IASI In-Orbit Experience

CLARREO workshop, University of Maryland,

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Presentation given in the name of many people and agencies involved in

IASI (Infrared Atmospheric Sounding Interferometer)

This presenter (co-chairman with J. Taylor of the **I**ASI **S**ounding **S**cience **W**orking **G**roup or **ISSWG**) is a « speaker » for all of them. In particular **Denis Blumstein** from **CNES**, responsible for the IASI L1 Cal/Val team provided plates presented during the 2nd Meeting of GSICS Research Working Group at EUMETSAT, Darmstadt, Germany on 12-14 June 2007

CNES Team

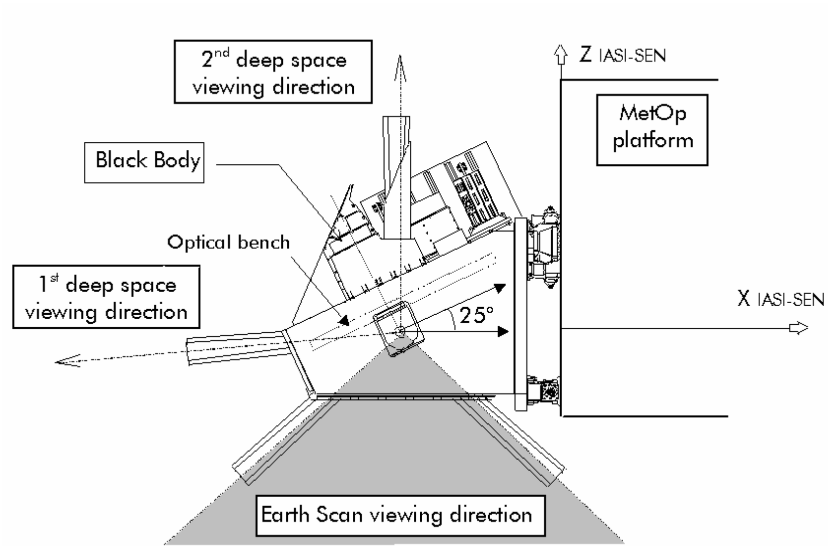
- TEC
  - I.Gaudel
  - C.Baque
  - R. Bach
  - D. Saïd
- Cal/Val
  - B.Tournier
  - F.Cayla
  - R.Fjortoft
  - T.Phulpin
  - C.Buil
  - D.Coppens
  - D.Blumstein

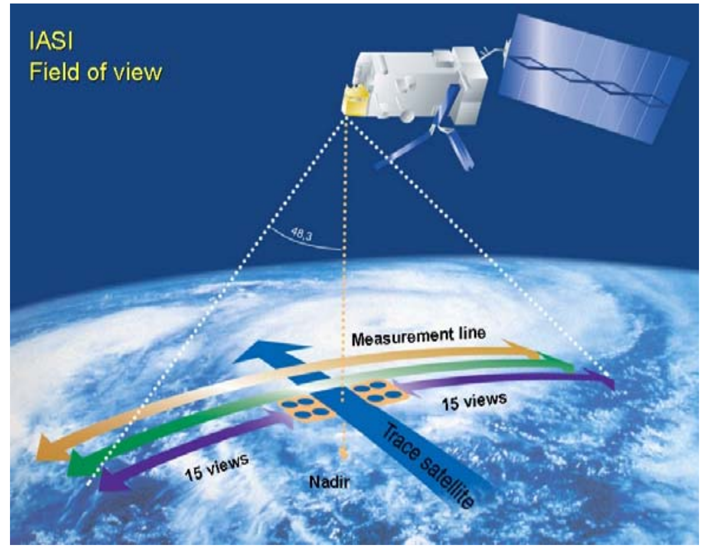
TEC = Technical Expertise Center at CNES in Toulouse

TEC is preparing tables of instrument parameters to be uploaded to the IASI instrument by the core EPS ground segment as needed

Thanks to Florent Prel for his work on AIRS data

Overview of the instrument





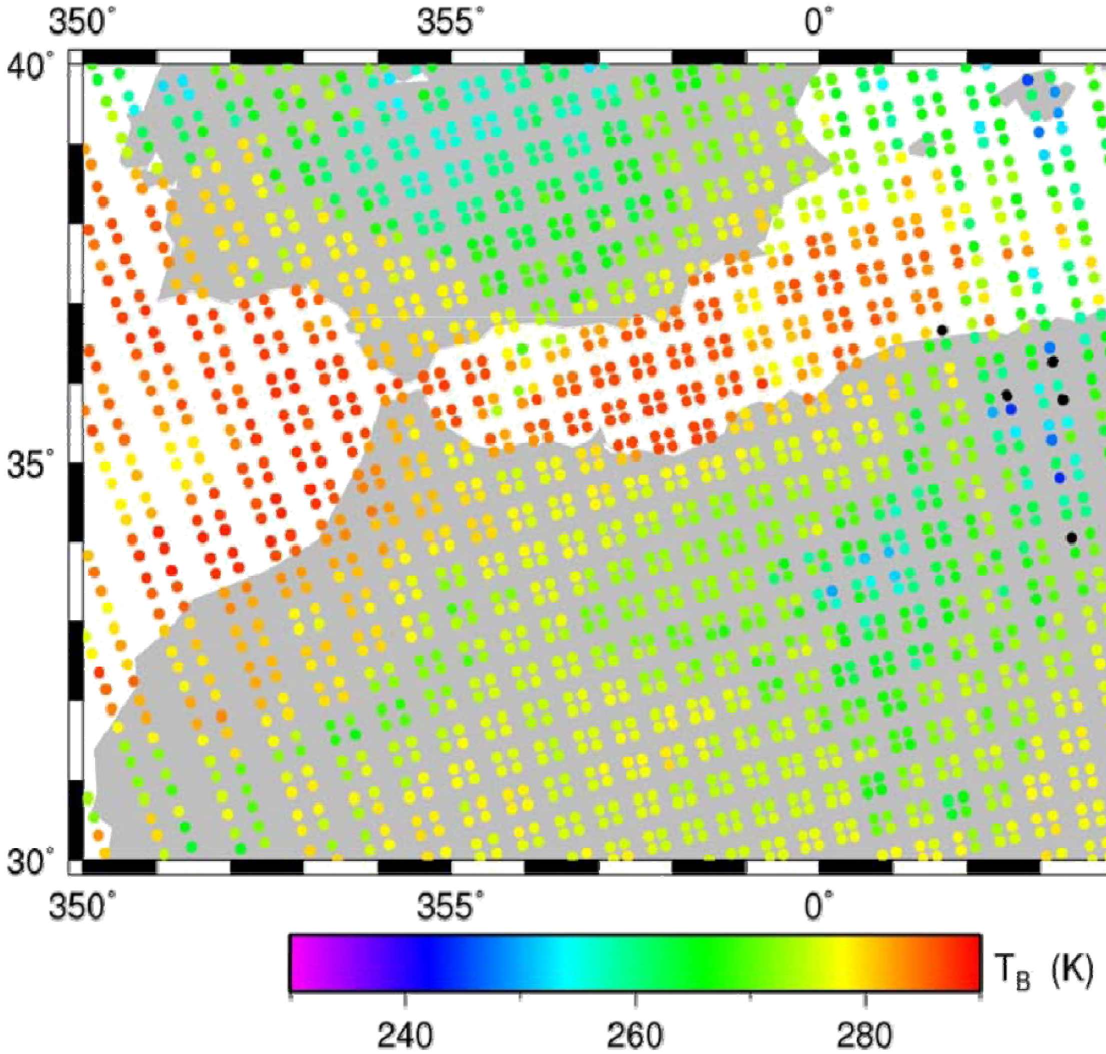
- Normal Operation (N. Op) mode : 30 ground footprints (4 pixels each) every cycle (8 sec)

2 features of the instrument will be used intensively for Cal/Val activities

- External Calibration (E. Cal) mode ➔ Viewing dir. (i.e. Scan Position : SP) remains fixed
  - On-board radiometric calibration is performed as in Normal Operation mode
  - Fixed position can be changed at each cycle : SP=1..30 (30 Earth Views or EV), BB, CS1, CS2 or SM (Scan Mirror)
- Verification Data Selection (in N. OP mode and in E. Cal mode)
  - 1 raw interferogram (over 408) is available in scientific telemetry every 8 sec
  - Pixel Number, Step Number and Spectral Band (PN, SN, SB) which define this interferogram can be modified every 8 sec (periodic pattern modified by TC)

OPD_{max} = 2 cm, level 1c 0.5cm^{-1} resolution, 0.25 cm^{-1} sampling

IASI spatial sampling



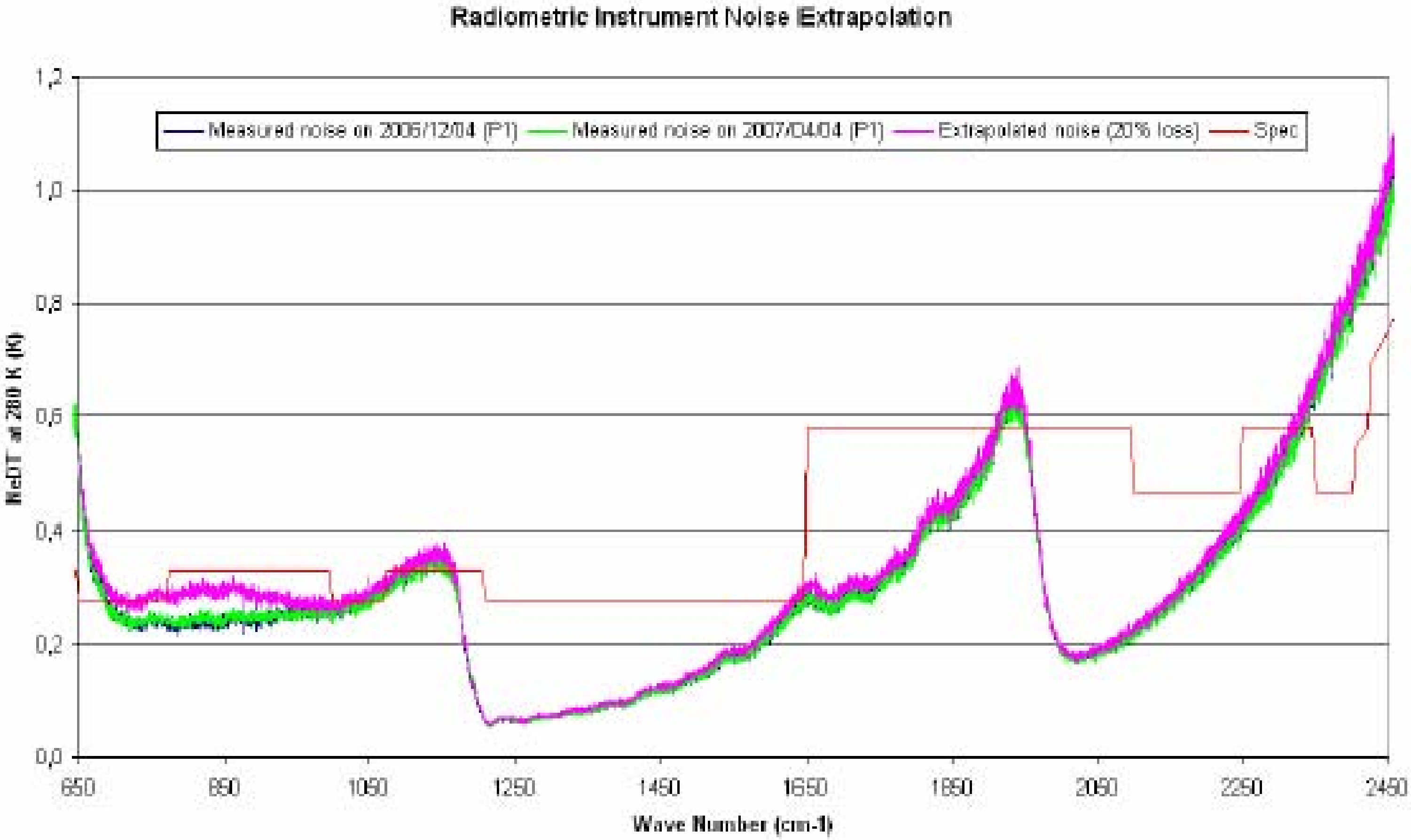
Schlüssel and Hultberg, 2007

- Measured Performances
  - Radiometry
  - Spectral
  - Geometry and IPSF
  - Field Of View
  - First feedback from end users (NWP)
- Operational aspects
- Summary
  - Performances versus requirements

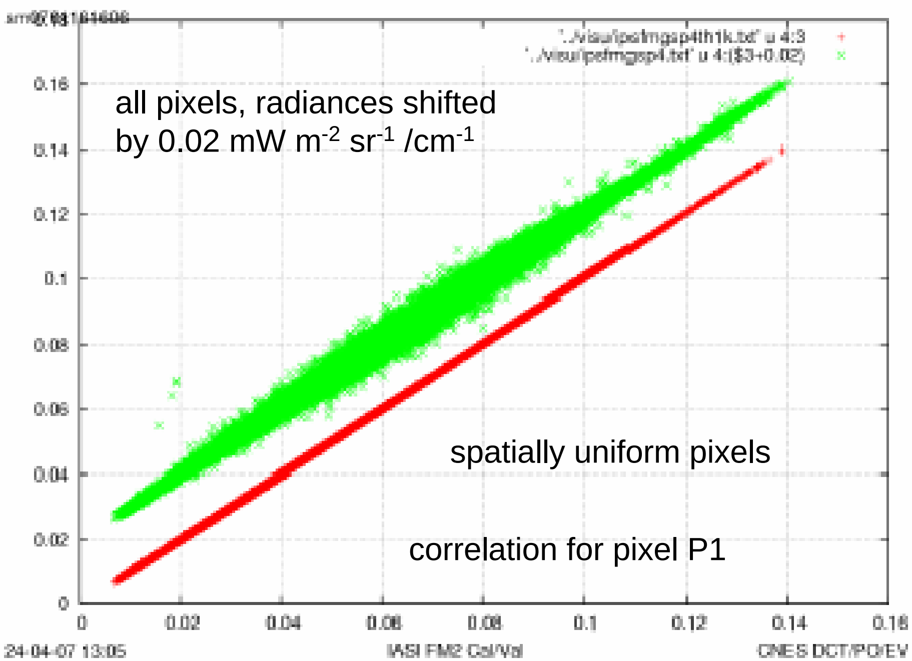
Radiometric Performances

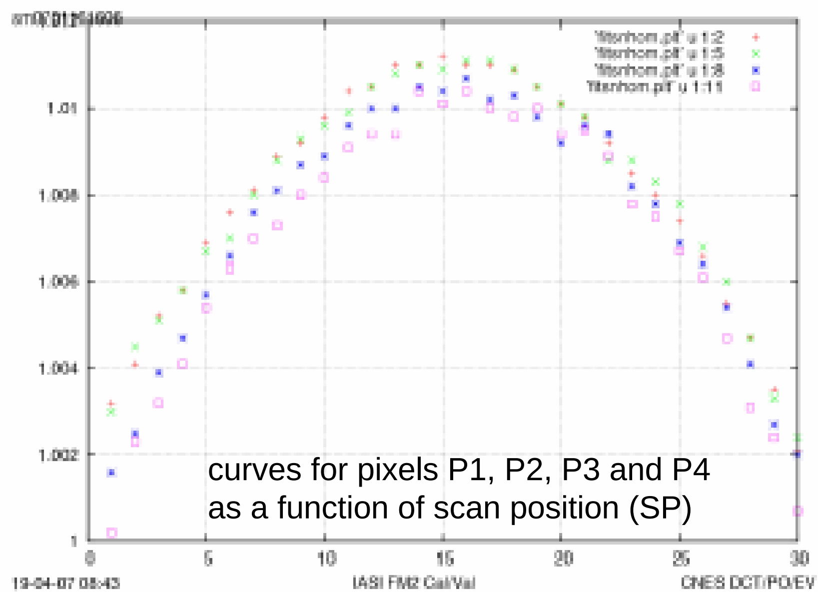
Radiometry — Noise

- Measured on Black Body (293 K) specified at 280 K
- Very stable : < 7 % loss from Dec 2006 to April 2007 (peak at 850 cm-1)



