Ice cloud properties, an information content analysis from high spectral resolution measurements in the thermal infrared (IASI-like)

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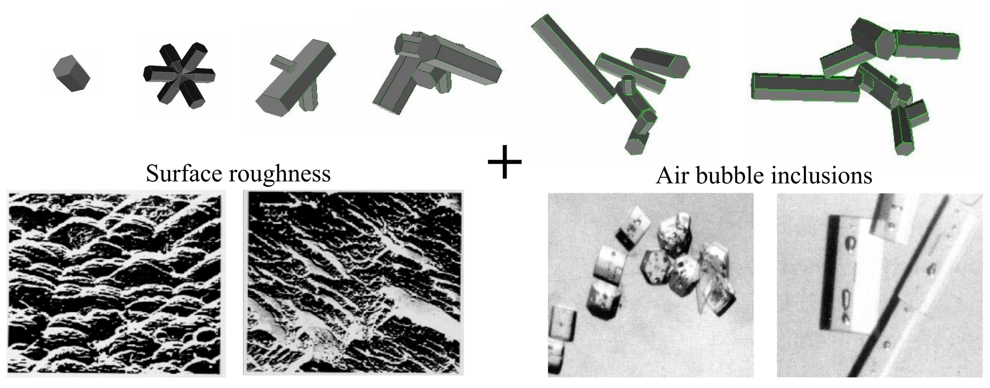
Abstract: The present study aims in quantifying the potential of retrieving ice cloud properties, and more specifically, the ice water content (IWC) profile, or column ice water path (IWP) together with layer position. This being retrieved from thermal infrared sounders such as IASI (and the future IASI-NG). The method used here is based on a Shannon information content analysis (ICA). We ran this ICA for different ice cloud opacities, by taking into account the Signal-to-Noise ratio of the instrument and the inherent non-retrieved atmospheric and surface parameters errors. The synthetic measurements have been simulated by a line-by-line model developed at the Laboratoire d'Optique Atmosphérique (LOA), and the multiple scattering by the open source radiative transfer code LIDORT (Spurr et al., 2008). The ice cloud microphysics has been simulated by the ensemble model developed by Baran and Labonnote (2007) and its size distribution parameterization as a function of IWC and the in cloud temperature by Baran et al. (2009). Results shows that the IWP as well as layer position (top and bottom layer altitude) should be well retrieved with expected errors that decrease with cloud opacity, until signal saturation is reached. Because of better SNR and spectral resolution, IASI-NG will also provide more accurate retrievals.

Ice cloud microphysical 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.

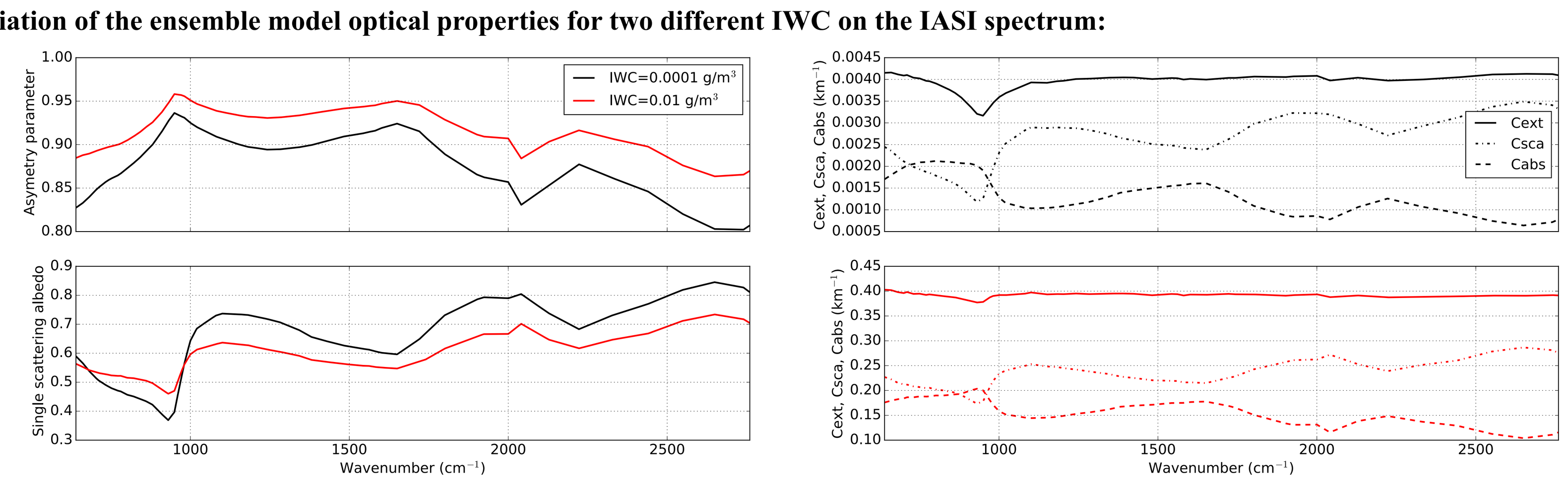
The scattering phase matrix and total optical properties are integrated over the PSD obtained from Field et al. (2007) and Field and Heymsfield (2006).

