

Contribution of IASI & IASI-NG for the characterization of CO over the globe

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1) CO modeling in the MOCAGE CTM at Météo-France

- Originally CO is present in small amount in the atmosphere. It is emitted naturally from sources like volcanoes, biomass burning and the oxidation of methane from the oceans. Its emission also comes from anthropogenic sources due to incomplete combustion of carbon-composed fuel and from biomass burning. Carbon monoxide is a major precursor of greenhouse gases making it an indirect contributor to radiative forcing in the atmosphere. Especially, it interacts with the OH, which is a sink of methane but also contribute to the production of tropospheric ozone. Accurate CO simulation is therefore essential for studying and monitoring greenhouse gases.
- Currently, the MOCAGE global chemistry transport model is able to model CO with a resolution of 0.5° on 60 vertical levels from the surface down to 0.1 hPa.

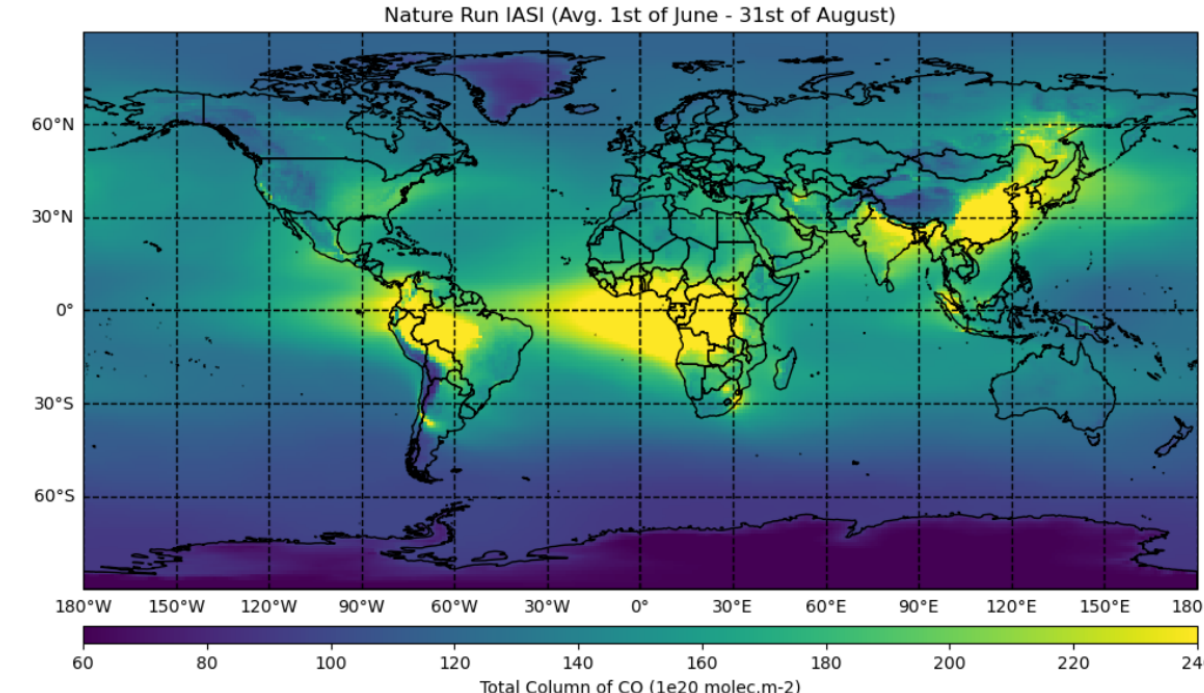


Fig.1 Average over a 3 month period from 1st of June to 31 of August, 2019 of the CO total columns issued from MOCAGE model

2) Objectives of this study

- The aim of this study is to evaluate and compare the contribution of IASI and IASI-NG observations to the characterization of CO in the MOCAGE global model.
- The launch of IASI-NG is scheduled for late 2025. We are working within an OSSE (Observing System Simulation Experiment) framework that enables us to simulate synthetic IASI and IASI-NG observations from an atmospheric state considered as reality (Nature Run), which can then be used in a data assimilation system.
- We use the OSSE framework used by Vittorioso et al. (2024) for his thesis on IRS. The Nature Run configuration uses the MOCAGE global model at 1° resolution and 60 vertical levels.

