Water-vapour profiles from EUM sounders, characteristics and application in weather forecasting

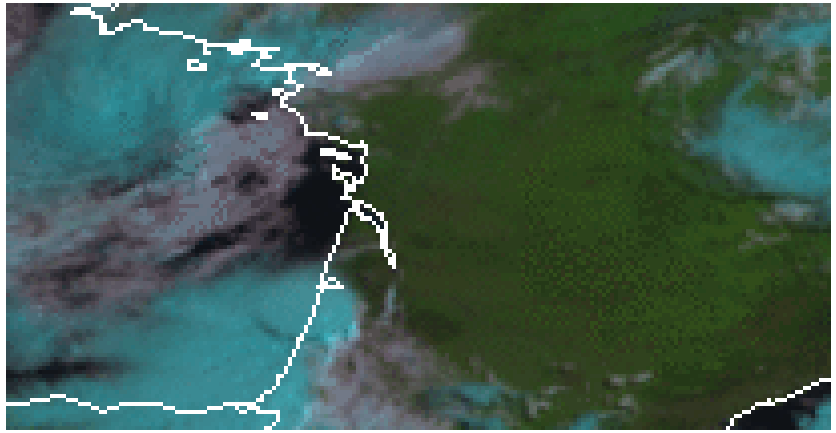
Thomas August + EUM L2* and external study teams
EUMETSAT

Event Week Water-Vapou nline, 13/12/2022

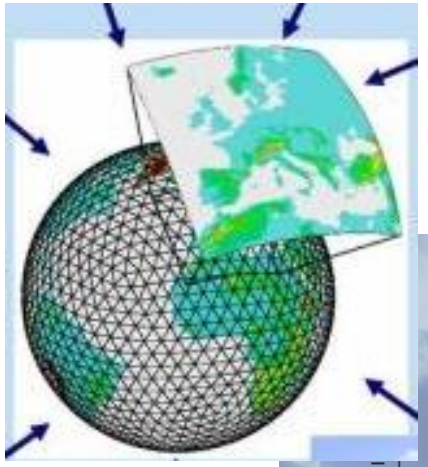
** Tim Hultberg,*
Marc Crapeau,
Stefan Stapelberg

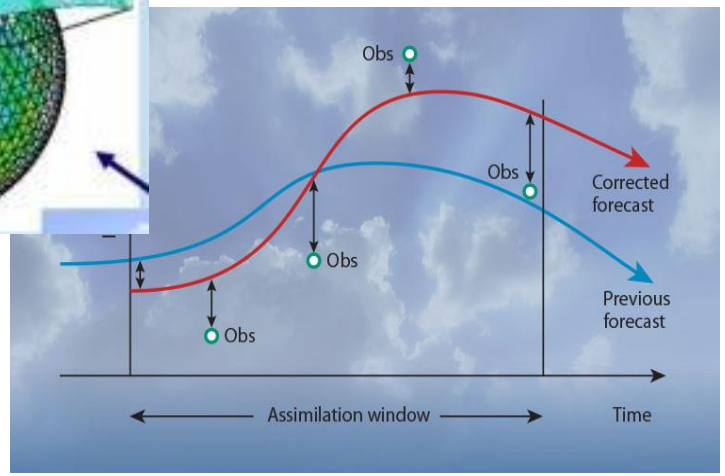
… water-vapour satellite products…

Anticipating severe weather



before clouds develop





NWP

NWC

Agenda

EUM sounders

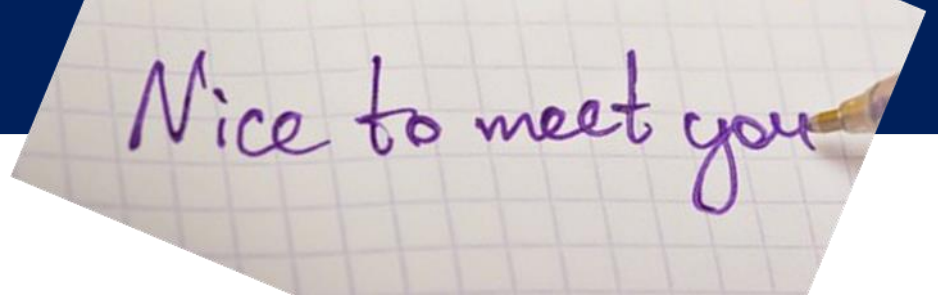
Missions and sampling overview

Products characteristics

Validation, uncertainty estimates

Application and case studies

IASI regional service, preparing future missions



Forecaster

Research & Dev

Manager

Student

Ever heard of IASI or hyperspectral sounding L2 products?

First time
Nice meeting you!

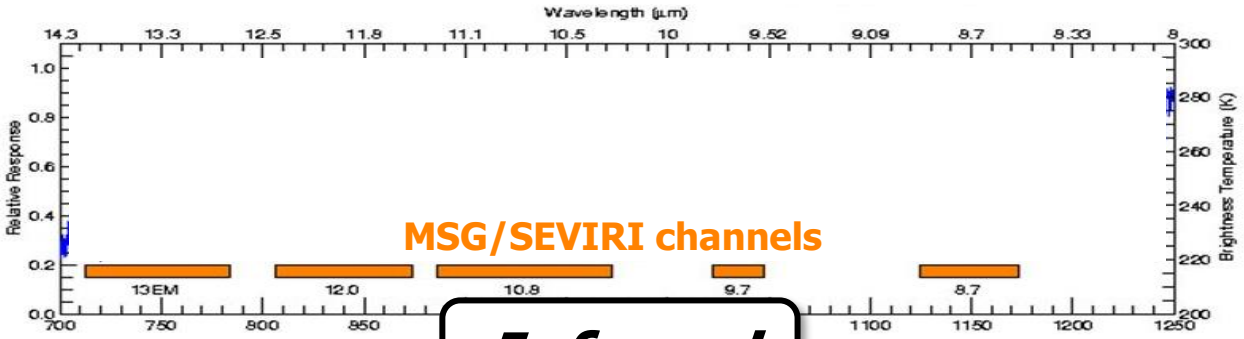
I know someone who had some already
(and they liked it!)

I have seen some

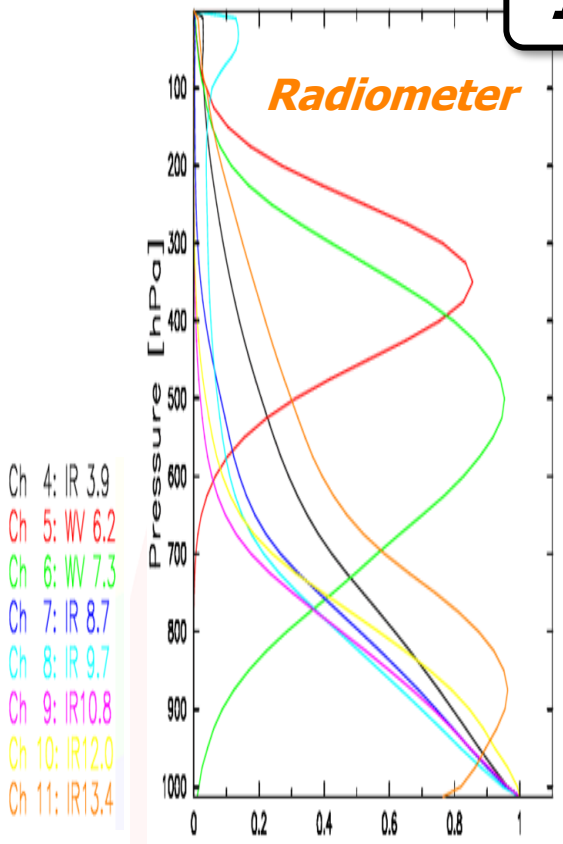
I have tried some

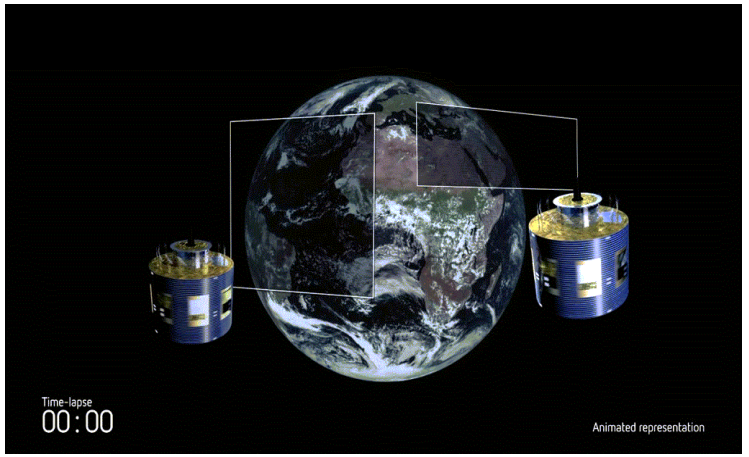
Using it operationally

Atmospheric « profiles » with traditional satellite imagery



Infrared

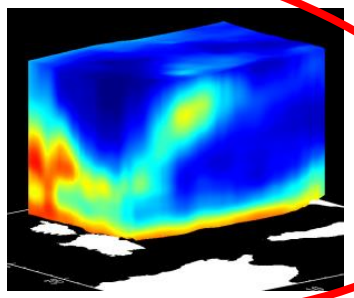


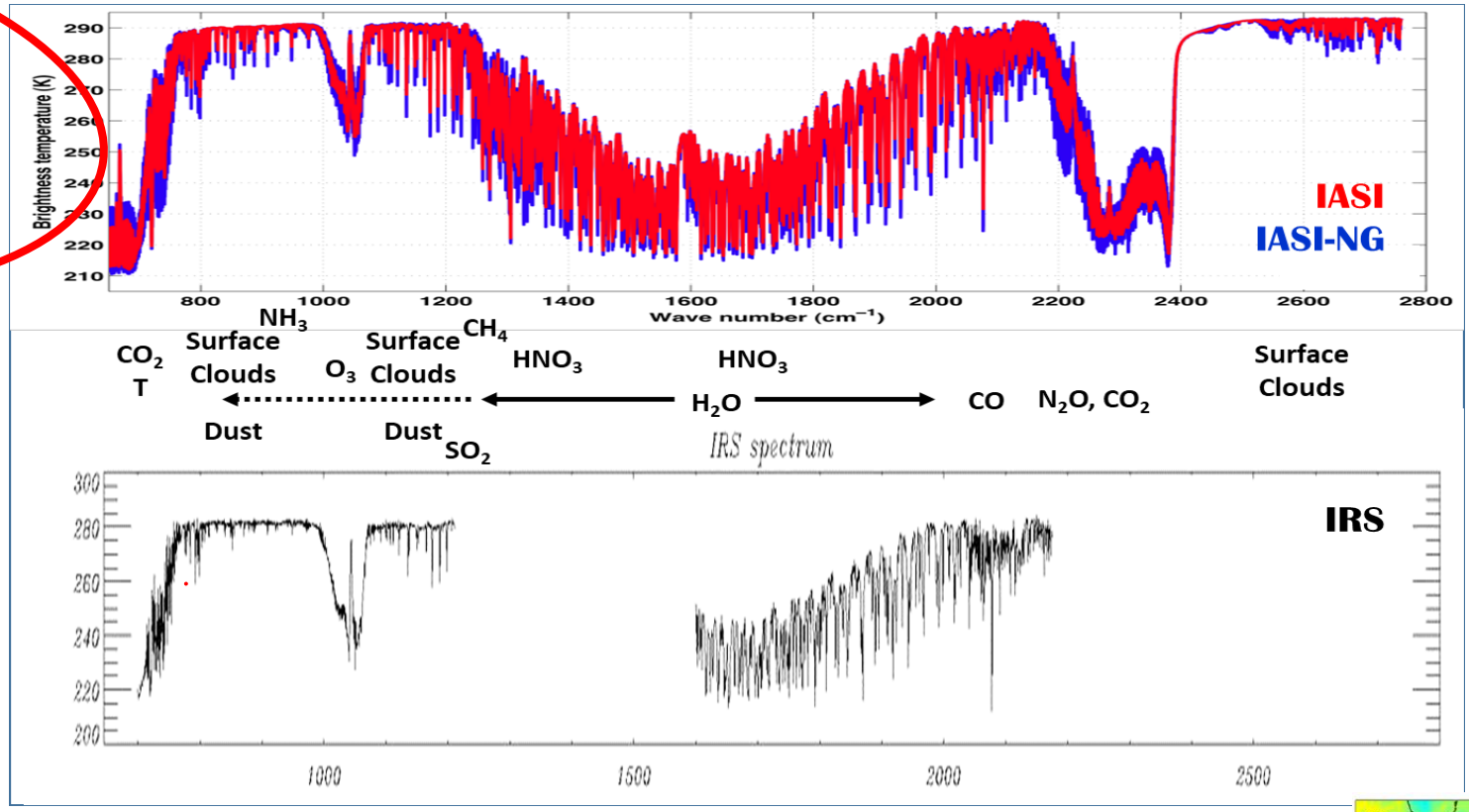


MSG/SEVIRI

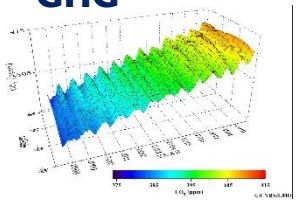
The hyperspectral sounding "Swiss army knife"

Temperature, Humidity profiles

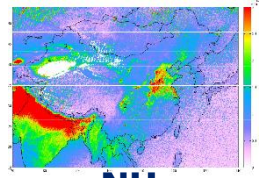




GHG

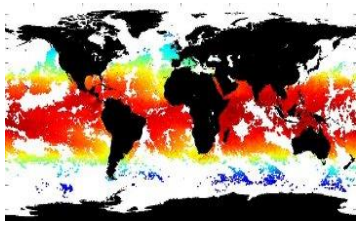


Cloud mask, fraction, top height



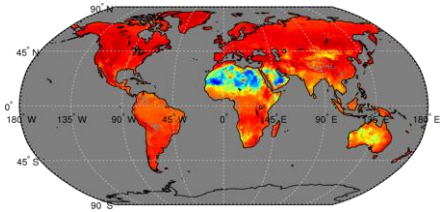
NH_3

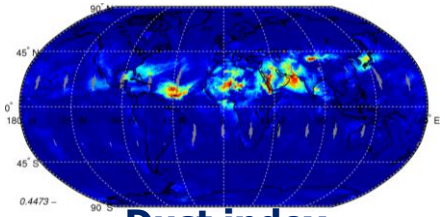
Sea surface temperature



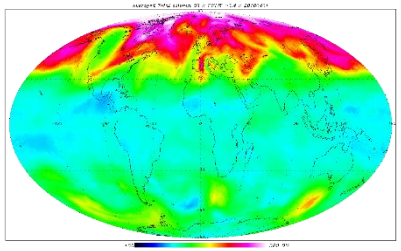
SO_2

Land surface temperature and emissivity

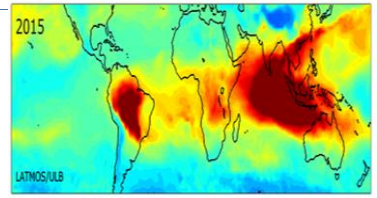




Dust index

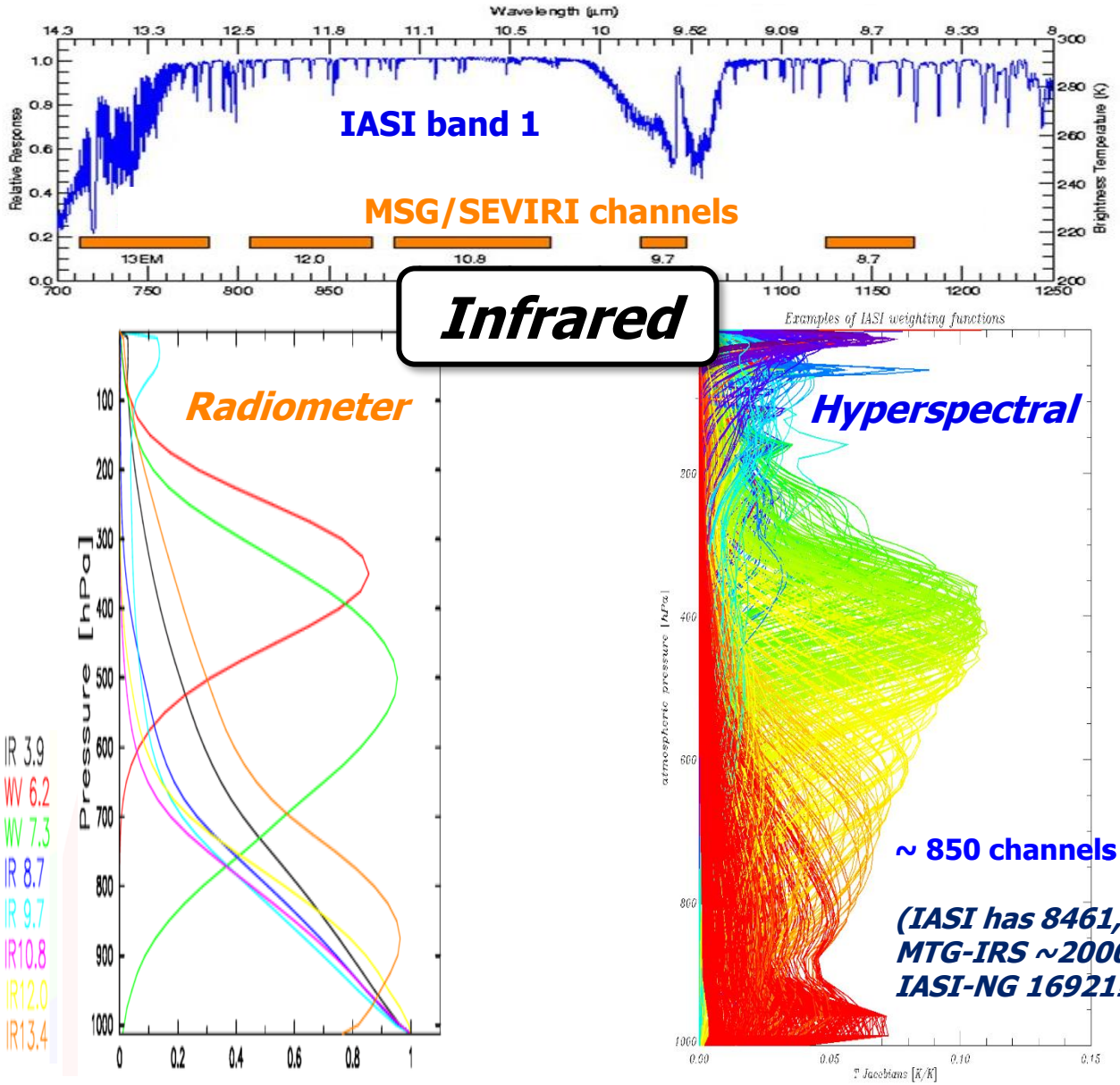


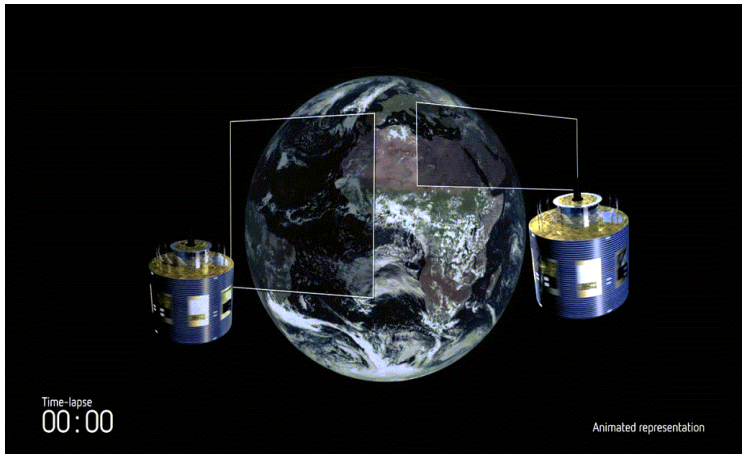
Ozone



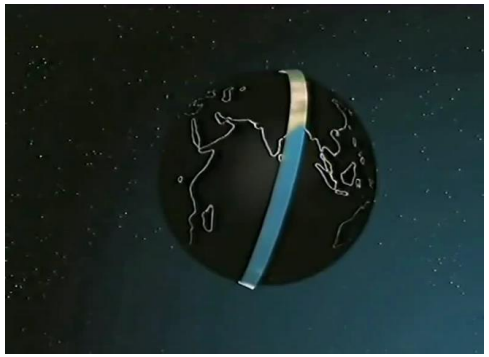
Carbon monoxide

Atmospheric profiles with hyperspectral IR sounders



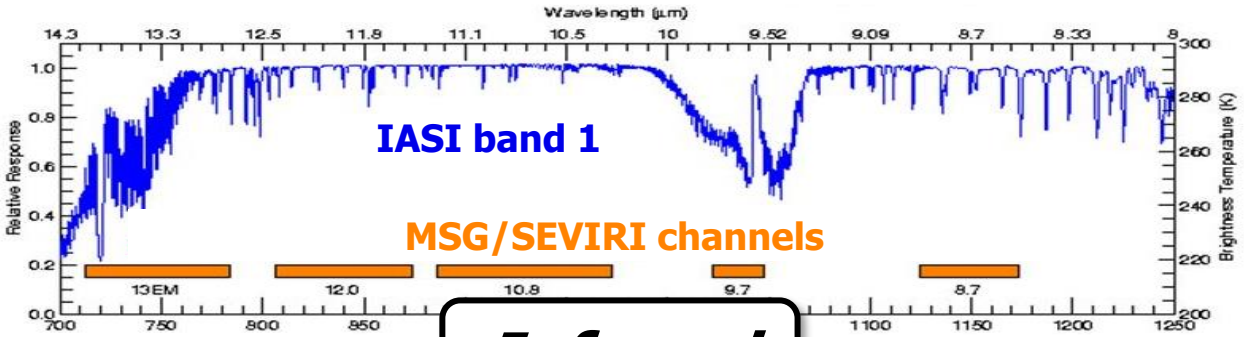


MSG/SEVIRI
MTG/IRS

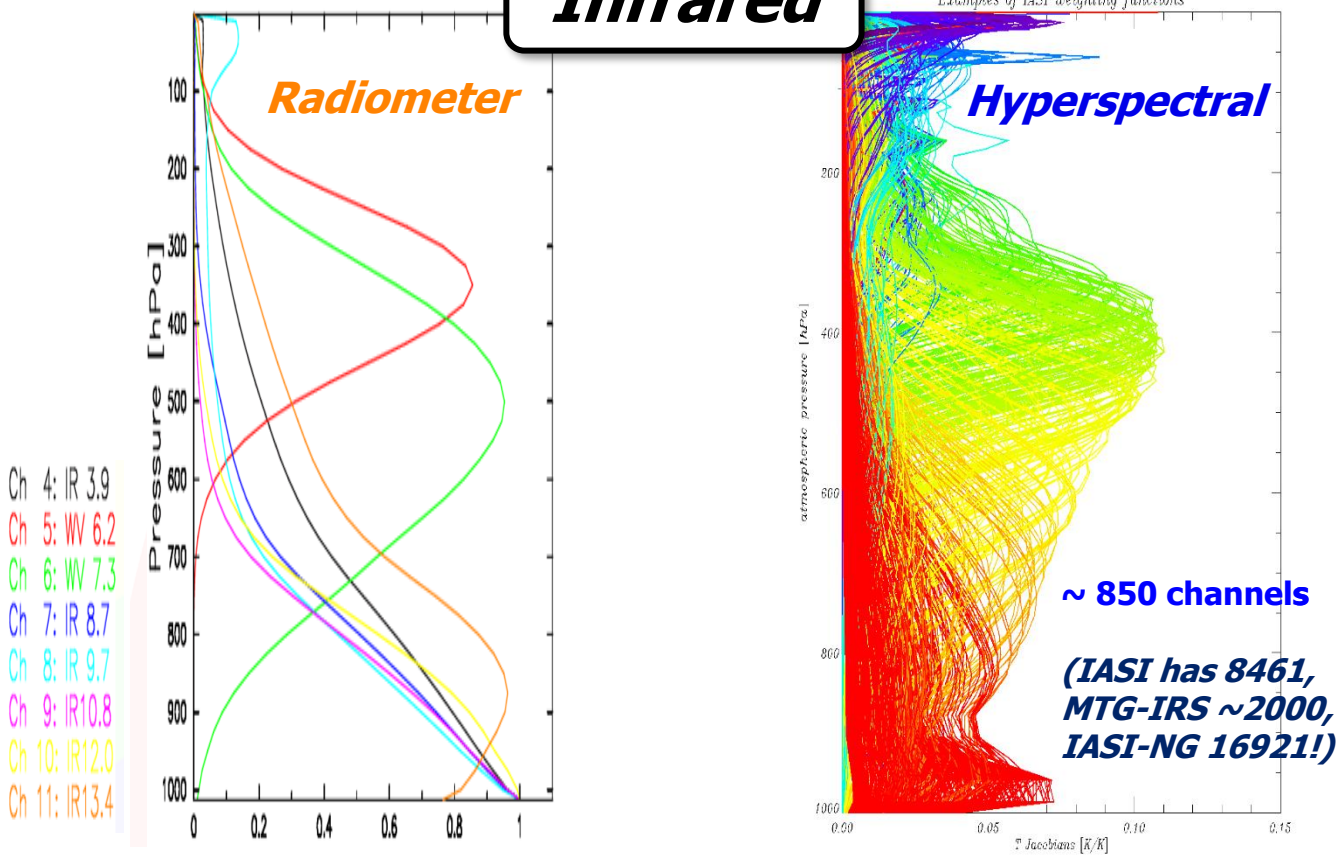


EPS/IASI
EPS-SG/IASI-NG

Atmospheric profiles with hyperpectral IR + MW sounders



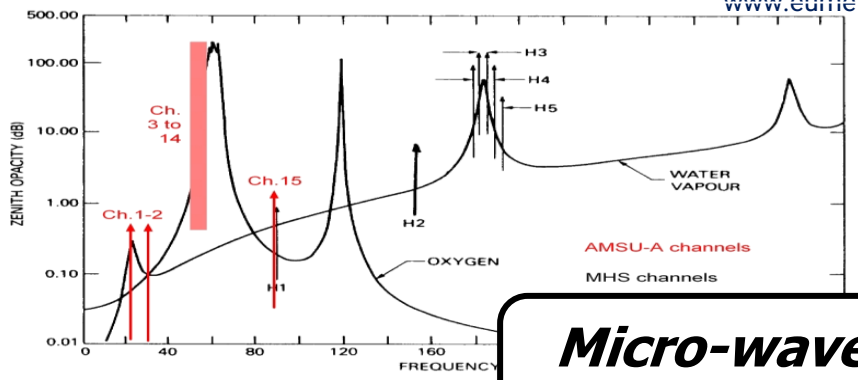
Infrared



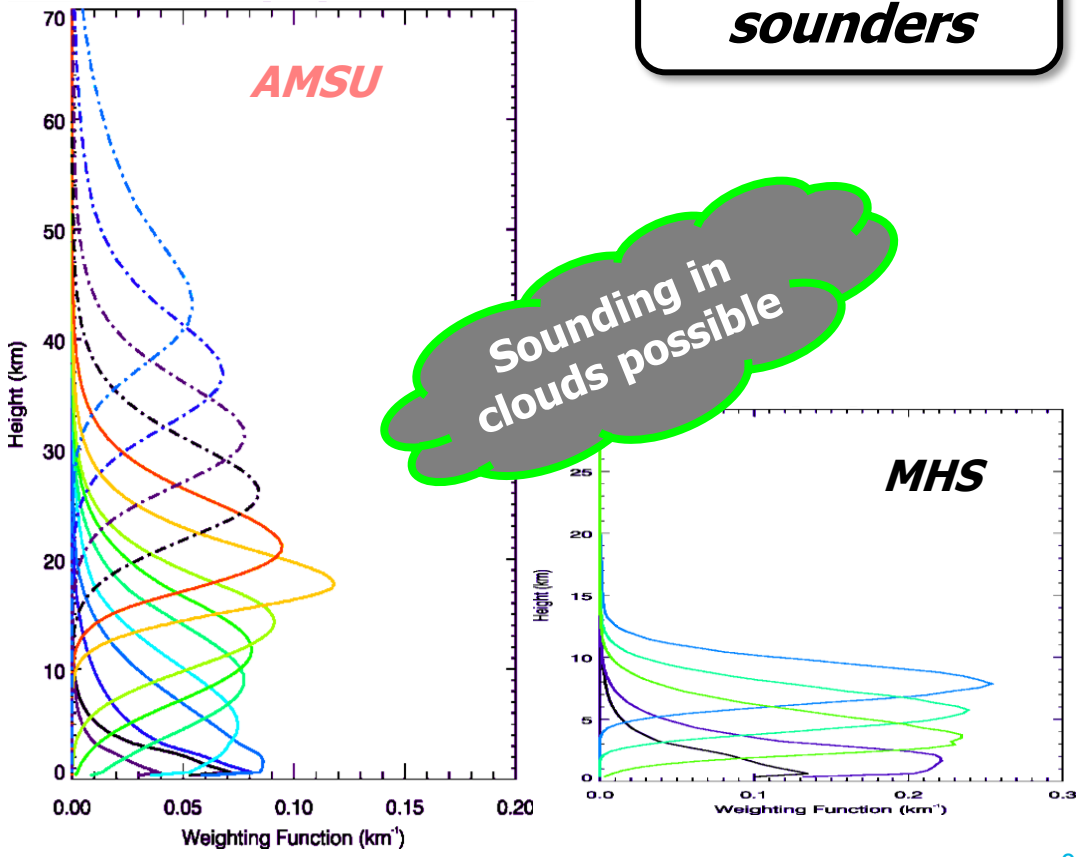
~ 850 channels

(IASI has 8461, MTG-IRS ~2000, IASI-NG 16921!)

