Impact of the all-sky assimilation of a satellite constellation of passive microwave observations within AROME NWP model

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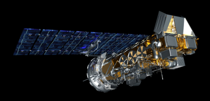
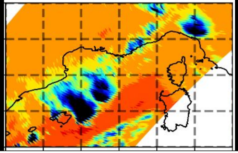
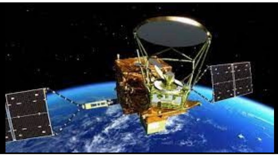
Météo-France, CNRM

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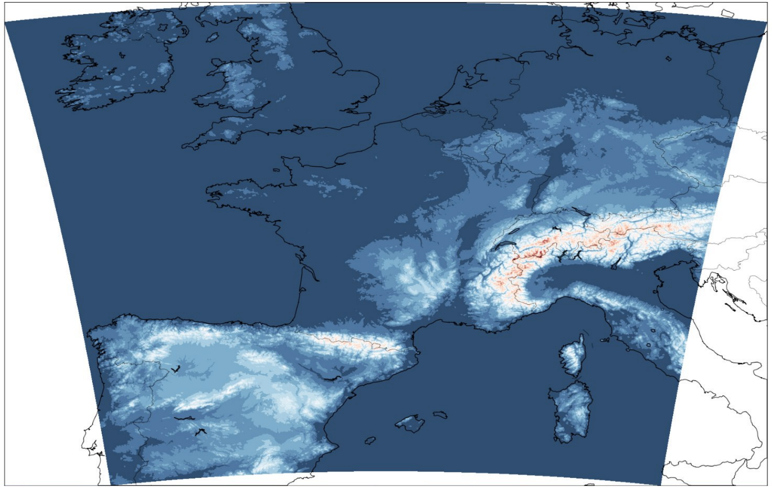
Introduction - The kilometre-scale NWP model AROME-France of Météo-France



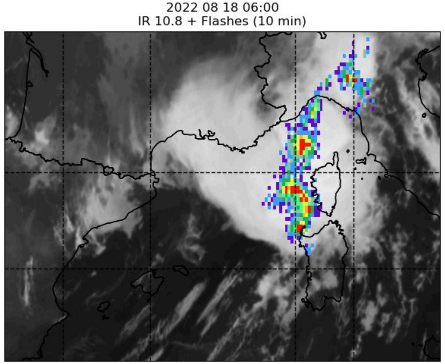
- ★ 90 vertical levels
- ★ Horizontal resolution : 1.3km
- ★ 8 forecasts per day
- ★ Operational data assimilation system : 3D-Var
- ★ Future operational data assimilation system : 3DEnVar
- ★ 15% of the observations are coming from satellites.

Introduction - Providing information in cloudy and precipitation areas

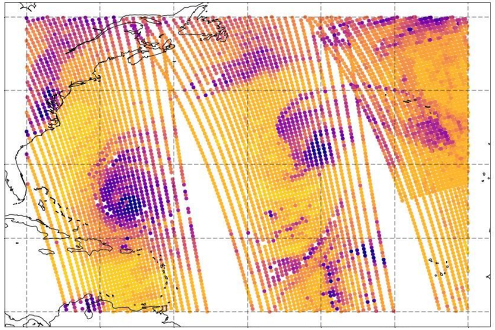
Currently assimilated

In progress

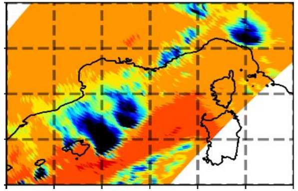
French and European radar networks



Lightning observations from Meteosat Third Generation [3]



Infrared sounding [4,5]

