A global Observing System Simulation Experiment to evaluate the impact of the EPS-Sterna constellation of microwave sounders

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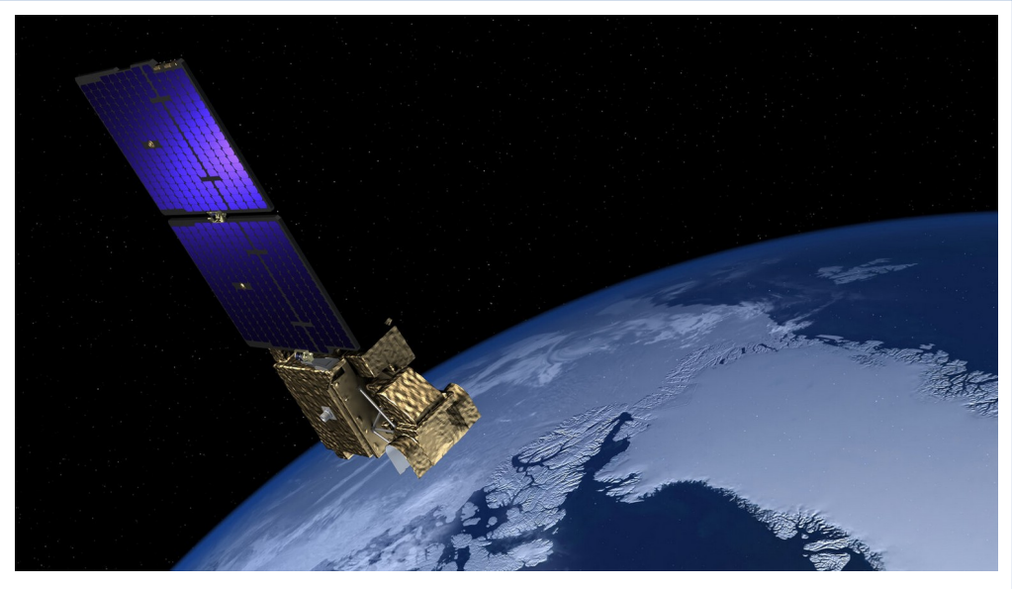
1. Introduction



A new constellation of satellites with microwave sounding capability, based on the Arctic Weather Satellite (AWS) developed by the European Space Agency (ESA), is under study at the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) as a complement of the EPS-SG program. One of the aims of this project is to increase the number of satellites with microwave sounding capabilities in space, beyond the ones available from the MetOp and JPSS backbone missions. Called EPS-Sterna, this constellation may be launched from 2030 onward on sun-synchronous low earth orbits. In support of the definition of this constellation, in terms of number of satellites and constellation architecture, the Centre National de Recherches Météorologiques (CNRM) will evaluate the impact of the various scenarios for this constellation on Numerical Weather Prediction (NWP) through an Observing System Simulation Experiment (OSSE).

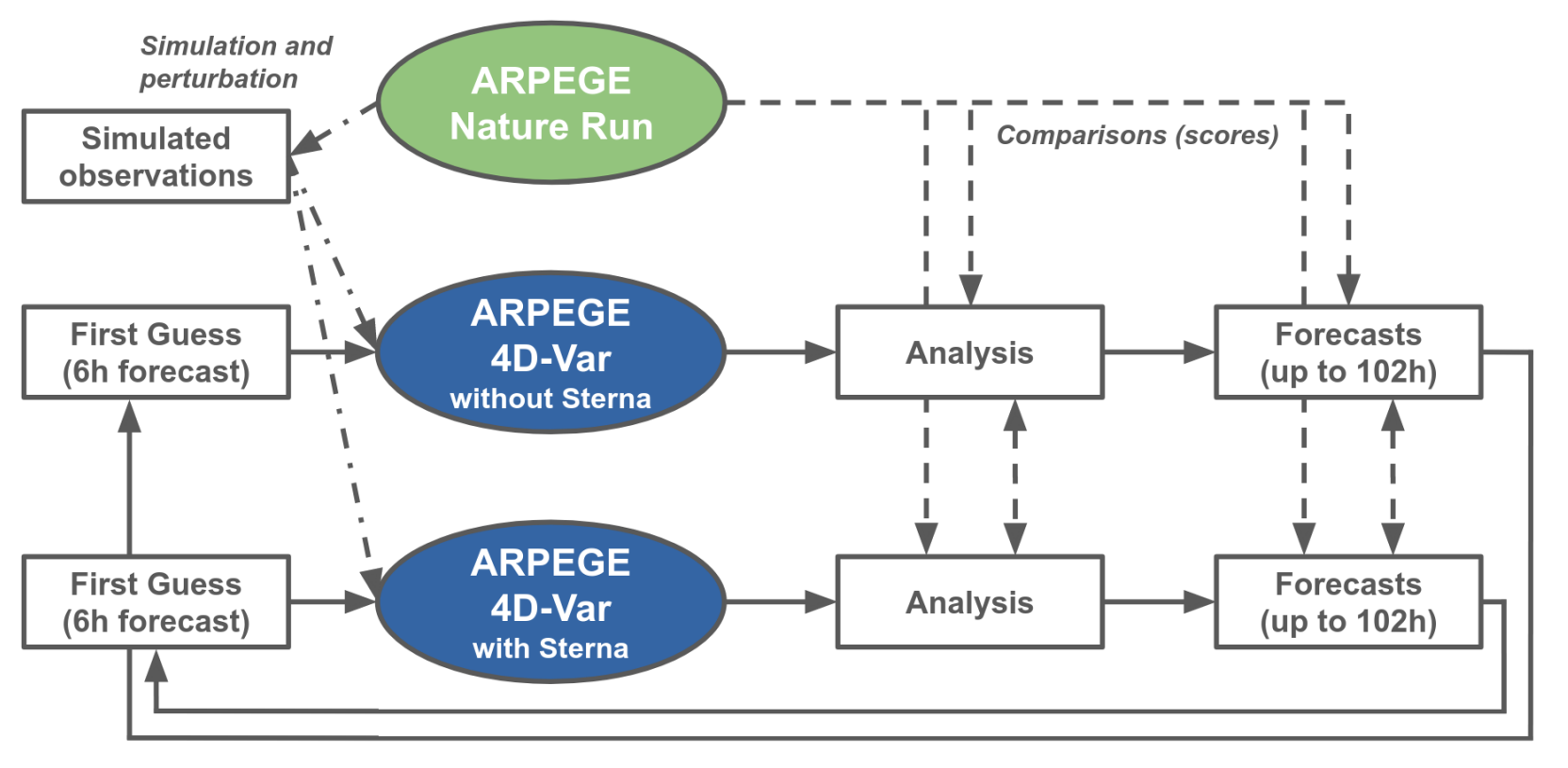
2. Construction of an OSSE framework

An Observing System Simulation Experiment consists of an entirely simulated environment. It requires several ingredients :

