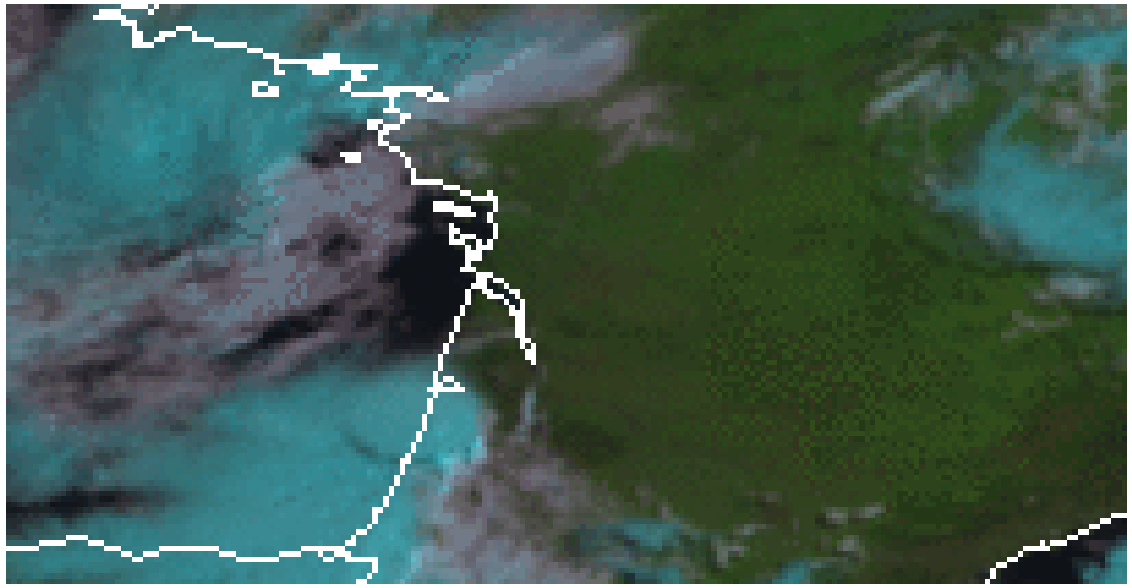
EUM hyperspectral sounder missions, products and applications

Thomas August + EUM L2* and external study teams
EUMETSAT

Convection Working Group, Budapest, 19/05/2022

* *Tim Hultberg,*
Marc Crapeau,
Stefan Stapelberg

Observing instabilities before clouds develop… ?



Bordeaux - Cognac area, France
26/05/2018

Agenda

EUM hyperspectral sounders

Missions and algorithm overview

Products performances

Validation, uncertainty estimates

Application and case studies

IASI regional service, preparing future missions

EUMETSAT hyperspectral sounders

EPS EPS-SG MTG

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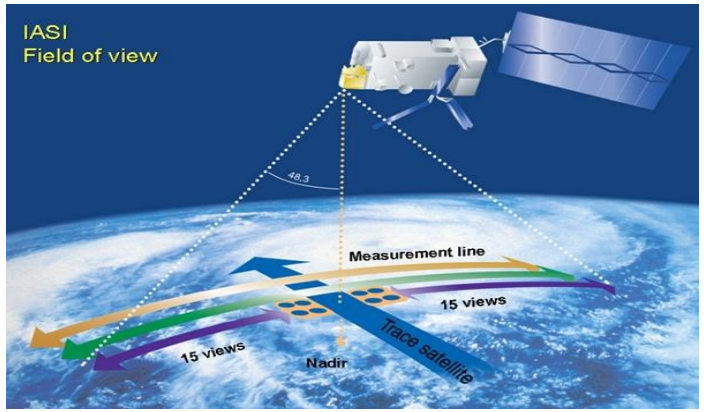
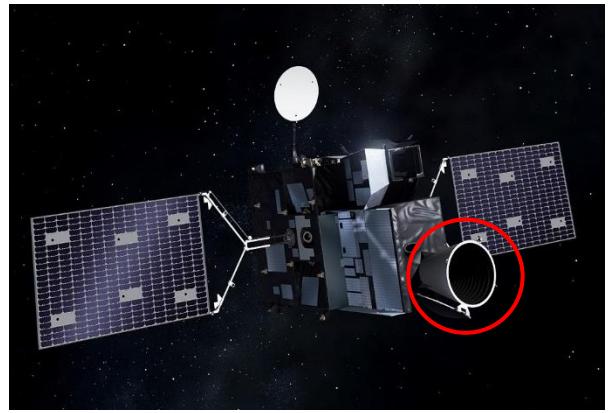
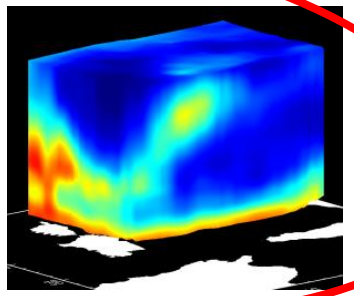


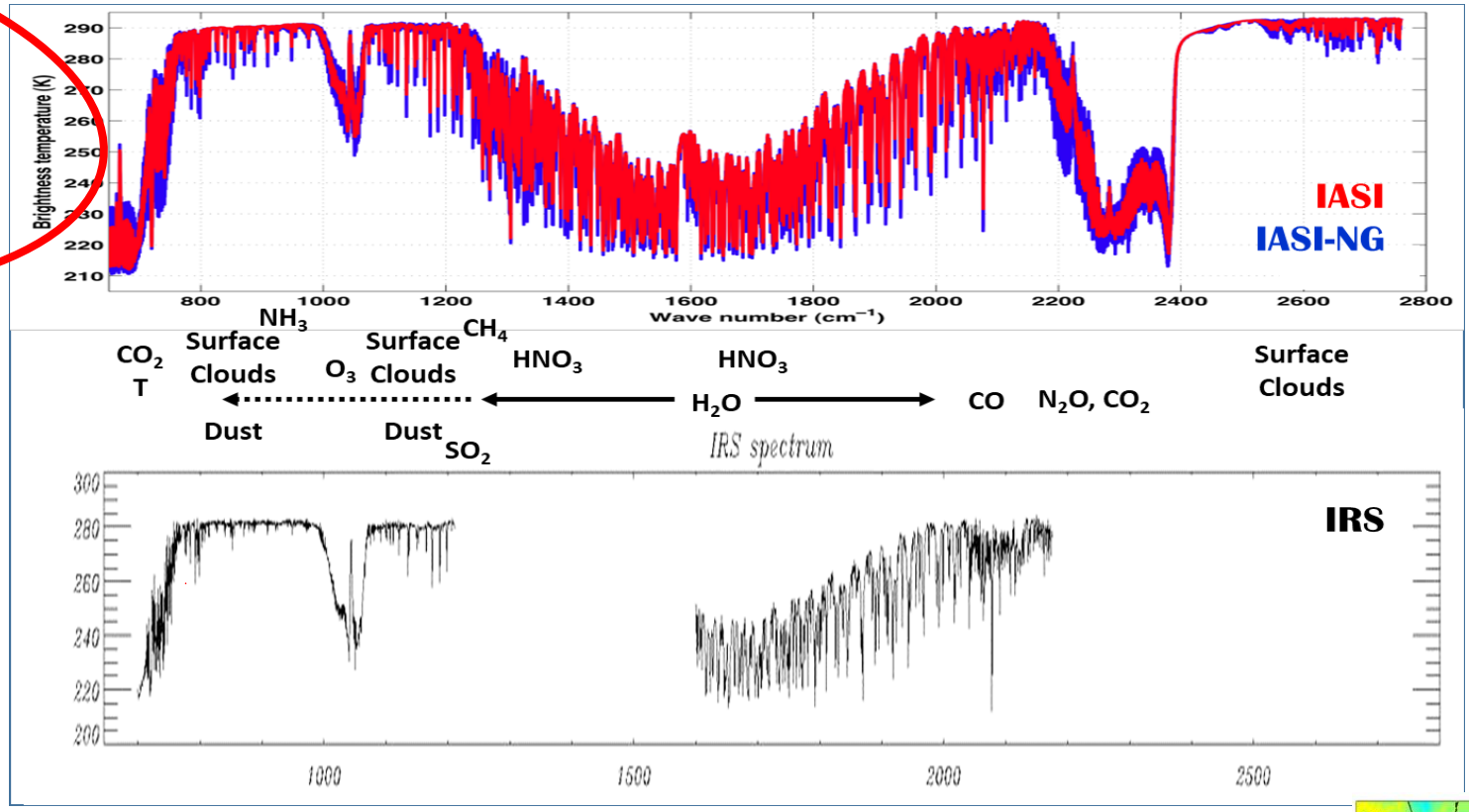


IASI	IASI-NG		MTG-IRS
Polar orbit (LEO)		**Orbit**	**GEO**stationnary
2x2	4x4	**Sensor**	160x160
12 km	12 km	**Spatial (Nadir)**	4 km
0.25 cm^{-1}	0.125 cm^{-1}	**Spectral sampling**	~0.6 cm^{-1}
2x / day	2x /day	**Temporal**	Every 30 min Europe
Metop-A 19 October 2006-2021 Metop-B 17 September 2012 Metop-C 06 November 2018	2024		2024

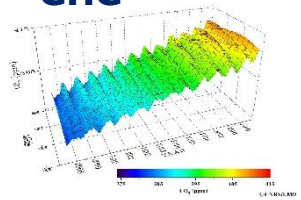
The hyperspectral sounding "Swiss army knife"

Temperature, Humidity profiles

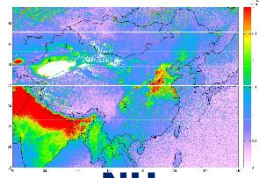




GHG

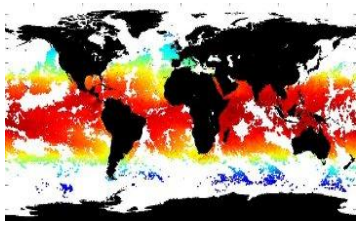


Cloud mask, fraction, top height



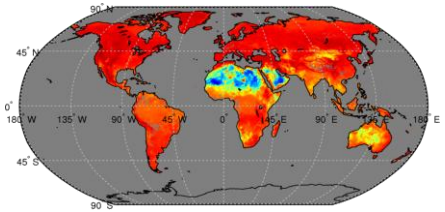
NH_3

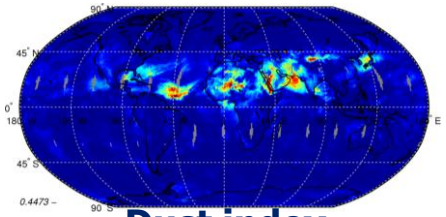
Sea surface temperature



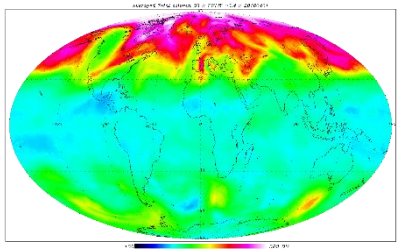
SO_2

Land surface temperature and emissivity

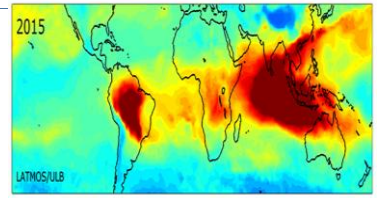




Dust index

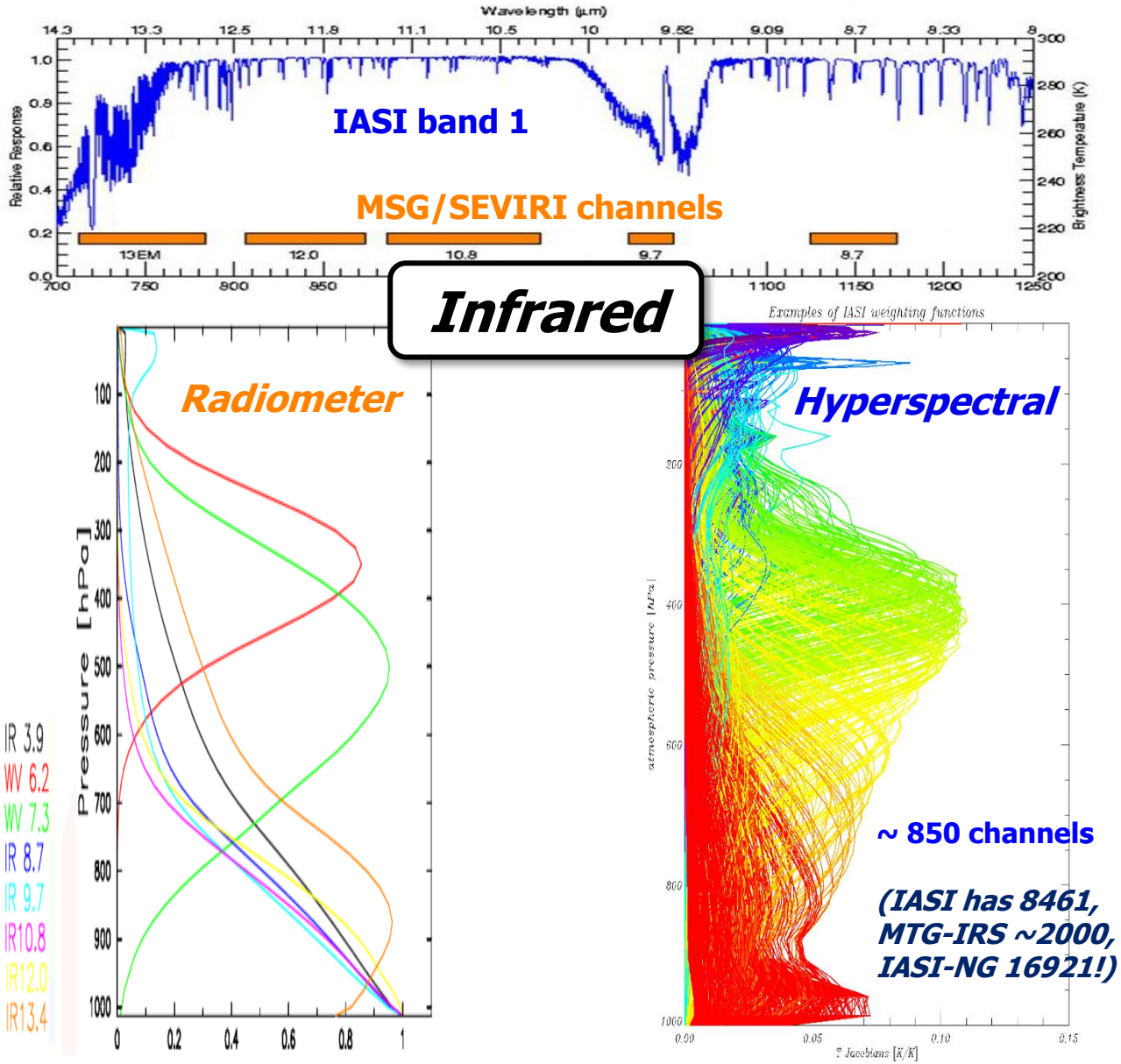


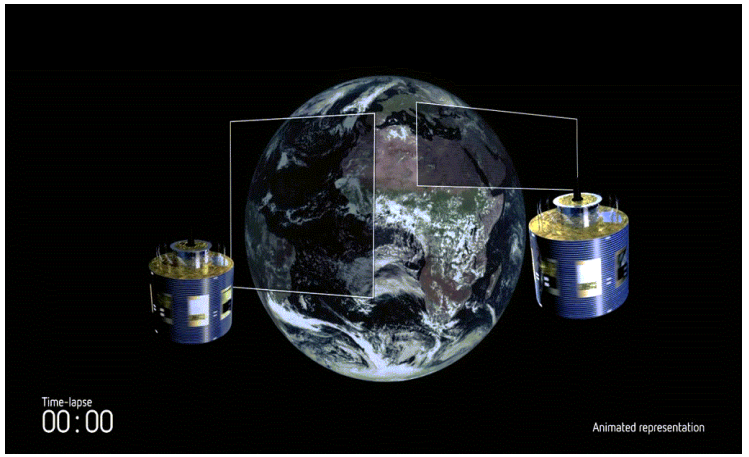
Ozone



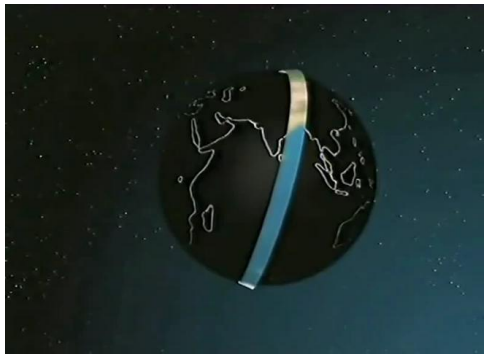
Carbon monoxide

Atmospheric profiles with hyperspectral IR sounders



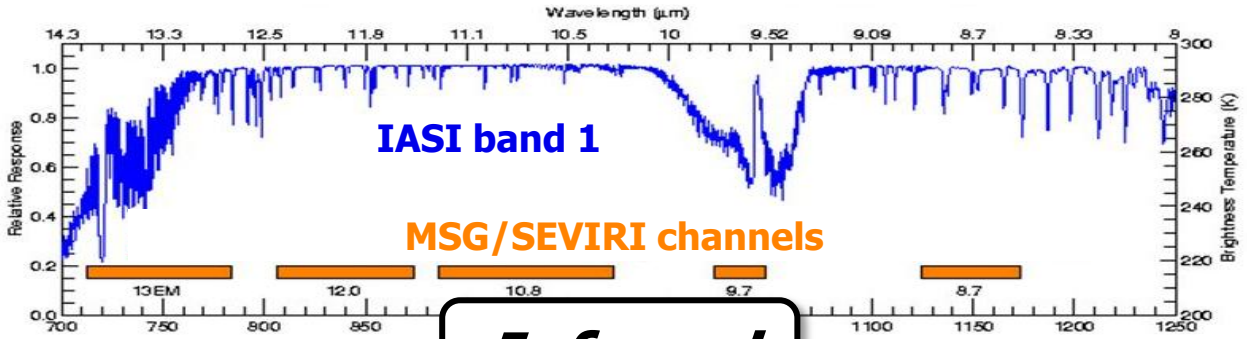


MSG/SEVIRI
MTG/IRS

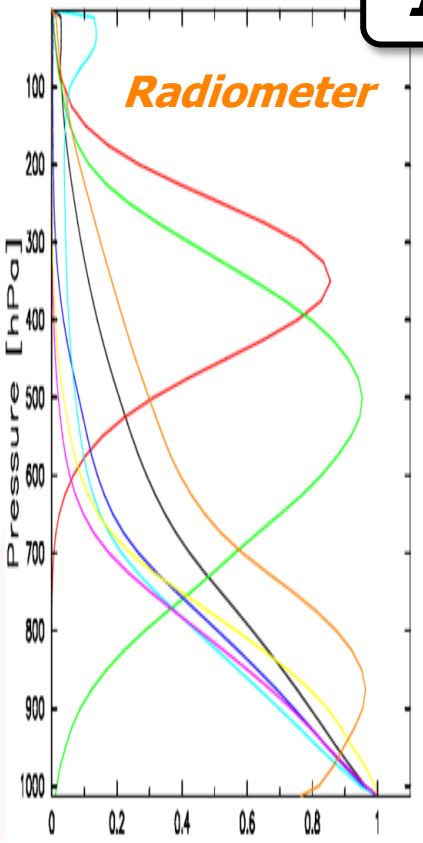


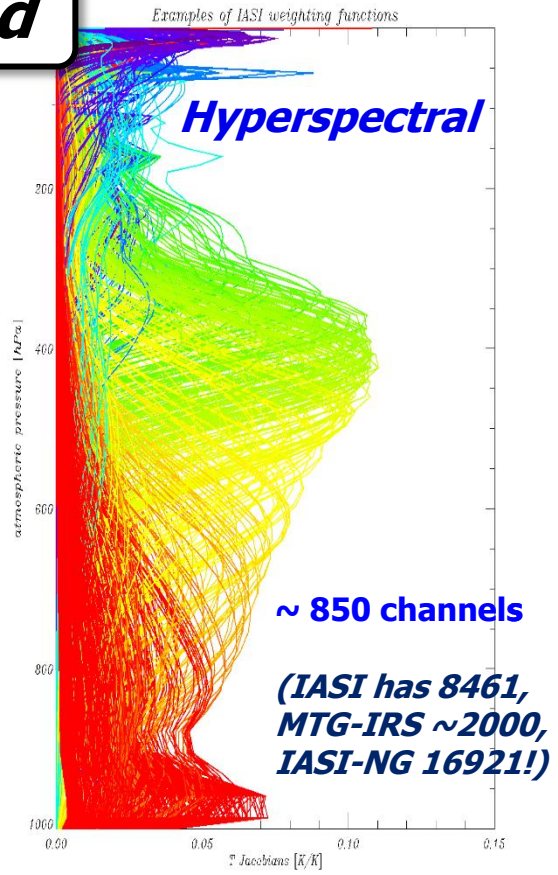
EPS/IASI
EPS-SG/IASI-NG

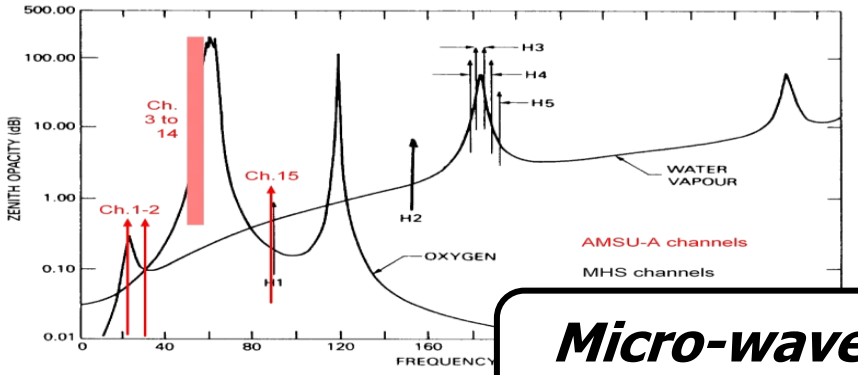
Atmospheric profiles with hyperpectral IR + MW sounders



