CENTRE NATIONAL D'ÉTUDES SPATIALES

The IASI Instrument

ECMWF / NWP-SAF Workshop on the assimilation of IASI in NWP Reading, May 6-8, 2009

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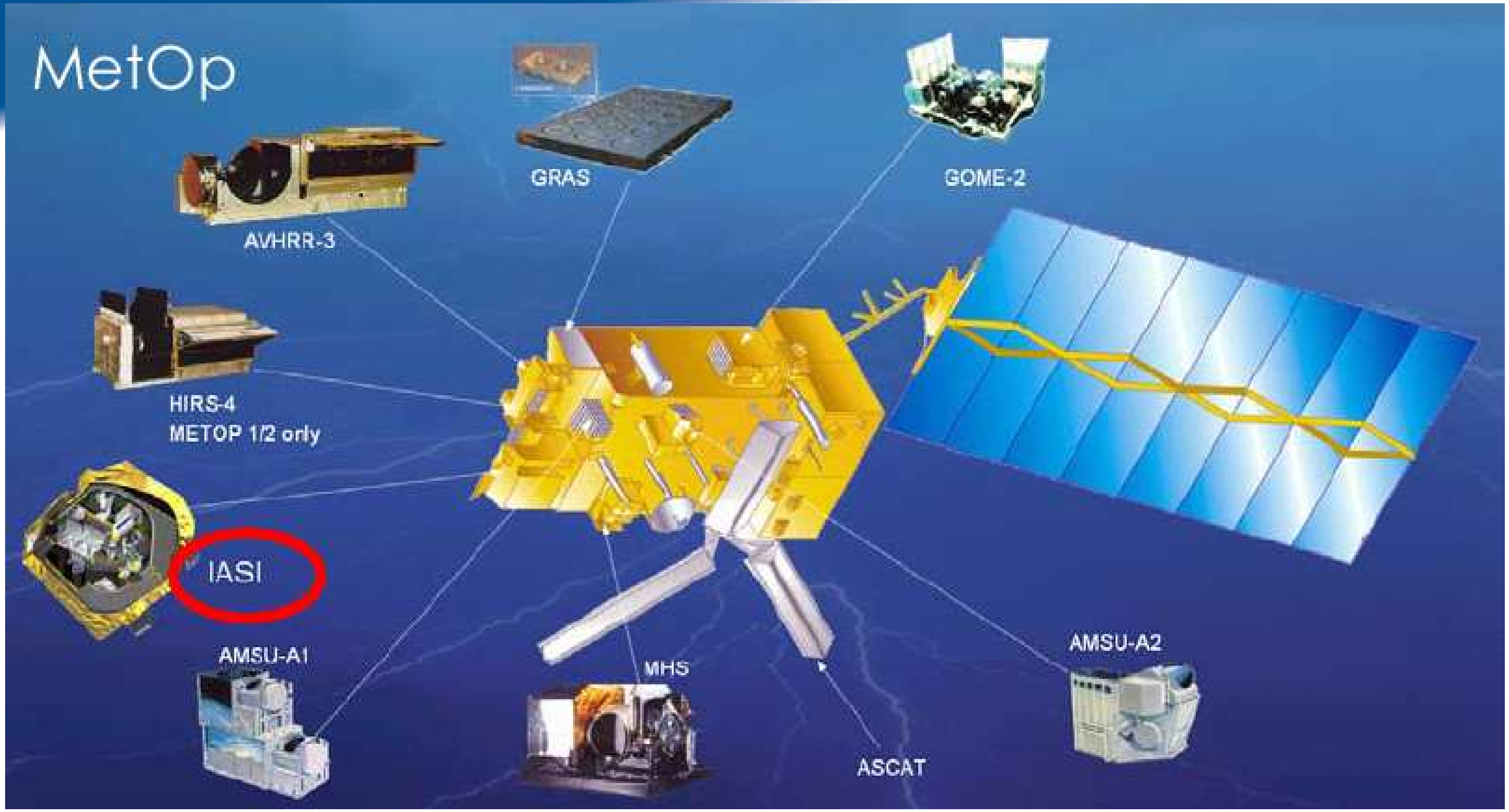
Outline

1. Introduction
2. Functional Behaviour & Availability
3. Radiometric noise & Ice contamination
4. Radiometric calibration
5. Spectral performances
6. Geometry
7. Processing and L0 / L1 data Quality

IASI on-board MetOp-A, B & C



- 3 instruments have been built → mission duration > 15 years
- MetOp-A launch : October 2006 → IASI declared operational : July 2007
  - IASI spectra assimilated by some NWP Center as early as June 2007

2.5 years of in-orbit experience

Main characteristics

IASI : nadir Fourier Transform Interferometer

- **For atmospheric sounding**
- **Cover without gap the thermal infrared region from 645 to 2760 cm-1**
- **Maximum Optical Path Difference (OPD) : +/- 2 cm**

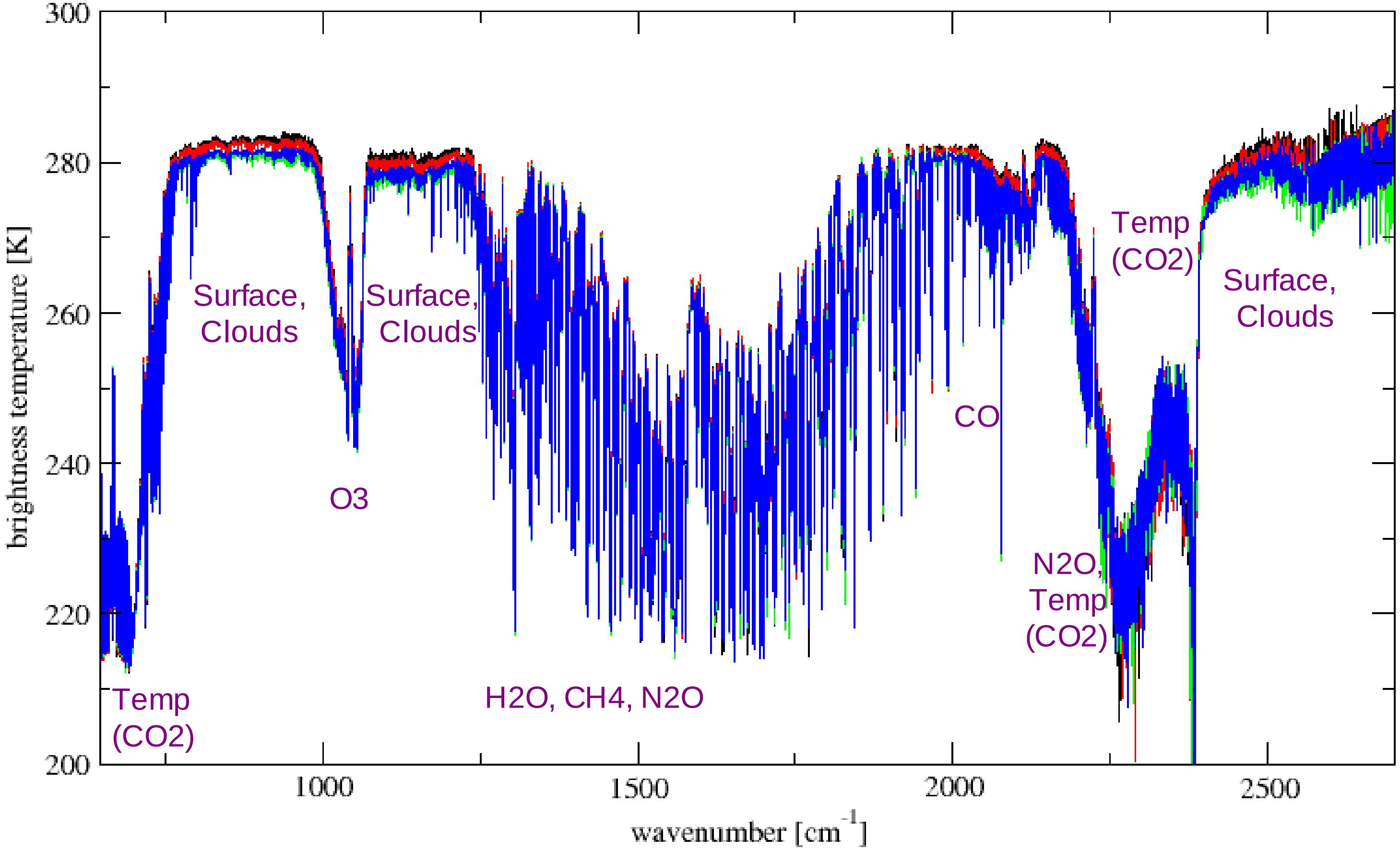
- **Spectral bands: 3.62 µm to 15.5µm**
  - B1 : 8.26 - 15.5 microns
  - B2 : 5.0 - 8.26 microns
  - B3 : 3.62 - 5.0 microns
- **4 off-axis pixels**
- **Field of view**
  - -48°20' / +48°20'
- **Spatial resolution :**
  - Pixel diameter of 12Km
- **Spectral resolution**
  - 0.5 cm-1 (apodized spectra)

- **Radiometric resolution :**
  - 0.2 to 0.4 K (apodized spectra)
- **Data flow:**
  - 1.5 Mb/sec (average)
- **Dimensions of sounder :**
  - 1.1 x 1.1 x 1.2 m3
- **Mass sounder < 200 Kg**
- **Power consumption < 240 Watt (worst case EoL)**
- **Reliability > 0.8**
- **Availability > 95% over 5 years**

+ Integrated Imager Subsystem 64 x 64 (0.8 km @ nadir), 10.3 µm – 12.5 µm

First IASI Level 1C Spectra

29/11/2006, 13:42:11 UTC



Generated by the IASI L1 PPF and Cal/Val Facility

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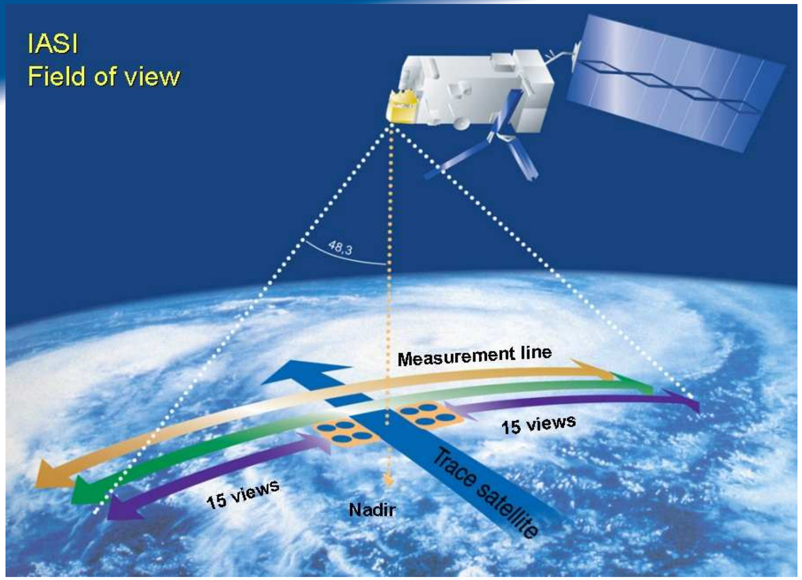
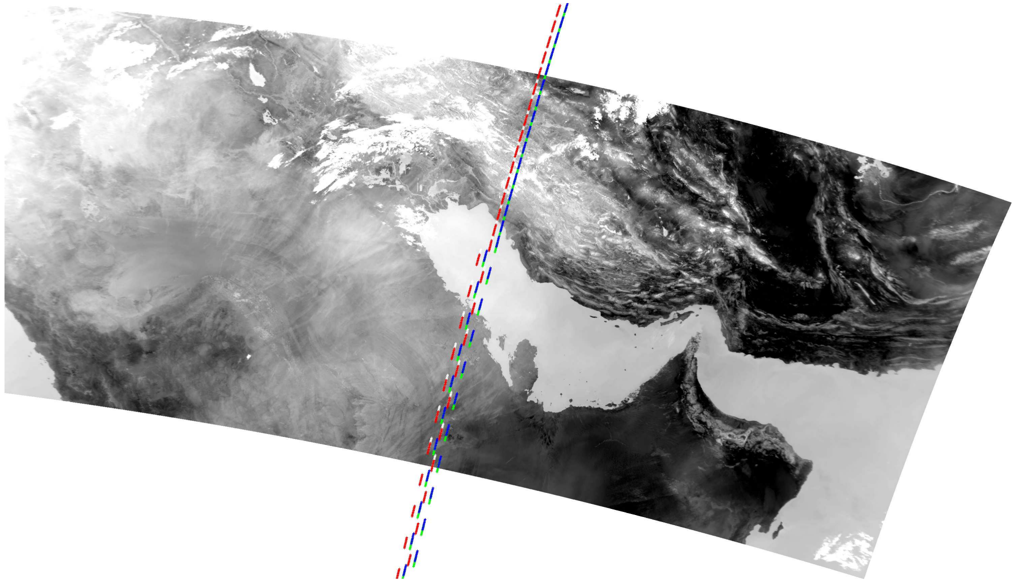
IASI : 2 operational modes





Normal Operation Mode

- Scanning the swath
- 30 views / 8 sec

External Calibration Mode

(here quasi-nadir looking)

- Fixed viewing direction for 8 sec
- 27 views / 8 sec

Pre-calibrated spectra computed on-board → science data TM

+ 1 raw interferogram available on ground every 8 seconds (over 408)