www.eumetsat.int



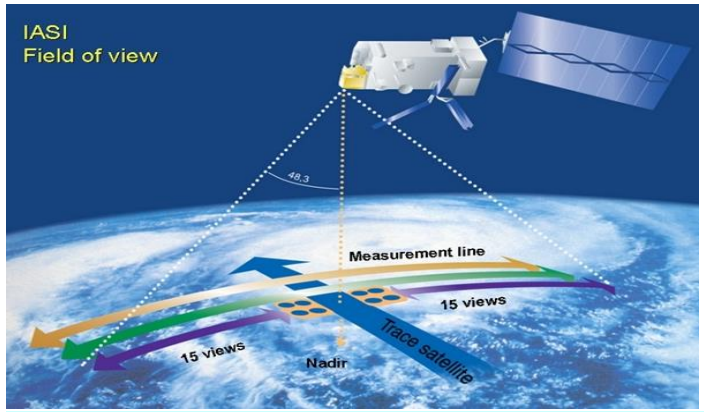
Micro-wave sounders

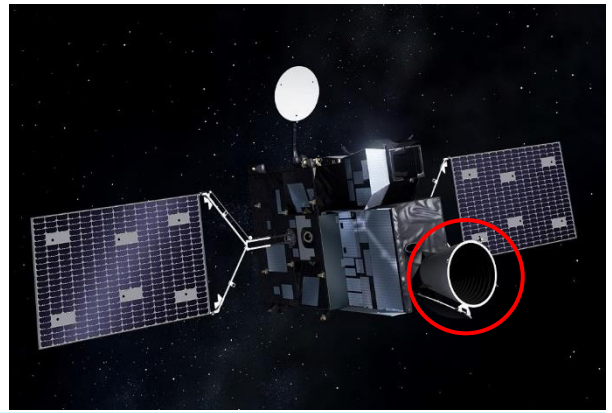


Sounding in clouds possible

EUMETSAT hyperspectral sounders

EPS EPS-SG MTG

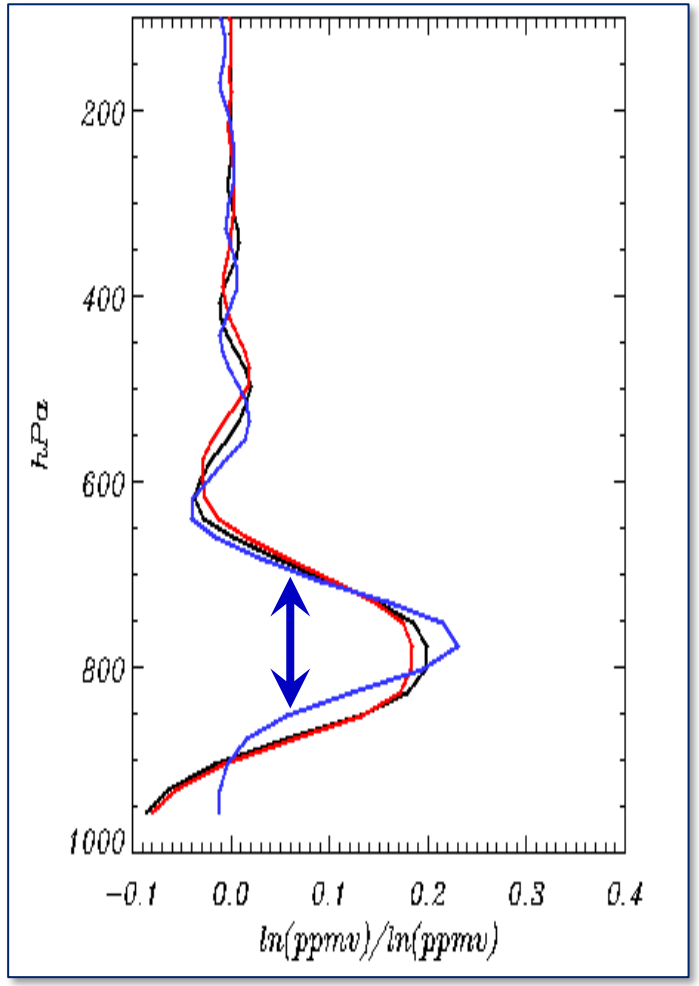




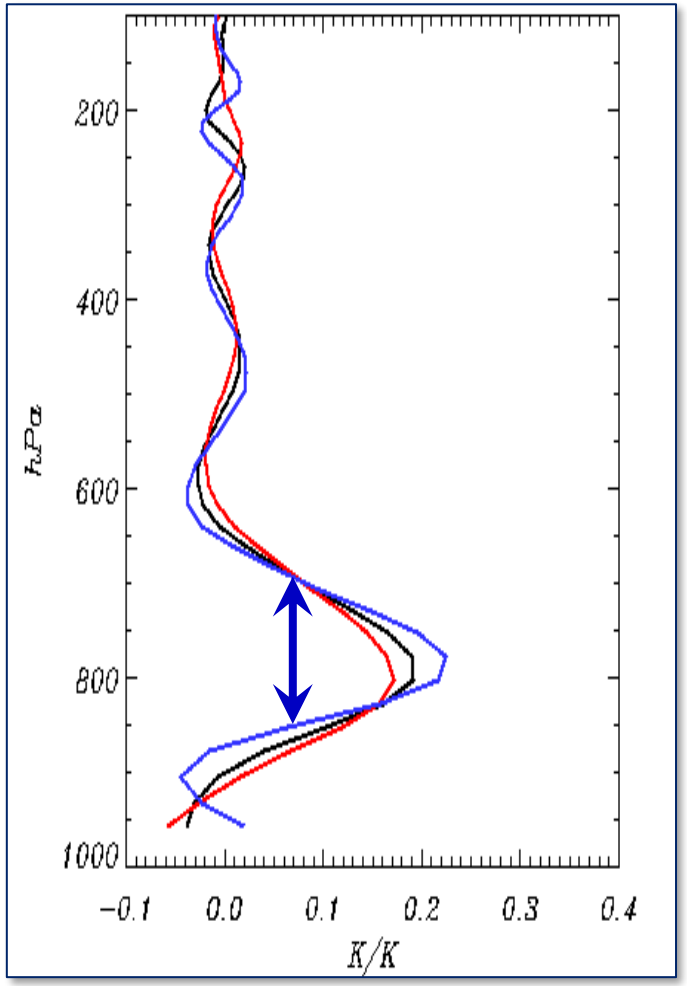
IASI	IASI-NG		MTG-IRS
Polar orbit (LEO)		**Orbit**	**GEO**stationnary
2x2	4x4	**Sensor**	160x160
12 km	12 km	**Spatial (Nadir)**	4 km
0.25 cm^{-1}	0.125 cm^{-1}	**Spectral sampling**	~0.6 cm^{-1}
2x / day	2x /day	**Temporal**	Every 30 min Europe
AMSU/MHS	MWS	**Microwave**	-
Metop-A 19 October 2006-2021 Metop-B 17 September 2012 Metop-C 06 November 2018	2025		2024

Hyperspectral missions – vertical information content and resolution

Averaging Kernel
H_2O 777 hPa

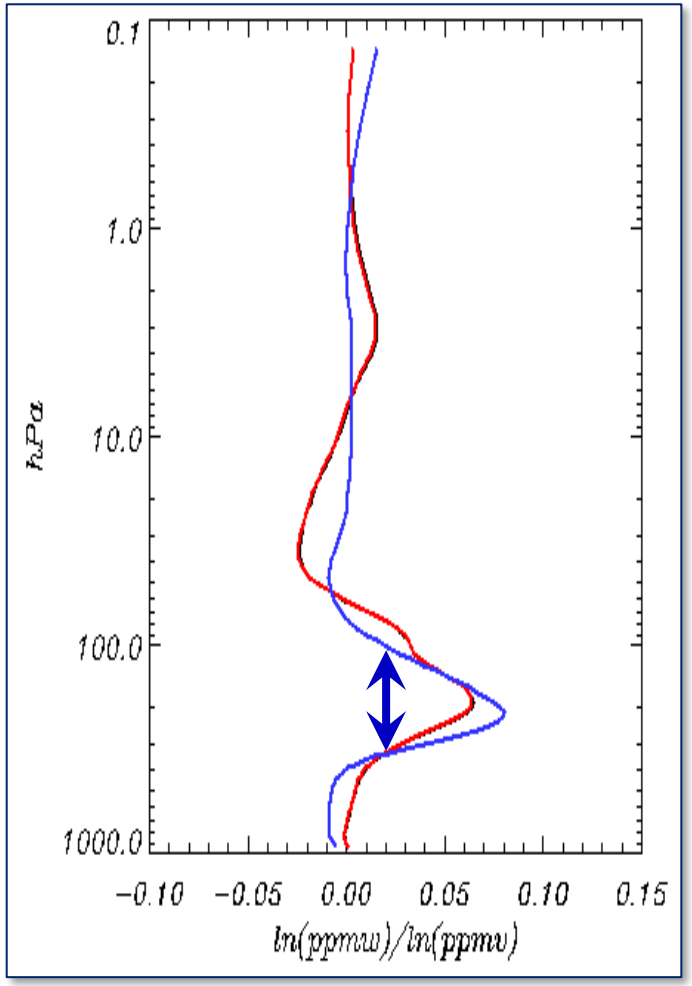


Averaging Kernel
T 777 hPa



— **IRS**
— **IASI**
— **IASI-NG**

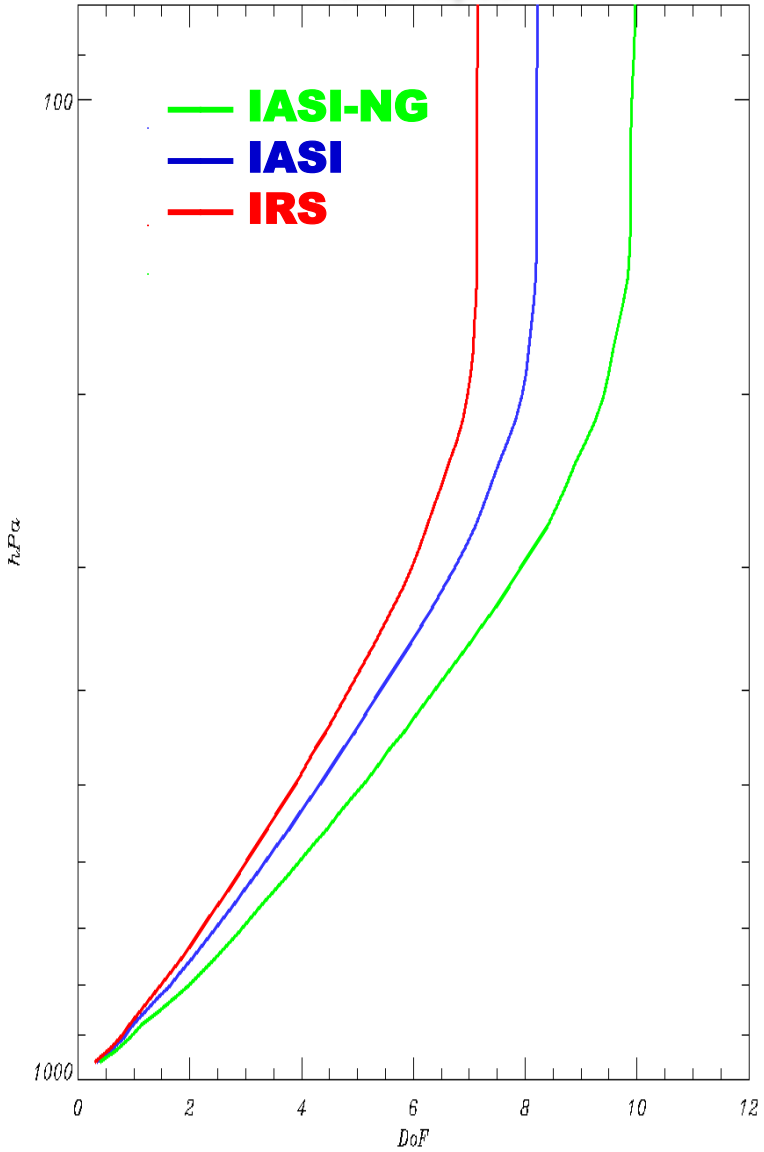
Averaging Kernel
O_3 191 hPa



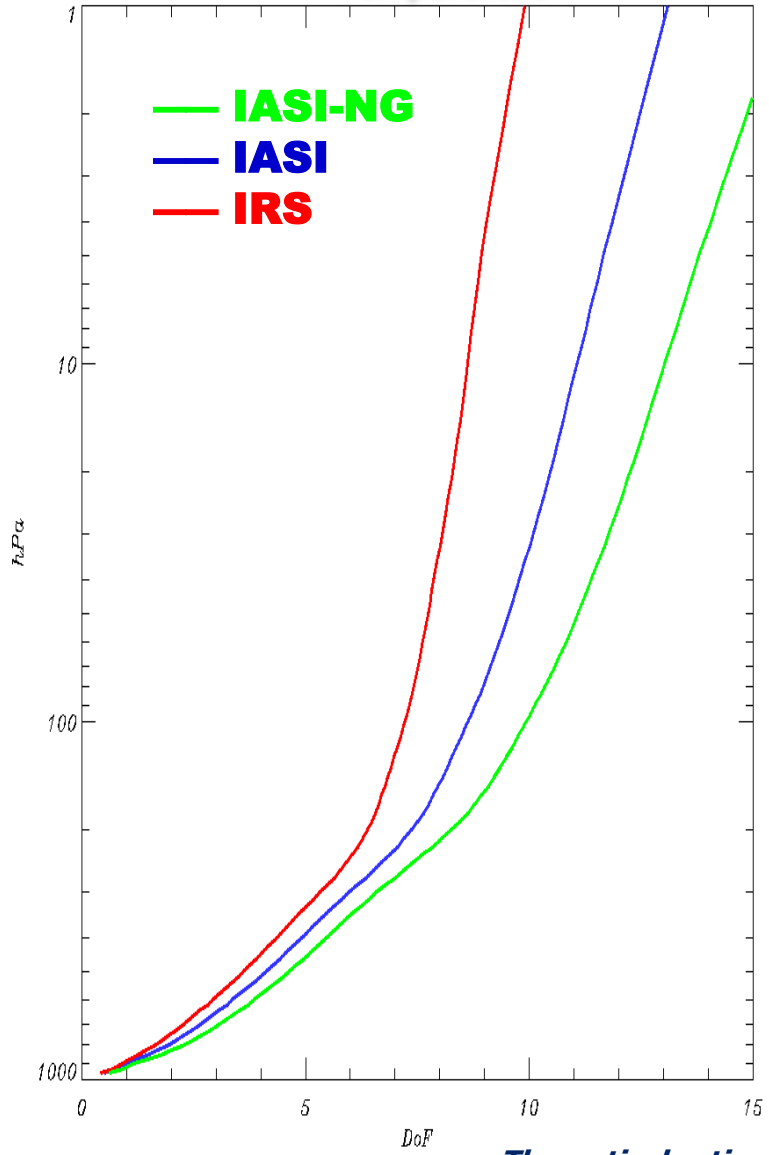
Theoretical estimates - Single evaluation on US standard atmosphere

Hyperspectral missions – vertical information content and resolution

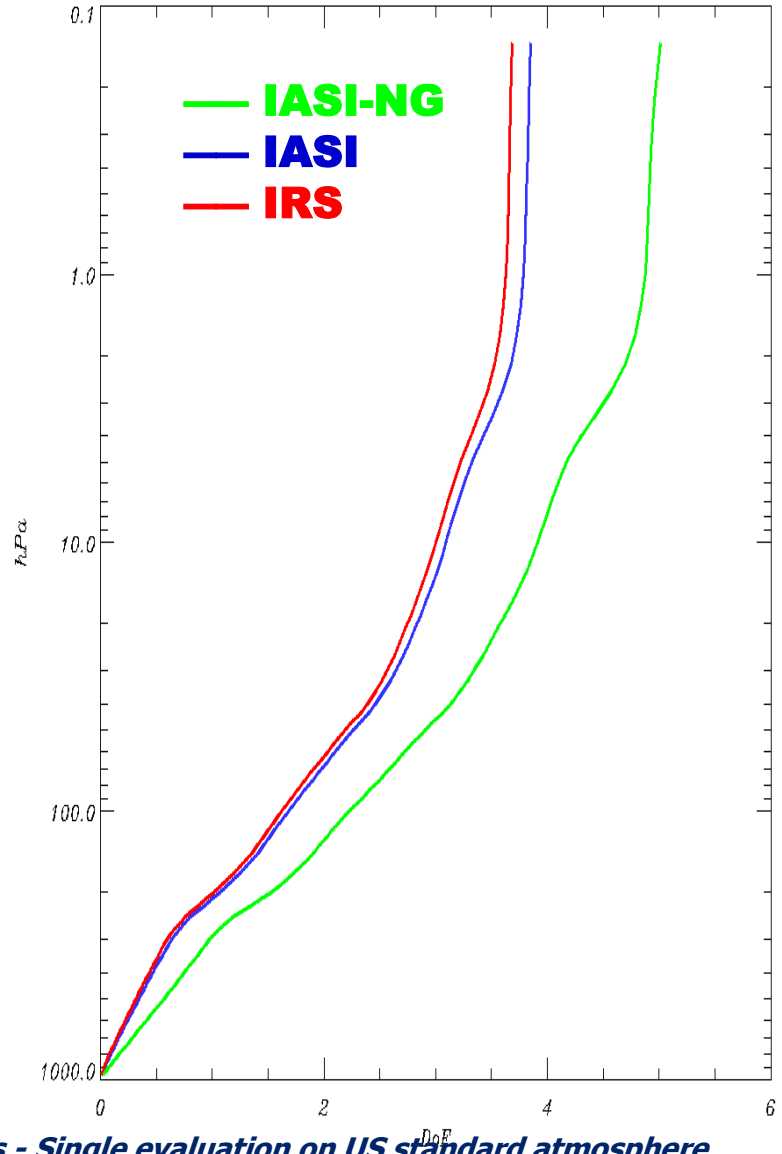
Cumulative degrees of freedom
Water-vapour



Cumulative degrees of freedom
Temperature



Cumulative degrees of freedom
Ozone



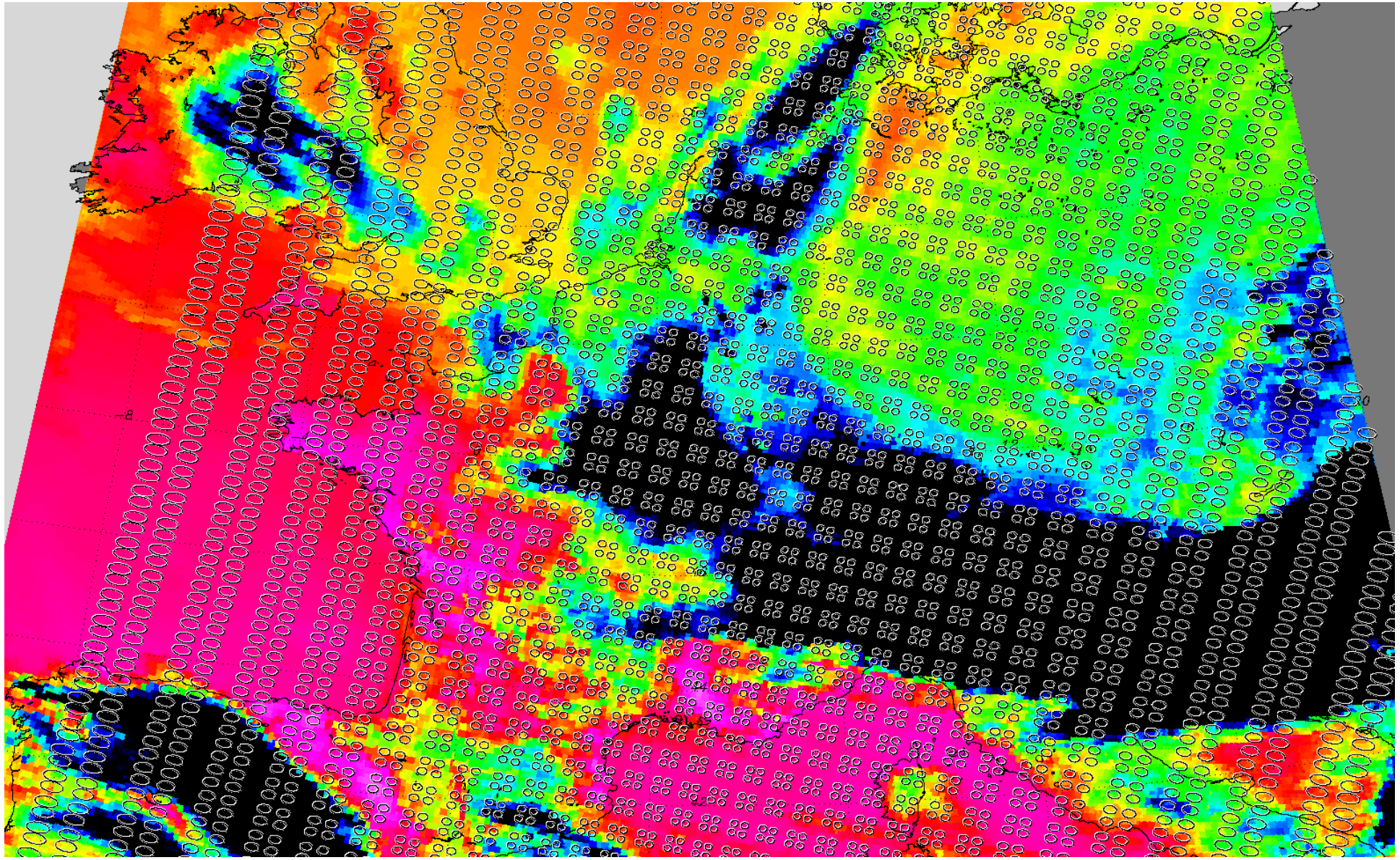
Theoretical estimates - Single evaluation on US standard atmosphere

MTG-IRS: unique 4D look into the atmosphere

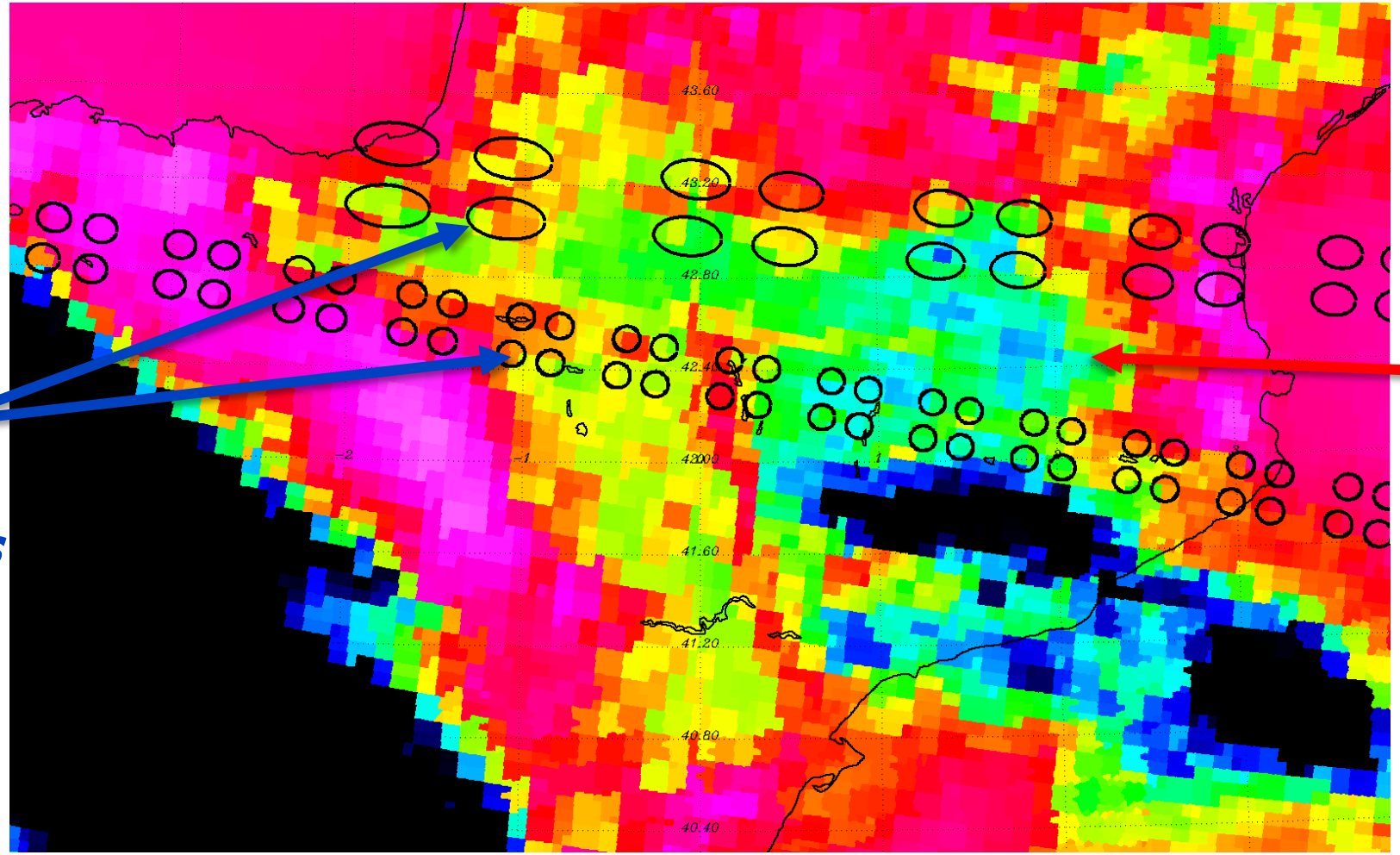
IRS

vs

IASI(-NG) spatial sampling

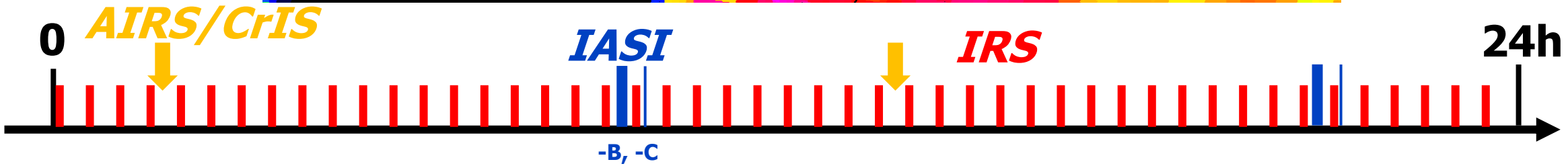


MTG-IRS: unique 4D look into the atmosphere



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

IRS pixels ~7km Contiguous every 30mn



Agenda

EUM sounders

Missions and sampling overview

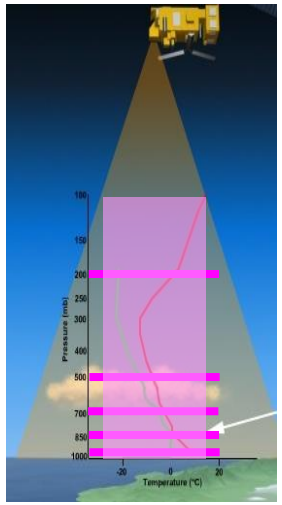
Products characteristics

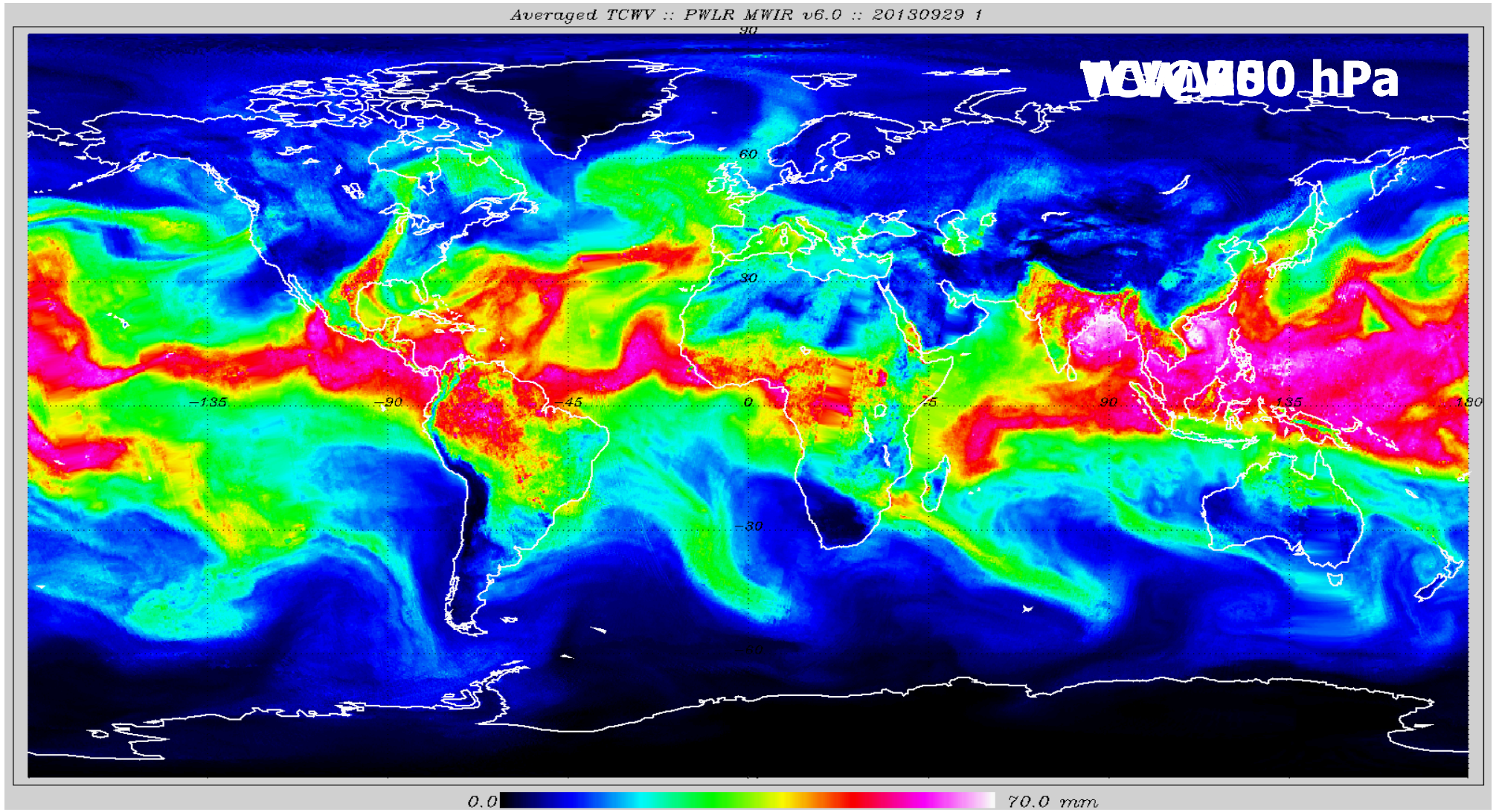
Validation, uncertainty estimates

Application and case studies

IASI regional service, preparing for MTG-IRS

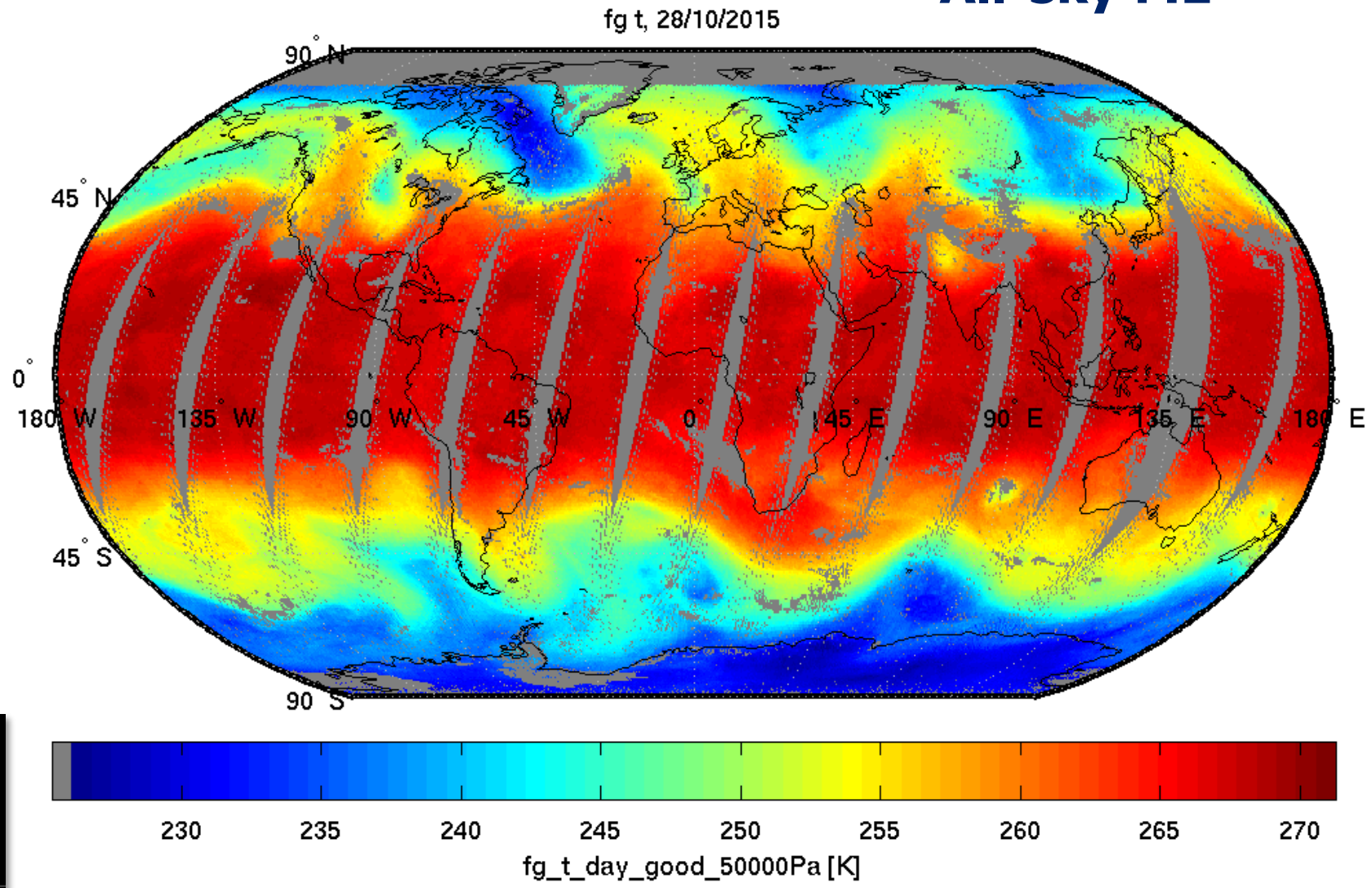
IASI L2 sounding – Atmospheric humidity profiles





