Ice cloud properties, an information content analysis from high spectral resolution measurements in the thermal infrared: Application to IASI and IASI-NG

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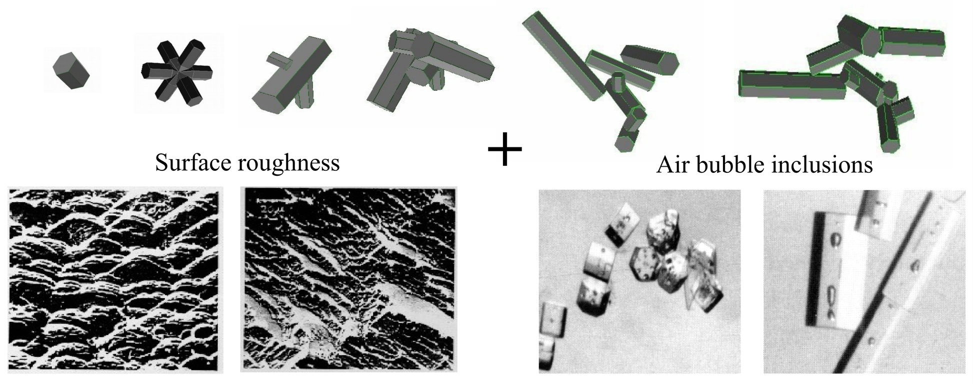
Abstract: The present study aims in quantifying the potential of retrieving ice cloud properties, and more specifically, the Ice Water Path (IWP) and layer altitude, from thermal infrared sounders IASI and the future IASI-NG. The method is based on the Shannon information content analysis (ICA). We applied this ICA to different ice cloud profiles coming from a global database originate from the NWP (ECMWF IFS NWP model) by taking into account the Signal-to-Noise ratio of the instruments and the inherent non-retrieved atmospheric and surface parameters errors. The forward model used is the fast radiative transfer model RTTOV (Saunders *et al.* (1999), Matricardi *et al.* (2004)) with ice cloud microphysics from the ensemble model developed by Baran and Labonnote (2007) and size distribution parametrization by Baran *et al.* (2009).

ICE CLOUD MICROPHYSICS MODEL

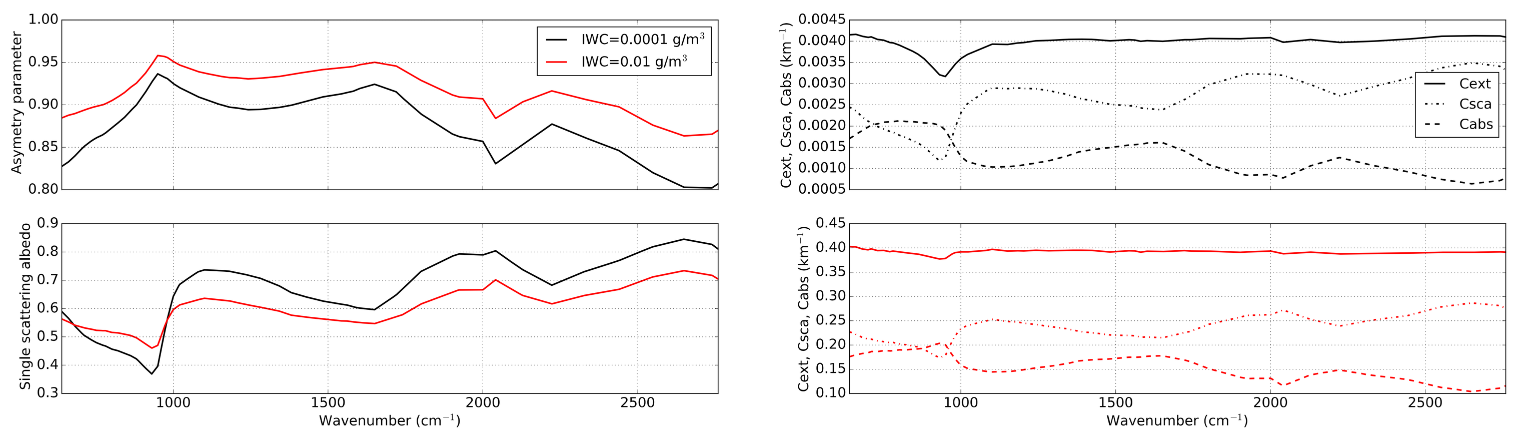
The ensemble model is composed of six individual ice particles with increasing complexity as a function of size. Concentration of each individual particle depends on their maximum dimensions.