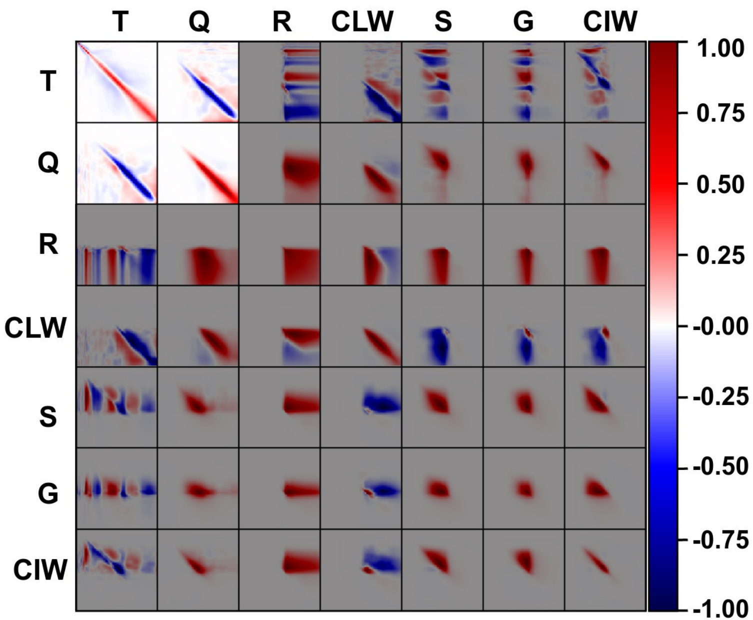


Passive microwave sounding [6]

3. Combarnous et al. (2024)
4. Villeneuve et al. (2024)
5. Antoine Chemouny's phd
6. Marylis Barreyat's phd

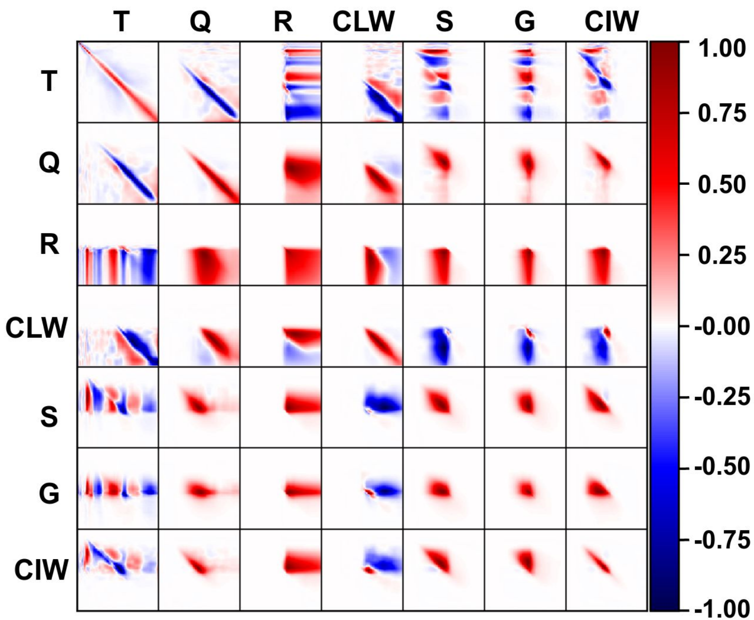
Introduction - Data assimilation system used

A suitable data assimilation system for projecting the information content derived from cloud and precipitation observations onto the model variables.



Current parrallel suite :
Flow-dependent B matrix (3DEnVar)

Extension of the Background error matrix (B)



Extension of the control vector

Vertical error covariances matrix of background B, valid for the case of 8 May 2023 at 21 a.m CET

I. Problematic & Outline

Impact of the all-sky assimilation of a satellite constellation of passive microwave observations within AROME

1 — **How do interact the observation operator (RTTOV-SCATT) and the AROME-France EnVAR including hydrometeors in the control vector ?**

2 — **What are the impacts of activating the assimilation within clouds and precipitation onto AROME-France forecasts ?**

→ *This work builds on the ECMWF “all-sky” route for global model (A. Geer et al.) adapted to the AROME mesoscale context.*

→ *New algorithmic developing in Météo-France (3DEnVar, hydrometeors in the control vector)*

II. Observation operator & data assimilation 3DEnVar

Impact of the all-sky assimilation of a satellite constellation of passive microwave observations within AROME