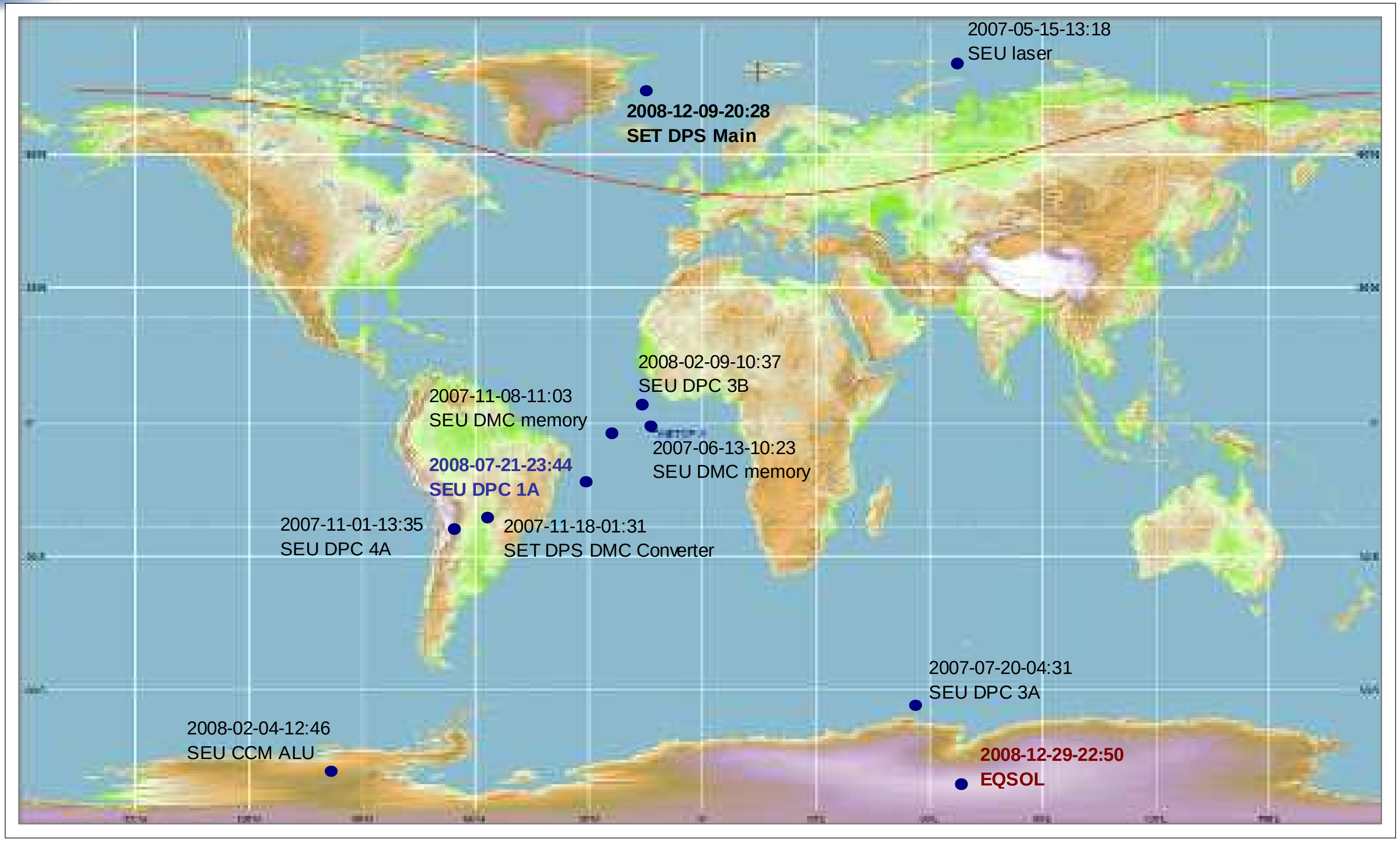
► selection fully programmable

IASI mode budget

- **Normal Op Mode**
  - **95.7 %**
- **External Cal Mode**
  - **1.2 %**
- **Instrument outage**
  - **3.1 %**
  - → **Strong pressure from users to minimize outage duration**

- **On-board software update designed to mitigate SEU affecting Data Processing Subsystem (most of the events)**
  - **Automatic restart of suspended Data Processing**
  - **Will be uploaded before summer**
  - **Will not cover all the anomalies**
    - In case focal plane temperature is lost, recovery still takes at least 2 days and 14 hours (passive cooling)

Geo location of IASI SEU/SET anomalies



- **Instrument outages caused by protons or heavy ions**
  - **Mainly over South Atlantic Anomaly & at High latitudes (North & South)**

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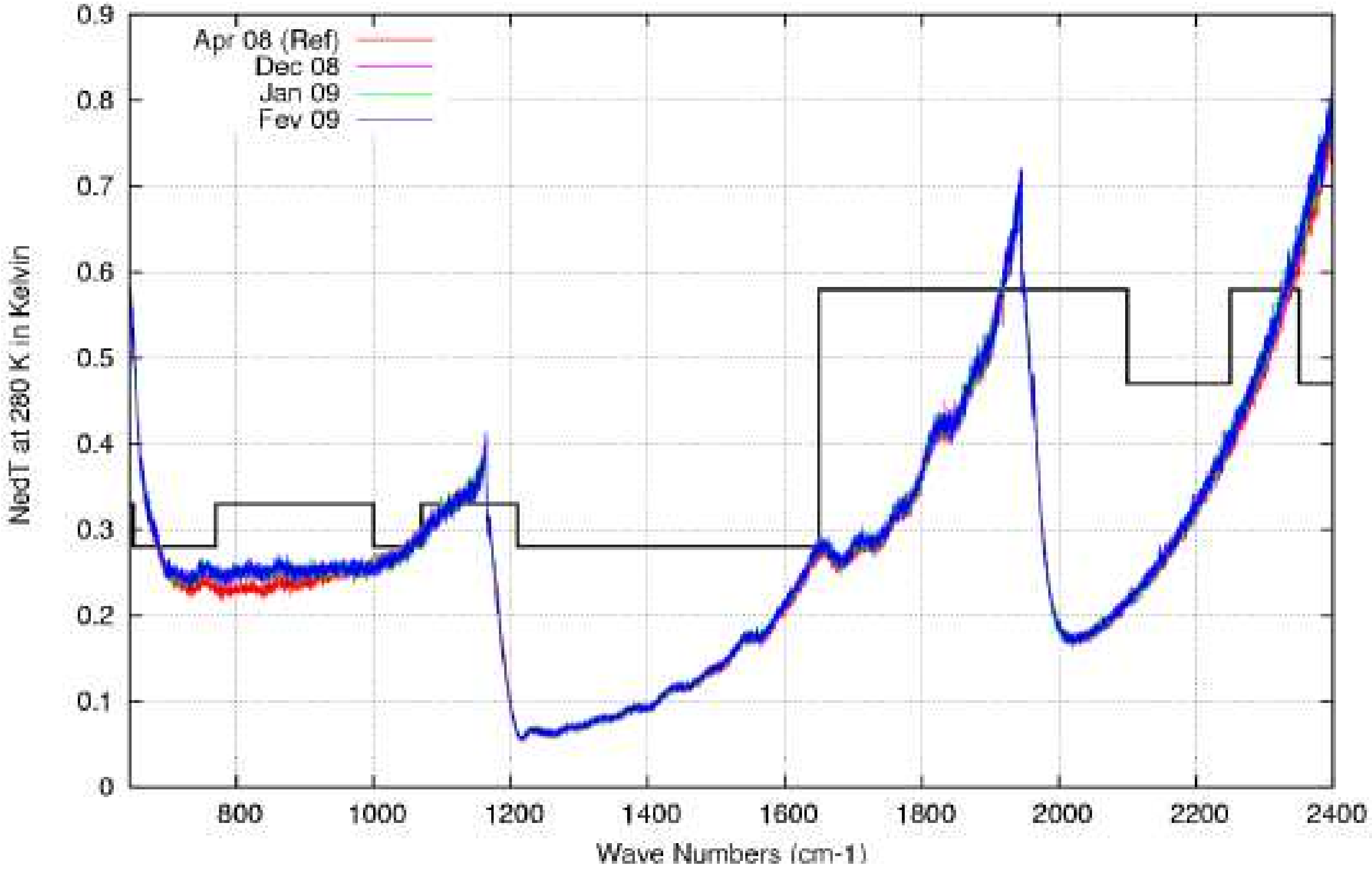
Radiometric noise since last decontamination (March 2008)

Monthly Estimation (Ext.Cal.) by using Hot Black Body target

NeDT evolution between April 2008 and February 2009



Stable since last decontamination, except ice effect between 750 et 900 cm^{-1}

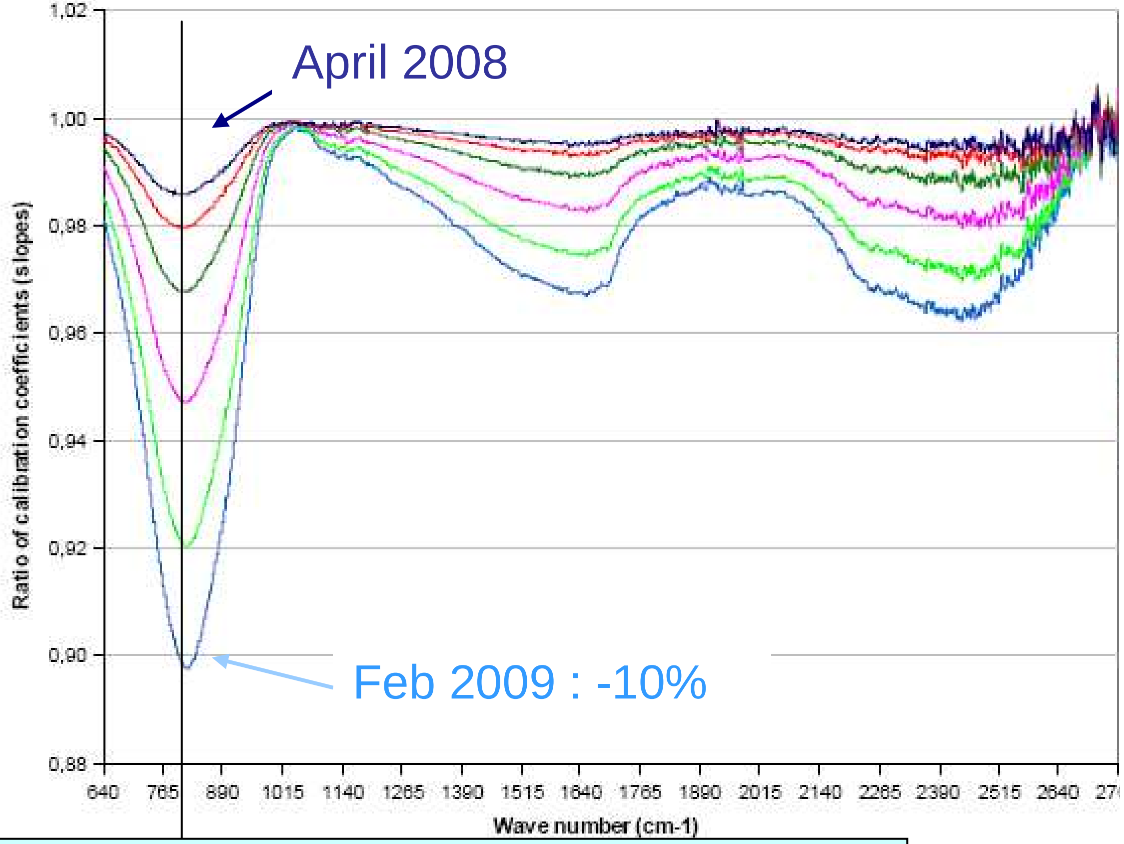
Instrument transmission evolution since last decontamination (march 2008)

Estimation by using radiometric calibration coefficient (slope)

Physical phenomenon : water released by materials at 300K (MLI, electronics)

- → **condensation on field lens at 100K (entrance of Cold Box Subsystem)**
- → **formation of ice**
- → **instrument transmission decreases**
- → **less signal**
- → **SNR decreases**
- → **NeDT increases**

Instrument transmission evolution

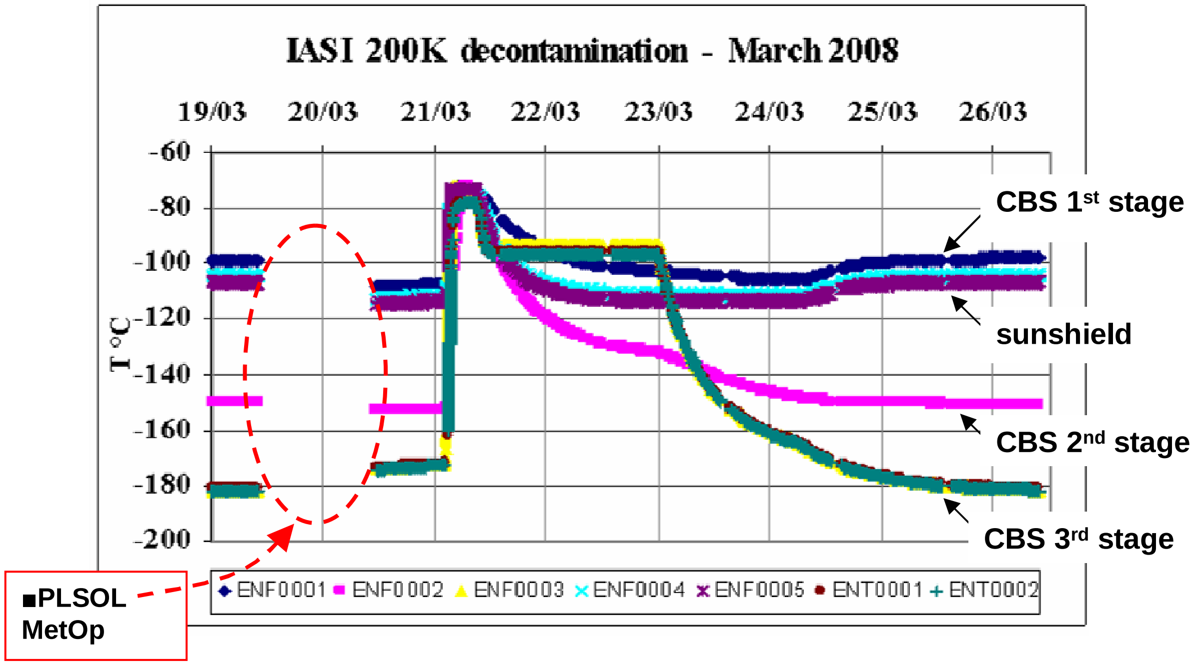


Maximum loss due to water ice at 850 cm^{-1}

First decontamination in routine phase (21th March 2008)

■ Decontamination

The decontamination lines heat the different parts of the Cold Box Subsystem (the three passive radiator stages and the sunshield) up to a temperature of 200 K (-73°C) for a duration of 4 hours. Then during the cooling down of the first and second stages, the third stage is maintained at -93°C in order to avoid re-deposition of ice on the cold optics. About 1.5 day later, when the second stage reaches -131°C, the third stage decontamination line can be switched off and the cooling of the first stage begins. It takes about 4 days to cool down the CBS third stage from -73°C to -181.8°C, the final temperature being exactly the same as before the outgassing phase.

