Preparation for the assimilation of the future IRS sounder in NWP models

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Part I: The future MTG-IRS (InfraRed Sounder) in AROME model

### 1) The future MTG-IRS (InfraRed Sounder)

- Planned launch in 2024 onboard geostationary sounding satellite **MTG-S**
- Measurement with 4 Local Area Coverage (**LAC**) zones and Earth disc covered with ~ 313 Dwells
- **LAC 4** covering Europe every 30 minutes
- Each Dwell is taken in **10 s** and covers about **640 x 640** km² at nadir with **160 x 160** spatial samples
- Each Pixel covers ~ **4 x 7 km²** over Europe (4 x 4 km² at nadir)
- **1960** channels between 680 - 1210 cm⁻¹ and 1600 - 2250 cm⁻¹
- Spectral sampling of ~ 0.6 cm⁻¹ for both bands

Mean of IRS simulated Brightness Temperature
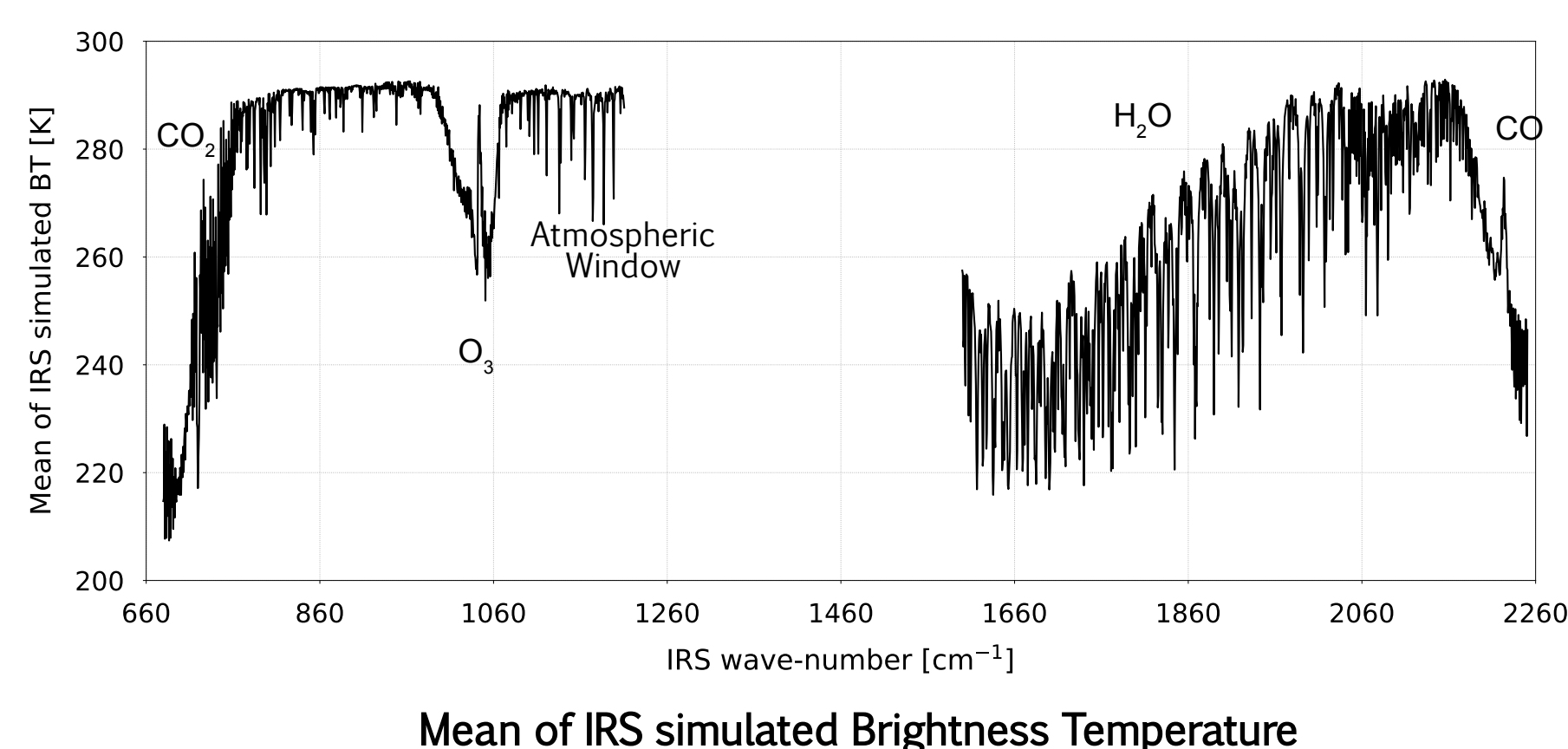
2) The regional AROME model
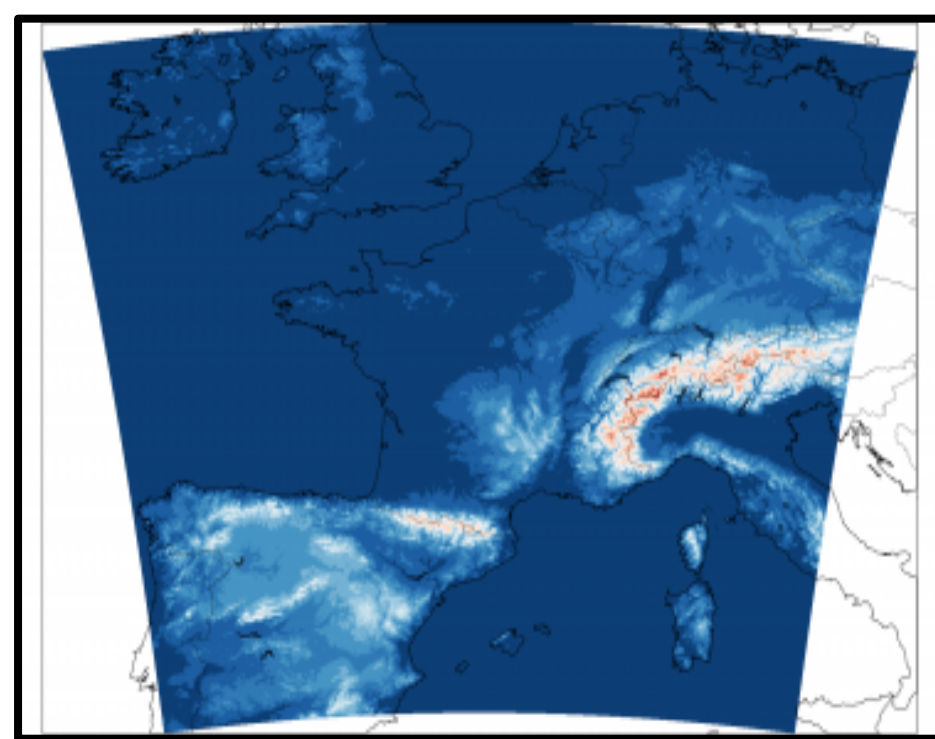
Arome domain
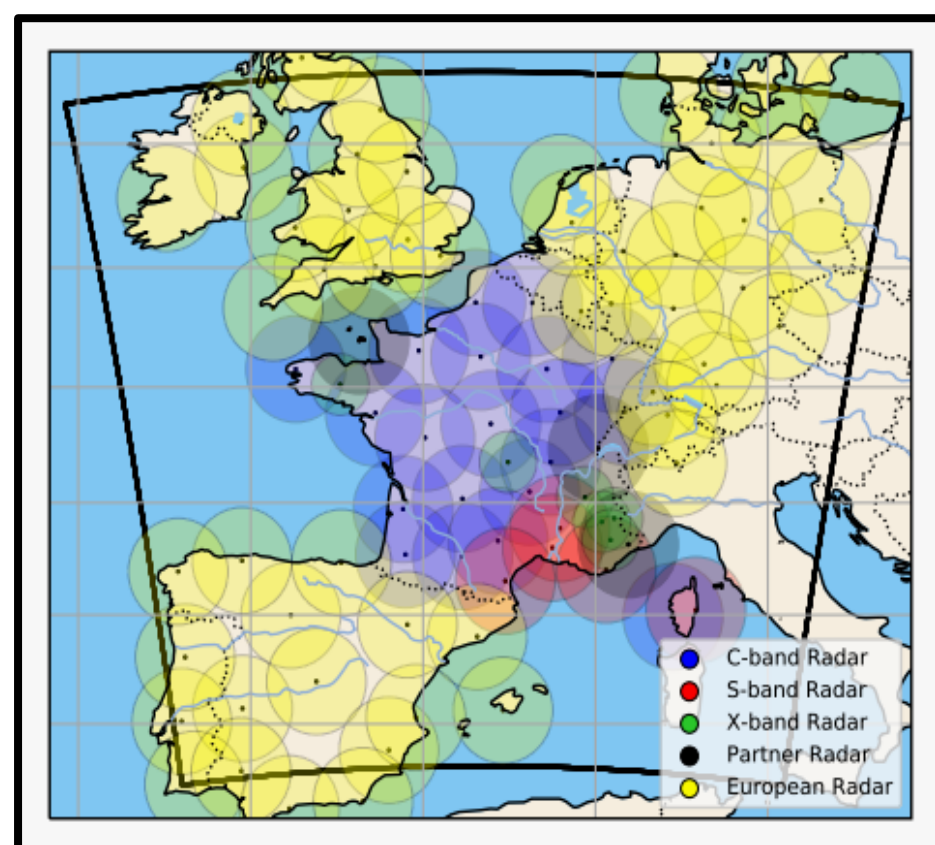
The Météo-France radar network

