TRAINING
COURSE

EUMETSAT/ ECMWF NWP-SAF satellite data assimilation

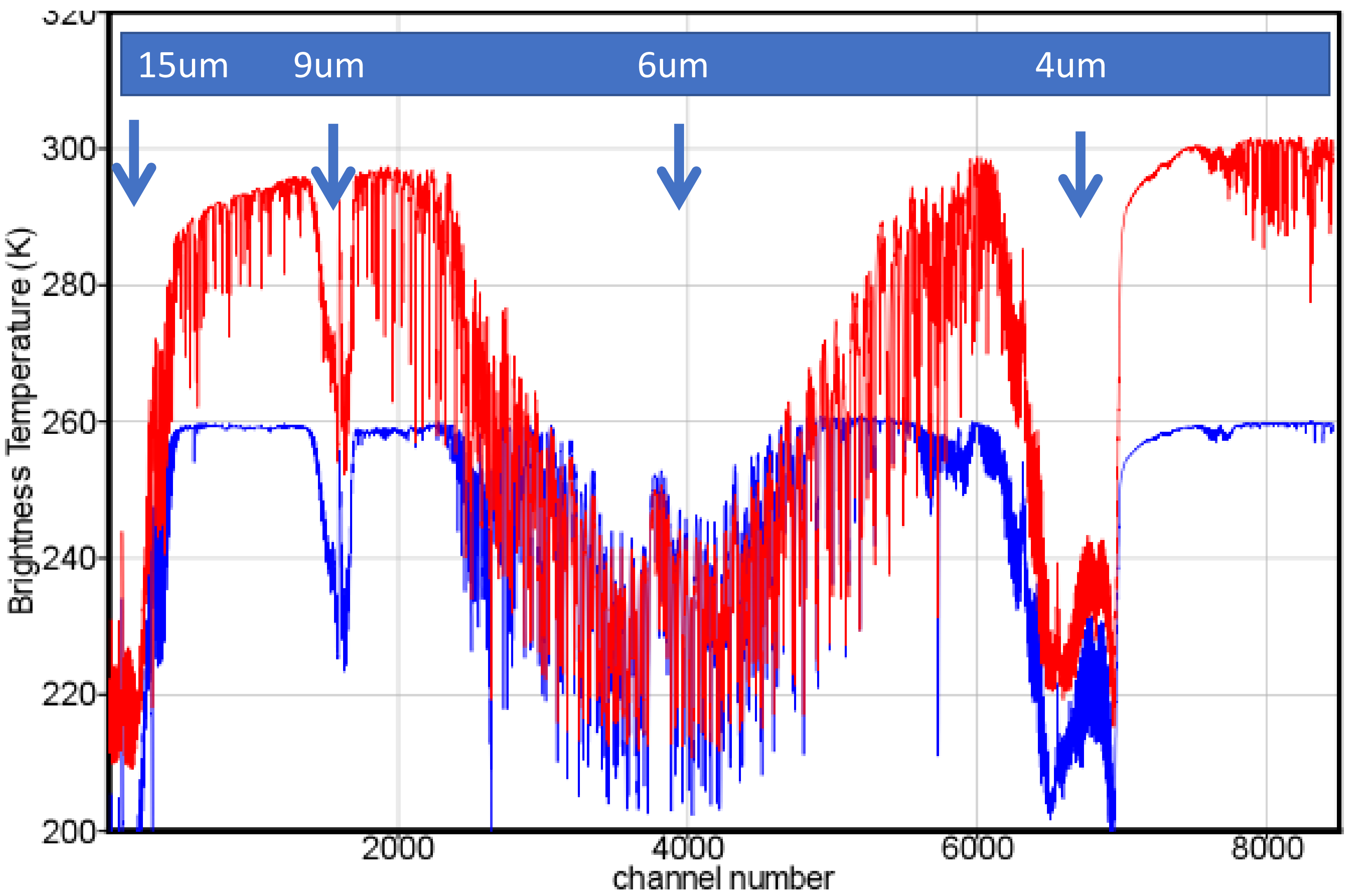
NWP SAF
Numerical Weather Prediction

ECMWF

ECMWF/EUMETSAT NWP-SAF
Satellite data assimilation Training Course

The infrared spectrum, measurement and information content

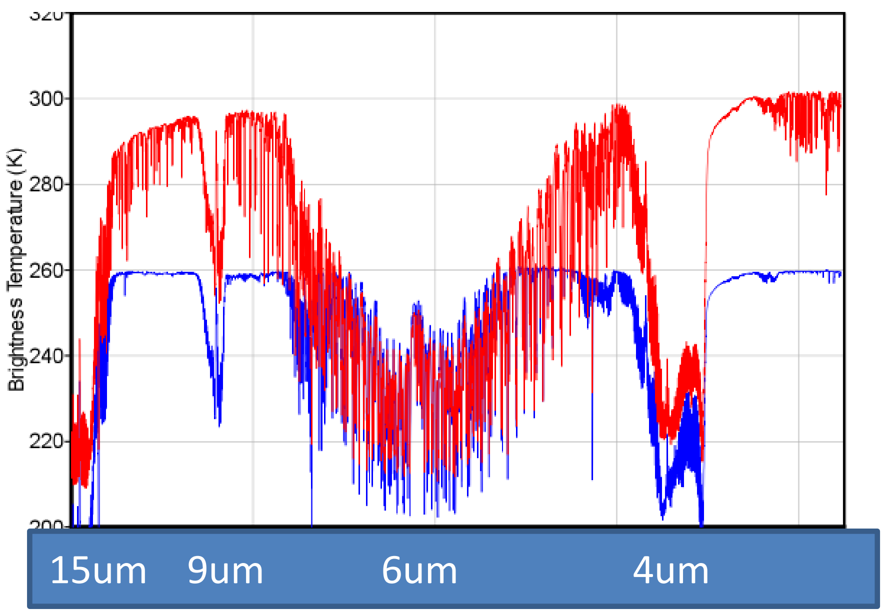
The IR spectrum in a Tropical and Polar atmosphere

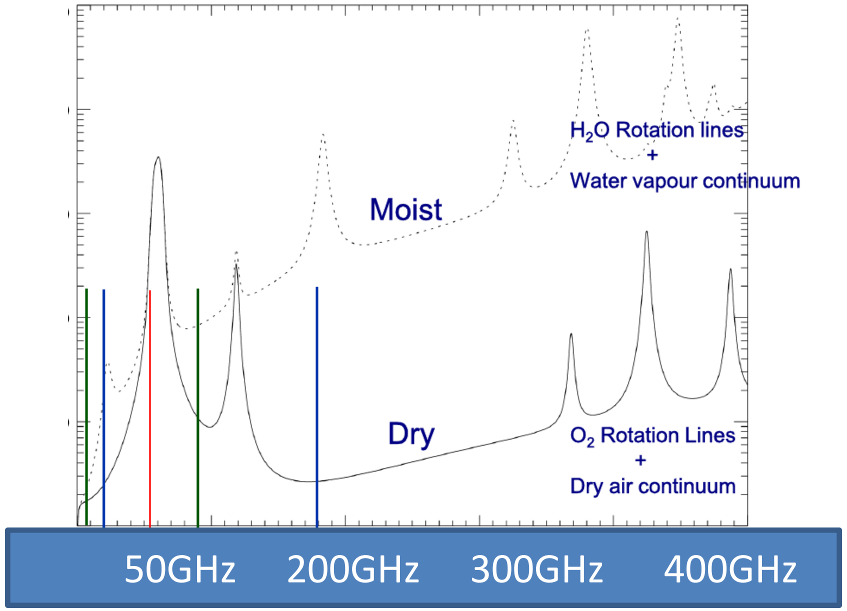


Why infrared ….?

….high spectral resolution

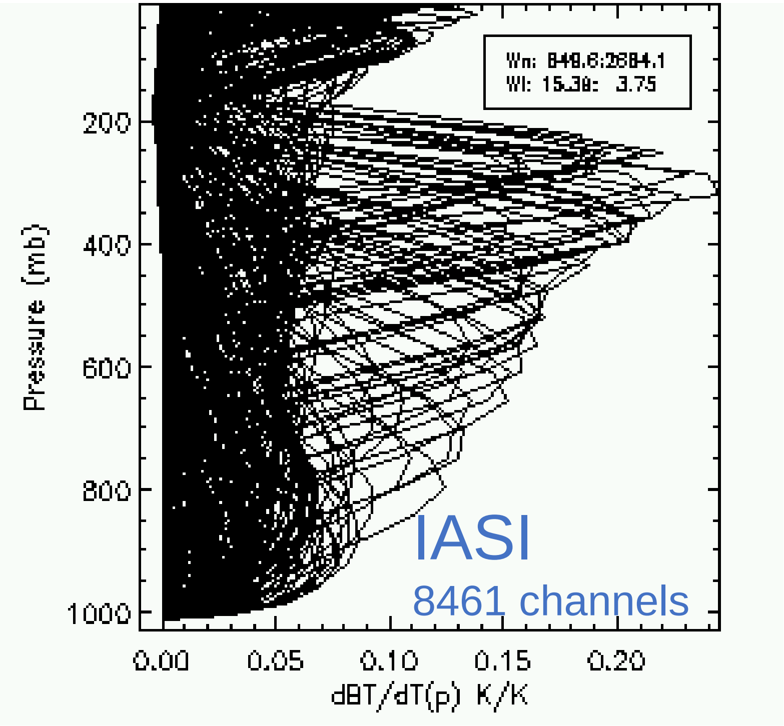
Infrared v Microwave

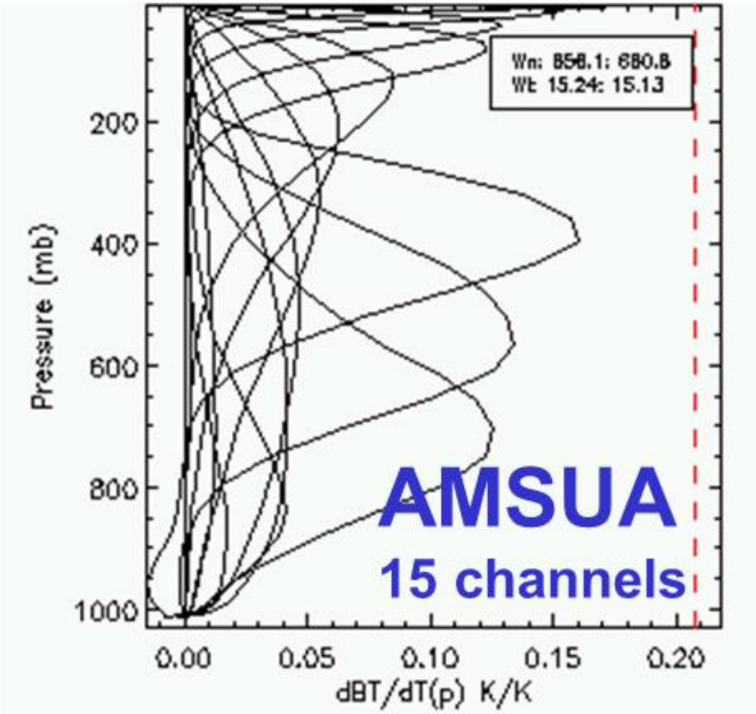




In the infrared, the many thousands of distinct resolvable spectral lines allows us to measure atmospheric radiation many thousands of channels – in the microwave there are only a handful on spectral lines !

Infrared v Microwave





Each channel has a slightly different weighting function – providing information on a slightly different part of the atmosphere

Why high spectral resolution..?

…high vertical resolution

…a helpful linear analogue …

It can be shown that the state that minimizes the cost function is equivalent to a linear correction of the background using the observations:

$$\underline{x_a} = \underline{x_b} + \underline{[\mathbf{HB}]^T[\mathbf{HBH}^T + \mathbf{R}]^{-1}(y - \mathbf{H}x_b)}$$

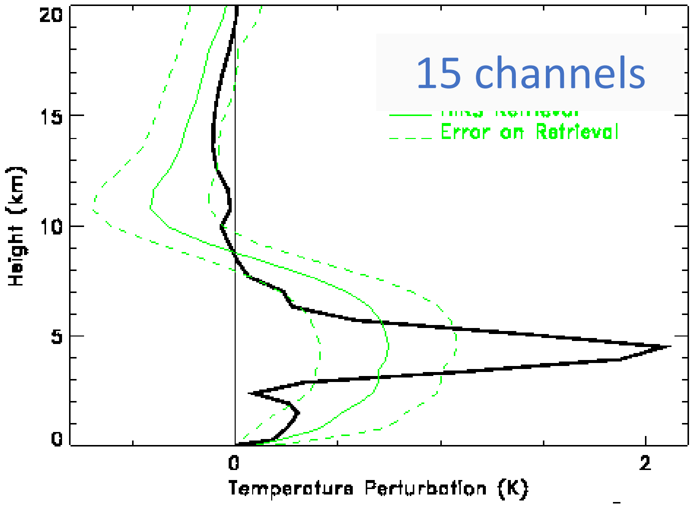
correction term

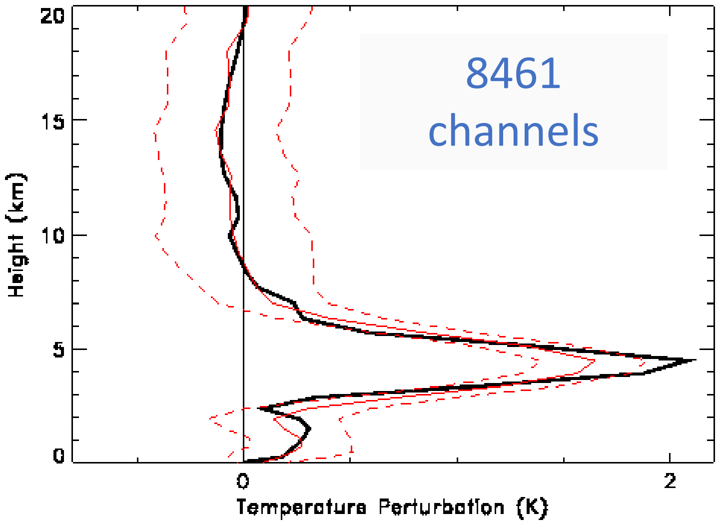
…and the improvement can be quantified in terms of the key parameters of the assimilation…(i.e. B, R, H)

$$S_a = B - \underline{[\mathbf{HB}]^T[\mathbf{HBH}^T + \mathbf{R}]^{-1}\ HB}$$

improvement term

Infrared v Microwave

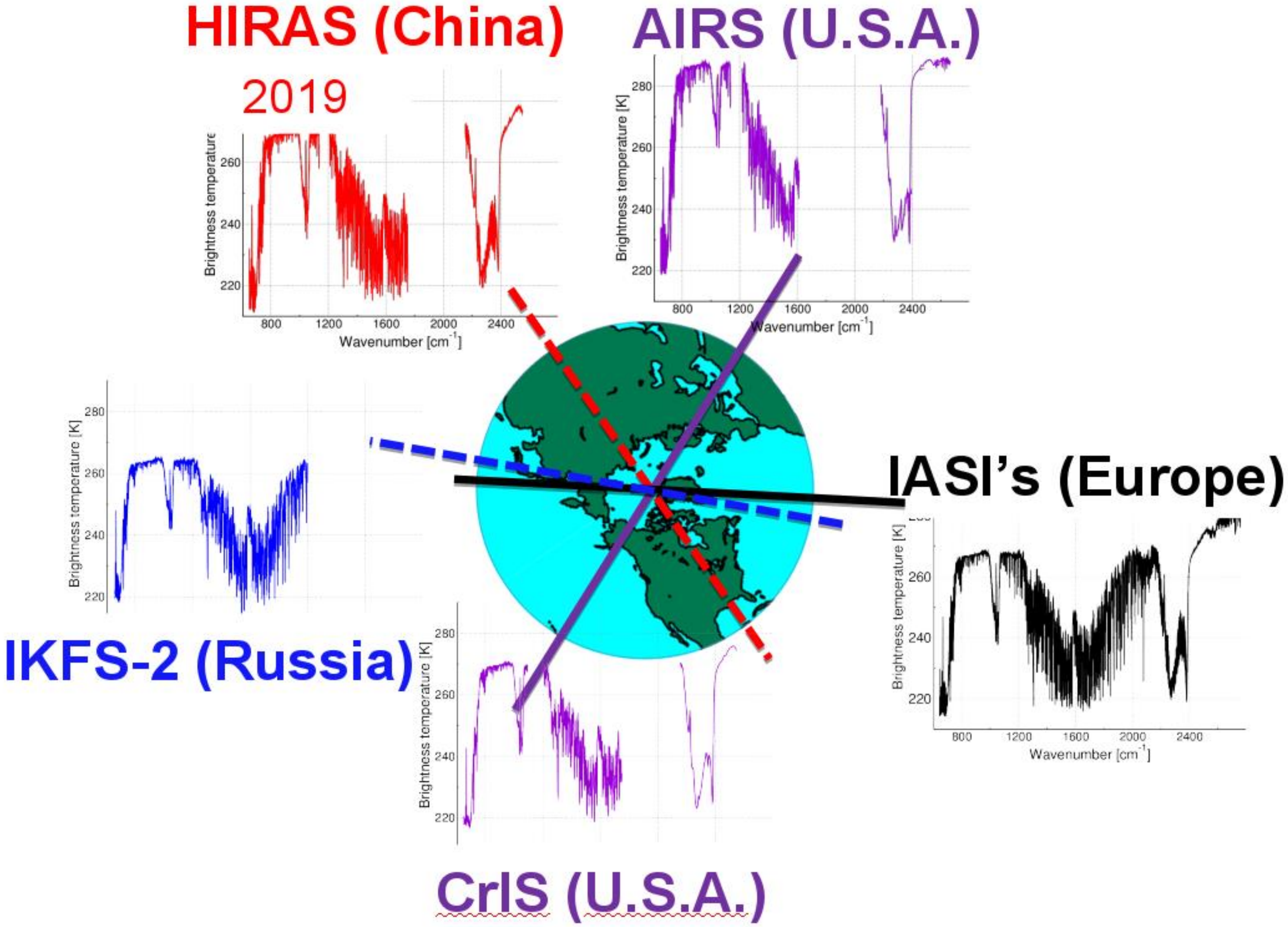




With only a few channels fine vertical feature in the atmosphere are not resolvable – but become more visible with more channels

