A Global Observing System Simulation Experiment to evaluate the impact of the IASI-NG hyperspectral infrared sounder

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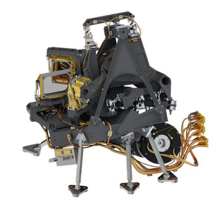
1. Introduction



IASI-NG is a hyperspectral infrared sounder developped by the CNES and AIRBUS meant to replace the successful IASI instrument on MetOp satellites (Bermudo et al., 2014, 2022). In order to prepare the assimilation of IASI-NG data within the operational Numerical Weather Prediction (NWP) system, the Centre National de Recherches Météorologiques (CNRM) set up an Observing System Simulation Experiment (OSSE). It allowed us to fine tune IASI-NG data assimilation parameters and measure the impact IASI-NG will have on the quality of weather predictions.

2. Construction of a Data Assimilation Framework

An Observing System Simulation Experiment (OSSE) is a numerical experiment used to evaluate the value of a new observing system when actual observational data is not yet available. It consists of a long, uninterrupted forecast called the nature run, which provides a realistic evolution of the atmosphere considered as truth, a 4DVAR NWP data assimilation system used to compute the best estimation of the variables of the atmosphere and to produce a realistic weather forecast, and "observations" simulated from the nature run with realistic observation errors.
The models used in the nature run and in the data assimilation system need to be different to avoid the « identical twin problem » already identified by the scientific community (e.g. Hoffman and Atlas, 2016). They are documented in Table 1.

Parameters of the model	Nature run	Data assimilation and forecasting system
Truncation	TL1798	TL798
Resolution over Europe	About 5 km	About 10 km
Resolution over New-Zealand	About 24 km	About 61 km
Physics package	Tiedtke convection scheme	Bougeault convection scheme
Period of study	July to October and November to February (one month of spin-up)	August to October and December to February

Table 1: Characteristics of the individual constituents of the OSSE

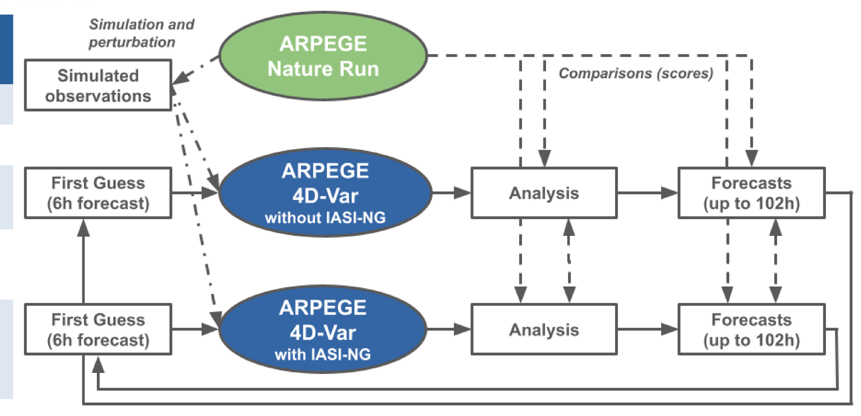


Figure1: Scheme of the OSSE

3. Computation and Validation of the Nature Run

The Nature Run is split into a summer and a winter run and acts as a perfect reality used as a reference for our assimilation experiments. It is set like a regular forecast experiment that runs for 4 months with no assimilation. In order to stay within a realistic meteorological reality, the sea surface temperature is forced with the OSTIA SST product. The Nature Run's physical coherence is validated by comparing the mean temperature and humidity patterns over different periods with the operational forecast outputs.