‘All-sky’ atmospheric sounding yield

All-sky ML



Piece-Wise Linear Regression (PWLR) algorithm for IASI

https://www.eumetsat.int/IASI-PWLR

IASI L2 sounding – Performance assessment

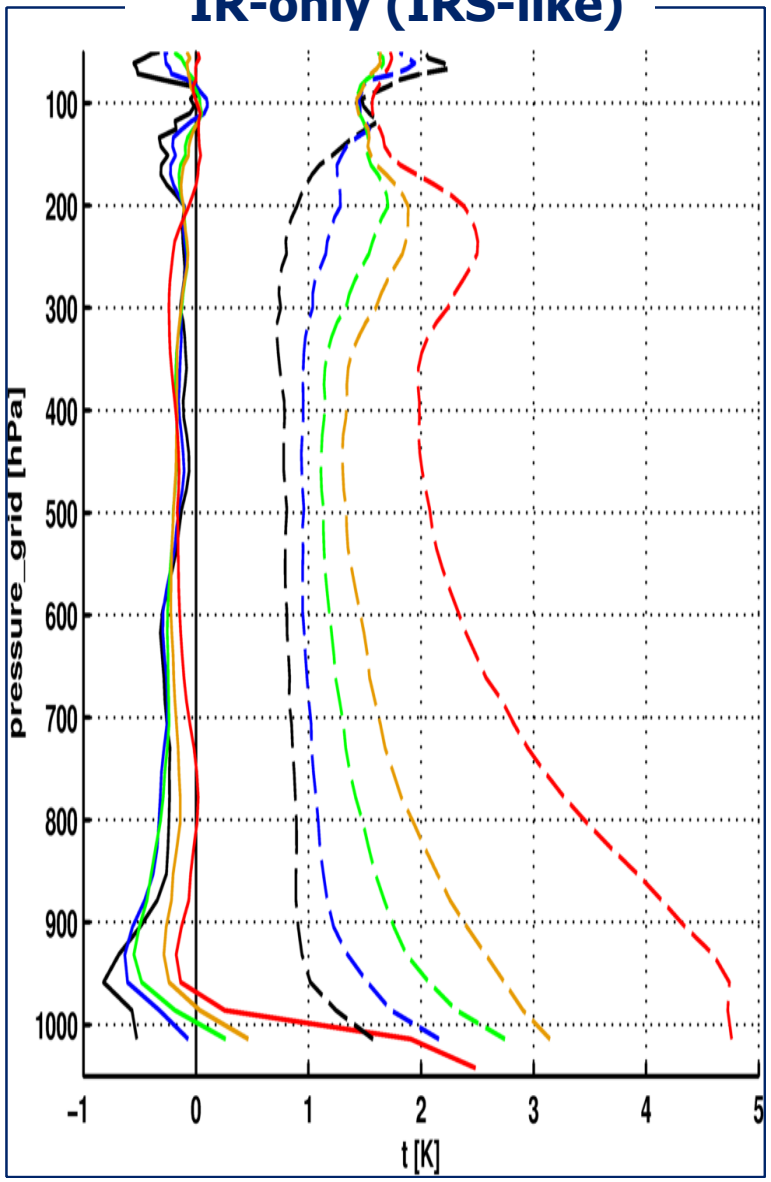
Extensive validation of temperature and humidity products**:**

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

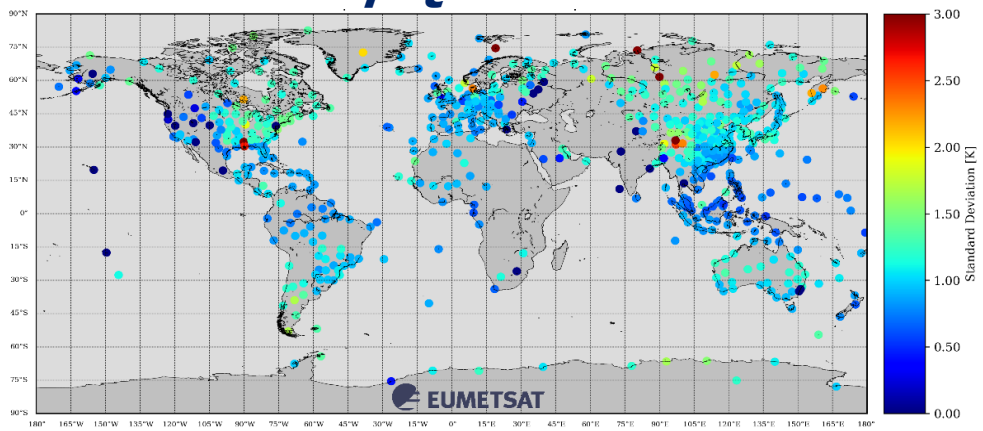
"IASI L2 TCDR T/q validation Report", EUM/OPS/DOC/19/109137, 163pp
"IASI L2 v6 Validation Report" EUM/TSS/REP/14/776443, 290pp
"IASI L2 v6.2 Validation Report" EUM/RSP/REP/16/857500, 73pp
"IASI L2 PPF v6.3 Validation Report" EUM/RSP/REP/17/920559, 45pp
"IASI L2 PPF v6.4 Validation Report" EUM/RSP/REP/18/974859, 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**

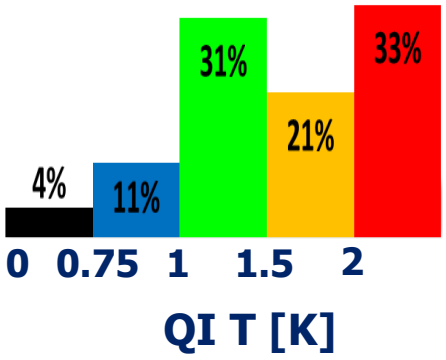
IR-only (IRS-like)



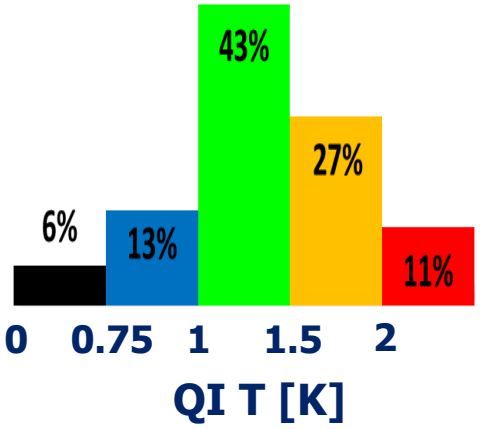
Jan. – Oct. 2017
< 50km ; < 3h
Match-up QC still needed



Yield IR-only

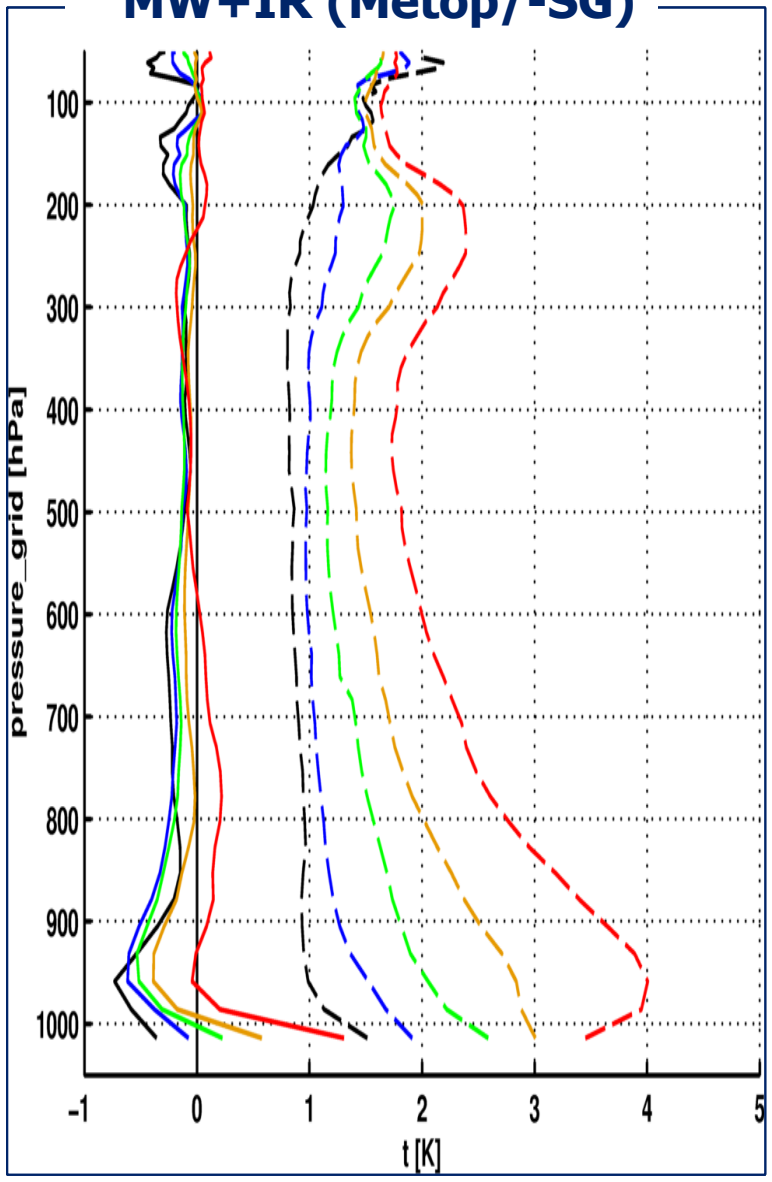


Yield MW+IR



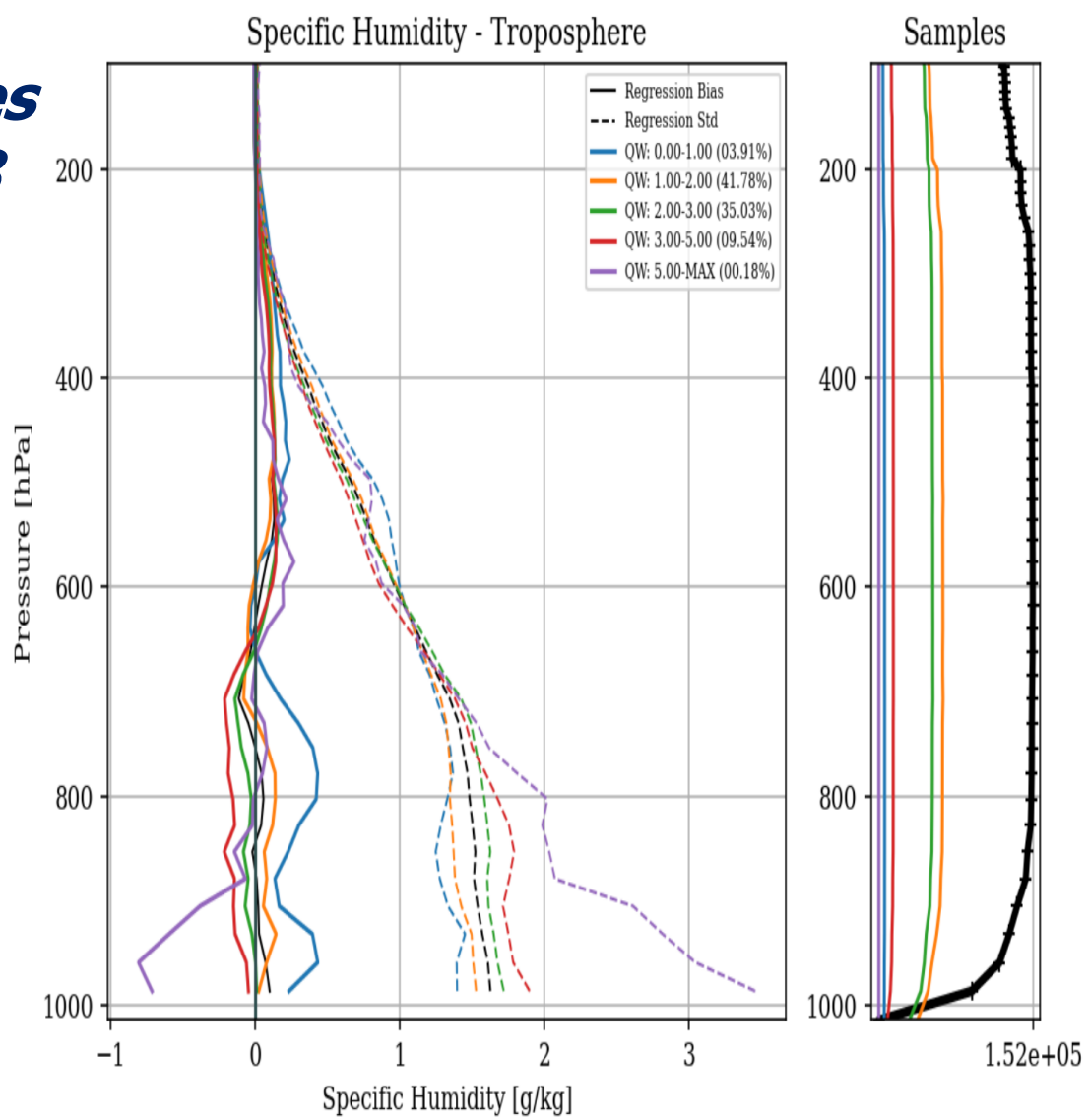
Tropospheric error estimate

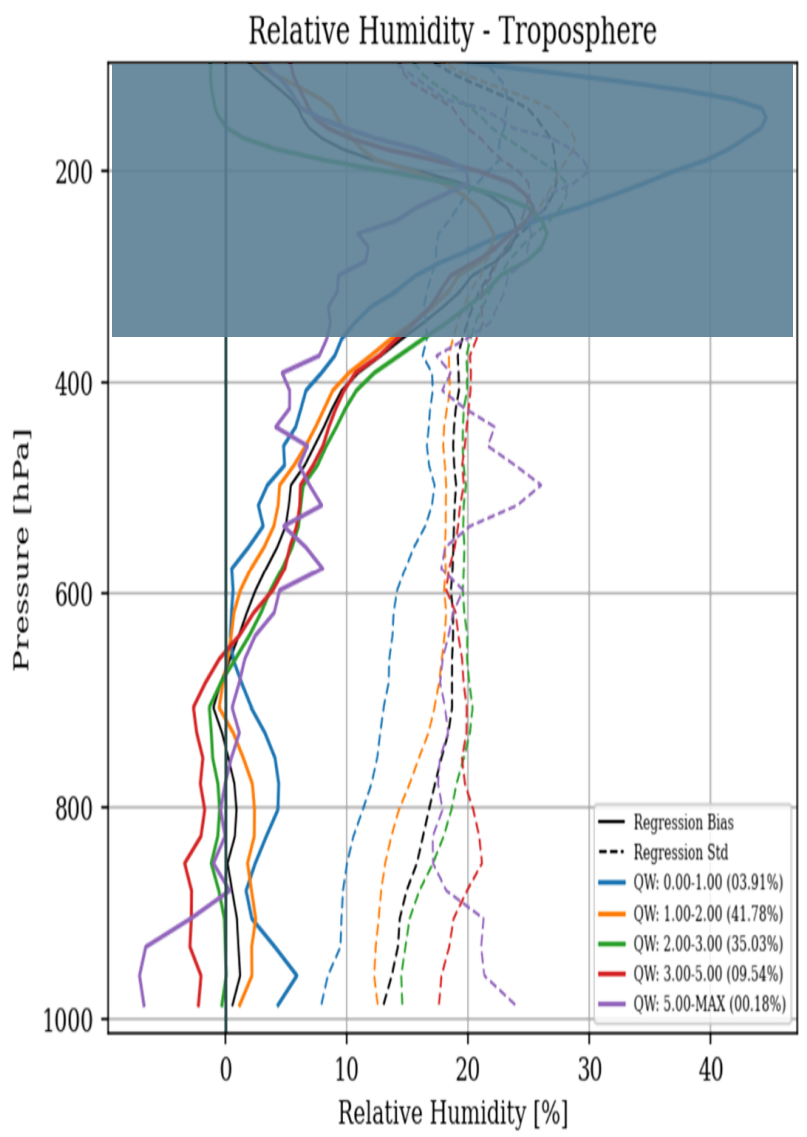
MW+IR (Metop/-SG)



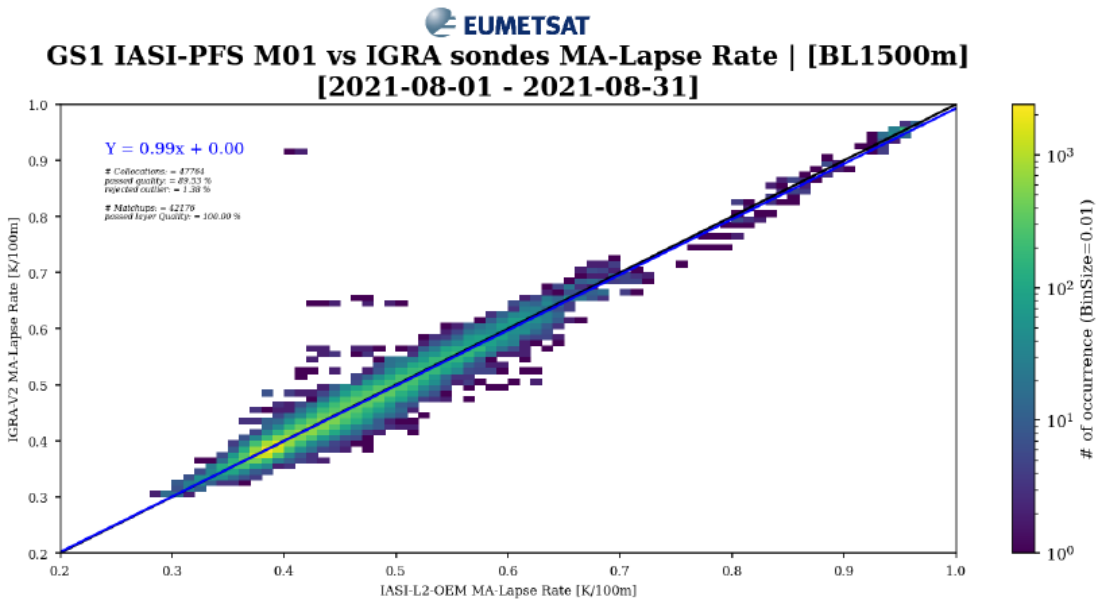
Humidity sounding – Quality indicator significance *vs* radiosondes (IGRA)

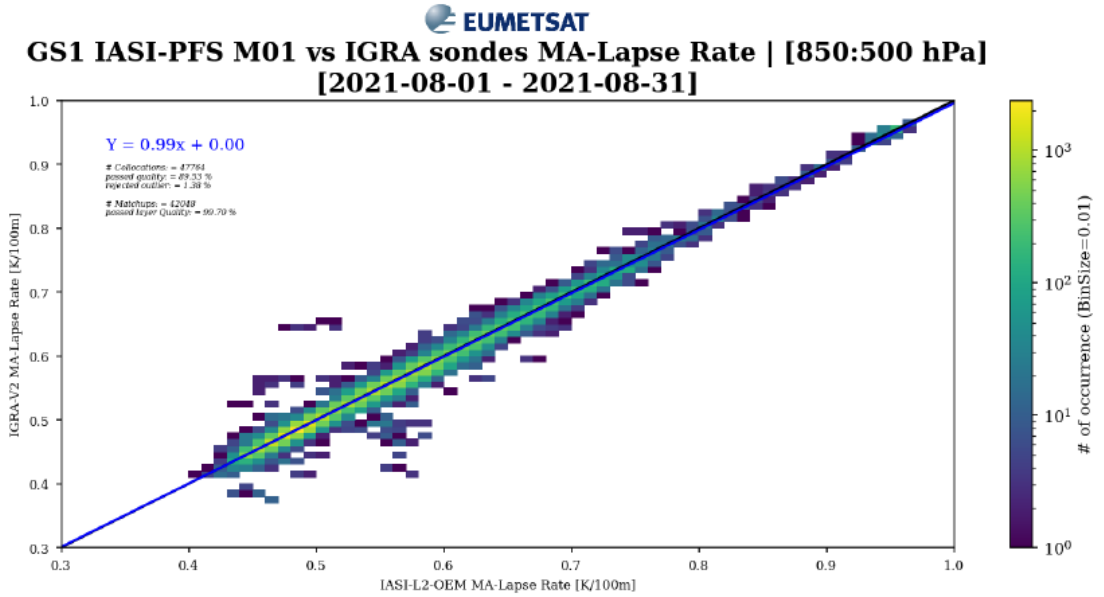
vs radiosondes August 2018

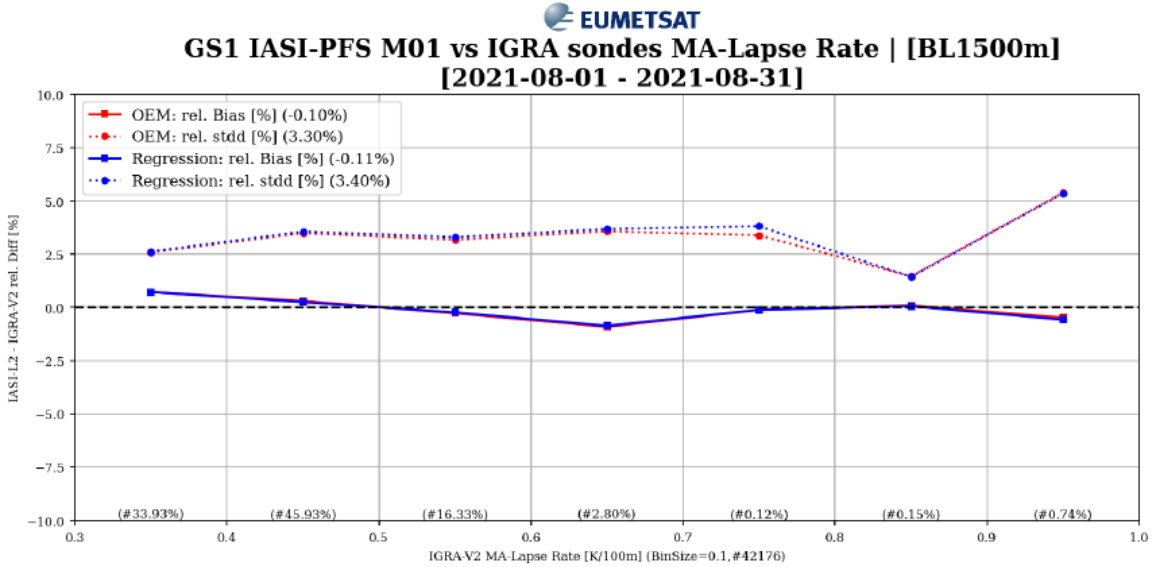


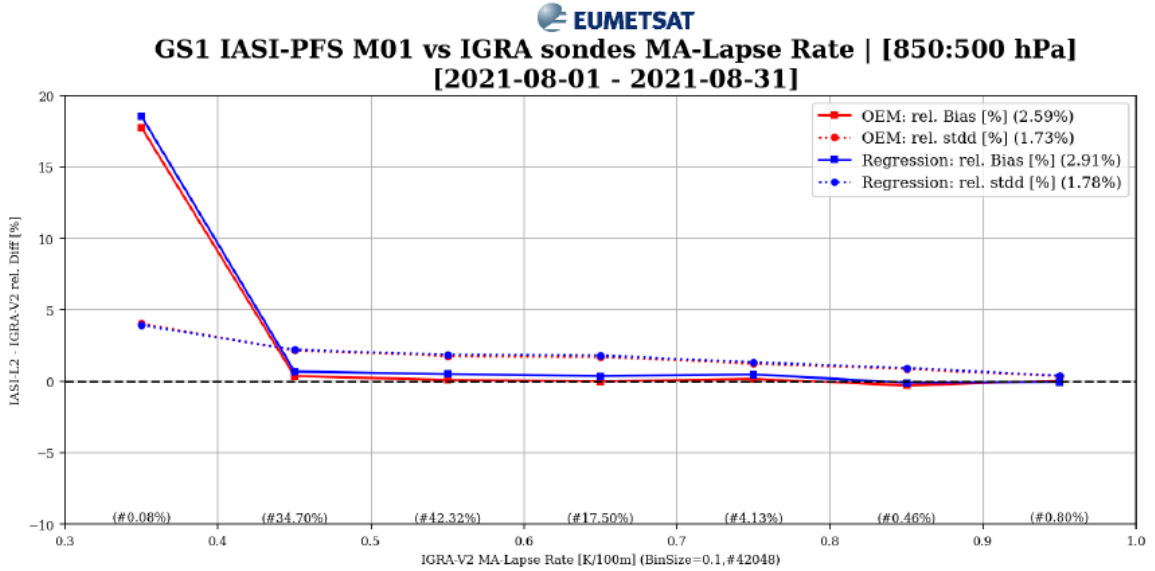


Temperature sounding – Lapse rate *vs* radiosondes (IGRA)