Optical properties are parametrized, from integrating them over 20662 parametrized PSDs, as a function of IWC and Tc.



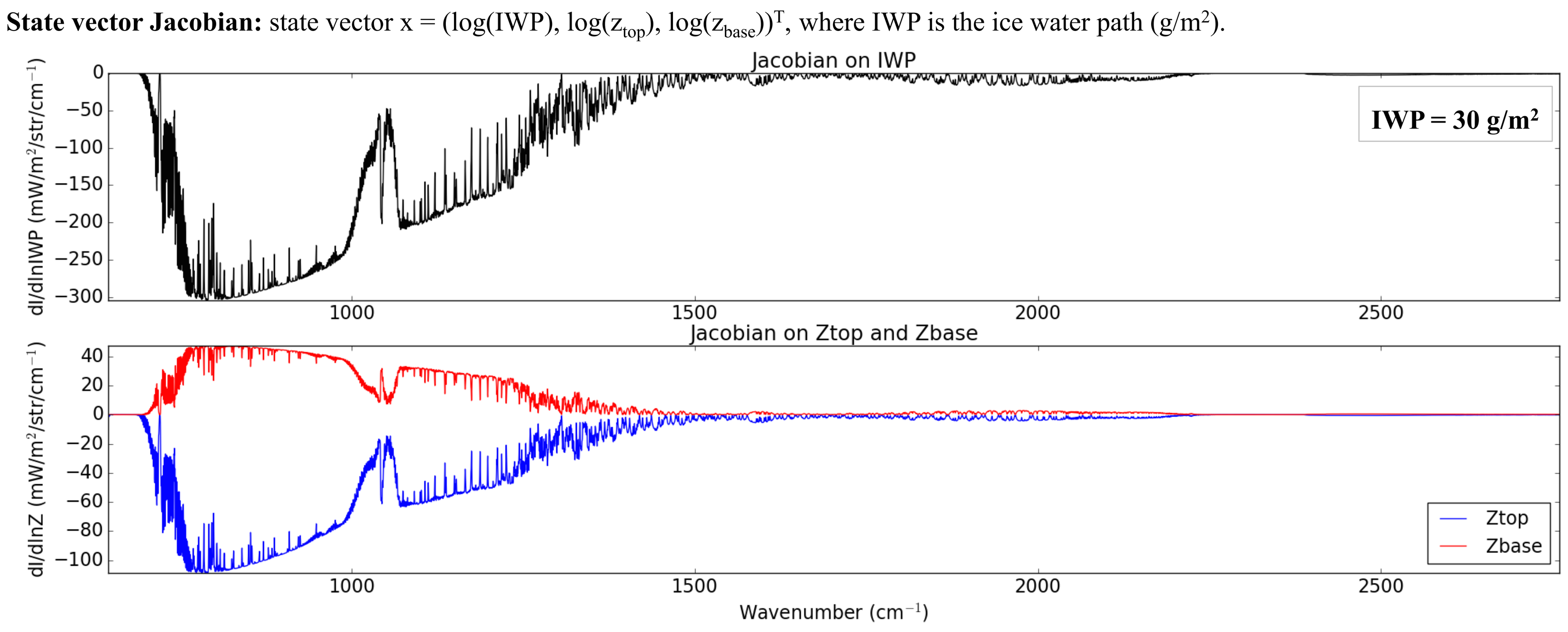
Baran and Labonnote (2007)