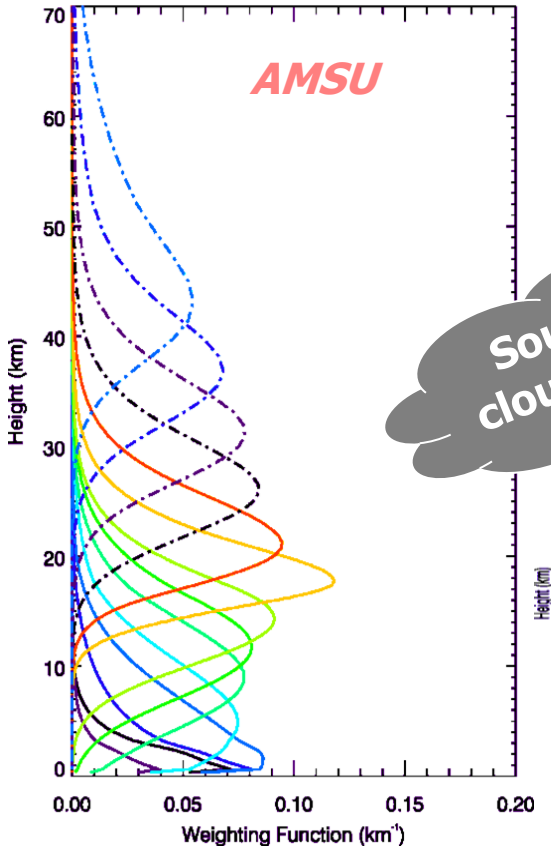
Infrared



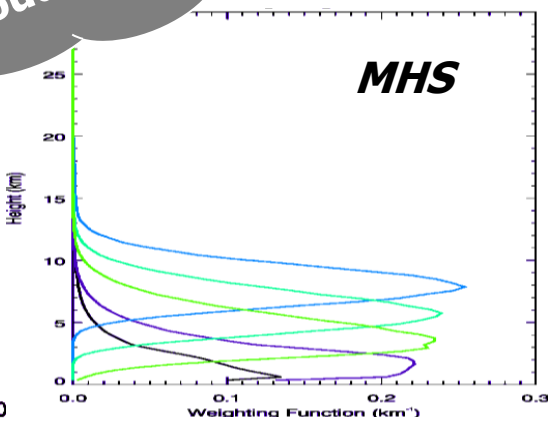




Micro-wave sounders

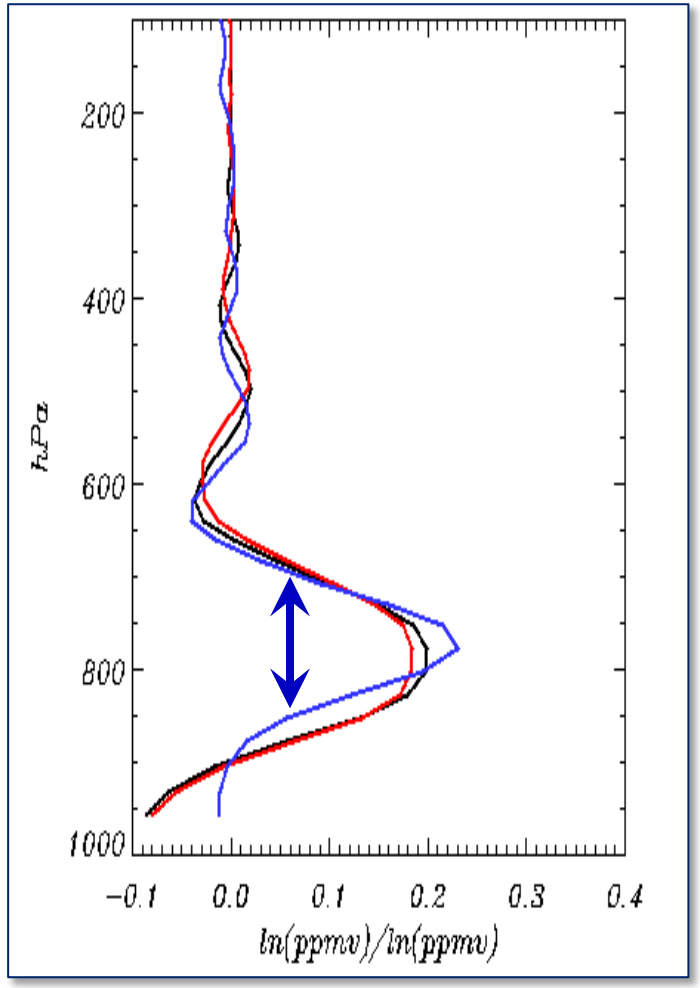


Sounding in clouds possible

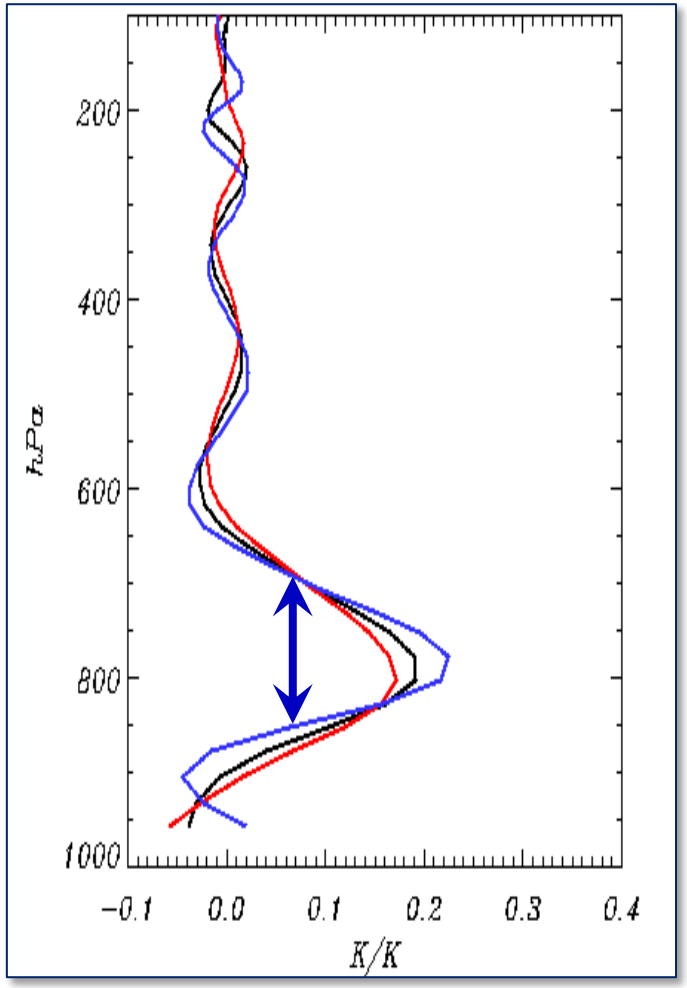


Hyperspectral missions – vertical information content and resolution

Averaging Kernel
H_2O 777 hPa

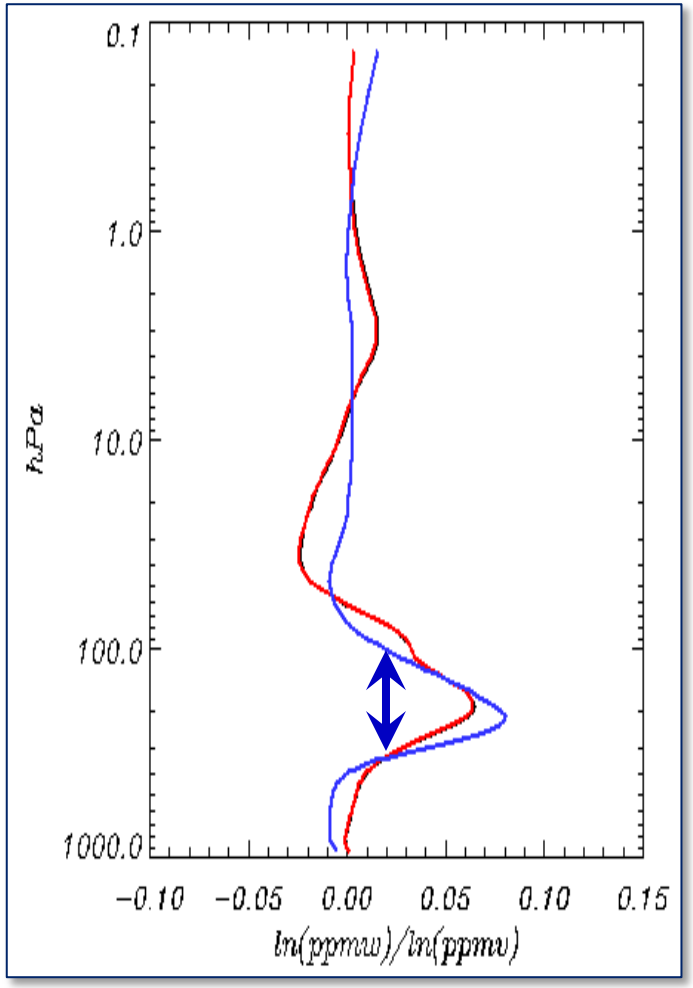


Averaging Kernel
T 777 hPa



— IRS
— IASI
— IASI-NG

Averaging Kernel
O_3 191 hPa



Theoretical estimates - Single evaluation on US standard atmosphere

Hyperspectral missions – vertical information content and resolution

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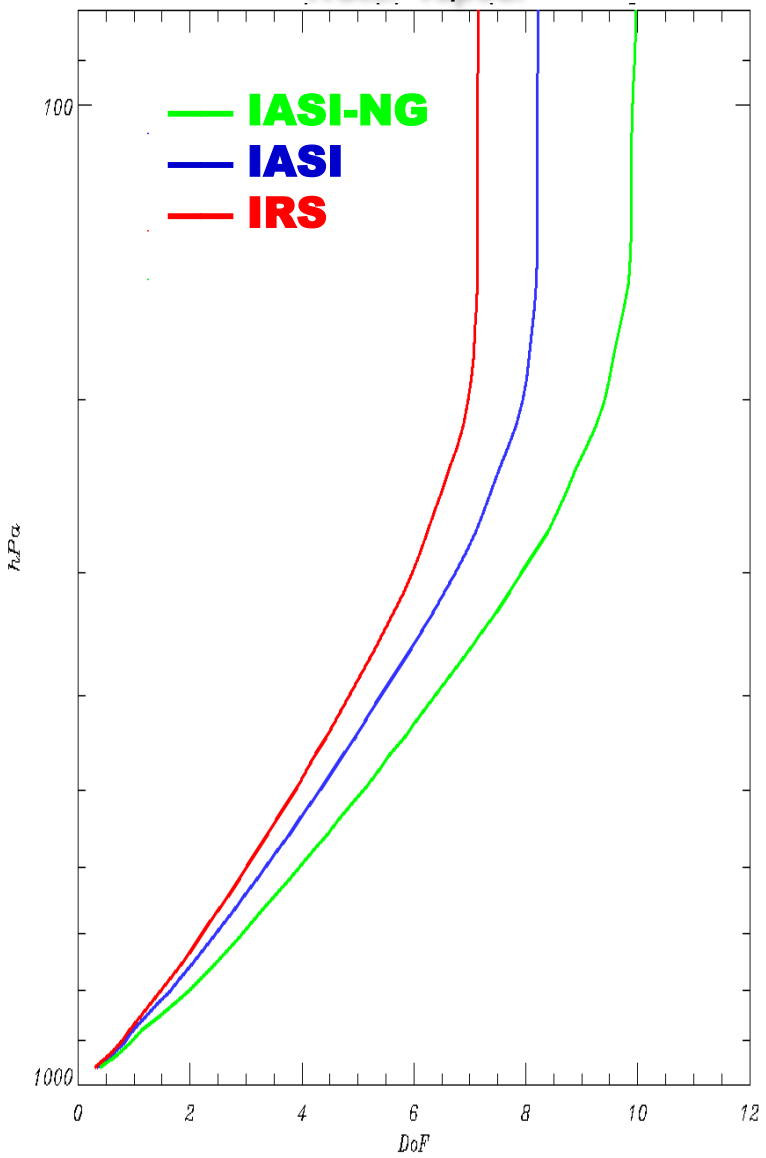
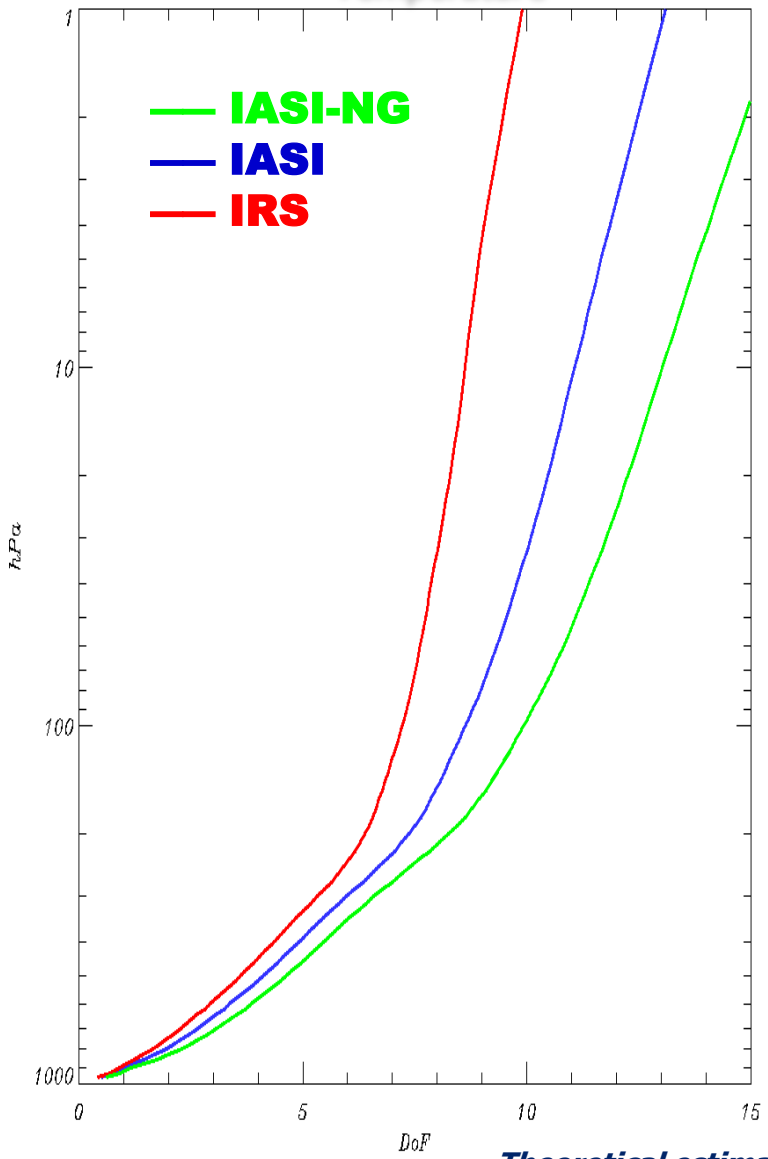
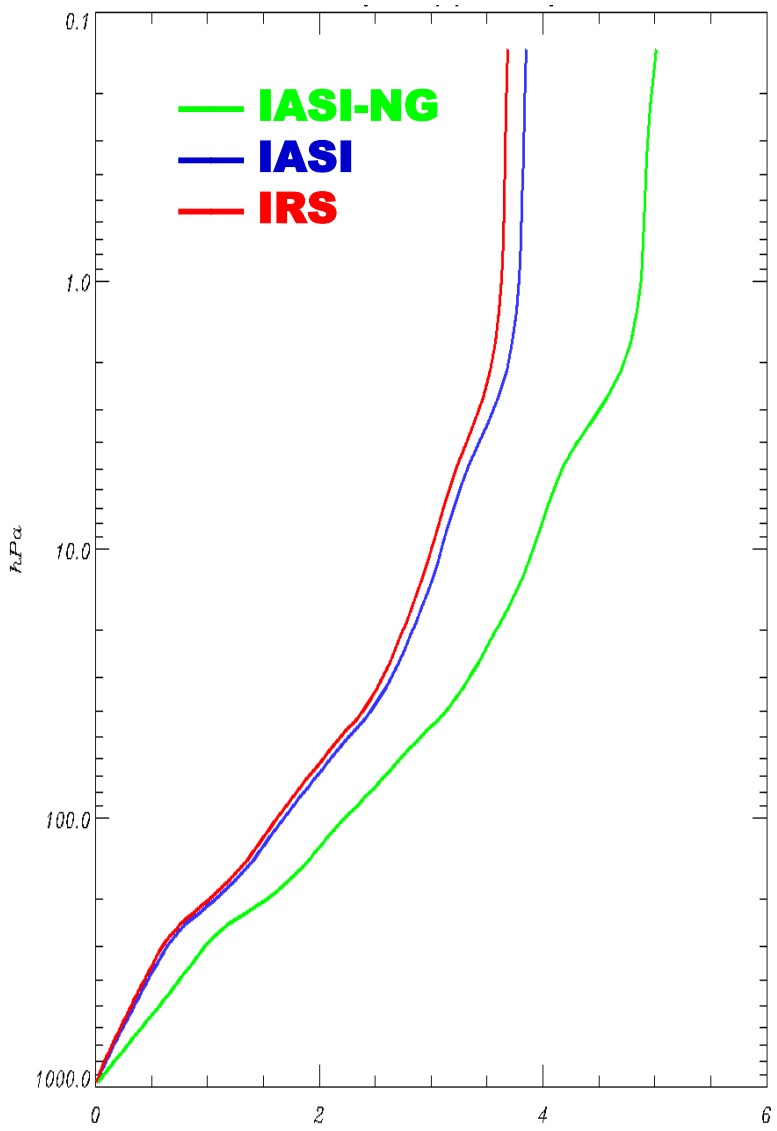
Cumulative degrees of freedom
Water-vapour



Cumulative degrees of freedom
Temperature

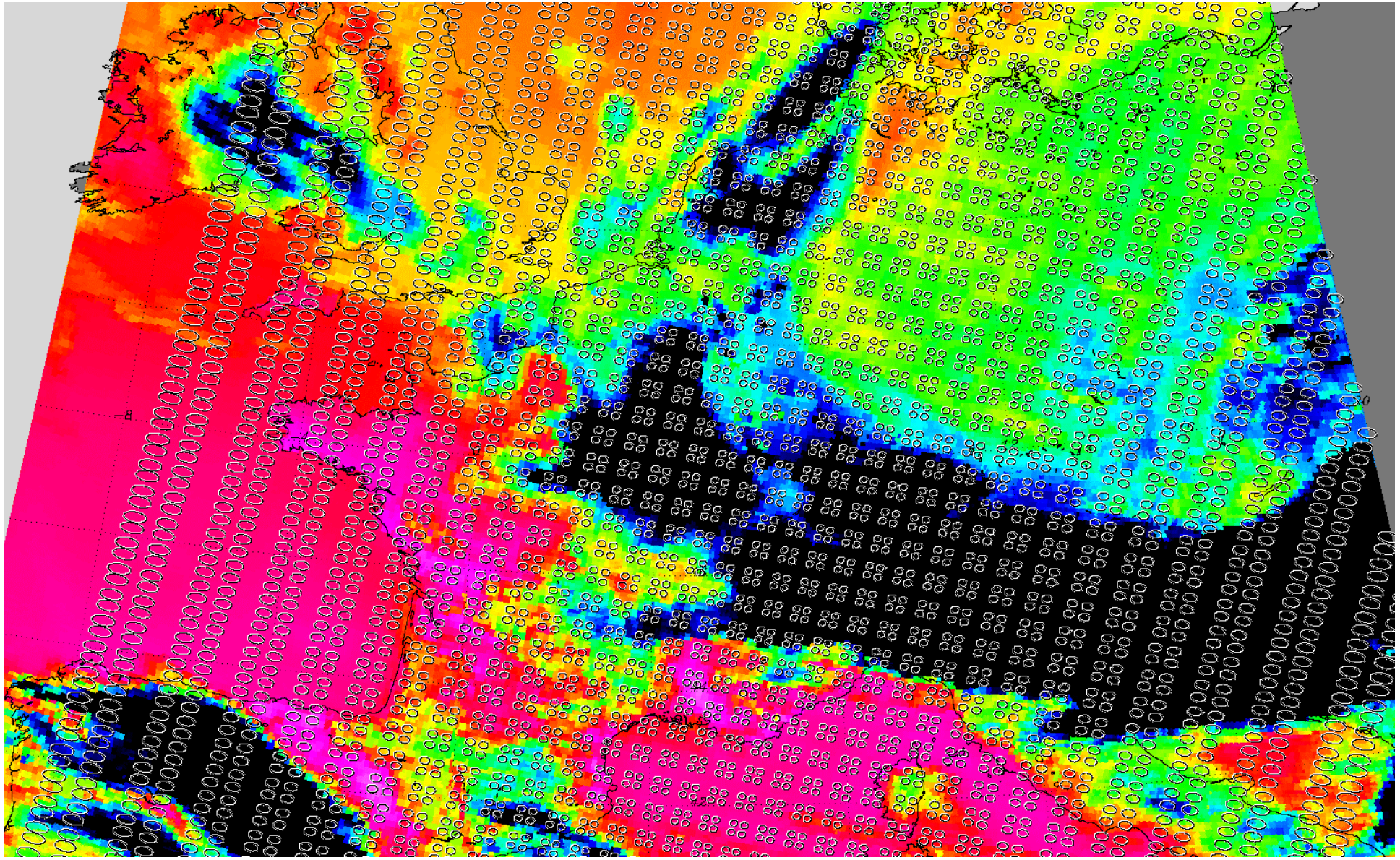


Cumulative degrees of freedom
Ozone

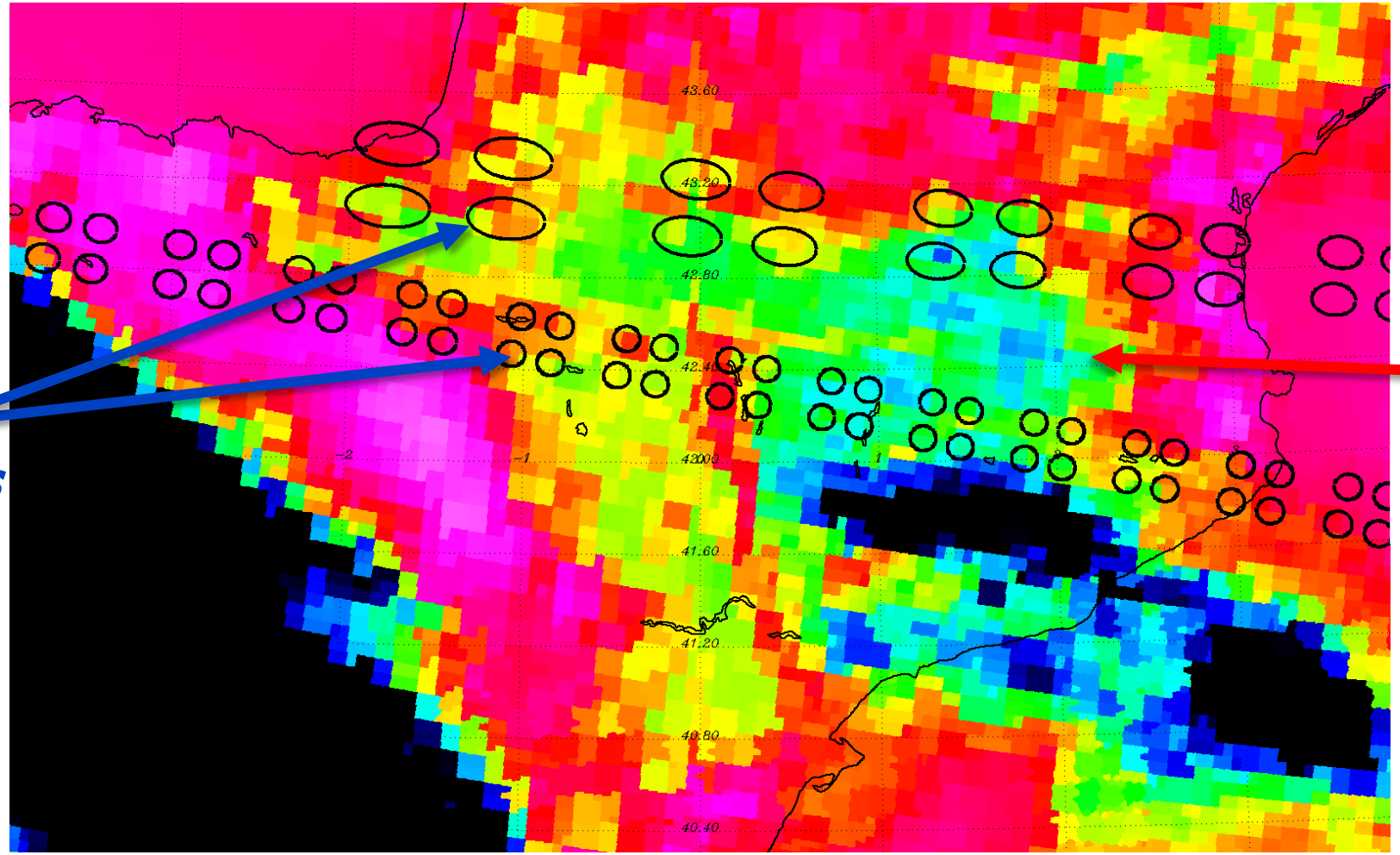


Theoretical estimates - Single evaluation on US standard atmosphere

IRS and IASI spatial sampling

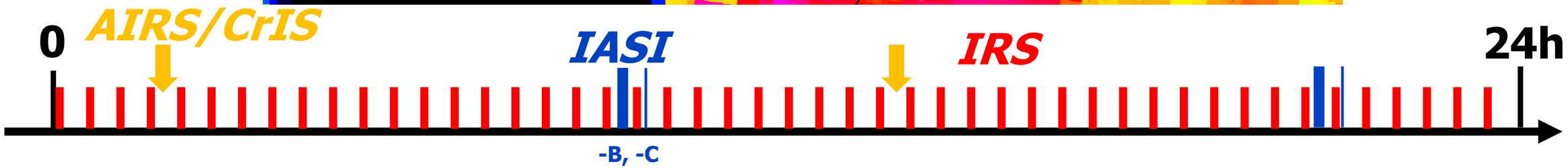


MTG-IRS: unique 4D look into the atmosphere



IASI footprints 12-40km Not-contiguous 2x per day

IRS pixels ~7km Contiguous every 30mn



IASI L2 operational processor overview – Day-1 baseline to all IR missions

Preparation Collocation

L1 IASI AMSU MHS

AVHRR

~~Forecasts~~

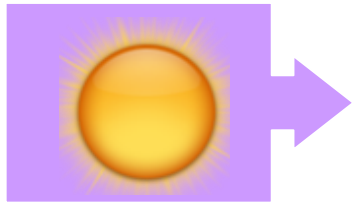
Statistical retrieval

PWLR³

All-sky

T, H_2O, O_3 profiles
SST, LST, land emissivity
CO_2

Scene analysis



Cloud mask, Cloud fraction, top height

Dust index

Optimal estimation

OEM

Clear-sky

T, H_2O, O_3, T_s

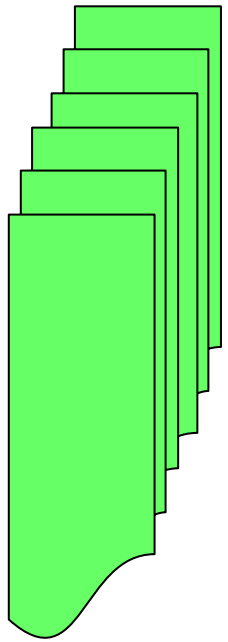
Atmospheric composition

OEM
ANN
LUT

CH_4, (N_2O)

EUM AC SAF
CO, SO_2
O_3, HNO_3

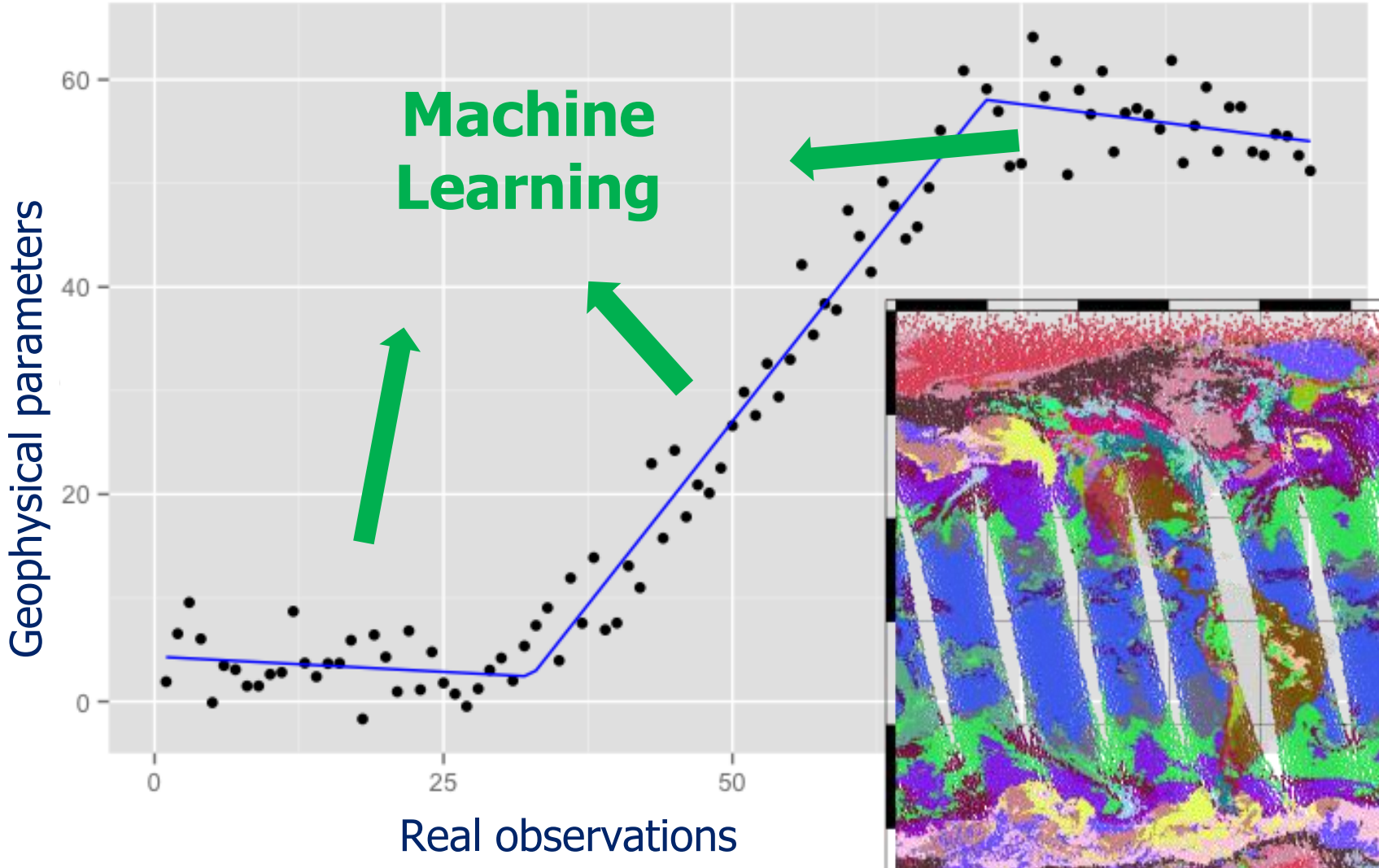
L2



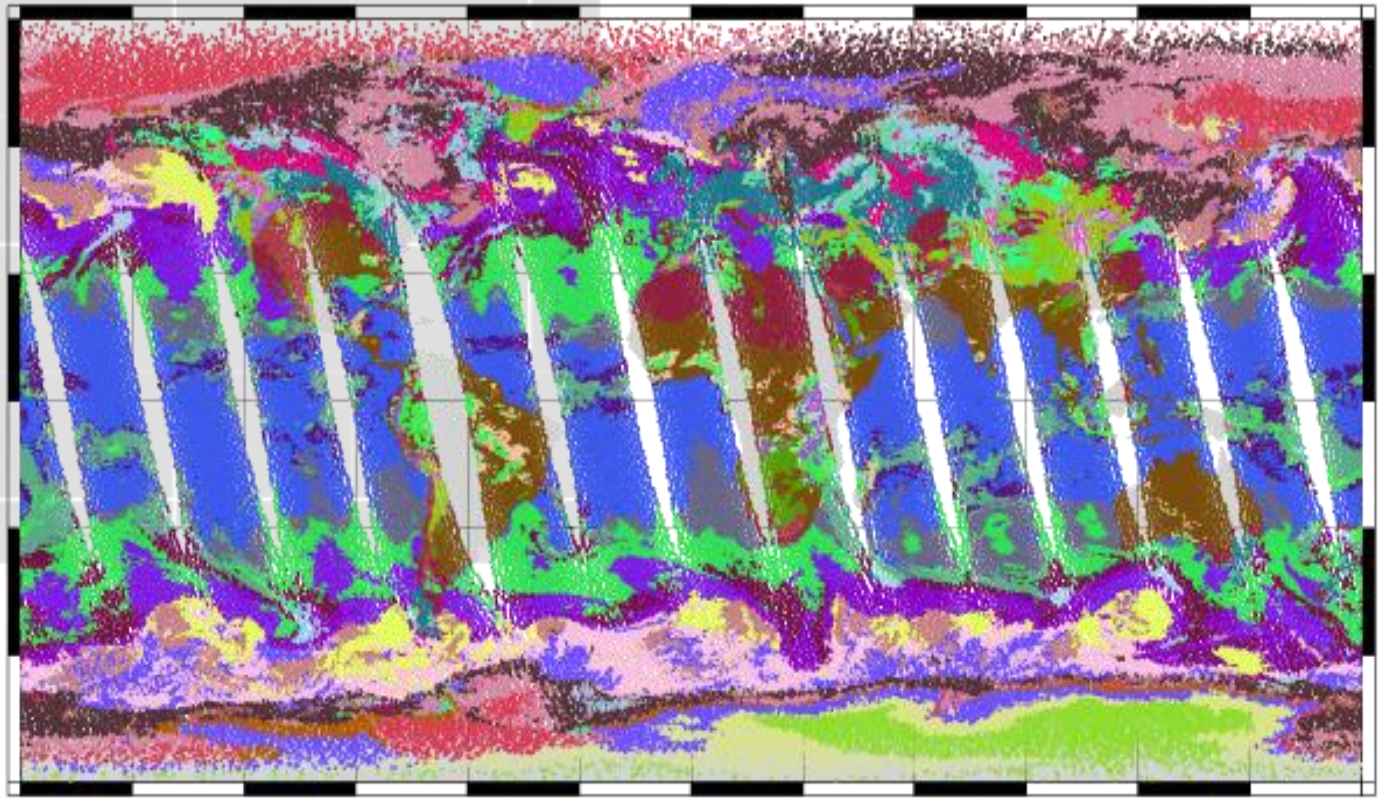
IR+MW

IR-only

PWLR: PieceWise Linear Regression for hyperspectral sounders



Regression classes (k-mean)



Agenda

EUM hyperspectral sounders

Missions and algorithm overview

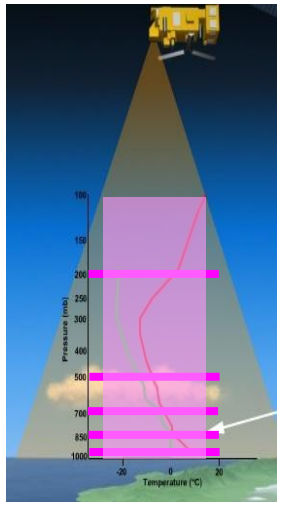
Products performances

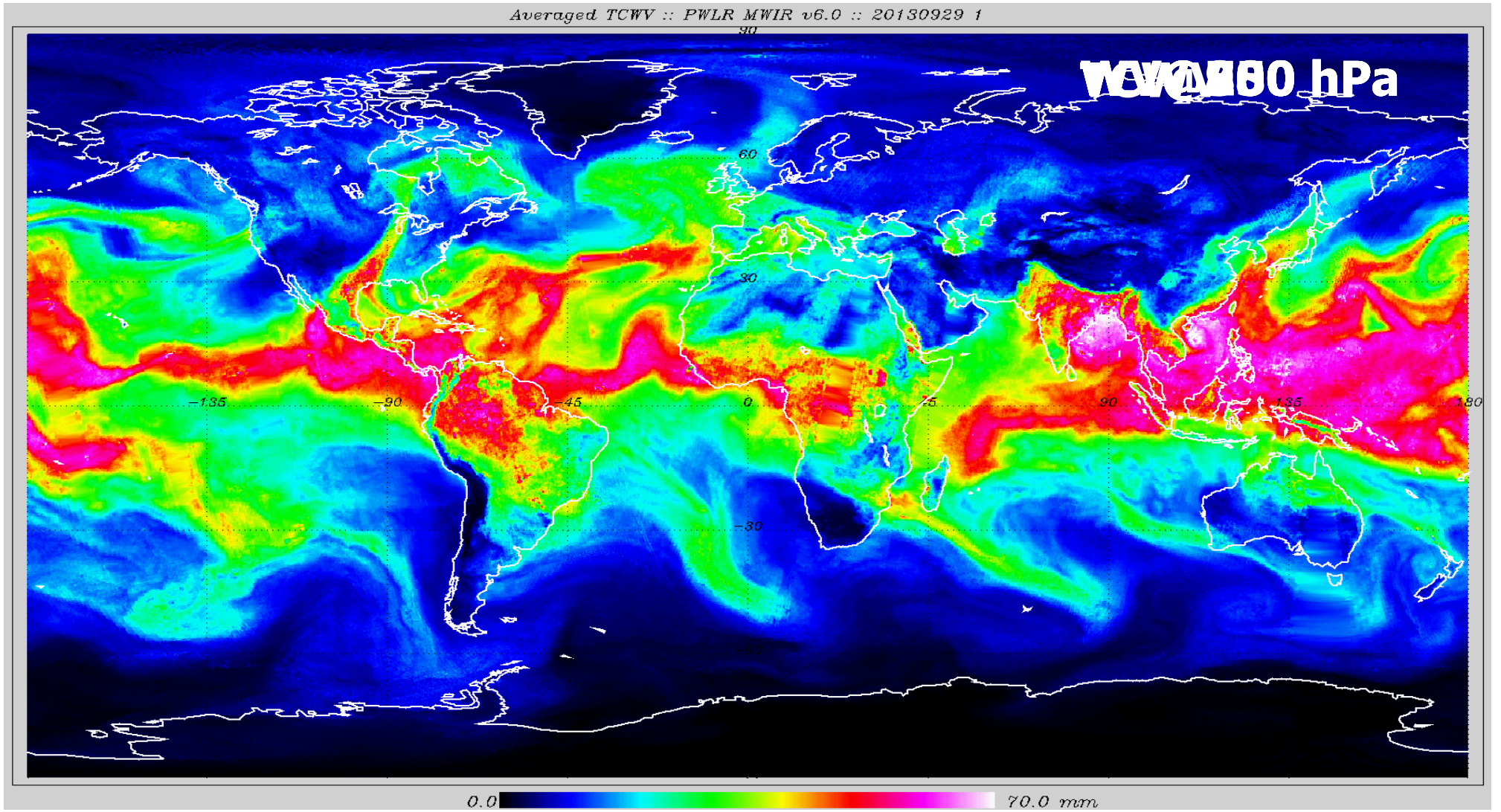
Validation, uncertainty estimates

Application and case studies

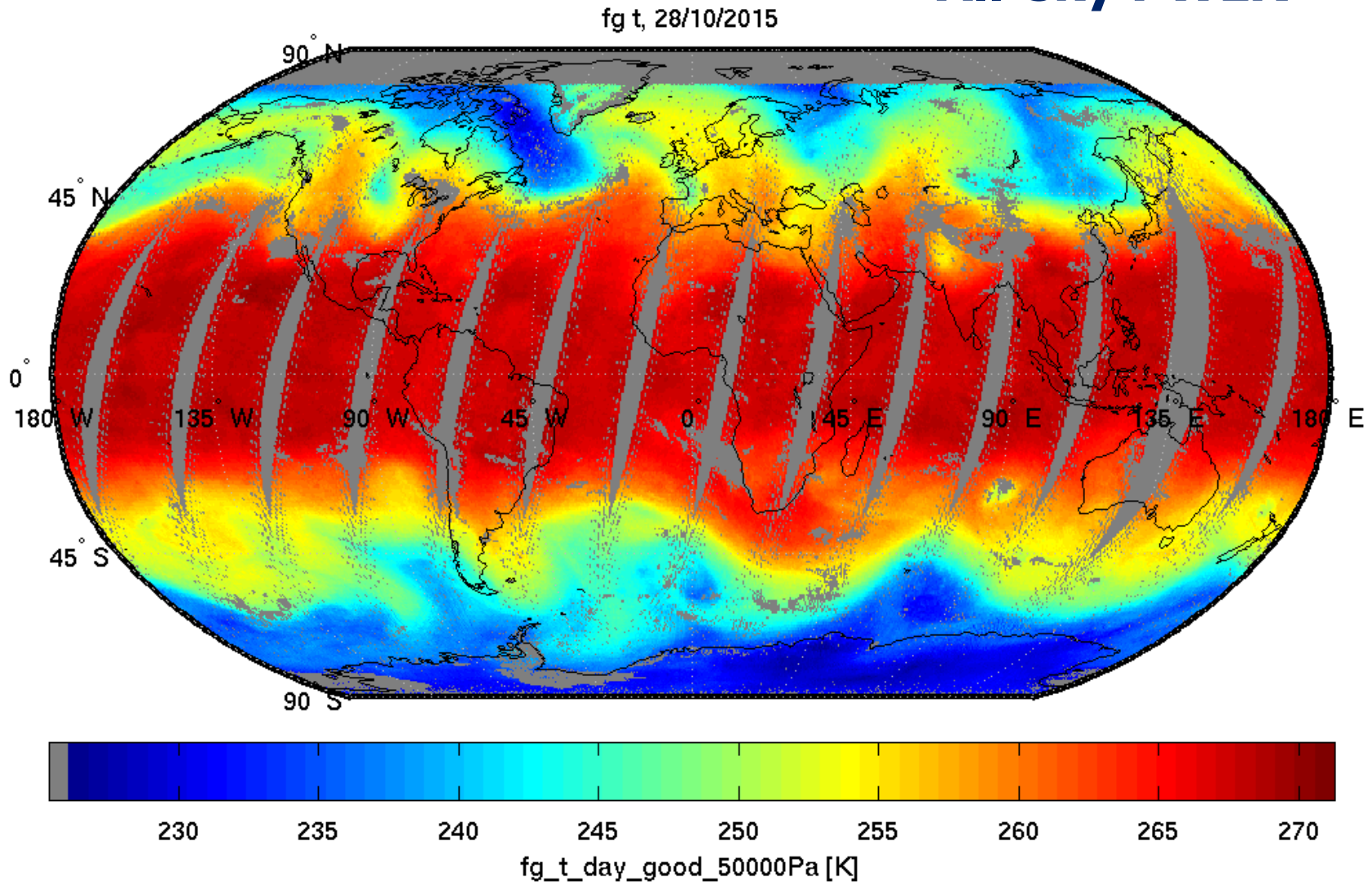
IASI regional service, preparing for MTG-IRS