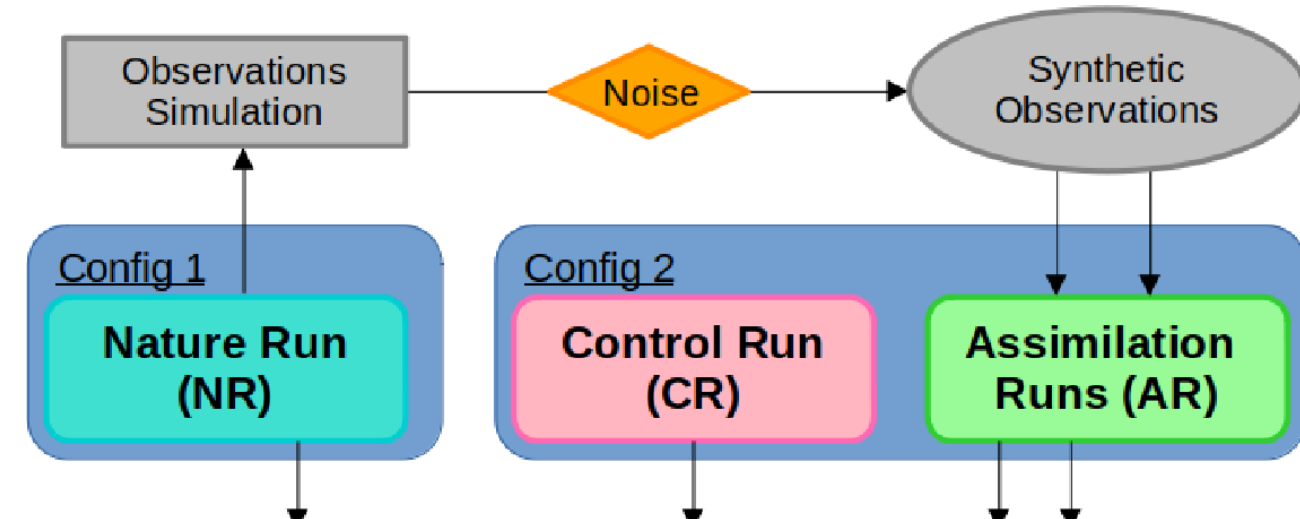


Fig.2 Illustrative representation of OSSE

3) IASI and IASI-NG sensitivity to carbon monoxide

- Of the 8461 and 16921 IASI and IASI-NG channels respectively, 281 IASI and 561 IASI-NG channels are sensitive to carbon monoxide between 2146 – 2216 cm^{-1} .

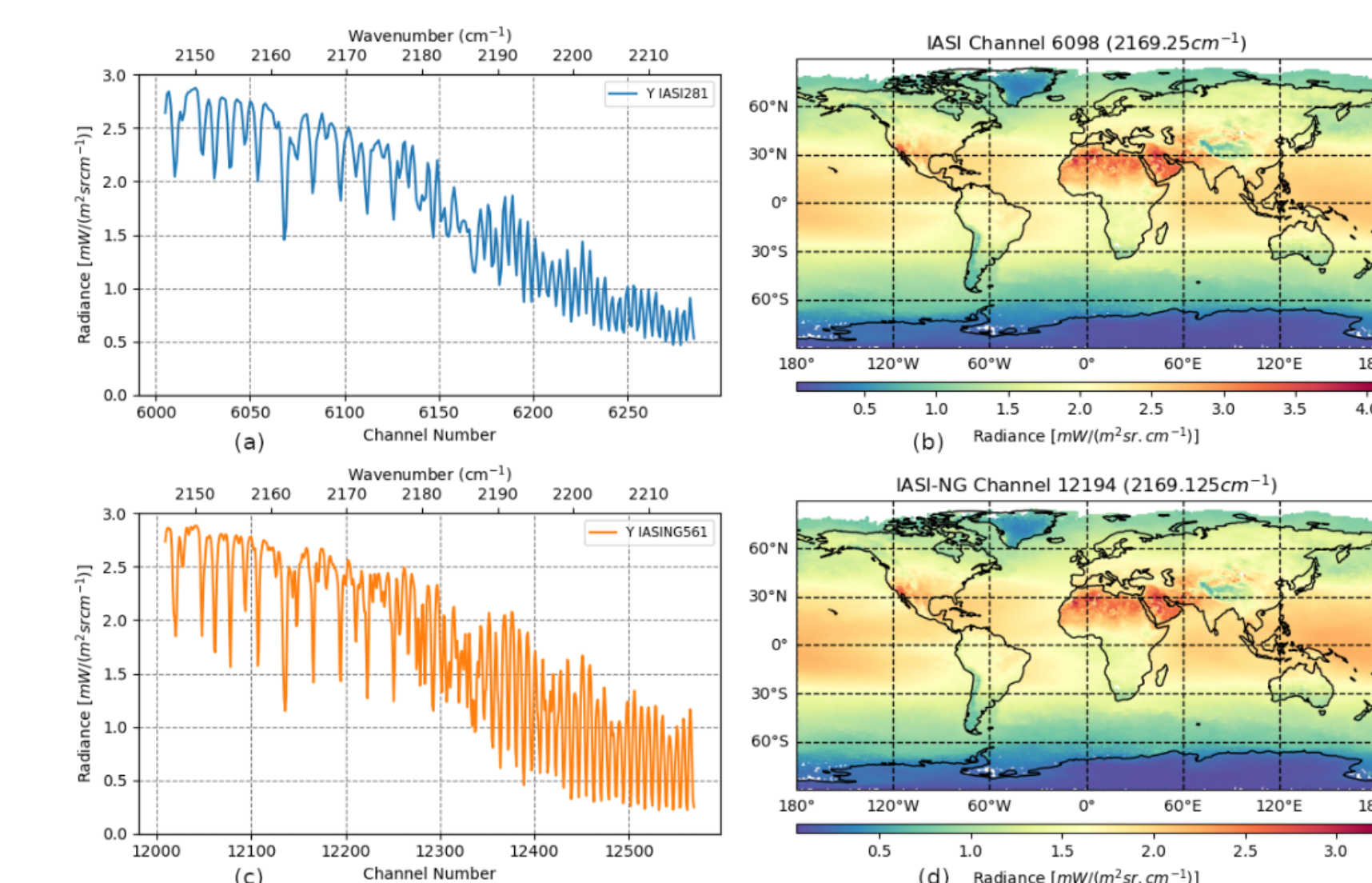


Fig.3 Representation of the IASI and IASI-NG synthetic observations over the period from June to August 2019. The radiance mean spectra of channels over the CO sensitive band (left) is represented for IASI (top) and IASI-NG (bottom). Maps of mean radiance evaluated at wavelength 2169.25 cm^{-1} are shown on the right.