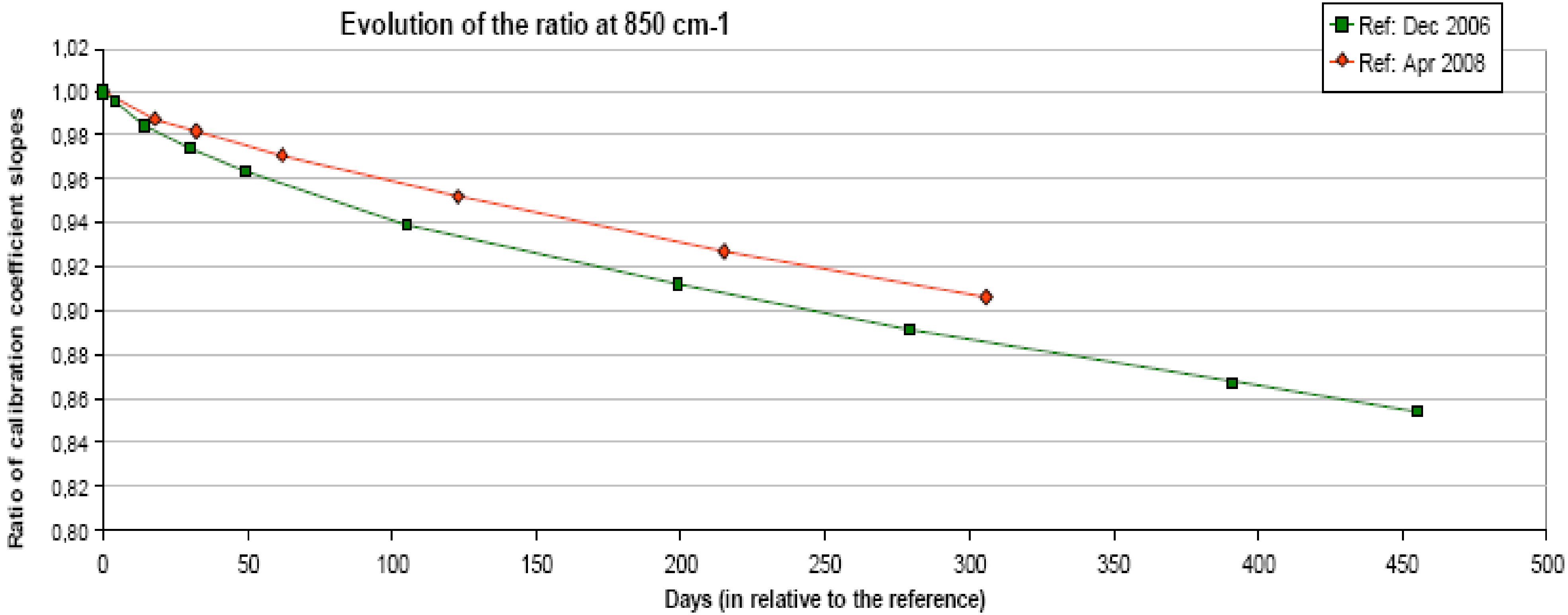


■ **Performed during MetOp outage recovery**

- ■ **mission outage < 5 days.**
- ■ **After 1.5 year in-orbit**

■ **Recovery of the initial noise measured end of 2006**

Next decontamination

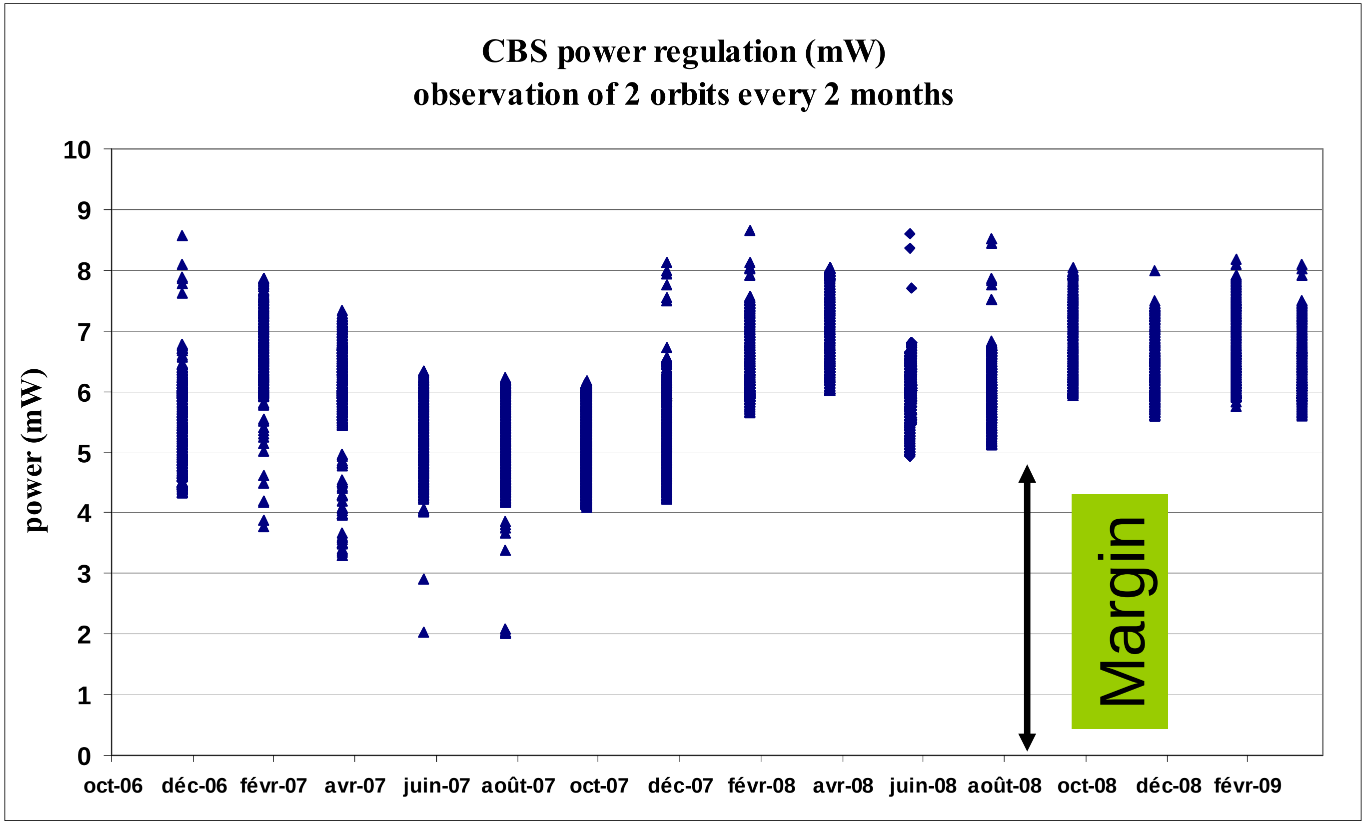


- **Criteria :** **maximum noise increase of 20% (= transmission loss of 20%)**
- **Last IASI decontamination :** **21-24th March 2008 (1.5 year after launch)**
- **Next one :** **Mid 2010**

Stability of detector temperature

- Focal plane temperature regulated at 91.7 K

- Power regulation
  - Stable (No trend towards 0)
  - Seasonal effect



- Conclusions
  - Contamination of the sun shield is low
  - Margin sufficient : No need to increase focal plane temperature target

→ Stability of the radiometric noise expected in the next years

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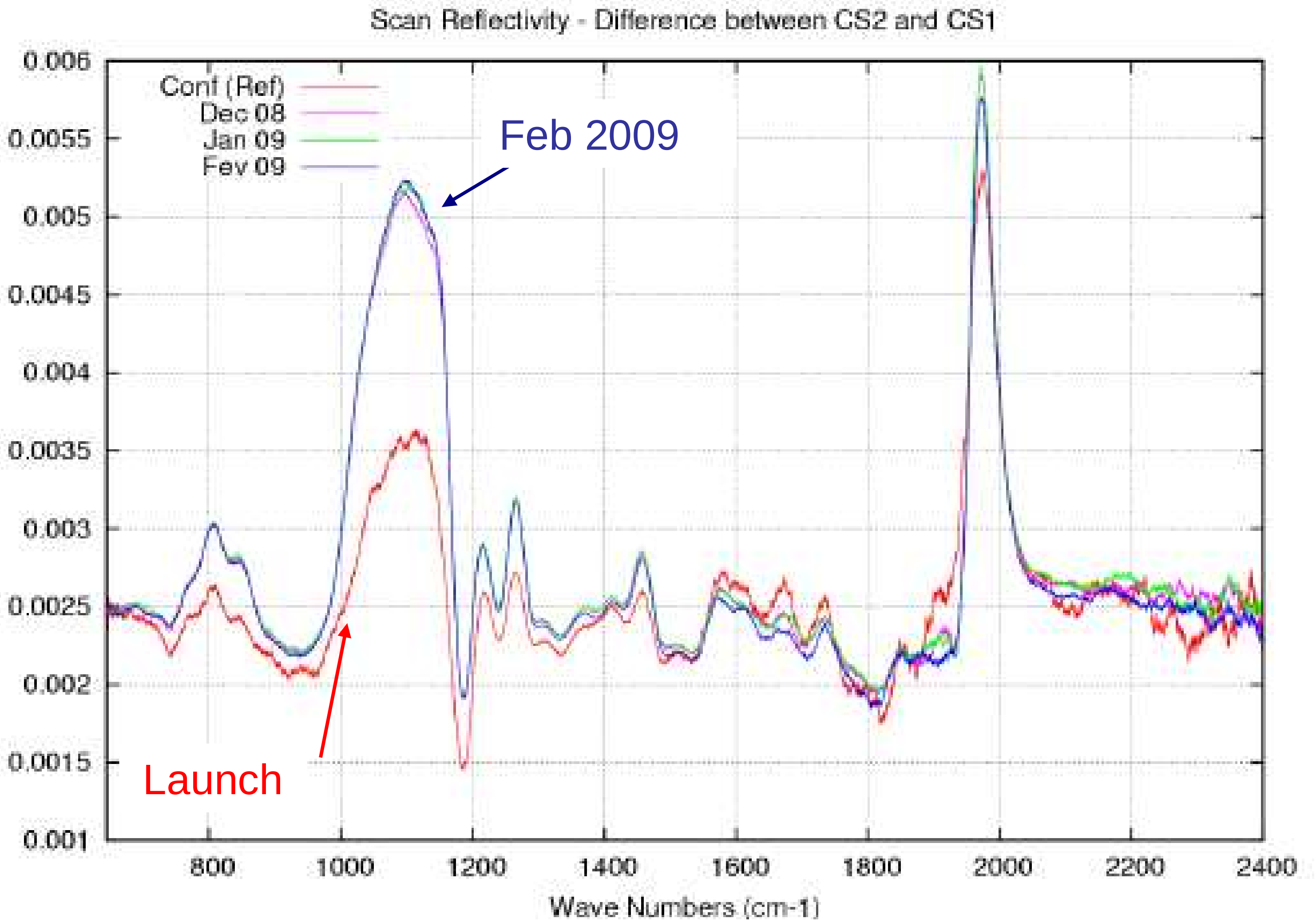
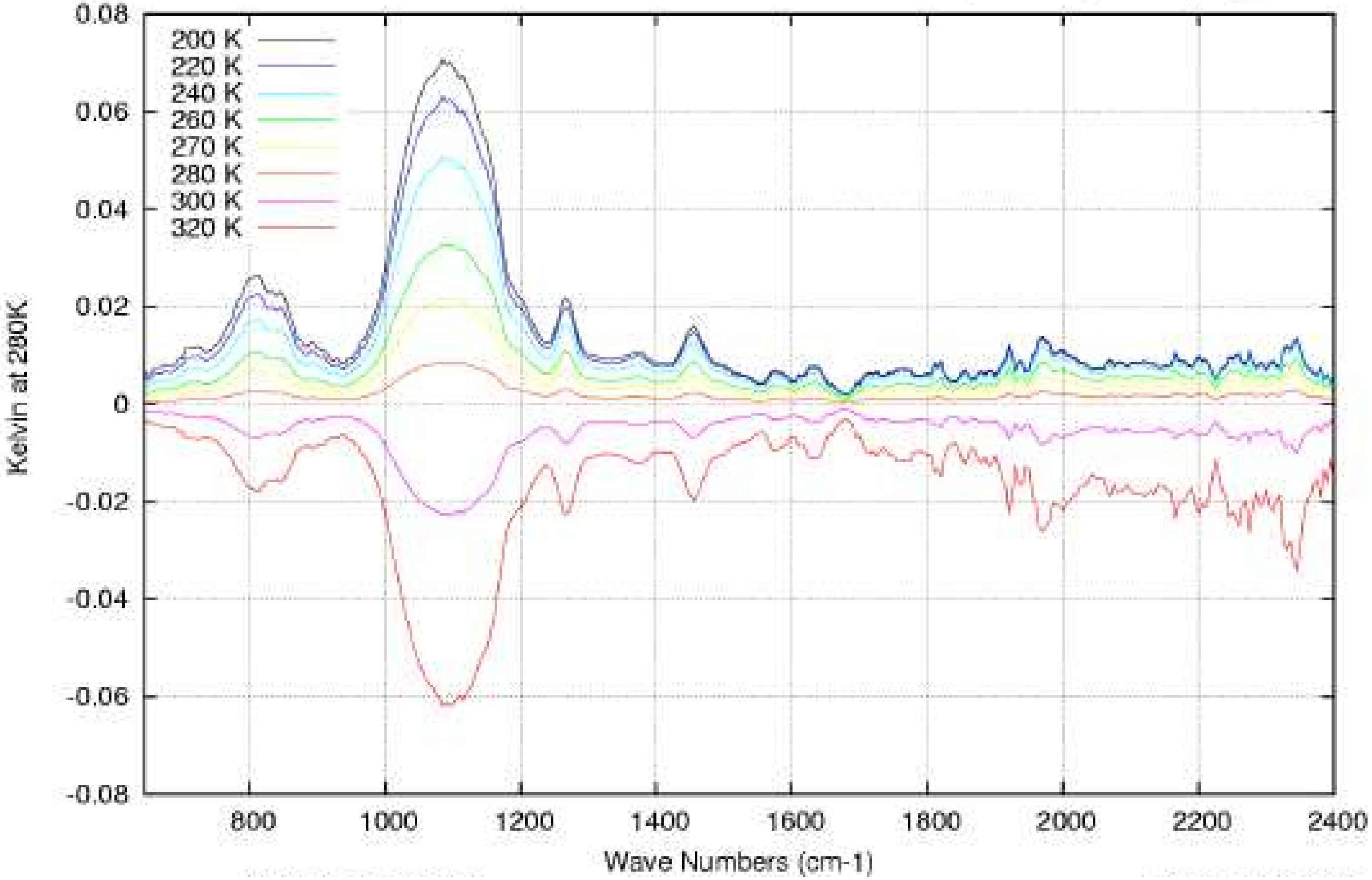
Scan mirror reflectivity : variation with incidence