IASI L2 sounding – Atmospheric humidity profiles





All-sky PWLR^3



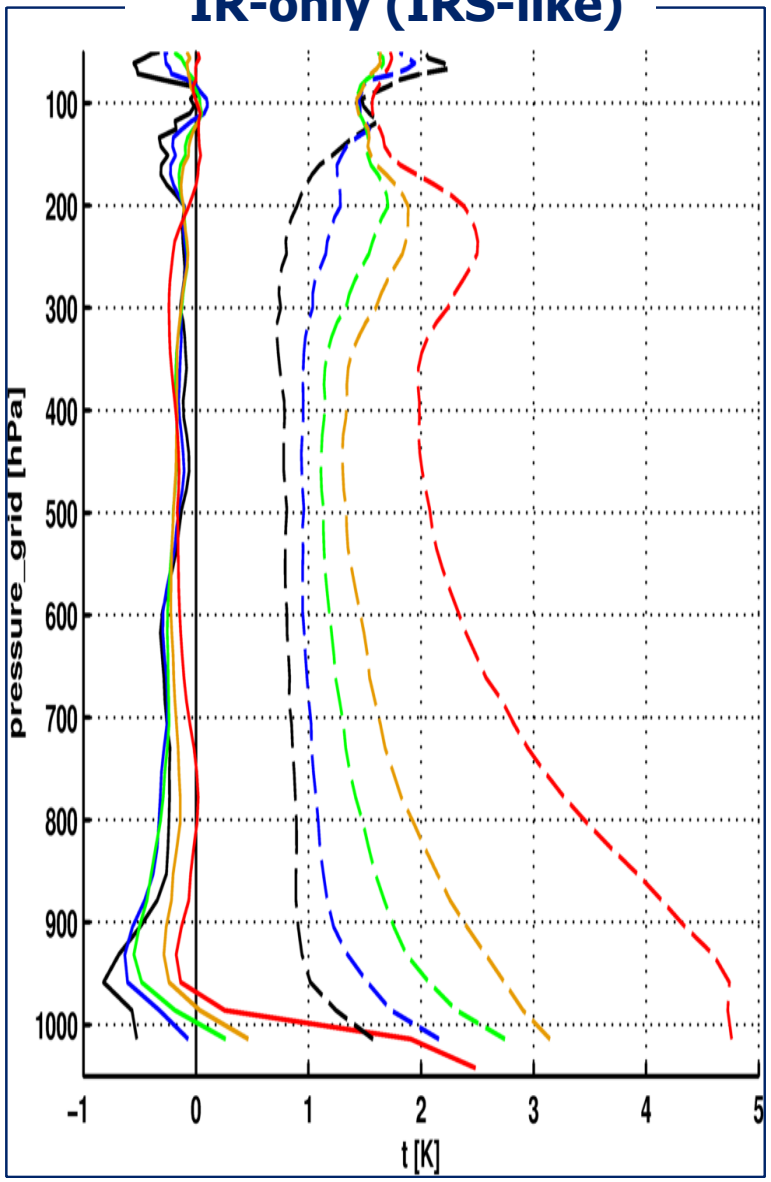
Extensive validation of temperature and humidity products:

- ✓ assessed in-house, with validation and routine monitoring tools
- ✓ through co-operations : CIMSS/U. Wisconsin, NCAR, NOAA…
- ✓ *vs* radiosonding, numerical models, ground-based measurements…

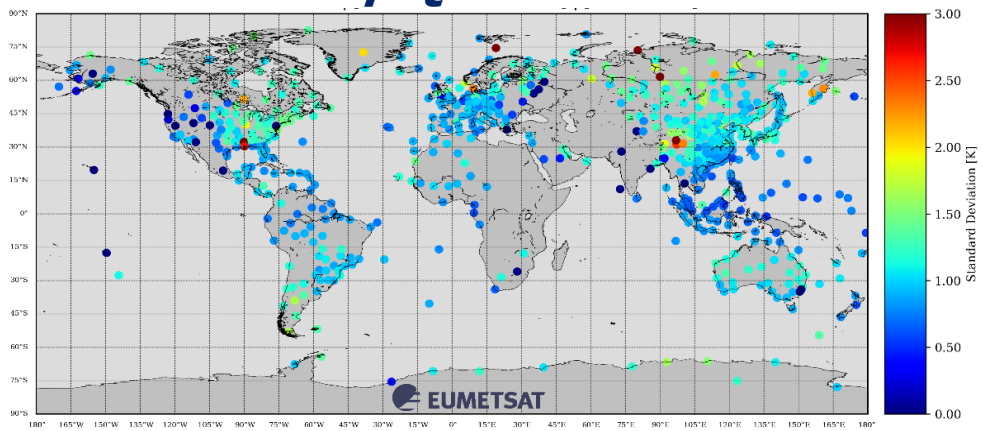
"IASI L2 TCDR T/q validation Report", EUM/OPS/DOC/19/109137, 163pp
"IASI L2 v6 Validation Report" EUM/TSS/REP/14/776443, 290pp
"IASI L2 v6.2 Validation Report" EUM/RSP/REP/16/857500, 73pp
"IASI L2 PPF v6.3 Validation Report" EUM/RSP/REP/17/920559, 45pp
"IASI L2 PPF v6.4 Validation Report" EUM/RSP/REP/18/974859, 59pp
Feltz et al., JGR 2017, *10.1002/2017JD026504*;
Roman et al., JGR 2016, *10.1002/2016JD024806*;
Boylan et al., JGR 2015, *10.1002/2015JD024724*;
communications in conferences
...

Sounding precision, uncertainty estimates and yield **IR-only** *vs* **MW+IR**

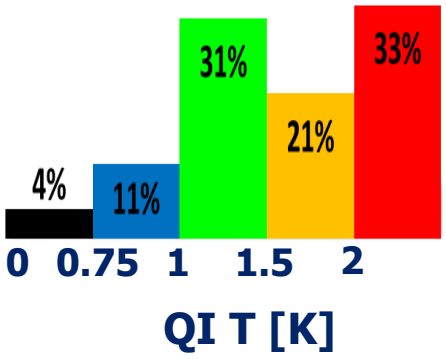
IR-only (IRS-like)



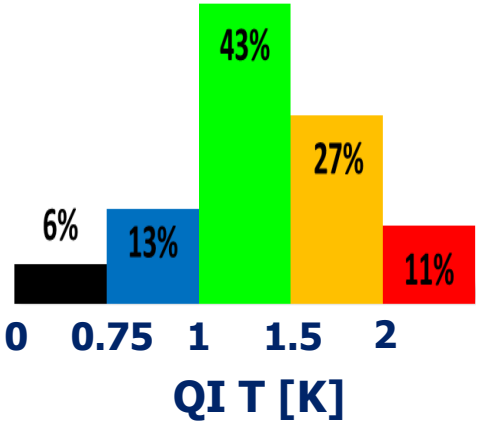
Jan. – Oct. 2017
< 50km ; < 3h
Match-up QC still needed



Yield IR-only

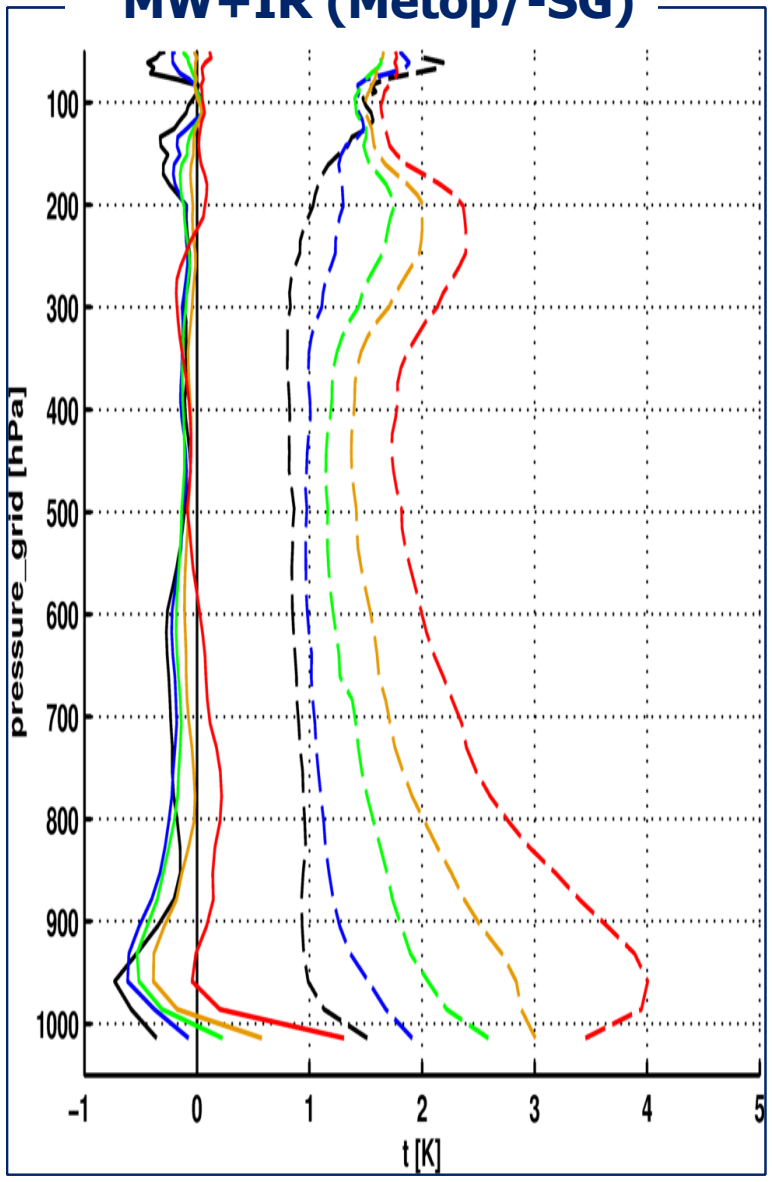


Yield MW+IR



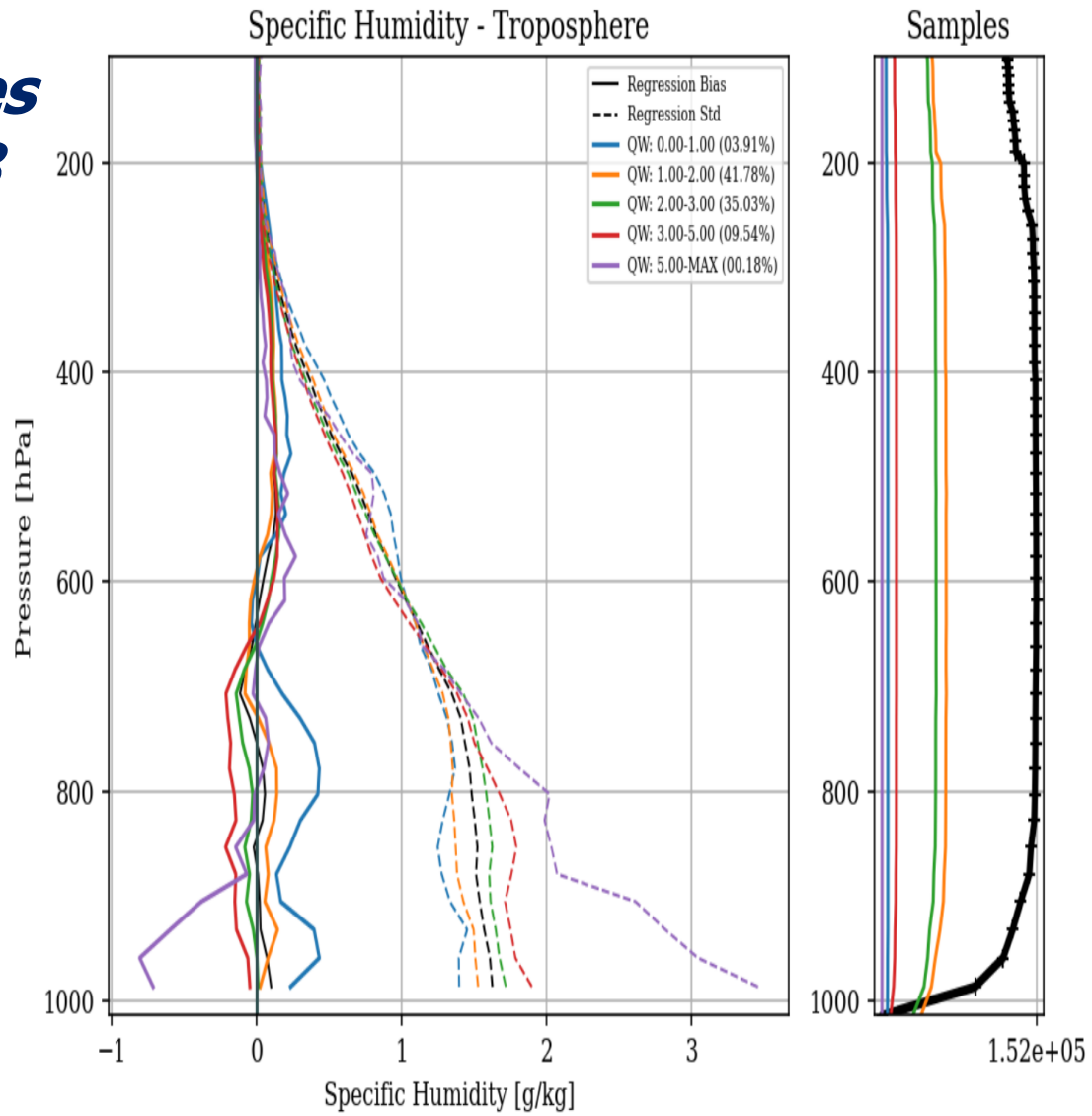
Tropospheric error estimate

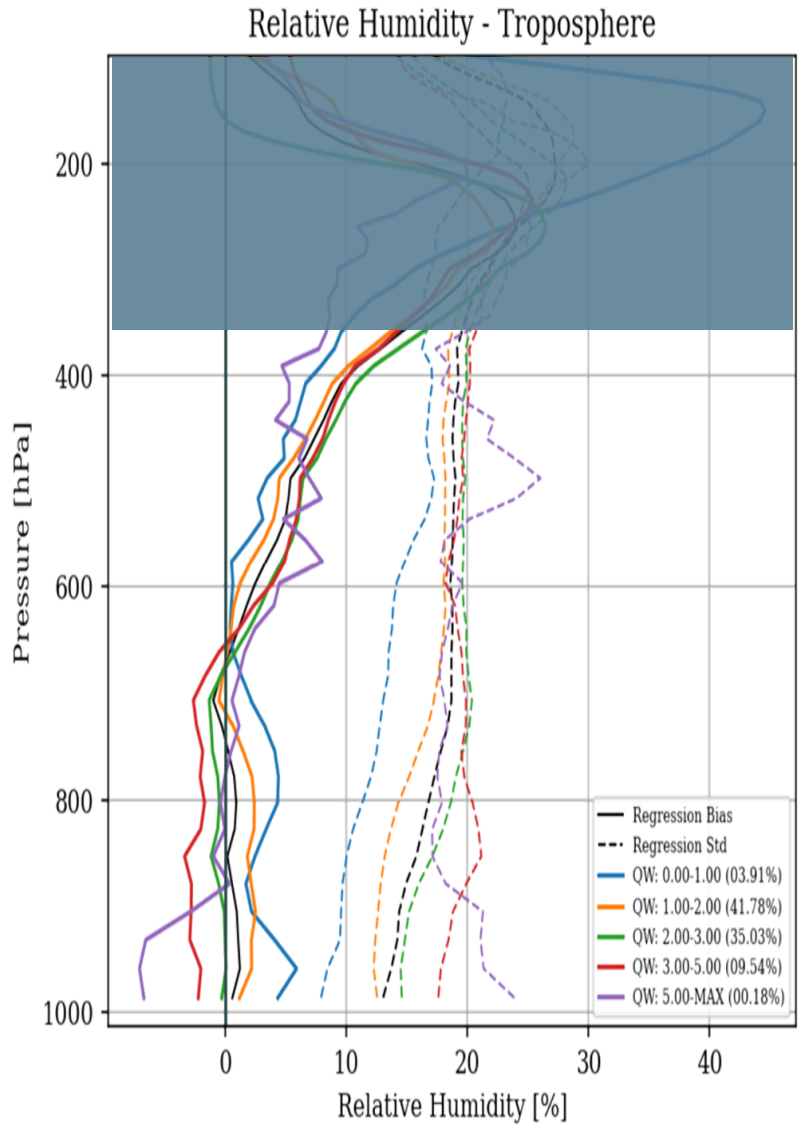
MW+IR (Metop/-SG)



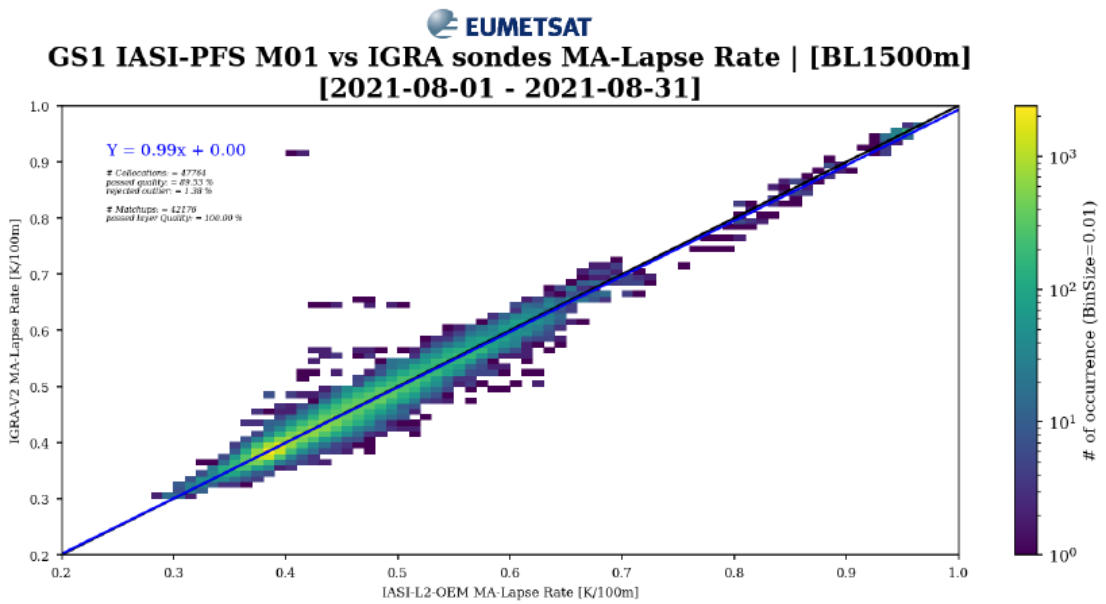
Humidity sounding – Quality indicator significance *vs* radiosondes (IGRA)

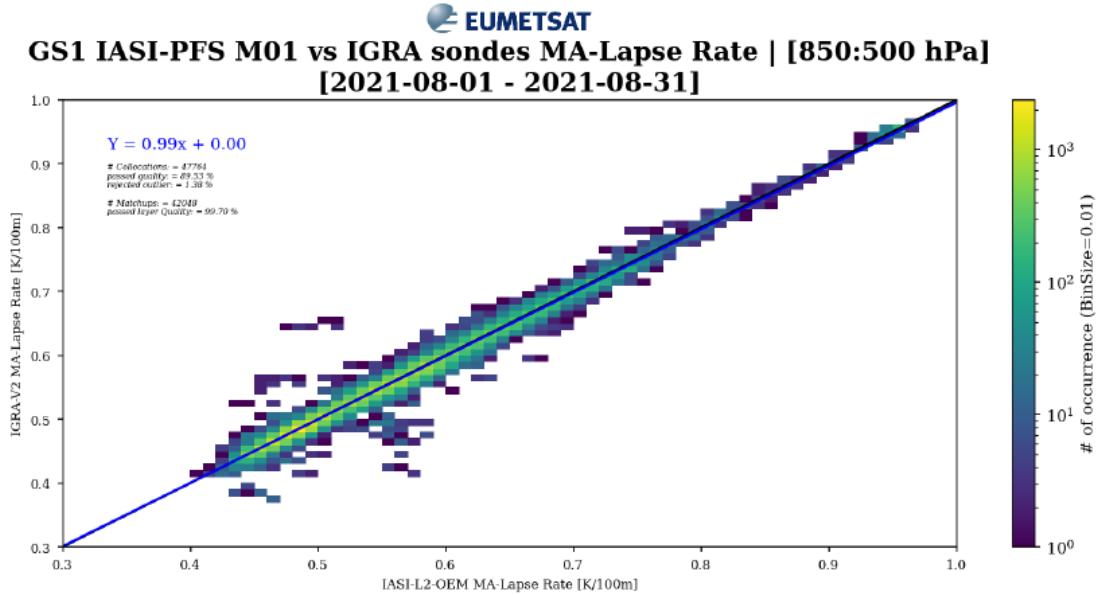
vs radiosondes
August 2018

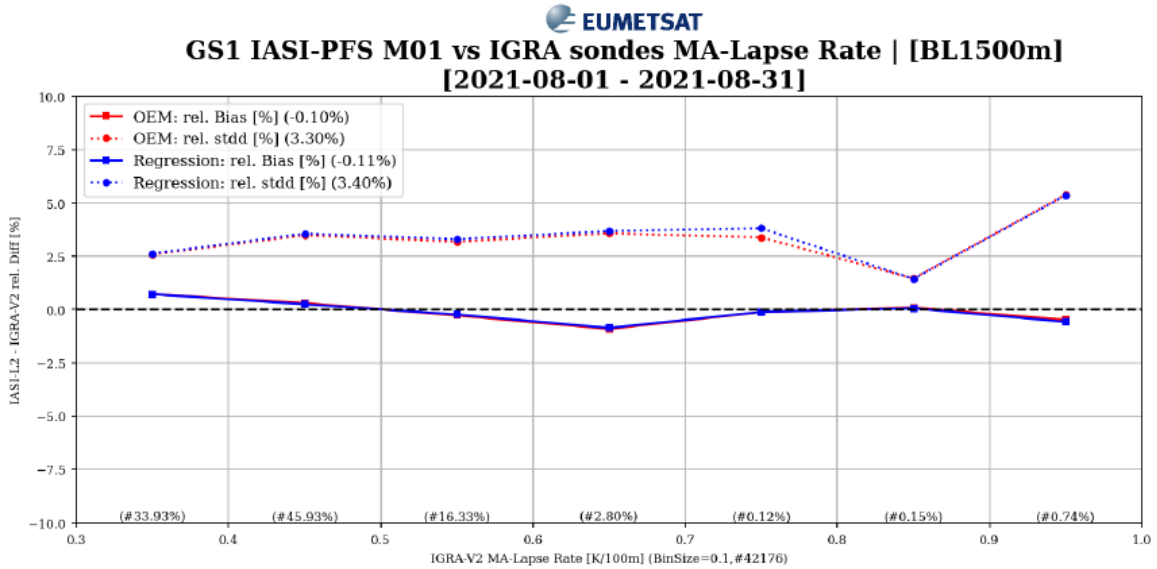


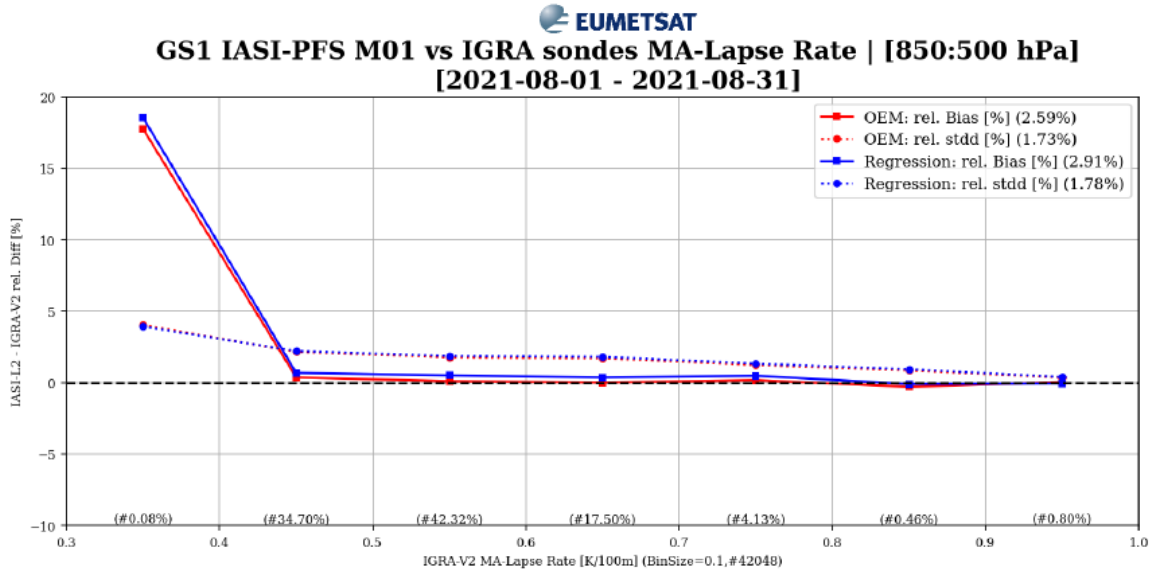


Temperature sounding – Lapse rate *vs* radiosondes (IGRA)

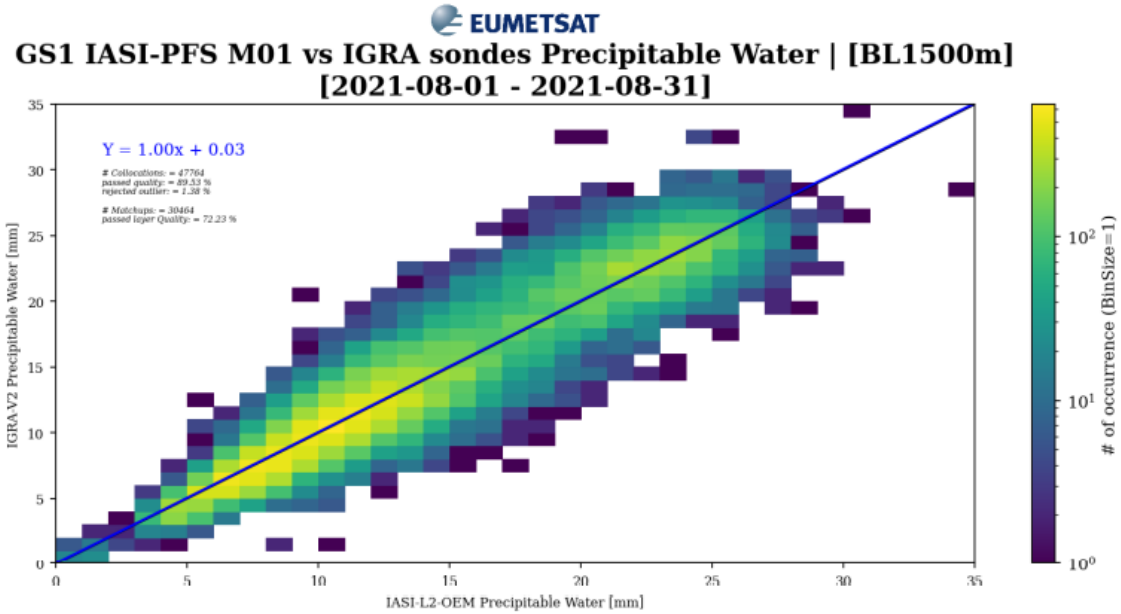


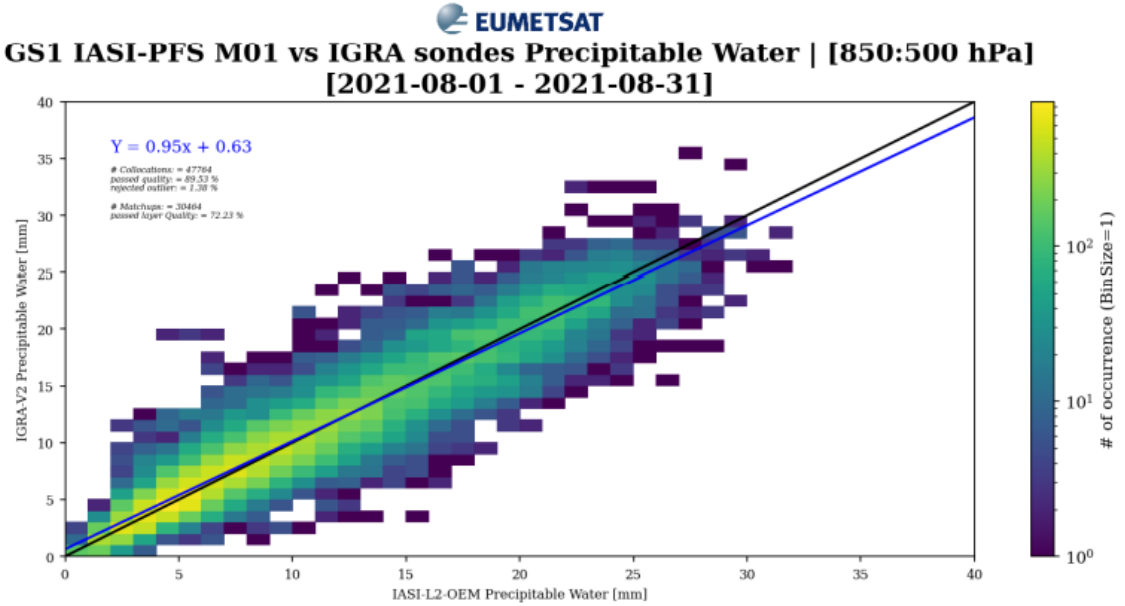


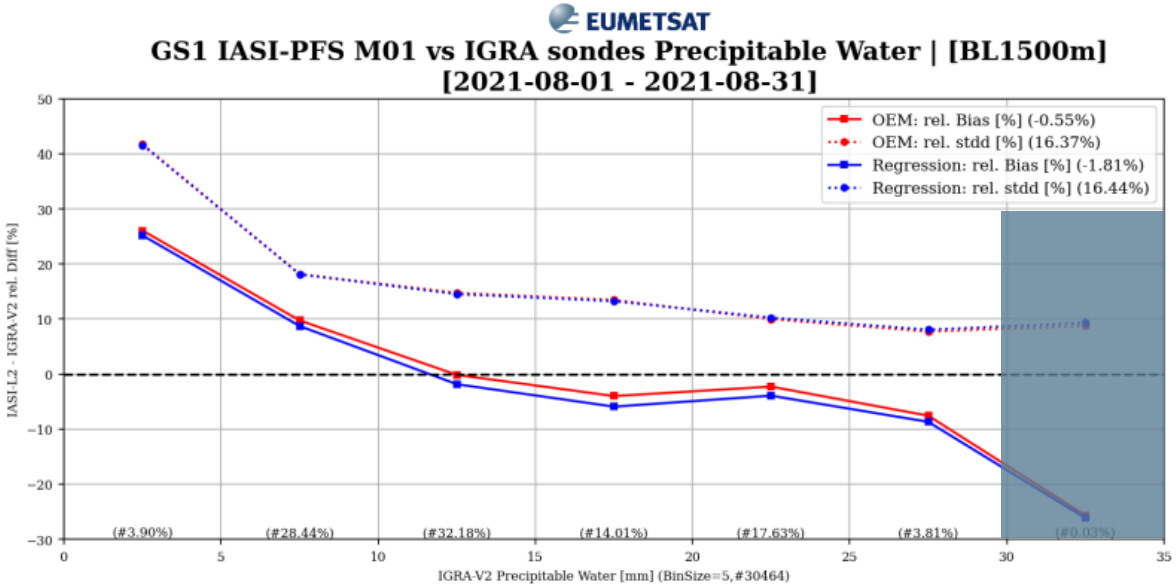


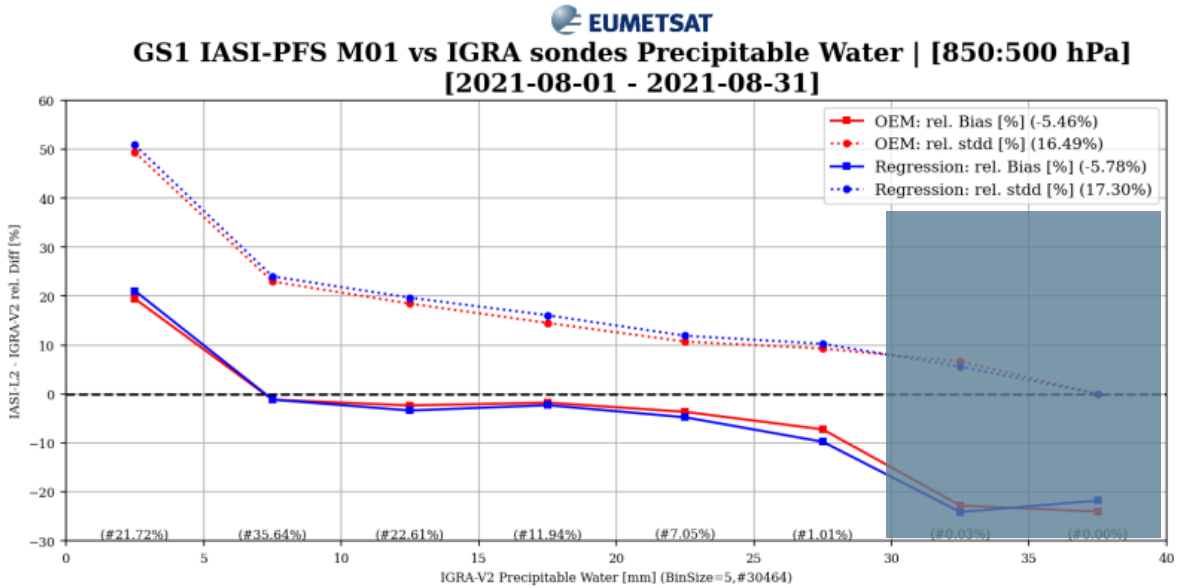


Humidity sounding – Partial columns *vs* radiosondes (IGRA)