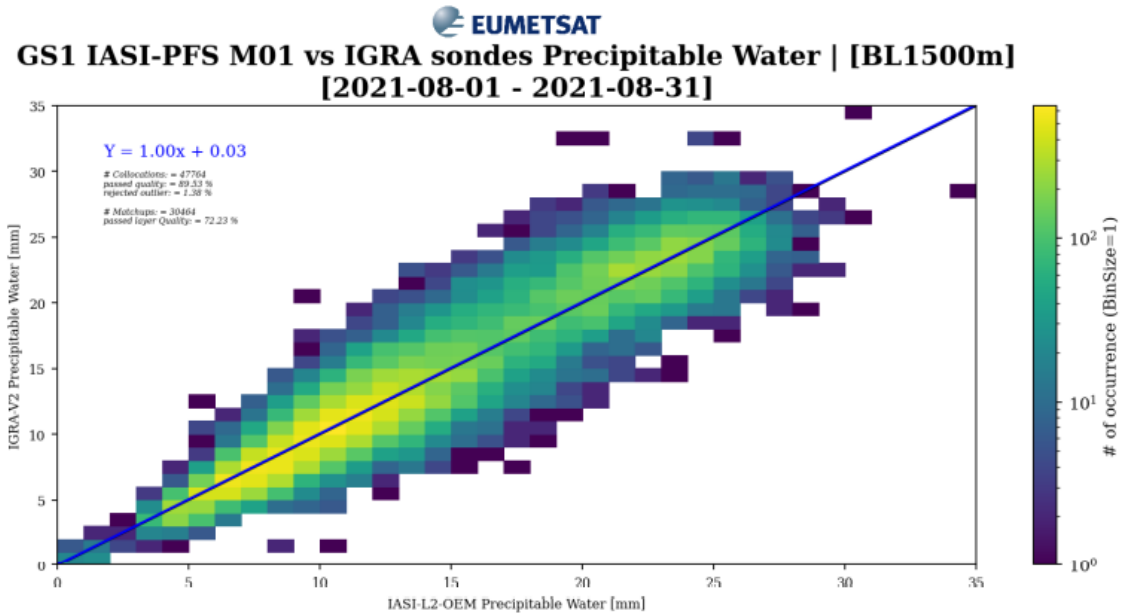


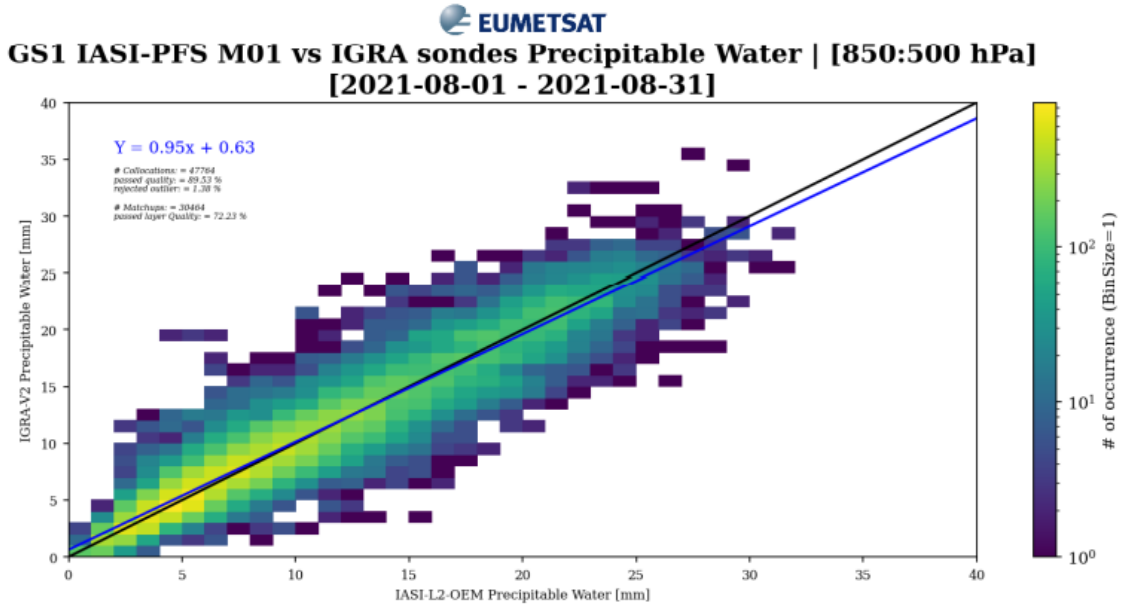


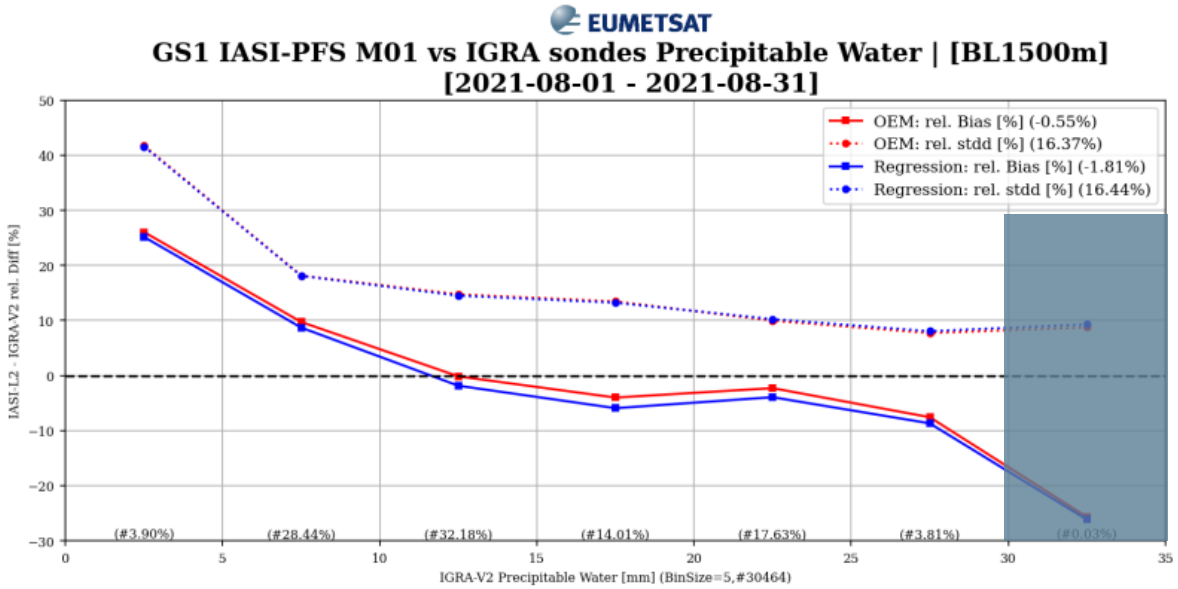


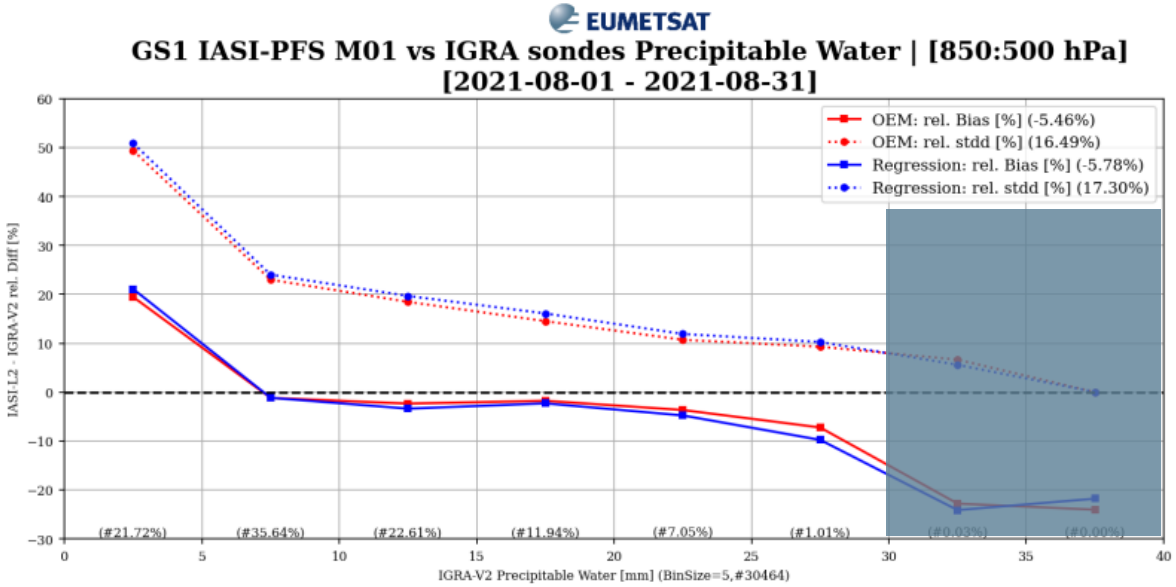


Humidity sounding – Partial columns *vs* radiosondes (IGRA)

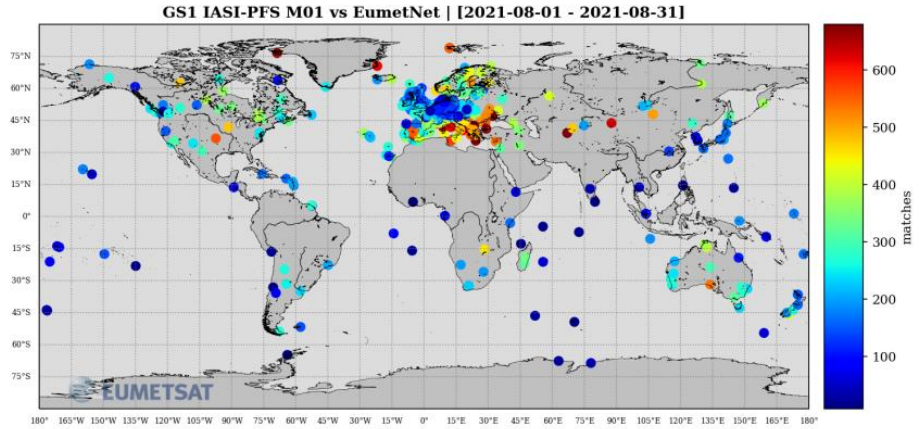


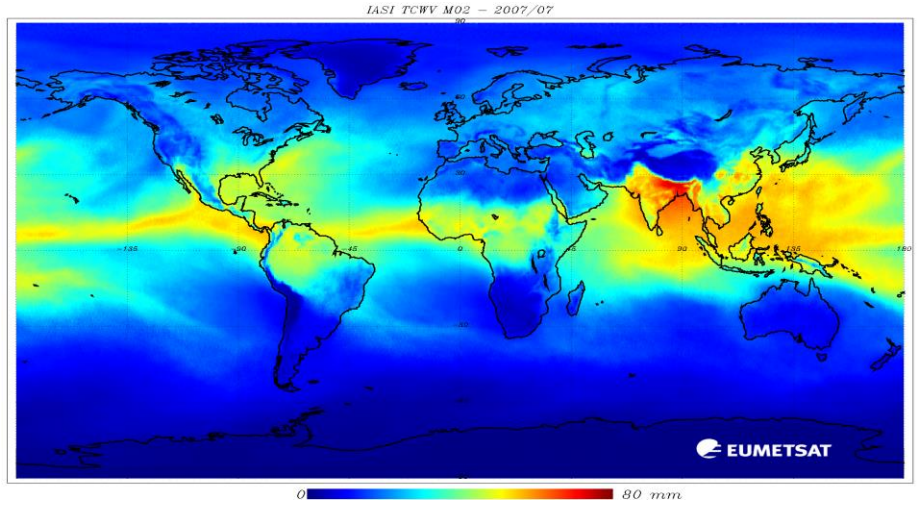




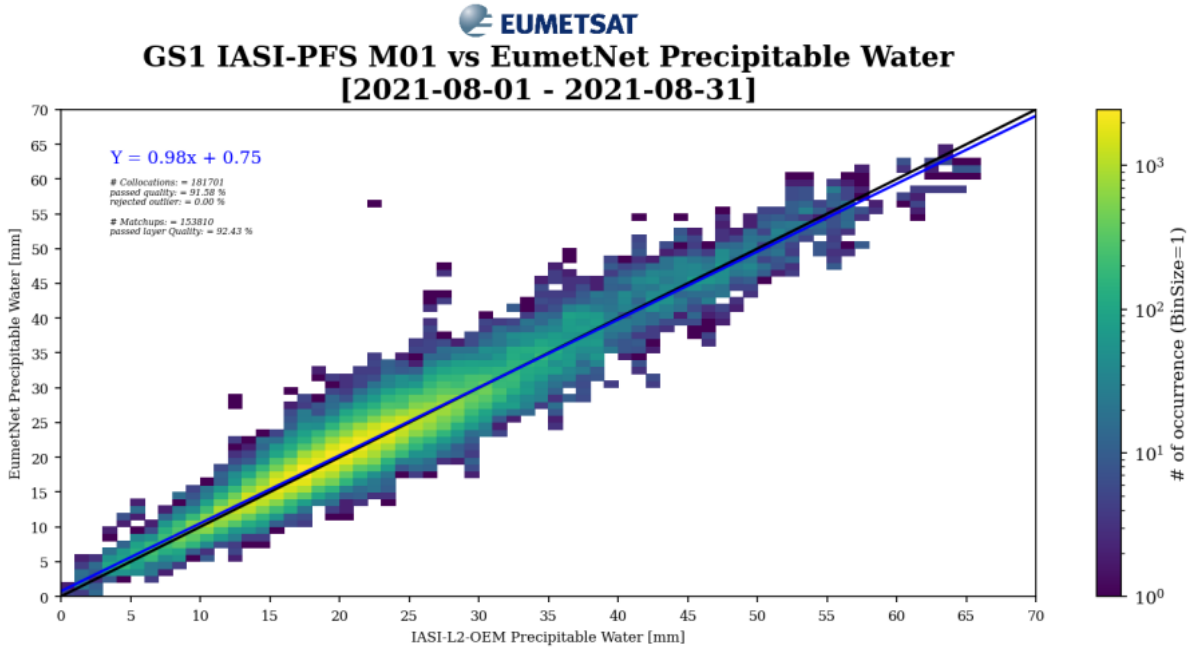


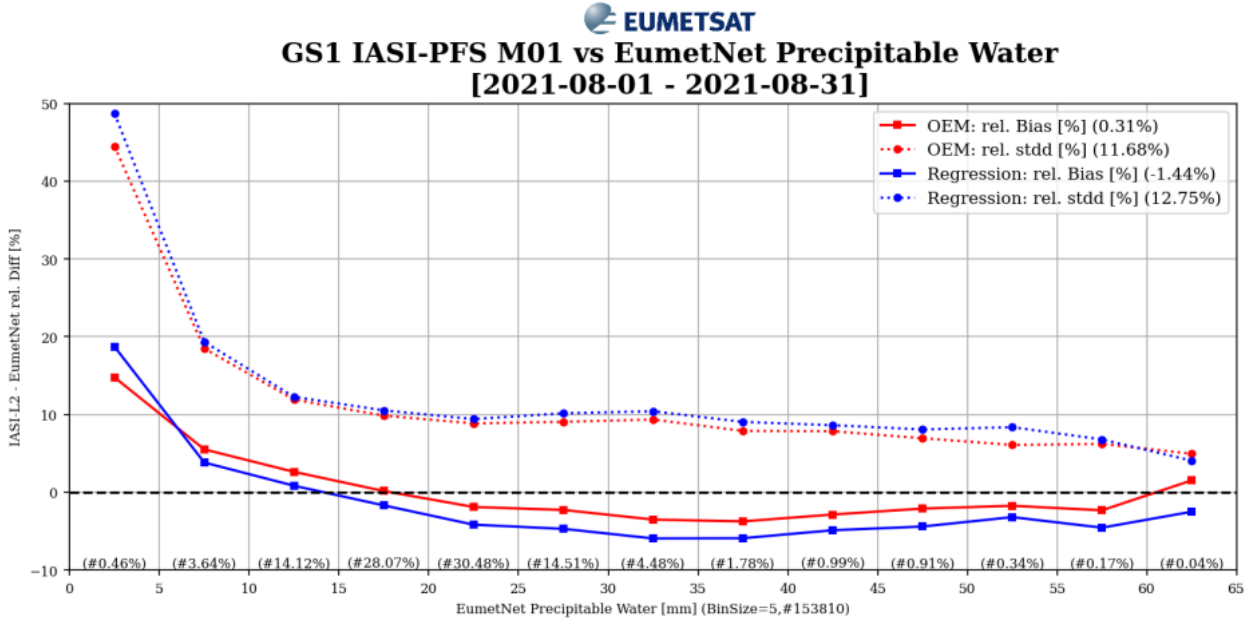
Humidity sounding – Total columns *vs* ground-GPS (EUMetNet)





Metop-A TCWV 2007-2018



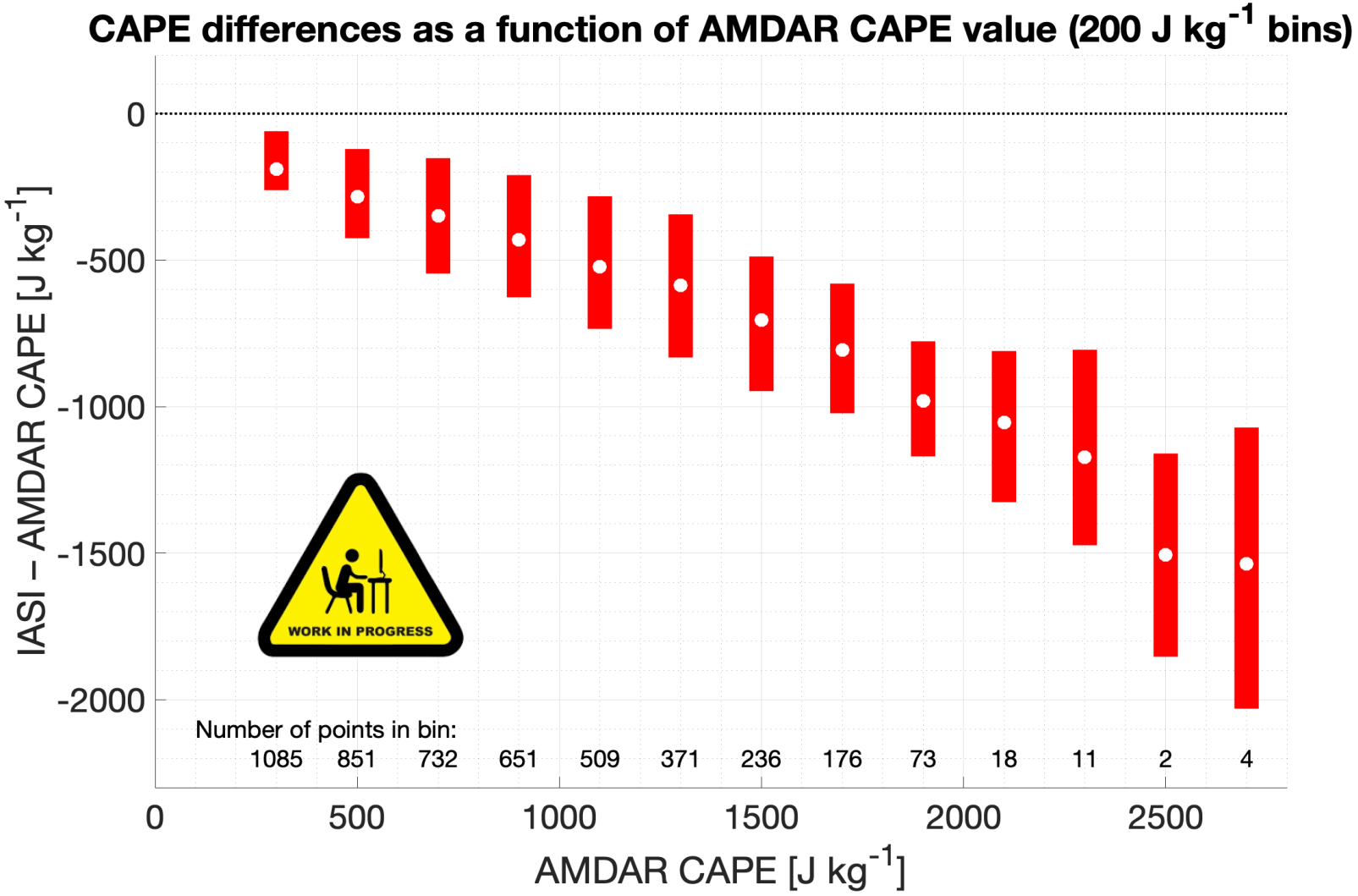


Evaluating sounding profiles in pre-convective situations

Preliminary results of evaluating IASI L2 products through 2017 with airborne measurements from the AMDAR system.

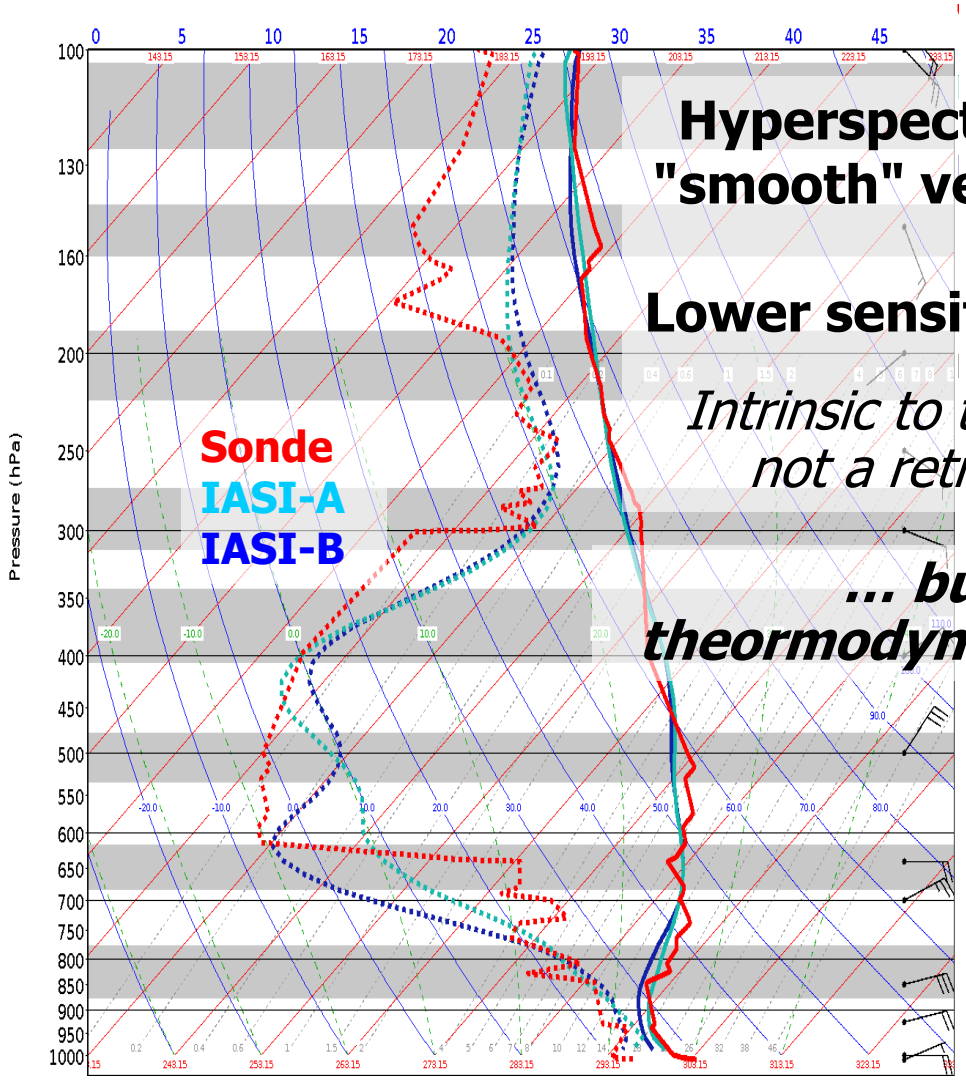
Dr T. Wagner, visiting scientist @EUM

Work in progress
- *CAPE usually underestimated*
- *Smoothness and near-surface sensitivity?*



Credits: T. Wagner (SSEC/U. Wisconsin)

Atmospheric profiles from space – manage expectations



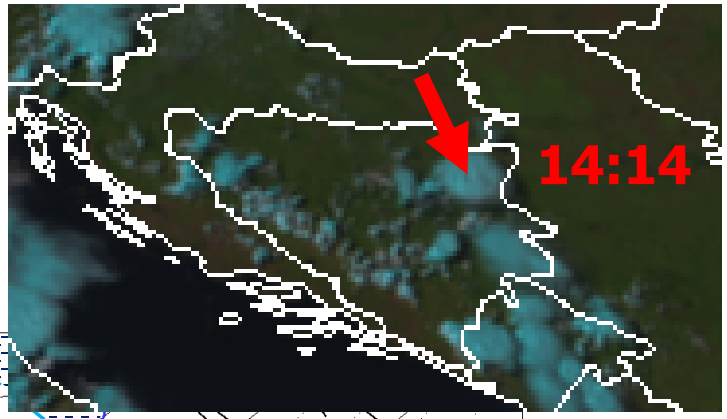
Hyperspectral sounding are "smooth" version of the truth

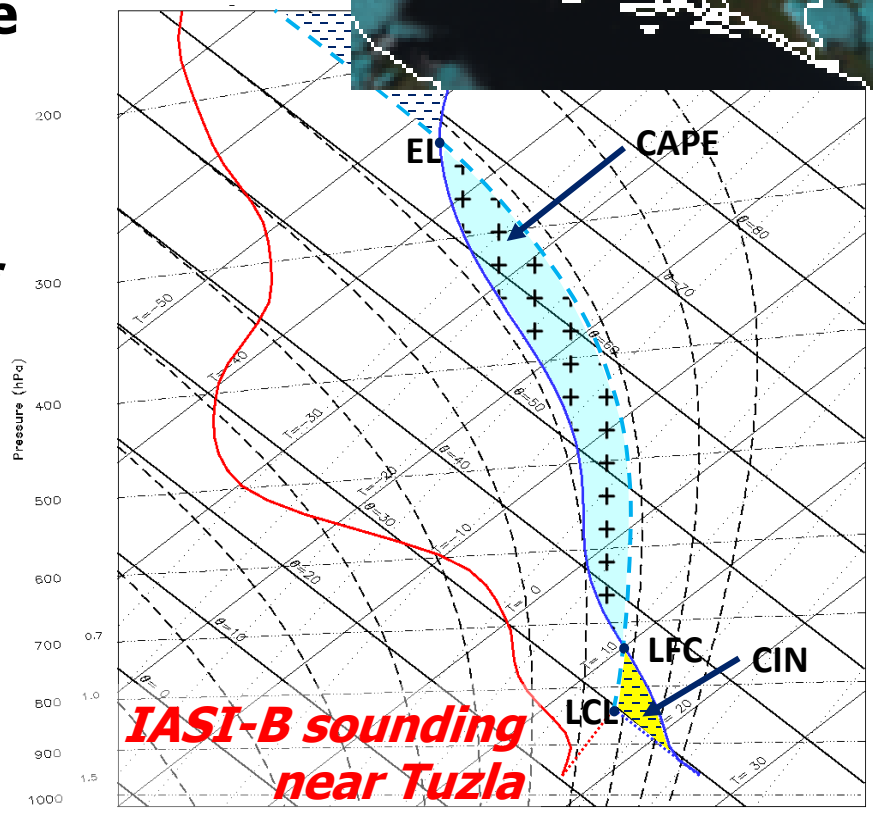
+

Lower sensitivity near surface

Intrinsic to the measurements, not a retrieval deficiency.