- a nature run considered as true state of the atmosphere for forecast verification and observations simulation. It consists of a long, uninterrupted forecast and produces a realistic evolution of the atmosphere.
- a NWP data assimilation system used to compute the best estimate of the atmospheric state and to produce weather forecasts. It ingests the observations simulated using the nature run.

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).

Parameters	Nature run	Data assimilation and forecasting system
Model	ARPEGE (version 46t1)	ARPEGE (version 46t1)
Truncation / nb of levels	TL1798 / 105 levels	TL798 / 105 levels
Resolution over Europe	About 5 km	About 10 km
Resolution over New-Zealand	About 24 km	About 61 km
DAS	None	4D-Var 6h cycle
Forecasts	None	102h
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



General framework of the OSSE

3. Computation and validation of the nature run

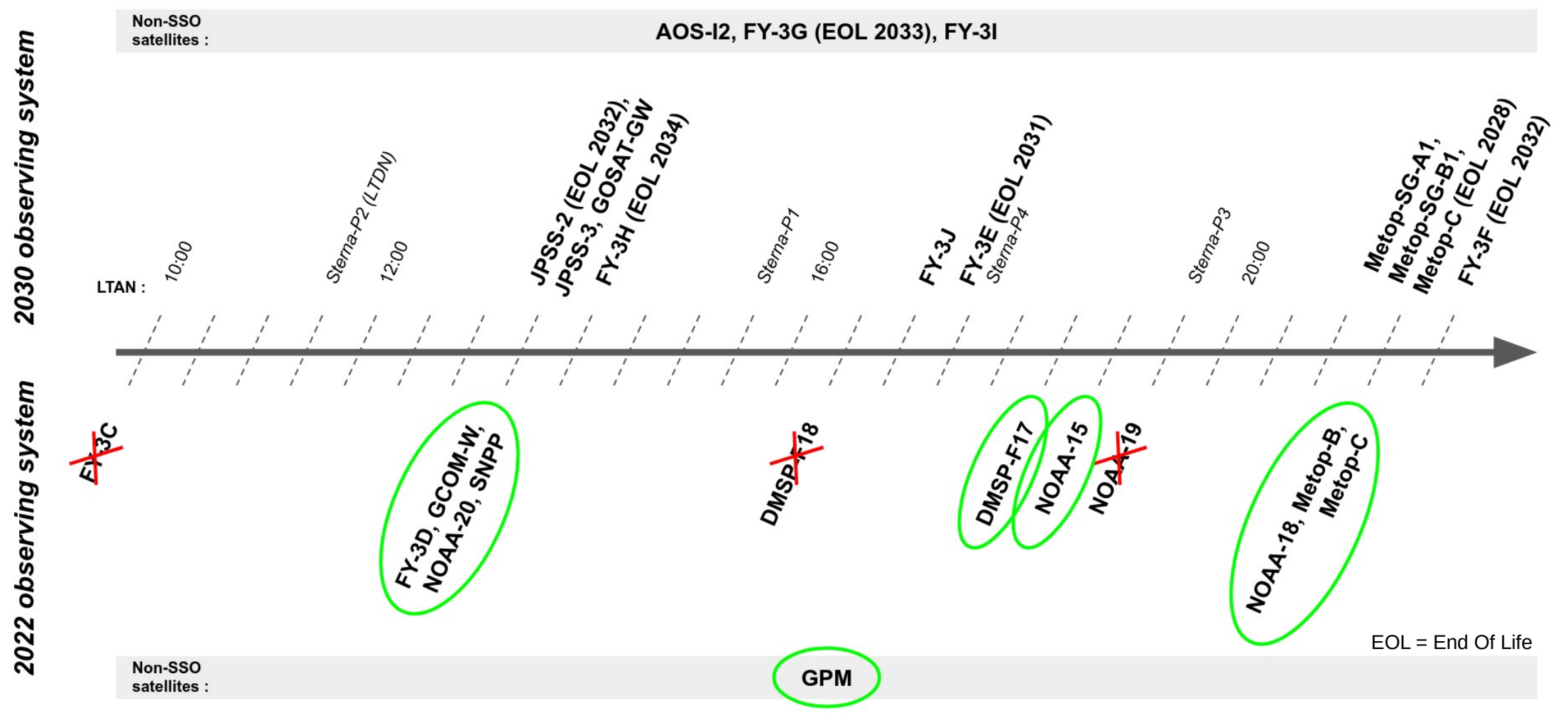
The nature run has been computed over the two periods of study. It has then been validated by comparing climatological averages of various variables (temperature, relative humidity) from the nature run and from a real atmospheric analysis. For more details, see the poster of Marty et al.

