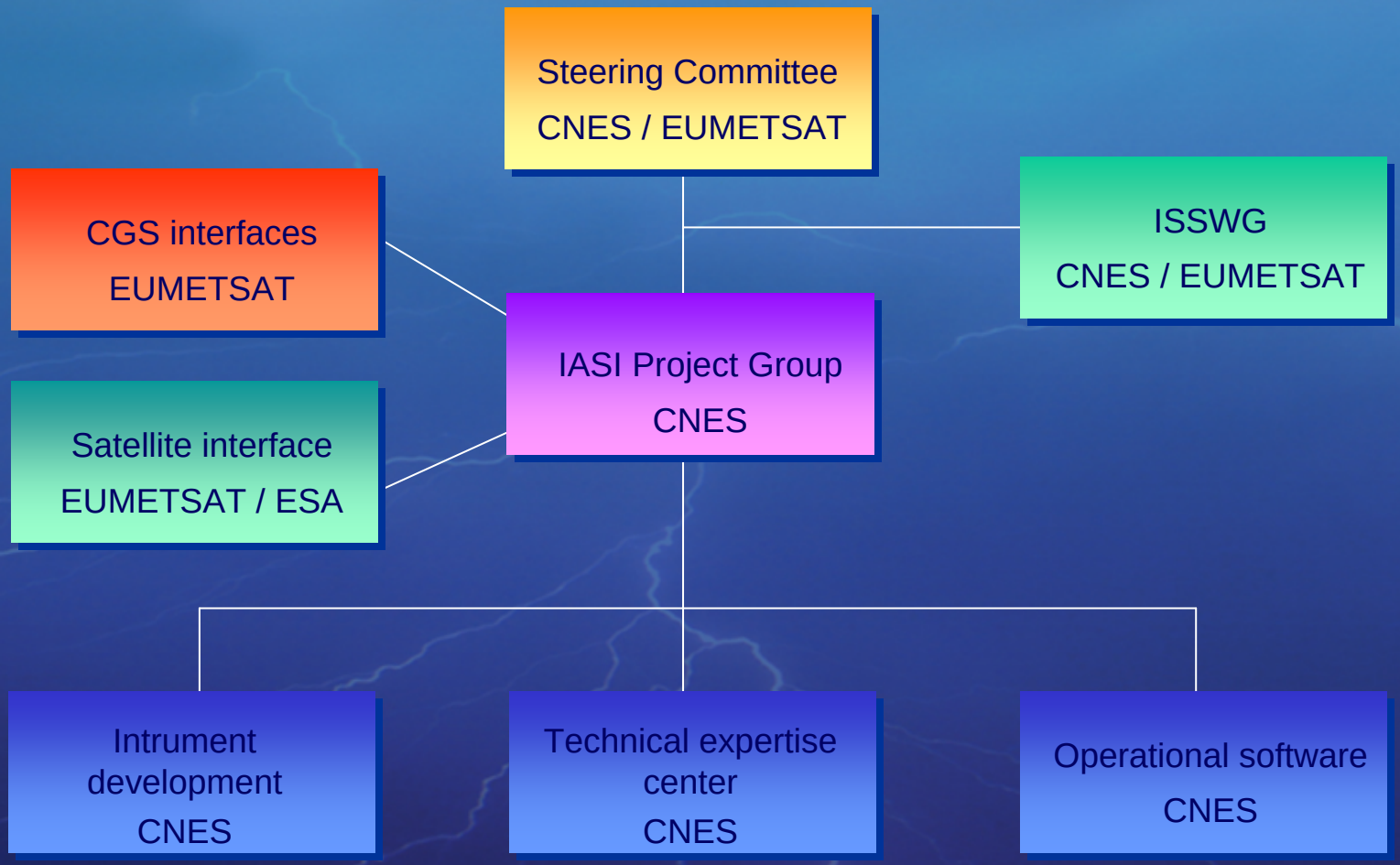
IASI instrument performances just before the launch of MetOp

Camy-Peyret C., Phulpin T., Blumstein D., Tournier B., Schlüssel P.

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
Noveltis
EUMETSAT
LPMAA
Laboratoire de Physique Moléculaire pour l'Atmosphère et l'Astrophysique
UNIVERSITE PIERRE & MARIE CURIE

cnes

Partners

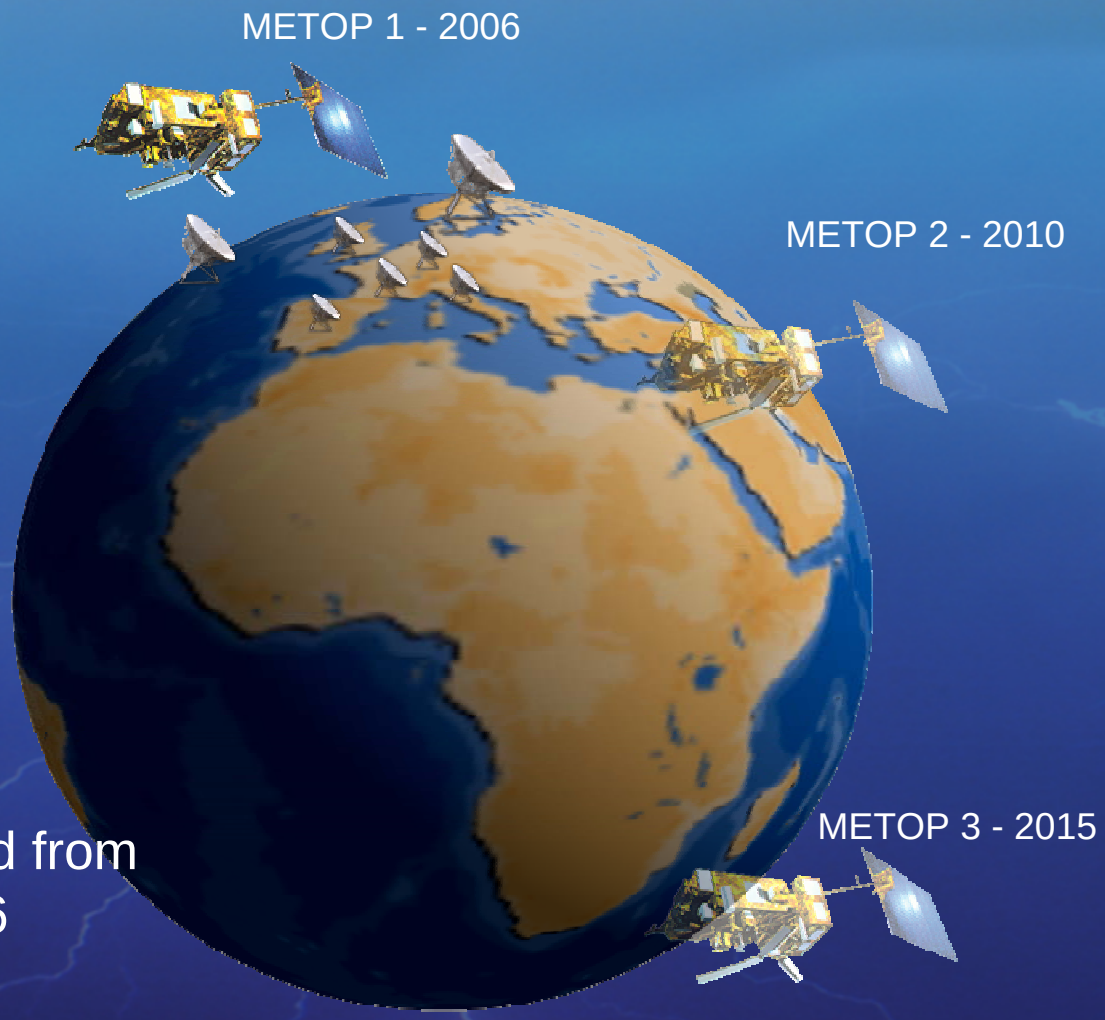

Steering Committee
CNES / EUMETSAT
CGS interfaces
EUMETSAT
ISSWG
CNES / EUMETSAT
IASI Project Group
CNES
Satellite interface
EUMETSAT / ESA
Intrument development
CNES
Technical expertise center
CNES
Operational software
CNES

Requirements

GEOPHYSICAL VARIABLES	ACCURACY	VERTICAL RESOLUTION	HORIZONTAL SAMPLING
Temperature profile	1K (cloudfree)	1 km	25 km (cloudfree)
Humidity profile	10%(cloudfree)	1-2 km troposphere (cloudfree)	25 km (cloudfree)
Ozone total amount	5%(cloudfree)	N/A	25 km (cloudfree)
Ozone vertical distribution	10%(cloudfree)	2 or 3 pieces of independant information	25 km
Fractional cloud cover	10%		
Cloud top temperature Cloud emissivity	2K		
CO, CH_4, N_2O column	10%	N/A	100 km
SO_2, CFCs	10%-20%		
Sea surface temperature	<0.5K (cloudfree)		25 km
Land surface temperature	1K (cloudfree)		25 km
Land surface emissivity	1%		25 km

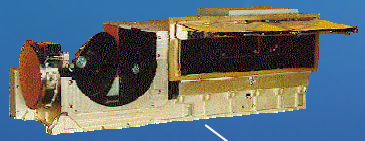
METOP

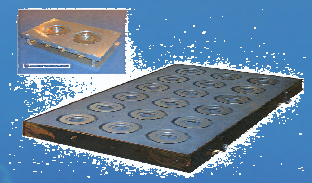
- Eumetsat Polar System Elements
- 14 years of operation
- >95% reliability on 5 years

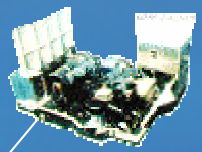


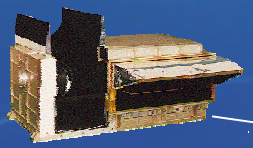
Launch of METOP 1 slated from Baikonour on 17 July 2006