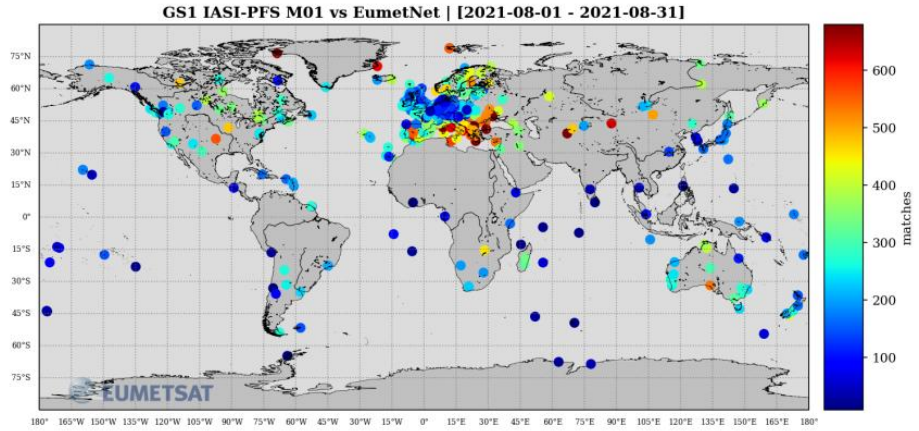


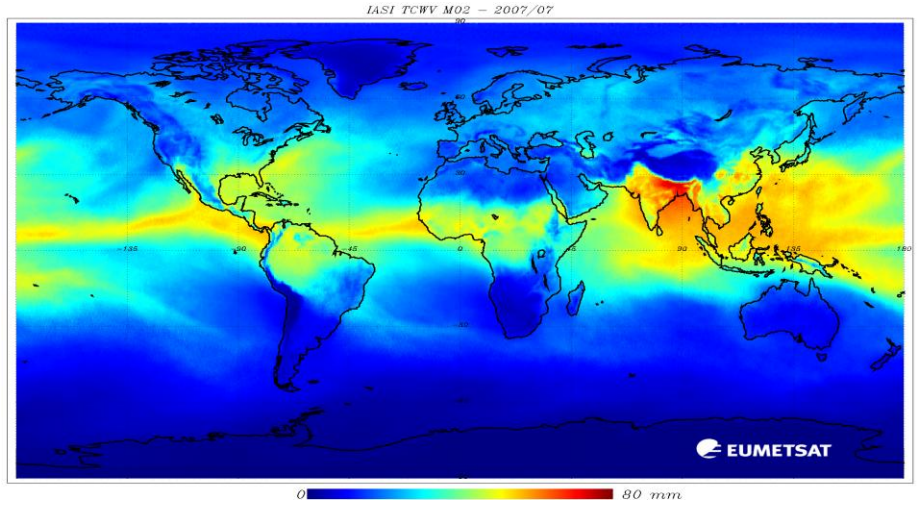




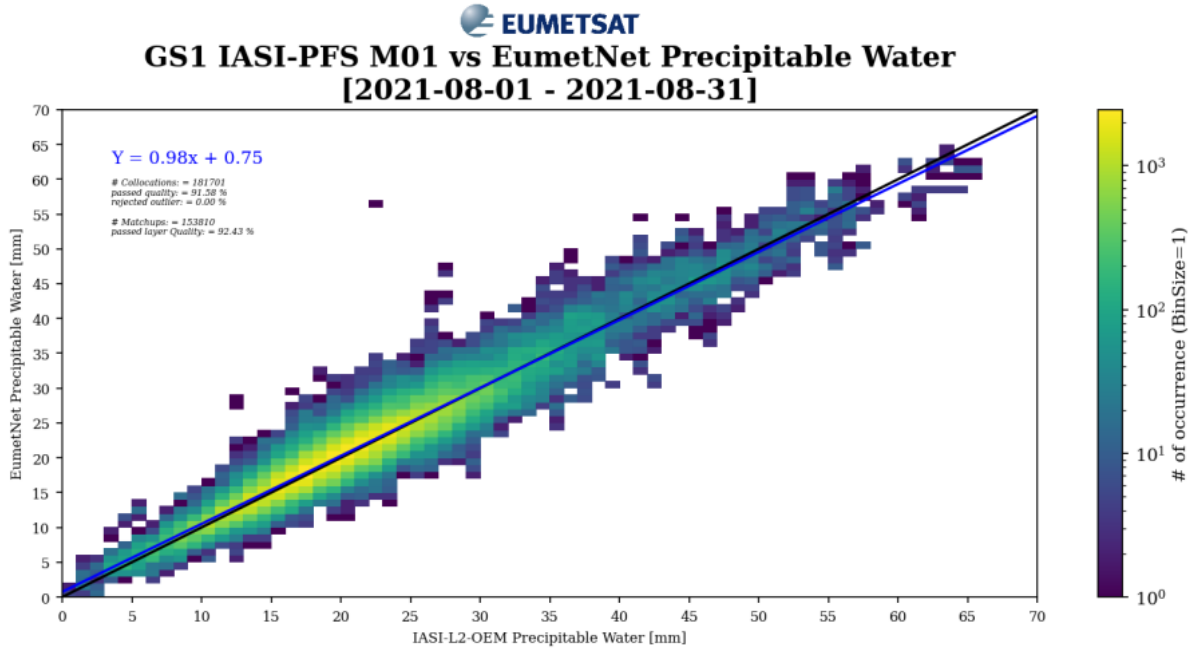


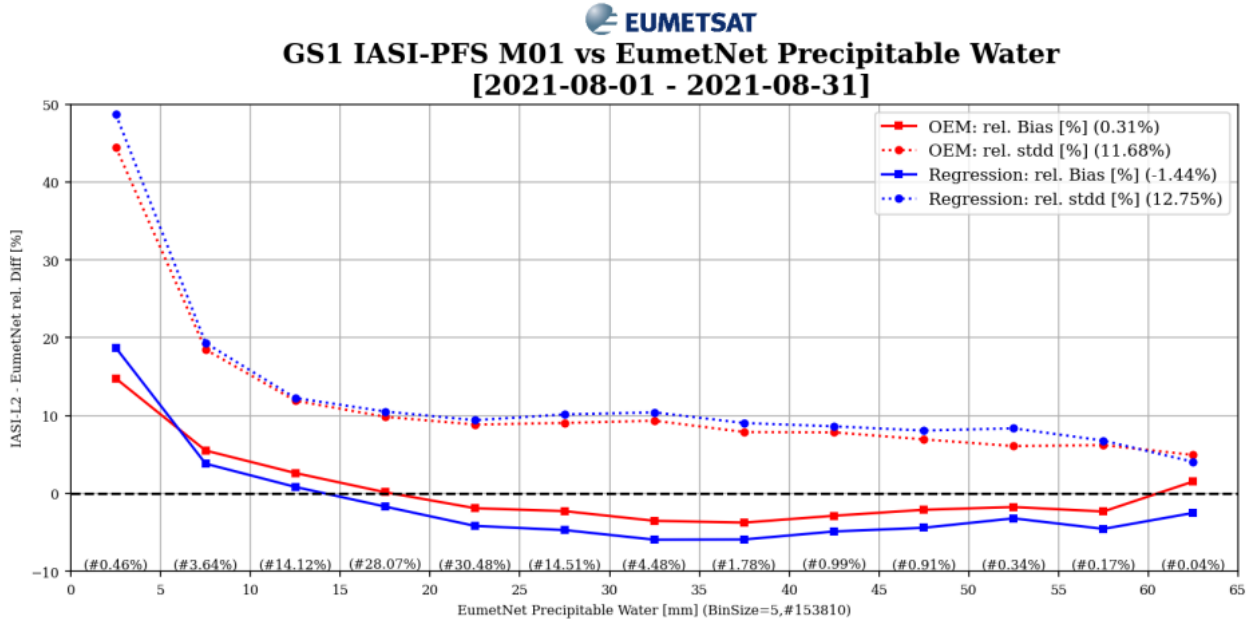
Humidity sounding – Total columns *vs* ground-GPS (EUMetNet)





Metop-A TCWV 2007-2018





Agenda

EUM hyperspectral sounders

Missions and algorithm overview

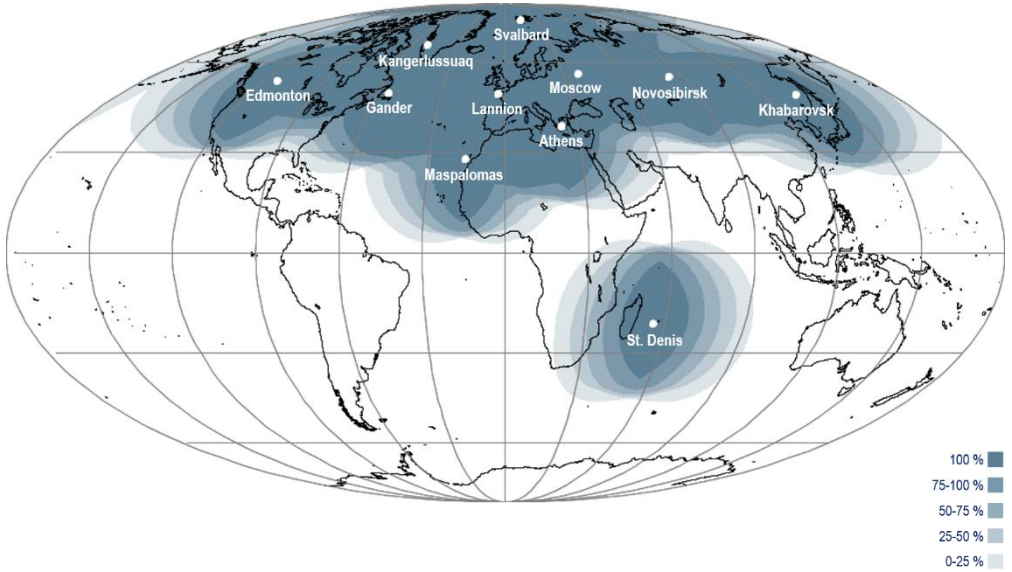
Products performances

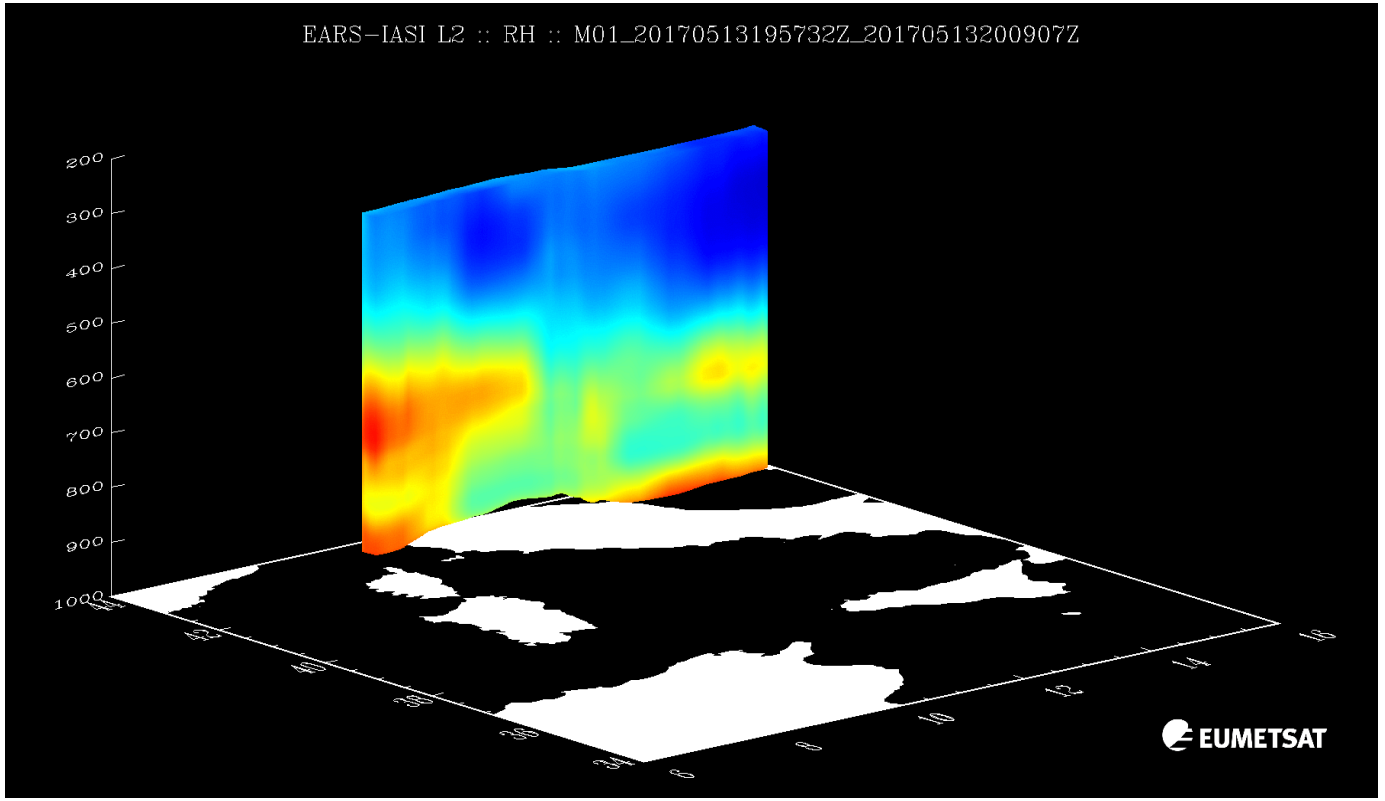
Validation, uncertainty estimates

Application and case studies

IASI regional service, preparing for MTG-IRS

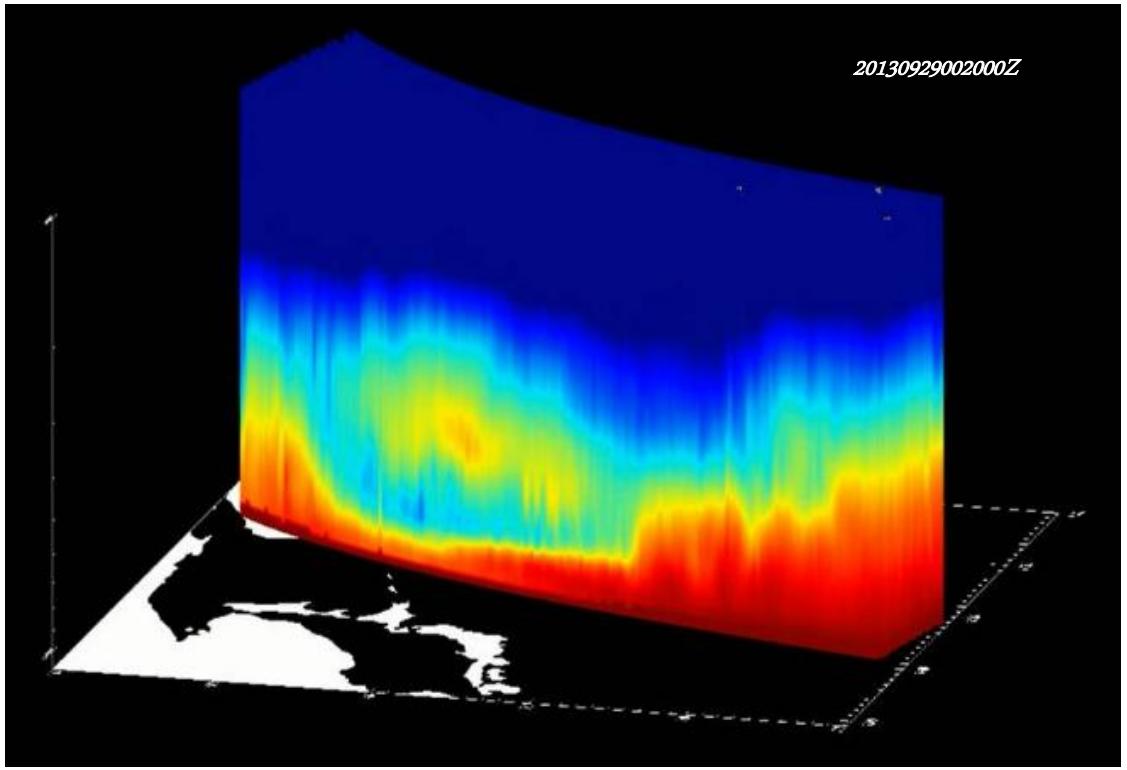
EARS-IASI L2 regional services - timely for nowcasting

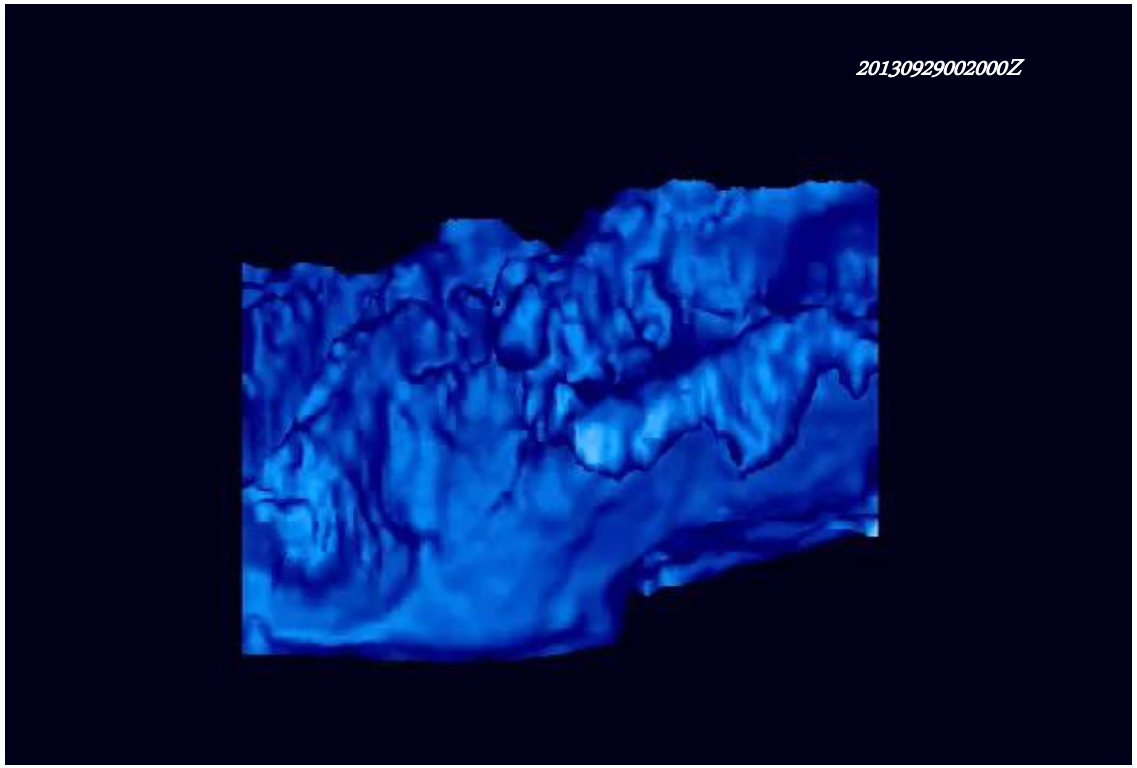




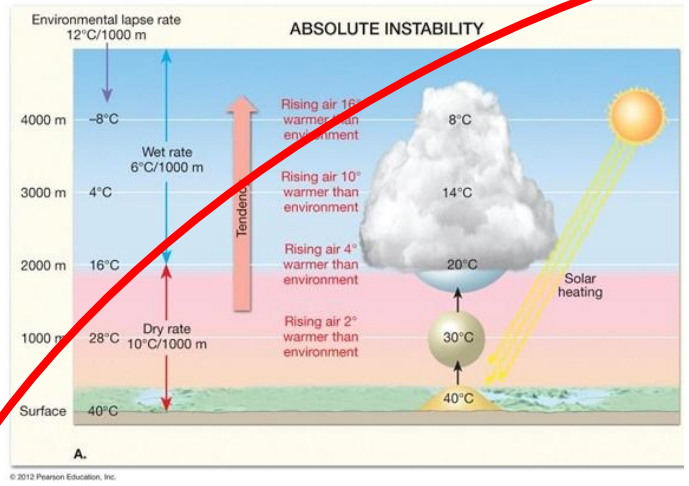
- ✓ Direct broadcast stations
- ✓ Timeliness < **30min from sensing**
- ✓ Forecast-free products + uncertainty estimates

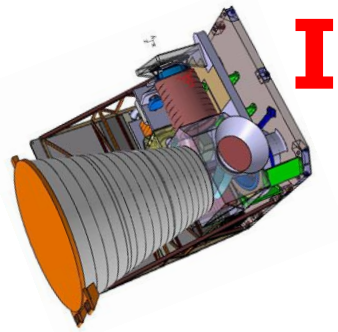
EARS-IASI L2 – Retrieving 3D humidity structures



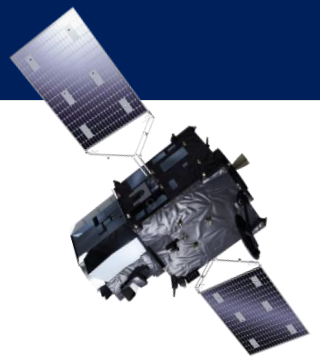


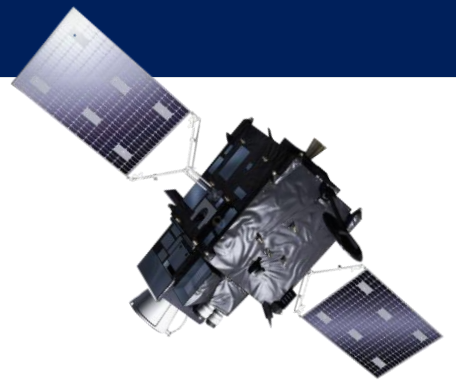
A full weather story with MTG



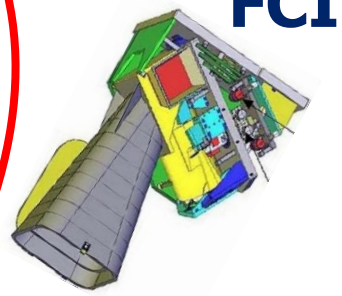


IRS

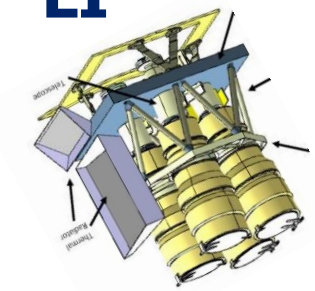




FCI

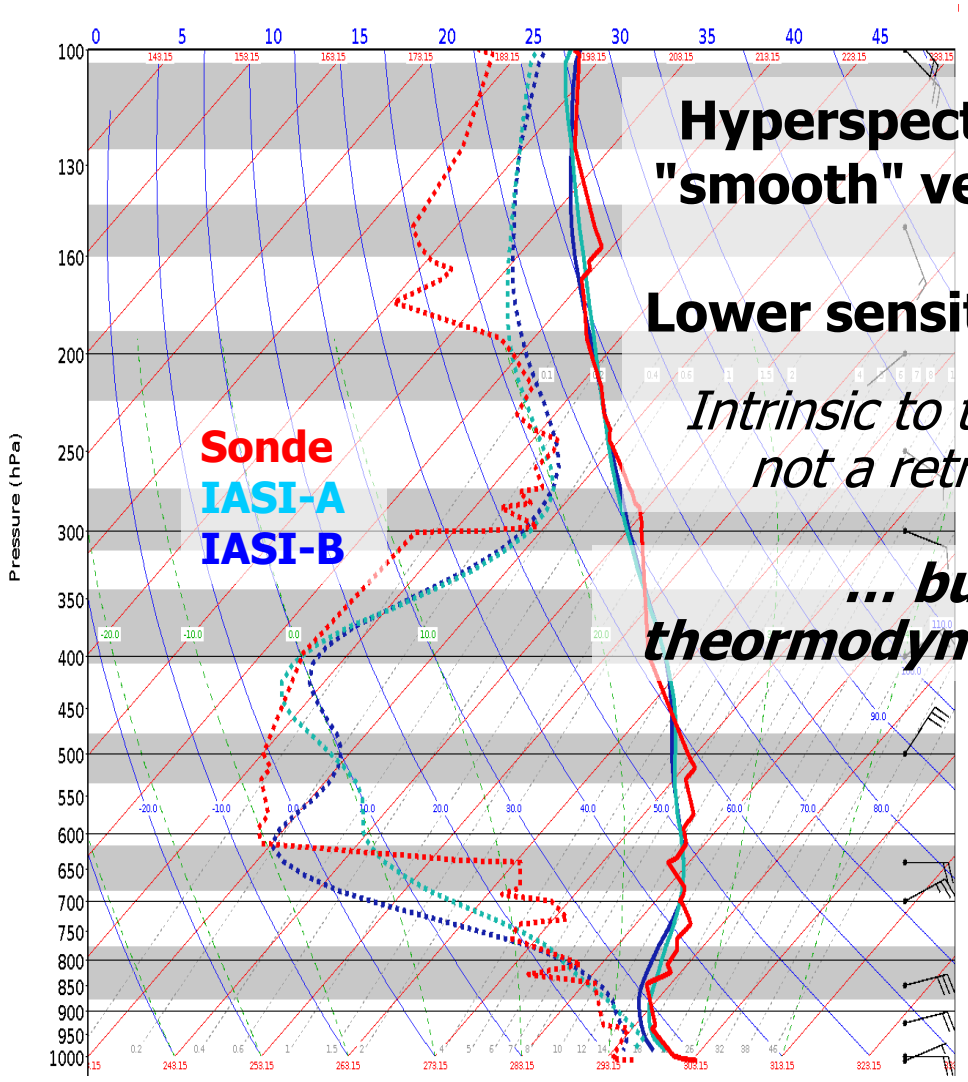


LI



Evaluate the thermodynamic state before clouds form.

Gain precision and lead-time in the assessment of potential severe weather.



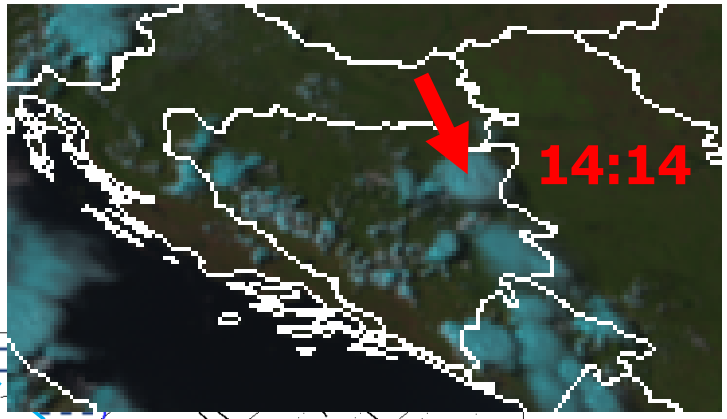
Hyperspectral sounding are "smooth" version of the truth

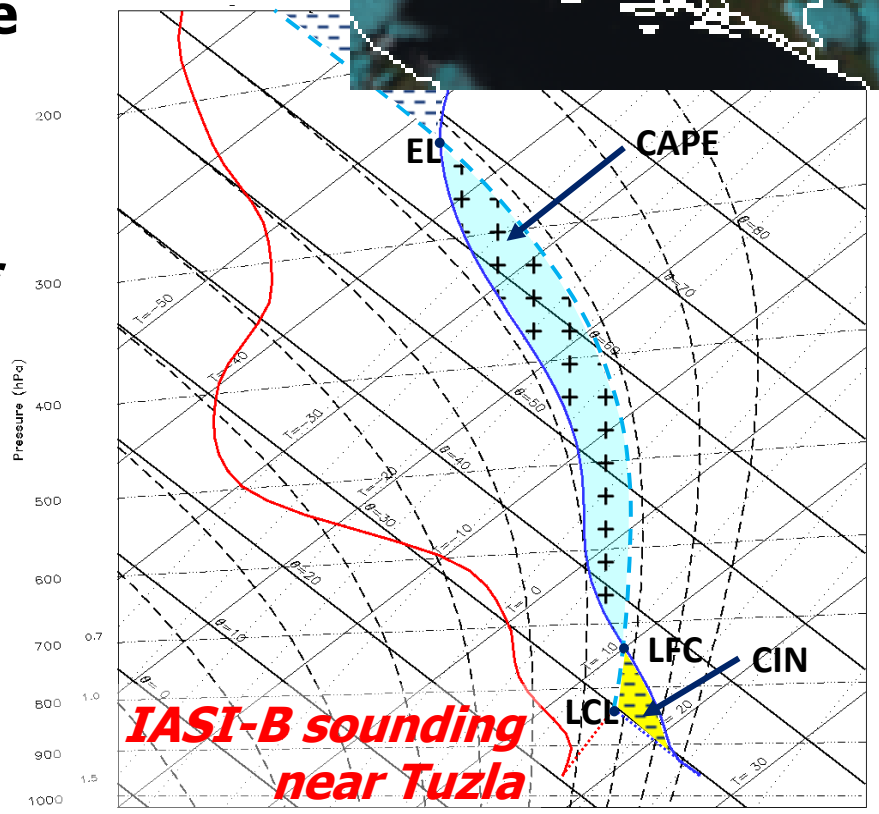
+

Lower sensitivity near surface

Intrinsic to the measurements, not a retrieval deficiency.

... but still, capable of theormodynamic information





IASI-B sounding near Tuzla

10/08/2018 @08:45

- use satellite sounder T/q for regional weather forecasts
- ! no operational heritage yet, unlike with e.g. imagers

Potential for nowcasting:

¿ What can be done with IASI already today ?

¿ What can we learn ?

