MTG-IRS L2
Baseline for Day-1 operations

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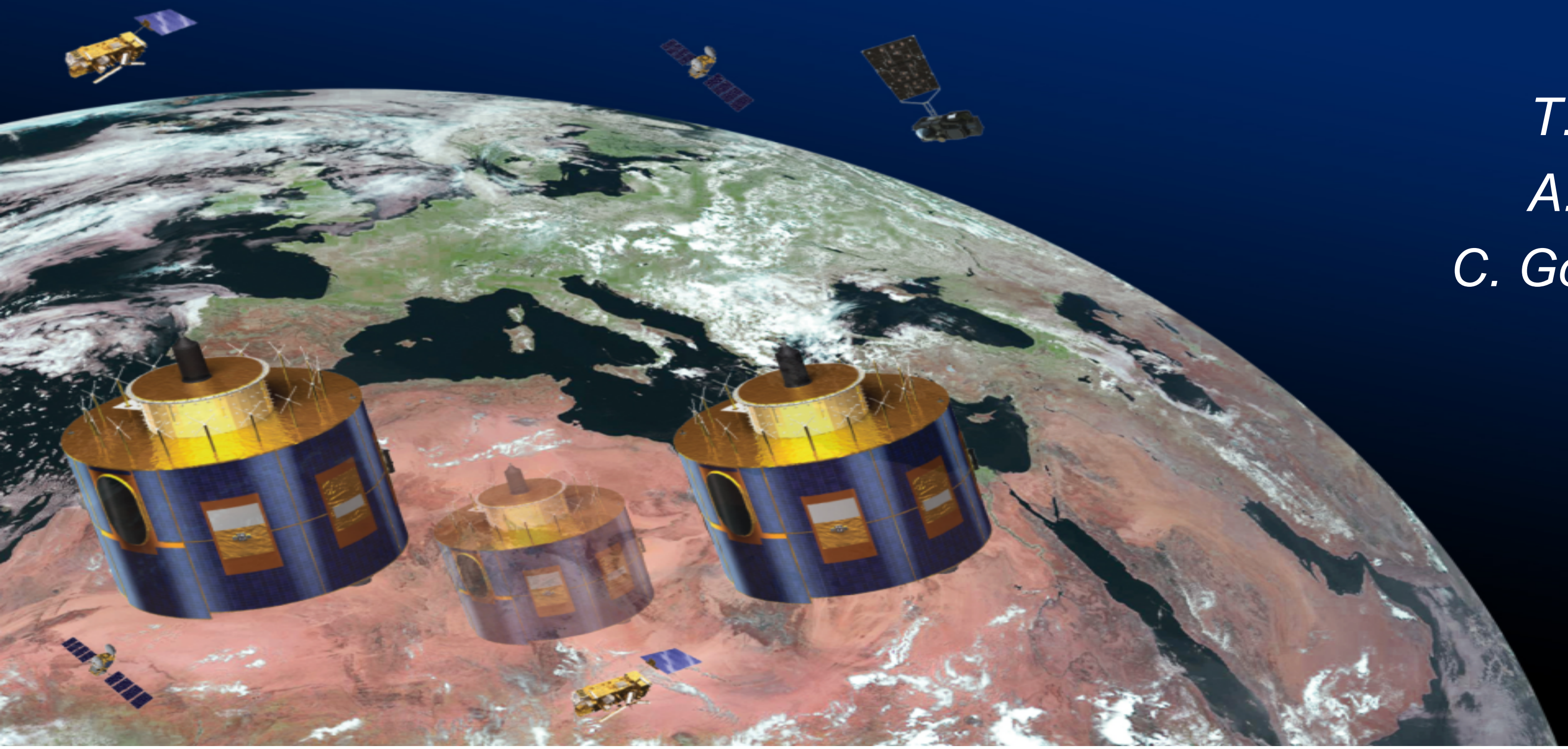


Objectives

Specify a viable Day-1 baseline for IRS L2;
In time for MTG ground segment procurement;
Yielding accurate products with useful coverage.

- ✓ mature algorithms
- ✓ proven products
- ✓ CPU-affordable

- ➔ re-use and adapt IASI L2 operational concept
- ➔ understand limitations and mission specificities
- ➔ define Day-1 & Day-2 scopes ; identify studies

IRS processing, specificities and heritage from IASI

- Strong applicable heritage, assuming calibrated and harmonised spectra (L1 processing)
- Similar types of measurements, from GEO in 160x160 array *vs from LEO in 2x2 detectors*
- Differences wrt EPS:

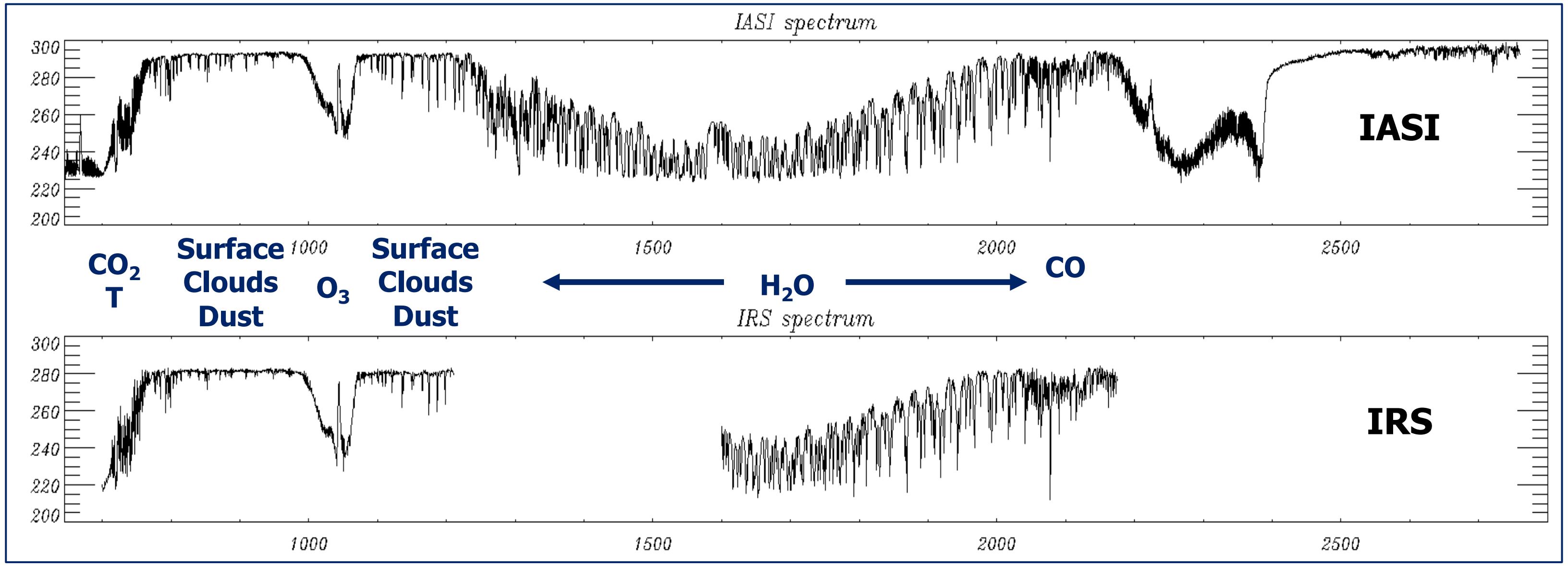
!! Limitations / Hurdles

- IR-only, no micro-wave companion → *more sensitive to clouds*
- coarser spectral resolution/coverage → *sounding precision, AC/AQ detectability*
- viewing geometry → *high local zenith angles, quasi-limb view*
- Data volume: ~100x more than IASI → *CPU-effective processing required*

?? Apodisation
?? OEM *a priori*

++ Opportunities

- Spatial resolution
- Temporal repetition
- Complementarity GEO/LEO

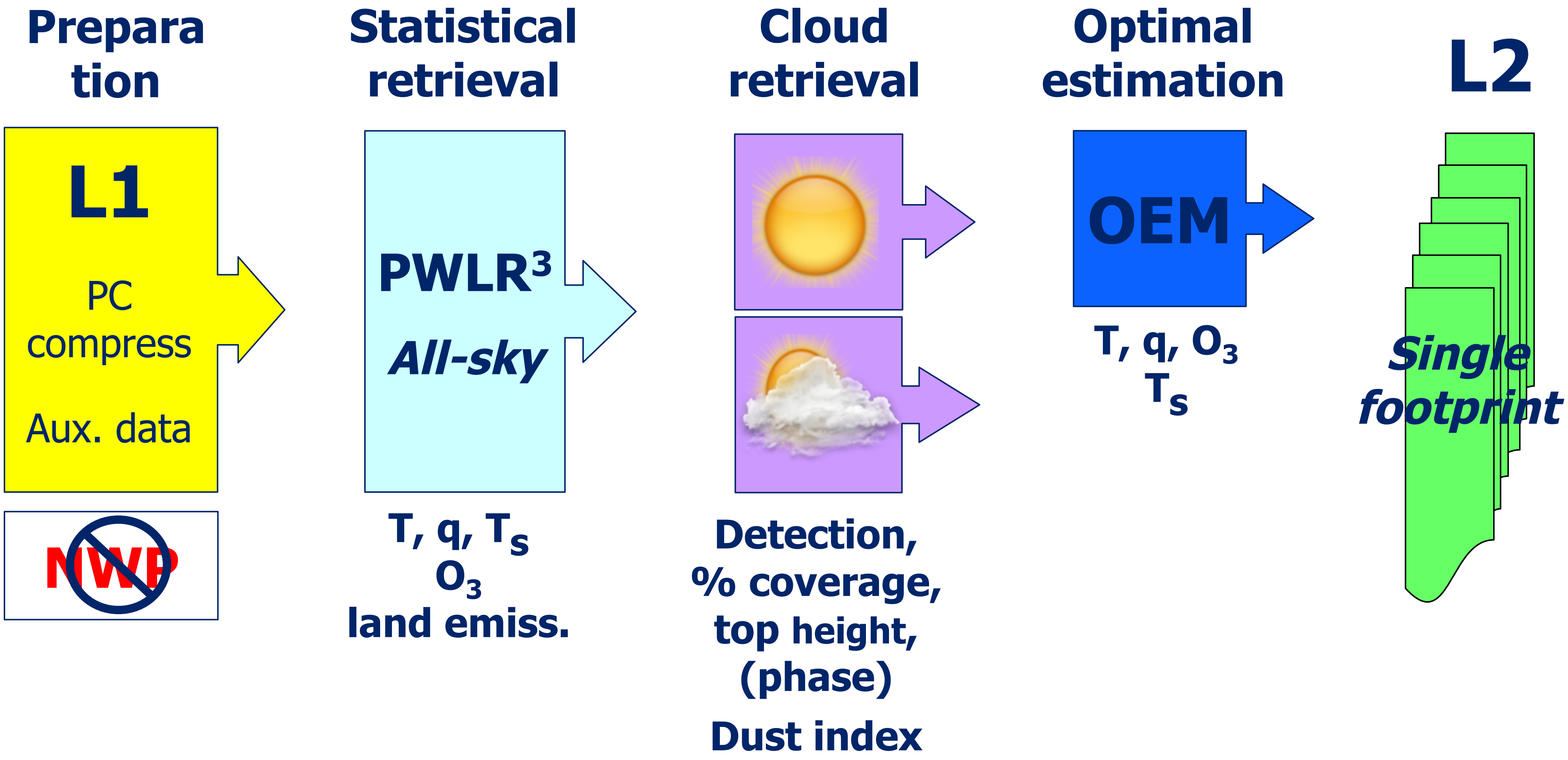


EUMETSAT

Outline

- Overview of L2 operational products
  - Algorithms
  - Performances
- IRS specificities and open questions
- Products processing and dissemination

High-level L2 processing steps



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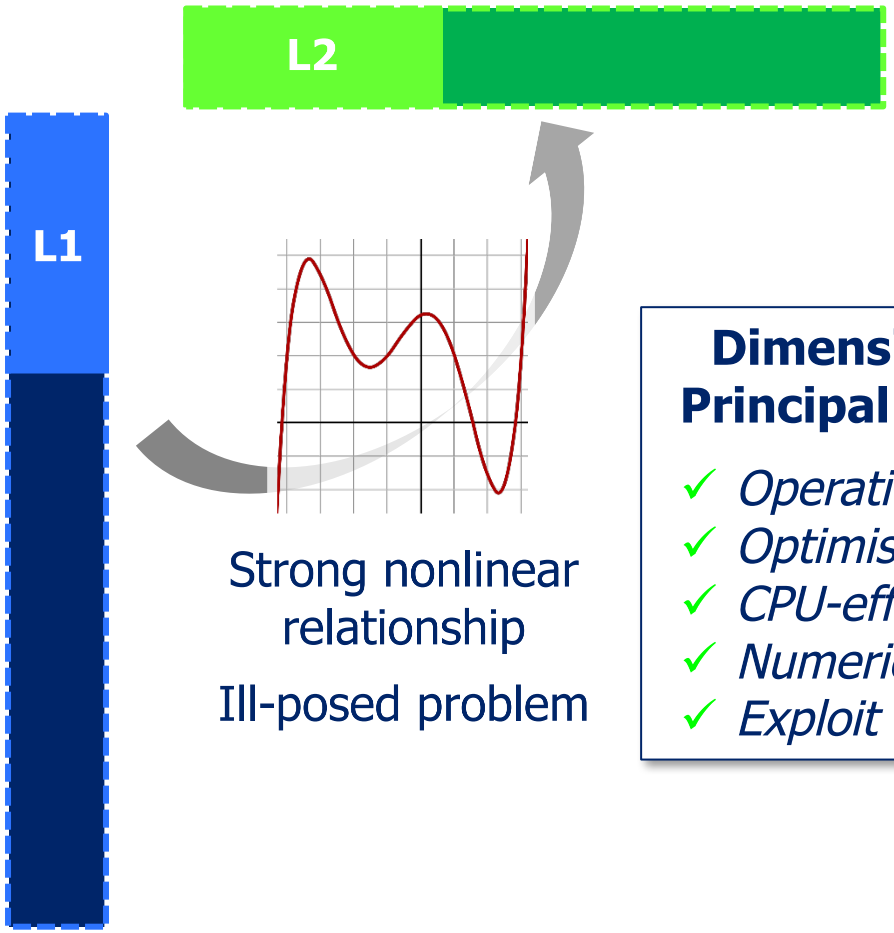
Applicable processing concept from IASI L2 PPF

Geophysical parameters



Strong nonlinear relationship

Ill-posed problem

Measurements input spectrum

Dimensionality reduction by Principal Components Analysis

- ✓ *Operational since 2010 (v5)*
- ✓ *Optimised for H_2O in 2014 (v6)*
- ✓ *CPU-effective computations*
- ✓ *Numerically stable*
- ✓ *Exploit all information*

Statistical first retrieval

PWLR³: Piece-Wise Linear Regression

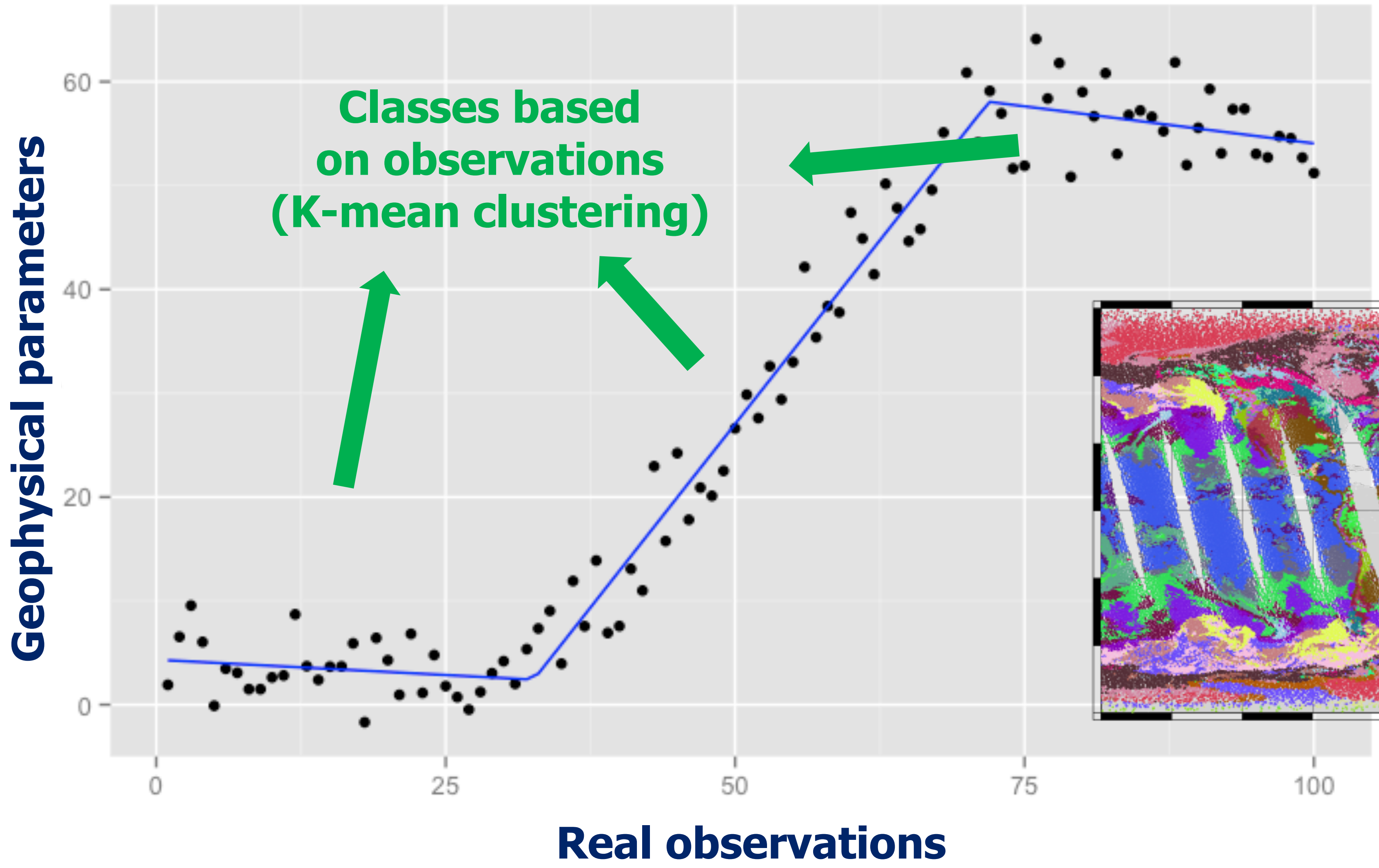
No radiative transfer modelling

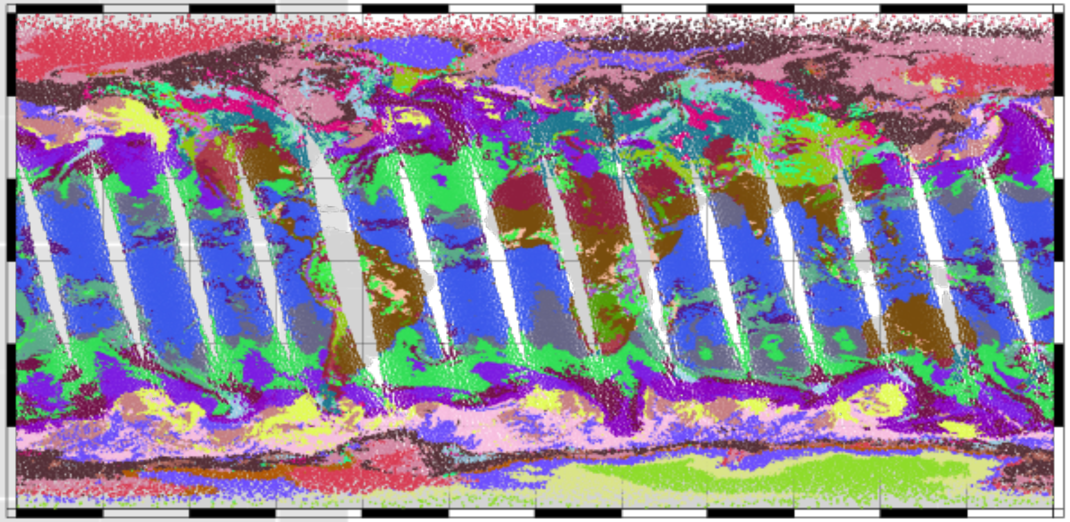
- ✓ *Accurate and fast (~10'/day with IASI)*
- ✓ *Compatible with NWC NRT timeliness*
- ✓ *Applicable to cloudy pixels: large yield*
- ✓ *3D retrieval: suited for spectro-imager*

Retrieval with physical modelling e.g. OEM (Optimal Estimation)

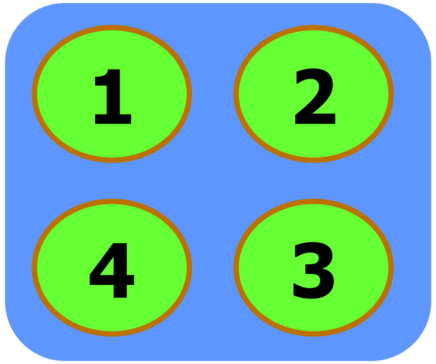
- ➢ *Clear pixels only (RTM maturity & speed)*
- ➢ *Requires regularisation: which a priori?*
- ➢ *CPU-affordable with PCA and good prior*

The Piece-Wise Linear Regression





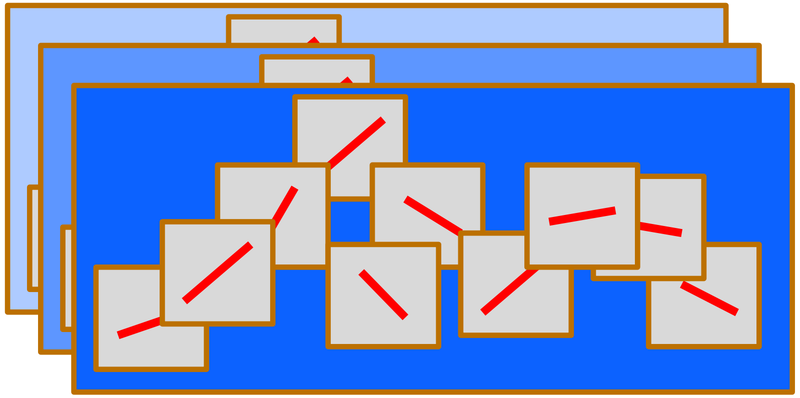
PWLR³ – 3D retrieval, exploiting horizontal correlation