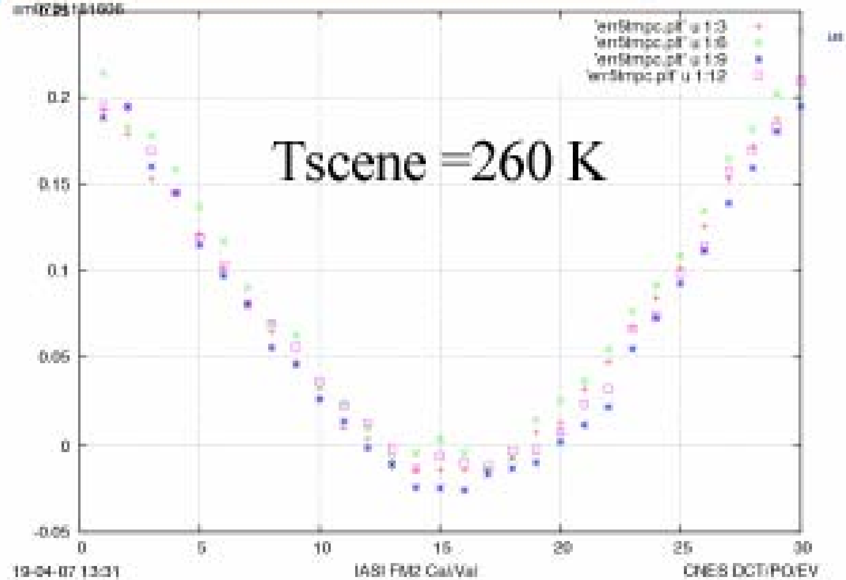
- Method
  - Compute slope of AVHRR (ch4) vs IASI radiances
  - Analysis of slopes vs IASI scan angle
  - Good fit with cos (scan angle)
  - Polarization of AVHRR scanning mirror ?
  - IASI effect : slight asymmetry

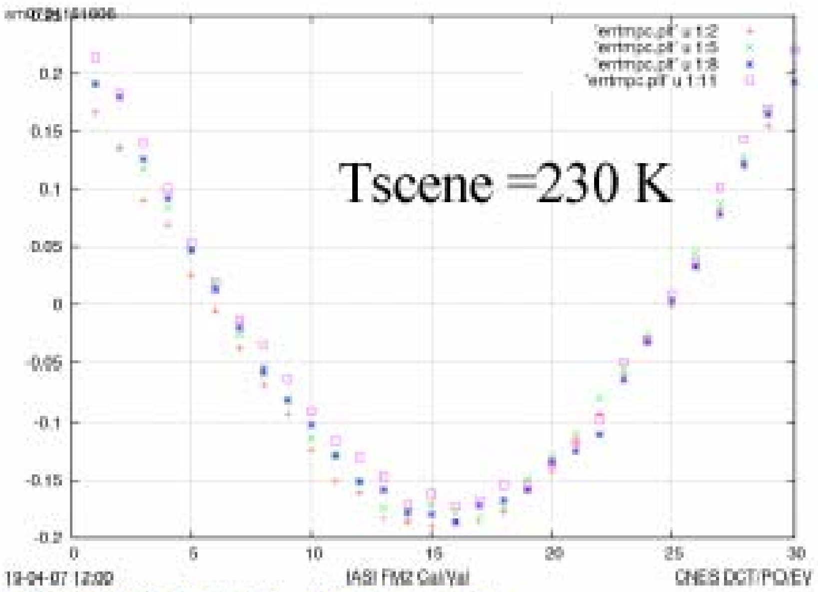


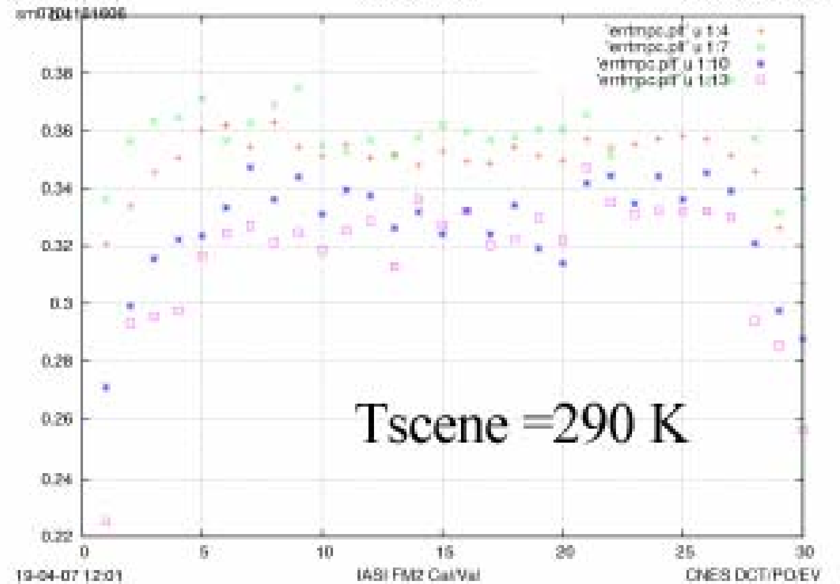


Results

- Reminder : IASI spec (absolute)
  - 0.5 K at 280 K
- Small discrepancy
  - -0.2 K < DT < 0.4 K (scaled at 280 K)
- IASI interpixel calibration error
  - A few 0.01 K (typ. 0.05 K)

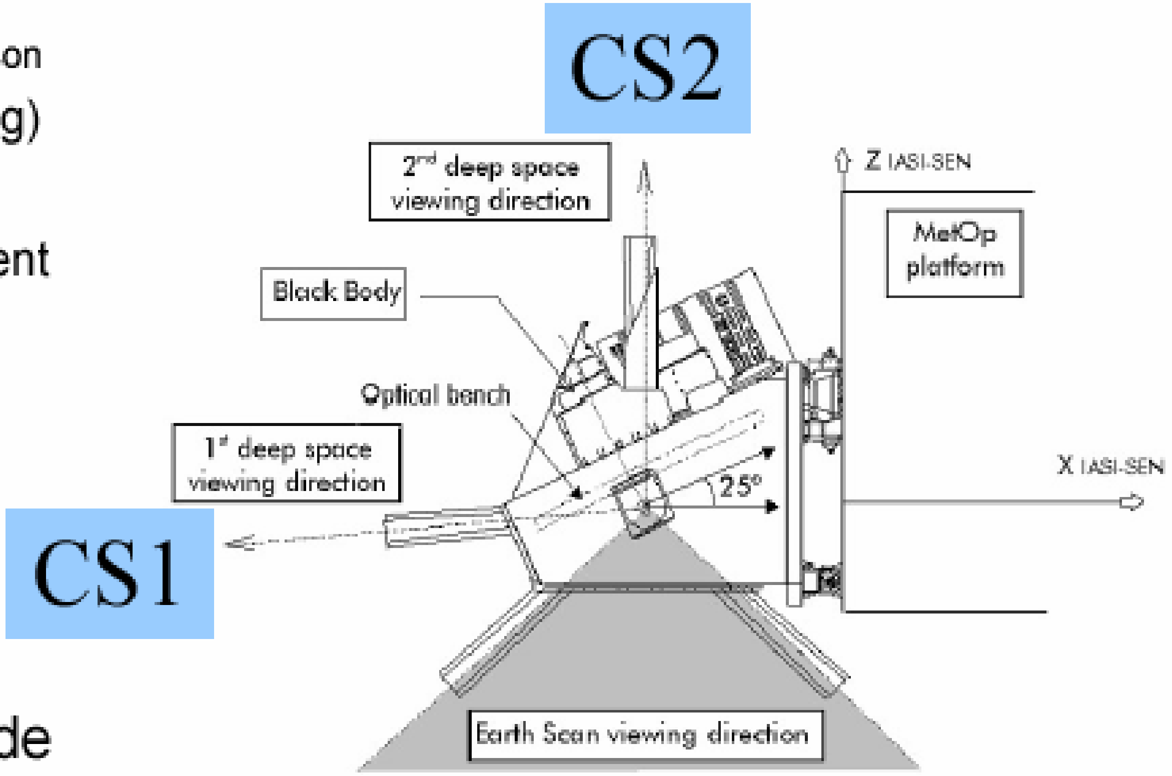






Method

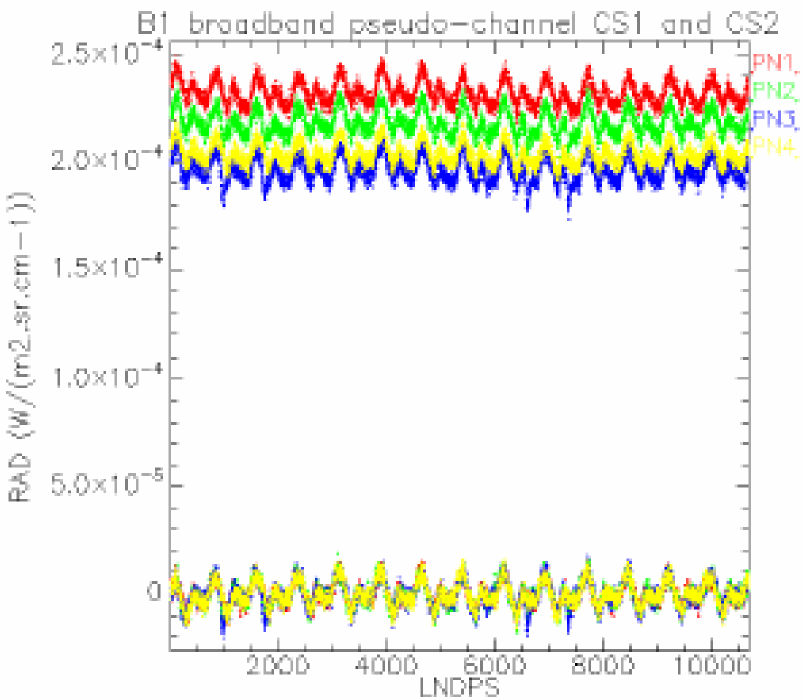
- First component
  - Offset calibration coefficient
  - Cold Space views (CS1)
  - Lack of parasitic flux
    - CS1 vs CS2 comparison
  - Temporal stability (filtering)
- Second Component
  - Slope calibration coefficient
  - Black Body views (BB)
  - Lack of sensitivity to BB environment
  - Temporal stability (filtering)

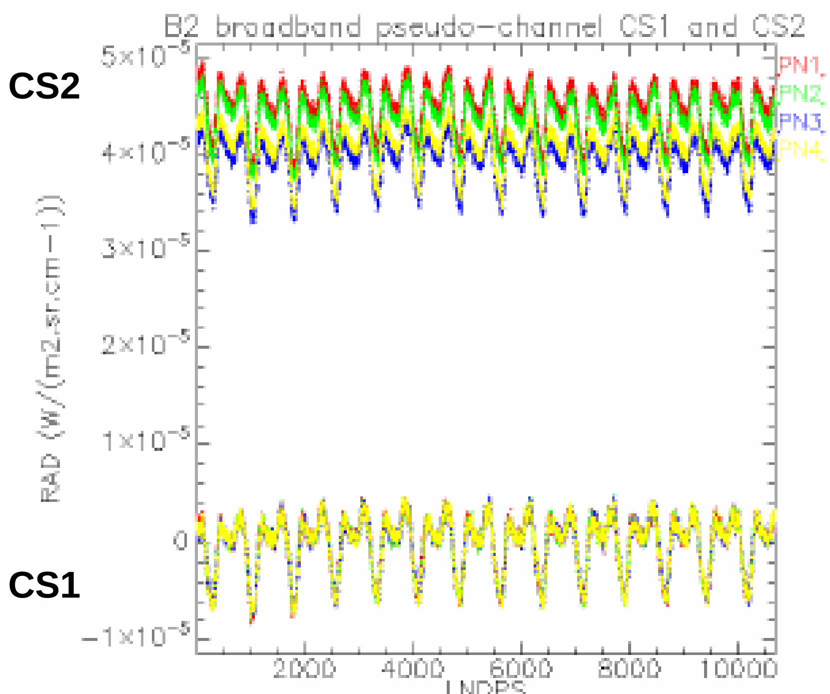


- External Calibration Mode
- Broadband pseudo-channels

Results on Offset calibration coefficient (14 consecutive orbits)

- Reminder : specification +/- 0.15 K (scaled to 280 K)
- No Parasitic flux in CS1 or CS2
- Orbital fluctuations caused by lag on filtered parameters
  - Today : 0.02 K (B1), 0.03 K (B2), 0.04 K (B3) peak to peak
  - Will be reduced to : 0.008 K (B1), 0.012 K (B2), 0.016 K (B3) after 26th of June





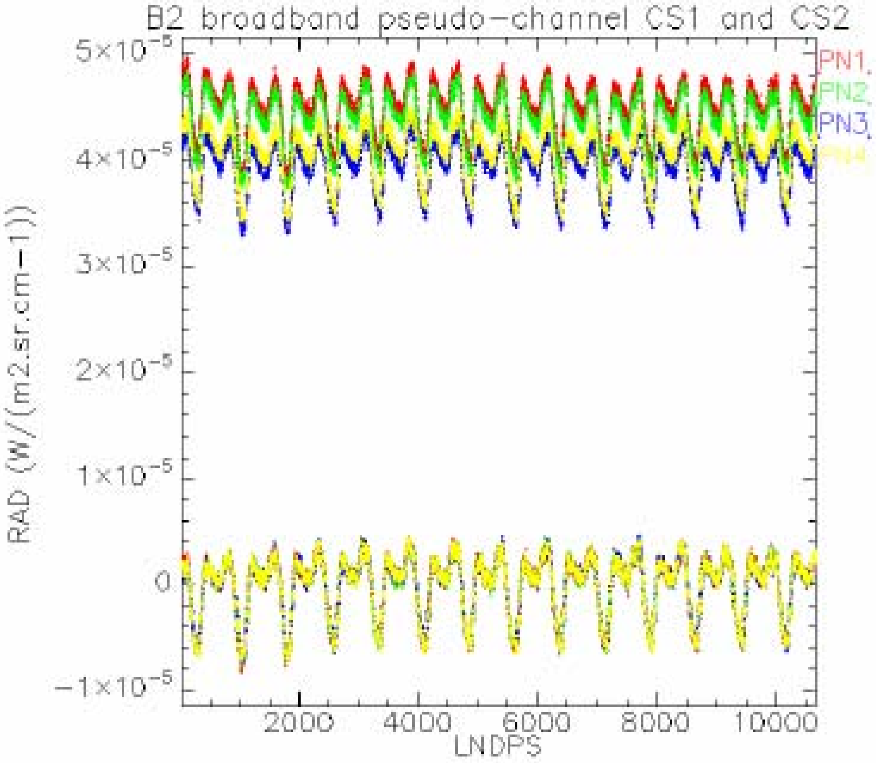
Difference beween CS1 and CS2 ~0.2 % of B(285 K) explained by difference of angles on the scan mirror. Well explained by instrument model.