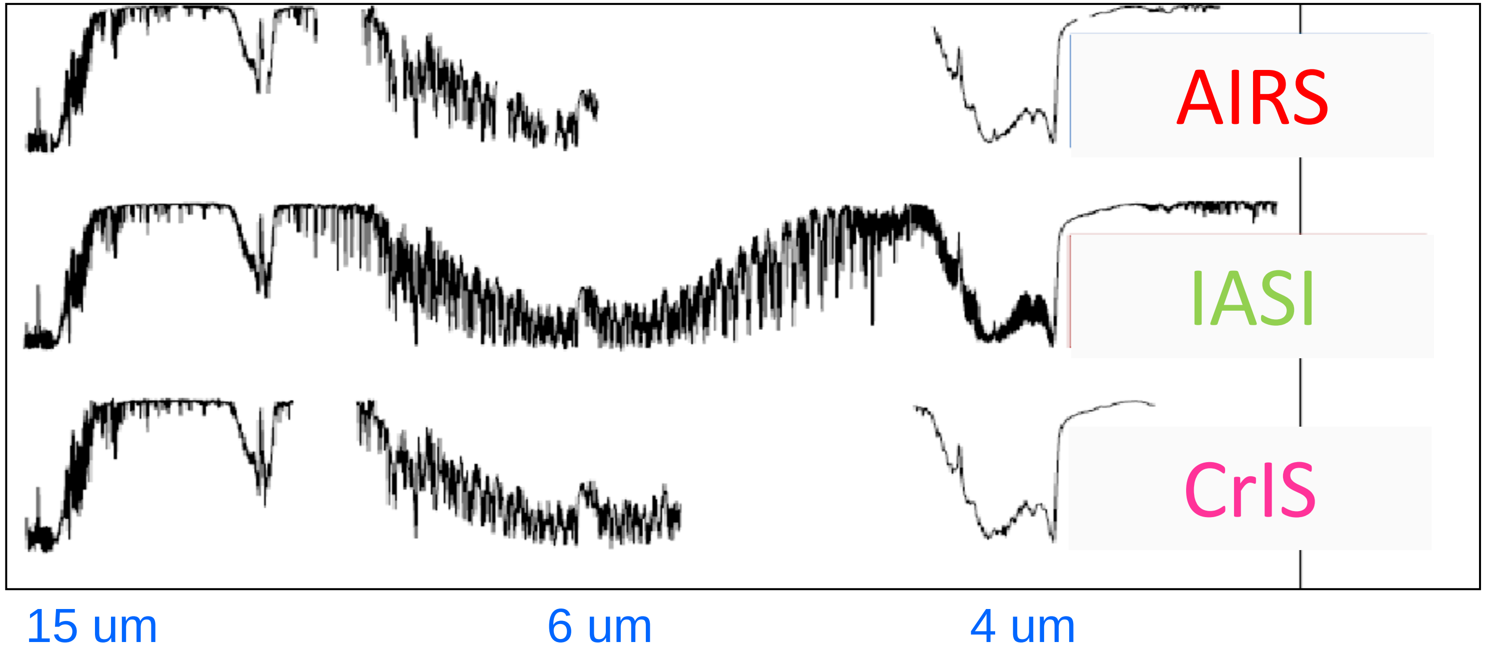
High Spectral Resolution IR sounders on Polar Spacecraft

High Spectral Resolution IR sounders on Polar Spacecraft



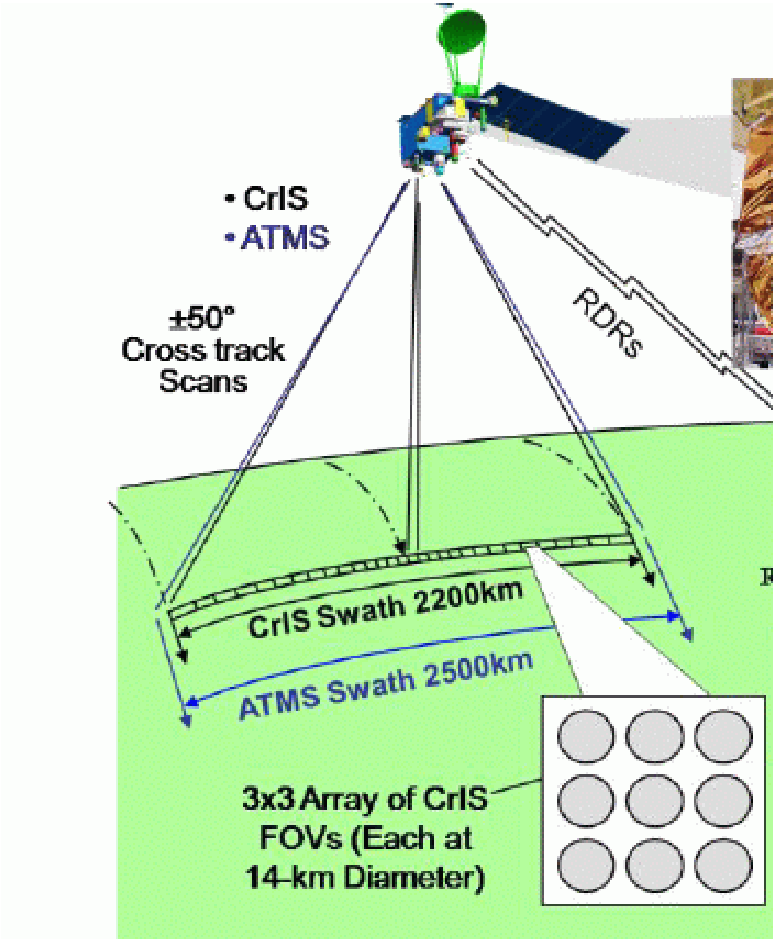
Operational High Spectral Resolution IR sounders

Instrument/ Satellite/	No. of Channel	Spectral Range	Spectral Res.	IFOV	Type/ Orbit
AIRS/ Aqua(EOS-PM)/	2378	650-2760cm^{-1}	~1cm^{-1}	13.5km	Grating Spectrometer/ Polar
IASI/ MetOp/	8461	645-2760cm^{-1}	0.5cm^{-1}	12km	Interferometer /Polar
CrIS/ NPP & JPSS/	1400	635-2450cm^{-1}	1.125-4.5cm^{-1}	12km	Interferometer /Polar

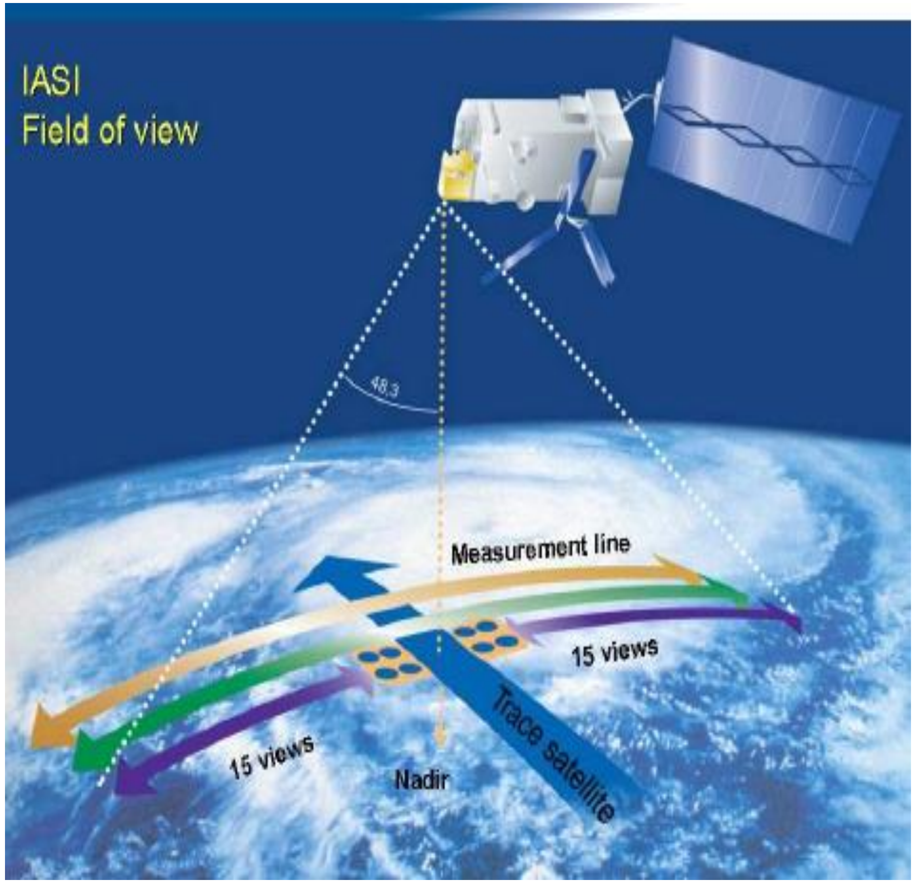


IASI v CrIS

Cross-track Infrared Sounder (CrIS)



Infrared Atmospheric Sounding Interferometer (IASI)



IASI has higher spectral resolution compared to CrIS

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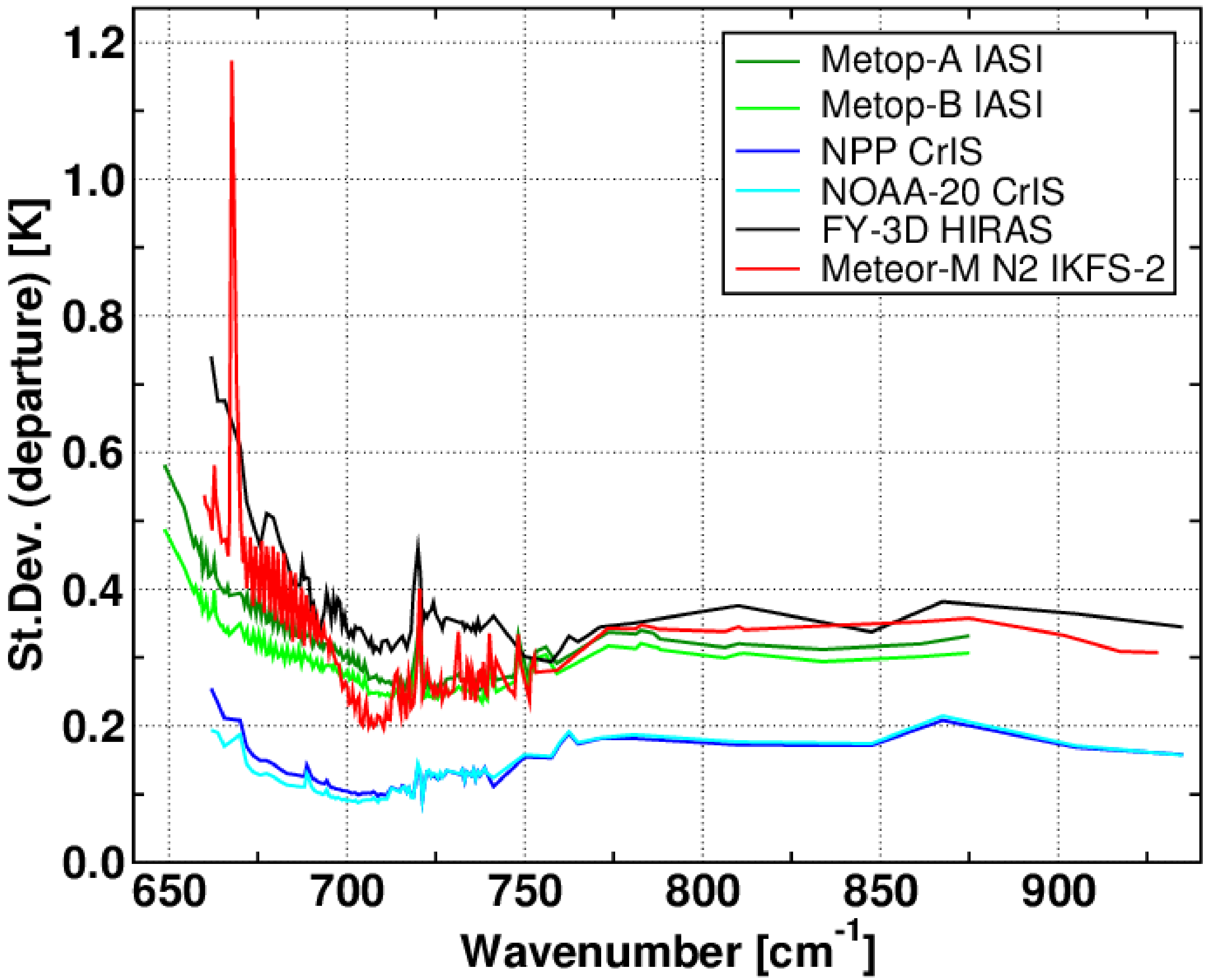
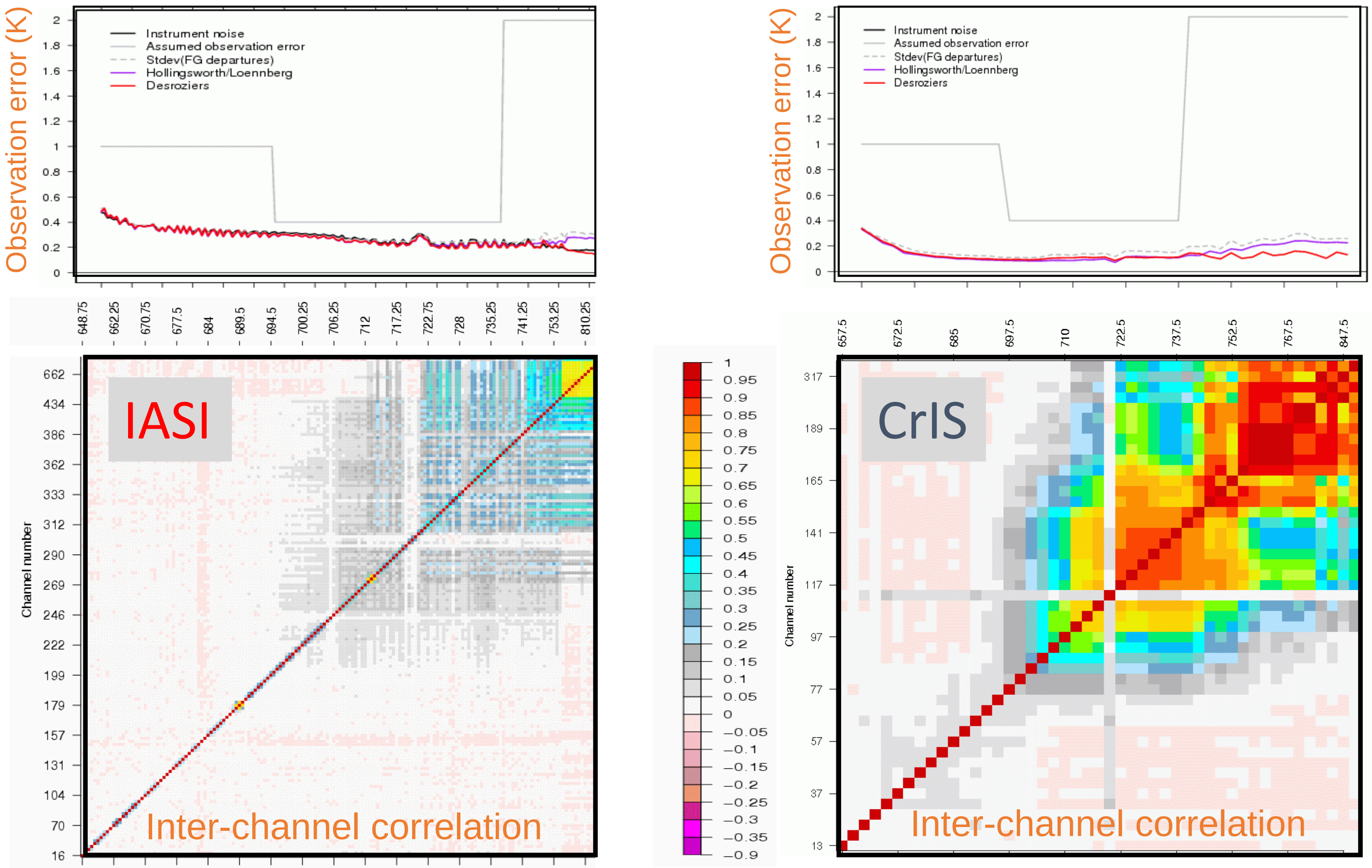
IASI has higher noise compared to CrIS



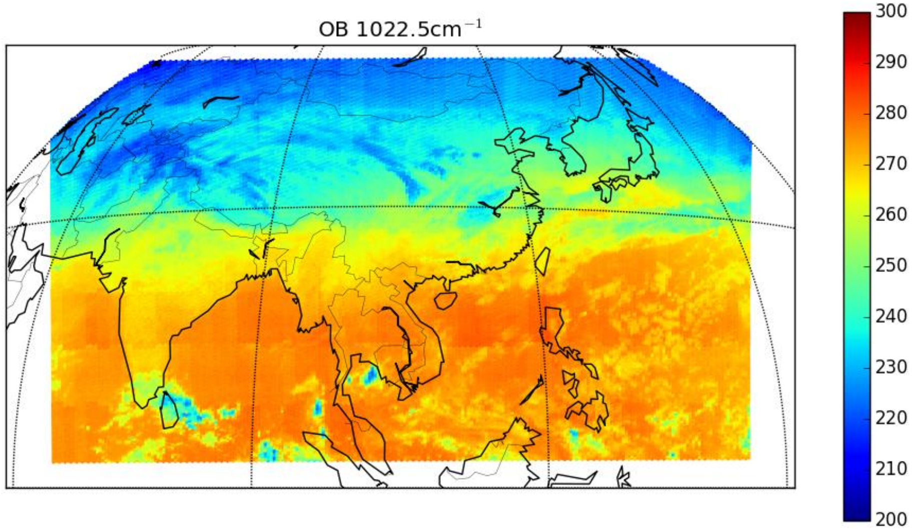
CrIS has stronger inter-channel correlations than IASI