Scan the QR code to display a video of the evolution of the simulated atmosphere in the nature run in August and September

4. Simulation and calibration of the observations

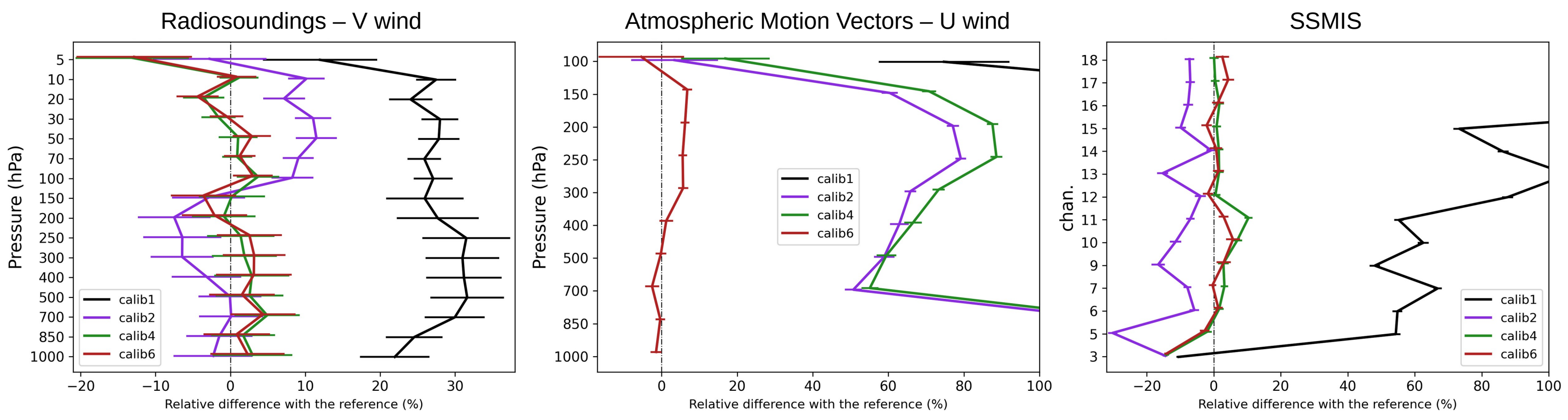
The objective of the study is to measure the impact of the EPS-Sterna constellation in a 2030-like environment. Thus, the choice of the observations to simulate is made according to the available information on the planned missions for 2030 and the available proxies in the 2021 observing system. The list of the satellites used as proxy and the corresponding planned satellites for 2030 are given in the figure beside.

The choice of reference observing system is subject to several uncertainties, for example : new instruments not already launched cannot be simulated without significant additional efforts (e.g. MTG/IRS), some follow-on missions have not officially been planned yet (e.g. DMSP satellites), etc.



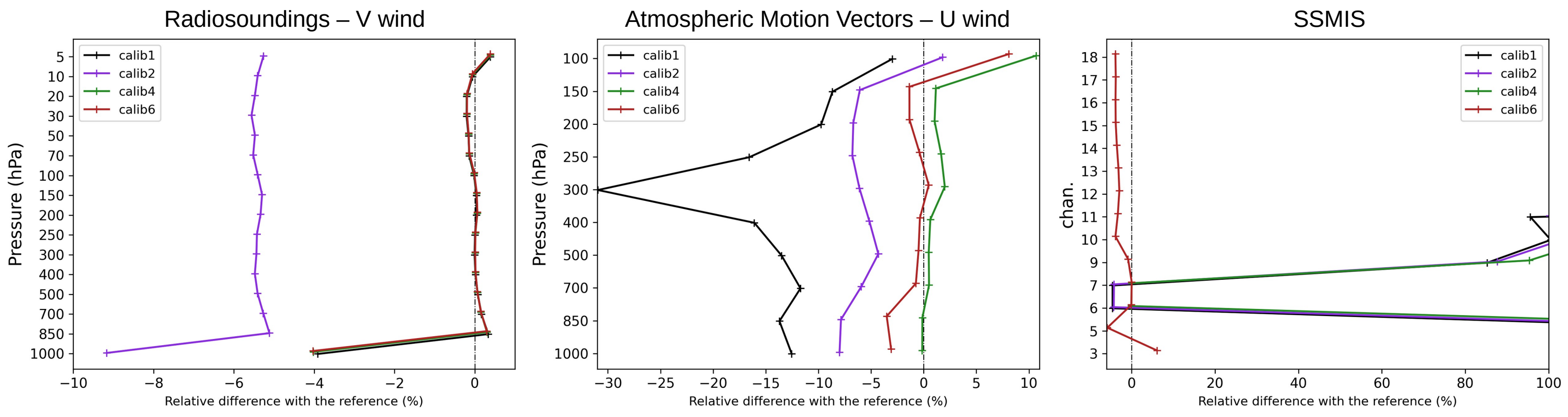
The observations are simulated using the nature run and perturbations are added to simulate measurements errors. The magnitude of these perturbations needs to be calibrated in order to ensure that each observing system has a realistic weight within the OSSE. The process of calibration is iterative and is repeated until each observing system ends up having similar first-guess departure statistics and number of active observations in the OSSE and in reality.

Relative first-guess departures standard deviation - simulated versus real observations - 15 days – globe – 99% confidence interval



A channel is considered calibrated for first-guess departure when the difference with real observations is not significative at 99% confidence level. Most of the channels can be considered calibrated for first-guess departure.

Relative number of observations - simulated versus real observations - 15 days - globe – 99% confidence interval



A channel is considered calibrated for the number of observations when the difference with real observations is not higher than 5%. Almost all channels can be considered calibrated for the number of observations.

5. Integration of EPS-Sterna

The EPS-Sterna satellites will fly on sun-synchronous orbits at 595 km of altitude. To avoid correlation between the samples, we select one observation every 100 km. To simulate the selected observations, RTTOV v12 is used. Various scenarios for the constellation, in terms of number of satellites and orbital planes, are studied and described below.

