

# Optimal configuration of a far infrared radiometer based on information content

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## Introduction

Data assimilation optimally combines numerical weather predictions (NWP) and huge amounts of observations to provide the best estimate of the state of the atmosphere. In this context, a large part of the observations comes from satellite radiances particularly in the mid-infrared (M-IR), from sensors such as AIRS and IASI. However, the M-IR constitutes only half of the Earth's emitted radiance, the other half being the far infrared (F-IR), ranging from 15 to 100  $\mu\text{m}$ . Recently, a number of theoretical studies have shown the added-value of F-IR observations for remote sensing of water vapor and clouds, especially in dry and cold regions for already existing instruments<sup>5,7</sup>. For this study, we consider a synthetic F-IR radiometer and we will discuss the optimal configuration with respect to its spectral resolution and the noise needed with information content calculations. Also, the added-value of F-IR radiometry, with the analysis error, in polar regions is shown alone and in complement to M-IR measurements with the instrument AIRS.

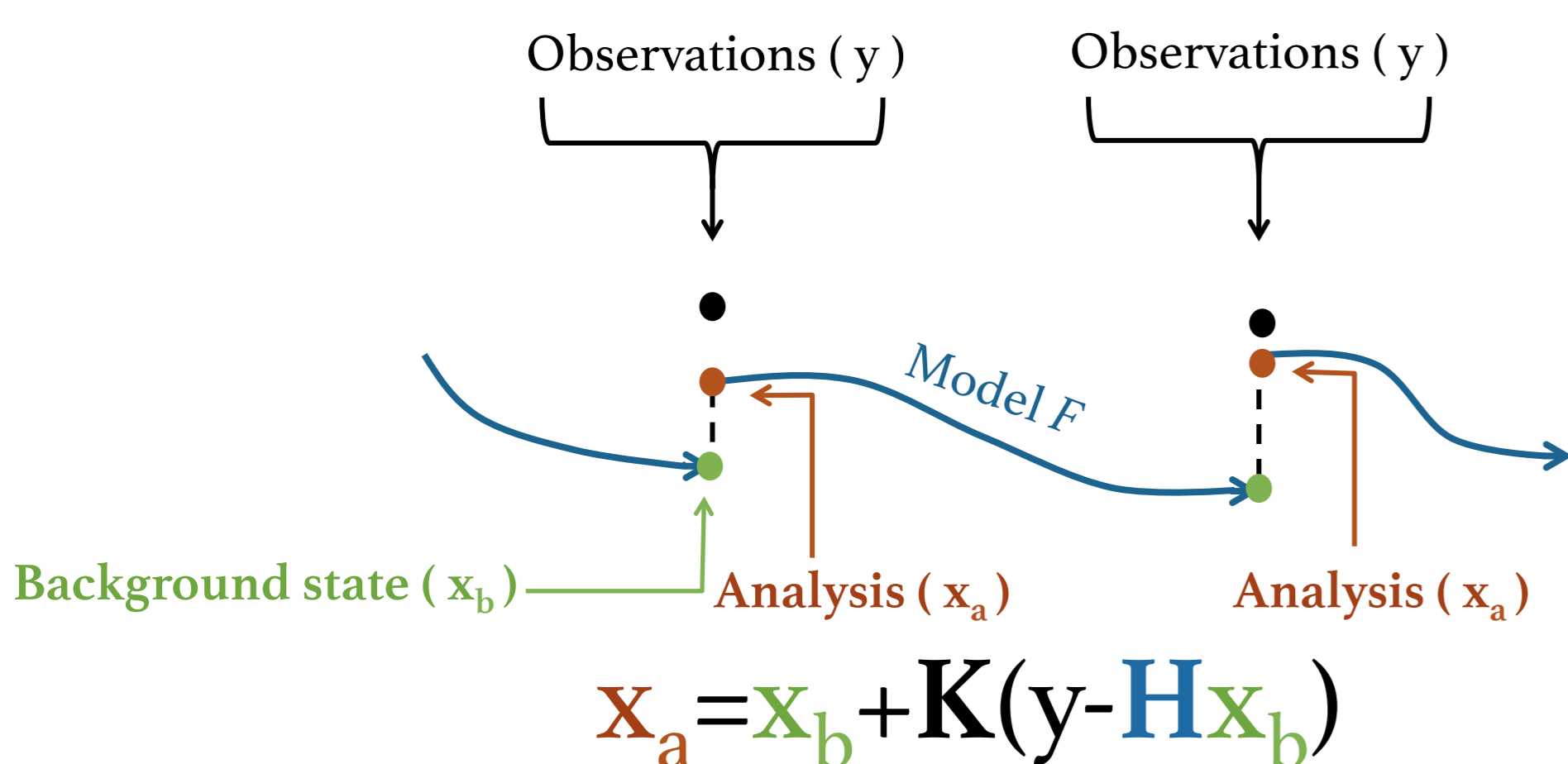
## Objectives

To determine the added-value of assimilating F-IR radiances in NWP systems

- Explore the trade-off between spectral and radiometric resolution for a radiometer in the F-IR (16.5 to 100  $\mu\text{m}$ )
- Quantify the added information brought in by F-IR measurements alone and when added to those in the M-IR in polar regions