PWLR³

Input vector with adjacent measurements (PCS)+ viewing angle…

$IASI_1$	…	$IASI_4$	IR-only applicable to IRS. Exact window size, to be studied



T, q, Ts, O_3, surface emissivity, cloud
for every pixel separately

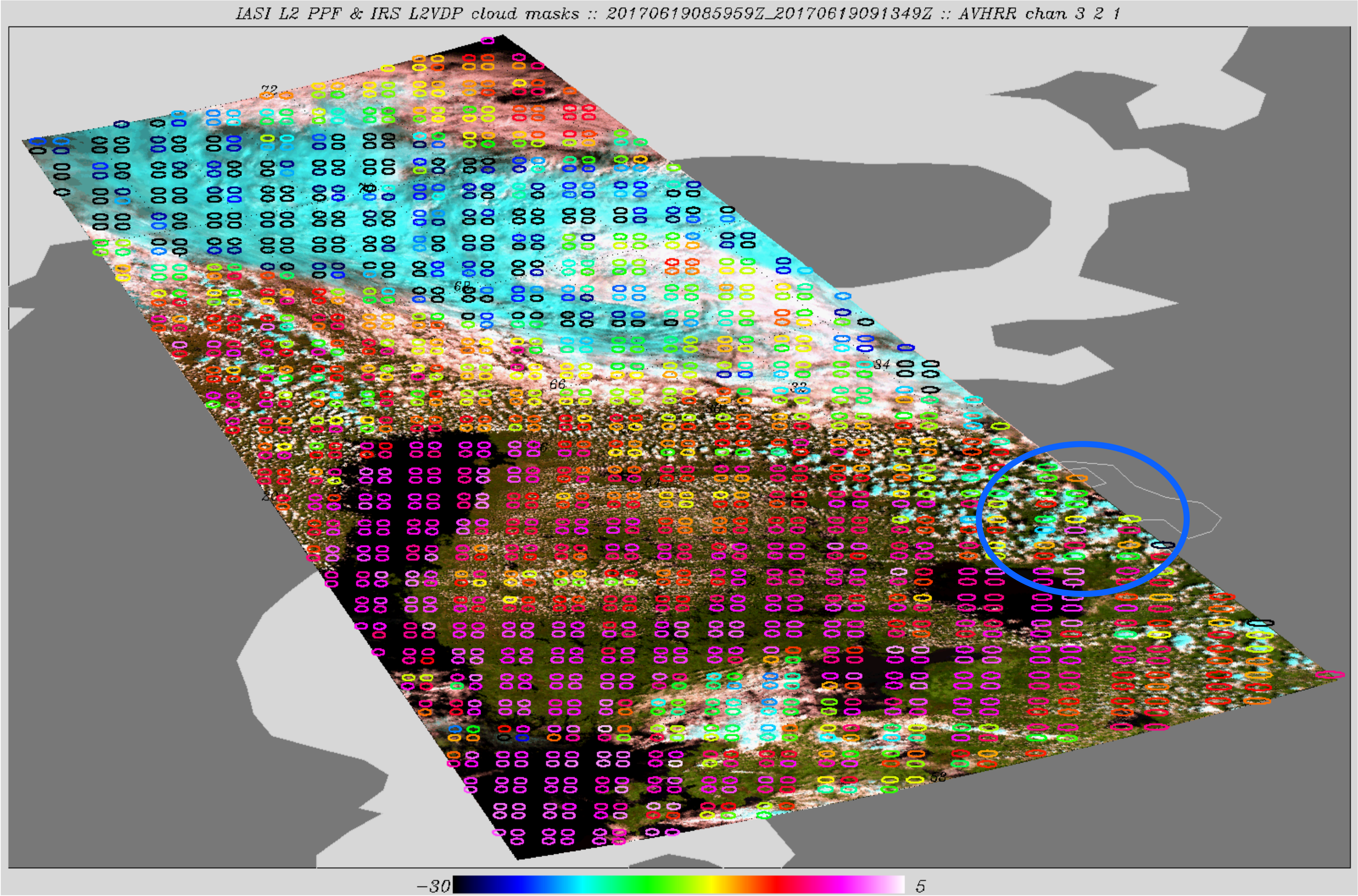
- **K-mean clustering based on observations**
- **Supervised statistical learning with real obs. matched with ECMWF re-analysis, CAMS**
- **~100 millions teaching pairs**
- **Ensemble retrieval to reduce random noise**
- **Quality indicators (uncertainty estimates)**

Cloud detection: OBS-CALC in window channels

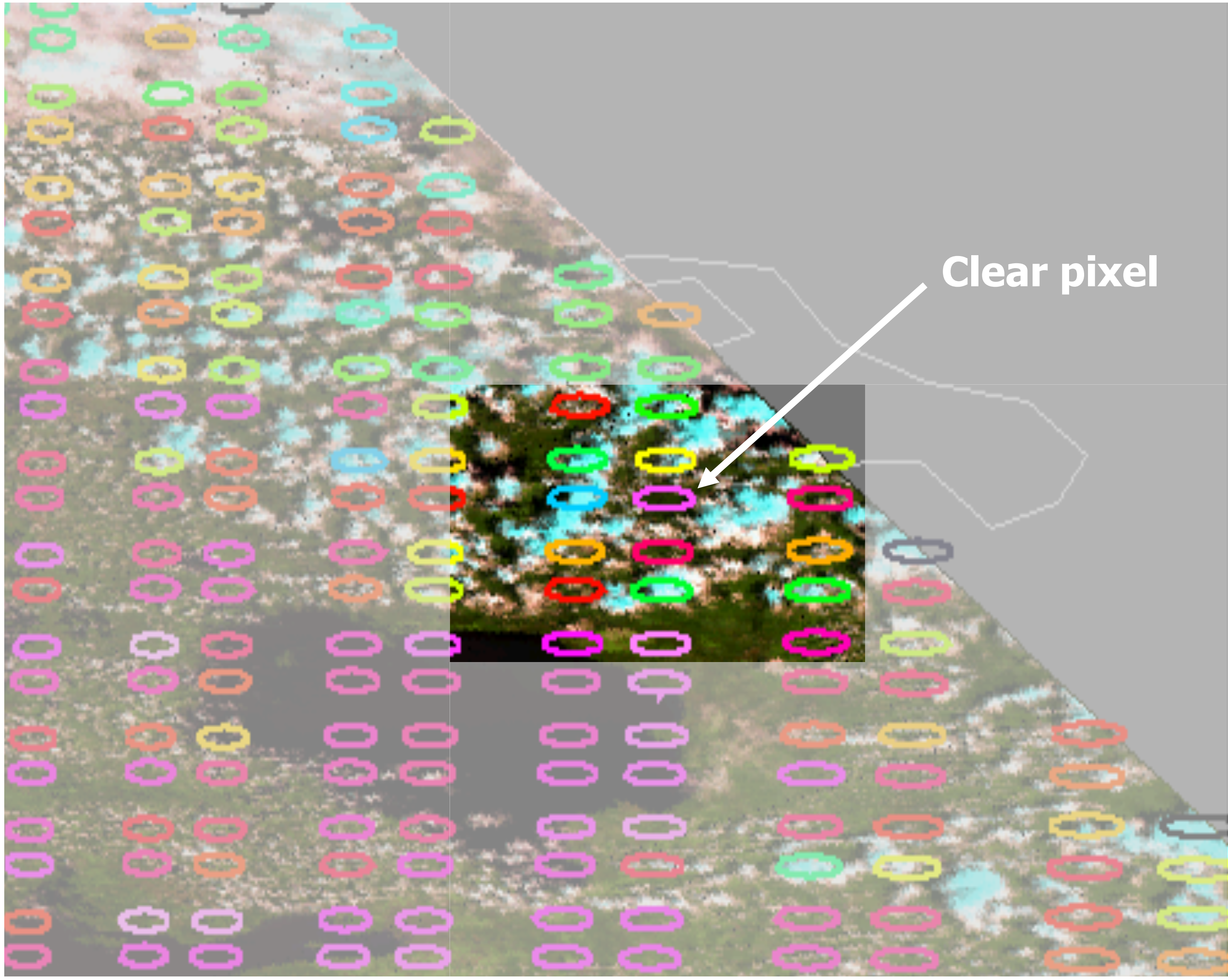
- **Computed online with RTTOV and PWLR³ profiles**
- **Can be also predicted by PWLR³ (faster)**
- **Completed with a neural network classifier**

The outcome of the cloud detections and cloud retrieval is combined in a 4-stage cloudiness flag:

1. **Clear-sky**
2. **Clear enough**
3. **Partly cloudy**
4. **Fully cloudy**



Cloud detection: OBS-CALC in window channels

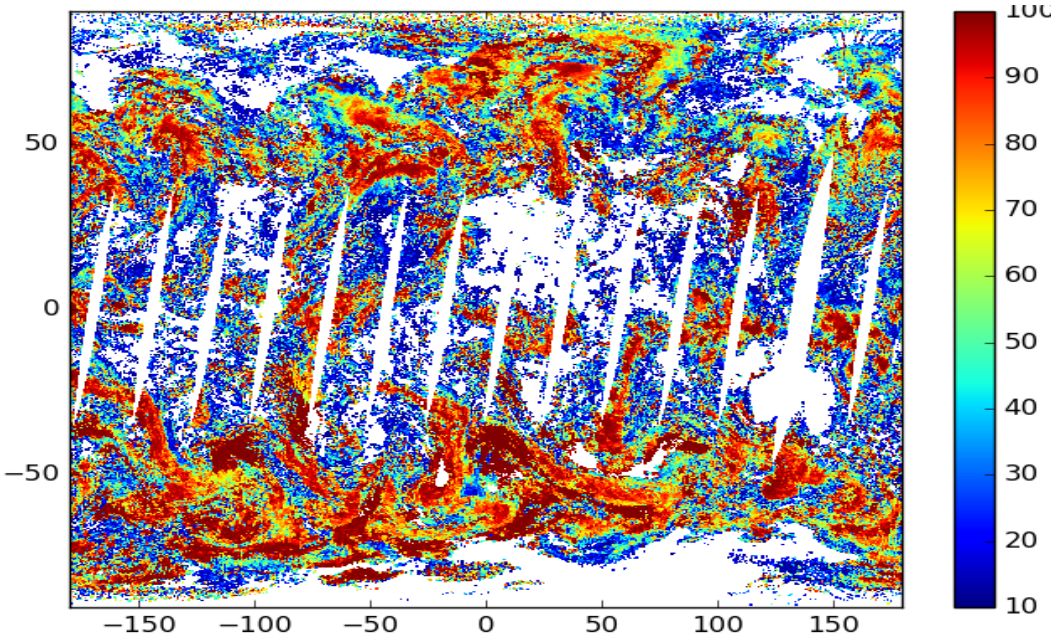


Cloud top and cloud fraction retrieval

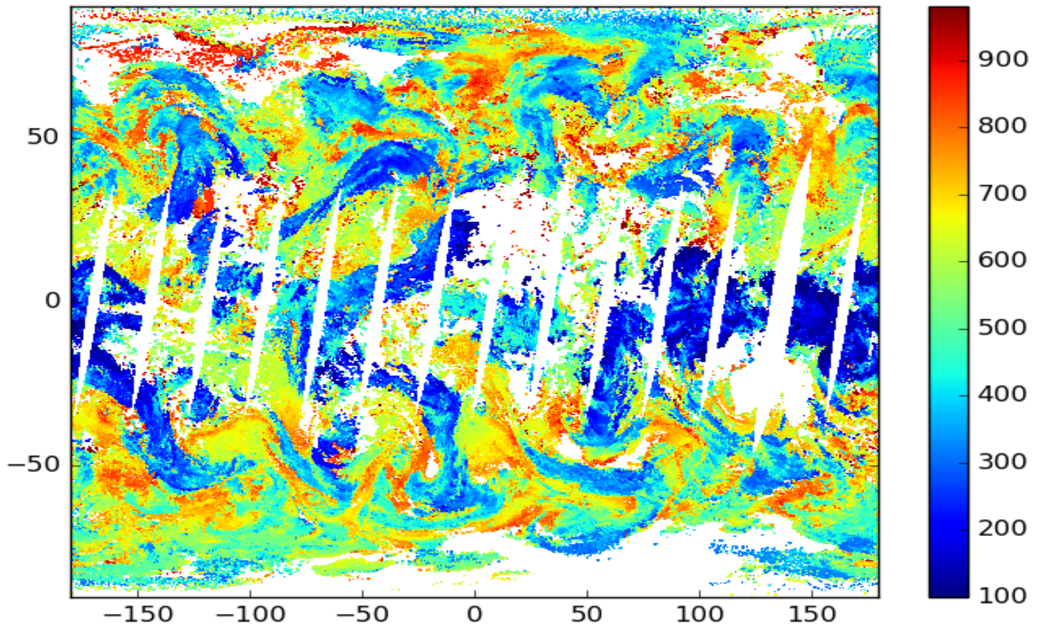
- Minimising cost function $\Sigma(OBS[k] - CALC[k])^2$, in selection of CO_2 channels [k]
- Parametric expression of CALC = (1-η) . RTTOV_clear + η . RTTOV_cloud(p)

  where η is the cloud fraction, p is the cloud top pressure and

  RTTOV_cloud a simple cloud radiance modelling (grey body)

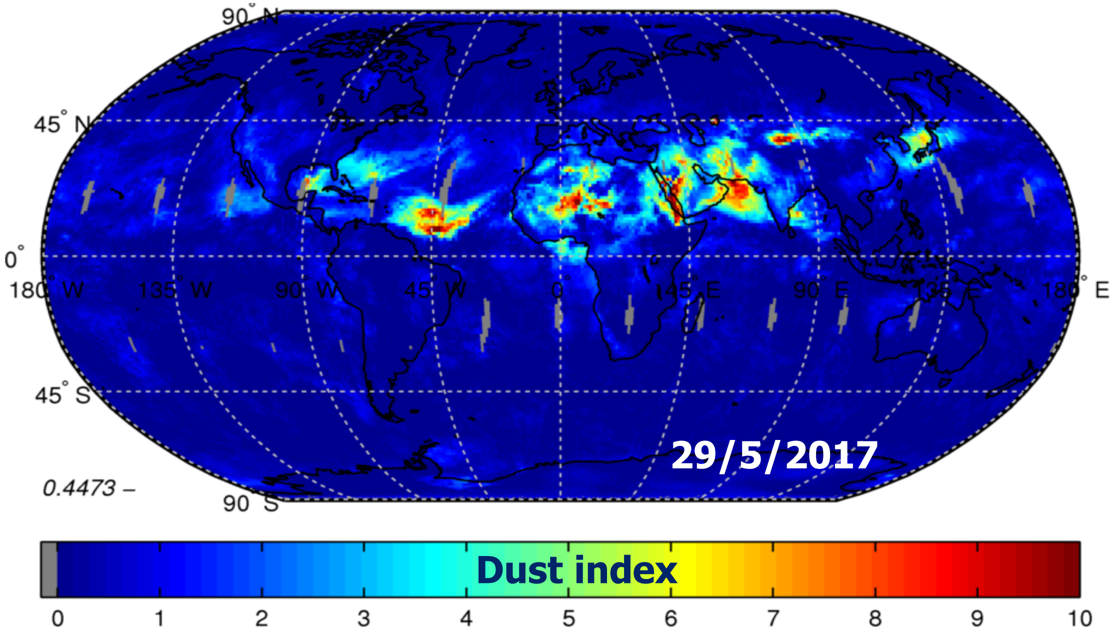


Cloud fraction [%]

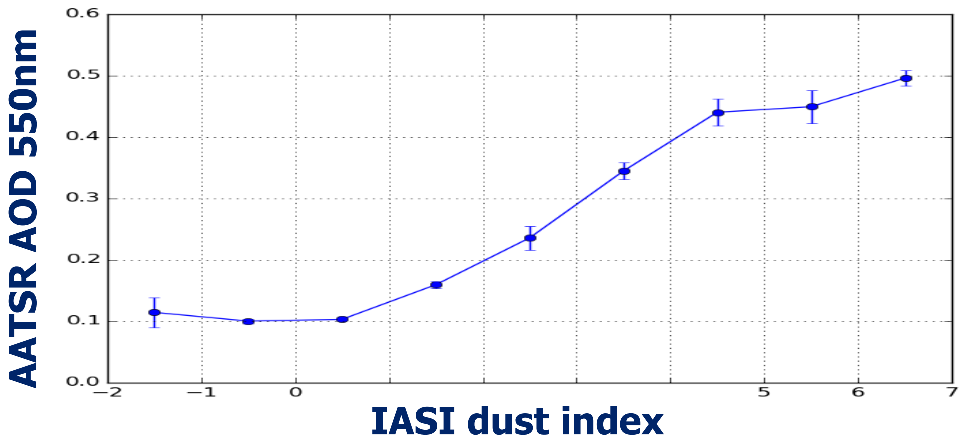


Cloud top pressure [hPa]

Dust indicator

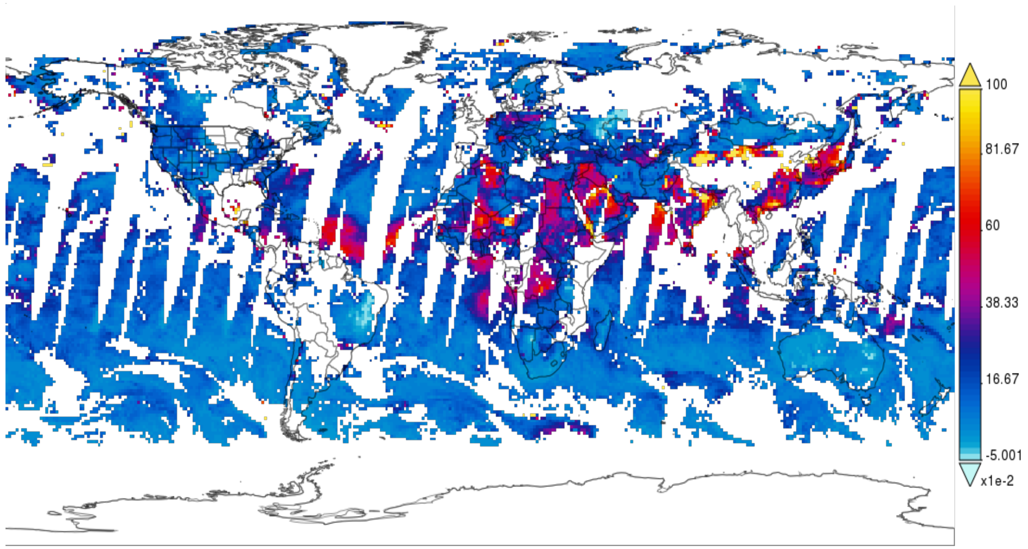


- **Linear regression, after Clarisse et al.,** ACP 2013, "A unified approach to infrared aerosol remote sensing and type specification"
- **Unitless indicator of dust strength**
- Correlates well with loss of accuracy in IASI L2 SST due to dust, evaluated *vs* AATSR AOD…



Results: T. Trent (U. Leicester), EUM Study

MODIS AOD 550nm



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Optimal estimation

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

solution *vs* background atmospheric state, weighted by the background error covariance S_x

Measurements (y) fit by RT model F() with the retrieved state (x), weighted by the observation error S_y = instrument noise + forward modelling uncertainties

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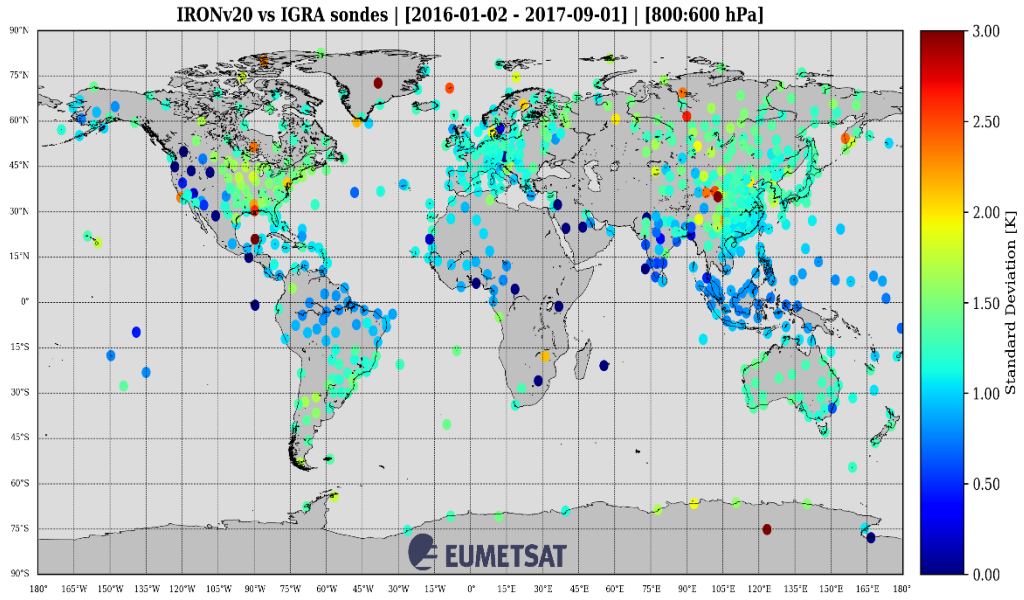
Optimal estimation in operations

- Scope = **clear-sky** and using **IASI measurements** only
- Retrieved parameters: **T, H_2O and O_3 profiles, Ts**
- Minimisation with atmospheric profiles in principal components
- Exploits **all spectral information** from Band 1 and 2, via **reconstructed radiances** in **common directions of measurement and forward** model subspaces. *(3rd IASI Conf., 2013; Met. Satellites Users Conf., Vienna 2013; NWP-SAF workshop on PC for hyperspectral data, 2013; ITSC-19 2014)*
- Dedicated **channel selection**, 139 in Band 1 and 2 *(ITSC-18 2012)* ⇔ PCS information content
- **Variable radiance tuning**, using the scan angle as predictor
- **Variable *a priori***, from the PWLR[3]
- **Variable observation error** for land and sea surfaces
- Much **faster 1D-Var**, 1 or 2 pure Newton iterations only
- Provision of the **full retrieval error covariance matrix** (compressed) and ***a priori***; allowing post-computation of the **averaging kernels**.