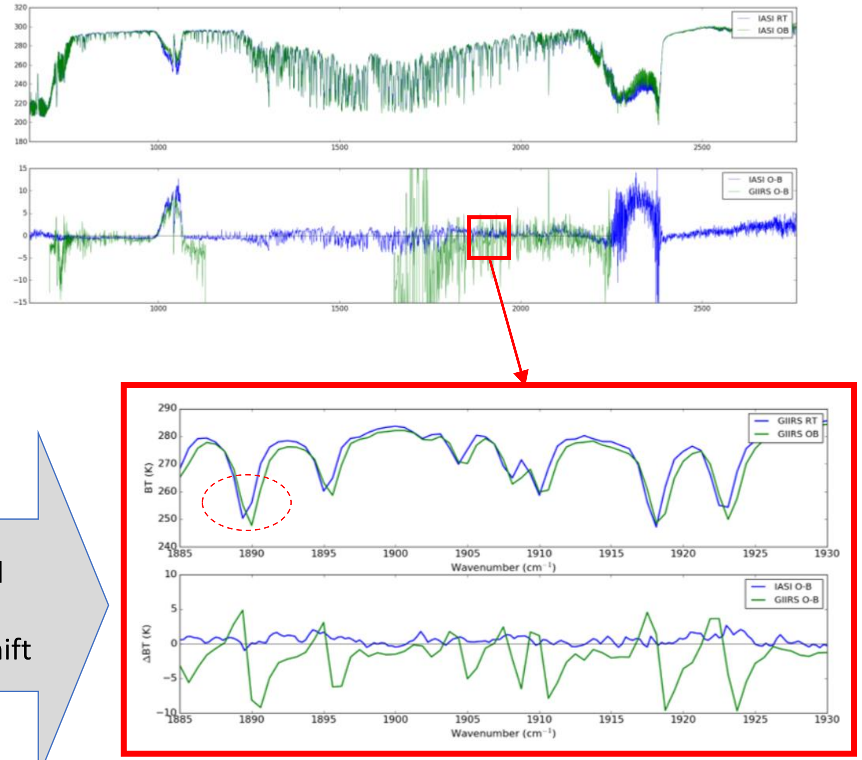
High Spectral Resolution IR sounders on GEO Spacecraft

First ever GEO High Spectral Resolution IR sounder

FY- 4A GIIRS radiance observations 20190301



Initial evaluations suggested the GIIRS radiances were significantly more noisy than similar IASI channels



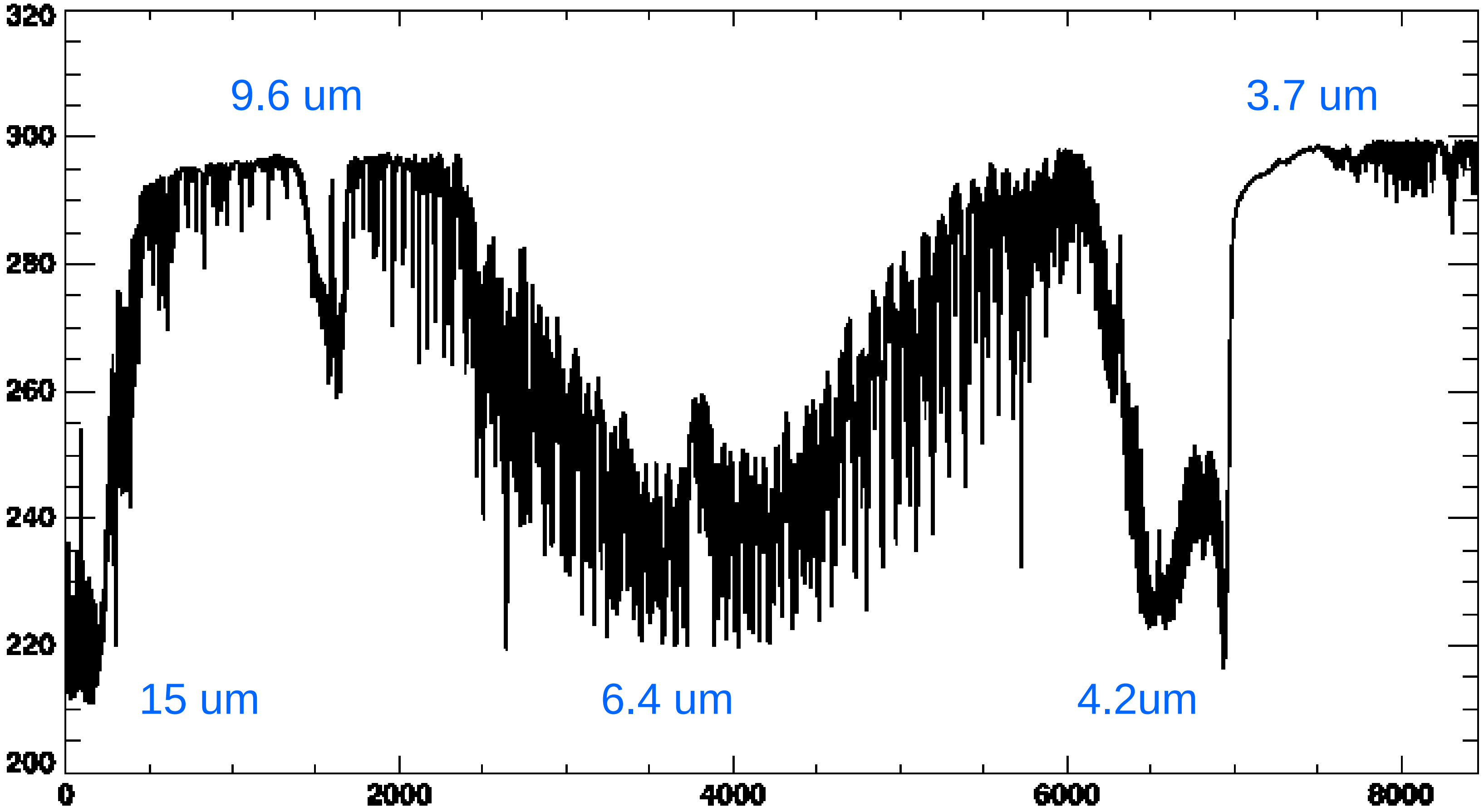
Cross checking with model simulations and IASI suggests much of the noise can be explained (and removed) with a spectral shift

Case study:
The assimilation of IASI

What does IASI measure

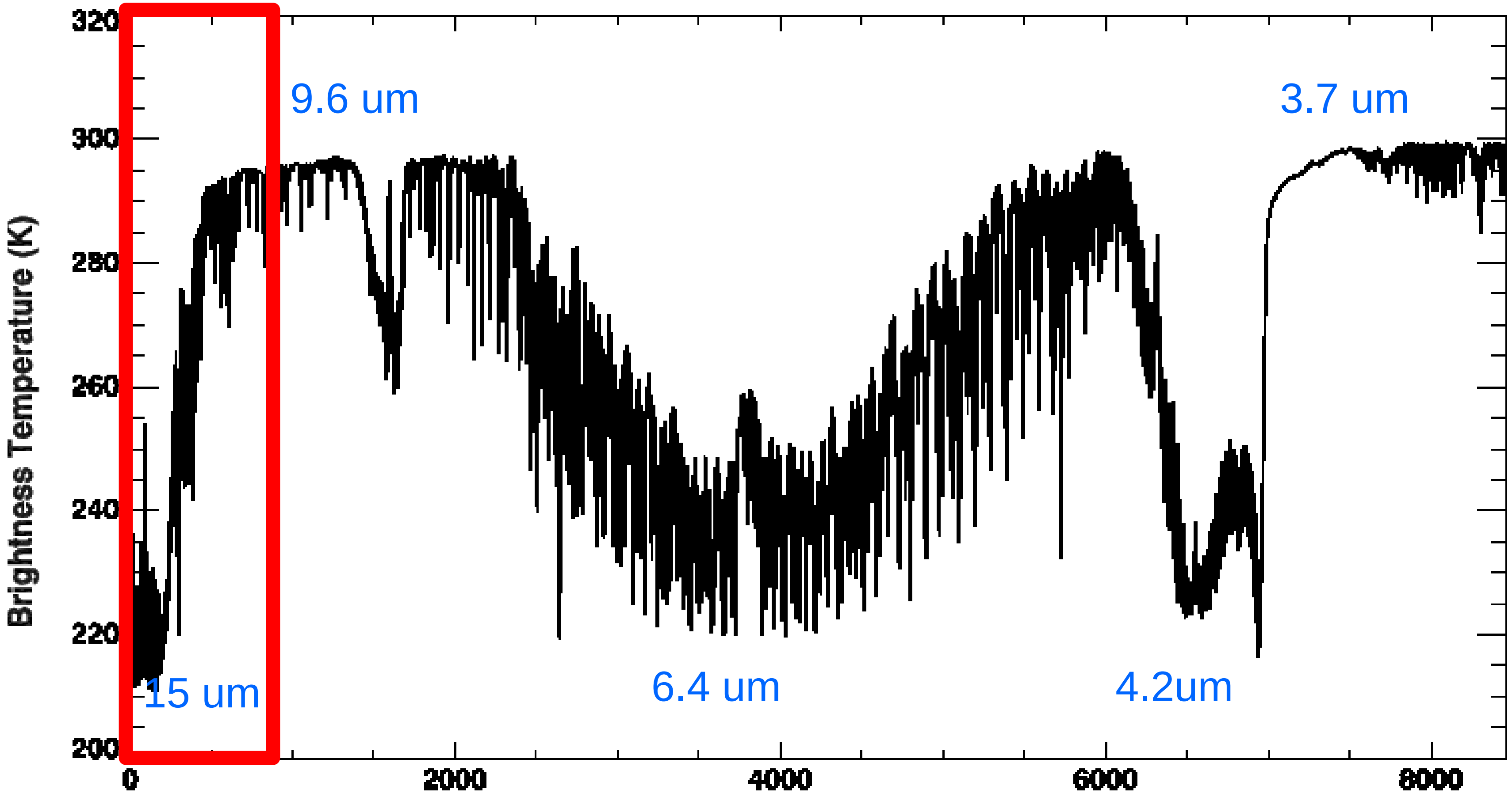
(and what do we assimilate)

The infrared spectrum of atmospheric radiation



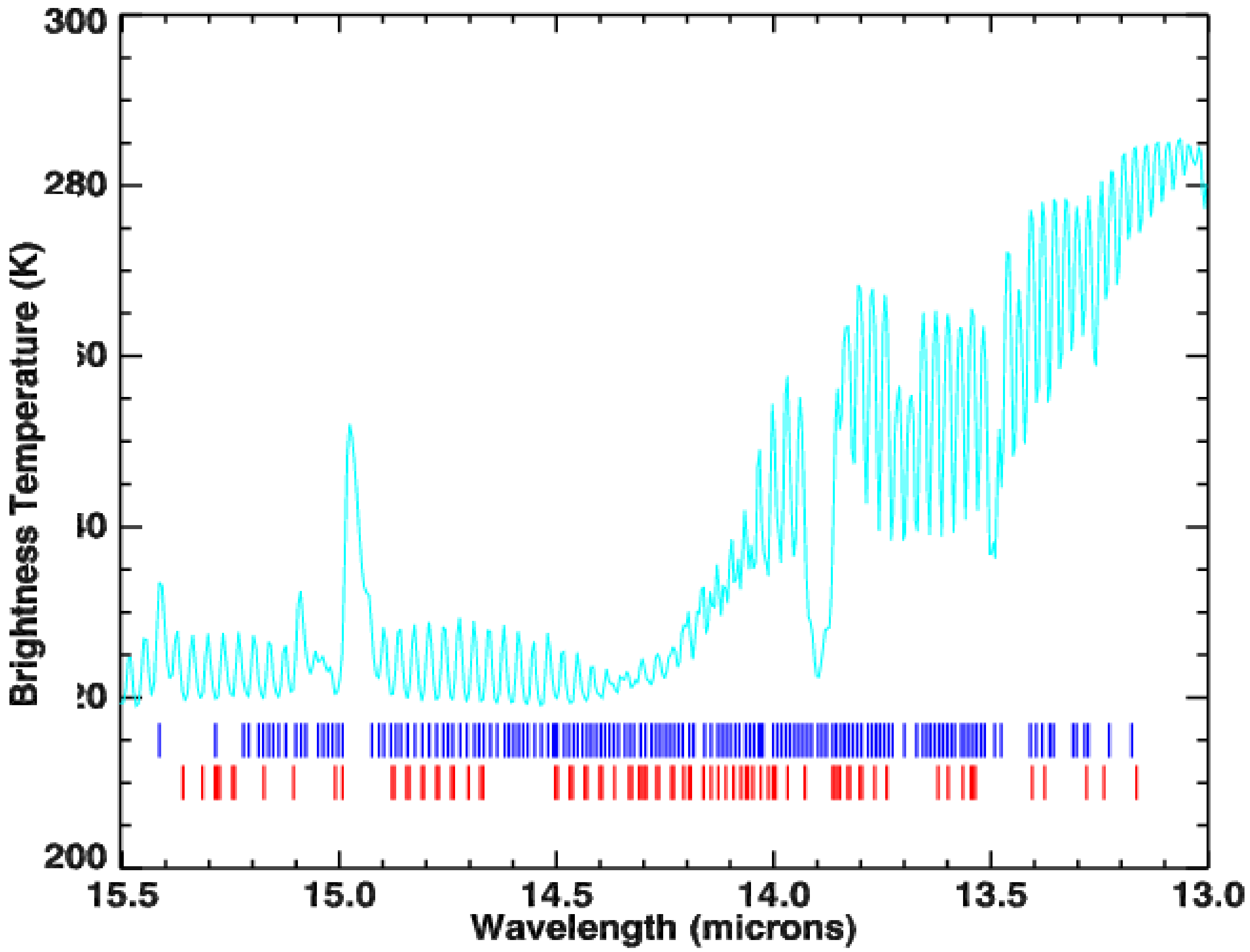
The infrared spectrum of atmospheric radiation

