Satellite Hyperspectral Workshop
Miami, 29-31 March 2011

Capability of hyperspectral IR sounders to retrieve CO_2 and CH_4

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Two European initiatives

http://www.gmes-atmosphere.eu/

•MACC: Monitoring of Atmospheric Composition and Climate

MACC is the current pre-operational atmospheric service of the European GMES programme. MACC provides data records on atmospheric composition for recent years, data for monitoring present conditions and forecasts of the distribution of key constituents for a few days ahead. MACC combines state-of-the-art atmospheric modelling with Earth observation data to provide information services covering European Air Quality, Global Atmospheric Composition, Climate, and UV and Solar Energy.

http://www.esa-ghg-cci.org/

•ESA Climate Change Initiative - GHG

The ESA project GHG-CCI aims at delivering the high quality satellite retrievals needed for adding important missing global information on regional CO_2 and CH_4 sources and sinks required for better climate prediction. GHG-CCI is one of several projects of ESA's Climate Change Initiative (CCI) which will deliver various Essential Climate Variables (ECVs). The GHG-CCI project started 1. Sept. 2010.

Greenhouse gases from infrared sounders: A brief history

•Study of the ability of Thermal-IR sounders to measure CO_2 *(Chédin et al. 2002, 2003)*

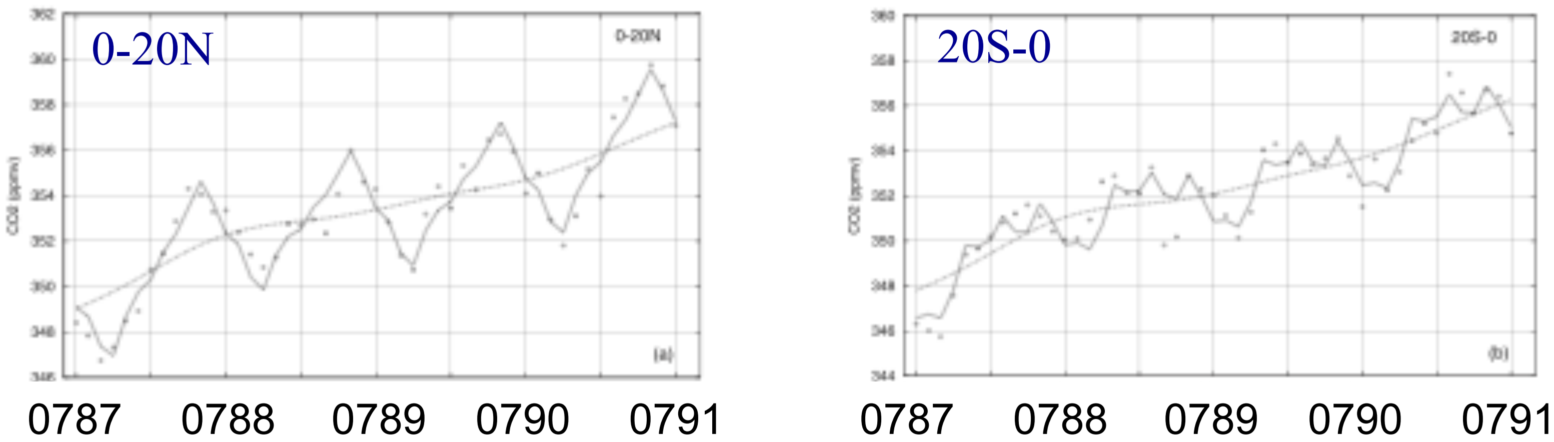
•1st generation TOVS on NOAA platforms since 1978 (20 channels)

First retrieval of CO_2 from space *(Chédin et al. 2003)*

→ Seasonal cycle, trend, ENSO, CO_2 emitted from biomass burnings

Precision:
~3.0 ppmv
(1 month-15ºx15º)

CO_2 seasonal cycle in the northern tropics over 1987-1991



Greenhouse gases from infrared sounders: A brief history

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  First retrieval of CO_2 from space *[Chédin et al. 2003]*

  Precision: ~3.0 ppmv (1 month-15ºx15º)

- AIRS-AMSU onboard NASA/Aqua since 2002 (2378 channels)
  CO_2: *Crevoisier et al. 2004; Engelen et al. 2004, 2009; Chahine et al. 2005, 2010; Maddy et al. 2008; Strow and Hannon 2008*
  CH_4: *Xiong et al., 2008ab*

  ~2.5 ppmv (1 month-15ºx15º)

- IASI-AMSU onboard MetOp-A since 2007 (8461 channels)
  + MetOp-B and C in 2012 and 2016
  CO_2: *Crevoisier et al. 2009a*
  CH_4: *Crevoisier et al., 2009b, Razavi et al., 2010*

  ~2.0 ppmv (1 month-5ºx5º)

- *IASI-NG onboard EPS-SG in 2019? (16921 channels)*

  ~1.3 ppmv

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Study of TIR channel sensitivities to GHG

• For a given instrument (AIRS, IASI, IASI-NG),

for a given atmospheric situation (use of the TIGR atmospheric database)

for each channel,

→ we compute the brightness temperatures, transmittances and Jacobians (T, H_2O, CO_2, O_3, N_2O, CO, CH_4, T_{surf}, ε_{surf}) using the LMD radiative transfert code 4A/OP-2009 based on the last (2009) version of GEISA spectroscopic database.

•Computation of the sensitivities:

For each channel and each TIGR situation, we compute the variation of BT (in K) obtained for a given variation of one atmospheric variable using the 4A Jacobians:

$$\Delta T_B(T) = \sum_{nl=1}^{nl=42} \frac{\partial T_B}{\partial T}(nl) * \Delta T(nl)$$ for temperature

$$\Delta T_B(q_{gas}) = \sum_{nl=1}^{nl=42} \frac{\partial T_B}{\partial q_{gas}}(nl) * \Delta q_{gas}(nl)$$ for a given gas

Variations : **T (1K)** **H_2O (20%)** **CO_2 (1%)** **O_3 (10%)** **N_2O (2%)** **CO (10%)** **CH_4 (10%)** **Tsurf (1 K)**

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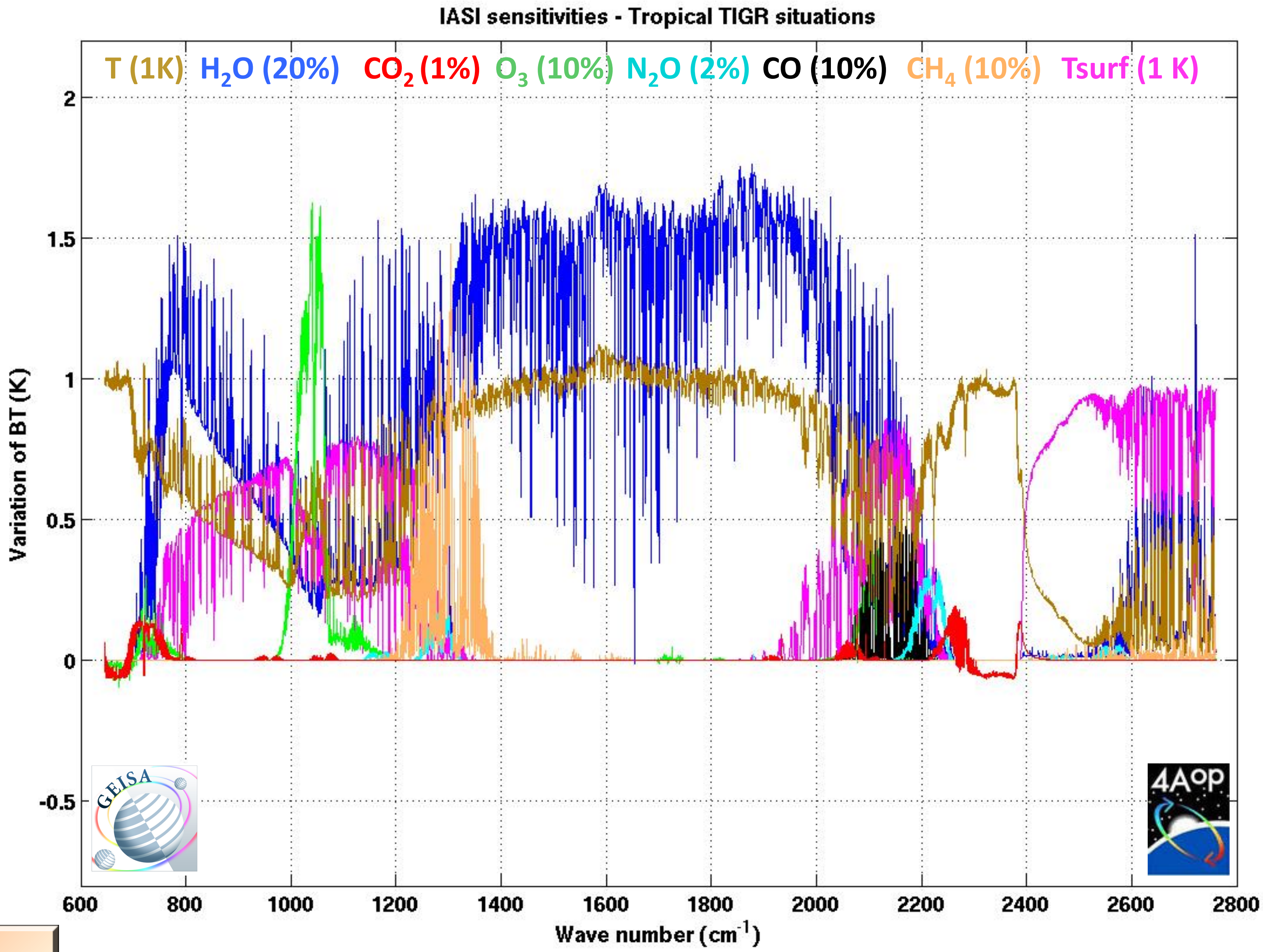
Jacquinet-Husson et al., 2008
http://ether.ipsl.jussieu.fr

