IASI L2 processor at EUMETSAT: status and developments

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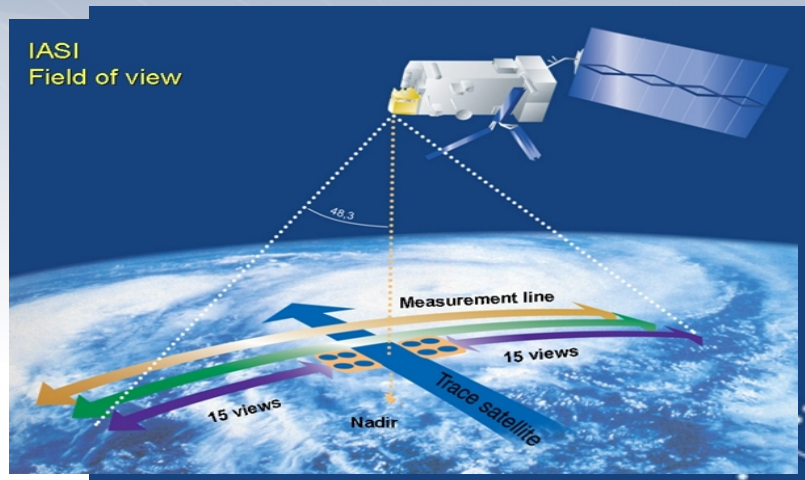
The IASI instrument



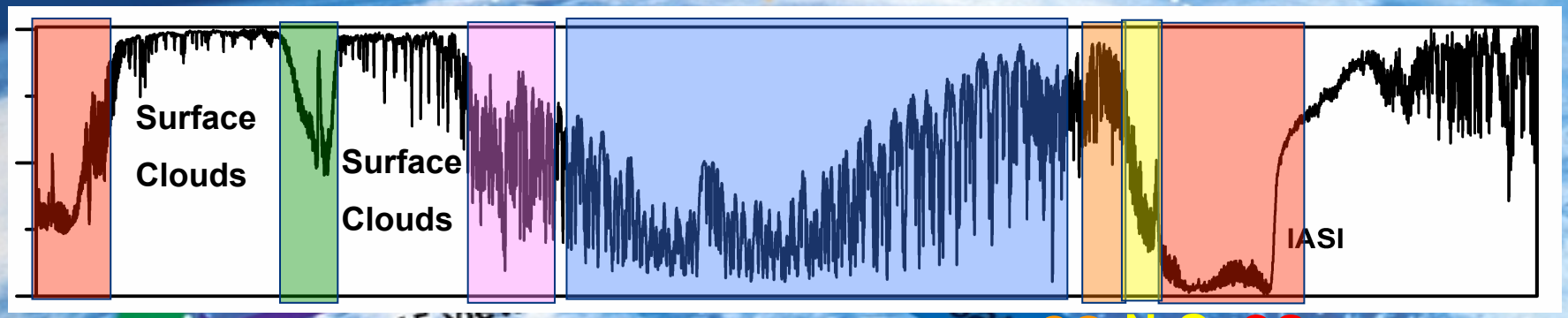
Infrared Fourier transform interferometer

Spectral range: 645 to 2760 cm^{-1} (15.5-3.62 µm)

Spectral sampling: 0.25 cm^{-1}

Footprint: 12 km (Nadir)

Swath: ±1000km (± 48.3°)



CO_2 T profiles

O_3

CH_4

Nadir H_2O

CO N_2O CO_2

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Outline

I. The IASI L2 processor v5 (since 14/09/2010)

- algorithms overview
- examples of validation results

II. Cloud screening

- concurrent detection algorithms
- impact on L2 quality & yield

III. Current developments towards v6

- FORLI-CO, SO_2, O_3 and HNO_3
- New OEM configuration
- Non-linear IR retrievals
- MWIR statistical retrievals

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1. IASI L2 version 5

Processed and disseminated in NRT (sensing +2h)

TWT	**Temperature (vertical profiles)** **Humidity (vertical profiles)** **Surface Temperature (Land & Sea)**	**+ AK**
EMS	**Surface emissivity**	
CLD	**Cloud detection and characterisation**	
OZO	**O_3 total & partial (0-6, 0-12, 0-16 km) columns**	
TRG	**CO, N_2O, CH_4, CO_2 Total columns**	
v6	**CO & O_3 profiles + AK, SO_2, HNO_3**	

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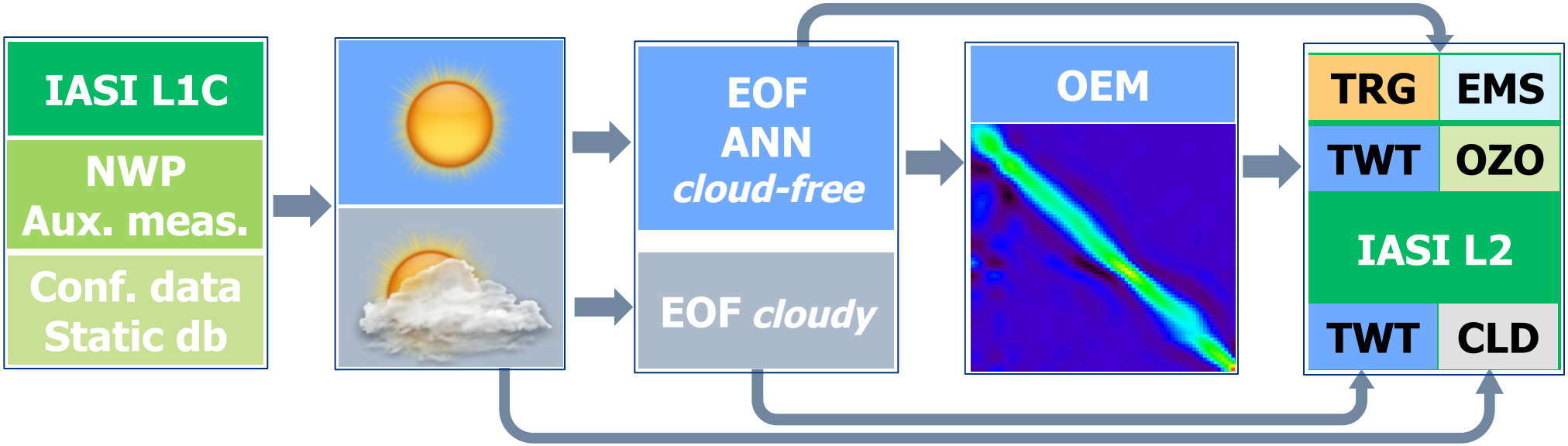
1. IASI L2 version 5

The operational processor

1. Input data pre-processing
2. Cloud detection and characterisation
3. Statistical retrievals: T, q, Ts, ε, CO (N_2O, CH_4, CO_2)
4. Optimal Estimation Method (OEM): T, q, Ts, O_3



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1. IASI L2 version 5

The static databases

Data type	Origin	Resolution
Land/Sea mask	AAPP	quadtree
Surface elevation	GTOPO 30 *(US Geological Survey)*	30” x 30” (~1 km)
Emissivity Atlas	Global land surface climatology from IASI measurements *(Zhou et al., TGRS 2011)*	0.5°x0.5° Full spectrum (via PCs) Monthly means

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1. IASI L2 version 5

Auxiliary products

- **ECMWF 3h-forecasts**: 00, 03, 06, 09, 12, 15, 18, 21 UTC
  - Up to 1.5h difference with sensing-time
  - Spatial & Temporal interpolation
  - Used in support to cloud detection and characterisation only
- **AVHRR**
  - Intregrated cloud-fraction embedded in IASI 1C
  - Used for cloud screening
- **AMSU & MHS 1B**
  - Not used in IASI L2 v5, foreseen in v6

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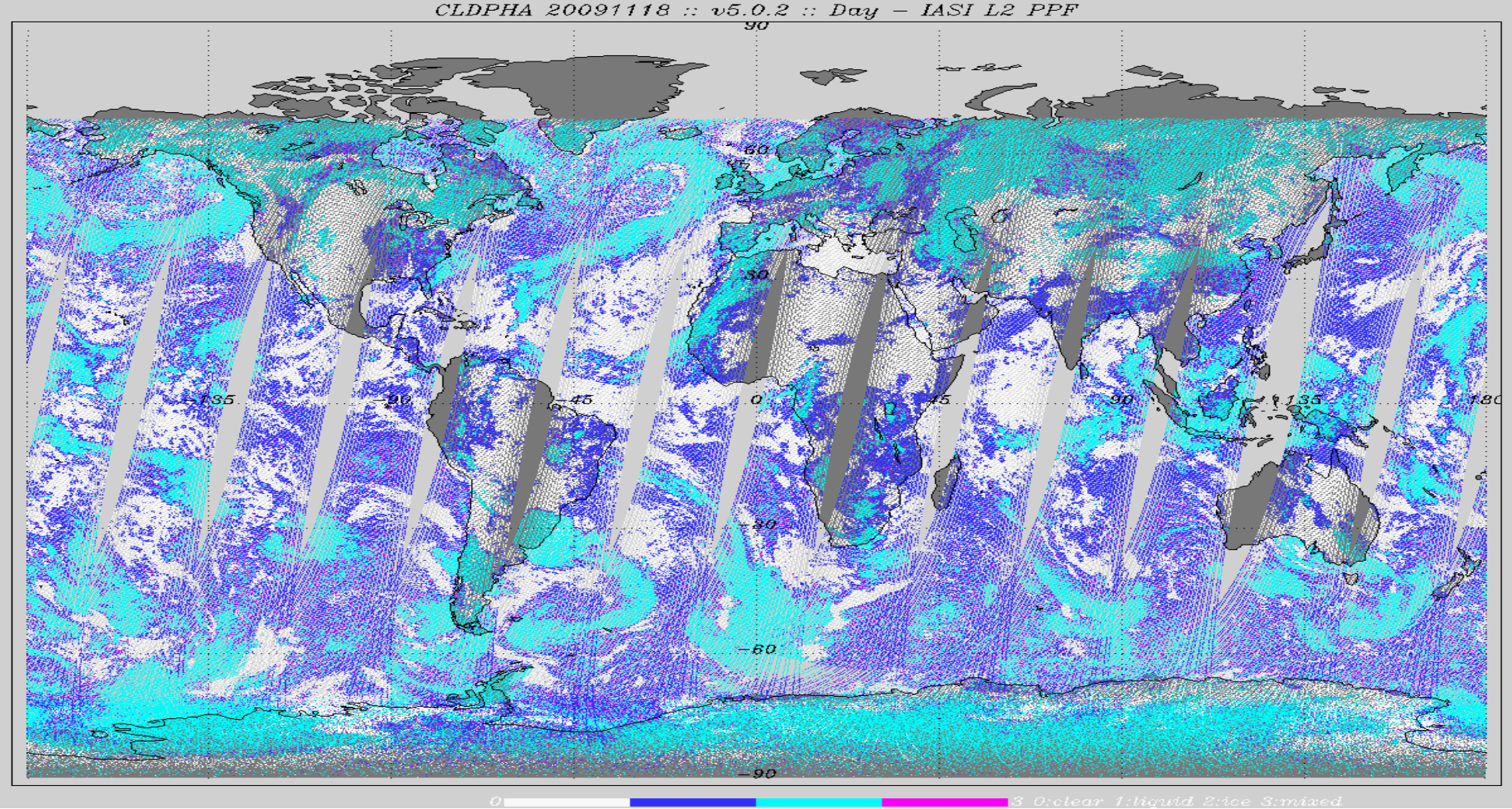
1. IASI L2 version 5

The cloud characterisation



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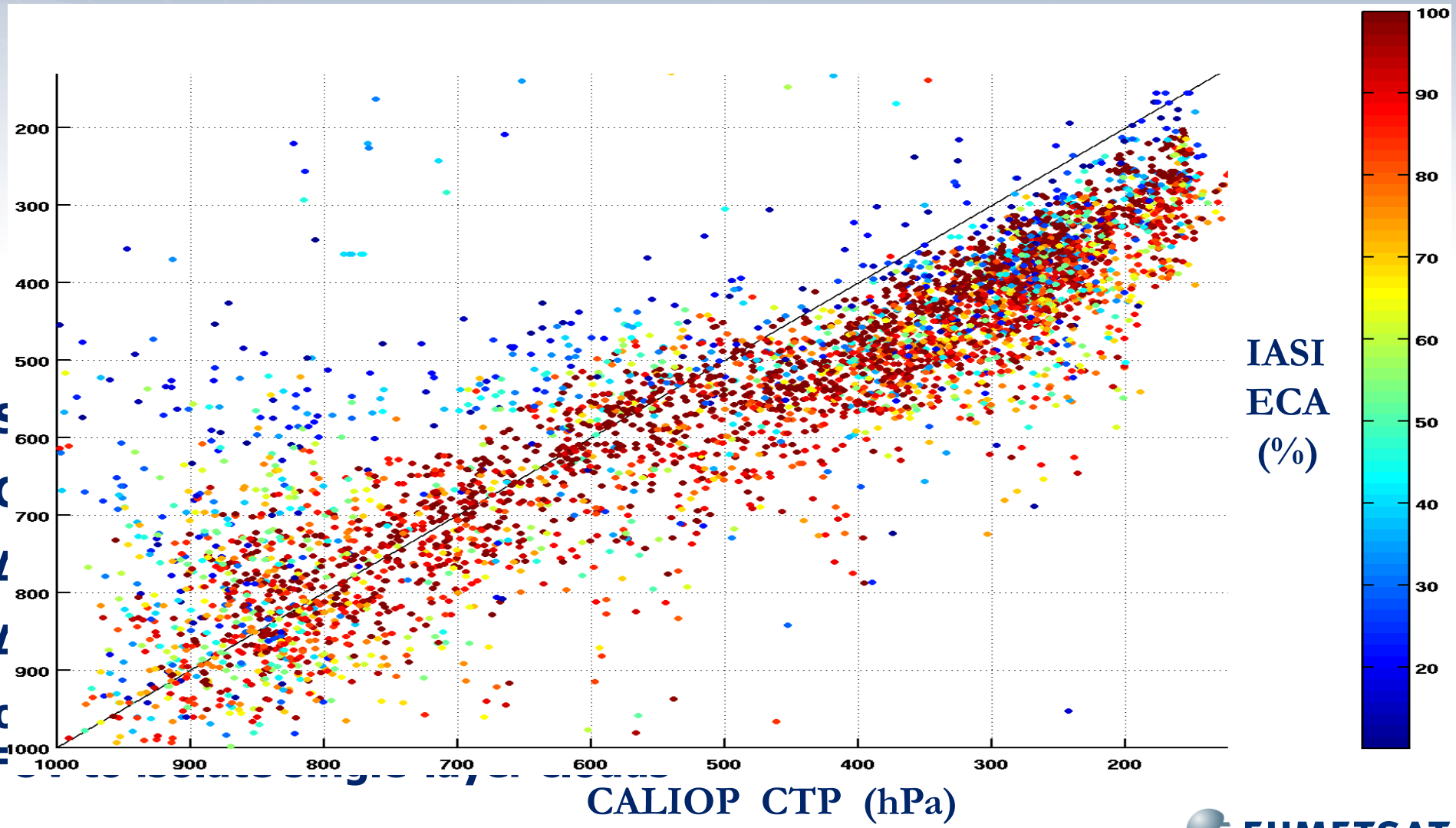
1. IASI L2 version 5

The cloud-top pressure: validation



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1. IASI L2 version 5 Statistical retrievals: Surface products

- **SST**
  - linear regression: Empirical Orthogonal Functions (**EOF retrieval**)
  - Training with synthetic spectra: Le Chevallier climato (ECMWF 2001) + RTIASI
  - validation against AATSR
  - validation and monitoring with buoys, AVHRR and SEVIRI
  - **Contributes to** the Group for High-Resolution SST (**GHRSST**): IASI L2P SST

- **Land surface T and ε**
  - **linear regression (EOF) retrieval, after Dan Zhou et al, TGRS 2011**
  - Training set based on the soil IR emissivity database, University of Wisconsin (Seemann et al, Journal of Applied Met. And Clim, 2007)
  - Emissivities retrieved in principal components domain
  - **LST evaluated** against **MODIS, SEVIRI LST** and **in-situ measurements**
  - ε qualitatively assessed against MODIS IR emis. atlas (Seeman, Borbas et al.)

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1. IASI L2 version 5

Statistical retrievals: T, q profiles

- **Temperature, humidity profiles**

  - EOF retrieval *(D. Zhou et al., 2005, GRL)*, Linear regression on IASI radiances principal components

  - Trained with synthetic cloudy radiances

  - Different sets of coefficients for different viewing angle

  - Full profiles available under clear and partly cloudy conditions

  - Clear-sky IFOVs: **first-guess in the final iterative retrieval**

  - Clear-sky IFOVs: **q profiles enters final L2 products**

  - Cloudy IFOVs: after users request, the **T,q profiles retrieved in partially cloudy IFOVs** are added to the final IASI L2 products. Distributed since v5.1.0 (02/12/2010).

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1. IASI L2 version 5

Iterative retrieval: the OEM

- Standard **Optimal Estimation Method** (OEM) after Rodgers:

$$J = (x - x_a)^T . S_a^{-1} . (x - x_a) + (F(x) - y)^T . S_y^{-1} . (F(x) - y)$$

Marquardt-Levenberg minimisation (5 iterations max.)

- Active parameters: $\mathbf{T_{skin}}$ and **T, q** & $\mathbf{O_3}$ profiles
- **Background term** computed in the **EOF space** of the atmospheric parameters: T -> 28 PCs, q -> 18 PCs, O_3 -> 9 PCs
- One unique **global *a priori*** and **covariance matrix**
- **316 channels** after Collard *(Collard et al., QJRMS 2007)*
- **global radiance tuning** and **measurement error covariance matrix:** prior clear sky OBS-CALC
- **Forward model: RTIASI, RTTOV-10** since v5.2 (20/10/2011)
- **First guess**: statistical retrievals

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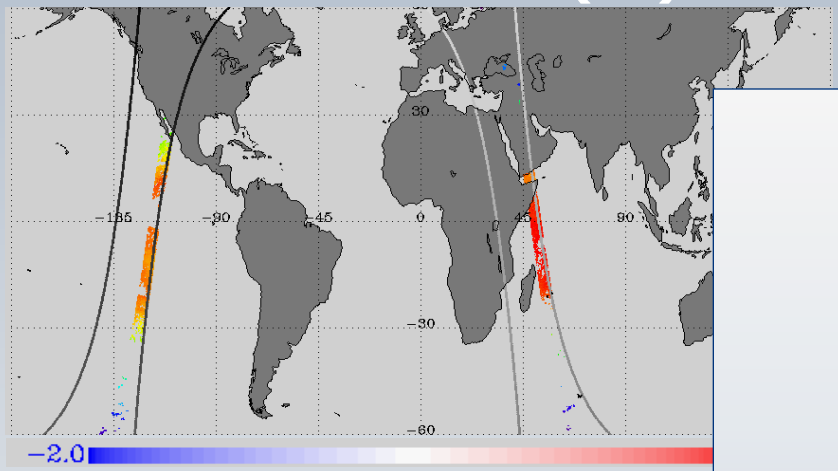
1. IASI L2 version 5

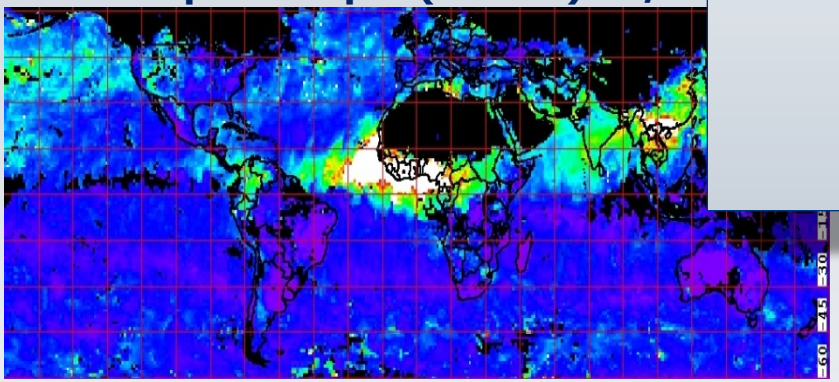
Sea Surface Temperature: validation

19-24 March 2010

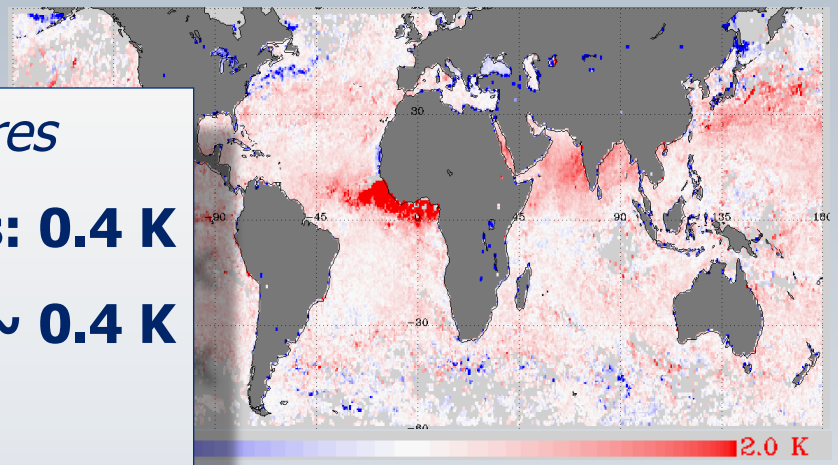
AATSR – IASI (v5)