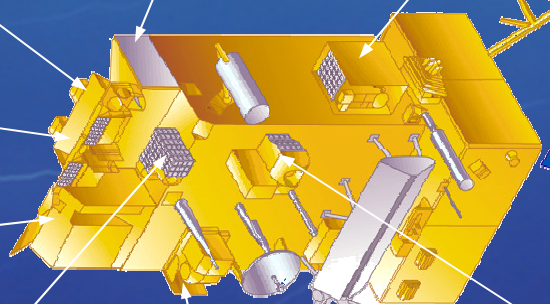
Spacecraft and Instruments

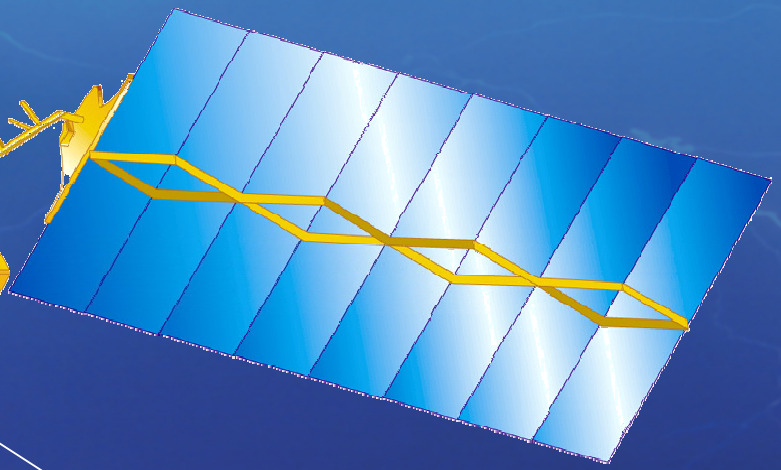

AVHRR-3

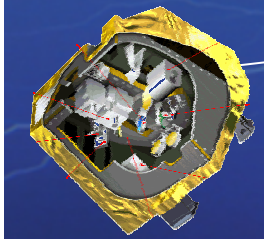

GRAS

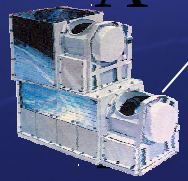

GOME-2

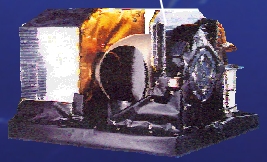

HIRS-4
METOP 1/2 only



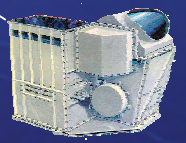



IASI

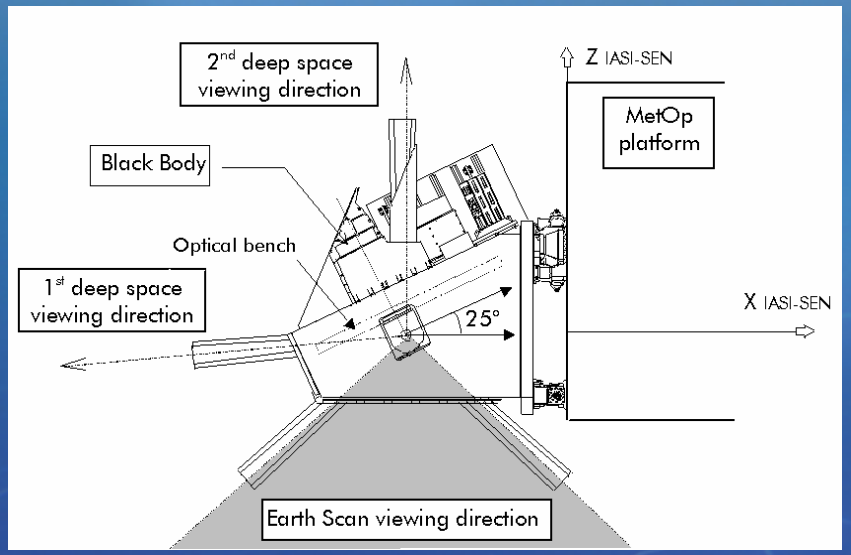

AMSU-A1

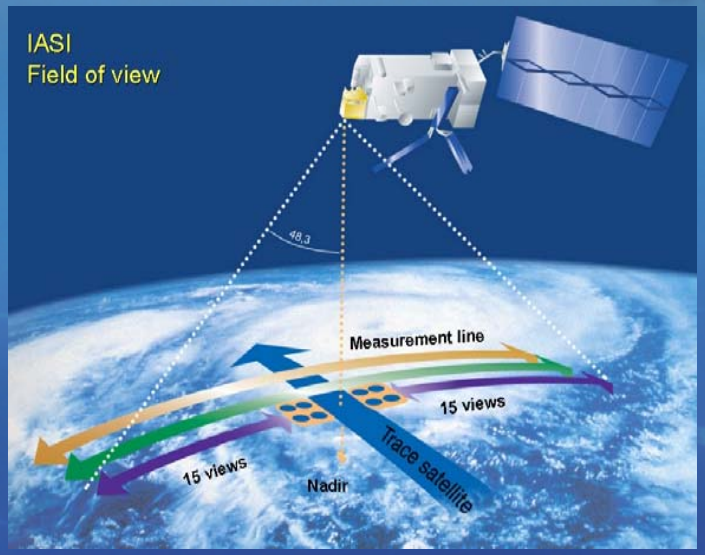

MHS

ASCAT


AMSU-A2

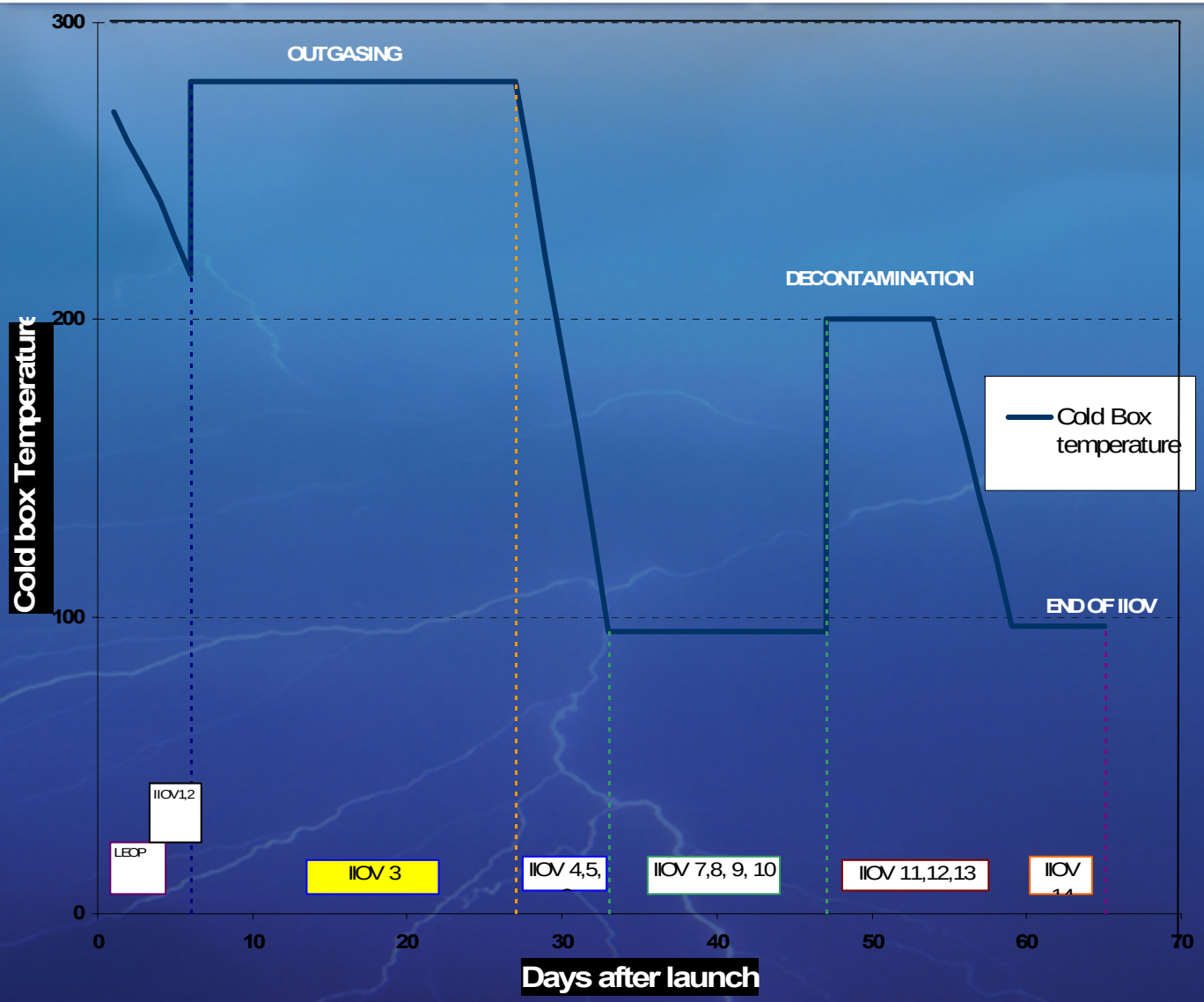
Overview of the instrument





- Normal Operation 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 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), BB, CS1, CS2 or SM
  - 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 VDS)


300
200
100
0
OUTGASING
DECONTAMINATION
END OF IIOV
Cold box Temperature
Cold Box temperature
IIOV1,2
LEOP
IIOV 3
IIOV 4,5,
IIOV 7,8, 9, 10
IIOV 11,12,13
IIOV
0
10
20
30
40
50
60
70
Days after launch

Phasing of the activities

METOP Launch

IASI ON

IASI Level 1 early delivery

IASI System Commissioning Review (SCR)

(SCR held in conjunction with EPS CHR)

Pre-launch | IASI Level 1 Commissioning (6 months) | EPS Pre-operationnal phase | Routine operations

Phase A — Instrument activation & evaluation / system technical evaluation

Phase B — Early validation of Level 1 Products

Phase C — In-depth validation of Level 1 products

- instrument test & calibration
- system V & V
- Cal/Val tools & procedures

- instrument activation & evaluation
- system verification
- calibration & processing parameters optimization
- performance assessment
- define performance monitoring threshold
- update
  * processing (if necessary)
  * Cal/Val procedures (if necessary)

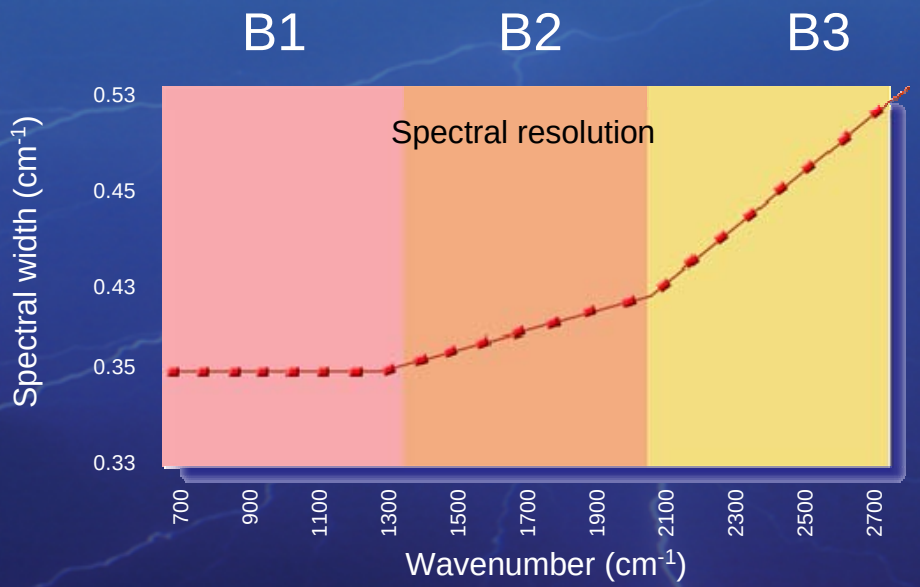
- operational delivery of Level 1 Products

This is a logical view, some overlap between the different phases is expected

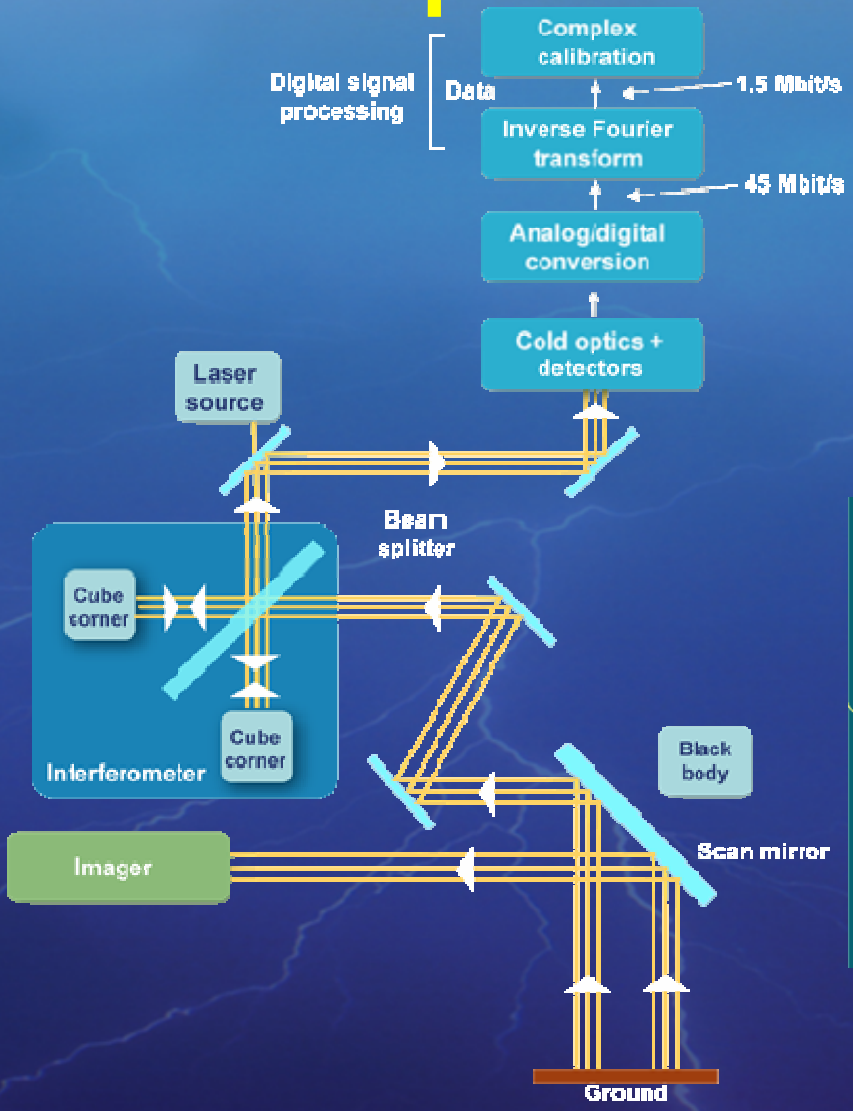
- Accuracy of the validation and diversity of the conditions in which the validations are performed increase with time
  - Type of reference measurements and their accuracy evolve accordingly
    - stand alone IASI measurements
    - comparison with other spaceborne instruments
    - meteorological soundings and dedicated correlative measurements (balloons, aircraft)