Scott et Chédin, 1981
http://www.noveltis.fr/4AOP/

Chédin et al., 1989
http://ara.lmd.polytechnique.fr/

Sensitivity of IASI channels to atmospheric and surface variables



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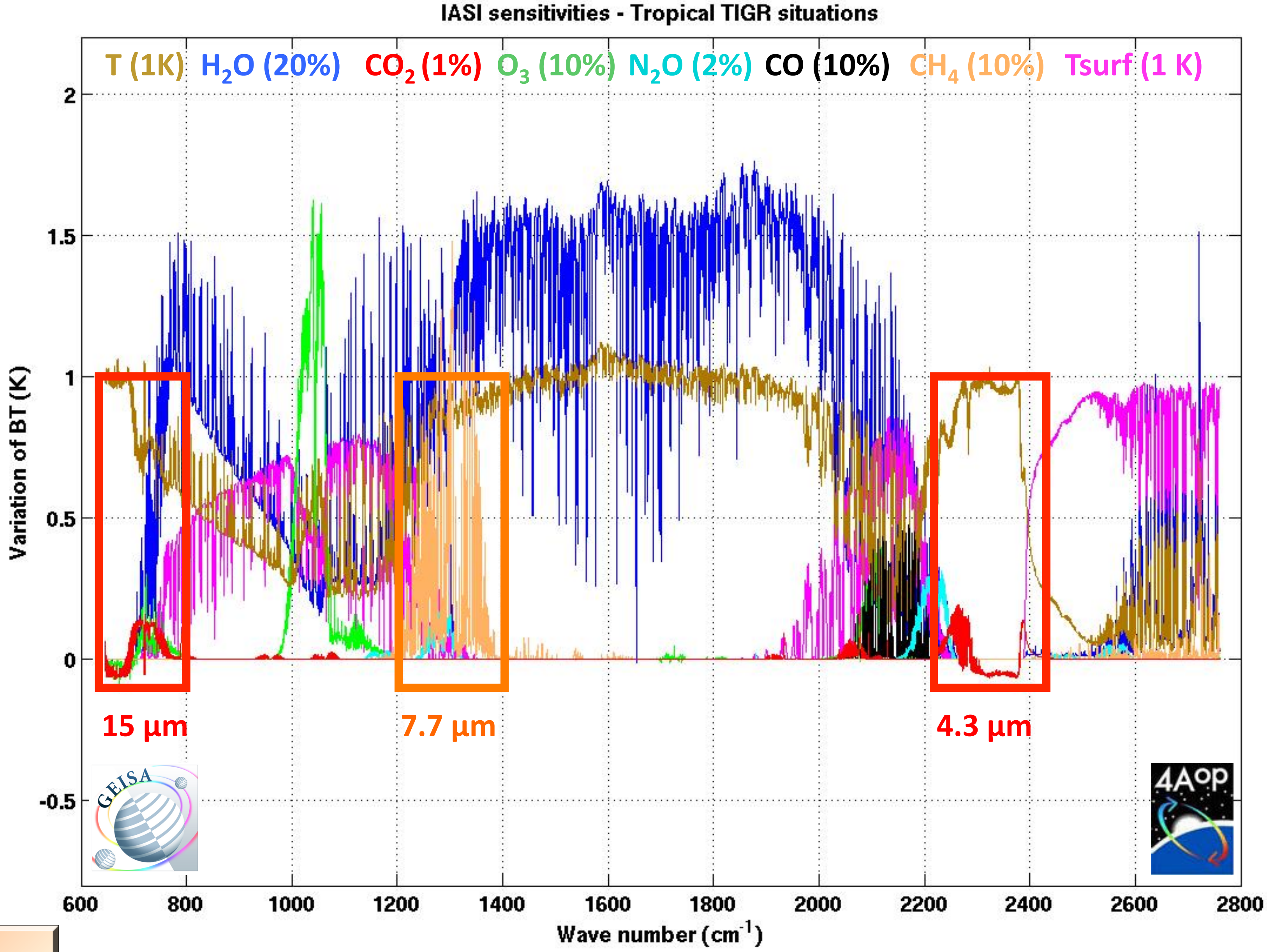
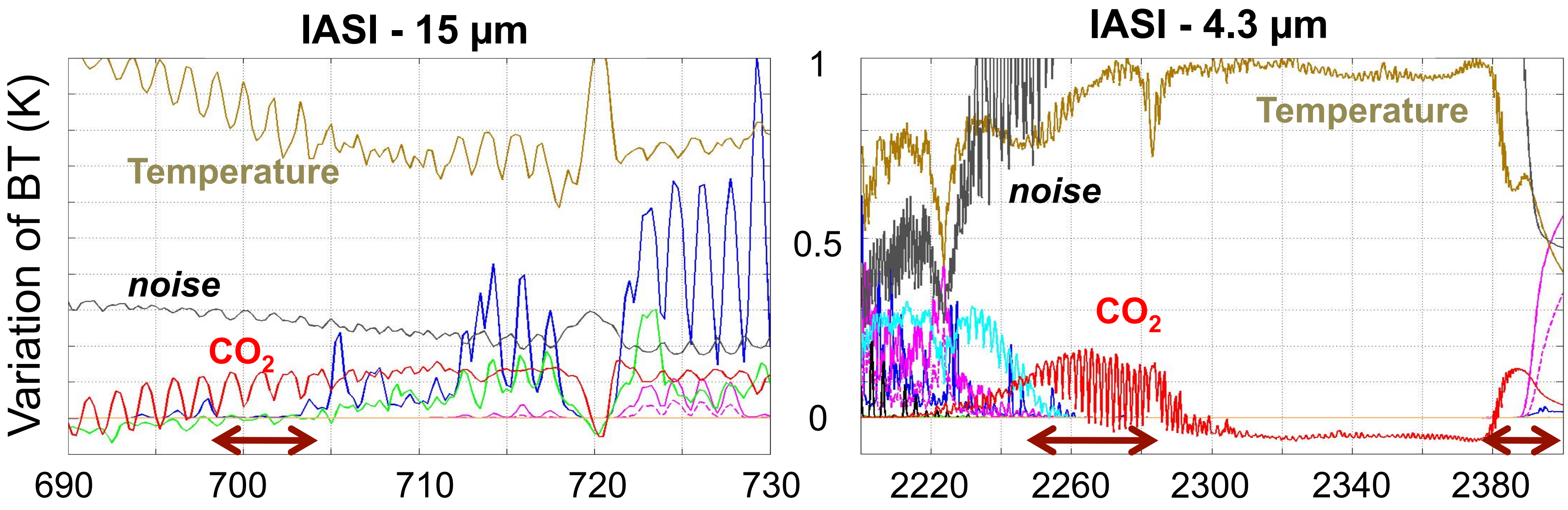