Monthly Estimation (Ext.Cal.) by using spectra from CS1 (10°) and CS2 (60°) targets



Scan mirror reflectivity

Maximum impact of scan reflectivity variation on radiometric calibration within a scan line for different scene temperature



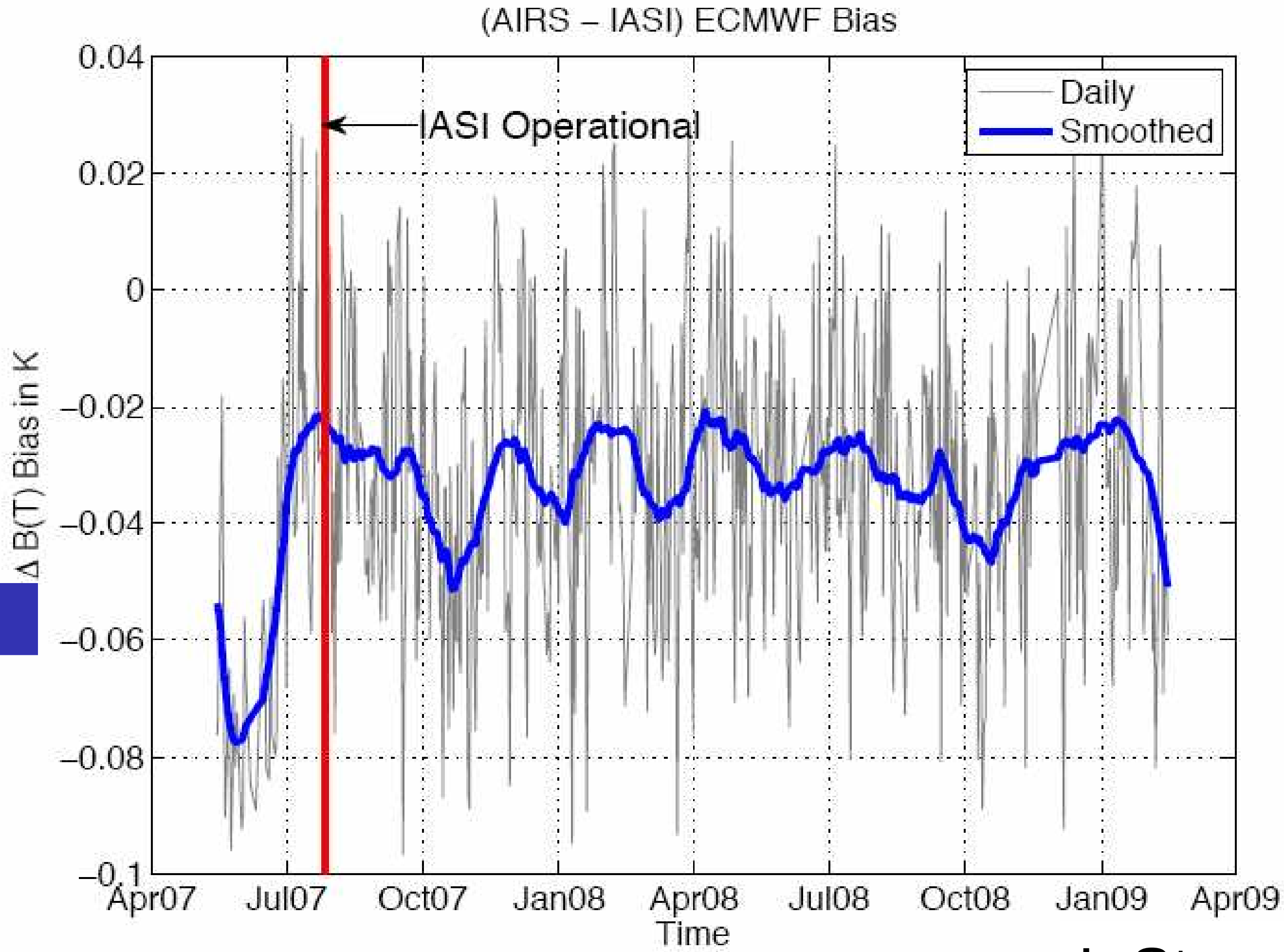
- specification = 0.1K
- Update of scan reflectivity in April 2009 (ground segment)
- Used in Level 1 Processing to correct for this effect (radiometric post-calibration)

AIRS versus IASI Stability

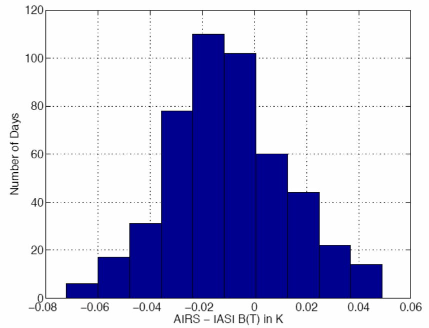
-0.0019K/year ± 0.008K/year (corrected for lag-1 correlation of 0.45)

IASI/AIRS

L. Strow
UMBC



Histogram of Daily Observations



L.Strow (2009)

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Specifications

Specification for IASI spectral calibration :

• A priori knowledge (instrument design) $\delta\sigma/\sigma < 2.10^{-4}$

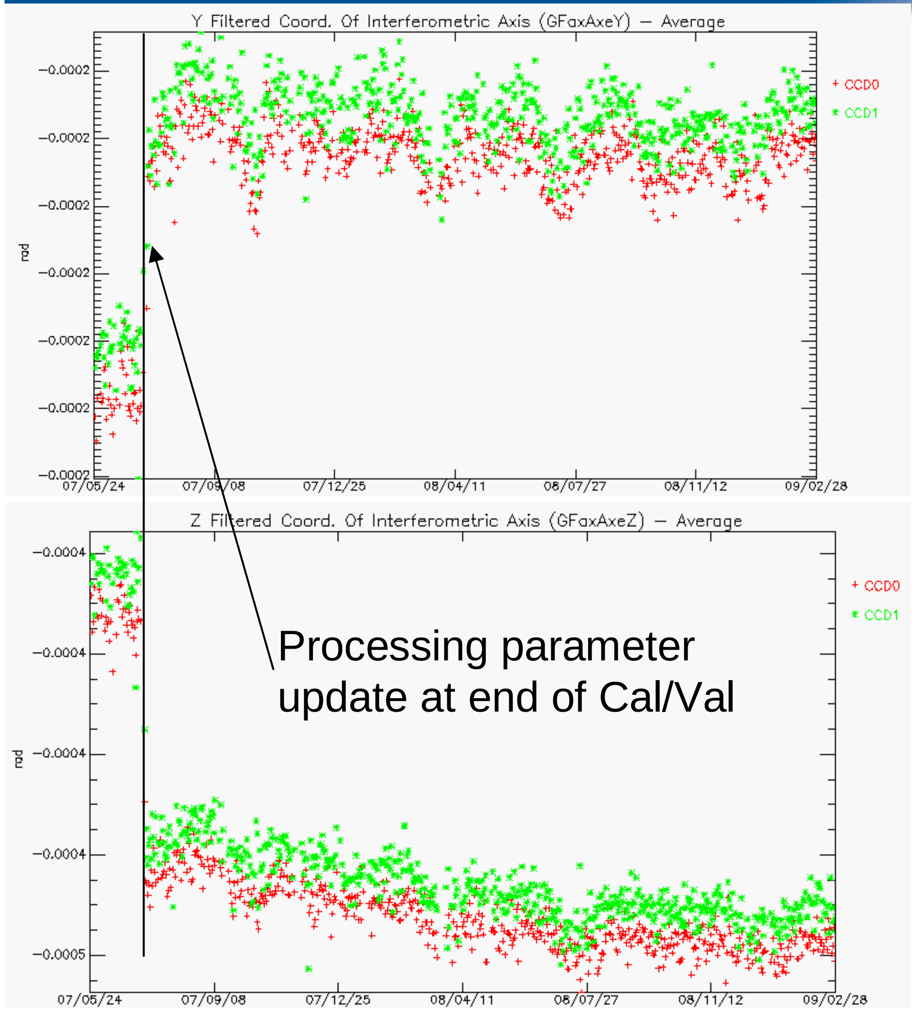
➢ It means $\delta\sigma = 0.5\ cm^{-1} @ 2500\ cm^{-1}$ = IASI spectral resolution (~ 1/3 of the spacing between two CO_2 absorption lines in [2340 - 2380 cm^{-1}] band used operationally for IASI spectral calibration)

• A posteriori knowledge (after on-ground spectral calibration) $\delta\sigma/\sigma < 2.10^{-6}$

➢ It means $\delta\sigma = 0.005\ cm^{-1} @ 2500 cm^{-1}$ = 1% of IASI spectral resolution)

For a good accuracy of IASI spectral calibration, we need a very good knowledge of Instrument Spectral Response Function (ISRF) => model

Interferometric Axis (tilt)



<u>Y position of IA at the end of Cal/Val</u> : Y0 = -159 µrad

<u>Long term drift</u>: $Y-Y_0$= - 8 µrad

<u>Seasonal cycle amplitude</u>: 15 µrad

<u>Z position of IA at the end of Cal/Val :</u> Z0 = -443 µrad

<u>Long term drift:</u> $Z-Z_0$ = - 25 µrad

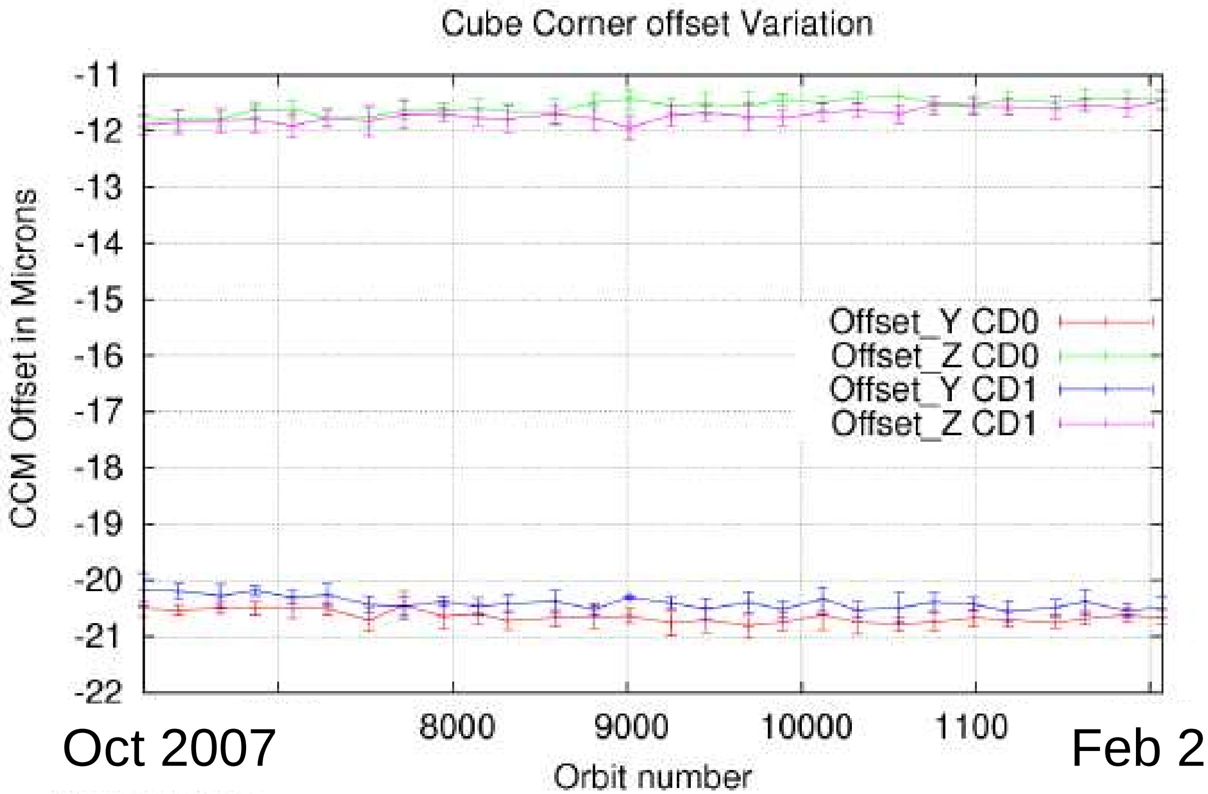
<u>Seasonnal cycle amplitude:</u> 20 µrad