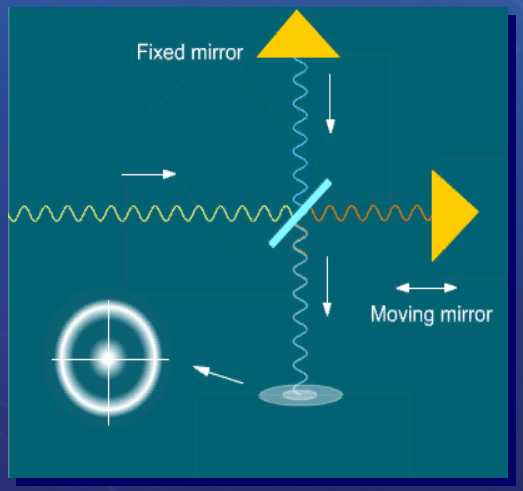
Spectral : resolution (1/2)

- Spectral resolution (FWHM)
  - The spectral resolution specification is based on the line spacing in the 650 cm^{-1} CO_2 absorption band
  - This spacing is about 1.5 cm^{-1}
- Spectral sampling interval = 0.25 cm^{-1}

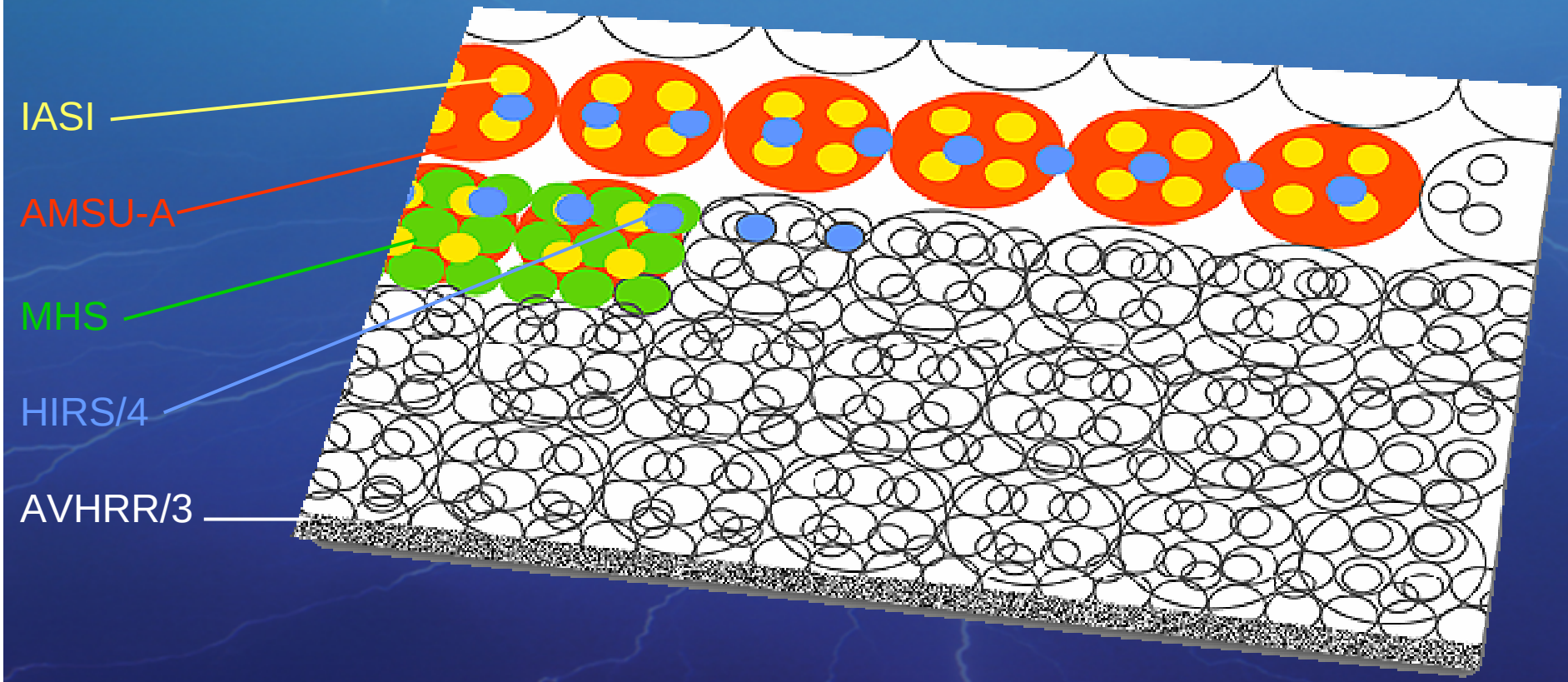


Functional description





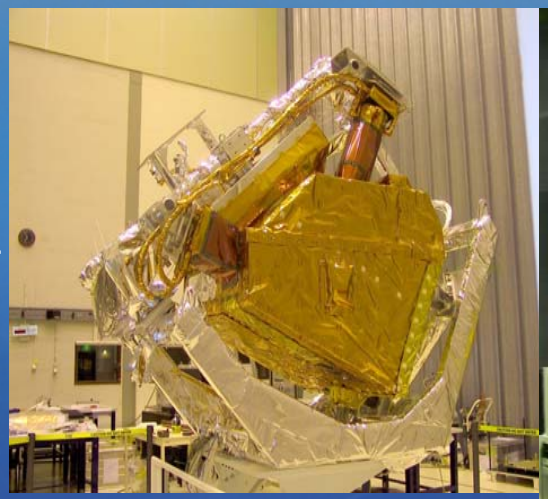
Instrument Scan Patterns



Performances Tests

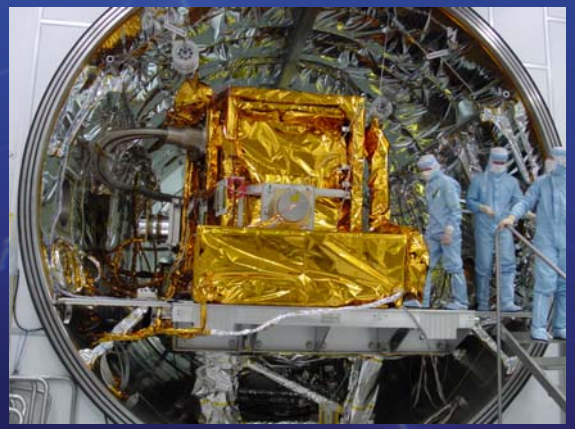
PFM Optical vacuum test : Oct 2003

PFM test on-board Metop: Feb 2004



Courtesy EADS

FM2 optical vacuum test : Sept. 2004



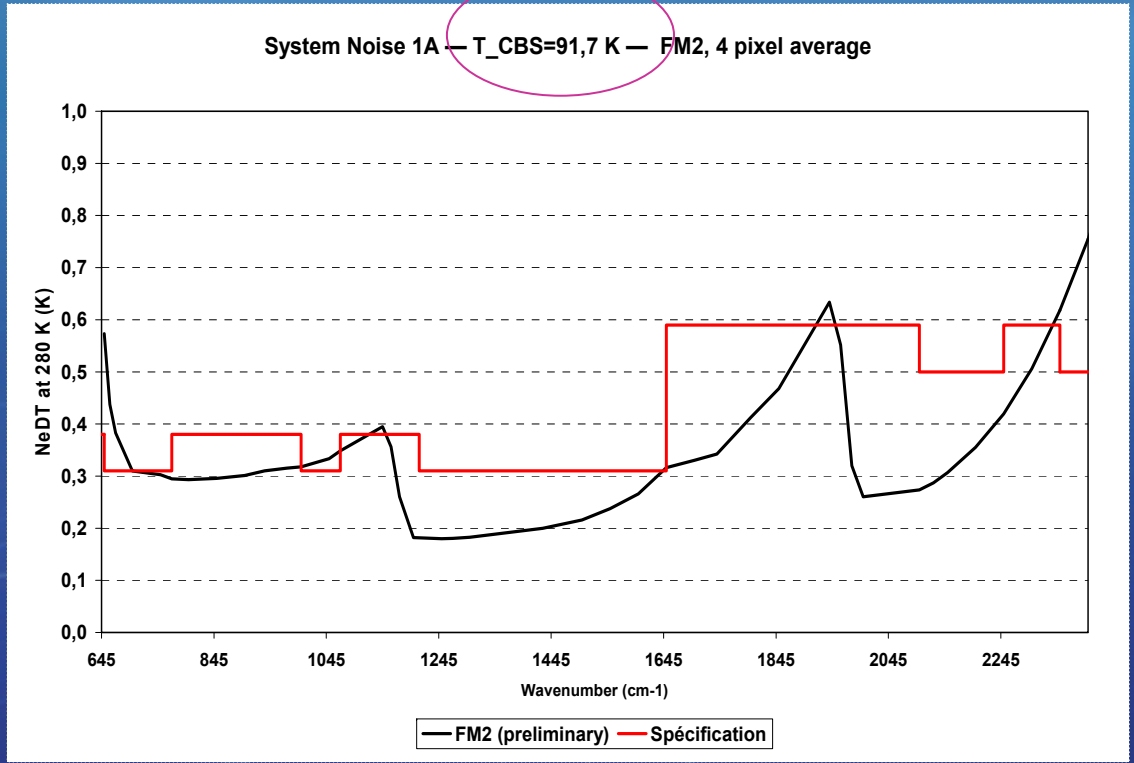
FM3 optical vacuum test : Oct. 2005

Courtesy Alcatel

Metop - fully integrated

System radiometric noise for FM2 :

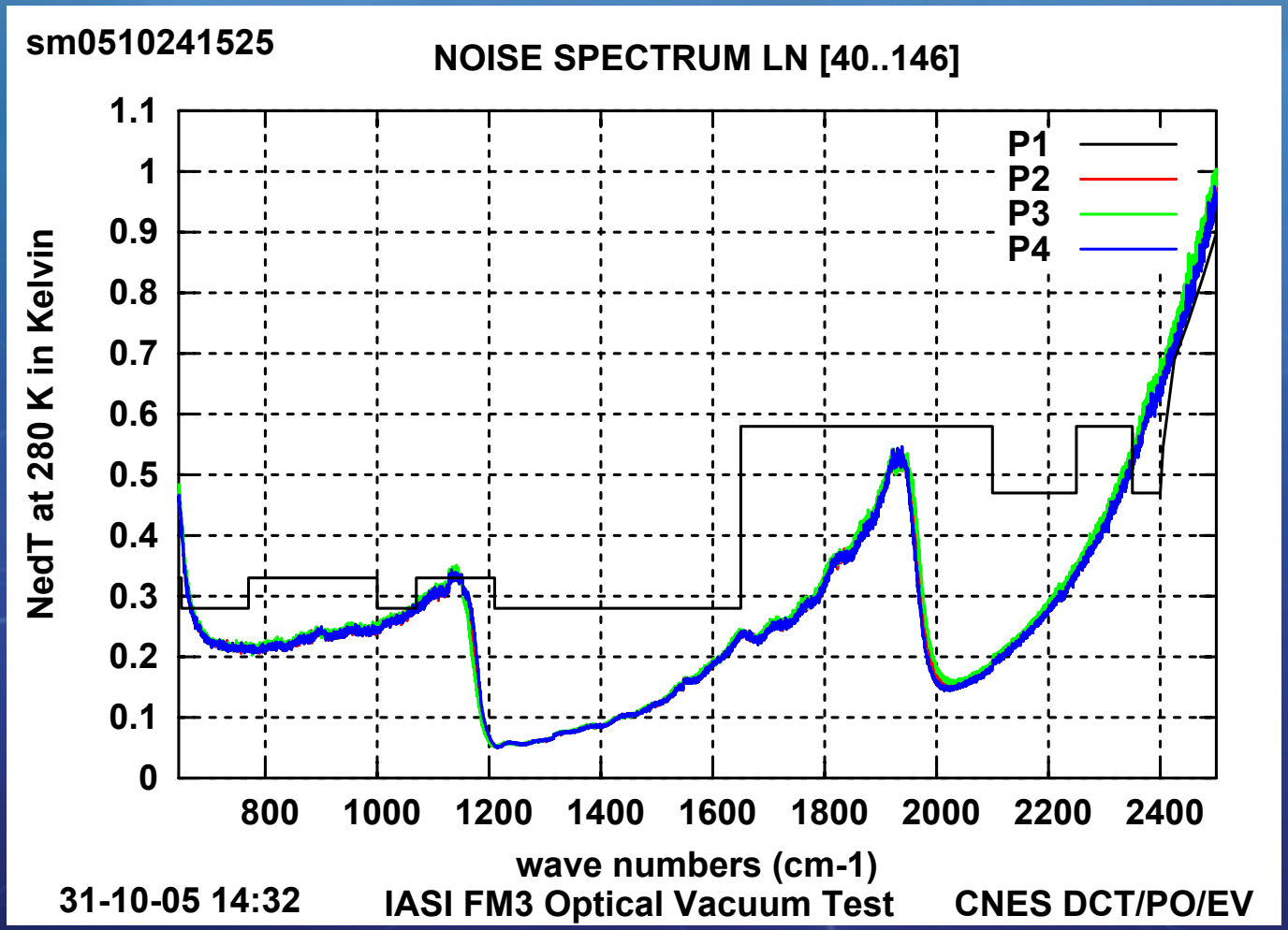
- Raw inteferograms processed with DPS
- Average of 4 pixel *27scan angle*40 lines
- Noise for each line and averaged on 40 lines