Radiometric calibration – orbital stability (2/4)

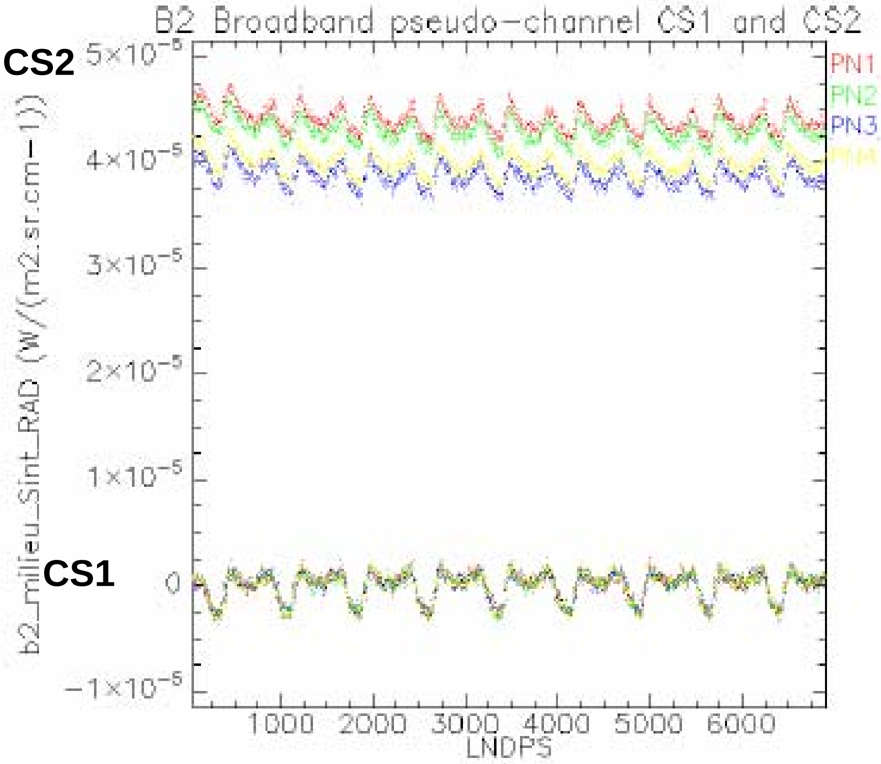
- Effect of TOP update (27th June)

  TOP = Table of On-board Parameters

Before

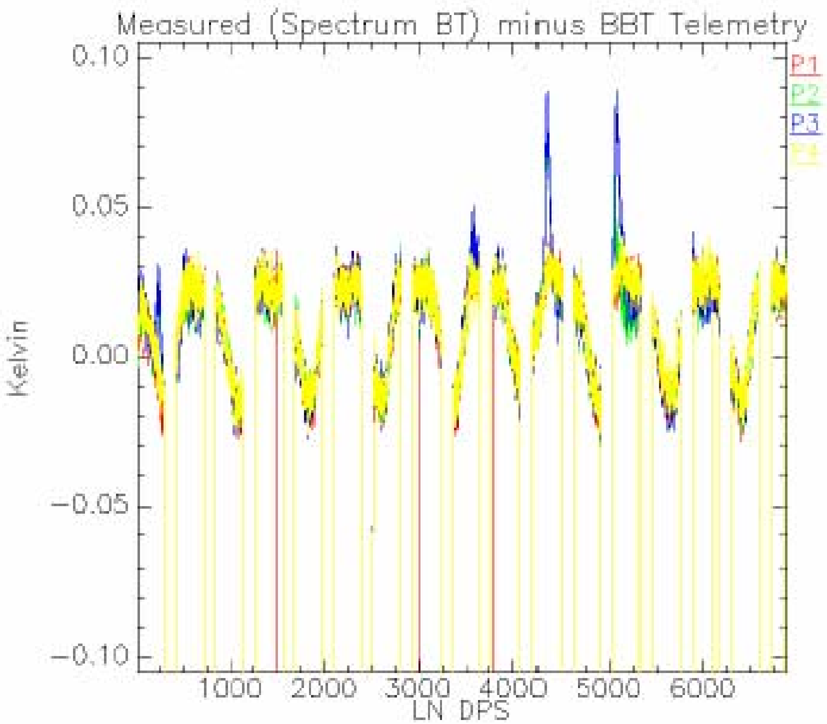


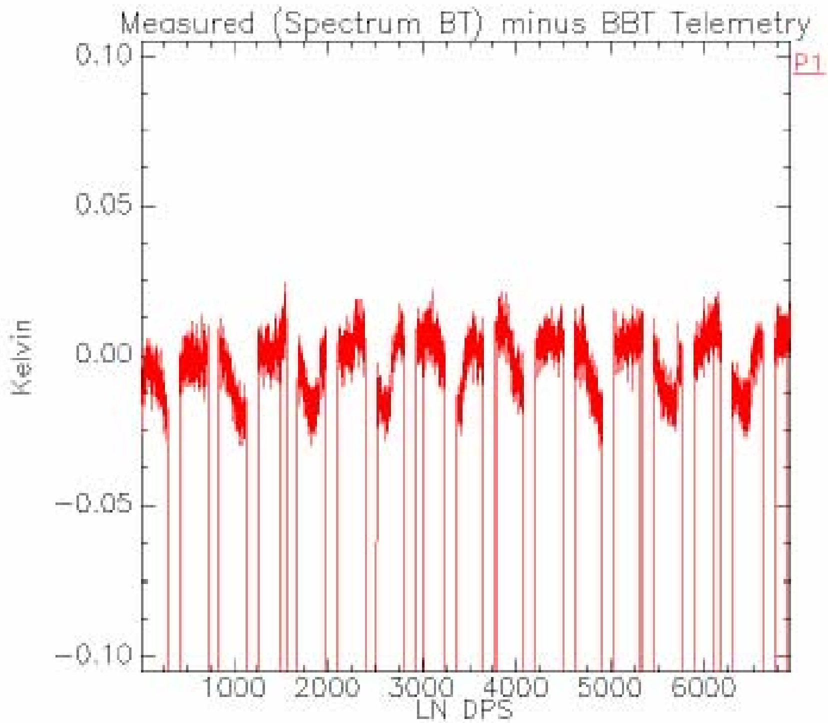
After



- Results on Slope calibration coefficient (9 consecutive orbits)
  - spectrum brightness temperature – BB temperature telemetry

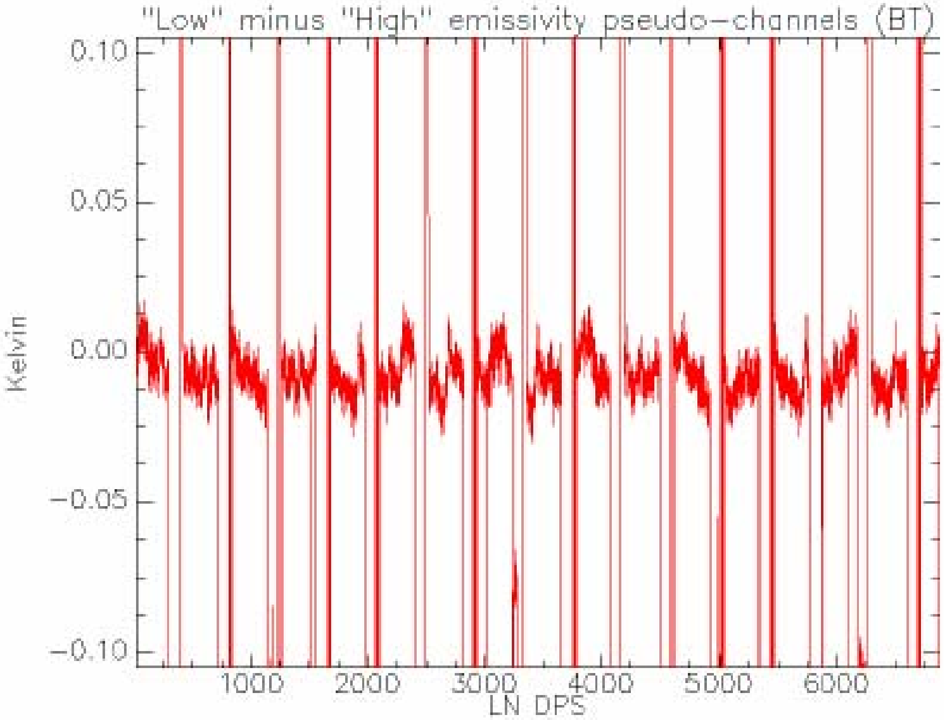
- Orbital fluctuations caused by lag on filtered parameters
  - Today – B1: 0.1 K (P1 & P4), 0.06 K (P2 & P3), B2: 0.04 K, B3: 0.05 K (B3) p-p
  - Will be reduced to : 0.04 K (B1), 0.024 K (B3), 0.016 K (B3) after 26th of June

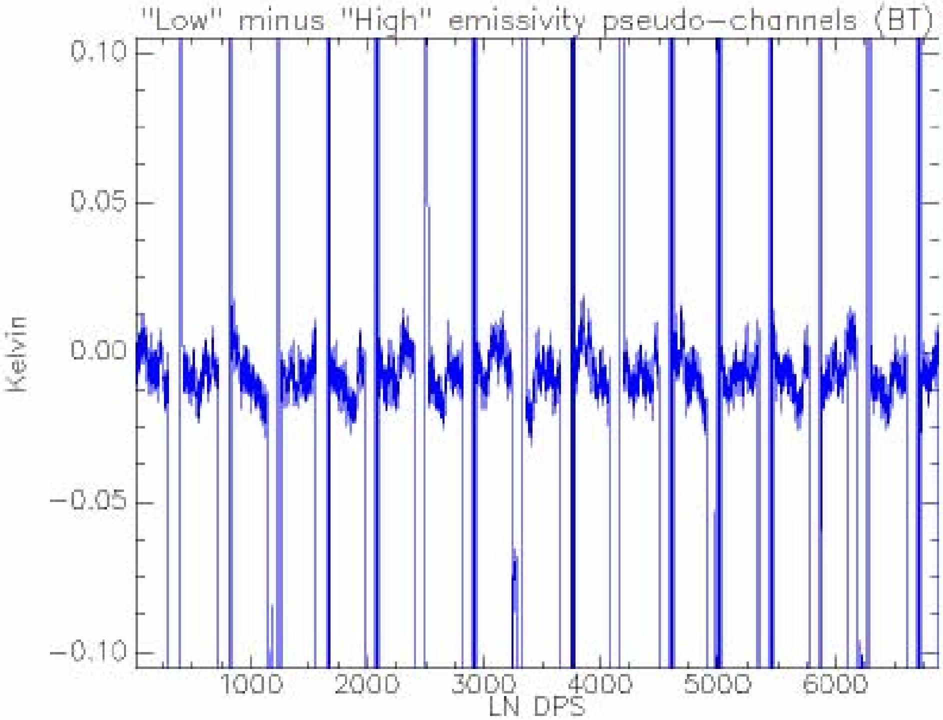




- Results on Slope calibration coefficient (9 consecutive orbits)
  - BB « High » emissivity - « Low » emissivity channels

- No rapid variation of BB environment (end of eclipse, terminator, etc)
  - Vertical transitions caused by measurements on CS1 target (BT not meaningful)
- Estimated effect : less than 0.09 K p-p for worst case IASI channels

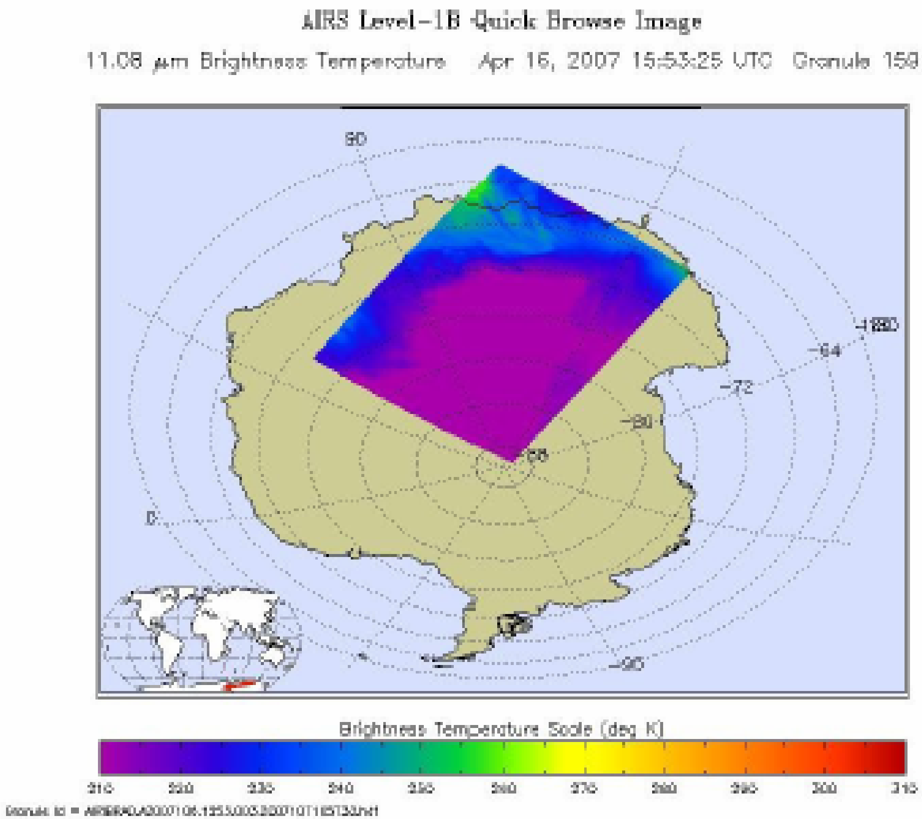


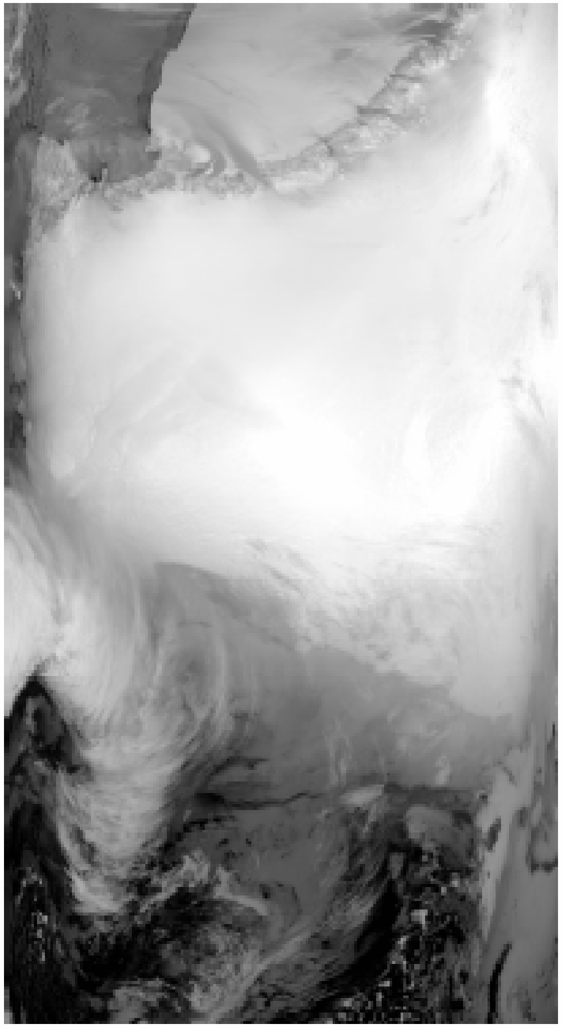


Radiometric calibration — IASI versus AIRS

- At orbit crossing points : high latitudes only (Nord and South 73 deg)
- Difficulties
  - Pixel size : AIRS : 13.5 km, IASI : 12 km
  - Missing AIRS channels
  - Spectral response function (first order resolution)
- Work around
  - Comparison of AIRS and IASI broadband pseudo-channels
  - Selection of scenes with good spatially uniformity