4) Study framework and method

- After a sensitivity study, we have chosen to evaluate the assimilation of IASI and IASI-NG over the summer period of 2019 (JJA) using two methods (i.e. 4 experiments):
- Assimilation experiments with all CO
 - > AR_IASI_281
 - > AR_IASING_561
- Assimilation experiments with a selection of the most CO-sensitive channels based on the DFS method
 - > AR_IASI_61
 - > AR_IASING_98

- The background error covariance matrix B is the primary contributor to the spatial propagation of the observations in our assimilating system. In the present study, the background error is represented as a proportional coefficient related to the CO concentration and define as a percent of the CO background profile. The coefficient value was set uniformly along the entire atmospheric column with a value of 20%. Horizontal and vertical covariances are defined as Gaussian.

5) Observation errors

- In addition, assimilation experiments were carried out to diagnose the observation error covariance matrix for IASI and IASI-NG. The results show behaviour and values consistent with similar OSSE results.

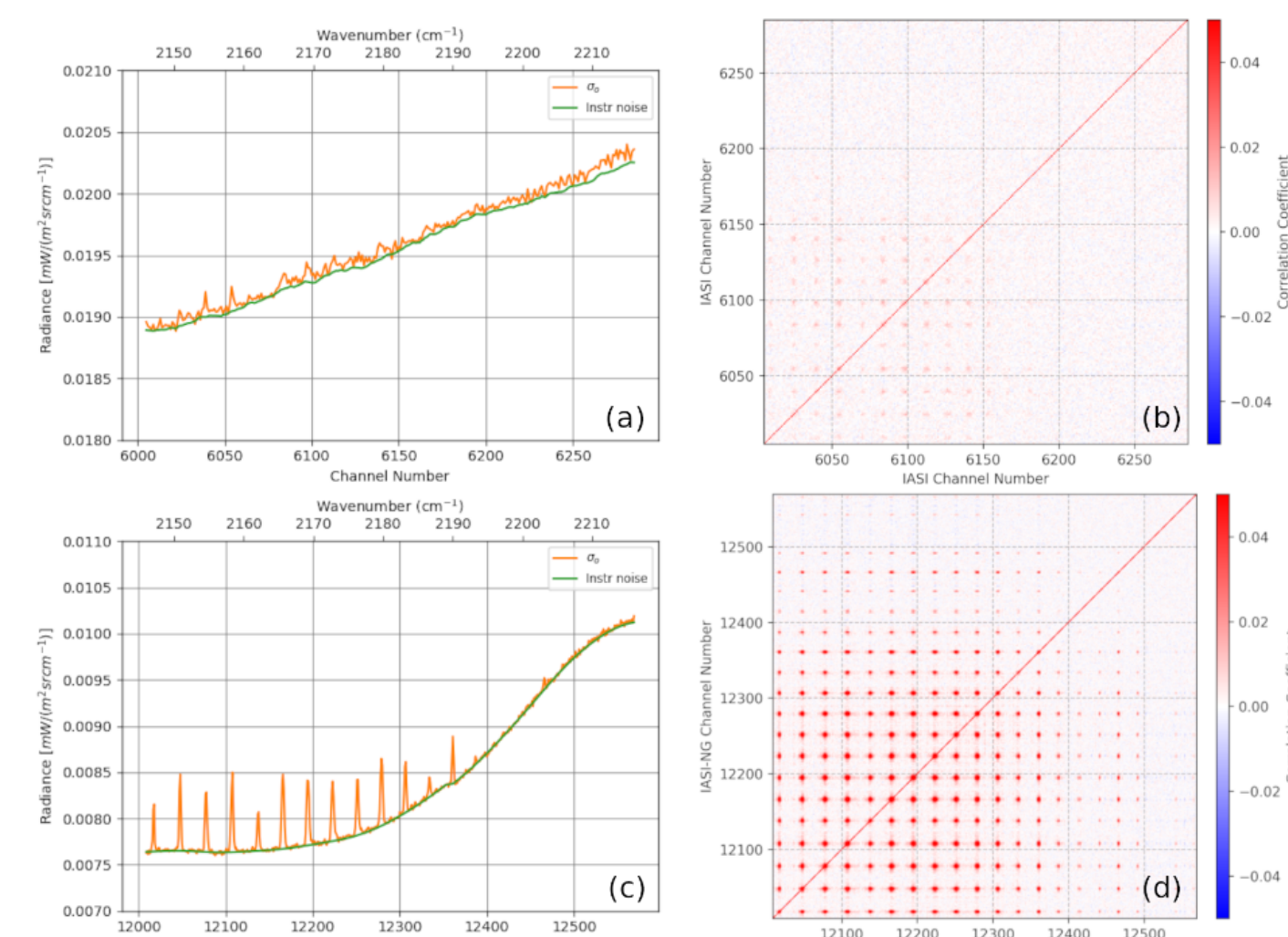


Fig.4 Diagnosed observation-error standard deviation and instrument noise for both IASI (a) and IASI-NG (b) instrument. The corresponding diagnosed error correlation in represented on (c) and (d), respectively for IASI and IASI-NG.

6) Data usage (all CO sensitive channels)

- The statistics of the (O-A) and (O-B) by hour of the day for the 3 months period are displayed on Fig. 5. The reduced analysis departures average compared to the first guess departures, on Fig. 5 (a), indicate the effectiveness of the assimilation of IASI-NG data. The analysis from IASI and IASI-NG are both close to the observations and are hardly be distinguished. The standard deviation, on Fig. 5 (b), shows that since the errors in the IASI-NG observations are smaller than those in the IASI observations, the assimilation brings MOCAGE closer to the IASI-NG data.