Plane number	Plane priority	Local Time of Descending Node (LTDN)
1	1 (high)	3:30
2	1 (high)	11:30
3	2 (moderate)	7:30

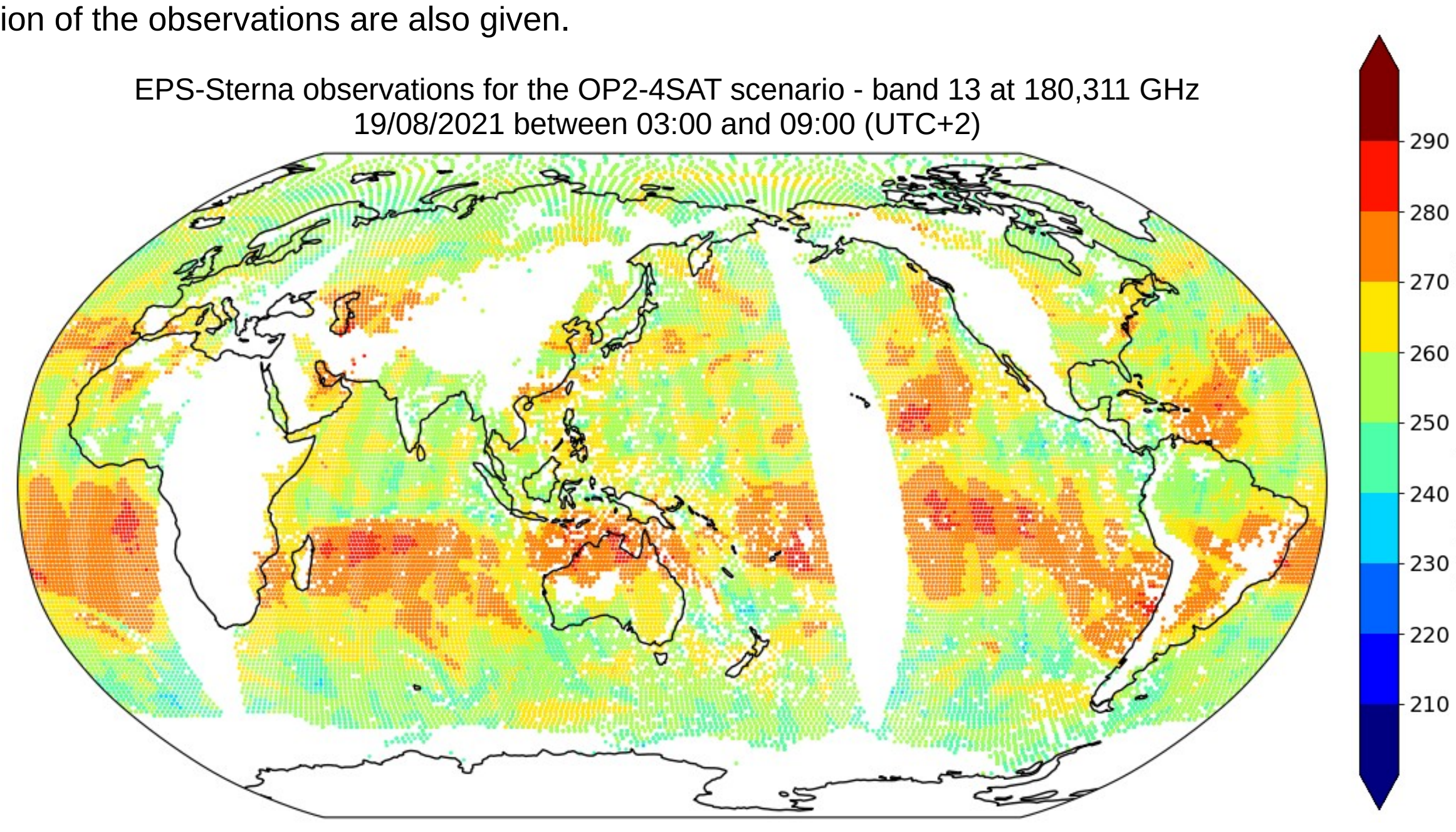
Scenario	Number of satellites	Repartition of the satellites over planes
OP3-6SAT	6	3 orbital planes, 2 satellites per plane, relative phasing 180 degrees
OP3-3SAT	3	3 orbital planes, 1 satellite per plane
OP2-4SAT	4	2 orbital planes, 2 satellites per plane, relative phasing 180 degrees

To simulate the observations, we use for the noise of the channels the raw NEΔT divided by 3, to simulate a superobbing using 3x3 pixels. The exact values are described hereafter. Examples of the simulation of the observations are also given.

Channel number	Frequency (GHz)	Noise (K)
1	50,3	0,33
2	52,8	0,21
3	53,246	0,21
4	53,596	0,22
5	54,4	0,20
6	54,94	0,20
7	55,5	0,21
8	57,290344	0,22
9	89	0,10
10	165,5	0,18

Channel number	Frequency (GHz)	Noise (K)
11	176,311	0,18
12	178,811	0,18
13	180,311	0,25
14	181,511	0,25
15	182,311	0,35
16	325,15	0,47
17	325,15	0,39
18	325,15	0,32
19	325,15	0,25

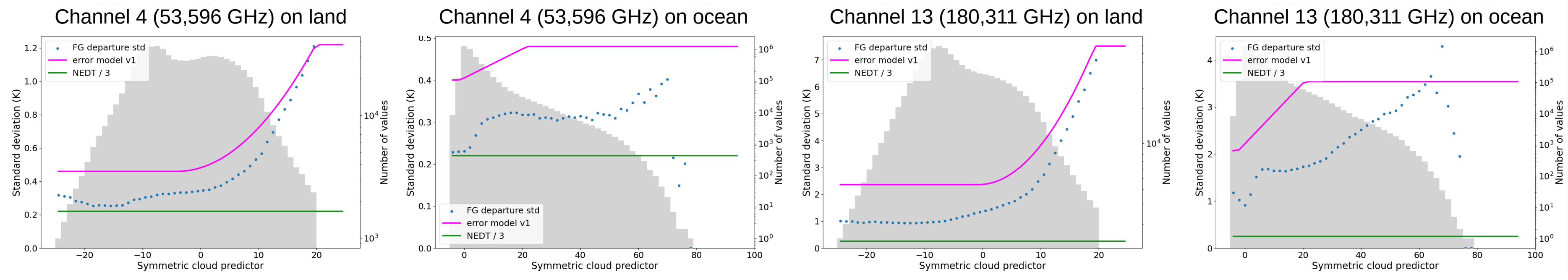
EPS-Sterna observations for the OP2-4SAT scenario - band 13 at 180,311 GHz
19/08/2021 between 03:00 and 09:00 (UTC+2)



Scan the QR code to display a video of the satellites of the OP3-6SAT scenario sounding the atmosphere (channel 13)

The observations from EPS-Sterna are assimilated in all-sky conditions, over oceans and land using the all-sky approach developed at the European Centre for Medium-Range Weather Forecasts (ECMWF) (see Geer and Bauer, 2011). 325 GHz channels are not assimilated yet. The error models for EPS-Sterna are constructed by fitting the standard deviations of first-guess departures. Examples are given below, with the scattering index used for the symmetric cloud predictor both on land and on ocean.

