid}, r_{eff}^{mid}: Mid-altitude liquid water cloud layer

Measurement vector:

$$y = \begin{pmatrix} R_{8.5\mu m}^{IIR} \\ R_{10.8\mu m}^{IIR} \\ R_{12.0\mu m}^{IIR} \\ R_{0.8\mu m}^{MODIS} \\ R_{2.1\mu m}^{MODIS} \end{pmatrix}$$

- The **ice cloud optical properties** are obtained from a parameterization by Baran *et al.* (2011, 2013) which provides the scattering and absorption properties of cirrus as a function of the **IWC** and **in-cloud temperature**.

Information content analysis

- **Degrees of freedom** (DOF) are calculated prior to the retrievals in order to comprehend the **capabilities and limitations** of our methodology under diverse cloud configurations.

- The **total** and **partial DOFs in the state space** are obtained from the diagonal elements of the averaging kernel matrix A:

$$A = \frac{\partial \hat{x}}{\partial x} = \hat{S}_x K^T S_\varepsilon^{-1} K$$

K: Jacobian matrix

S_x: Errors covariance matrix representative in the state space

S_ε: Errors covariance matrix representative in the measurement space (non-diagonal)

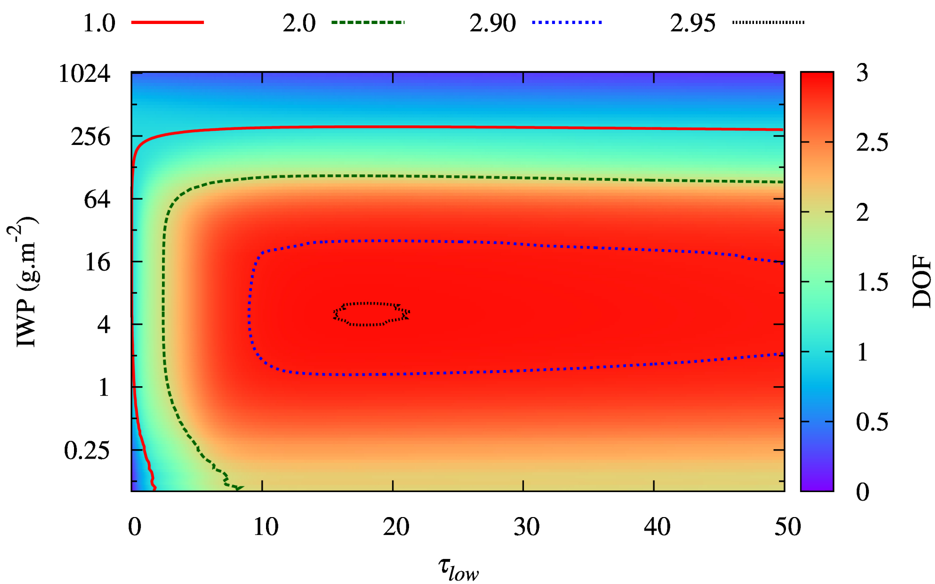
- A **channel selection method** (Rodgers, 1996) can later be used for determining which components of the measurement vector provide the information.

Example for the case a double layer configuration (ice + low liquid)

- The total degrees of freedom indicate the **amount of independent pieces of information** available on the state vector (DOF=3 – full information ; DOF=0 – no information)

<u>Example:</u> one ice cloud (10 to 12 km) and one liquid layer (1 to 2 km, $r_{eff} \approx 11.0\mu m$)

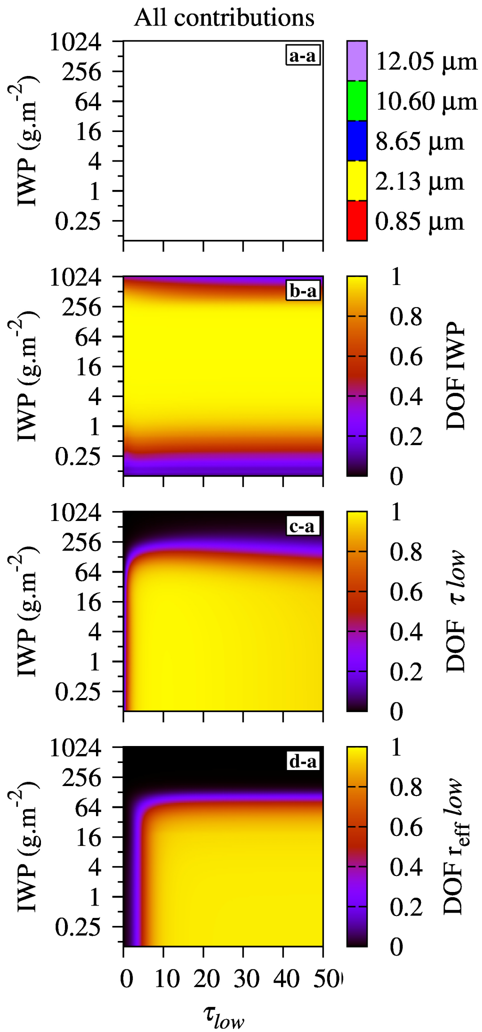
Total degrees of freedom:



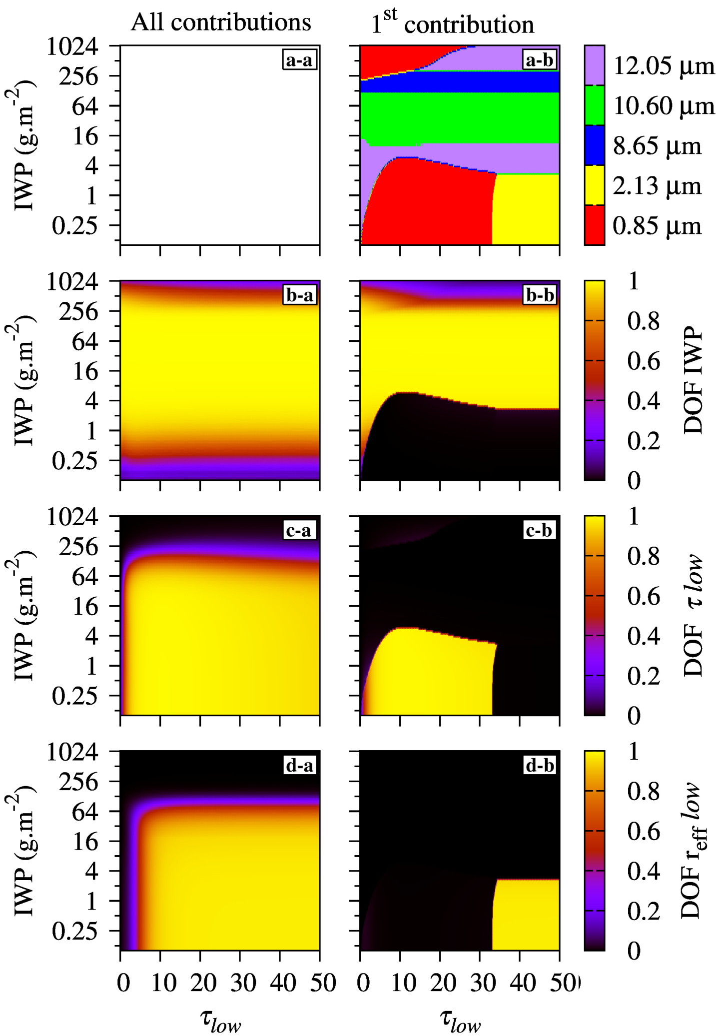
- Very good information on 3 parameters (DOF>2.90) if IWP between 1g.m^{-2} and 30 g.m^{-2}, and if $\tau > 10$. Information on 2 parameters (DOF>2.0) if the optical thickness is not too low and IWP < 100g.m^{-2}.

➡ Which channels provide this information, and on which parameter?

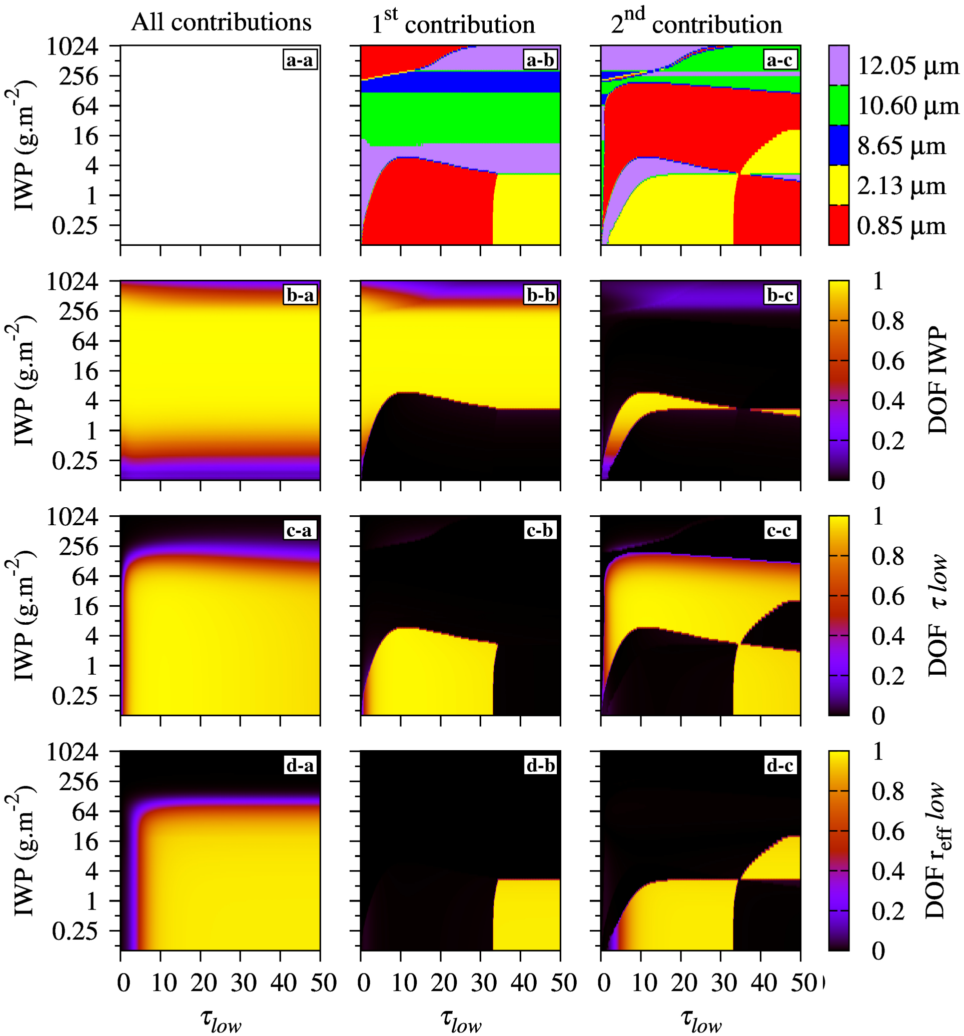
Partial degrees of freedom and channel selection