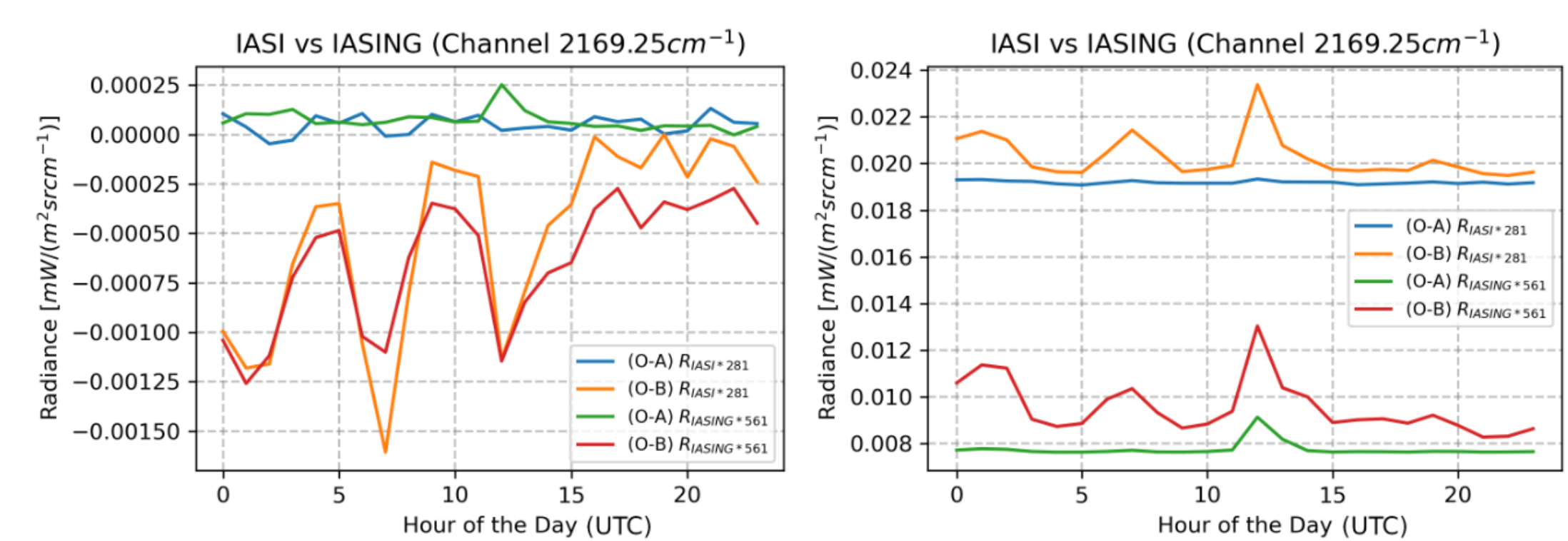


Fig.5 Statistics of the innovation (O-B) and residuals (O-A) calculated per hour of day over the period June 1 to August 31, 2019. The averages in (a) and the standard deviations in (b) refers to wavelength 2169.25 cm^{-1} , corresponding to IASI (resp. IASI-NG) channel 6098 (resp. 12195).

7) Impact on CO forecast (all CO sensitive channels)

- The relative difference between the standard deviation of the difference ARIASING – NR and those of the difference ARIASI – NR, shows even more the different impact of both instrument on the CO tropospheric column representation. The graphical representation over the Globe is displayed on Fig. 6. The assimilation of IASI-NG have a tendency to reduce the variability around the NR, in the Northern hemisphere (~ 25–50% overseas and ~ 0–25% overland) and Antarctica (~ 75%). However IASI-NG seems to degrade the variability around the NR on the Southern hemisphere ocean (~ 25 – 50%), Africa (~ 25%) and over the Amazonian forest (~ 100%) compare to IASI.

- The assimilation runs (Fig. 7) show a markedly different vertical distribution of the relative difference, alternating between layers of over-estimation and under-estimation. These differences are more marked in the assimilation run with IASI-NG. IASI assimilations runs differ from Nature Run, particularly between layers 3 and 10 where the quantity of CO is 10 % higher than in NR. This indicates that more work will be needed in the future for the description of the background error.