The long-wave temperature sounding band



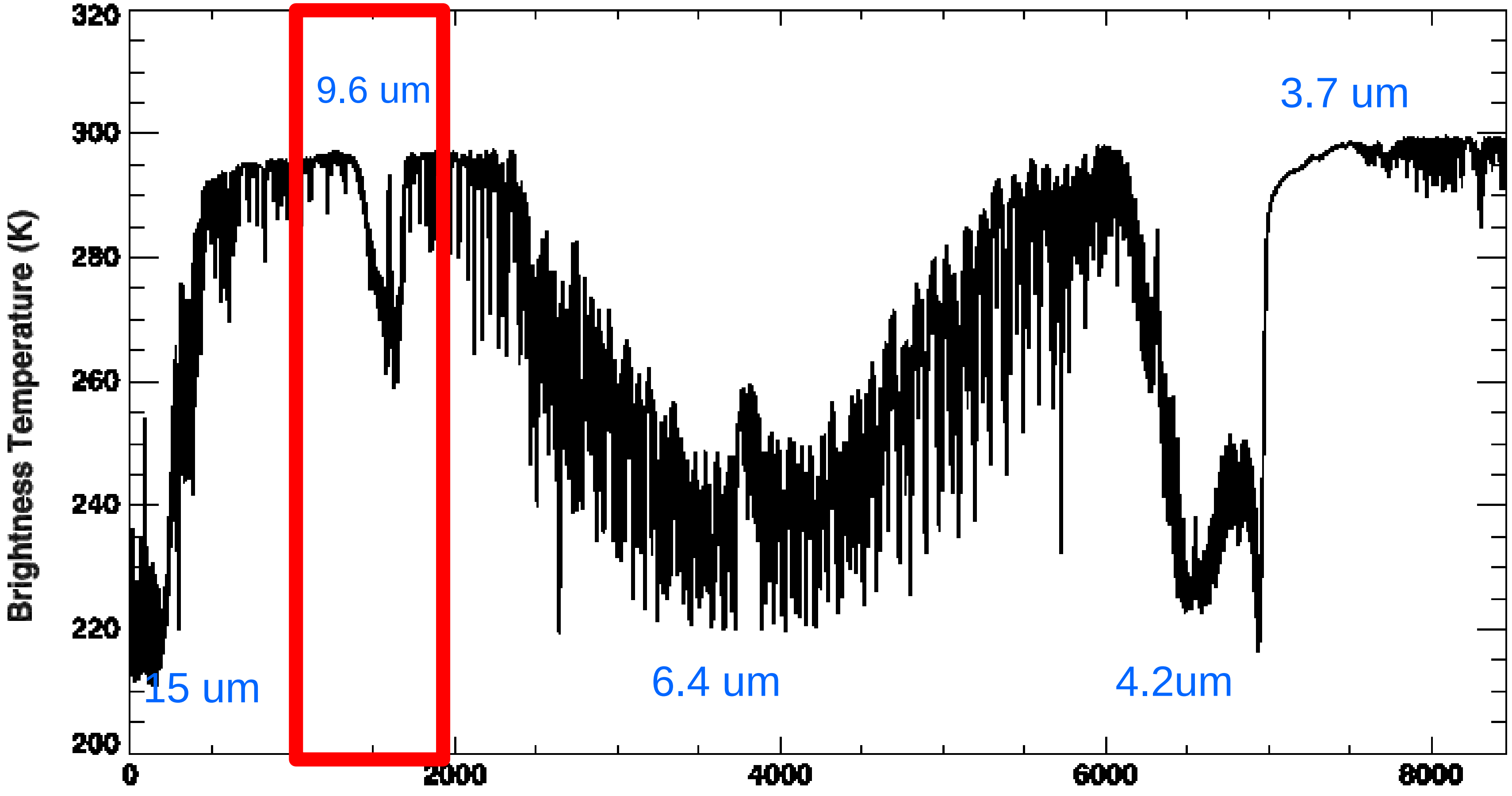
~ 200 channels assimilated

Zoom of long-wave temperature sounding channel usage for IASI



The infrared spectrum of atmospheric radiation

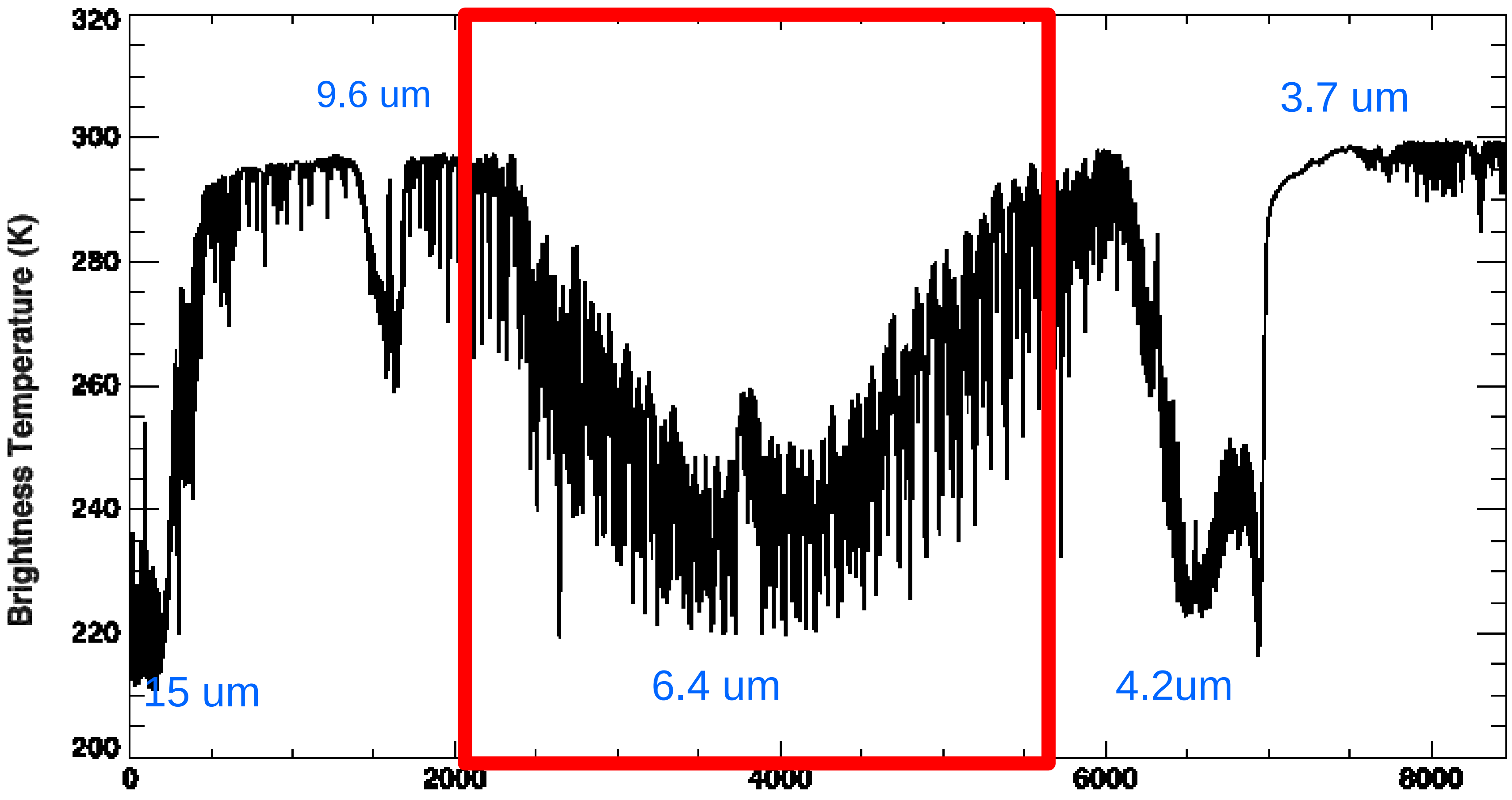
The long-wave ozone sounding band



~ 20 channels assimilated

The infrared spectrum of atmospheric radiation

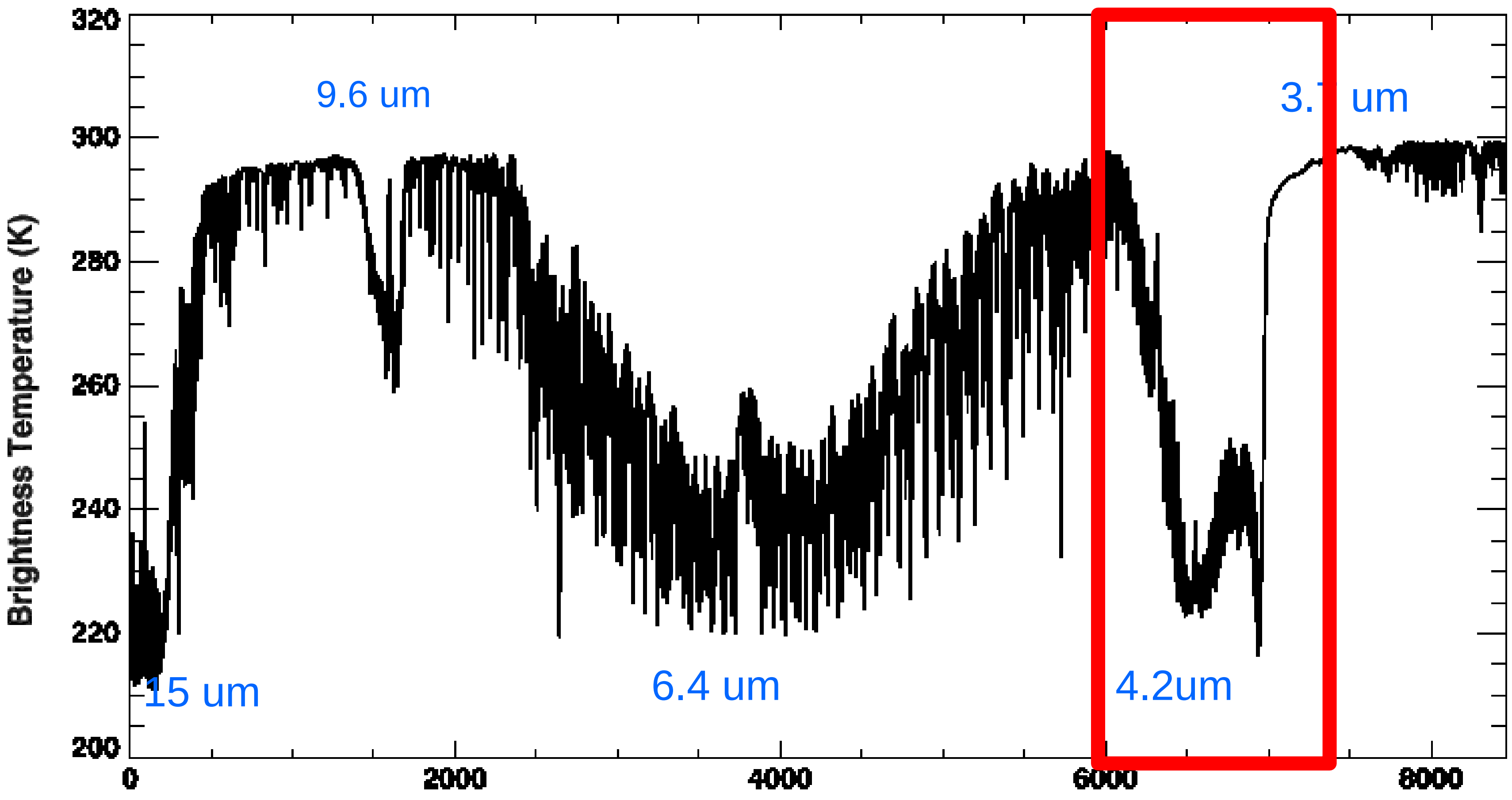
The mid-wave water vapour sounding band



~ 50 channels assimilated

The infrared spectrum of atmospheric radiation

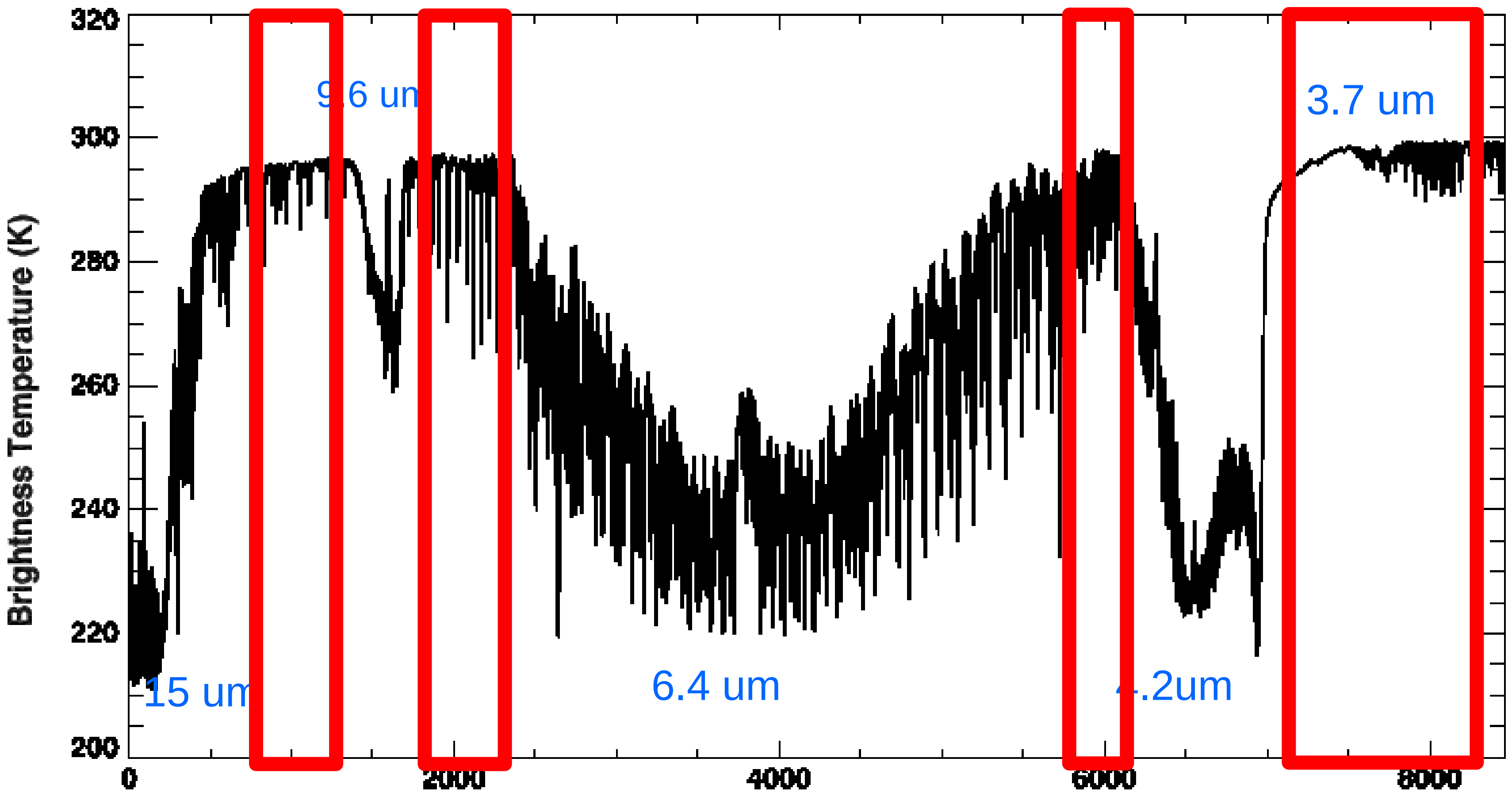
The short-wave temperature sounding band



~ 0 channels assimilated – IASI noise high

The infrared spectrum of atmospheric radiation

The surface sensing channels (window channels)



channels mostly used for cloud detection

Weighting functions of IASI sounding channels

Atmospheric sounding channels

…selecting channels where there is no contribution from the surface….

$$L(\nu) = \int_0^{\infty} B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz \; + \text{Surface emission} + \text{Surface reflection/ scattering} + \text{Cloud/rain contribution} + \ldots$$

ATMOSPHERIC TEMPERATURE SOUNDING

If radiation is selected in an atmospheric sounding channel for which

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz$$

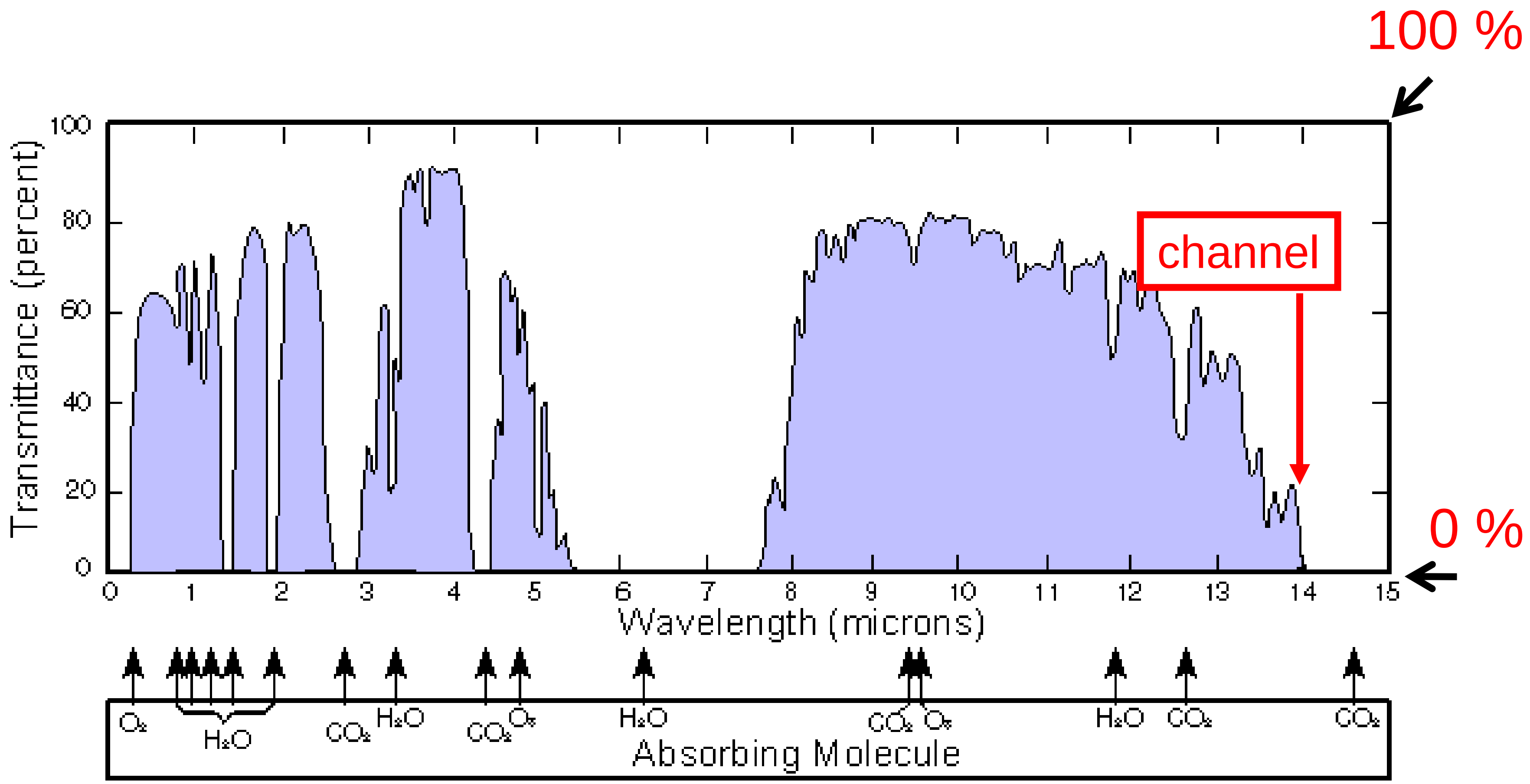
and we define a function $H(z) = \left[\frac{d\tau}{dz} \right]$

When the primary absorber is a well mixed gas (e.g. oxygen or CO_2) with known concentration it can be seen that the measured radiance is essentially a weighted average of the atmospheric temperature profile, or