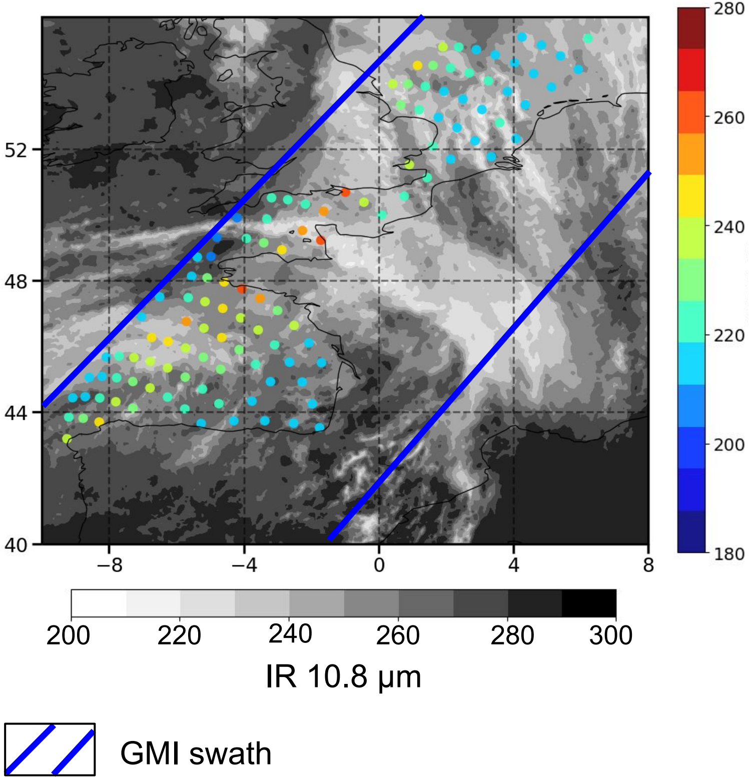
1 **How do interact the observation operator (RTTOV-SCATT) and the AROME-France EnVAR including hydrometeors in the control vector ?**