Focus on the CO_2 absorption bands



CO_2: 1% → 0.1 K

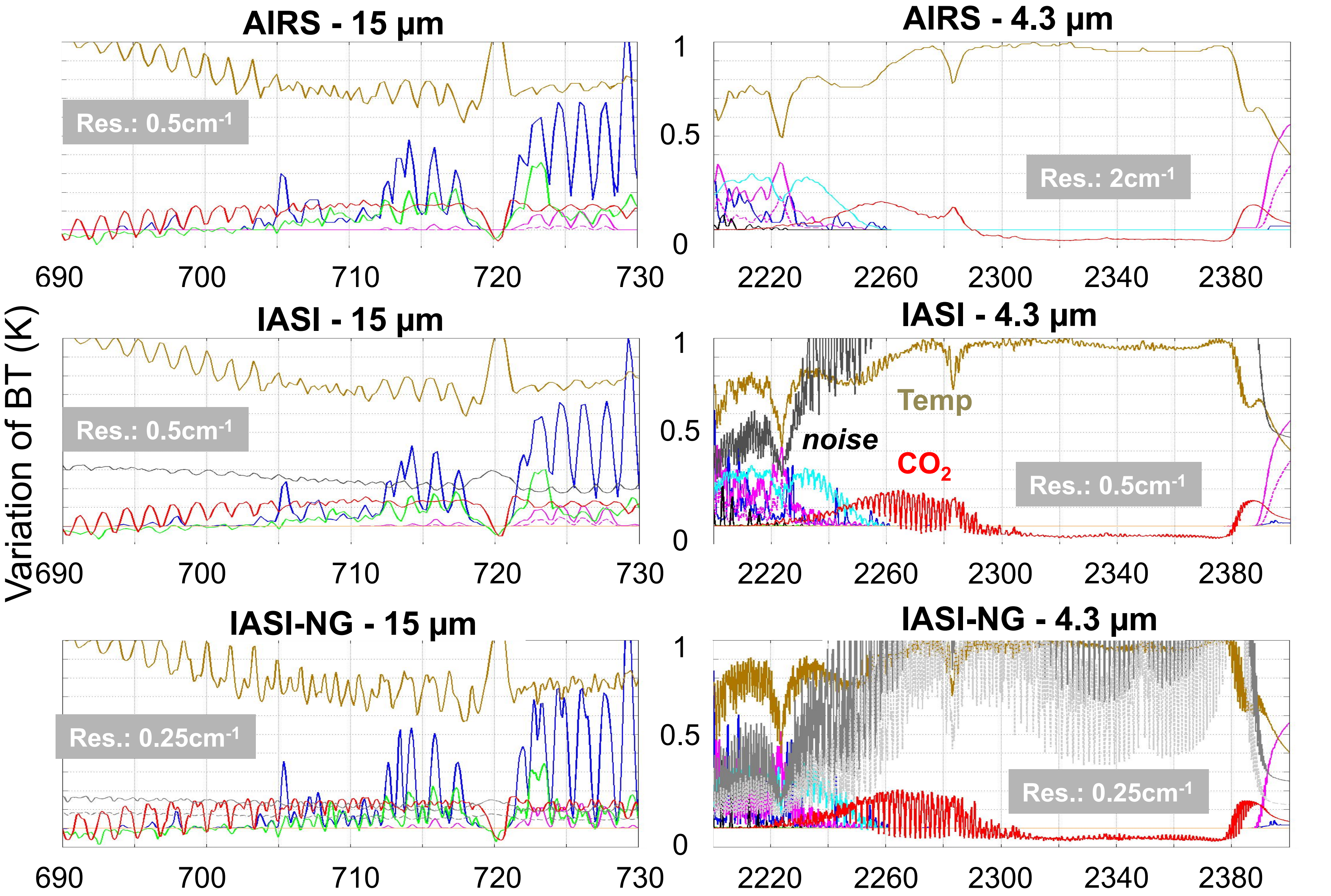
T: 1 K → 1 K

Radiometric noise ~0.2 K

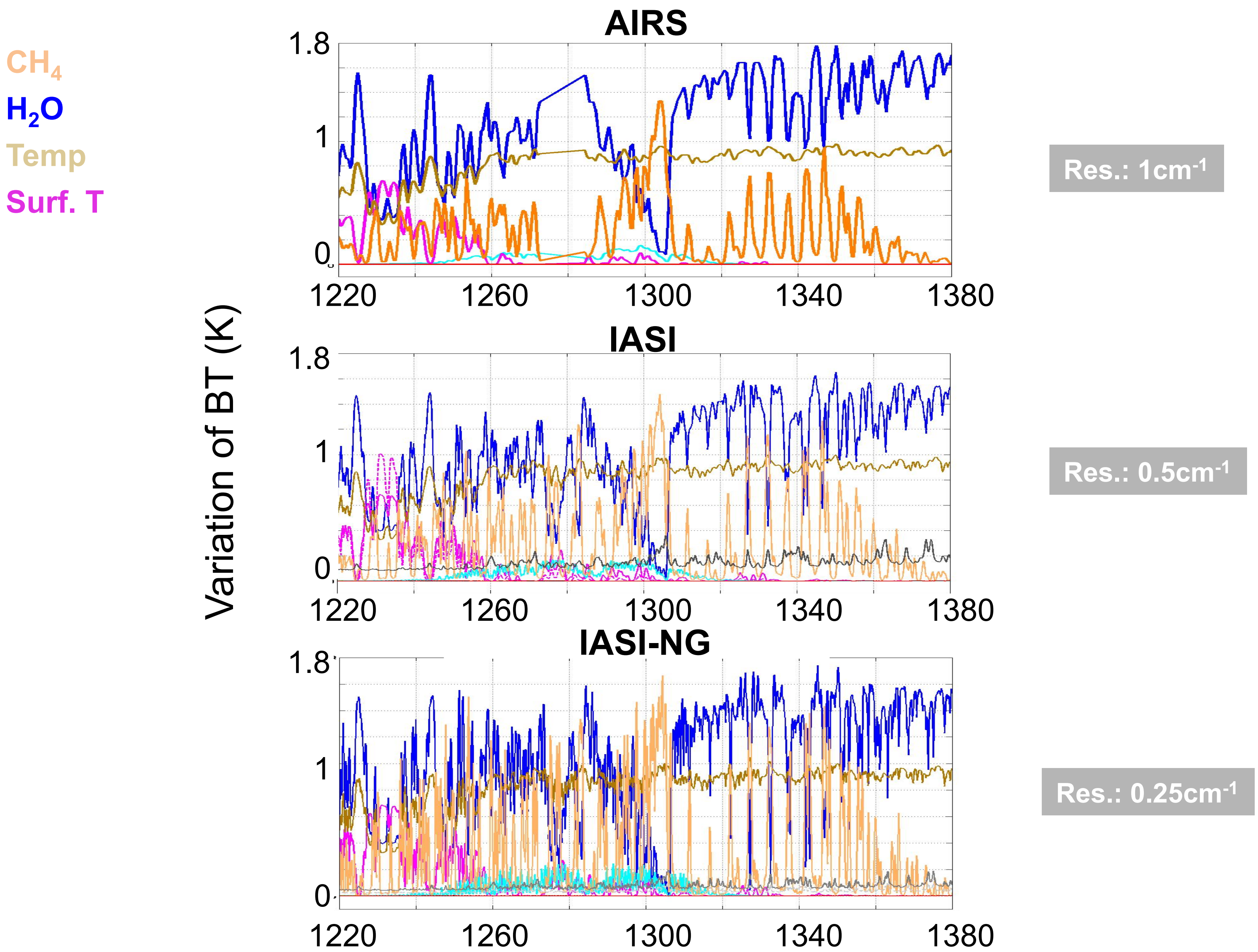
⇨ Very low signal/noise ratio!

- Channels are most sensitive to T:
  → Need to decorrelate T/CO_2 (or T/CH_4)
- Interferences with other species (H_2O, O_3, N_2O)
- Need to average the retrievals (eg: for IASI 1 month, 5ºx5º).

Influence of the spectral resolution – CO_2 bands



Influence of the spectral resolution – CH_4 band at 7,7 µm

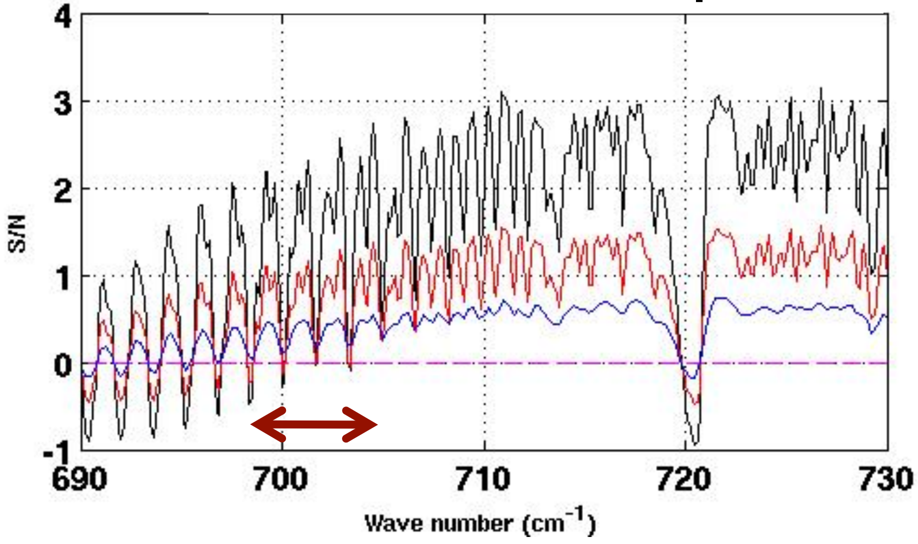


Influence of the radiometric noise

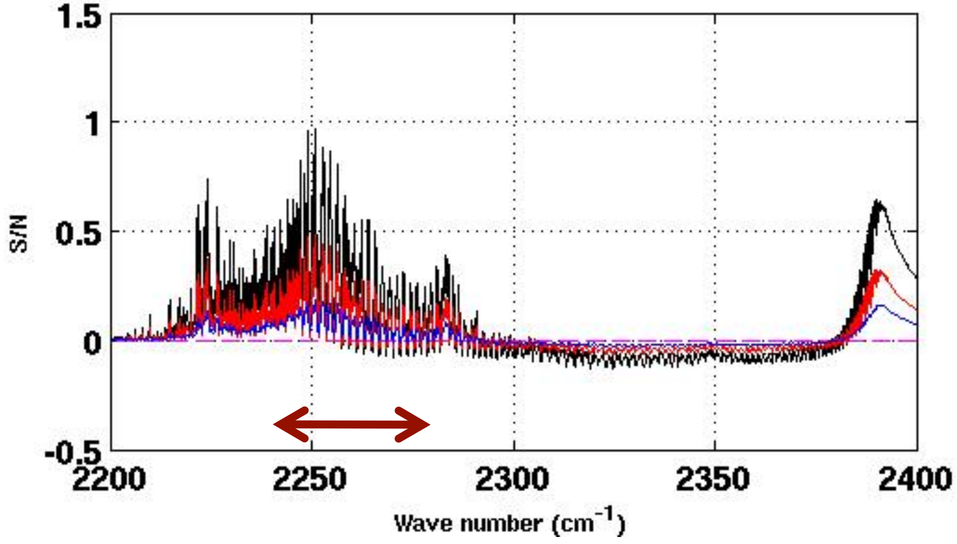
•Signal (CO_2) to (radiometric) noise ratio in the CO_2 absorption bands for:

- IASI
- IASI-NG (factor of 2 on the noise)
- IASI-NG (factor of 4 on the noise)

IASI and IASI-NG - 15 µm



IASI and IASI-NG - 4.3 µm



•The lower the noise the better!...
•That really matters for the small signals we are after.