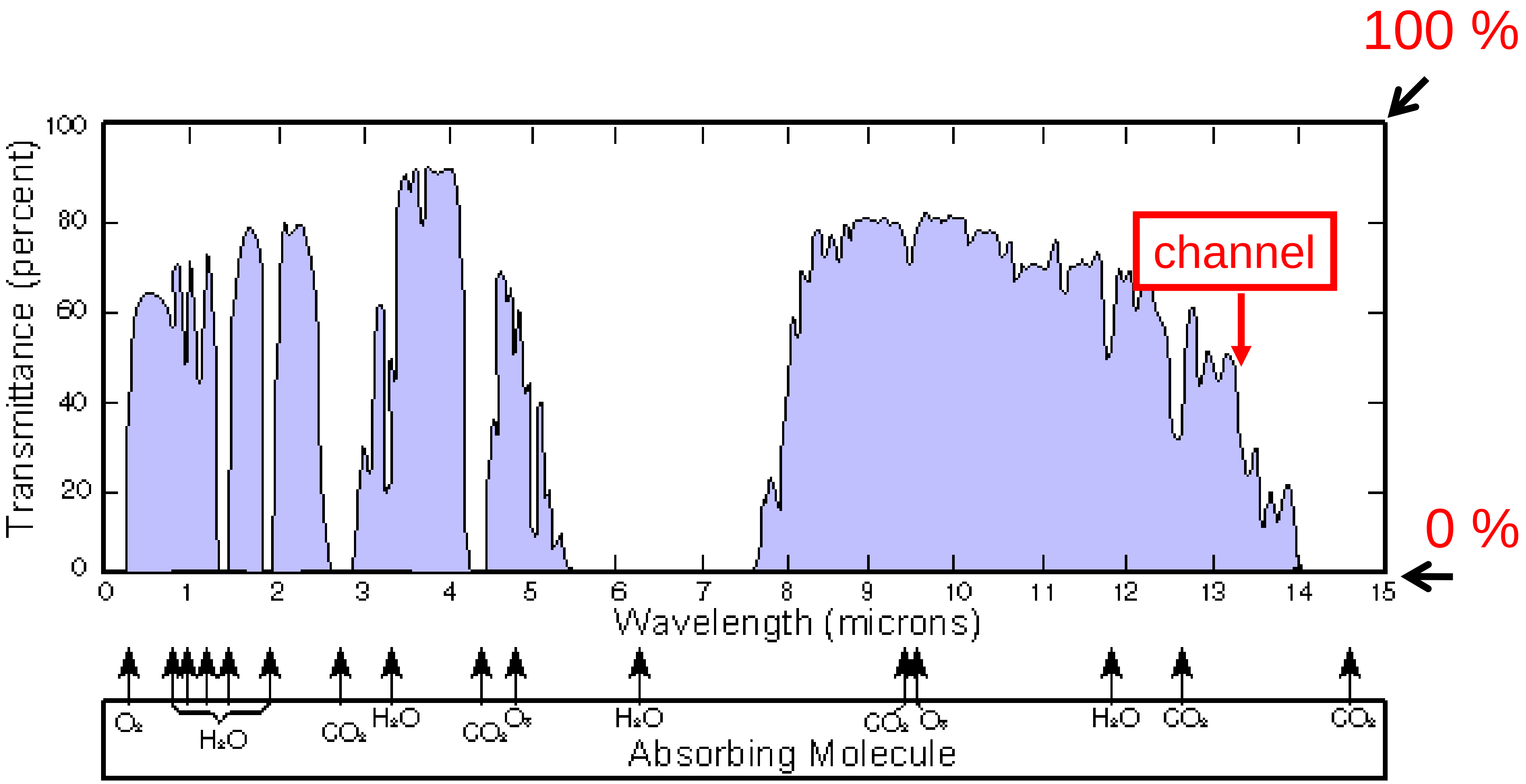
$$L(\nu) = \int_0^\infty B(\nu, T(z)) \, H(z) dz$$

The function *H(z)* that defines this vertical average is known as a WEIGHTING FUNCTION

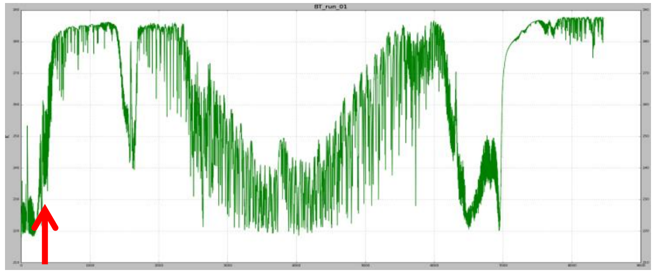
Strong absorbing sounding channels

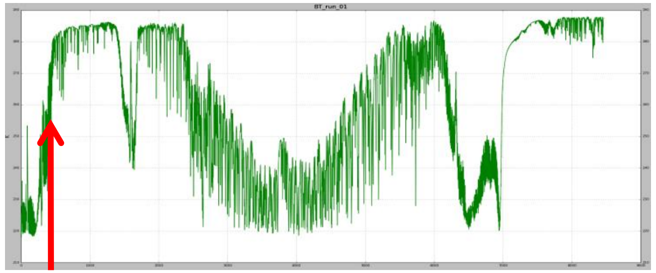


Weaker absorbing sounding channels



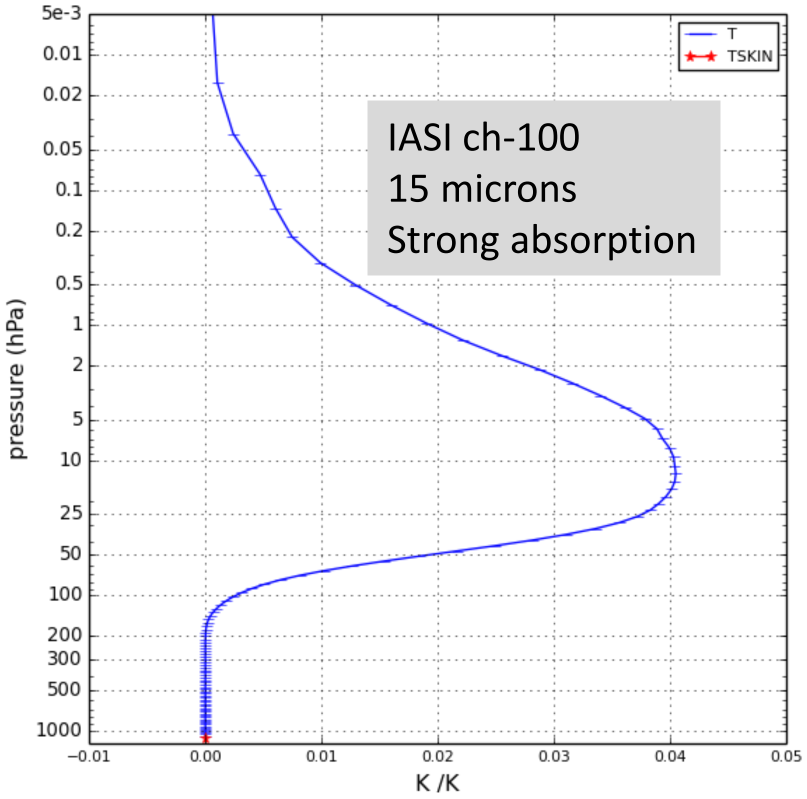
IASI weighting functions for strong and weak absorption channels

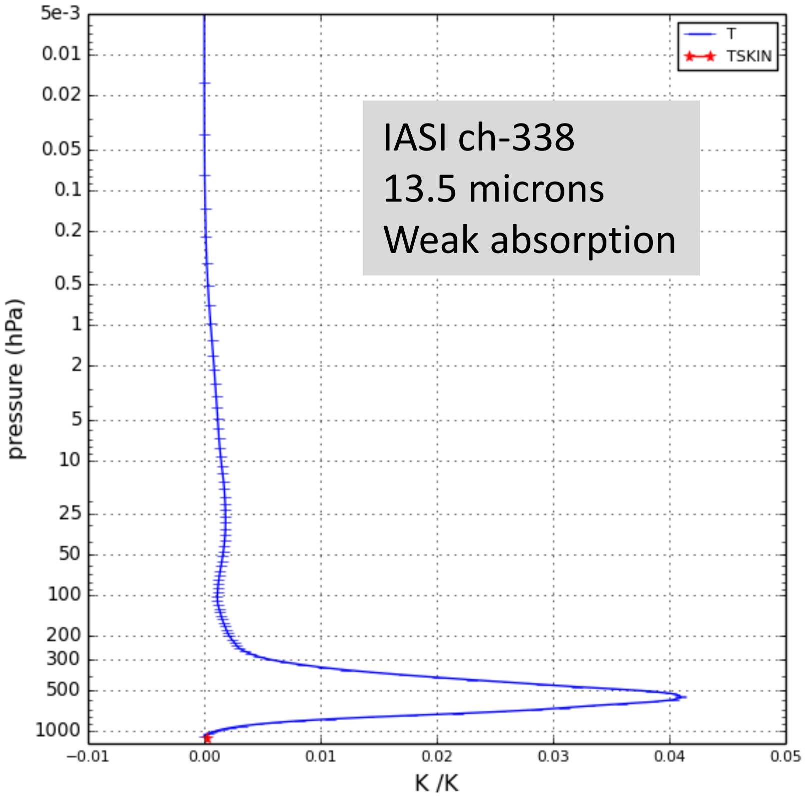




Strong > stratospheric channel

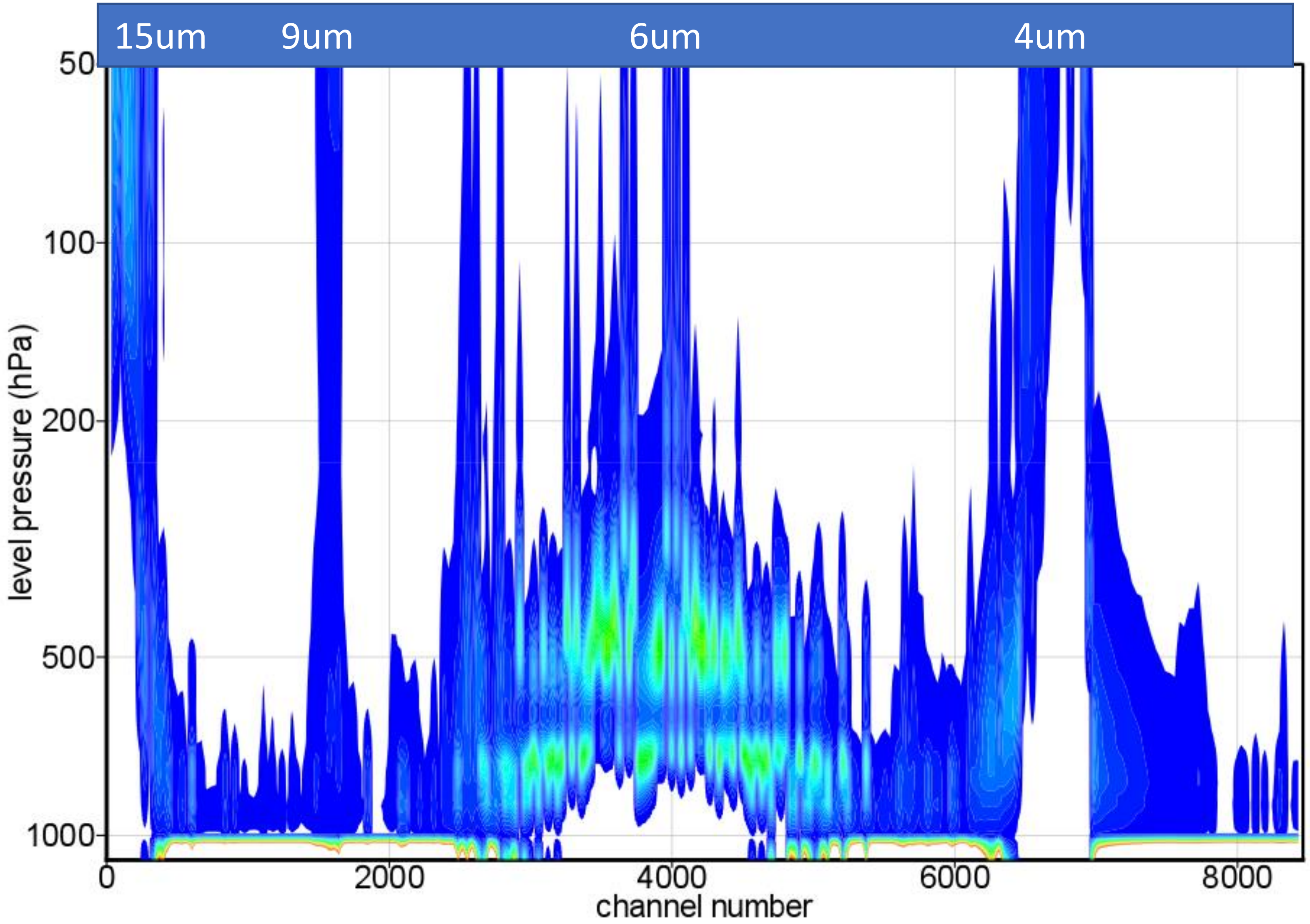
Weak > tropospheric channel



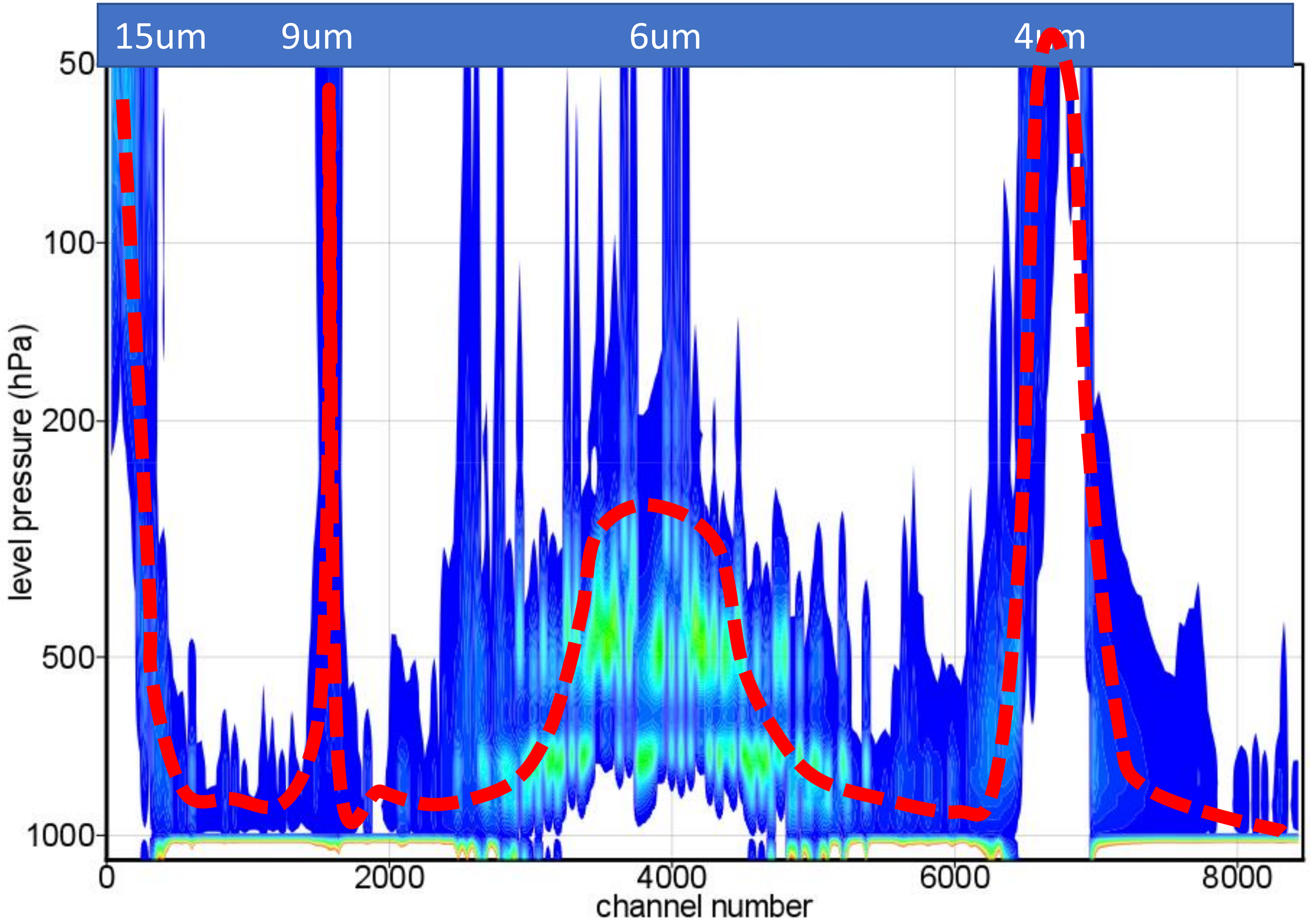


Sampling lines of varying absorption strength IASI provides good vertical coverage of the atmosphere

Peaks altitudes of IASI channel weighting functions



Peaks altitudes of IASI channel weighting functions



Three challenges to the successful assimilation of infrared radiances:

1) Sounding the lower atmosphere

2) Variable absorbing gasses

3) Clouds

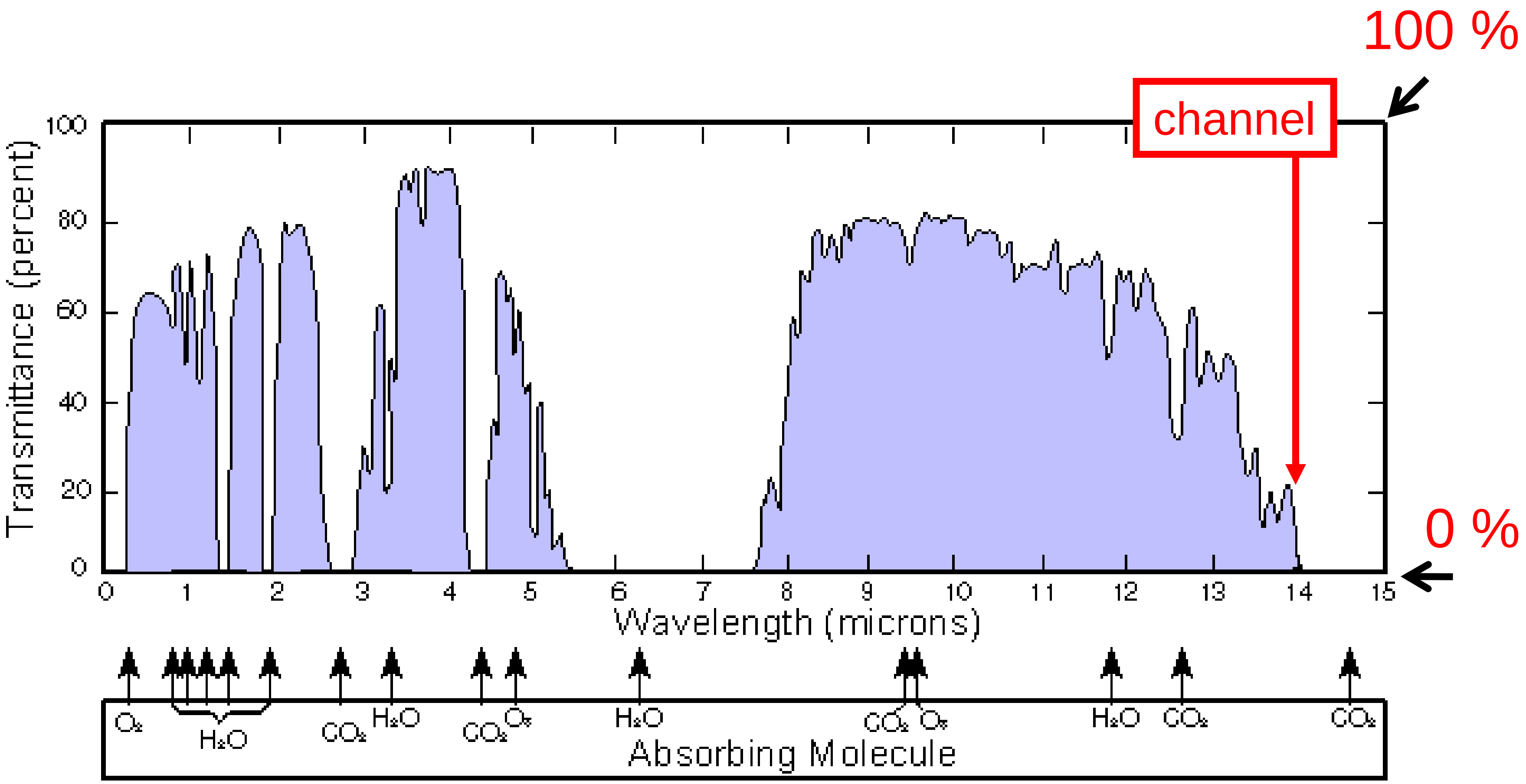
Challenge 1:
Sounding channels for the lower troposphere …

Atmospheric sounding channels

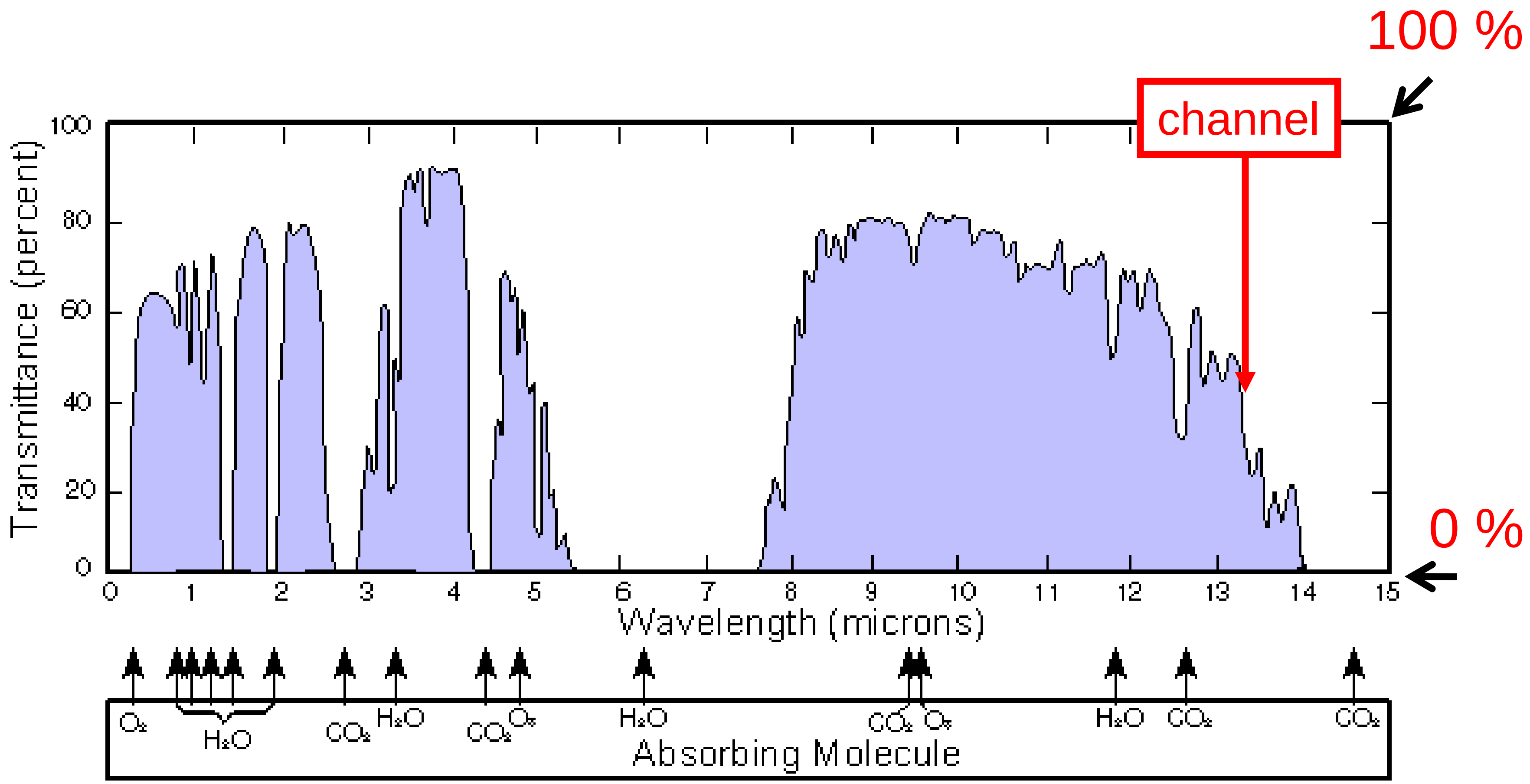
…selecting channels where there is no contribution from the surface….

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots$$

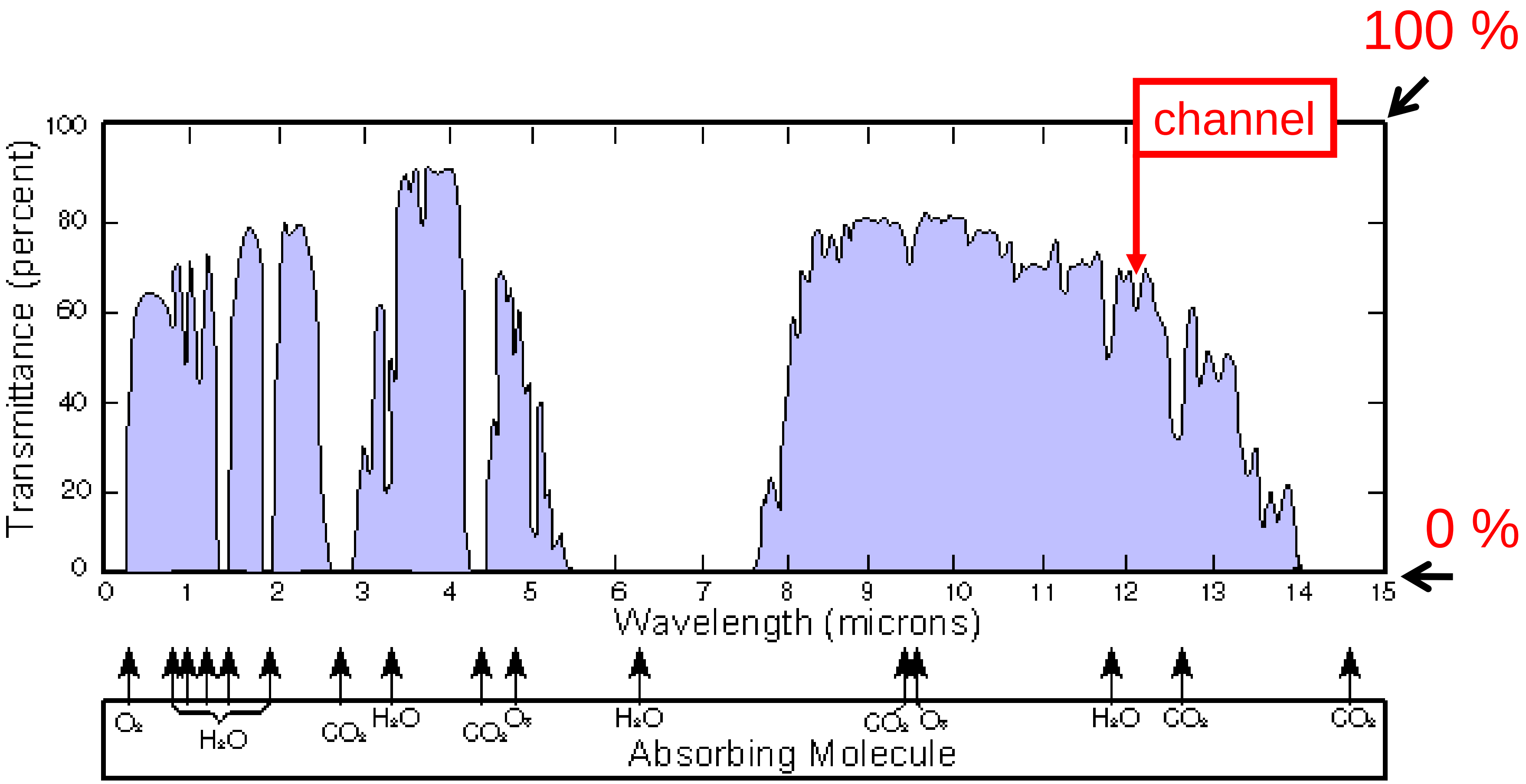
Strong absorbing sounding channels



Weaker absorbing sounding channels



Weak absorbing sounding channels



Weak absorbing sounding channels

…selecting channels where there is no contribution from the surface….

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/ scattering} + \text{Cloud/rain contribution} + \ldots$$

Weak absorbing sounding channels

…selecting channels where there is no contribution from the surface….

$$L(\nu)=\int_0^\infty B(\nu,T(z))\left[\frac{d\tau(\nu)}{dz}\right]dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots$$

Weak absorbing sounding channels

…selecting channels where there is no contribution from the surface….

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz + \text{Surface emission} + \text{Surface reflection/scattering} + \text{Cloud/rain contribution} + \ldots$$

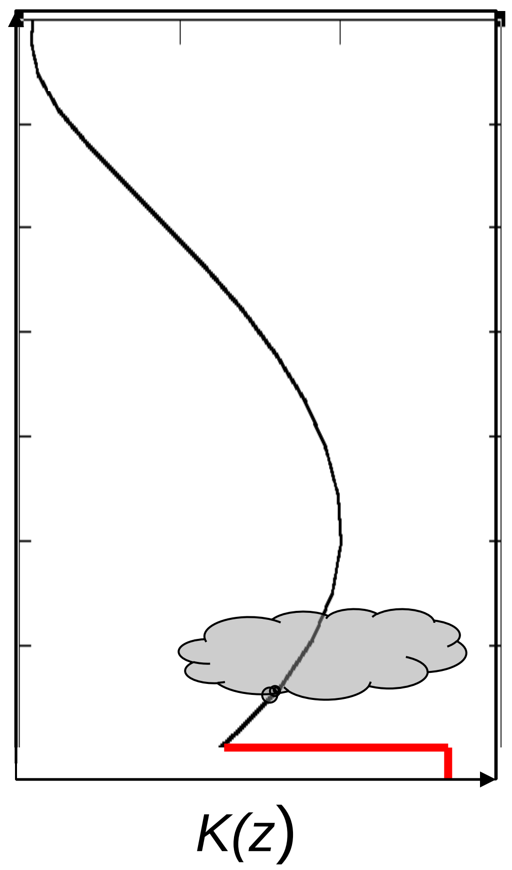
Sensitivity to the surface skin and clouds

By placing sounding channels in parts of the spectrum where the absorption is weak we obtain temperature (and humidity) information from the lower troposphere (low peaking weighting functions).

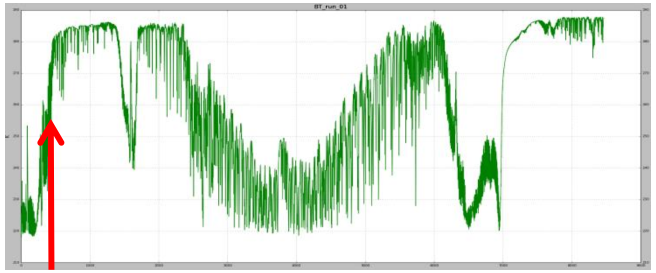
BUT …

These channels (obviously) become more sensitive to surface emission and the effects of cloud and precipitation.

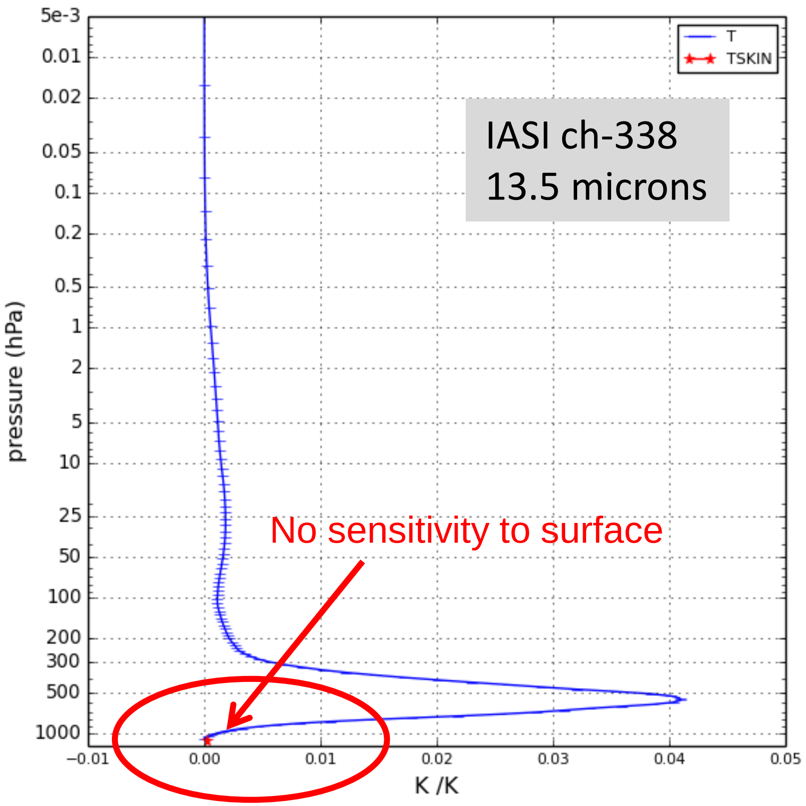
In most cases surface or cloud contributions will dominate the atmospheric signal in these channels and it is difficult to use the radiance data safely (i.e. we may alias a cloud signal as a temperature adjustment)