- Total drift with respect to reference position in the spectral database: (+40 µrad,-60 µrad)
- As soon as |Total Drift| < 300 µrad => <u>No spectral database configuration update needed</u>

Cube corner Motion

Velocity : continuous on-board monitoring
+ regular in-depth checks (no evolution)

Position : cube corner offset (shear)

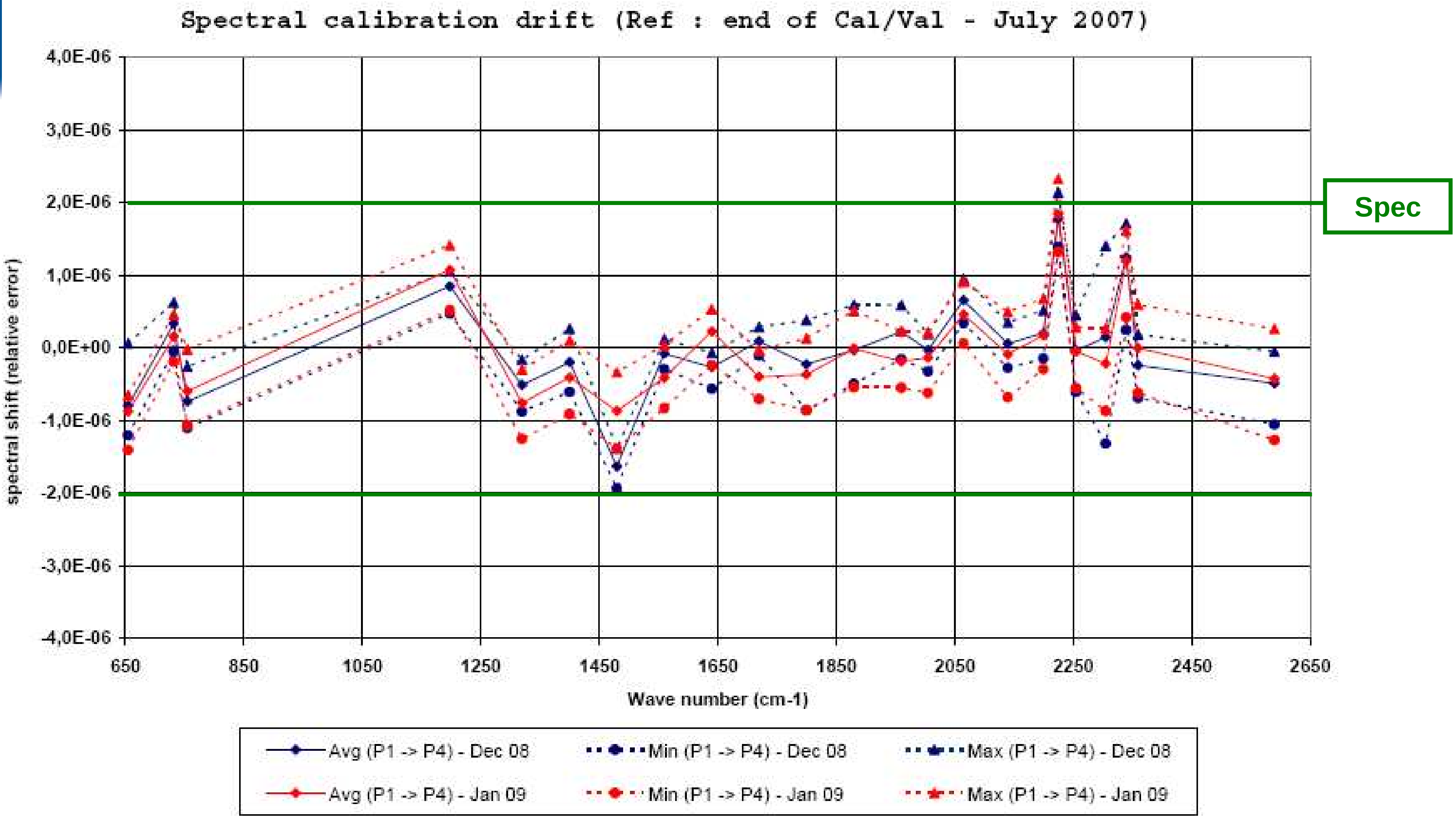


Oct 2007 Feb 2009

Drift < 1µm
(for 2.5 years)

=> No spectral database configuration update needed (up to 4 µm)

Spectral calibration monitoring



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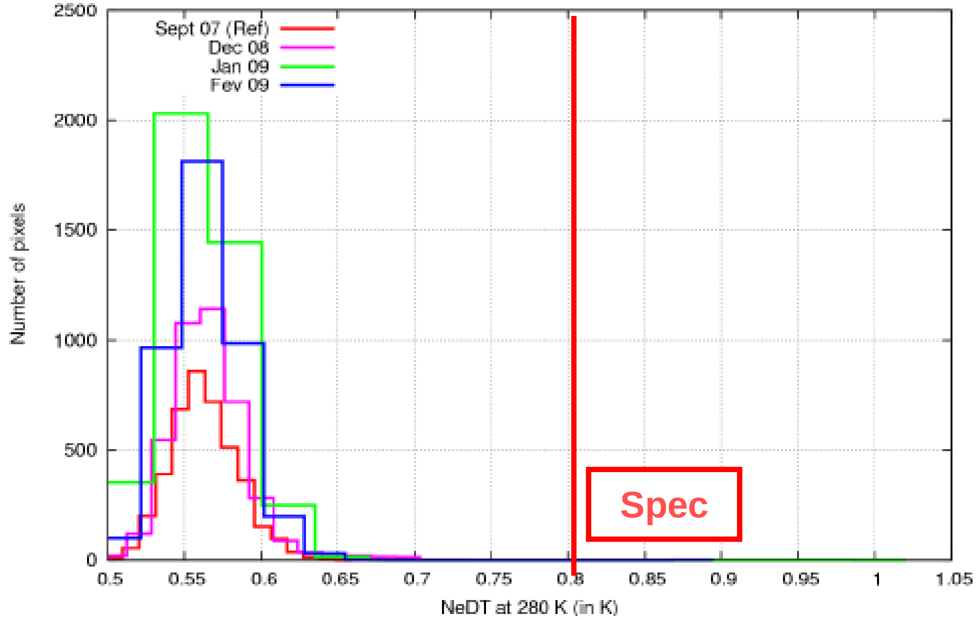
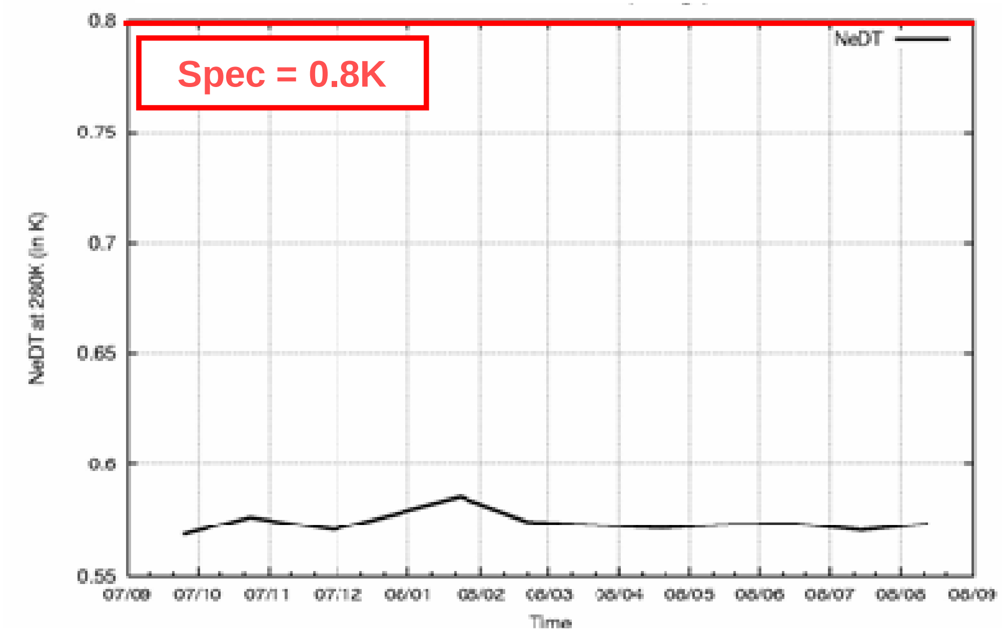
Integrated Imager Subsystem (IIS) noise

Geometry of IASI sounder controlled with respect to the companion imager (IIS)

Temporal evolution of IIS noise (histogram with all the pixels)

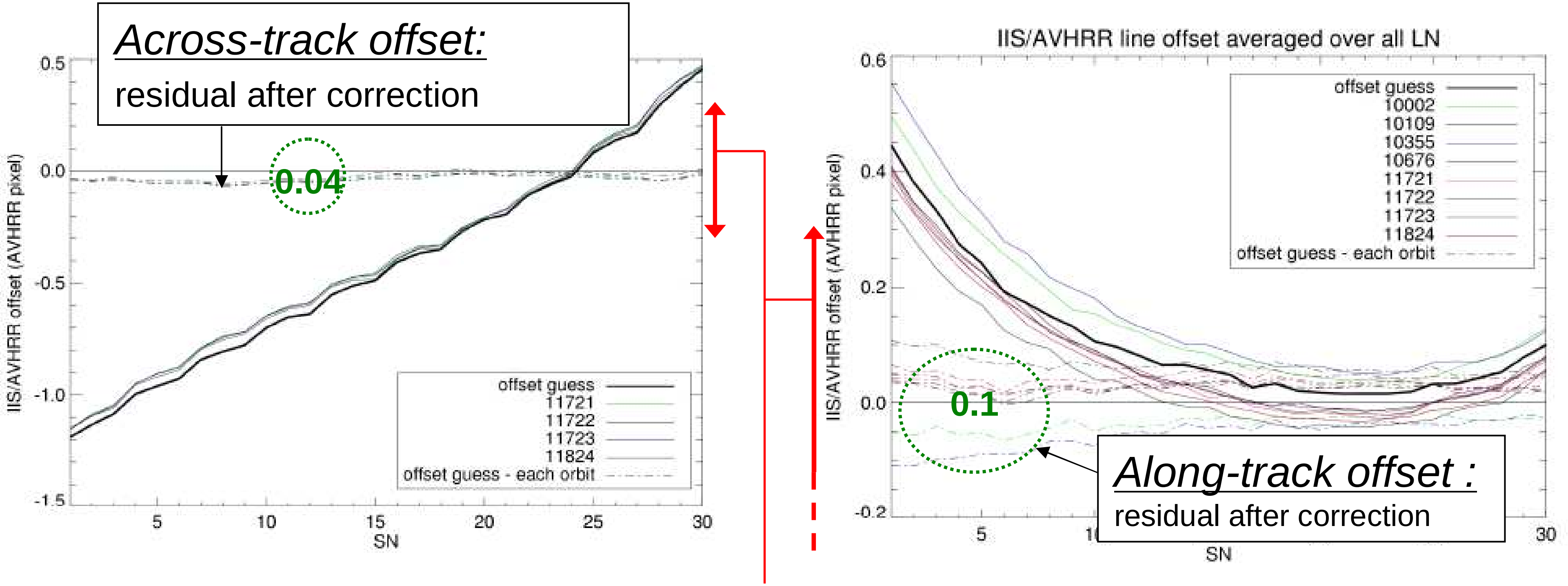


Temporal evolution of IIS average noise



• <u>Stable</u> (0.57K) and widely within the specification (0.8K)

• IIS offset in AVHRR raster : along-track (0.1 AVHRR pixel), across-track (0.04 AVHRR pixel)
• IASI pixel centre localisation accuracy in AVHRR raster ~ 100m

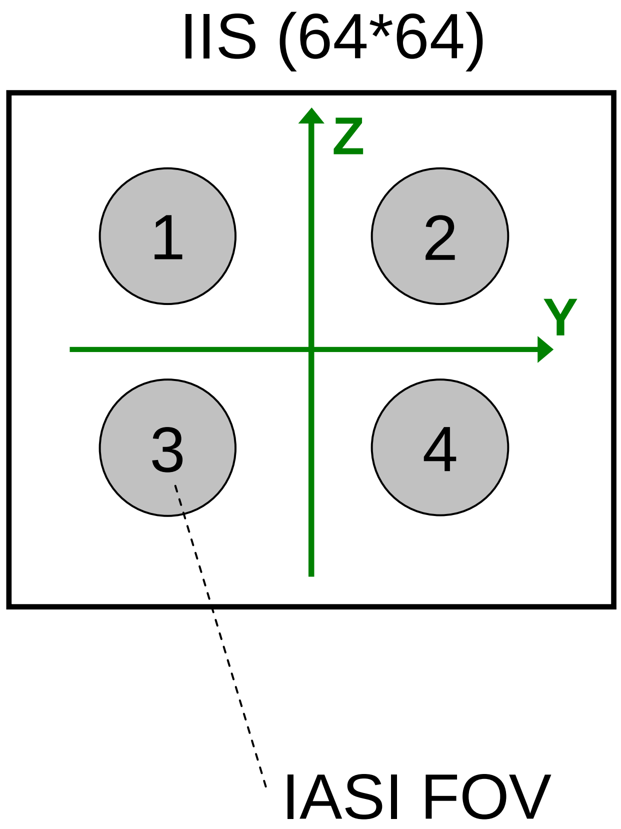


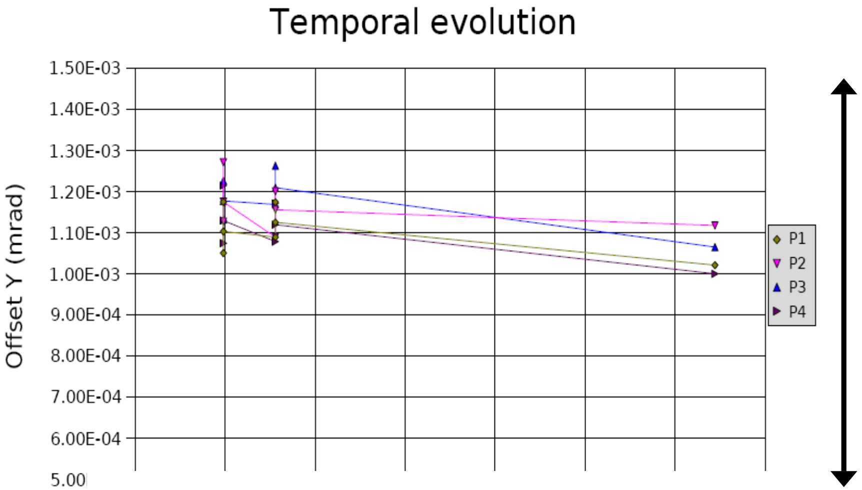
Very good stability since the end of the Cal/Val