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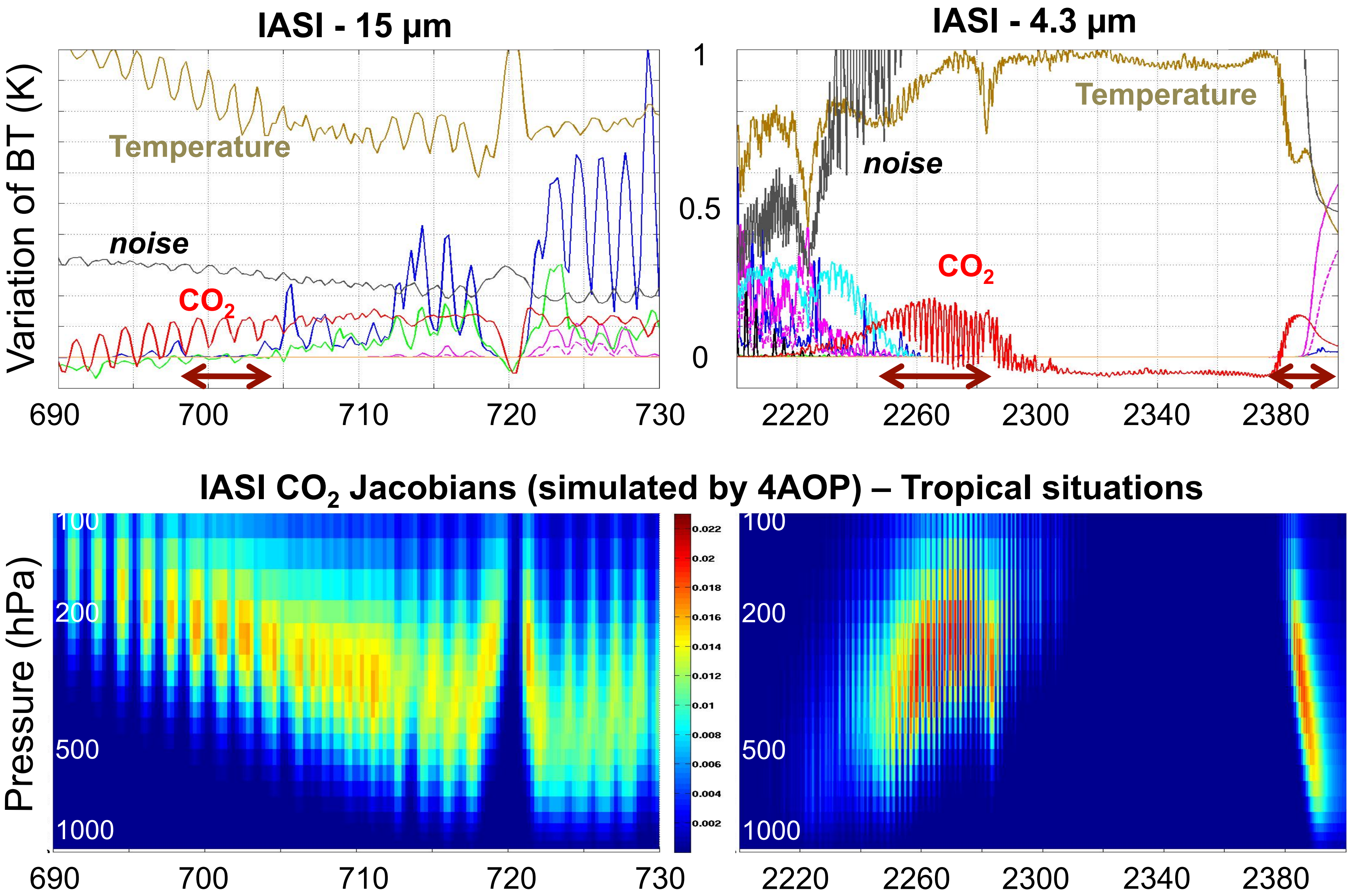
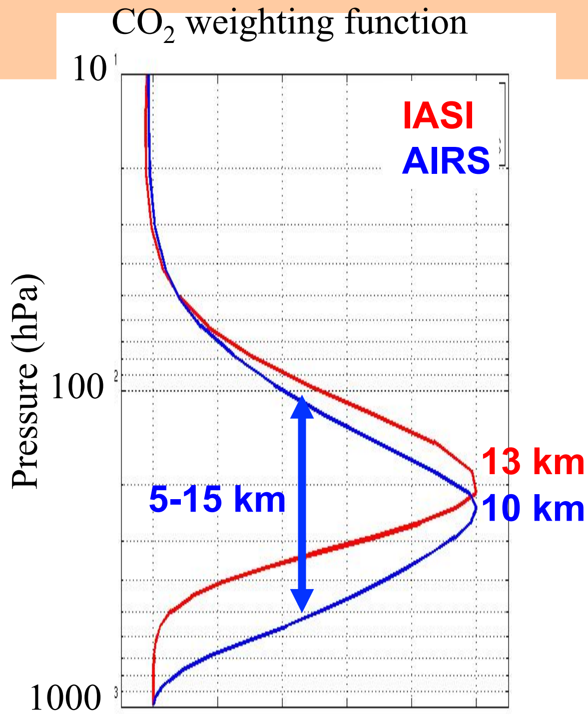
Vertical resolution – CO_2 bands



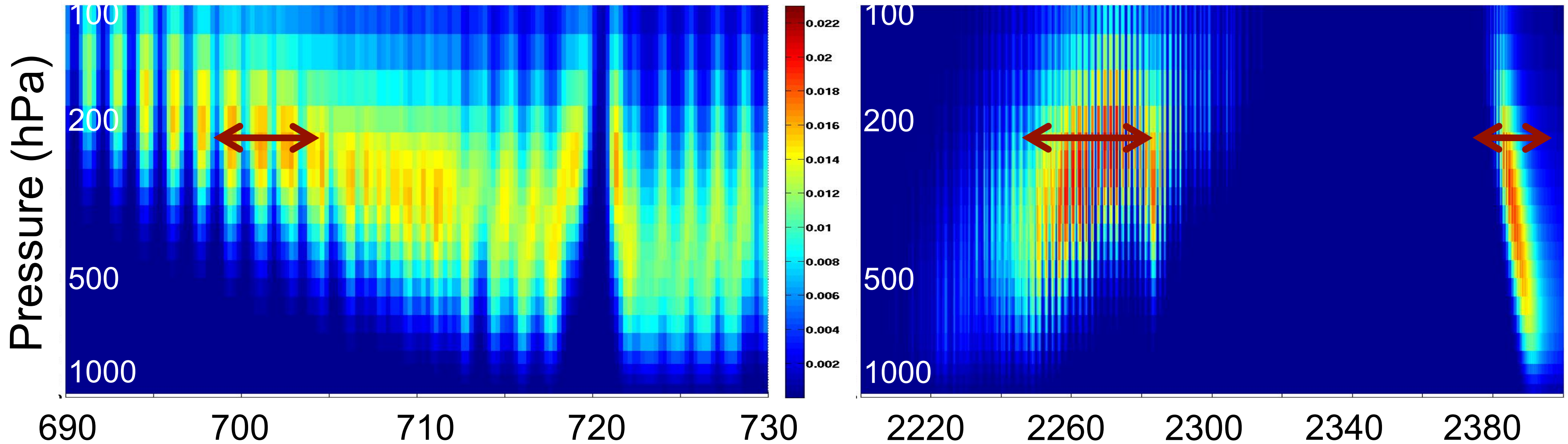
Vertical resolution – CO_2 bands



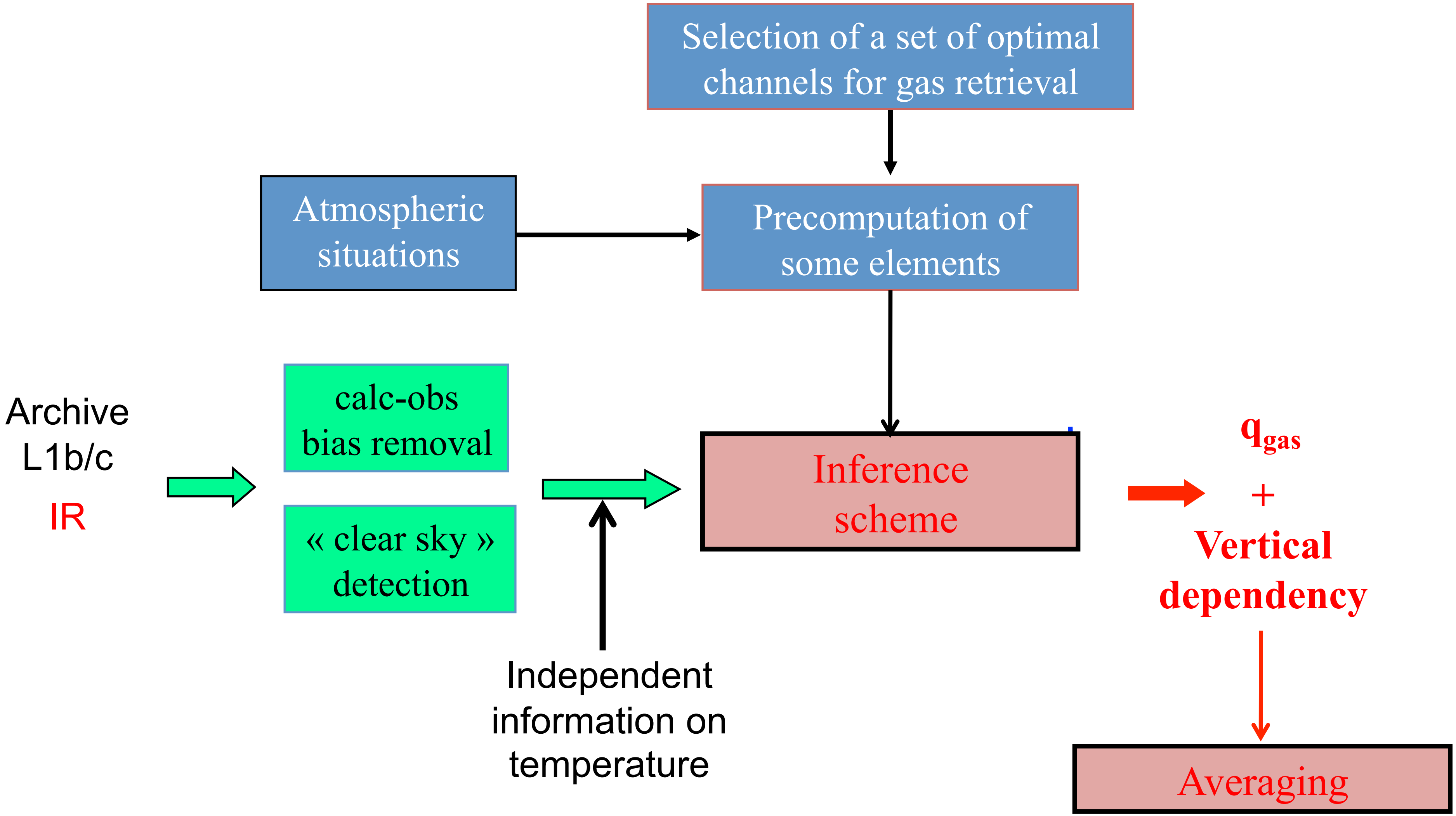
- No sensitivity to the Boundary Layer nor to the tropopause.
  - → Retrieval of a mid-to-upper tropospheric content.
    - ~One degree of freedom on the vertical

- The 4.3 µm band sees (much) lower than the 15 µm band.
- But the use of the 4.3 µm band requires dealing with non-LTE effects…

IASI CO_2 Jacobians (simulated by 4AOP) – Tropical situations



General scheme of a retrieval



•At LMD, we use a non-linear inference scheme based on neural networks.
[Chédin et al. 2003, Crevoisier et al. 2004, Crevoisier et al. 2009]

Decorrelation between CO_2 (CH_4) and temperature

•Need to decorrelate T/CO_2 (or T/CH_4)

⇒ Use of independent info on T:

- reanalyses (ECMWF, NCEP, etc).
- TIR Level 2 temperature profiles.
- simultaneous retrieval of T/gas/etc.
- simultaneous microwave observations sensitive to T and not CO_2