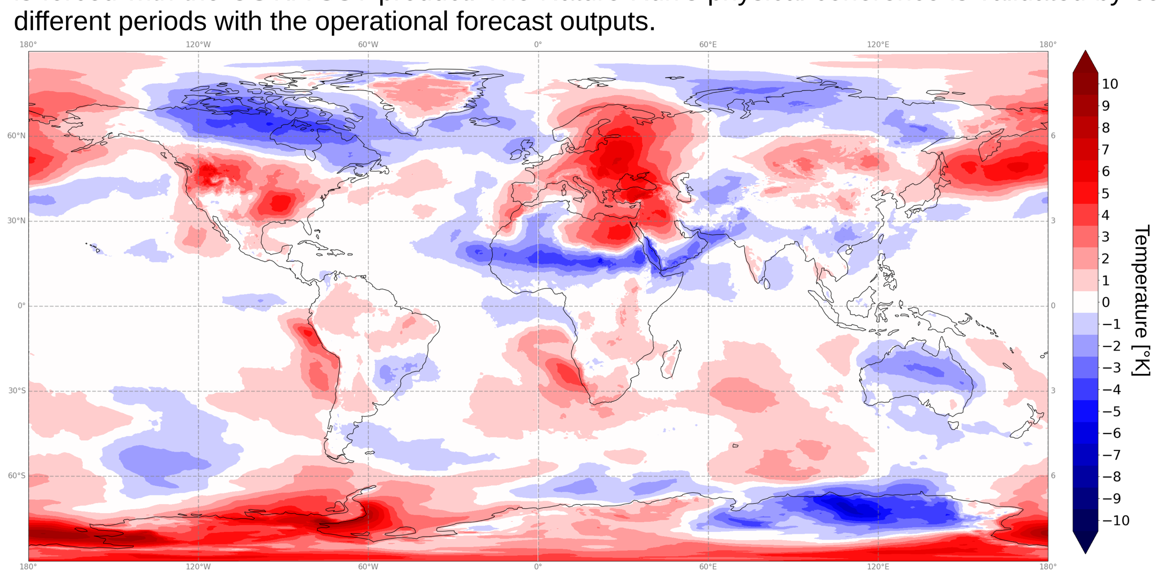


Figure 2: Mean temperature difference over 2 months at 900hPa between the nature run and the operational forecast (summer)
(Nature Run – Operational Forecast)
2021-08-01-00 - 2021-10-01-00
Min: -7.22 K
Max: 9.67 K
Mean: 0.42 K
STD: 1.74 K

When comparing the nature run's temperature with the operational forecast output over 2 months, we observe substantial regional differences (~10°C), but a very small mean and std. The longer the considered period, the smaller the regional differences become.

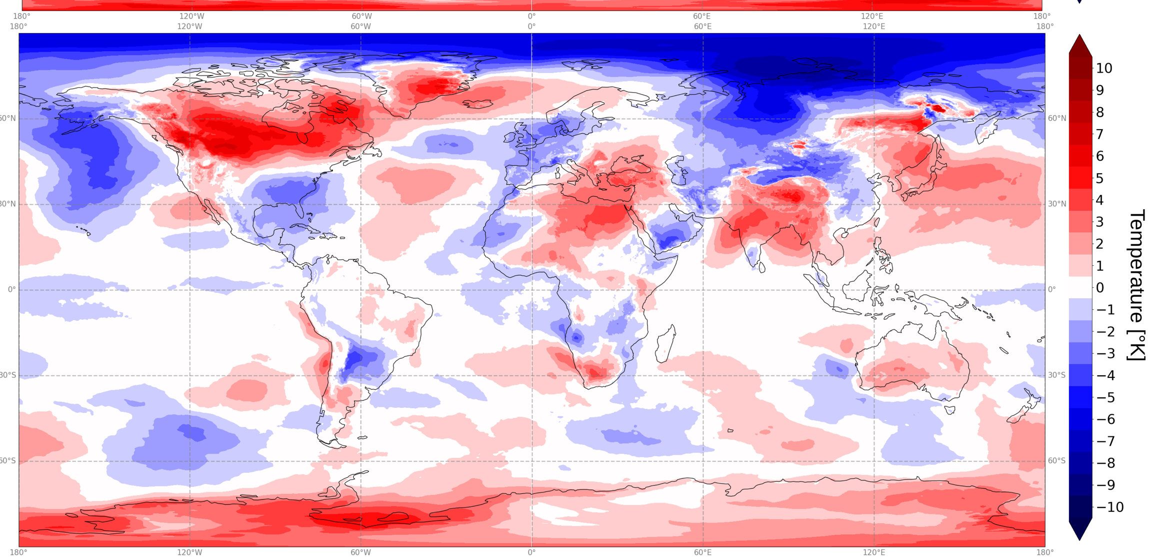


Figure 3: Mean temperature difference over 2 months at 900hPa between the nature run and the operational forecast (winter)
(Nature Run – Operational Forecast)
2021-12-01-00 - 2021-02-01-00
Min: -8.94 K
Max: 8.04 K
Mean: -0.11 K
STD: 2.28 K

The nature run behaves the same over the summer and the winter period. To validate the nature run we also plotted the mean temperature depending on the latitude, where we also observed realistic meteorological physics (not shown).

4. Simulation and Calibration of the Observations

To perform our OSSE, we need to feed realistic observations to our 4DVAR experiment. For this matter we sample the nature run using the real observation locations from the observation system already in use, and for IASI-NG we use simulated orbitals. The data is sampled as physical variables (temperature, pressure, etc…) and then converted back into radiances and brightness temperatures using RTTOV 12. Finally, we add noise corresponding to instrumental errors to match real data's uncertainties. The simulated data of infrared sounders like IASI, CRIS and microwave sounders like ATMS, AMSU-A MHS also take into account clouds.