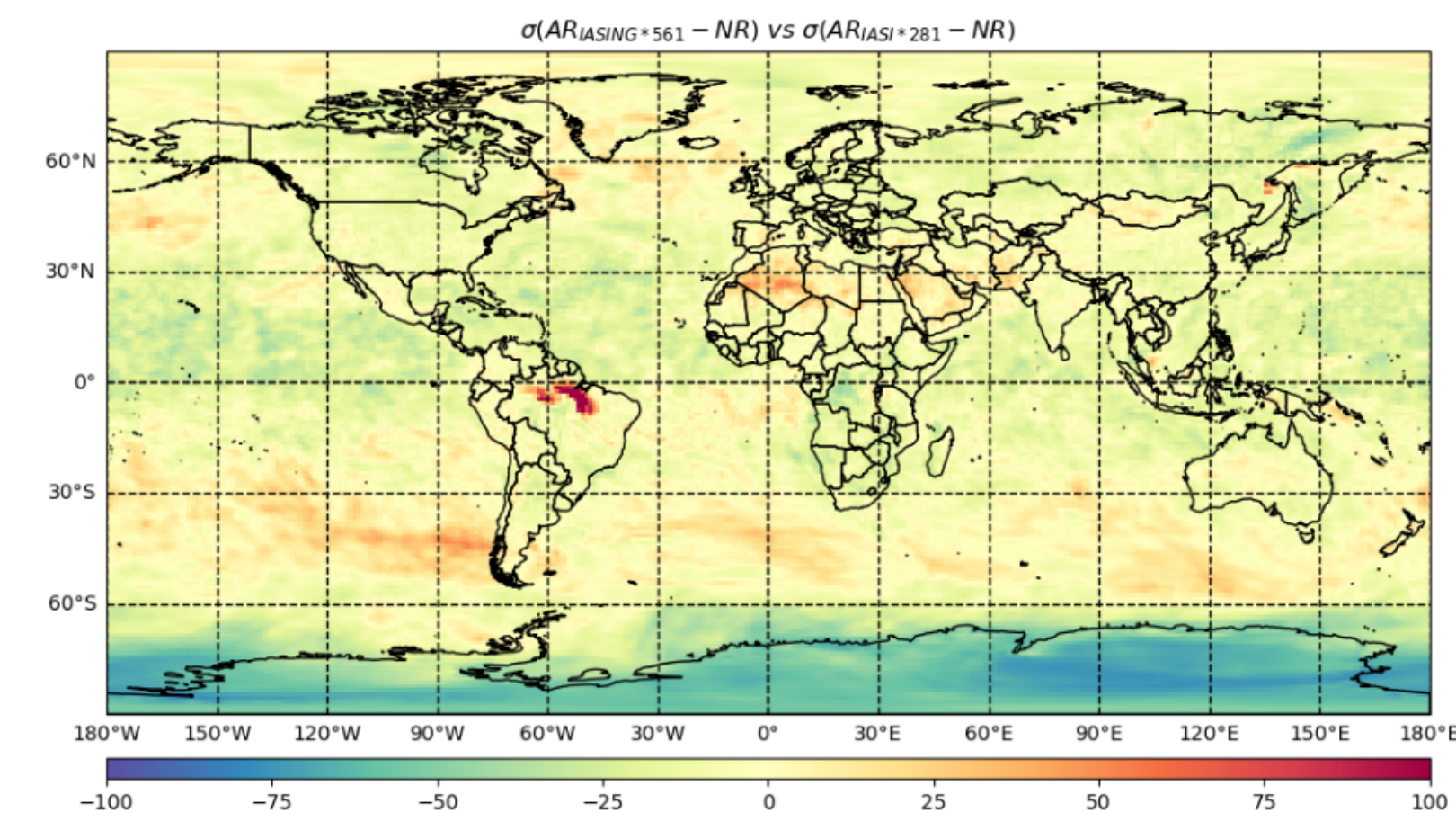


Fig.6 Relative difference in standard deviation of the difference between NR and ARs tropospheric columns of CO. The difference with the NR of the AR IASI-NG with 561 channels is compared to the difference with the NR of the AR IASI with 281 channels.