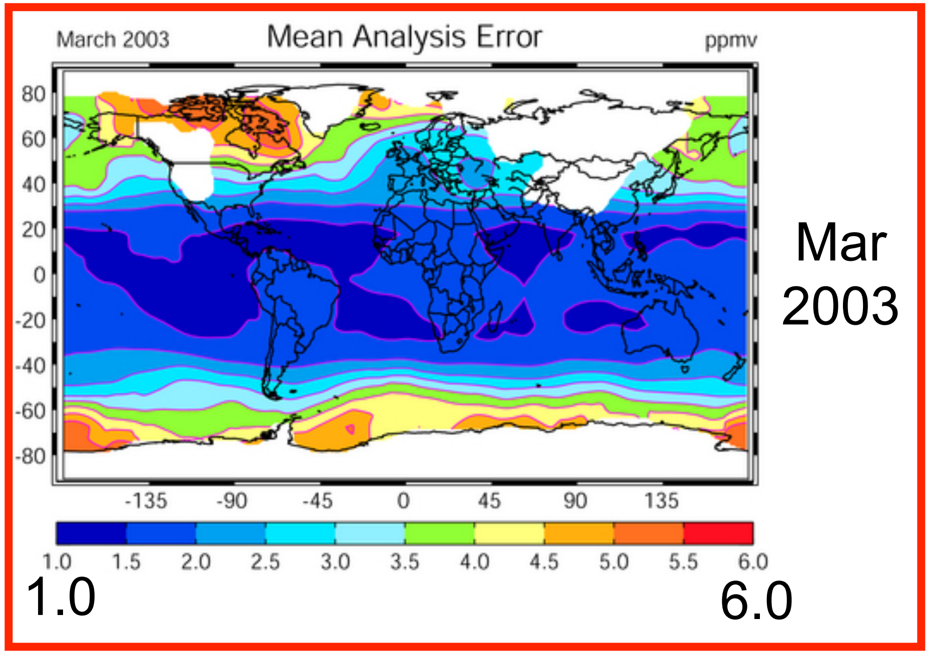
eg: AMSU flying onboard both Aqua and MetOp-A.

(Chédin et al. 2003, Crevoisier et al. 2004, 2009).

•Impact on the precision:

-Better precision in the tropics due to the greater stability of the tropospheric temperature vertical profile.

-Stronger convective vertical mixing from surface to mid-troposphere.



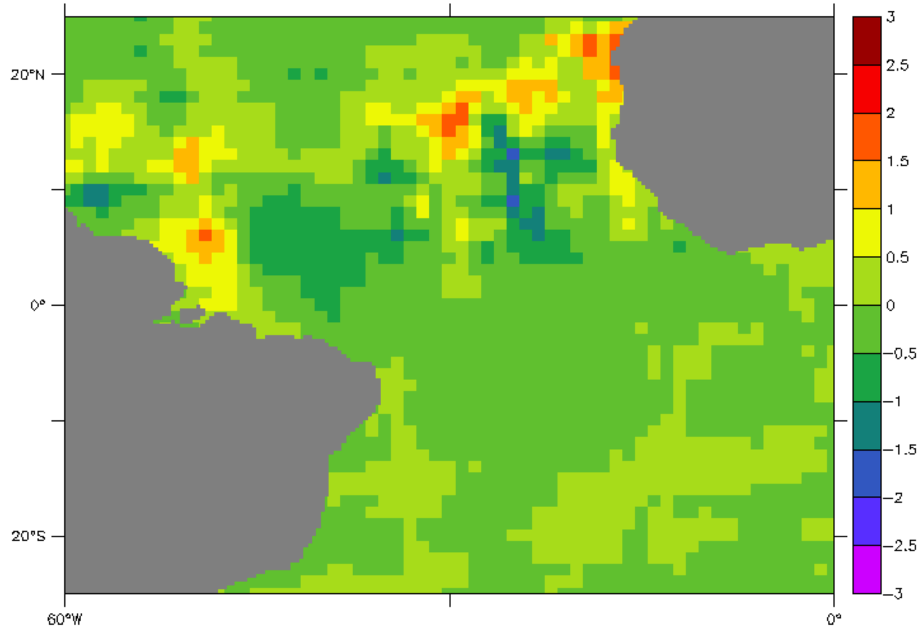
Courtesy of R. Engelen

Cloud and aerosol detection

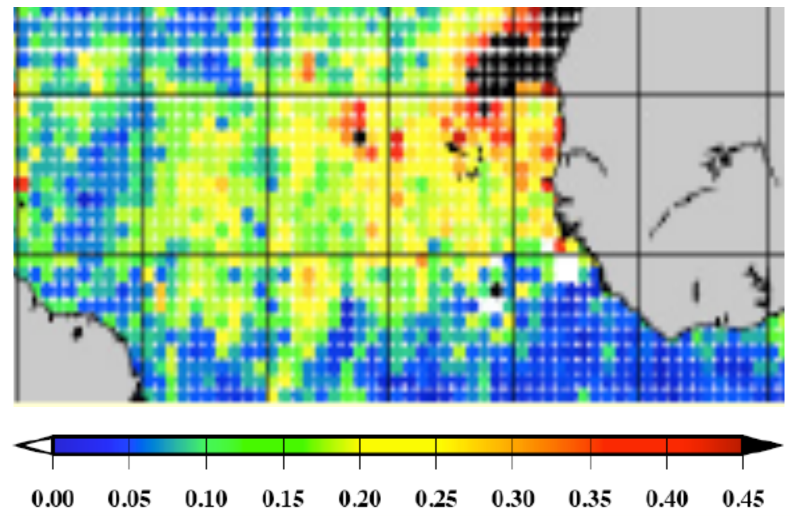
•Retrievals of CO_2 and CH_4 are very sensitive to clouds and aerosols.

Impact of undetected dust aerosols on IASI retrieved CO_2 (July 2010)

CO_2 (with dust detection) - CO_2 (without dust detection)



Dust Aerosol Optical Depth from IASI (10 µm)

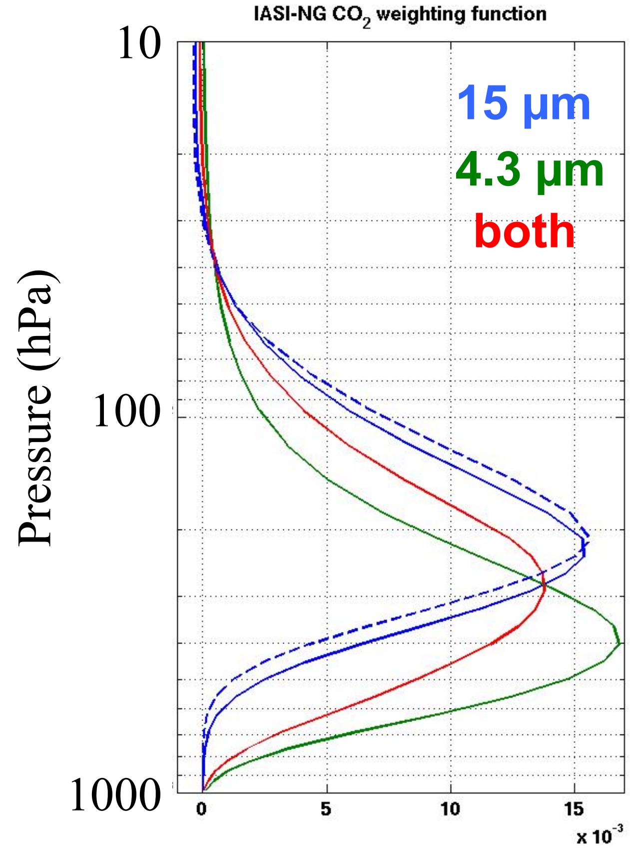


Peyridieu et al. (2010 and in prep.)

Precision of the CO_2 retrievals

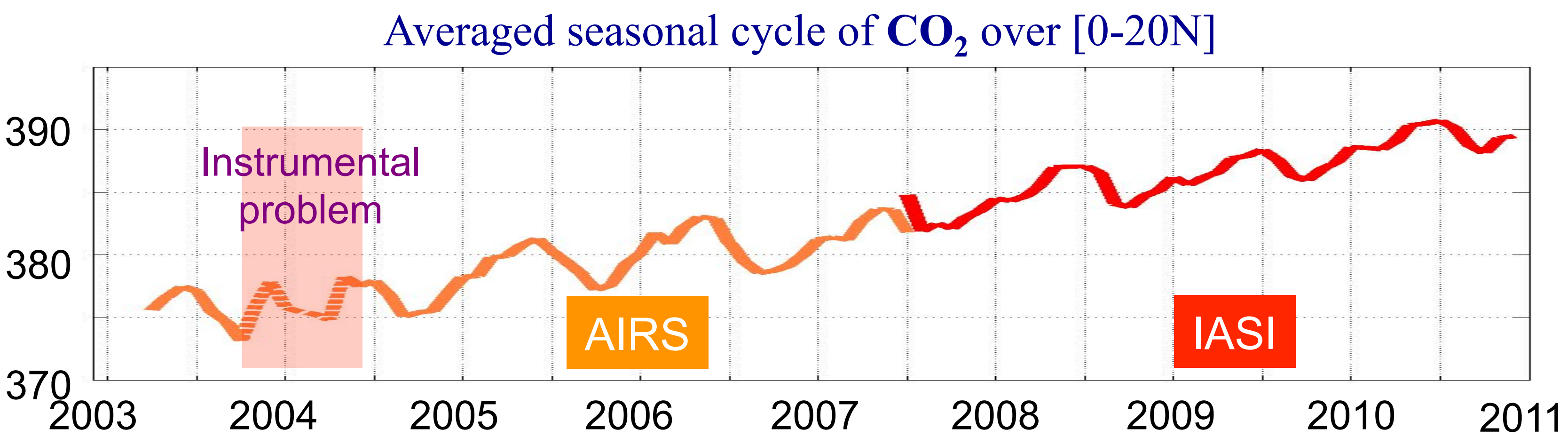
•Using the LMD inference scheme, we have studied the evolution of the precision with various configurations compared to the IASI current precision (which uses the 15 µm band only):