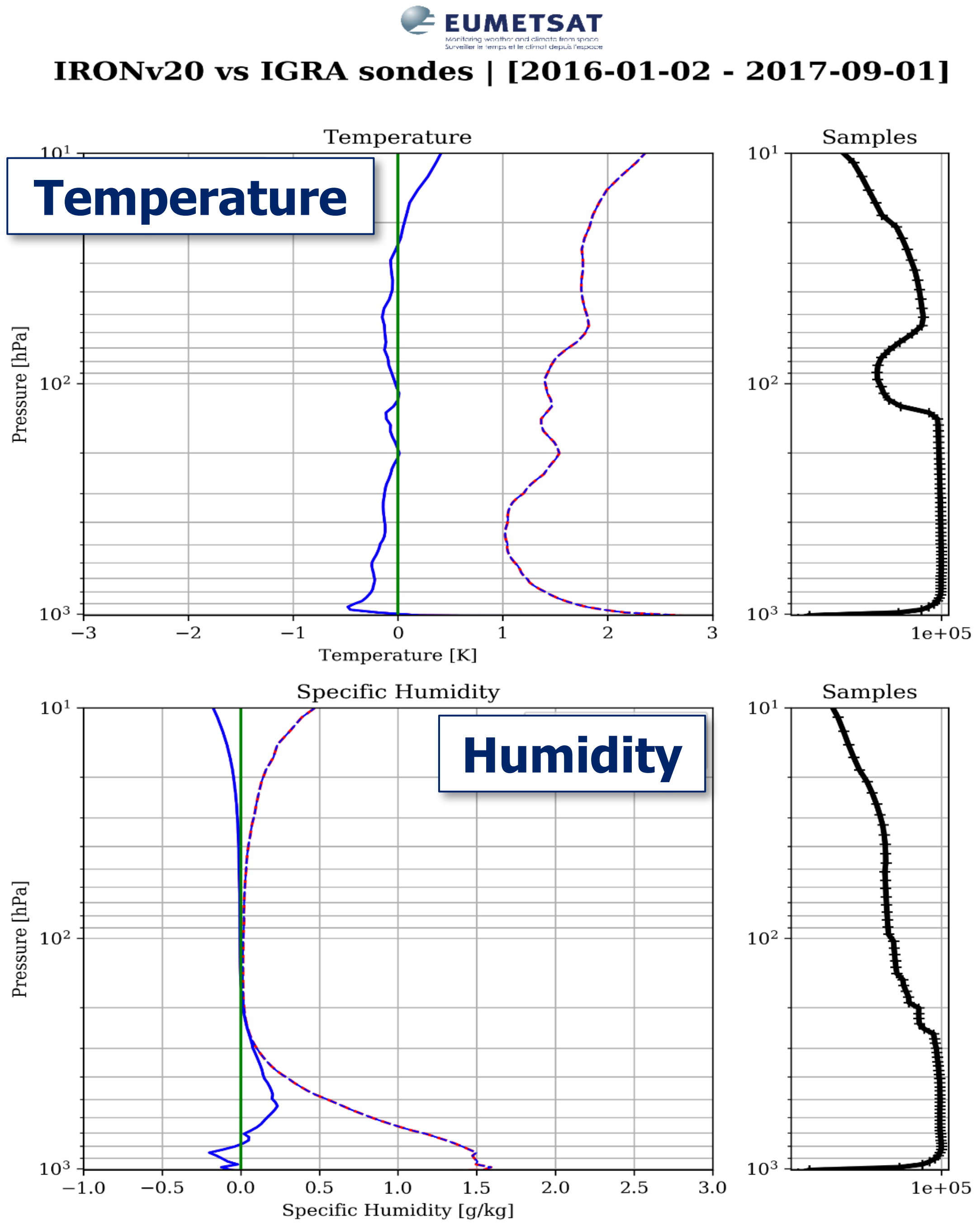
Assessment *vs* sondes

IASI L2 IR-only PWLR[3]

20 months: January 2016 – August 2017
***vs* radio-sondes (±3h ; <50km)**



Yield ~50%,
includes cloudy pixels



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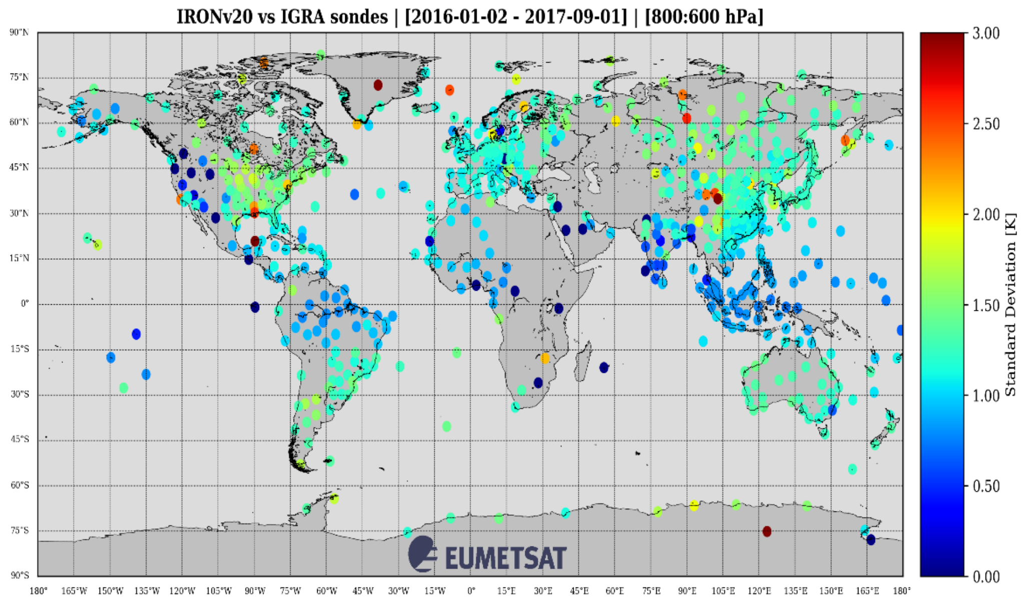

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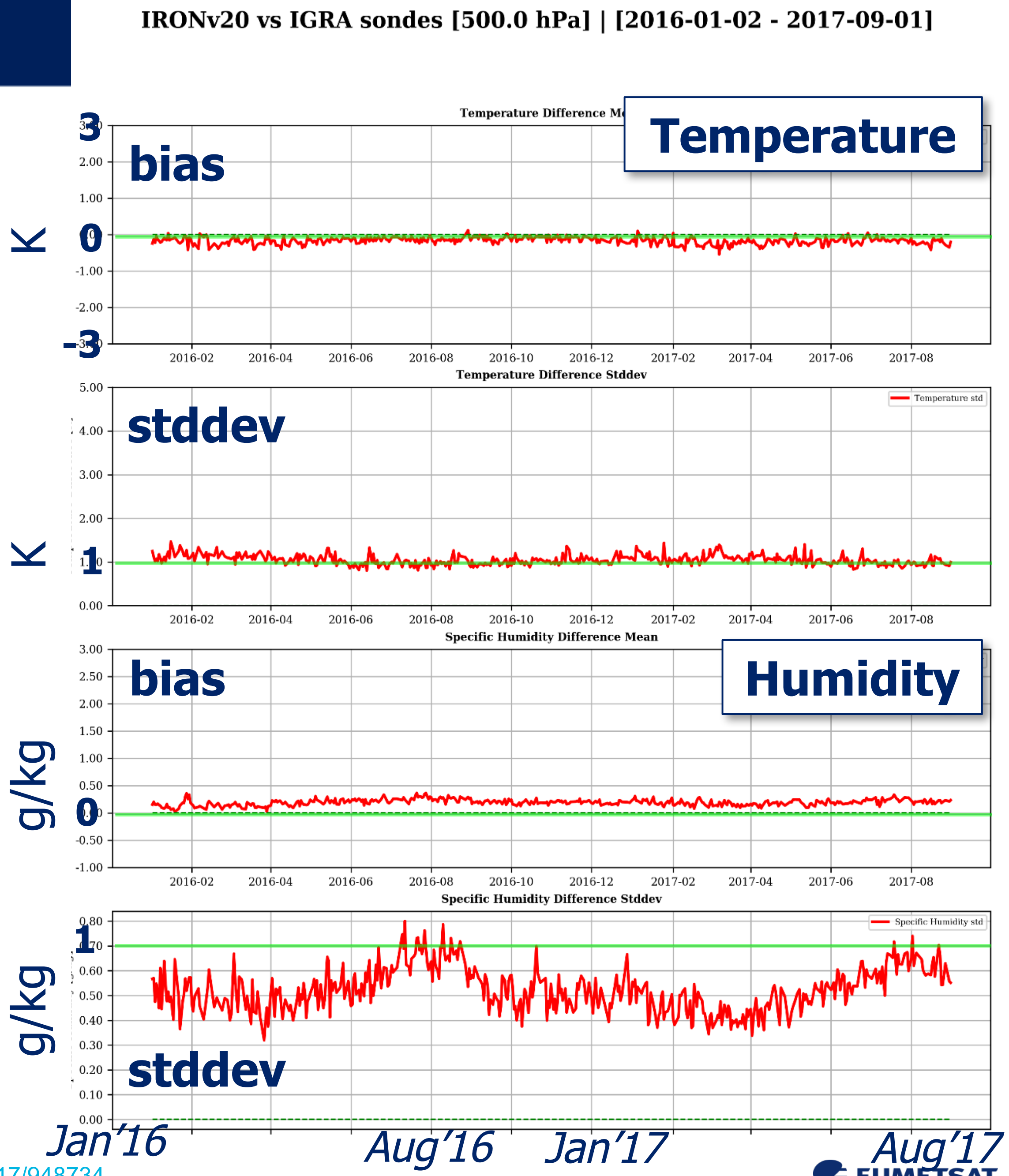
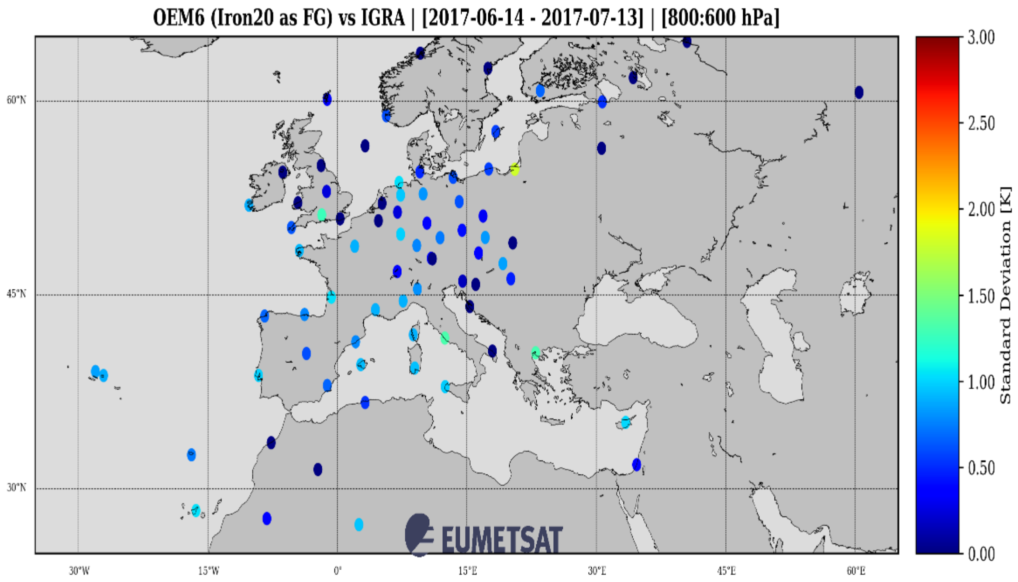


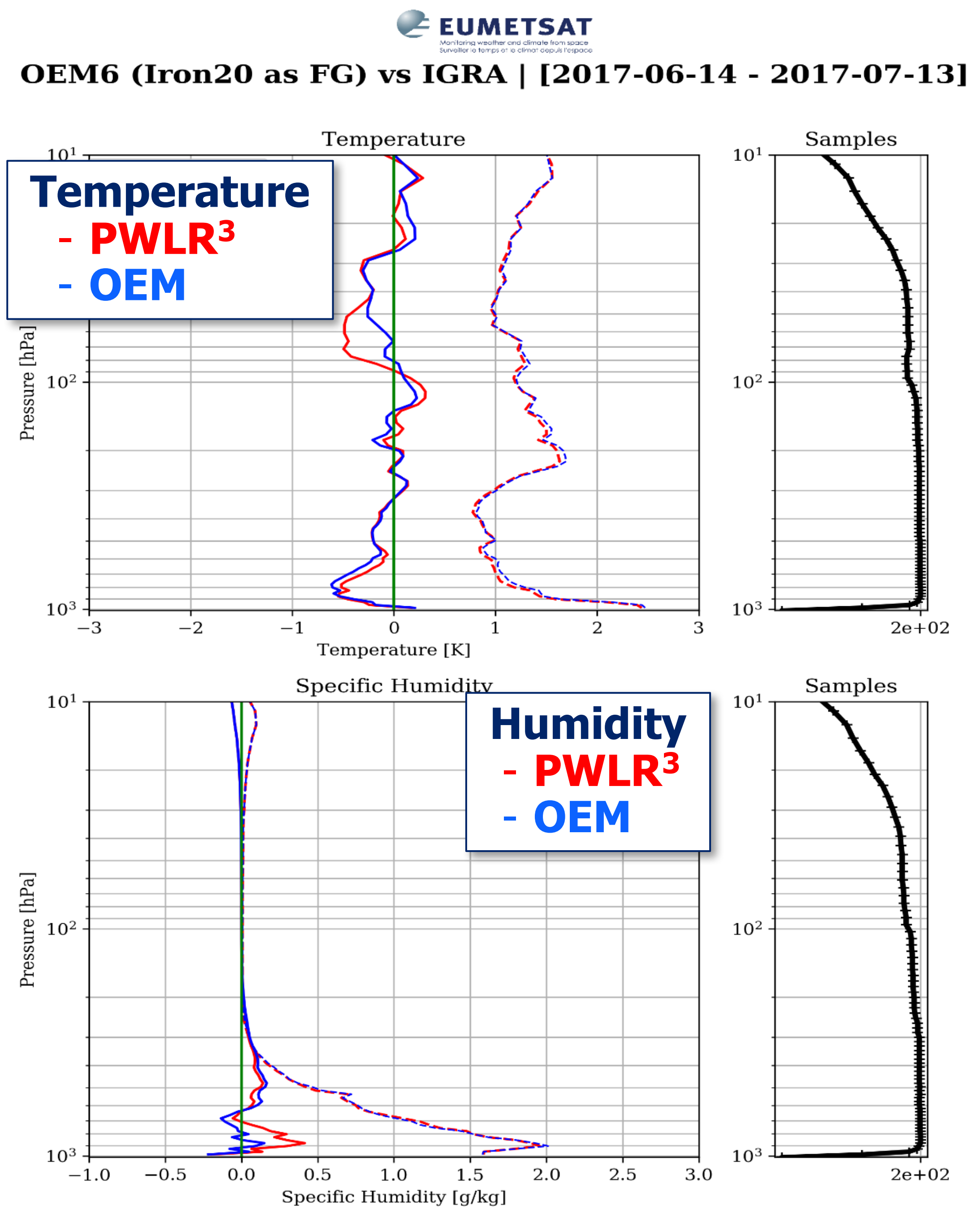
Assessment *vs* sondes

IASI L2 IR-only OEM

5 Wednesdays June-July 2017
***vs* radio-sondes (±3h ; <50km)**



Clear-sky only

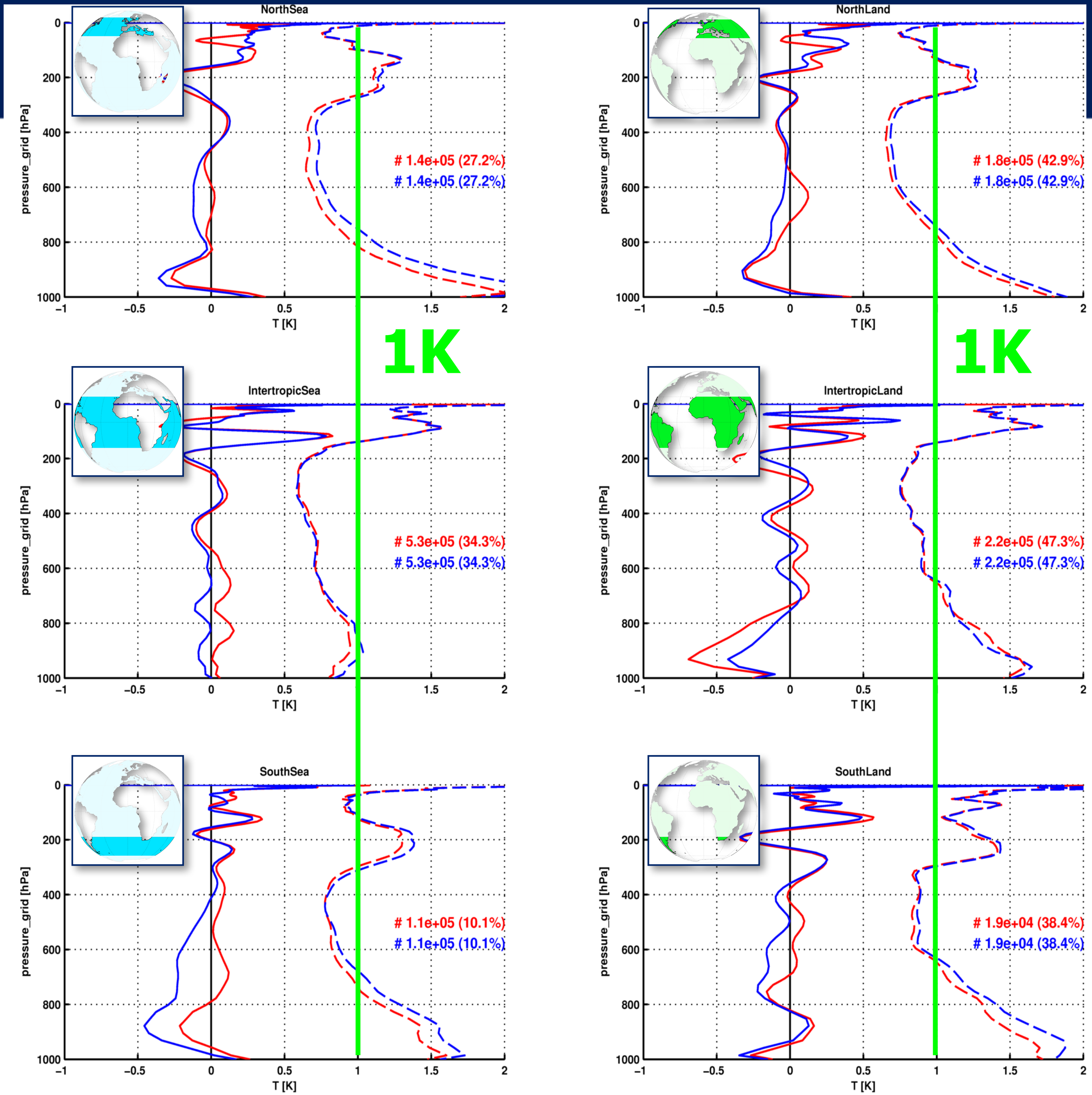


Comparison to model

IASI L2 IR-only
Cloud-free and clear-enough pixels
(e.g. ~40% yield over Northern lands)

5 Wednesdays June-July 2017
***vs* ECMWF analyses**

- **First retrieval: PWLR³**
- **Second retrieval: OEM**



IASI sounding products applications

- T/q profiles are input to AC/AQ processing
- Cloud product and T/q/O_3 profiles used in AMVs products
- Potential for regional applications → studies on-going
- Regional service EARS-IASI L2, timeliness < 30’
- T/q profiles monitored in Met. Services
- ... more to be studied

EUMETSAT

Outline

- Overview of L2 operational products
- IRS specificities and open questions
  - Apodisation
  - Spectral coverage, relative perfo. IRS vs IASI
  - Choice of *a priori* for the OEM
  - Viewing geometry
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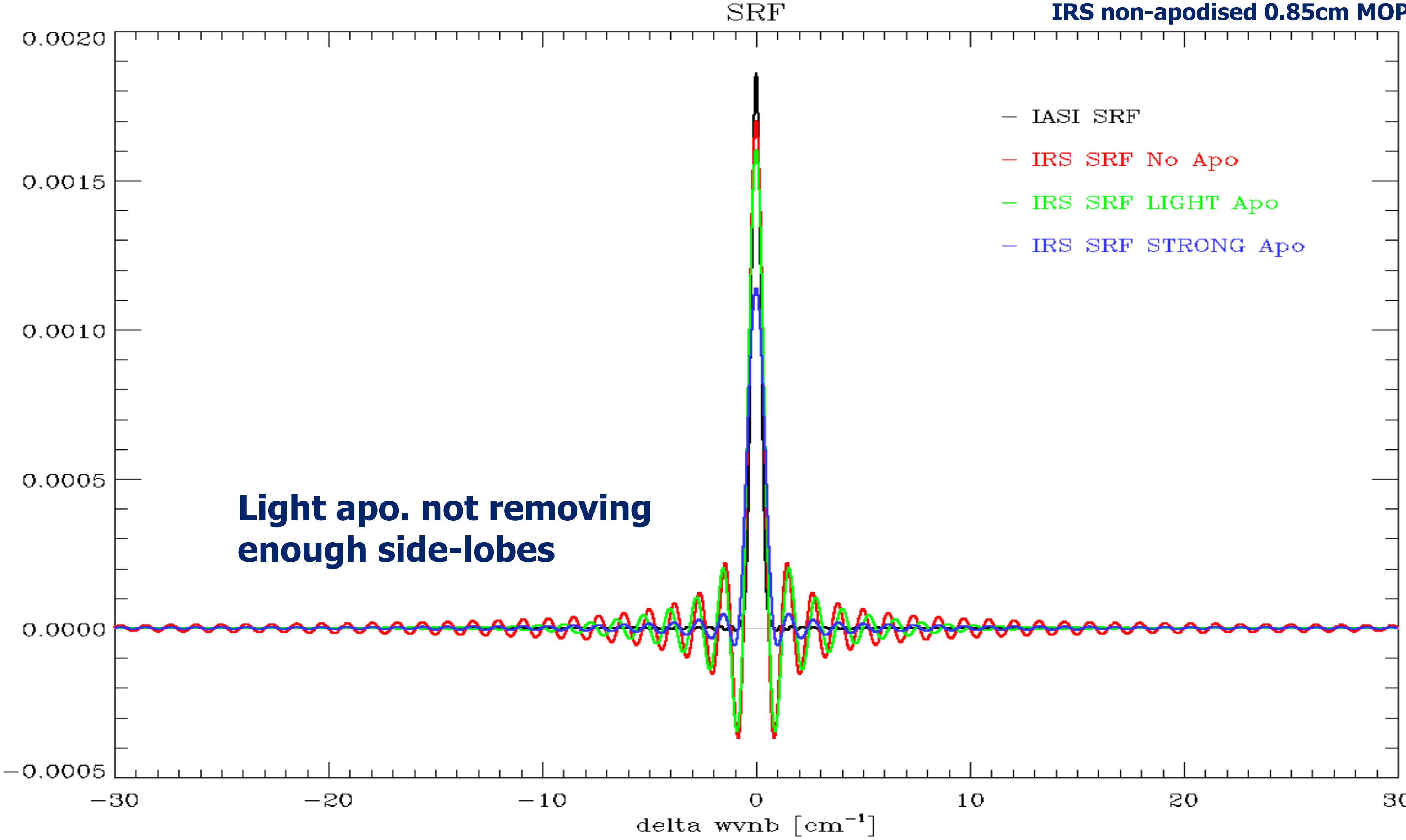
Apodisation question

IRS non-apodised 0.85cm MOPD



Light apo. not removing enough side-lobes

Apodisation question

Practical issues with non-apodised spectra

✓ In principle, PWLR^3 could work with non-apodised spectra

‼ **Negative channel radiances and layer channel transmittance**

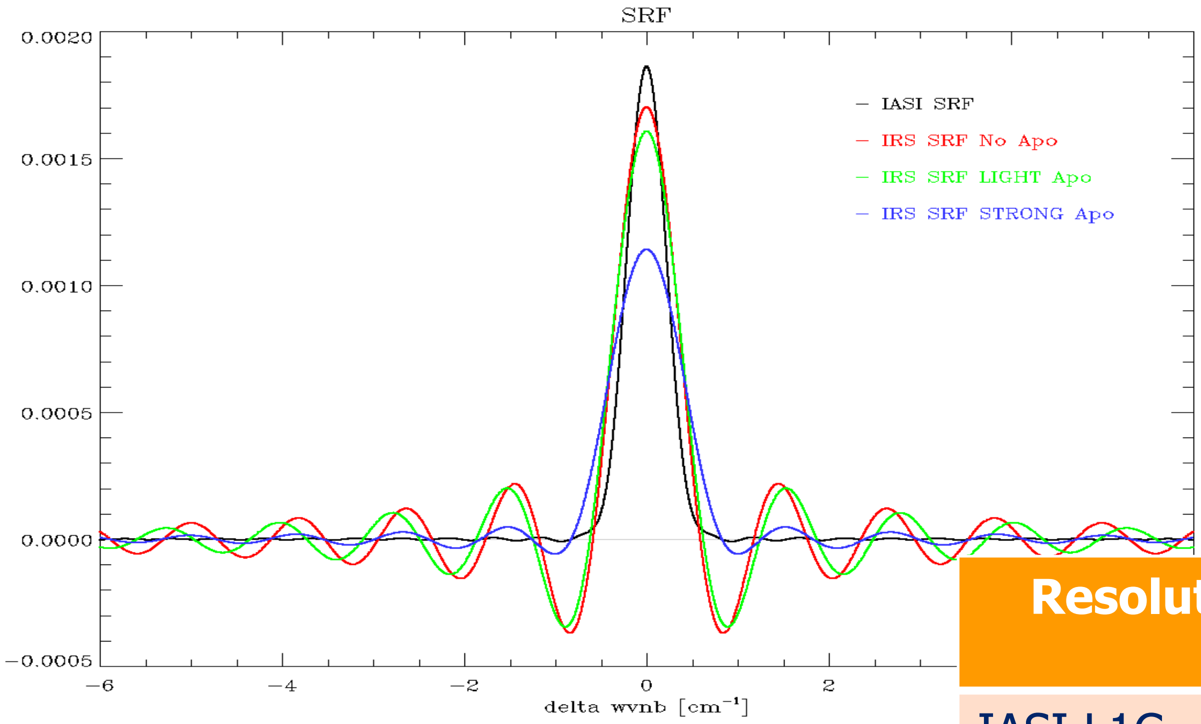
- ➢ not physical
- ➢ problem with BT channel-based algorithms
- ➢ some FRTM (including RTTOV) would need re-design