… but still, capable of theormodynamic information





Agenda

EUM sounders

Missions and sampling overview

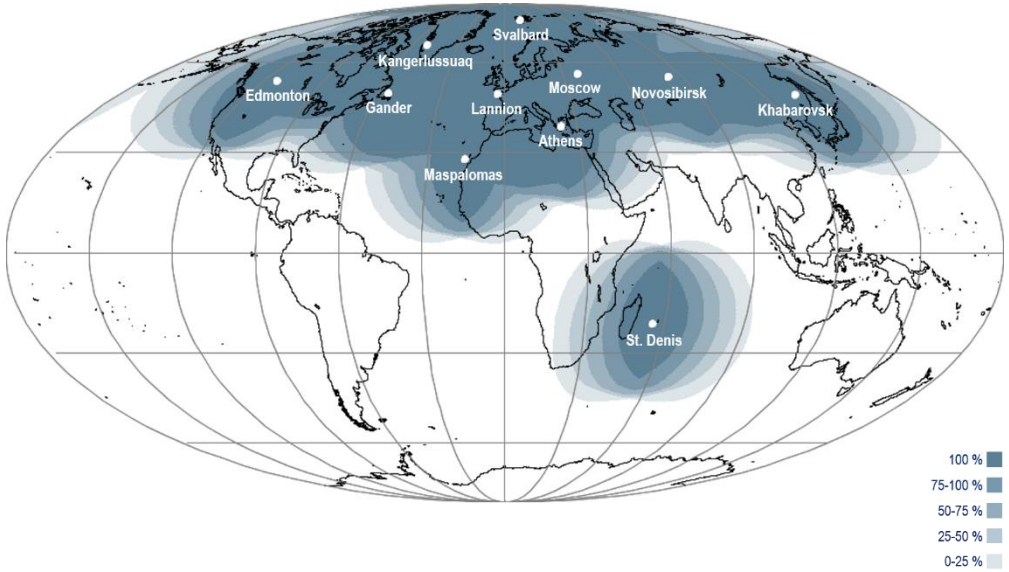
Products characteristics

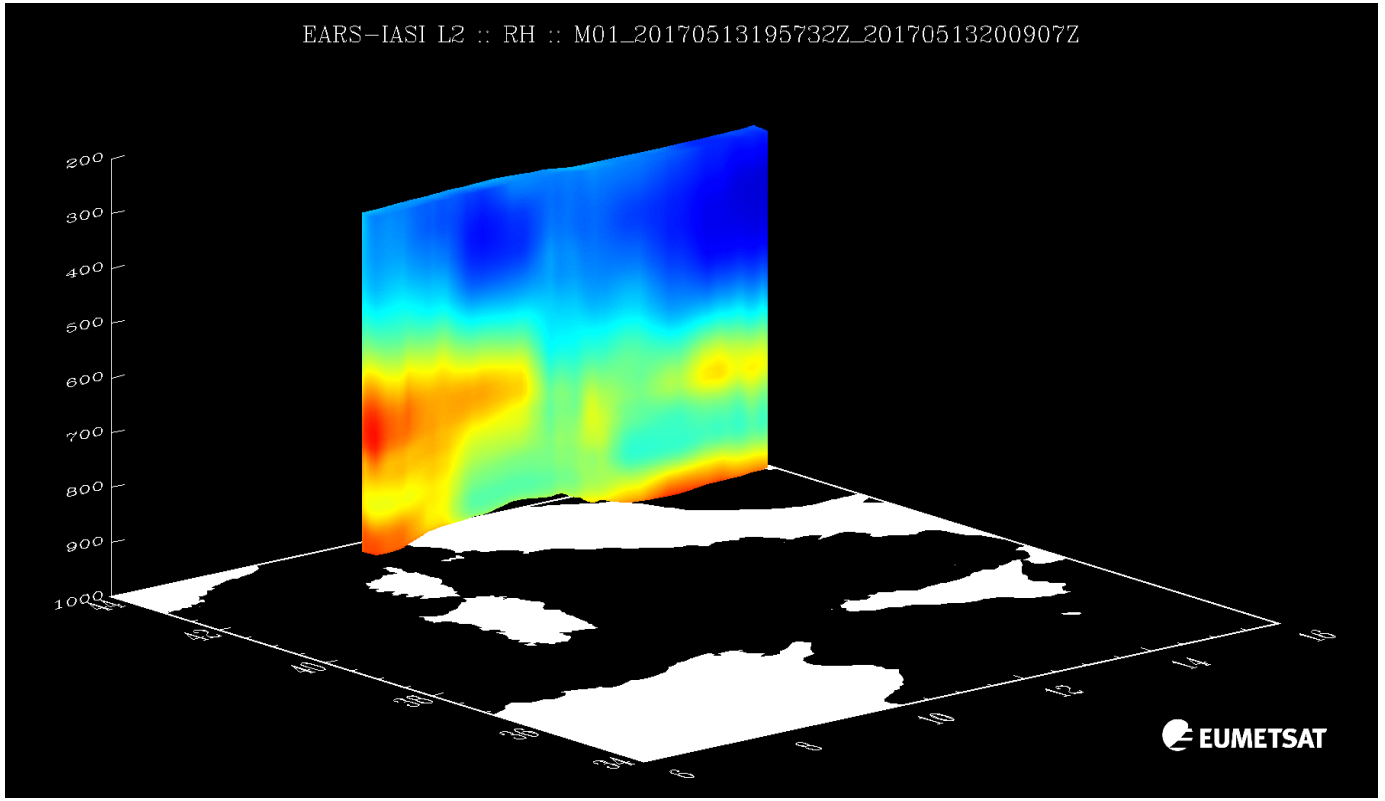
Validation, uncertainty estimates

Application and case studies

IASI regional service, preparing for MTG-IRS

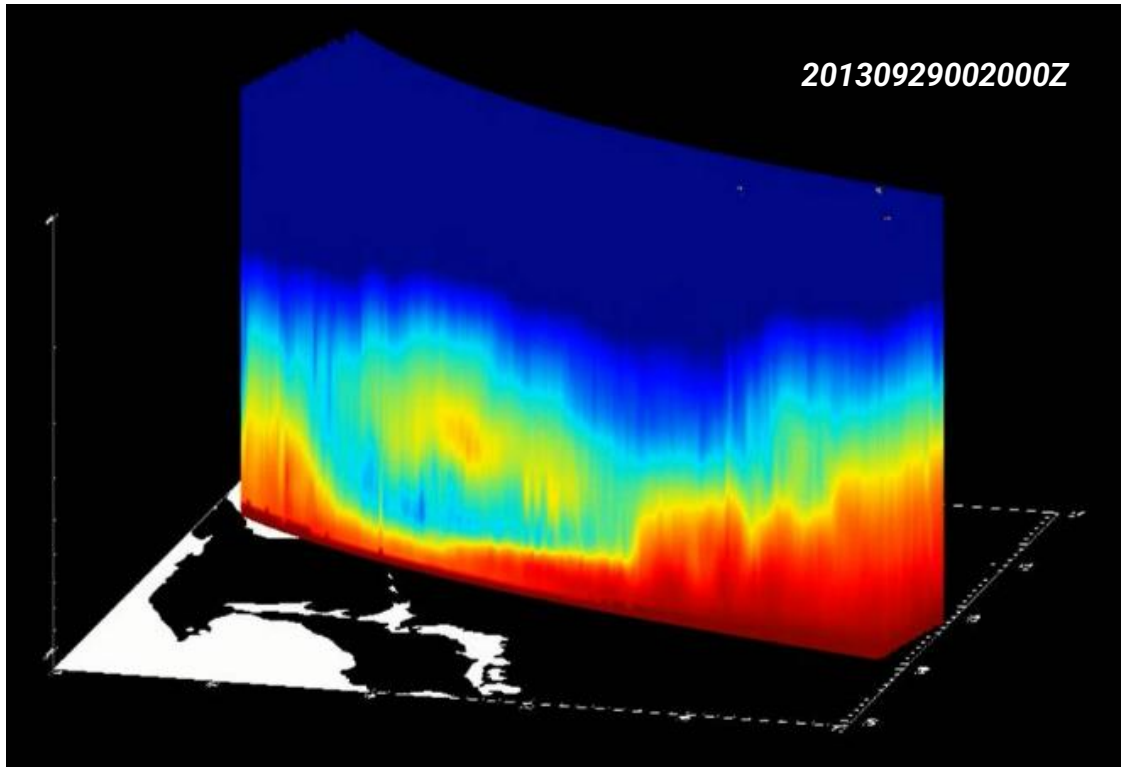
EARS-IASI L2 services – timely for regional applications

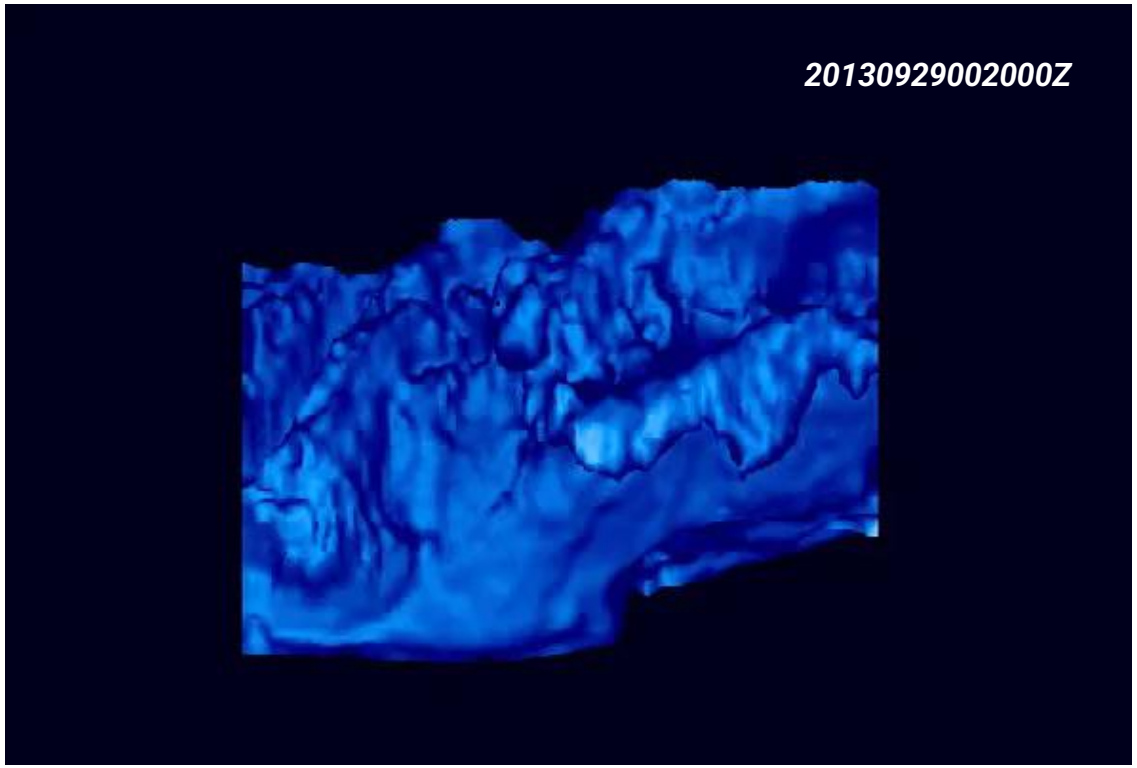




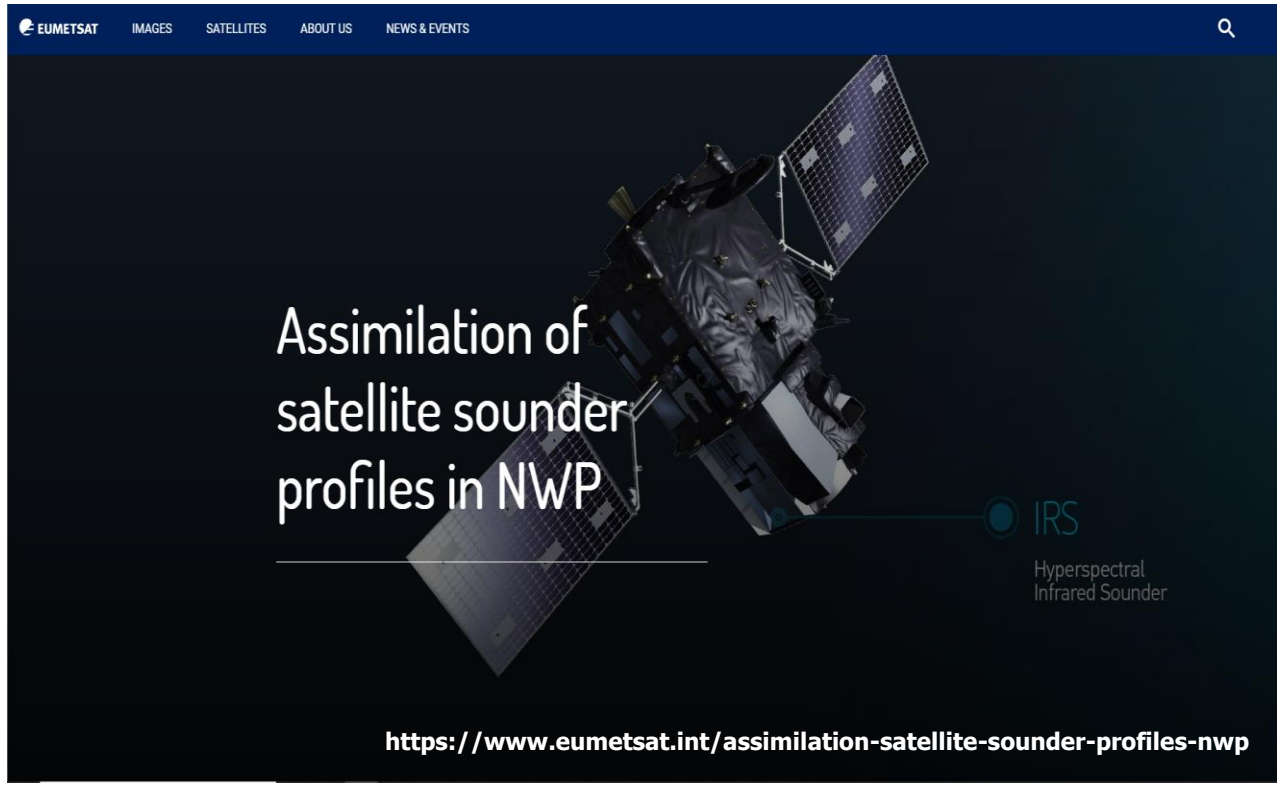
- ✓ Direct broadcast stations
- ✓ Timeliness < **30min from sensing**
- ✓ Forecast-free products + uncertainty estimates

EARS-IASI L2 – Retrieving 3D humidity structures





Assimilation experiments @ECMWF



IFS - depleted environment, maritime pixels

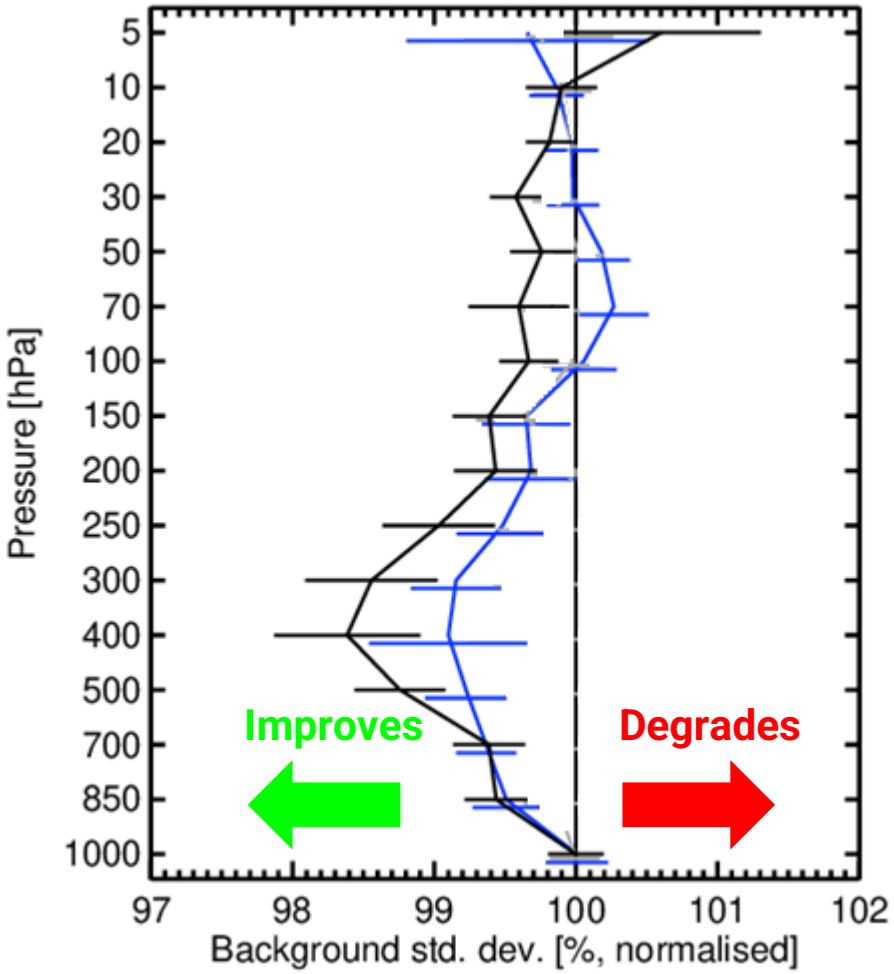
- **Control (CTL)** conventional + AMSU-A
- **IASI** CTL + IASI radiances from Metop-C as in operations
- **L2** CTL + IASI L2 PC_T and PC_q scores from Metop-C

! Scene-dependent observation operators !

IASI L2 in IR-only mode (no MW data used)

First assimilation experiments, depleted system, ocean … it works!

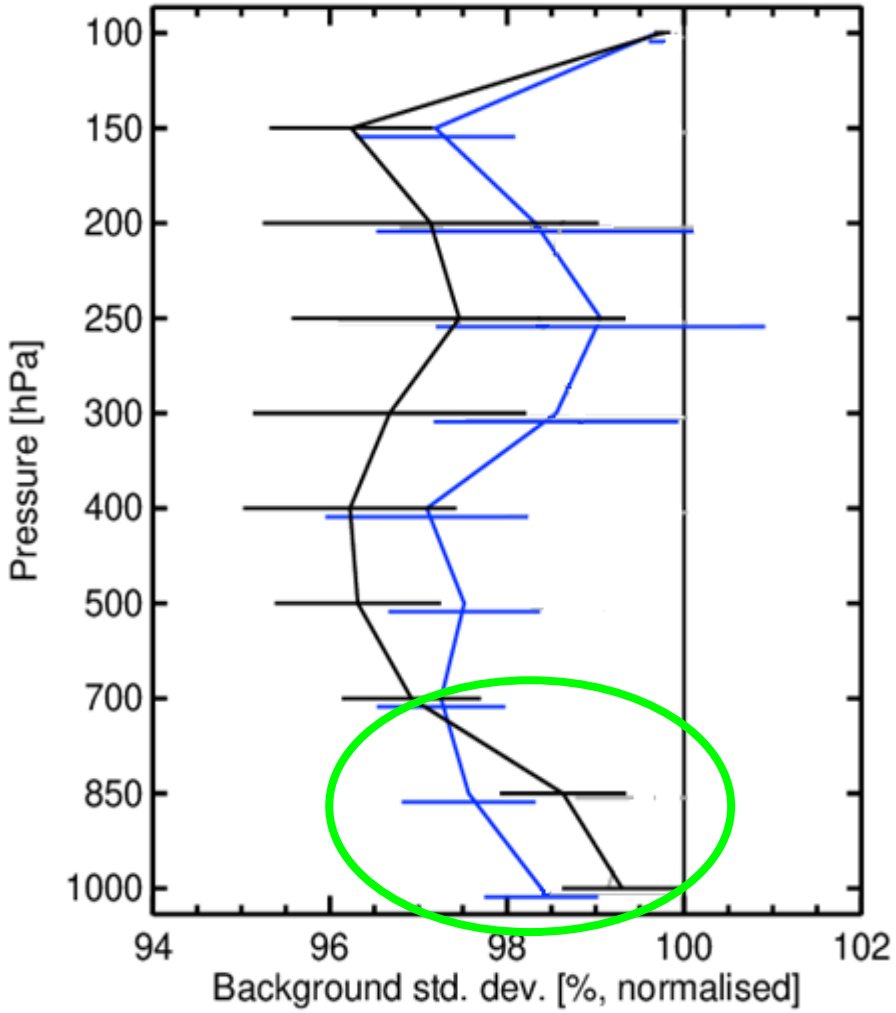
Radiosonde temperature



IASI L1 radiances
IASI L2 T and q (PC)

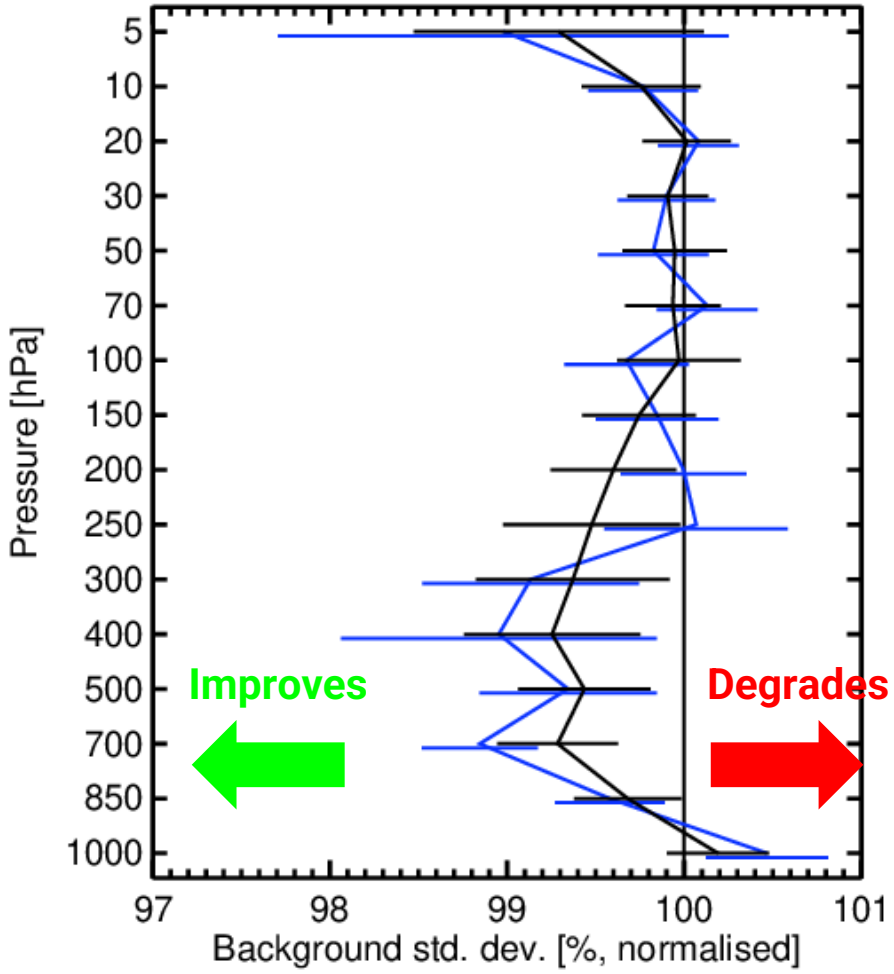
Obs. error = 1,
Clear-sky |OmC| < 1

Radiosonde humidity



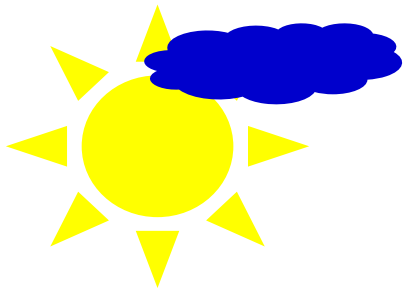
Assimilating cloudy retrievals further improves forecasts

Radiosonde temperature

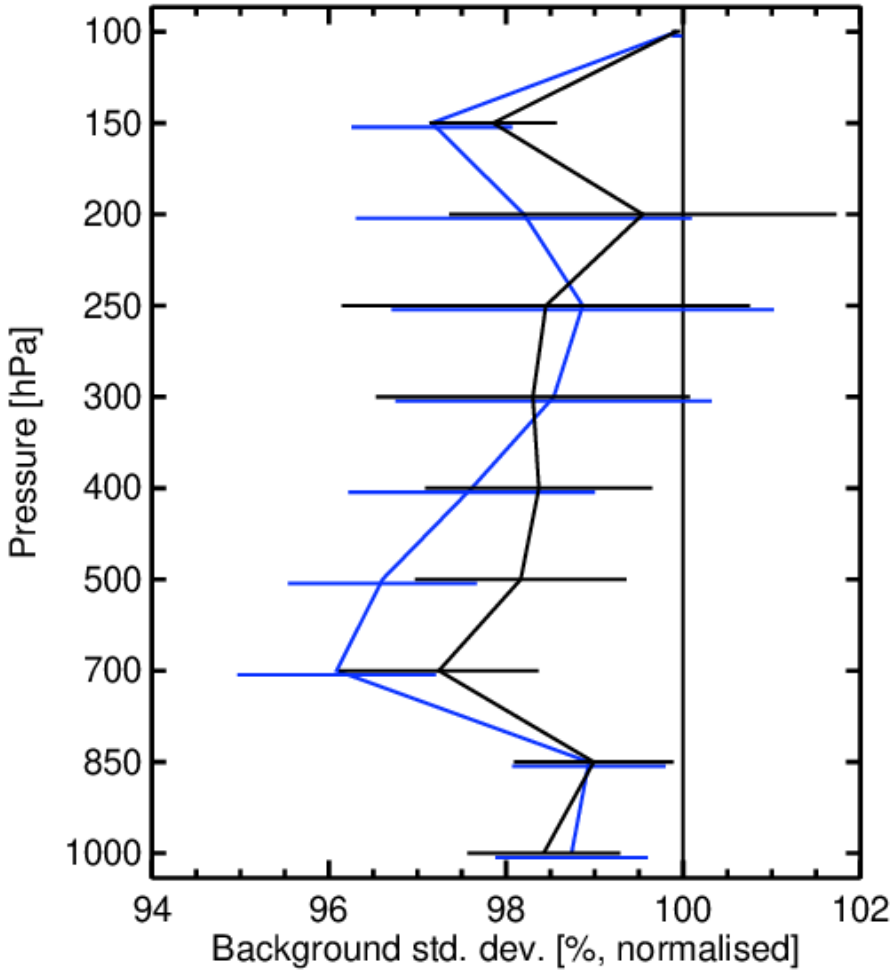


L2 T/q assimilation

Clear -1 < OmC < 1
Cloudy -5 < OmC < -1

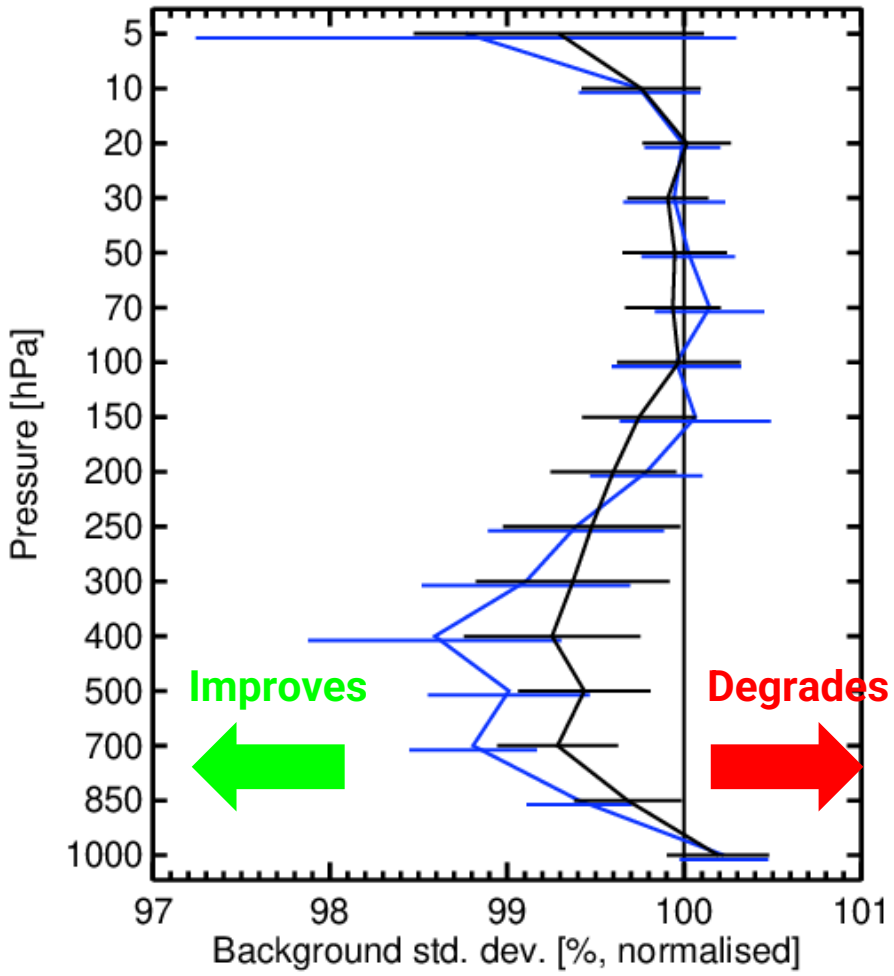


Radiosonde humidity



Assimilating cloudy retrievals further improves forecasts

Radiosonde temperature

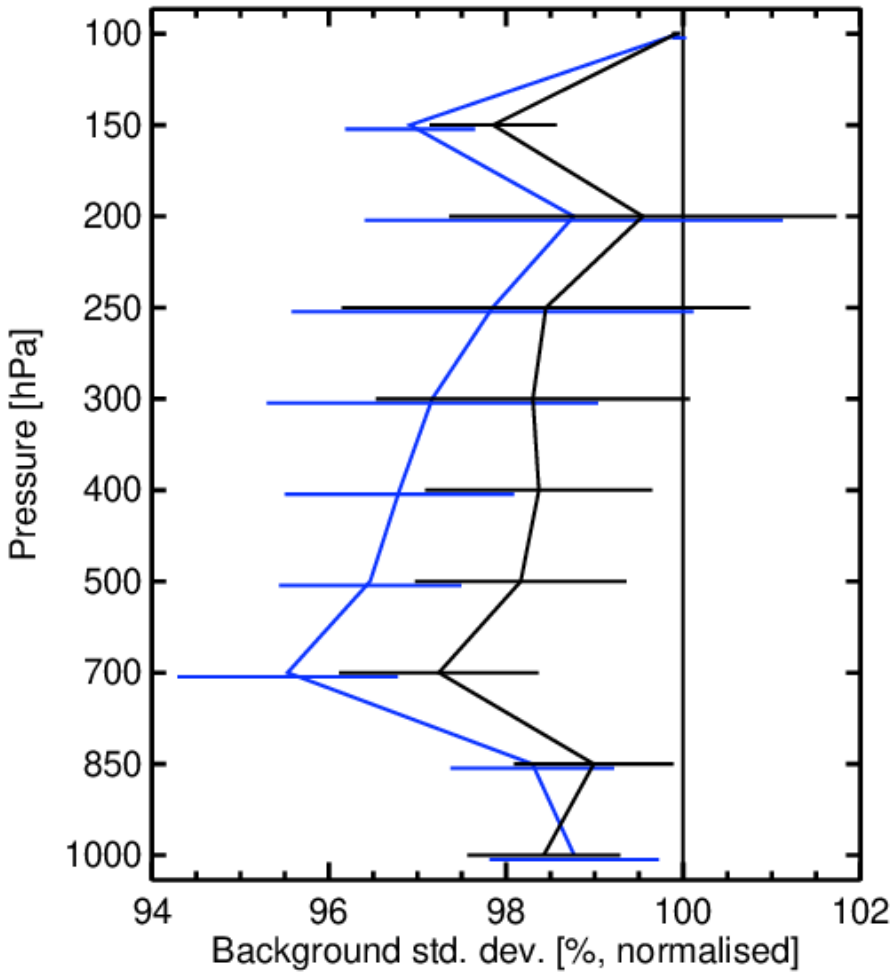


L2 T/q assimilation

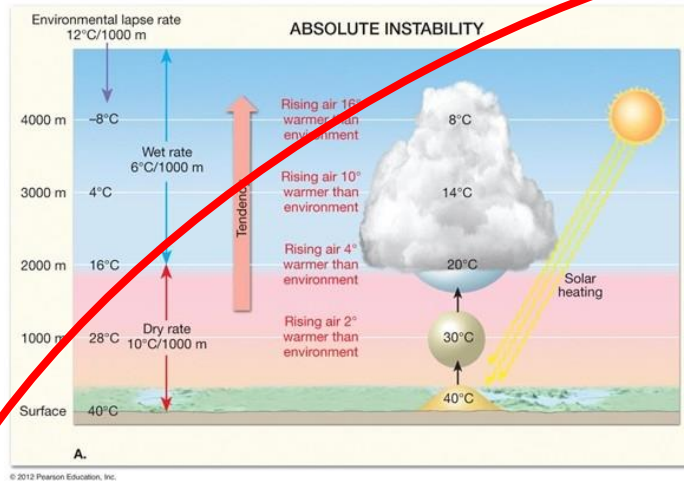
Clear -1 < OmC < 1

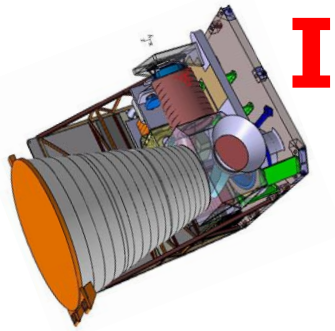
Cloudy -10 < OmC < -1

Radiosonde humidity

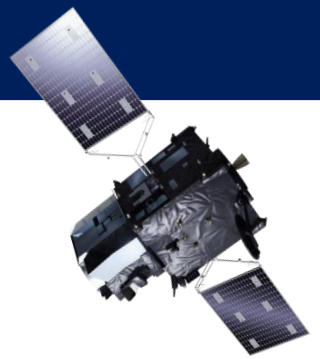


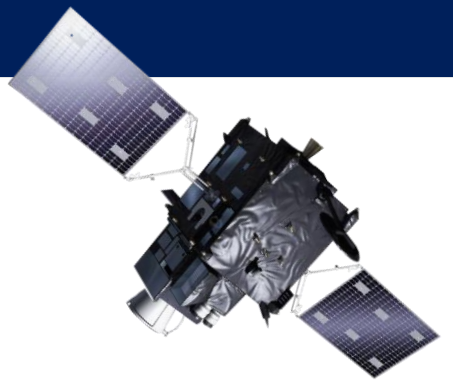
A full weather story with MTG



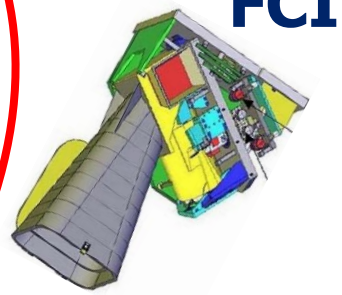


IRS

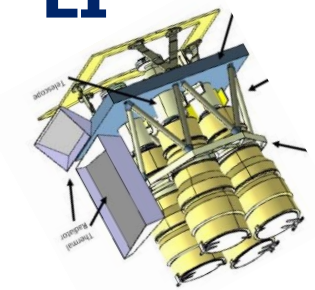




FCI



LI



Evaluate the thermodynamic state before clouds form.