→ Health check for scanning mirror mechanism

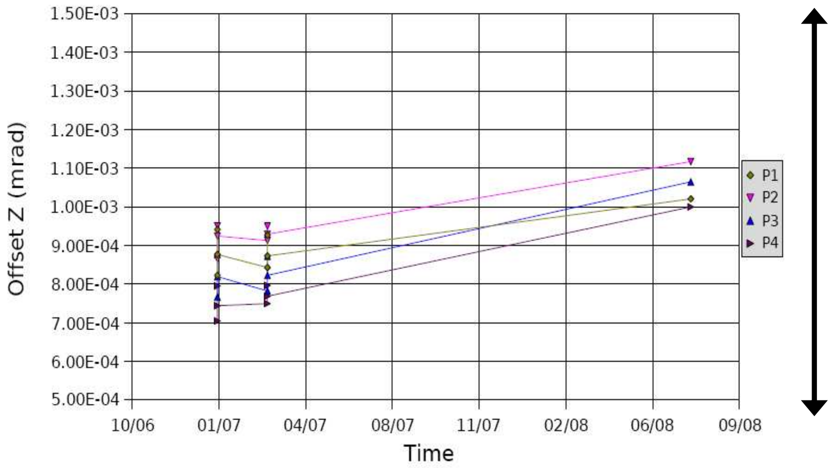
Method:

- Selection of a continuous sequence of scenes with important contrast (coast line, fractional clouds)
- Spectral integration of IASI spectra in IIS spectral band => $U_{ref}(i)$
- Spatial integration of IIS pixels in IASI FOVs for j different positions of IASI FOVs => U(i,j)
- Correlation between U_{ref} and U series for all j
- Look for the maximum of correlation => IASI FOVs positions in IIS



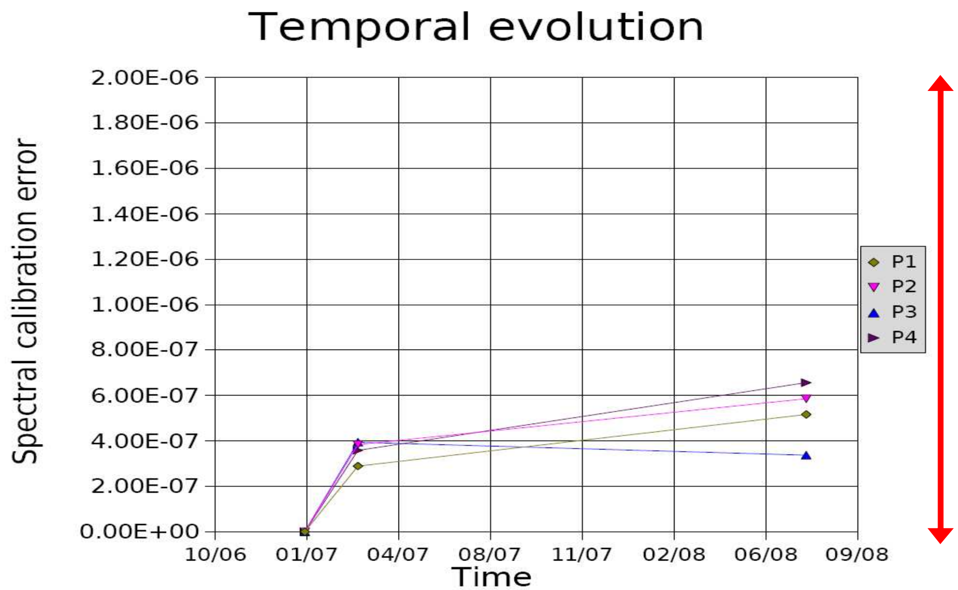


- Specification = +/- 0.8 mrad
- Target = +/- 0.5 mrad



=>

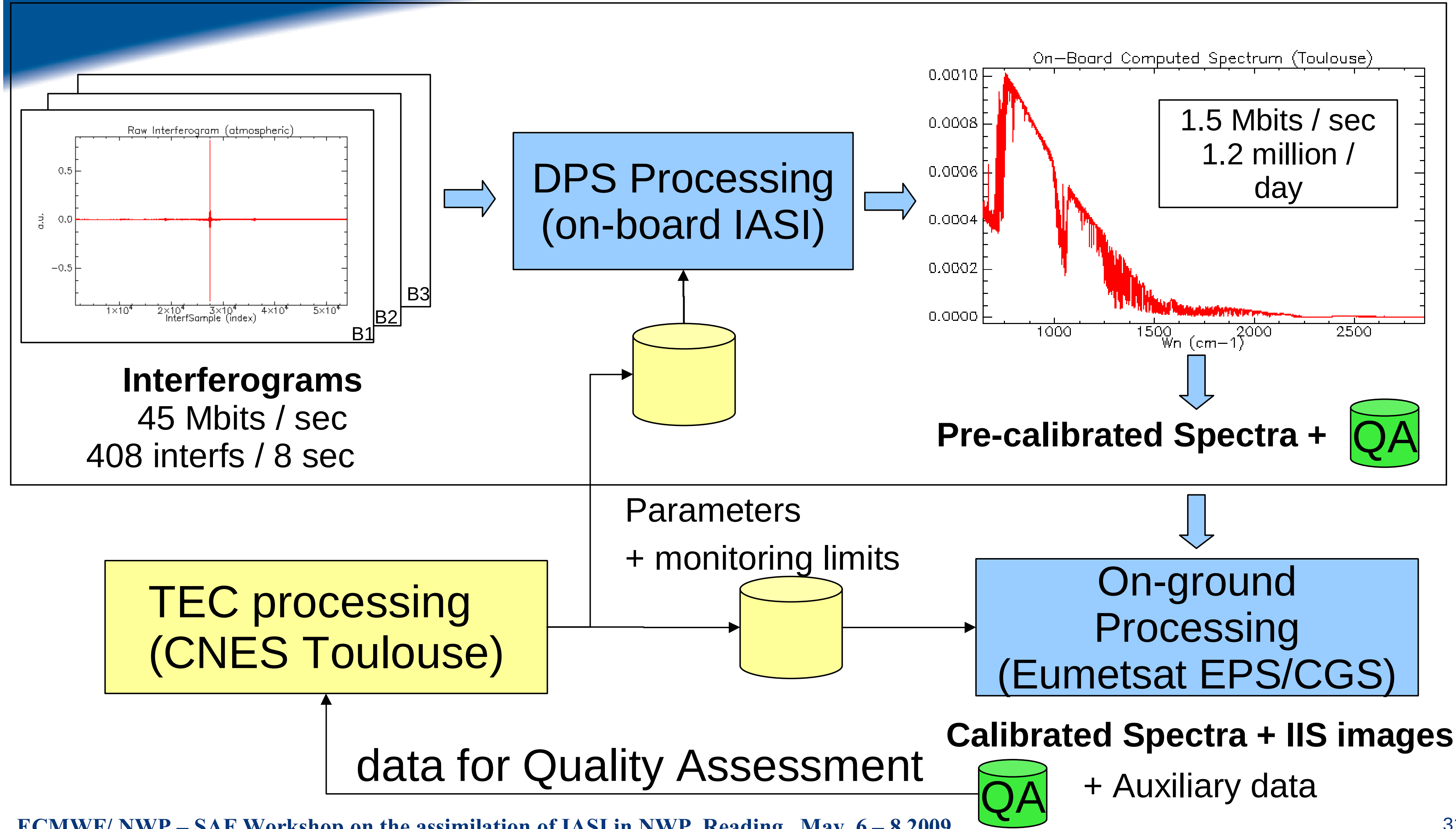
Effect of a IASI FOV offset on spectral calibration quality



Specification: $\Delta\sigma/\sigma < 2.10^{-6}$

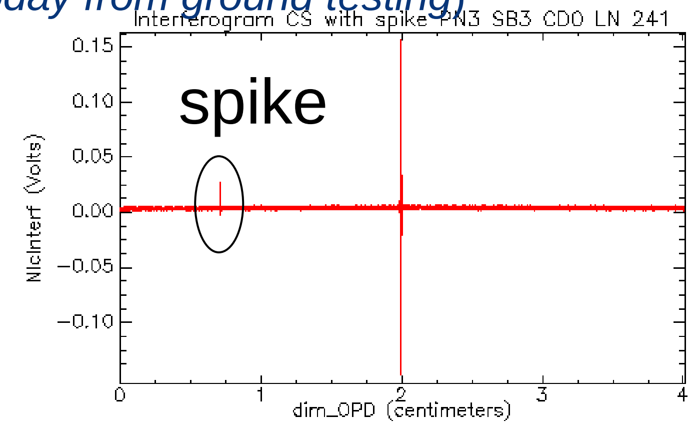
Outline

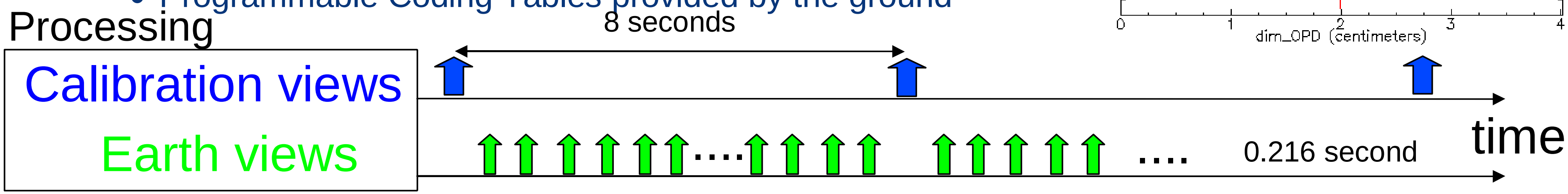
Overview of IASI processing



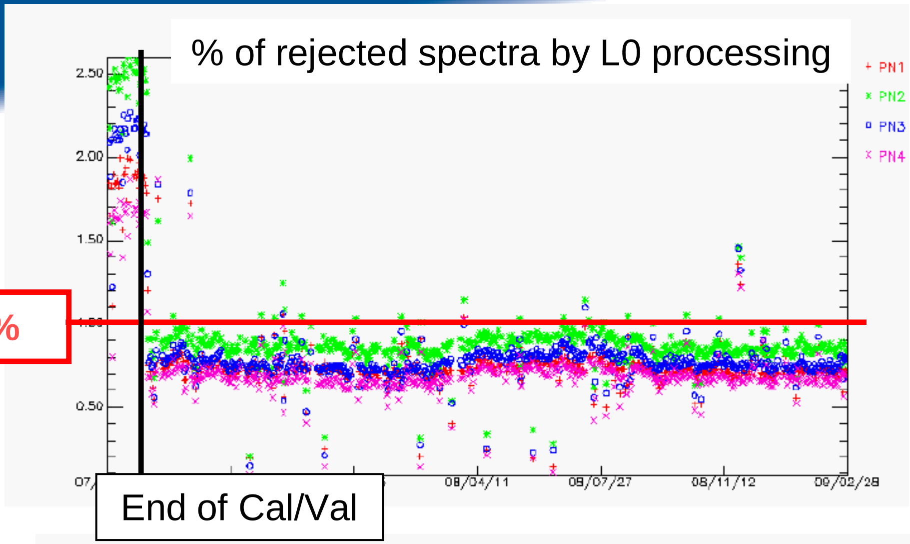
Overview of on-board processing

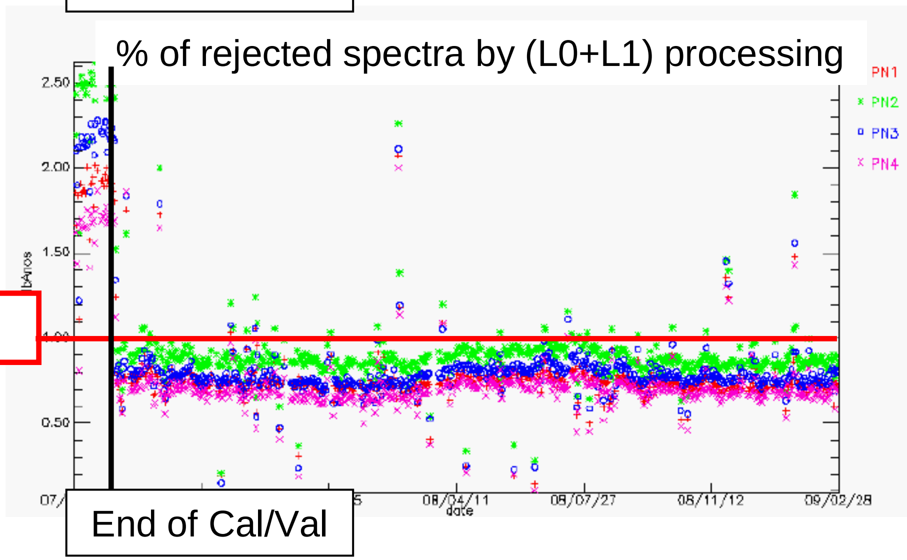
- **8 seconds cycle**
  - **30 views (times 4 pixels) for the Normal Op. Mode (27 in Ext.Cal Mode)**
  - **2 x 2 calibration views : hot (Black Body), cold (space), 2 scanning directions**
- **Main functions**
  - **Preprocessing of the interferograms (raw measurements of the interferometer)**
    - Integrity checks (spikes detections, etc.) : limits provided by the ground
    - Non-Linearity correction : tables provided by the ground (*today from ground testing*)
  - **Computation of calibrated spectra (radiometry)**
    - Internal tables used by calibration updated every 8 sec
      - Reduced spectra — Initial values provided by the ground
      - Integrity checks : limits provided by the ground
  - **Spectra encoding to reduce data rate**
    - Programmable Coding Tables provided by the ground