‼ **SRF large spectral spread**, well beyond the claimed channel range

- ➢ Information not localised
- ➢ Large computation / spectral convolution of LBL monochromatic radiances required

‼ **linear assumptions behind physical retrievals requires localised** (apodised) channel SRF
A. Gambacorta, excerpts from "Comprehensive Remote Sensing", Elsevier 2017

FWHM and localised spectral information



Resolution claimed after FWHM		% weights in FWHM	range for 72% contributing
IASI L1C	0.5 cm^{-1}	72%	0.5 cm^{-1}
IRS NoApo [0.85]	0.71 cm^{-1}	36%	9.2 cm^{-1} !!!!
IRS Light Apo	0.75 cm^{-1}	46%	3.2 cm^{-1}
IRS Strong Apo	0.89 cm^{-1}	61%	1.3 cm^{-1}
CrIS NoApo [0.80]	0.75 cm^{-1}	33%	15.6 cm^{-1}
CrIS Hamming	1.13 cm^{-1}	72%	1.1 cm^{-1}

Apodisation question

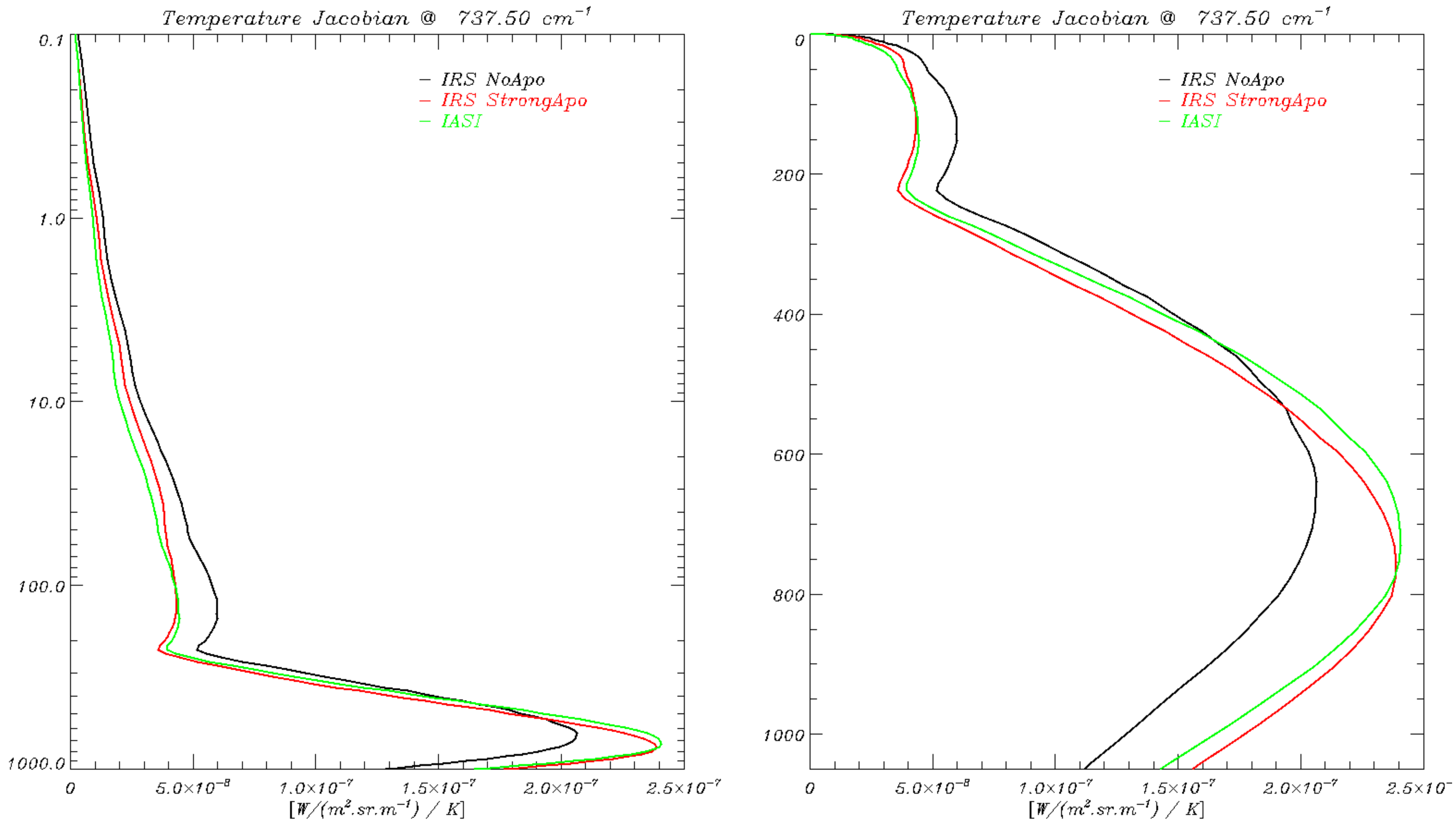
Apodisation
does NOT degrade
the spectral information content,
does NOT affect retrievals performances

if reversible
(apo. and non-apo. are then linear combination)

Mathematically demonstrated:

- practical application to IASI in Amato et al. (Serio), Applied Optics 1998.
- practical application to CrIS in Barnet et al., IEEE TGRS 2000.
- rationale and practical discussion of apodisation for CrIS in “CrIS data processing ATBD”, 2009.

Effect of different SRFs on channel weighting functions



SRFs and information content

Independent measurements
made to better than measurement error
are in singular values of
(Rodgers 2000)

$$S_y^{-1/2} . K . S_x^{1/2}$$

Measurement error

Jacobians: measurements sensitivity to state vector

Background state uncertainty

Instrument dependent

Instrument independent

SRFs and information content

Jacobians at "infinite" spectral resolution (0.001cm^{-1}) computed for the US Standard Atmosphere with LBLRTM

courtesty of M. Matricardi (ECMWF)

convolved with

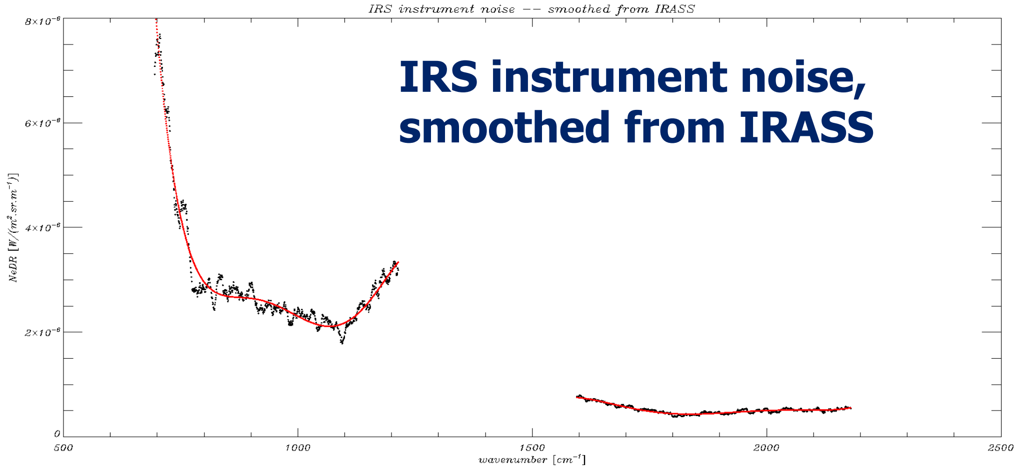
Instrument	SRF	Noise
IASI Band 1,2	Apodised, L1c	CNES noise covariance matrix
IASI Band 1,2,3	Apodised, L1c	CNES noise covariance matrix
IRS NoApo	Unapodised, MOPD=0.8cm	Smooth noise, diagonal matrix
IRS Hamming	Hamming apodised, MOPD=0.8cm	Above smooth noise, Hamming-convolved covariance matrix

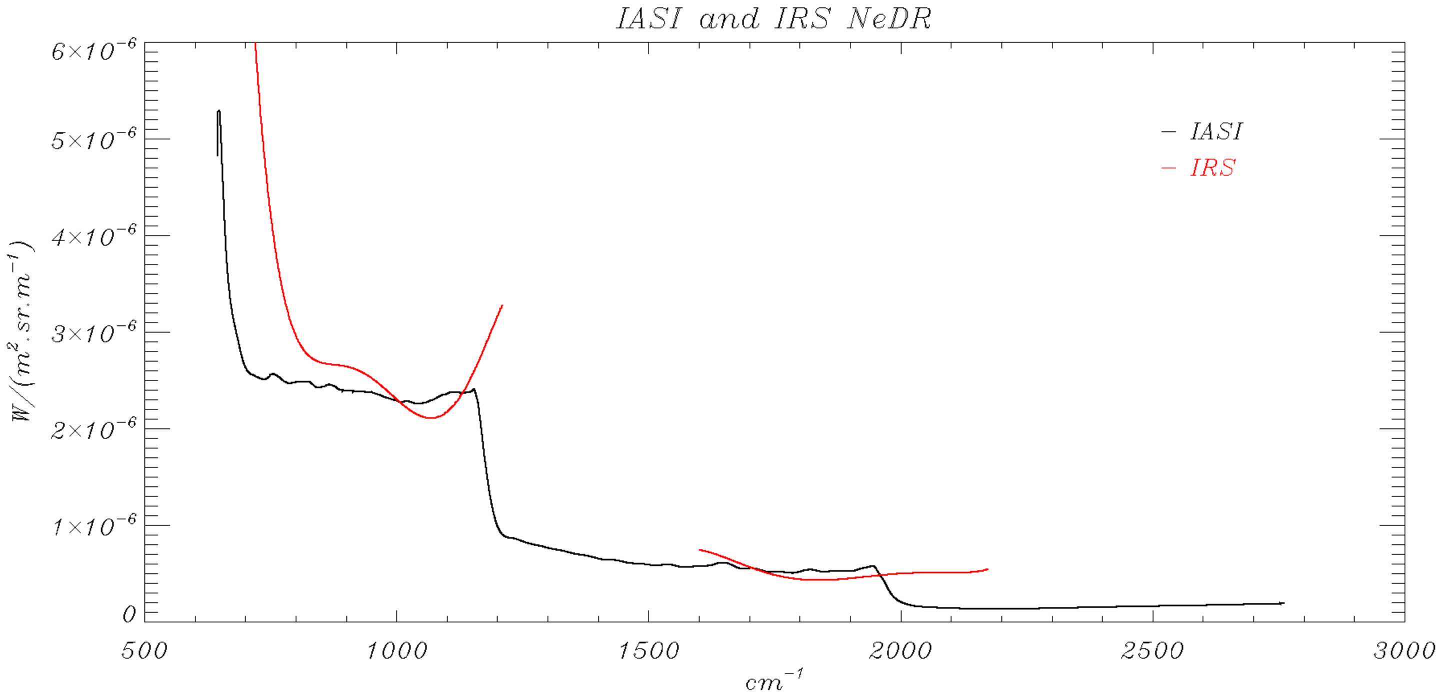
IRS definition in this study:

Spectral sampling: 0.625 cm^{-1}

spectral range: 700-1210 and 1600-2175 cm^{-1}

IRS and IASI instrument noise





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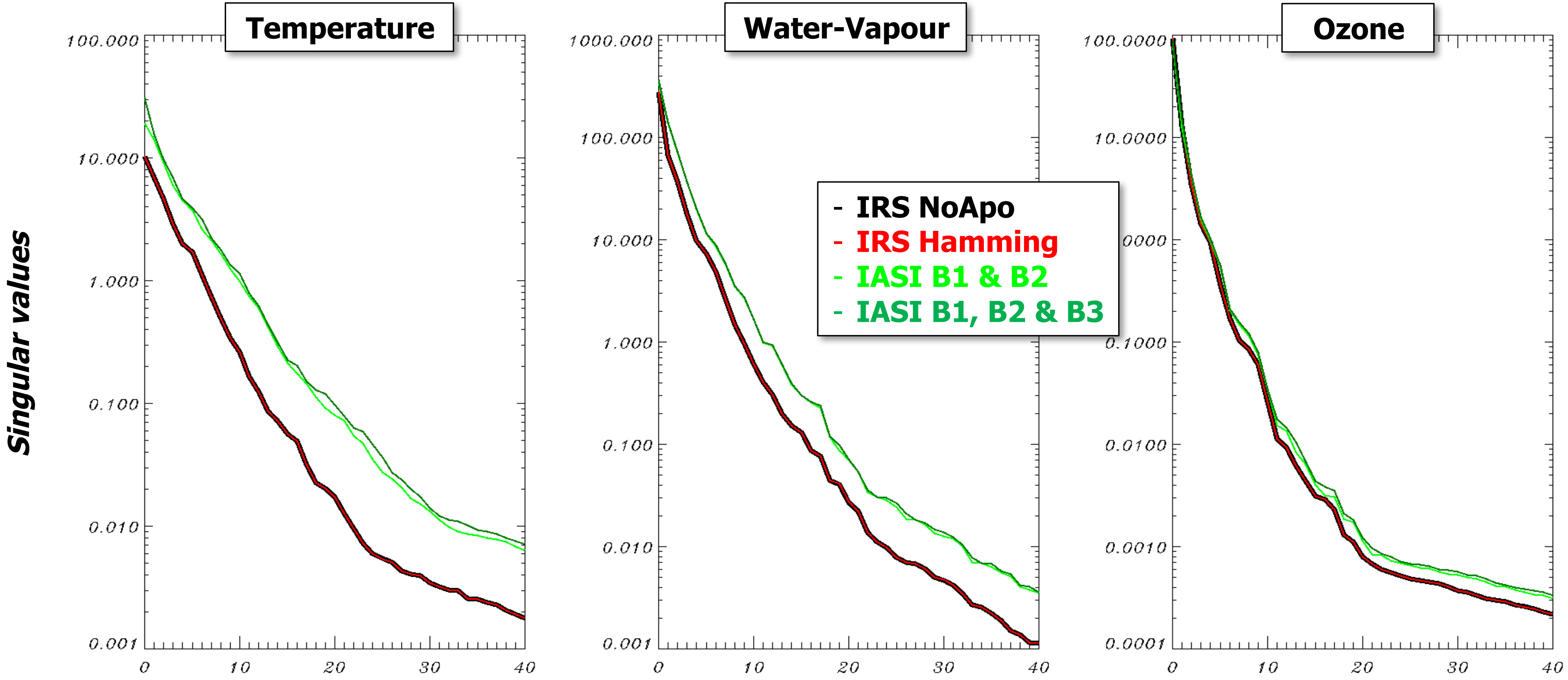
SRFs and information content



Same information content with or without apodisation.

Less information than IASI ➔ relative performances?

EUMETSAT

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  - Relative performances IRS vs IASI
  - A pseudo-IRS product
  - Choice of *a priori* for the OEM
  - Viewing geometry
- Products processing and dissemination

Theoretical relative performances IRS *vs* IASI

Total posterior theoretical error

$$S = [K^T . S_y^{-1} . K + S_x^{-1}]^{-1}$$

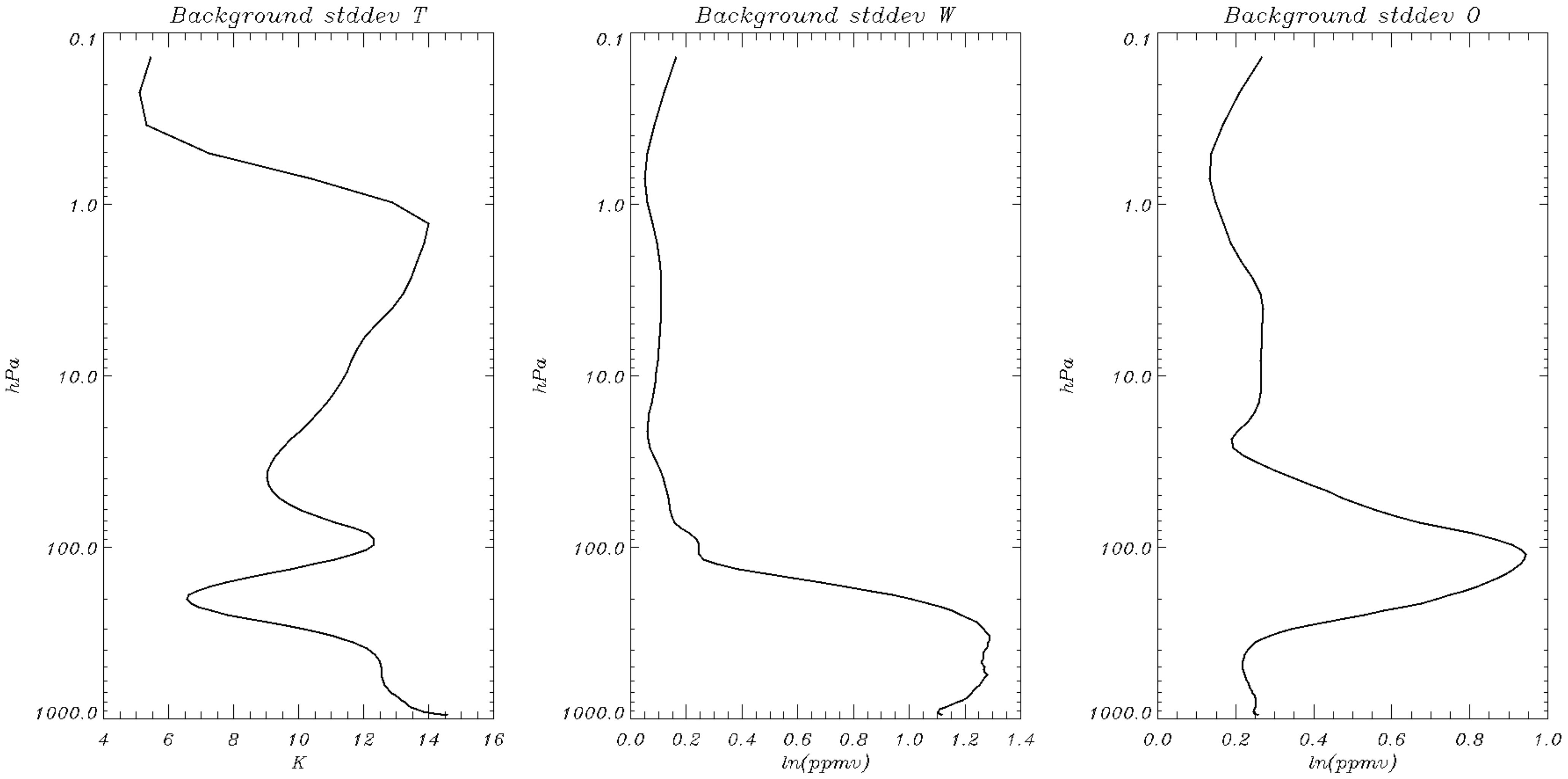
Averaging Kernels

$$AK = S . K^T S_y^{-1} K$$

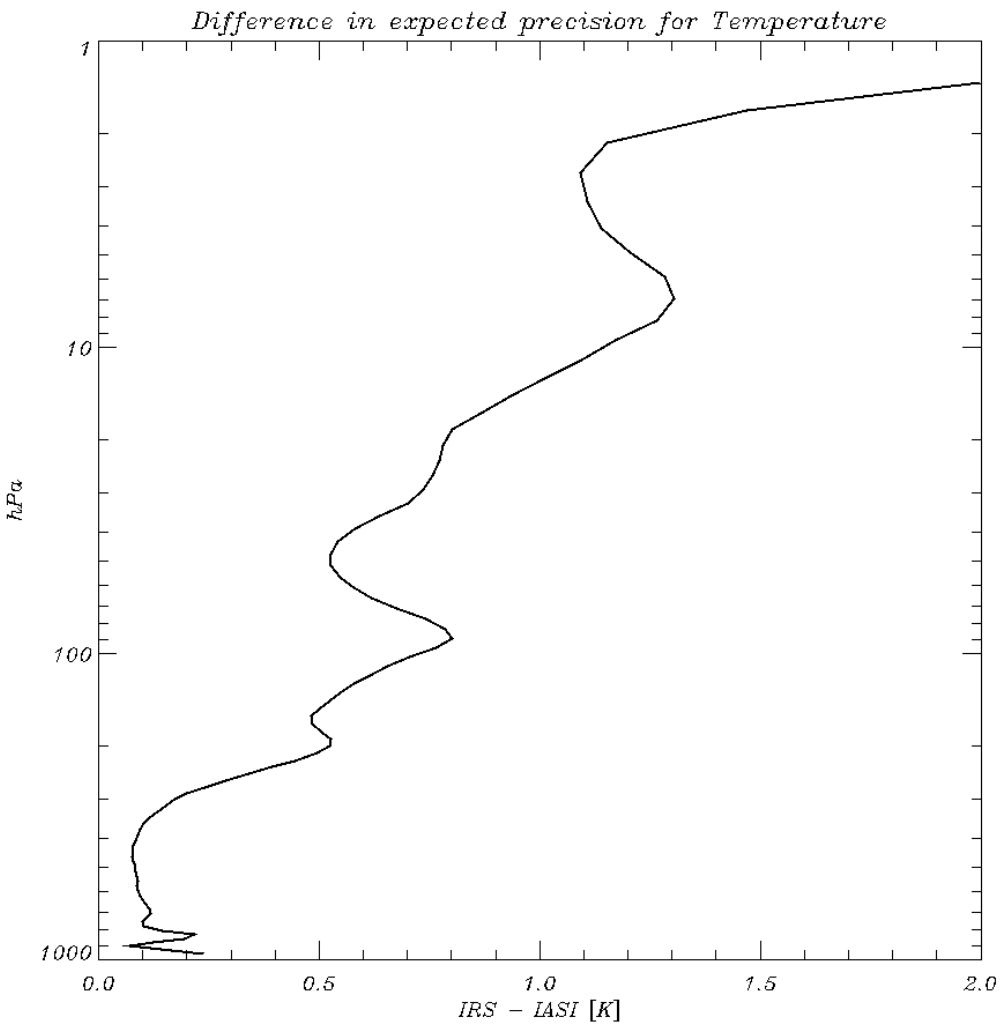
evaluate $S_{IASI} - S_{IRS}$ **and** AK_{IASI} *vs* AK_{IRS}