- **to evolve the current Polar services**
- **to consolidate requirements and prepare for MTG-IRS**

Case study: Central Europe Flooding 20 June 2013

Results: R. Petersen, L. Cronce, (U. Wisconsin)
"Using hyper-spectral sounding products to improve forecasts of the pre-convective environment as a prelude to MTG-IRS"
EUMETSAT User Conference 2014

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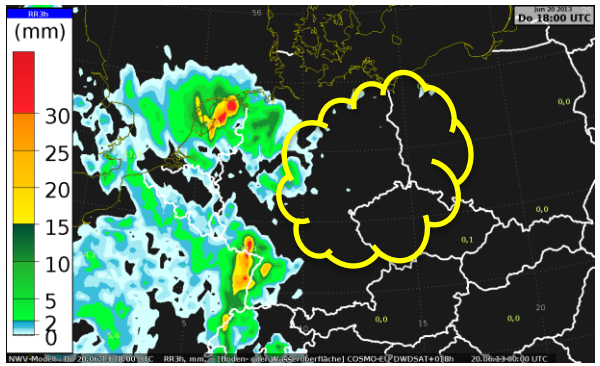
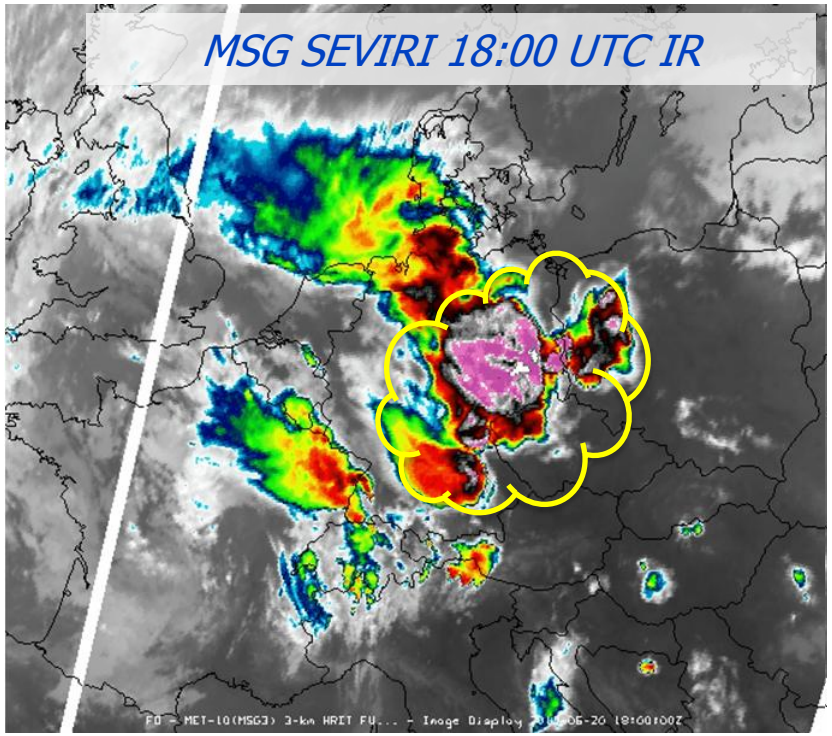
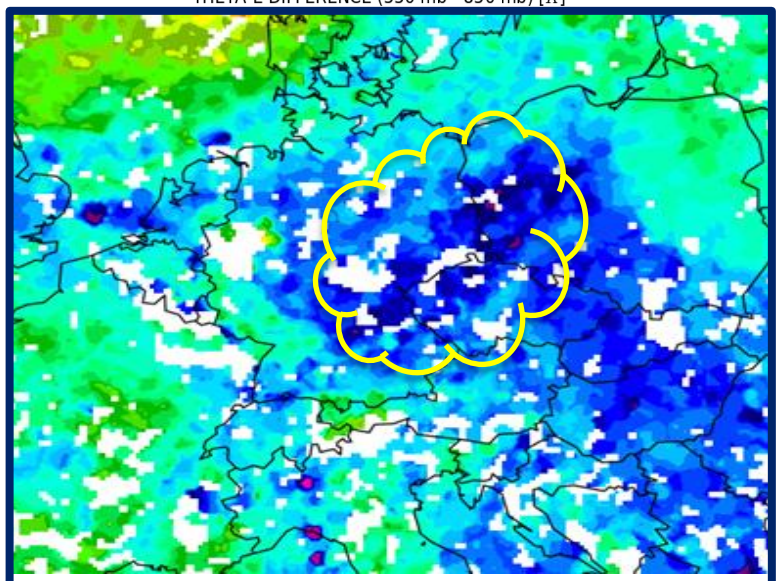
COSMO_EU 00Z forecast 18 UTC

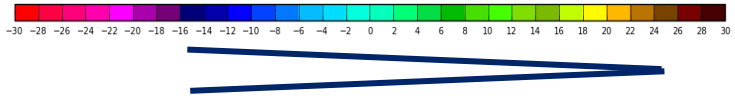




THETA-E DIFFERENCE (550 mb - 850 mb) [K]

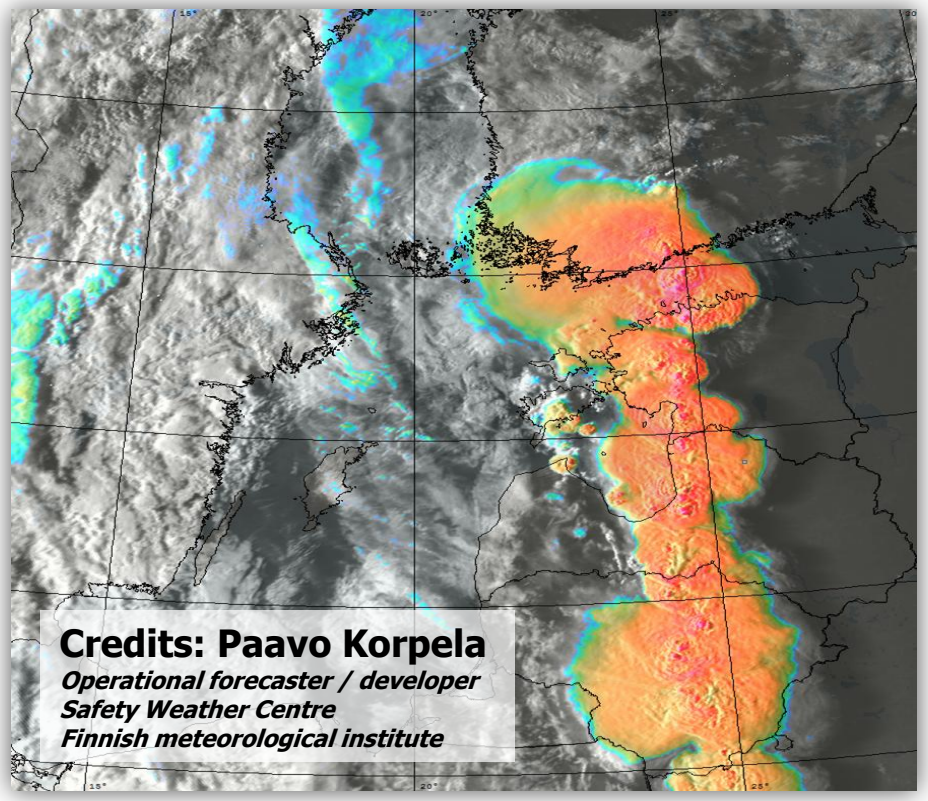


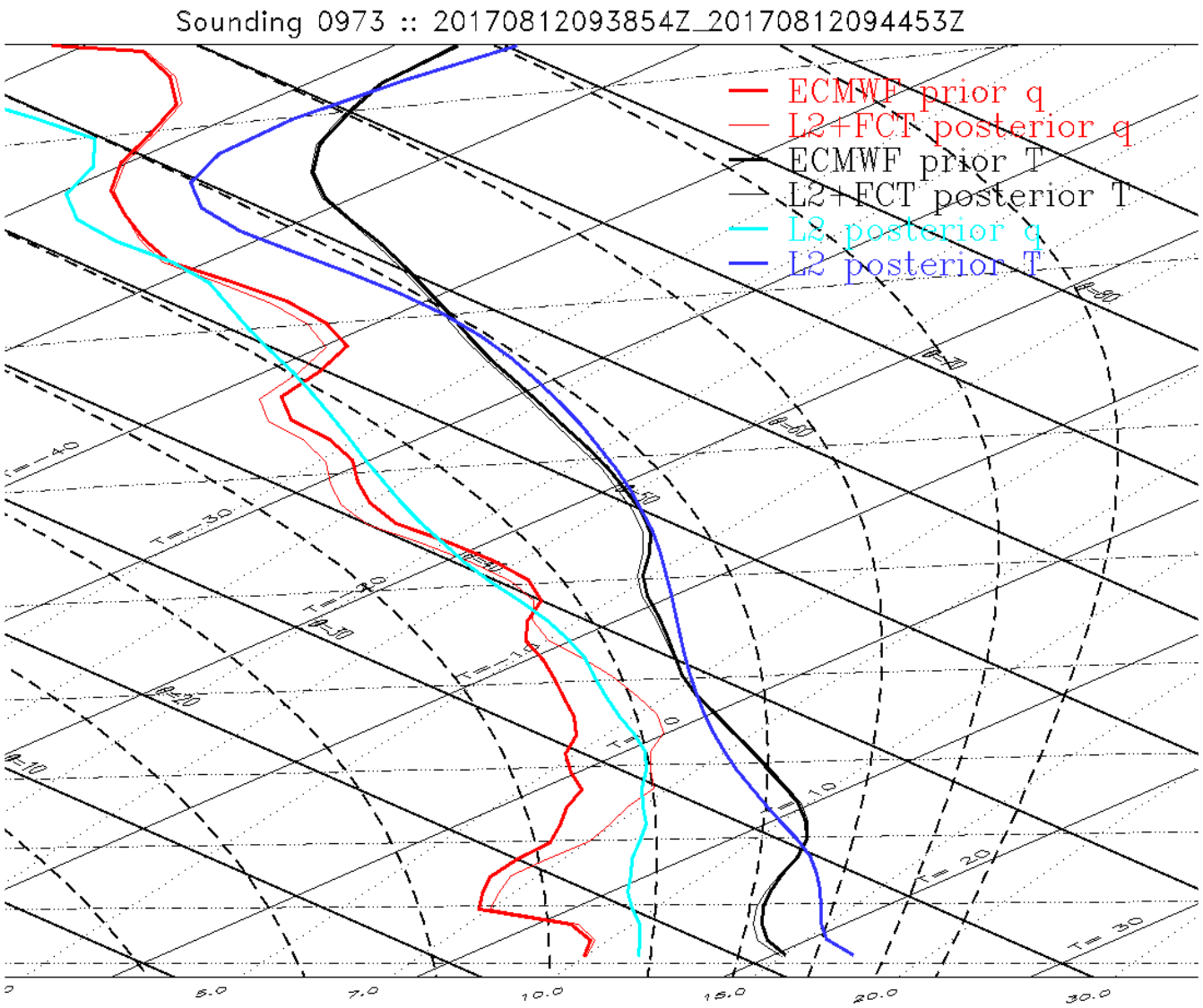
IASI L2 v6 Morning
+
NearCast at 18:00



Instability

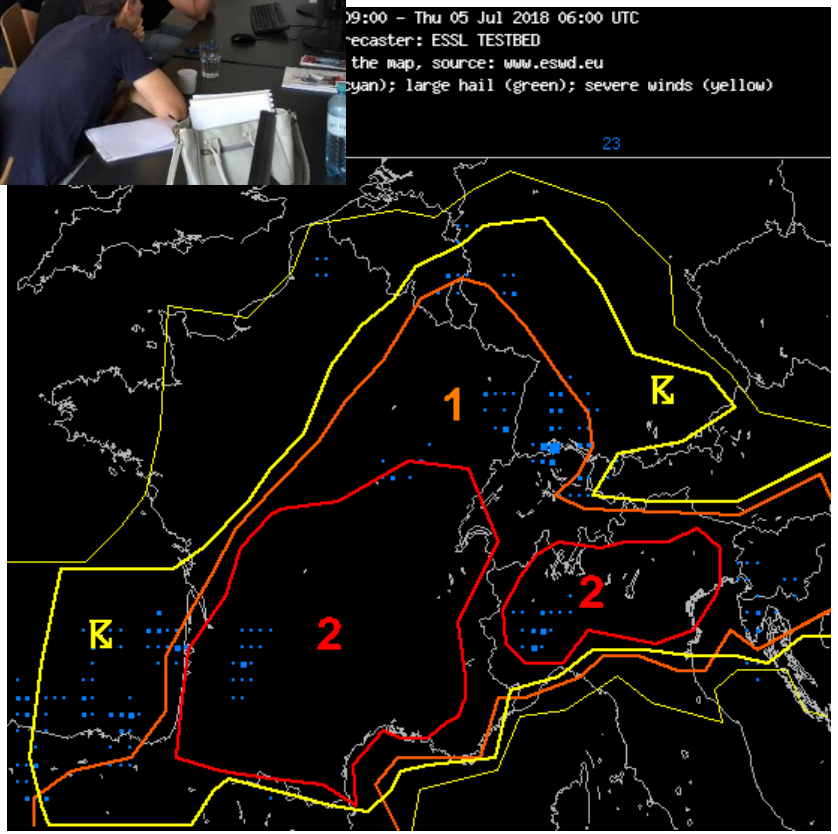
Kiira storm, 12/08/2017





IASI T/q products evaluation and dialog with users
ESSL
Test Beds & Experts workshops

- to ***raise awareness and train European forecasters*** *with products derived from EUMETSAT hyperspectral Infrared sensors for the prediction of severe storm*.
- to ***collect the feed-back from European users*** to evaluate and ***consolidate the requirements*** on hyperspectral products and associated services for short-term severe weather forecasting.
- to ***constitute a catalogue of relevant situations***, to serve as test bed for algorithms experiments, case studies and feed into products and services developments.
- to ***perform detailed case studies*** by experts from the above catalogue with existing and protoype L2 products.

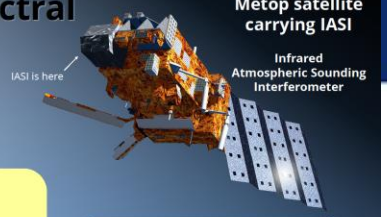


European Severe Storms Laboratory
Science & Training

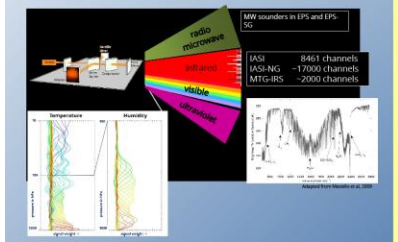
EUMETSAT

Evaluating the use of IASI hyperspectral sounder data for severe storm forecasting at the ESSL Testbed

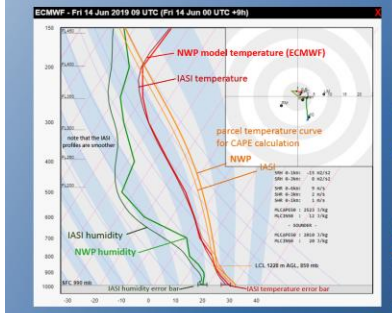
Pieter Groenemeijer, Tomáš Púčik (ESSL)
Thomas August (EUMETSAT)



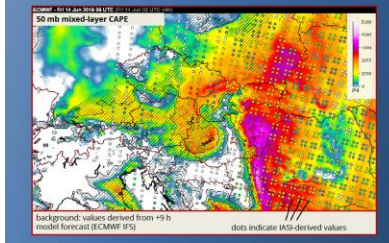
The IASI sounder measures infrared radiances ...



...from which vertical profiles of temperature and humidity are derived.
They can be compared to the profiles from numerical weather prediction (NWP) models:



... from those, we can compute convective parameters, such as CAPE:

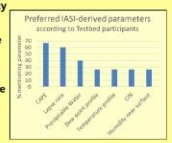


ESSL Testbed

In June and July 2019, over 40 Testbed participants worked with IASI profiles and parameters to make experimental forecasts for severe convective storms

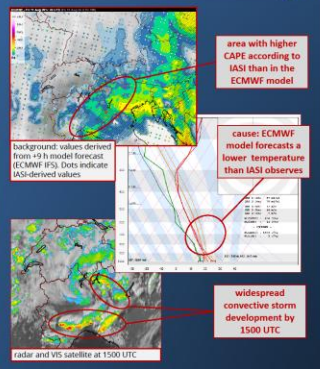
Main conclusions:

- **almost all forecasters found the type of data useful**
- **forecasters would like to have a higher (spatio-) temporal availability**
- **IASI profiles should stay completely independent of the model data**
- **forecasters found greatest discrepancies between IASI and NWP in the near-surface humidity**
- **preferred parameters are**
  - **CAPE**
  - **lapse rates**
  - **precipitable water**



Studies of past cases

ESSL is evaluating the potential of IASI by evaluating past cases of severe convection that were impactful or not well anticipated by NWP models. An example is provided below:



Operational IASI — now available!

Infrared Atmospheric Sounding Interferometer

- flies on polar satellites Metop-A/-B/-C launched 2006, 2012, 2018
- has a pixel size of 12 km at Nadir – 2000km swath
- Two overpasses per day across central/southern Europe, in the morning and evening
- More frequent overpasses in northern Europe

IASI-NG — coming soon...

IASI-Next Generation

- will have the same coverage but **improved** sounding performance

MTG-IRS — coming soon...

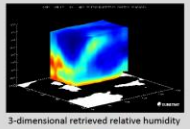
Meteosat Third Generation – InfraRed Sounder

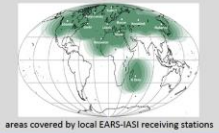
- will fly on the geostationary Meteosat Third Generation
- Similar sounding data to IASI, but **every 30 min** and with a pixel size of **7 km**

The first MTG sounder satellite is scheduled to be launched in **2023**.

EARS – IASI service — now available!

The EARS-IASI level 2 service is routinely providing temperature and humidity sounding from IASI within 30 minutes maximum from sensing. The products are available through the EUMETCast service, for the areas covered by the local receiving stations of the EARS-IASI network. The products exploit the MW companion instruments, hence data is also provided in most cloudy regions. The retrievals are fully independent from numerical weather forecasts.


3-dimensional retrieved relative humidity


areas covered by local EARS-IASI receiving stations

The **European Severe Storms Laboratory** is a non-profit research organization located in Germany and Austria (Wiener Neustadt). It supports by operating the European Severe Weather Database, organizing the ESSL Testbed and scientific meetings. It carries out research on the climatology, impacts and forecasting of severe storms and provides forecaster trainings. Its members include 20 European weather services and research centres, as well as 17 commercial supporting members.
For more information, visit: www.essl.org

Corresponding author: Pieter Groenemeijer (pieter.groenemeijer@essl.org)

Reference:
Masiello et al, 2009: Application of φ-IASI to IASI: Retrieval products evaluation and radiative transfer consistency, *Atmos. Chem. Phys.*, **9**, doi: 10.5194/acpd-9-9647-2009.

This study is carried out by European Severe Storms Laboratory – Science & Training for EUMETSAT under contract EUM/CO/184600002214

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Main conclusions:

IRS baseline to study

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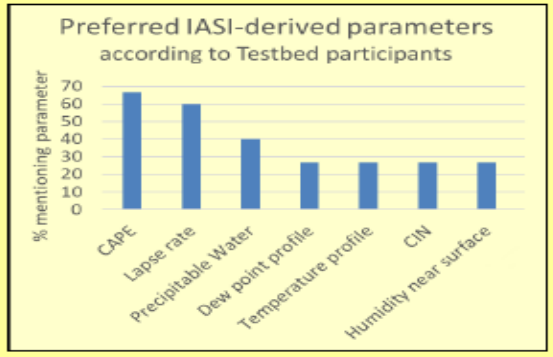
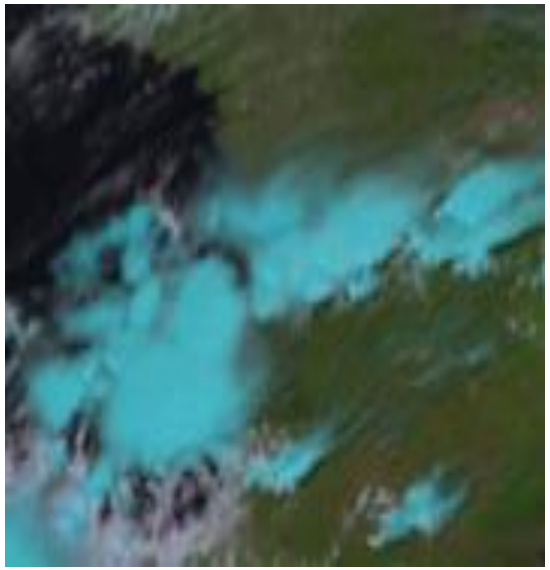


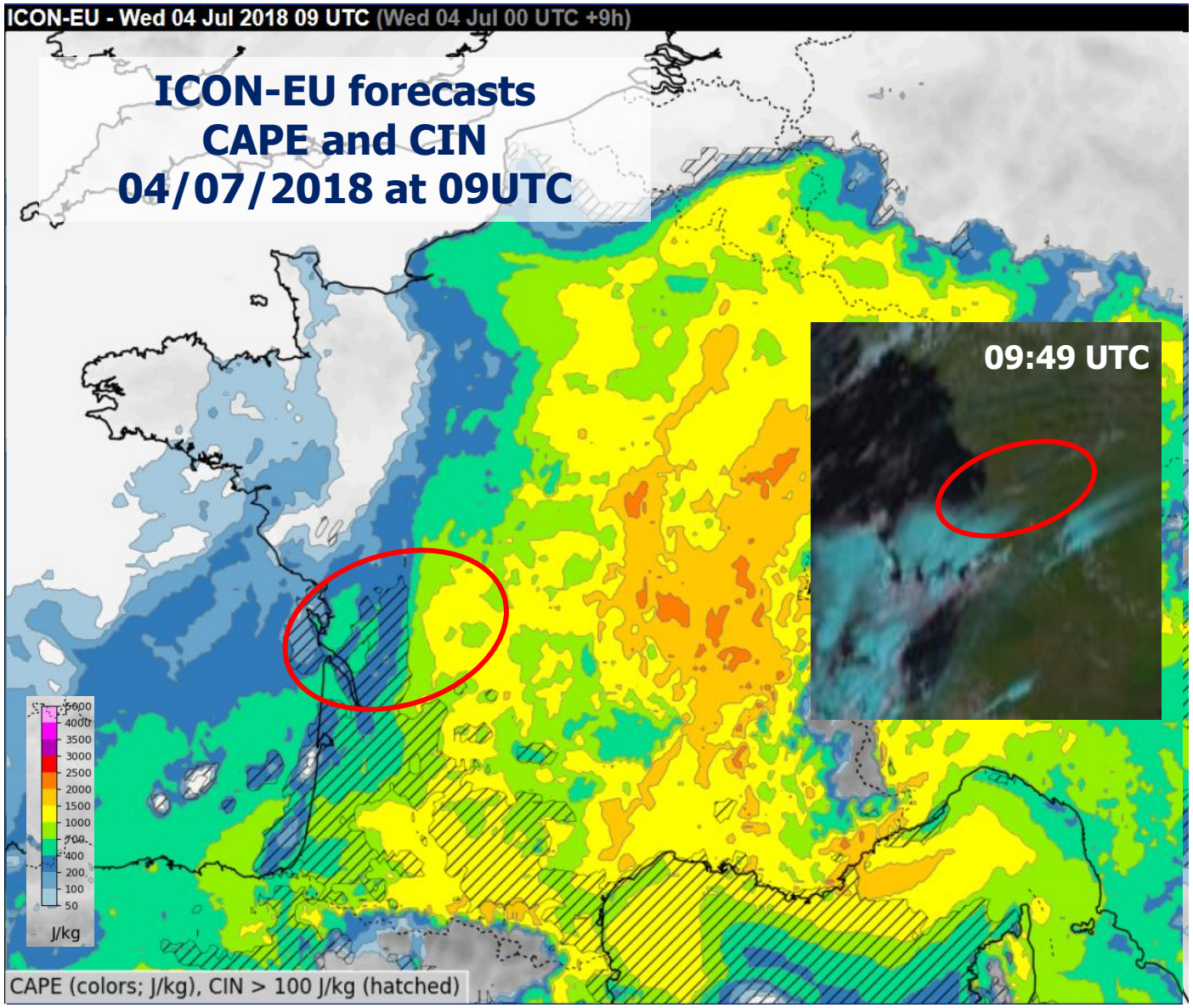
P. Groenemeijer, T. Pucik (ESSL)
European Meteorological Society
Copenhagen 2019

EUMETSAT

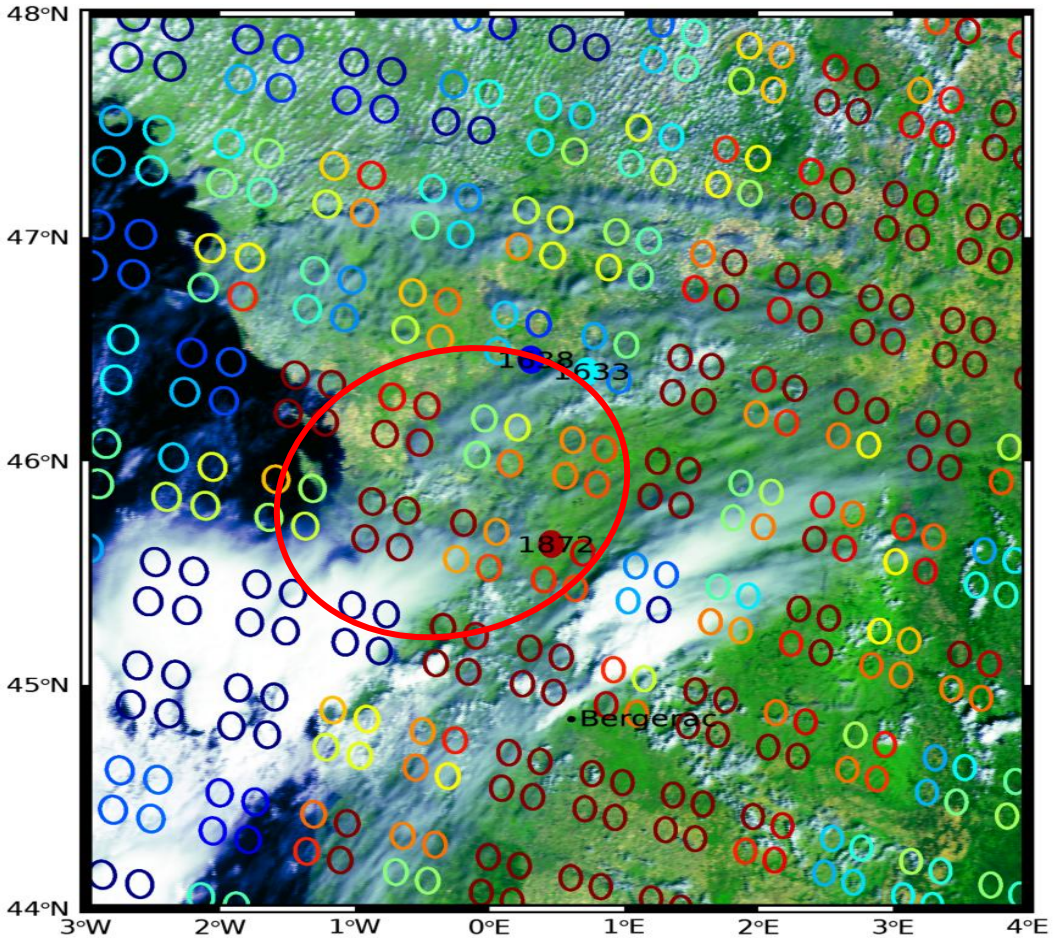
Wind, Lightning, Hail storm in Dordogne – 04/07/2018



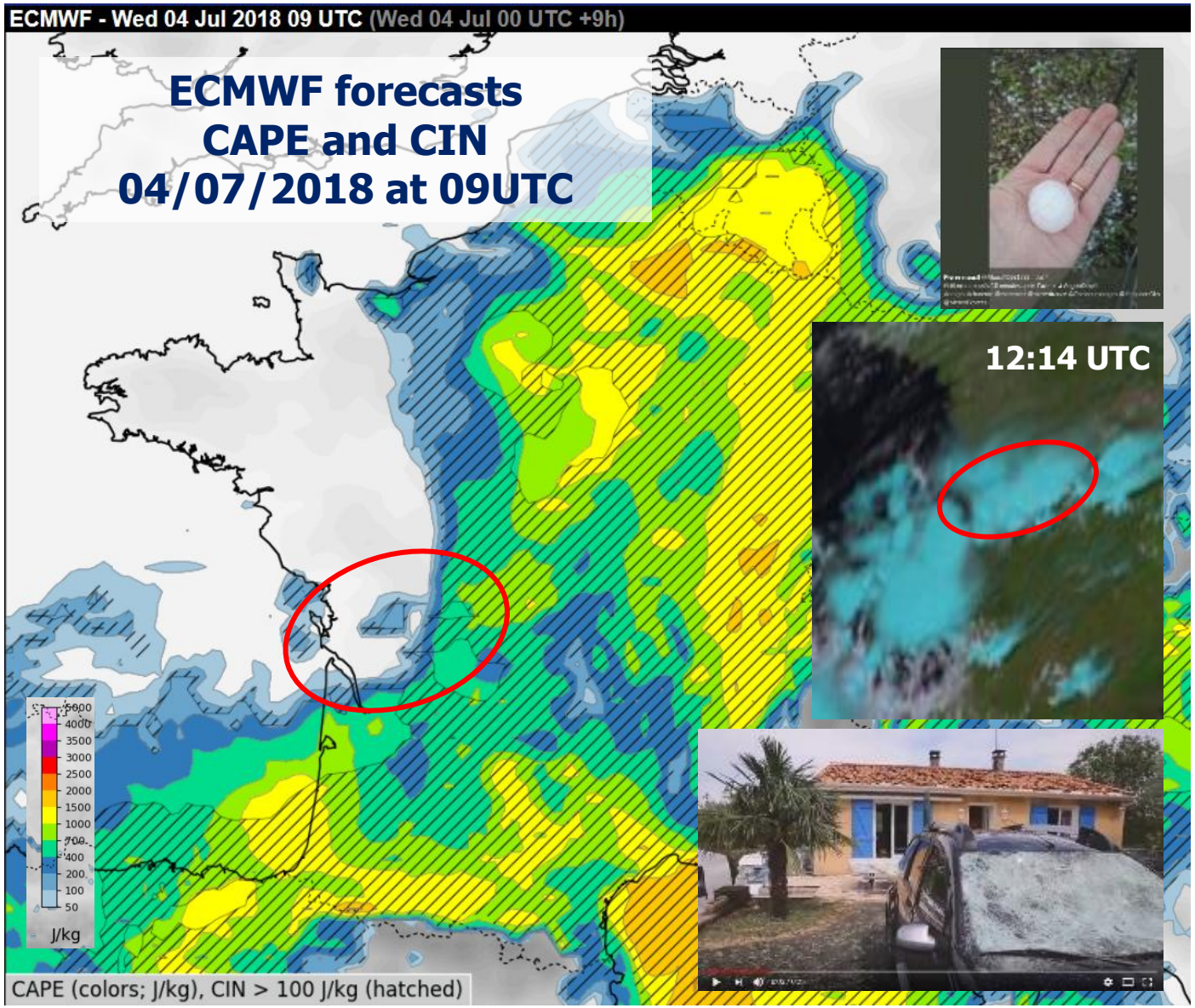
Wind, Lightning, Hail storm in Dordogne – 04/07/2018