After cold box design modifications, ice contamination issue solved

FM3 Optical vacuum tests

- FM3 OVT tests were carried out successfully at Alcaltel in October 2005
- FM3 showed the same behavior than FM2
- Radiometric performances are slightly better (specially in B1) and confirm the validity of the models.
- Calibration is as good as for the FM2
- Water contamination is weak and could lead to a loss of about 0.2%/day
- Instrument was accepted by the Technical Review board
- It is now stored at Alcalel for integration on a next MetOp platform

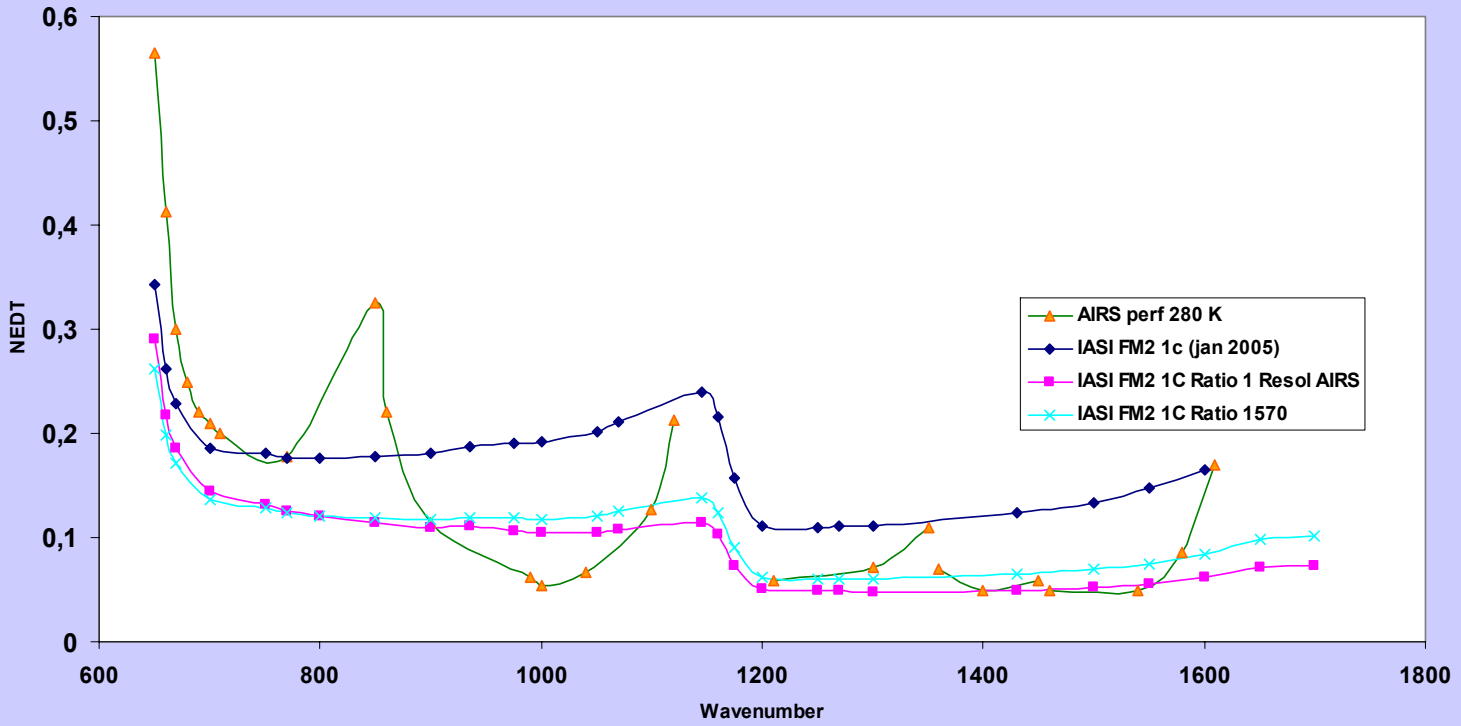

sm0510241525
NOISE SPECTRUM LN [40..146]
NedT at 280 K in Kelvin
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
800
1000
1200
1400
1600
1800
2000
2200
2400
wave numbers (cm-1)
P1
P2
P3
P4
31-10-05 14:32
IASI FM3 Optical Vacuum Test
CNES DCT/PO/EV

Radiometric calibration

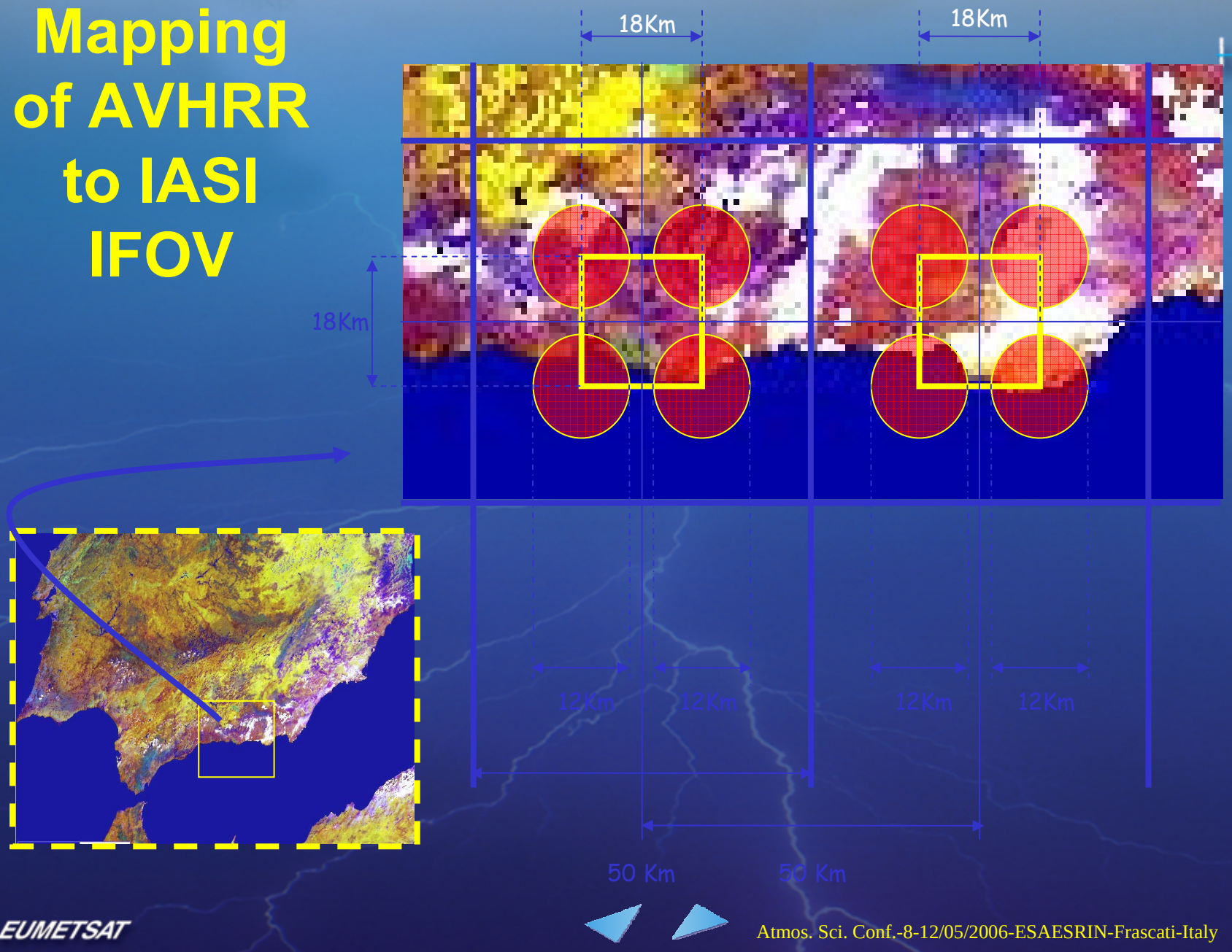
- Objectives of the Mission Specification on radiometric calibration are expected to be achieved in orbit
- Absolute Calibration error
  - < 0.5 K
- Intercalibration errors at a given time for all geophysical conditions
  - < 0.2 K
  - 4 pixels, all scan directions, all channels
- Intercalibration errors over time
  - < 0.3 K
  - Random variations (over orbit period)
  - Long term variations

Comparison IASI/AIRS

	AIRS on AQUA	IASI on MetOp
Overpass time	13:30	9:30 AM
Spectral coverage	2378 channels 650 to 2670 cm^{-1} with gaps (1136-1216, 1614-2170)	8461 channels 645 to 2760 cm^{-1} continuous
Radiometric performances	See plot	See plot
Spectral Performances	From 0.4 to 2.5 cm^{-1}	From 0.32 to 0.46 cm^{-1}
Geometry	3*3 pixels of 15*15 km^2	2*2 pixels of 12*12 km^2

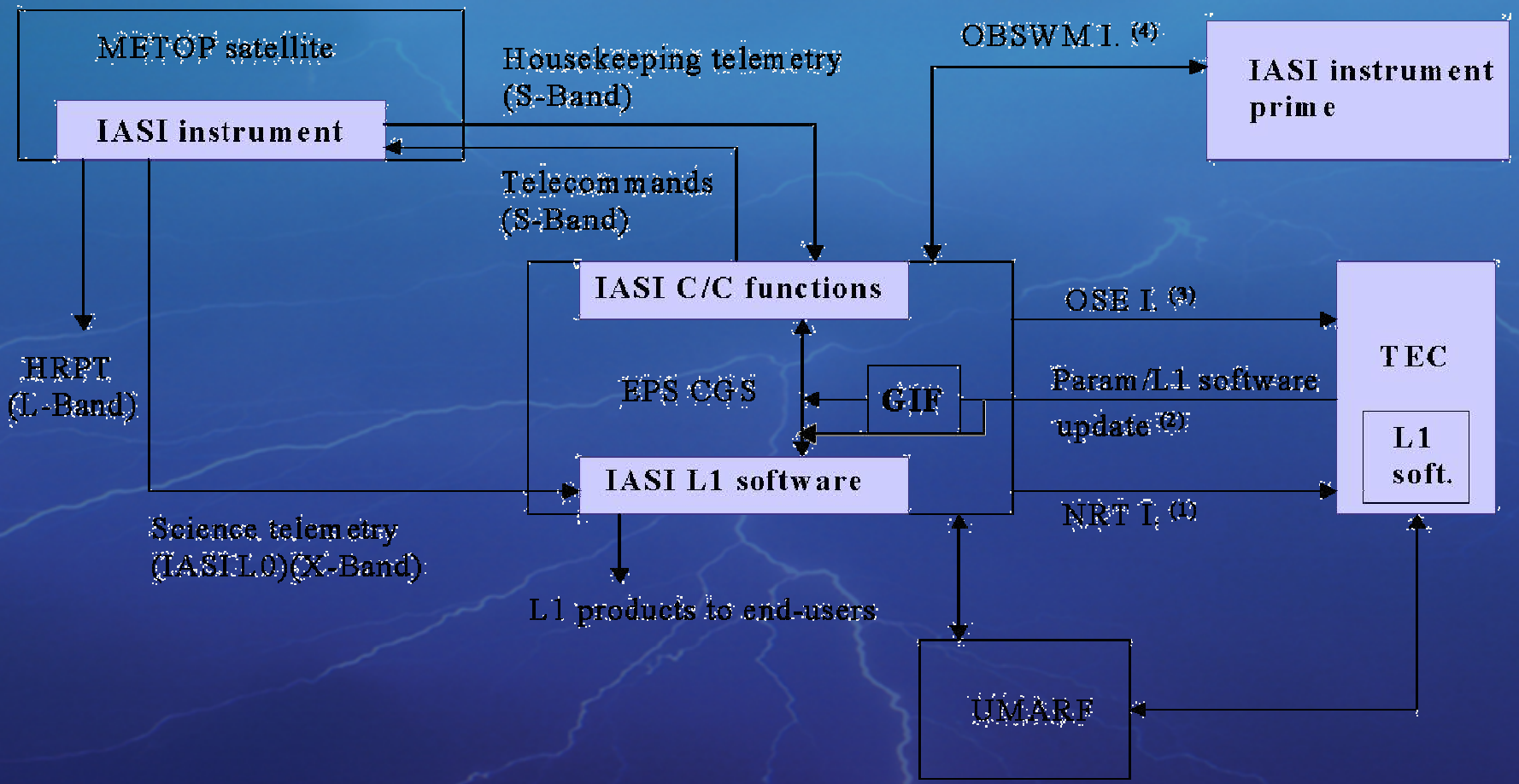

0,6
0,5
0,4
0,3
0,2
0,1
0
NEDT
600
800
1000
1200
1400
1600
1800
Wavenumber
AIRS perf 280 K
IASI FM2 1c (jan 2005)
IASI FM2 1C Ratio 1 Resol AIRS
IASI FM2 1C Ratio 1570