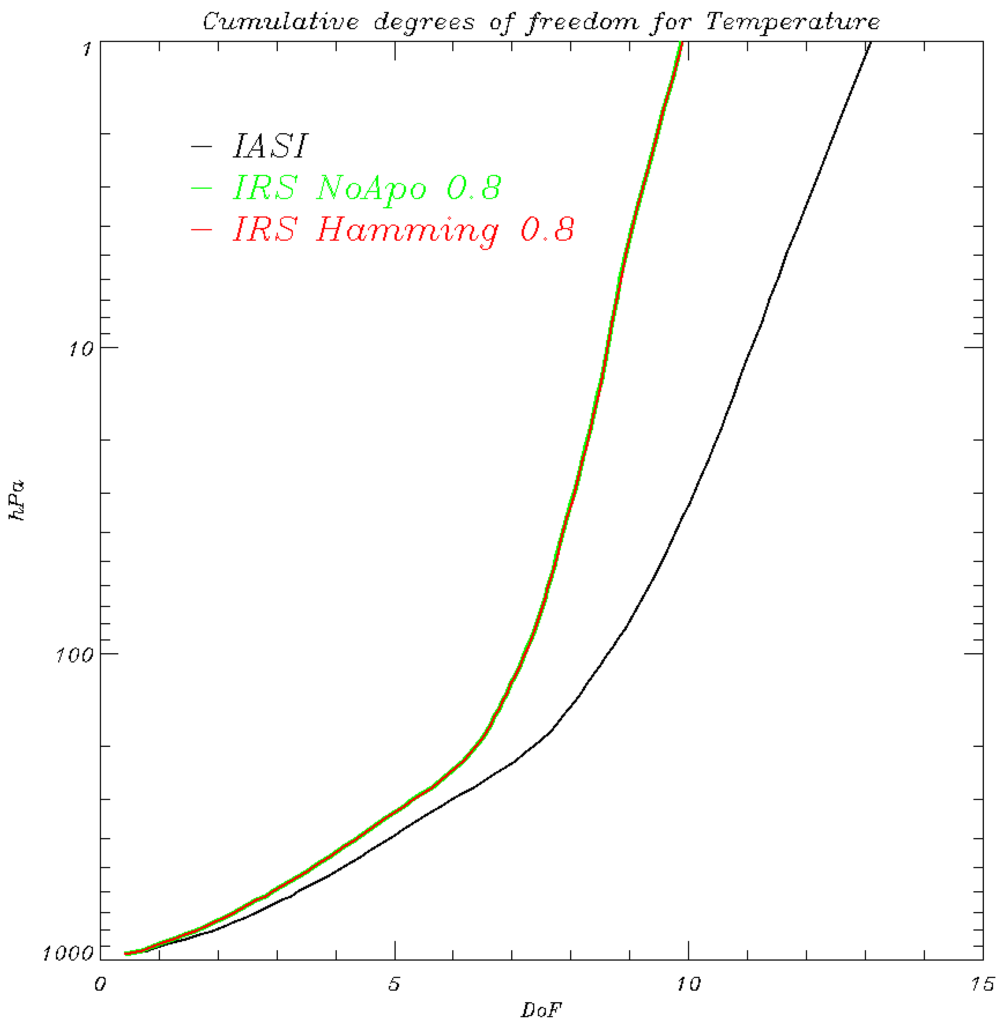
with same background error covariance matrix:
Global climatology (ECMWF analyses), from 1-year of T, q, O_3 profiles

Climatological background spread

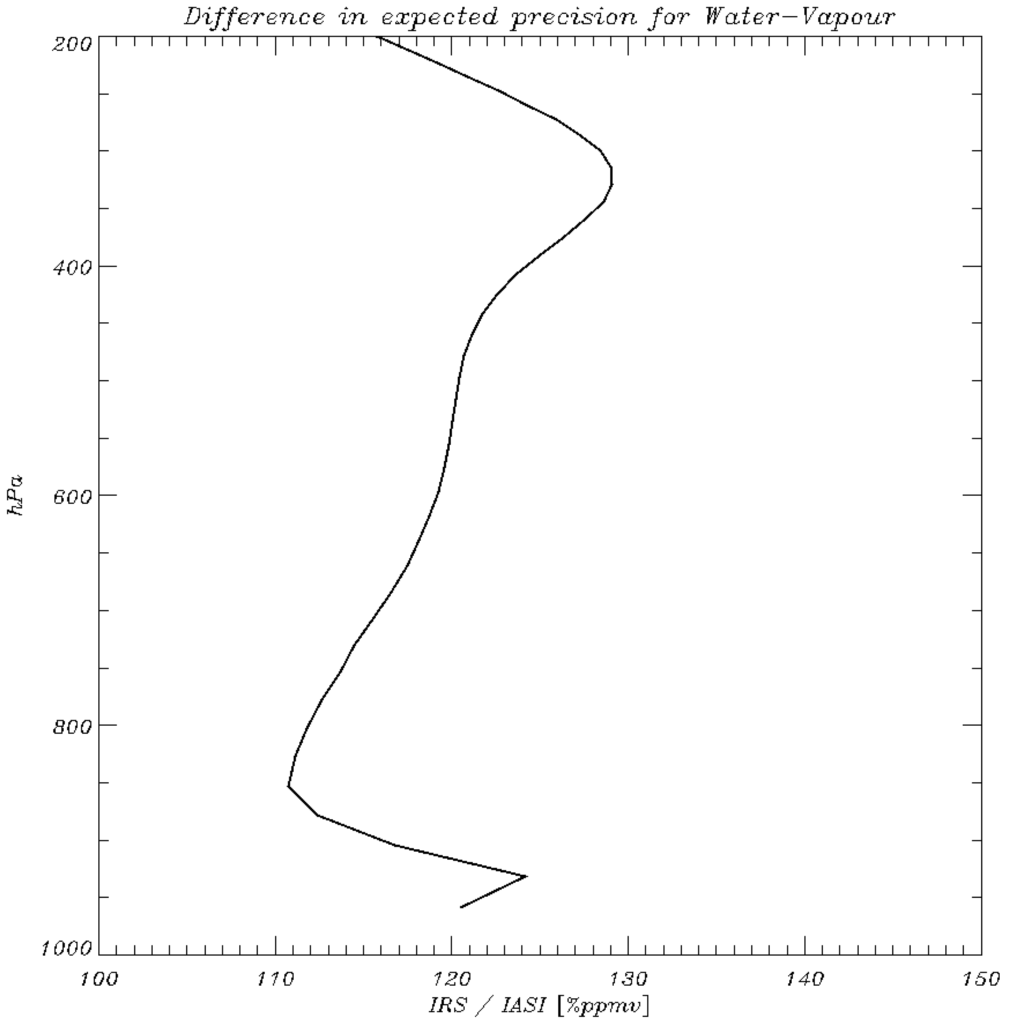


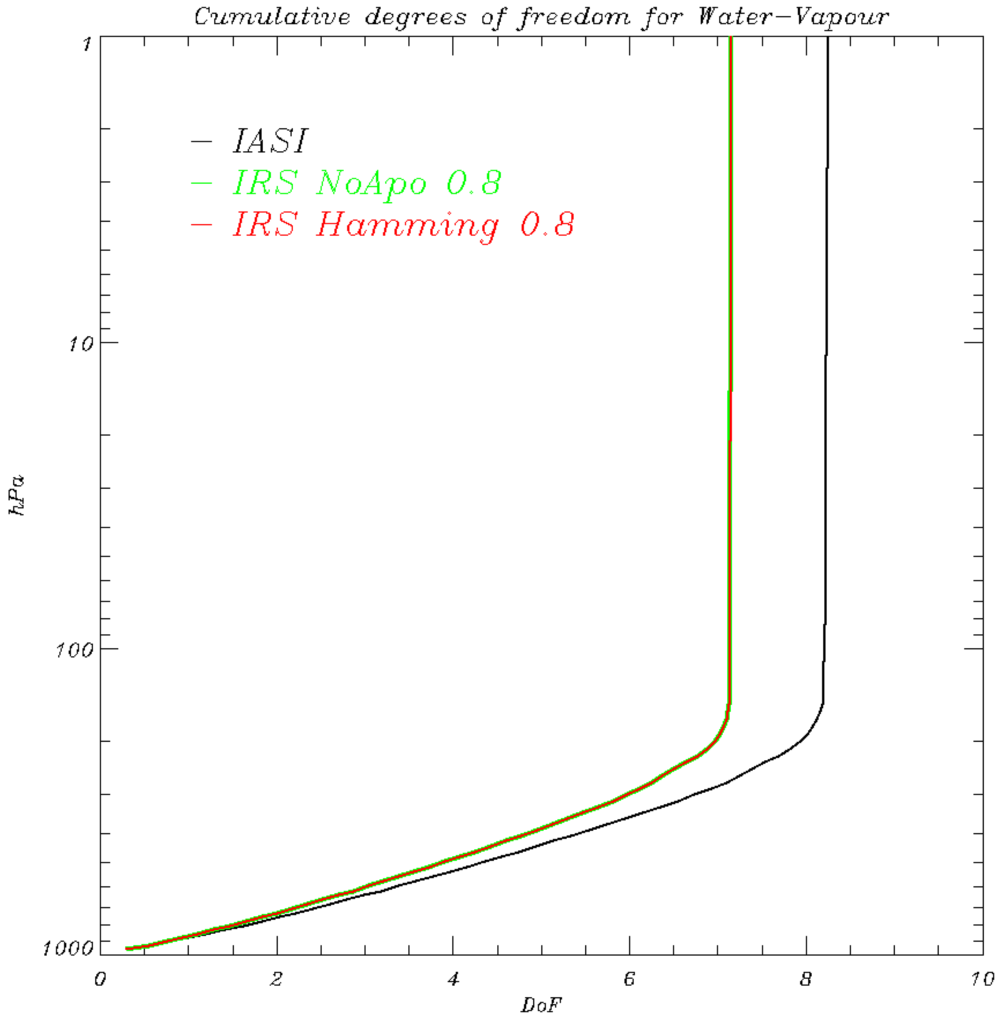
Theoretical performances IRS *vs* IASI - Temperature



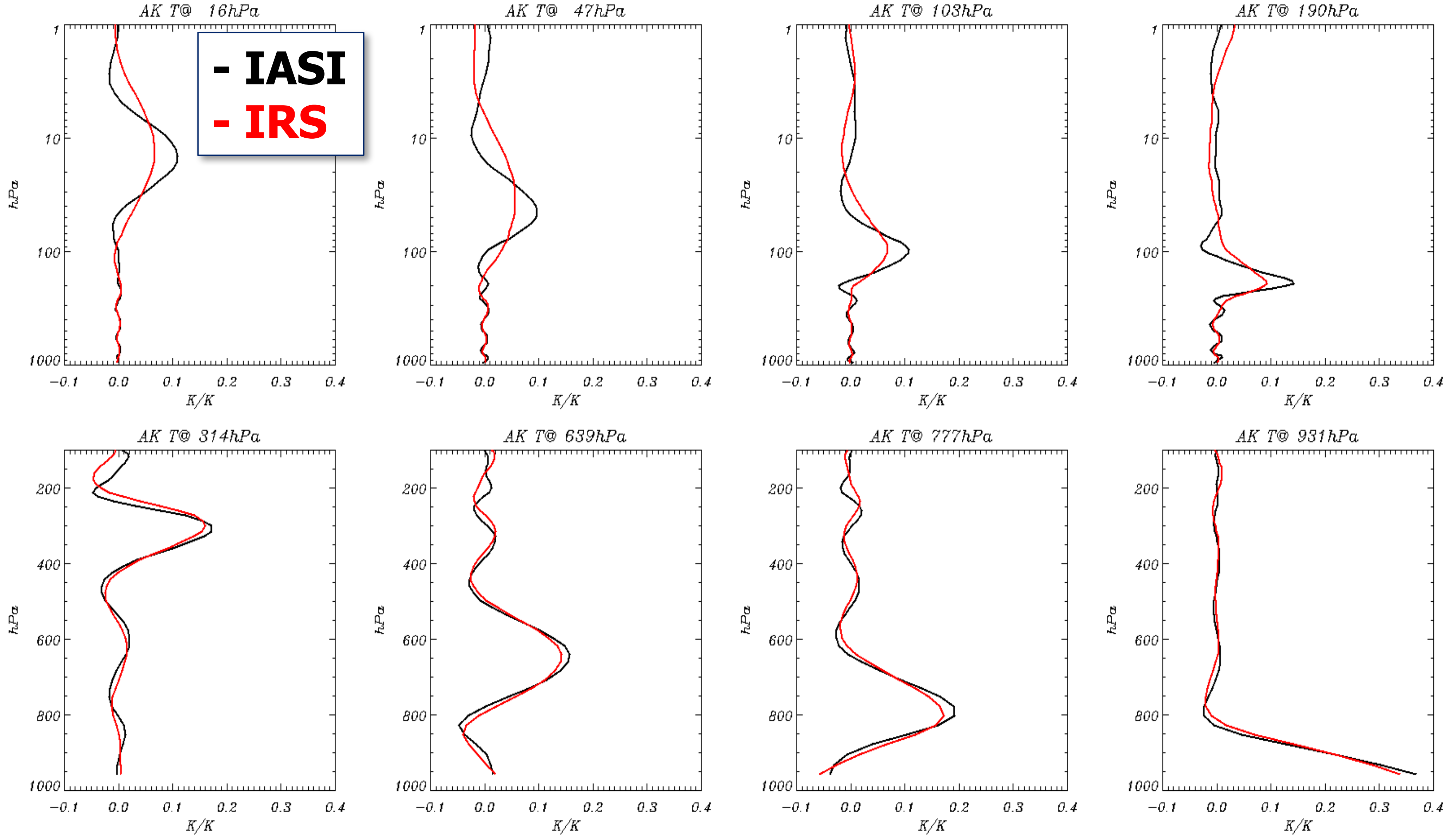


Theoretical performances IRS *vs* IASI – Water-vapour

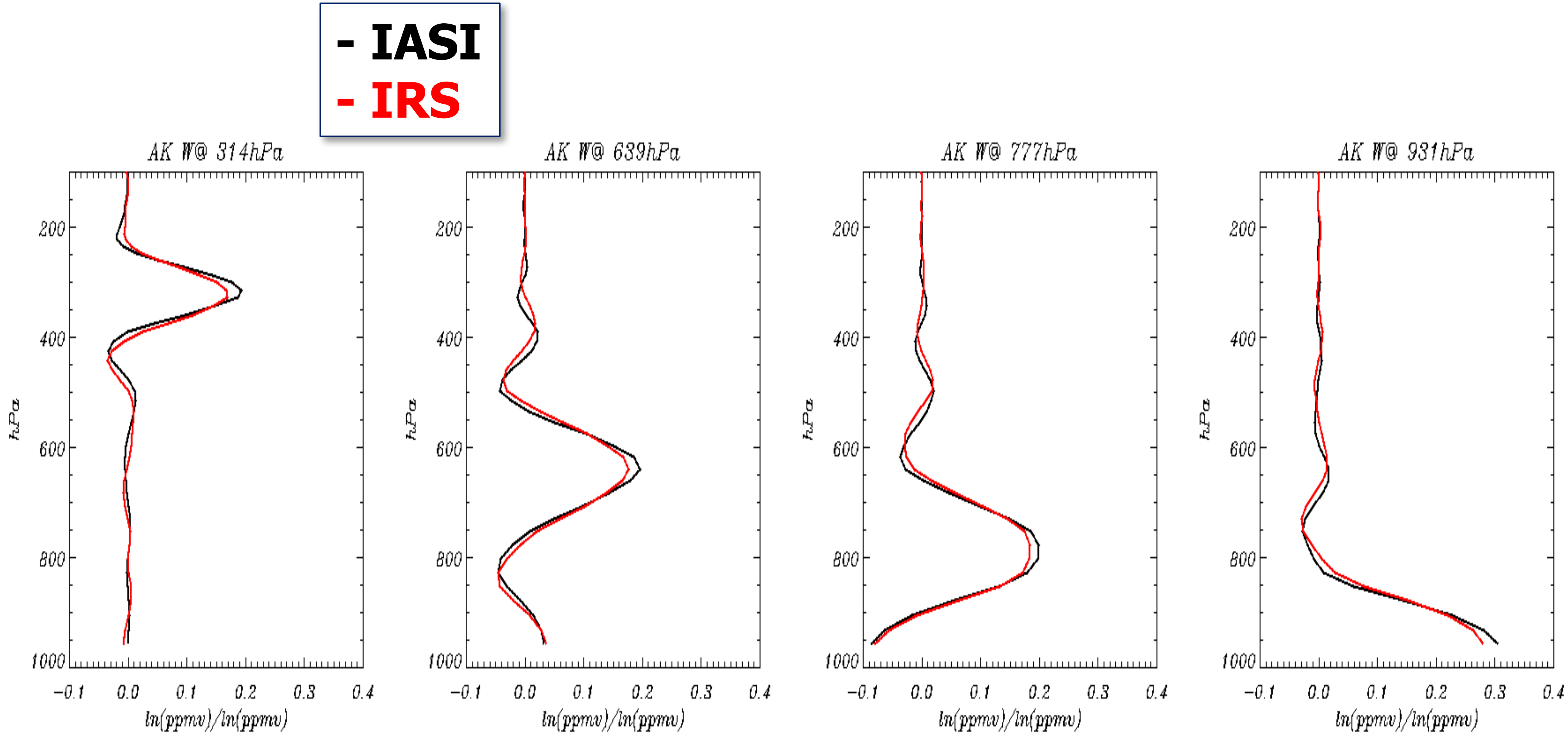




IASI vs IRS averaging kernels - Temperature



IASI vs IRS averaging kernels – Water-vapour



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A pseudo-IRS product from real measurements

Step 1. Emulate IRS observations from IASI

$$IRS_{PCS} = E_{IRS}^{T} \,.\, S \,.\, M_{Box0.8} \,.\, M_{Gauss}^{-1} \,.\, E_{IASI} \,.\, IASI_{PCS}$$

Pseudo-IRS eigenvectors → E_{IRS}^{T}

Channel selection matrix → S

BoxCar 0.8cm truncation → $M_{Box0.8}$

Gauss apodisation matrix → M_{Gauss}^{-1}

IASI eigenvectors → E_{IASI}

After DFT expressions in Amato et al., 1998

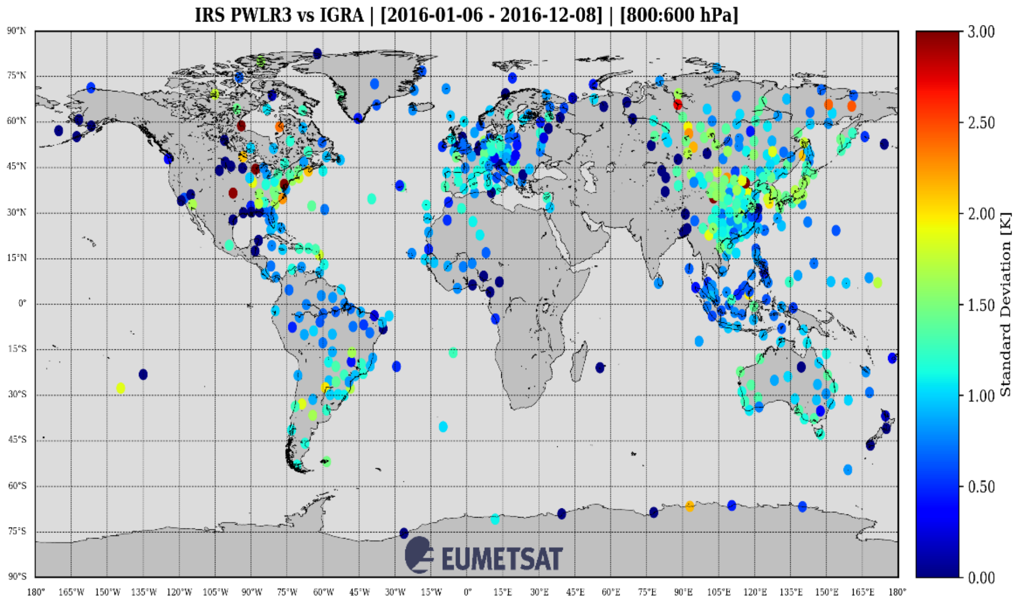
Step 2. Train PWLR^3 with pseudo-IRS PC scores

Step 3. Apply to IASI obs. and assess performances

A pseudo-IRS product

IASI L2 IR-only and pseudo-IRS, PWLR³

1st wednesday each month of 2016
***vs* radio-sondes (±3h ; <50km)**



Yield ~50%,
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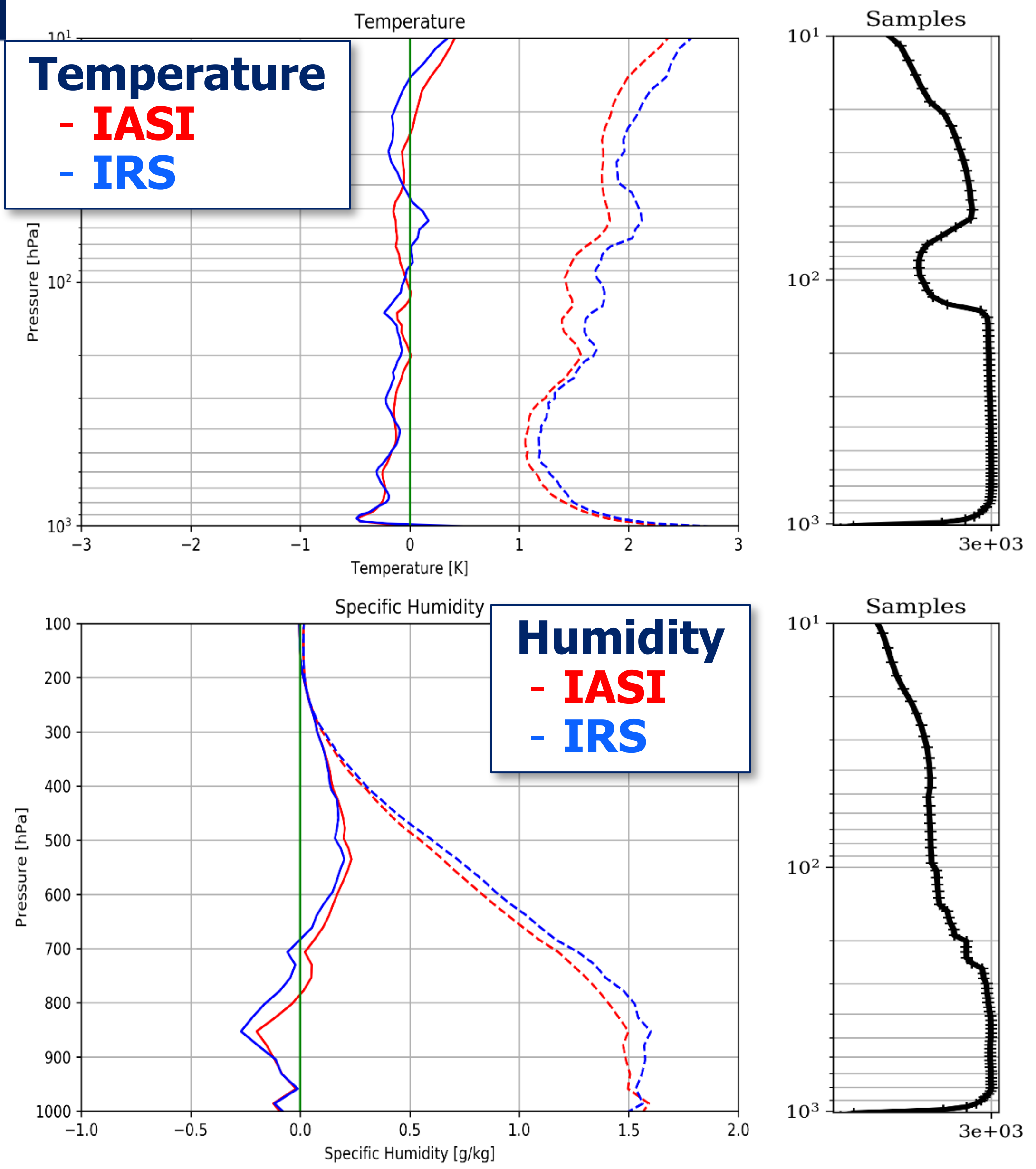