Spectral bands for IASI-NG	Noise	Improvement of the precision
15 µm		30 %
4.3 µm	IASI/2	0 %
15 + 4.3 µm		45 %
15 µm		40 %
4.3 µm	IASI/4	14 %
15 + 4.3 µm		54 %



100-400 hPa, max at 200 hPa
100-500 hPa, max at 300 hPa
200-650 hPa, max at 400 hPa

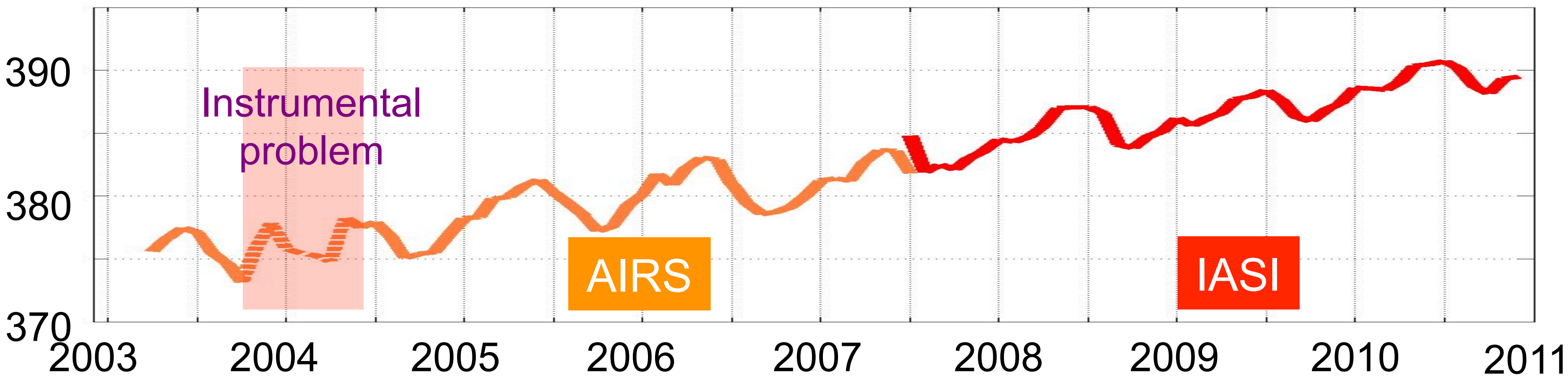
Results (1) - Time series of mid-tropospheric CO_2



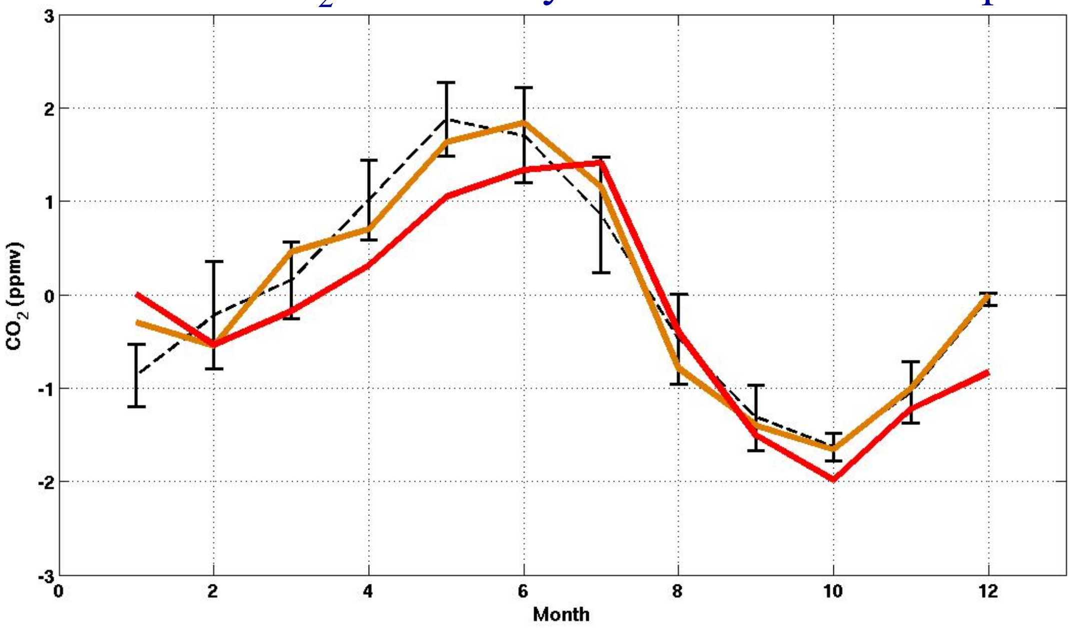
Oct. 2003: AIRS shut down… No impact on temperature, strong impact on CO_2!

Results (1) - Time series of mid-tropospheric CO_2

Averaged seasonal cycle of **CO_2** over [0-20N]



Detrended CO_2 seasonal cycle in the northern tropics



AIRS 5-15 km (max ~**10 km**)
mean over **2003-2007**
(Crevoisier et al. 2004)

CONTRAIL JAL aircrafts ~**10 km**
mean over **2003-2007**
(Matsueda et al. 2008; Machida et al. 2008)

IASI 9-15 km (max ~**13 km**)
mean over 2007-2009
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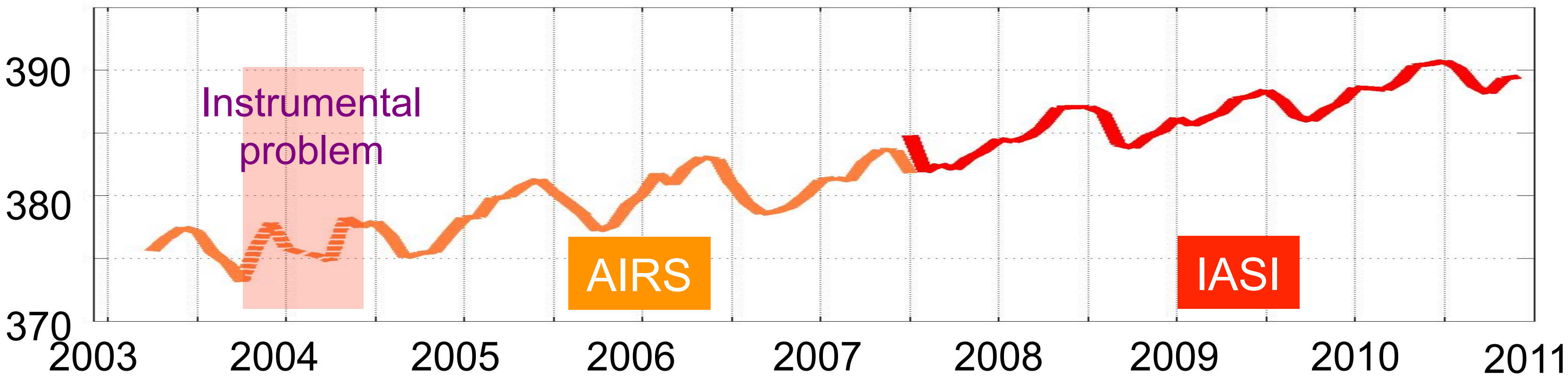
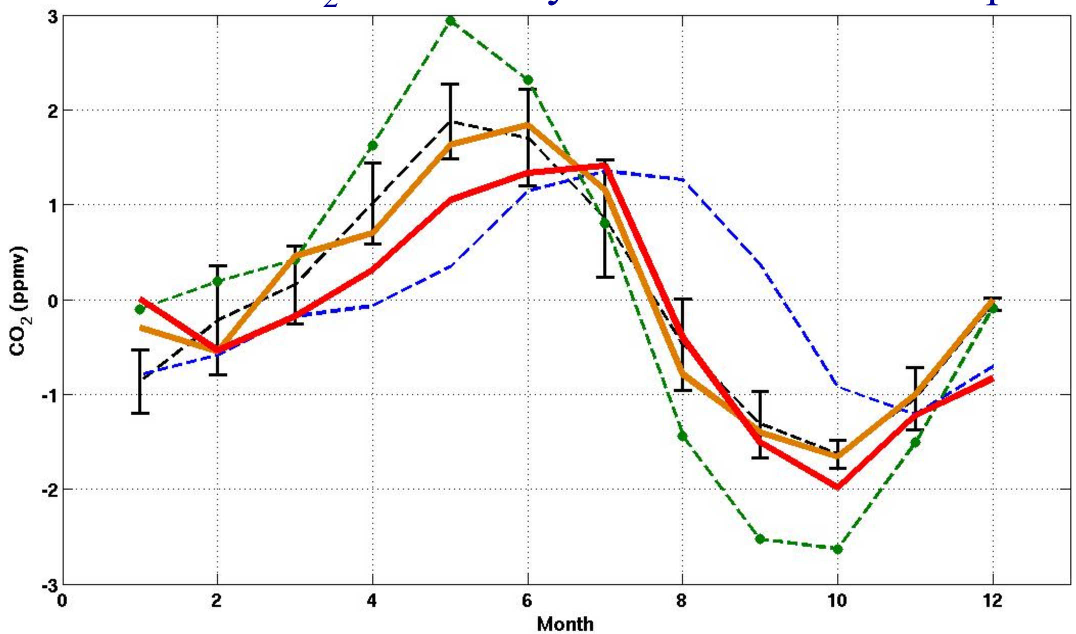


Detrended CO_2 seasonal cycle in the northern tropics



⇒ Time-lag of CO_2 while transported upwards.