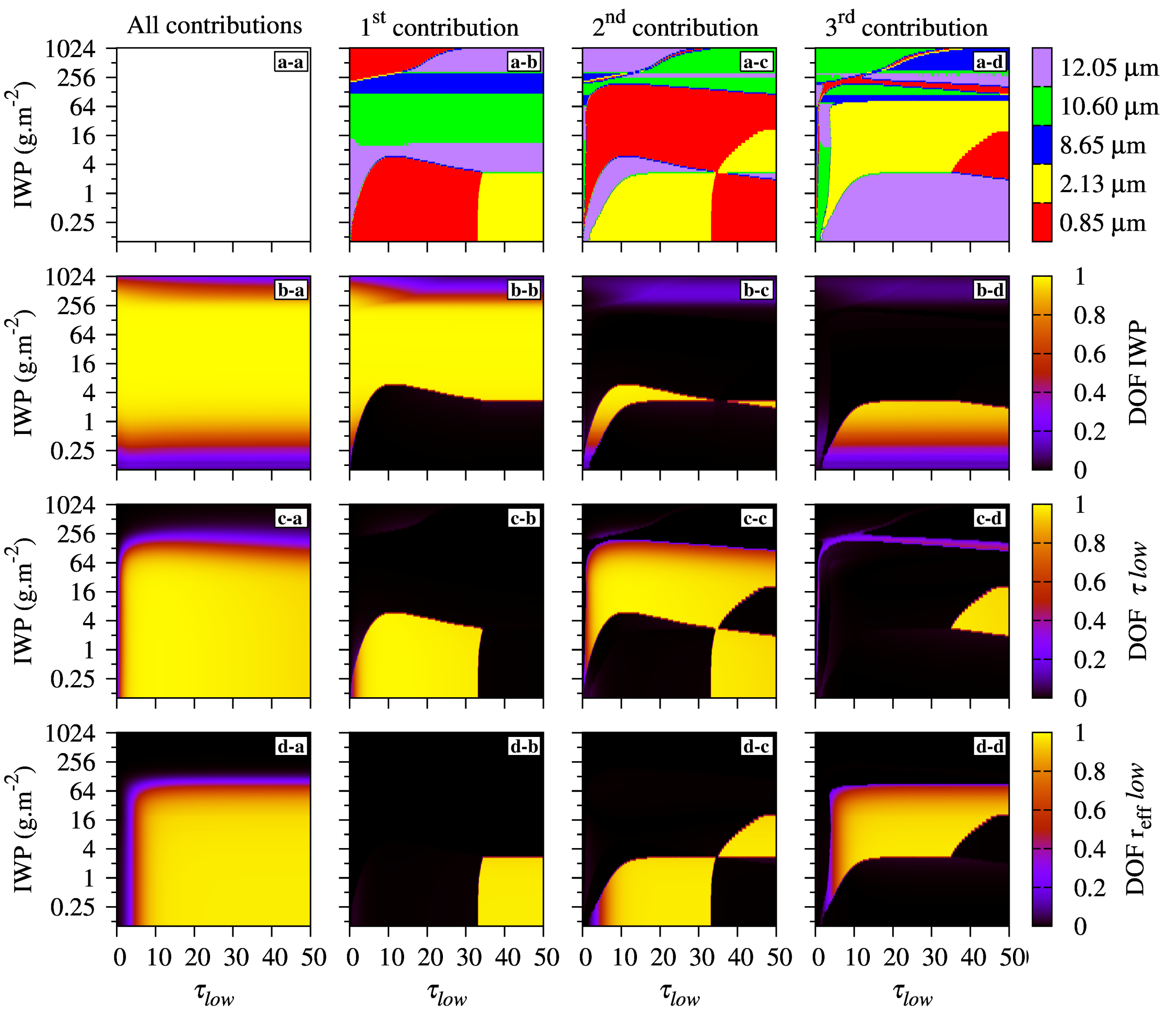
Partial degrees of freedom and channel selection



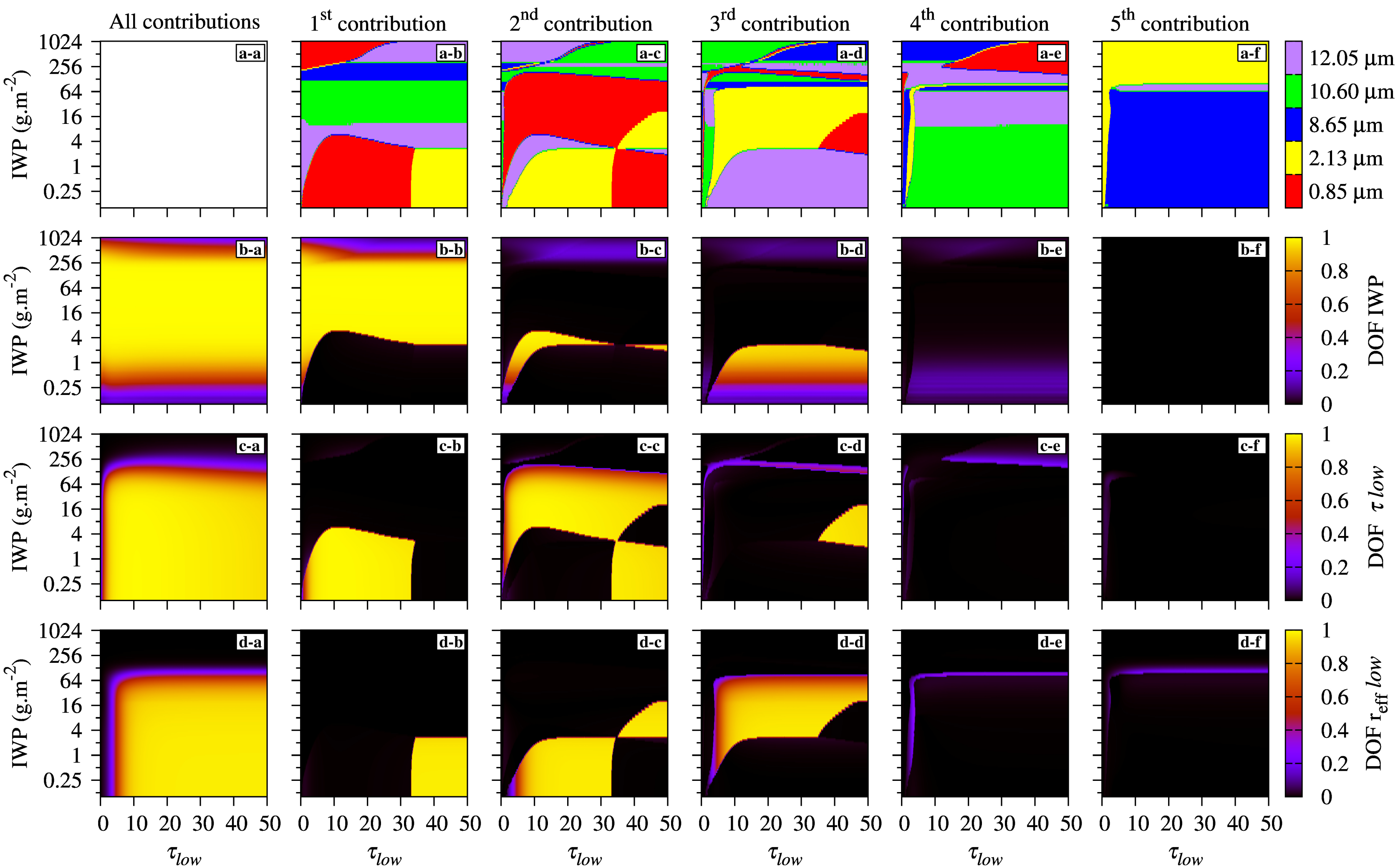
Partial degrees of freedom and channel selection