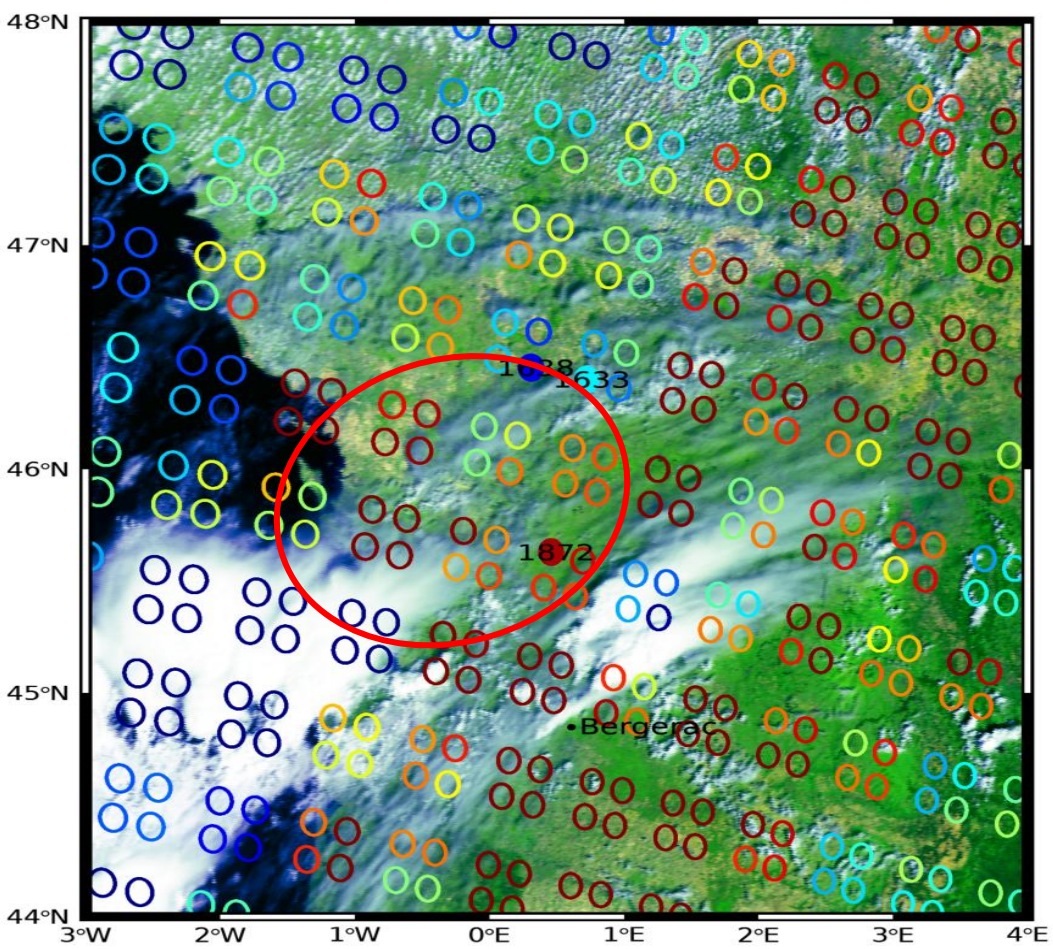


Metop-B/IASI – MLCAPE50
04/07/2018 09:50

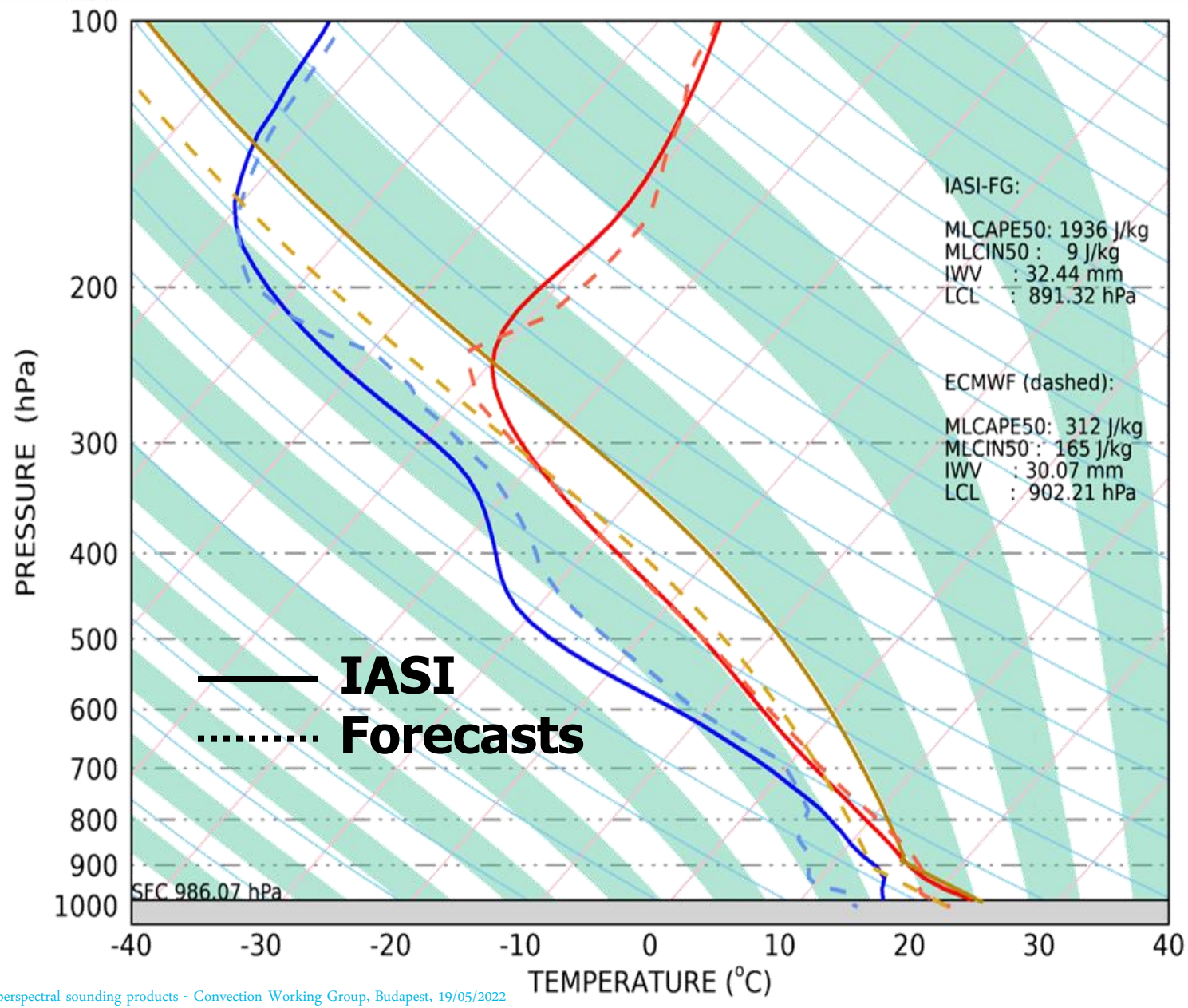


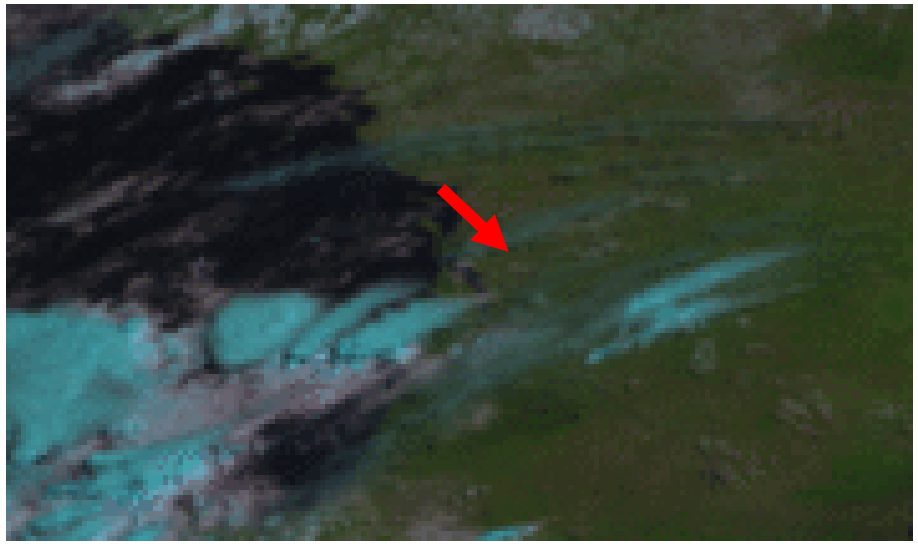
Wind, Lightning, Hail storm in Dordogne – 04/07/2018



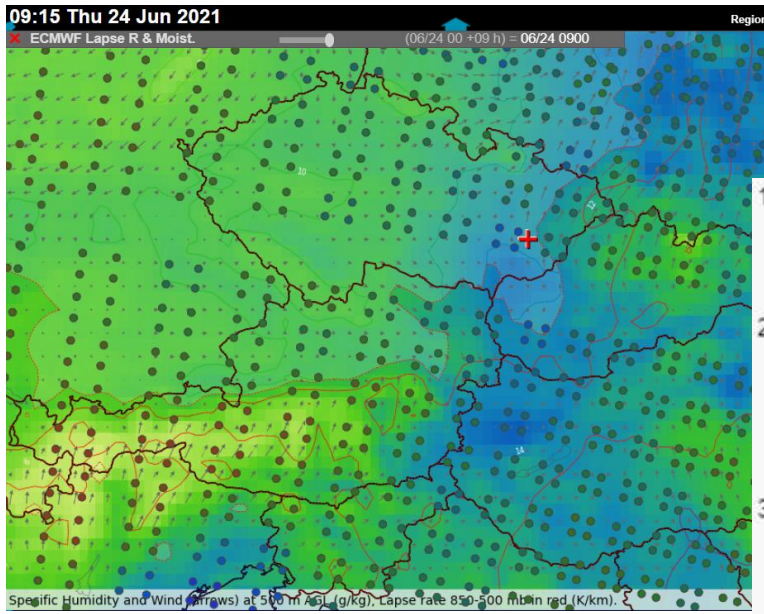


Wind, Lightning, Hail storm in Dordogne – 04/07/2018





24 June 2021: Severe weather outbreak over Central Europe



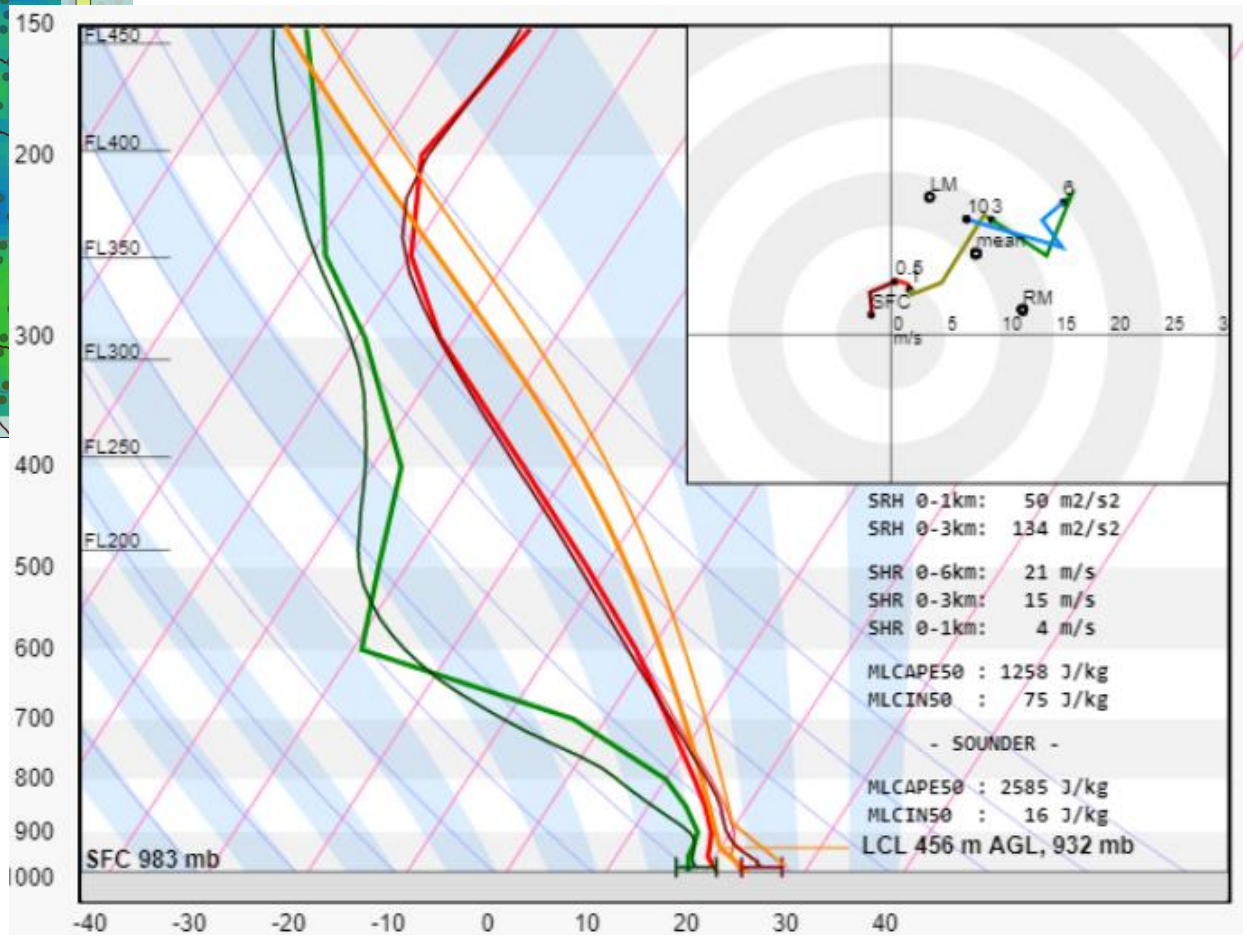
2 tornadoes

Violent F4 tornado in East Czechia

Giant (≥10 cm) hail in Austria, Poland

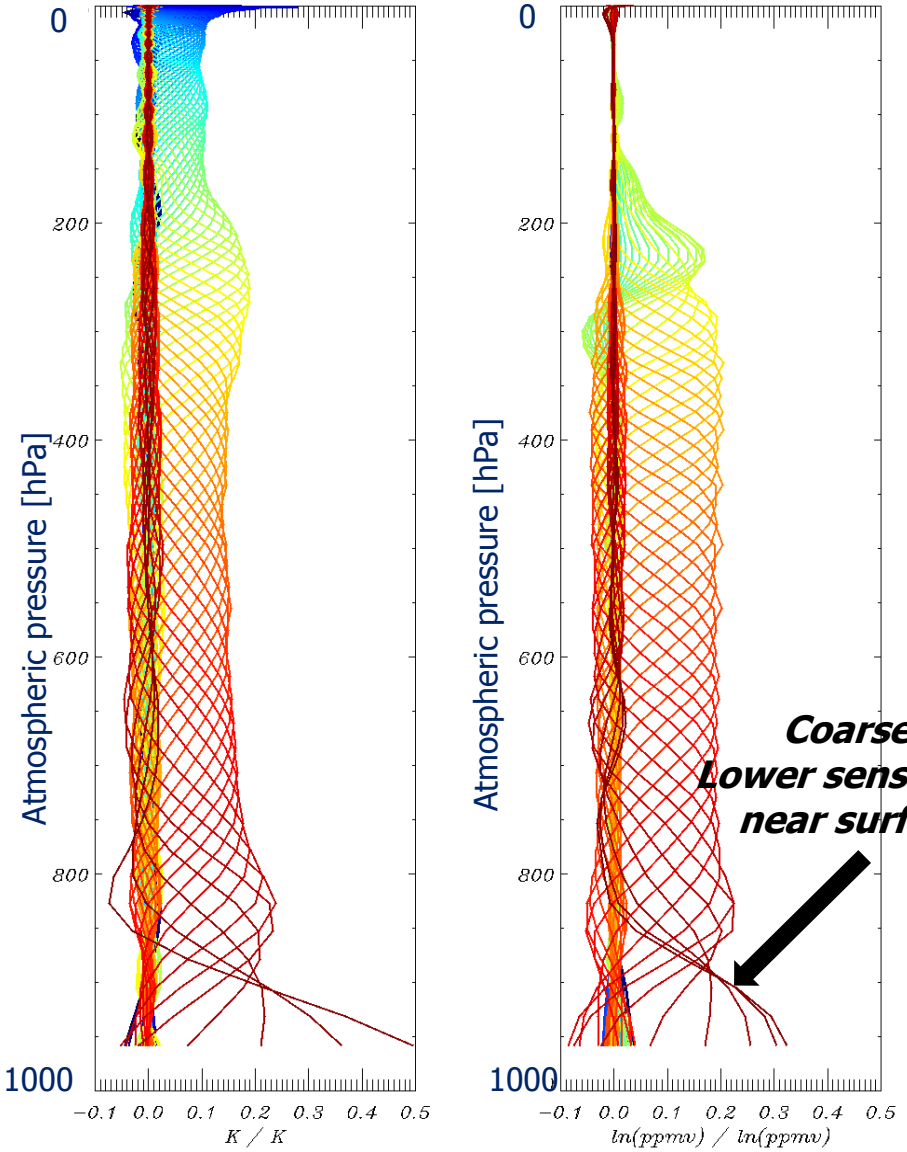
615 hail reports in Poland

IASI indicates higher temperature
(confirmed with ground obs)
and higher CAPE than forecast

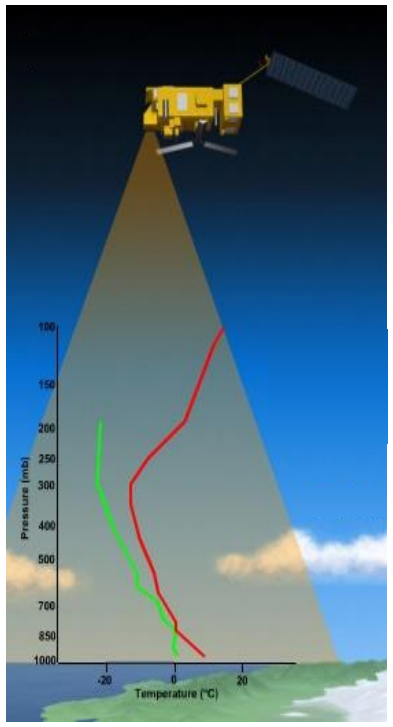


Studies with OMSZ – Blending satellite and surface observations

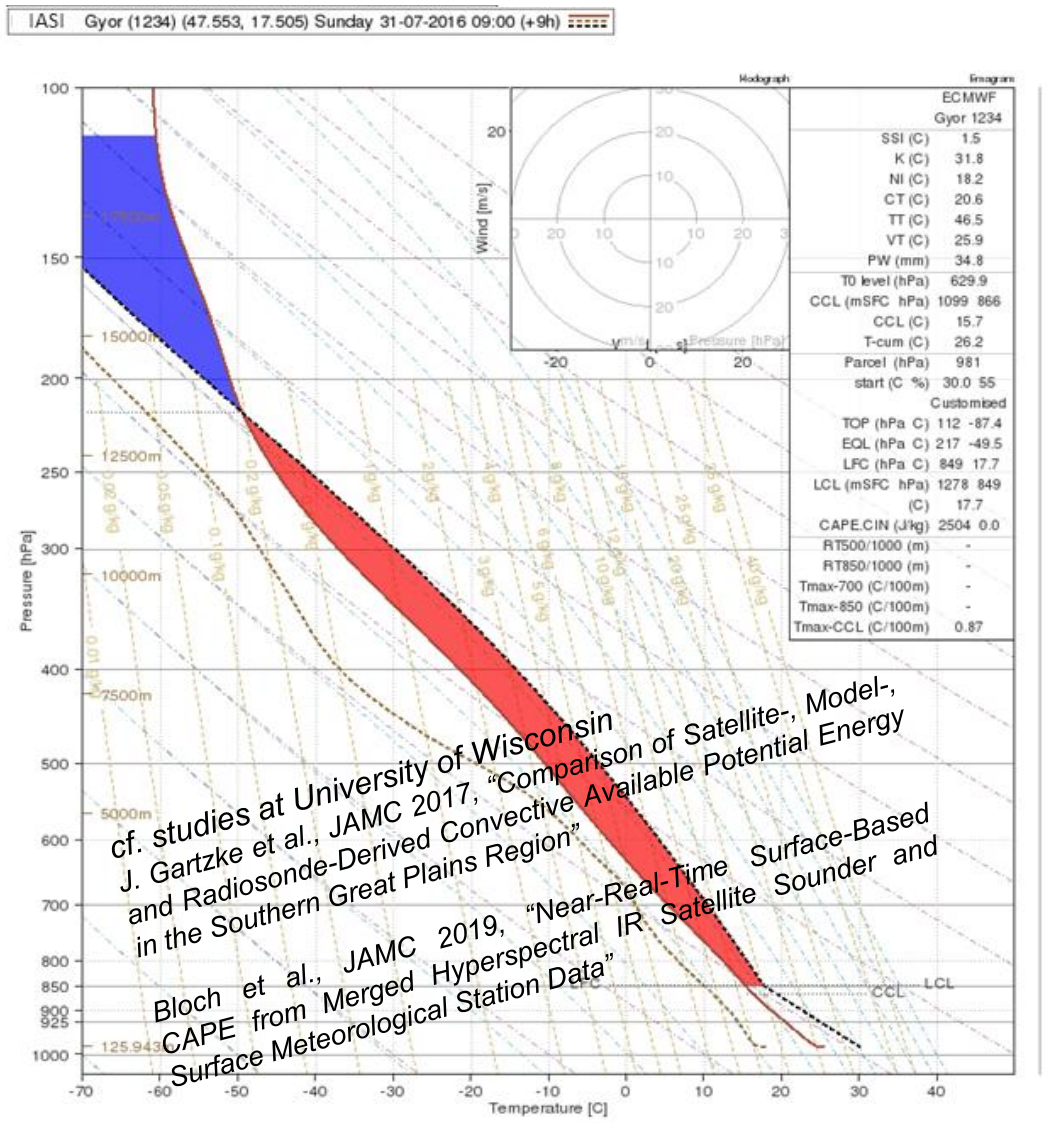
Averaging Kernels



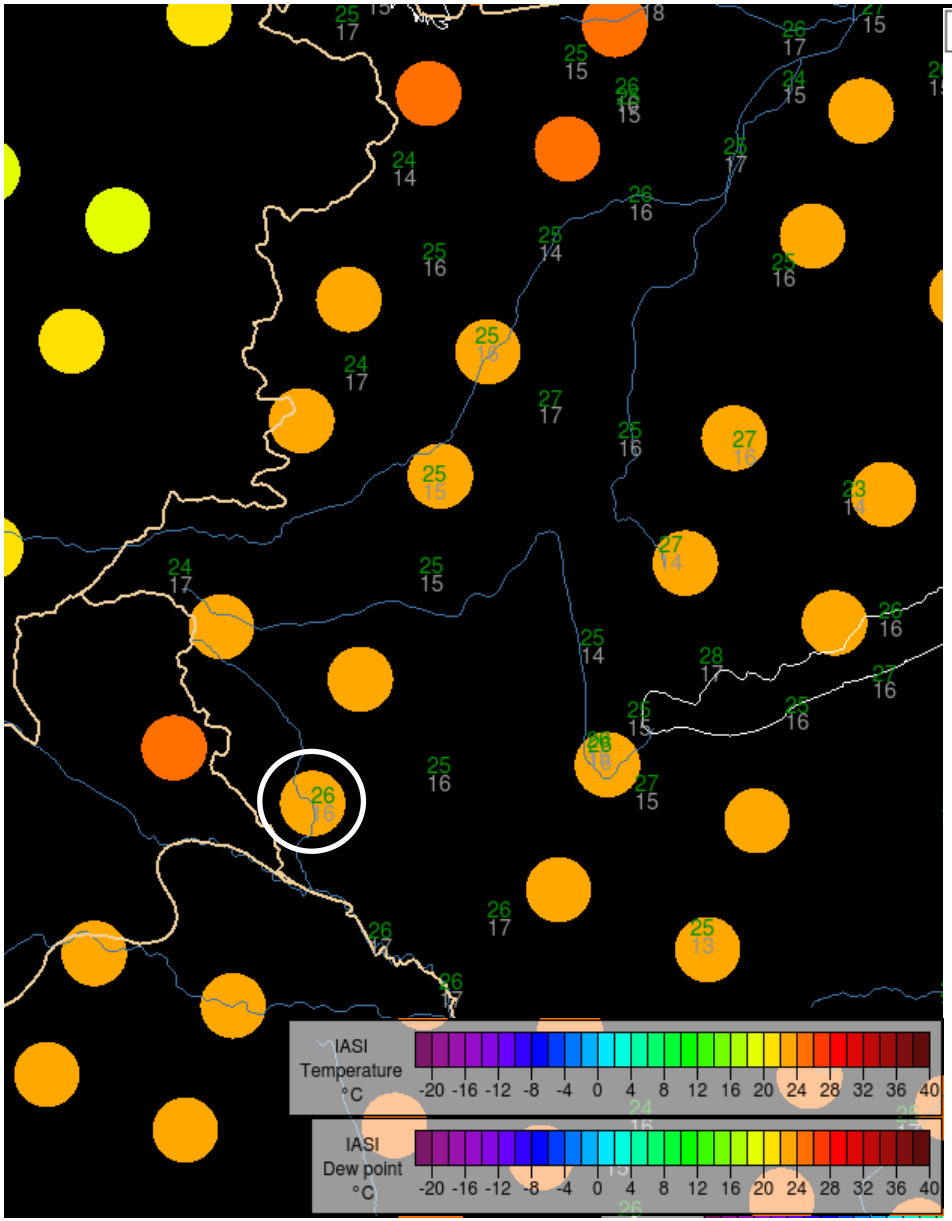
Coarser
Lower sensitivity
near surface

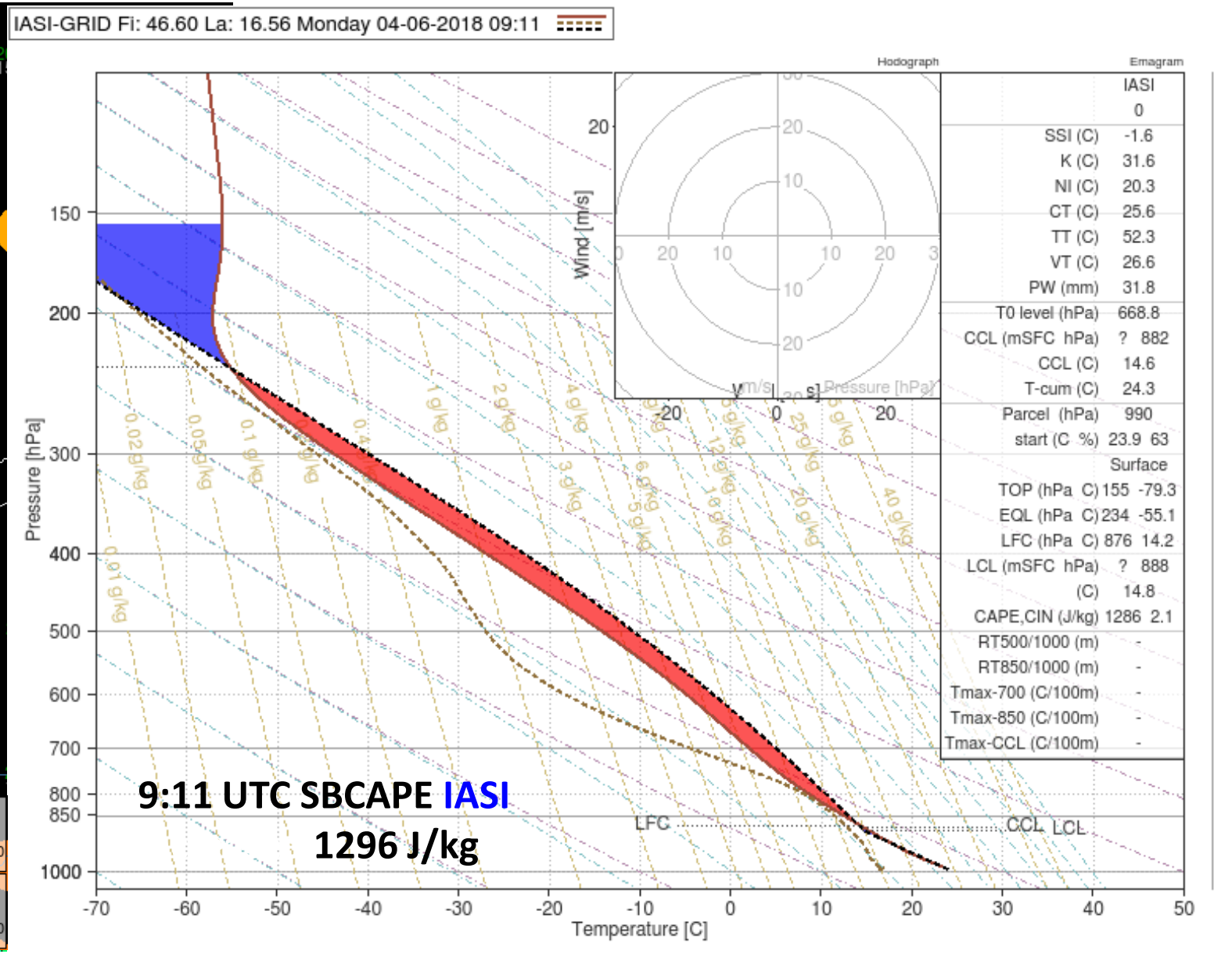


+

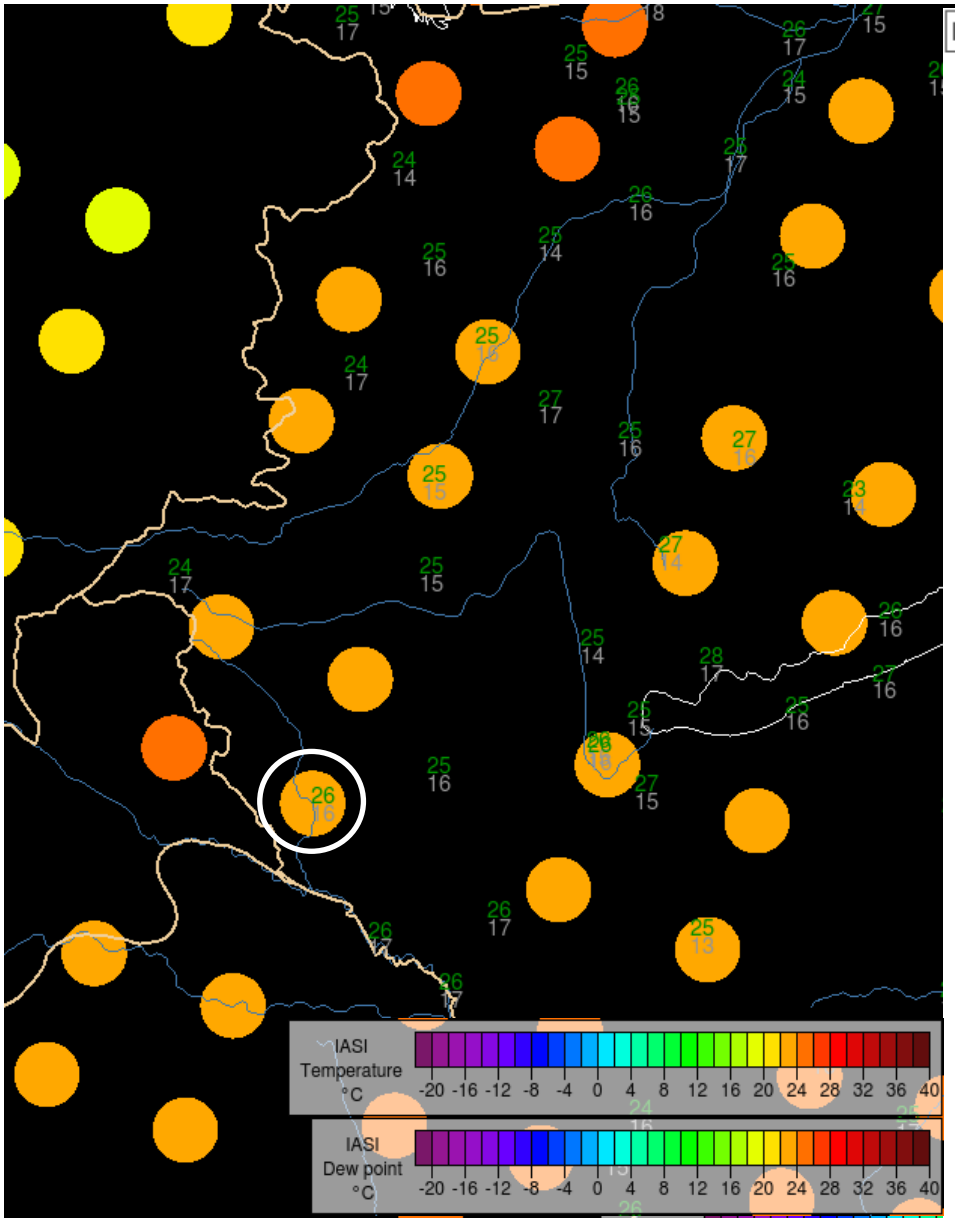


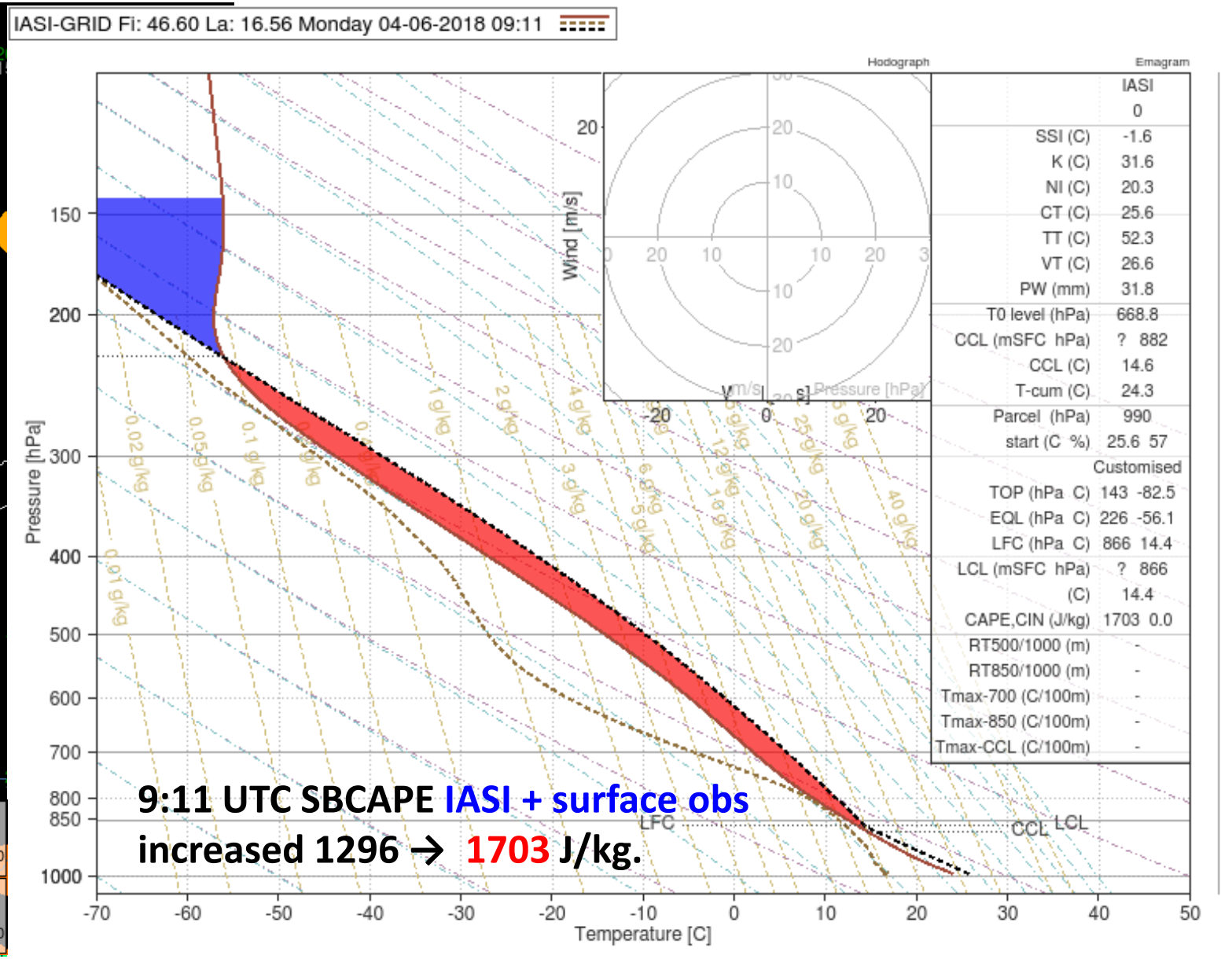
Studies with OMSZ – Blending satellite and surface observations