MLO — MLO: **4 km**
mean over **2003-2007**
(GLOBALVIEW-2008)

AIRS — 5-15 km (max ~**10 km**)
mean over **2003-2007**
(Crevoisier et al. 2004)

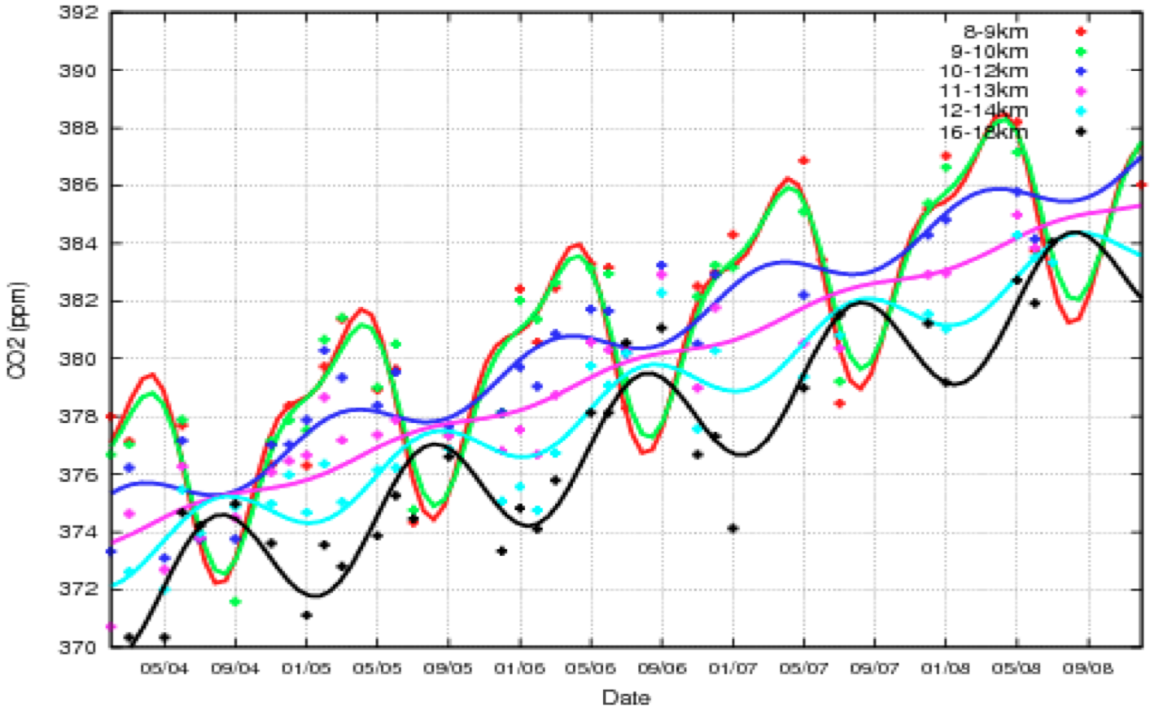
CONTRAIL — JAL aircrafts ~**10 km**
mean over **2003-2007**
(Matsueda et al. 2008; Machida et al. 2008)

IASI — 9-15 km (max ~**13 km**)
mean over 2007-2009
(Crevoisier et al. 2009)

16 km — *[adapted from Strahan et al. 1998]*

Results (1) - Time series of CO_2

Good agreement with the seasonlaity derived from the newly available vertical profiles of CO_2 from ACE-FTS



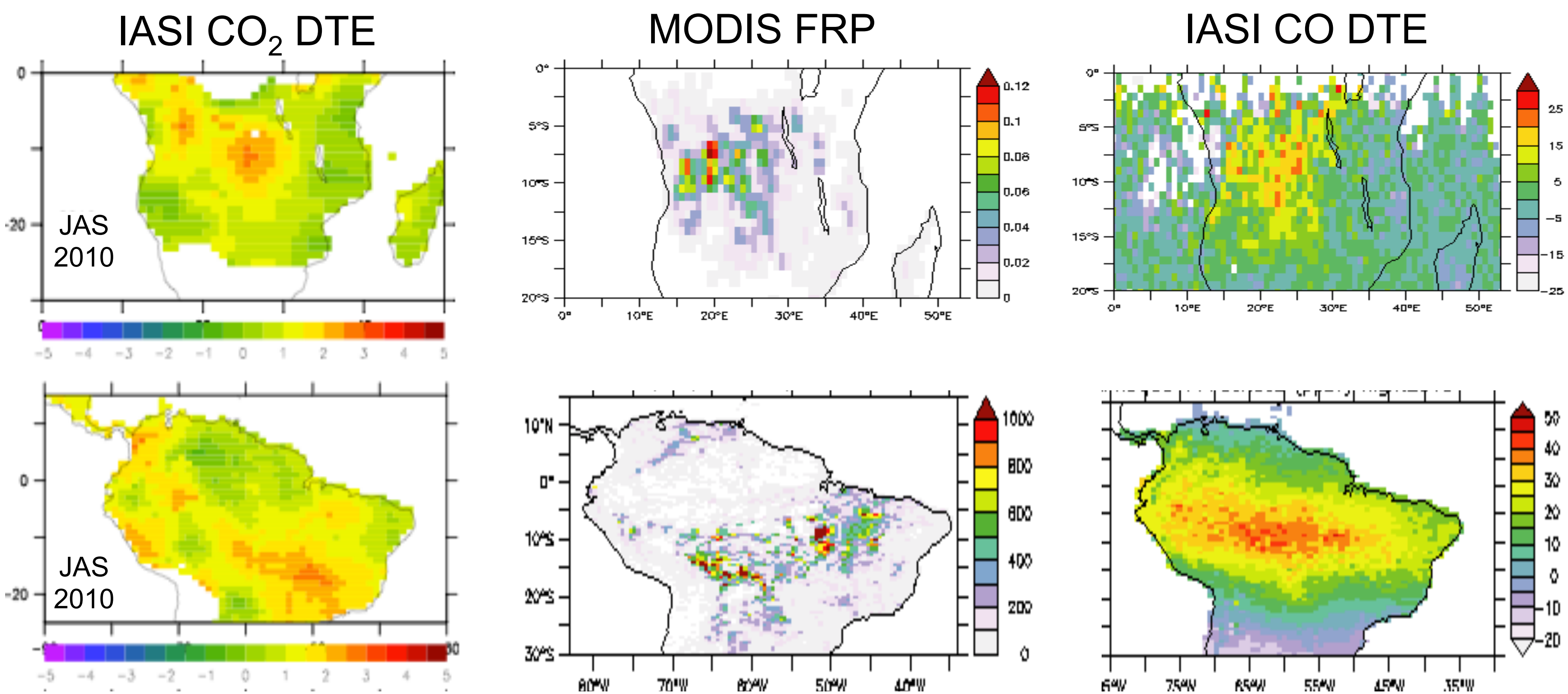
•**Characteristics:** retrieval of CO_2 vertical profiles from about 7 km to 25 km with a precision of ~2 ppmv and a resolution of 2 km from the limb viewing instrument ACE-FTS, working in solar occultation mode, flying on board the Canadian satellite SCISAT [Foucher et al. ACP 2009, 2010].

•**Key features:** variation in altitude of the seasonal cycle amplitude and extrema, seasonal change of the vertical gradient, and mean growth rate.

→ **Study of atmospheric transport.**

Results (2) - Study of emissions from biomass burnings

•Chédin et al. (2005, 2008) have shown that the Diunal Tropospheric Excess (DTE) of CO_2 measured by TIR sounders (7.30am/pm for TOVS/NOAA10, 9.30am/pm for IASI) could be linked to CO_2 emitted by fire during the dry season.



Crevoisier et al. in prep. Roy et al. 2008 Thonat et al. in prep.

⟹ Study of correlations between CO_2, CO, CH_4 (all available from IASI).

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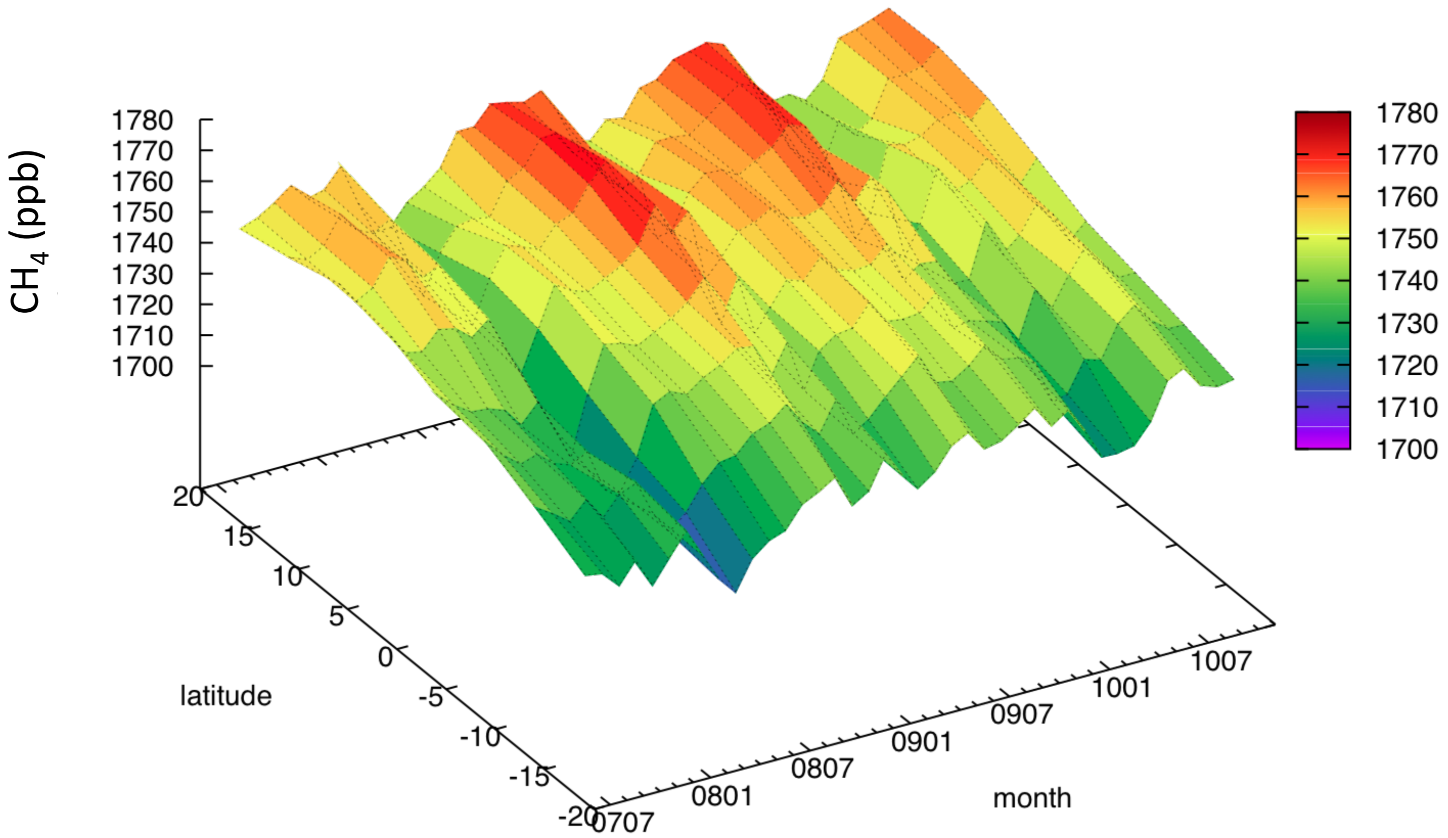
Results (3) - CH_4 retrievals with IASI