- Fine scale NWP model characterized by a non-hydrostatic dynamical core
- Horizontal resolution of 1.3 km and 90 vertical levels (5 m to 10 hPa)
- The AROME forecasts are initialized using analyses from a **3D-Var** data assimilation system with 1 h cycling
- High skill short range forecasts of severe events such as intense Mediterranean precipitation, severe storms …
- **Radar data represent 75%** (France + Europe) of the observations assimilated mainly on land
- Infrared observations represent only 5% of the assimilated data for a rainy day
- The maritime areas of the AROME domain have a lack of observations even though they are sensitive regions for meteorology and extreme event prediction

3) Objectives of this study

- Preparation of the assimilation of IRS for AROME
- Assessing the impact of IRS in addition to radars
- To be ready to assimilate real IRS data from day one
- Tools:
  → 1D study – IRS analysis & selection of information
  → 3D study – OSSE – AROME 3D-Var IRS assimilation

Scheme of OSSE framework for AROME 3D-Var data assimilation system (Part III)
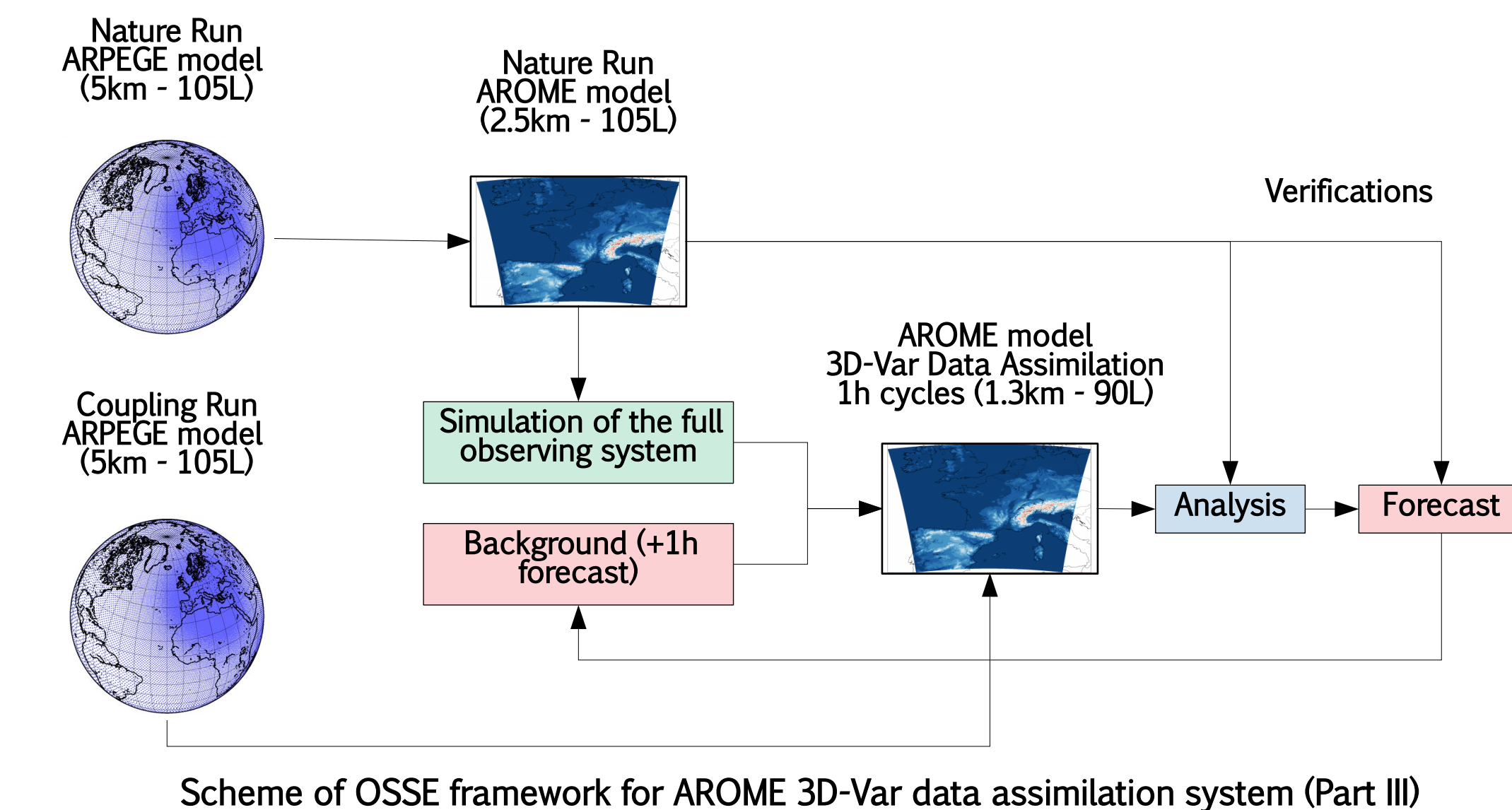
Part II: 1D study – IRS analysis and general selection of information