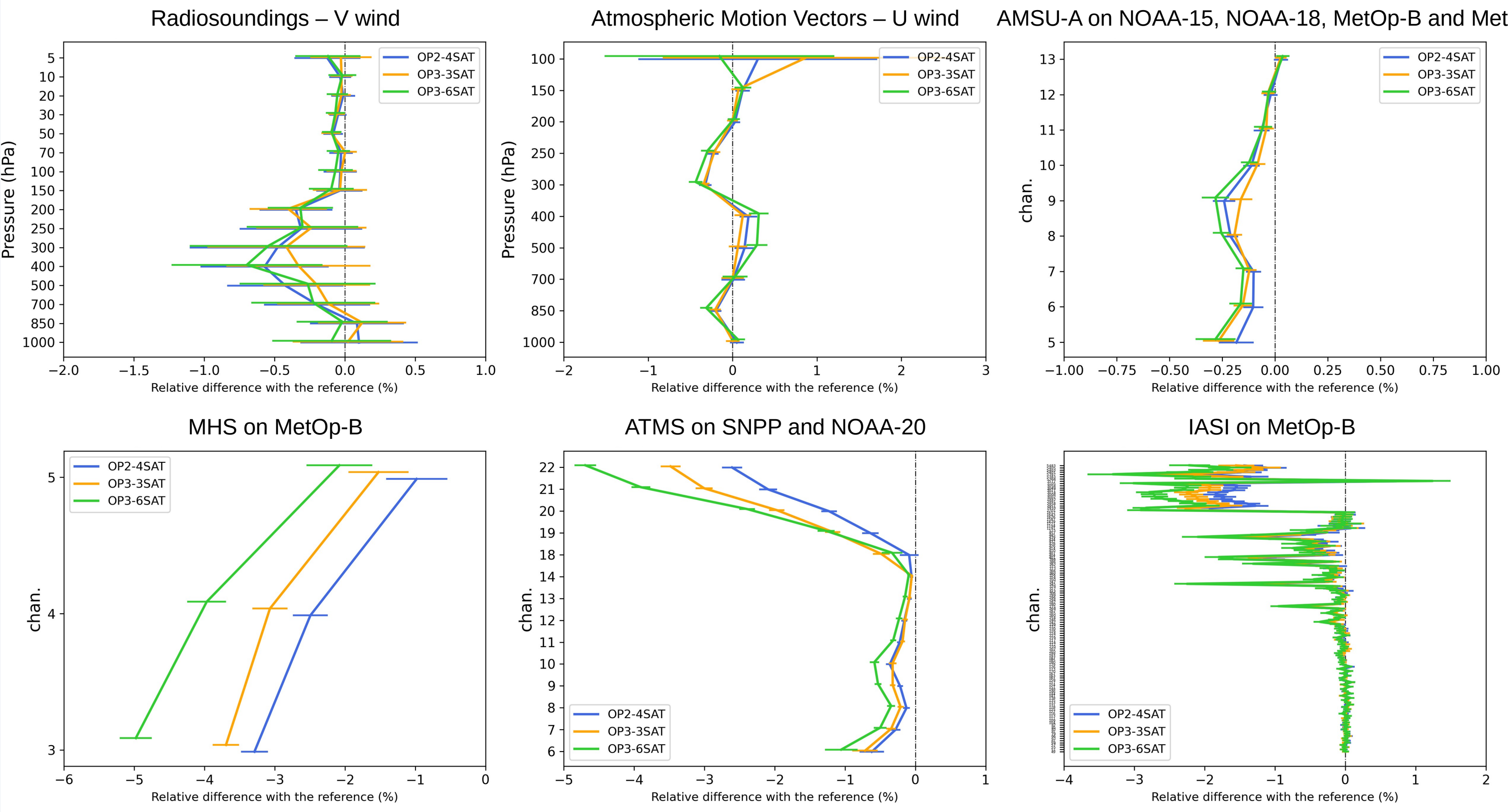
Standard deviation of EPS-Sterna FG departures, binned as a function of scattering index - noise and error model used for the simulation and the assimilation