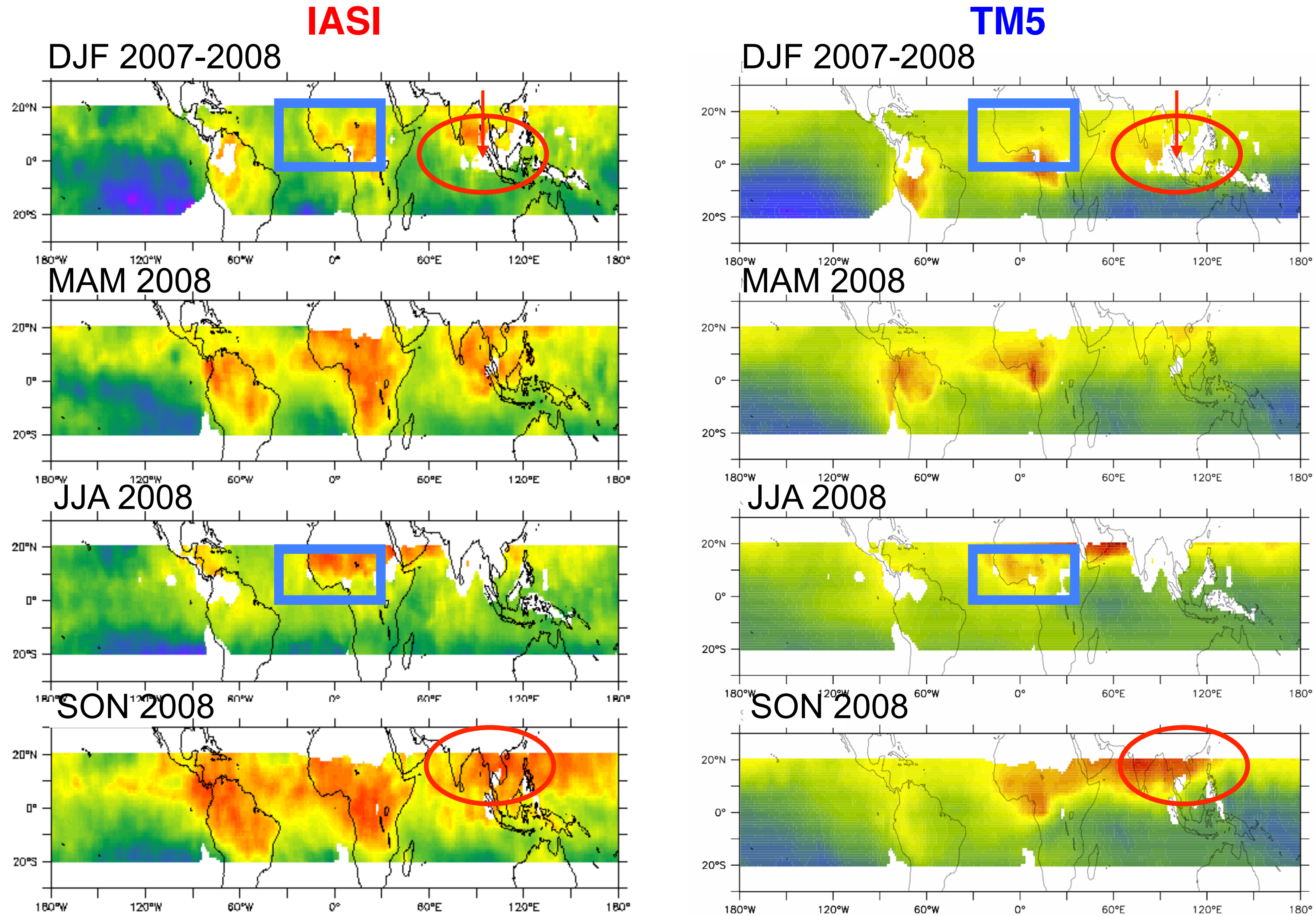
Since July 2007, 3.5 years of monthly mean mid-tropospheric contents of CH_4 have been retrieved from IASI in the tropical band (Crevoisier et al. ACP 2009b).

IASI CH_4 monthly zonal variation over [20S-20N]



We find a trend of +10 ppb.yr^{-1} in 2007-2008, which then decreases in 2009 and becomes negative in 2010 (Crevoisier et al., in prep.)

Results (3) - CH_4 retrievals with IASI



•TM5: with surface sources constrained by NOAA surface stations (4Dvar), sampled at the spatio-temporal resolution of IASI and with CH_4 weighting function applied to the profiles (courtesy of P. Bergamaschi).

A few concluding thoughts (1)

•Hyperspectral infrared sounders give access to many information on greenhouse gases: trend, seasonality, strong emissions uplifted to the mid-troposphere (e.g. fires), atmospheric transport.

• From an 'integrated carbon system' point of view, there is a need for a combination of different techniques:

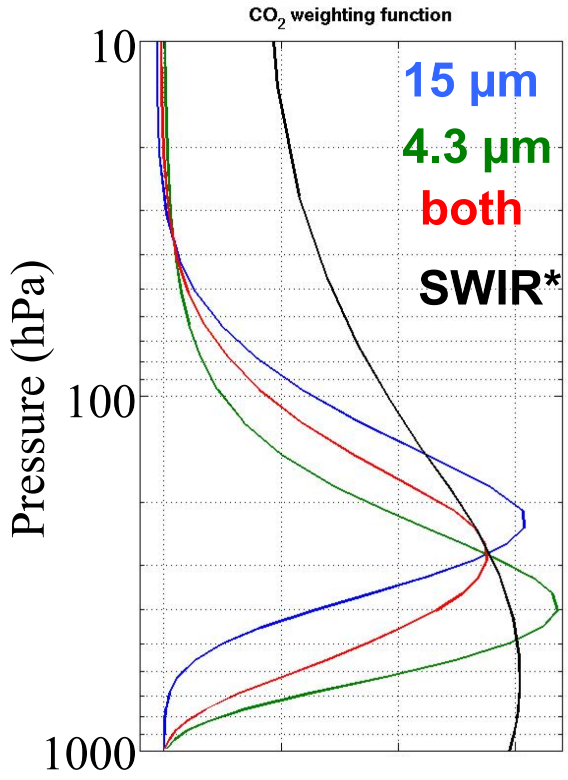
-SWIR (GOSAT, OCO-2, Microcarb) for total column.

-TIR for low-, mid- and/or upper-troposphere.

-limb sounding (ACE-FTS) for vertical profiles.

-And of course: **surface and aircraft!!**
→ calibration/validation is essential;
it needs to be supported.

• Different times are needed to study the diurnal cycle of GHG.



*courtesy of C. Pierangelo

•Hyperspectral sounders offer the opportunity:
- to study the correlations between several gases.
- to study new species (eg: N_2O).

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A few concluding thoughts (2)

•The decorrelation between T and CO_2/CH_4 is the key.

→ Strong need for independent / simultaneous 'high resolution' observations of temperature (again 0.1 K <-> 3ppmv).

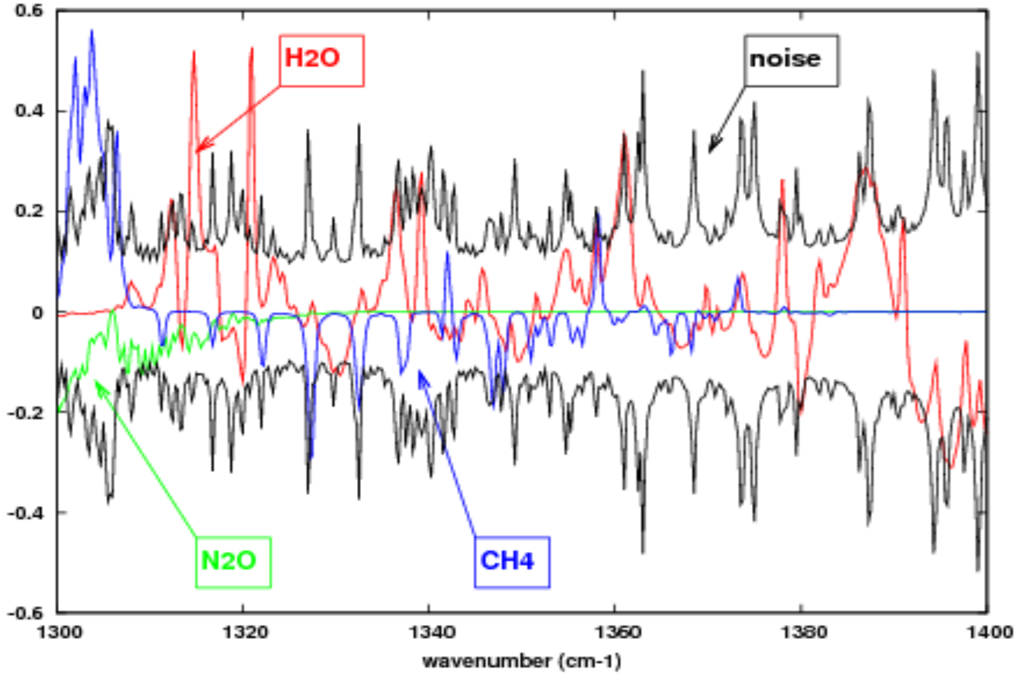
•Improving the spectral resolution helps limiting interferences between the species.

•We need to keep working on improving spectroscopy and RT codes (non-LTE, line-mixing, etc.)

→ Such activities need to be supported!

•Reducting the noise is (one of) the main objective.

Variation of IASI BT simulated by 4AOP based on GEISA-08 – GEISA 03



Courtesy of N. Jacquinet-Husson