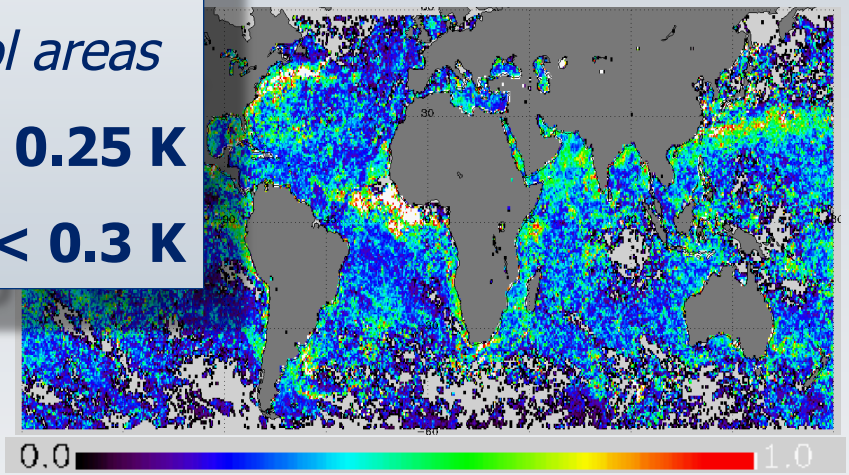


aerosol optical depth (MODIS) 20/03



ECMWF - IASI





Global figures

Cold bias: 0.4 K

σ ~ 0.4 K

Outside aerosol areas

Cold bias: 0.25 K

σ < 0.3 K

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1. IASI L2 version 5

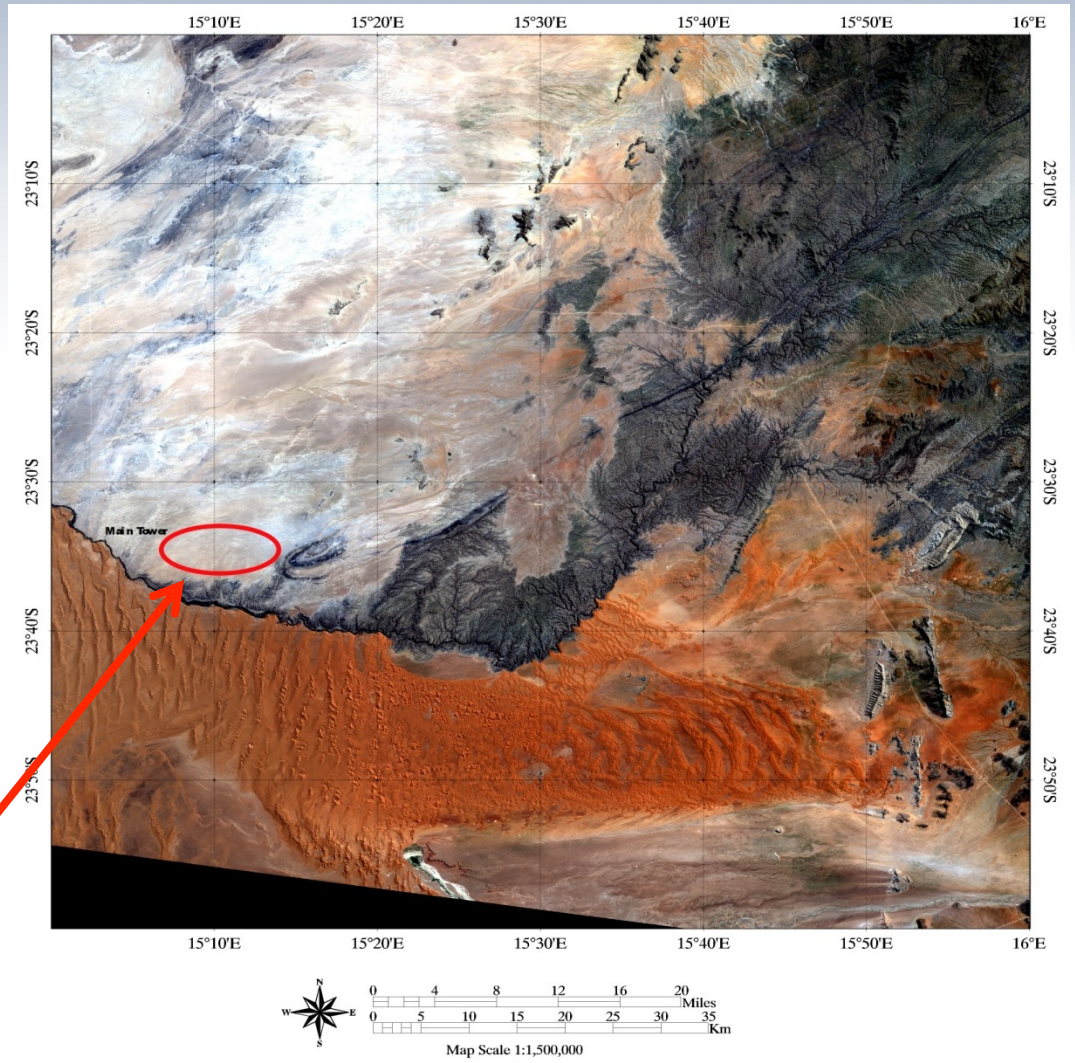
Land Surface Temperature: validation

LST

Retrieved
vs
In-situ measurements

IR radiometers measuring ground and sky brightness temperature from 9.6 to 11.5 micrometers, operated by Folke Olesen and Frank Goettsche (IMK/KIT)

3 validation sites:
Evora (Portugal), Gobabeb and RMZ-farm (Namibia)



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1. IASI L2 version 5

Land Surface Temperature: validation

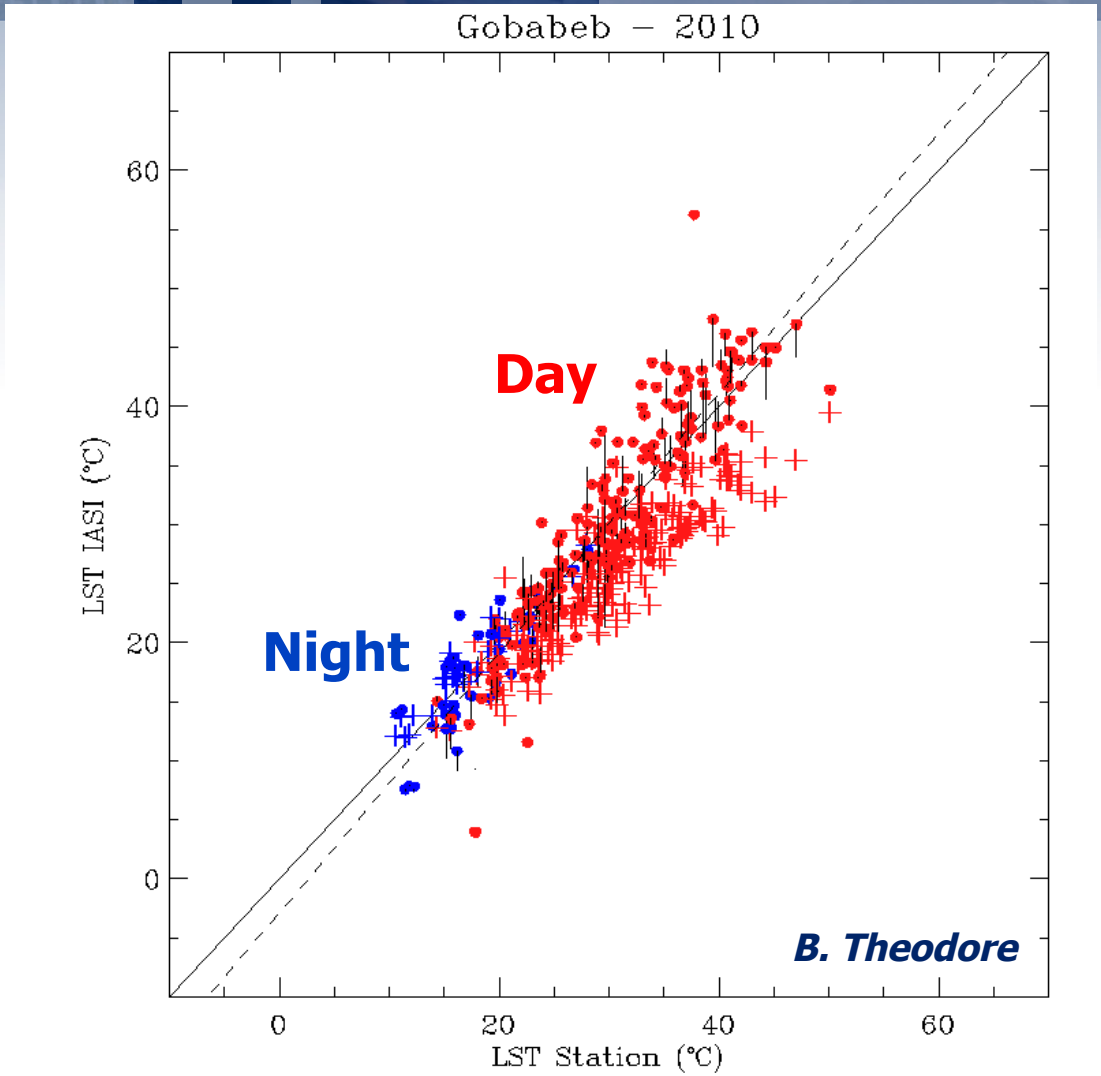
LST

Retrieved
vs
In-situ measurements

Gobabeb (Namib desert)

405m asl

- **IASI L2**
- **ECMWF**



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1. IASI L2 version 5

Land Surface Temperature: validation

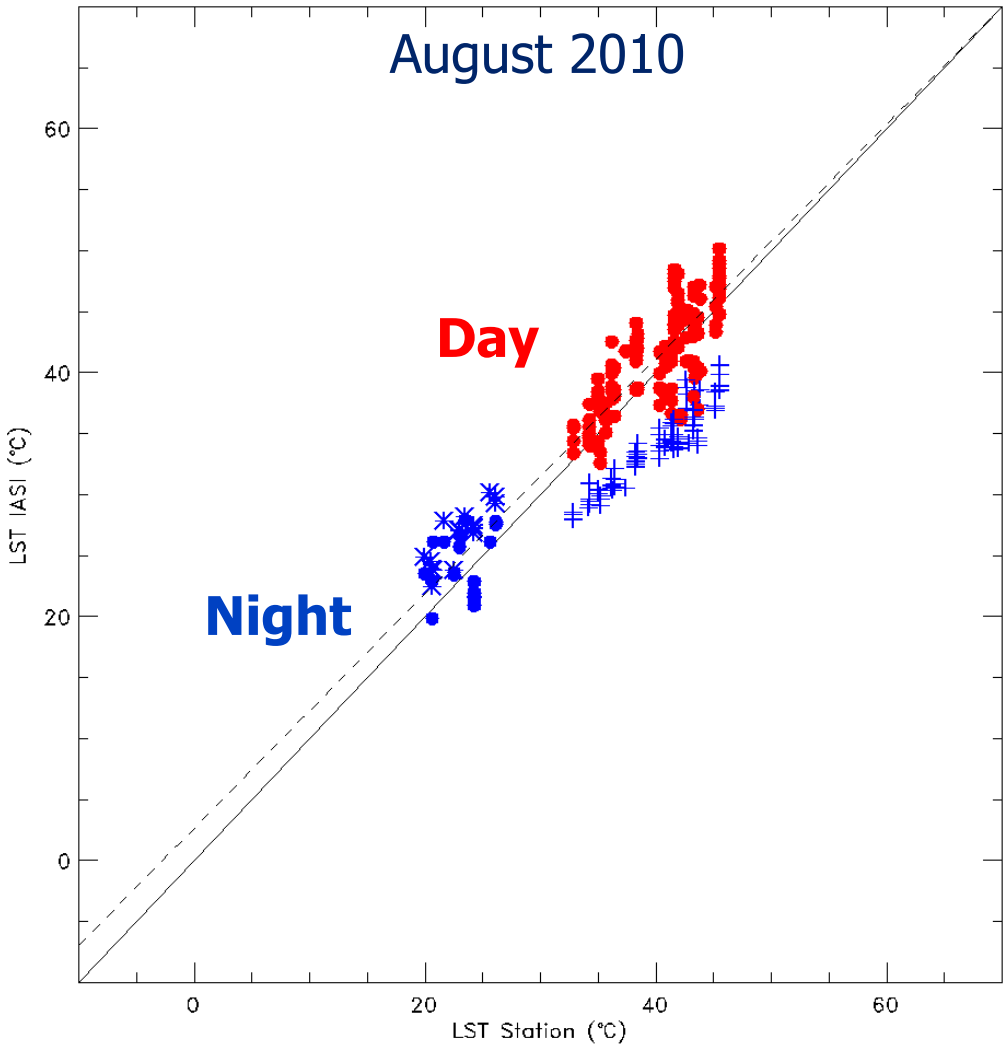
LST

Retrieved
vs
In-situ measurements

Evora (Portugal)

300m asl

- **IASI L2**
- **ECMWF**



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1. IASI L2 version 5

Land Surface Temperature: validation

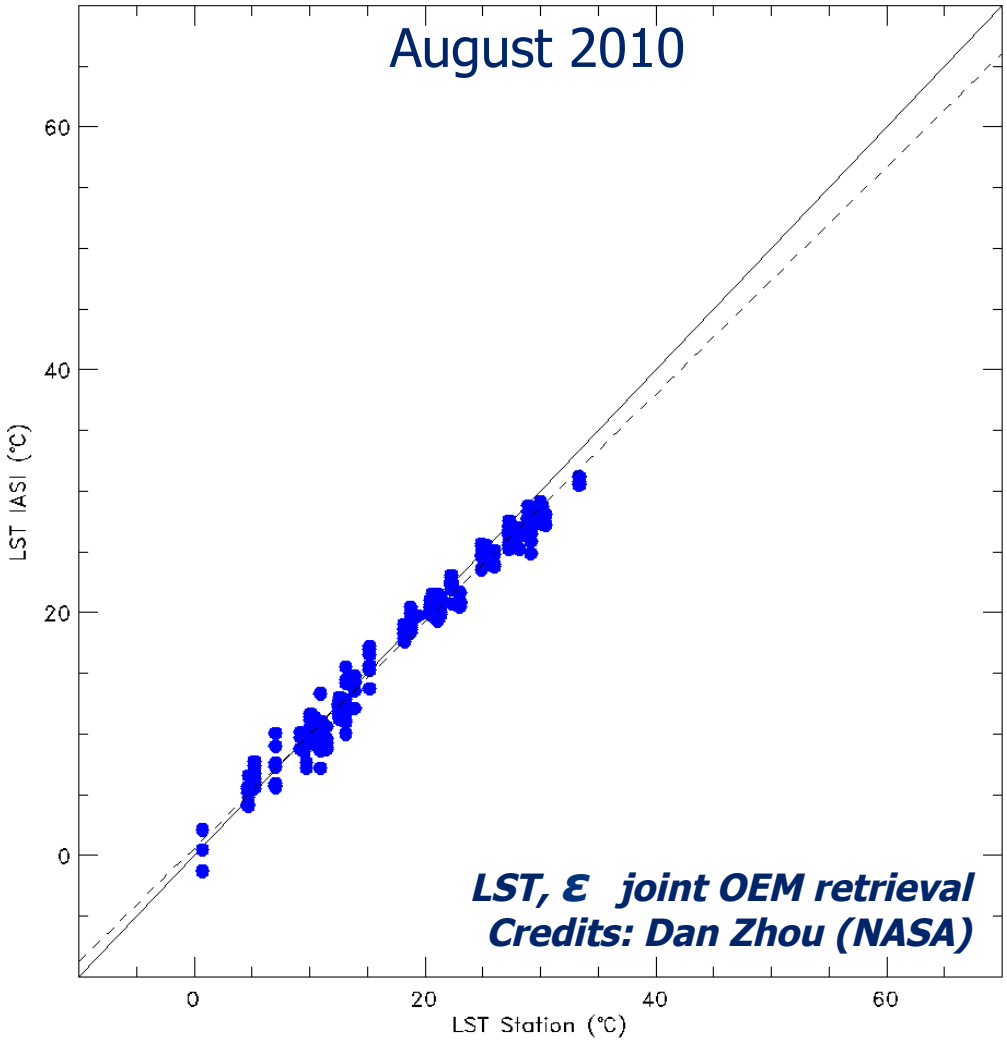
LST

Retrieved
vs
In-situ measurements

RMZ-Farm (Namibia)

1360m asl

- **IASI L2**
- **ECMWF**



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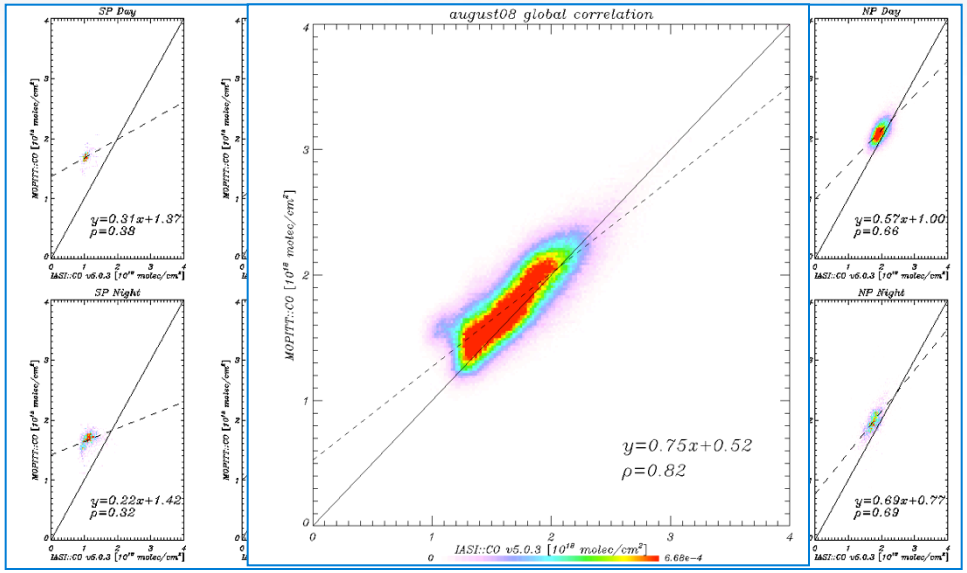
1. IASI L2 version 5