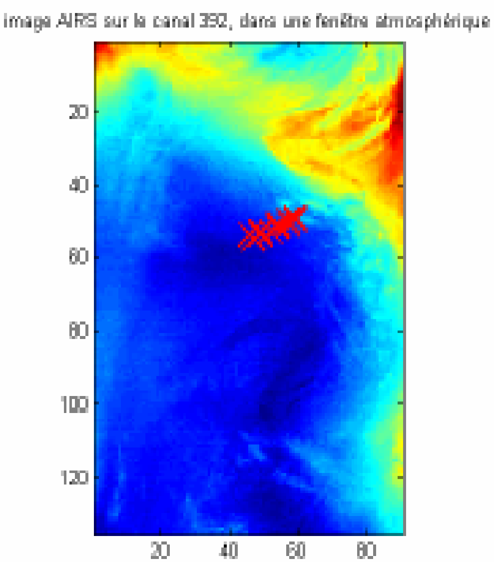
Situation : 16th April 15:53

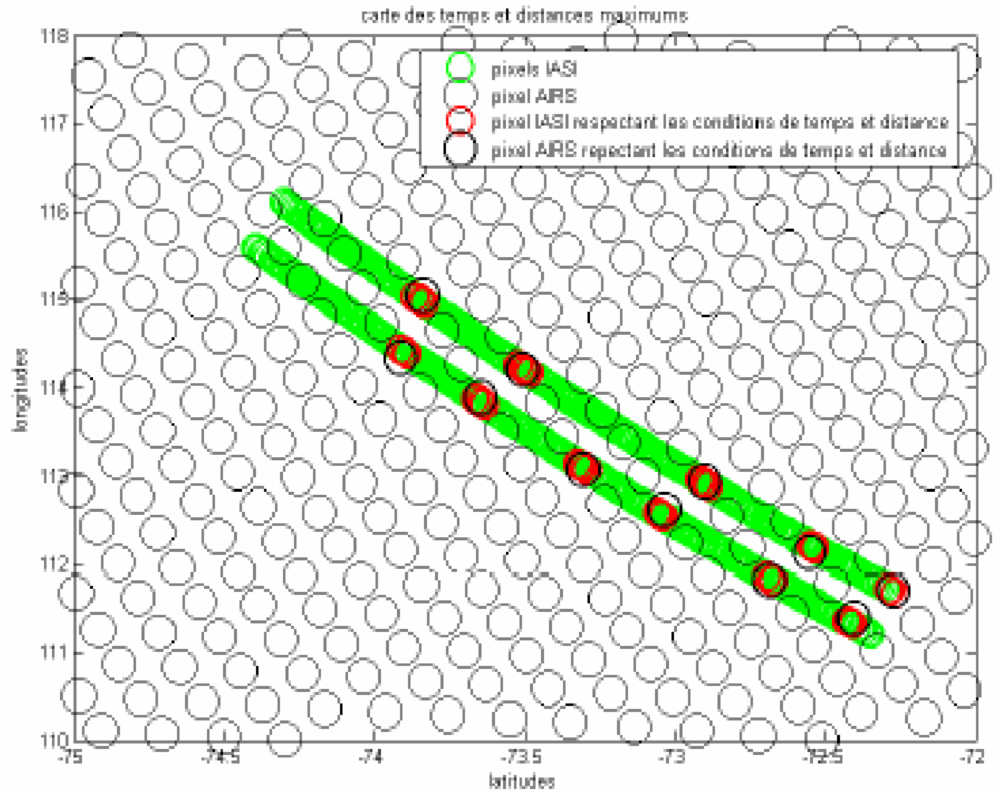




Situation 16th of April

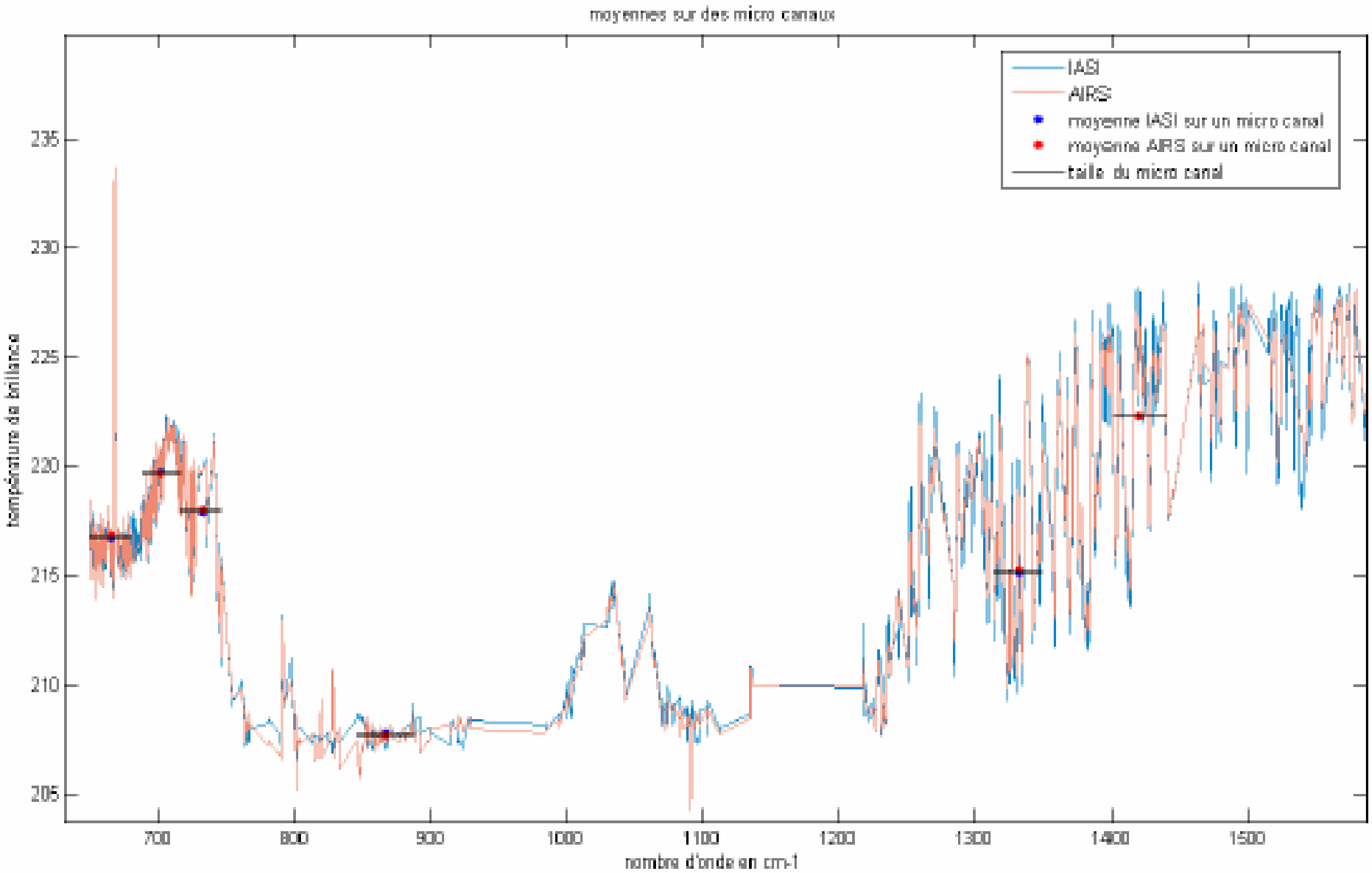
- IASI in External Cal.
  - Close to nadir
- Many comparison opportunities
  - 49 used
- Good uniformity
  - Cold scene



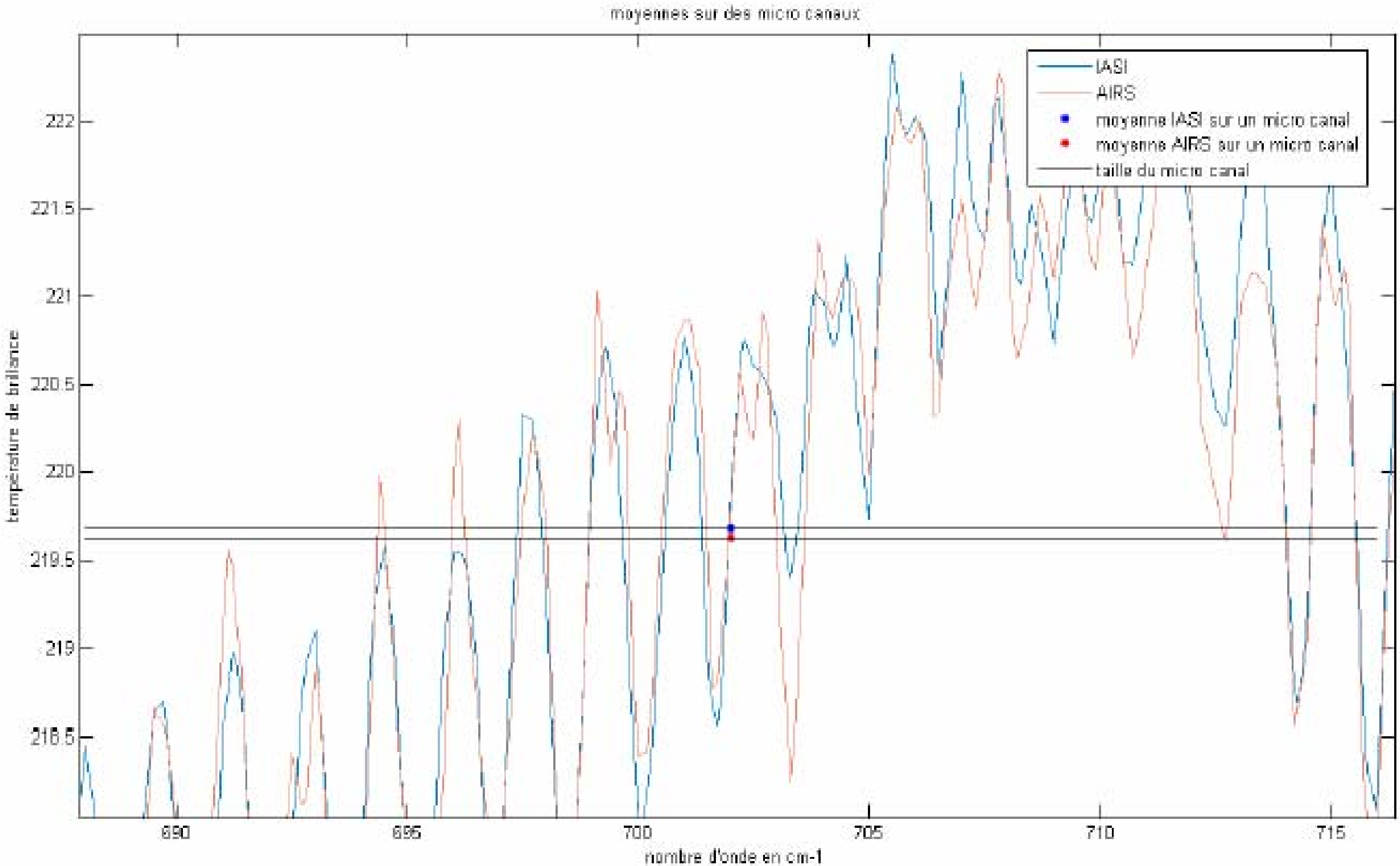


Radiometric calibration — IASI versus AIRS

Pseudo-channels

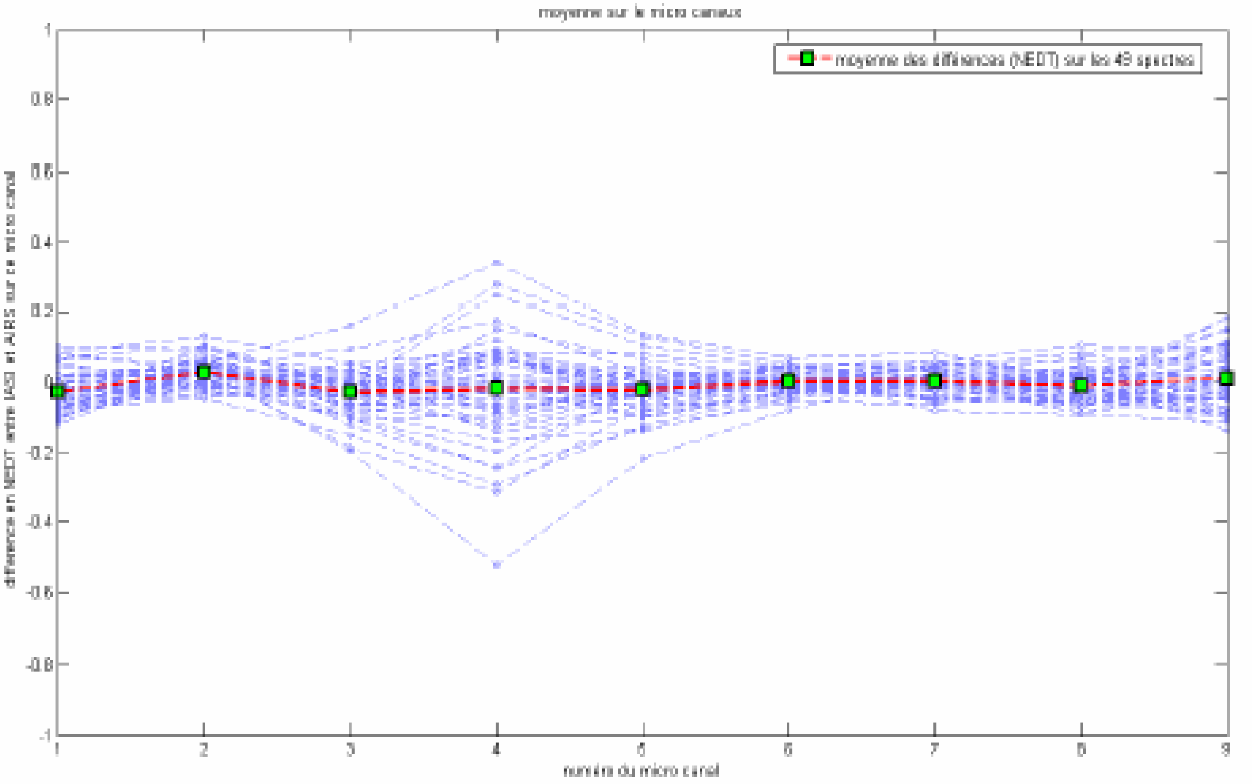


Pseudo-channels : zoom on CO_2



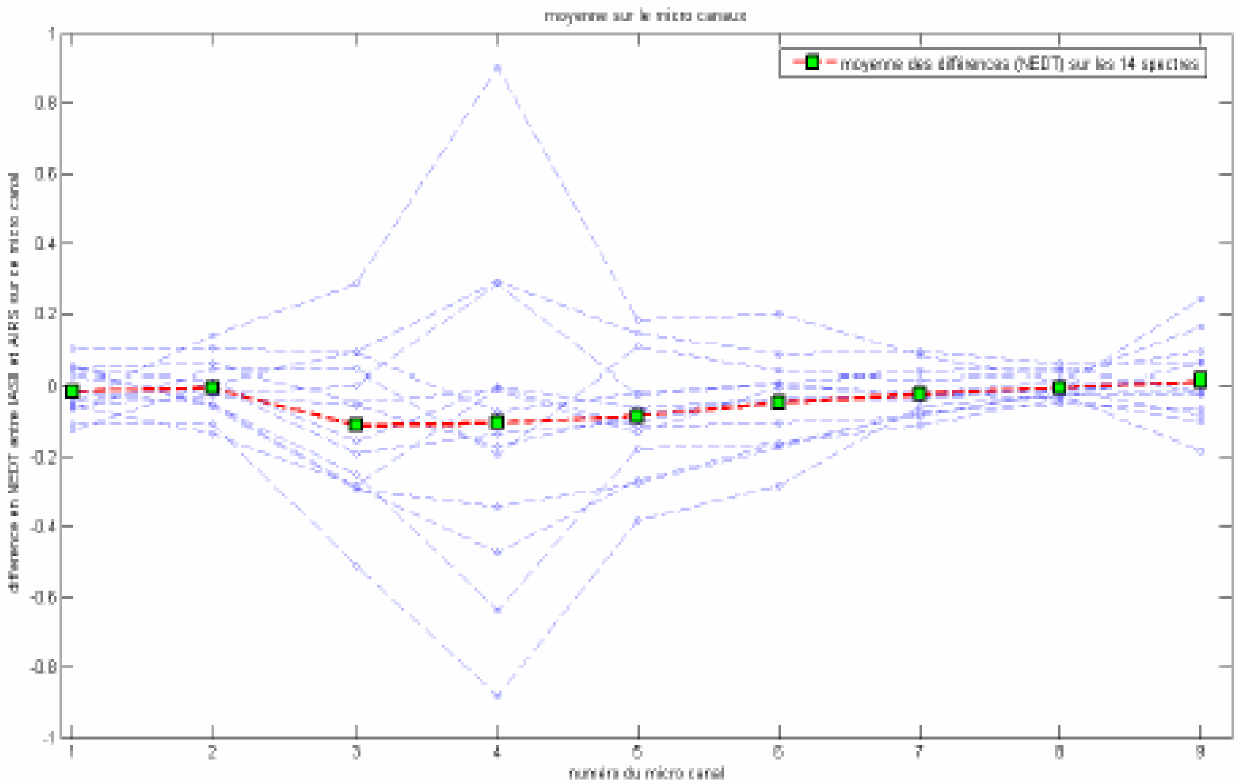
Summary results (case 16th of April 2007)

- IASI External Calibration Mode. Very uniform situation
- 9 pseudo-channels / 49 soundings / 210 K in atmospheric window
- Differences scaled to 280 K reference temperature



Summary results (case 19th of April 2007)