Partial degrees of freedom and channel selection



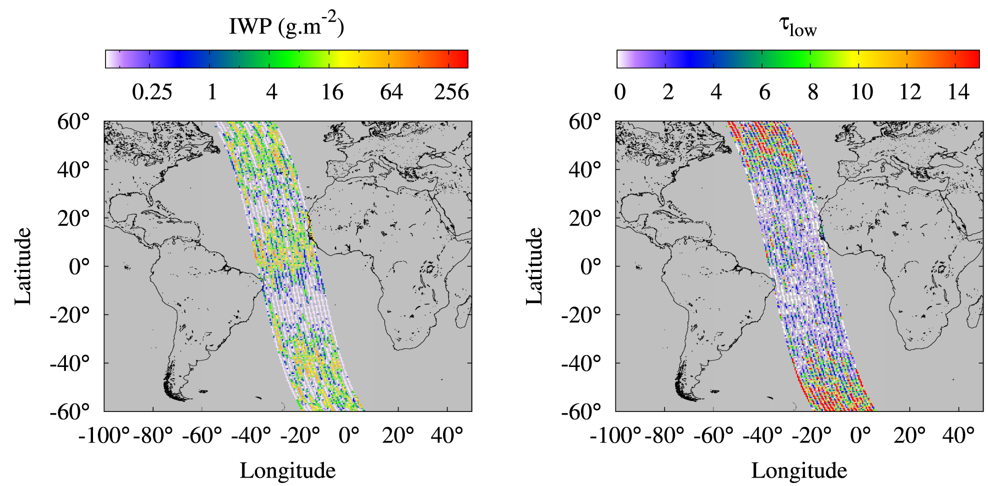
Partial degrees of freedom and channel selection

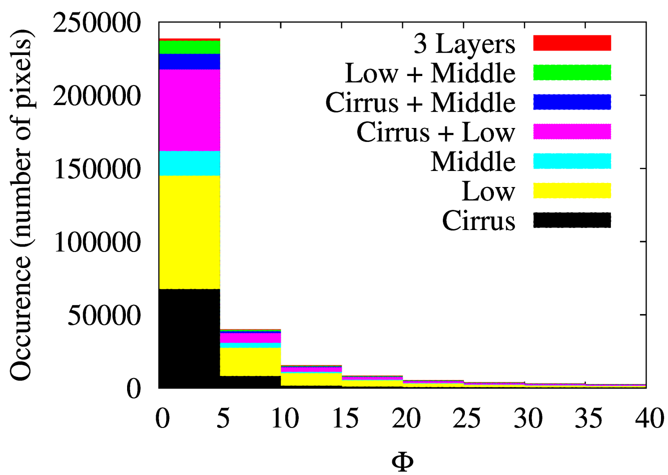


Example of retrievals (preliminary results over several orbits)

- **2 months** of data collected over the Atlantic ocean, under the track of CALIOP.

- Around 340 000 px treated, almost **one third** corresponding to double layer cases!





- The cost function estimates of the convergence between $F(\mathbf{x})$ and $\mathbf{y}$ (with respect to their associated errors). Good confidence in the convergence when Φ is lesser than the size of the measurement vector [Marks and Rodgers, 1993].

- Good overall convergence (Φ < 5 in most cases).

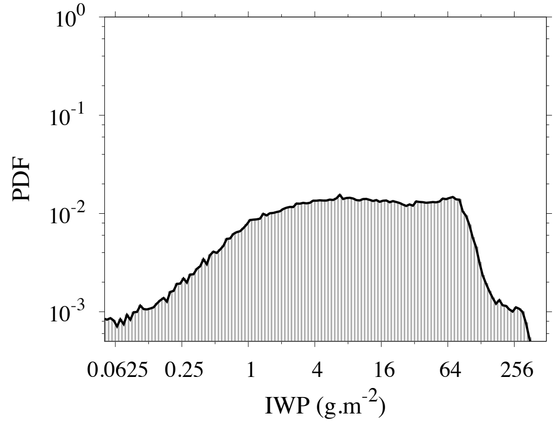
- No particular signature of type of scene in the evolution of Φ.