## Theory and instruments

### Data assimilation



Where  $\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{R} + \mathbf{H}\mathbf{B}\mathbf{H}^T)^{-1}$  is the gain matrix which gives a statistical weight to measurements and observations<sup>6</sup>

$\mathbf{H} = \frac{\partial \mathbf{F}(\mathbf{x})}{\partial \mathbf{x}} \Big|_{\mathbf{x}_b}$  is the Jacobian which gives the sensitivity of TOA

radiance to small changes in atmospheric properties where  $\mathbf{F}(\mathbf{x})$  is the radiative transfer model MODTRAN 5.4

- The humidity Jacobian ( $\ln q$ ) is obtained by finite difference taken around a background state<sup>2</sup>, which is taken from a radiosonde profile at Eureka, Canada.

-  $\mathbf{B}$  is the background error covariance matrix, which is the stationary components of the background term in the ECCO system<sup>1</sup>

### Degrees of freedom per signal (DFS)

$$\text{DFS} = \text{tr}(\mathbf{H}\mathbf{K}) = \text{tr}(\mathbf{H}\mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1})$$

- Quantify the added-value of a set of observations

### F-IR Radiometer

- Synthetic spaceborne F-IR radiometer

- Measures radiation in the F-IR with a spectral coverage of 16.5 - 100  $\mu\text{m}$

- Fixed detector noise of  $0.01 \text{ Wm}^{-2}\text{sr}^{-1}$ , value taken for the diagonal of the error covariance matrix  $\mathbf{R}$ . This NER value corresponds to the F-IR radiometer FIRR<sup>4</sup>

- Multiples configurations considered

- Equi-energetic bands
- Bands with equal bandwidths
- Bands with equal Jacobian's peak

### AIRS

- Measures radiation in the M-IR (3.75 - 15.4  $\mu\text{m}$ ) with 2378 channels

- Subset of 142 channels taken

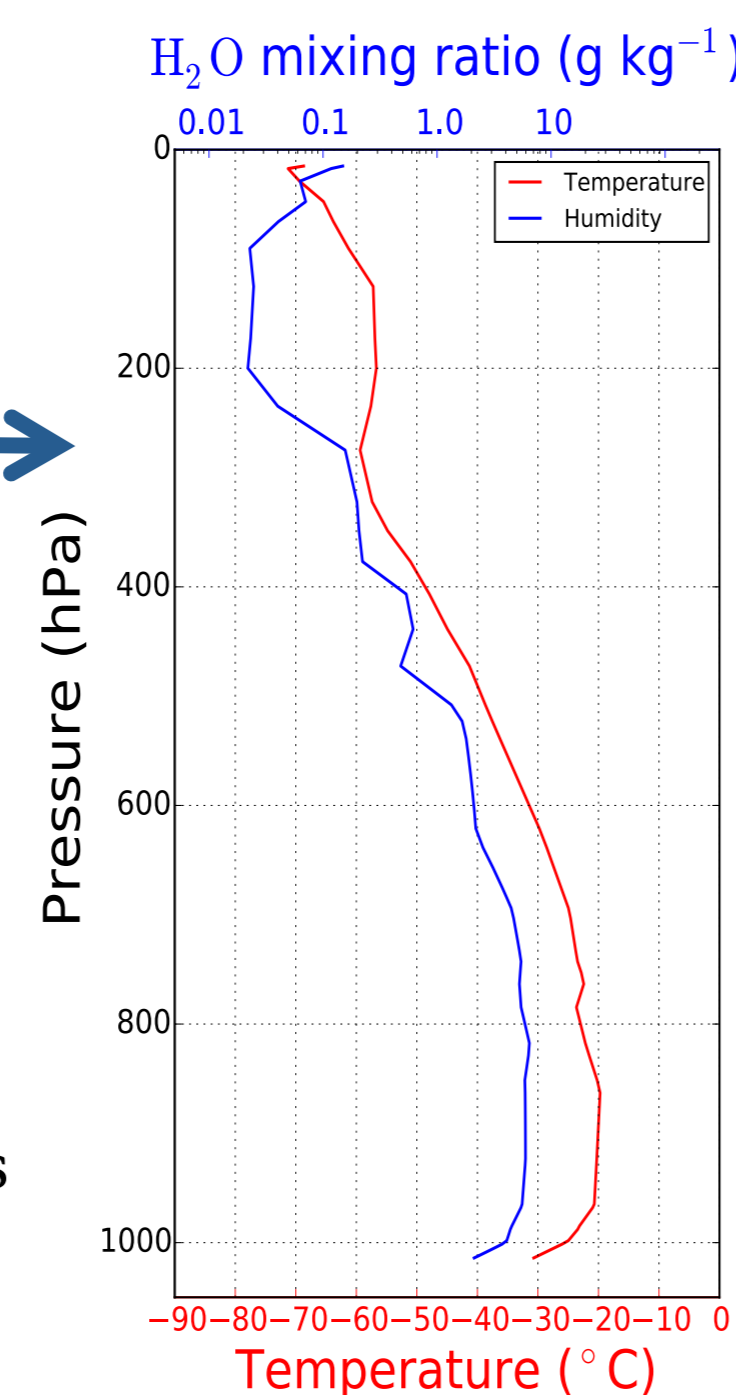


Figure 1 : Atmospheric profile at Eureka, Canada

## References

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## F-IR radiometer configurations