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



Jacobian simulations

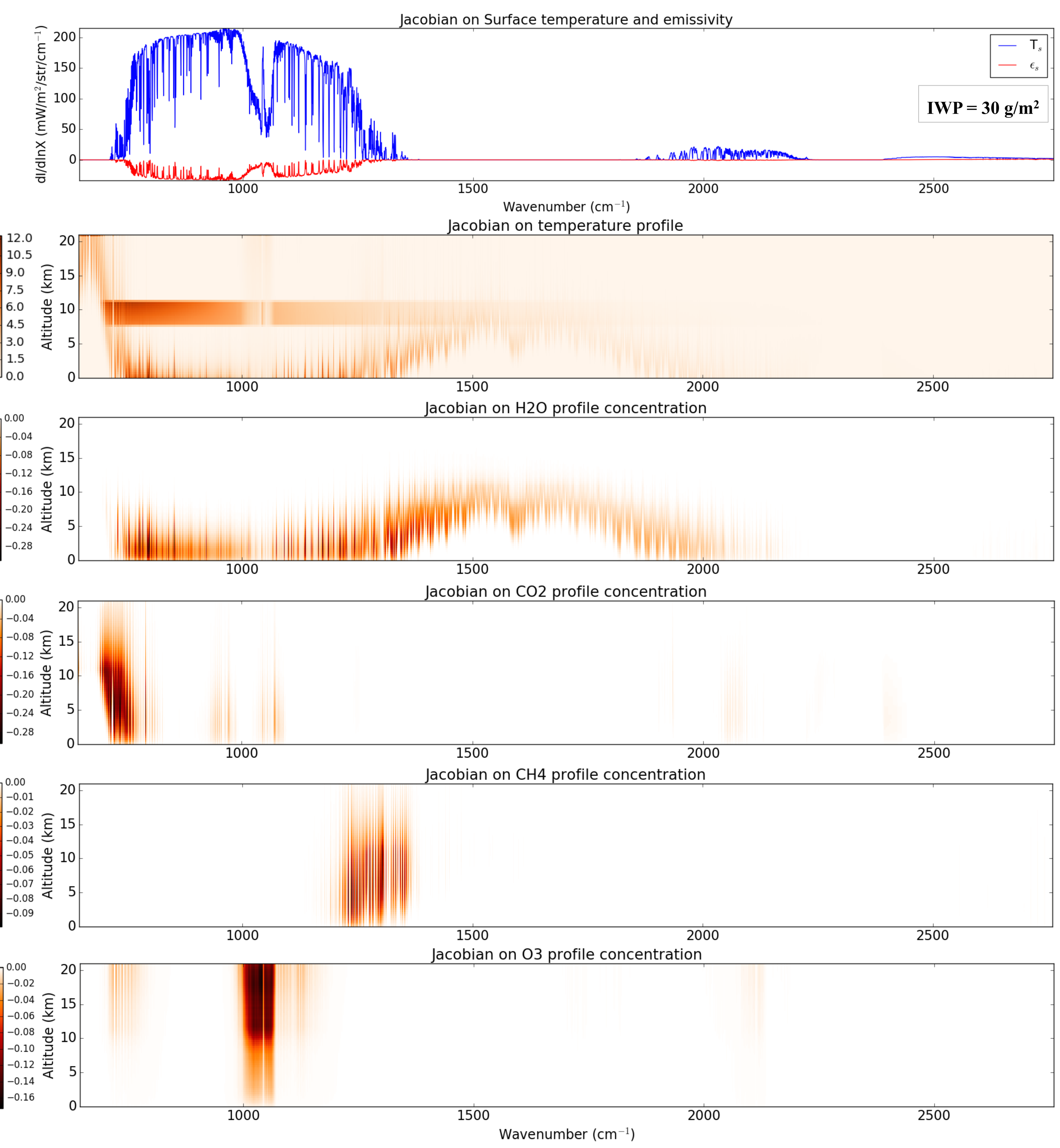
State vector Jacobian: state vector x = (log(IWP), log(z_{top}), log(z_{base}))^T, where IWP is the ice water path (g/m²).



Errors due to a missing knowledge of the non-retrieved parameters, which also need to be computed. We required their Jacobians as well.