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

Ongoing dialog with forecasters

- 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**

Tracking instability with IASI L2 products

Case study:
Central Europe Flooding 20 June 2013

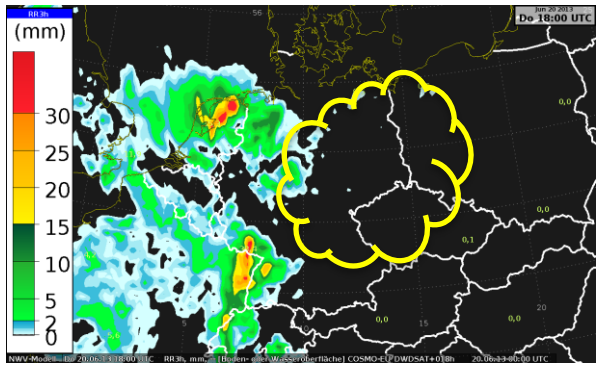
Results: R. Petersen, L. Cronce, (U. Wisconsin)
"Using hyper-spectral sounding products to improve forecasts of the pre-convective environment as a prelude to MTG-IRS"
EUMETSAT User Conference 2014

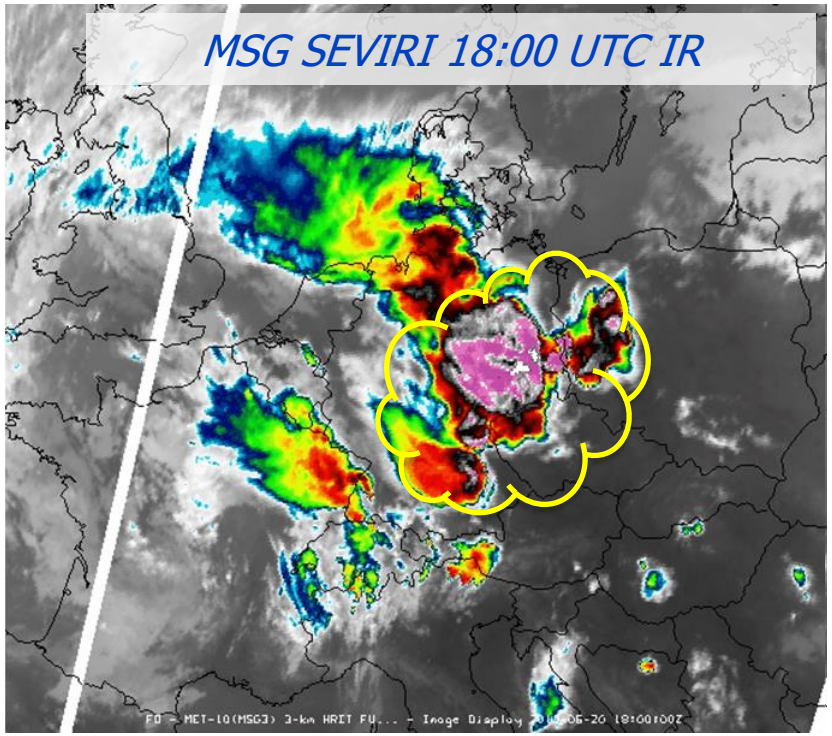
Tracking instability with IASI L2 products → *R. Petersen & L.Cronce talk*

Case study: Central Europe Flooding 20 June 2013

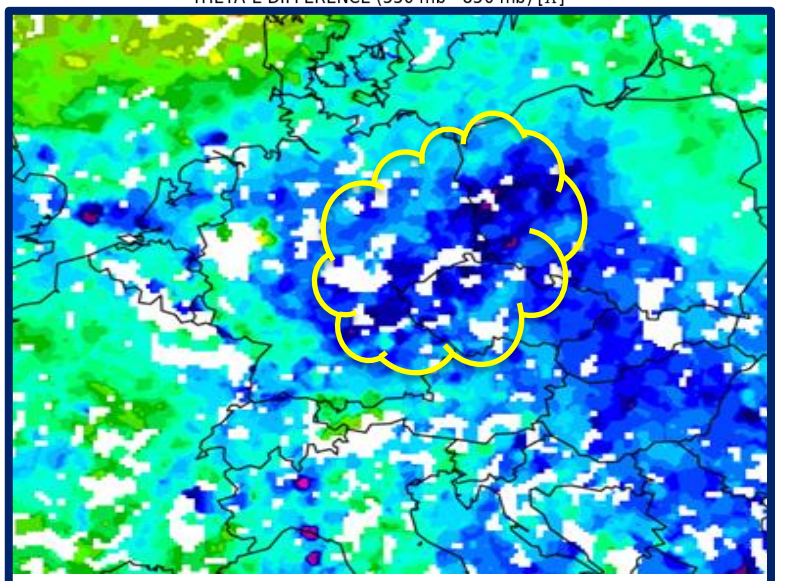
Results: R. Petersen, L. Cronce, (U. Wisconsin)
"Using hyper-spectral sounding products to improve forecasts of the pre-convective environment as a prelude to MTG-IRS"
EUMETSAT User Conference 2014

COSMO_EU 00Z forecast 18 UTC

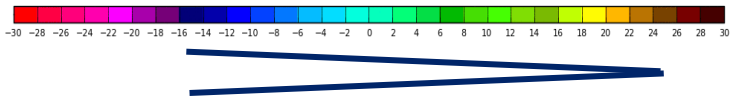




THETA-E DIFFERENCE (550 mb - 850 mb) [K]

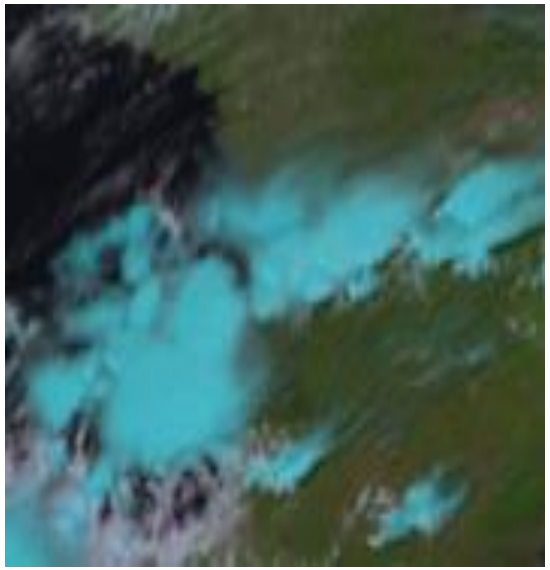


IASI L2 v6 Morning
+
NearCast at 18:00

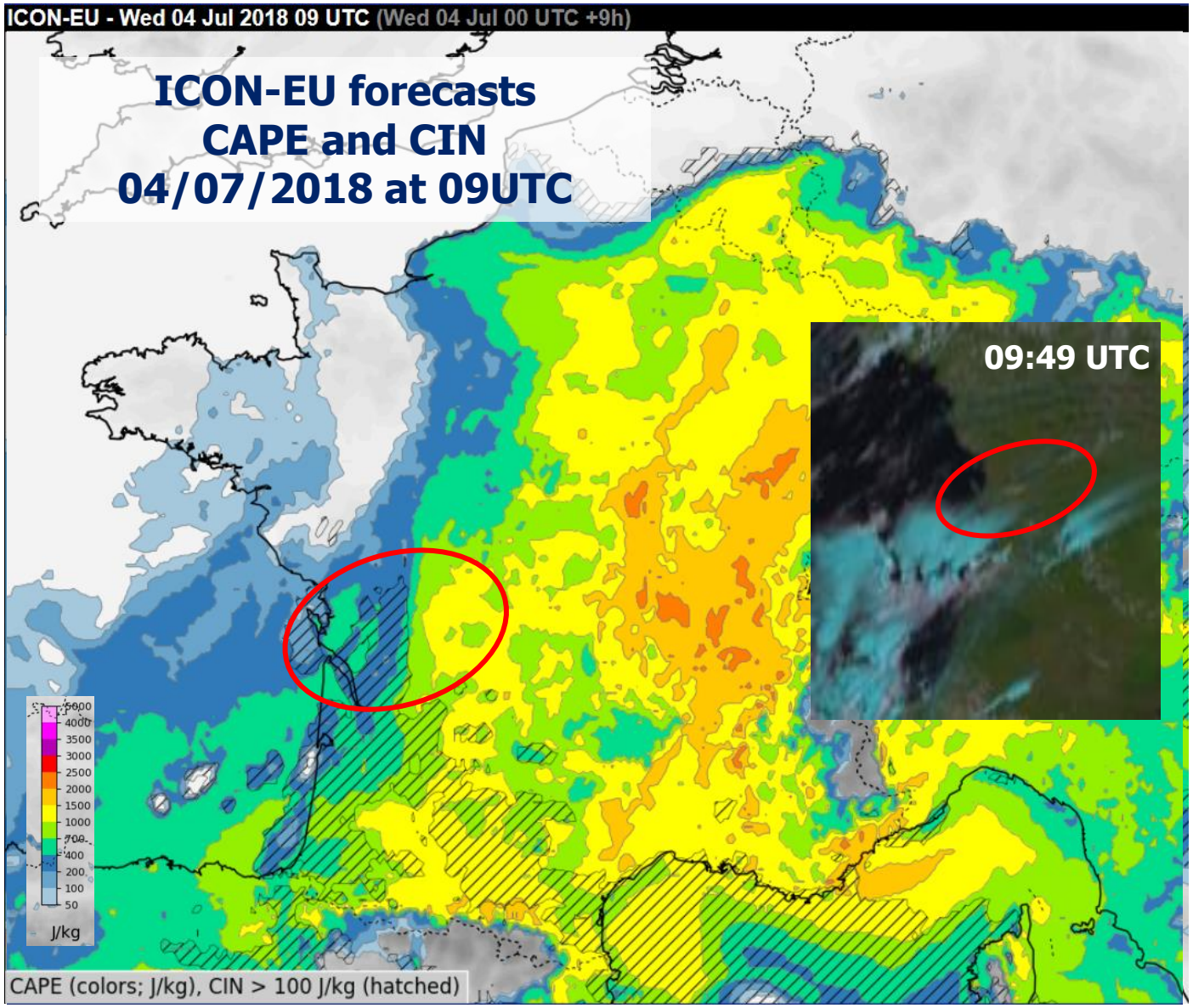


Instability

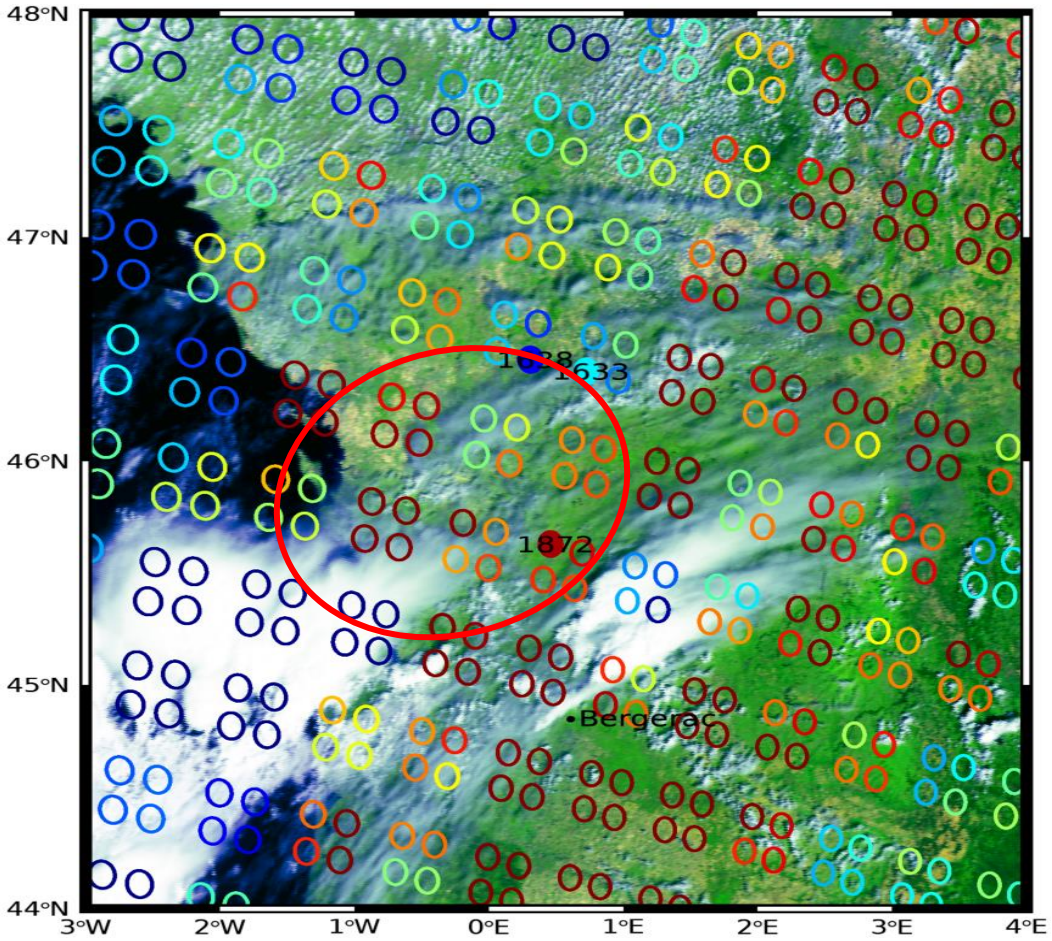
Wind, Lightning, Hail storm in Dordogne – 04/07/2018



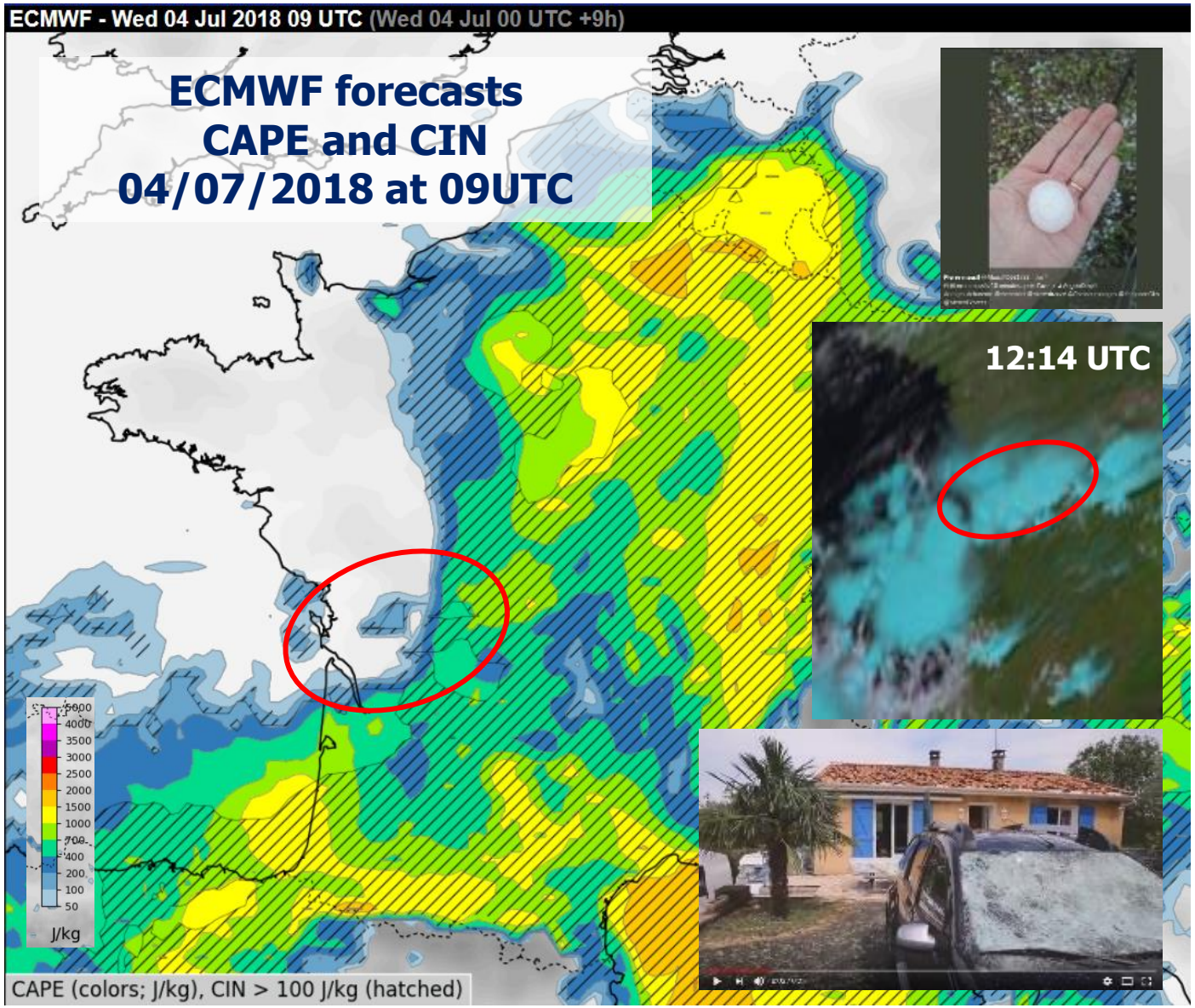
Wind, Lightning, Hail storm in Dordogne – 04/07/2018



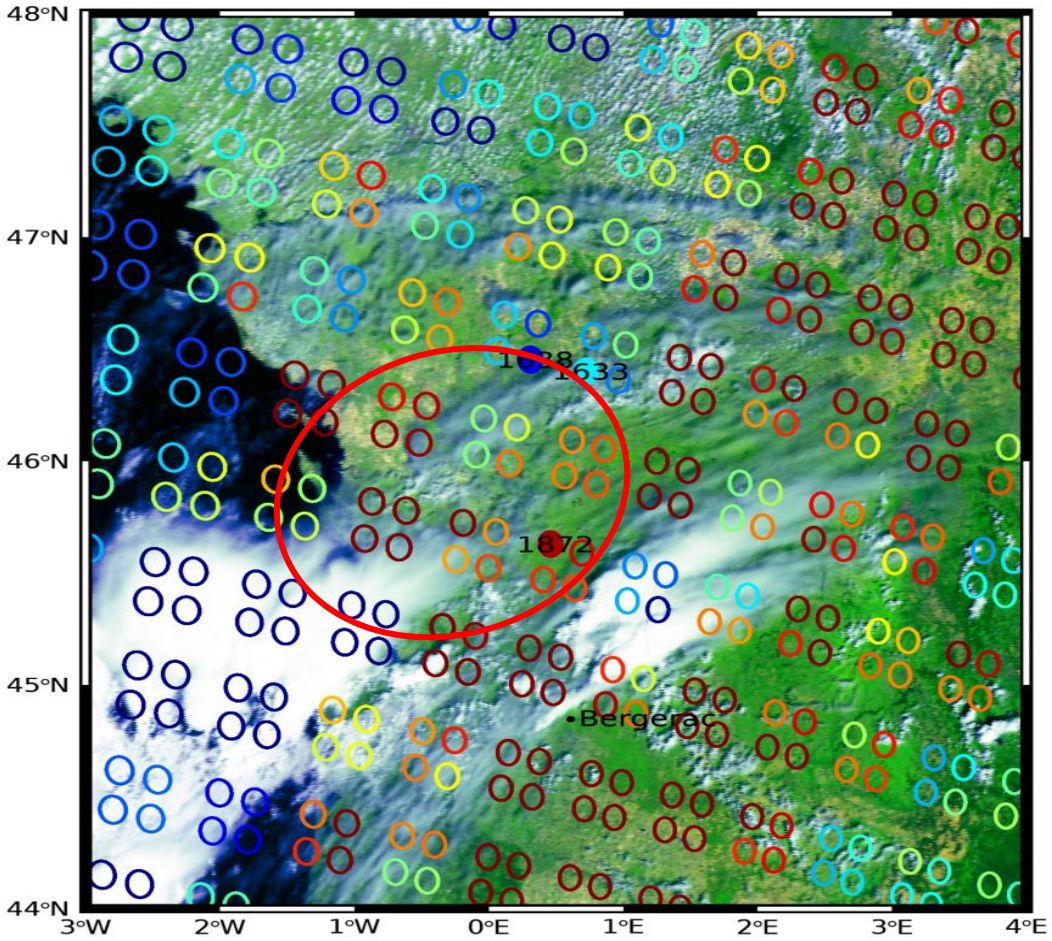
Metop-B/IASI – MLCAPE50
04/07/2018 09:50



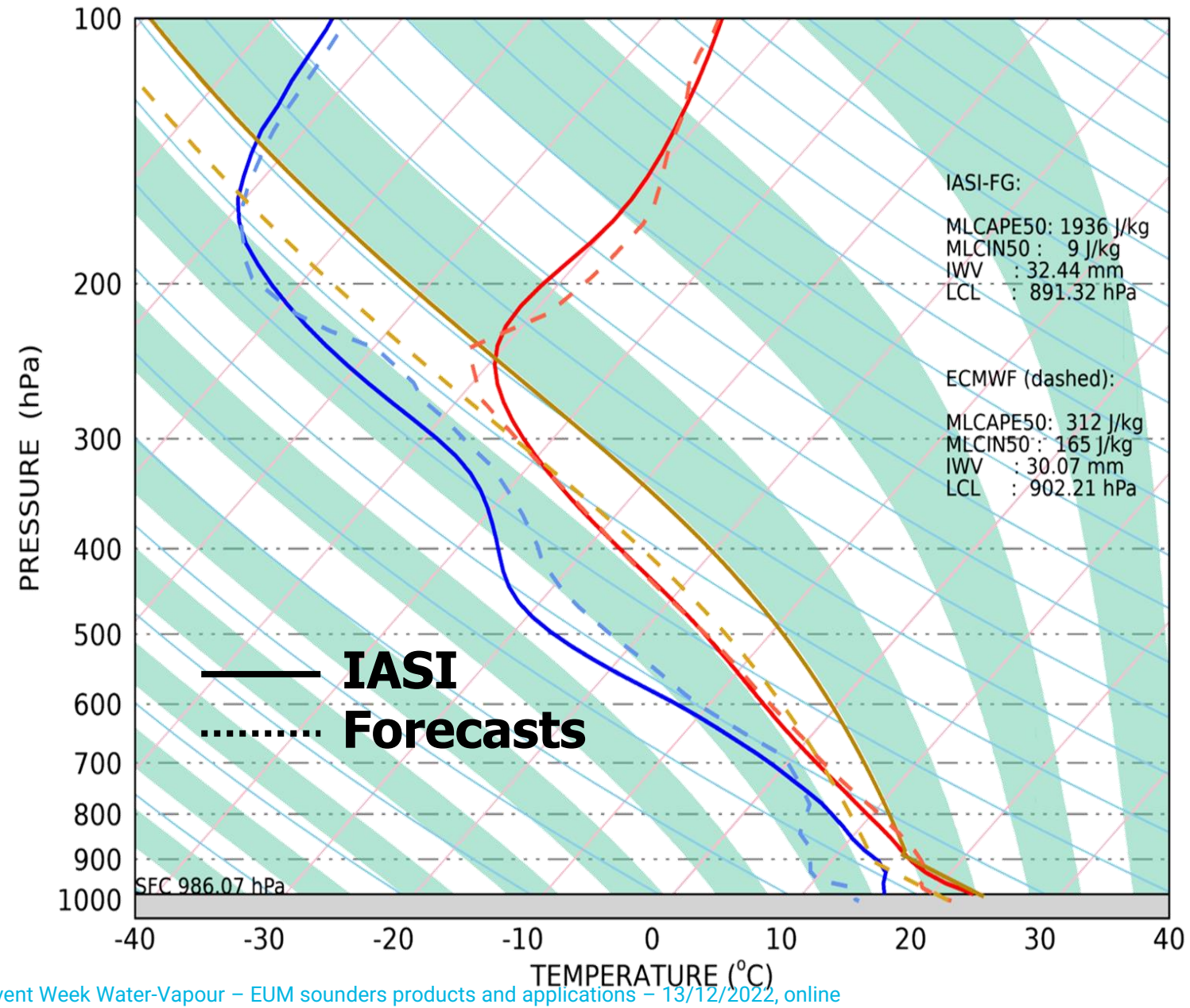
Wind, Lightning, Hail storm in Dordogne – 04/07/2018

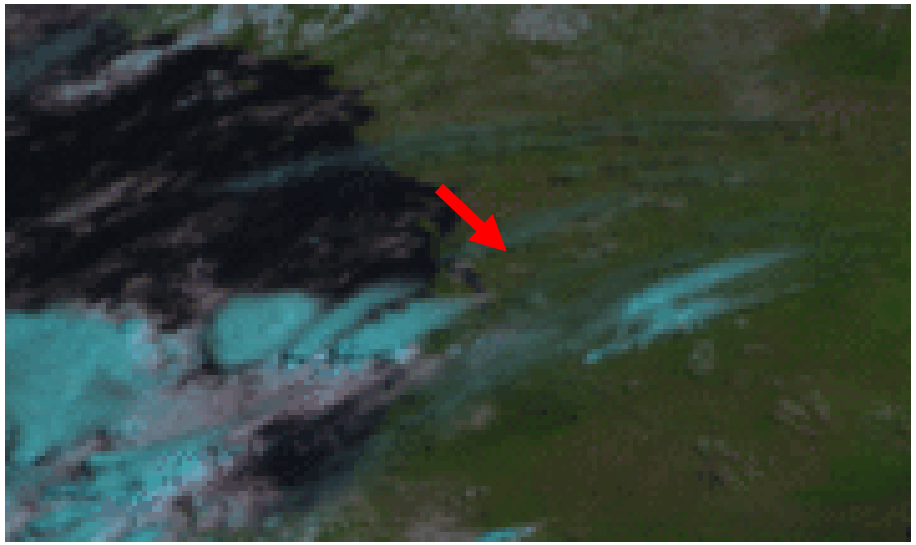


Metop-B/IASI
04/07/2018 09:50



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





24 June 2021: Severe weather outbreak over Central Europe

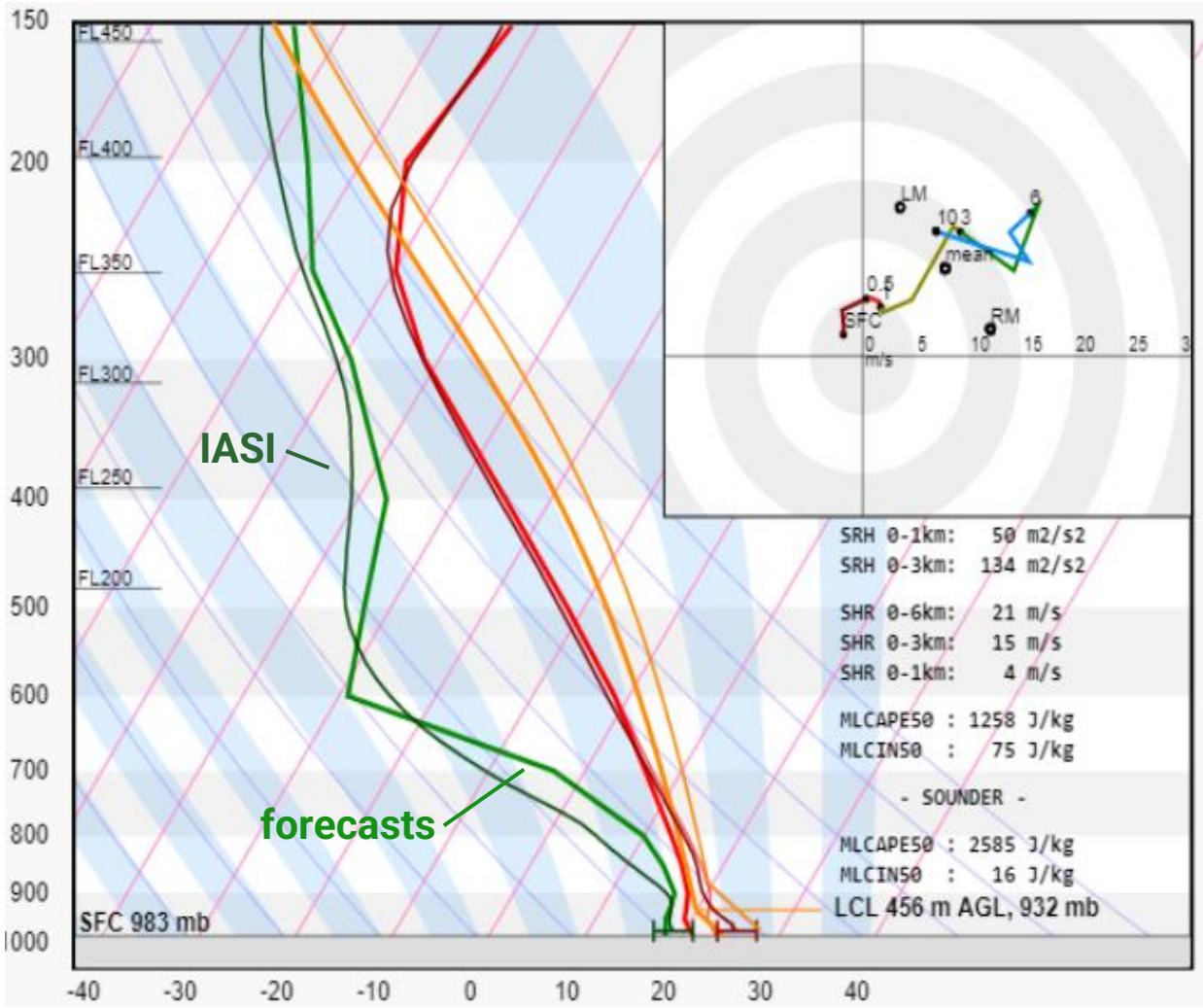
2 tornadoes

Violent F4 tornado in East Czechia

Giant (≥10 cm) hail in Austria, Poland

615 hail reports in Poland

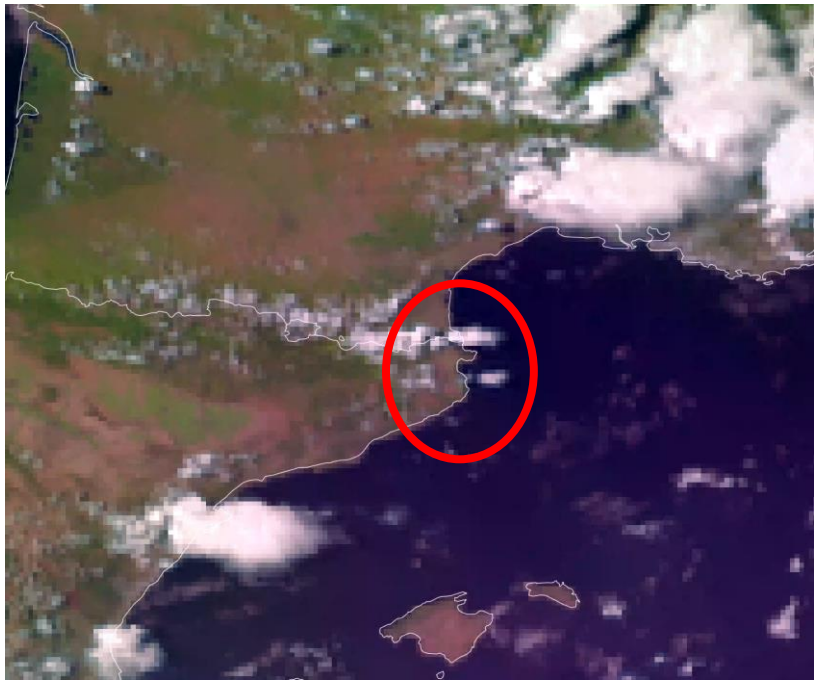
IASI indicates higher temperature
(confirmed with ground obs)
and higher CAPE than the forecasts