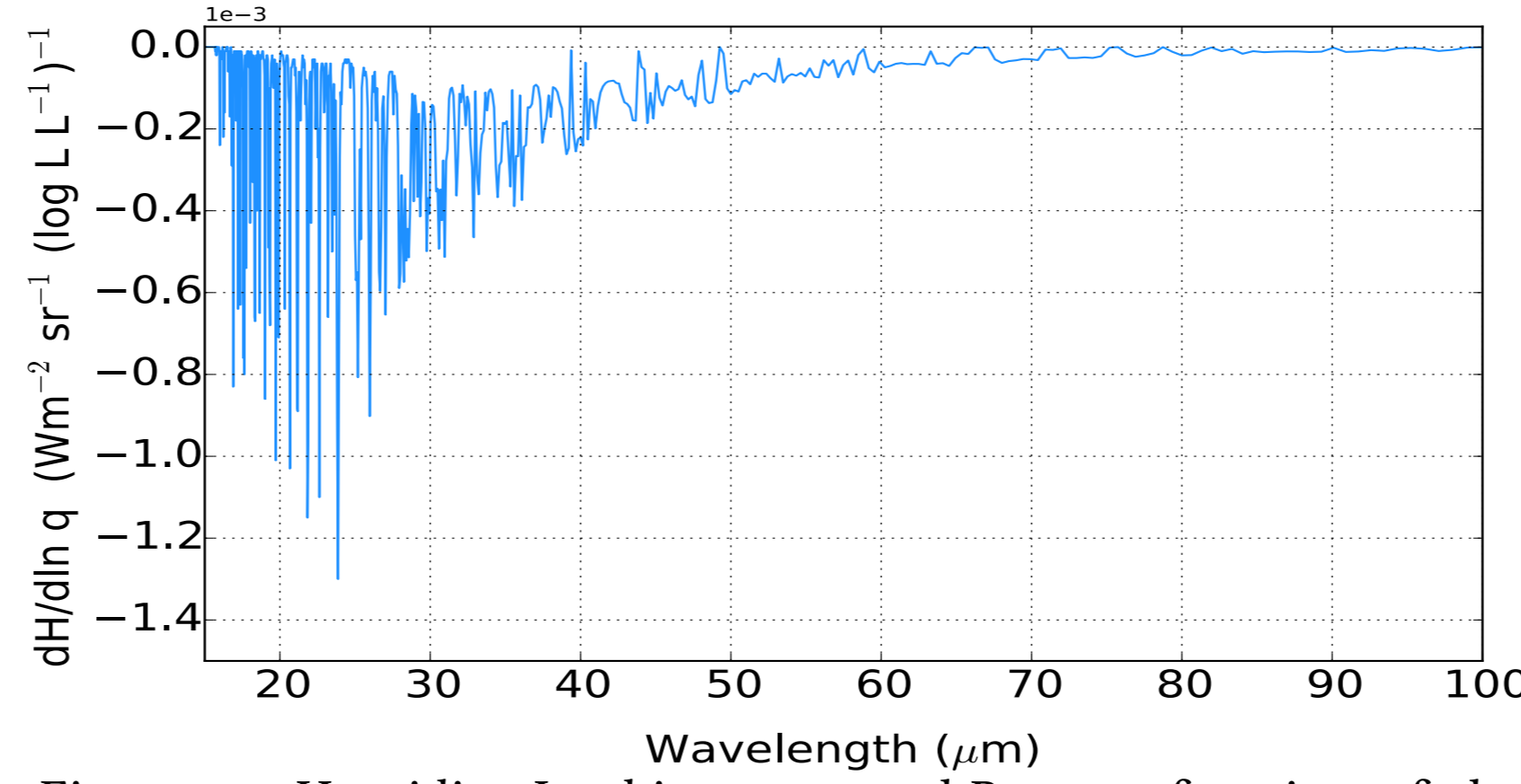


Figure 2 : Humidity Jacobians at 300 hPa as a function of the wavelength for a bandwidth of  $1 \text{ cm}^{-1}$ .