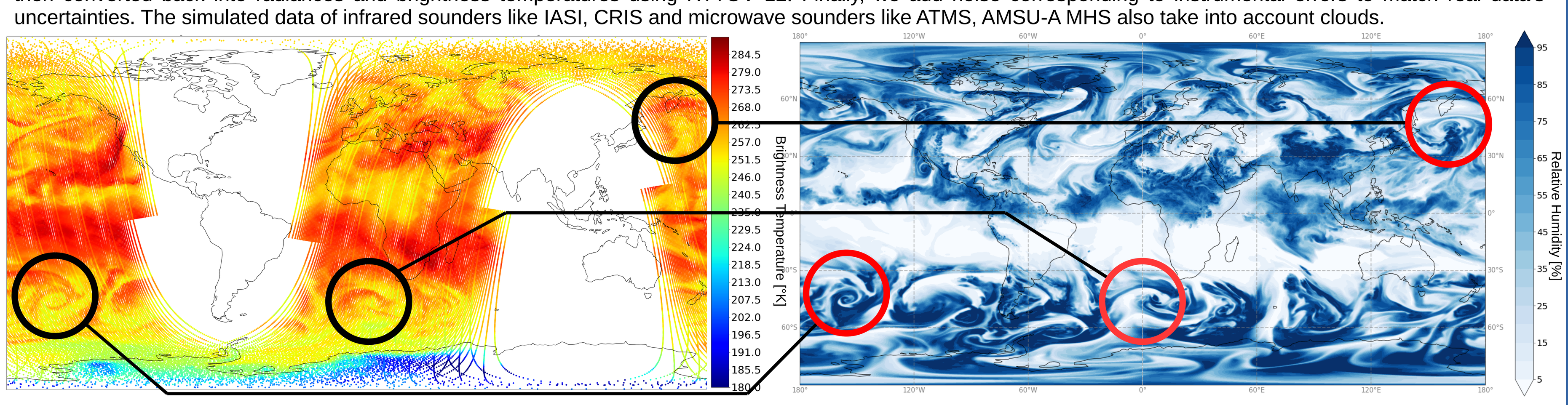
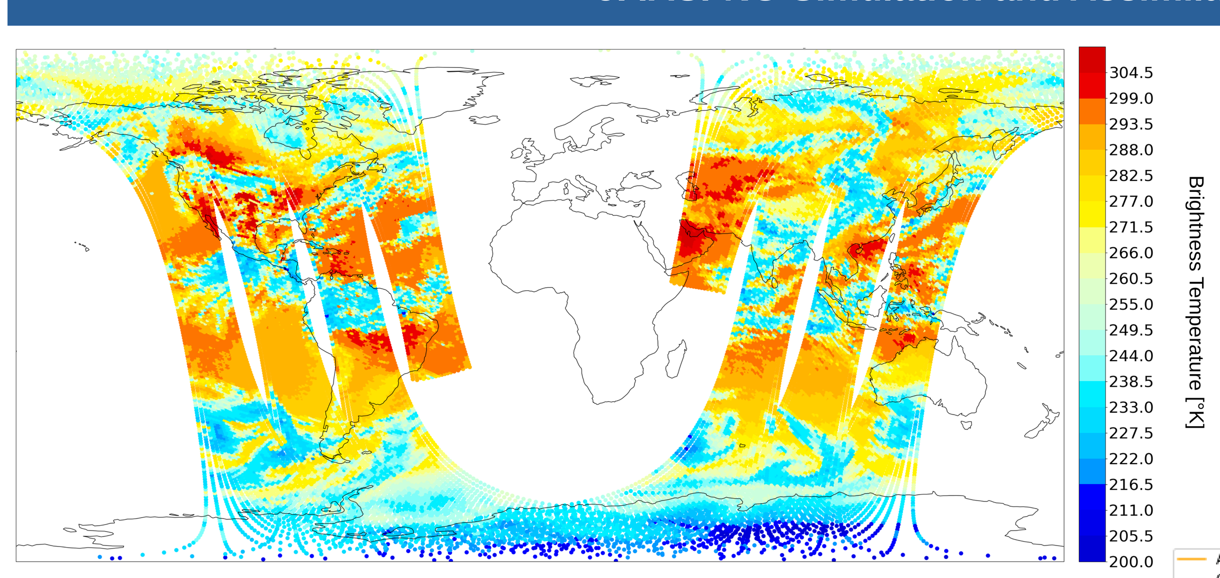


Figure 4: ATMS microwave sounder simulated brightness temperature for channel 20 and the nature run's relative humidity field at 500 hPa on the 08/14/2021 at 0:00 am.
ATMS channel 20 is sensitive to humidity around 500 hPa, and when we compare its simulated brightness temperature to the nature run, we can see that the patterns match. The simulated observations are thus coherent with the nature run. On the 4DVAR's assimilation side, the noise applied to each individual instrument had to be calibrated in order to match the impact they have in the real operational forecast system. This was done using a trial and error method and is more extensively explained in the poster by Rivoire et al, 8p.06.