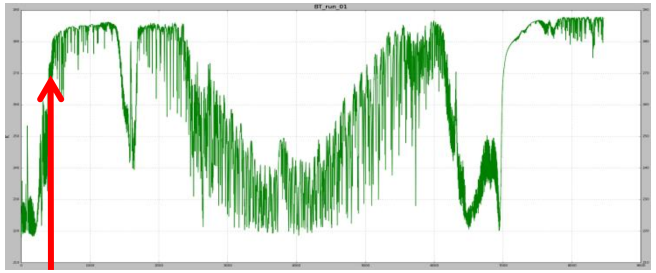


Lower Tropospheric Channels

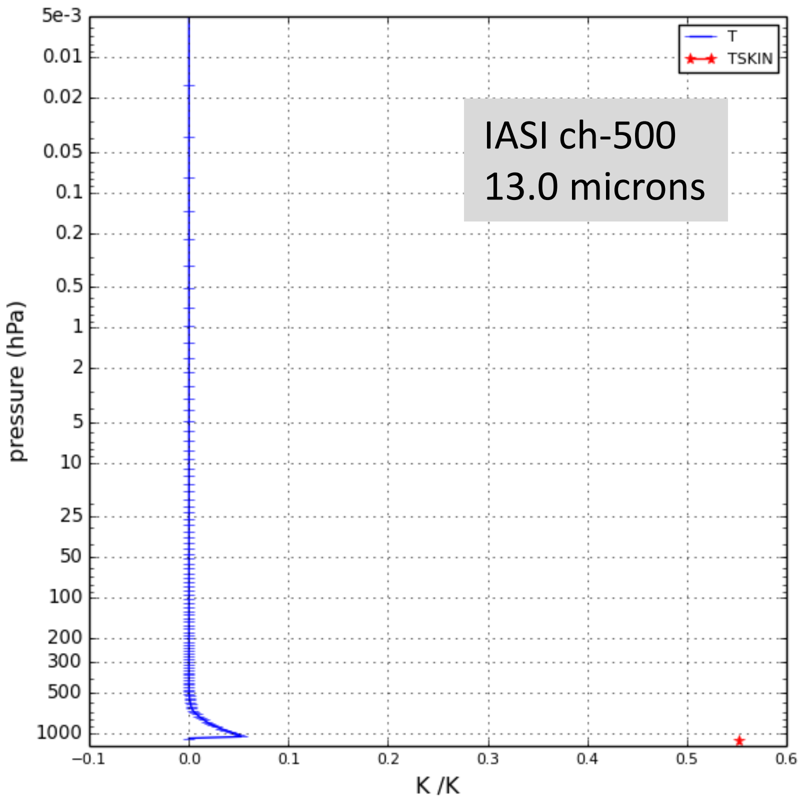


Tropospheric channel

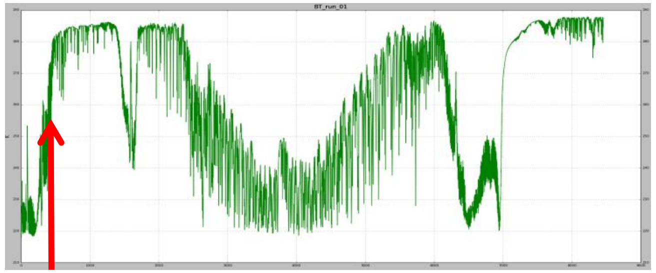




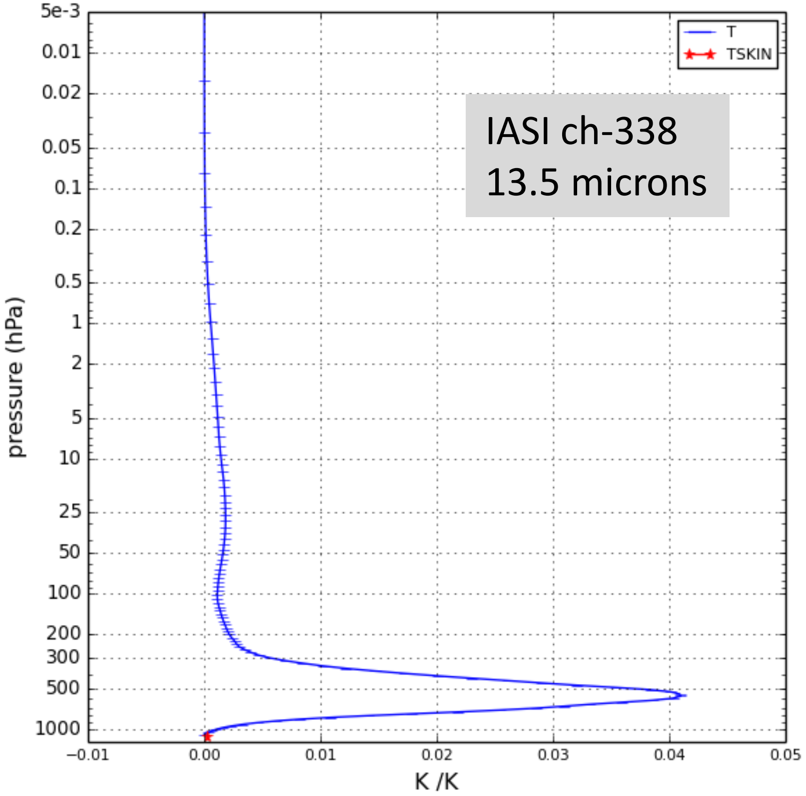
Low tropospheric channel

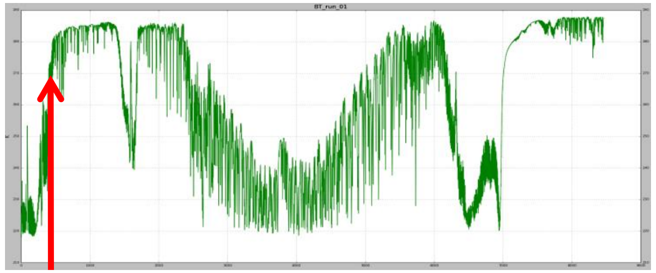


Lower Tropospheric Channels

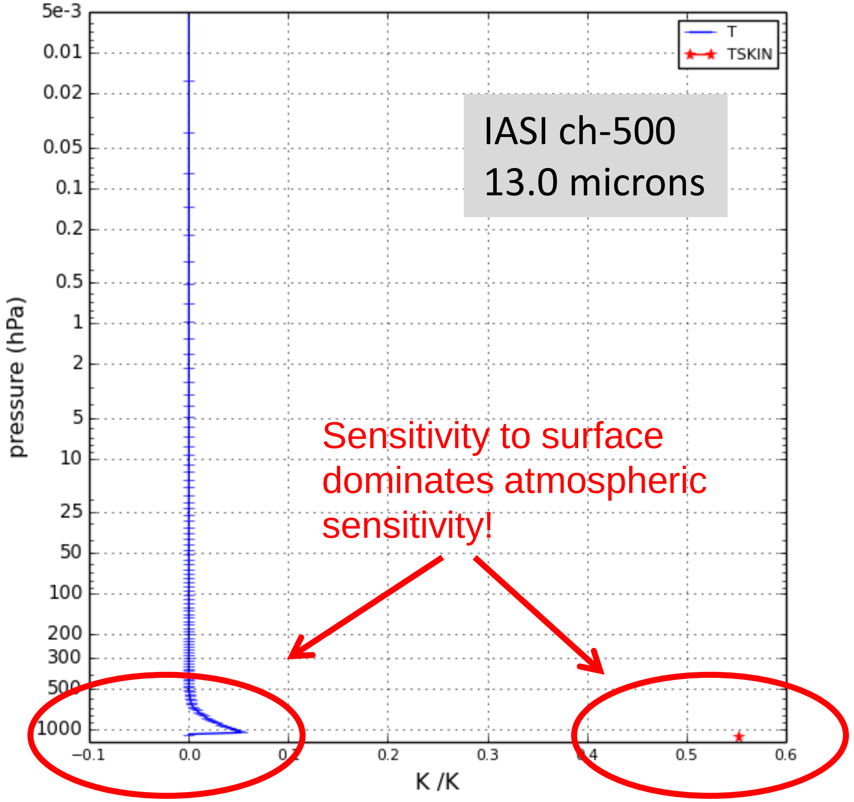


Tropospheric channel





Low tropospheric channel



Challenge 2:

When the absorbing gas is itself a variable …

When the absorbing gas is itself a variable …

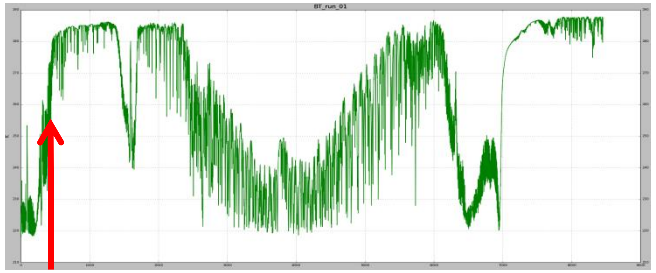
When the primary absorber in a sounding channel is a well mixed gas (e.g. oxygen or carbon dioxide) the radiance essentially gives information about variations in the atmospheric temperature profile only.

$$L(\nu) = \int_0^\infty B(\nu, T(z)) \left[\frac{d\tau(\nu)}{dz} \right] dz$$

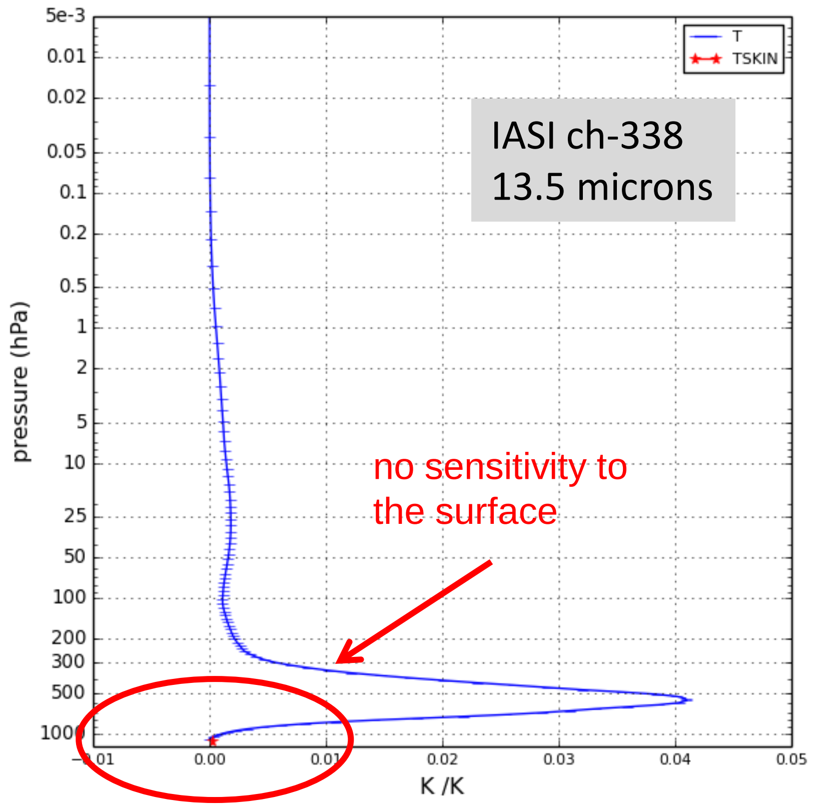
When the primary absorber is not well mixed (e.g. water vapour, ozone) the weighting functions depend on the state of the atmosphere and radiance gives ambiguous information about the temperature profile and the absorber distribution. This ambiguity must be resolved by :

- differential channel sensitivity
- synergistic use of well mixed channels (constraining the temperature)
- the background error covariance (+ physical constraints)

Temperature Channels sensitive to water vapour

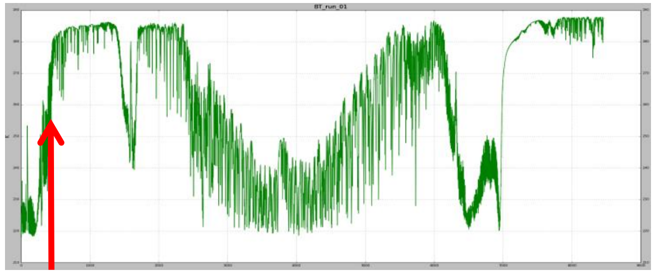


Tropospheric channel

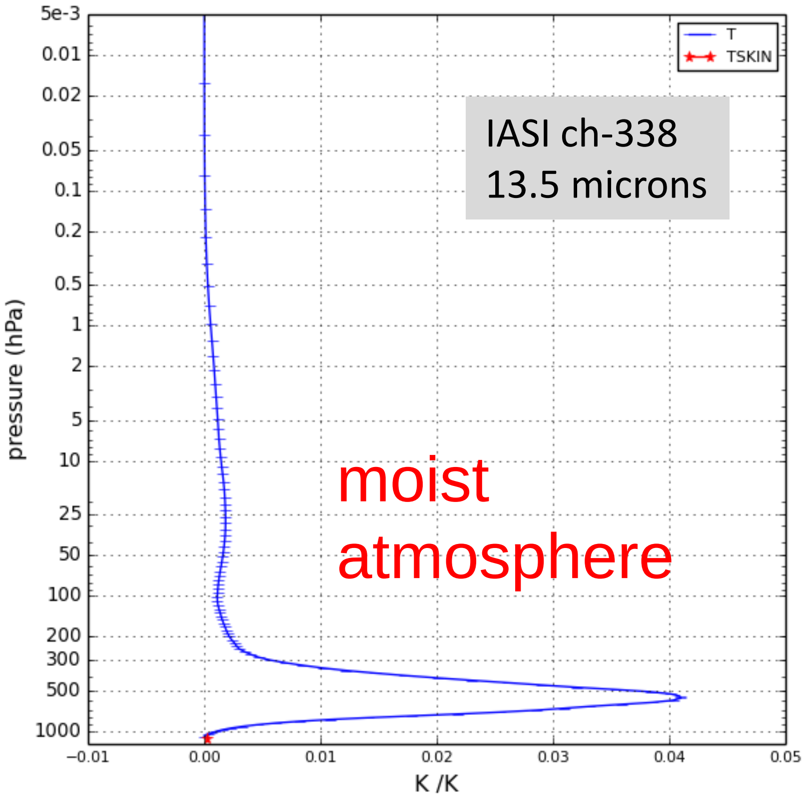


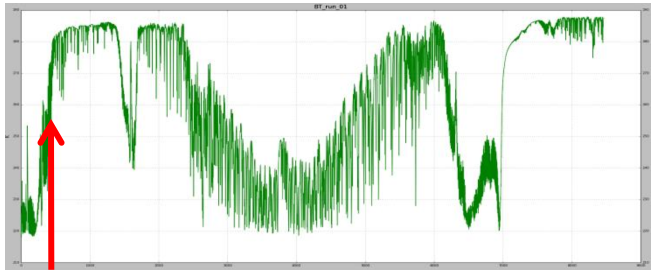
What happens in a very **dry** atmosphere ?