Overall quality of L0/L1 data





	PN 1	PN 2	PN 3	PN 4
Total % of rejected spectra	**0.83**	**1.01**	**0.88**	**0.77**
% of rejected spectra by L0 processing (on-board)	**0.81**	**0.99**	**0.86**	**0.75**

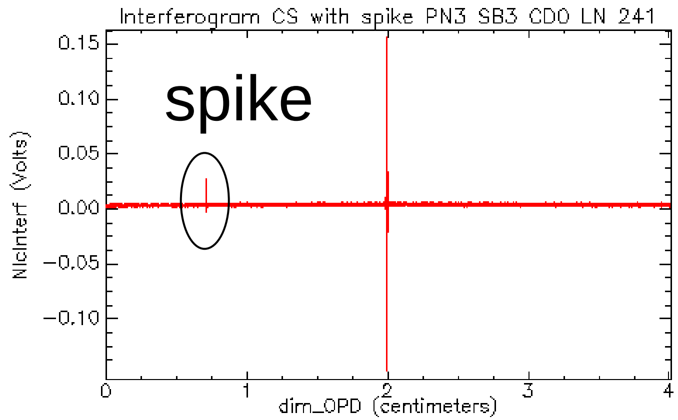
- In NOp, 99% of good quality spectra
- Ground segment is very reliable

Stable since end of Cal/Val

Main contributors to rejected spectra

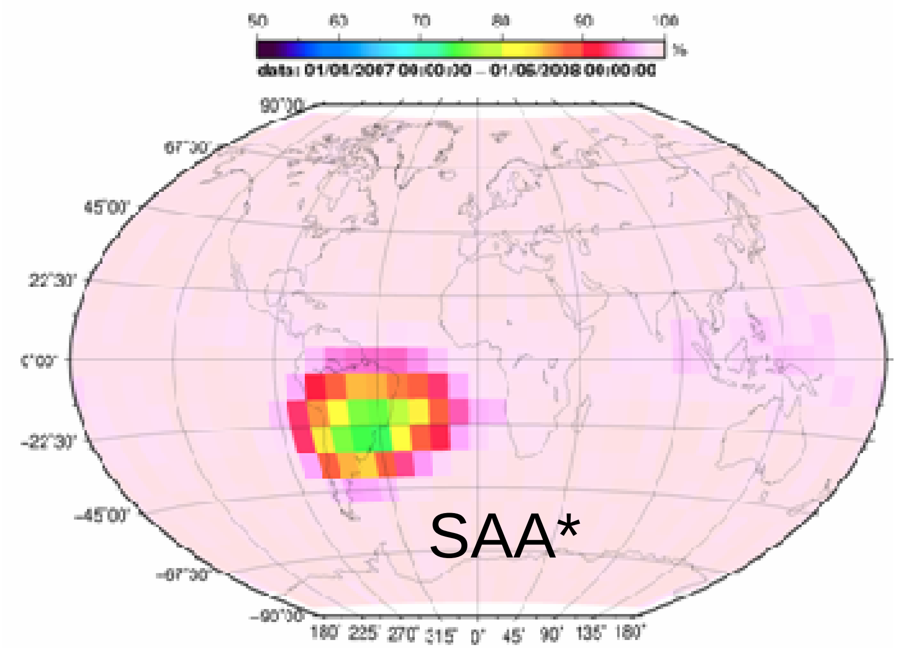
	Pixel 1	Pixel 2	Pixel 3	Pixel 4
ON-BOARD				
% Spikes (mainly in B3)	0.55*	0.55*	0.55*	0.55*
% NZPD calculation failure	0.15	0.29	0.24	0.15
% radiometric calibration failure	0.02	0.02	0.02	0.02
GROUND				
% Over/Underflows	0.02	0.02	0.02	0.02
TOTAL	0.74	0.88	0.83	0.74
All other parameters	0.09	0.13	0.05	0.03

* Part of « DAY-2 » evolutions



Spikes (Impact of protons on detectors)

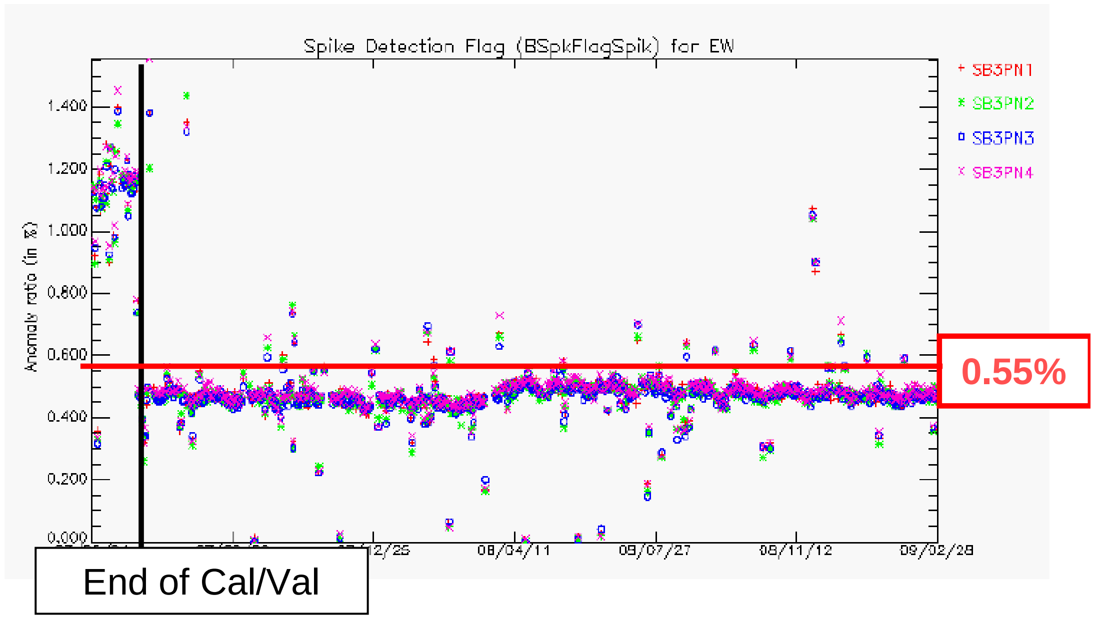
Geographical distribution



Courtesy L.Fiedler (EUMETSAT)

*South Atlantic Anomaly

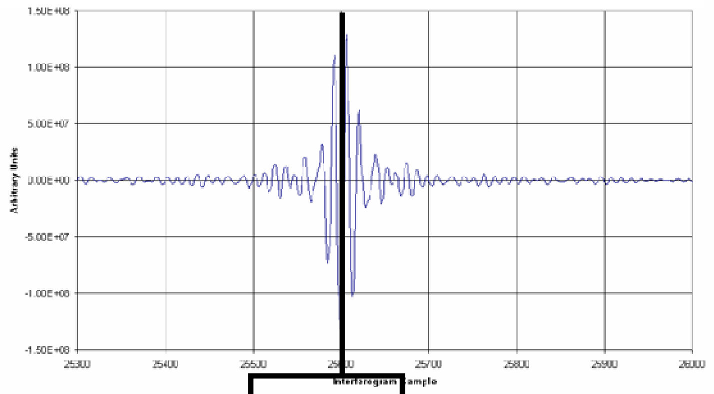
Temporal evolution



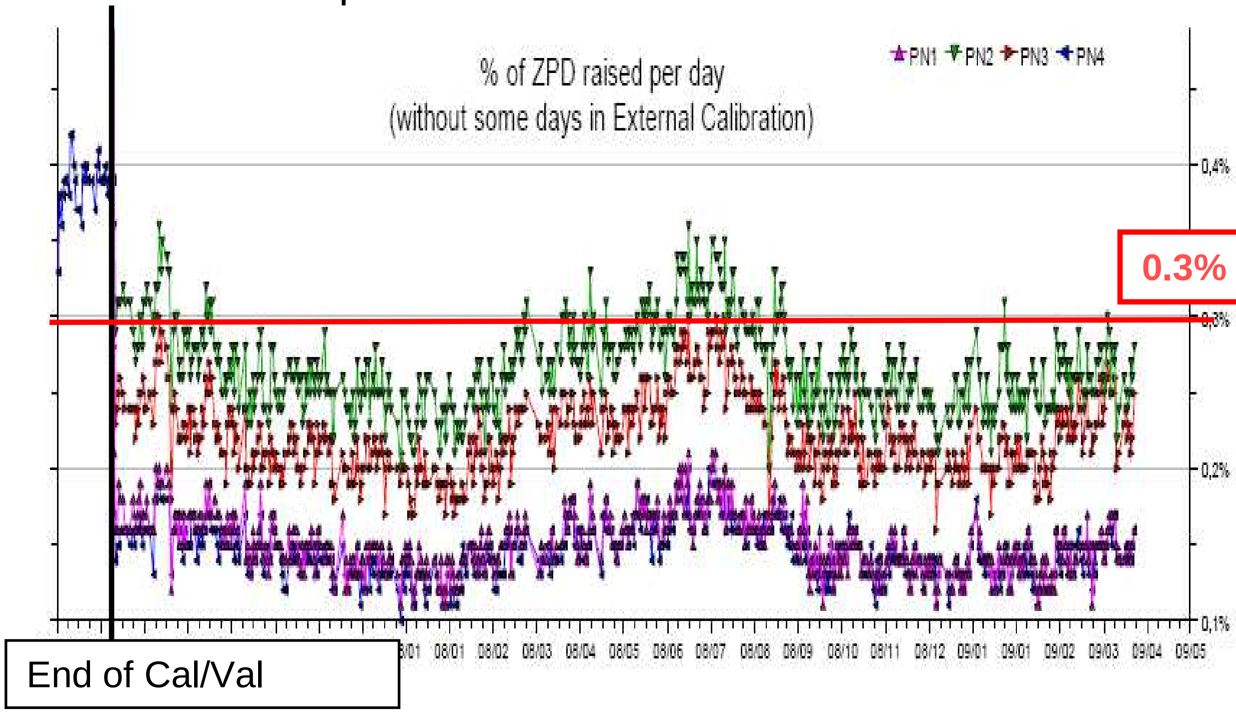
Stable since end of Cal/Val

ZPD ("Zero Path Difference")

IASI Interferogram



Temporal evolution of NZPD detection failure

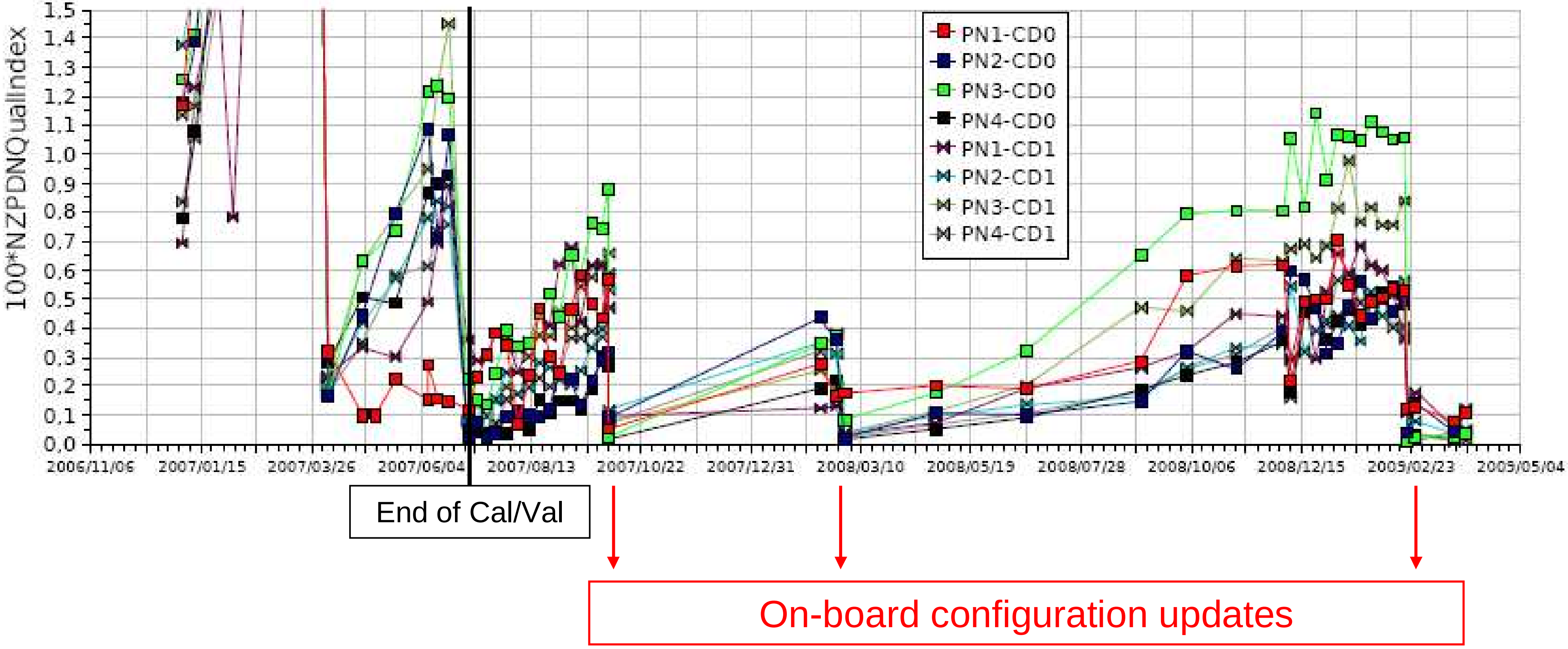


NZPD = sample number at ZPD (calculated by algorithm)