5. IASI-NG Simulation and Assimilation



For the IASI-NG observations simulation, we only simulated the 500 channels selected by Vittorioso et al. (2021) with RTTOV v12 taking into account clouds.

Figure 5: IASI-NG simulated radiances for surface channel 2445 (950.5 cm-1)
This channel is sensitive to surface temperature. We can observe simulated cloud formations which have much lower temperatures (High level clouds with corresponding brightness temperature around 230 °K).

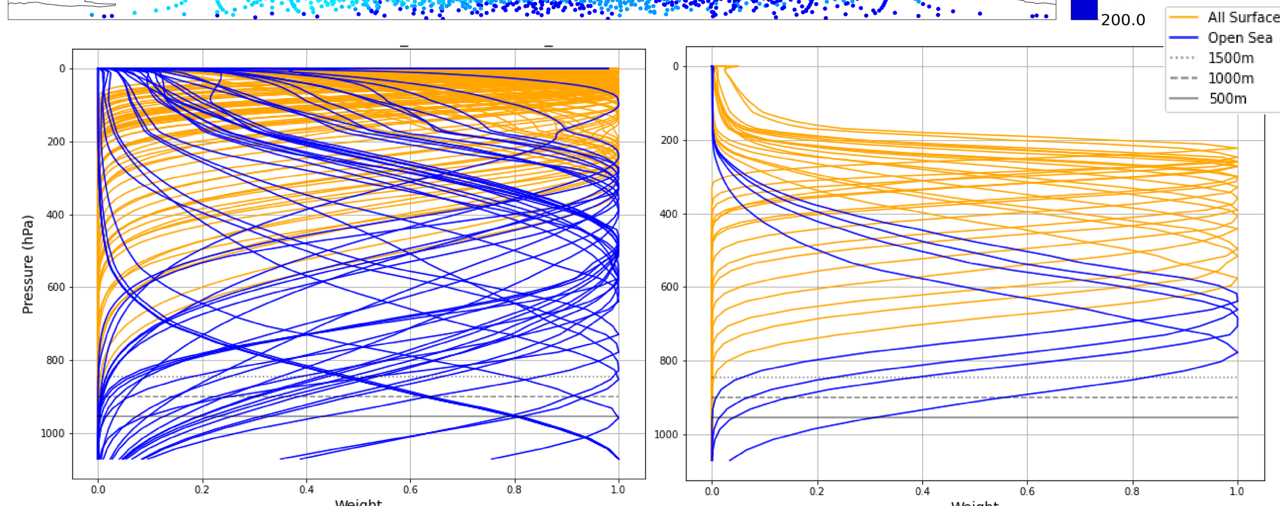


Figure 6: Weighting functions of 122 selected IASI-NG channels. 101 selected channels from band 1 and 21 channels from band 2, channels in orange are assimilated over land and water, channels in blue are assimilated over water only
To select which IASI-NG channels we want to assimilate, we first considered the 500 channels selected by Vittorioso et al, 2021 corresponding to the IRS sounding bands. However the current forecast system isn't capable of processing this amount of data (only 129 IASI channels are currently assimilated in the Météo France operational forecast system), therefore it had to be narrowed down more. For the first band of the IASI-NG spectrum we mapped IASI-NG channels to the IASI channels already in use. For the second band, we chose a set of water vapour sensitive channels whose combined weight functions cover the whole atmosphere as shown on the right pannel of Figure 6.

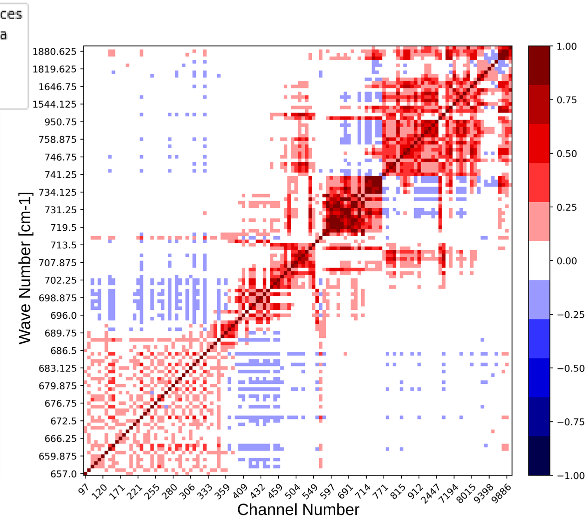


Figure 7: IASI-NG error correlation matrix
IASI-NG channels have correlated observation errors as the other hyperspectral infrared sounders. In order to succesfully assimilate the 122 selected IASI-NG channels, we computed an interchannel correlation error matrix as proposed by Desroziers et al 2005. Figure 7 shows the matrix computed over 5 days of 4DVAR. We observe very strong correlations for CO2 channels sensitive to the tropospheric temperature, to the surface and humidity channels. This matrix is then used in the 4DVAR IASI-NG impact experiment.