1) IRS sensitivity analysis

- The main IRS sensitivities are in the troposphere. The channels the most sensitive in temperature and humidity are observed in the lower troposphere for the first band of the atmospheric window. Ozone band channels are sensitive to temperature and humidity in the lower troposphere.
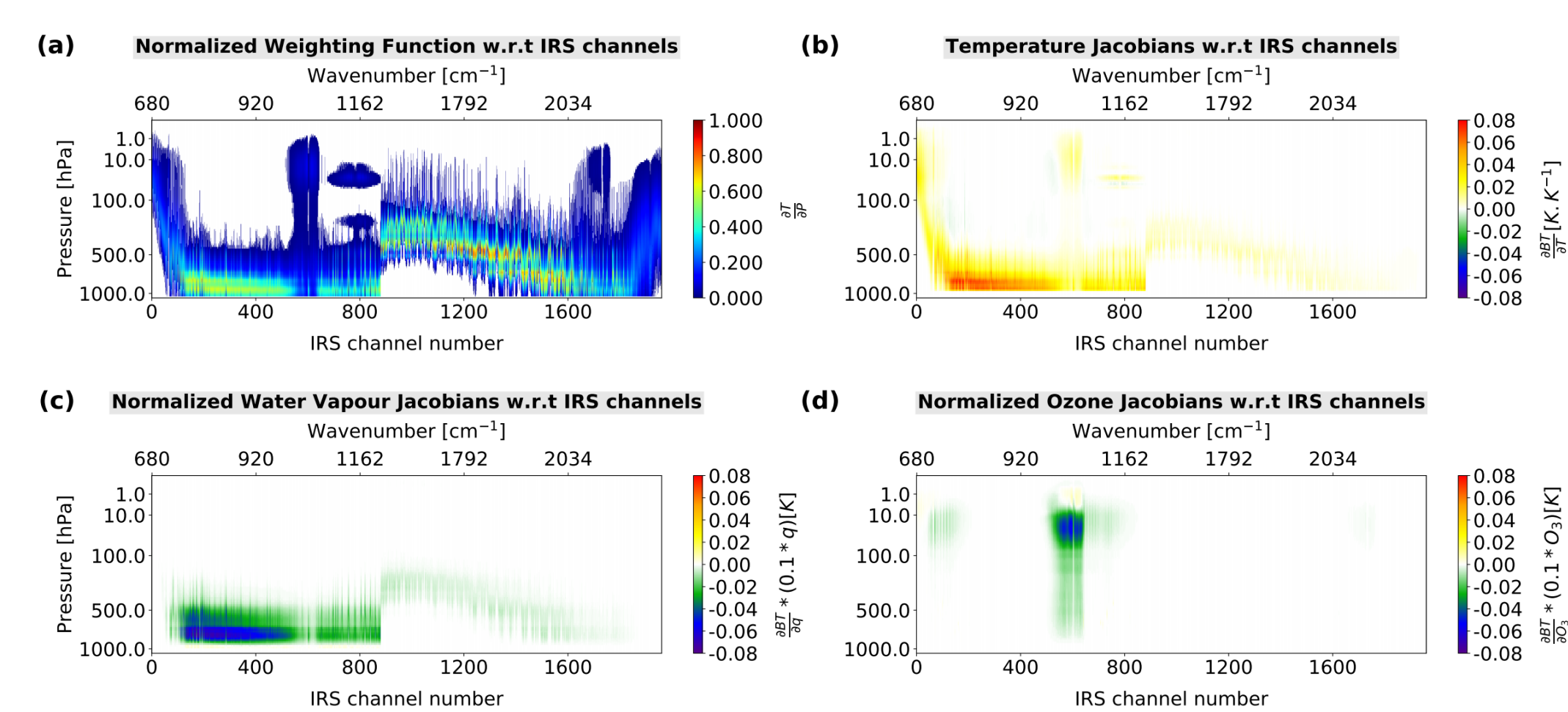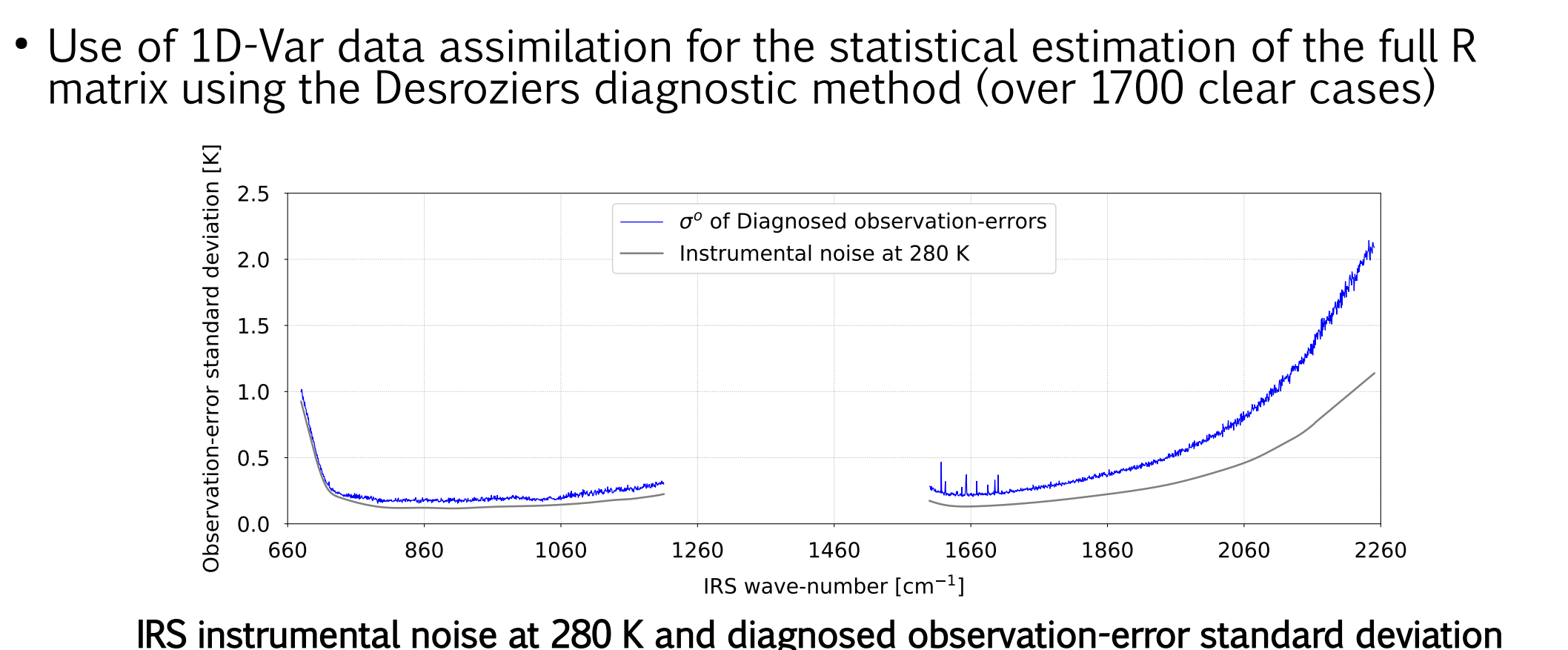