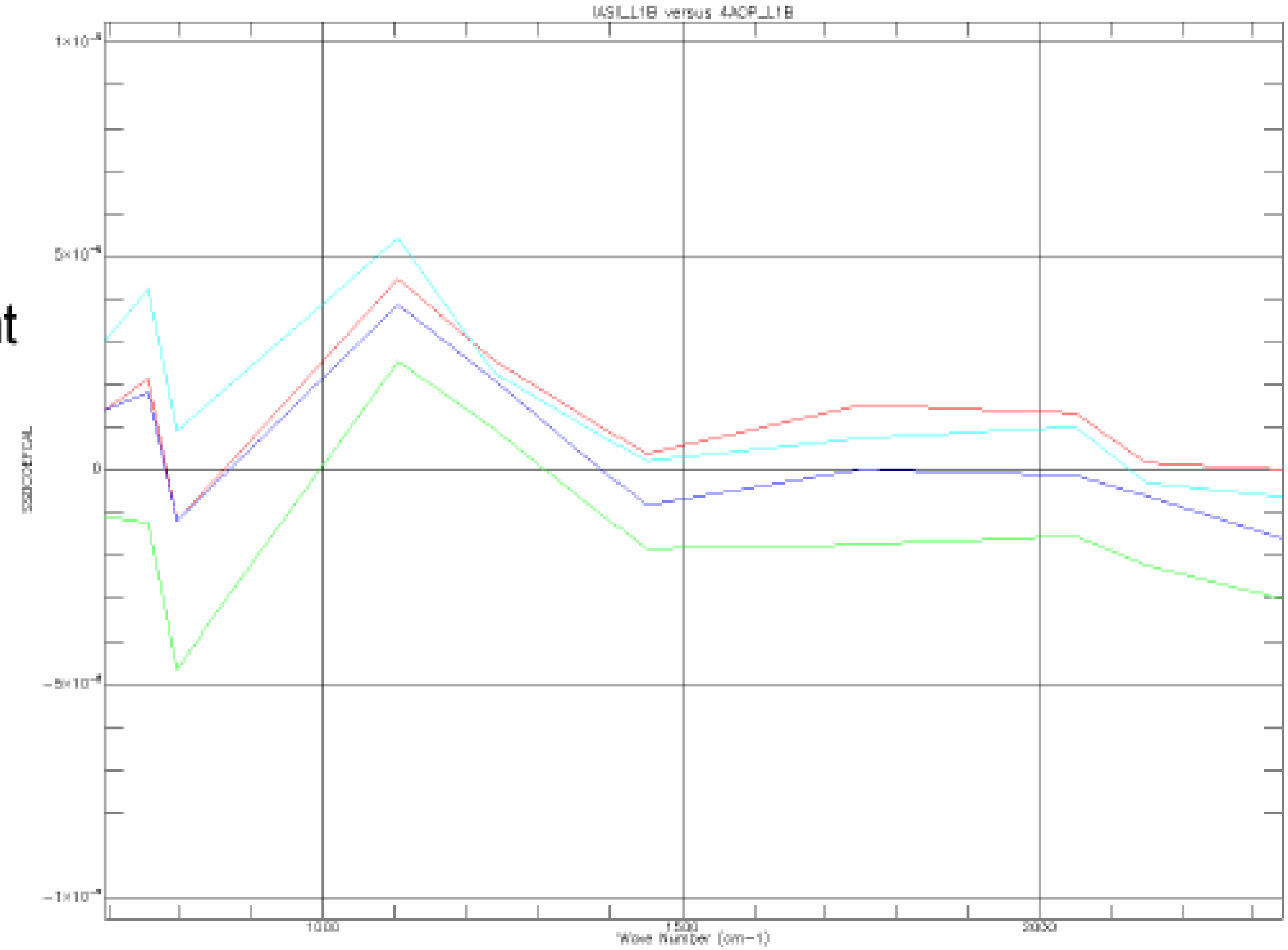
- IASI Normal Operation Mode , Not very uniform situation
- 9 pseudo-channels / 14 soundings / 245 K in the atmospheric window
- Differences scaled to 280 K reference temperature



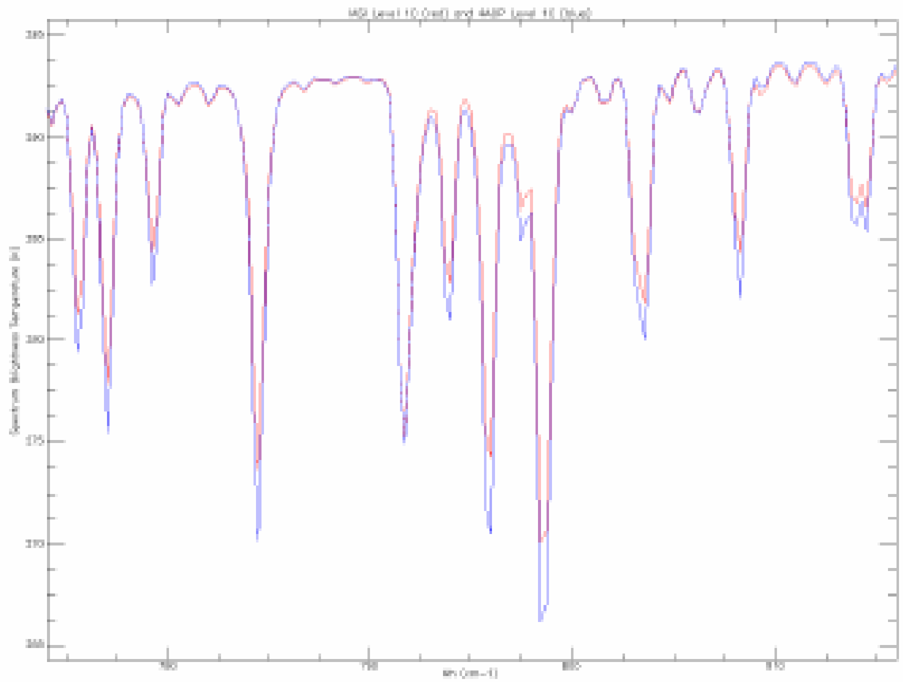
Spectral performances

End of Cal/Val A results

- 1st Improvement needed
  - 790, 1125 cm-1
  - H2O low tropo
  - Introduction of pressure shift in 4A-OP
- 2nd improvement
  - IPSF fine characterization
  - On-going (see geometry presentation)



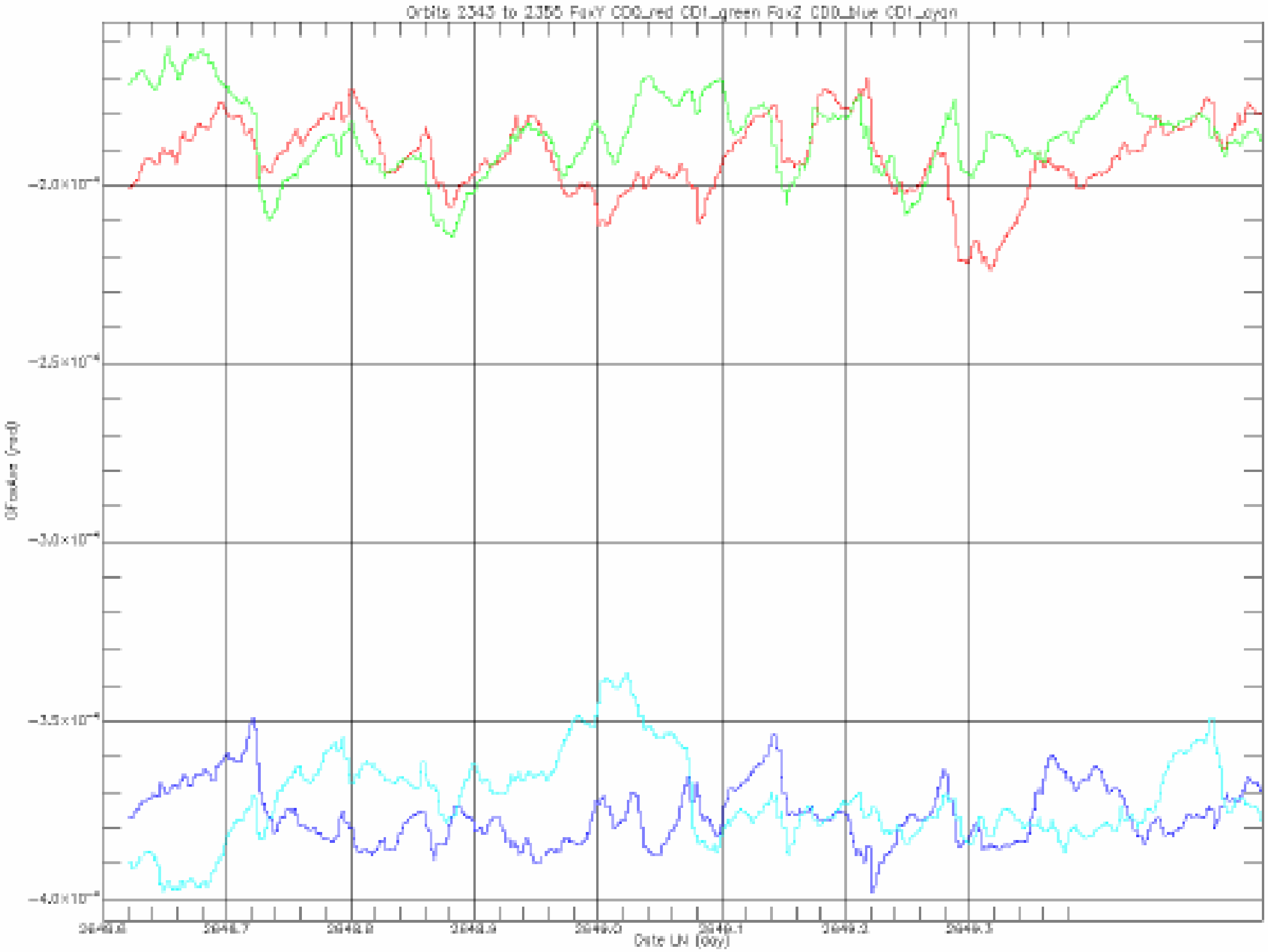
Spectral



- Introduction of pressure shifts in 4A-OP

Central wave number in cm-1	Without pressure shifts	With pressure shifts
790	-2.5 10-06	-0.6 10-06
1125	3.1 10-06	+0.4 10-06

- Stability of the interferometric axis position
  - 50 µrad equivalent to 7.5 10^{-7} ($\Delta\nu/\nu$)
  - Average in rad
  - In January
    - Y = -170 10^{-6}
    - Z = -360 10^{-6}
  - In April
    - Y = -190 10^{-6}
    - Z = -380 10^{-6}
  - No significant evolution



- Validation by correlation between simulated and measured spectra
  - Use of 4A / GEISA for radiative transfer model
  - Use of homogeneous situations (around 5000 spectra averaged for 100 situations)
  - Results presented per orbit

		PN1	PN2	PN3	PN4	ALL PN
January	**701161106**	6.1E-8	-4.9E-8	5.6E-7	1.7E-7	1.8E-7
	701161427	3.0E-7	-9.0E-8	3.7E-7	3.6E-7	2.3E-7
	701161745	7.3E-8	-6.0E-7	3.6E-7	3.0E-7	3.3E-8
	701161927	3.9E-7	-1.1E-7	6.5E-7	6.8E-7	4.0E-7
	701162109	-6.0E-8	-6.1E-7	4.9E-7	6.3E-7	1.1E-7
April	**704130054**	2.0E-7	2.9E-7	8.0E-7	6.3E-7	4.8E-7
	704130236	5.7E-7	3.4E-7	5.3E-7	8.3E-7	5.7E-7
	704130421	1.8E-7	-2.6E-7	6.4E-7	7.4E-7	3.3E-7
	704130603	3.5E-7	-1.7E-7	6.5E-7	-6.1E-7	5.3E-8
	704130745	4.8E-7	-4.8E-8	7.2E-7	8.5E-7	5.0E-7
	704130927	9.0E-7	-8.5E-8	7.7E-7	6.9E-7	5.7E-7
	704131106	1.3E-7	-4.1E-7	4.7E-7	6.2E-7	2.0E-7
	704131248	2.5E-7	-3.4E-7	7.2E-7	7.8E-7	3.5E-7
	704131427	7.4E-8	-4.7E-7	7.1E-7	7.2E-7	2.6E-7
June	**706041451**	3.5E-7	-1.4E-7	5.3E-7	7.7E-7	3.8E-7

Global	**Average**	2.8E-7	-1.8E-7	6.0E-7	5.4E-7	3.1E-7
Global	**STD**	4.9E-7	4.6E-7	3.5E-7	5.6E-7	3.3E-7

- Use of atmospheric spectra :
  - Analysis of a small number of measurement sessions
  - Concentration on B2 band (H20) : very low radiometric noise -> high sensitivity
  - Confirmation of previous preliminary results
    - Noise measured on atm.spectra very close to noise measured on Calibration Views (after elimination of atmospheric variability)
    - Estimation of the perturbation close to the noise level (at the minimum)

- Recommendation from the Cal/Val Team
  - No release of LFD

Geometric Performances

Geometric Performances and IPSF

Method

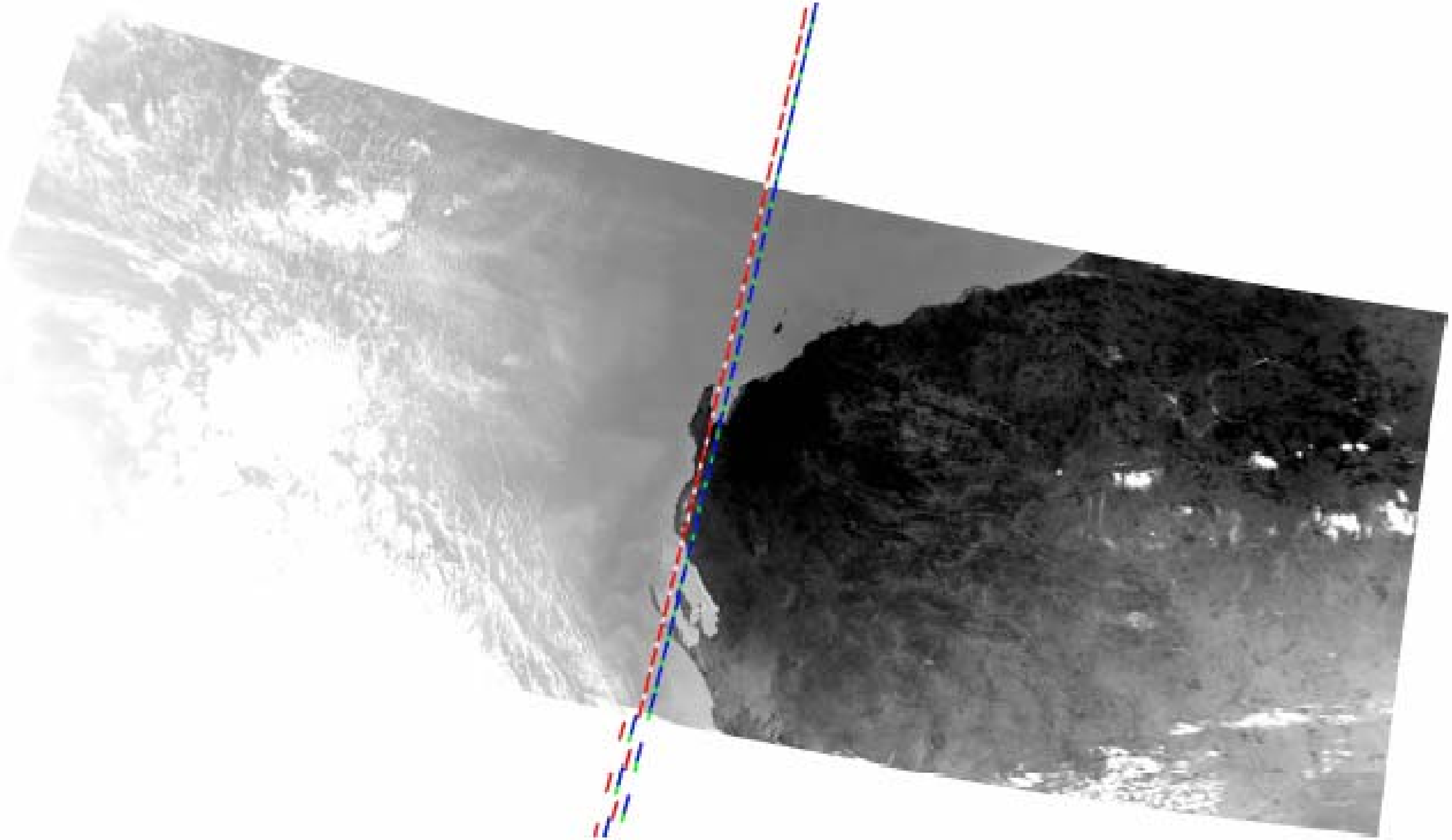
Computation of

- accurate integration of AVHRR radiance inside IASI IPSF
  - through the Radiance Analysis Algorithm (OPS task CCS)
  - IASI like pseudo channel (CCSpsch)
- integral of IASI spectrum on the AVHRR channel SRF (SINTpsch)