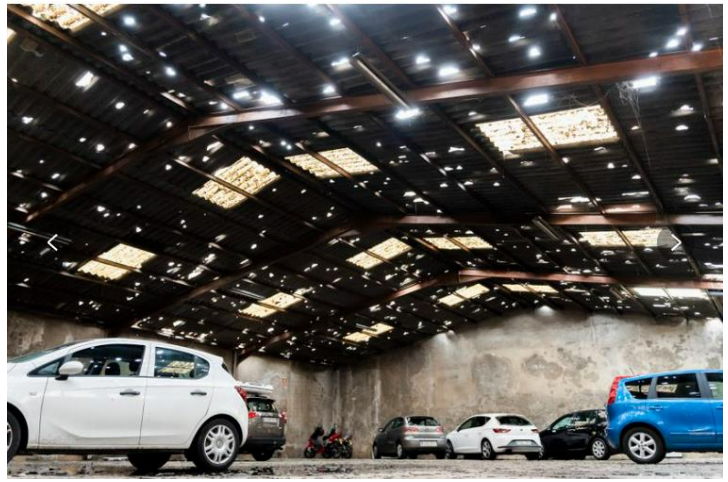


Giant hailstones in Girona, 30 August 2022

30/08/2022 - **Girona/La Bisbal** (Spain)

- **Storm with >10cm hail stones**
- **20-month toddler killed**
- **Over 30 injuries - mostly head**
- **Many destructions**





Source: El Pais, The telegraph

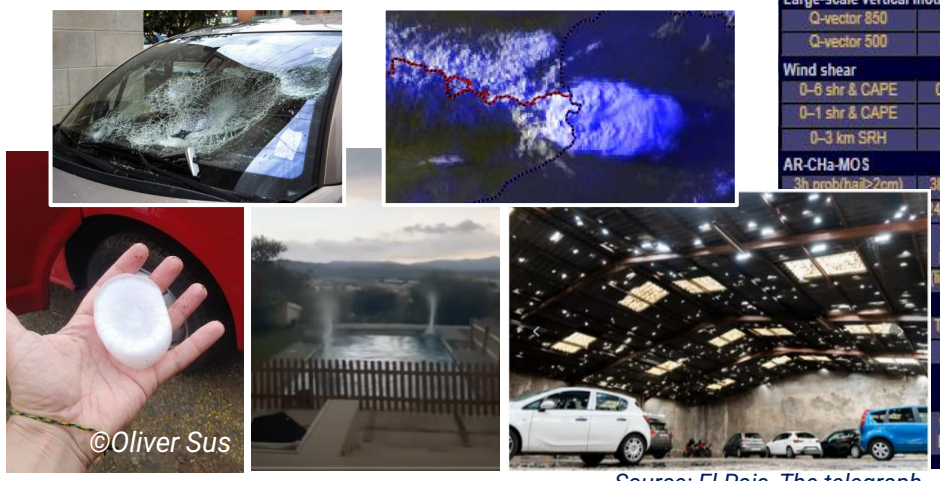
Giant hailstones in Girona, 30 August 2022

30/08/2022 - Girona/La Bisbal (Spain)

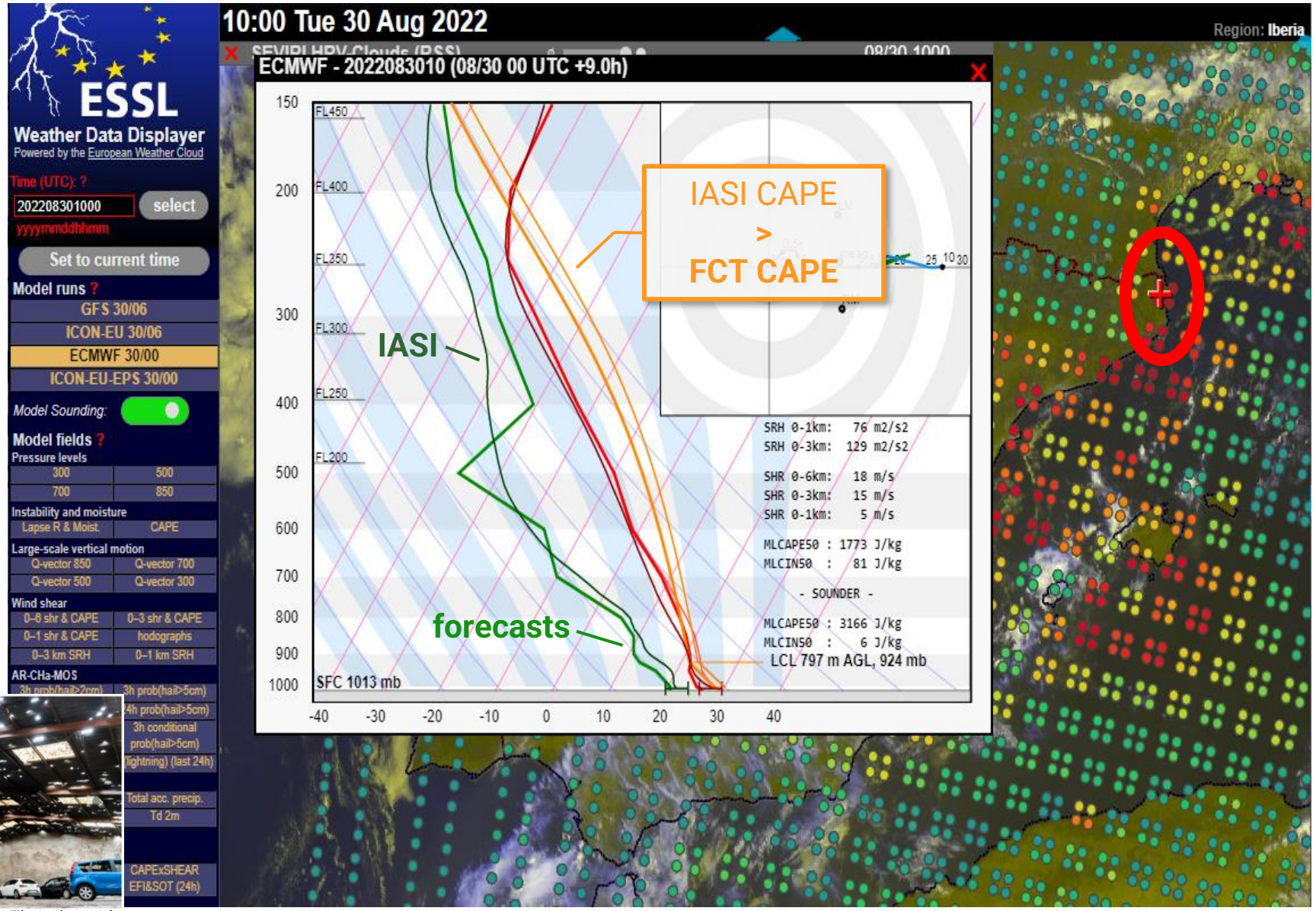
- **Storm with >10cm hail stones**
- **20-month toddler killed**
- **Over 30 injuries - mostly head**
- **Many destructions**

Atmospheric instability visible in the forecasts and IASI profiles.

IASI CAPE larger *(3100 vs 1700 J/kg)*, with higher temperature and moisture content near surface.

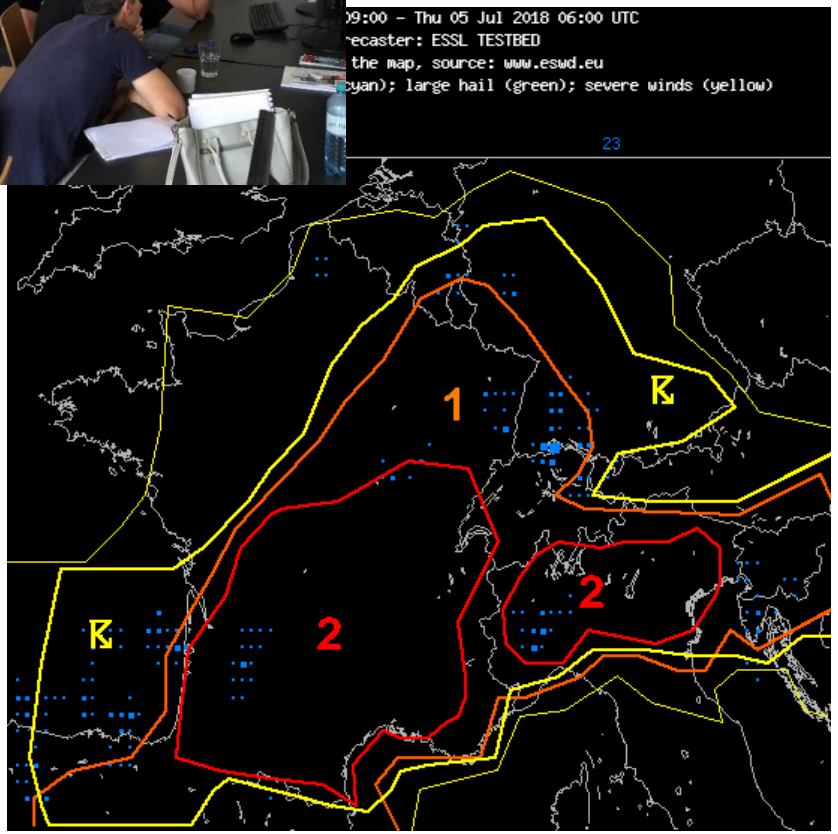


Source: El Pais, The telegraph



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.



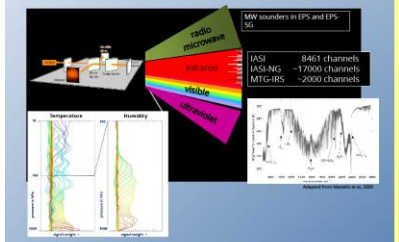
European Severe Storms Laboratory
Science & Training

EUMETSAT

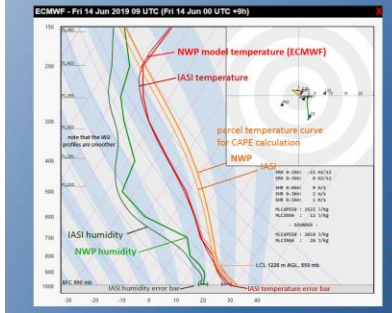
Evaluating the use of IASI hyperspectral sounder data for severe storm forecasting at the ESSL Testbed

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

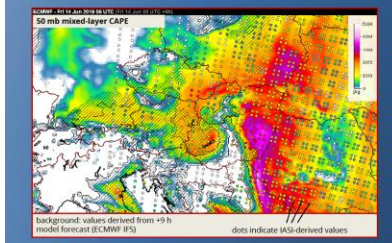
The IASI sounder measures infrared radiances ...



...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:

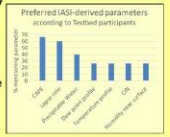


ESSL Testbed

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

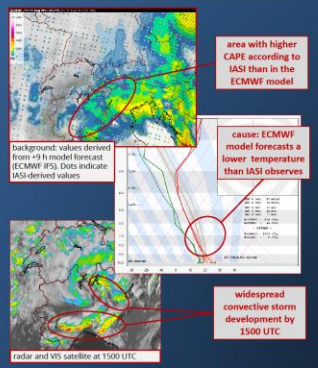
Main conclusions:

- **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...

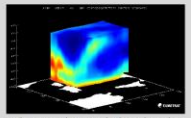
Meteosat Third Generation – InfraRed Sounder

- 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

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:

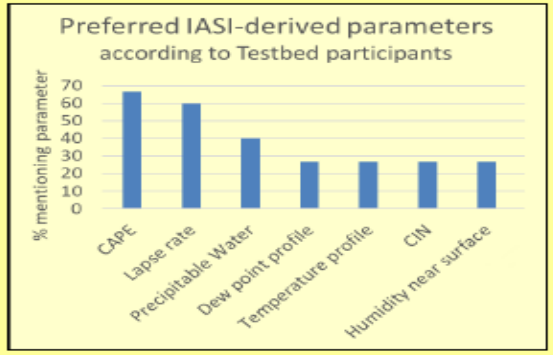
- **almost all forecasters found the type of data useful**

IRS ✓ **forecasters would like to have a higher (spatio-) temporal availability**

baseline ✓ **IASI profiles should stay completely independent of the model data**

to study - **forecasters found greatest discrepancies between IASI and NWP in the near-surface humidity**

- **preferred parameters are**
  - **CAPE**
  - **lapse rates**
  - **precipitable water**



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

EUMETSAT

Feed-back from studies with ESSL and OMSZ

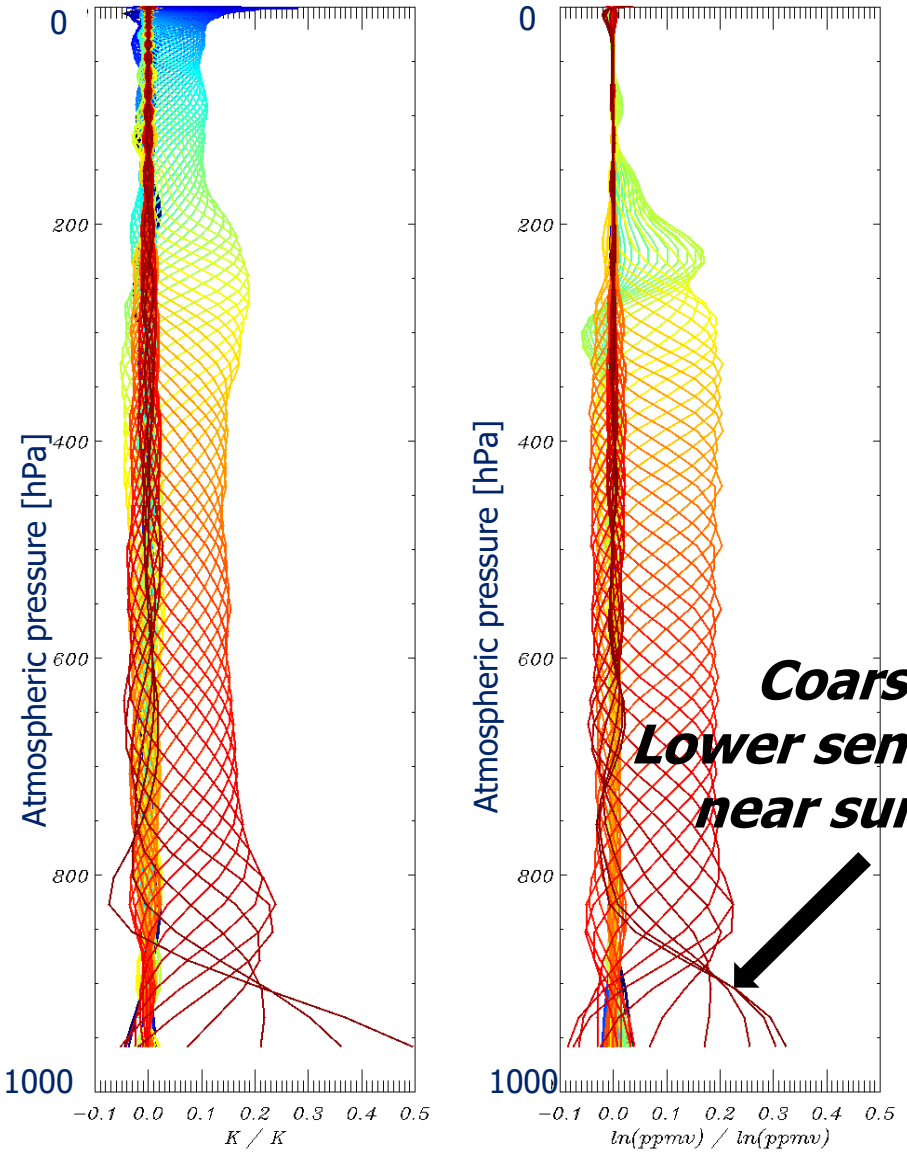
See study webstories for more details…

https://www.eumetsat.int/severe-storm-forecasting-lab
https://www.eumetsat.int/hyperspectral-instability-monitoring-using-iasi

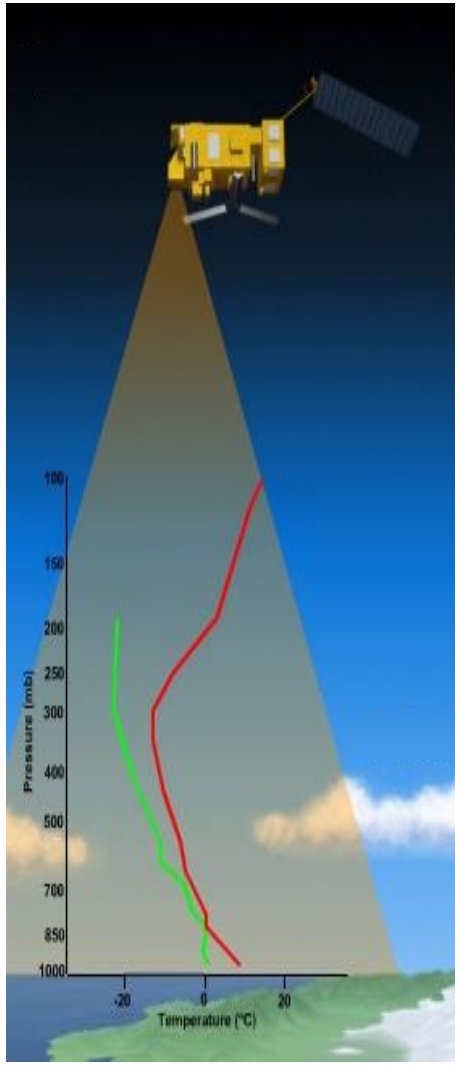
- ✓ **Forecast-free products required**
- ✓ **Sometimes IASI L2 != forecasts**
- ✓ **Usually IASI low-tropo temperature is more representative**
- ¿ **Dry bias in IASI L2 reported near surface in some** *(moistest)* **situations**
- ¿ **Usually IASI CAPE are lower** *(“smooth” profiles)*

Satellite-Ground synergy – Study with OMSZ → *Z. Kocsis talk*

Averaging Kernels



Coarser
Lower sensitivity
near surface



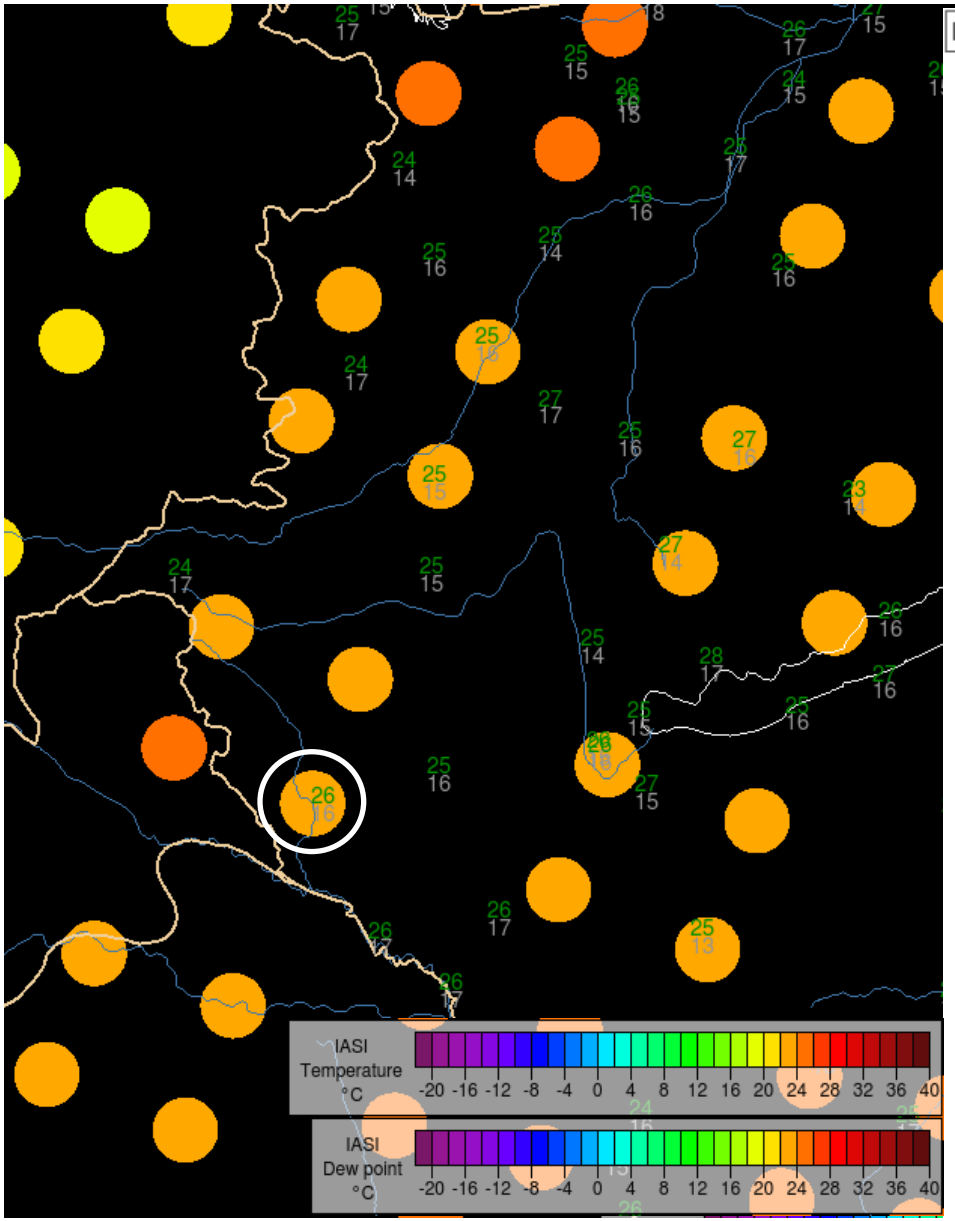
cf. studies at University of Wisconsin

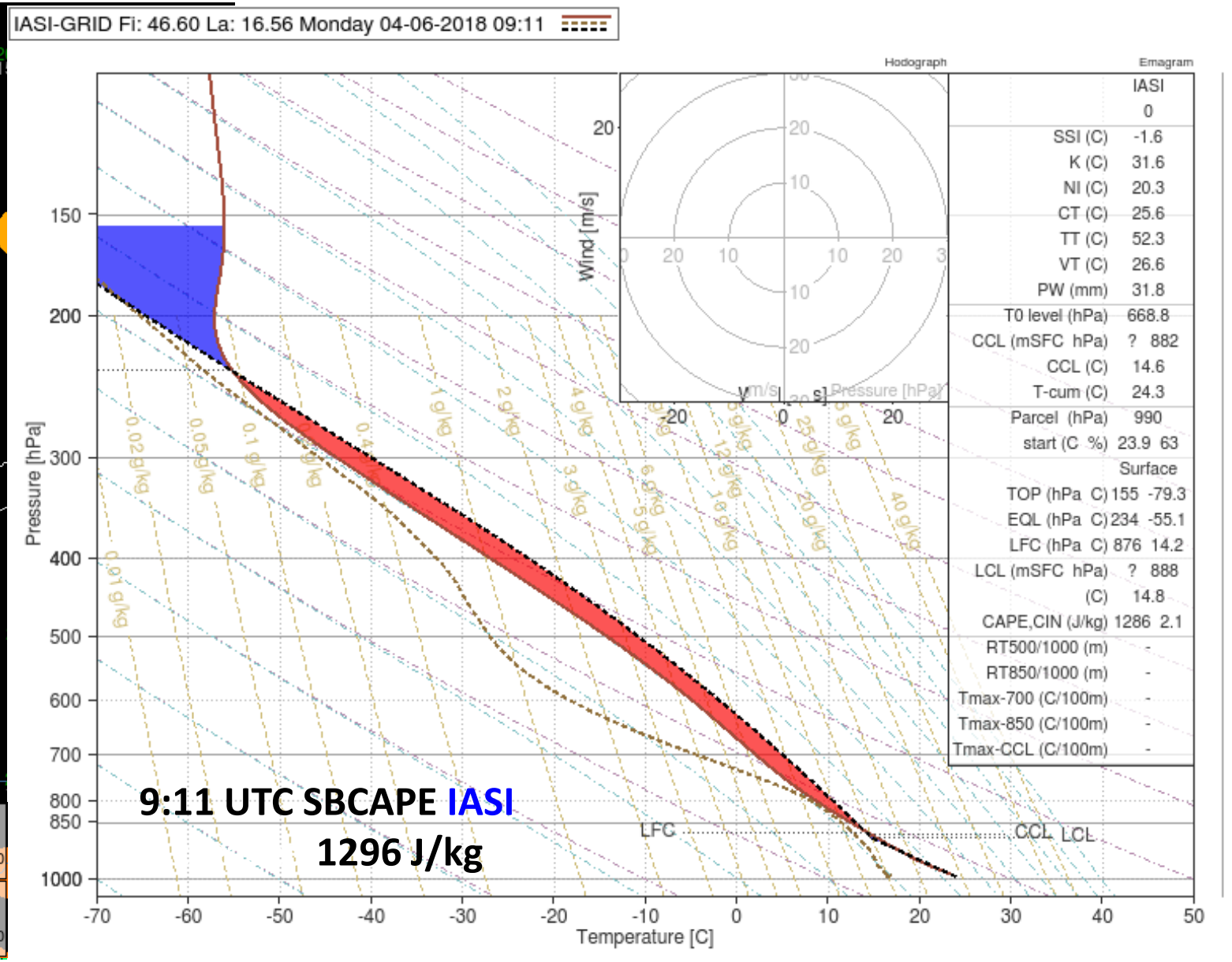
J. Gartzke et al., JAMC 2017, "Comparison of Satellite-, Model-, and Radiosonde-Derived Convective Available Potential Energy in the Southern Great Plains Region"

Bloch et al., JAMC 2019, "Near-Real-Time Surface-Based CAPE from Merged Hyperspectral IR Satellite Sounder and Surface Meteorological Station Data"