This model also takes into account surface roughness as well as spherical air bubble inclusions (Baran and Labonnote (2007)).



The scattering phase matrix and optical properties are integrated over the PSD obtained from Field *et al.* (2006) and Field *et al.* (2007). Optical properties are parametrized, from integrating them over 20662 parametrized PSDs, as a function of IWC and incloud temperature (Baran *et al.* (2009)).

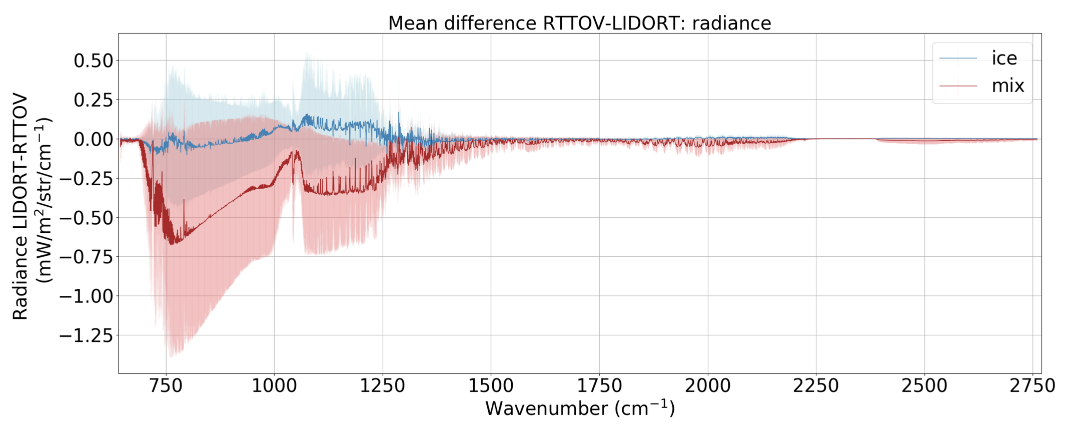
Variation of the ensemble model optical properties for two different IWC on the IASI spectrum :



FORWARD MODEL / SENSITIVITY STUDY

The fast radiative transfer code RTTOV (Saunders *et al.* (1999), Matricardi (2004)) including Baran parametrization (Vidot *et al.* (2015)) with Chou approximation (1999) is used for this study.

Jacobians and radiances are compared with the radiative transfer model LIDORT which computes exact multiple scattering in ice clouds. Results show a good agreement between the two models.

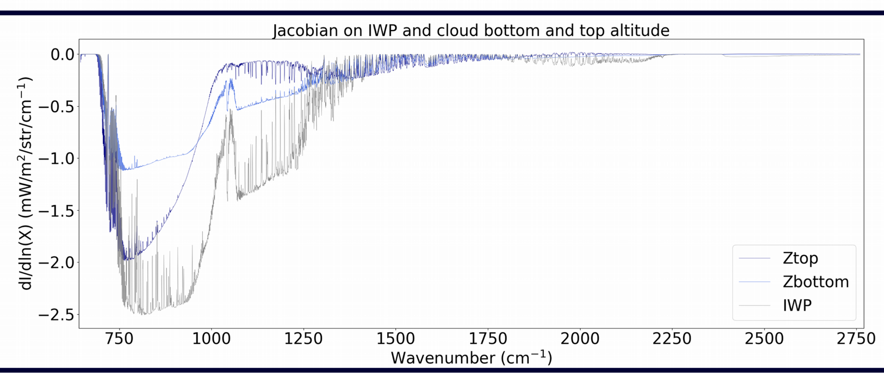


State vector :

Ice Water Path : ln(IWP)