➤ Strong wavelength dependence of the Jacobians

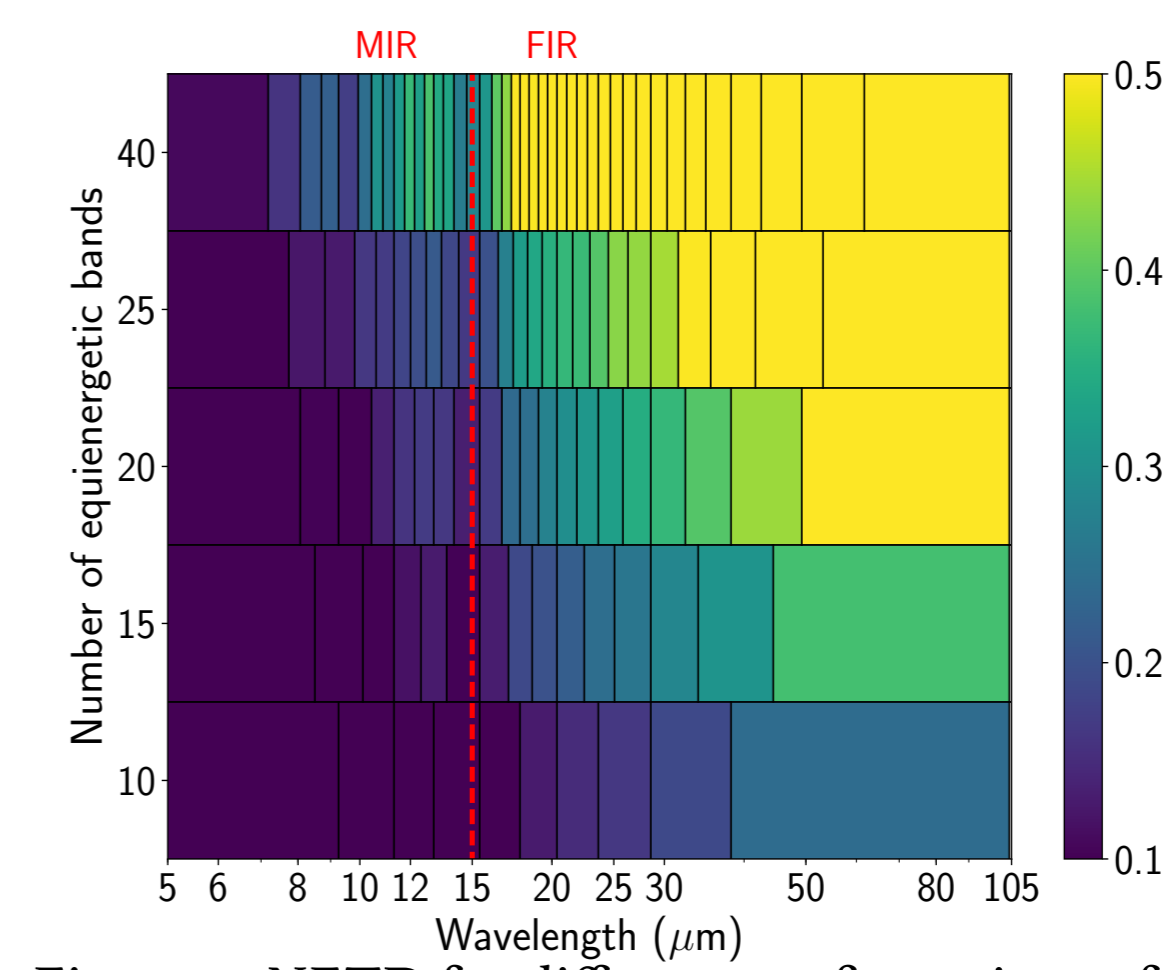


Figure 3 : NETD for different configurations of equi-energetic bands for a blackbody at 250 K with a constant NER of  $0.01 \text{ W/m}^2\text{sr}$ .

- Noise-equivalent temperature difference (NETD) not constant for a configuration with a noise-equivalent radiance (NER) of  $0.01 \text{ W/m}^2\text{sr}$
- Spectral widths vary for equi-energetic bands

- Jacobians vary depending on the configuration for the same profile, which impact the DFS
- These variations are linked to the atmospheric transmittance since there are large variations in it in the F-IR region
- The positive peak is due to the inversion layer whereas the negative peak is due to the greenhouse effect