Mapping of AVHRR to IASI IFOV



IASI SYSTEM

IASI System



IASI Level 2 Product Generation High Level Break-Down

IASI Level 1c | AVHRR Cloud Mask and S/CTT | Configurable Databases

ATOVS Level 2 | AMSU-A Level 1 | MHS Level 1 | NWP Forecast

Pre-Processing

Cloud Processing

Geophysical Parameters Retrieval

Monitoring Information | Level 2 Product | Quality Information

Properties of the Operational IASI L2 Processor (1/3)

- For a best use of IASI measurements the level 2 processing can combine IASI with concurrent measurements of AVHRR, AMSU-A, MHS, and ATOVS Level 2 products
- IASI stand-alone processing is possible if other measurements are not available, or if Product Processing Facility is explicitly configured to exclude other instruments
- NWP forecast is included to provide surface pressure as reference for the profiles to be retrieved and surface wind speed over sea for the calculation of surface emissivity
- Optionally, the NWP forecast profiles of temperature, water vapour and ozone can be used to initialise and/or constrain the retrieval

Properties of the Operational IASI L2 Processor (2/3)

- Processing is steered by configuration settings (80 configurable auxiliary data sets), which allows for optimisation of Product Processing Facility before and during commissioning
- Online quality control supports the choice of best processing options in case of partly unavailable IASI data or corrupt side information (data from other instruments or NWP forecast)
- Besides error covariances a number of flags are generated steering through the processing and giving quality indicators; 40 flags are specified, which are part of the product

Properties of the Operational IASI L2 Processor (3/3)

- All 8461 IASI spectral samples, covering the spectral region from 645 to 2760 cm^{-1}, are used in the retrieval to maximise the retrieved information
- The Product Processing Facility supports nominal and degraded instrument modes (e.g. failure of single detectors/bands)
- Bias control by radiance tuning via configuration

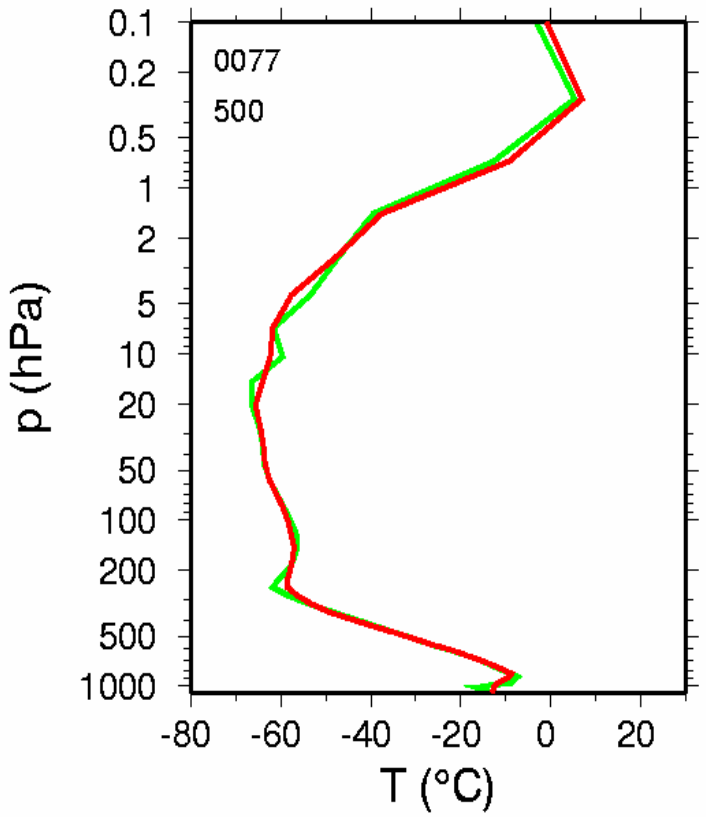
Geophysical Parameters Retrieval
State Vector to be Retrieved

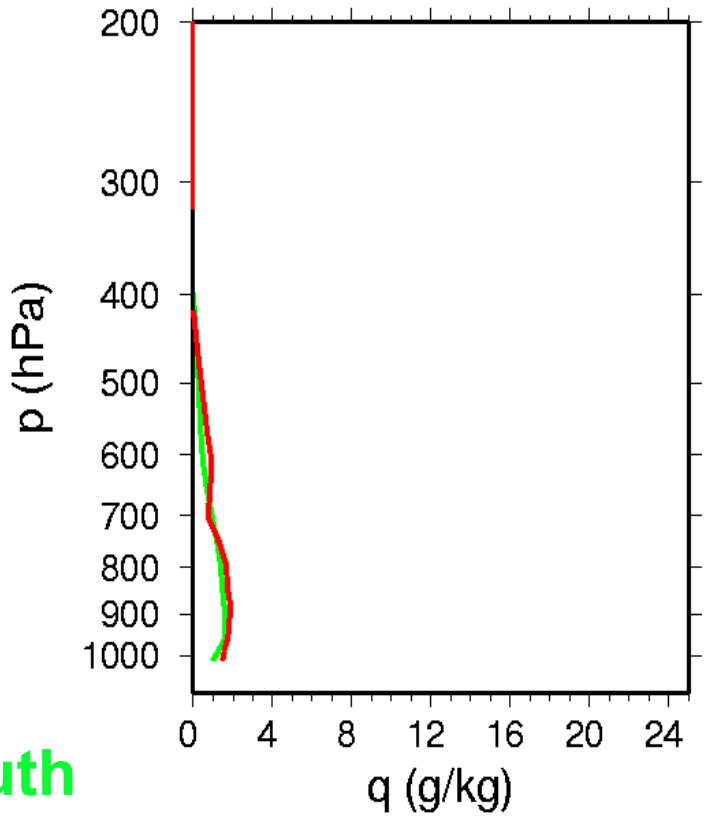
- The state vector to be retrieved consists of the following parameters
  - Temperature profile at a minimum of 40 levels
  - Water vapour profile at a minimum of 20 levels
  - Ozone columns in deep layers (0-6km, 0-12 km, 0-16 km, total column)
  - land or sea surface temperature
  - surface emissivity at 12 spectral positions
  - Columnar amounts of N_2O, CO, CH_4, CO_2
  - Cloud amount (up to three cloud formations)
  - Cloud top temperature (up to three cloud formations)
  - Cloud phase
- In case of clouds and elevated surface the state vector has to be modified
- The level 2 product contains the state vector along with information on quality and processing options and compressed error covariance

Geophysical Parameters Retrieval
First Retrieval

- Spectra PC scores regression for temperature and water-vapour, and ozone profiles, surface temperature, and surface emissivity
- Artificial neural network (multi-layer perceptron) for trace gases (optionally also for temperature, water-vapour and ozone, depends on configuration setting)
- The results from the first retrieval may constitute the final product or may serve as input to the final, iterative retrieval; the choice depends on configuration setting and on quality of the first retrieval results

Retrieval Simulation:
Example for Single Retrieval
Arctic Atmosphere

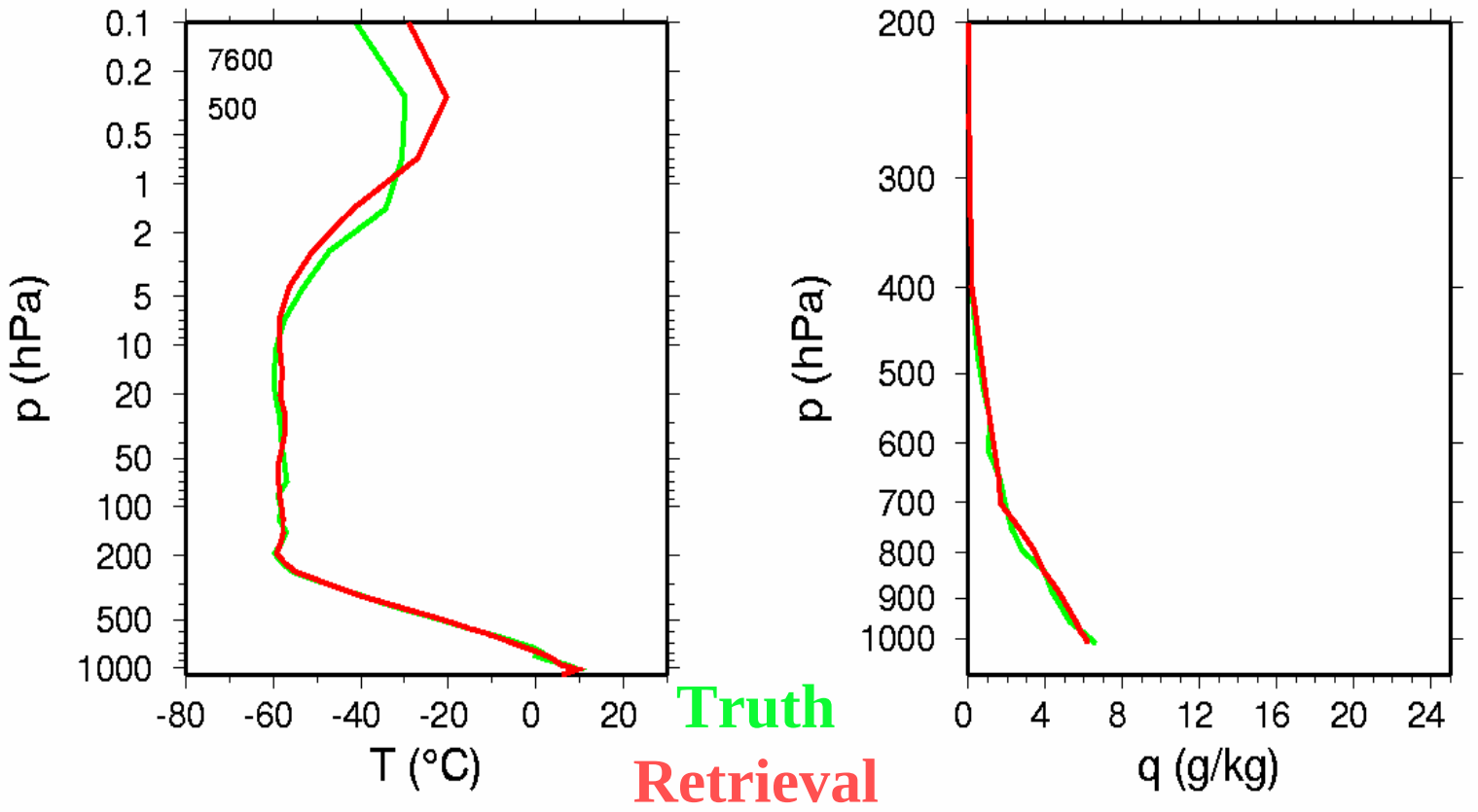




Truth

Retrieval

Retrieval Simulation:
Example for Single Retrieval
Mid-Latitude Atmosphere



Final, Iterative Retrieval

- Simultaneous iterative retrieval, seeking maximum probability solution for minimisation of cost function by Marquardt-Levenberg method, using a subset of IASI channels, combined to super-channels
- Initialisation with results from first retrieval
- Other choices of initialisation may be selected, depending on configuration setting and availability (e.g. NWP forecast, climatology, ATOVS Level 2 product)
- Background state vector from climatology, ATOVS Level 2 product, adjacent retrieval, or NWP forecast, depending on configuration and availability
- State vector to be iterated depends on cloud conditions and configuration setting (clear, cloudy, variational cloud clearing)