6. Cloud Detection & Thinning

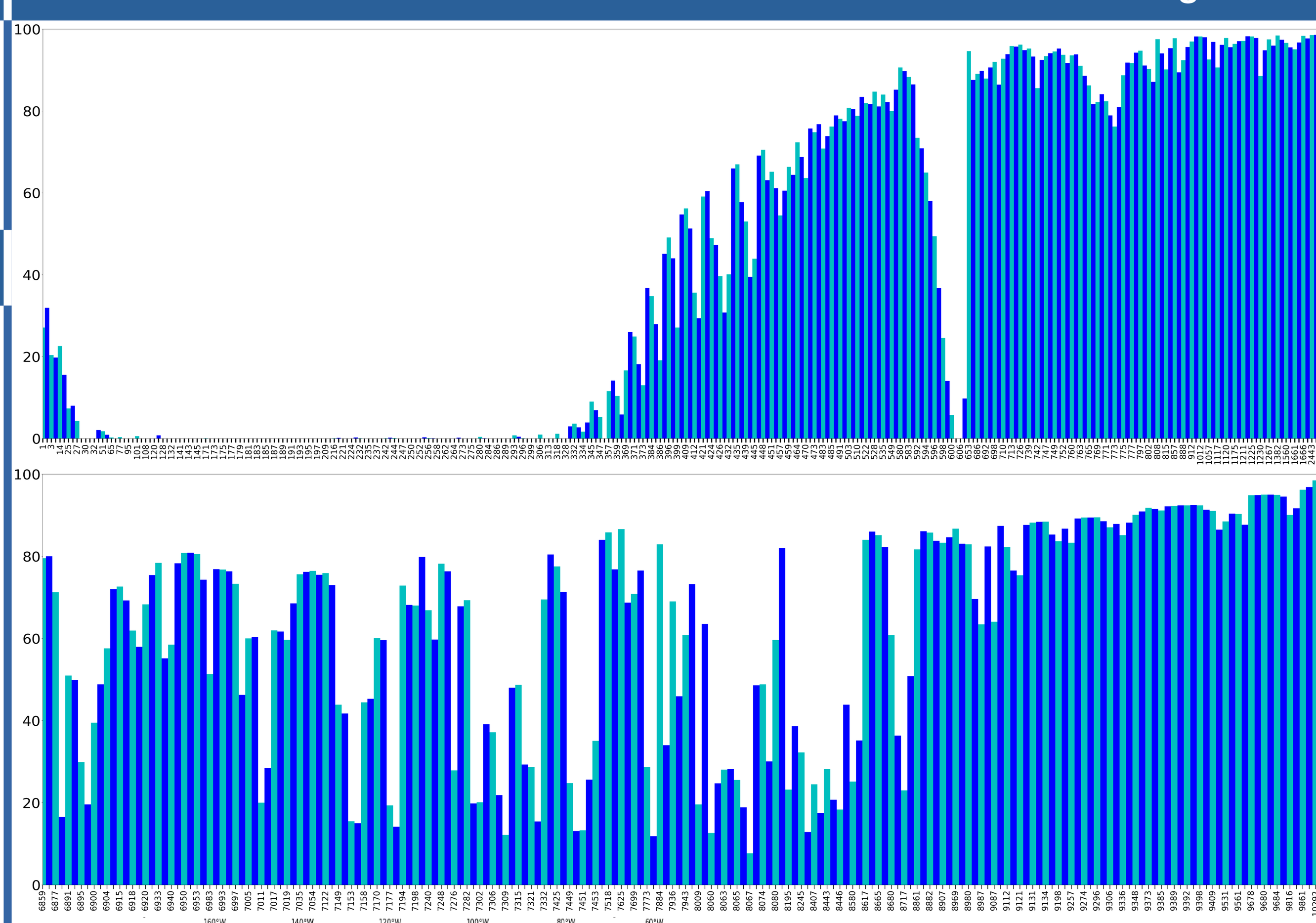


Figure 8: Percentages of IASI-NG observations flagged "cloudy" per channel for CO2 channels (top panel) and water vapour channels (bottom panel)
IASI-NG data is cloud sensitive and observations made over clouds have to be discarded. The cloud detection system proposed by McNally and Watts(2003) was adapted to process IASI-NG data and the ratio of flagged observations had to be validated. In figure 8 we can see that the first channels which are sensitive to the higher parts of the atmosphere and thus not impacted by clouds have very little to no cloud flags. As we move on to the higher channels, we travel down the atmosphere and channels start being sensitive to clouds, which corresponds to the steep increase in cloud flags that starts around channel 332 (686.375 cm-1) whose weight function peak is at 100hPa.
In our IASI-NG impact study experiment however, the percentage of cloudy observations is too high compared to IASI and other infrared instruments. Most surface channels in our experiment have between 90% and 99% observations flagged "cloudy", when they should lay at around 80%. For the second band channels we can see that many channels have from 80% to 99% of cloudy observations, when they should have around 60%. This problem remains to be fixed.