The non-retrieved parameters are as follow:

- Surface and atmospheric temperature profile (1K)
- Surface emissivity (5%)
- Ice water content profile (radiance difference between an homogeneous and a inhomogeneous profile)
- Gas profile concentration (H_2O, CO_2, CH_4 and O_3) (10%)



Effects of an Ice cloud layer on IASI like measurements

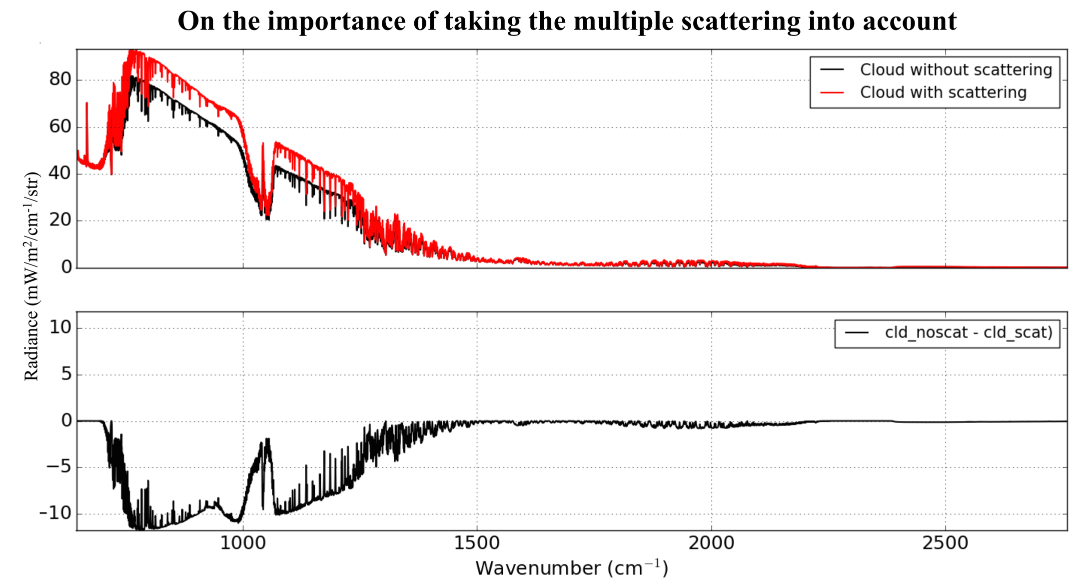
On the importance of taking the multiple scattering into account

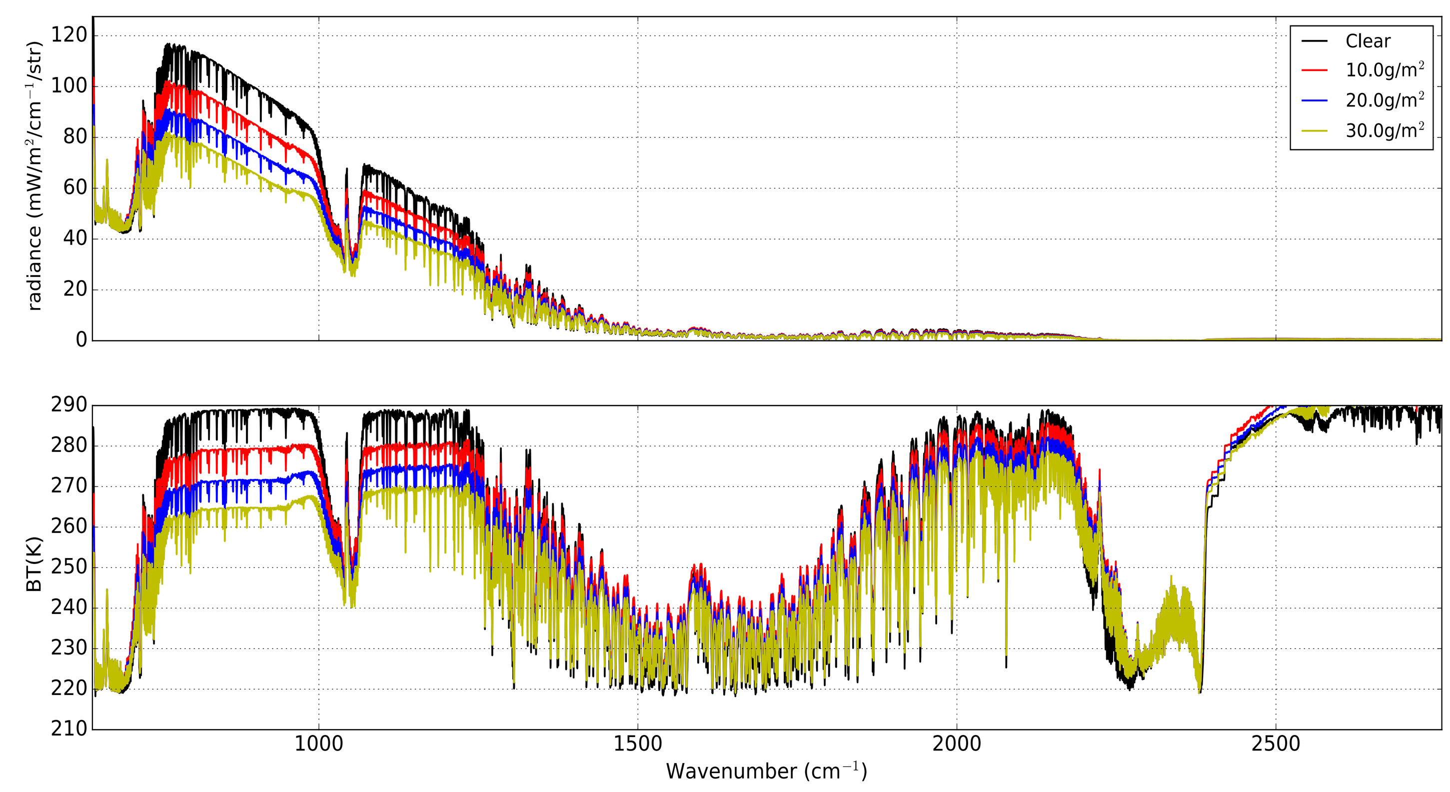
Radiative transfert code used for these computations : LIDORT (8 streams with TMS correction).