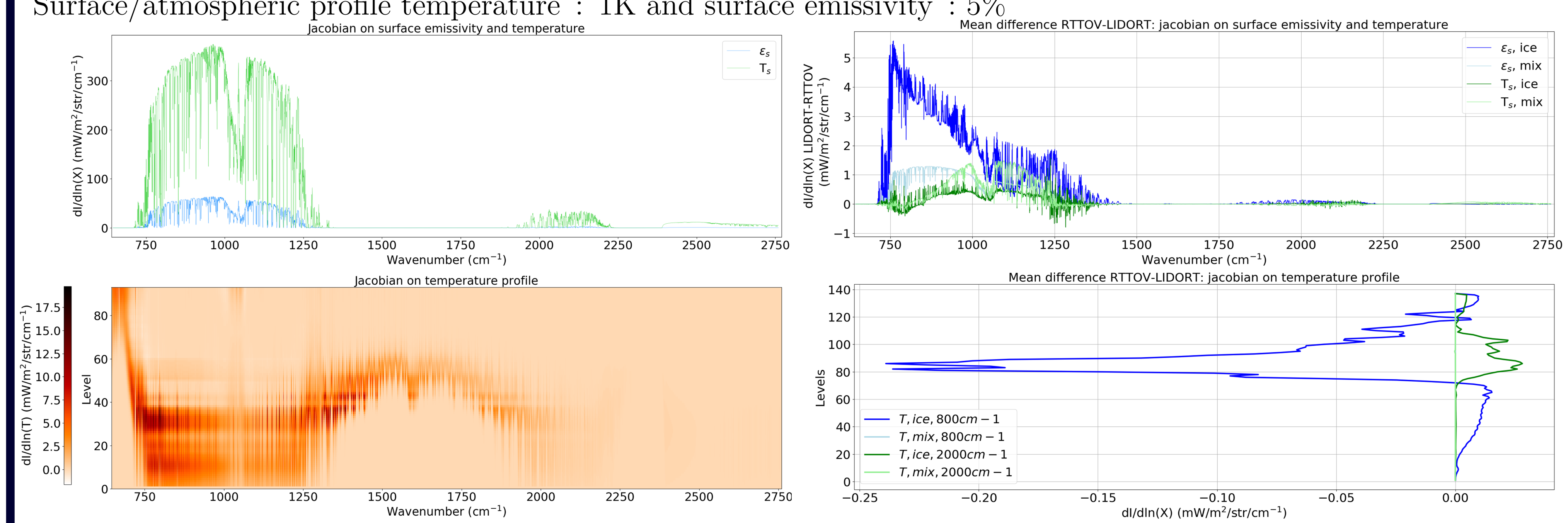
Top and bottom altitudes :

$\ln(Z_{bottom})$, $\ln(Z_{top})$

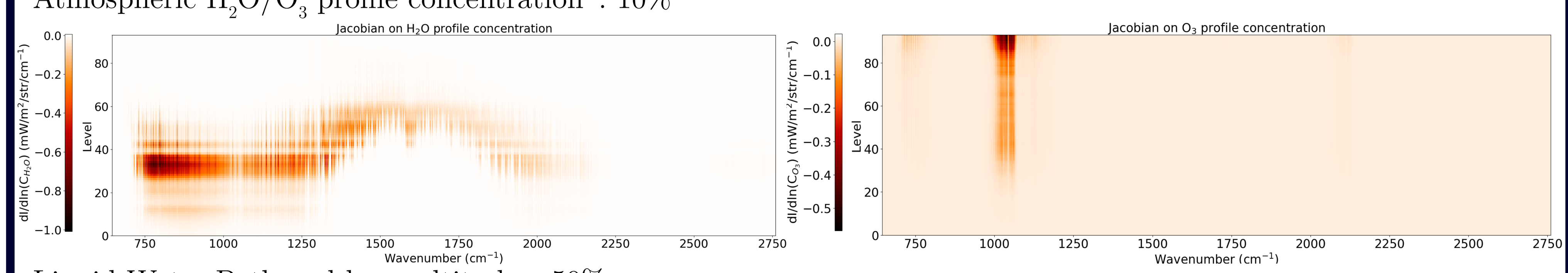


Non-retrieved parameters / associated errors :