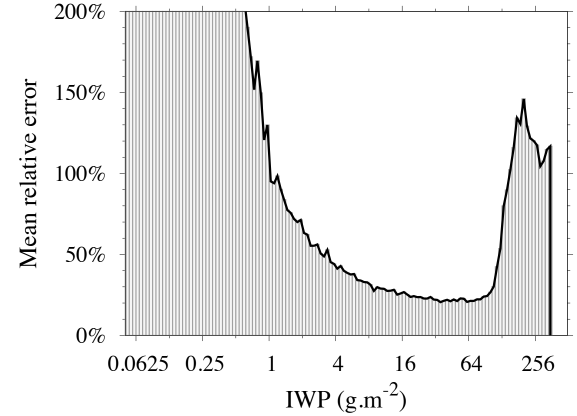
Retrievals in multi-layer configuration

Retrievals | **Associated uncertainties**

Ice cloud

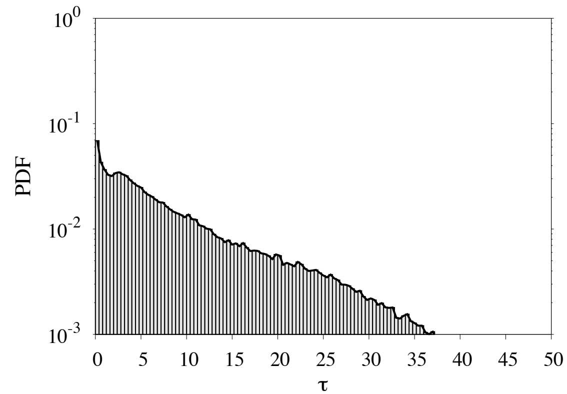
IWP

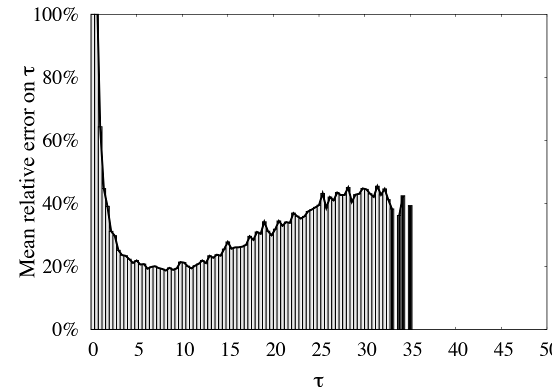




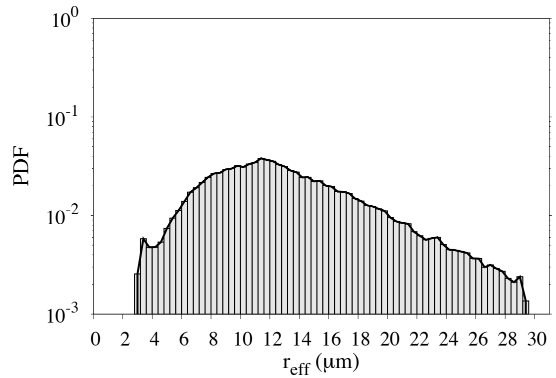
Liquid cloud

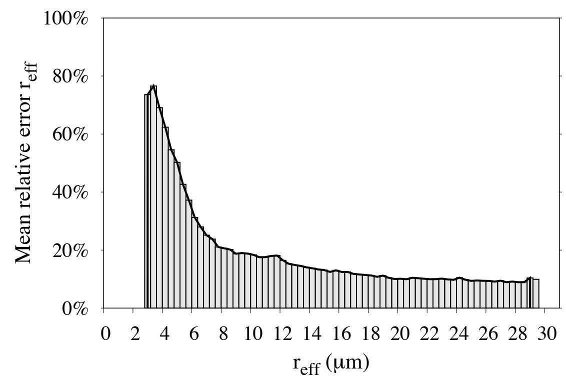
OD





r_{eff}





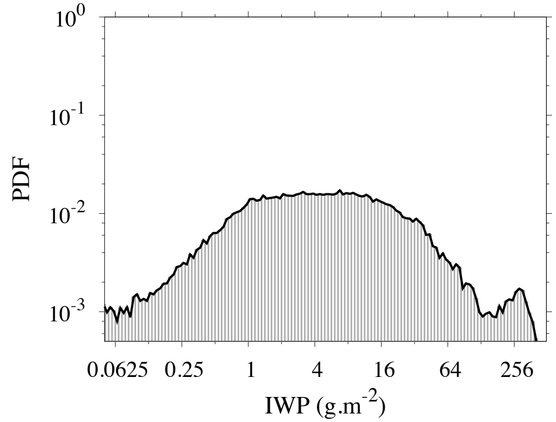
Retrievals in single-layer configuration