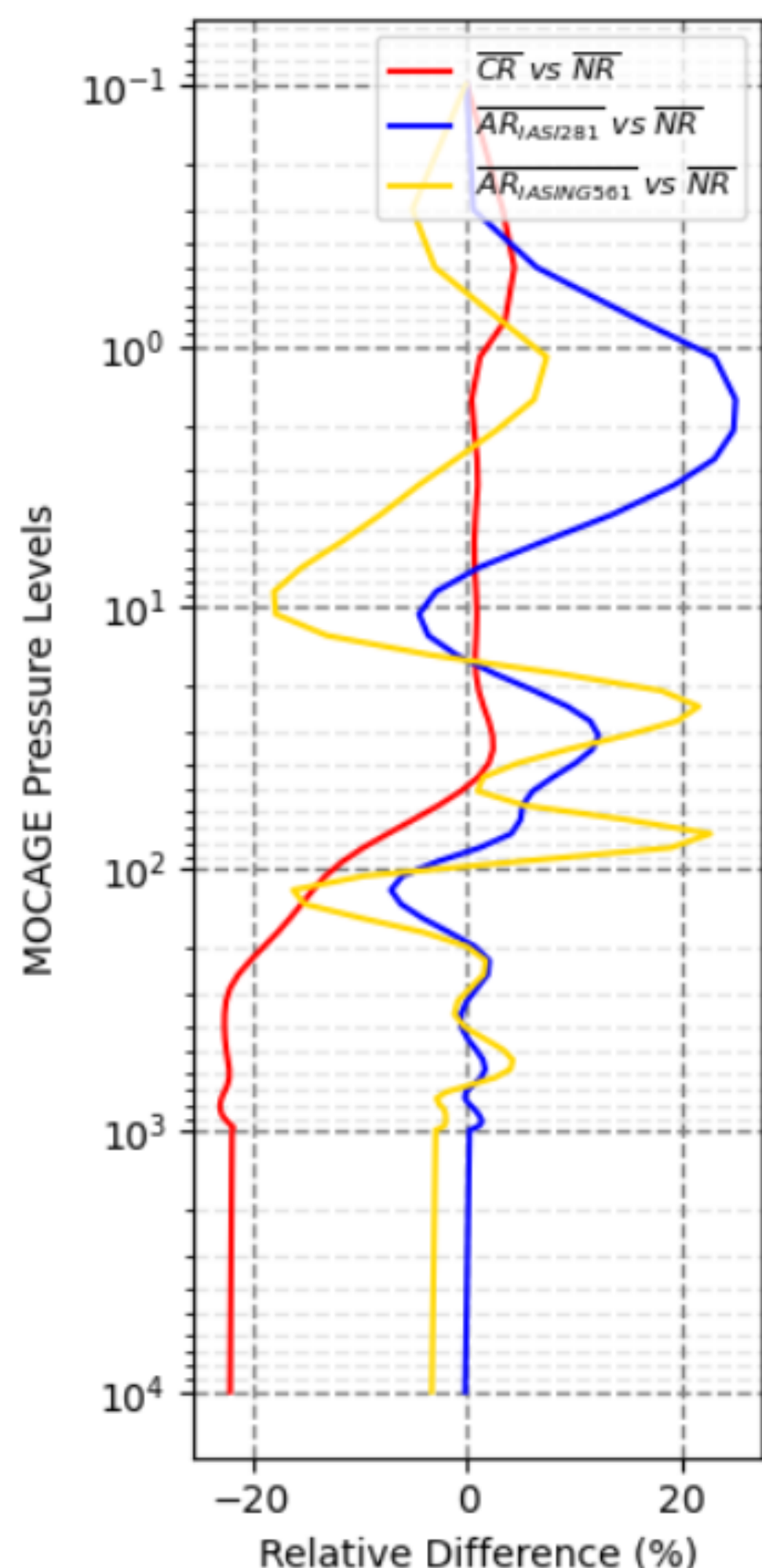


Fig.7 Profiles over the 3-month period of study (June 1, 2019 to August 31, 2019), for each of the 60 MOCAGE levels on the GLOB11 domain. Figure represent he relative difference between the experiments and the NR.

8) Channel selection for IASI & IASI-NG

- Previous set of channels allowed to select a full part of the CO sensitive region to reduce the number of channels considered in the assimilation of IASI and IASI-NG instruments. In this section, we propose to refine further this selection by building subsets of channels from the selection of 281 channel for IASI and 561 channels for IASI-NG. A method based on Degrees of Freedom for the Signal (DFS) was employed in order to achieve an optimal selection (Coopmann et al. (2022); Vittorioso et al. (2021)).

- The challenge of this selection process is to identify the optimal subset of channels that retains the maximum information in the signal while reducing the amount of data volume to be considered. Using this selection process, multiple subsets were built. For this work, it was necessary to ensure that selected sub-groups were nearly as representative of the CO signal as the 281 and 561 channels ensembles. This implies that the subsets were ordered based on their DFS scores, with the highest possible DFS value obtained by considering all the channels in the subsets. A 95% representativeness condition of the DFS was established. The two subsets selected, a group of 61 channels for the IASI instrument and a group of 98 channels for IASI-NG, indeed verify a conservation of at least 95% of the DFS on all 4341 observation sites distributed across the globe.

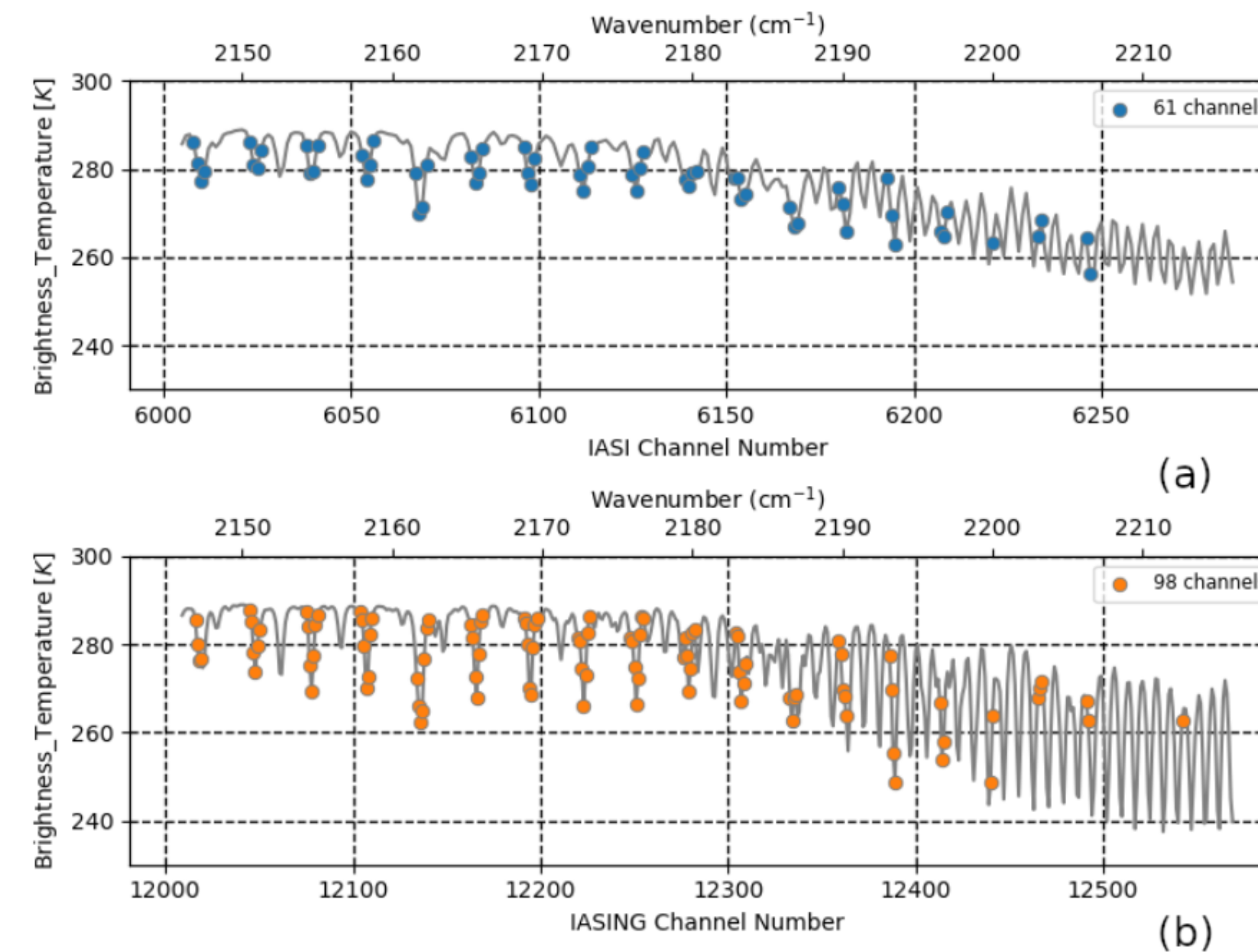


Fig.8 Spectral localisation of the two selected subset of channels. On (a), the selection of 61 channels for IASI and on (b) the selection of 98 channels for IASI-NG.