Temperature Channels sensitive to water vapour

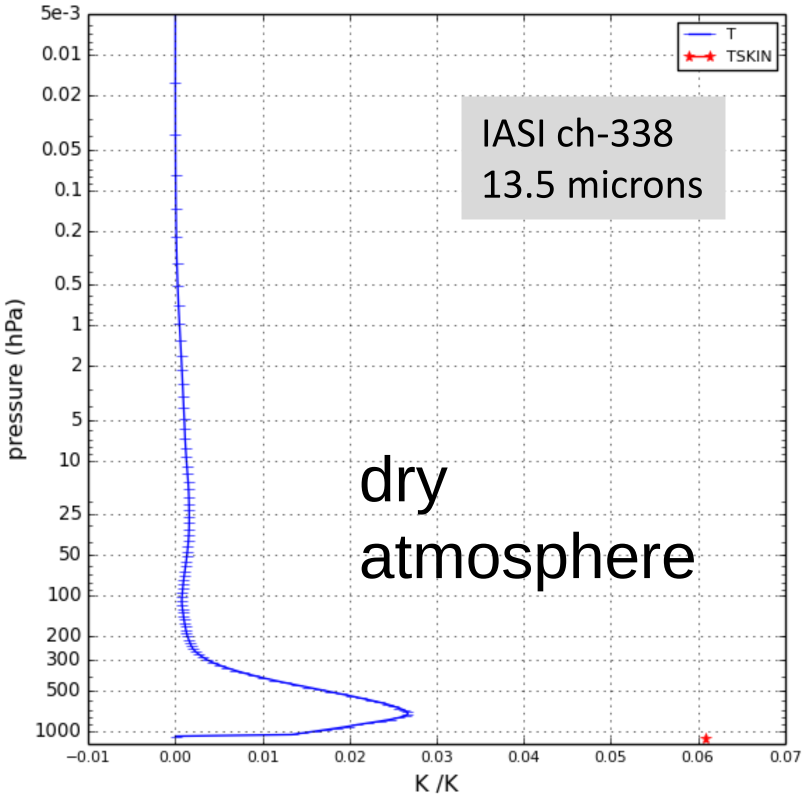


Tropospheric channel

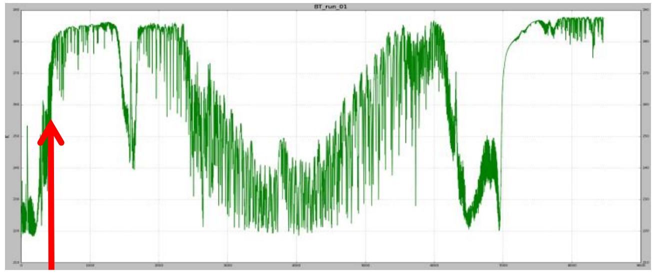




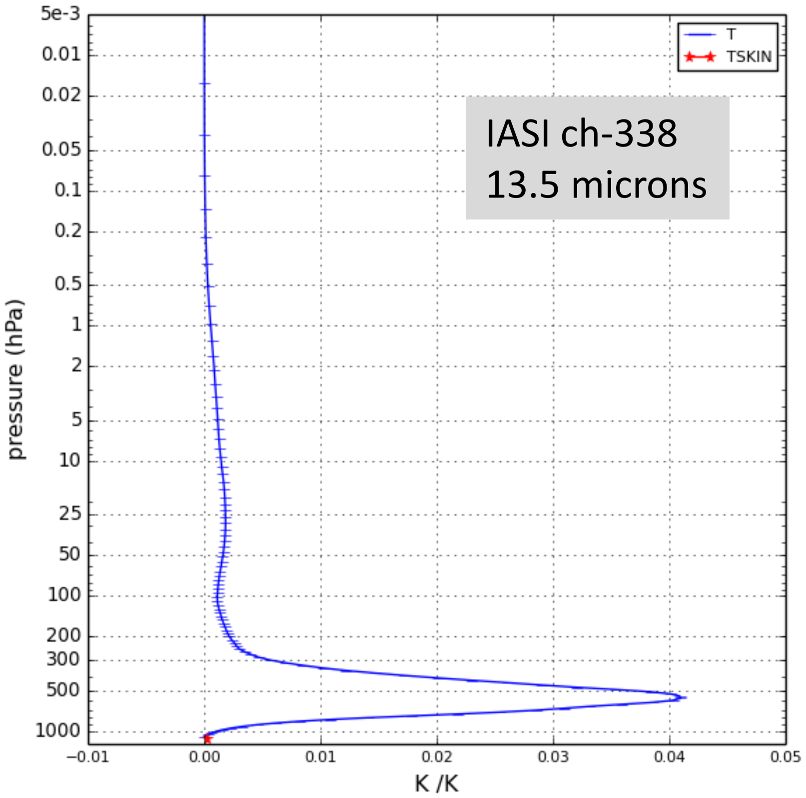
Tropospheric channel

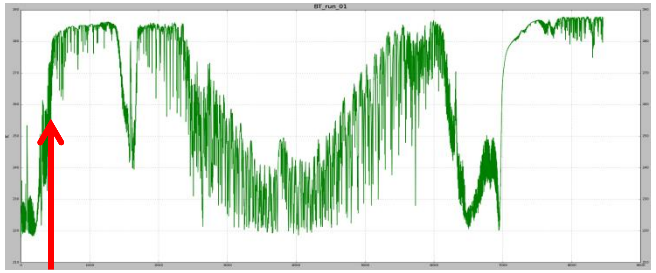


Temperature Channels sensitive to water vapour

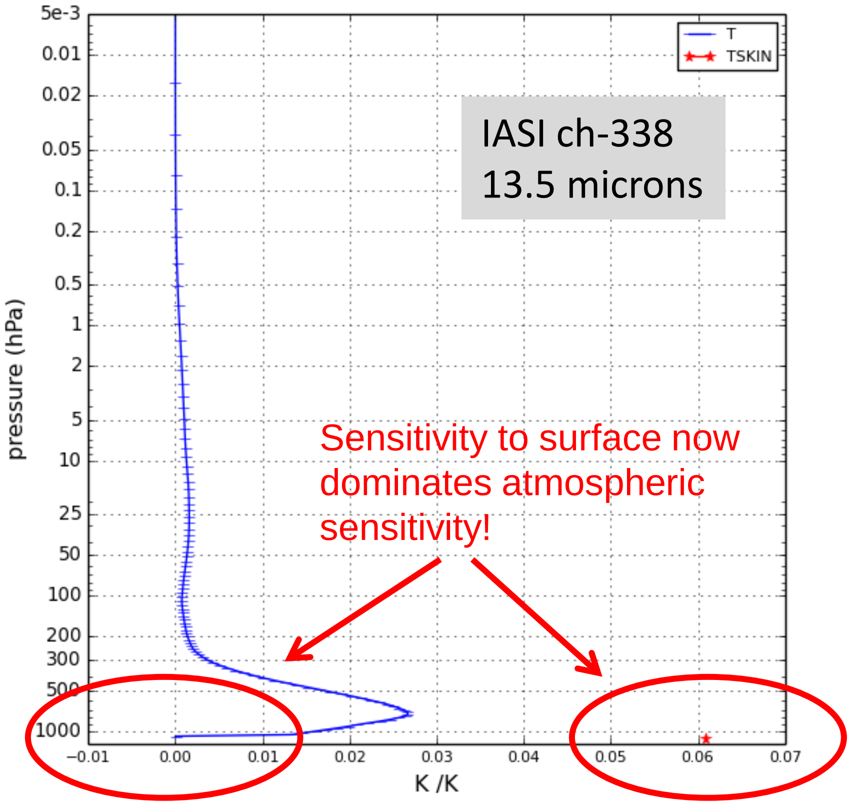


Tropospheric channel



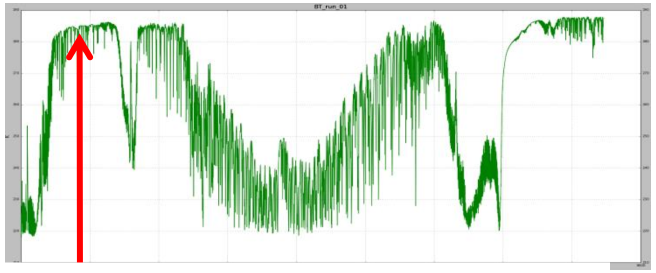


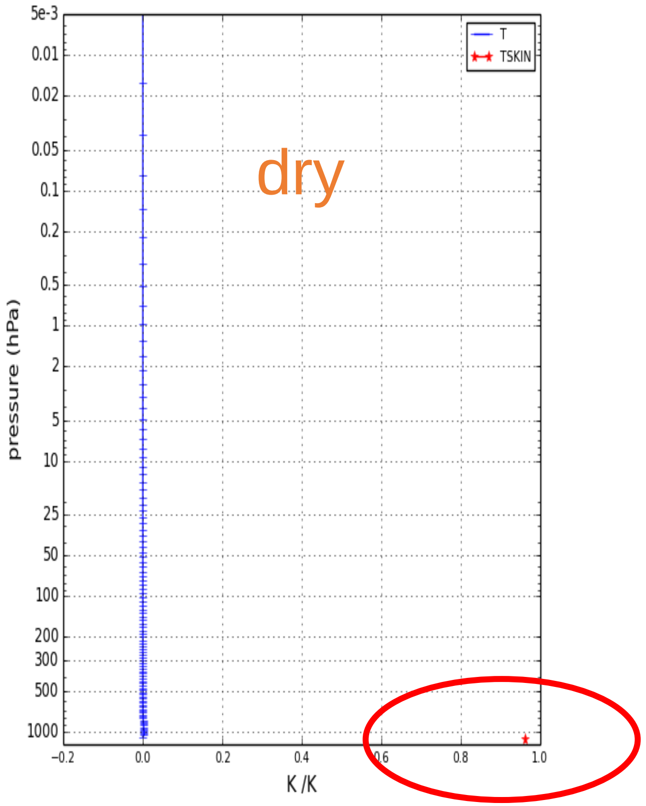
Tropospheric channel

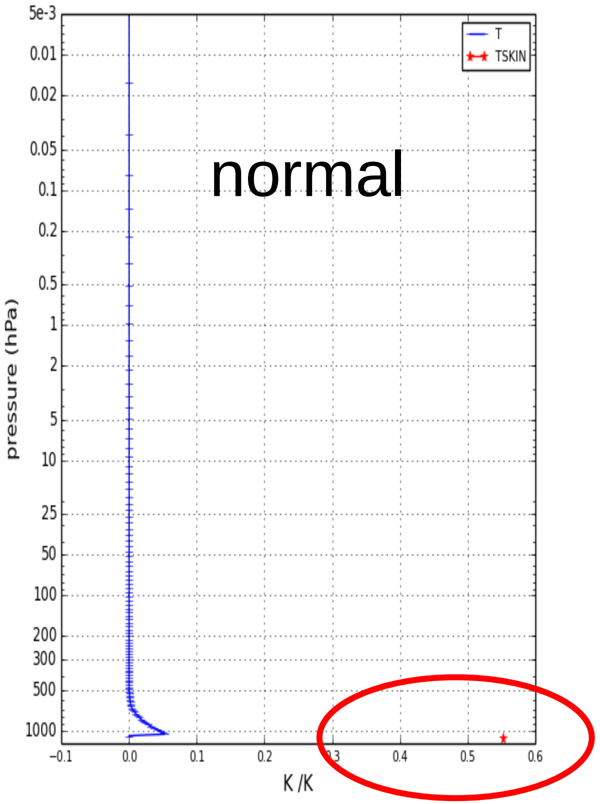


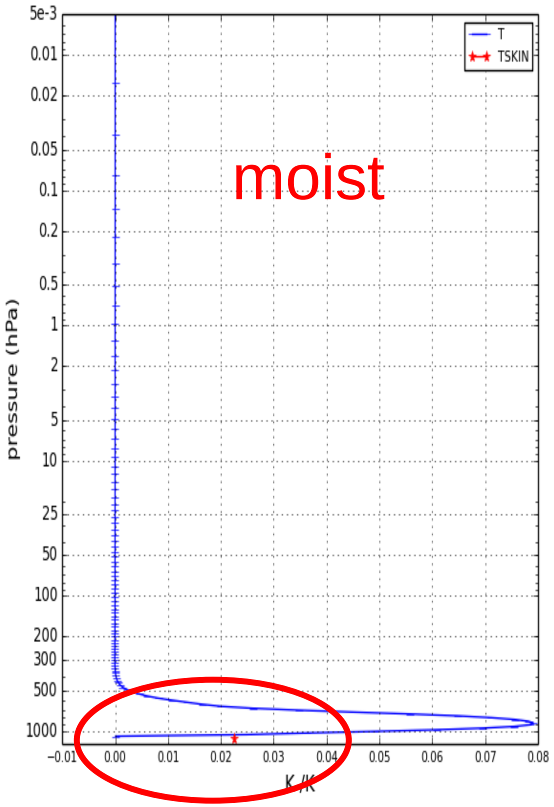
Window Channels sensitive to water vapour

IASI ch-1200
10.5 microns



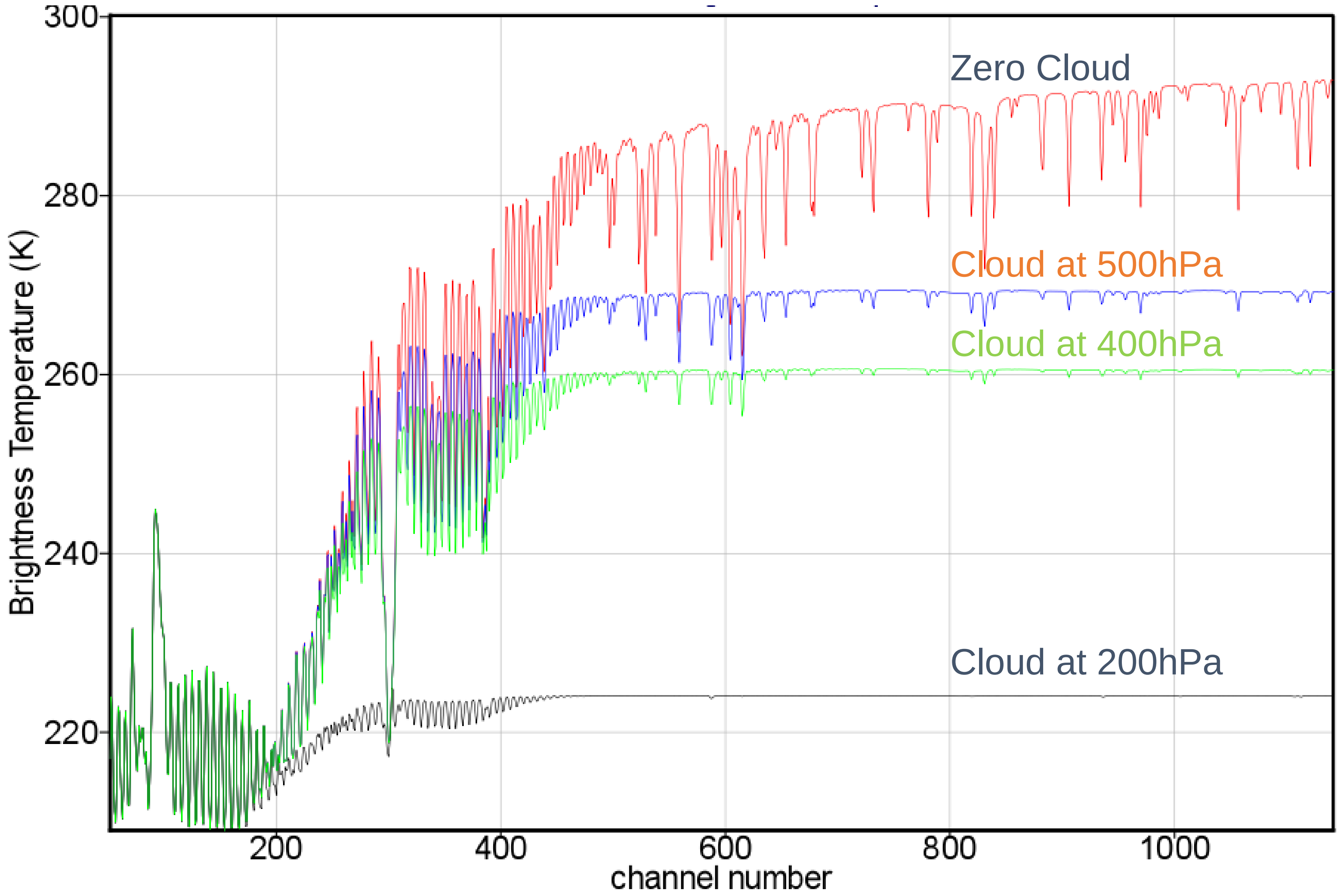




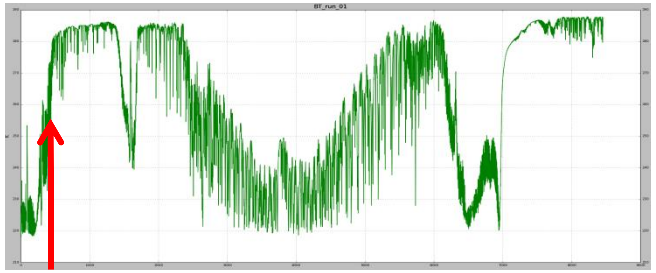


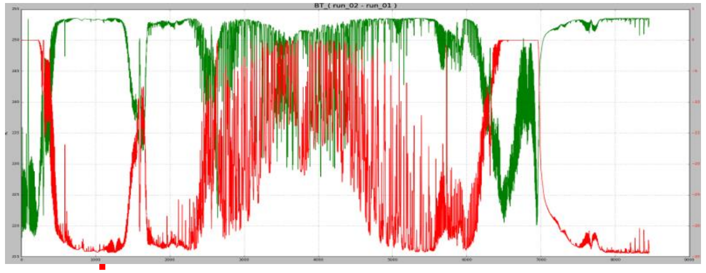
Challenge 3:
Clouds…

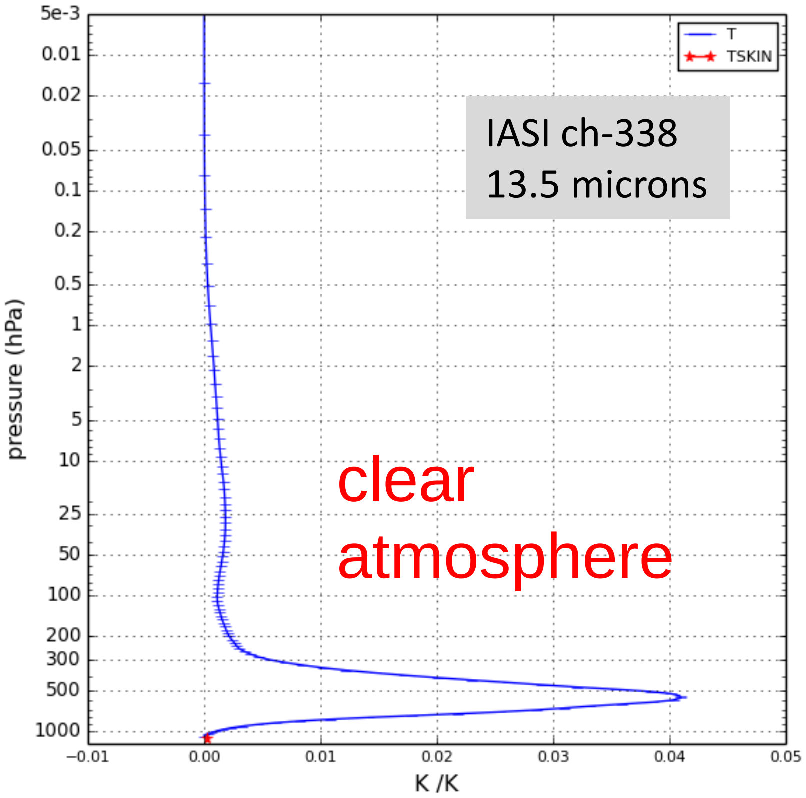
Temperature Channels sensitive to clouds

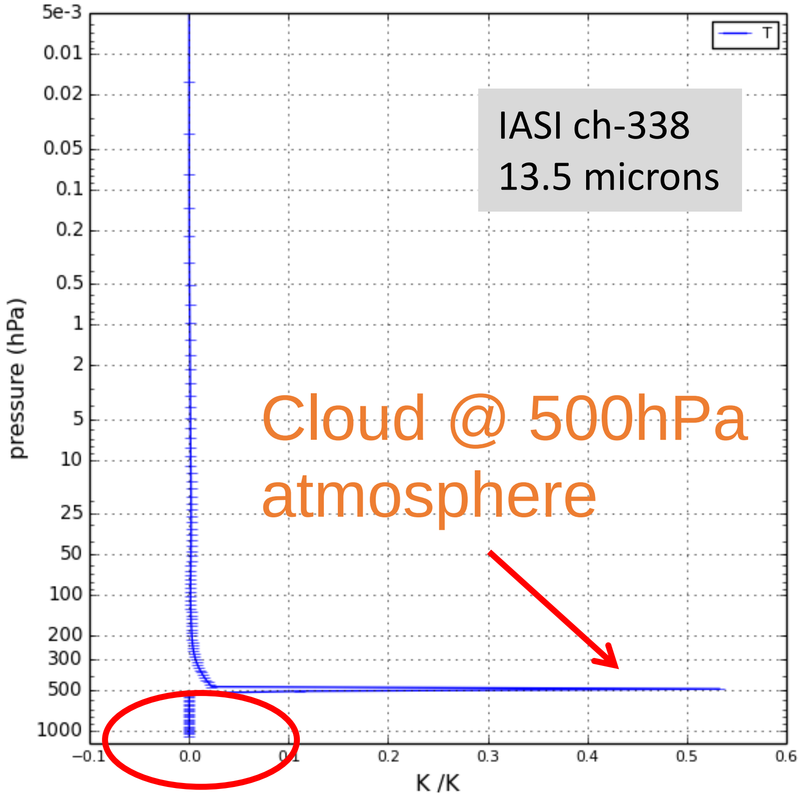


Temperature Channels sensitive to clouds









Challenge 3:
Clouds…

Dedicated lecture on clouds in IR next…..

Summary

We now have excellent high quality (and **high spectral resolution**) measurements of atmospheric infrared radiation.

Instruments such as IASI provide good vertical coverage of the atmosphere by sampling absorption of variable strength. Higher **vertical resolution** is achieved due to the **high number of channels**.

Channels in the **lower troposphere** are also sensitive to the **surface** (and clouds).

Channels affected by absorption by **variable species** (e.g. humidity) provide different information in different atmospheres.

Questions ?

Units

Radiance = W·sr−1·m−2·Hz−1

Brightness temperature (K)

$$T_b = \frac{h\nu}{k} \ln^{-1}\left(1 + \frac{2h\nu^3}{I_\nu c^2}\right)$$