Surface/atmospheric profile temperature : 1K and surface emissivity : 5%



Atmospheric H_2O/O_3 profile concentration : 10%

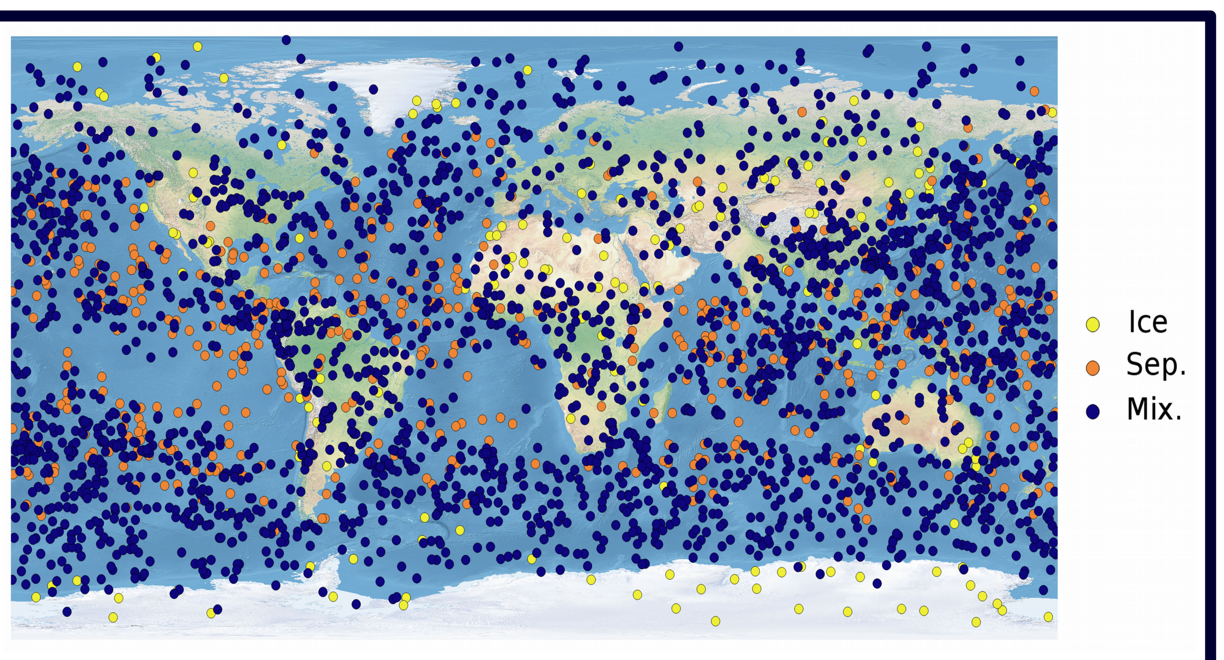


Liquid Water Path and layer altitude : 50%

PROFILES

212 profiles with ice-only clouds and 3151 profiles with liquid and ice clouds from the NWP based on the ECMWF IFS NWP model at 137 atmospheric levels are used for this study. They are chosen to encapsulate normal conditions, typical variability, and the extremes of the model's behavior.

Clouds from these profiles have been then modified with constant IWC in each layer and IWP kept at initial value.



REFERENCES

Saunders *et al.*, QJRMS, 125(556) :1407–1425, 1999

Matricardi *et al.*, QJRMS, 130(596) :153–173, 2004

Baran and Labonnote, QJRMS, 133(629) :1899–1912, 2007

Baran, JQSRT, 110(14-16) :1239–1260, 2009

Field *et al.*, JAOT, 23(10) :1357–1371, 2006

Field *et al.*, JAS, 64 :4346–4365, 2007

Vidot *et al.*, JGR, 120(14) :6937–6951, 2015

Chou *et al.*, JC, 12(1) :159–169, 1999

Shannon *et al.*, University of Illinois Press, 1951

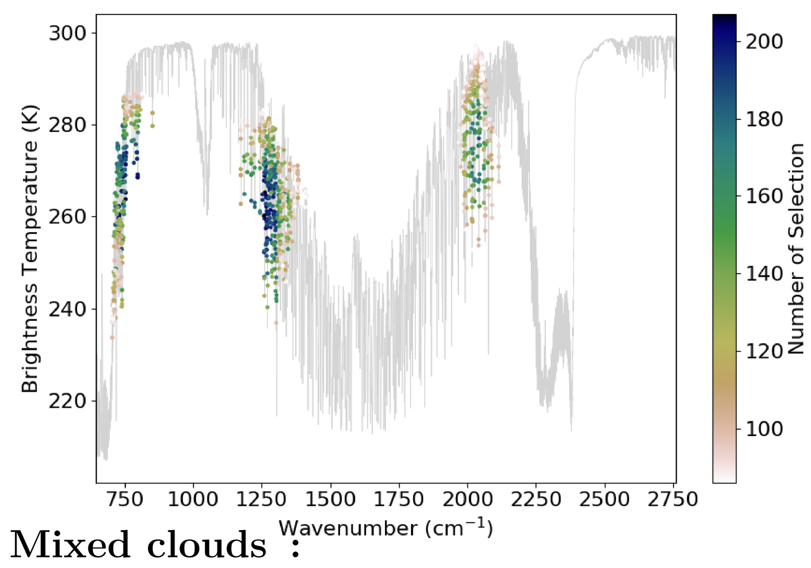
INFORMATION CONTENT ANALYSIS

Information brought by the observing system is assumed to be given by the averaging kernel (A) and posterior covariance (S_x) matrices as :