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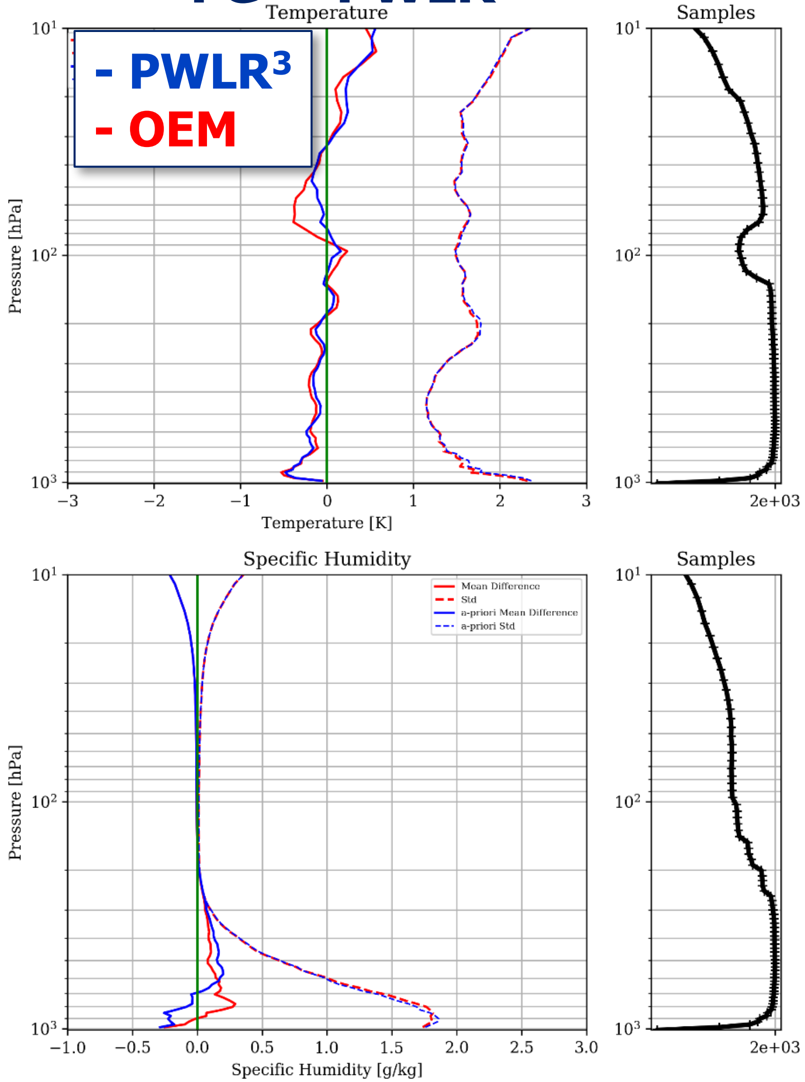
OEM retrieval dependency on *a priori*

5 Wednesdays in June-July 2017 vs radiosondes (±3h ; <50km)

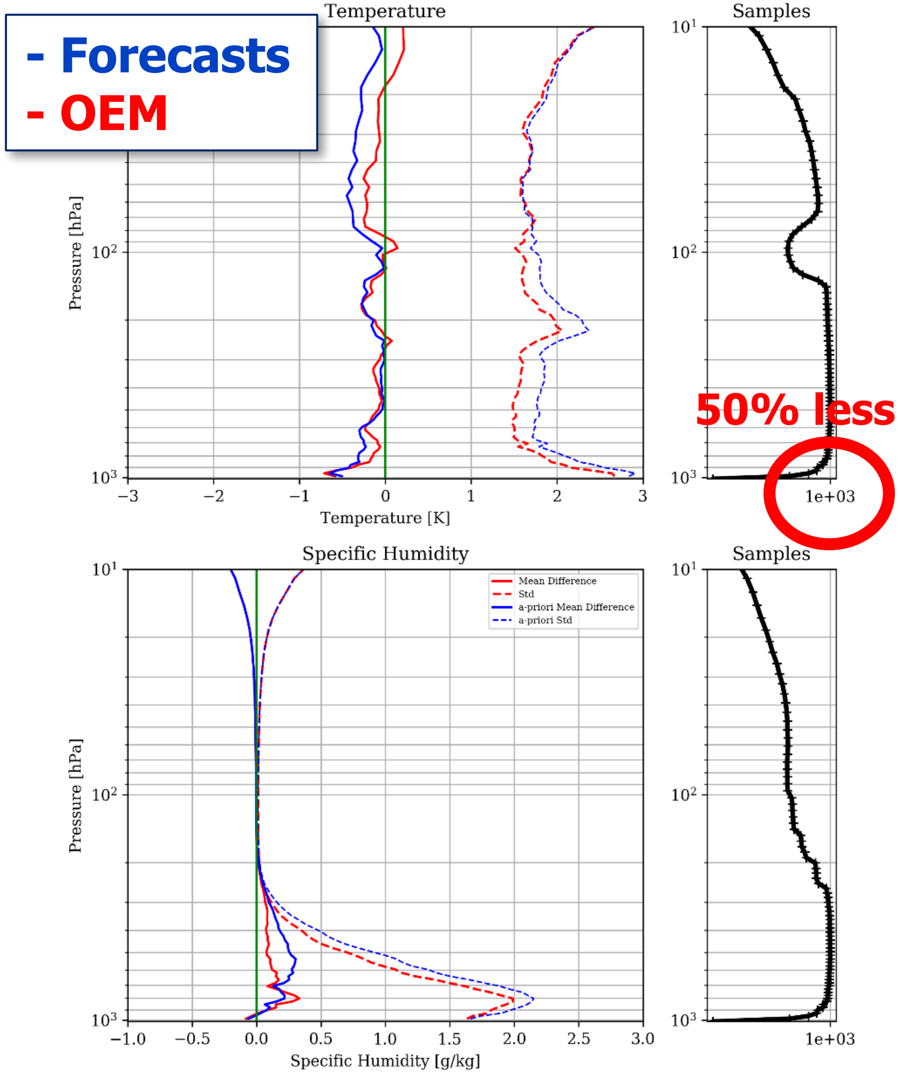
FG = PWLR^3



IASI L2 PPF:

- Is FCT-free (EPS requirement)
- Can successfully process NWP forecasts (MTG assumption)
- Posterior stays close to prior if accurate *a priori*
- Some resilience to inaccurate *a priori* but not as good as stand-alone OEM(PWLR^3)
- Brings independent accurate information

FG = 9h-outdated FCT



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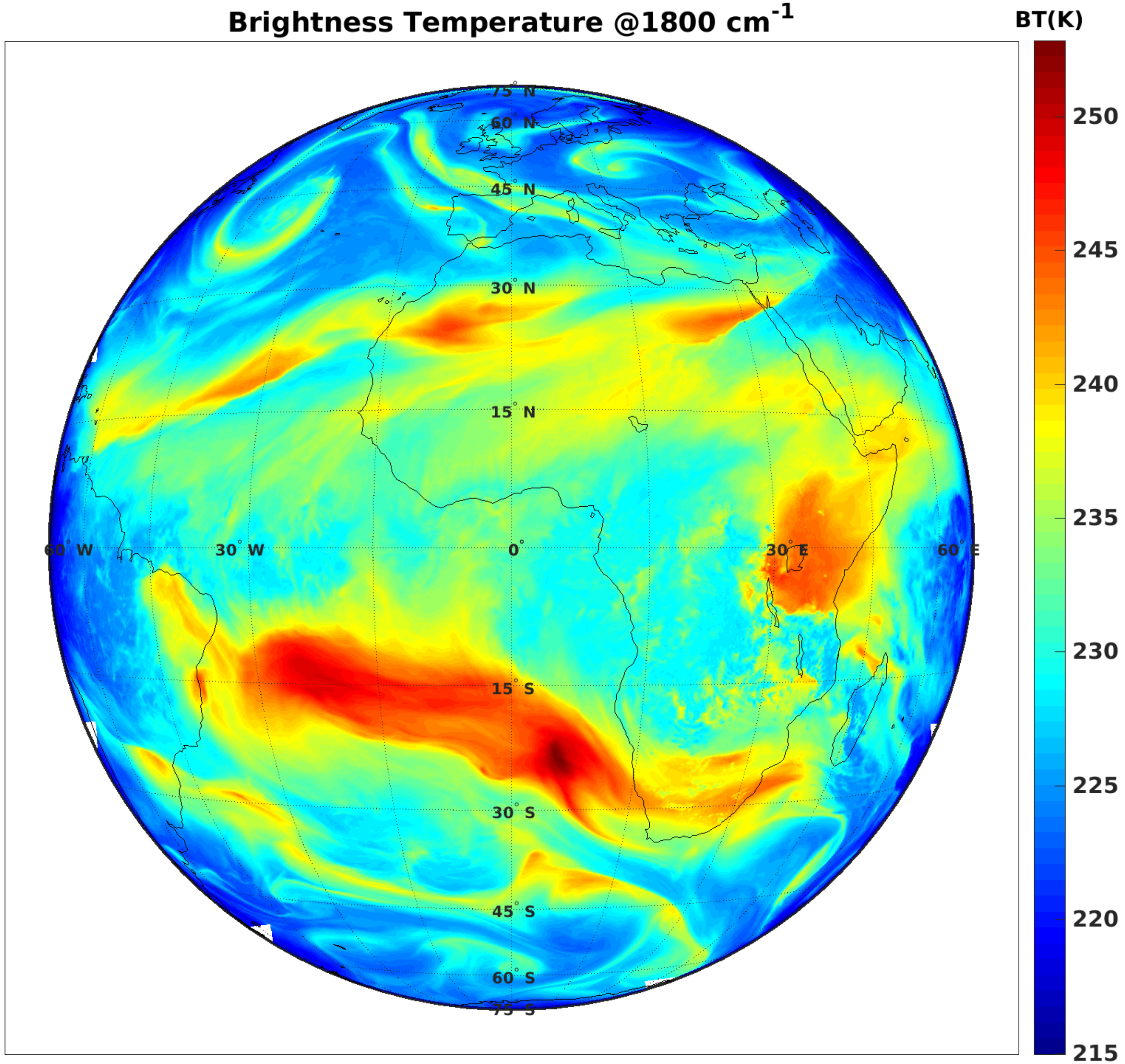
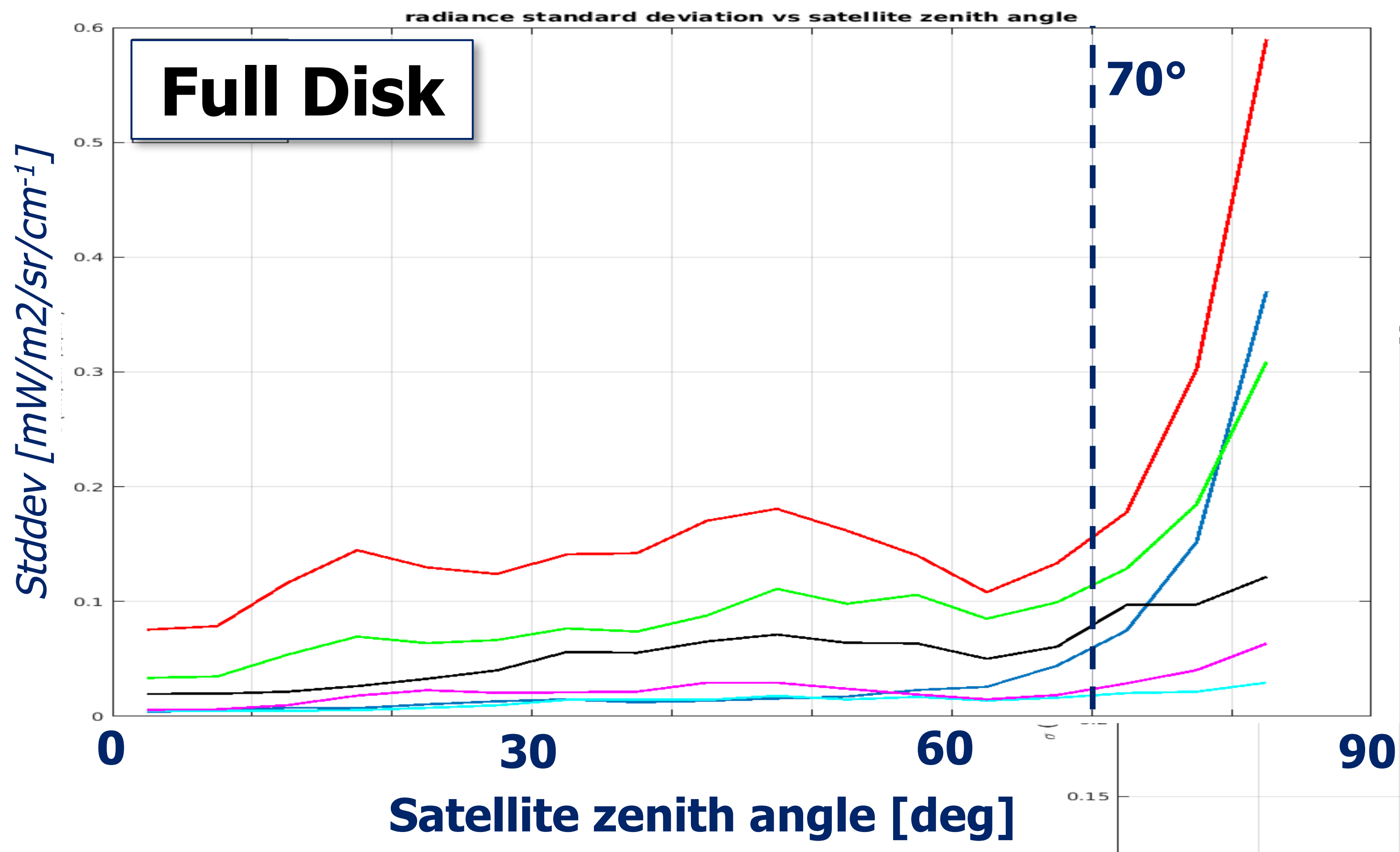
A training set for PWLR³ and viewing sensitivity study



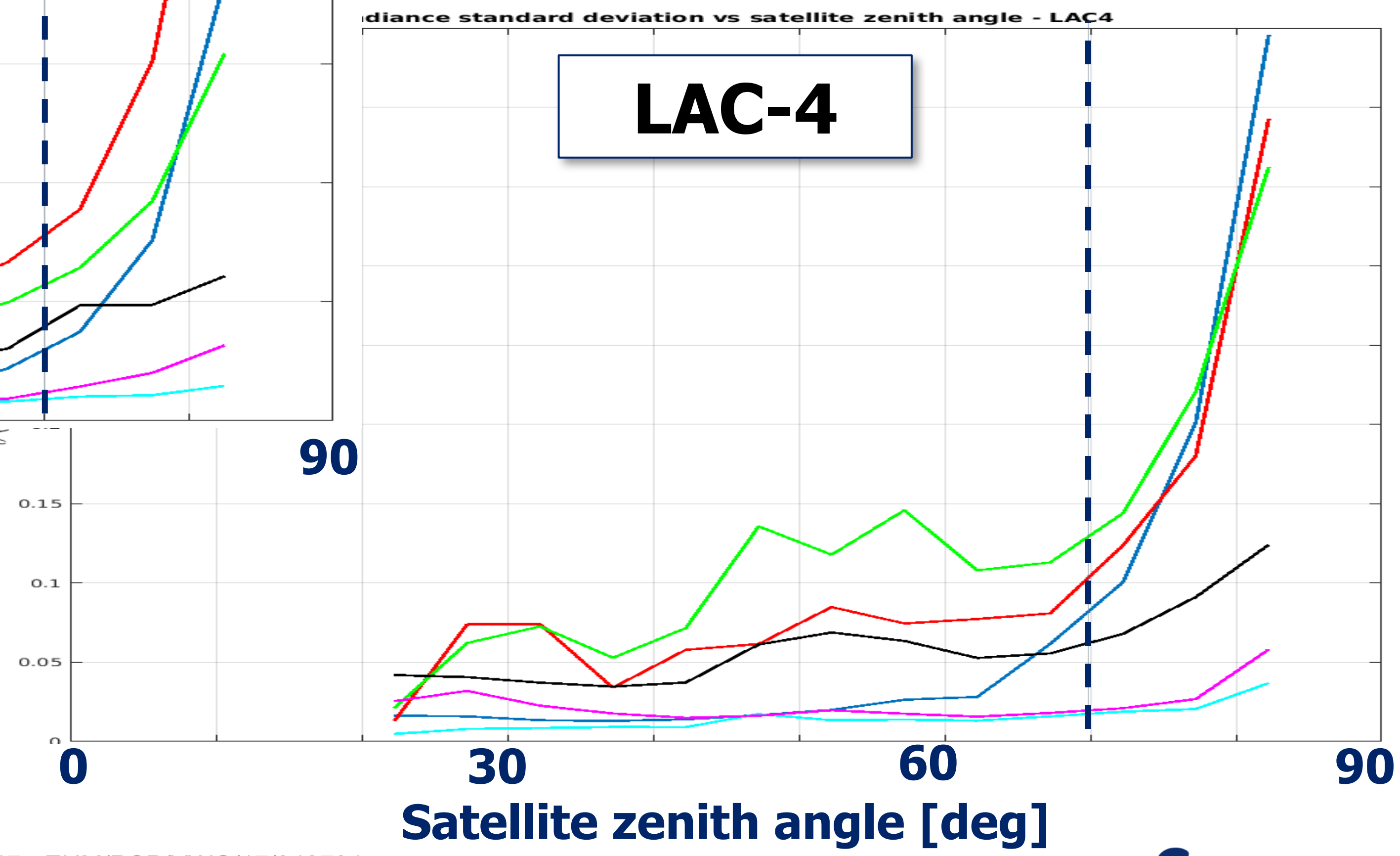
One disk simulation so far

- ✓ Simulations with RTTOV-IRS, trained out to 85°
- ✓ Clear-sky radiances
- ✓ Surface emissivity built-in RTTOV
- ✓ T/q/O_3 and Ts, Ps from ECMWF model (15/03/2016 @ 12:UTC)
- ✓ Data stored in realistic dwells (viewing angle, lat/lon)
- ✓ Slant radiances simulation with slant path and vertical profiles

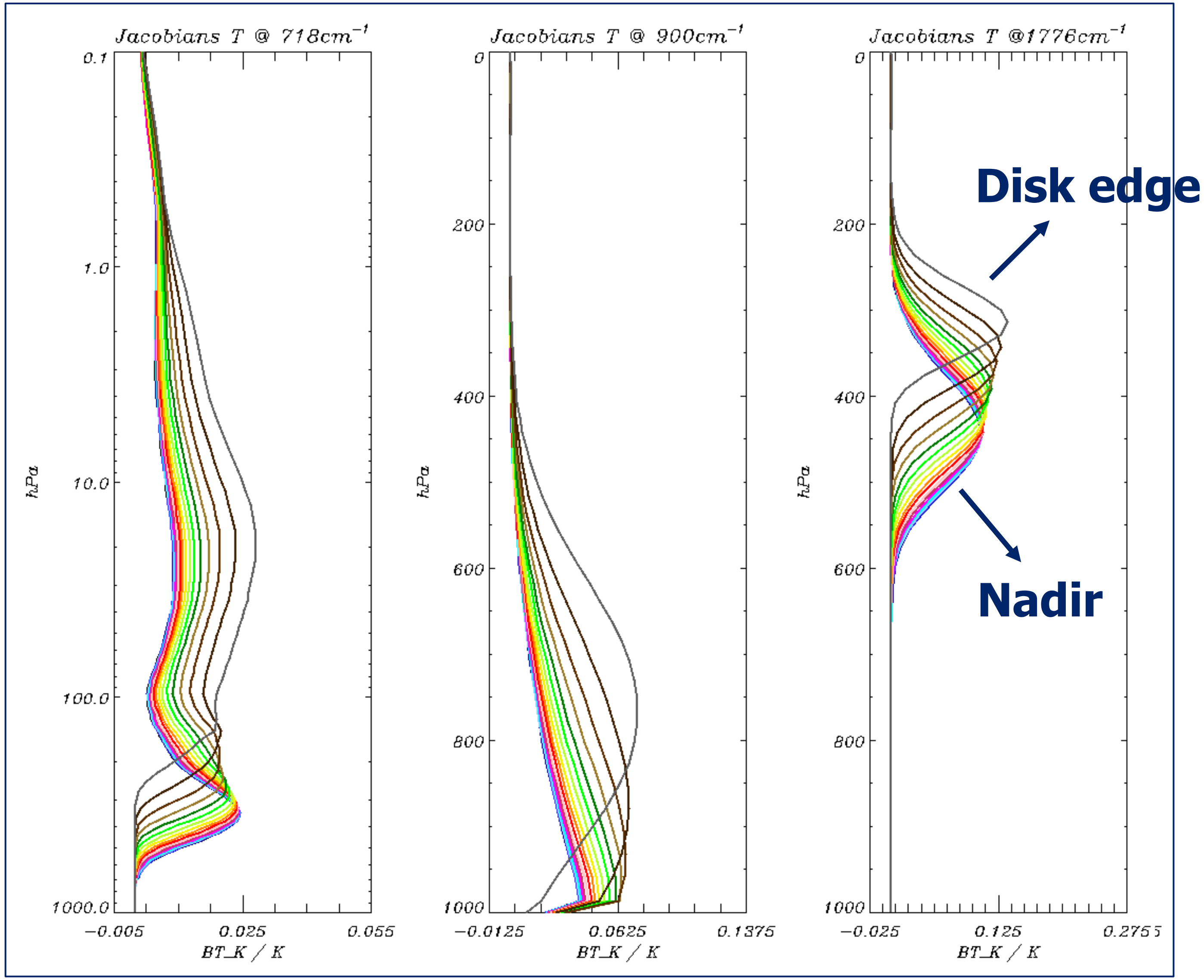
Slant RT with slant path *vs* vertical profiles at pixel location

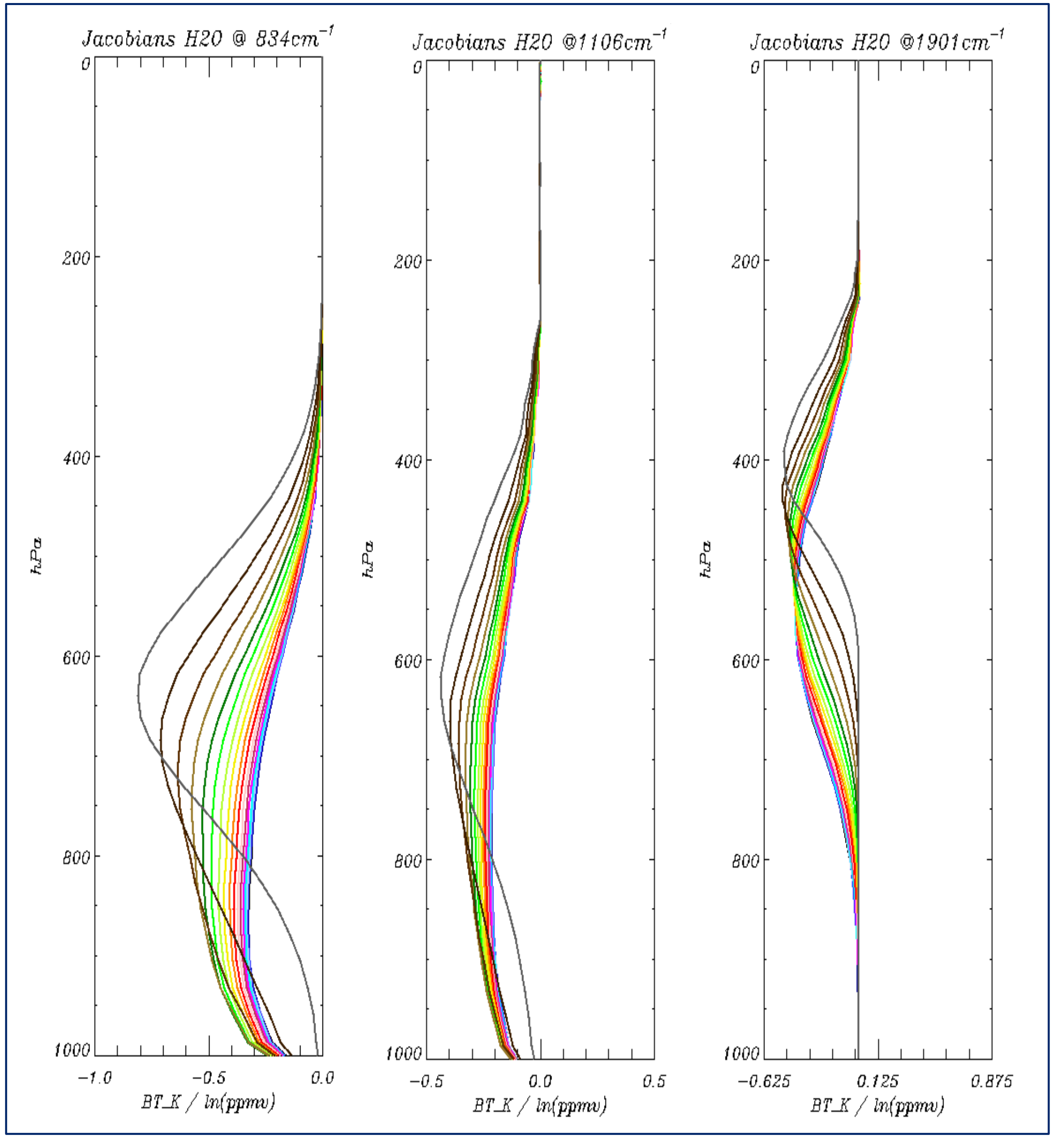


- 710 cm^{-1}
- 900 cm^{-1}
- 1030 cm^{-1}
- 1600 cm^{-1}
- 1800 cm^{-1}
- 2000 cm^{-1}