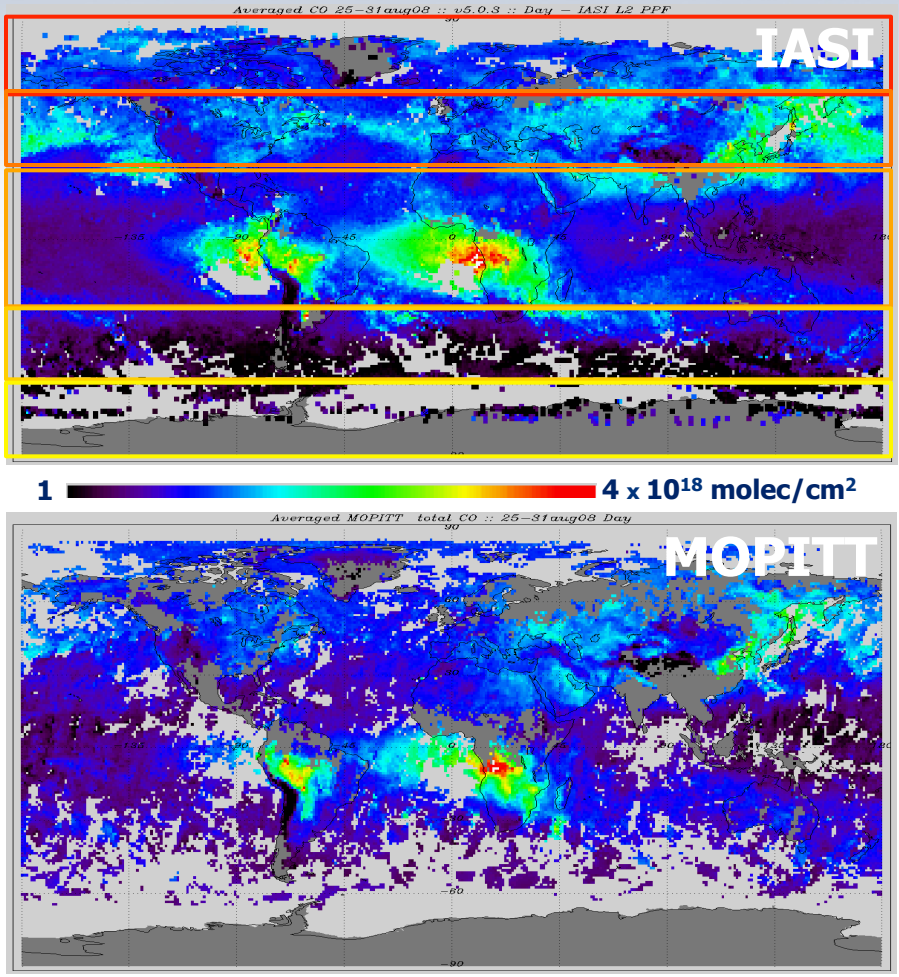
CO, comparison with MOPITT

Total column retrieved with ANN

Inter-comparison with MOPITT/Terra



August 2008



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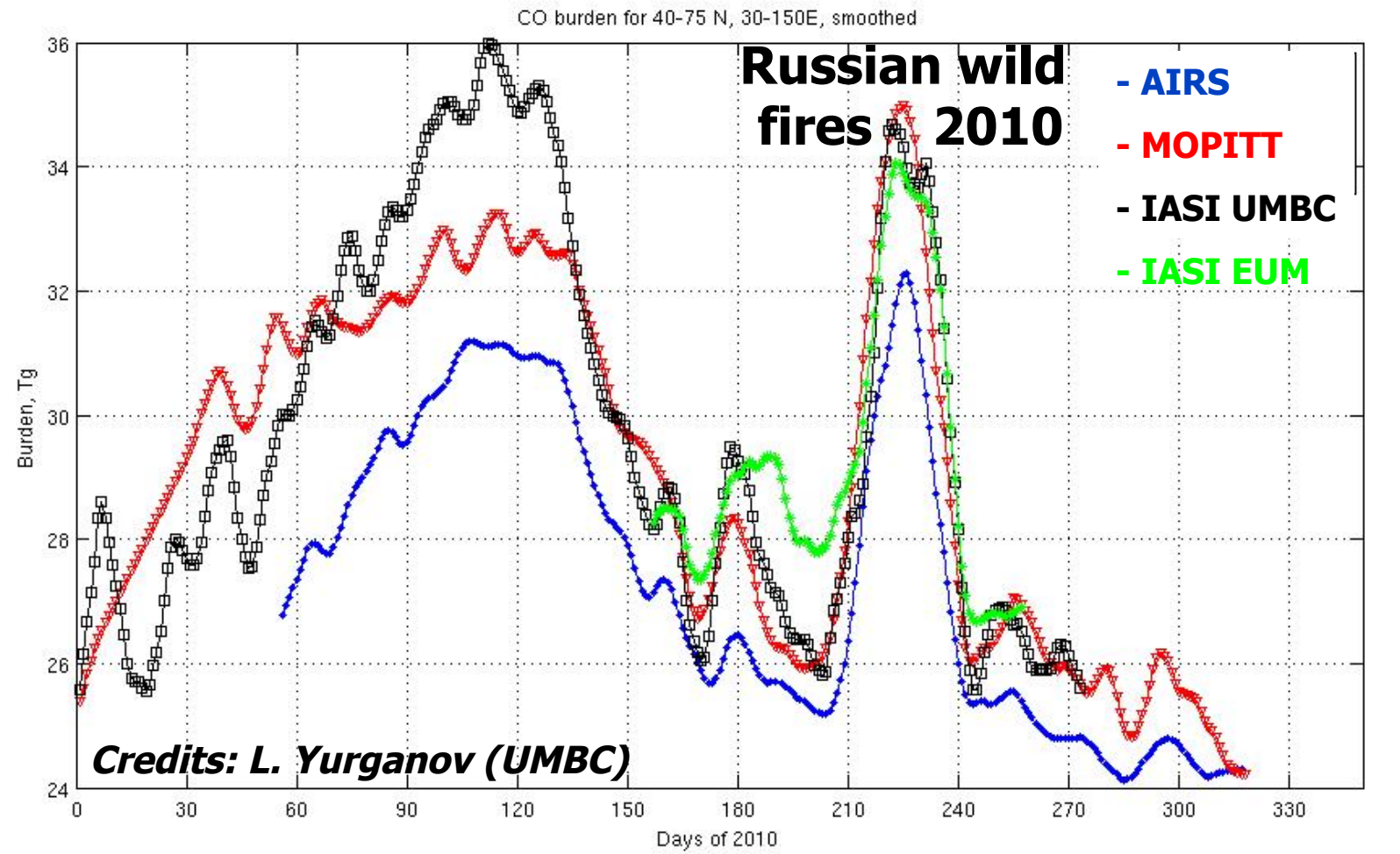
1. IASI L2 version 5

Statistical retrievals: CO total column



Yurganov et al., "Satellite- and ground-based CO total column observations over 2010 Russian fires: accuracy of top-down estimates based on thermal IR satellite data", ACP 2011

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1. IASI L2 version 5

T,q profiles: validation

- Validation campaign, Lindenberg & Sodankyla (Pougatchev et al, ACP 2009 and Calbet, AMT 2011)
- Evaluation against ECMWF analyses, 3 datasets:
  - "One Year" orbits centred on analyses synoptic times
  - "Focus days" (8 Sep 2007, 5 March and 9 May 2008)
  - **19-24 March 2010**
  - Detailed results in Tech.Note EUM/MET/TEN/09/0448
- External monitoring: e.g. NOAA/NPROVS, Italian Met Services
- Campaign data: ConcordIasi (presented at EUM Conference 2011)

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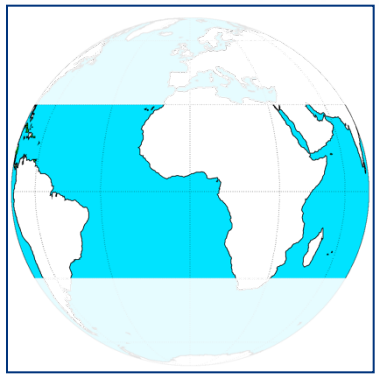
1. IASI L2 version 5

Temperature profiles: validation

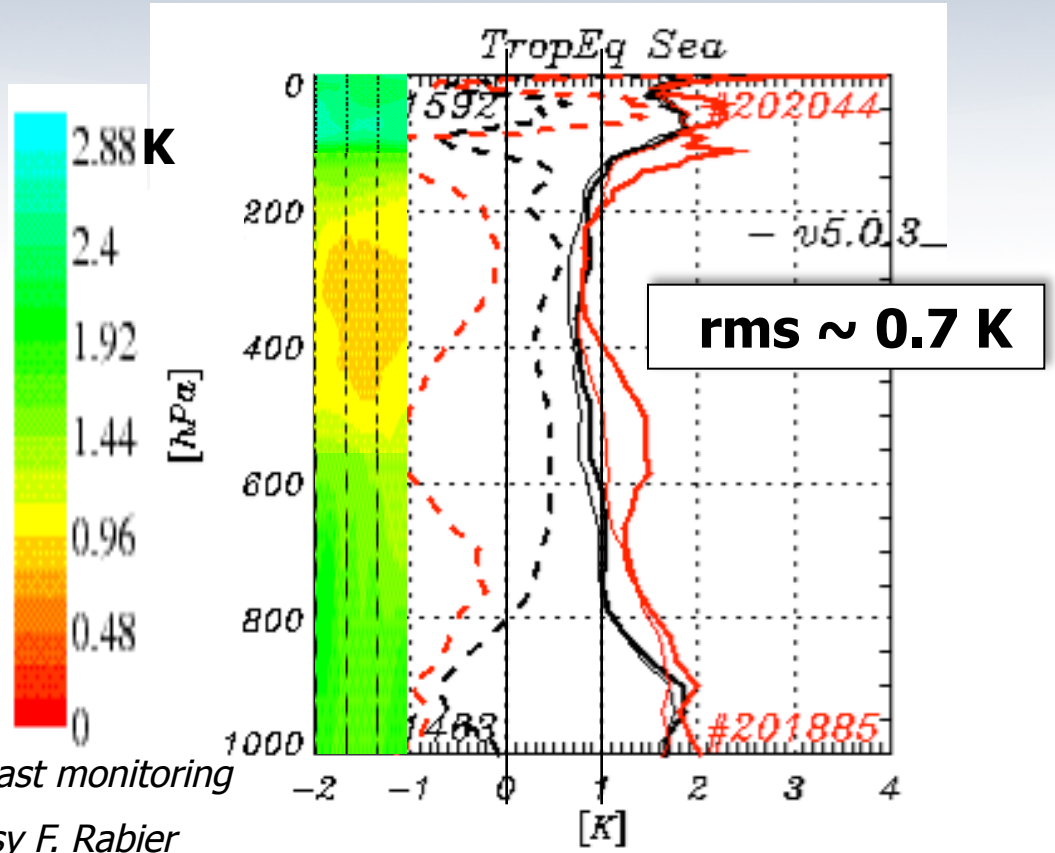
19-24 March 2010

Temperature profiles

IASI L2 – ECMWF Analysis



Intertropical Ocean cases



NWP forecast monitoring

Courtesy F. Rabier

(Meteo-France)

- v5

- v4

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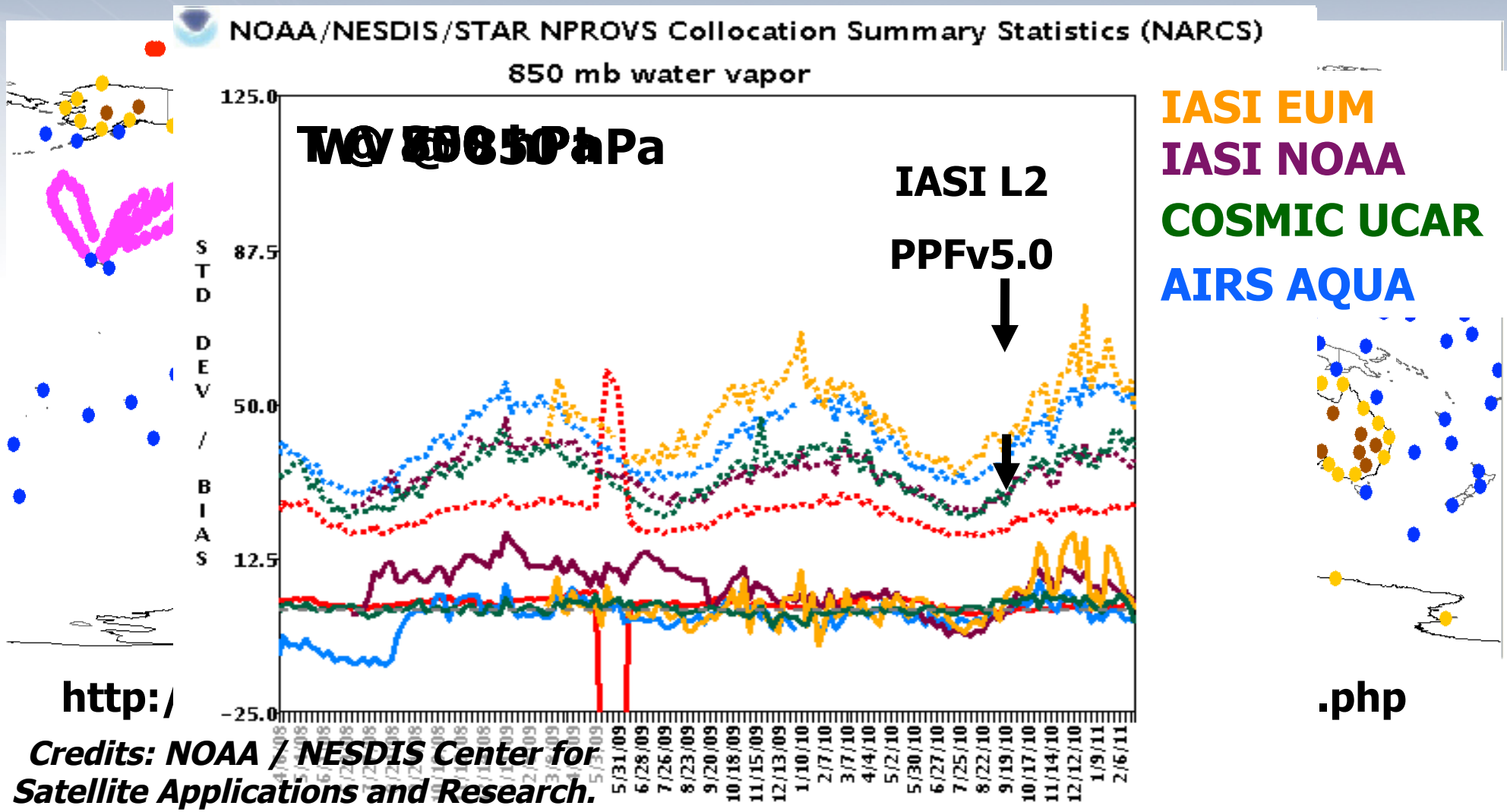
1. IASI L2 version 5

T, q profiles: monitoring at NOAA



http:/ .php

Credits: NOAA / NESDIS Center for Satellite Applications and Research.

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1. IASI L2 version 5

References

- **Papers**

  - August et al, *"IASI on Metop-A: Operational Level 2 retrievals after five years in orbit"*, JQSRT 2012

  - Schlüssel et al, *"The operational IASI Level 2 Processor"*, Adv. in Space Res., 2005

  - Pougatchev et al, *"IASI temperature and water vapor retrievals; error assessment and validation"*, ACP 2009

  - …

- **Validation reports (SST, LST, T&q, CO, O3…)**

eumetsat.int/Home/Main/DataProducts/Resources/index.htm#val_reports

- **Product Generation Specification**

eumetsat.int/groups/ops/documents/document/PDF_TEN_990013-EPS-IASIL2-PGS.pdf

- **Product Guide**

eumetsat.int/Home/Main/DataProducts/Resources/index.htm#productguides

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I. The IASI L2 processor v5 (since 14/09/2010)

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- validation results summary

II. Cloud screening

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III. Current developments: prototypes & new products

- FORLI-CO
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Cloud detection in v5

➢ **NWP cloud test**

- **OBS – CALC**(NWP, ems, …) in window channels
- Cloudy if |OBS-CALC| > 1K

! Relies on accurate forecasts and surface ems

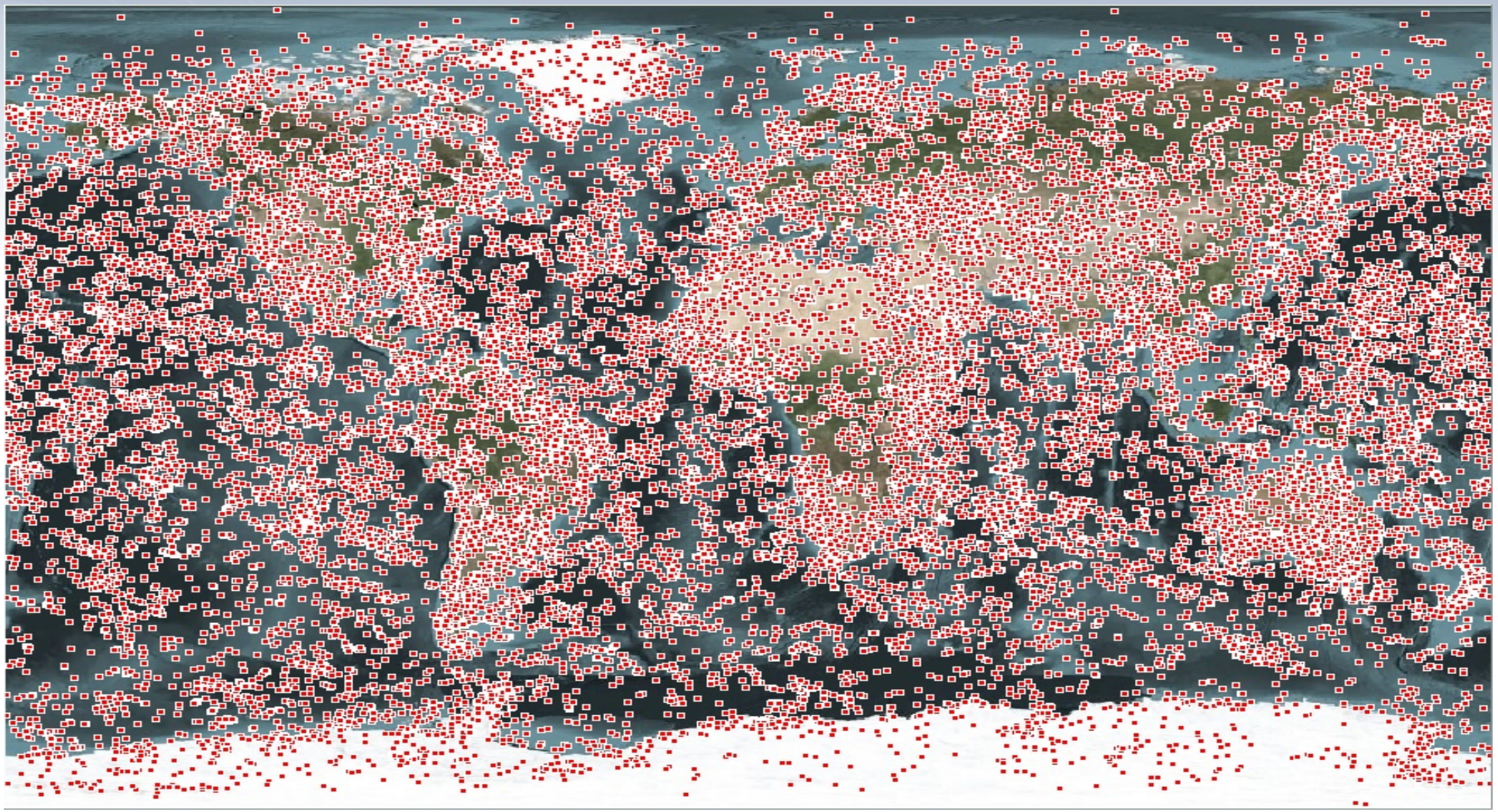
➢ **AVHRR integrated cloud-fraction**

- IASI PSF weighted count of AVHRR cloudy pixels
- Cloudy if CFR > 2%

! Confused by ice/Snow covers

2. Cloud screening

Concurrent detection algorithms



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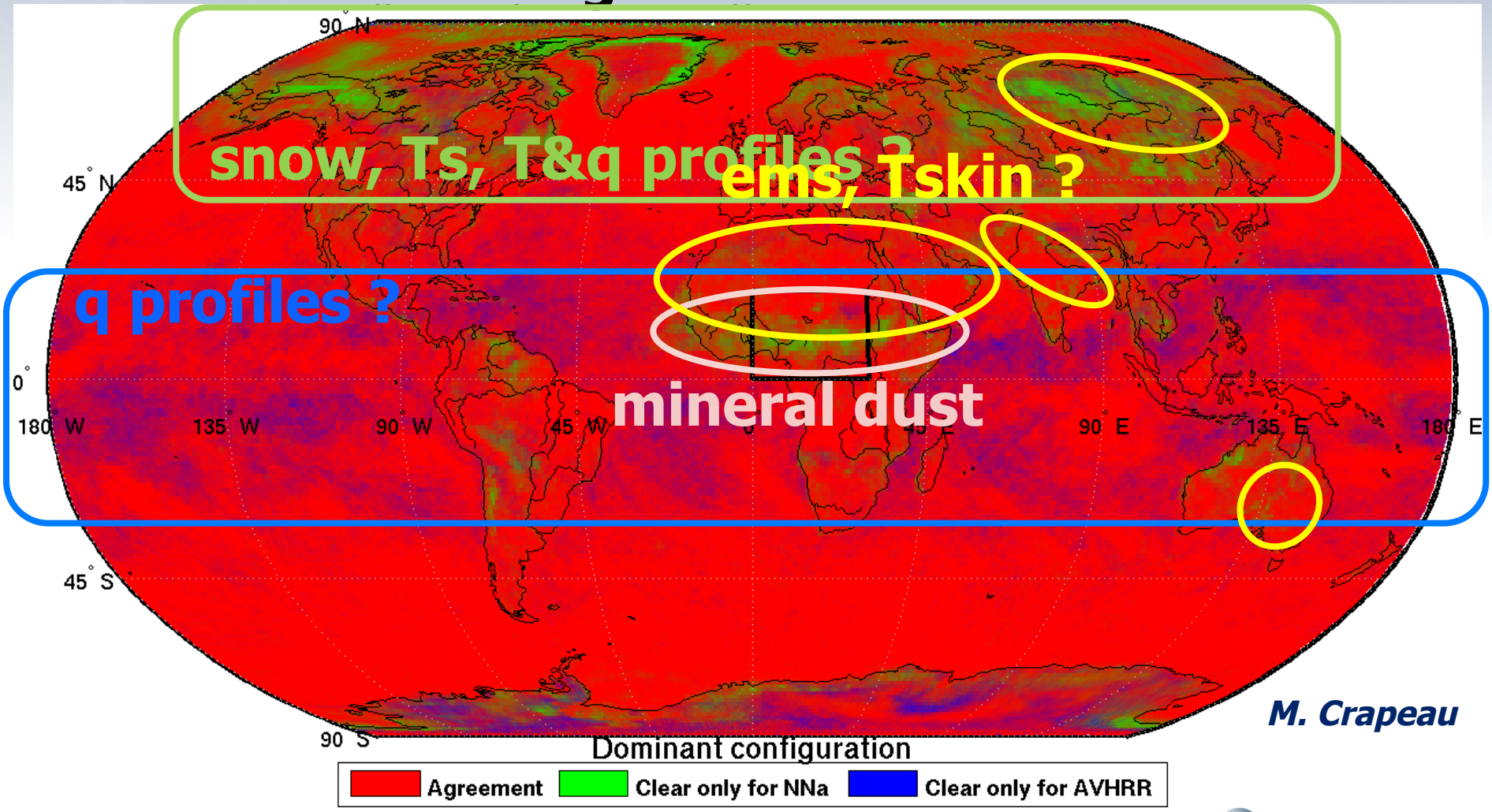
2. Cloud screening