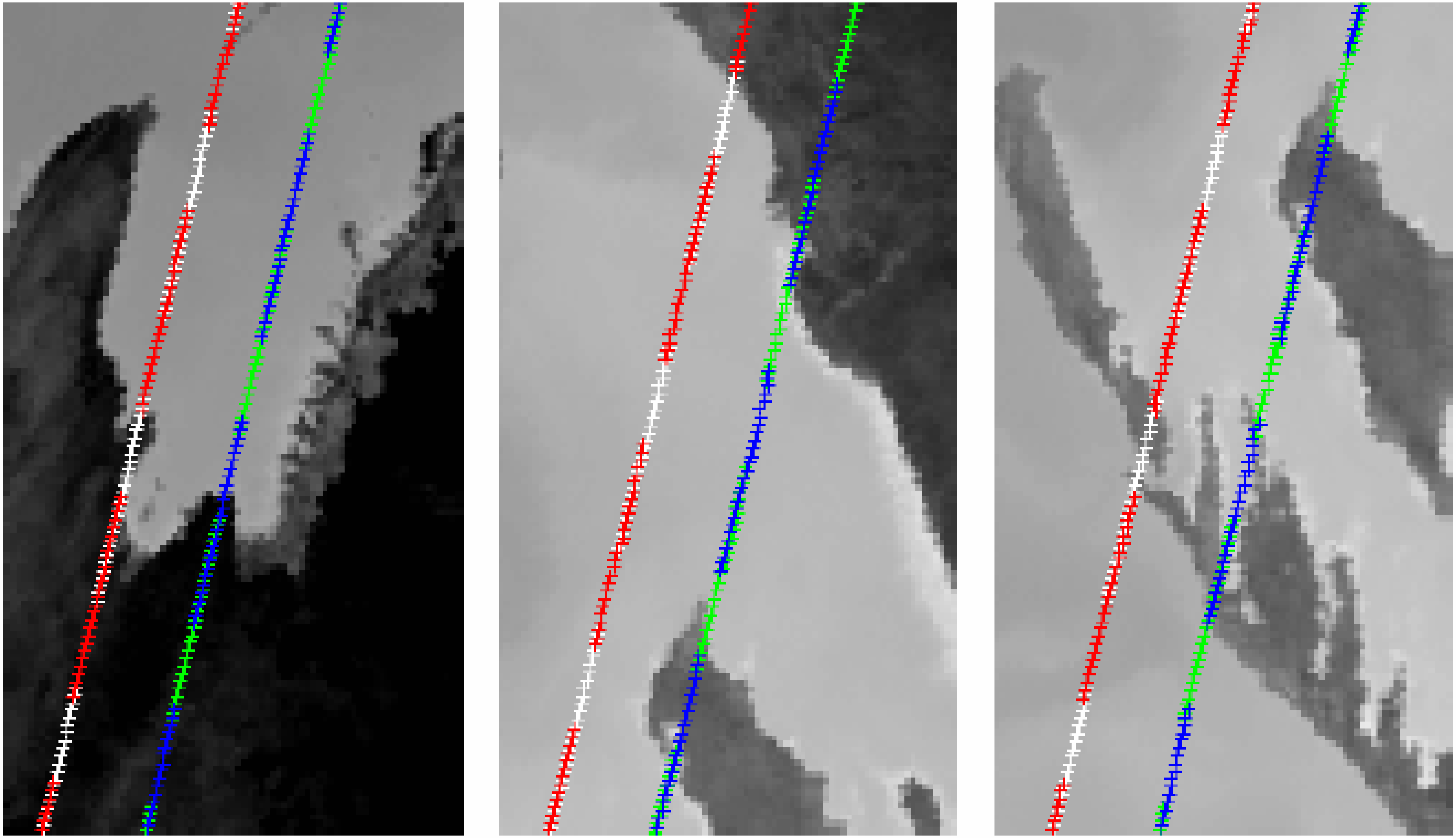
Maximization of the correlation between CCSpsch and SINTpsch

- varying position of COG of the IPSF
- for a large set of suitable situations
  - clear sky
  - high landmark contrast
- Other parameters can be optimized
  - Pixel size
  - "sharpness" of pixel boundary

- Example : First situation *0704170111*

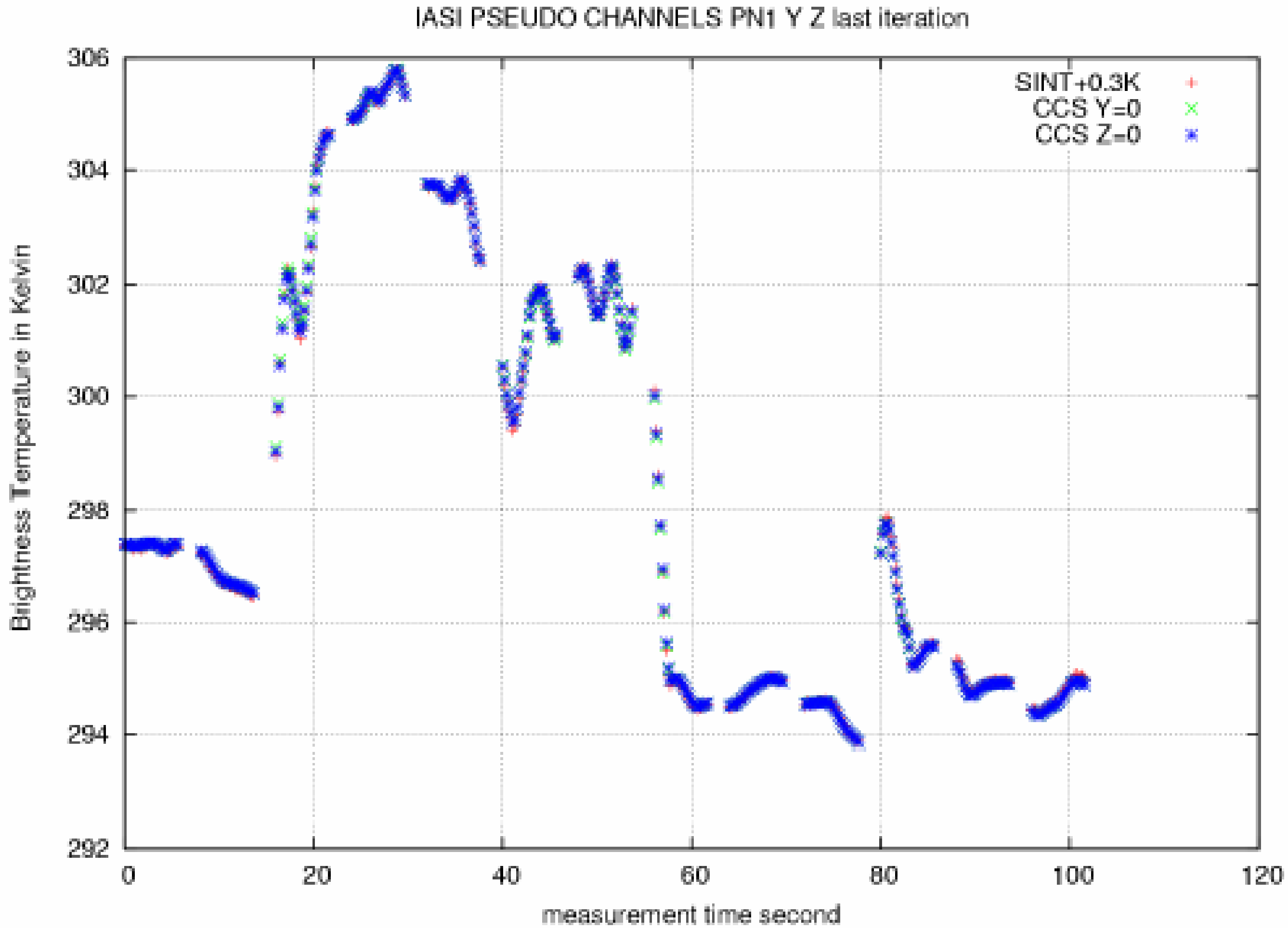


First situation (zoom)

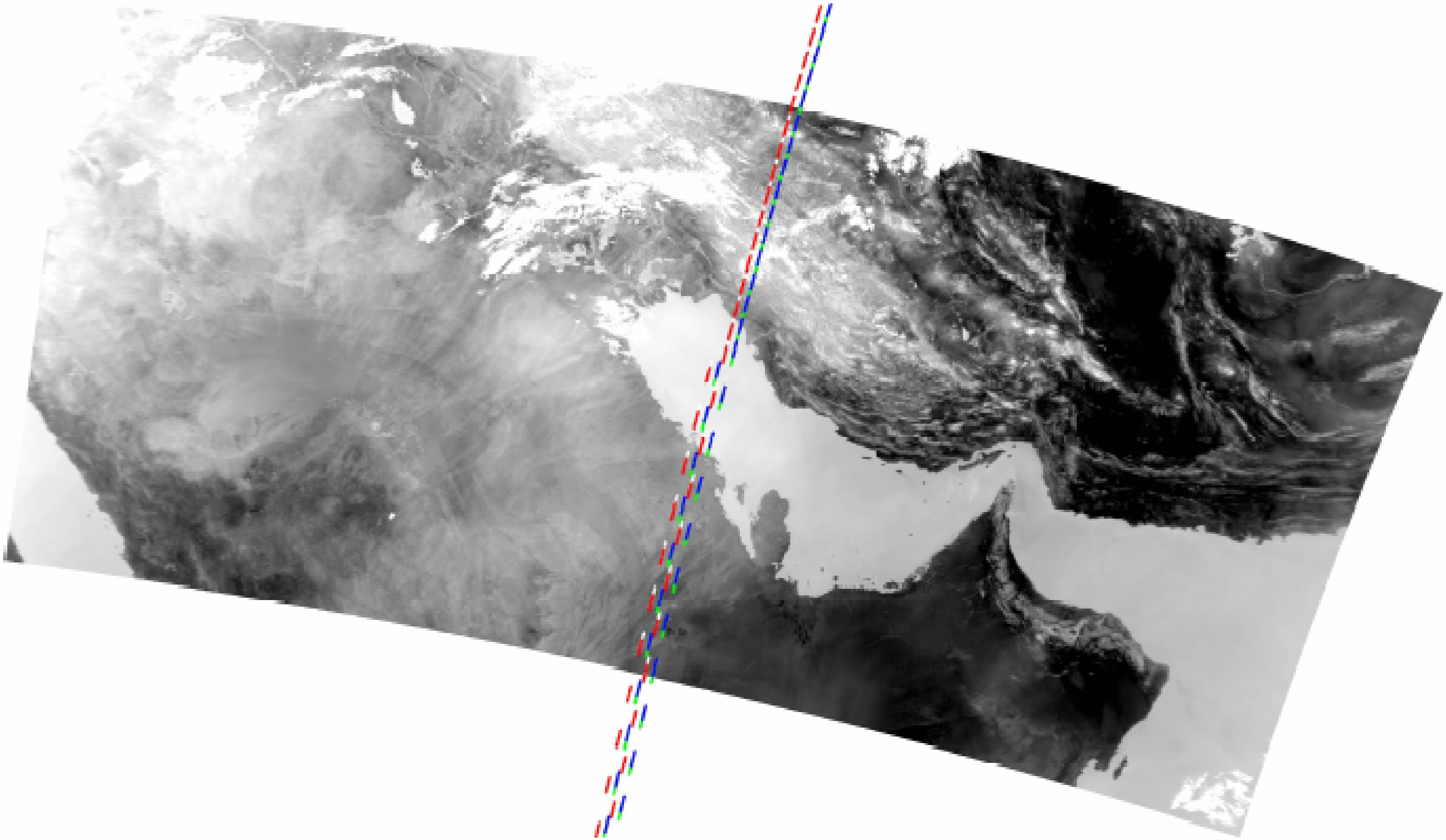


Results

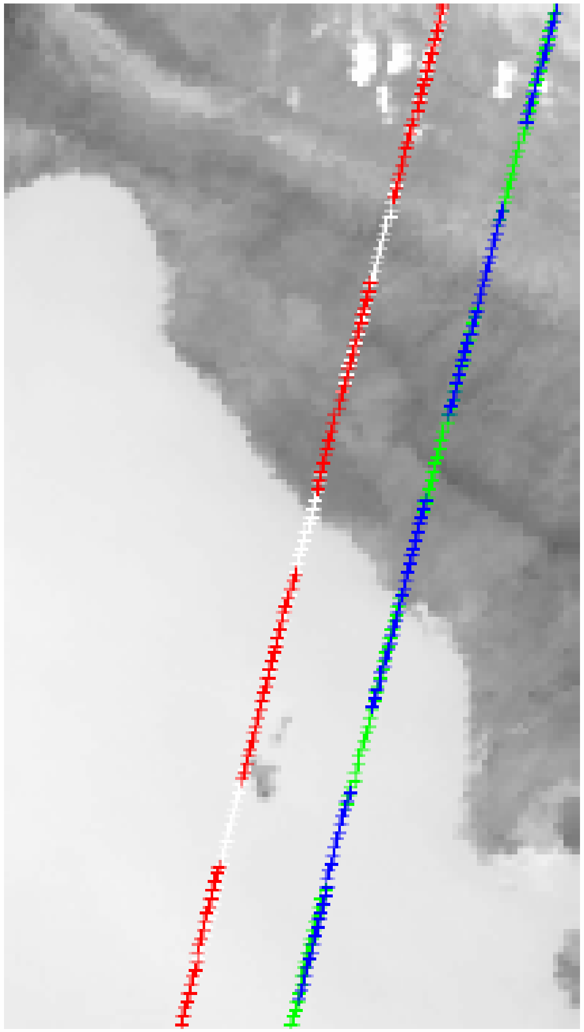
- Comparison of CCSpsch and SINTpsch after optimization of IPSF position