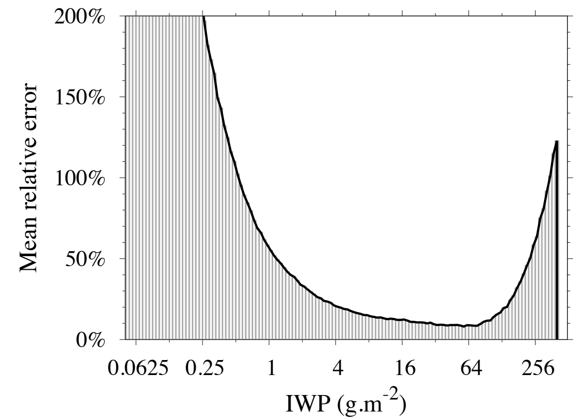
Retrievals

Associated uncertainties

Ice cloud

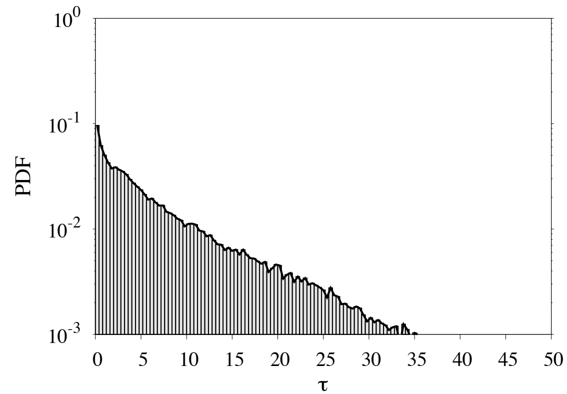
IWP

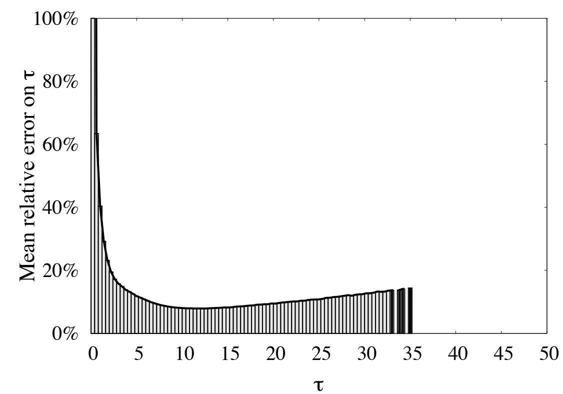




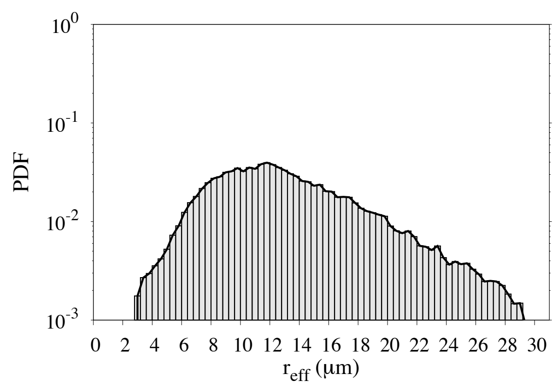
Liquid cloud

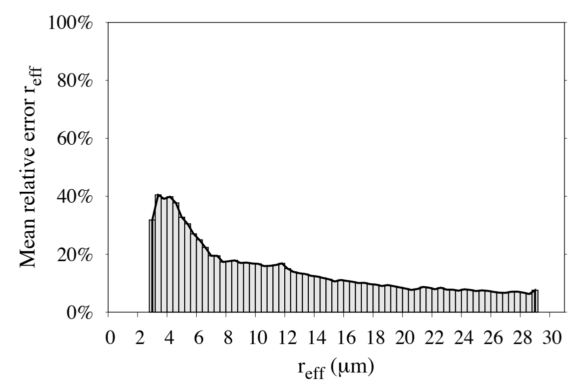
OD





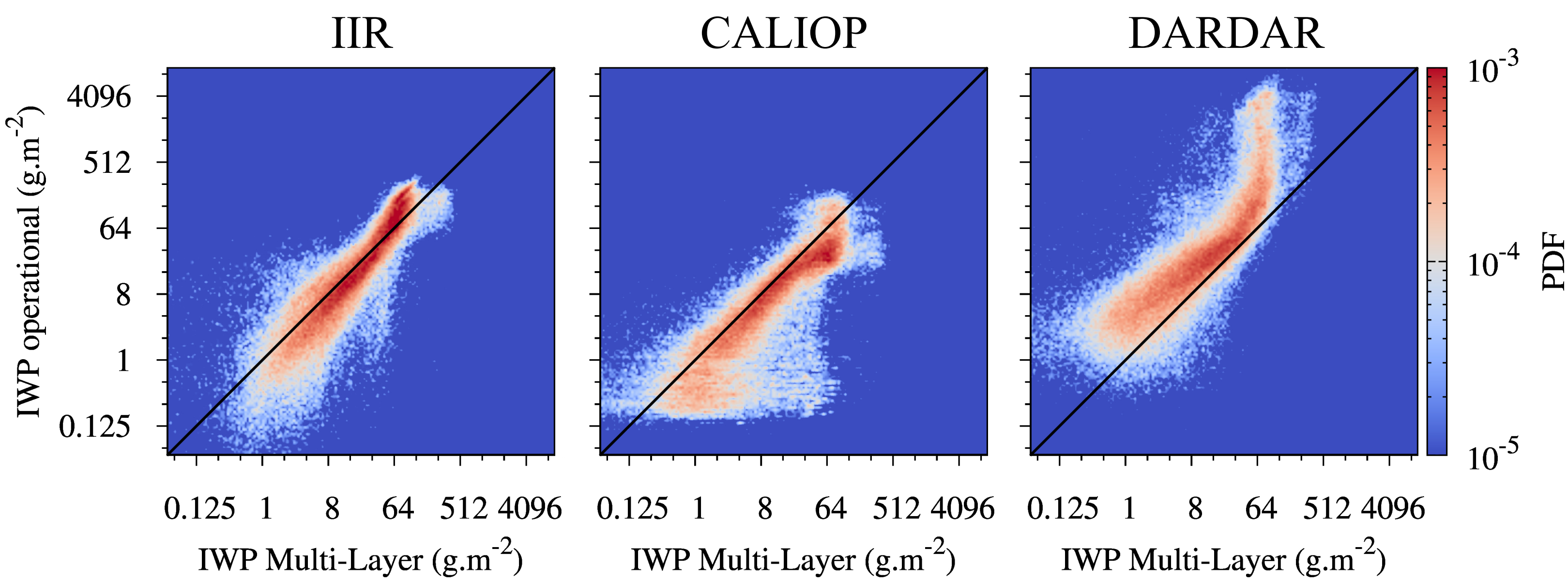
r_{eff}





Comparison with A-Train operational products

- Comparisons with the operational products from **IIR** (Garnier *et al.*, 2012, 2013), **CALIOP** (Young and Vaughan, 2009) and **DARDAR** (Delanoë and Hogan, 2008, 2010)



➡ Good global coherence with other products obtained from active and passive measurements.