Concurrent detection algorithms

19-24 March 2010 Agreement rate: ANN vs AVHRR



M. Crapeau

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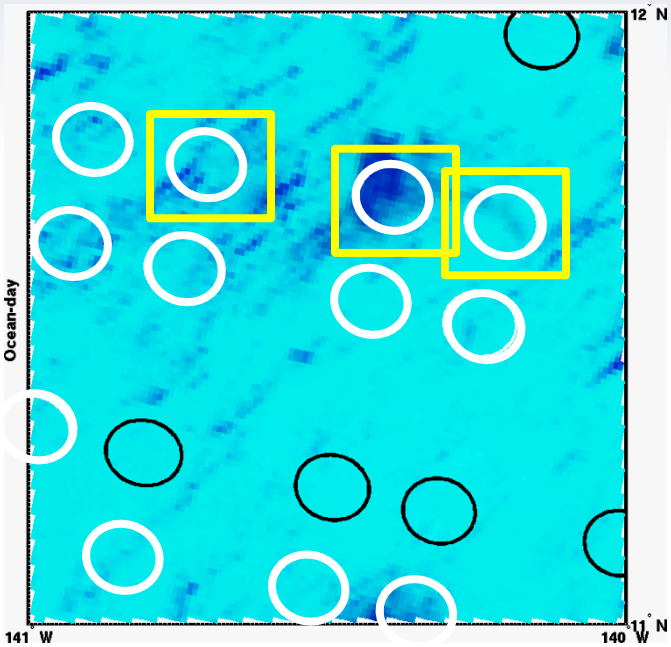
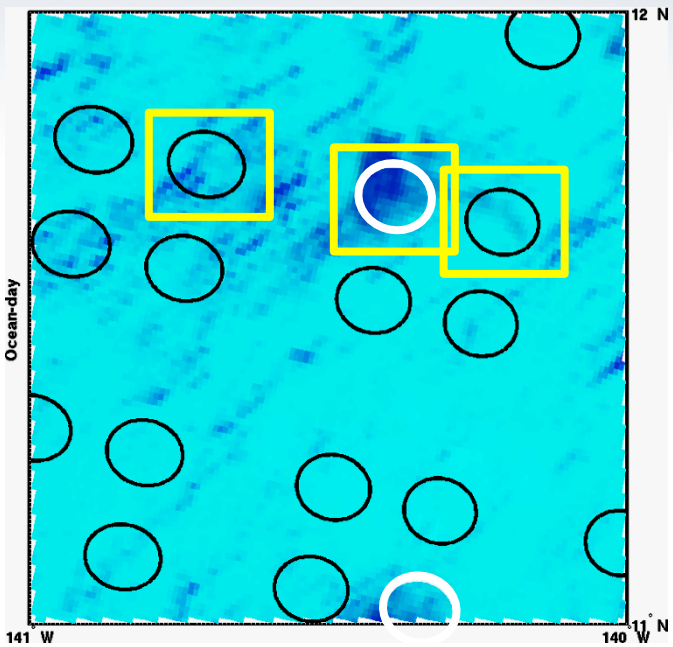
2. Cloud screening

Concurrent detection algorithms

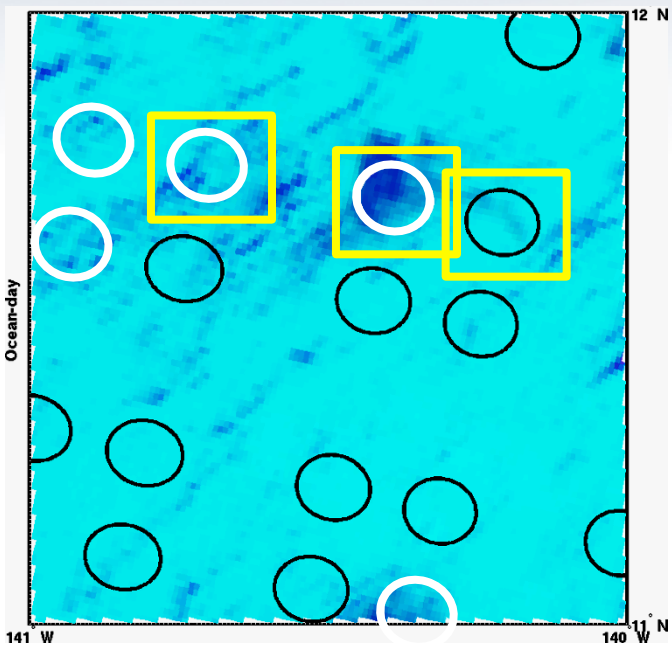
ANN test



NWP test



AVHRR test



White: cloudy **Black: clear**

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2. Cloud screening

Impact on IASI L2 yield and quality

Objectives: Relate cloudiness estimate to IASI L2 quality indicator

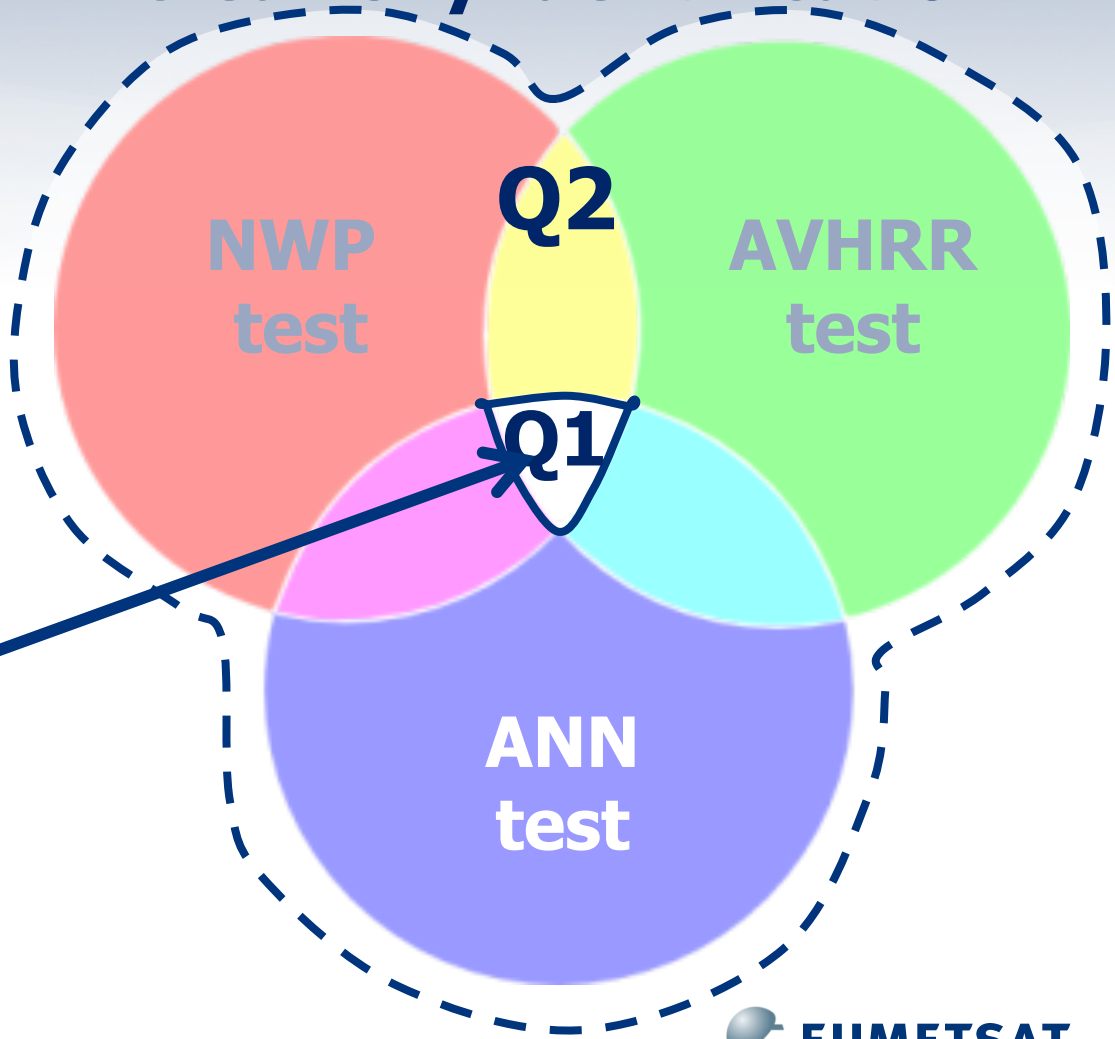
Cloudiness flag in v6	
1	Clear-sky
2	Potential small cloud contamination, cloud not characterised with confidence
3	IFOV partially cloudy
4	IFOV fully cloudy

+ High confidence

- Low yield

! Some area may be systematically excluded

Clear-sky identification



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2. Cloud screening

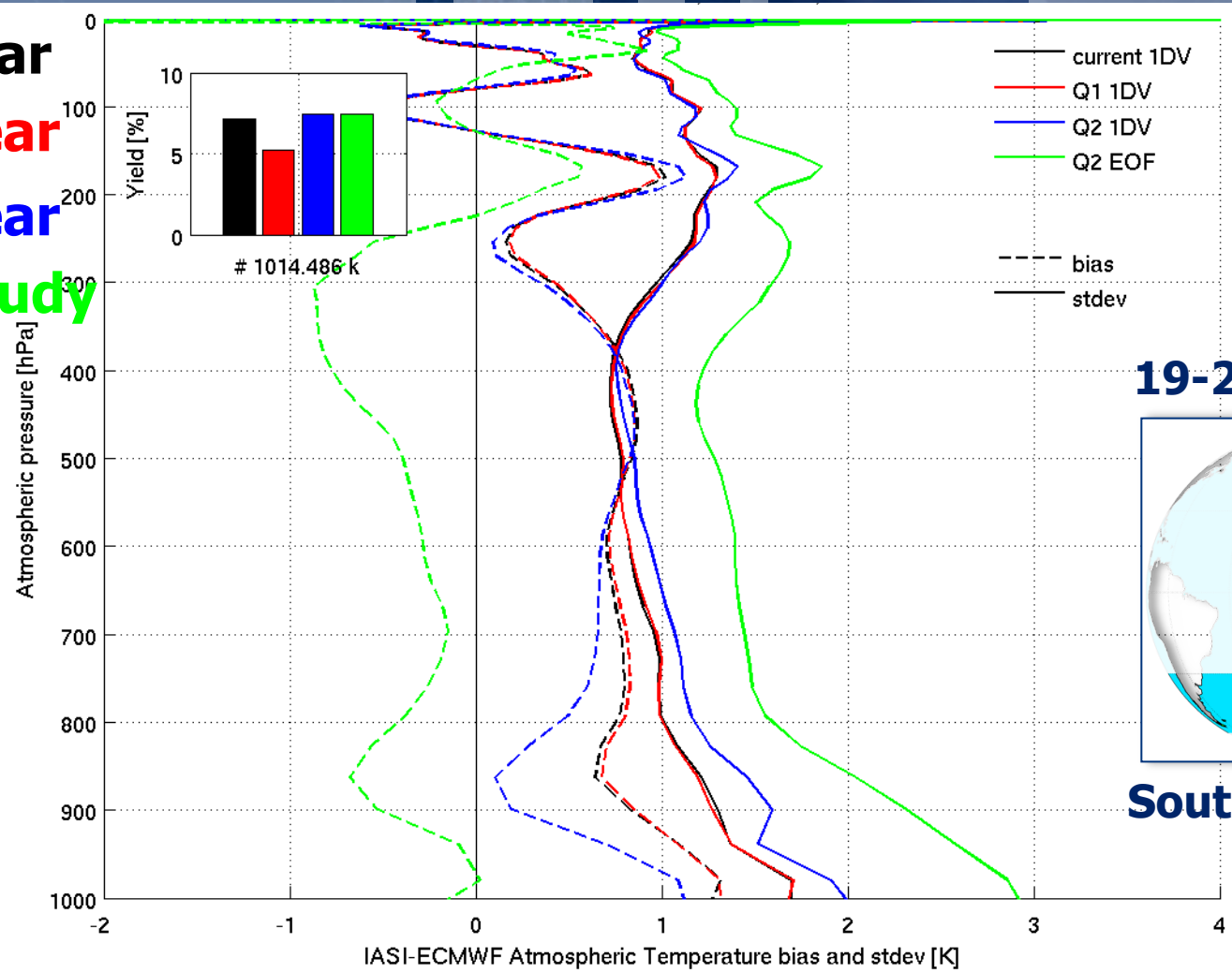
Impact on yield and quality: T profiles

Current clear

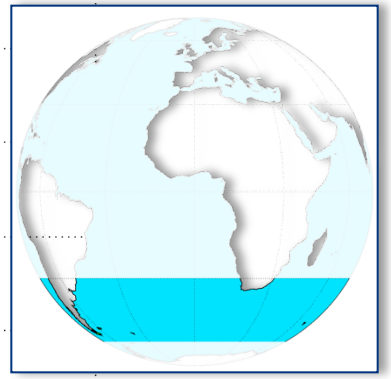
Q1 OEM clear

Q2 OEM clear

Current cloudy



19-24/03/2012



Southern oceans

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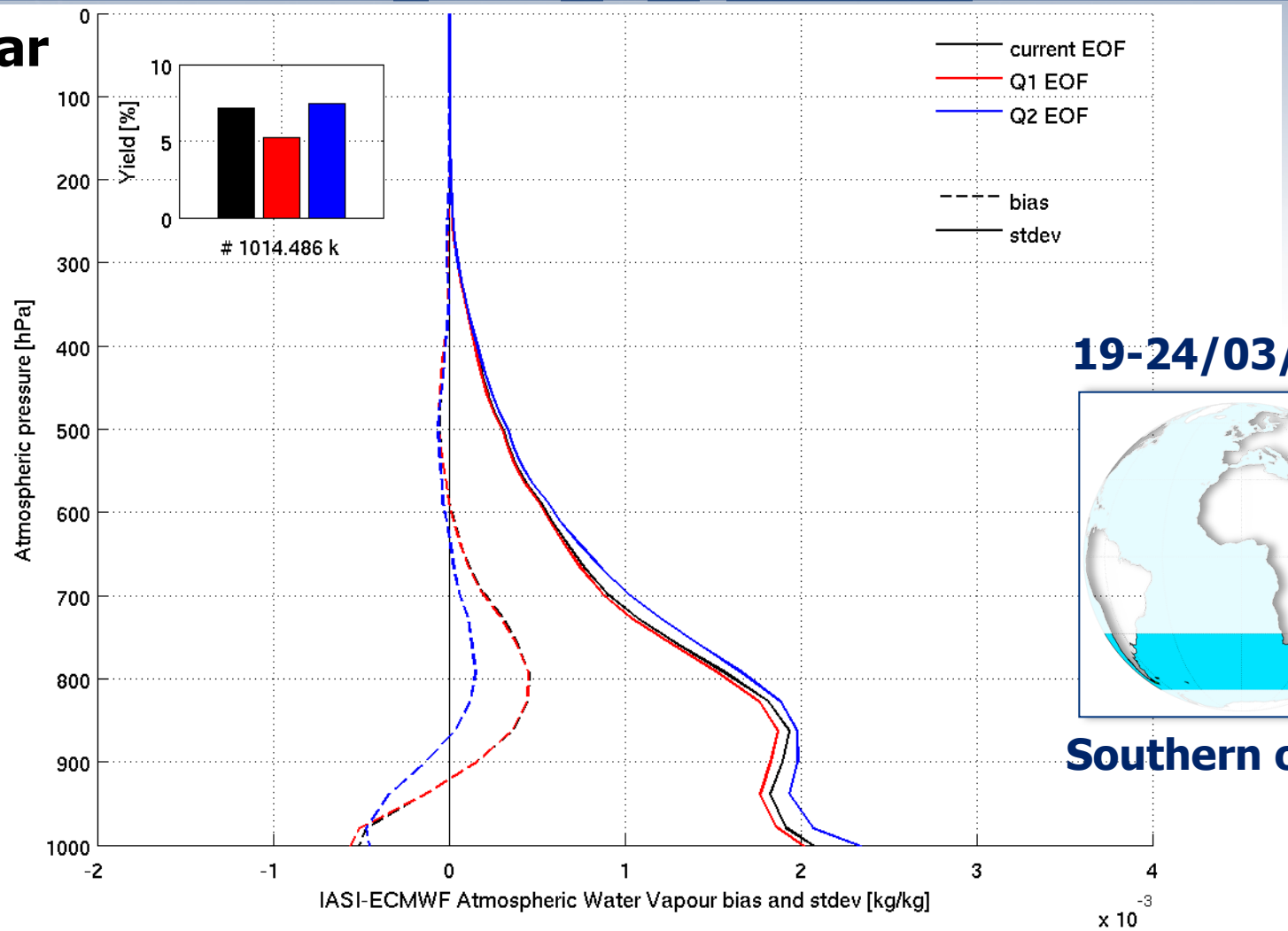
2. Cloud screening

Impact on yield and quality: q profiles

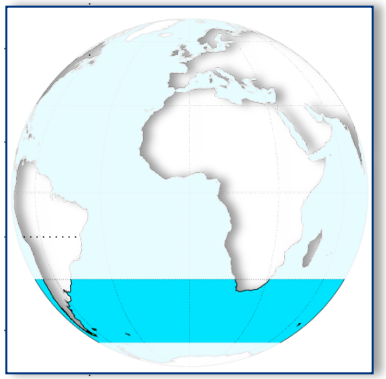
Current clear

Q1 EOF

Q2 EOF



19-24/03/2012



Southern oceans

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2. Cloud screening

Impact on yield and quality

Summary

√ Quality improved/preserved in Q1

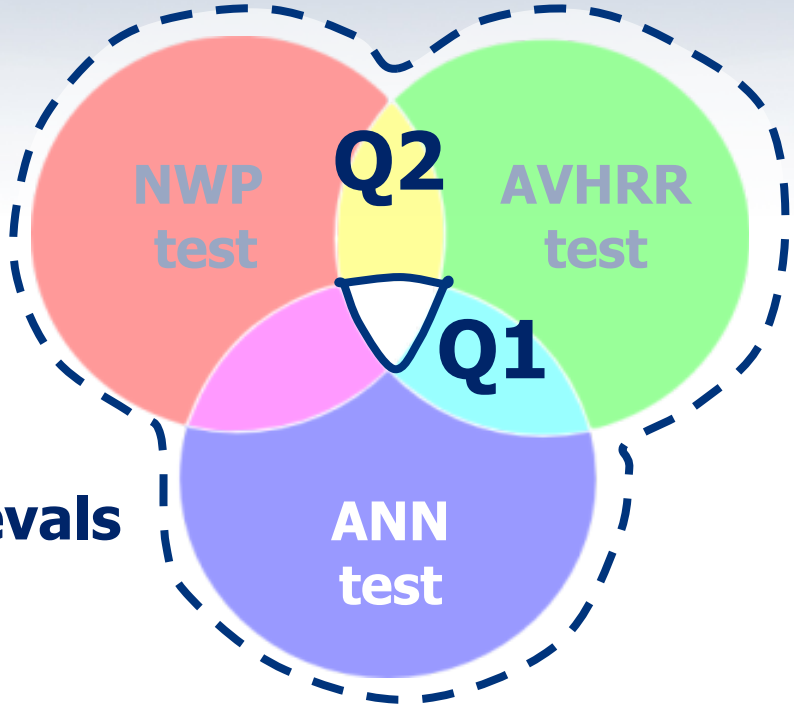
√ Quality improved in Q2

√ Overall yield increased

Future work

- Include cloud parameters in the retrievals
- Improve T retrievals in lower levels
- Improve q retrievals (esp. bias) in low tropo
- Repeat the study with radio-sondes data

Clear-sky identification



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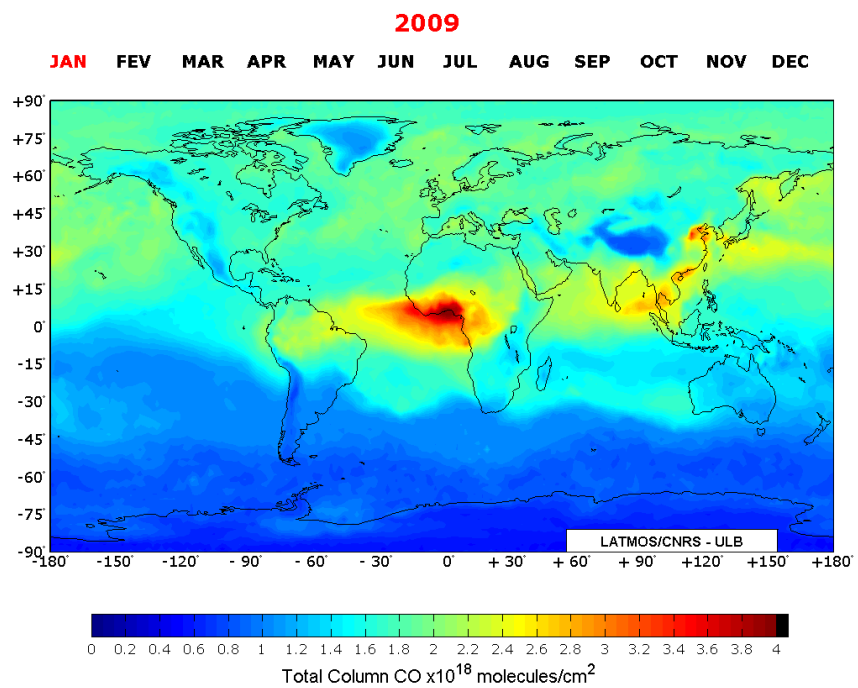
3. Current developments New products: CO, O_3, SO_2, HNO_3

Implementation in the EPS ground segment of a series of atmospheric compositi6 on products developped by Clerbaux & Coheur (ULB/LATMOS).