Weighting functions (a) and normalised Jacobians of temperature (b), humidity (c) and ozone (d) as a function of pressure and calculated from the RTTOV radiative transfer model over the 1960 IRS channels.

2) 1D database and IRS observation-errors
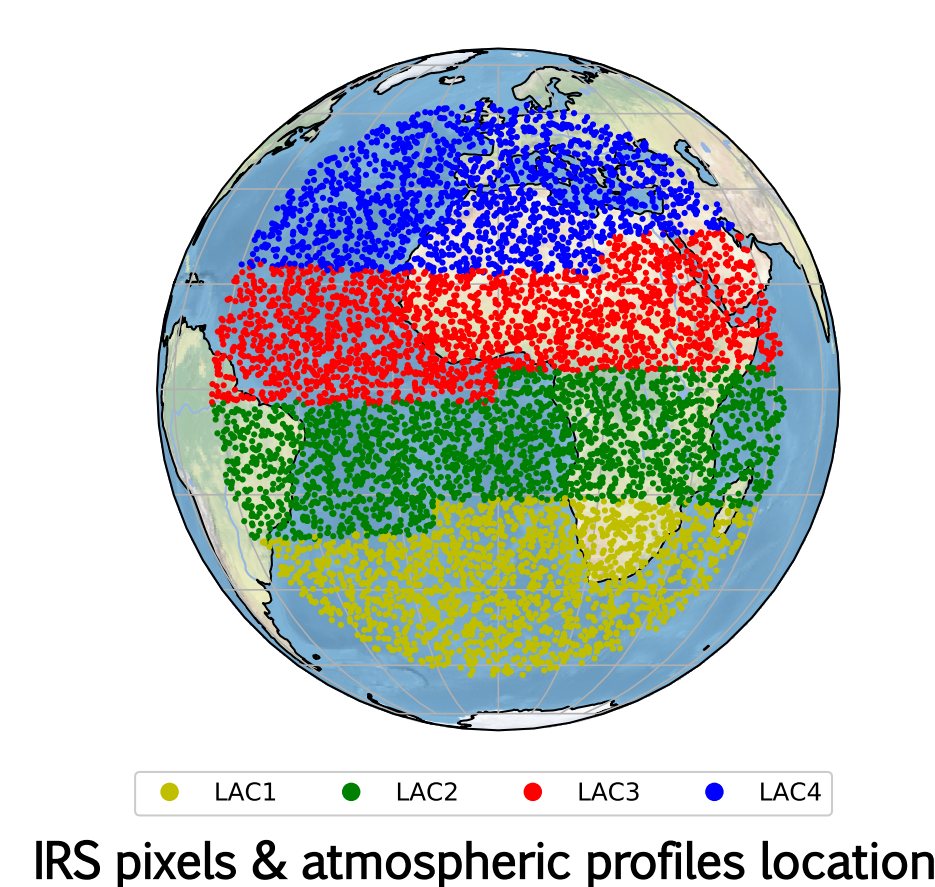
IRS pixels & atmospheric profiles location

- 7500 background profiles (ARPEGE):
  → $x^b = x^t + B^{1/2} \cdot \eta^b$

From "true" atmospheric profiles (x^t) with background-error covariance matrix (B) and a random vector drawn from a Gaussian distribution with zero mean and unit standard deviation (η)

- 7500 synthetic IRS observations:
  → $y = H(x^t) + R^{1/2}(NE\Delta T) \cdot \eta^o$

From simulated observation using "true" profiles and observation-errors from the converted NEΔT for the corresponding scene temperature T for each pixel

- Use of 1D-Var data assimilation for the statistical estimation of the full R matrix using the Desroziers diagnostic method (over 1700 clear cases)
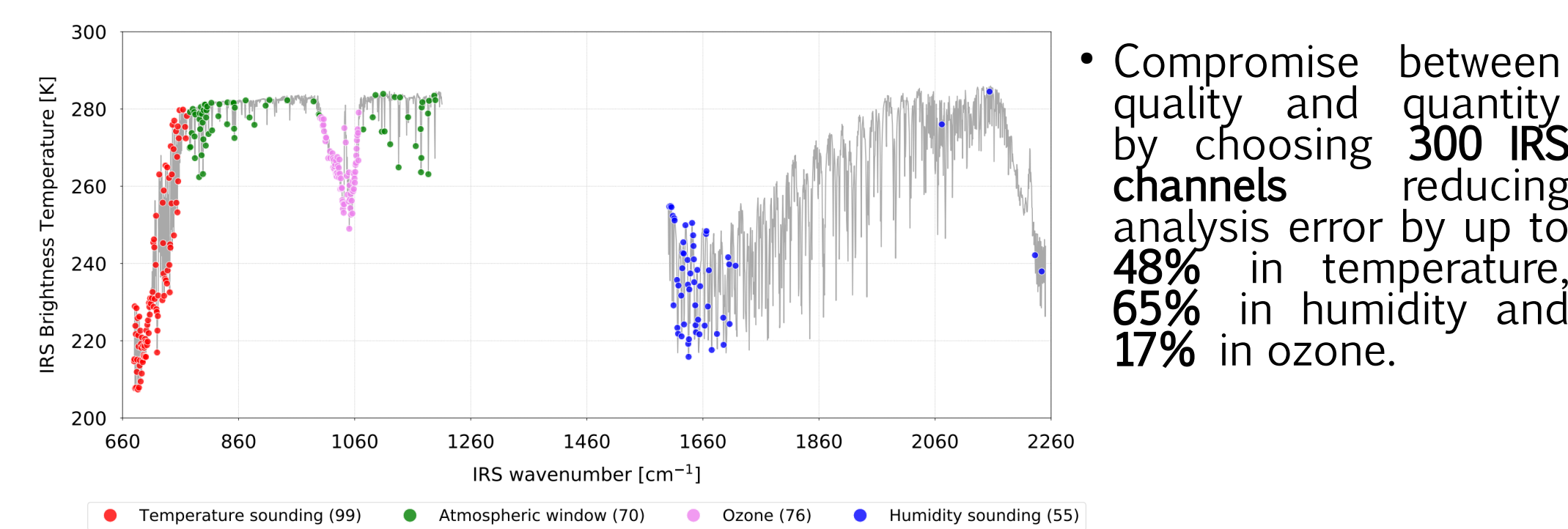