This code takes into account multiple scattering, polarization and pseudo-sphericity of the atmosphere, and is linearized about atmospheric properties such as gas concentration, IWC, temperature profile and surface emissivity,

Atmospheric profile: US standard divided in 99 layers (updated for CO_2 concentration).

Ice cloud between 7.9 and 11.5 km divided in 12 layers of 300 m thickness. The cloud is assumed homogeneous (constant IWC profile).





Effect of an ice cloud layer with different IWP on IASI–like measurements in terms of radiance (upper panel) or brightness temperature (lower panel). Surface temperature = 290 K.

Cloud optical depth at 10 microns

IWP (g/m²)	COD (λ=10 µm)
10	0.49
20	0.95
30	1.39
50	2.27
100	4.4
500	20.77
1000	40.74

Information content and expected improvement from IASI-NG

Theory: In this study, two matrices (**A** and **S**x) fully characterize the information provided by the observing system :

The averaging kernel **A** defined as : $A = \frac{\partial \hat{x}}{\partial x} = G.K$

Where **K** is the Jacobian, defined as : $K_{ij} = \frac{\partial F_i}{\partial x_j}$

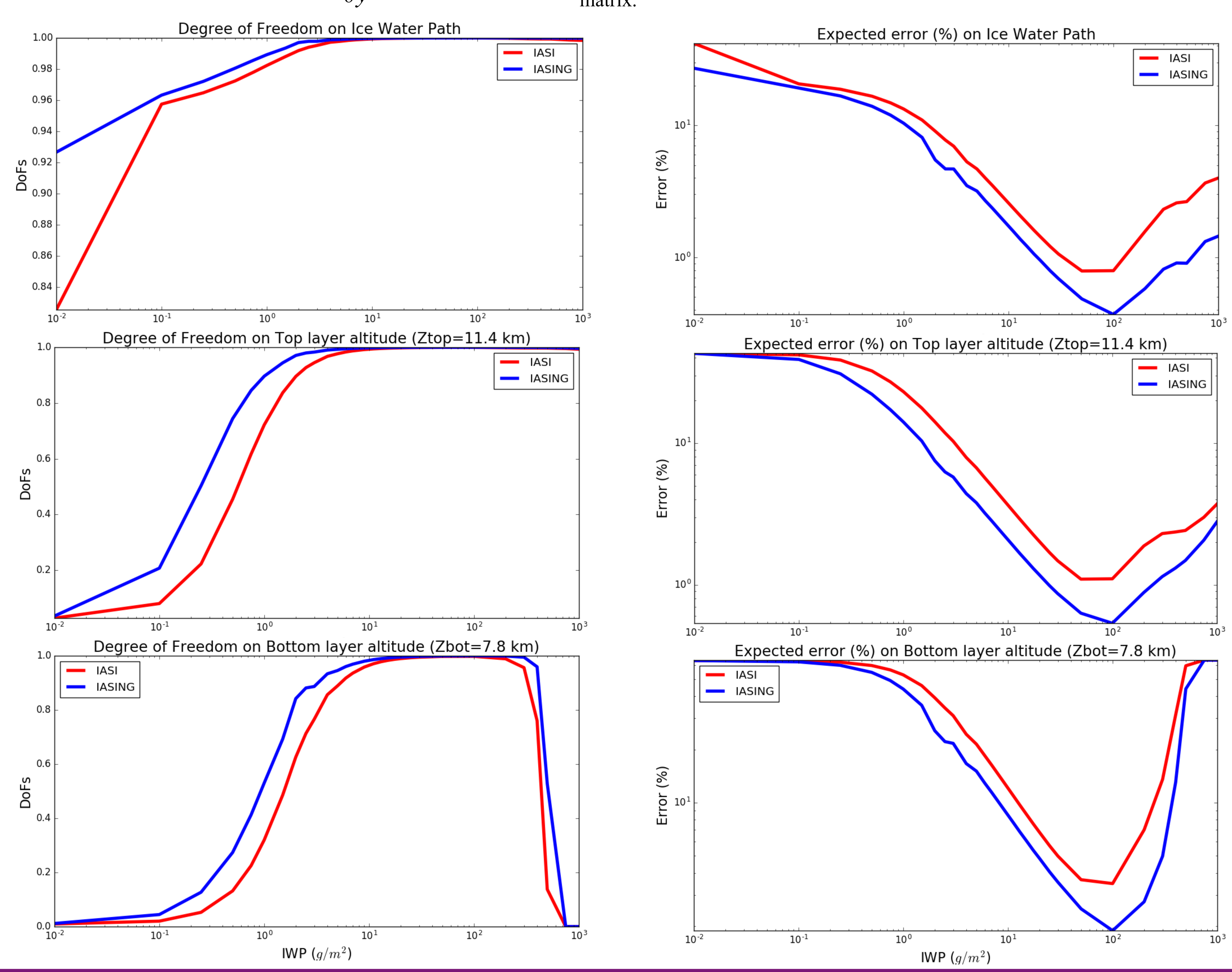
and **G** is the gain matrix, defined as : $G = \frac{\partial x}{\partial y} = S_x K^T S_\varepsilon^{-1}$

And the posterior covariance matrix $\mathbf{S_x}$, defined as : $S_x = (S_a^{-1} + K^T S_\varepsilon^{-1} K)^{-1}$

$\mathbf{S_\varepsilon}$ is the measurement plus forward model covariance matrix, defined as :