Essentially OEM based on FORLI (Fast Optimal Retrievals on Layers for IASI, *Hurtmans et al., JQSRT 2012*)

- **CO profiles + AK (2013)**
- **SO_2 column**
- **O_3 profiles + AK**
- **HNO_3 profiles**



Courtesy of C.Clerbaux ULB/LATMOS

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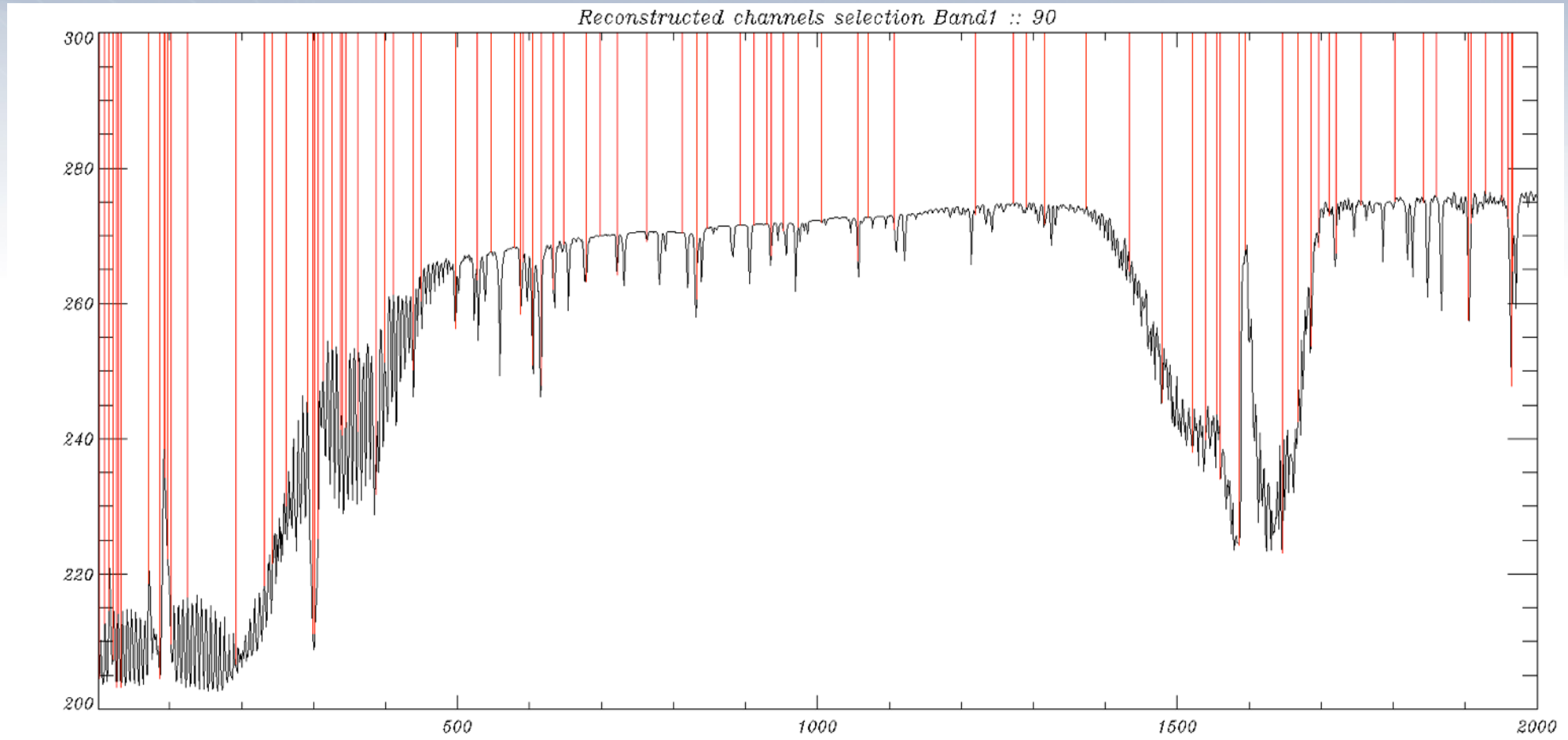
3. Current developments

New OEM configuration



➔ New channel selection in IASI Band 1

evaluated with cov(F(x) – F(x)) + ??

↘ projected onto observation space ➔ off-diagonal terms

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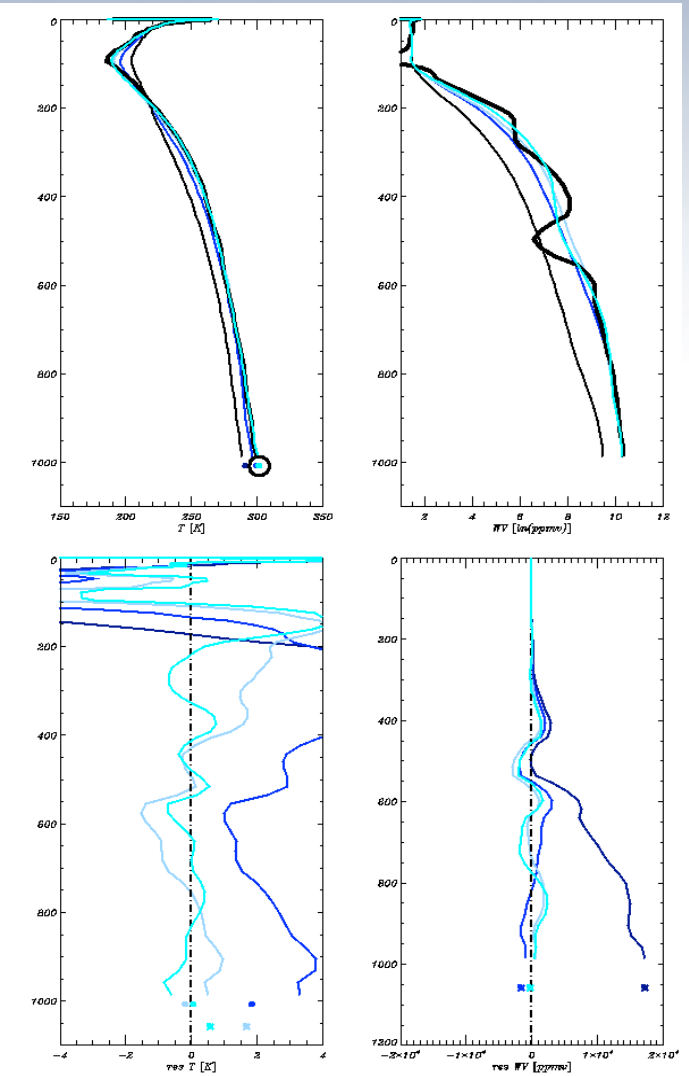
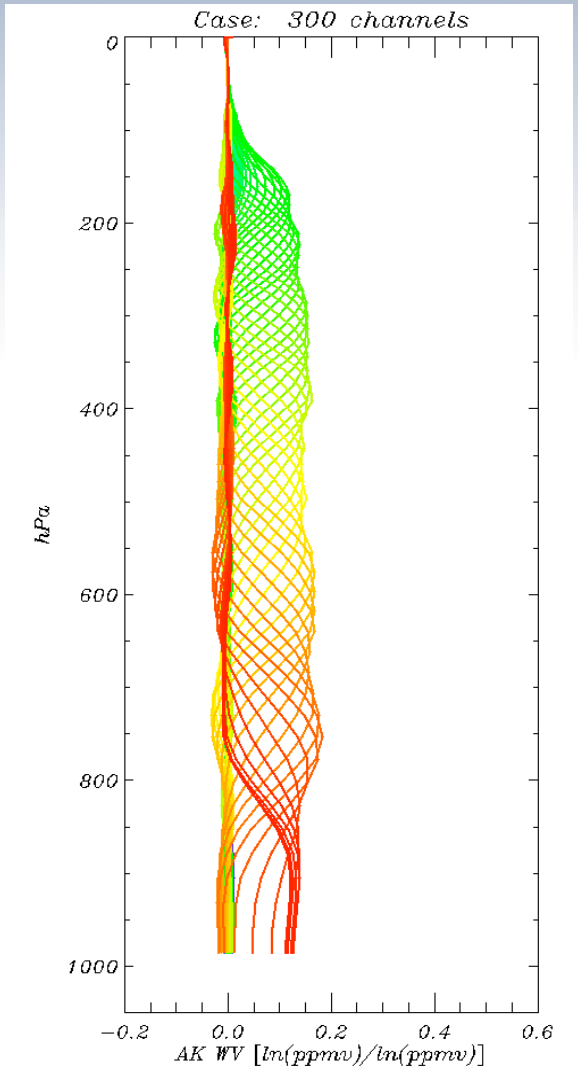
3. Current developments New OEM configuration: test case

Tropical case 19/03/2010 Comparison to ECMWF analyses

Clear-sky Night-time Ocean

BG and FG: global mean climatology





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Non-linear T,q statistical retrieval (NLR)

- External study lead by X. Calbet (EUM) performed University of Valencia (G. Camps-Valls et al.)
- Combination of EOF, ANN and support vector machines (SVM)
- Input: IASI radiances
- Training base: synthetic clear-sky IASI radiances simulated with OSS RTM and climatological database (Le Chevallier, ECMWF).
- Retrieved parameters: T, q, Ts, O3

!! More accurate than Linear Regression

!! Precision comparable to OE

!! Speed-up computations by 300

All sky, linear regression retrievals of T, q and O_3 profiles from co-located IASI, AMSU and AVHRR measurements.

T. Hultberg

80 predictors:

- Secant of satellite zenith angle
- Surface height
- Radiance in 14 AMSU channels (channel 7 excluded)
- 30 leading IASI band 1 PC scores
- 30 leading IASI band 2 PC scores
- Standard deviation and mean of AVHRR channel 4 radiance within IASI FOV
- Standard deviation and mean of AVHRR channel 5 radiance within IASI FOV

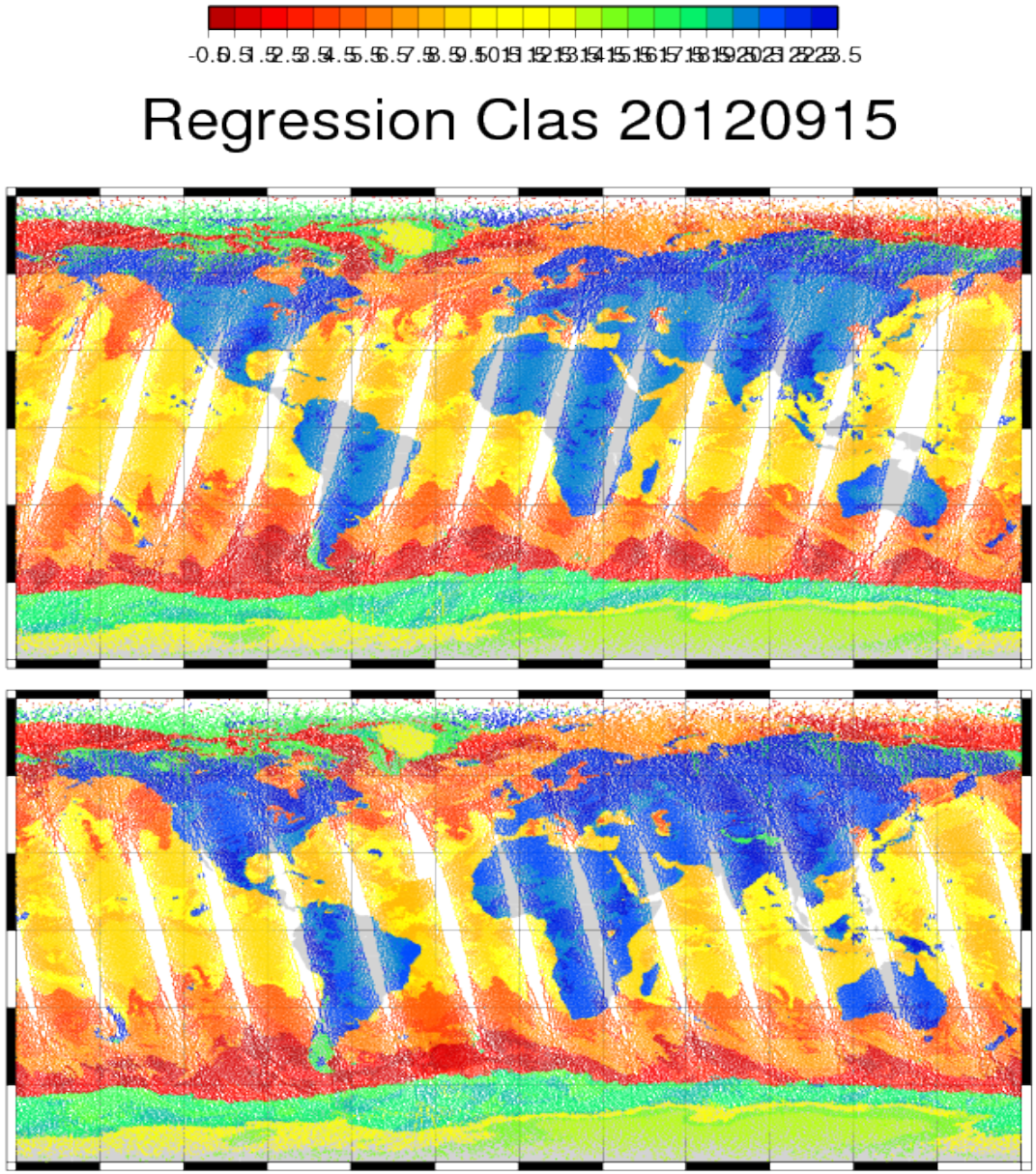
276 predictands:

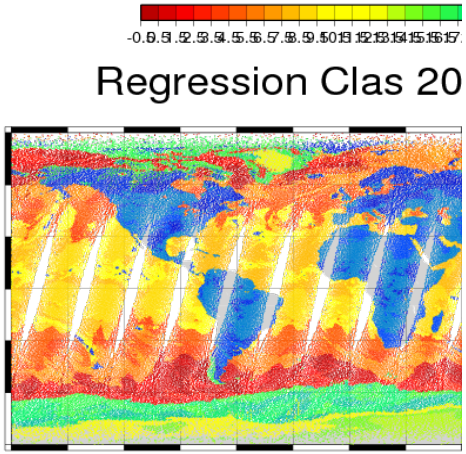
- Ta (K)
- Wa (K)
- Ts (K)
- T profile (K) at 91 model levels
- W profile (K) dew point temperature at 91 model levels
- O profile (K) “dew point temperature” (W formula) at 91 model levels

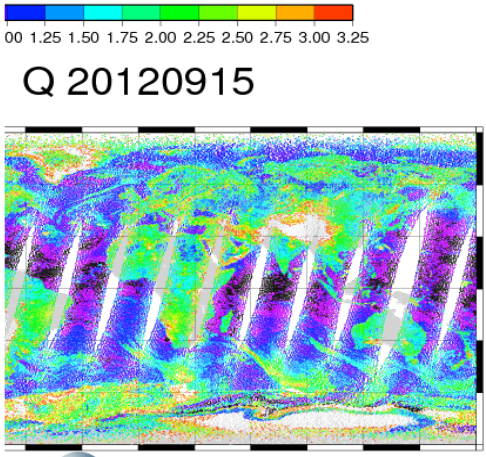
3. Current developments

MW+IR all-sky linear retrieval

- **Training set:** VF forecasts 3 nths).
- **24 regressio** ts. The classes are dete nnel 2 and 4 and the first tw
- **Error estima** m of the absolute values puted, which allows for an es rieval.