2 What are the impacts of activating the assimilation within clouds and precipitation onto AROME-France forecasts ?

Experiment REF - ALLSKY GMI

GMI is assimilated in cloudy and precipitation conditions

GMI assimilated observations 36.5 GHz



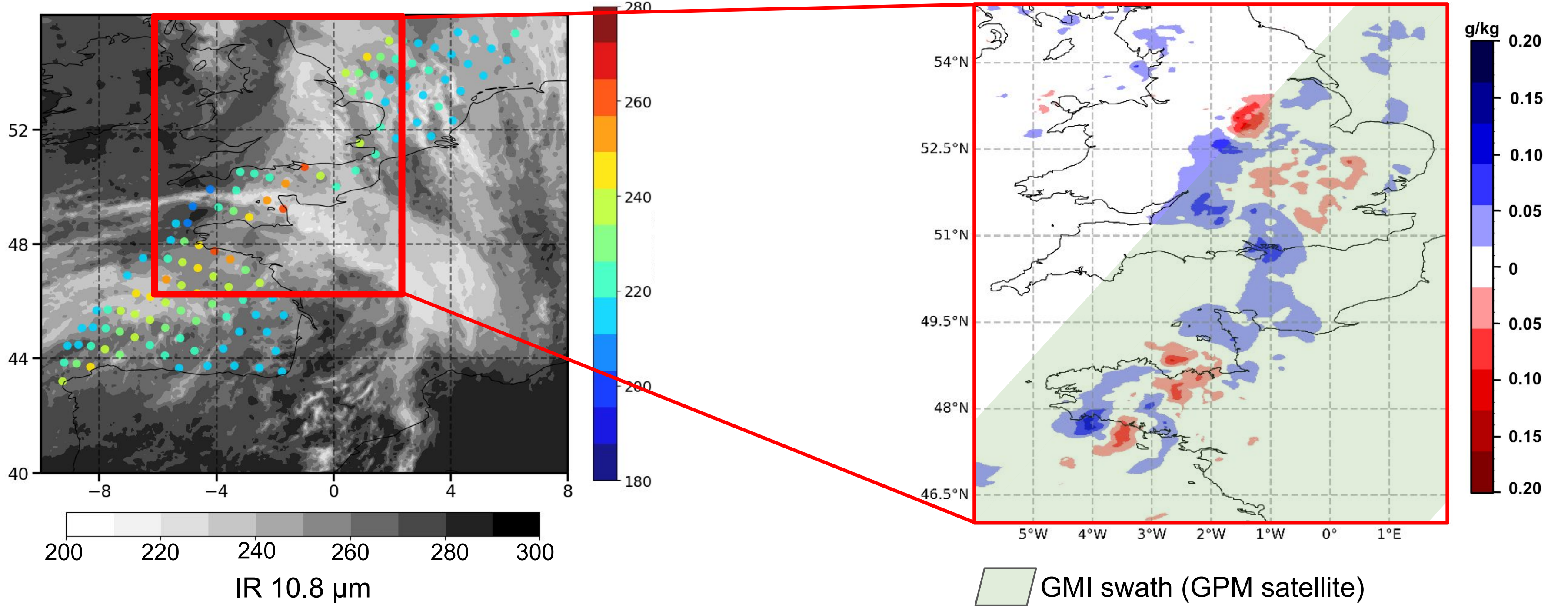
Case study *: 8th May 2023 - 10pm CET*

Experiment REF - ALLSKY GMI

GMI is assimilated in cloudy and precipitation conditions

GMI assimilated observations 36.5 GHz

Rain increments - level 60



How does GMI influence the analysis of rainfall profiles?

Does the maximum impact come from the correlations or from the observations themselves?

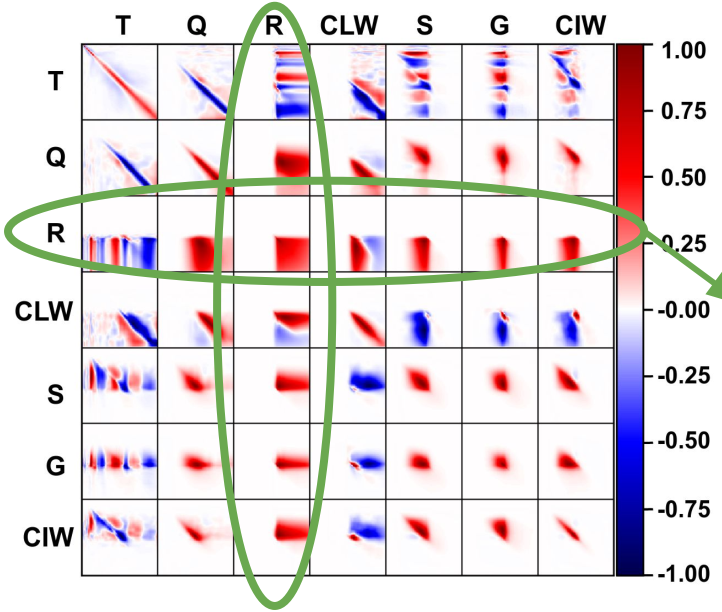
II. Observation operator & data assimilation 3DEnVar

Observations operator (H)

$$\begin{bmatrix} \frac{\partial H}{\partial T} \\ \frac{\partial H}{\partial q} \\ \frac{\partial H}{\partial r} \\ \frac{\partial H}{\partial q_s} \\ \frac{\partial H}{\partial q_i} \\ \cdots \end{bmatrix}$$

Rain sensitive channels frequencies of GMI

Error covariance matrix



Inter-variable correlations with Rain

Origin of increments for Rain (analysis - background)