9) Impact on CO forecast (CO selected channels)

- The relative difference between the standard deviation of the difference ARIASING – NR and those of the difference ARIASI – NR, shows even more the different impact of both instrument on the CO tropospheric column representation. The graphical representation over the Globe is displayed on Fig. 6. The assimilation of IASI-NG have a tendency to reduce the variability around the NR, in the Northern hemisphere (~ 25–50% overseas and ~ 0–25% overland) and Antarctica (~ 75%). However IASI-NG seems to degrade the variability around the NR on the Southern hemisphere ocean (~ 25 – 50%), Africa (~ 25%) and over the Amazonian forest (~ 100%) compare to IASI.

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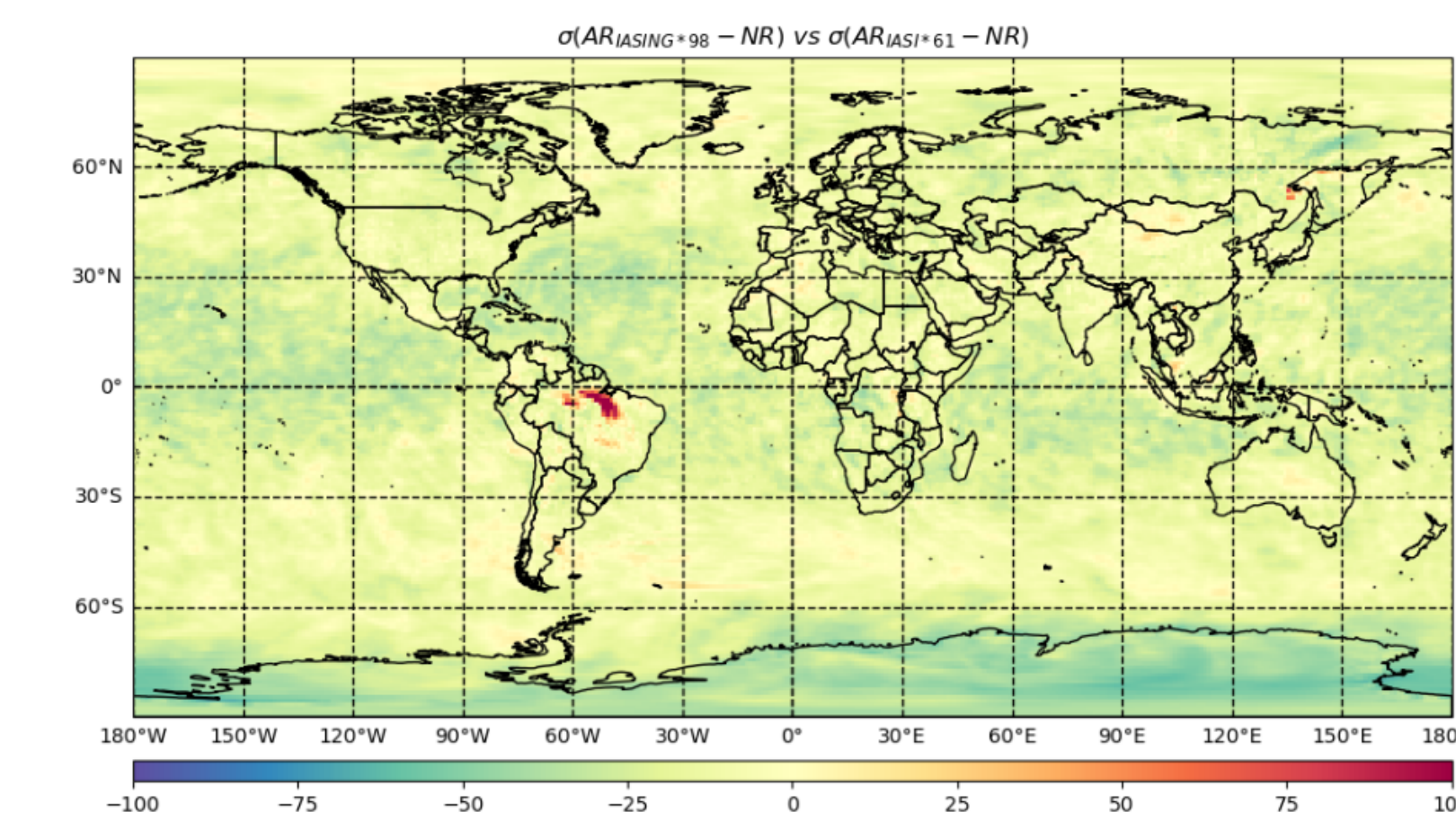


Fig.9 Relative difference in standard deviation of the difference between NR and ARs tropospheric columns. The difference with the NR of the AR IASI-NG with 98 channels is compared to the difference with the NR of the AR IASI with 61 channels.