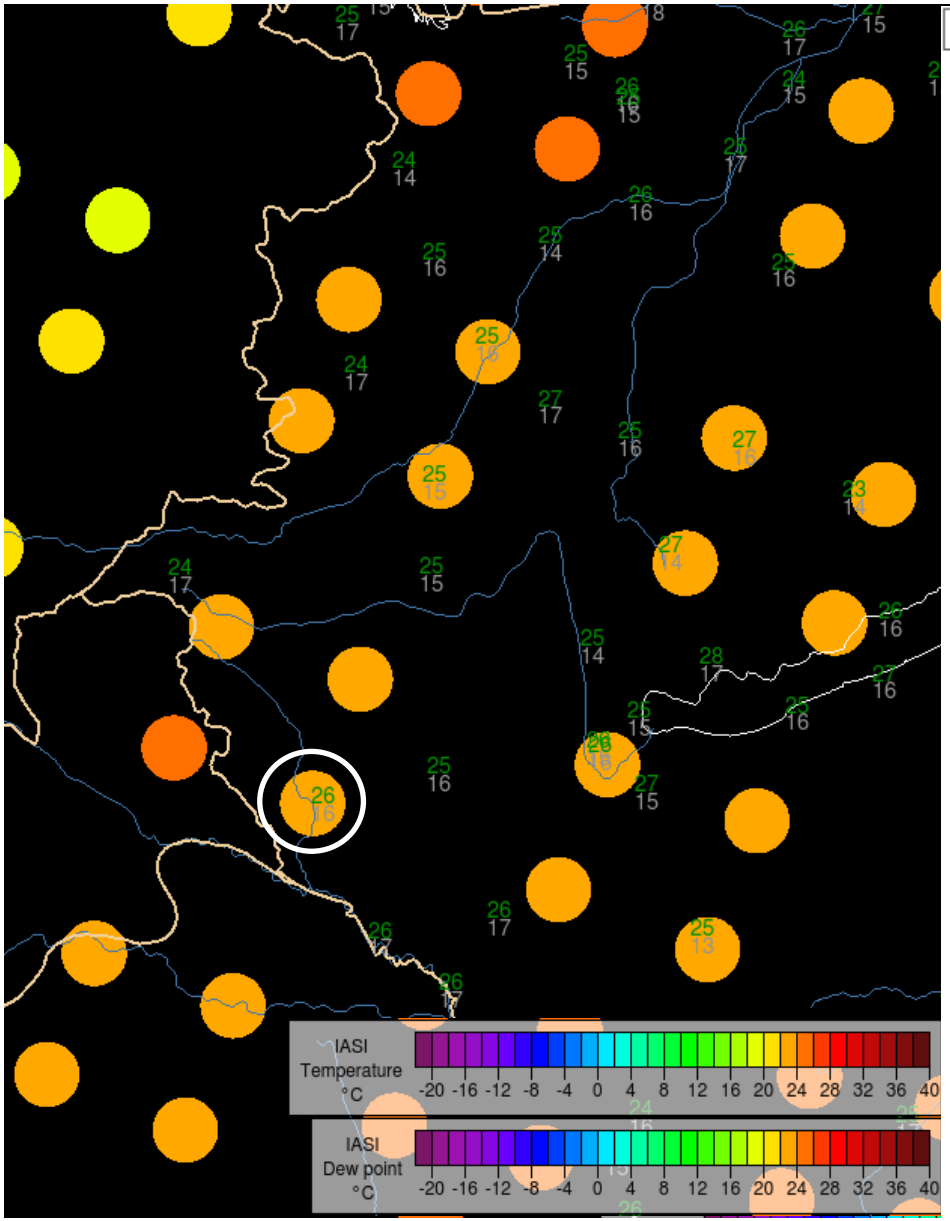
Studies with OMSZ – Blending satellite and surface observations

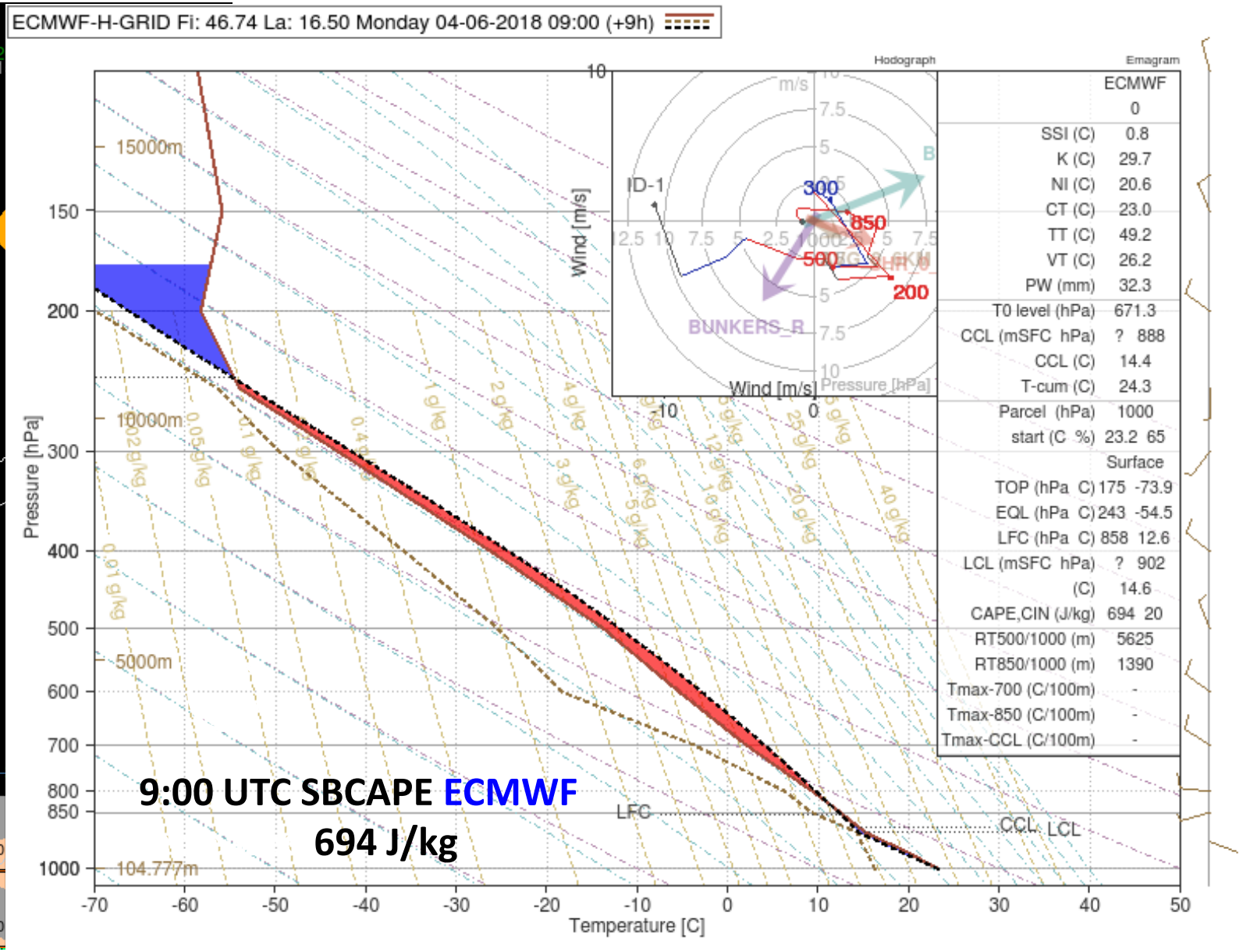




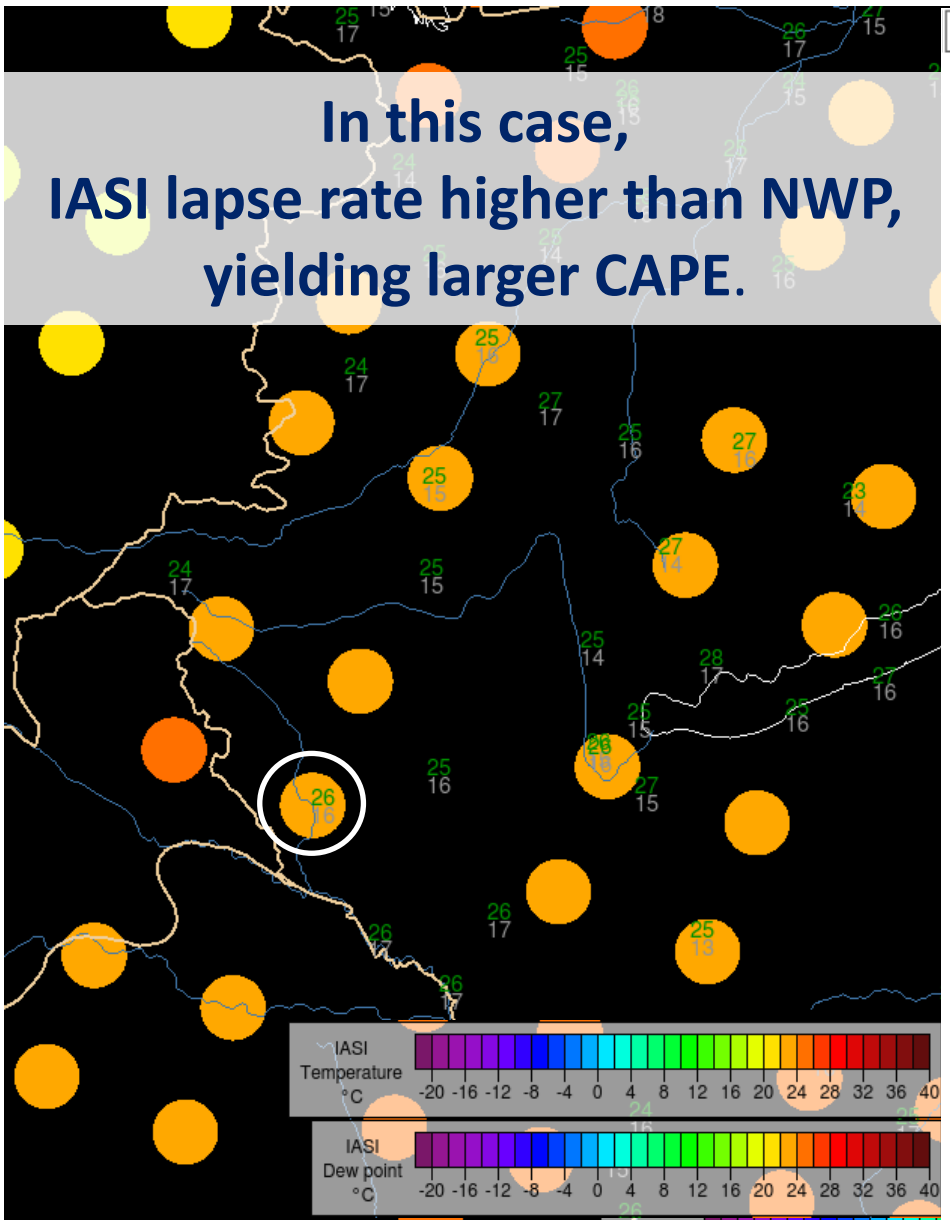
9:11 UTC SBCAPE IASI + surface obs increased 1296 → 1703 J/kg.

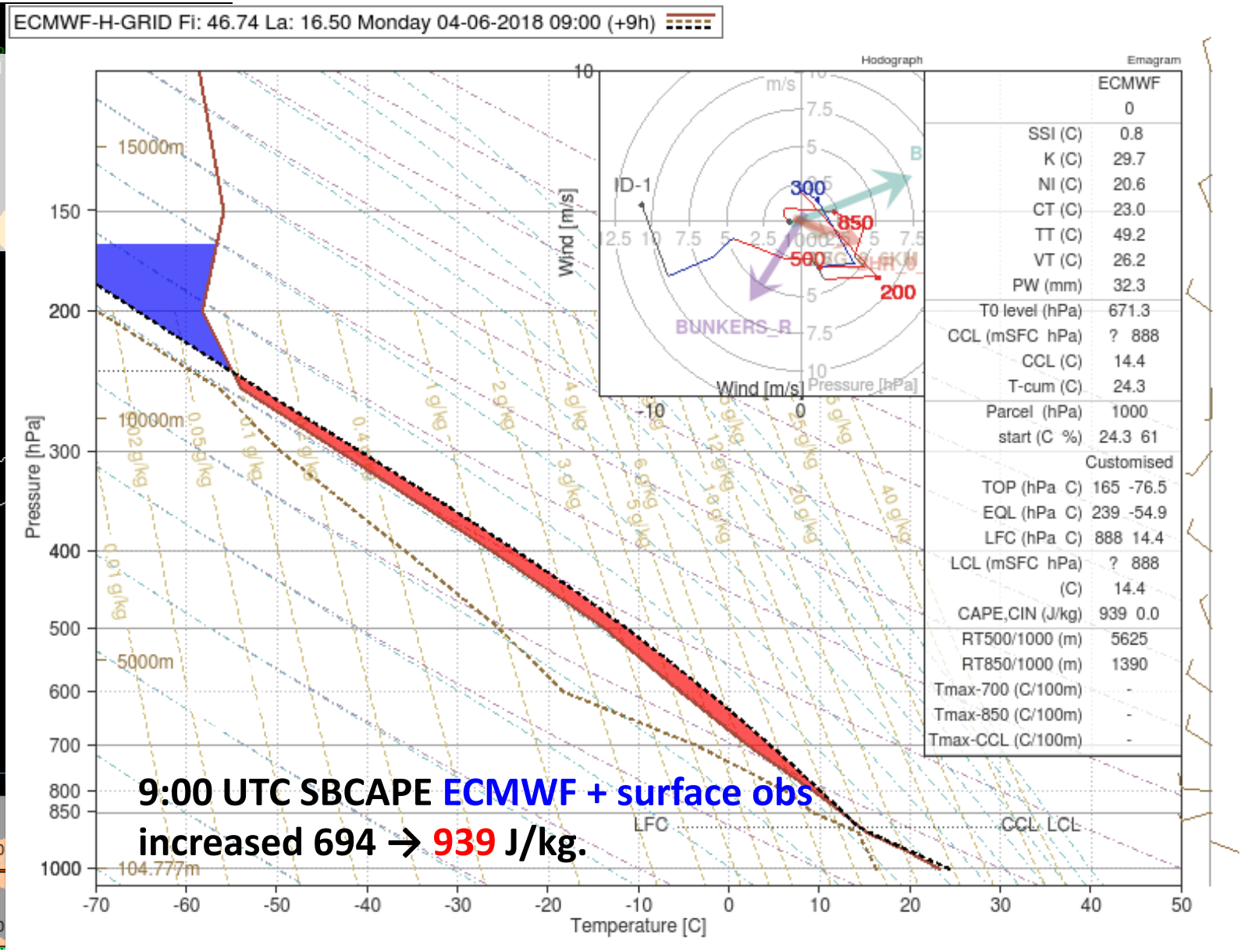
Studies with OMSZ – Blending satellite and surface observations





In this case,
IASI lapse rate higher than NWP,
yielding larger CAPE.





9:00 UTC SBCAPE ECMWF + surface obs
increased 694 → 939 J/kg.

Köszönöm !

Questions?

Hyperspectral meets forecasters

Forecast-free thermodynamic profiles:

most sensitive in free tropo,

but some potential in BDL too

Dialog with users → best actionable information?

Science goes on

Near-surface dry bias?

validate in pre-convective situations

blending satellite-ground obs.

synergy sounders - imagers

IASI regional service

Available within 15-30 min from sensing

MTG-IRS, a nowcasting mission

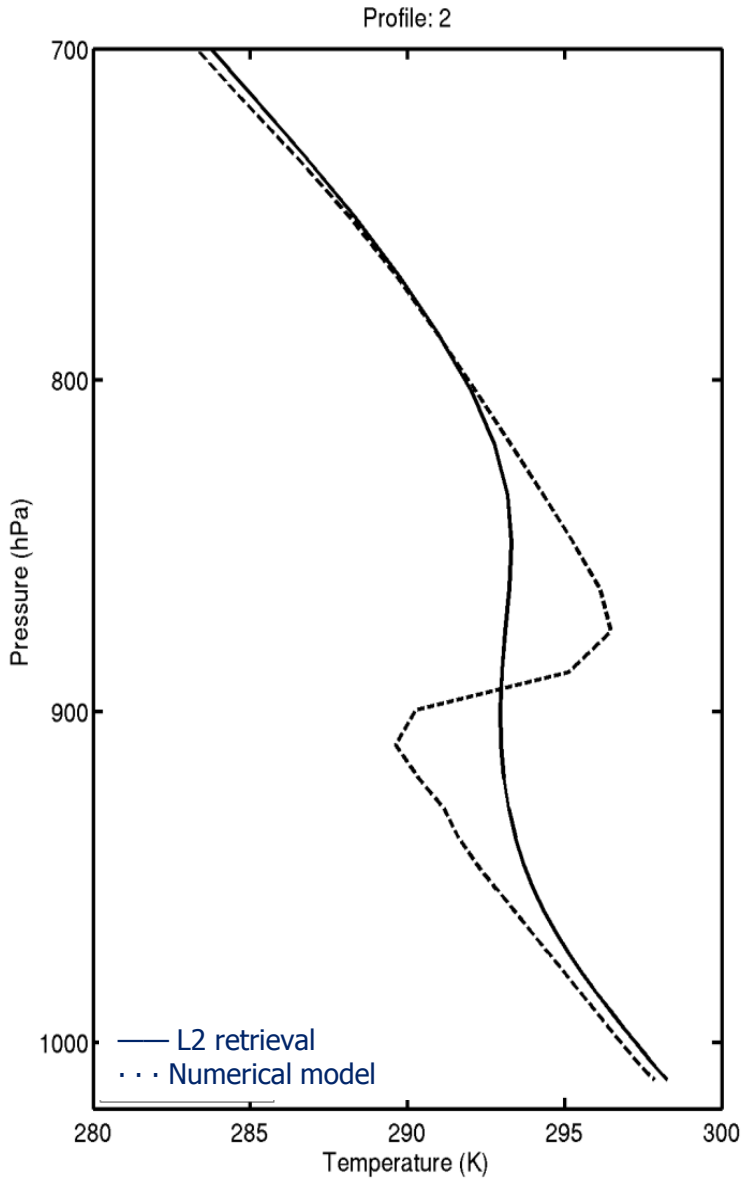
Unique 4D look into the atmosphere

Get ready! User familiarisation

Consolidate requirements

High lats and Polar missions...

- SPARE SLIDES



- Warning -

!! Small vertical structures have no signatures in IASI obs.

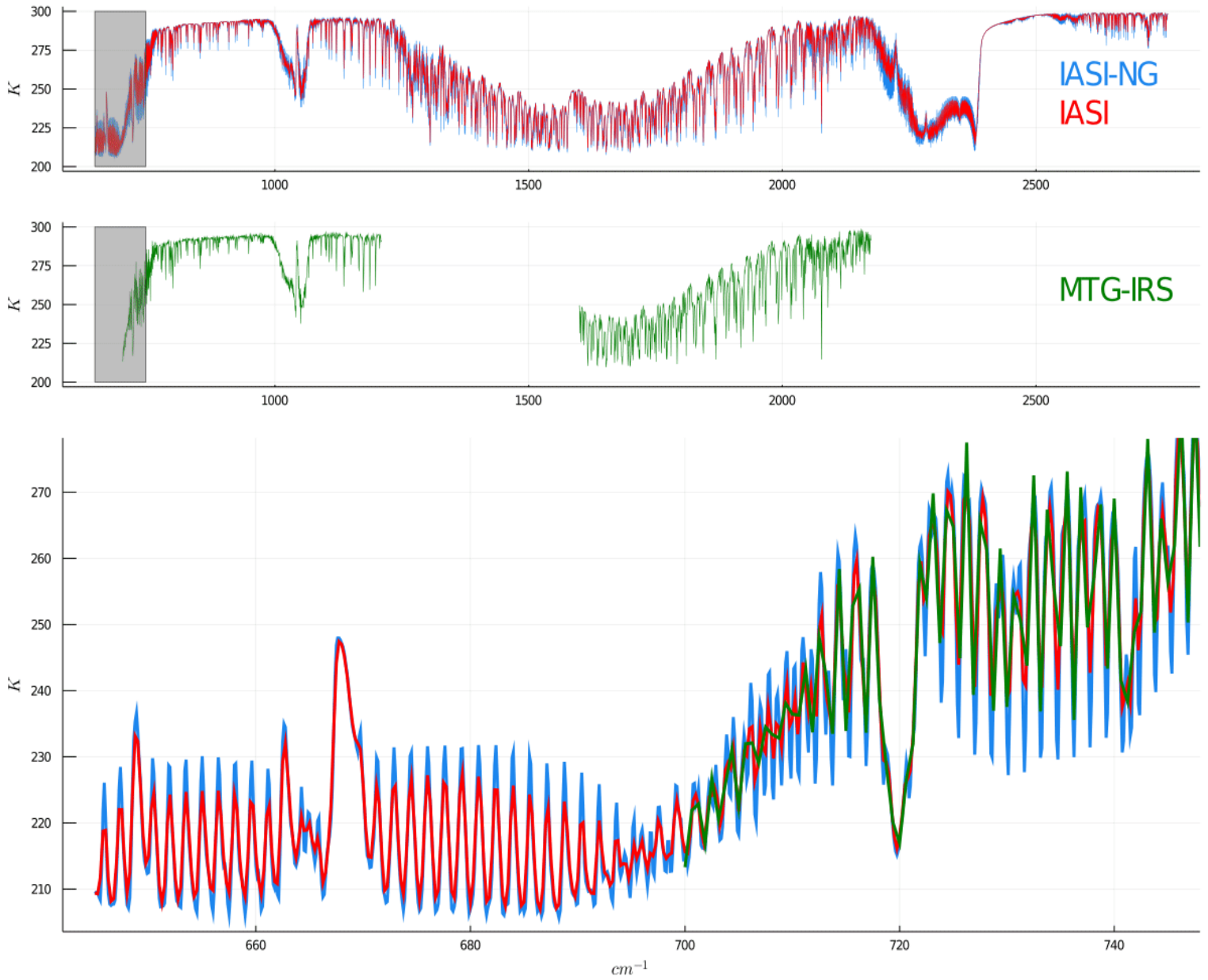
!! Sensitivity and resolution of hyperspectral sounders is lower near the surface.

The measurements do not contain information about e.g. small low-level inversion or fine-scale vertical variations.

What can be retrieved is hence smoother than profiles obtained from e.g. radiosondes, models

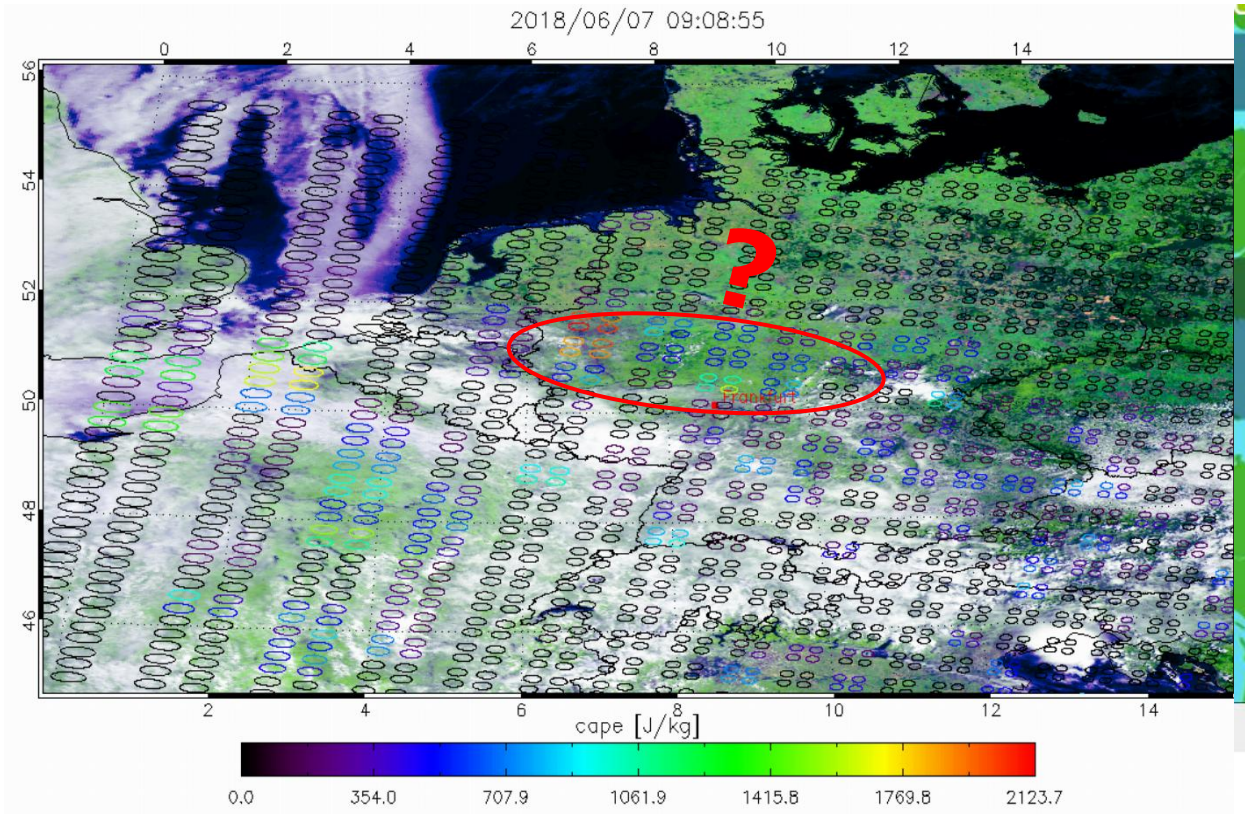
Requirements on IASI L2
Temperature 1K / 1km
Humidity 10% / 2km

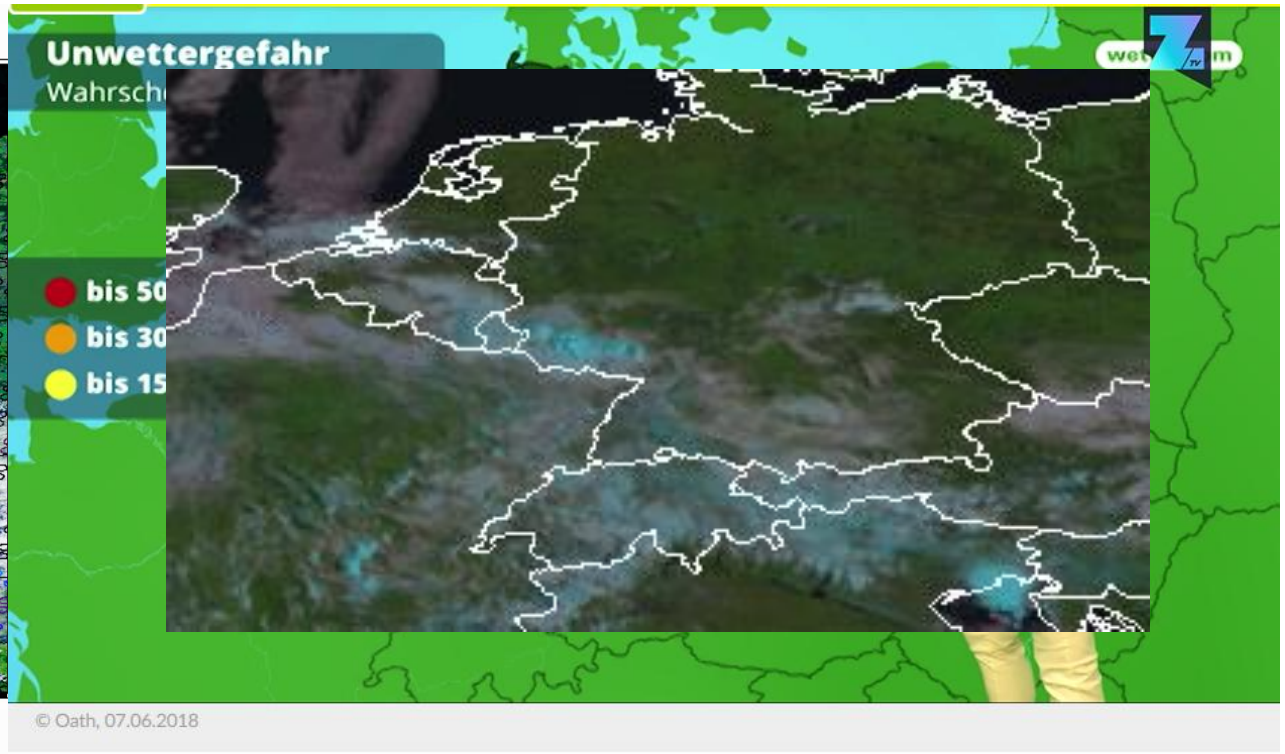
➔ *Actual performances, see presentation on 15/09/2020*


IASI-NG
IASI
MTG-IRS
K
cm^{-1}

Storm and flash flood Frankfurt – 07/06/2018

www.eumetsat.int





DAS WETTER IN DEUTSCHLAND AM 7. JUNI 2018

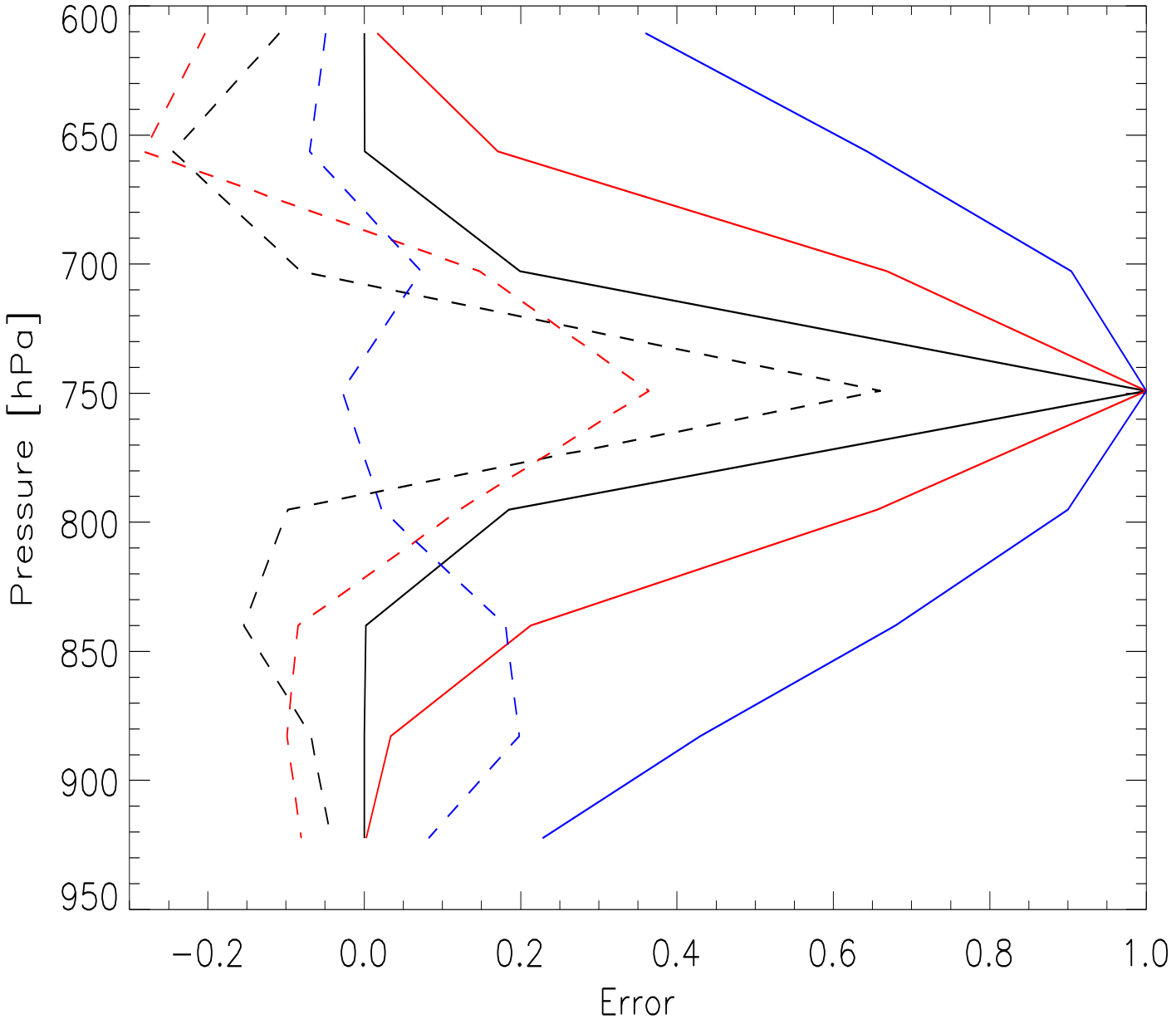
OEM formalism (Rodgers, 2000…)
Minimising

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

FCT
or not FCT ?