IRS instrumental noise at 280 K and diagnosed observation-error standard deviation

3) General IRS channel selection for NWP

- Selection among 60 profiles representative of the atmospheric variability
- Use of the information content method (Degree of freedom for signal)
  → DFS = Tr (I − AB⁻¹)
- 1D-Var data assimilation to evaluate several channel selection with 1700 atmospheric profiles
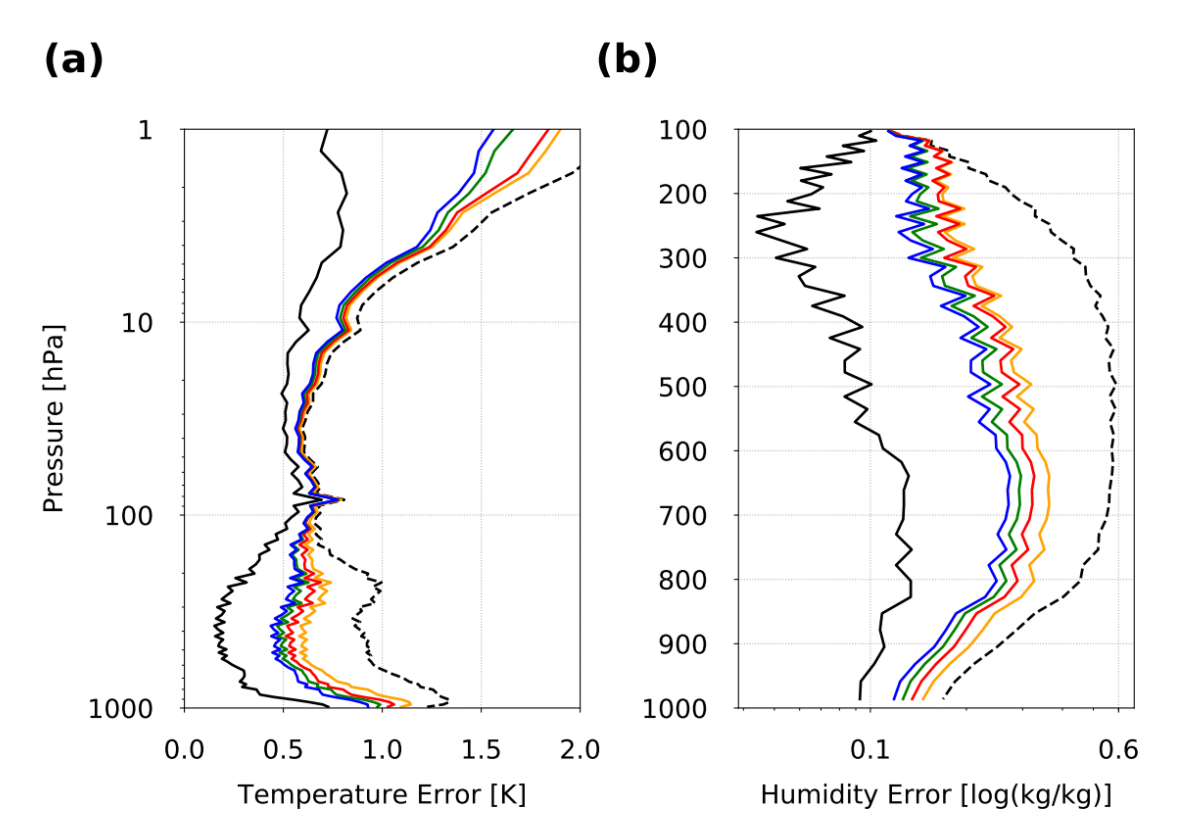
Analysis error reduction with several selections

Location of the 300 IRS channels selected over typical IRS spectrum

- Compromise between quality and quantity by choosing **300 IRS channels** reducing analysis error by up to **48%** in temperature, **65%** in humidity and **17%** in ozone.