ISSWG

- The IASI Sounding Science Working Group (ISSWG) has been acting as a Science Team for preparing and exploiting at best the IASI mission
- The ISSWG is jointly appointed by Eumetsat and CNES.
- J. Taylor (UKMO) and C. Camy-Peyret (LPMAA/CNRS) are presently co-chairs
- Several studies both by theroretical simulations and by experimental work have been performed in this framework. Examples are shown.
- This group together with other teams selected after the RAO ESA/EUMETSAT for MetOp will continue to participate in cal/val and scientific use of IASI data after launch

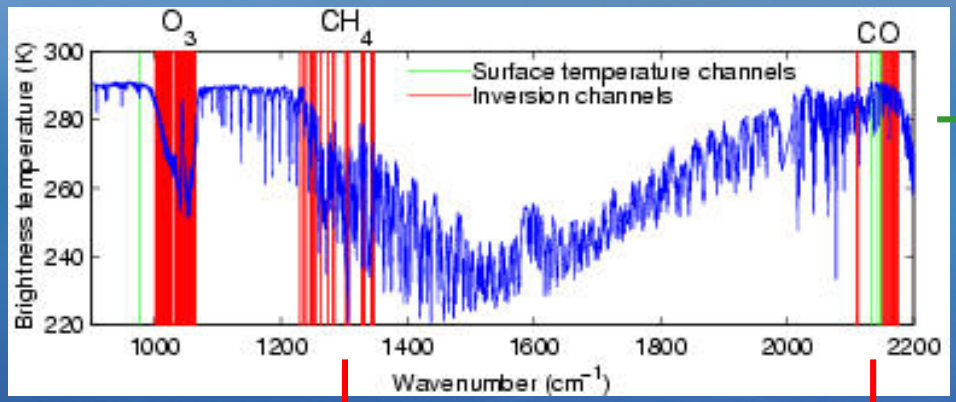
[a] The accuracy are provided for a 50 km horizontal resolution (averaged of 4 pixels) and for cloud-free conditions

[b] Coarse profiles will be tentatively retrieved (research products)

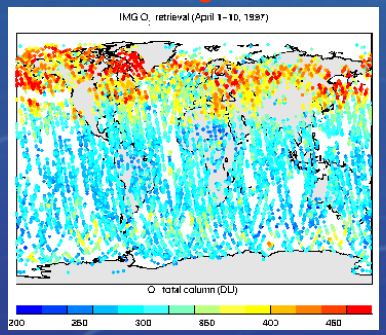
[c] For 500 km × 500 km and 15 days in time

Retrieved quantity	Horizontal resolution (km)	Vertical resolution (km)	Typical accuracy[a]	Reference(s) of retrieval algorithm
Temperature	25	1 km (tropo)	1 K	*Operational product* Schlüssel *et al.*, 2005
Water vapour	25	1-2 km (tropo)	10%	*Operational product* Schlüssel *et al.*, 2005
Ozone	25	Total column 0-6;0-12;0-16	2% 30%;15%;9%	*Operational product* Turquety *et al.*, 2004
CO	25	Total column[b]	5-10%	*Operational product* Turquety *et al.*, 2004
CH_4	25	Total column[b]	3%	*Operational product* Turquety *et al.*, 2004
N_2O	25	Total column	5%	*Operational product* Lubrano *et al.*, 2004
HNO_3	25	Total column[b]	NA	*Research product*
CO_2	500	Total column	1%[c]	*Research product* Chedin *et al.*, 2003
CFC-11;CFC-12	200	Total column	NA	*Research product* Coheur *et al.*, 2003

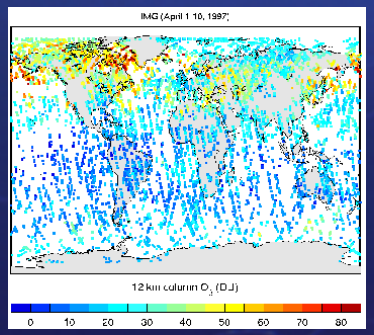
IMG distributions using IASI processing tools **(operational mode)**



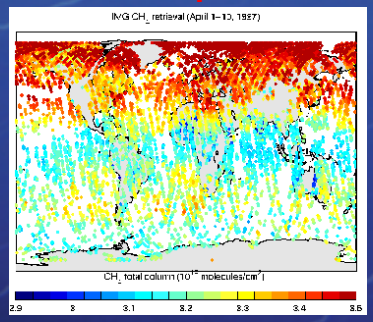
O_3



Turquety *et al.* GRL 2002

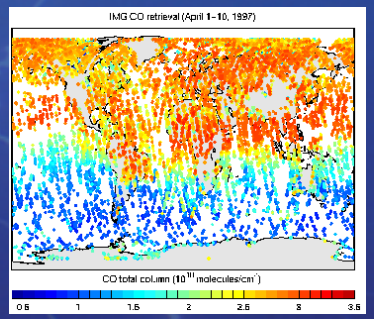


CH_4



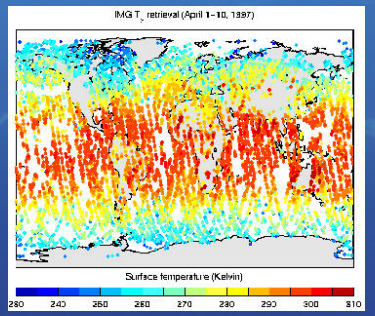
Clerbaux *et al.*, ACP 2003

CO



Clerbaux *et al.*, IEEE 1999; JGR 2001
Hadji-Lazaro *et al.*, JGR 1999

Ts



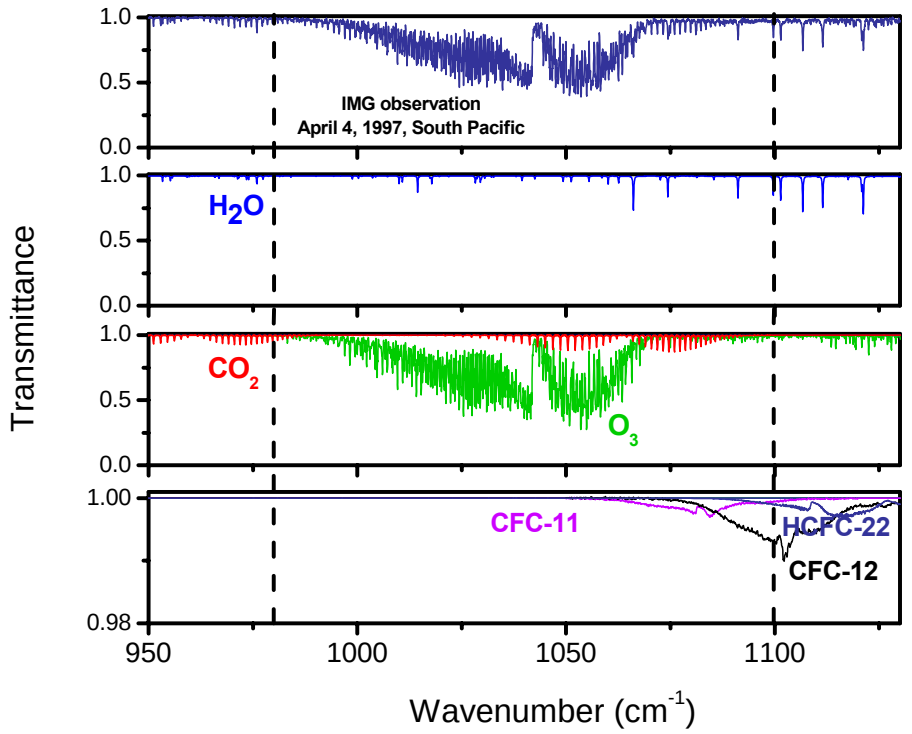
+ Cloud filtering
Hadji-Lazaro *et al.*, GRL 2001

SA-Neural network [Turquety et al, JGR 2004]

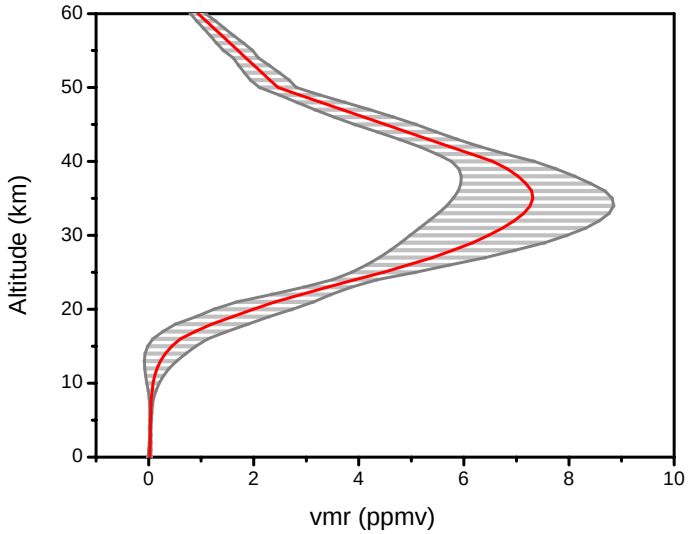
Implemented in the Eumetsat ground segment for IASI real-time data processing

Spectral window

- **Fitted quantities**
  - **O_3 profiles**
  - Surface temperature
  - H_2O columns
  - CO_2 columns

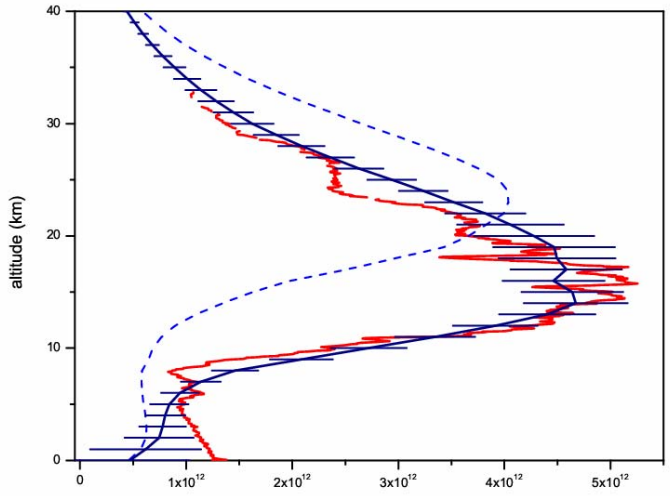


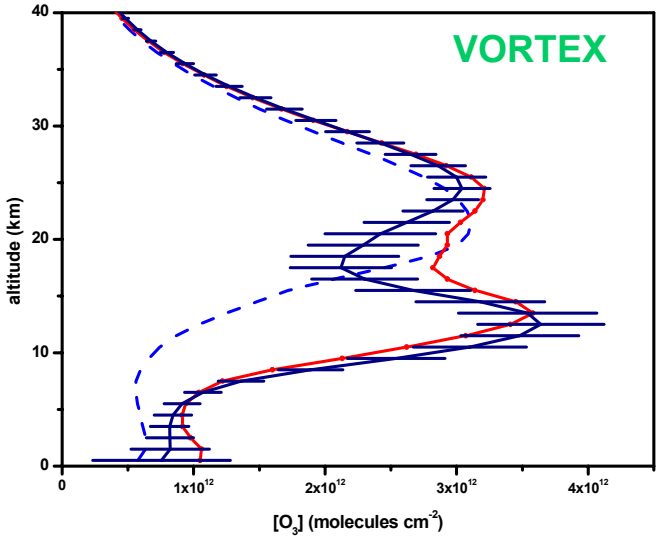
a priori information (MOZART + climatology)