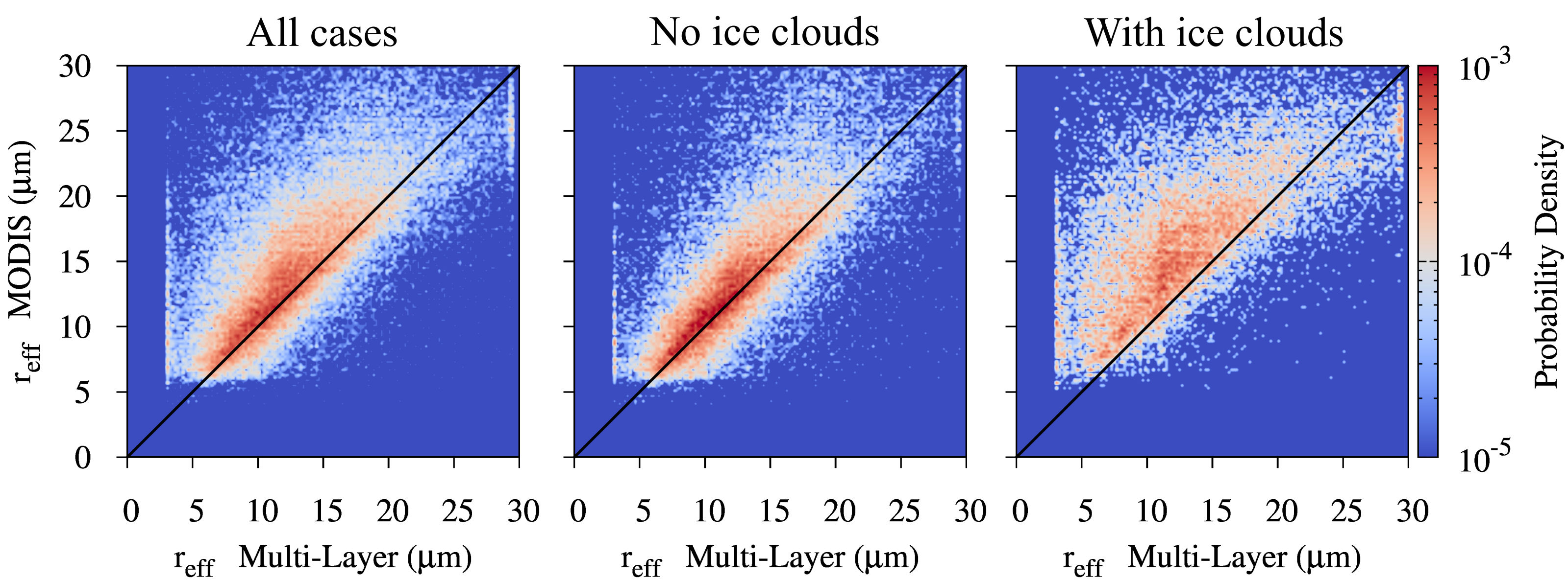
- Dissimilarities could be explained by differences in the **microphysical assumptions**, or part of clouds missing in our integrated retrievals (to be investigated).

- The IWP from these operational products do not seem too affected the presence of liquid layers (not shown here).

Comparison with A-Train operational products

- Comparisons with the **MODIS** (collection 5, *e.g.* King *et al.*, 1998) operational products

Effective radius of the liquid layer



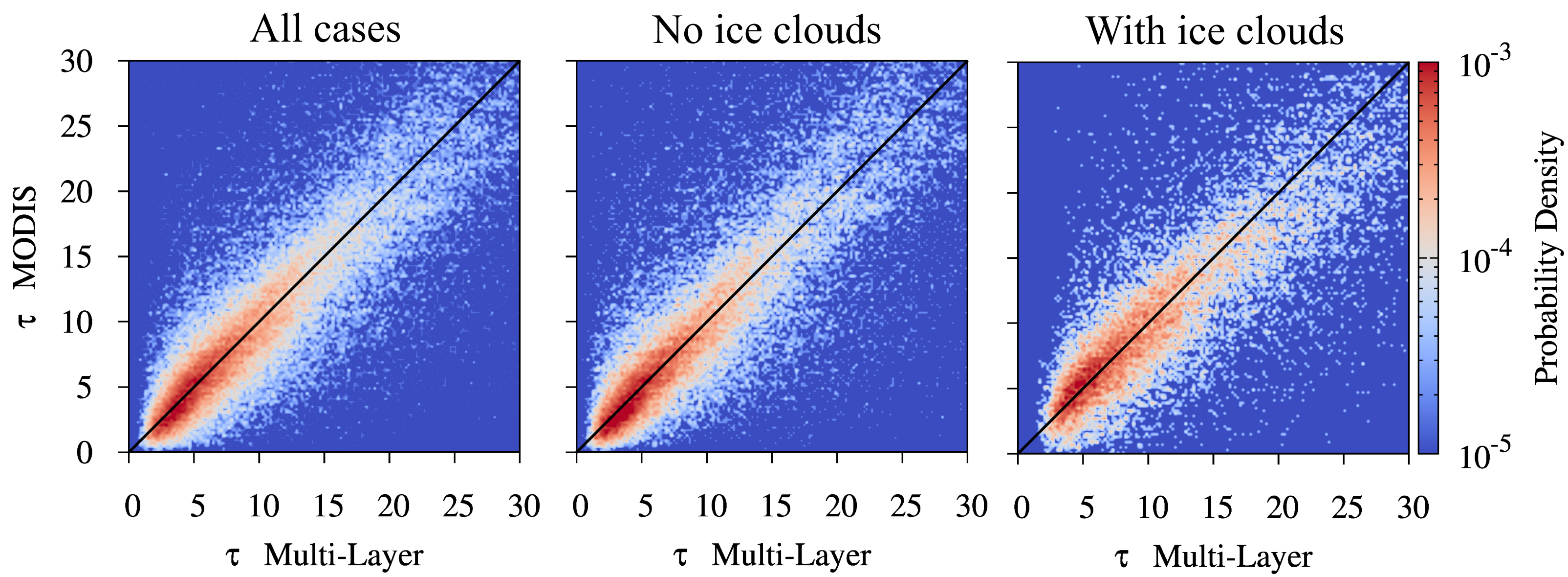
➡ Good global coherence with MODIS for the effective radius.