Part III: 3D study – OSSE – AROME 3D-Var IRS assimilation
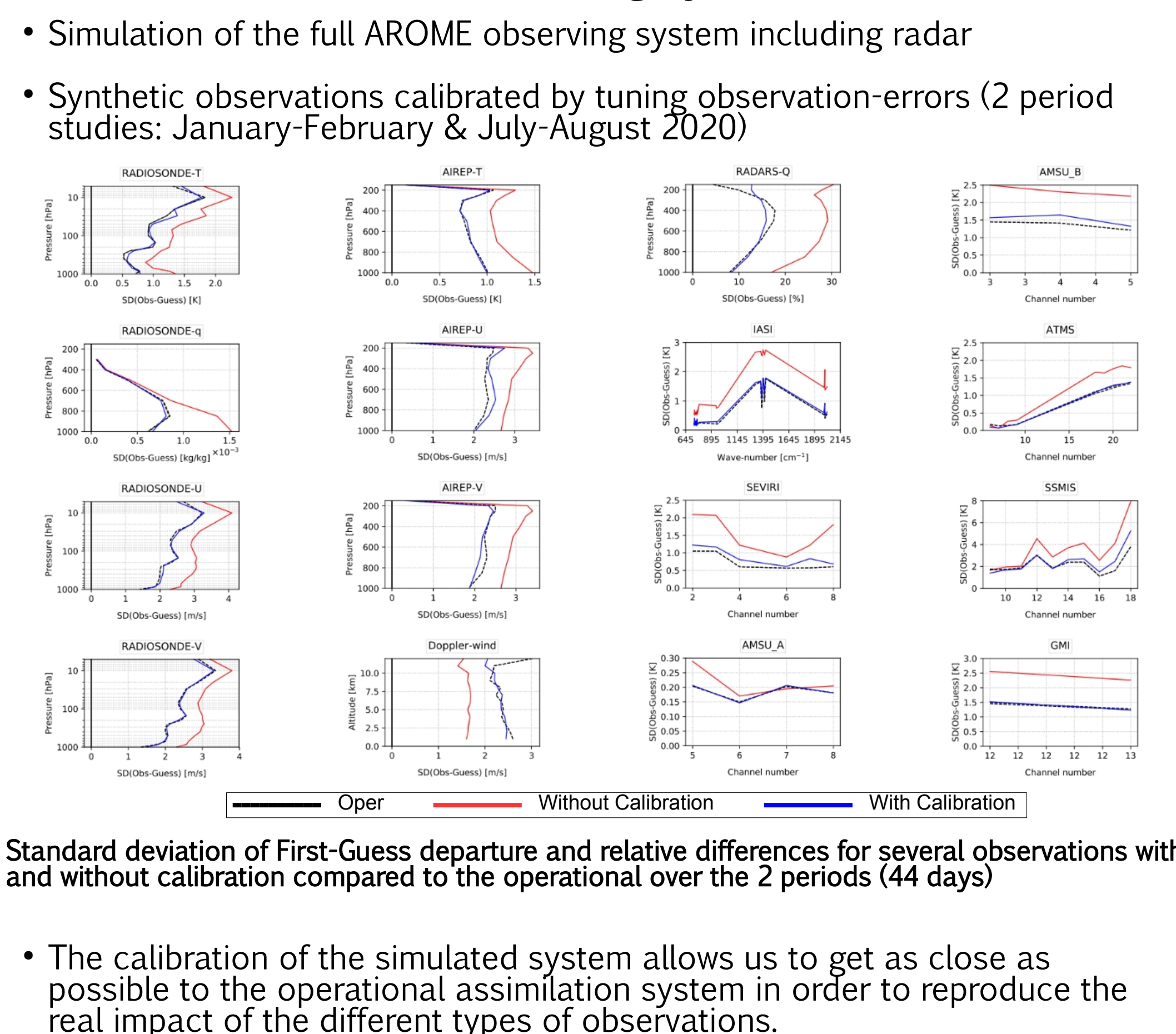
1) Validation of the AROME Nature Run
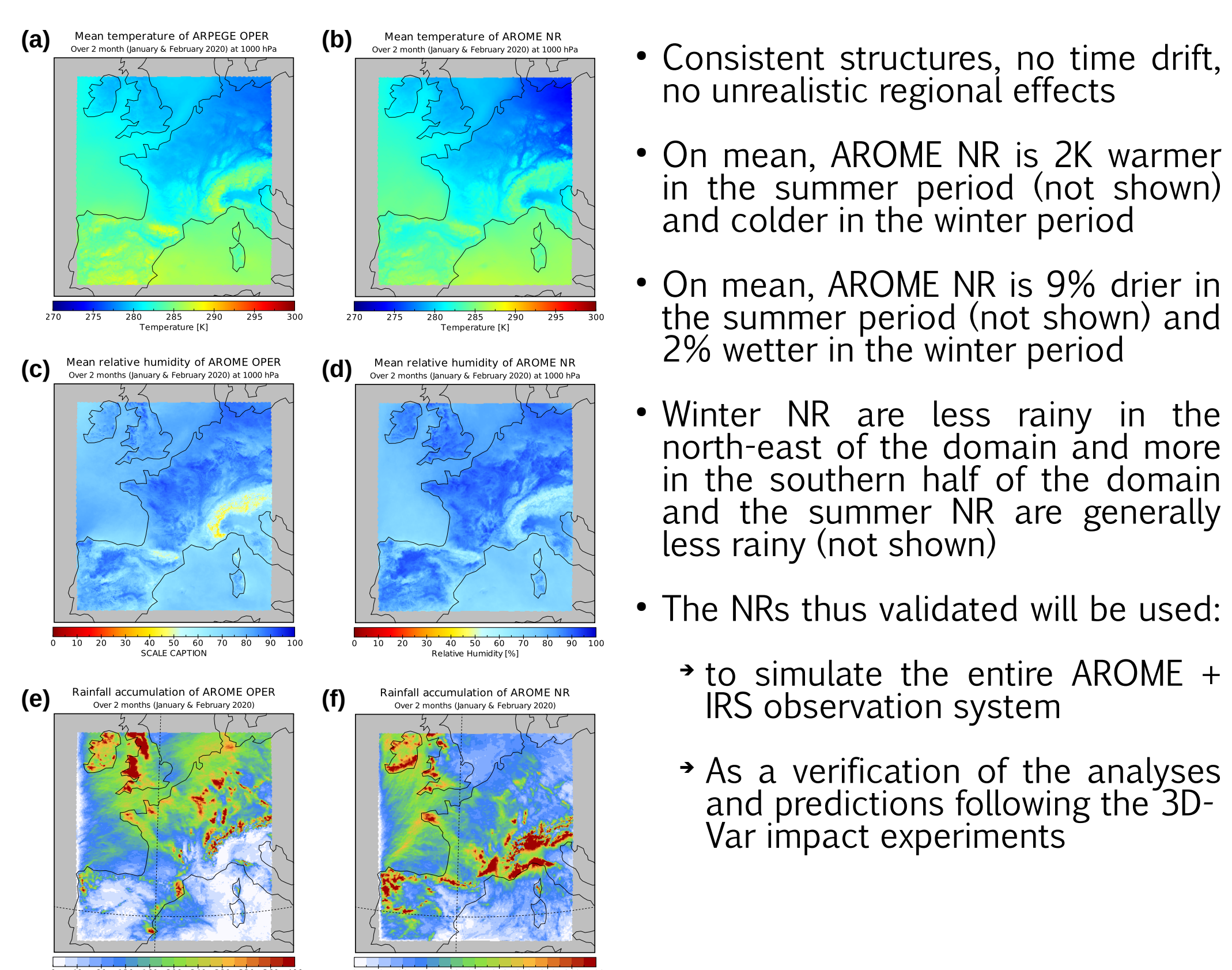
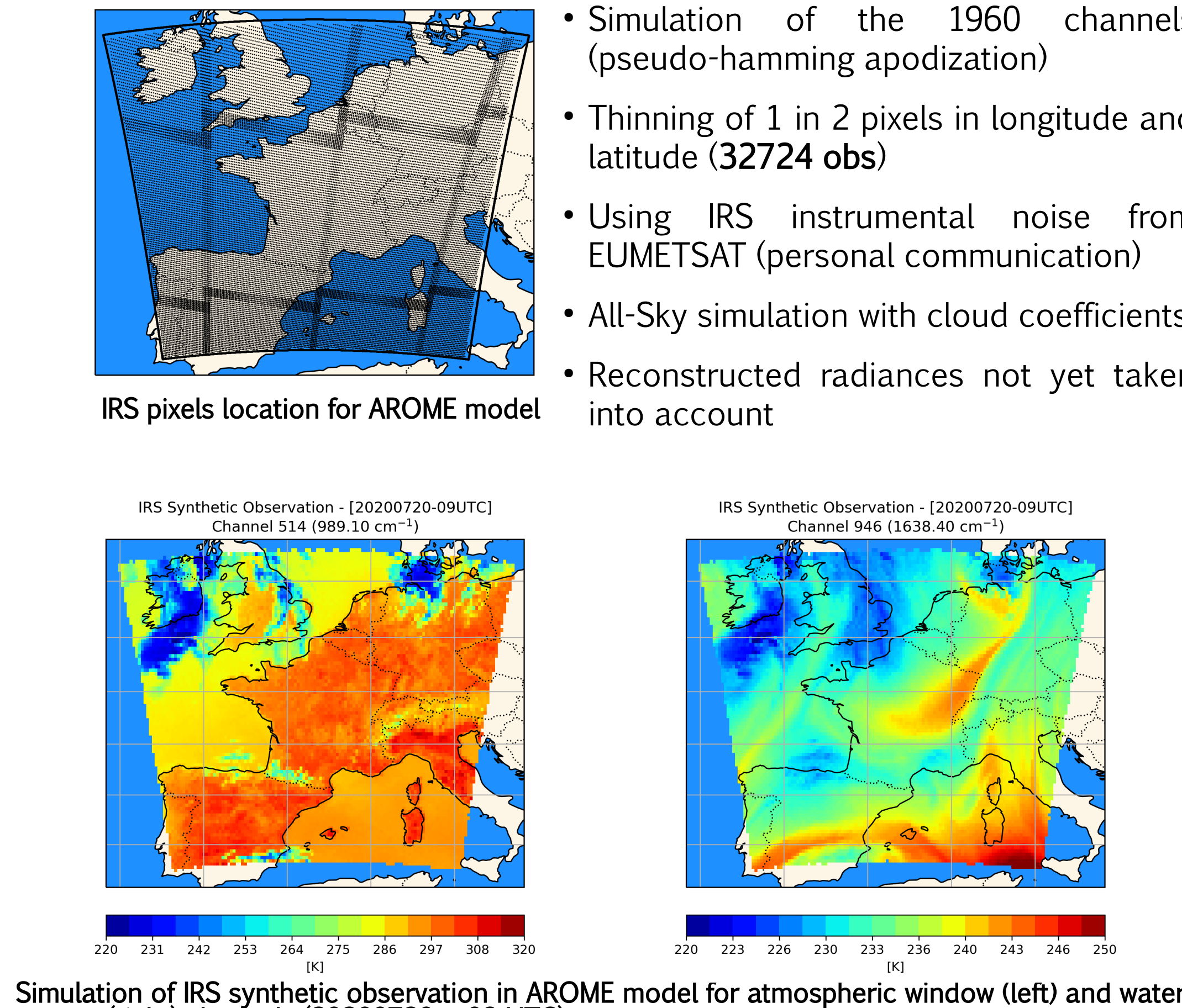Mean (T, q, rain) at 1000 hPa for AROME OPER & NR