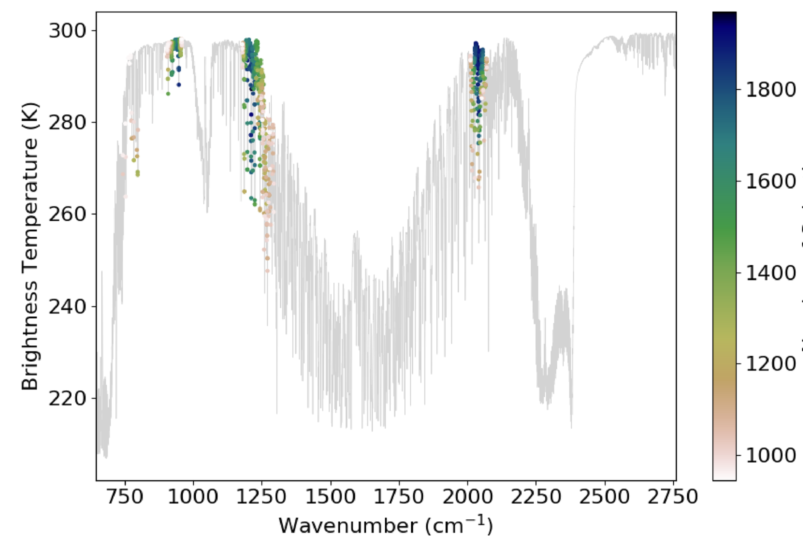
- The diagonal elements of $A=\frac{\partial \hat{x}}{\partial x}=GK$ provides an information on the ability of the observing system to capture any variation of the real state vector. $G=S_x K^T S_\epsilon^{-1}$ is the gain matrix and K the jacobian. S_ϵ is the sum of covariances matrices of non-retrived parameters and forward model including the errors (S_b) and jacobians (K_b) of the non-retrieved parameters : $S_\epsilon = S_y + K_b S_b K_b^T$
- $S_x^{-1} = K^T S_\epsilon^{-1} K + S_a^{-1}$ contains the expected (or posterior) errors on the state vector components.

CHANNEL SELECTION

Ice clouds :



Mixed clouds :



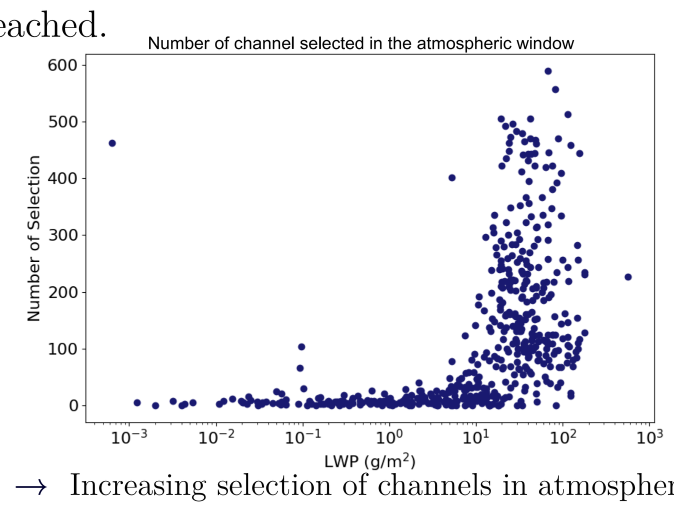
We assume that the information H brought by the measurement can be expressed as an entropy reduction (Shannon *et al.* (1951)) as :

$H=S(P_a)-S(P_x)$ with P_a and P_x the Gaussian *pdf a priori* and *a posteriori* of the state vector.