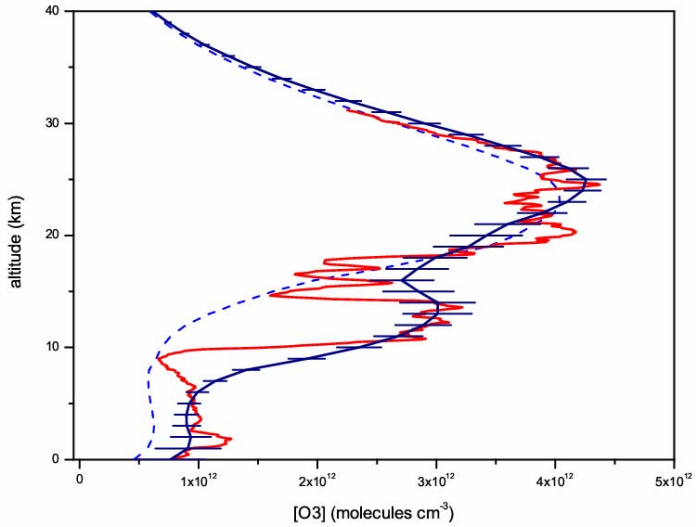
[Coheur *et al.* JGR 2005]

Arctic





Northern mid-latitudes



WOUDC O_3 sondes

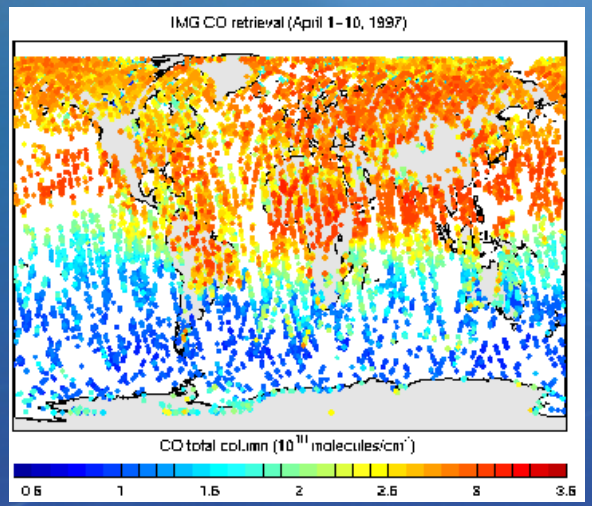
IMG O_3 measurement

A priori

Large scale features of the ozone profile are well reproduced, both in the stratosphere AND in the troposphere

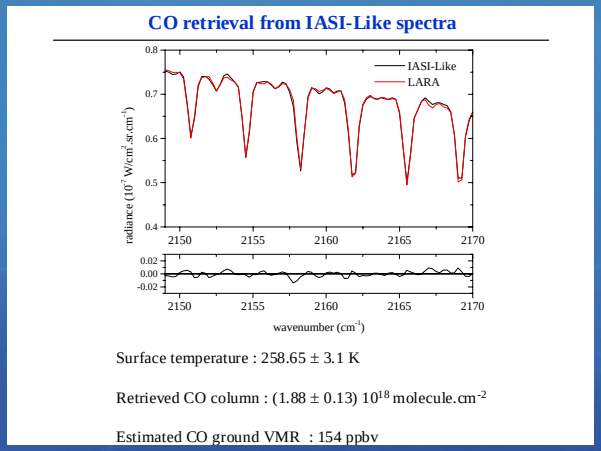
[Coheur et al. JGR 2005]

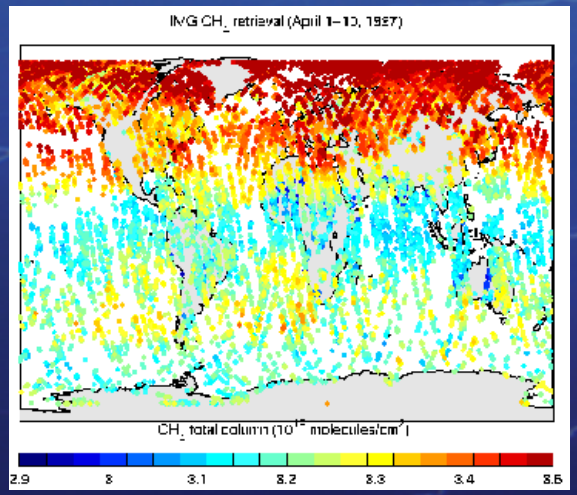
CO and CH_4



CO column:

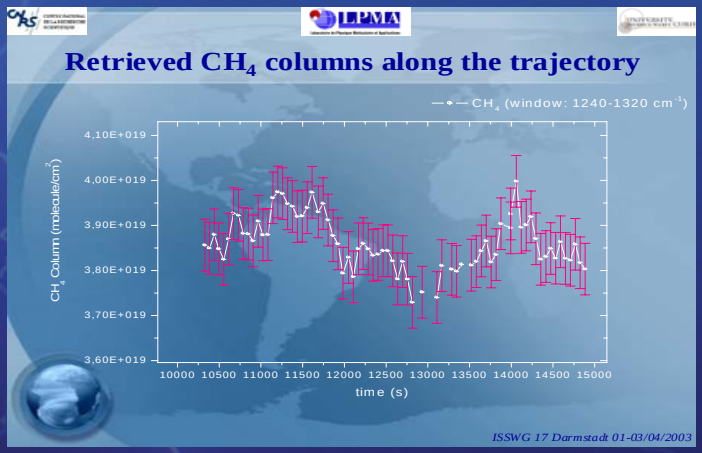
10-15%





CH_4 column:

3%

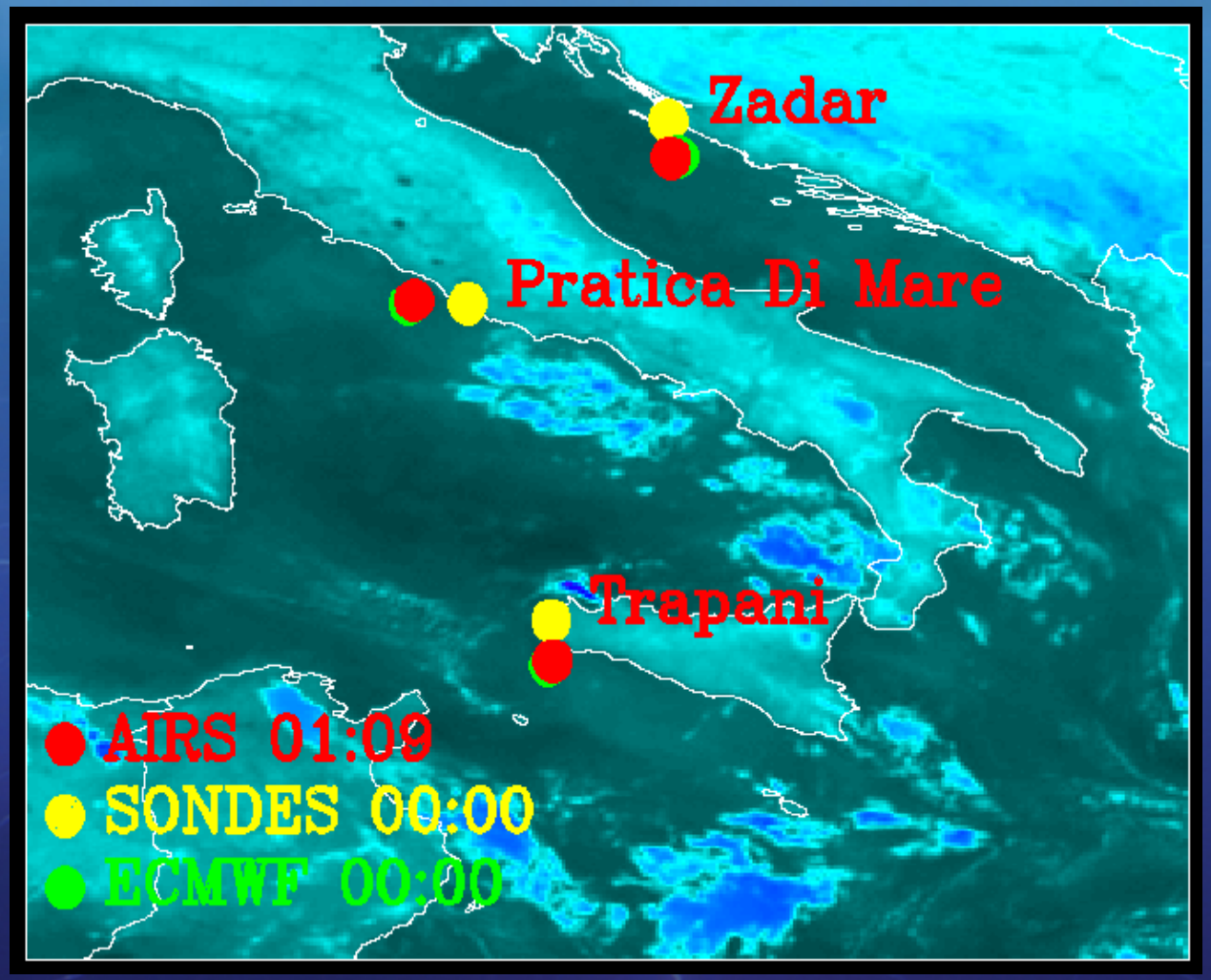


Clerbaux *et al*

Camy Peyret *et al*

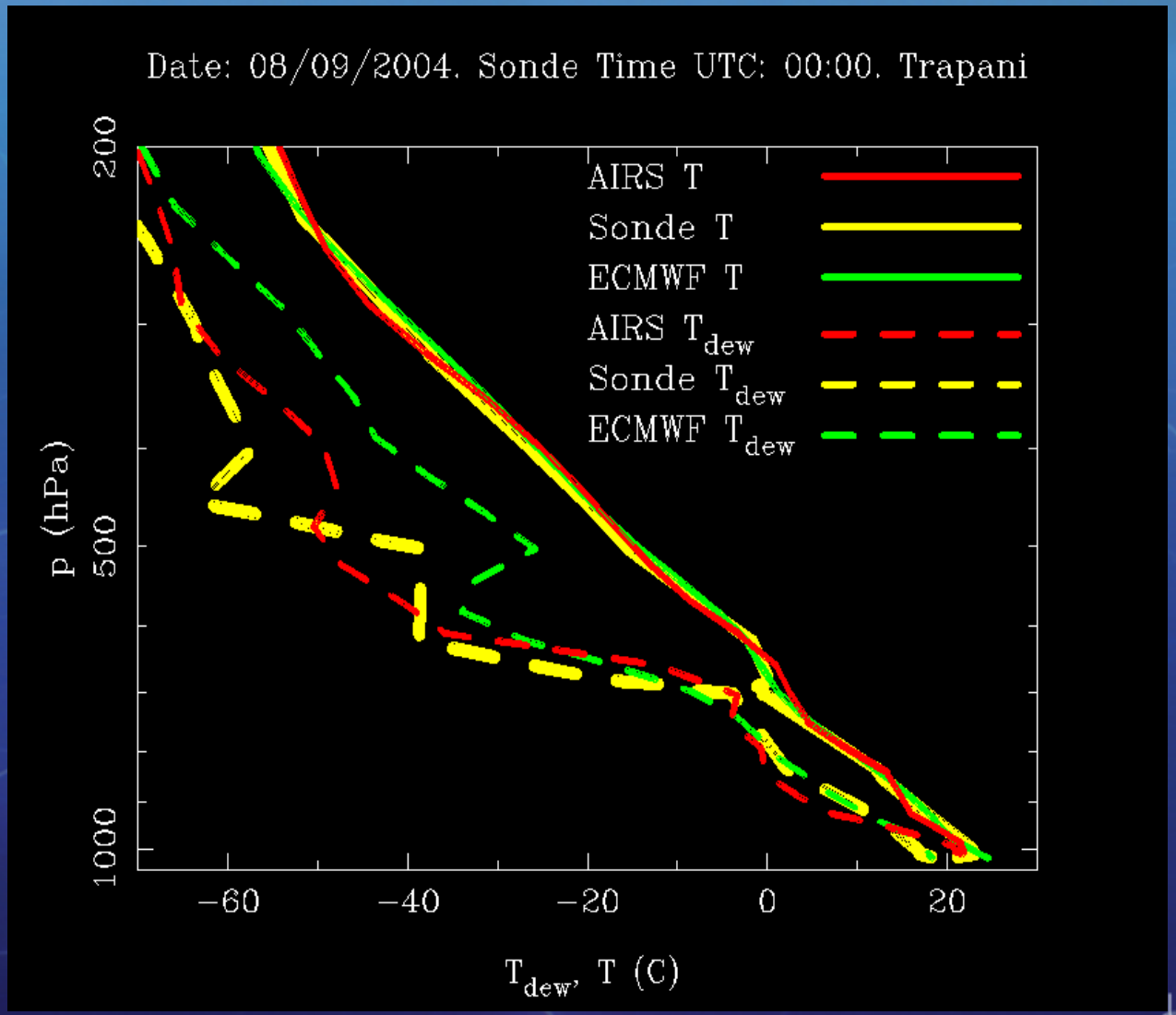
EAQUATE Radiosonde Locations

- MSG Ch 9
- 8 August 2004, 01:12 UTC



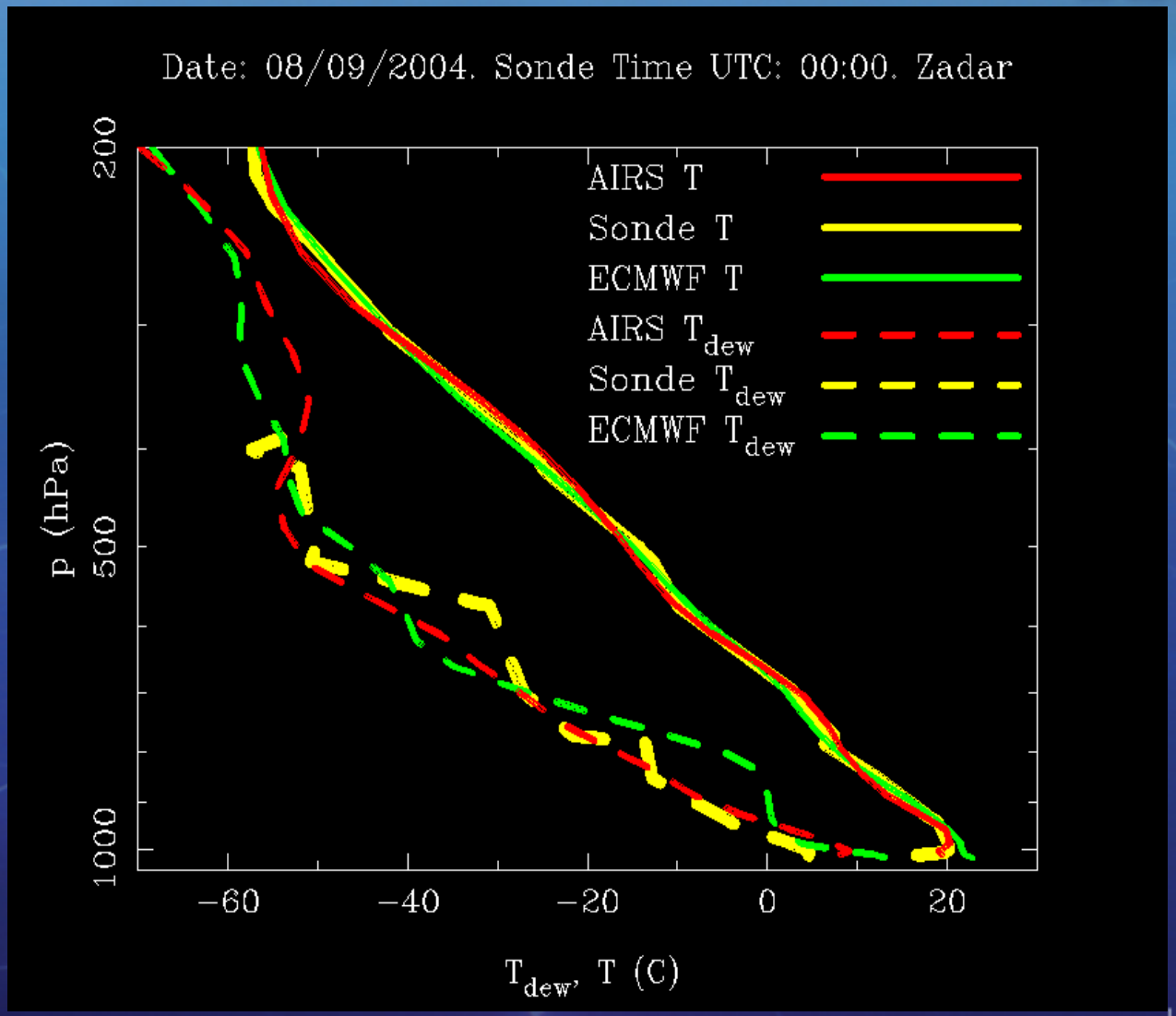
Inter-Comparison: Trapani

- EOF first guess
- No background
- Physical constraint
- 69 minutes time difference



Inter-Comparison: Zadar

- EOF first guess
- No background
- Physical constraint
- 69 minutes time difference



IASI Data Transmission and Processing

- Satellite to ground transmission:
  - On-board storage and direct broadcast to local users
  - Down-link of global data to Svalbard receiving station after each completed orbit
  - Transmission of data to EUMETSAT Headquarters at Darmstadt
- Data processing at EPS Core Ground Segment:
  - Generation of Level 1 products (decommutation, calibration, apodisation, geo-location, and mapping of imagery)
  - Generation of Level 2 products (geophysical parameters)
- Distribution to users:
  - Near-real time transmission of products to users (Level 1: 2.25 hours, Level 2: 3 hours) via satellite broadcast (EUMETCast)
  - Distribution of sub-sampled data (spatially, and spectrally in case of L1) via GTS to WMO users (same timeline as NRT transmission)
  - Storage in Unified Archival and Retrieval Facility (UMARF) for later access by users (7 hours after measurement)

Timeline for IASI Data Validation

- Metop-A launch: 17 July 2006
- IASI switch-on: 21 July 2006
  - Followed by CNES Cal/Val Phases A and B
  - A: Instrument activation and evaluation/system technical evaluation
  - B: Early validation of Level 1 products
- First IASI measurements: 31 August 2006
- Reference orbit for off-line testing available: 2 December 2006
- Early Level 1 products available: 28 December 2006
- CNES Cal/Val Phase C: In-depth validation of Level 1 Products
- Completion of Level 1 validation: 10 March 2007
- Start of Level 2 validation: 29 January 2007
- Completion of Level 2 validation: 21 May 2007

Overview of the processing chain (1/2)

- On-board processing
  - Bring the data production rate from 45 Mbps down to 1,5 Mbps
  - Performs the following operations
    - Non-Linearity correction of the raw interferograms
    - Selection of NZPD for consistency of the spectra complex argument (CS1, BB and EW)
    - Complex radiometric calibration of the EW spectra
    - Band Merging and coding the spectra performs the data compression

- Level 1 processing
  - Build products using the best estimation of the interferometer geometry at the measurement time (to minimize errors in the forward model)
  - Performs the following operations
    - Interferometric axis position estimation at the time of measurement
    - ISRF model computation that will be used for each Level 1 product (1A, 1B, 1C)
    - Radiometric post-calibration of the sounder products
    - Radiometric calibration of the IIS images
    - Coregistration of the IASI products with AVHRR products
    - AVHRR radiances analysis in the sounder Field Of View

Overview of the processing chain (2/2)

- Init and performance monitoring processing (TEC)
  - Initialization of on-board processing computes and updates
    - Non-Linearity correction tables
    - Reduced Spectra used for NZPD computations
    - Coding tables used for spectra encoding
    - Spectral band limits, band merging coeff., various failure detection cutoffs
  - Initialization of IASI Level 1 processing computes and updates
    - Cube Corner offset (alignment parameter of the Michelson interferometer)
    - Spectral function databank (implementation of the ISRF model)
    - Key data for spectral calibration
    - Scan mirror reflectivity laws (as function of the Scan Position)
    - Offset between the IIS and the sounder
    - Radiometric noise spectrum of the instrument and error covariance matrix
    - Various failure detection cutoff
  - Monitoring of the performance
    - Analyses flags/quality indices send by both on-board and Level 1 processing
    - Detects the necessity to change some initialization parameters above
    - Detects the necessity to change some settings of the detection chain (gains, offset)
    - Analyzes contamination and detects need to perform a decontamination
    - Etc.,

Overview of the Cal/Val approach (1/4)

- Use of already developed, state-of-the-art methods applicable to every infrared sounder of the same class of performance

- Cal/Val activities will begin when first goal of the commissioning phase will be achieved : to establish a stable and nominal behavior of the system
    - Health parameters of the instrument monitored by the CGS
    - All the needed products verified and available in the IASI TEC
    - Problems, if any, either from hardware or processing clearly identified and flagged

- IASI Level 1 Cal/Val activities and performance monitoring will be mostly performed in the IASI TEC using
    - Products obtained via Eumetcast
    - Reference version (latest update) of the Level 1 processing software
  – Involve external partners (**EUMETSAT, METEO FRANCE, LPMAA, ECMWF**,**UKMO**, ...)

- In-flight Cal/Val activities broken in Geometry, spectral and radiometry.

Overview of the Cal/Val activities (2/4)

		Activation & Evaluation	Early validation	in depth validation
Geometry	Localisation	- co-registration IIS/AVHRR - co-registration IIS/sounder - validation of navigation - validation of radiance spatial distribution in sounder IFOV - line of sight short term stability	- co-registration IIS/AVHRR → stability check - co-registration IIS/sounder→ stability check	- validation of radiance spatial distribution in sounder IFOV (from Level 2 feedback)
	IPSF	- approximate check	- sounder inter band co-registration	- sounder inter band co-registration → stability check

- Navigation of IASI products based on co-registration of IIS images and soundings with AVHRR products (Level 1B AVHRR full resolution, fully navigated)
- First version of IIS-sounder co-registration offset available from on-ground calibration
- Validation on highly contrasted scenes (e.g. coastlines)

Overview of the Cal/Val activities (3/4)

		Activation & Evaluation	Early validation	in depth validation
Spectral	calibration	- verify operational calibration (B3) - approximate validation in B1, B2 using synthetic spectra (climatology)	- validation of spectral calibration in B1,B2,B3 (use of radiosondes or ECMWF profiles)	- validation w.r.t. IASI balloon spectra
	ISRF	- Cube Corner Offset → stability check	- validation of ISRF not considered as part of "early validation"	- analysis of residuals w.r.t. IASI balloon spectra

- Use of off-axis detectors induces possible spectral calibration defects
  - Correction achieved by using the atmosphere itself (CO_2 2350-2380 cm-1 in B3 band)
  - Then extrapolated to the whole IASI spectral band.
- GEISA/IASI used as the reference spectroscopic database
- It is expected that validation can be achieved using a Line by line RTM (4A will be used for validati at 3 wavenumbers in each 3 bands)
  - Selection of scenes with very good spatial uniformity (clear sky on sea) based on AVHRR imag analysis.

Overview of the Cal/Val activities (4/4)

	Activation & Evaluation	Early validation	In-depth validation
Radiometry	- non-linearity in-flight estimation - noise (sounder & IIS) - residual analysis of the on-board radiometric calibration - inter pixel calibration - inter band calibration	- Cold Space views CS1 /CS2 verification - approximate validation of calibration w.r.t. AVHRR (B1 & B3). - limited validation of B2 through interband B1/B2 & B2/B3 overlaps - idem w.r.t. HIRS (TBC) - direct comparison w.r.t AIRS radiance - micro-window analysis - IIS calib. w.r.t AVHRR	- intercalibration with AIRS radiances (direct and through IASI balloon) - statistical analysis of the residuals from radiance assimilation in NWP models - sounder noise covariance matrix in-flight

- Radiometric calibration of the IASI sounder level 1 products based on
  - Cold and Hot calibration views measured each 8 sec
  - Non-Linearity correction performed on the raw interferograms (on-board)
  - Initial radiometric calibration (on-board) and post-calibration (in level 1 processing).

  Lookup tables used known from the pre-launch calibration of the instrument ➔ to be updated in-flight (detectors temperature, etc.).
- Early validation of the radiometry based on comparison with other MetOp instruments + other sounders AIRS, TES, etc.
- In depth validation based on NWP Bias monitoring and comparison with other FTIR

STATUS

- IASI Level 1 Cal/Val Implementation Plan exists
- TEC
  - Cal/Val team built up
  - Cal/Val Implementation Plan refined with Cal/Val team
  - Full TEC system (software & database) validated
  - Rehearsals carried out
- Partners
  - CMS Lannion. Work plan established and agreed
  - LPMAA. IASI Balloon campaign 1 planned but still to be fully funded. Data processing software to be developed
  - NWP centres. Meetings to define activities held. Interface document in preparation