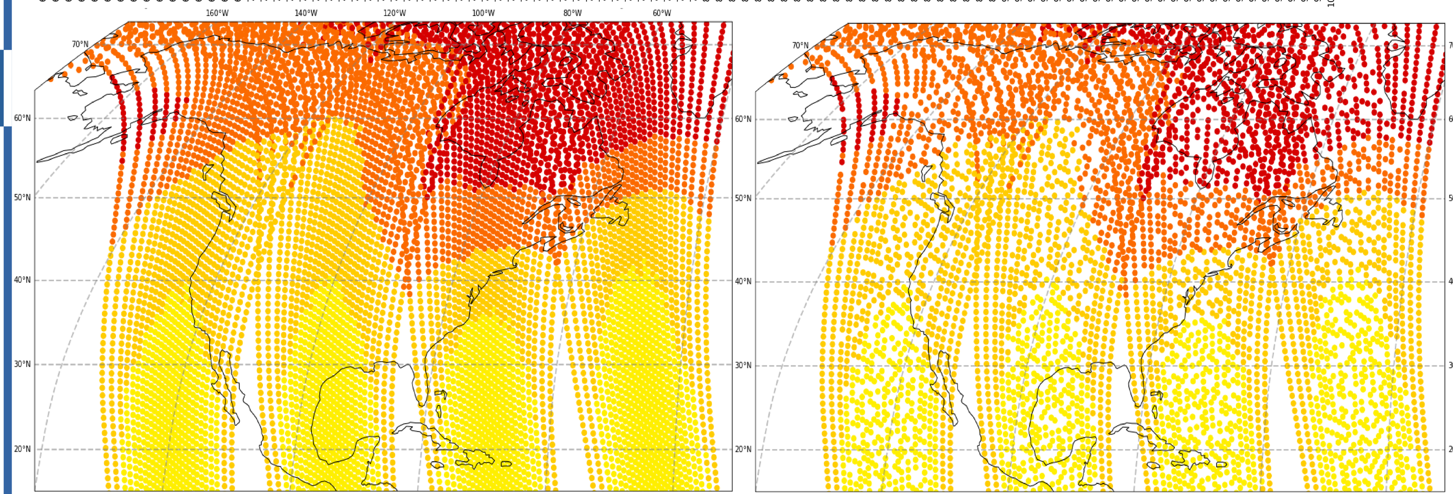


Figure 9: IASI-NG channel 97 (657 cm-1) observations before and after horizontal "thinning"
To reduce the amount of data processed by the 4DVAR, the "thinning" process downsamples observational datasets by selecting a single data point per grid point. In our case, we chose the same grid size as used for the IASI data thinning e.g 95km. For channels not affected by clouds like the one shown above, the amount of discarded data is around 30%.

7. Impact of IASI-NG

To diagnose the impact of IASI-NG observations on the forecast system, we analyse the differences between the first guess forecast of our reference experiment and the observations (fg_departure), and the first guess forecast of our experiment with IASI-NG and the observations. Below, these differences were computed over a 15 days period and a 99% confidence interval. When adding IASI-NG we observe that the first guess forecast produced by the 4DVAR is driven closer to IASI-NG observations, and is therefore driven closer or futher to the other instrument's observations. Because IASI-NG is decreasing forecast errors in certain areas, the difference between the first guess (6h forecast) and the other instruments is also decreased in these areas.

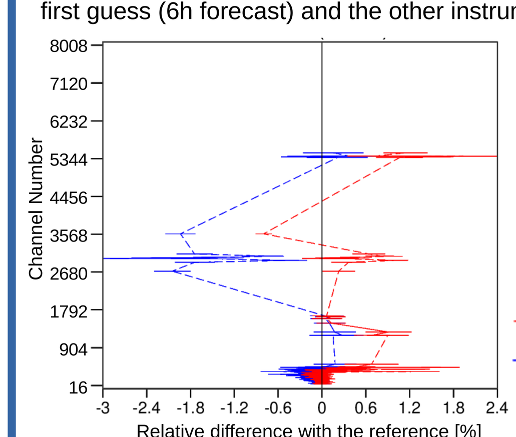


Figure 11: Relative IASI fg_departure STD difference with the reference 14/08/2021 - 28/08/2021
On this figure we can observe that IASI fg_depar std for humidity sensitive channels are decreased by adding IASI-NG observations, while temperature sensitive channels are mostly unaffected.