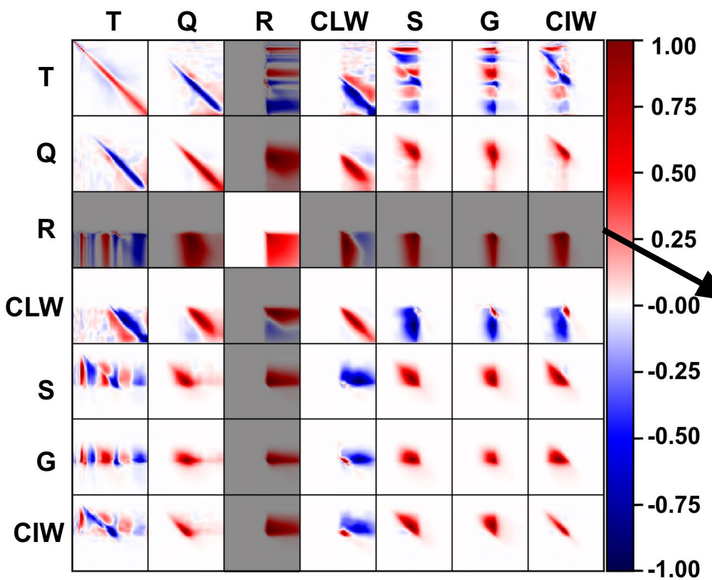
II. Observation operator & data assimilation 3DEnVar

Observations operator (H)

$$\begin{bmatrix} \frac{\partial H}{\partial T} \\ \frac{\partial H}{\partial q} \\ \cancel{\frac{\partial H}{\partial r}} \\ \frac{\partial H}{\partial q_s} \\ \frac{\partial H}{\partial q_i} \\ \cdots \end{bmatrix}$$

Rain sensitive channels frequencies of GMI

Error covariance matrix

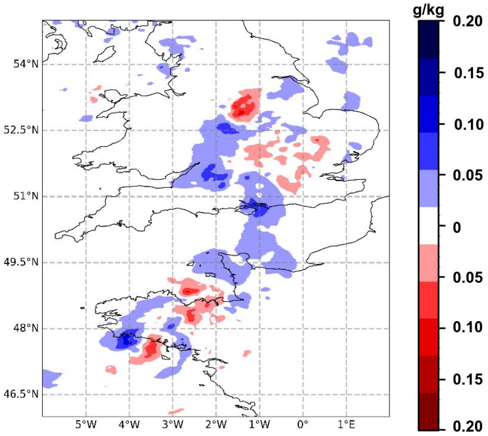


Inter-variable correlations with Rain

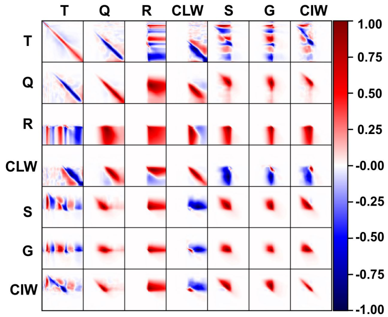
Increments origin ?
Do they provide synergistic corrections?
What is the weight of them?

II. Observation operator & data assimilation 3DEnVar

Experiment REF :
ALLSKY GMI



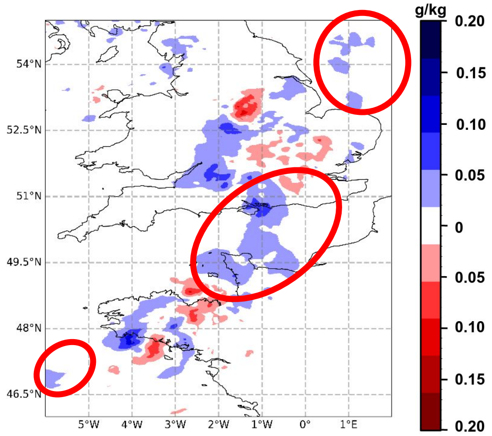
$$\begin{bmatrix} \frac{\partial H}{\partial T} \\ \frac{\partial H}{\partial q} \\ \frac{\partial H}{\partial r} \\ \frac{\partial H}{\partial q_s} \\ \frac{\partial H}{\partial q_i} \\ \cdots \end{bmatrix}$$