$$S_\varepsilon = S_m + S_f = S_m + K_b S_b K_b^T$$

With $\mathbf{K_b}$ the Jacobian about the non-retrieved parameters and Sb their error (%) matrix.



Conclusion and perspectives

We have shown in this study the potential of high spectral resolution measurements in the Infrared region (IASI-like) to obtain information on ice cloud layers. We have choosen to follow the parametrisation developed by Baran et al. in order to represent the ice cloud microphysical properties, and top and bottom layer altitude to represent the layer position and extent. In this study, we also took into account error contribution from the non-retrieved parameters that are in the forward model computation (e.g. temperature and gas profile, surface temperature and emissivity, IWC profile shape). The measurement noise was reallistically taken into account from the IASI SNR ratio and the expected one for IASI-NG.

Results show that despite the numerous error contributions the IWP should be well retrieved for IWP > 1 g/m² (COD(10mic)=0.06), with an expected error < 10%. The top layer altitude is also expected to be well retrieved with an error <10% for ice cloud with IWP > 10 g/m² (COD=0.49). Bottom layer altitude should be more difficult to retrieve with an expected error < 10% for IWP ranging between [10; 200g/m²]. As expected, and because of a higher resolution and better SNR, IASI-NG will improve these restitutions with much smaller posterior errors.