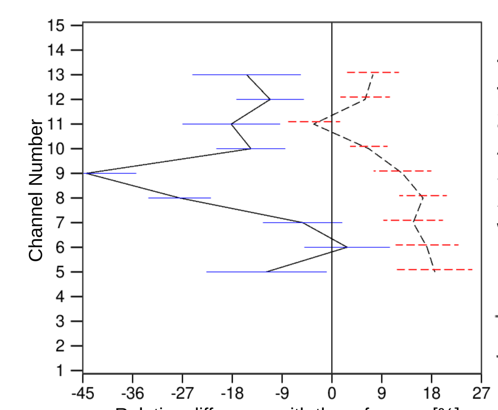


Figure 12: Relative AMSU-A fg_departure STD difference with the reference 14/08/2021 - 28/08/2021
All AMSU-A channels are temperature sensitive channels, and most of them show a slight fg_depar std decrease when adding IASI-NG data.

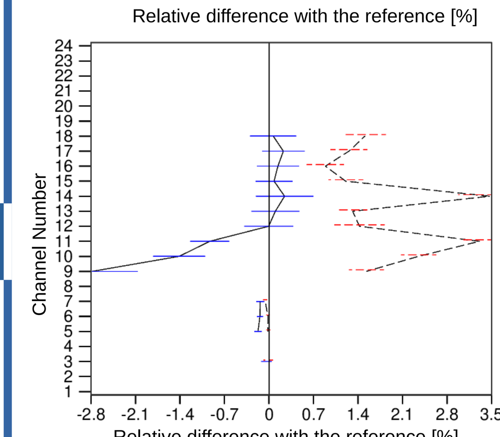


Figure 13: Relative SSMIS fg_departure STD difference with the reference 14/08/2021 - 28/08/2021
For SSMIS we observe a decrease in fg_depar std for channels 9 to 11, which are sensitive to temperature and humidty. ATMS and MHS show the same signal, a decrease in fg_depar std for humidity sensitive channels.

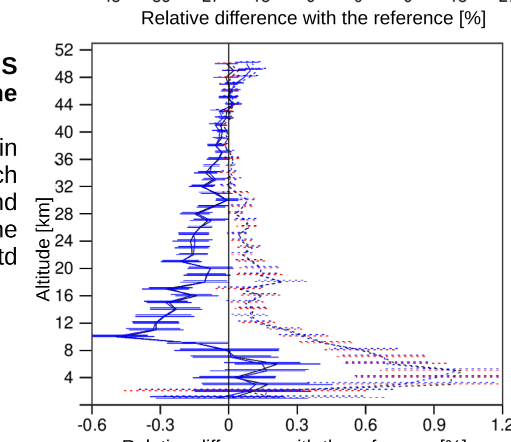


Figure 14: Relative GPSRO fg_departure STD difference with the reference 14/08/2021 - 28/08/2021
For GPSRO observations we observe a fg_depar std decrease for observations made between 10 and 36 km, which are all temperature sensitive.