7. Impact of EPS-Sterna

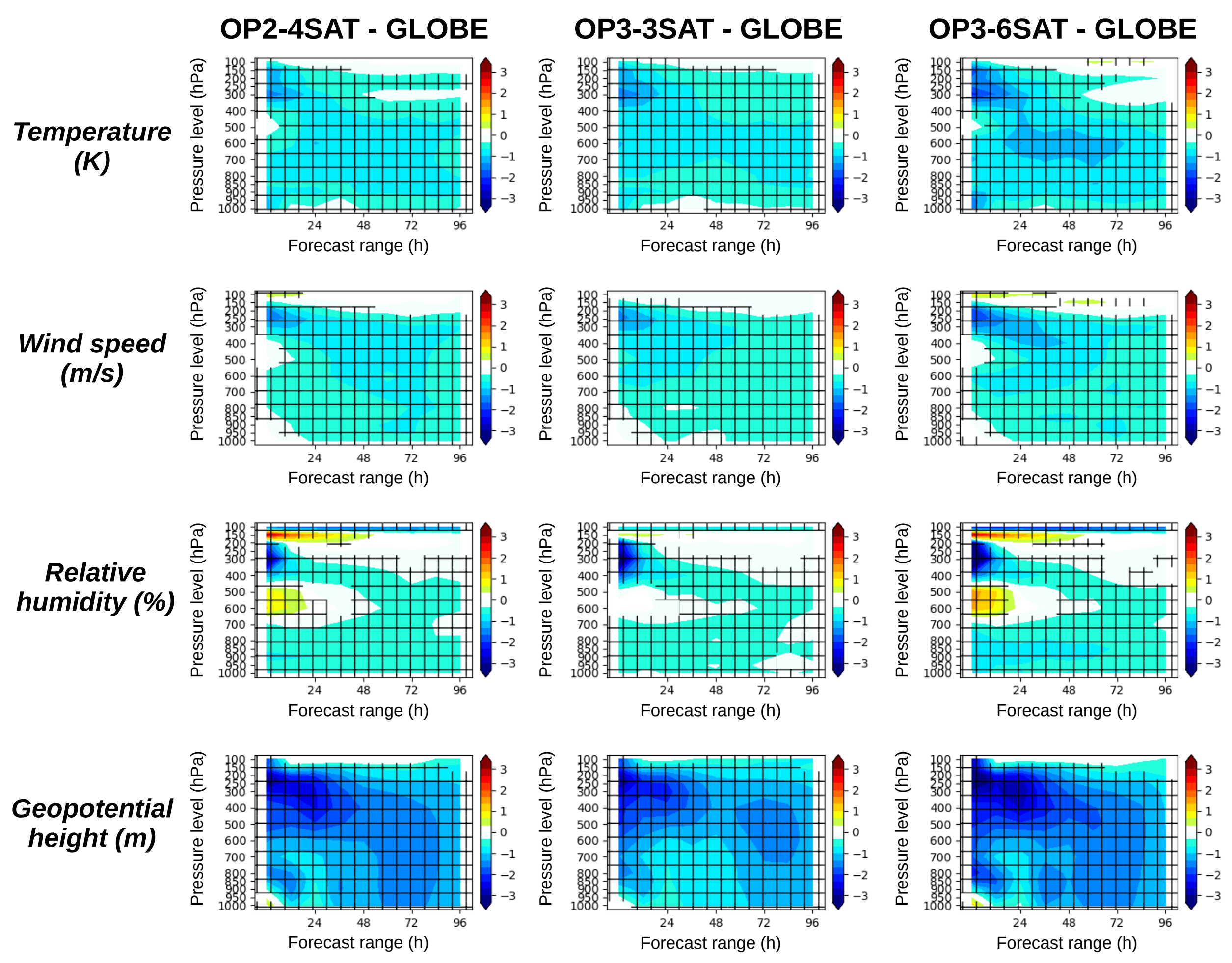
A control data assimilation experiment is run with the simulated, calibrated observing system planned for 2030. Data assimilation experiments with the same observing system plus simulated EPS-Sterna satellites are also run, using the various scenarios presented in section 5. We compare the forecasts produced in one data assimilation experiment with EPS-Sterna to the control experiment in order to measure the impact of the EPS-Sterna scenarios.
The relative impact of the EPS-Sterna scenarios can be estimated on relative humidty, temperature, winds, geopotential height, at different forecast ranges, at various vertical levels and over different geographical domains.

Impact of the EPS-Sterna scenarios on first-guess departures standard deviation – 2,5 months – globe – 99% confidence interval



The impact of EPS-Sterna on first-guess departures standard deviation is positive and significative at 99 % confidence level for all observation types. The impact is particularly important for satellite observations.

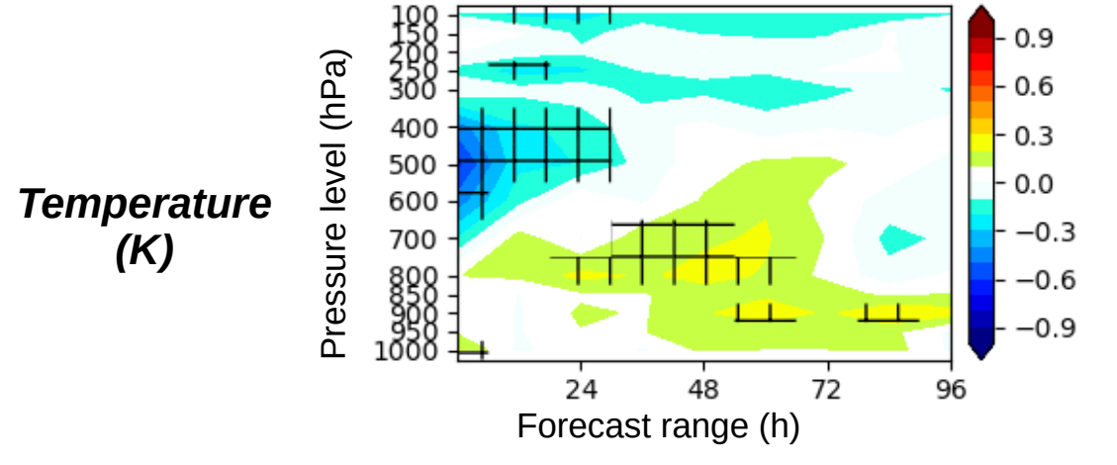
Relative impact of the EPS-Sterna scenarios on forecast errors (%) - 5,5 months (more than 150 days) - globe



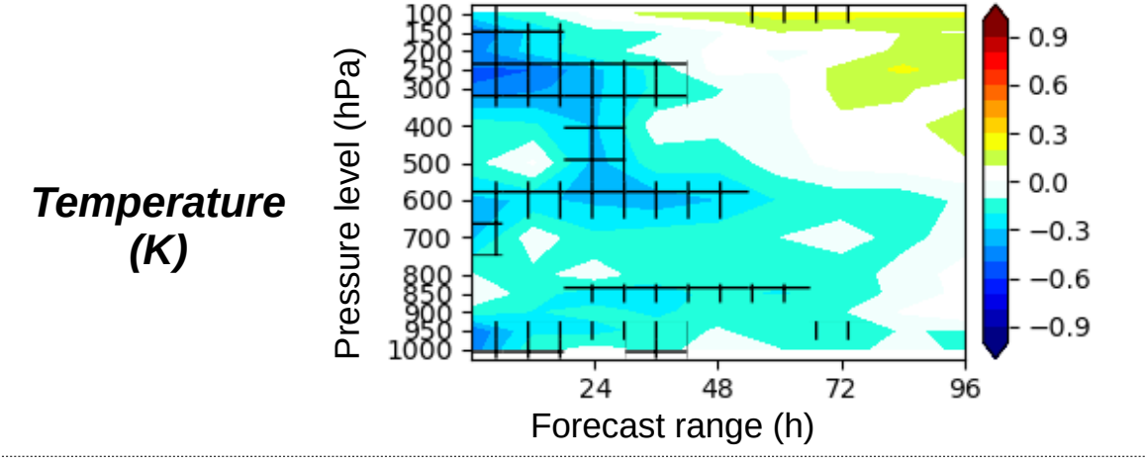
Hatched areas indicate statistical significant results at 99 % confidence level