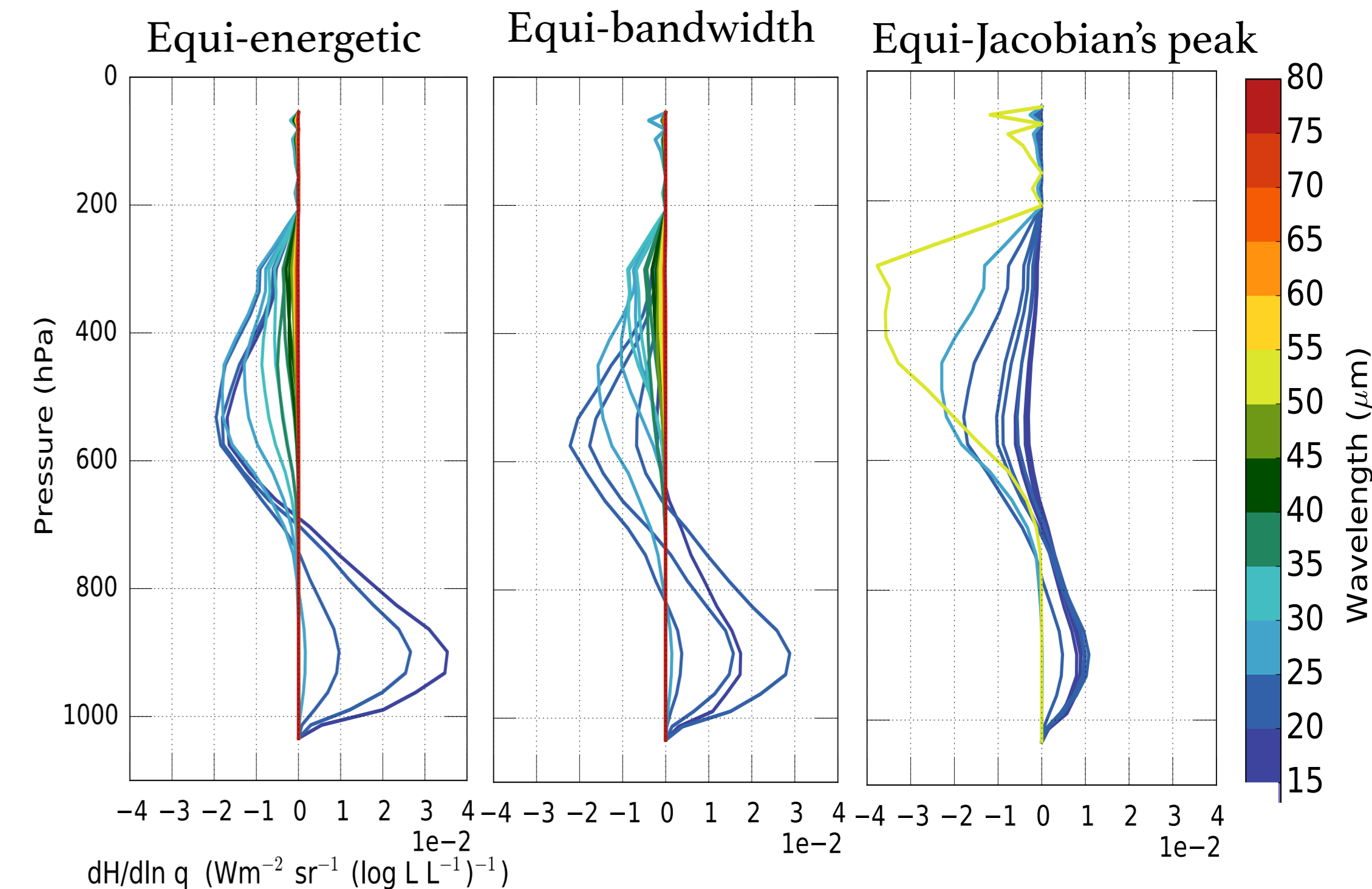


Figure 4 : Humidity Jacobians for the different optimal configurations. The color of the lines represent the wavelength of the band.