- Consistent structures, no time drift, no unrealistic regional effects
- On mean, AROME NR is 2K warmer in the summer period (not shown) and colder in the winter period
- On mean, AROME NR is 9% drier in the summer period (not shown) and 2% wetter in the winter period
- Winter NR are less rainy in the north-east of the domain and more in the southern half of the domain and the summer NR are generally less rainy (not shown)
- The NRs thus validated will be used:
  → to simulate the entire AROME + IRS observation system
  → As a verification of the analyses and predictions following the 3D-Var impact experiments

2) Calibration of AROME observing system

- Simulation of the full AROME observing system including radar
- Synthetic observations calibrated by tuning observation-errors (2 period studies: January-February & July-August 2020)
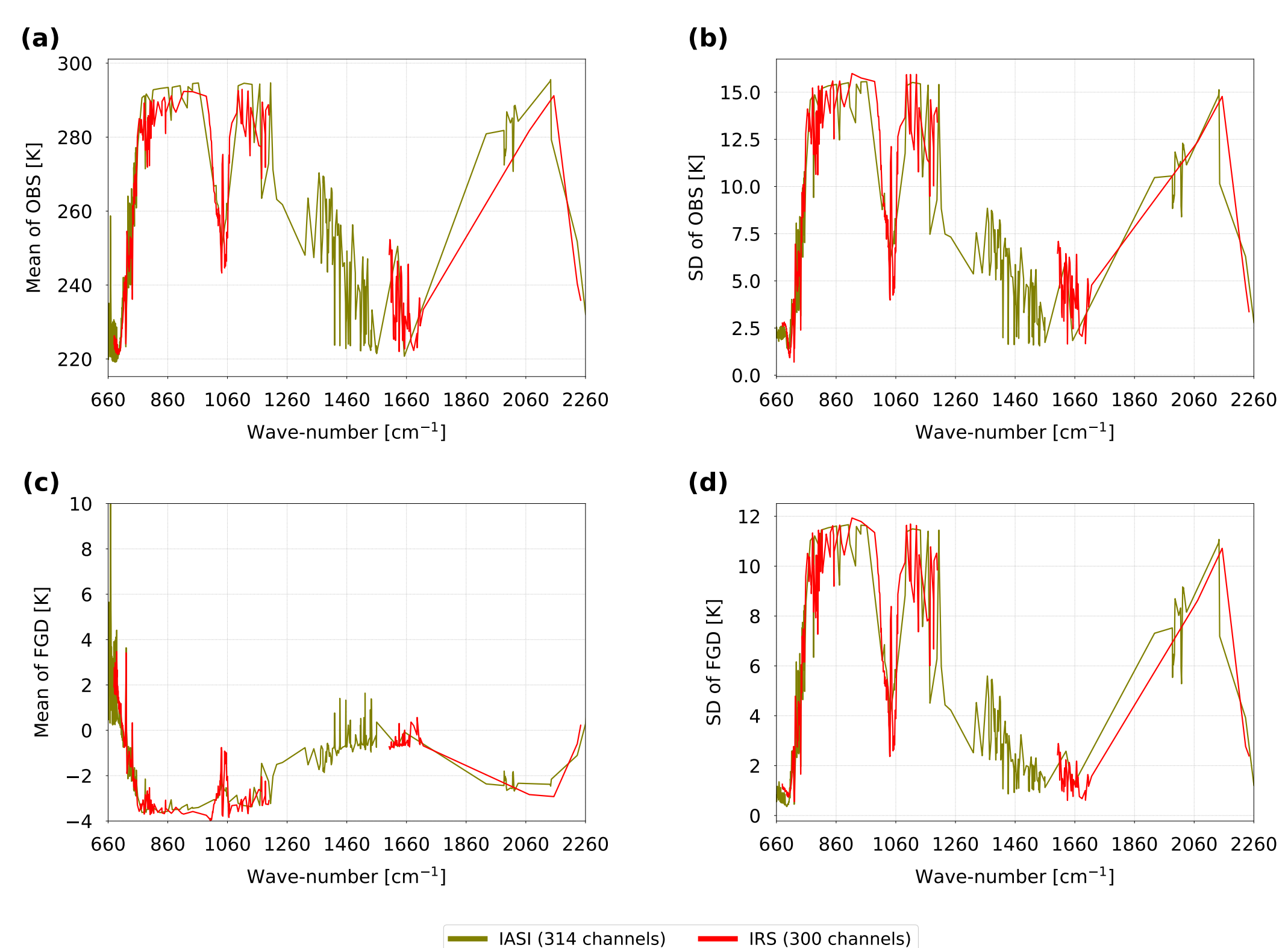

Standard deviation of First-Guess departure and relative differences for several observations with and without calibration compared to the operational over the 2 periods (44 days)

- The calibration of the simulated system allows us to get as close as possible to the operational assimilation system in order to reproduce the real impact of the different types of observations.