All EPS-Sterna scenarios tested have a positive impact on forecasts at the global scale, for all forecast ranges, all variables and almost all vertical levels, significant at 99% level in most of the cases.
The degradation on relative humidity forecasts between 500 hPa and 600 hPa at short range comes from the tropics, as presented below.
Hereafter are compared the temperature forecast errors between the EPS-Sterna scenarios.
Herafter are compared the forecast errors on temperature between the different EPS-Sterna scenarios.

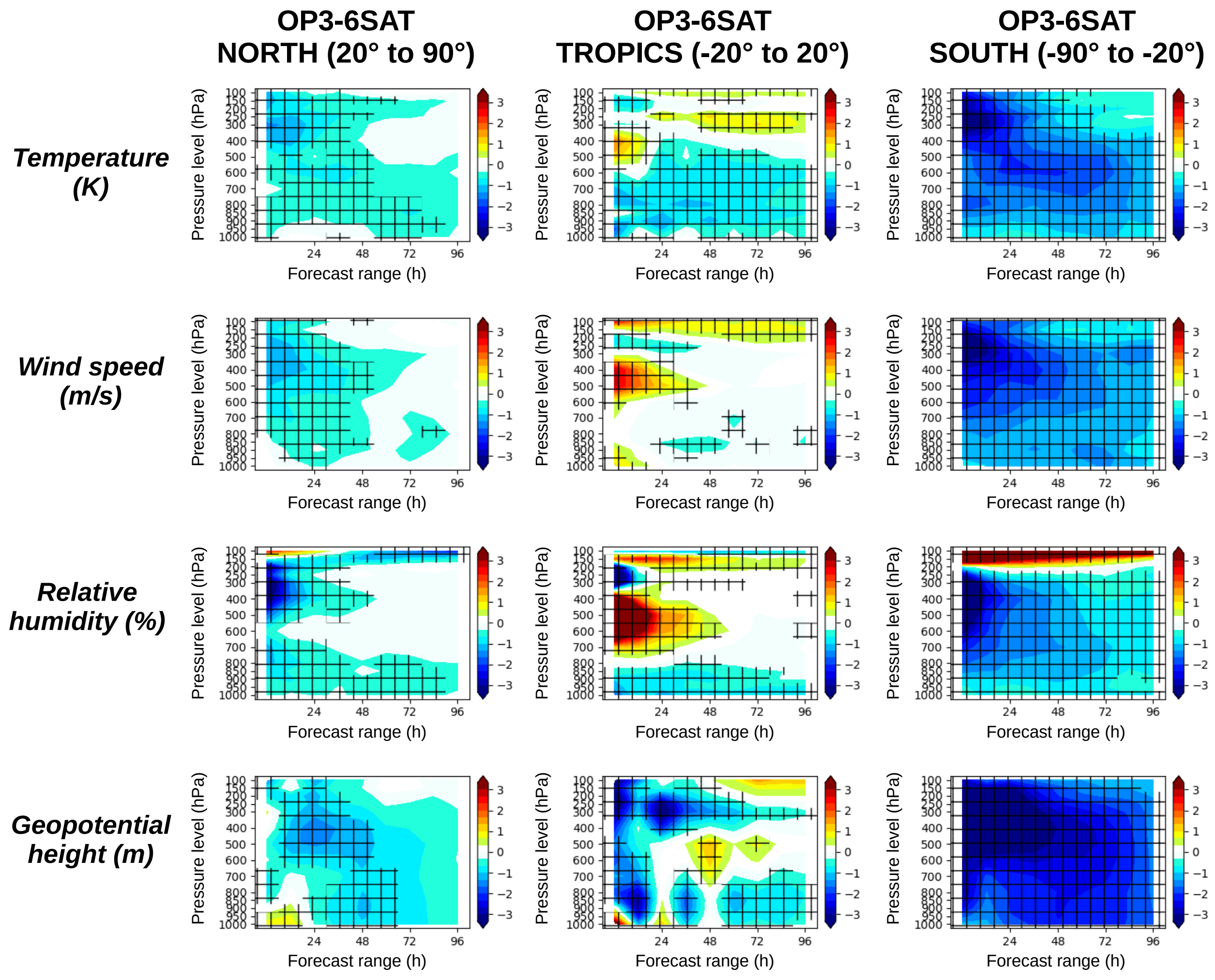
OP3-3SAT compared to OP2-4SAT - GLOBE



OP3-6SAT compared to OP2-4SAT - GLOBE



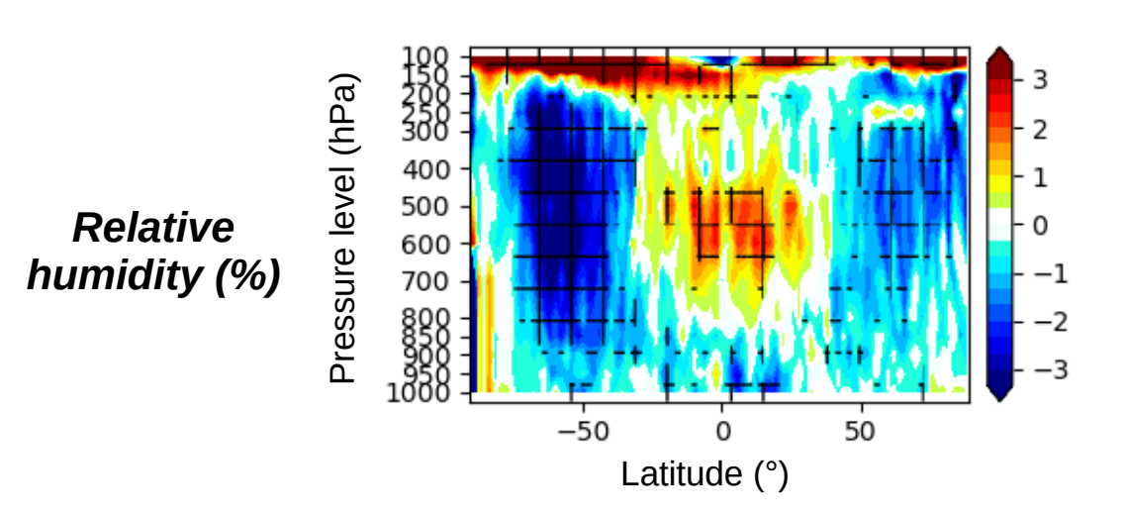
Relative impact of the OP3-6SAT scenario on forecast errors (%) – 5,5 months (more than 150 days) – northern hemisphere, southern hemisphere and tropics



Hatched areas indicate statistical significant results at 99 % confidence level

The impact of the OP3-6SAT scenario is the strongest in the Southern hemisphere, significant at 99% level up to +96h for all variables.
In the Northern hemisphere, the impact is significant at 99% level up to +48 for all variables for all variables.
In the tropics, the OP3-6SAT scenario improves the forecasts at 99% level up to +96h for the temperature and for most of the levels for the geopotential height. For the wind speed and the relative humidity, a degradation of the scores appears between 400 hPa and 600 hPa at short range (before 36 h).

OP3-6SAT – GLOBE – zonal STD – +24h range

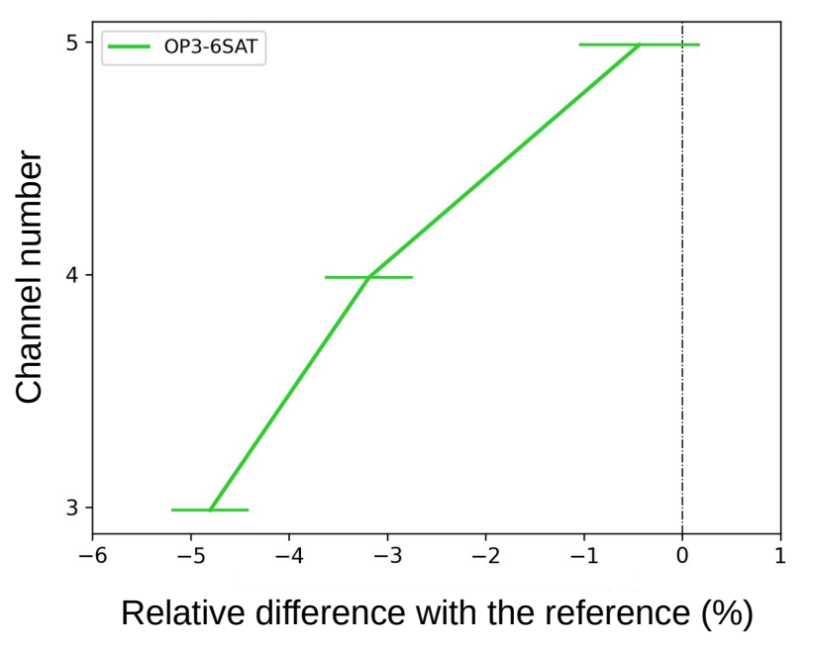


Two main degradations can be observed :

- in the tropics, at short range, between 400 hPa and 600 hPa, mainly on relative humidity.
- In the stratosphere, at all latitudes and all forecast ranges, mainly on relative humidity.

In the tropics, the degradation may be an artefact of the verification. Indeed, the microwave observations produce small-scale temperature and relative humidity increments. These increments are compared in the verification to a smooth analysis that does not contain small-scale structures (e.g. Geer et al., 2017). This leads to an apparent degradation in the computation of the scores. This degradation has already been noticed in the assimilation of SAPHIR/Megha-Tropiques (see Chambon and Geer, 2017). Yet, when we look at humidity channels peaking at about 500 hPa in the tropical region (from microwave sounders such as MHS on MetOp-B), the additional assimilation of EPS-Sterna observations improves the statistics of the first-guess departures : see the figure beside.