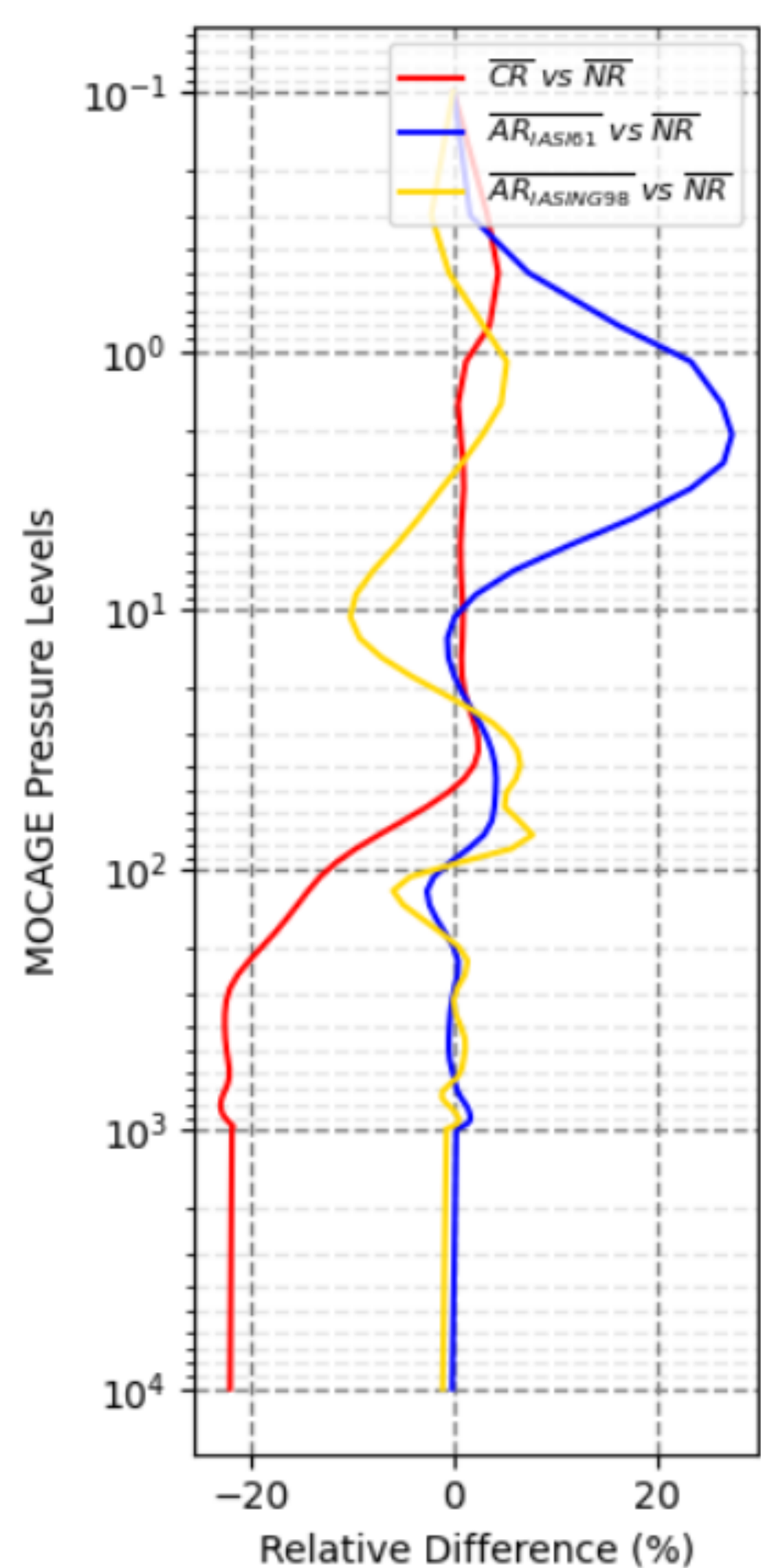


Fig.10 Profiles over the 3-month period of study (June 1, 2019 to August 31, 2019), for each of the 60 MOCAGE levels on the GLOB11 domain. Figure represent he relative difference between the experiments and the NR.

10) Conclusions

- The impact of the assimilation on the representation of the CO column over the studied period was found to be positive over the CR without assimilation (not display). When evaluating tropospheric columns of simulations, slightly lower variations have been estimated for IASI-NG over Antarctica (~ 50–75%) and the Northern Hemisphere (~ 25–50%). Degradation were therefore notifiable over the Saharan region (~ 25–50%), the Amazonian forest (~ 75–100%) and in the 30°S–60°S band (~ 25%) for IASI-NG compared to IASI.
- The investigation of reducing the assimilated channels revealed that it can have both a positive impact on both the assimilation performance and results. The impact of a reduced selection of channels, has an even greater impact on IASI-NG which has twice the resolution of IASI. The variability of IASI-NG is reduced below that of IASI over almost the entire globe, with the exception of the Amazonian rainforest. Overall the assimilation of IASI-NG improve the atmospheric CO representation compared to IASI in this OSSE framework. This instrument clearly have a great potential to represent the carbon monoxide.

11) Future prospects

- Assimilation of IASI-NG real data for CO, and also jointly for ozone and other gaseous species, in MOCAGE.
- Joint assimilation of IASI-NG and Sentinel-5 for CO.
- Synergy of IASI-NG on a LEO and IRS on a GEO.
- Assimilation of IASI-NG in a Earth System model, like ARPEGE with inline atmospheric composition.

- This study is the subject of an article to be submitted shortly.
- This study has been carried out in the frame of the IASI-NG TOSCA funded by CNES.