Entropy : $S(P)=\frac{1}{2}\log_2|S|+\frac{m}{2}\log_2(2\Pi e)$

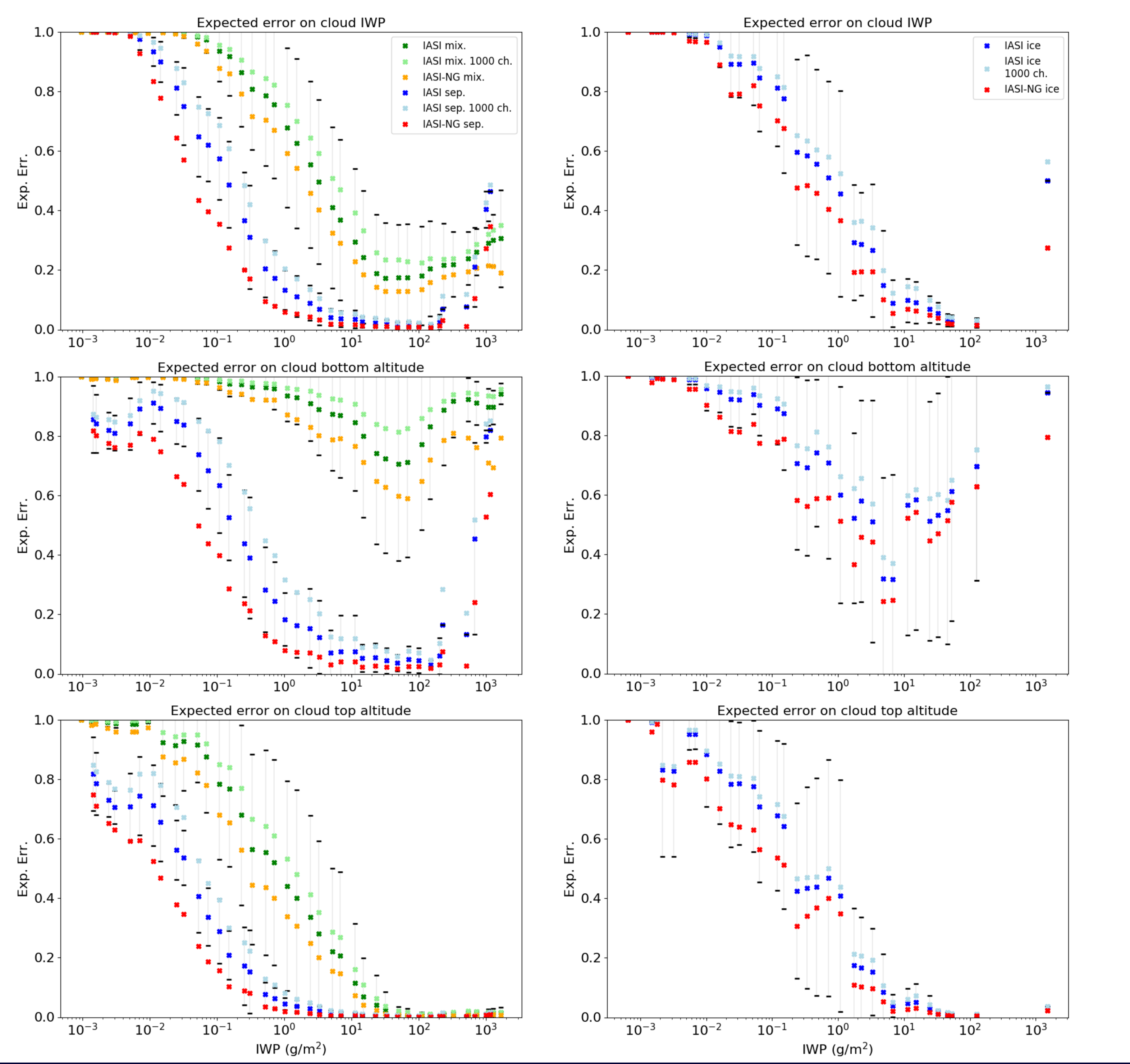
Information : $H=\frac{1}{2}\log_2|S_a S_x^{-1}|$

Channels with the largest information are chosen until 90 % of the total information is reached.



→ Increasing selection of channels in atmospheric window with increasing liquid water path.

ICA ON MIXED AND ICE CLOUDS



Conclusion and perspectives: Results show that IASI and IASI-NG would provide information on IWP as well as layer position, and should therefore be well retrieved with expected errors that decrease with cloud opacity until the signal saturation is reached. The study of mix clouds show that the information is sometimes greater because of the presence of the liquid cloud that reduces the influence of the surface. The main perspective is now to develop an algorithm based on an optimal estimation approach in order to retrieve ice cloud properties (e.g. IWP, Z_{top}, Z_{bot}) by taking into account a rigorous forward model error. This algorithm will also take advantage of the channel selection from this present study. We will also investigate the potentiality of IASI/IASI-NG to retrieve the column/profile of water vapour content in presence of ice cloud.