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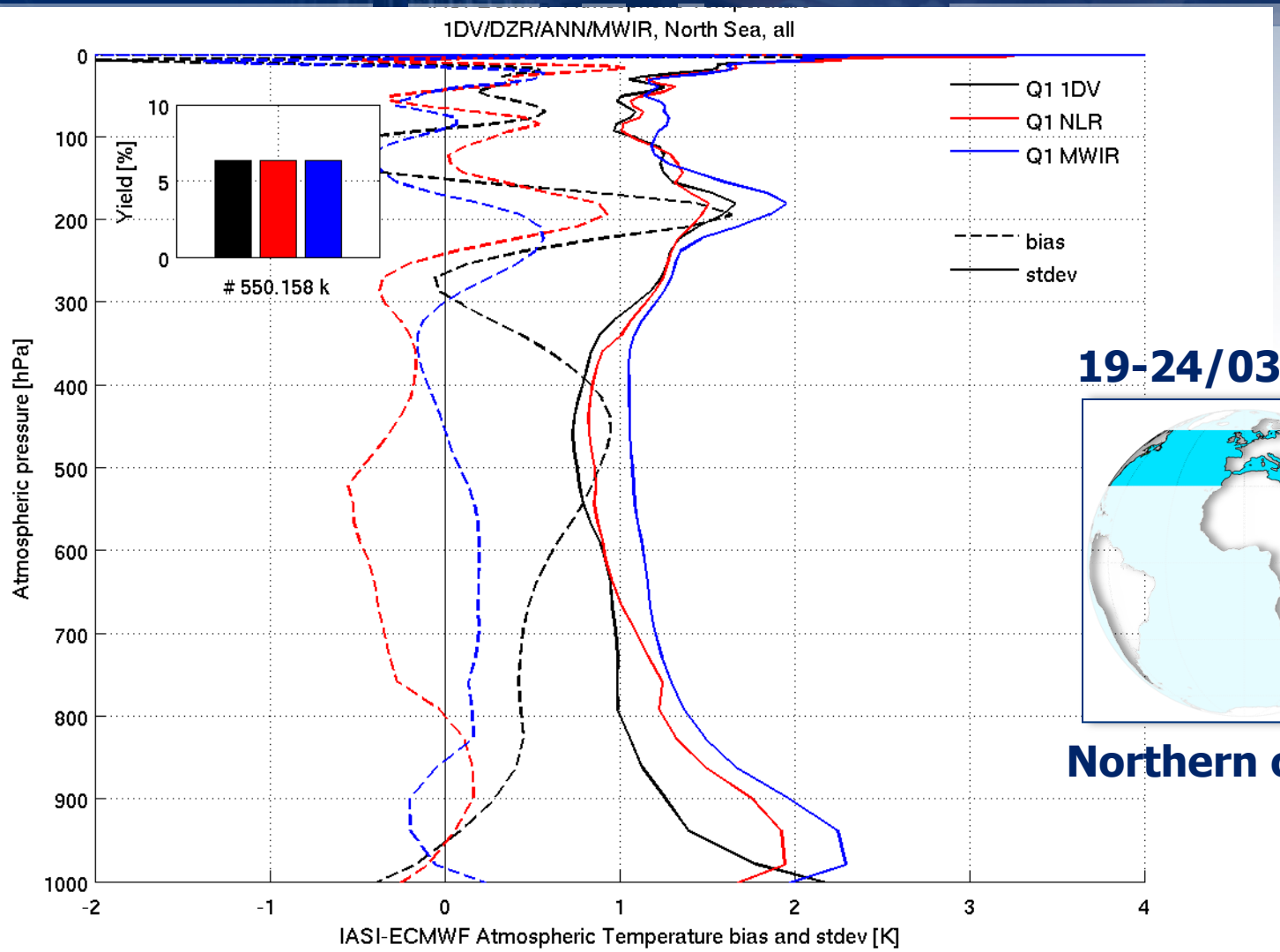
3. Current developments

Assessment of new T retrievals

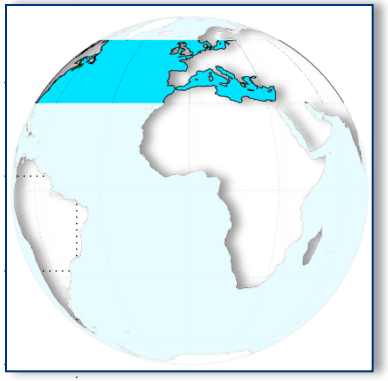
Q1 OEM

Q1 NLR

Q1 MWIR



19-24/03/2010



Northern oceans

EUMETSAT

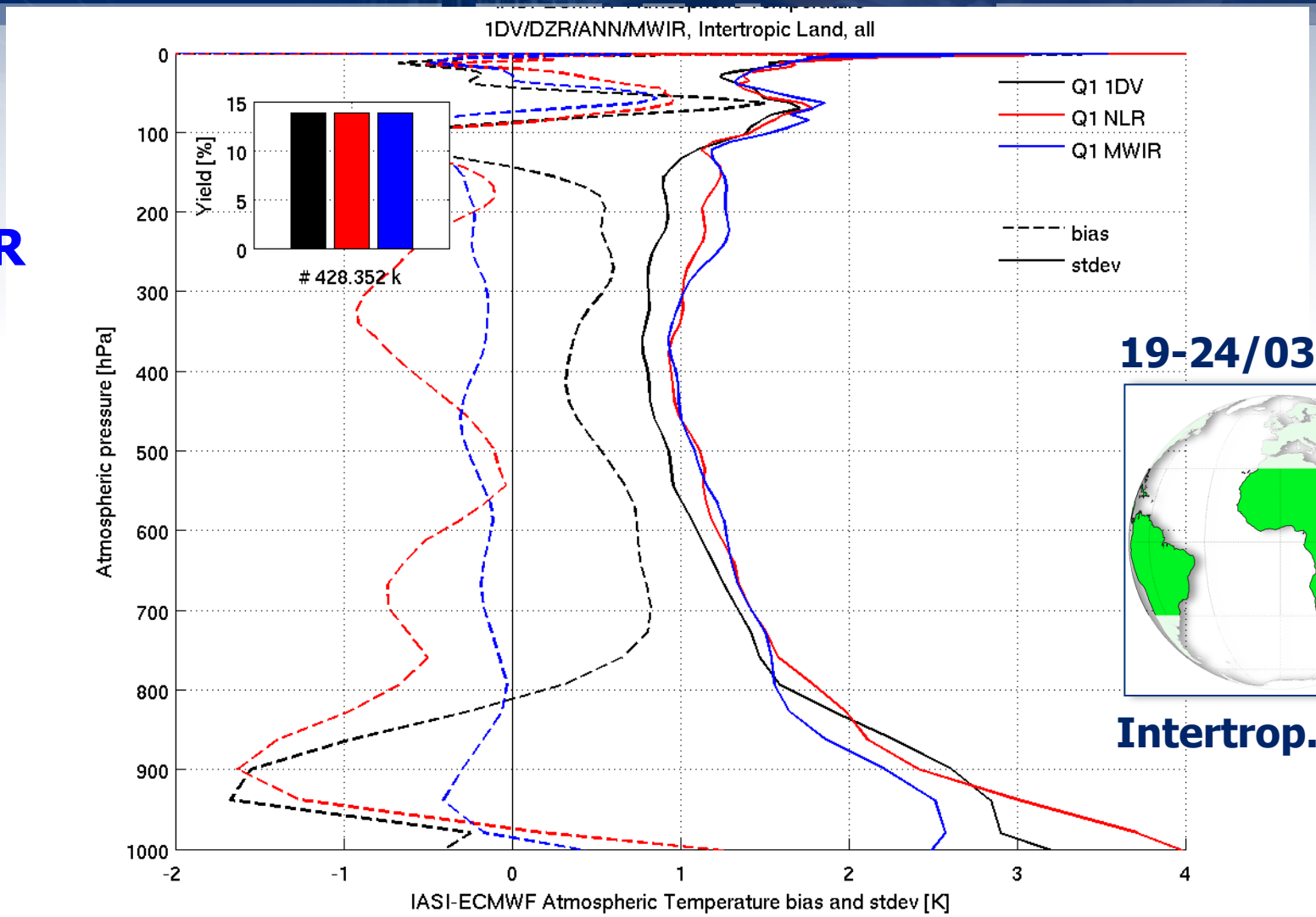
3. Current developments

Assessment of new T retrievals

Q1 OEM

Q1 NLR

Q1 MWIR



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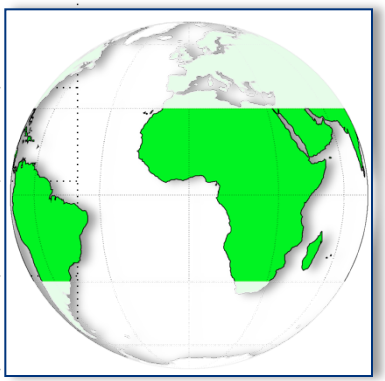
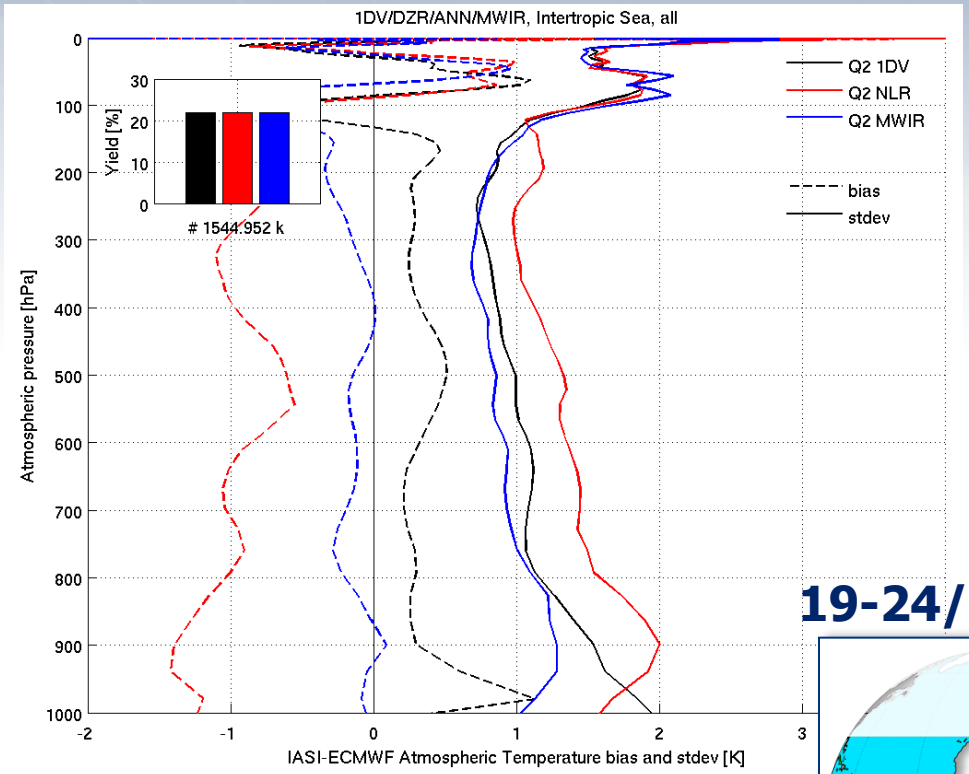


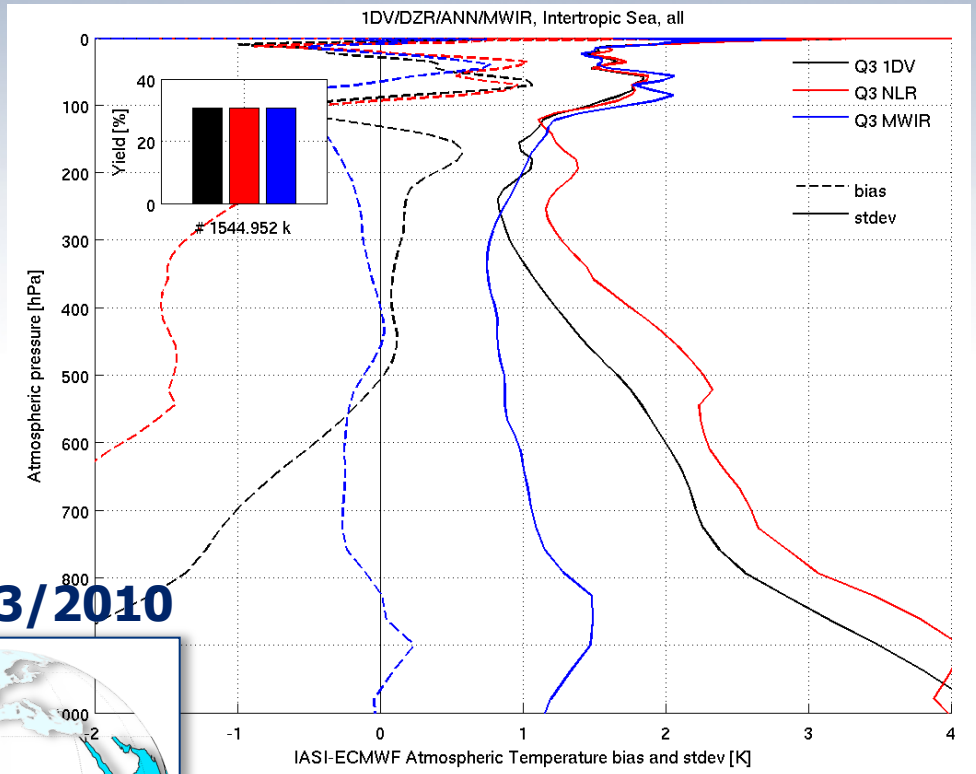
Intertrop. lands

EUMETSAT

3. Current developments

Assessment of new T retrievals





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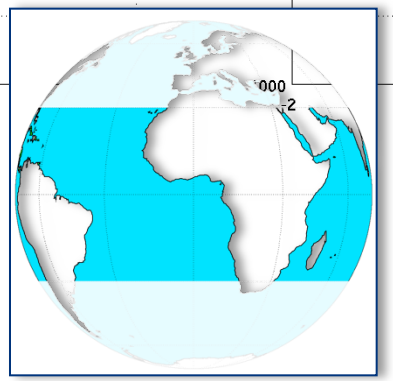

Intertrop. oceans

Q2 OEM clear

Q2 NLR clear

Q2 MWIR

Q3 OEM clear

Q3 NLR clear

Q3 MWIR

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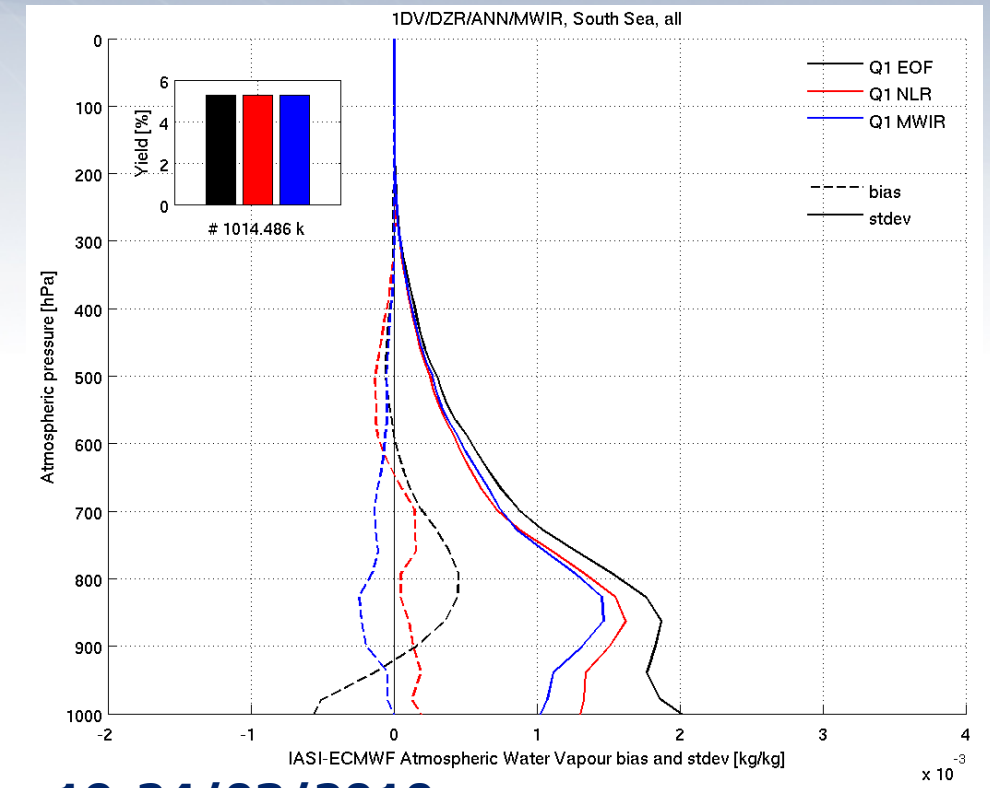
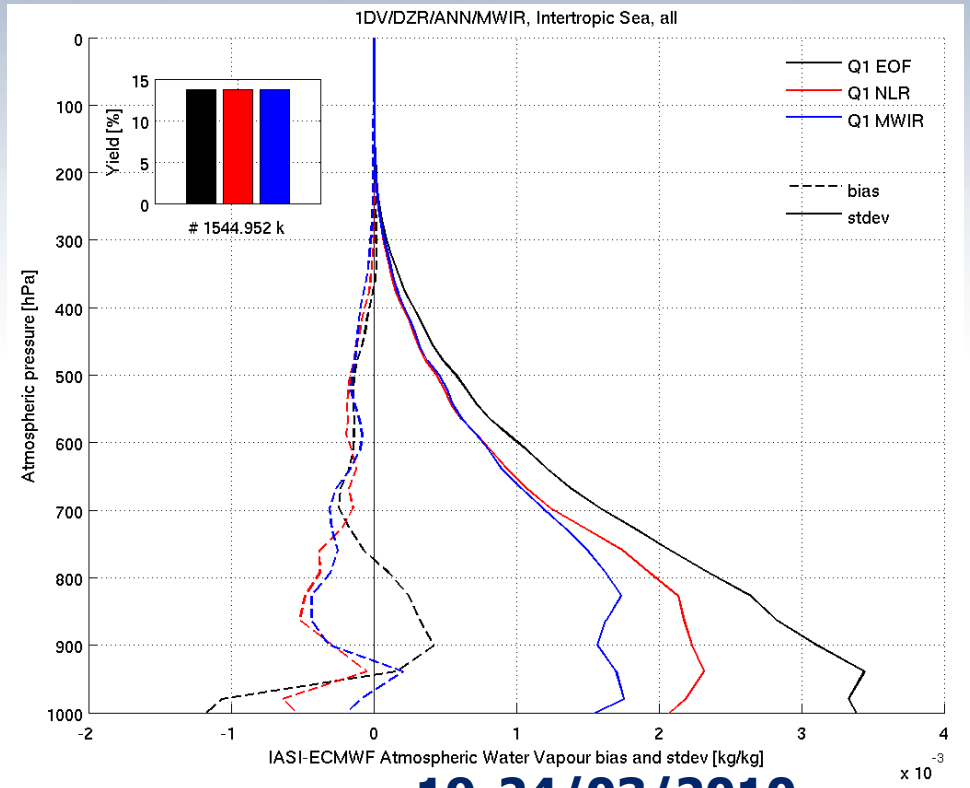
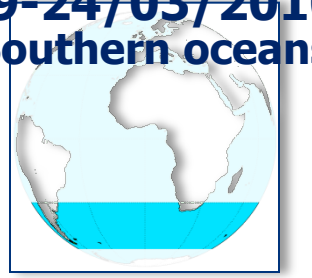
3. Current developments Assessment of new WV retrievals