OP3-6SAT – MHS on MetOp-B FG departures STD – TROPICS



In the stratosphere, the degradation observed on relative humidity may be related to the way the increments on humidity are currently handled in the ARPEGE model and not related to EPS-Sterna. Indeed a small increment on humidity in the troposphere can lead to large and long-lasting increments in the stratosphere (see Sheperd et al., 2018). The current cut for humidity increments is at 100 hPa and may need to be revisited for a lower level (e.g. 300 hPa) .

8. Conclusions, limitations and perspectives

The results presented in this study demonstrate that :

- All EPS-Sterna scenarios tested have a positive and significative impact on first-guess departures and forecasts at the global scale, particularly on temperature, wind speed and geopotential height. The impact on humidity is mostly positive, with a degradation at 500 hPa and at short range.
- EPS-Sterna impact is the strongest in the Southern hemisphere, significant at 99% level up to +96h. In the Northern hemisphere, EPS-Sterna impact is good, significant at 99% level up to +48h.

However, the framework built for this OSSE suffers from several limitations :

- Perfect sea surface conditions have been used. In the real world, the use of a sea surface conditions with errors would increase the differences between the reality (the nature run) and the analysis.
- The synthetic Atmospheric Motion Vectors have not been computed at the location of clouds in the nature run, but at the location of real atmospheric motion vectors.
- Climatological background errors have been computed and remain unchanged across the different scenarios. Yet, the effect of updating background errors is secondary to that caused by the observing-system change itself (Duncan et al. 2021).

In the coming months, the following point will be addressed :

- Validate the OSSE framework by comparing the impact of a MetOp-B denial with real observations and with simulated observations in the OSSE.

9. References

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EUMETSAT is acknowledged for funding the work presented in this poster.