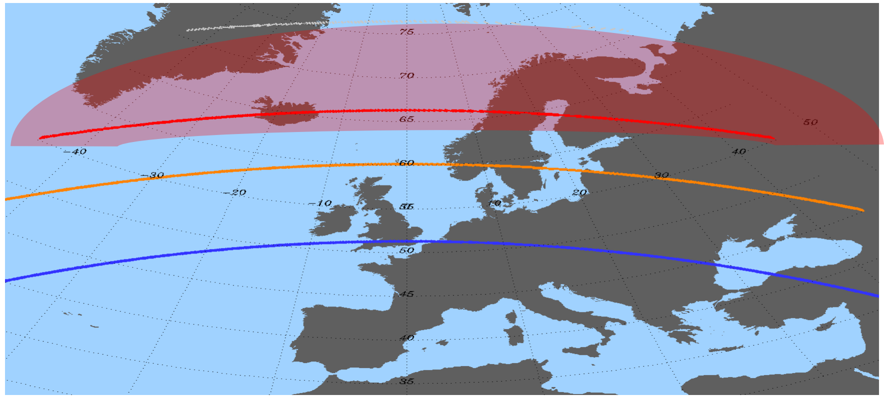


Sensitivity peak shift with viewing angle



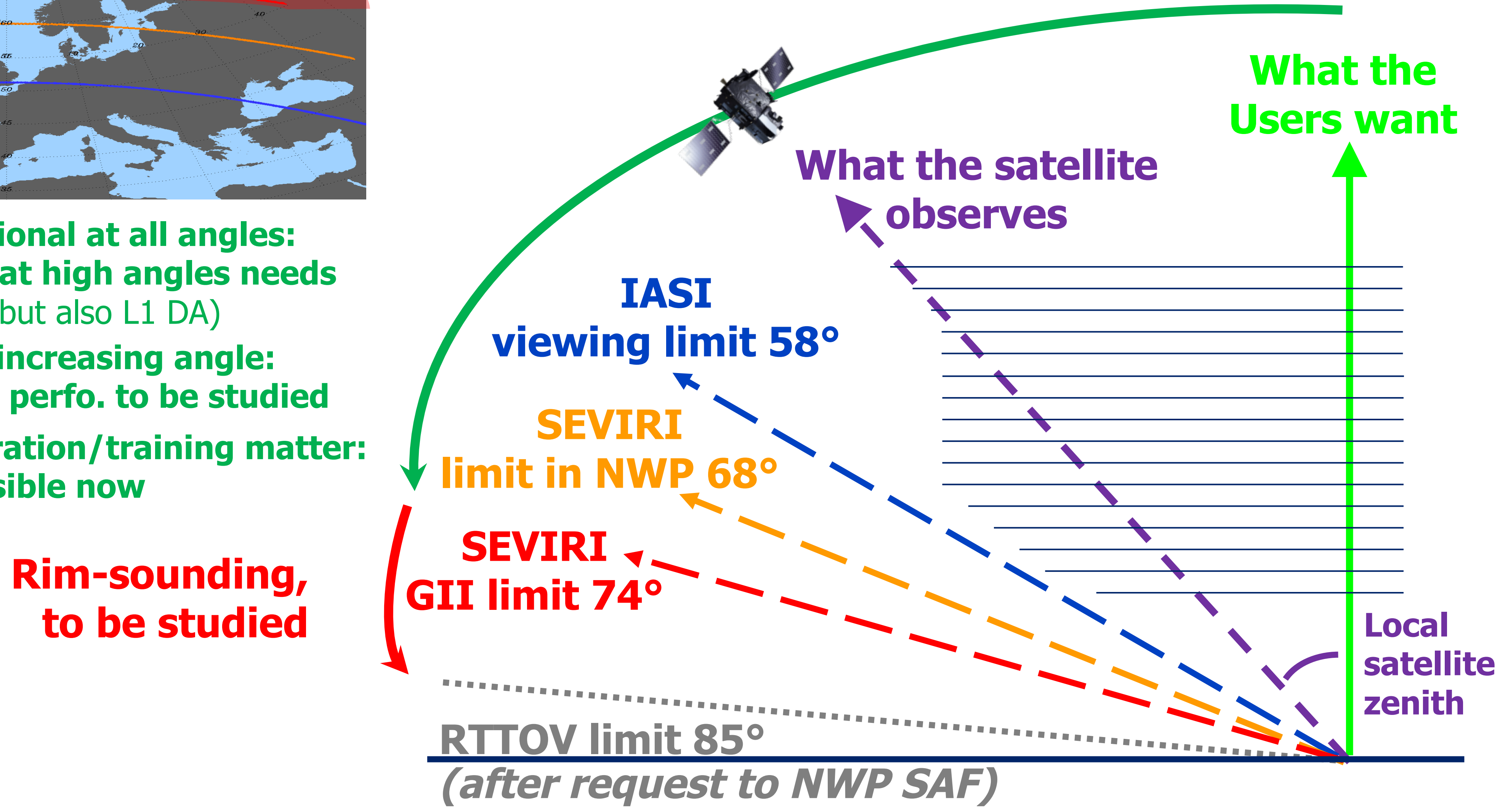


IRS specific viewing geometry, slant profiles

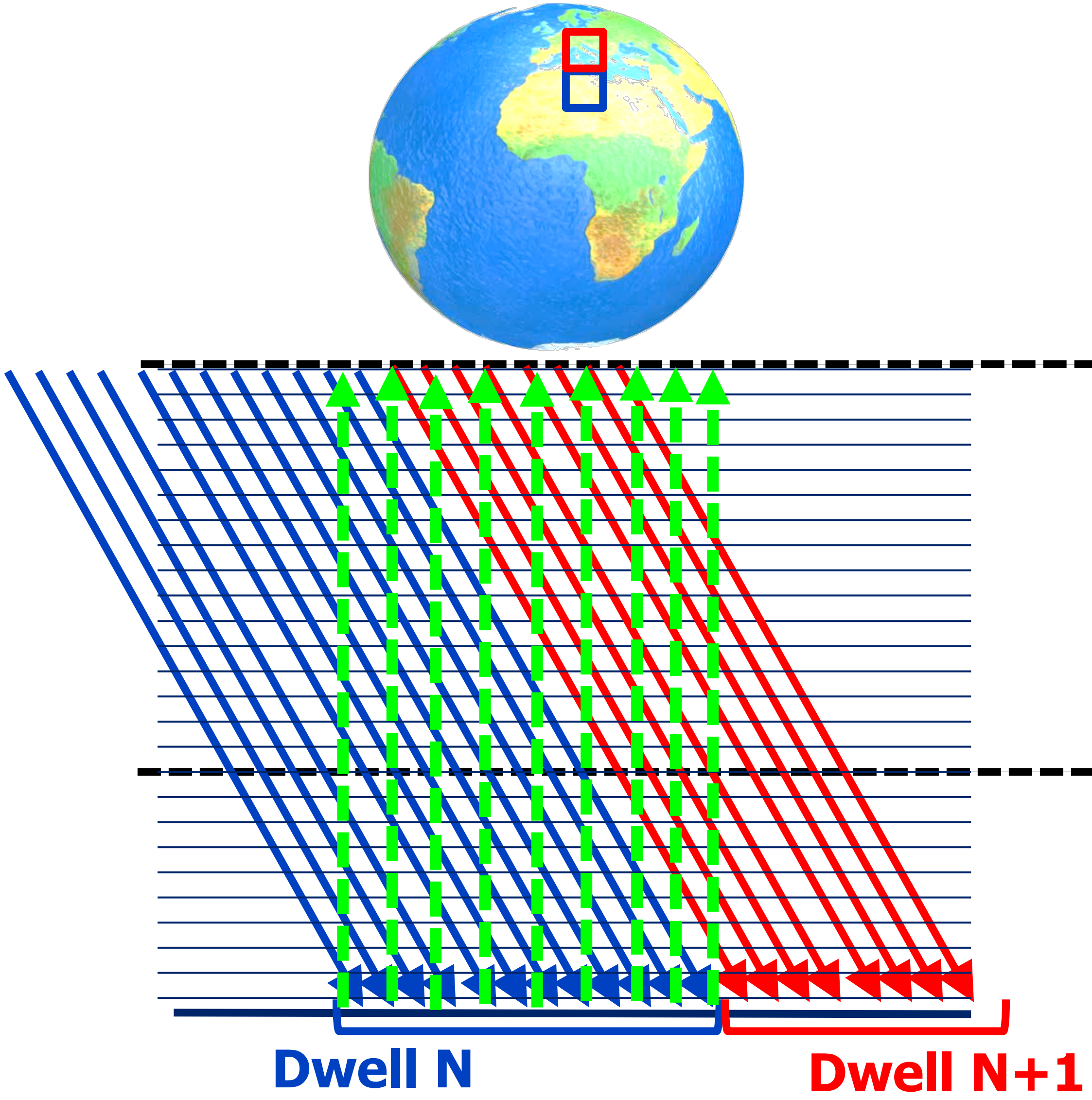


PWLR³ and OEM functional at all angles:
- **surface emissivity at high angles needs study** (e.g. for OEM but also L1 DA)
- **Lower signal with increasing angle: effect on sounding perfo. to be studied**

Application is configuration/training matter:
- **Specifications possible now**

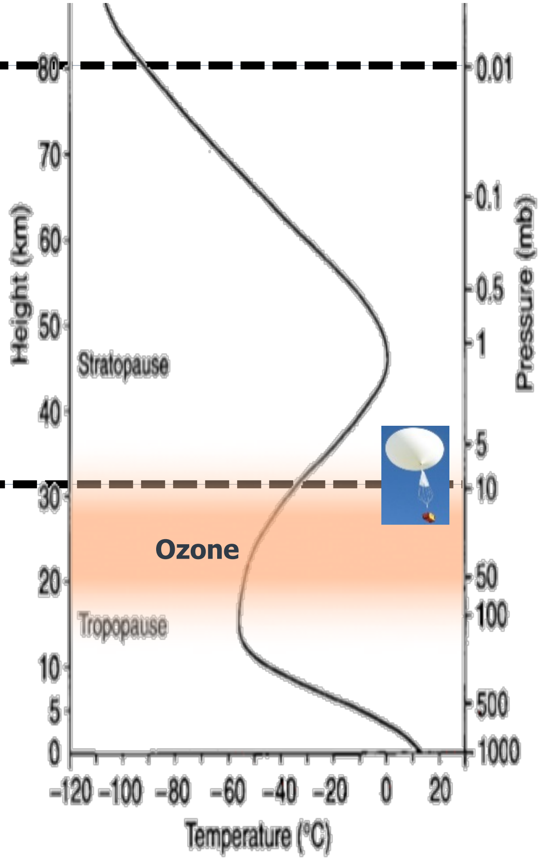


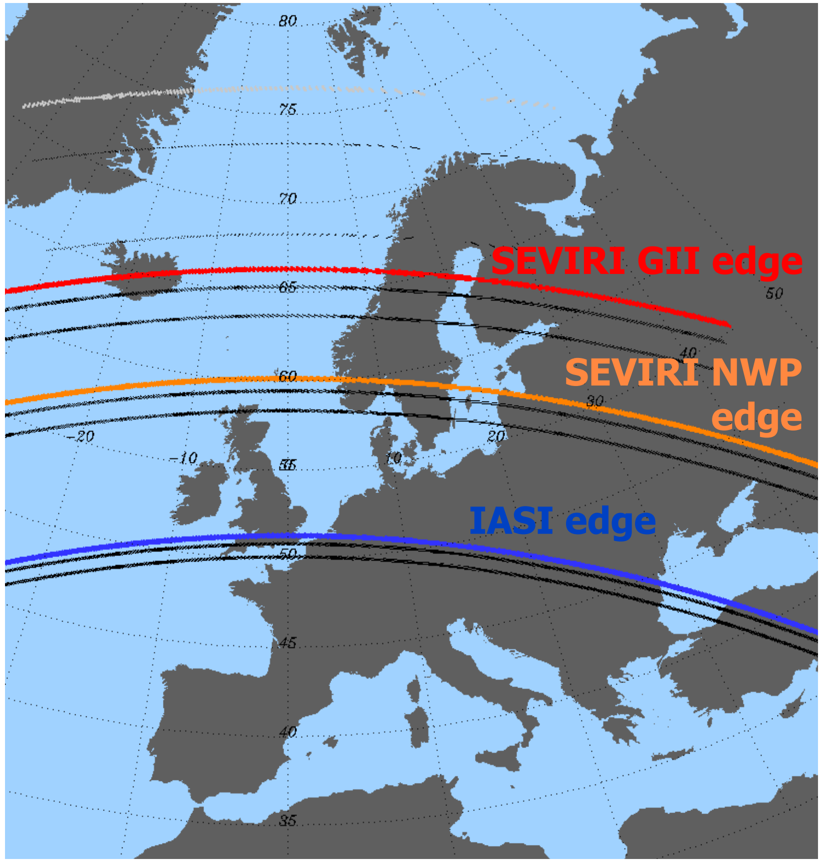
Staging required to reconstruct vertical profiles



Geometrical limits to vertical profiles reconstruction

Roof at 30km and 80km





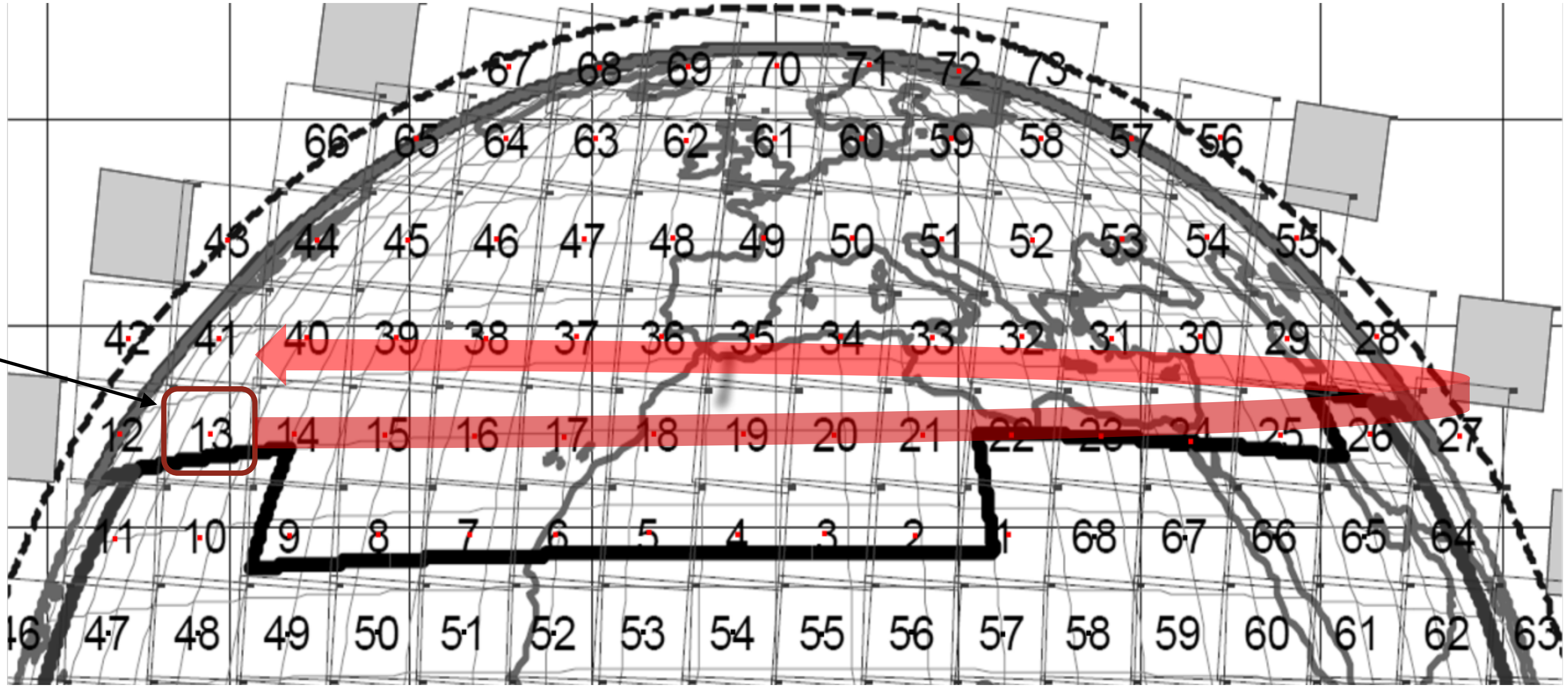
Outline

- Overview of L2 operational products
- IRS specificities and open questions
  - Apodisation
  - Relative performances IRS vs IASI
  - A pseudo-IRS product
  - Choice of *a priori* for the OEM
  - Viewing geometry
- Products processing and dissemination