19-24/03/2010
Southern oceans



Q1 OEM clear

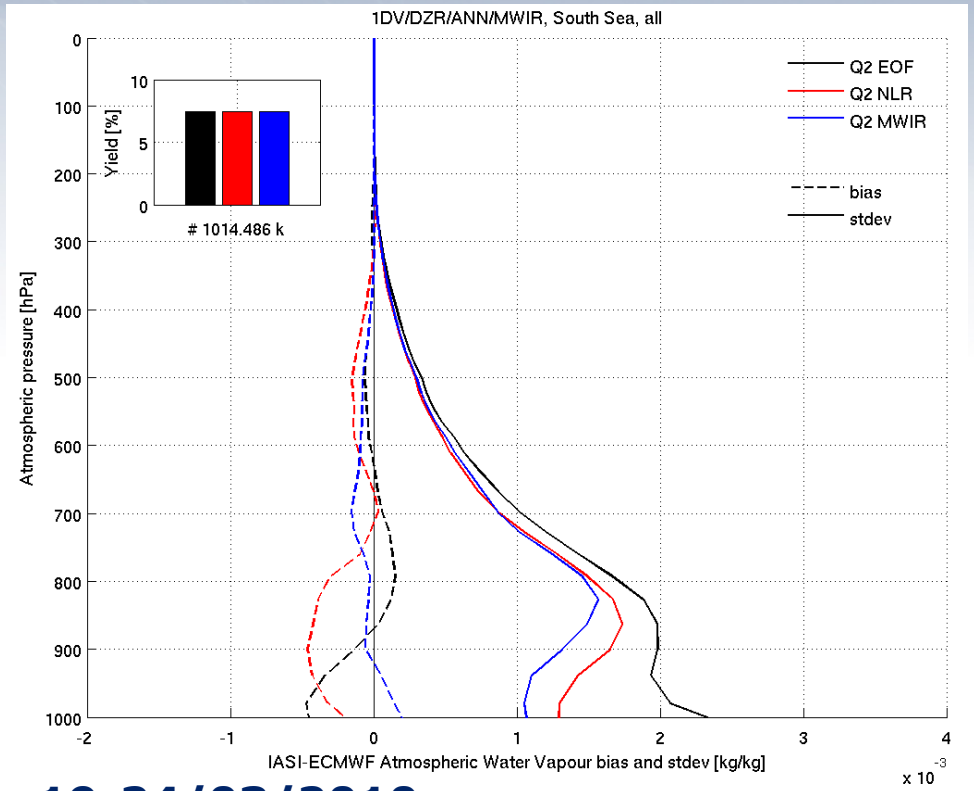
Q1 NLR clear

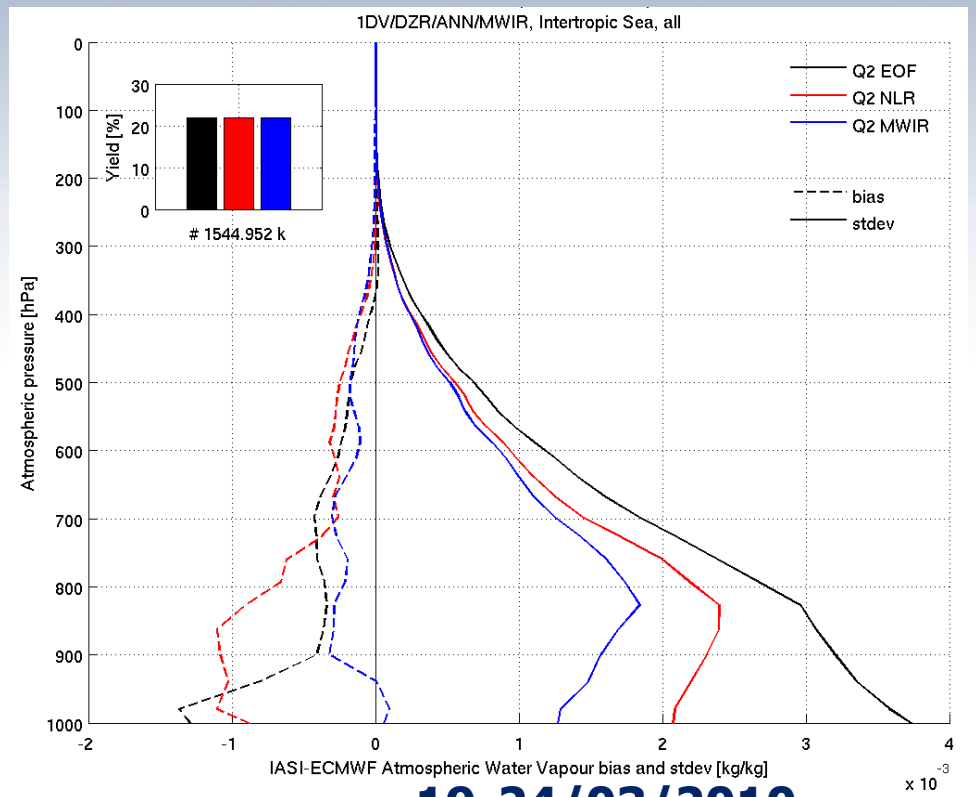
Q1 MWIR

19-24/03/2010
Intertrop. oceans

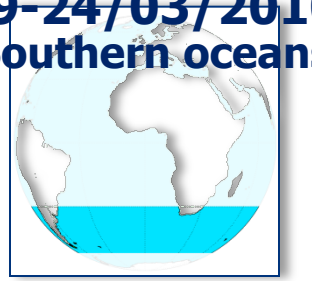
EUMETSAT

3. Current developments Assessment of new WV retrievals





19-24/03/2010
Southern oceans



Q2 OEM clear

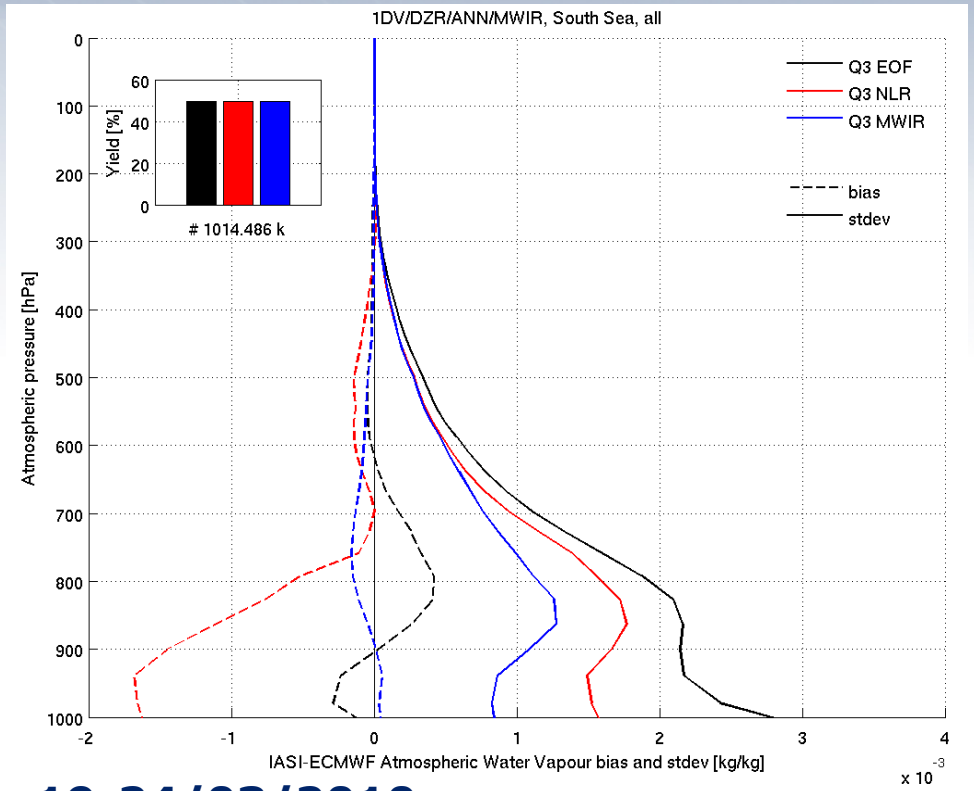
Q2 NLR clear

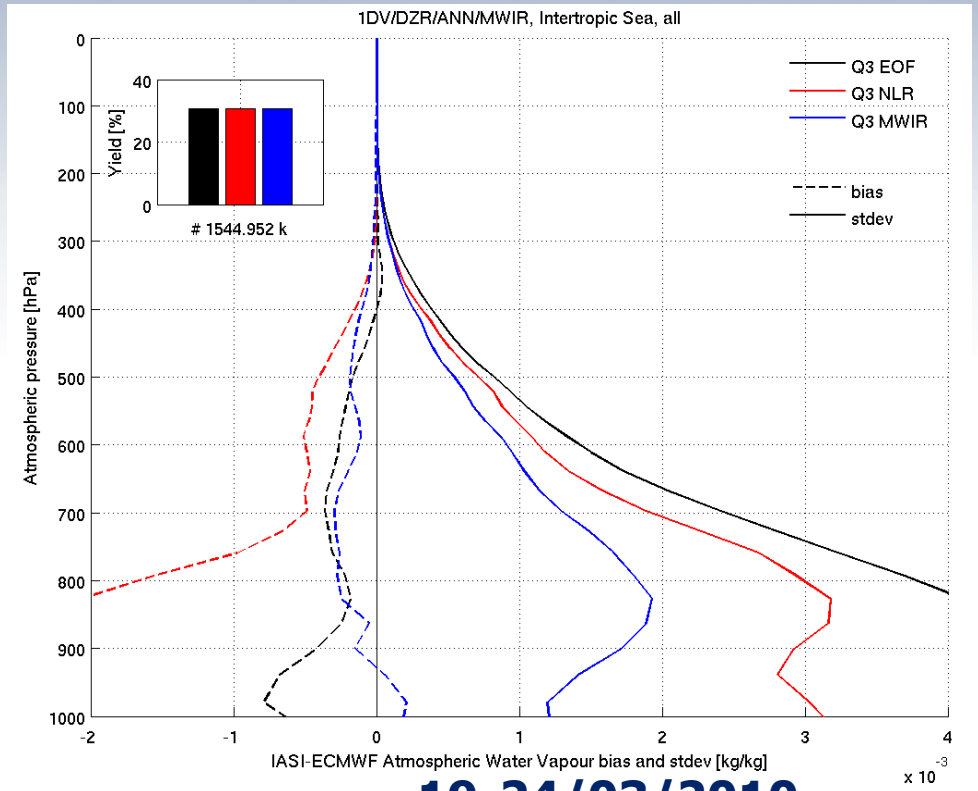
Q2 MWIR

19-24/03/2010
Intertrop. oceans

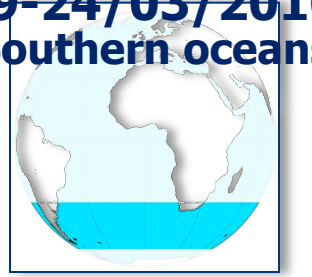
EUMETSAT

3. Current developments Assessment of new WV retrievals





19-24/03/2010
Southern oceans



Q3 OEM clear

Q3 NLR clear

Q3 MWIR

19-24/03/2010
Intertrop. oceans

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Summary & Outlook

- ✓ **PPFv5 operational since 14/09/2010**
- ✓ **Significant improvements: T, LST, clouds, CO, O_3**

Coming in 2013:

-> Cal/Val IASI L2 / Metop-B

-> Conclusion of the version 6 (new algorithms & products)

Various parts of the processing chain, with direct or indirect **positive impact on the T,q** profiles are being upgraded

- cloud detection
- Ems
- New atmospheric composition products
- use of reconstructed radiances
- improved FG (NLR and MWIR)

More accurate T,q sounding in lower tropo and in cloud-contaminated IFOVs, increased L2 yield expected.

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Summary & Outlook

Parameter	Algorithm	Status	Plans for V6
Cloud detection	NWP, AVHRR	Operational	NWP+AVHRR+ANN
Cloud fraction & height	CO_2-slicing + χ^2	Operational	
Cloud phase	BT difference	Trial	
T profiles	OEM	Operational	NLR, MWIR OEM(q) reconstructed rads AK
q profiles	EOF	Operational	
SST / LST	EOF	Operational	Fix angular variation OEM(LST & ems)
Emissivity	EOF	Trial	
O_3 total column	OEM	Operational	Profiles + AK
O_3 partial columns	OEM	Trial	
CO	ANN	Operational	Profiles + AK
N_2O, CH_4, CO_2	ANN	Experimental	SO2, HNO3, ???

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Open questions

¿ clouds/aerosol detection/simulation from IR and impact on sounding quality ?

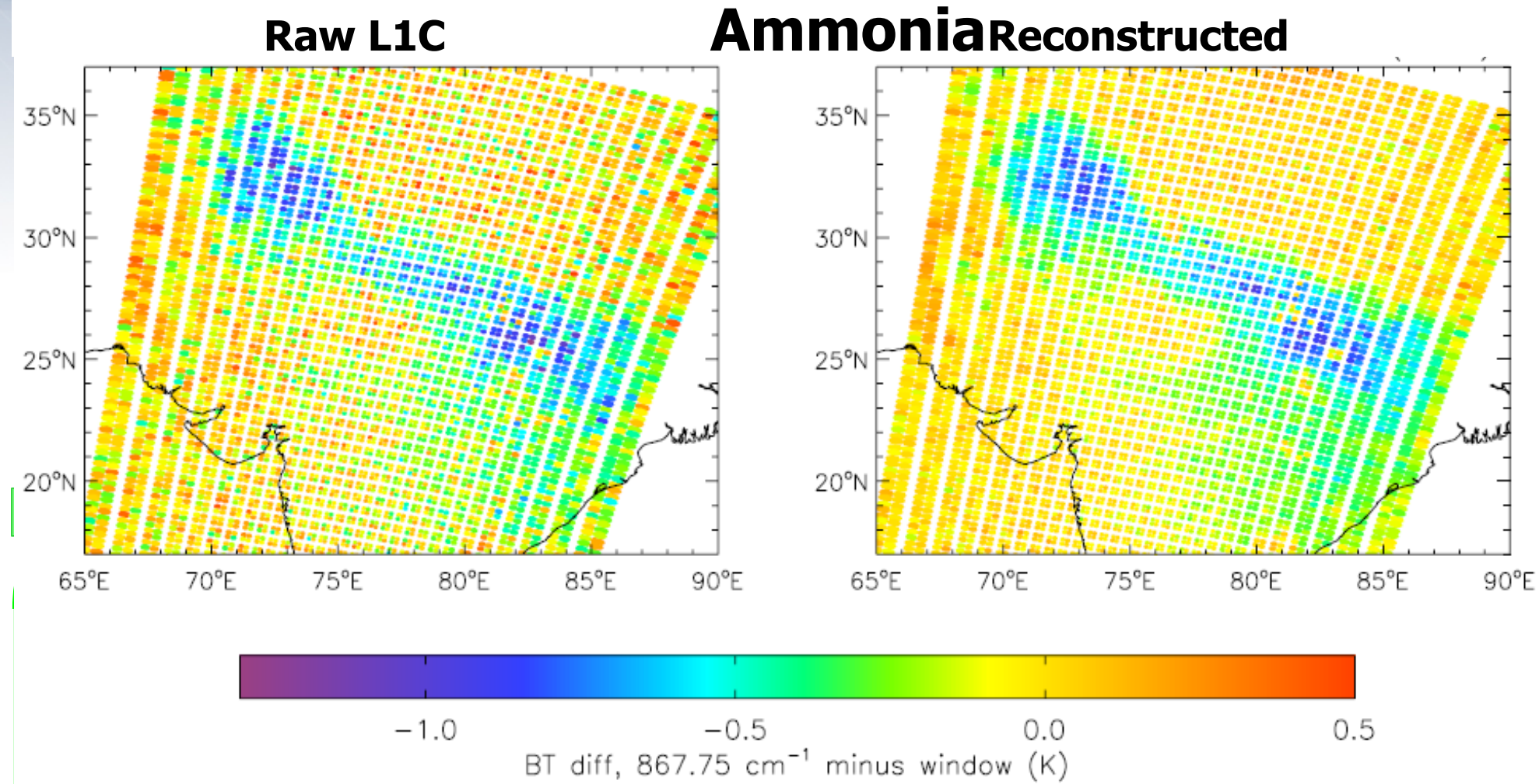
¿ What WV products references for the validation of satellite retrieved profiles with ground resolution of 12-30 km ?

¿ Calibration instrument/RTM, esp. in WV channels and characterisation of the observation error matrix ?

¿ Retrieving GHG with IASI ?

1. IASI L2 version 5

The radiance filtering



"Potential for the use of reconstructed IASI radiances in the detection of atmospheric trace gases", N. C. Atkinson, F. I. Hilton, S. M. Illingworth, J. R. Eyre, and T. Hultberg, AMT 2010

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1. IASI L2 version 5

The cloud fraction: validation

Cloud fr

NW Atlantic

Retrie

vs

Whole-Sky

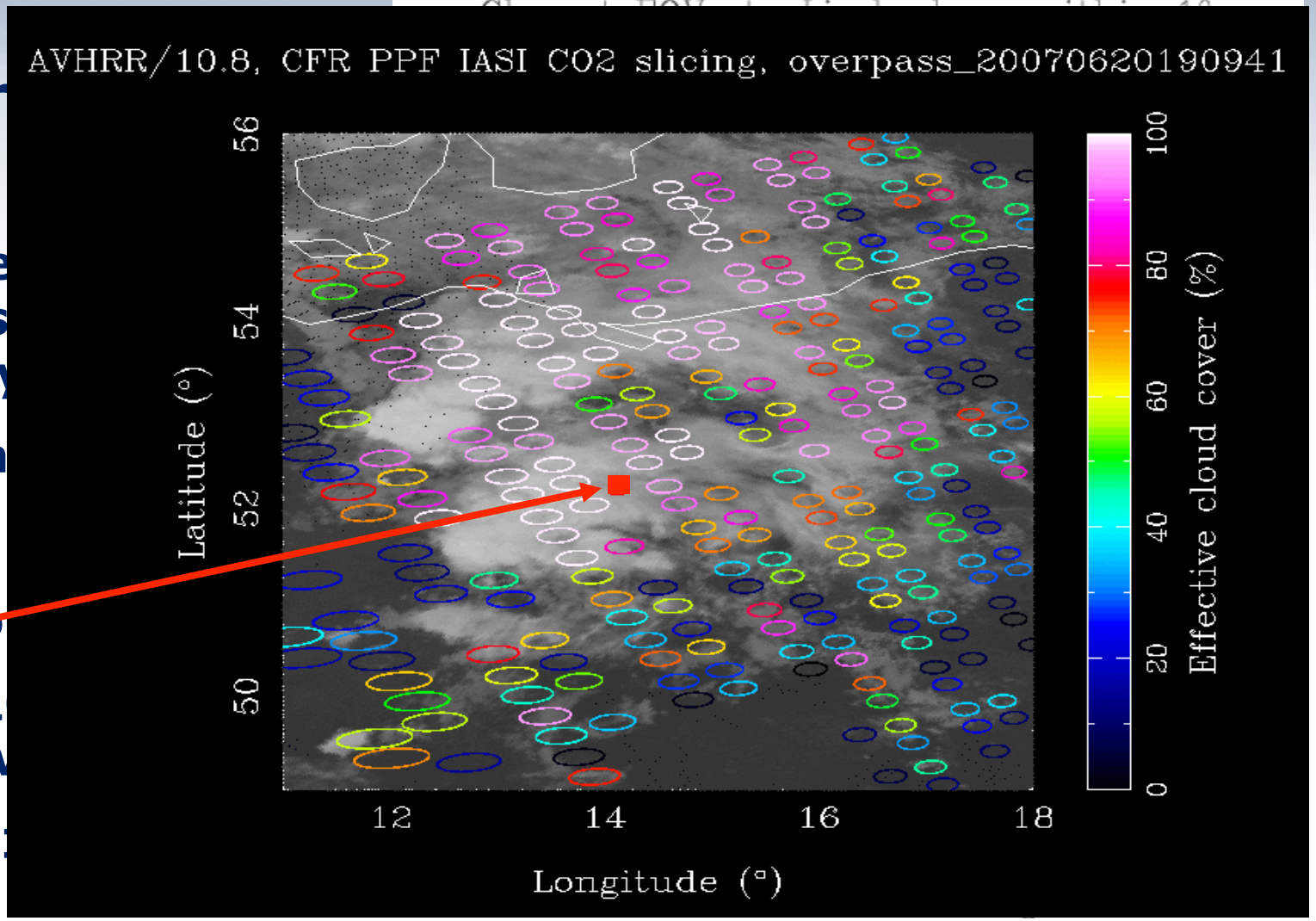
(Linden

Lindenberg

Time: 1

interv

Space:



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1. IASI L2 version 5

The cloud-top pressure: validation

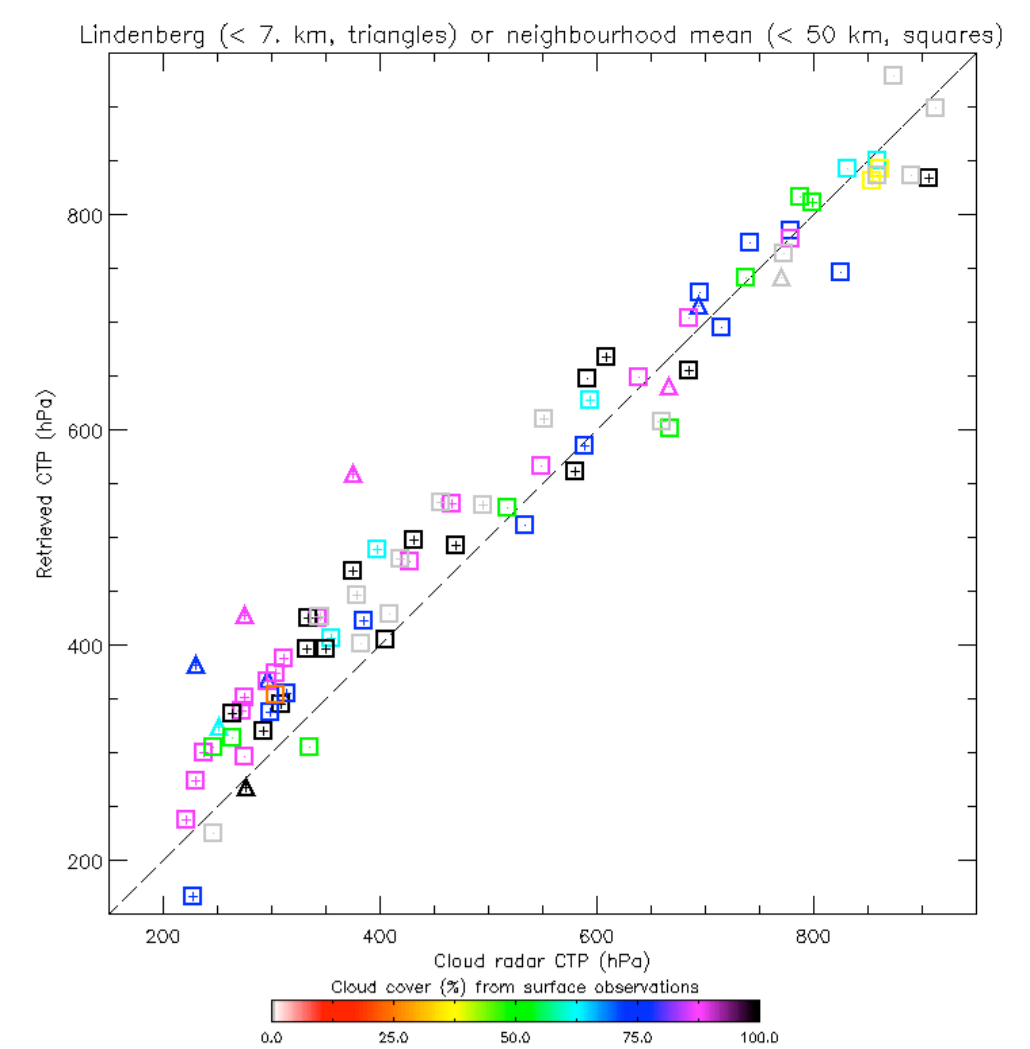
Cloud-top pressure

Retrieved
vs
ground-based radar
(Lindenberg)