3) IRS simulation in AROME

IRS pixels location for AROME model

- Simulation of the 1960 channels (pseudo-hamming apodization)
- Thinning of 1 in 2 pixels in longitude and latitude (32724 obs)
- Using IRS instrumental noise from EUMETSAT (personal communication)
- All-Sky simulation with cloud coefficients
- Reconstructed radiances not yet taken into account

Simulation of IRS synthetic observation in AROME model for atmospheric window (left) and water vapour (right) channels (20200720 – 09 UTC)
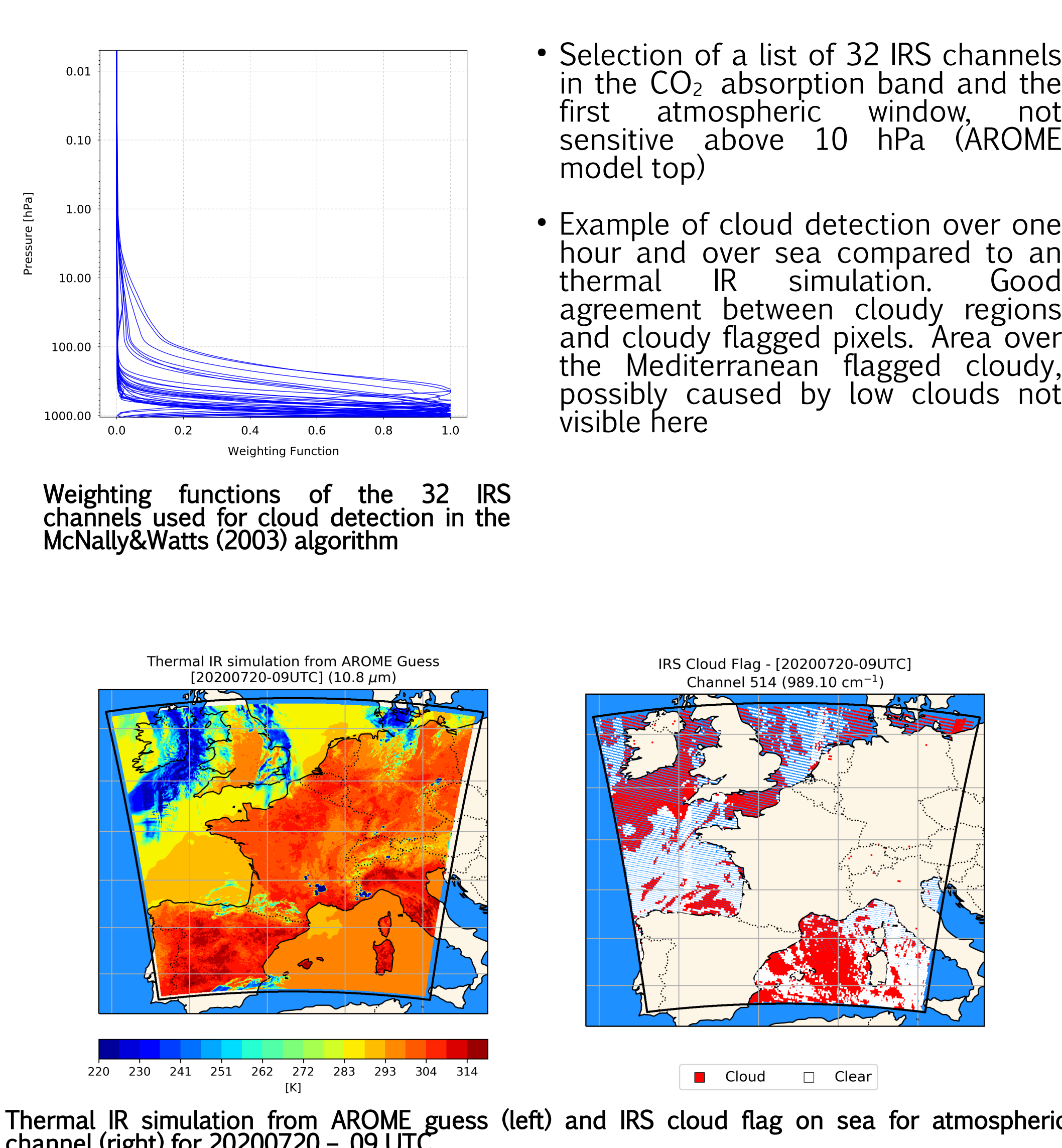
4) Preparation of IRS observations assimilation in AROME

- Assimilation of sub-selection channels from the previously performed channel selection (part II) + thinning
- Adaptation of the cloud detection code (McNally & Watts) for IRS
- New estimation of the R-matrix in the AROME 3D-Var (future work)

Mean (a & c) and standard deviation (b & d) of IRS and IASI observations (top) and first-guess departure (bottom) for 20200720 – 09 UTC with 2617 obs for IASI and 32724 for IRS

• Cloud detection

Weighting functions of the 32 IRS channels used for cloud detection in the McNally&Watts (2003) algorithm

- Selection of a list of 32 IRS channels in the CO₂ absorption band and the first atmospheric window, not sensitive above 10 hPa (AROME model top)
- Example of cloud detection over one hour and over sea compared to an thermal IR simulation. Good agreement between cloudy regions and cloudy flagged pixels. Area over the Mediterranean flagged cloudy, possibly caused by low clouds not visible here

Thermal IR simulation from AROME guess (left) and IRS cloud flag on sea for atmospheric channel (right) for 20200720 – 09 UTC

Conclusions & Future works

- Sensitivity study and channel selection → Article to be submitted soon

  Coopmann et al., (2022) Analysis of MTG-IRS observation and channel selection for Numerical Weather Prediction models

- Performing accurate and consistent Nature Runs
- The calibration of an accurate simulation of the observing system for AROME (conventional, radar, infrared, microwave, etc.) was carried out in order to be close to the real assimilation system
- A simulation of IRS observations has been created for AROME model with a thinning of 1 pixel out of 2 in latitude and longitude
- Prepare AROME system to assimilate IRS observations (Thinning + sub-channel selection) + First scores
- Consider reconstructed radiances + New diagnosed observation-errors
- New channel selection for AROME
- Finally, we will evaluate the impact of the new IRS observations in the AROME 3D-Var NWP system in terms of weather analysis and forecasts compared to the Nature Run

References

- *McNally, A. P., & Watts, P. D. (2003). A cloud detection algorithm for high-spectral-resolution infrared sounders. Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography, 129(595), 3411-3423.*

- *Brousseau, P., Seity, Y., Ricard, D., & Léger, J. (2016). Improvement of the forecast of convective activity from the AROME-France system. Quarterly Journal of the Royal Meteorological Society, 142(699), 2231-2243.*