If so, which error
to assume?

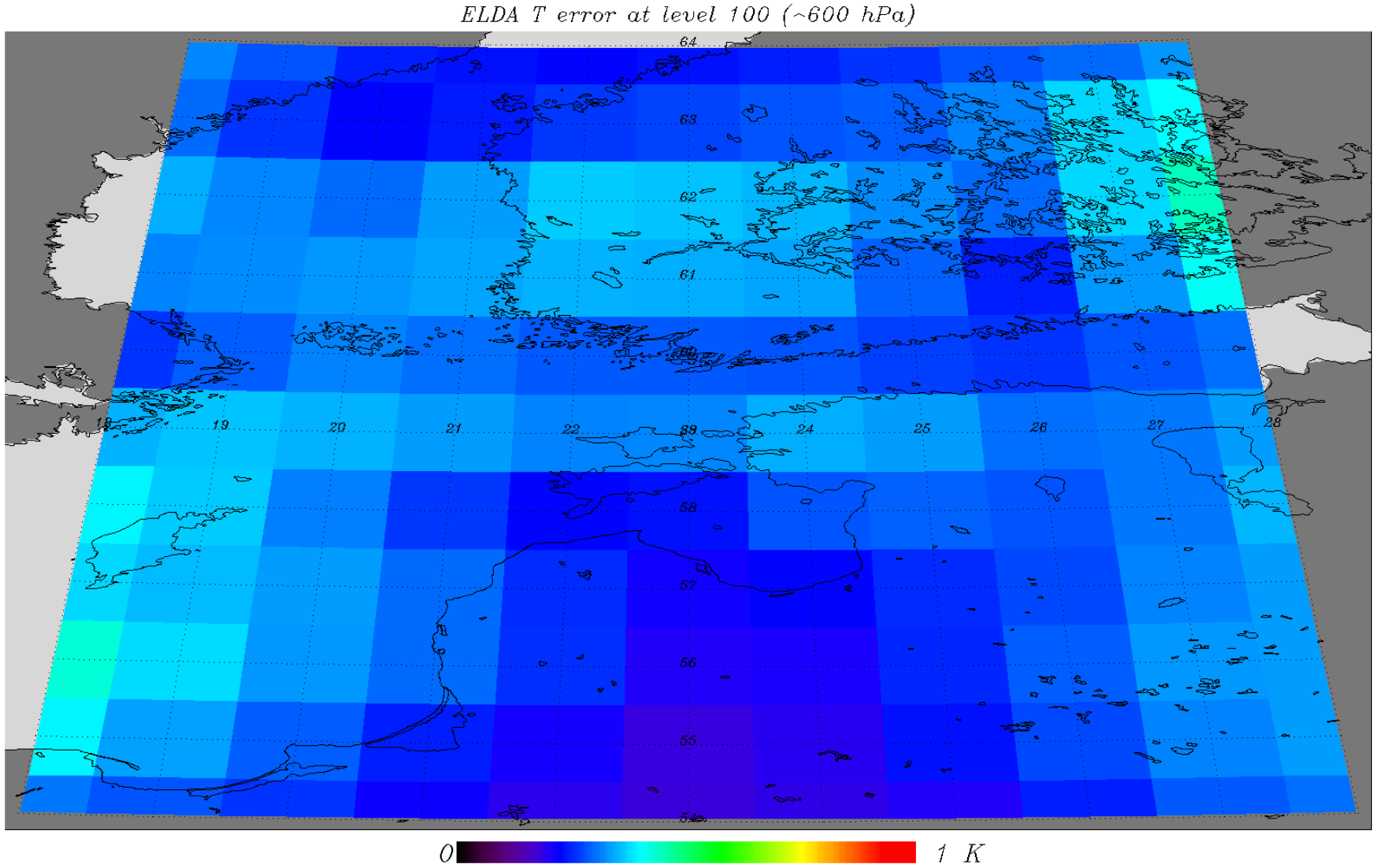
Fine structures *(not "seen" by IRS)* from prior to posterior



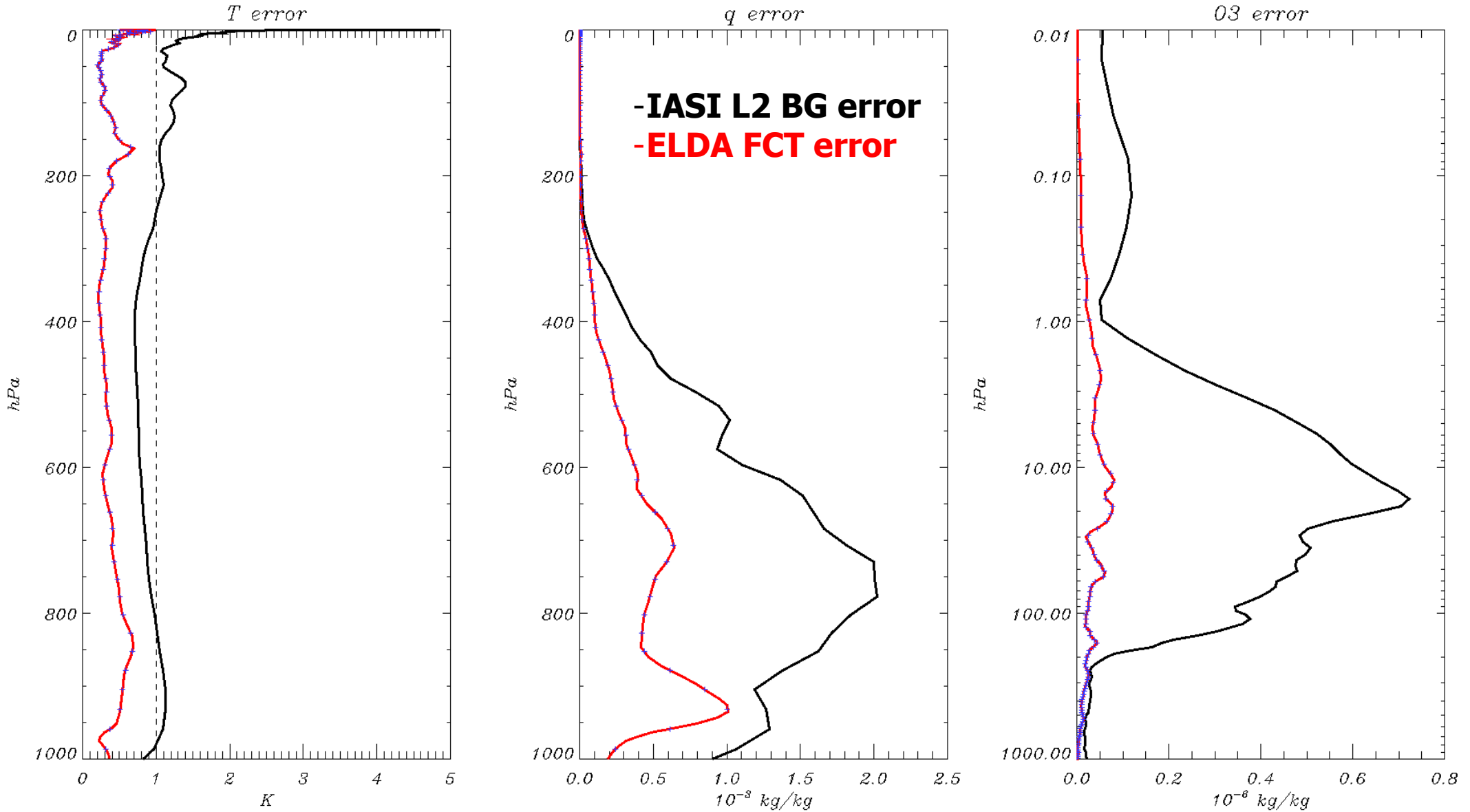
Propagation of prior structures (solid) into posterior retrieval (dash)

From MTG-IRS discussion paper, April 2011

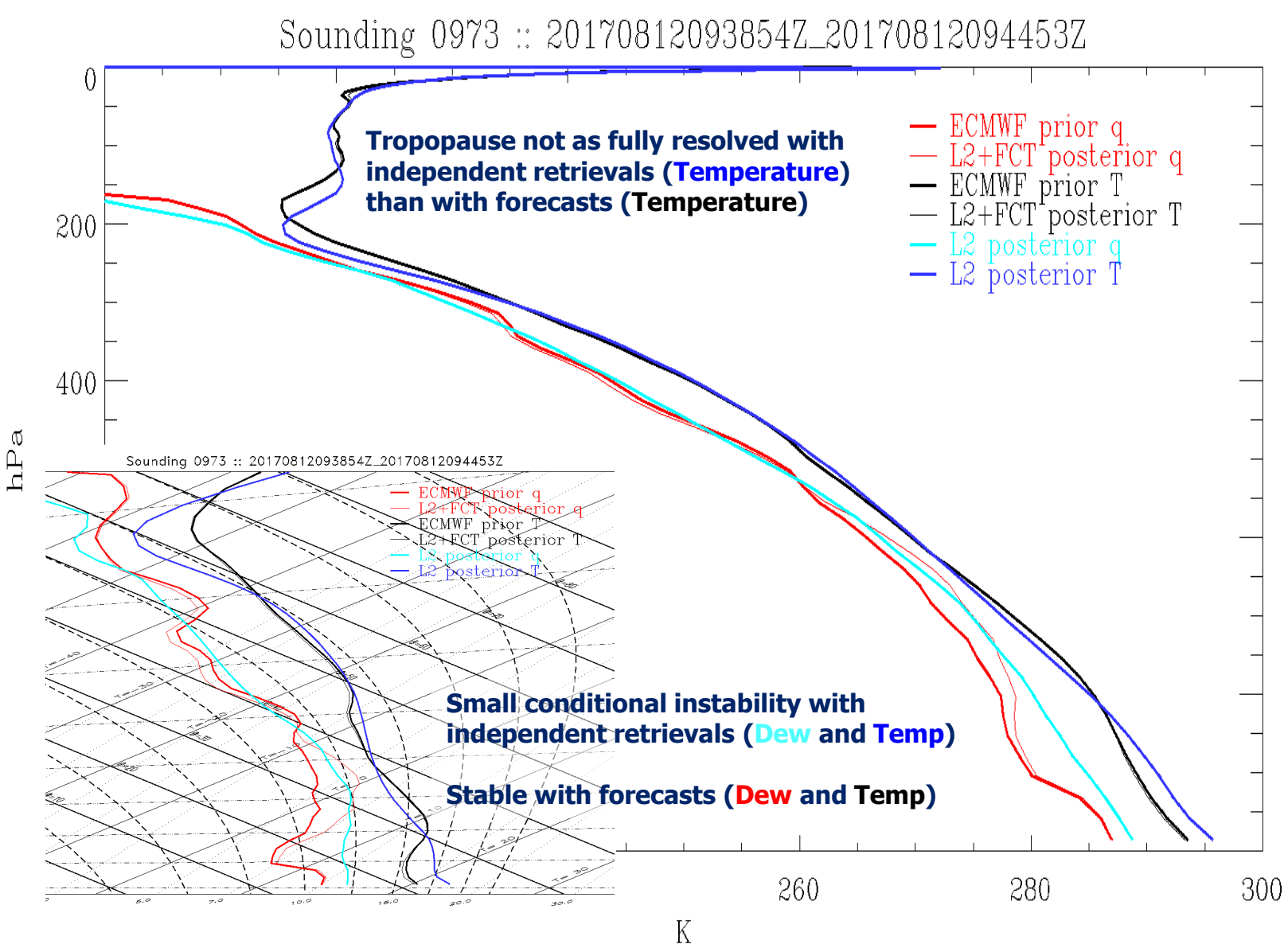
Experimenting ECMWF FCT and BG error in IASI L2 PPF

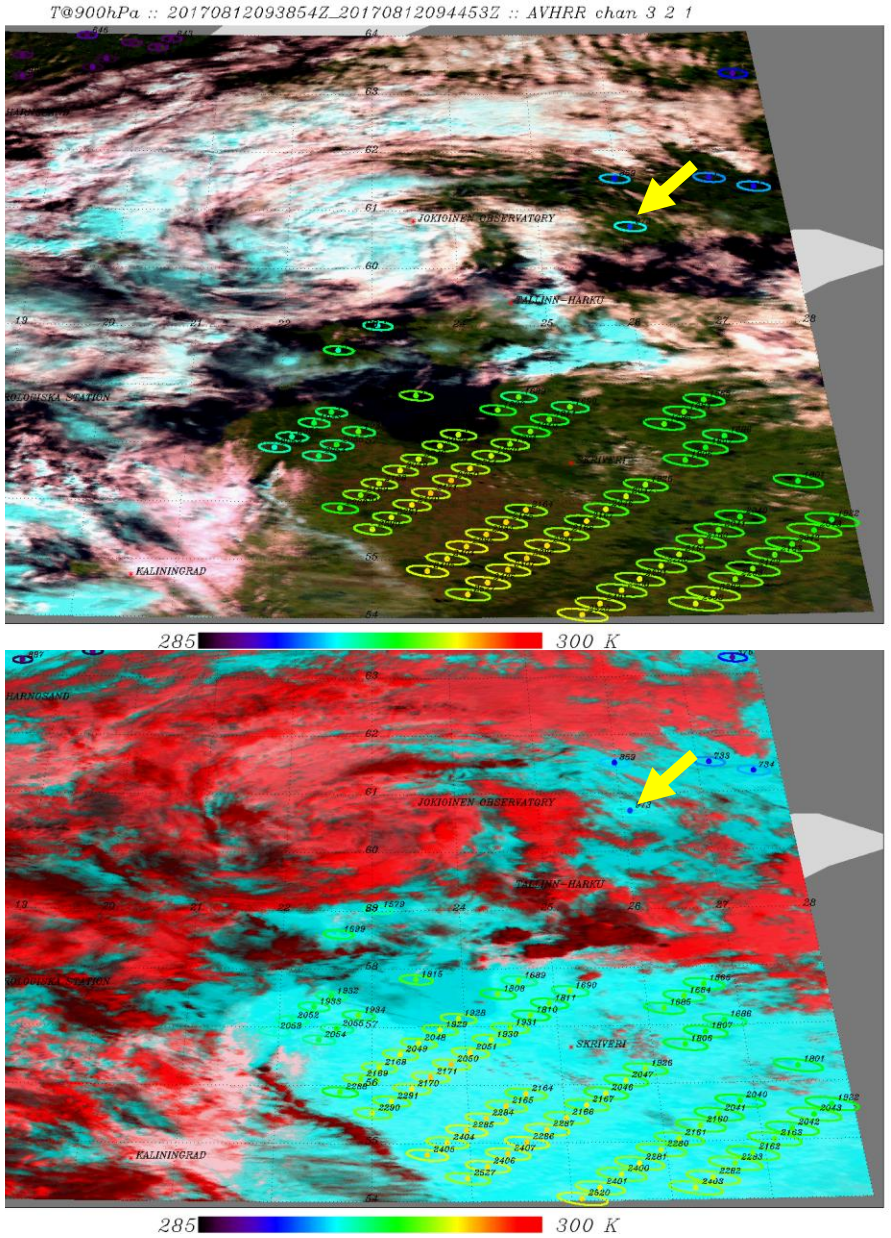


Experimenting ECMWF FCT and BG error in IASI L2 PPF



Retrieval dependency to forecasts? An experiment on 12/08/2017

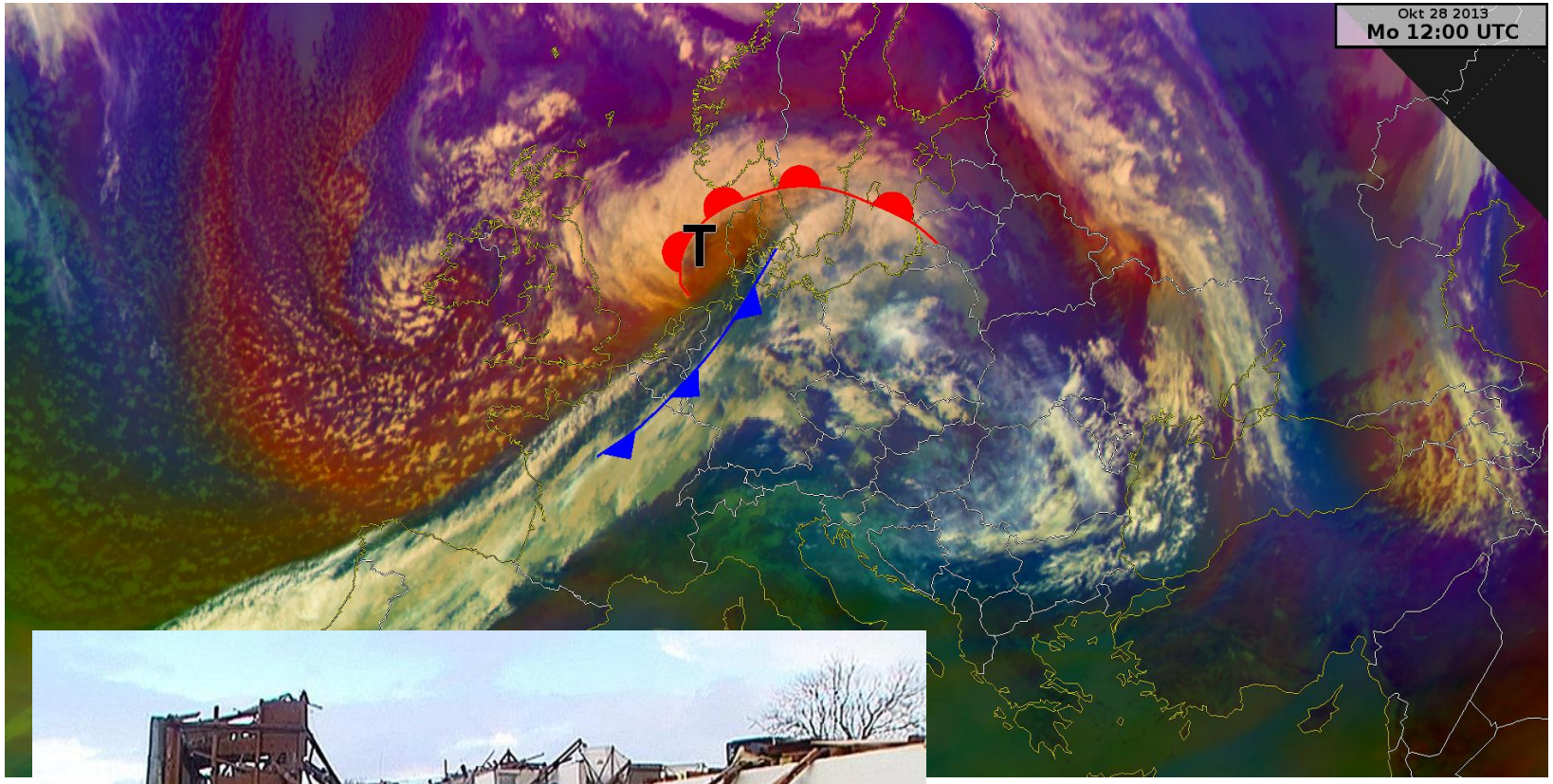




Cyclone Christian 27/10/2013

- Shapiro-Keyser **Cyclone „Christian“**
- Northern Europe 27-28/10/2013

- Hurricane-force gusts (sting jet)
- More than 15 people died
- Destructions, ground/air traffic chaos.
- Low-pressure system from Western Atlantic and passed over Southeast England, Northern Germany, Denmark and Sweden.
- Record breaking wind gust **191 km/h** at Helgoland (DE)



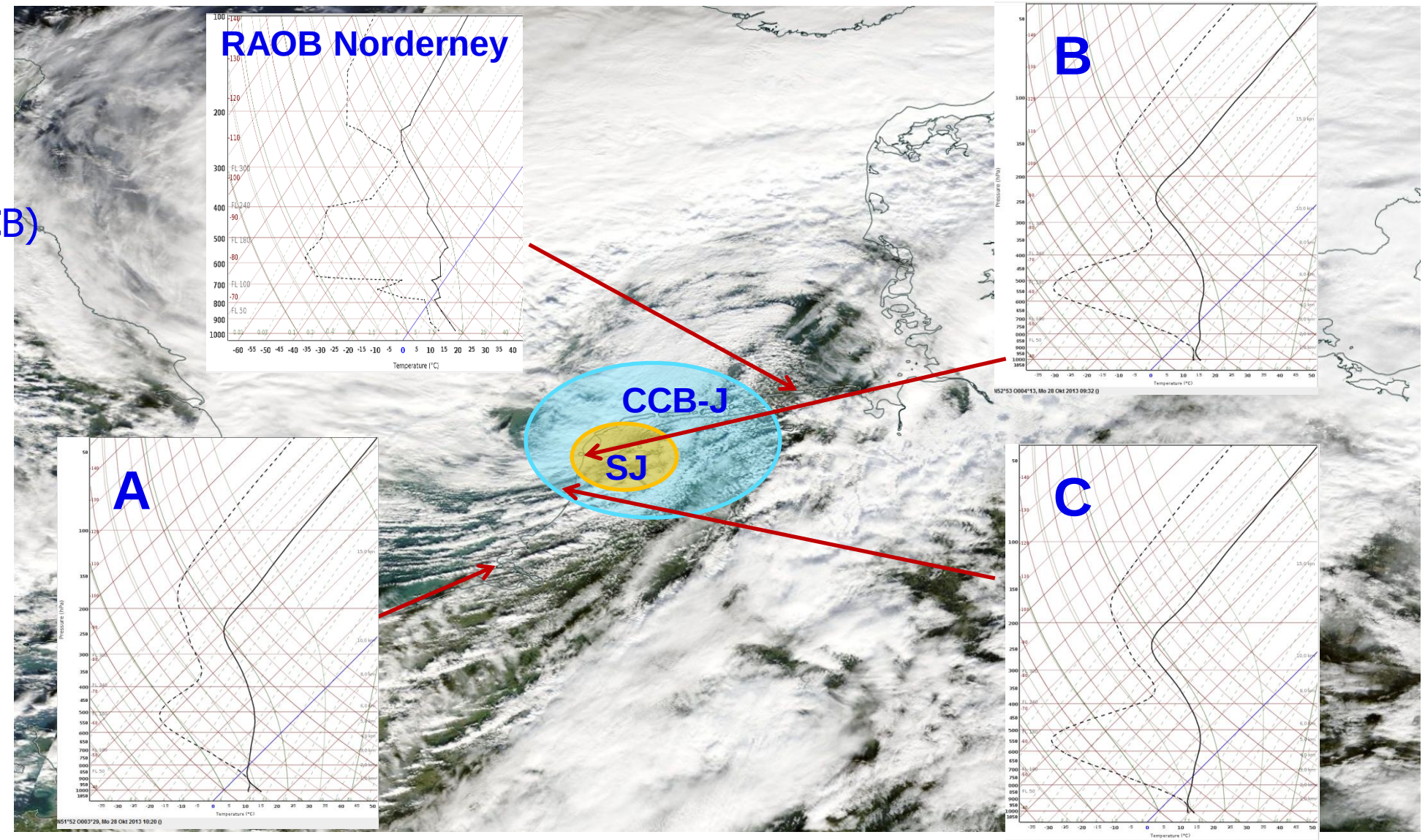
Credits: C. Herold et al. (DWD)

Deutscher Wetterdienst

Wetter und Klima aus einer Hand

IASI Profiles

in and around the Sting jet (SJ) and the Cold conveyor belt (CCB)



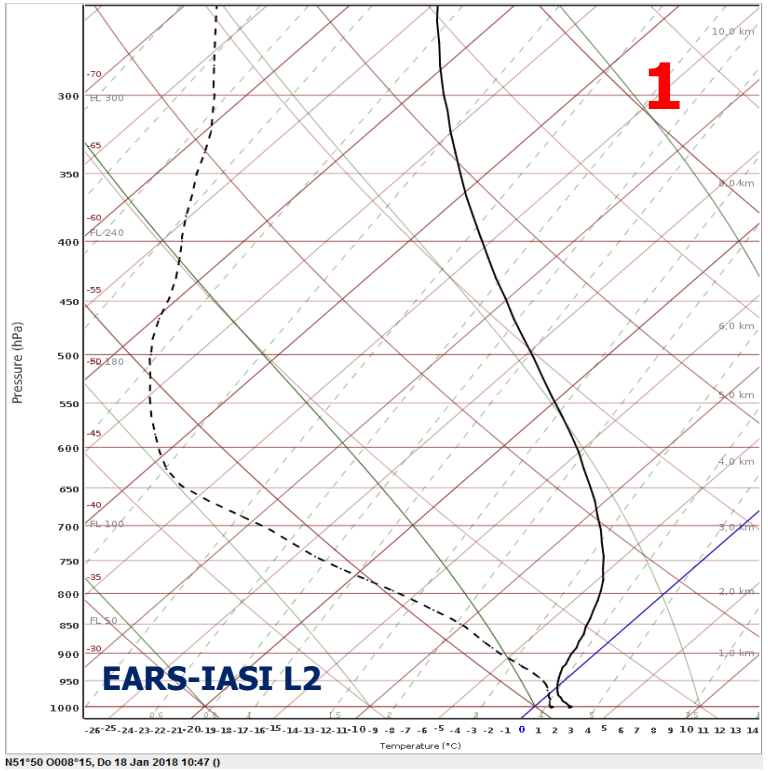
The descending dry stratospheric air in the sting jet area is clearly seen in IASI profiles B and C.

Both profiles agree well with te radiosonde.

Such profiles are extremely rare.

Case study: Cyclone Frederike 18/01/2018
(Shapiro-Keyser cyclone)

Forecast: The regional model COSMO-DE predicted the development of a sting jet with gusts up to 170 km/h. The challenge for the forecaster was to decide if the sting jet would reach the ground, resulting in fatal wind gusts.



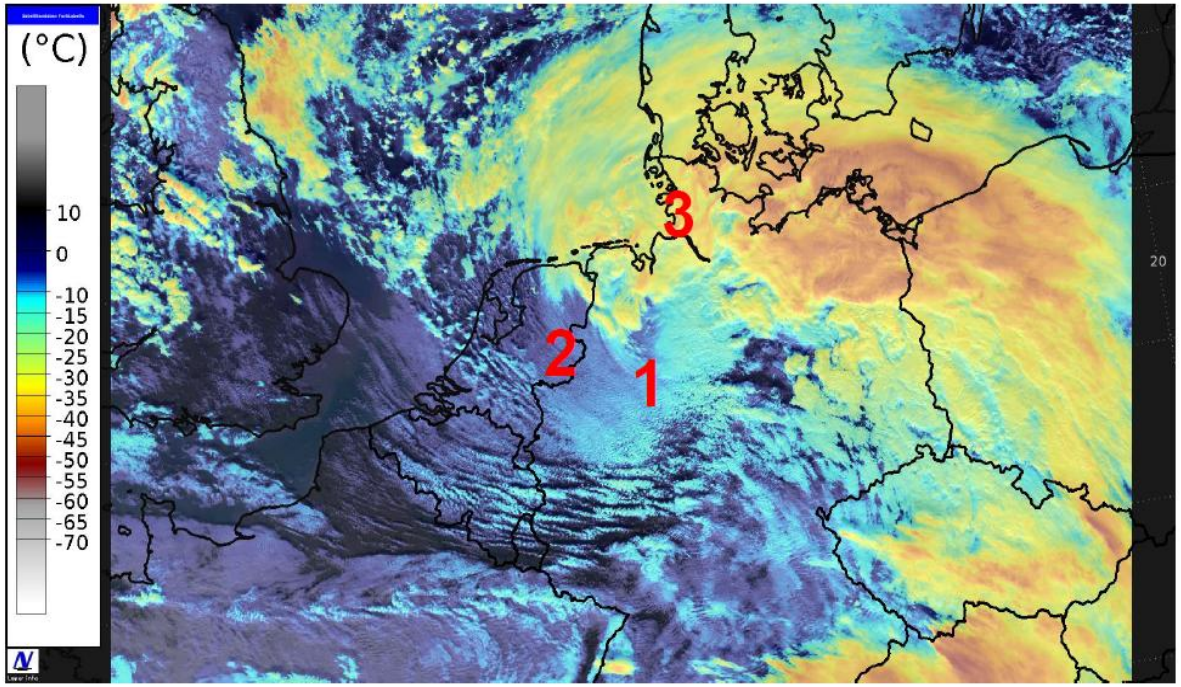


Fig.6: Suomi NPP VIIRS RGB image for 01-18-2018 11:30 UTC (top) and selected EARS-IASI L2 profiles (bottom) from the areas of the potential sting jet (1), the cold jet (2) and the cloud head (3). Source: DWD

Conclusion: COSMO-DE overestimated the gusts, but the stratocumulus clouds in the satellite picture and the IASI-Soundings (showing strong boundary layer) gave hints that the Sting Jet wouldn't reach the surface in the low lands.

Credits: K. Hungershöfer et al. (DWD)
"Are EARS-IASI L2 products useful for Nowcasting?"
EUM User conference, Tallinn 2018