Match-up criteria

Space: within 50km

Single layer clouds



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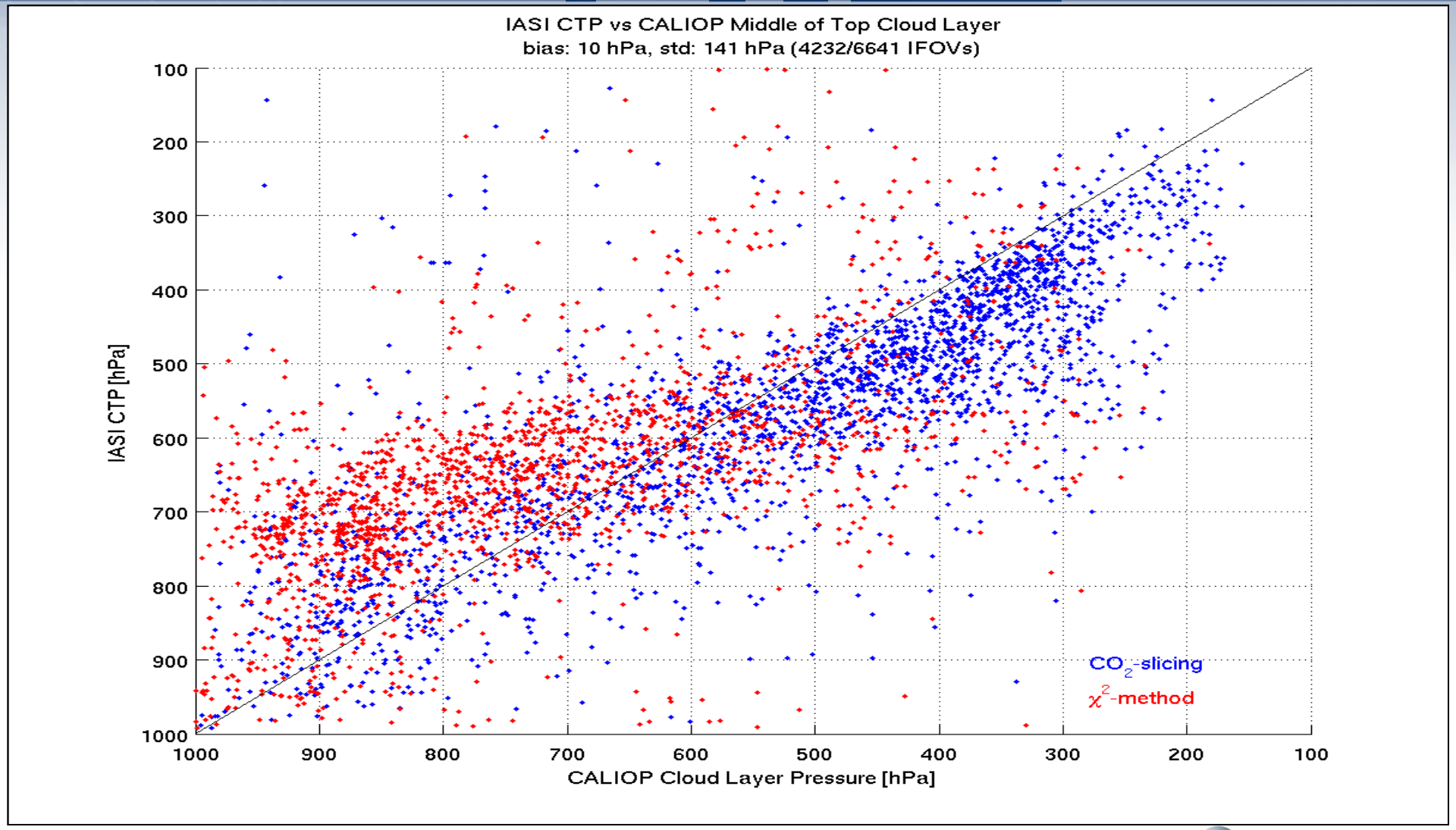
2. Cloud products

The cloud-top pressure



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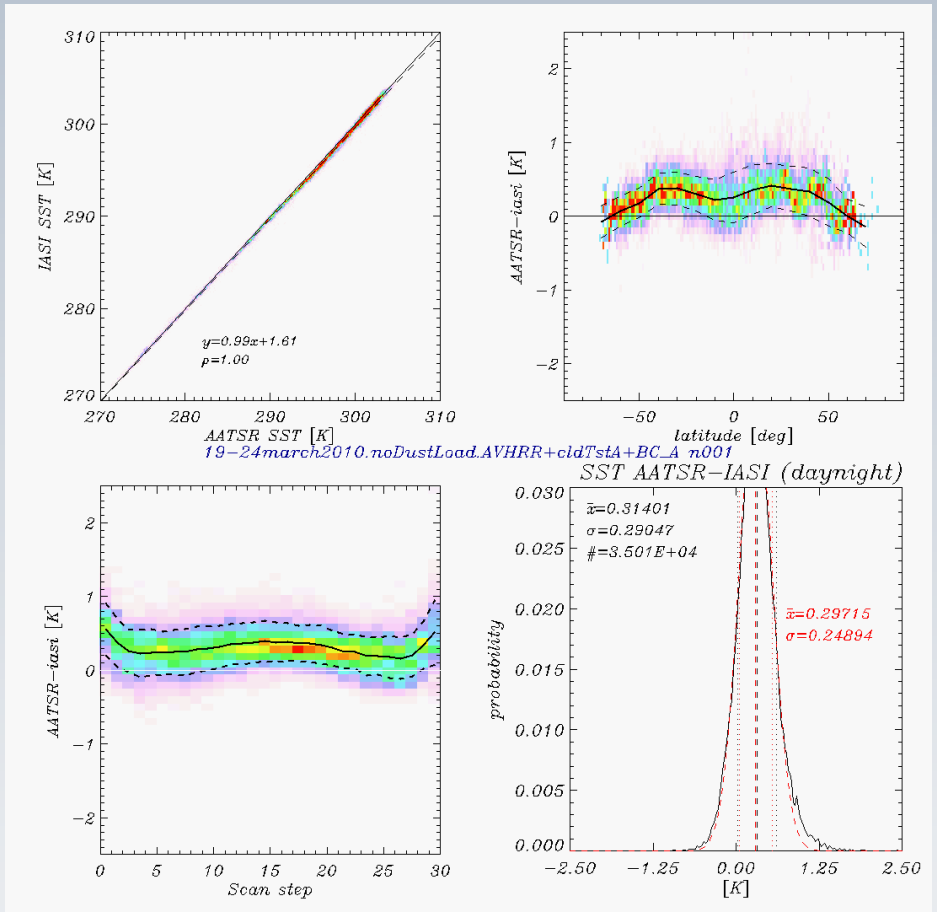
1. IASI L2 version 5

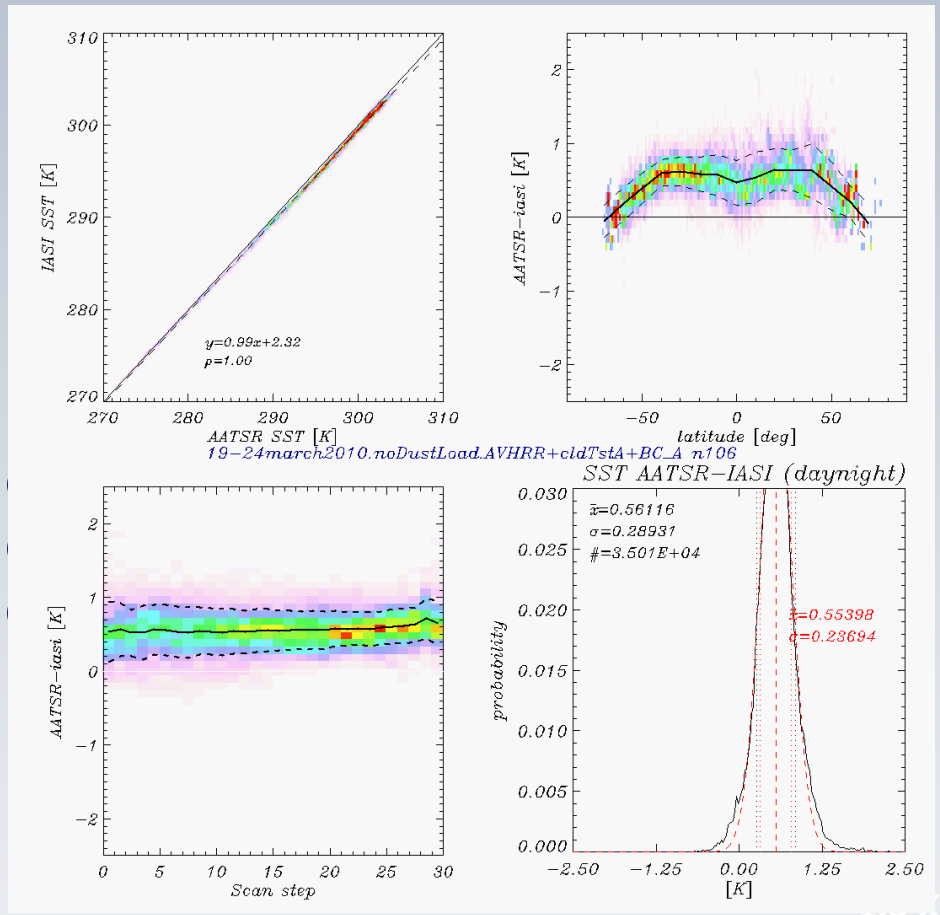
Sea Surface Temperature

19-24 March 2010

AATSR – IASI (v5)



AATSR – IASI (prototype v6)



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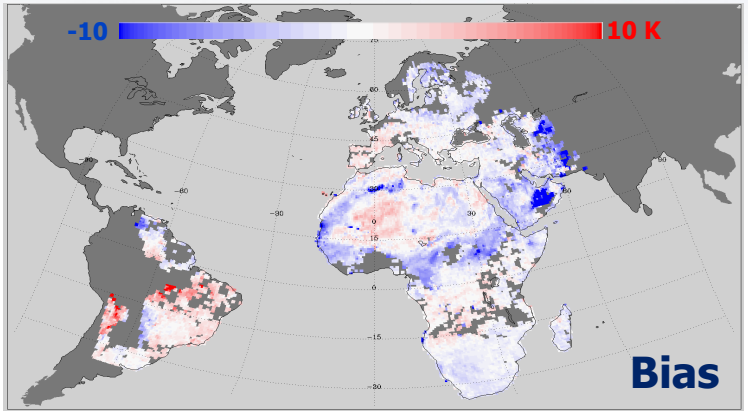
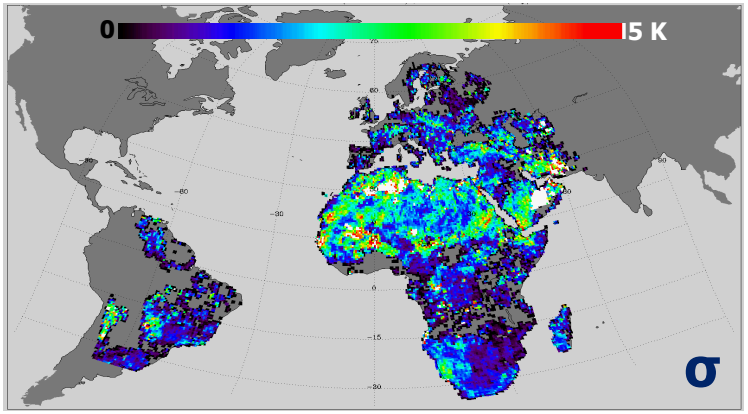
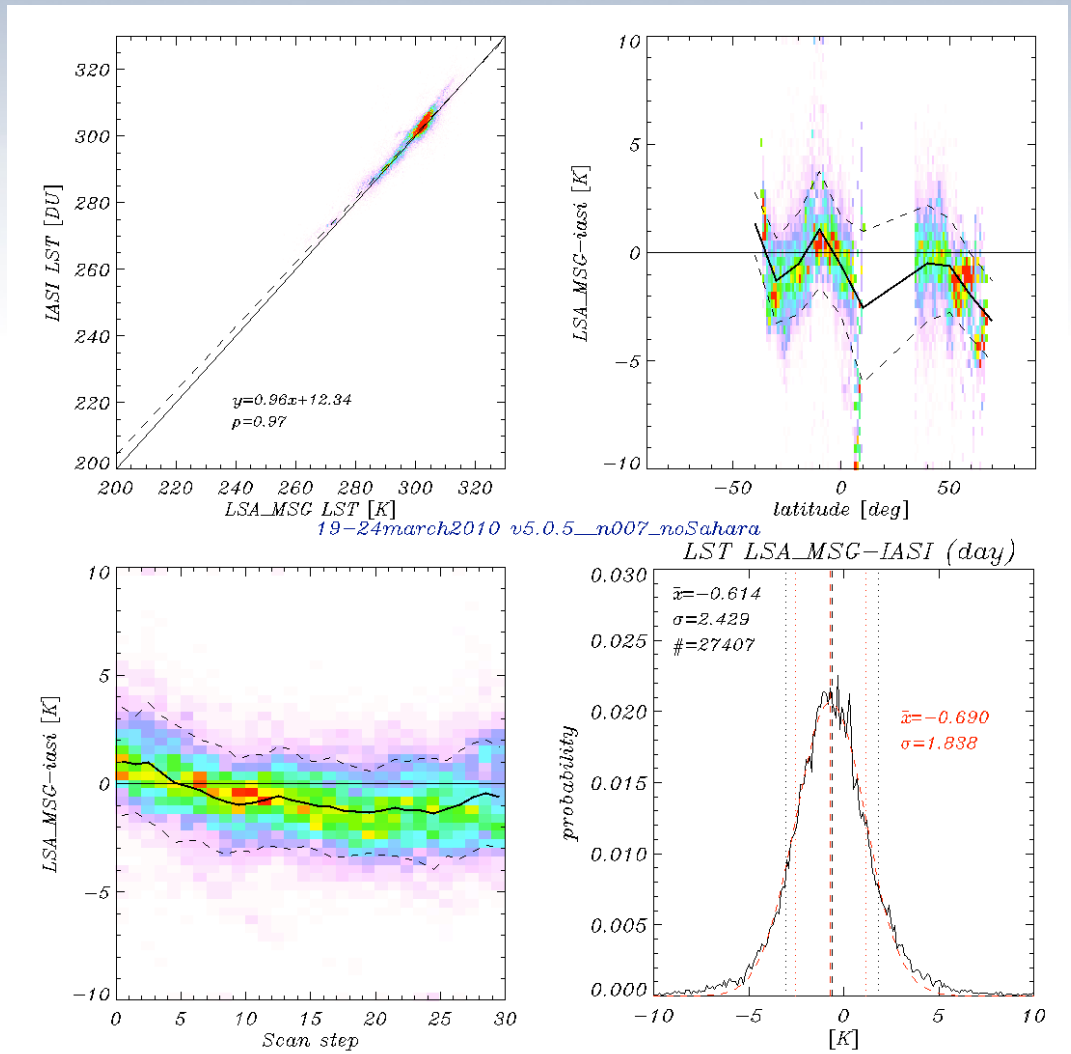
1. IASI L2 version 5 Land Surface Temperature: validation

19-24 March 2010 :: Day
(LANDSAF_MSG – IASI)

ρ ~ 0.97 bias ~ -0.6 K σ ~ 2.4 K







EUMETSAT

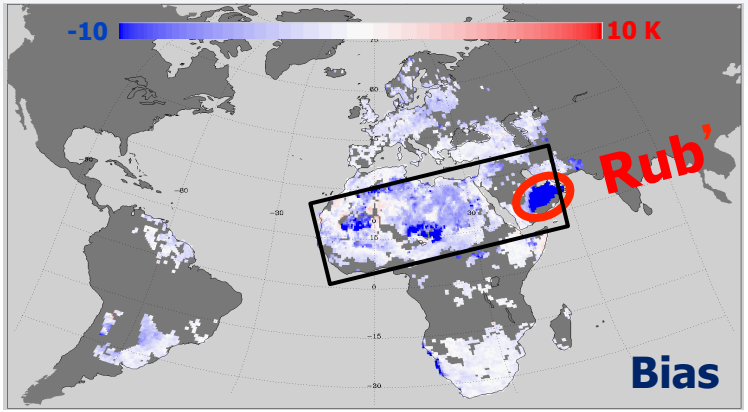
1. IASI L2 version 5

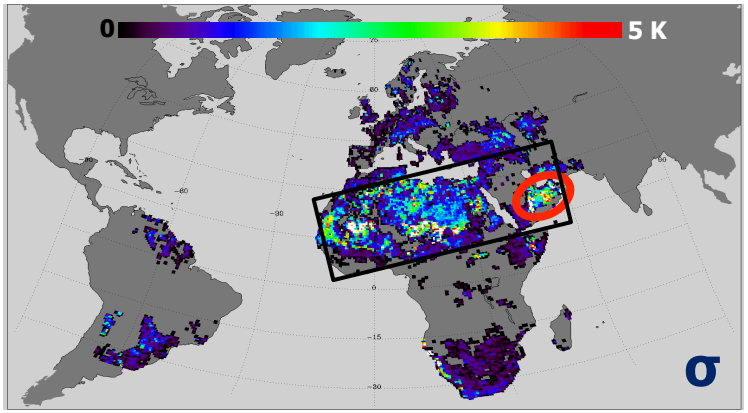
Land Surface Temperature: validation

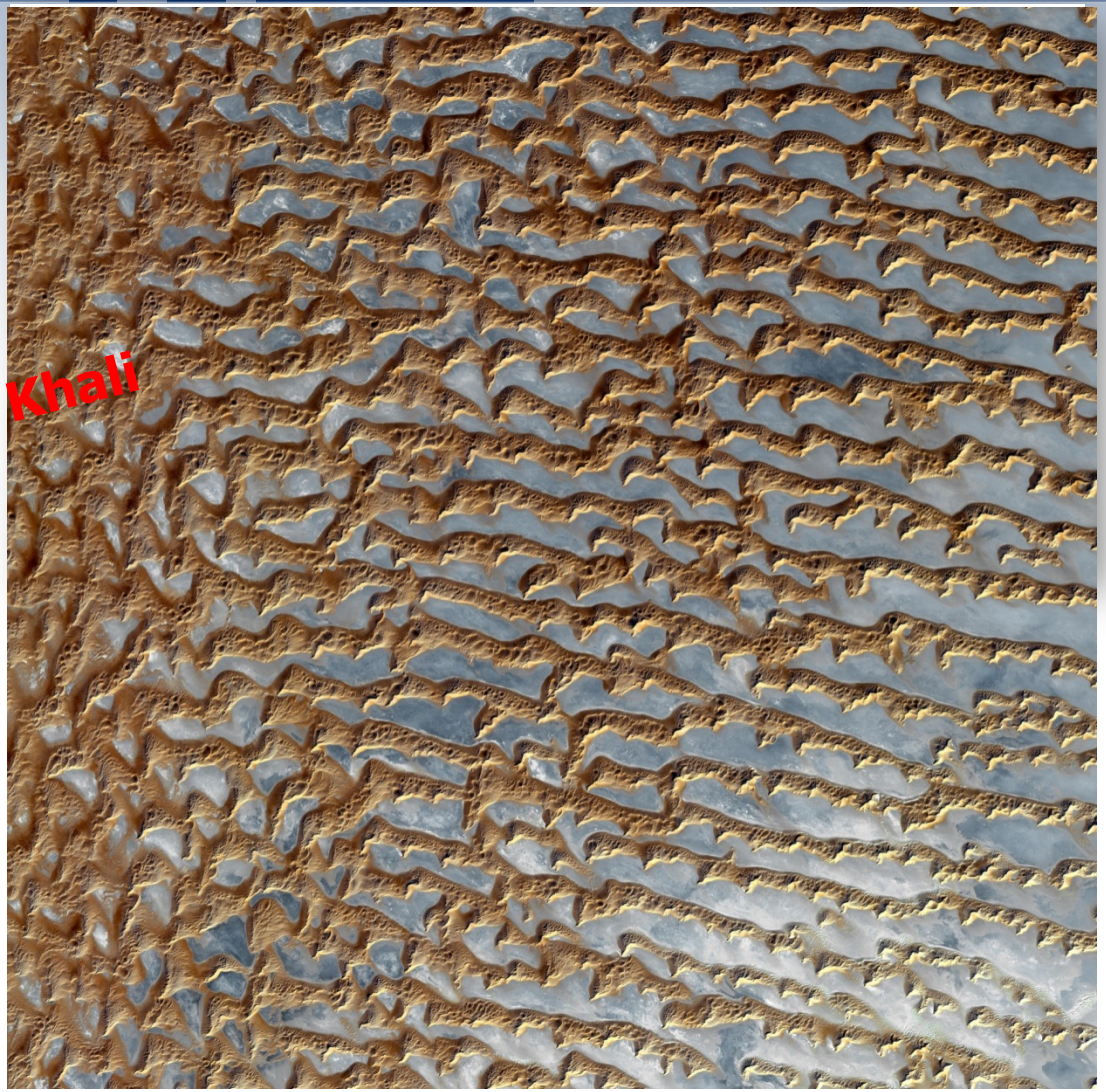
19-24 March 2010 :: Night

(LANDSAF_MSG – IASI)

ρ ~ 0.99 bias ~ -1.6 K σ ~ 1.6 K







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