Its knowledge and stability over a calibration period (80s) are necessary for a good radiometric calibration of spectra

Stable since end of Cal/Val
(slight seasonal variation of 0.1% => cold scene)

One of the most important monitoring of on-board processing : it ensures that radiometric calibration of IASI spectra remains good after a re-initialization of on-board configuration (typically after a mode transition NOp ↔ EC)



Lessons learned (1/2)

- **Instrument design provides good stability**
  - **In-flight behavior very close to the one measured on-ground**
  - **Optical bench accurate thermal control (at ambient temperature)**
    - Dimensional stability (hence spectral calibration stability)
    - Radiometric calibration stability
    - But effect of “warm” optical bench on noise in band B3
  - **Modifications after PFM ground testing against ice contamination**
    - In-flight confirmation of good results obtained on ground
    - Contamination rate continuously decreasing. BUT not very fast (in particular MLI keep desorbing for very long time in orbit)

- **Instrument design provides good testability**
  - **External Calibration Mode**
  - **Verification Data Selection (raw interferograms)**

Lessons learned (2/2)

- **Integrated Imager very valuable**
  - **Easy registration with sounder and AVHRR**
  - **Very useful for test scenes selections**
  - **Provide images for calibration views (CS1,CS2, ... moon)**
  - **Provide images during the ground testing**

- **On-board processing working flawlessly**
  - **All on-board monitoring algorithms proved useful to cope with real data**
    - Spikes detection, Reduced Spectra and Radiometric Calibration integrity checks

Conclusions

✓ After 30 months in orbit

- IASI is performing very well
  - **no redundancy used**
  - **all mission requirements are met : both instrument and processing**
  - **the instrument is extremely stable : radiometry, spectral, geometry**
  - **mechanisms (Cube Corner, Scan) show no evolution in orbit**
  - **radiator (passive cooling) show no evolution in orbit**
- There is still a lot of science to be done with IASI data
  - **Meteorology and Climatology**
  - **Atmospheric chemistry**

✓ During the routine phase, IASI Technical Expertise Center (IASI TEC in CNES premises in Toulouse) takes care of :

- In-depth Performance monitoring, Processing parameters updating

✓ In parallel with the operational monitoring performed by the EUMETSAT EPS/CGS teams :

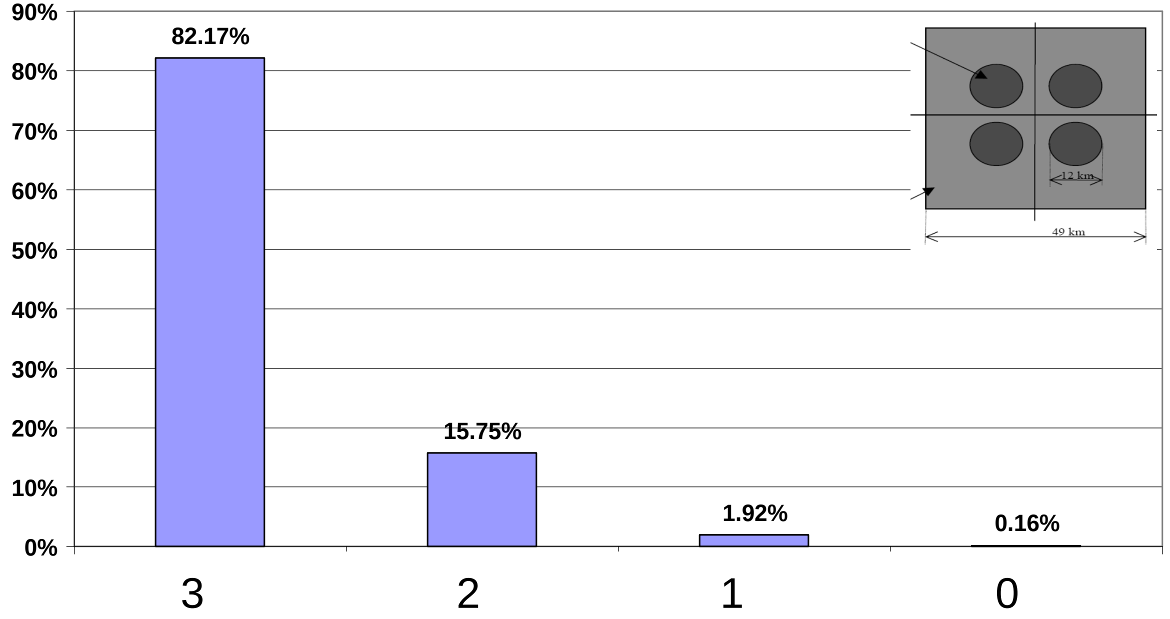
- Near Real Time PDU analyses, Radiance monitoring

Thank you for your attention!

- **Visit our web sites :**
  - **www.cnes.fr**
  - **www.smsc.cnes.fr/IASI**

BACK-UP

Spectra affected by Spikes



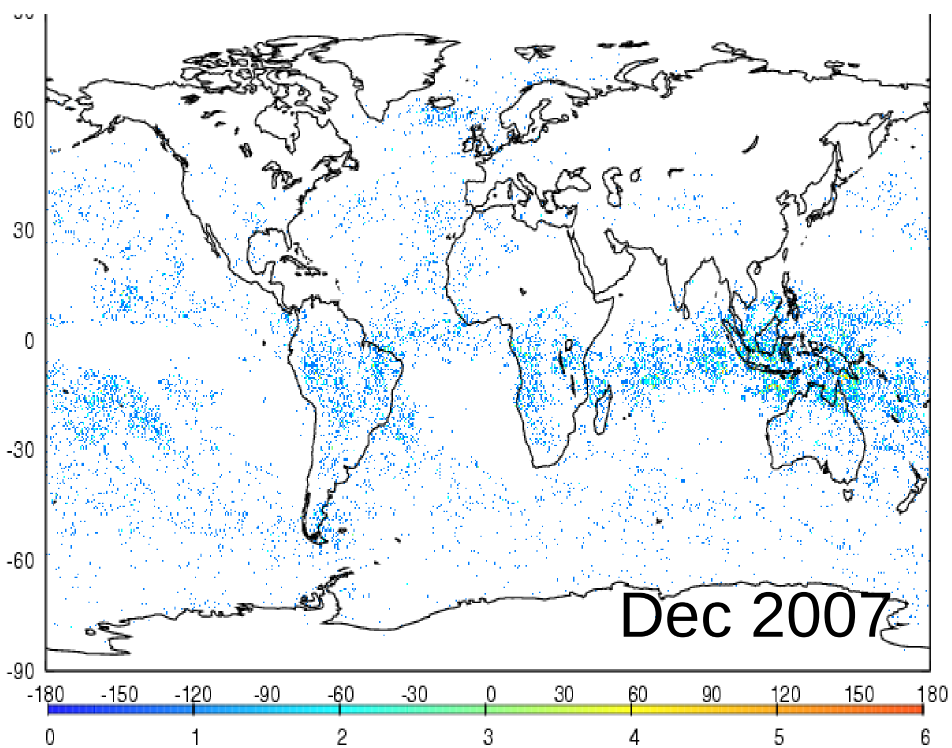
Number of IASI spectra available for each sounding in case of a spike

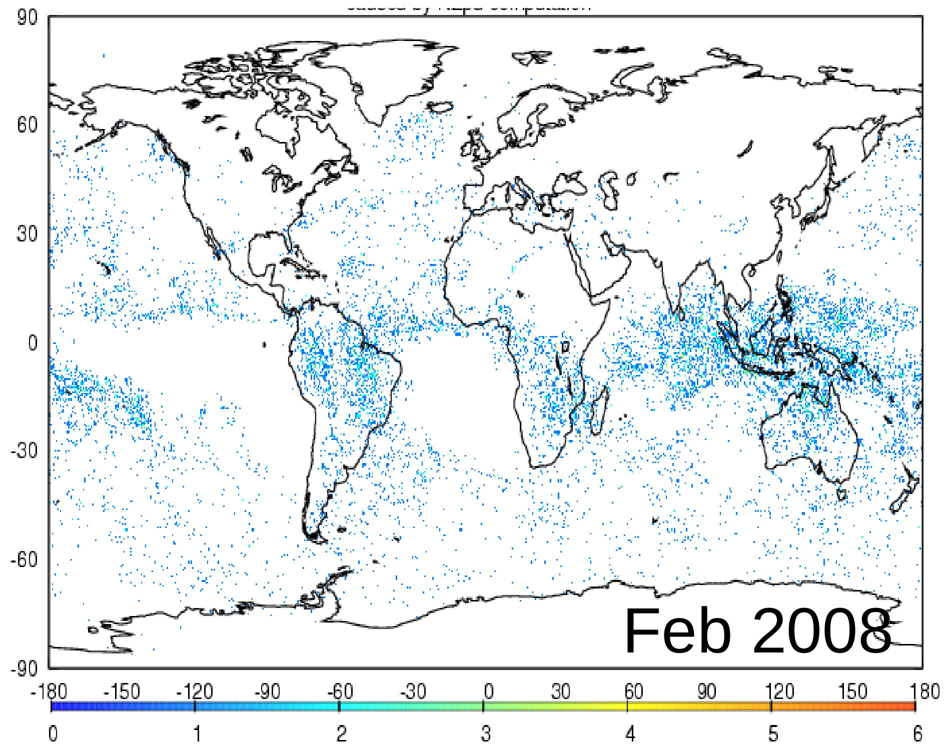
- 98.5 % of earth views (groups of 4 pixels) are not affected by spikes
- Among the 1.5 % of earth views affected by spikes
  - Mainly over the South Atlantic Anomaly (SAA) in band B3
  - 82.2 % have more than 3 spectra available
  - 97.9 % have more than 2 spectra available
  - 99.8 % have more than 1 spectrum

- Suggestion for short term
  - since the 4 IASI pixels are not assimilated, a dynamic selection of the selected pixel would increase drastically measurements availability.
- For long term
  - Day 2 evolution of ground processing : make spectra available for bands B1 and B2 when a spike occurs in B3.

Spectra rejected by NZPD calculation failures (1/2)

- A small fraction of spectra are not available because of not computed NZPD by on-board processing
  - Less than 0.3 % for all pixels
  - Stable since end of Cal/Val (slight seasonal cycle / amplitude ~ 0.1%)
- Geographic repartition
  - 1 or 2 occurrences max per month per box of 0.5 x 0.5 deg



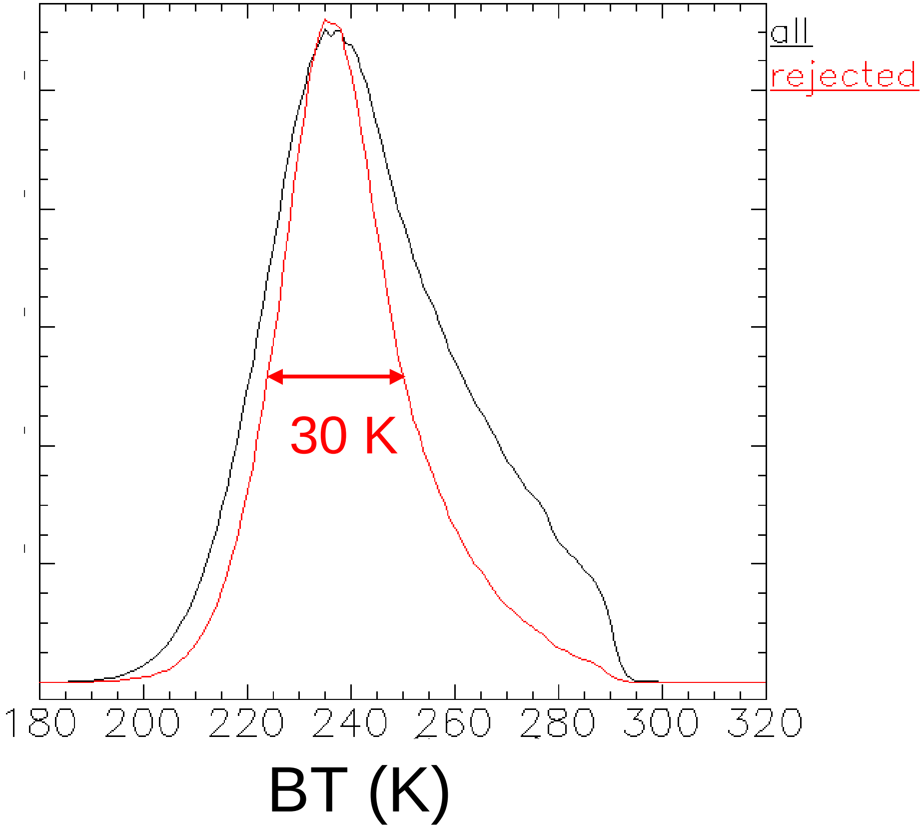


Spectra rejected by NZPD calculation failures (2/2)

**Brightness Temperatures from th
IIS imager**

Black curve : Histogram of BT in the vicinity of rejected spectra (about 1/4 c the IIS image)

Red curve : Histogram of BT in the IAS footprint for rejected spectra



- **Conclusions**
  - **Affected pixels : 0.3 %**
  - **Histogram of rejected pixels : FWHM = 30 K**
  - **Close shape of the 2 histograms → no significant impact on climatology**