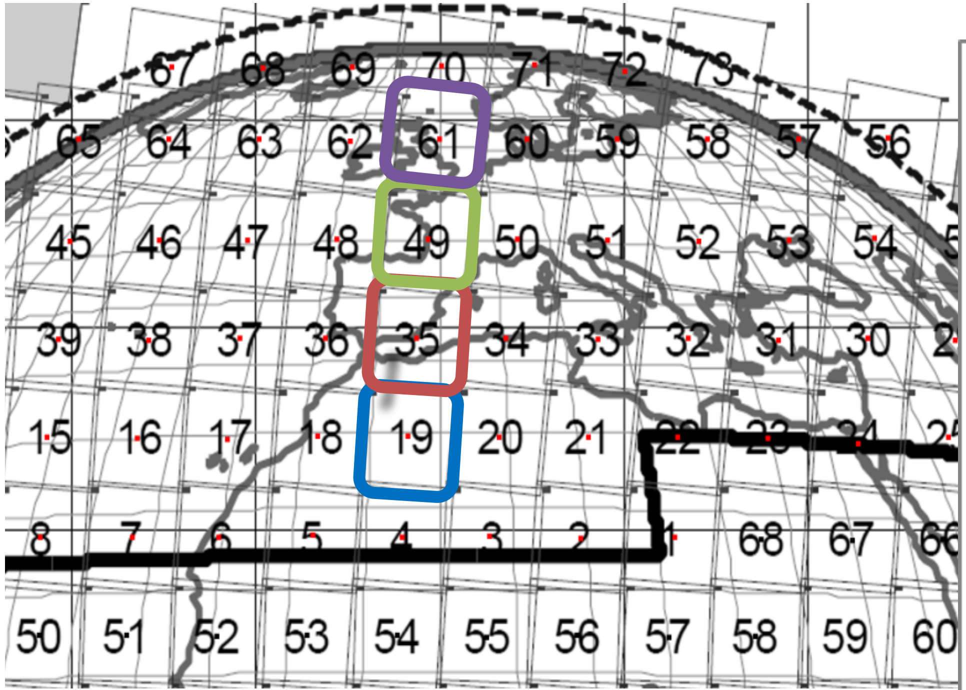
L2PF IRS Timeliness Simulator

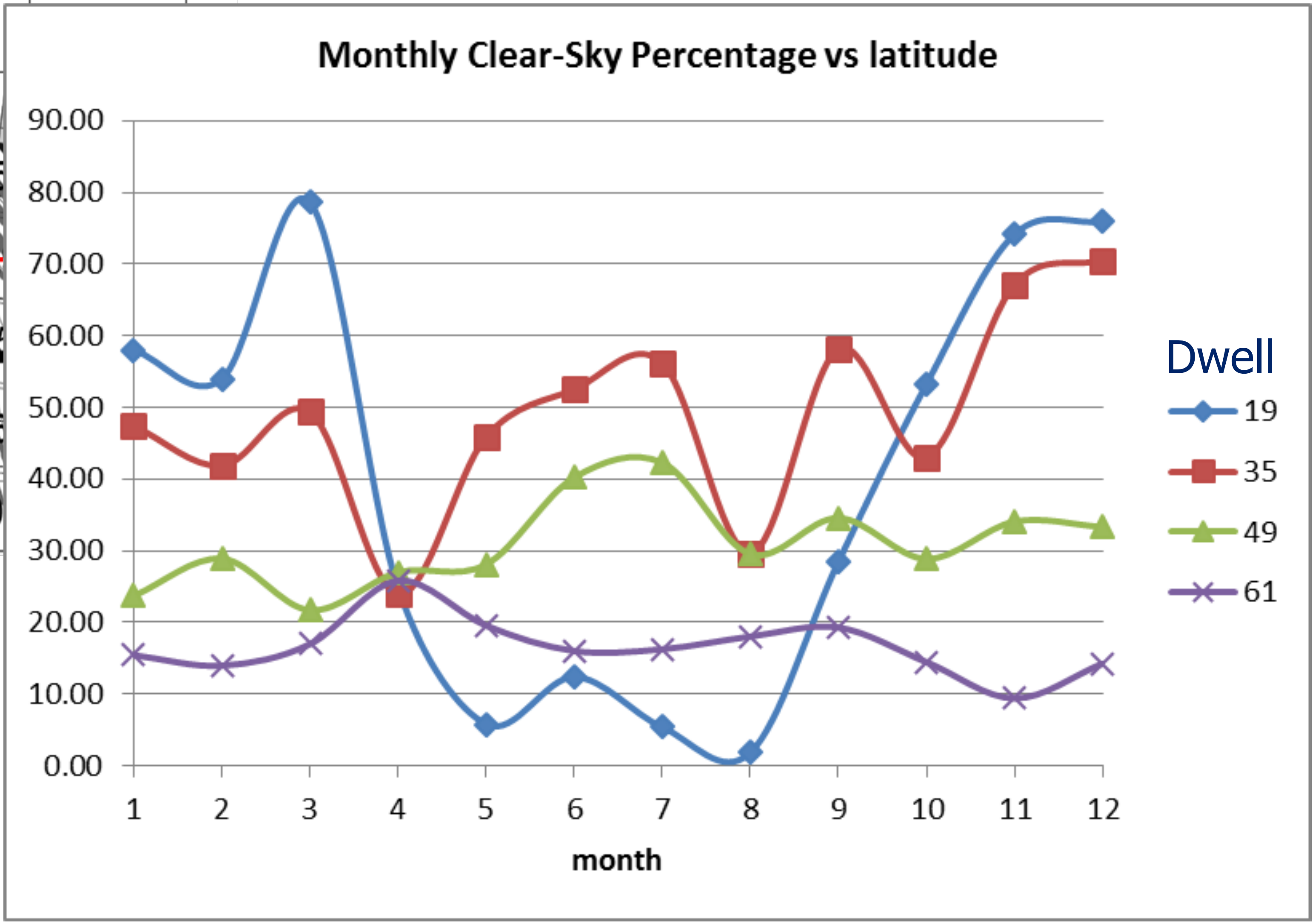
- Post-Processing constraints

Dwell 13 must wait for dwell 41 core processing



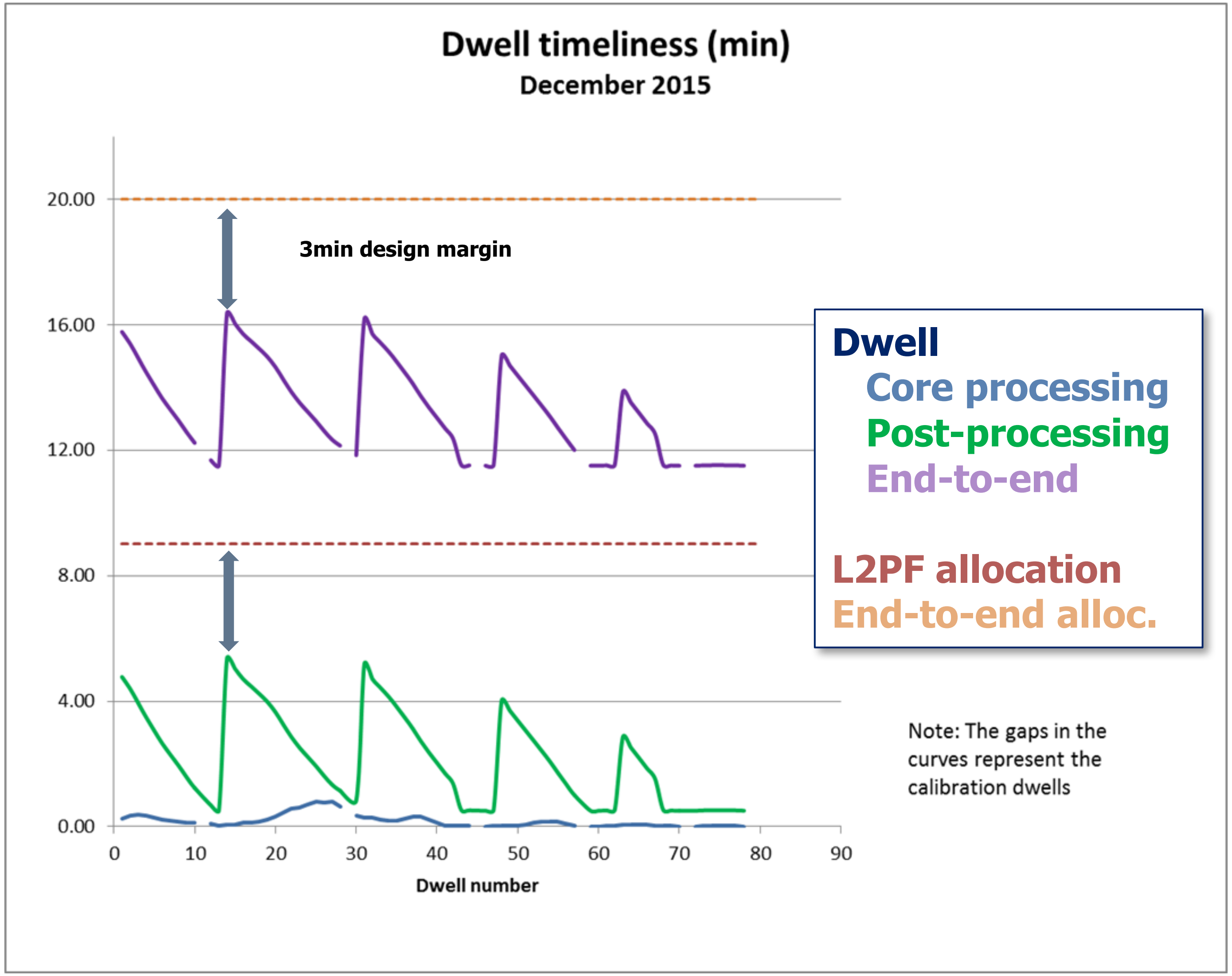
L2PF IRS Timeliness Simulator





Cloudiness climatology for 2015 based on SEVIRI cloud mask and MACC aerosol data

L2PF IRS Timeliness Simulator



End-to-end timeliness for IRS L2 products:

- Simulated with 200 CPU cores
- Dwell-staging is a major constraint
- 20 min achievable, with margins
- Worst case analysis and studies for other LACs still TBD

Dissemination not always in sensing order, but data-rate relatively constant

Production and NRT dissemination of:

- T/q/O_3 profiles
- Surface temperature and emissivity
- Cloud detection and characterisation
- All LACs, including cloudy pixels

Development approach for IRS L2

- Specific to IRS L2 development and demonstration:
  - Prototype initial configuration with synthetic test data
  - Emulate pseudo-IRS products from IASI
  - Estimate theoretical performances at high viewing angle:
    - FY4 - GIIRS
    - Surface emissivity modelling study
    - Airborne high-viewing angle measurement + *in situ* campaign
    - Long-path sounding - aiming production over Northern Member States
  - Advanced 3D-Var: practicalities/benefits TBD
  - AC/AQ feasibility and algorithms *[O_3 already in the Day-1 baseline]*
  - …

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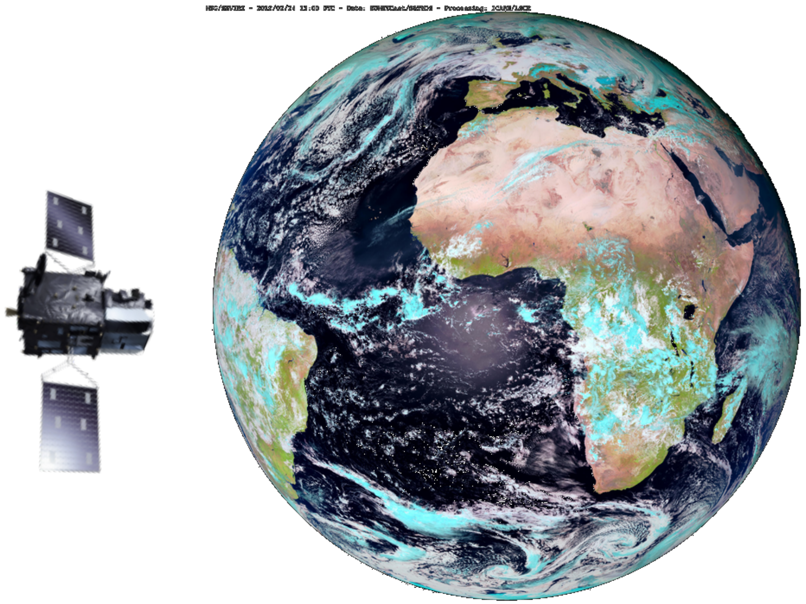
Summary

- IASI L2 concept [IR-only] is applicable ➔ rim investigations do not impact ATBD/PS
- Quality of IASI L2 operational product established: T<1K, q<1-1.5g/kg in tropo.
- PWLR[3] first retrieval: currently 10'/day IASI ➔ ~10 seconds / IRS dwell
- Pseudo-IRS product demonstrated from real IASI observations
- Expected IRS sounding performance relative to IASI
- Day-1 products: T, q, T_s, LSE, O_3, clouds ➔ all LACS + sounding in cloudy pixels
- Reasonable CPU budget (including OEM) to meet timeliness requirements
- Studies / Investigations needed with real observations (FY4-GIIRS, airborne high-viewing angles, rim sounding…)



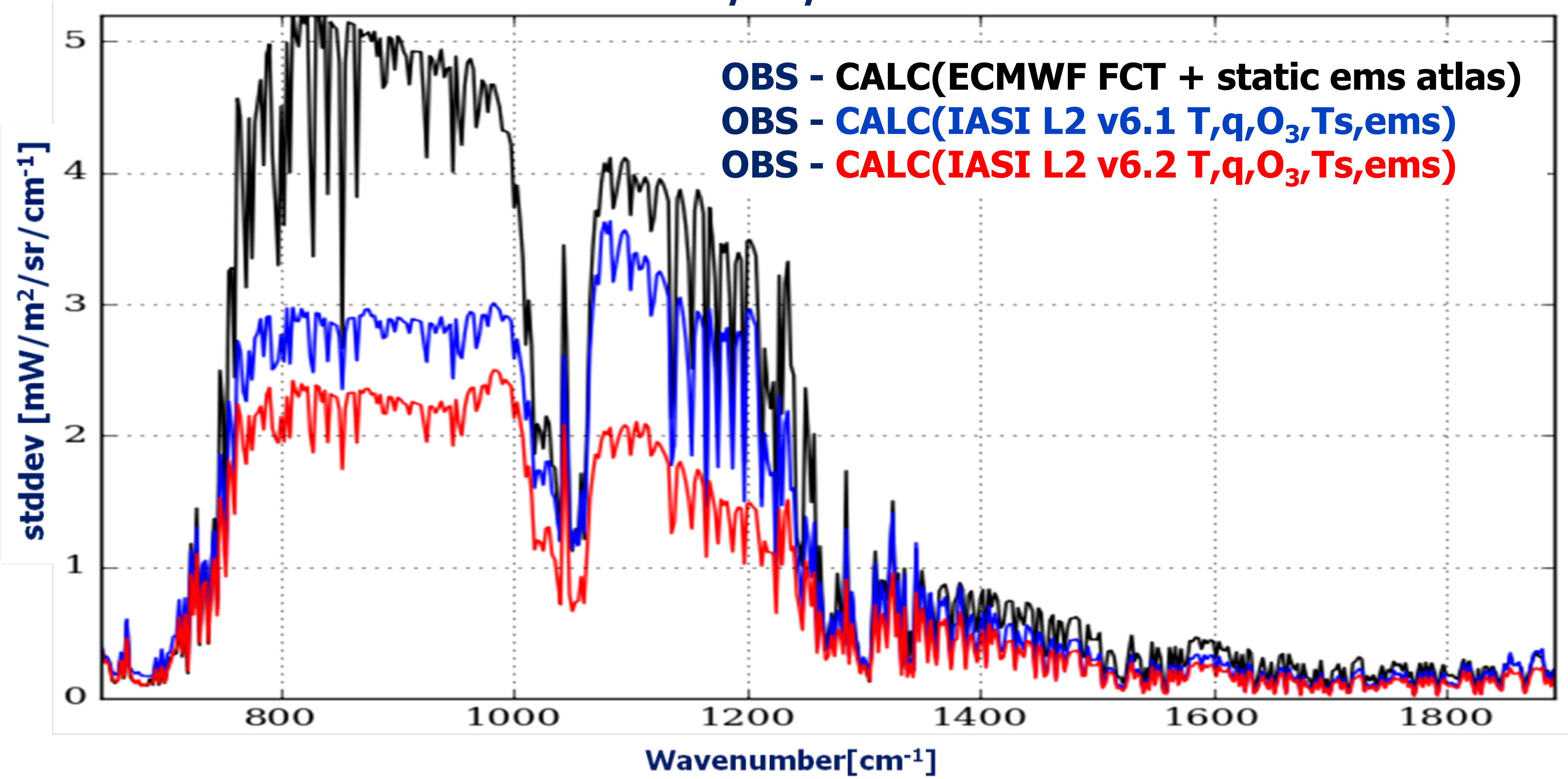
Thank you !

Questions ?

Spare

2. IASI L2 v6 perfo. Assessment in radiance space

Land surfaces within [60°S;60°N] latitudes
16/05/2016



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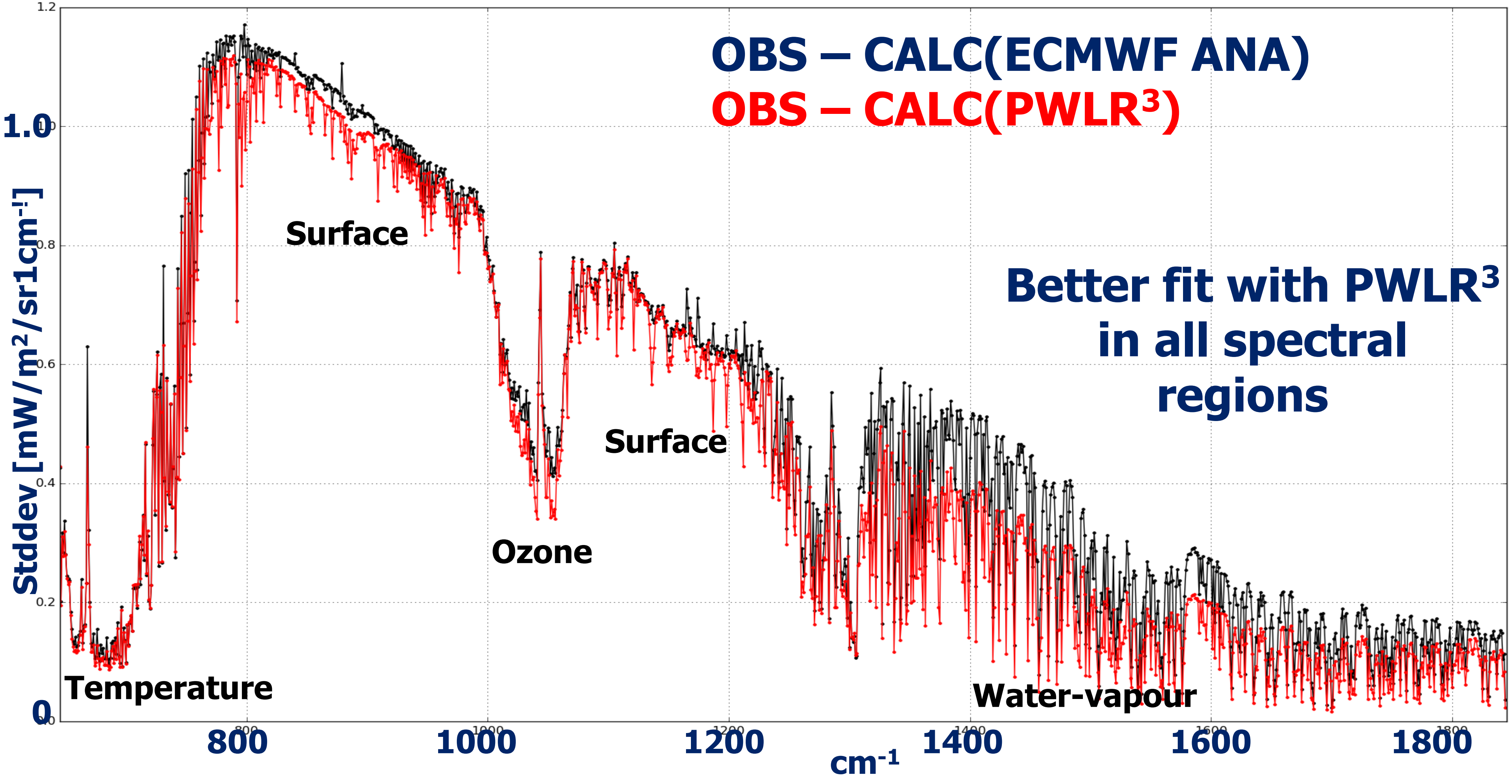
2. IASI L2 v6 perfo. Assessment in radiance space

13/01/2014 :: clear-sky maritime situations



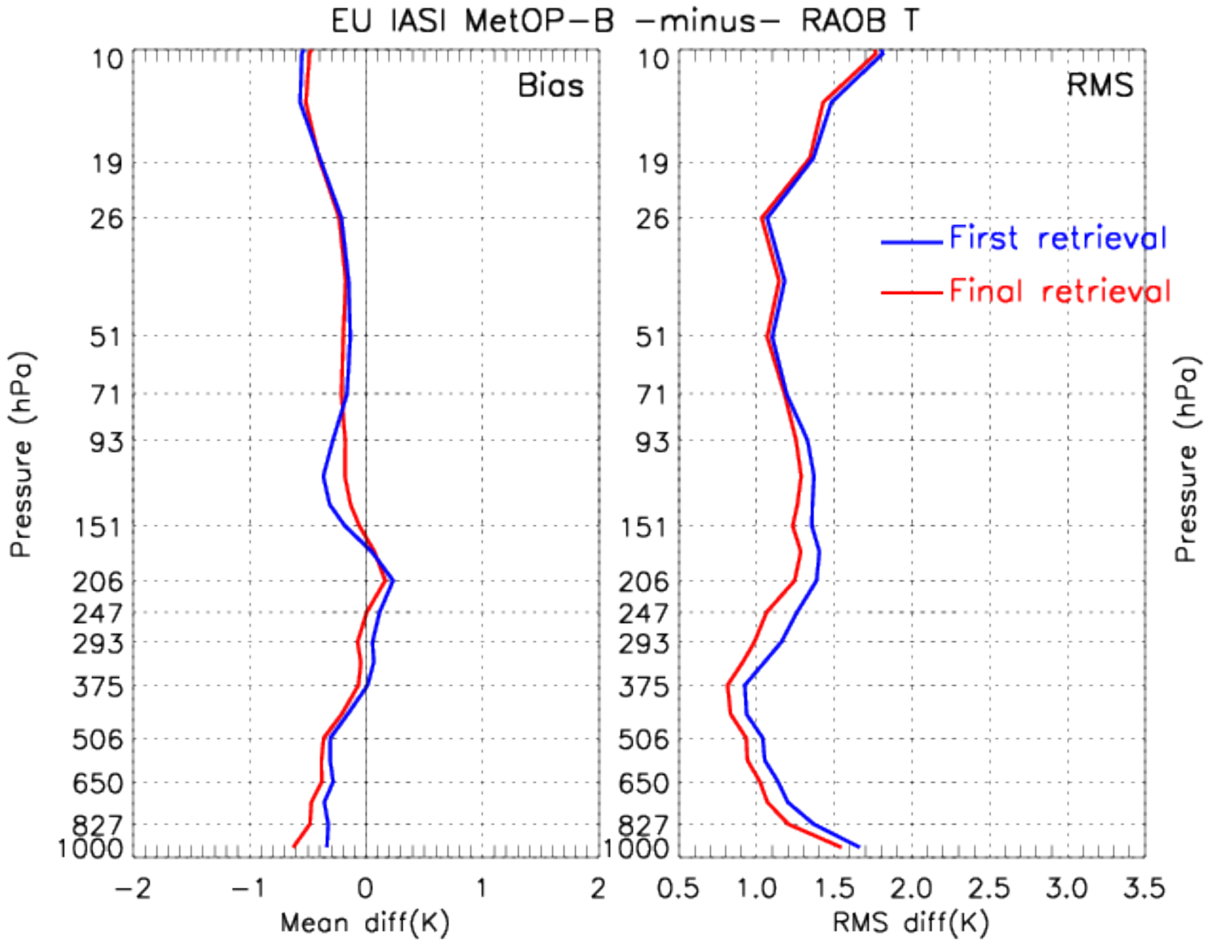
IASI Metop-B L2 performance
Conventional, Land

STAR Center for Satellite Applications and Research
formerly ORA — Office of Research and Applications

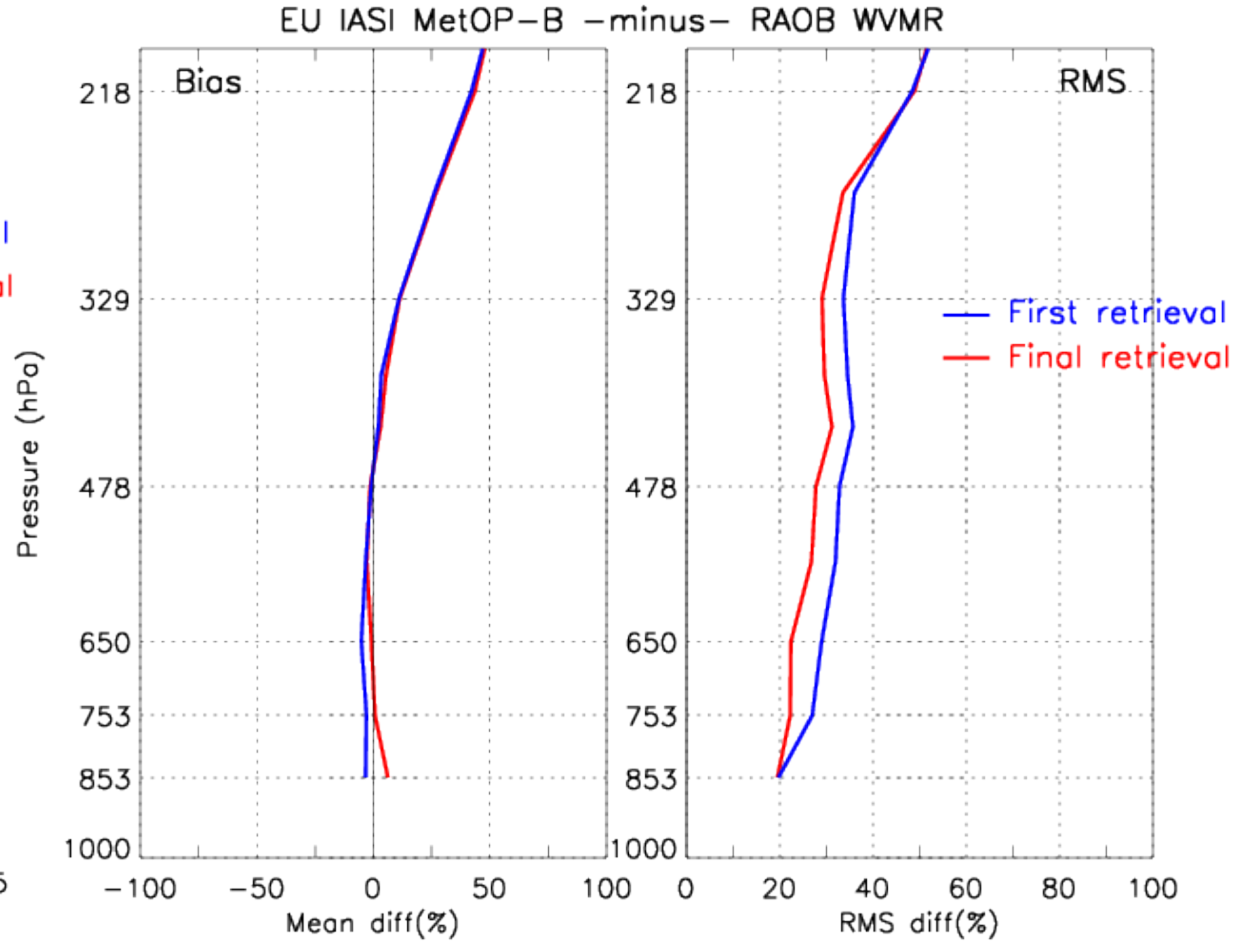
EUMETSAT Meteorological Satellite Conference 2017
October 2-6, 2017
Rome, Italy

Results: B. Sun (NOAA)
Talk at EUM User Conf'17

Temperature



Water vapor mixing ratio



Conventional RS92 & RS41, land, ~17,900 collocations (1hr/50km)

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