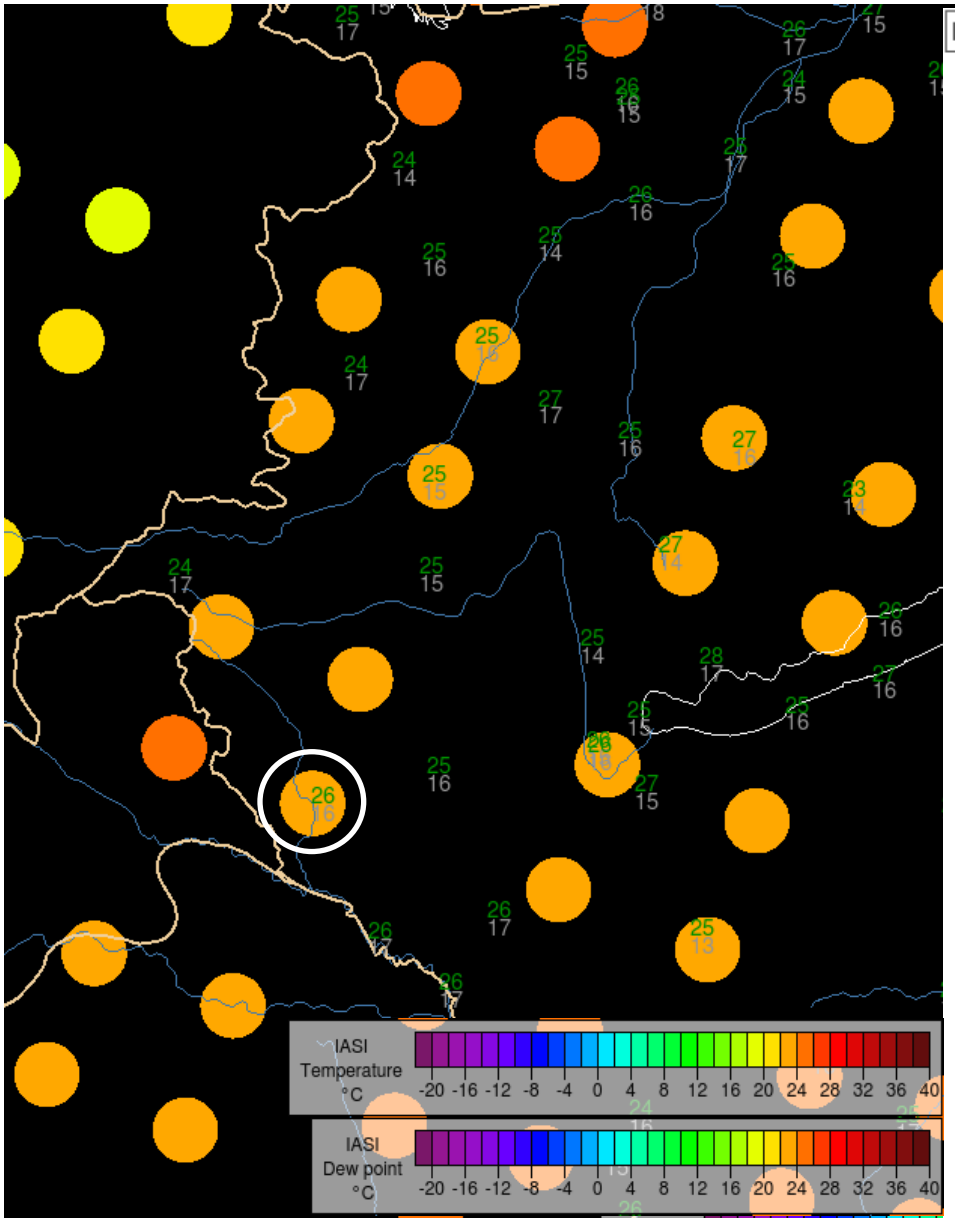
+

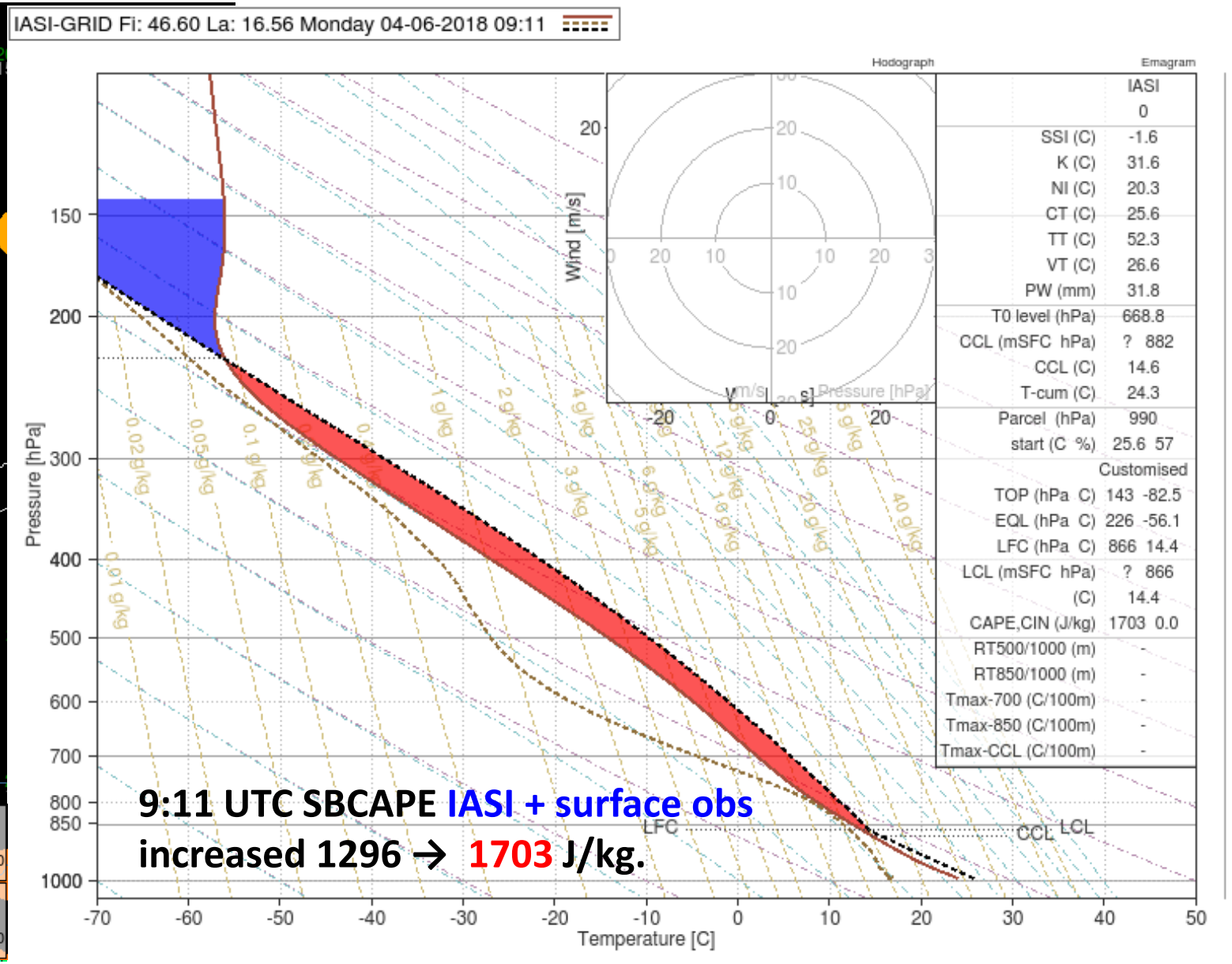
Satellite-Ground synergy – Studies with OMSZ



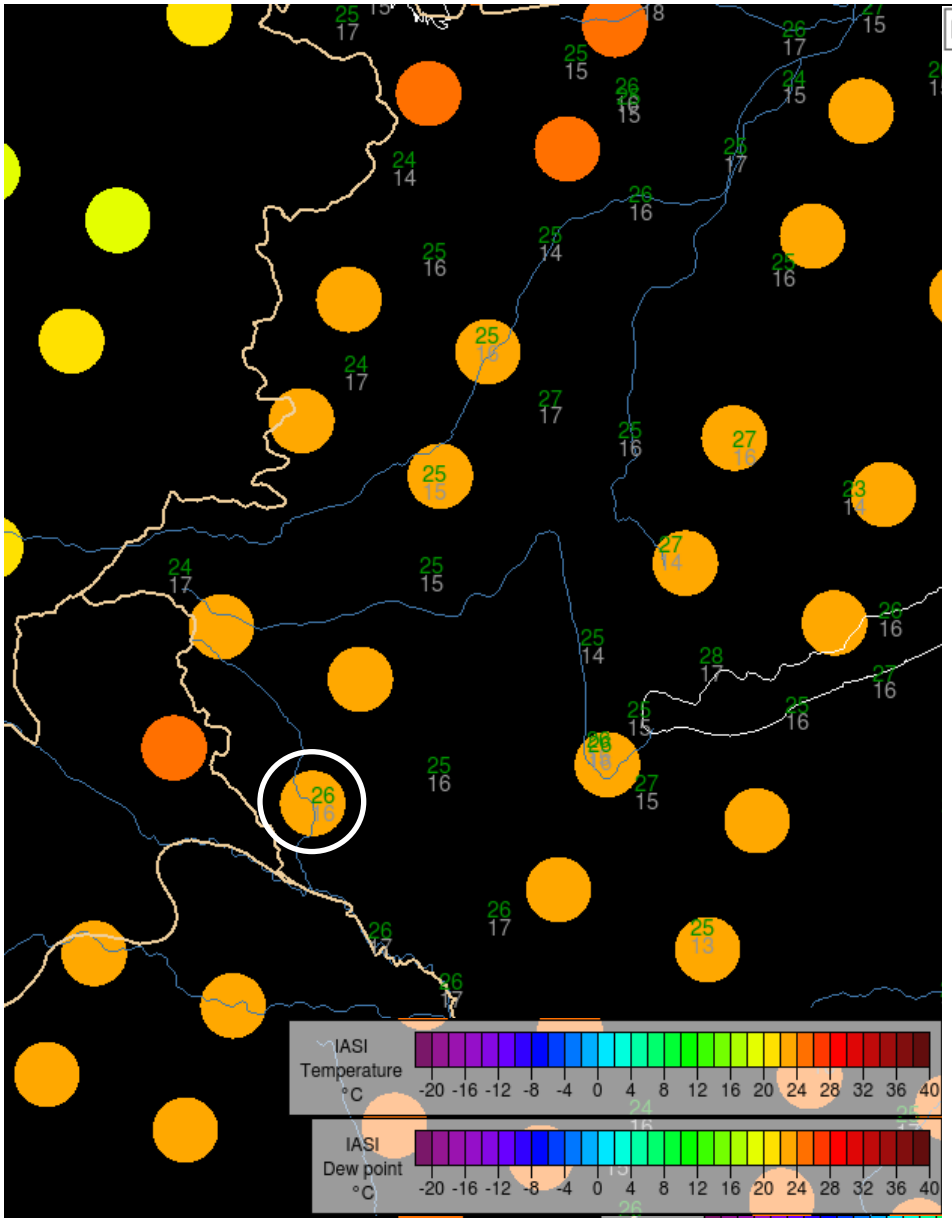


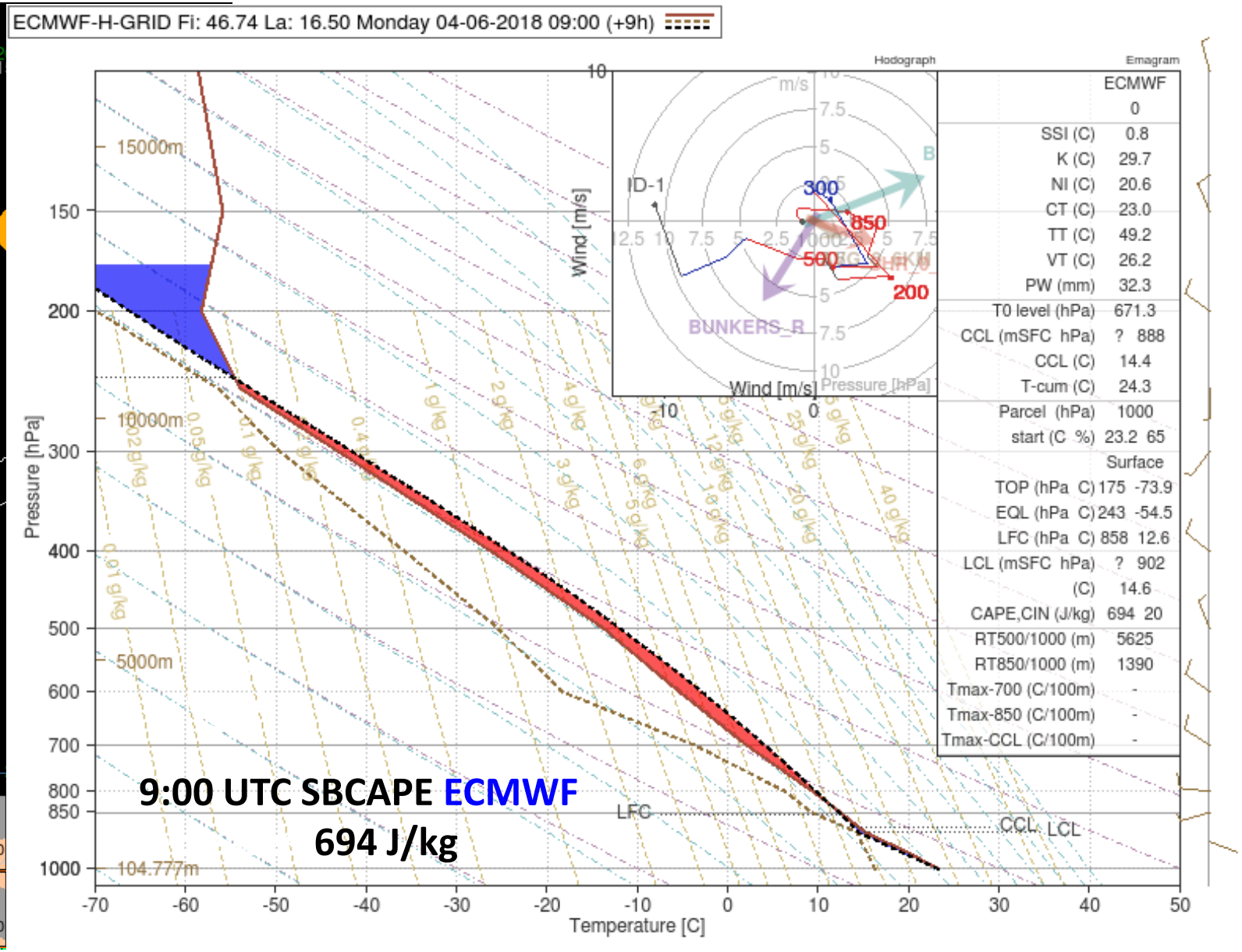
Satellite-Ground synergy – Studies with OMSZ





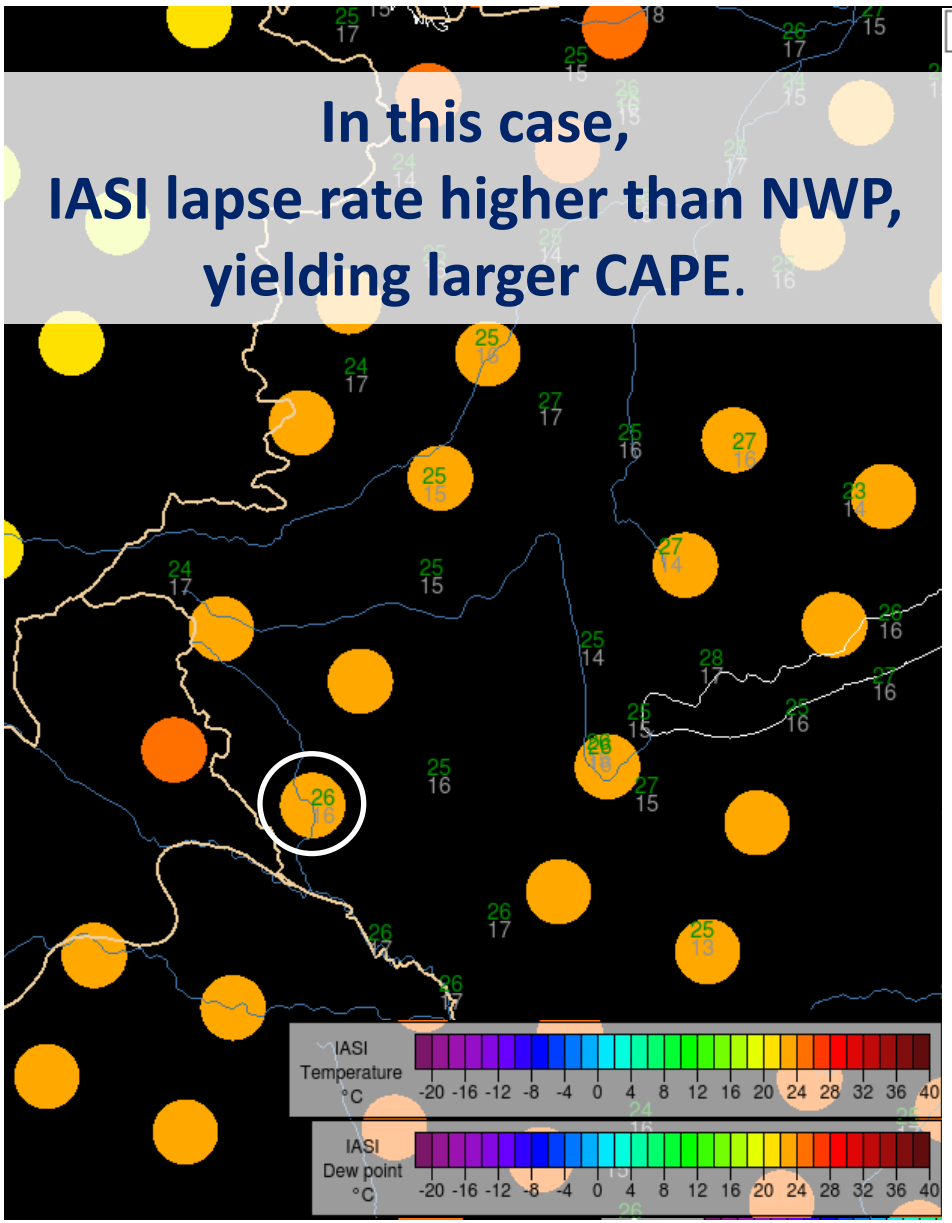
Satellite-Ground synergy – Studies with OMSZ

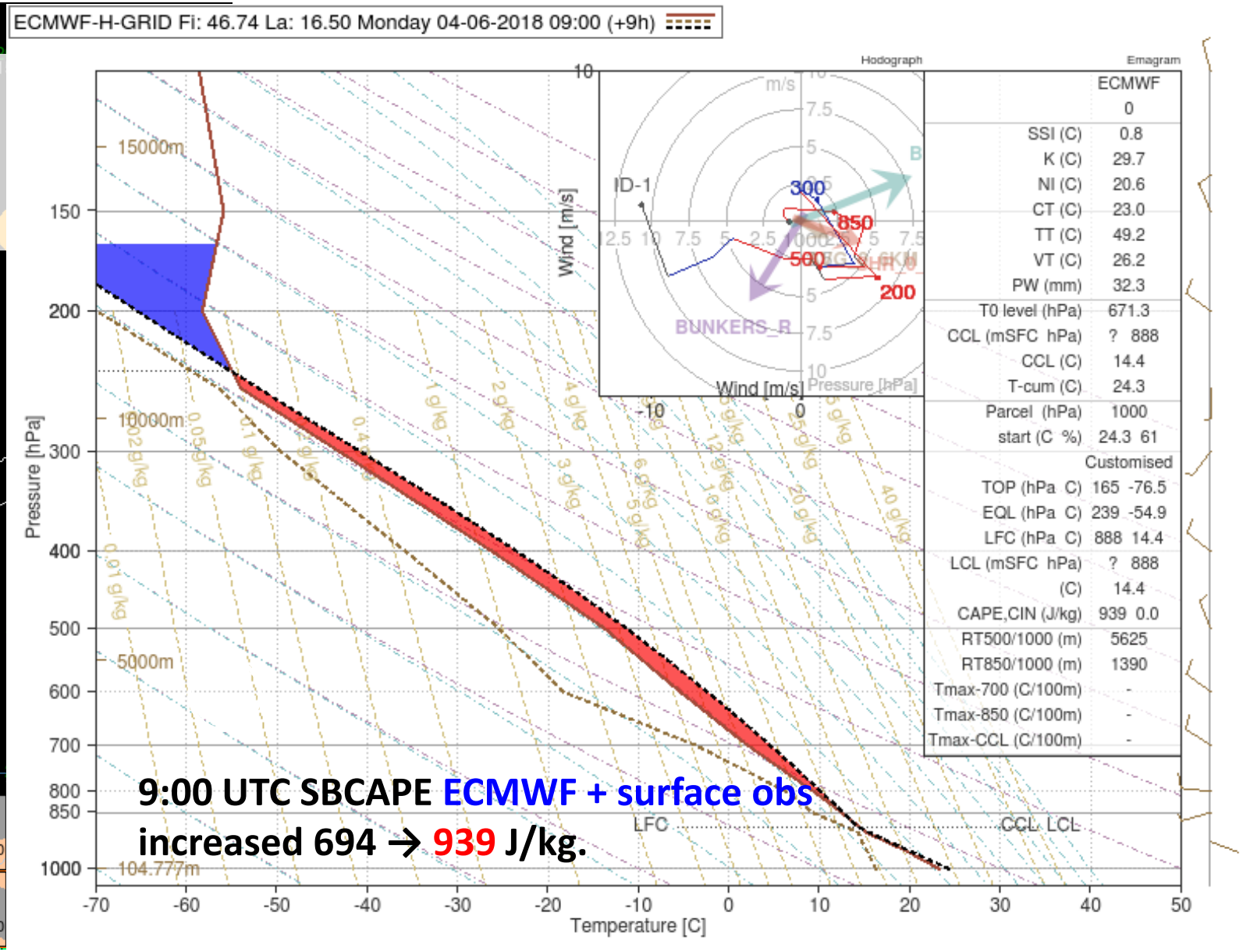




Satellite-Ground synergy – Studies with OMSZ

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

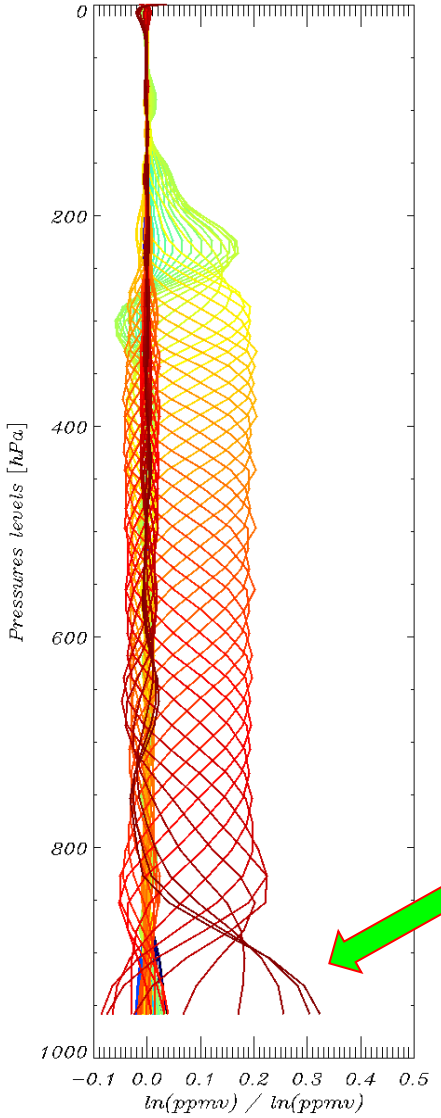




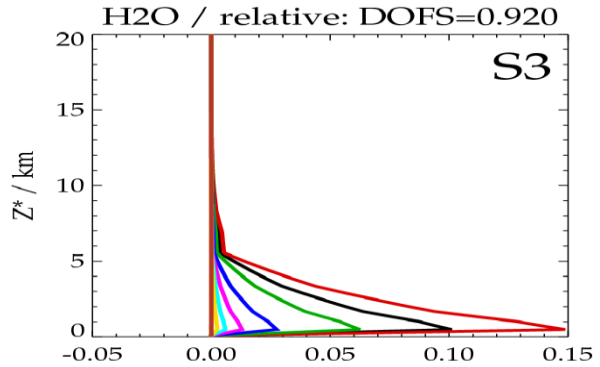
9:00 UTC SBCAPE ECMWF + surface obs increased 694 → 939 J/kg.

Satellite-Satellite synergies – Future plans → *with P.Watts & L.Spezzi*

MW+TIR sounders + ***VIS-NIR-TIR imagers***

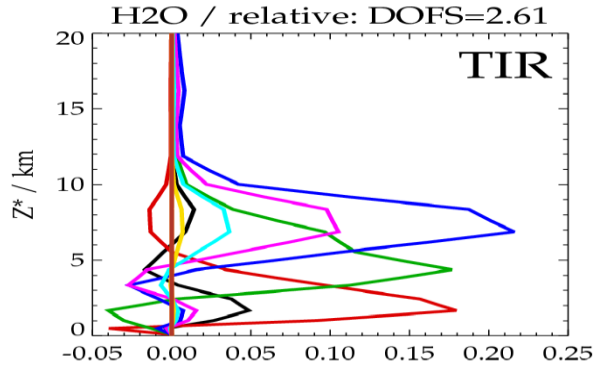


TCWV



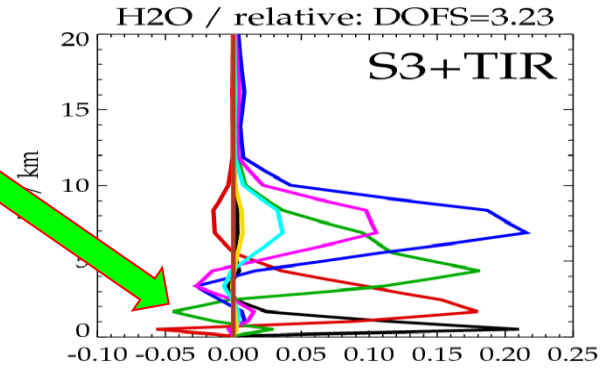
Solar channels

Coarse upper layers



Thermal channels

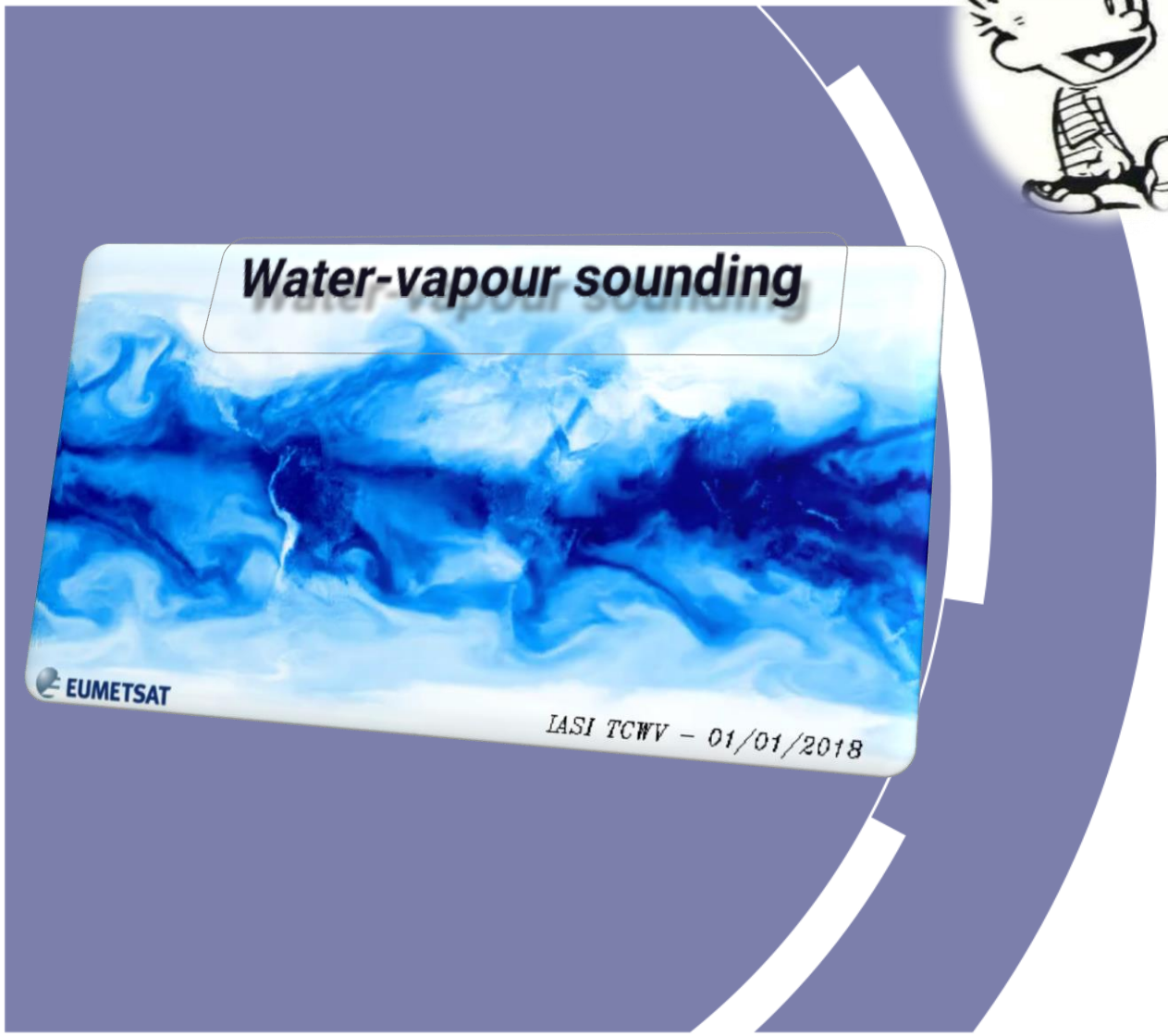
Isolate BDL-WV



Solar + Thermal

Thank you !

Questions?



Sounders meet forecasters

Forecast-free thermodynamic profiles:
- *most sensitive in free tropo,*
- *but some potential in BDL too*

User Dialog → define best actionable information

Science goes on

Near-surface dry bias?
- *validating in pre-convective situations*
- *blending satellite-ground obs.*
- *synergy sounders - imagers*

IASI regional service

Available within 15-30 min from sensing

Climate data records

2007-2022, extending out with new missions

MTG-IRS, a nowcasting mission

Unique 4D look into the atmosphere
Get ready! User familiarisation
Consolidate requirements

High lats and Polar missions…