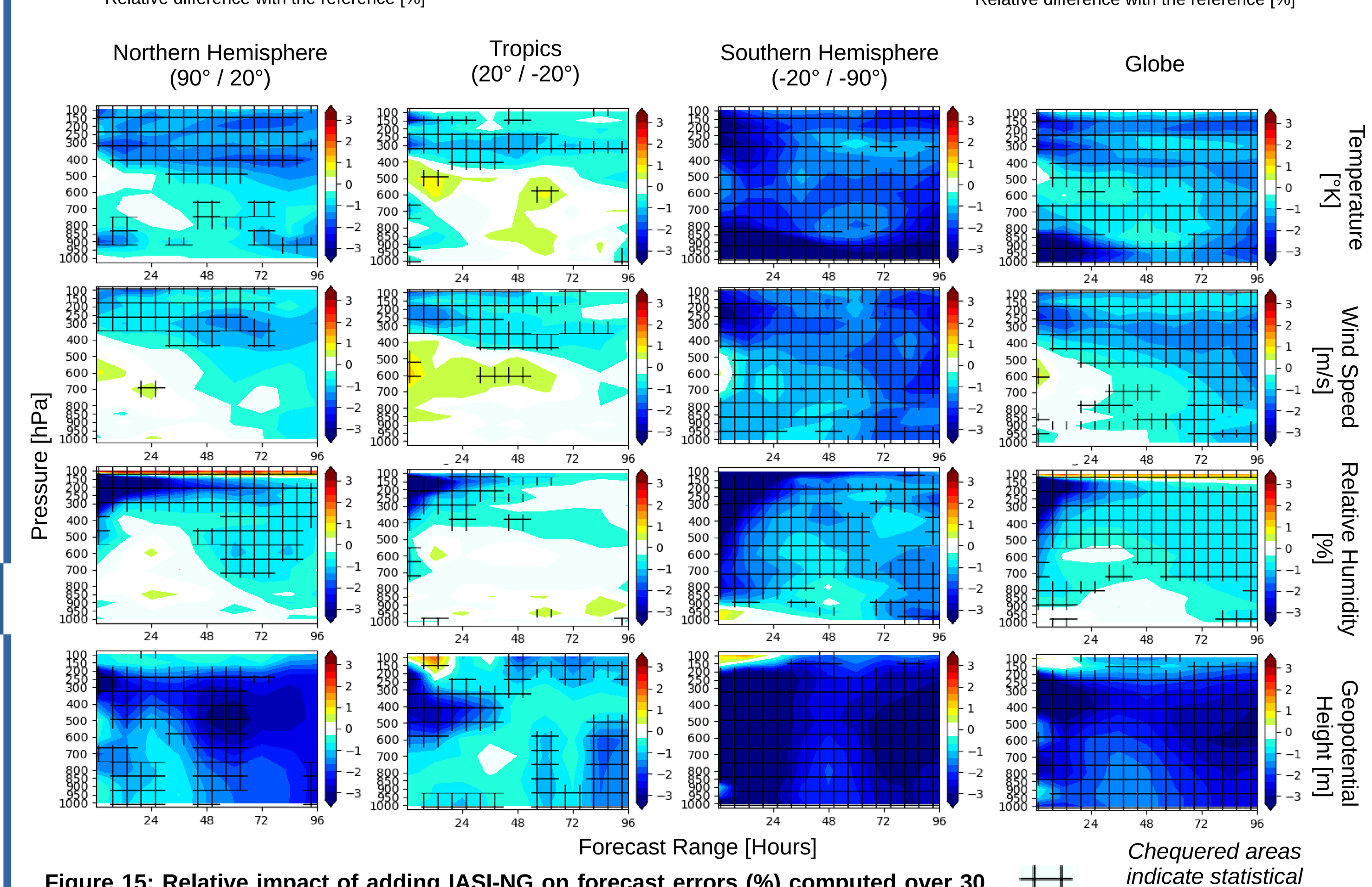


Figure 15: Relative impact of adding IASI-NG on forecast errors (%) computed over 30 days (14/08/2021 – 14/09/2021) (Exp - Ref)/Ref

Chequered areas indicate statistical significant results at 99 % confidence level

Figure 15 shows the IASI-NG impact diagnostics on different geographical areas. The impact on the globe shows that overall, adding IASI-NG observations to a 4DVAR has a small positive impact on short-term forecasts (up to 48 hours) and a substantial positive impact on longer forecasts (up to 96 hours). The geopotential height shows the most positive impact over the whole atmosphere and the whole forecast range up to 96h. For wind-speed and relative humidity, adding IASI-NG has a slightly positive or neutral effect on short term previsions. The impact on the northern hemisphere is very positive for the temperature and the geopotential forecast. The impact on humidity and wind speed is mostly neutral below 300hPa and positive above. The impact on tropical area forecasts is mixed. For the southern hemisphere however, the impact is very positive for all variables.
Furthermore, we can see that the positive impact on the humidity forecast in the high troposphere is coherent with the IASI fg_depar STD decrease of humidity channels shown in figure 11. The positive impact on the temperature forecast is coherent with the SSMIS, GPSRO and AMSU-A fg_depar STD decrease shown in figures 12, 13 and 14.

8. Conclusions and Perspectives

The results presented in this study demonstrate that:

- The forecast system is almost ready to assimilate IASI-NG observations.
- The first set of experiments shows that in a 4DVAR forecast system without IASI MetOp B, adding IASI-NG observations has a positive impact on the forecast skills. It decreases temperature, humidity, geopotential and wind forecast errors on the globe, especially in the southern hemisphere.
- Adding IASI-NG also has a positive impact on the other instruments observation assimilation and on the forecast system in general.

In the upcoming months, the following points will be addressed:

- These results were computed over a 1 month period, and will be computed over longer periods of several months.
- In order to improve IASI-NG's contribution to the forecast, we will try different sets of assimilation parameters to change the weight IASI-NG data has during the 4DVAR minimisation process. To do so we will diagnose the error correlation matrix again and check if the IASI-NG observation errors during the run correspond to the ones we set at the beginning of the experiment.
- we will fix the amount of observations flagged as "cloudy". This will greatly increase the amount of assimilated IASI-NG data, and could thus greatly reinforce the already positive impacts they have on the forecasts.
- If the impact of forecast errors stays positive over these longer periods, then we will go on and compare a forecast system with IASI MetOp B without IASI-NG, and a forecast system without IASI MetOp B with IASI-NG. This study will show the impact of replacing IASI MetOp B by IASI-NG, which is the final outcome of this study.
- To go further, we could try a different water vapour channel selection. It could be interesting to compare the impact of a water vapour sensitive channels from different regions of the second band.

9. References

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