- MODIS retrievals if the effective radius can be **overestimated** in the presence of an ice cloud (sensitivity of the 2.13-µm channel to the ice layer).

Comparison with A-Train operational products

- Comparisons with the **MODIS** (collection 5, *e.g.* King *et al.*, 1998) operational products

Optical Thickness of the liquid layer



➡ Good global coherence with MODIS for the optical thickness.

- MODIS retrievals of the optical thickness do **not seem too impacted** by the presence of ice clouds.

Summary/Outlook

- Methodology capable of retrieving simultaneously ice and liquid water cloud properties **with rigorous associated uncertainties**.

- An information content analysis has been performed and helps to understand the **capabilities** and **limitations** of our methodology. A **good accuracy** is expected in most double-layer configurations.

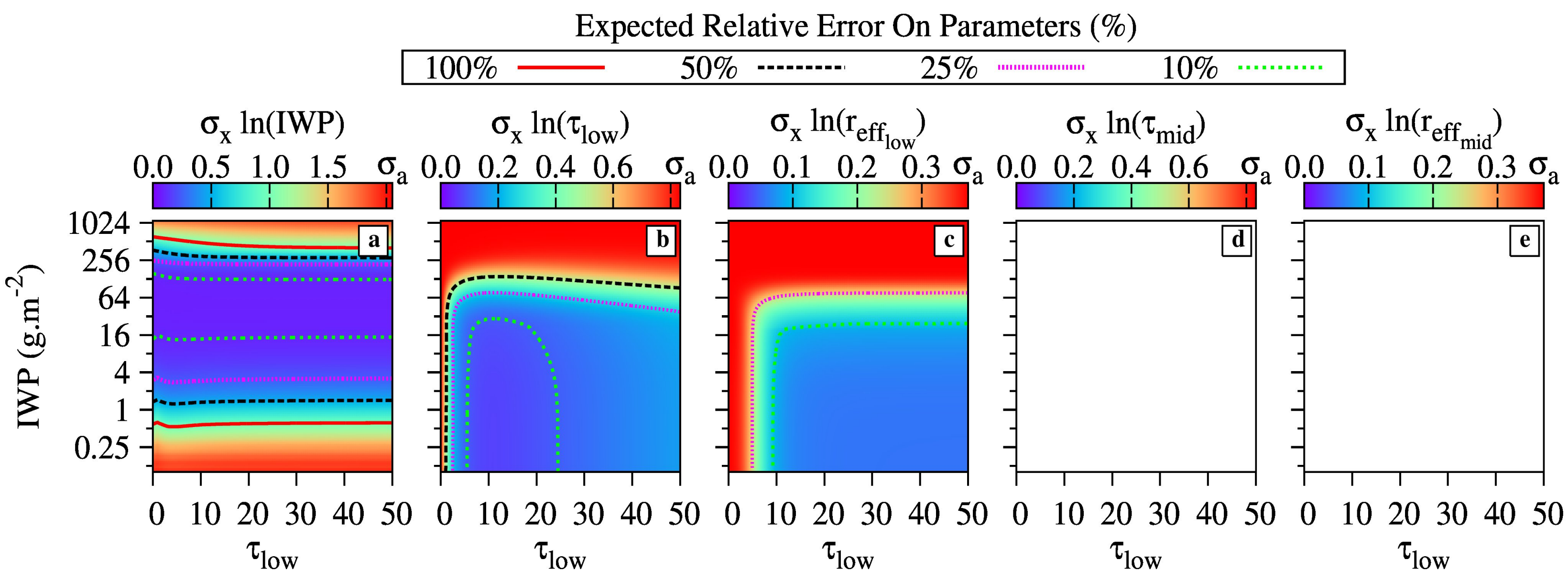
- Preliminary results show **strong similarities with several A-Train products**. The methodology can be used to test the **robustness** of these products to multi-layer configurations.

- **More statistics** are nevertheless necessary. Retrievals from an updated version are expected soon.

- Future modifications of the methodology could be the addition of measurements allowing to retrieve the **altitude and vertical extent** of cloudy layers, or the use of hyperspectral measurements for the retrieval of **profiled cloud properties**.

Thank you for your attention!

- The **uncertainties** attached to each components of the state vector can also be **estimated** prior to the actual retrievals (reduction of the *a priori* state space by the previously estimated information).



➡ Good accuracy can be expected on the retrievals in double layer configurations.

Information content analysis

- **Degrees of freedom** (DOF) are calculated prior to the retrievals in order to comprehend the **capabilities and limitations** of our methodology under diverse cloud configurations.

- A **full error covariance matrix** has been used (including non-diagonal elements) for a better precision:

$$S_{\varepsilon} = K_f S_f K_f^T + S_M$$

K_f: Jacobian matrix of the forward model

S_f: Errors covariance matrix representative of the non-retrieved parameters

S_m: Errors covariance matrix representative of the measurements

- The **total** and **partial DOFs on the state vector** are obtained from the diagonal elements of the averaging kernel matrix A:

$$A = \frac{\partial \hat{x}}{\partial x} = \hat{S}_x K^T S_{\varepsilon}^{-1} K$$

K: Jacobian matrix of the retrieved parameters

S_x: Errors covariance matrix representative of the retrieved parameters

- A **channel selection method** (Rodgers, 1996) can later be used for determining which components of the measurement vector provide the information.