## DFS Analysis of various configurations

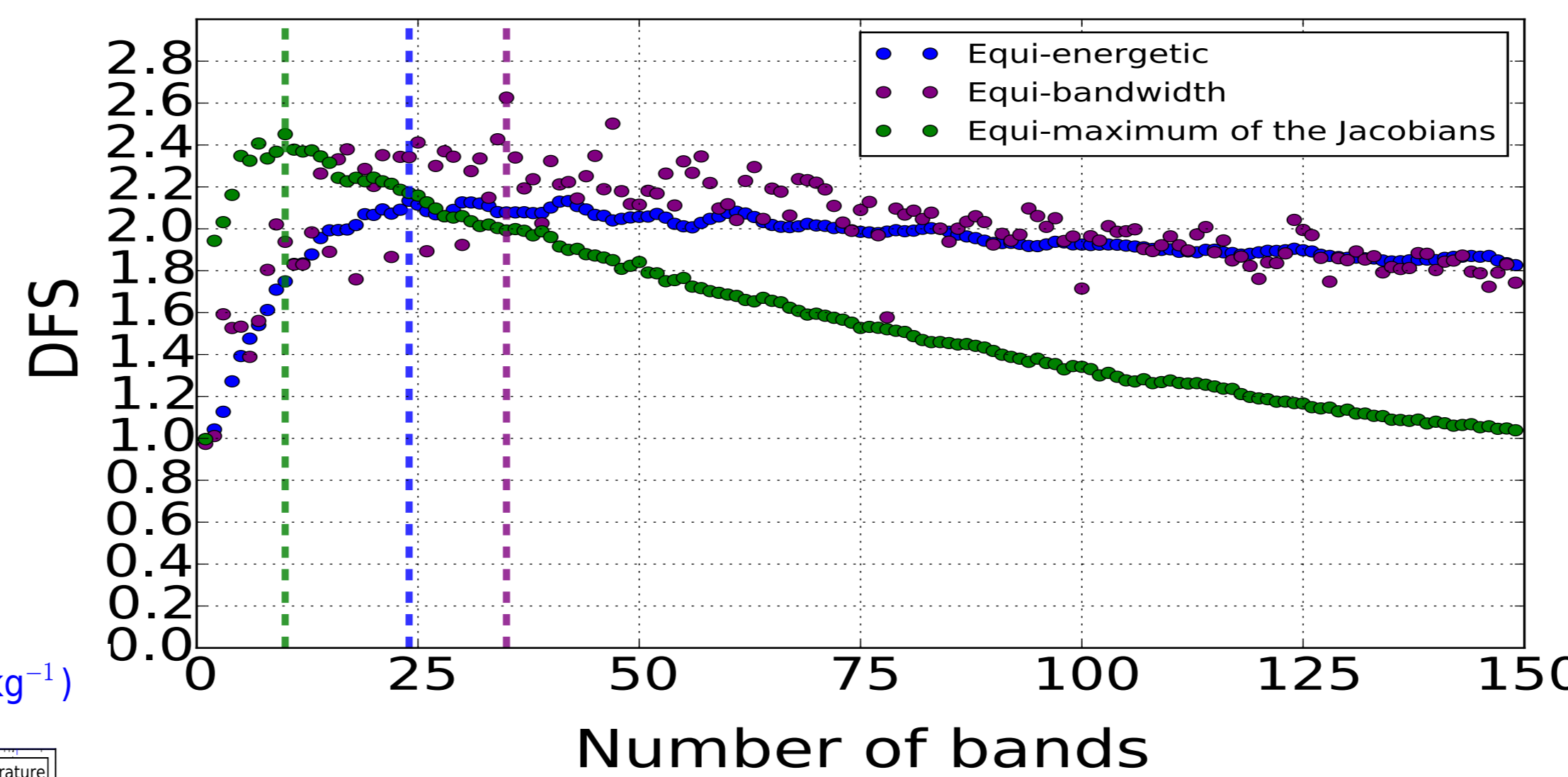


Figure 5 : Total DFS as a function of the number of bands the radiometer has for the three different configurations. The dashed lines represent where the maximum DFS is for each configuration.

- No advantage to have numerous but thin bands
- Gain in DFS  $\sim 25$  bands
- Variability of the equi-bandwidth configuration due to the micro-windows of the transmittance

Configuration	Total DFS (Number of bands)
Equi-energetic	2.13 (24)
Equi- bandwidth	2.63 (35)
Equi- Jacobians	2.45 (10)