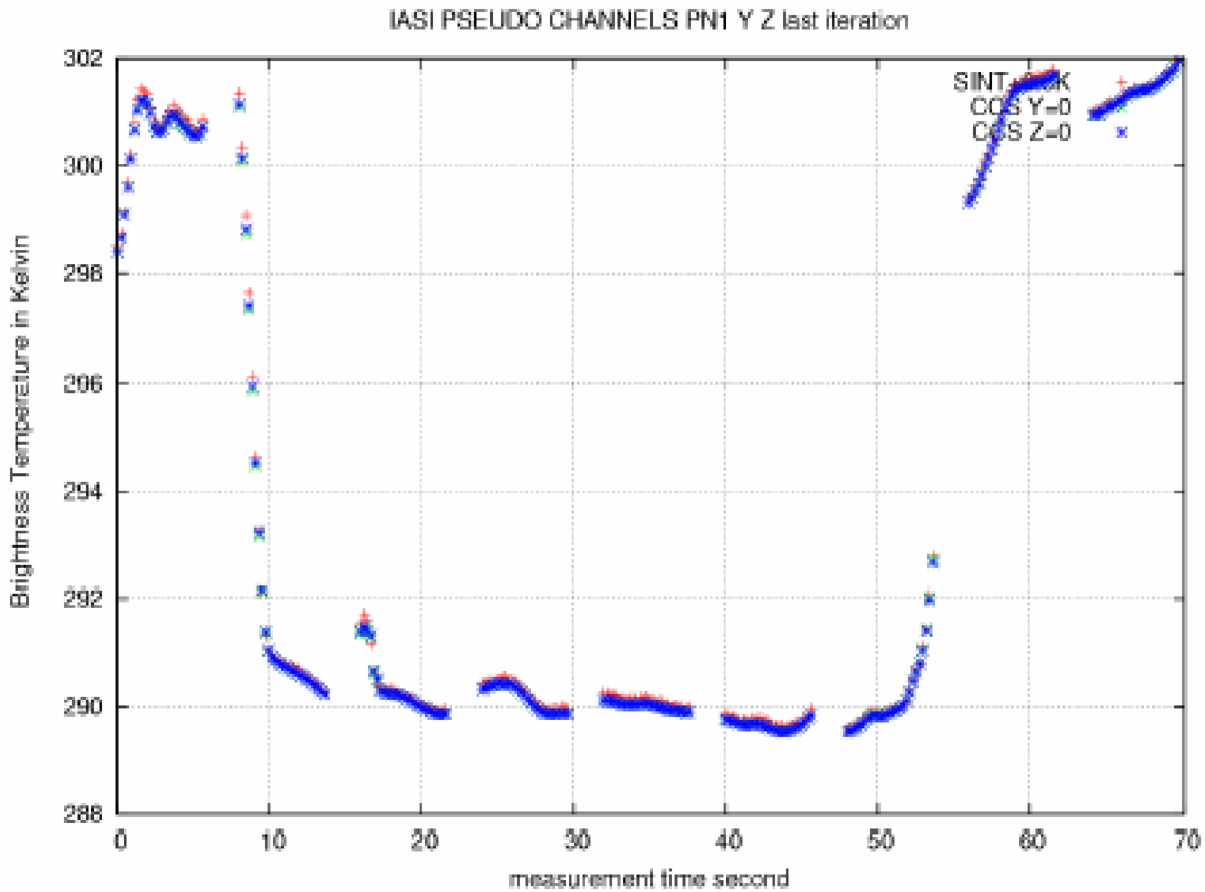


- Example : Second situation *0704170620*

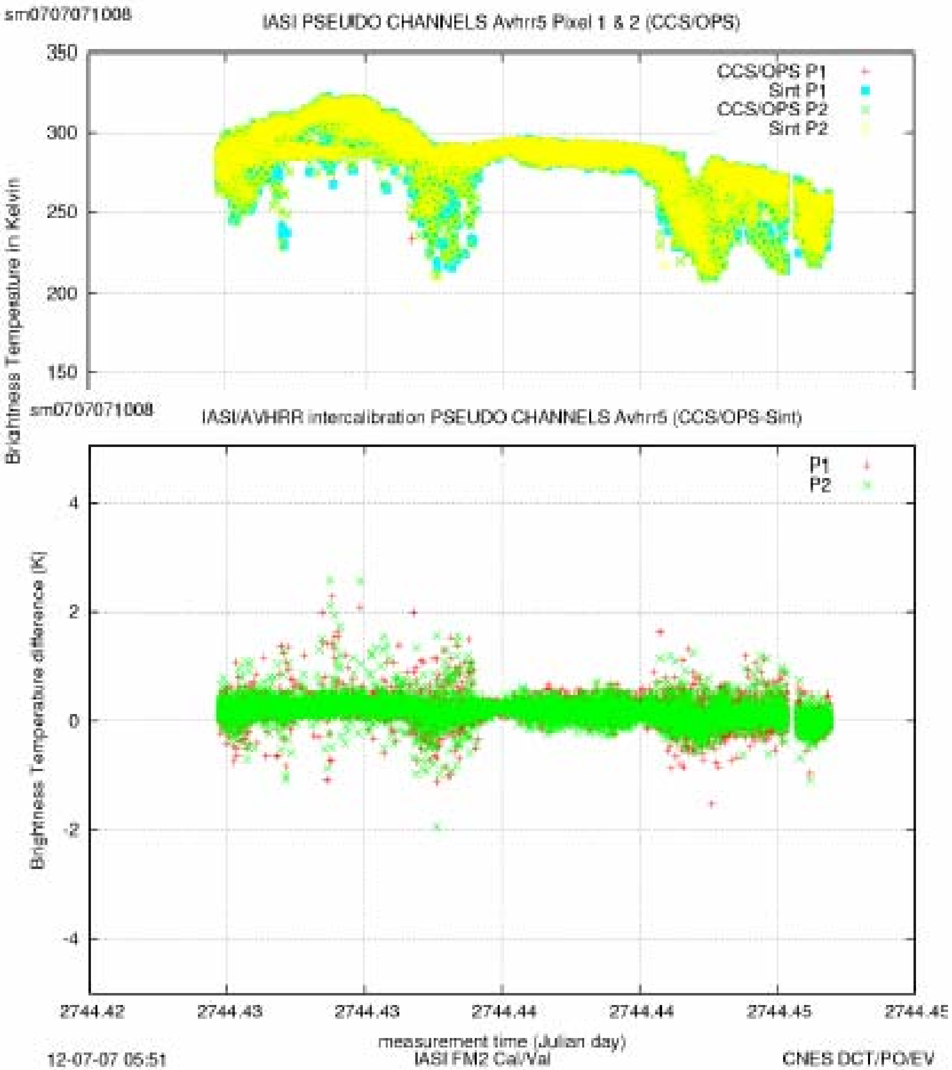


Second situation (zoom)

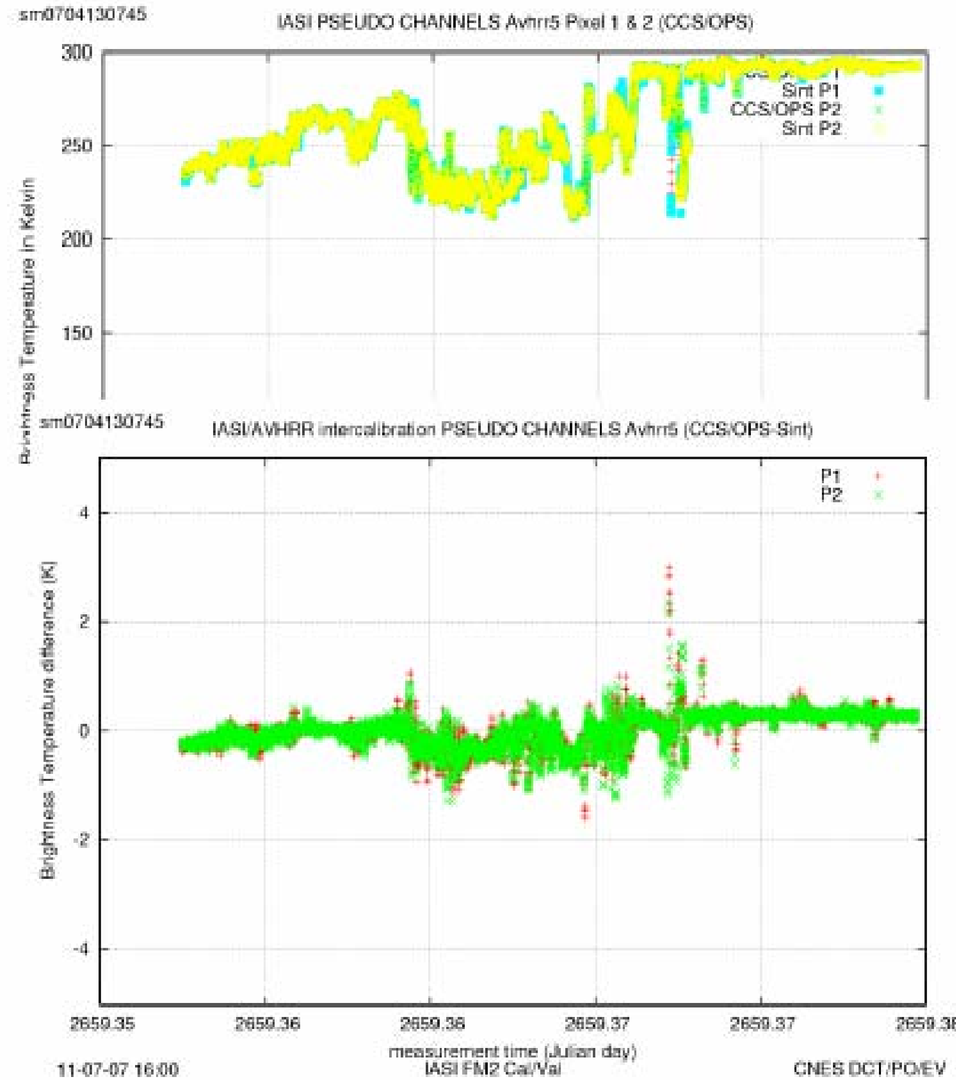




Normal Operation Mode (June)

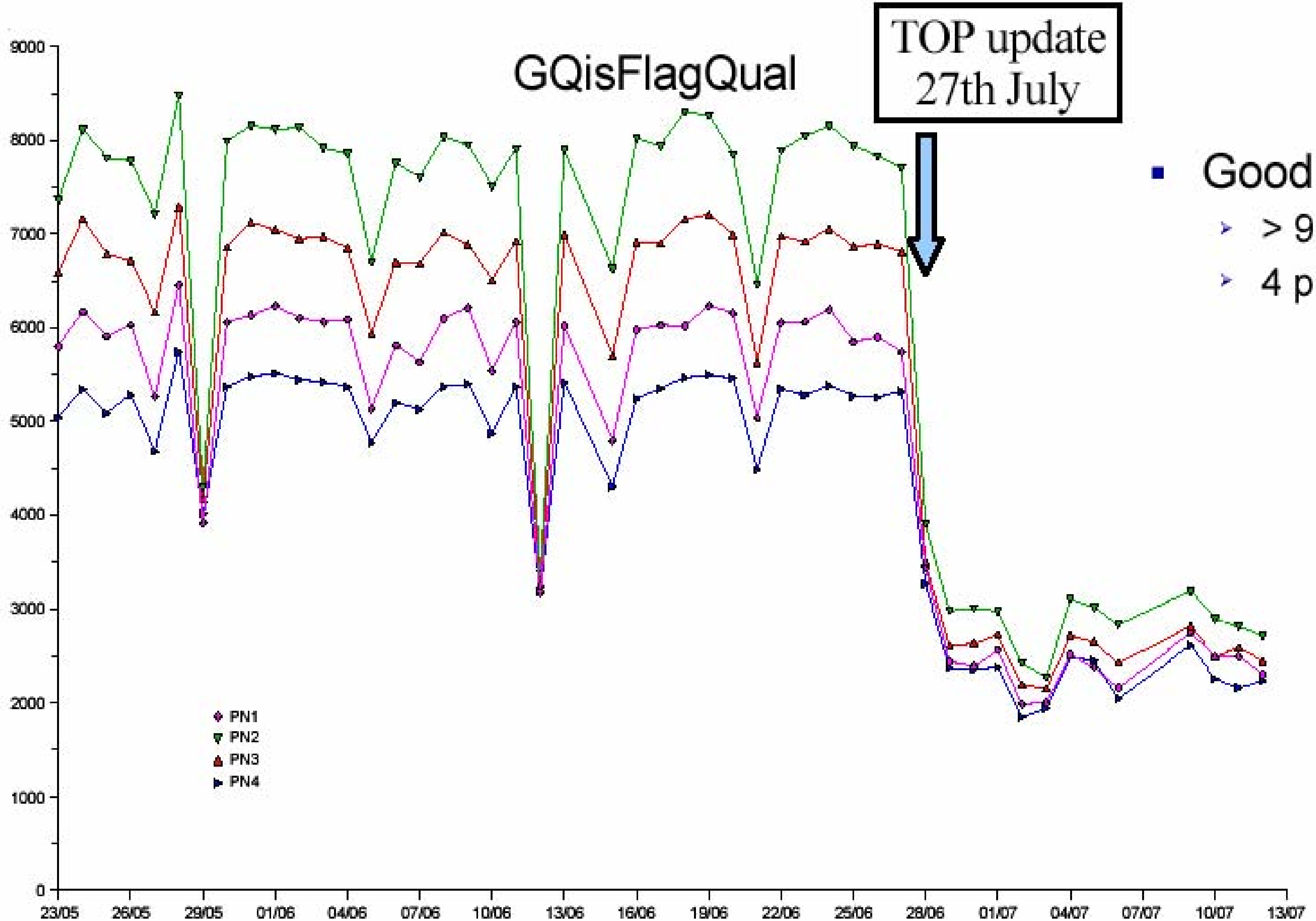


External Calibration (April)