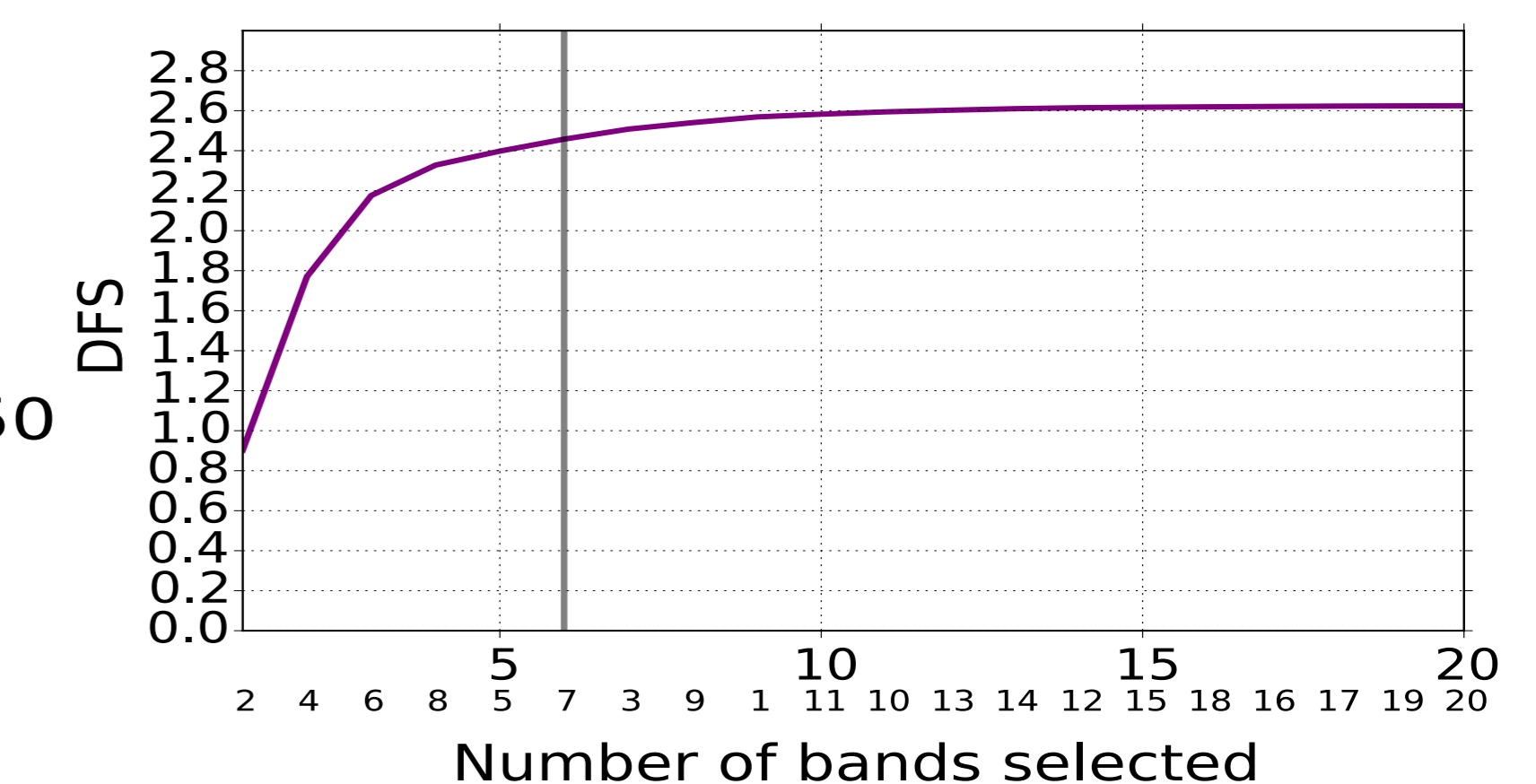


Figure 6 : DFS as a function of the number of bands assimilated for the configuration of 35 equi-bandwidth bands. The second x-axis shows the index of the bands selected. The grey line shows when 95 % of the information is reached.

➤ Only a few bands ( $\sim 6$ ) are needed to obtain most of the information

## Sensitivity to sensor noise

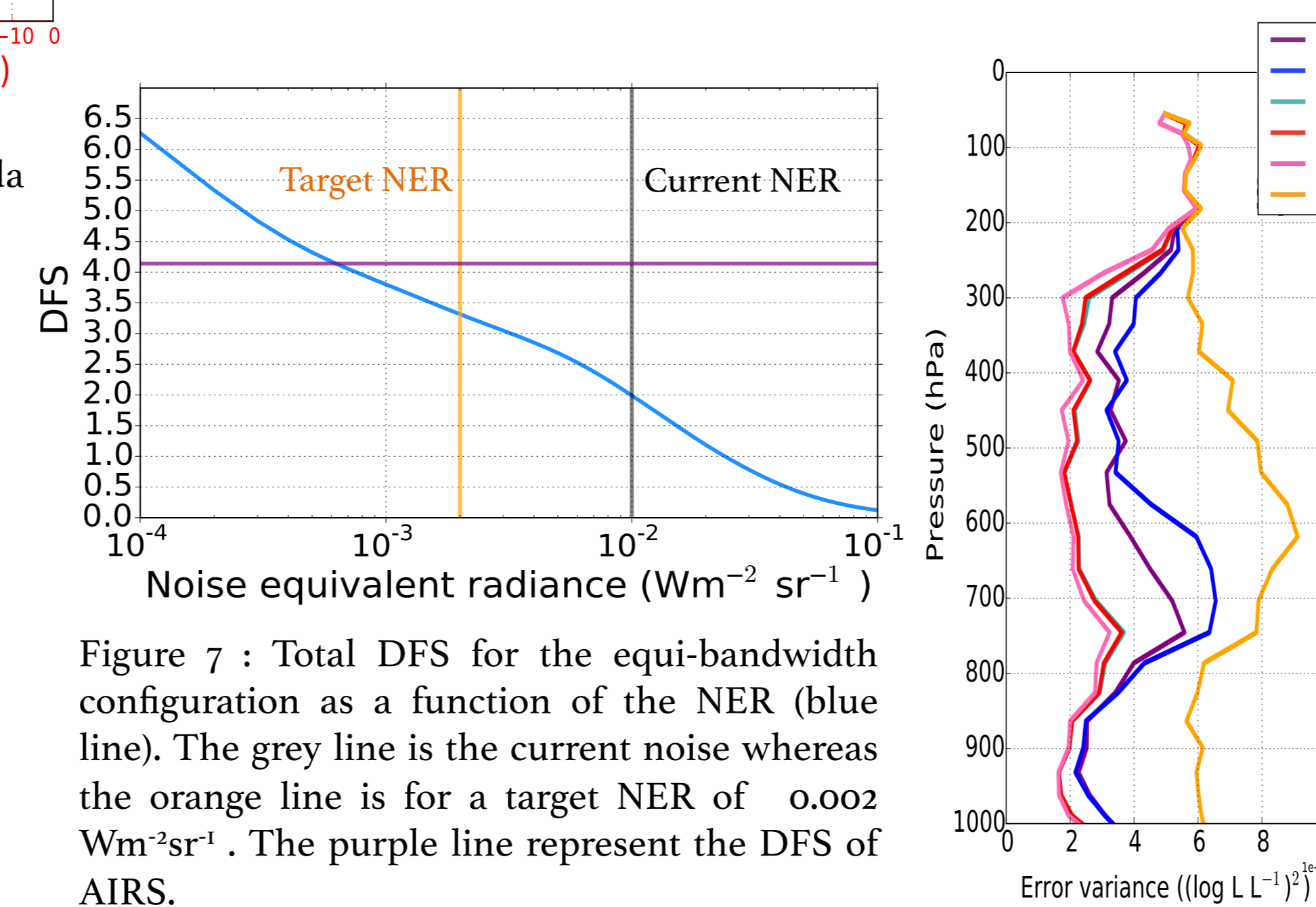


Figure 7 : Total DFS for the equi-bandwidth configuration as a function of the NER (blue line). The grey line is the current noise whereas the orange line is for a target NER of  $0.002 \text{ Wm}^{-2}\text{sr}^{-1}$ . The purple line represent the DFS of AIRS.

➤ Target NER gives a DFS close to AIRS

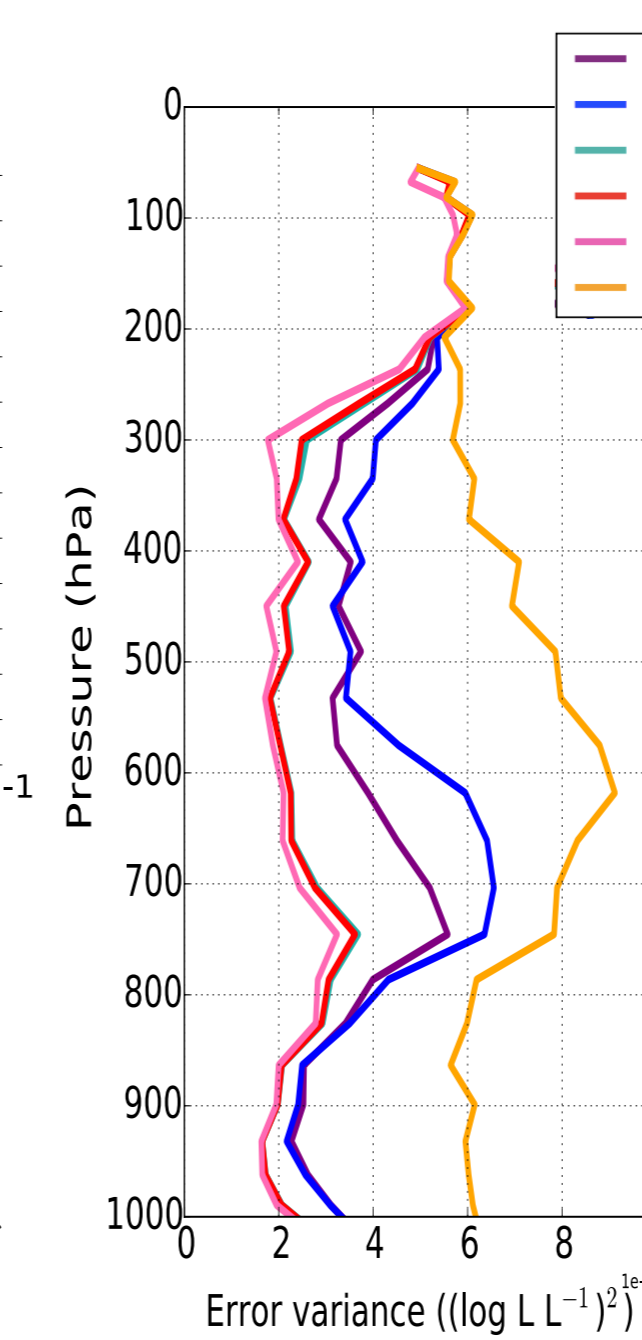


Figure 8 : Analysis error for humidity for the different configurations of the F-IR radiometer and also when assimilated on top of AIRS.

- Stand-alone, F-IR measurements reduces the analysis error between 700-200 hPa
- When assimilated on top of AIRS, for the target NER, the principal gain is between 350-200 hPa

Instruments	Total DFS Current NER	Total DFS Target NER
AIRS	4.136	4.136
Equi- bandwidth	2.626	3.929
AIRS + Radiometer	4.203	4.843

- There is a gain when assimilated on top of AIRS of 1.6 %, for the current NER
- Reducing the NER has a large impact, it increases the DFS by 15.5% when the F-IR measurements are assimilated on top of AIRS

## Conclusions

- The position and width of the bands have a big impact on the DFS
- We examine three configurations, which are equi-energetic, equi-bandwidth and equi Jacobian's peak, to optimize the instrument. The configuration with equi-bandwidth given the largest DFS, which is 2.63
- Results show that measurements in the F-IR over broader bands increases the SNR and results in a gain of information content, up to 25 bands
- There is a gain in DFS of 15.5 % when radiance measurements in the F-IR are assimilated on top of AIRS for the target NER