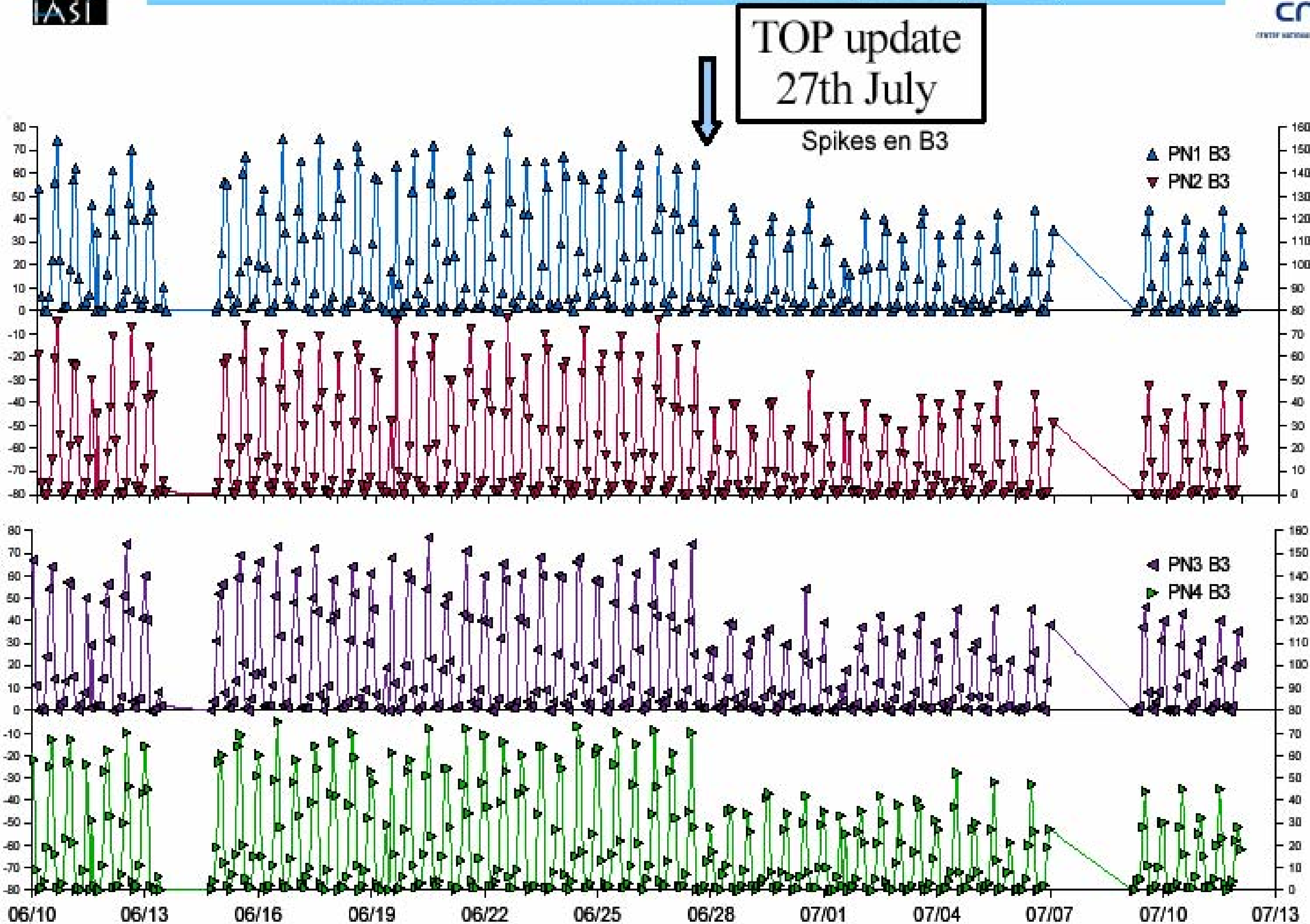
Operational aspects

Reduction of the number of general L1 quality flags raised

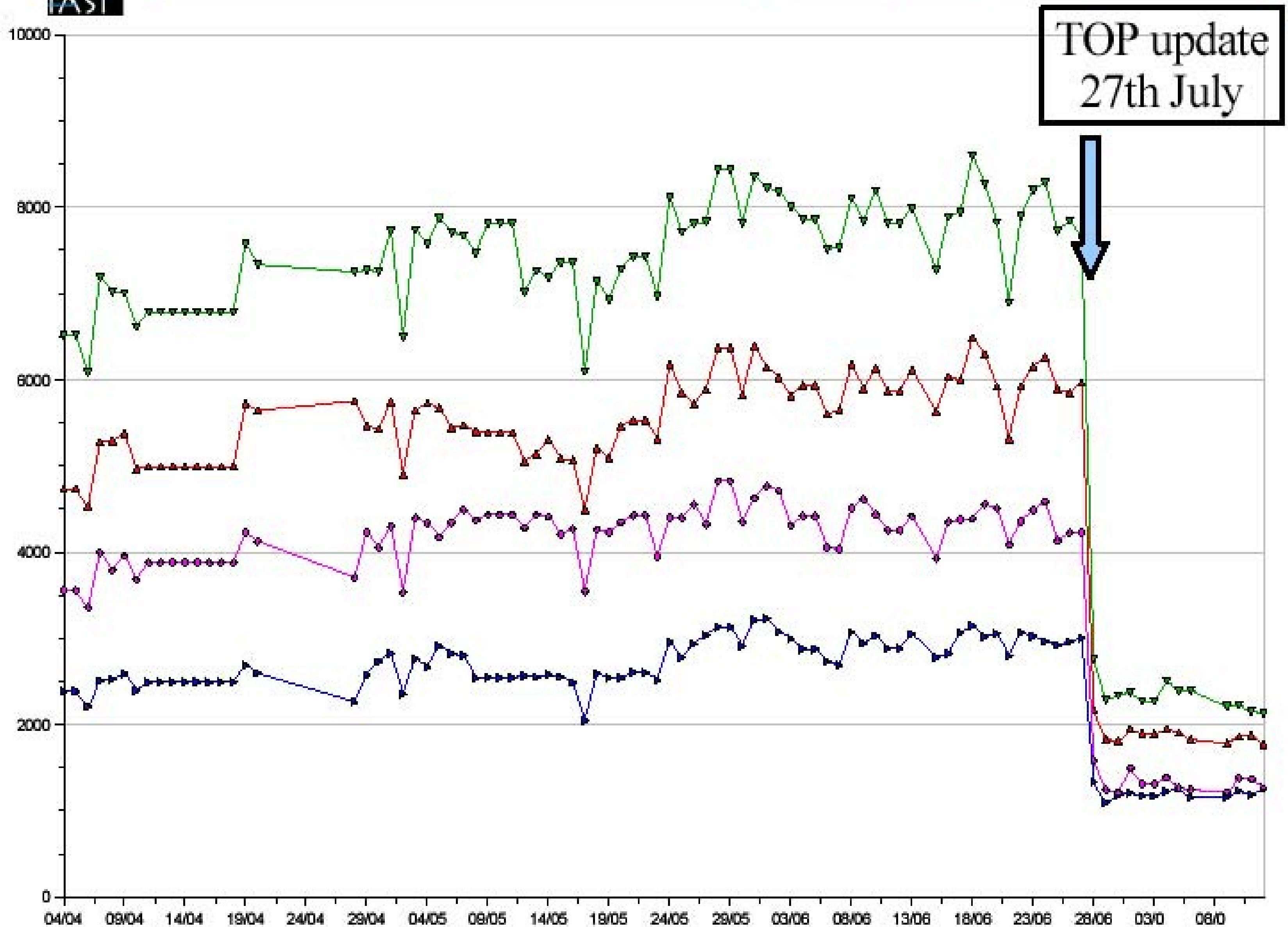


- Good quality
  - > 99 %
  - 4 pixels

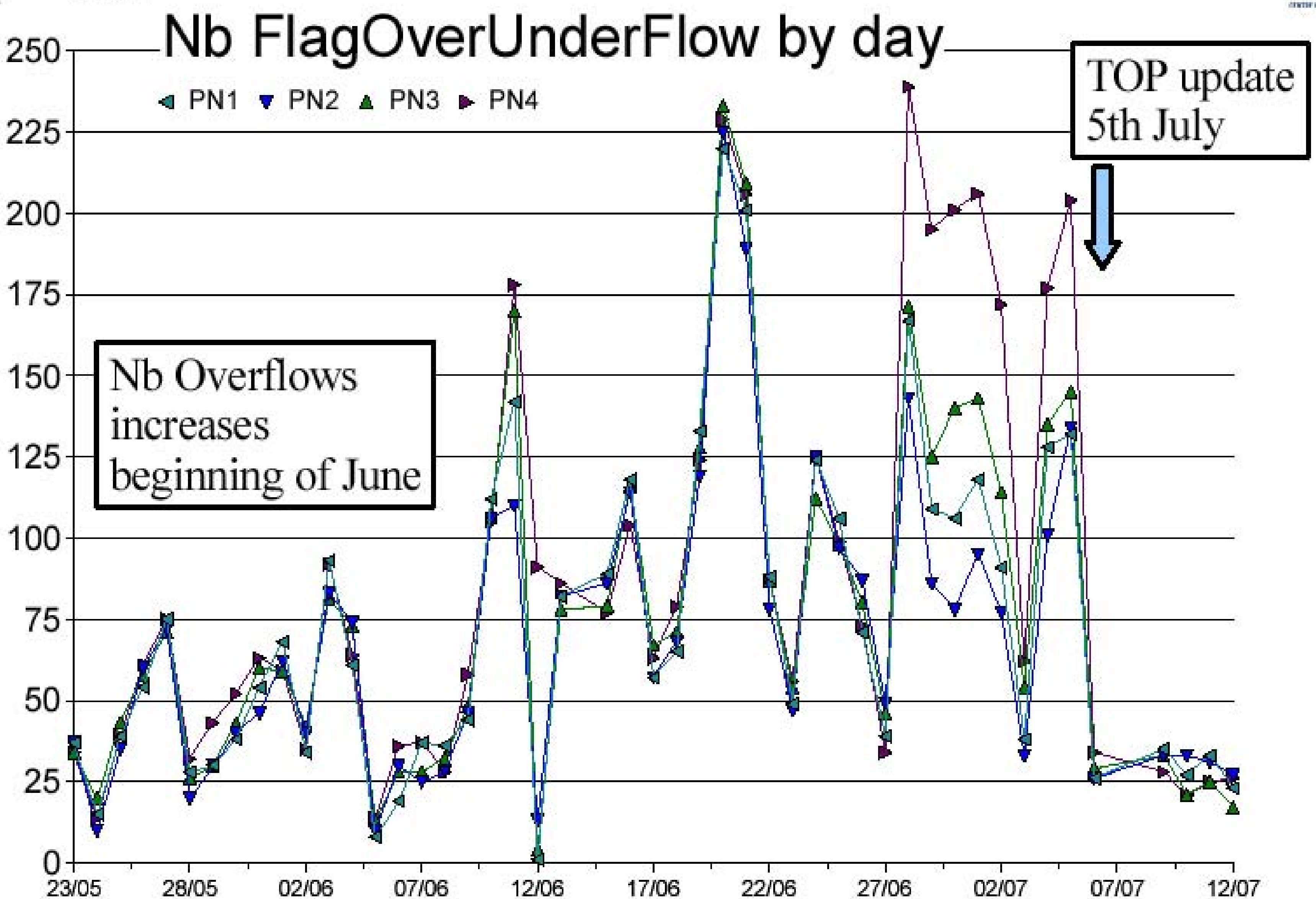
Reduction of the number of rejected spectra (spikes)



Reduction of the number of rejected spectra (NZPD)



Reduction of the number of overflows



Instrument programming

- Weeks 29, 30, august : nothing foreseen nominally
  - overflow frequency monitoring
  - Margins in coding table implemented today
  - Proposed criteria : 1% of spectra with overflows acceptable (today < 0.01 %)
- Week 31 : External Calibration CS1/CS2
  - Moon in CS1
  - Definition of Ext.Cal programmation will be provided next week
  - Time of transitions Ext.Cal -> Normal Op and return will be determined taking into account orbital parameters of monday (3 days after the manoeuvre)

- In September
  - TEC to confirm the date to update the Reduced Spectra (TOP update)
    - Probably end of September or beginning of October
  - 1 short External Calibration Mode to monitor instrument noise
    - 3 orbits sufficient (TBC)

Performances versus Requirements

Instrument performance (L0 Product) verification matrix (1/2)

	IASI Instrument Specification (Issue 6.1) – Performance specifications					
	Label	**Synthetic reminder**	**Spec.**	**Verif**	**Status**	**Comment**
Field Of View	IPC-1	Sounder pixel diameter (km at SSP for a 820 km altitude)	[9,12]	Flight+G	C	
	IPC-2	Sounder pixels nominal position (nominal square definition)		Design		
	IPC-3	Deleted				
	IPC-4	Sounder IPSF uniformity	+/- 5 %	Ground	C	
	IPC-5	Ground test specification for IPSF measurements				
	IPC-6	Electrical cross-talk and straylight – B1,B2,B3	0.1,0.15,0.2%	Flight+G	W	In-flight results better than on-ground results
	IPC-7	Interband coregistration	0.03	Ground	W	
Integrated Imager	IIS-1	IIS spectral channel in IR atmospheric window common with AVHRR		Design	C	
	IIS-2a	IIS Measurement range without saturation for BB scene (Kelvin)	[4,315]	Flight	C	With large margins
	IIS-2b	IIS noise (NeDT at 280 K in K) for scenes in 200-300 K range	0.8 K	Flight	NC	Sporadic small NC mainly on line 5
	IIS-3	Radiometric calibration accuracy for 200-300 K scenes	1	Ground	C	
	IIS-4	Image Field Of View	59.63 x 59.63	Flight	C	
	IIS-5	IIS matrix 64x64. Number of blind pixels	< 2 %	Flight	C	No blind pixels
	IIS-6	IIS operated continuously (day and night)		Design	C	
	IIS-7	MTF at Nyquist frequency greater than	0.3	Ground	C	

C = compliant
W = waiver

Instrument performance (L0 Product) verification matrix (2/2)

	IASI Instrument Specification (Issue 6.1) – Performance specifications					
	Label	**Synthetic reminder**	**Spec.**	**Verif**	**Status**	**Comment**
Spectral	IPS-0	Spectral calibration period (seconds)	80			Input for IPS4
	IPS-1	IASI useful spectral range (cm-1)	[645,2760]	Design	C	Actually [640.41,2764.09]
	IPS-2	Non apodised spectral resolution (between 0.35 and 0.5 cm-1)	Table	Flight+G	C	Interferometric position measured in-flight
	IPS-3	Maximum spectral shift ($\delta\nu/\nu$)	2E-4	Flight	C	
	IPS-4	Spectral calibration stability over calibration period	1E-6	Flight	C	
	IPS-5	Shape error index	Table	Ground	C	Small waivers accepted
	IPS-6	Unpredictable perturbations of the sounder SRF (around 0)	2%	Ground	C	
	IPS-7	Unpredictable perturbations of the sounder SRF	2%	Ground	C	
Radiometry	IPR-0	Radiometric calibration period (seconds)	2E-6	Flight	C	See detailed presentation
	IPR-1	Sounder Measurement range for Black Body scene (Kelvin)	[4,300]	Flight	C	With large margins
	IPR-2	Instrument radiometric noise (NeDT in Kelvin at 280 K)	Table	Flight	W	Compliance except in a few spectral regions (waivers after ground testing of the instrument)
	IPR-3	Range of scene temperatures (BB) for radiometric calibration specs	[200,300]			
	IPR-4	Radiometric calibration – absolute	0.5	Flight+A	C	Long term by analysis
	IPR-5	Radiometric calibration – orbital variations	0.15	Flight+A	C	
	IPR-6	Radiometric calibration – lifetime repeatibility	0.15	A	C	Main contribution : stability of BB temp. meas.
	IPR-7	Radiometric calibration – intercalibration between channels	0.1	Flight	C	
	IPR-8	Radiometric calibration – intercalibration between pixels and scans	0.1	Flight	C	
Geometry	IPG-1	Scanning pattern		Design	C	
	IPG-2	Scanning step accuracy (mrad)	2 (1 σ)	Flight	C	
	IPG-3	Deleted				
	IPG-4	Stability of viewing direction during 1 interferogram acquisition (mrad)	1 (1 σ)	Flight	C	
	IPG-5	Pointing direction wrt to METOP interface	+/- 4	Flight+G	C	
	IPG-6	Sounder/IIS co-alignement (mrad)	5	Flight	C	
	IPG-7	Sounder/IIS co-alignement stability (mrad)	0.8	Flight	C	
	IPG-8	Line cycle duration			C	
	IPG-9	Synchronisation requirements			C	

System performance (L1 Product) verification matrix

	IASI System Specification (Issue 7) – Products Requirements					
	Label	**Synthetic reminder**	**Spec.**	**Verif**	**Status**	**Comment**
L0	FRP-0	Random contributions taken as rms value				
	FRP-1	Level 0 data structure ...				
	FRP-2	Level 0 data supplemented as necessary by EPS ancillary data				
	FRP-3	Level 0 data rate < 1.5 Mbits/sec				
	FRP-4	N.A.				
L1A	FRP-5	Level 1a data shall contain ...				
	FRP-6	IASI useful spectral range (cm-1)	[645,2760]	Design	C	
	FRP-7	Sampling interval (cm-1)	0.25	Design	C	
	FRP-8	Spectral calibration – knowledge of sample position δν/ν	2E-6	Flight	C	See detailed presentation
	FRP-8c	Sounder Measurement range (Kelvin)	[180,315]	Flight	C	With large margins
	FRP-9	Level 1A noise (NeDT in Kelvin at 280 K)	Table	Flight+A	W	Compliance except in a few spectral regions (waivers after ground testing of the instrument)
	FRP-10	Radiometric calibration – Absolute (Kelvin at 280 K)	0.5	Flight+A	C	
	FRP-11	Radiometric calibration – Stability/Repeatability	0.3	Flight+A	C	Long term by analysis
	FRP-12	Radiometric calibration – inter band, inter pixels, scan angle	0.2	Flight+A	C	
	FRP-13	NeDT scaling rules for scene temperatures changes				
	FRP-13a	IIS Measurement range (Kelvin)	[180,315]	Flight	C	With large margins
	FRP-14	Accuracy on time of mid-measurements (second)	1		C	With large margins
	FRP-15	Geographical position of pixels (km at SSP)	7	Flight	C	Absolute
	FRP-16	IIS position wrt to AVHRR (km at SSP)	0.3	Flight	C	Rare out of specs (lack of spatial structure)
	FRP-17	Accuracy of measurements angles (radian)	0.002	Flight	C	
	FRP-18	Knowledge of sounder SRF -> error EW simulated temp. (K at 280 K)	0.1	Flight+G	C	Use of Flight + Ground test measurements
	FRP-18	Knowledge of IIS SRF -> error EW simulated temp. (K at 280 K)	1	Flight+G	C	Use of Flight + Ground test measurements
	FRP-19	IIS -Sounder coregistration (km at SSP)	1	Flight	C	
L1B	FRP-20	L1B characteristics same as L1A when not specified				
L1C	FRP-21	L1C characteristics same as L1A when not specified				
	FRP-22	Spectral resolution – +10% acceptable for ν > 2420 cm-1 (cm-1)	0.5	Flight+G	C	Interferometric position measured in-flight
	FRP-23	Level 1C noise (NeDT in Kelvin at 280 K)	Table	Flight+A	W	Compliance except in a few spectral regions (waivers after ground testing of the instrument)
	FRP-24	Description of AVHRR radiances in sounder pixels		Design	C	

Conclusion

- After more than 7 months in orbit
  - IASI is performing very well
  - Instrument and processing
- All performances very stable in the long term
  - Radiometry, spectral, geometry
- L1 commissioning using mainly IASI, AVHRR & HIRS data
  - Some controls done with respect to AIRS and IASI Balloon data
- Feedback from End Users Bias Monitoring (NWP)
  - Very positive
  - IASI L1 Cal/Val Meeting
  - EUMETSAT / ECMWF / UK MetOffice / METEO FRANCE / CNES

CLARREO in the context of other international efforts

MetOp of EUMETSAT with a series of 3 satellites (5 yr lifetime each) will provide precise/accurate climate related data over a span of 15 years (start end of 2006)

IASI for the **IR**

GOME-2 for the SW

IASI Level 1 IR radiances

- In-orbit internal radiometric calibration essential (BB temperature related to NIST standards by industry, BB emissivity determined on ground pre-flight, constant monitoring of instrument parameters at TEC)
- Overlap periods expected between « identical » IASI instrument models on 3 successive MetOp satellites
- Careful inter-comparisons between different IR satellite sensors (IASI, AVHRR, AIRS up to now, TES … in a later phase) proved very efficient to validate radiometric performances
- Importance of synergy between IR sounder (IASI) and imagers (IIS and AVHRR) for proper scene heterogeneity characterization (surface and clouds)

First IASI conference

Organized by CNES and EUMETSAT in Anglet (near Biarritz), France from 13 to 16 November 2007

http://smsc.cnes.fr/IASI