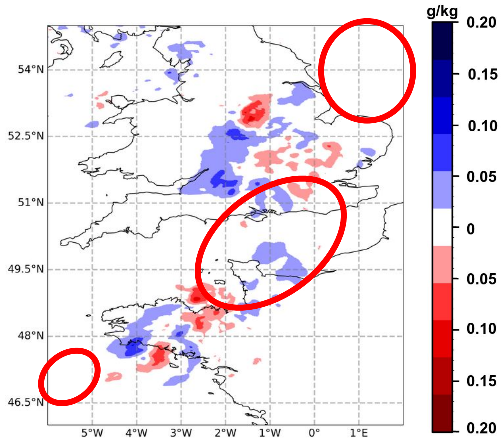


II. Observation operator & data assimilation 3DEnVar

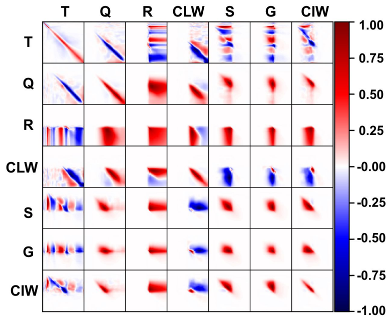
Experiment REF : ALLSKY GMI

Experiment 1 : LOW-FREQ CHANNELS OFF
Rain sensitive channels are not assimilated



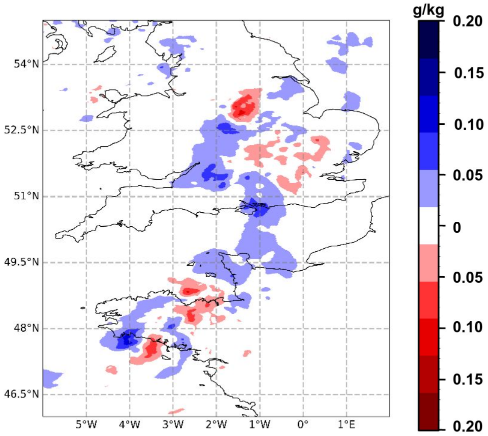


$$\begin{bmatrix} \frac{\partial H}{\partial T} \\ \frac{\partial H}{\partial q} \\ \frac{\partial H}{\partial r} \\ \frac{\partial H}{\partial q_s} \\ \frac{\partial H}{\partial q_i} \\ \cdots \end{bmatrix}$$

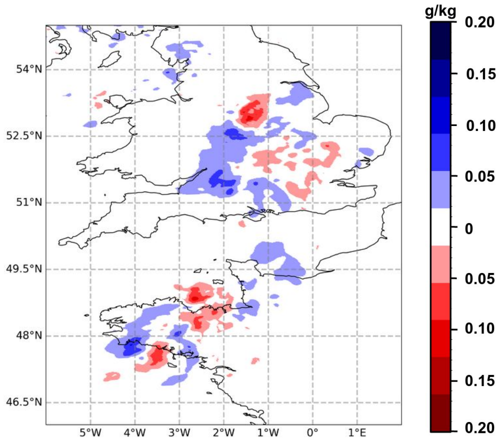


II. Observation operator & data assimilation 3DEnVar

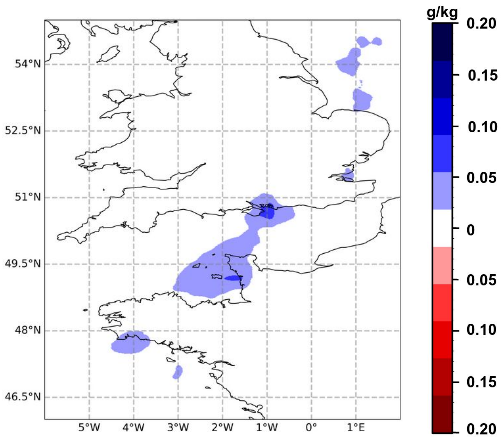
Experiment REF : ALLSKY GMI



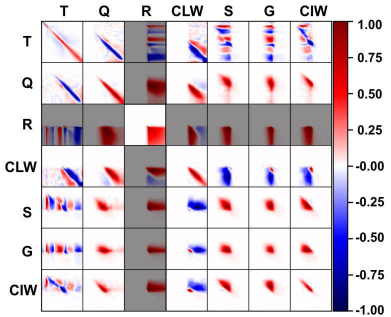
Experiment 1 : LOW-FREQ CHANNELS OFF



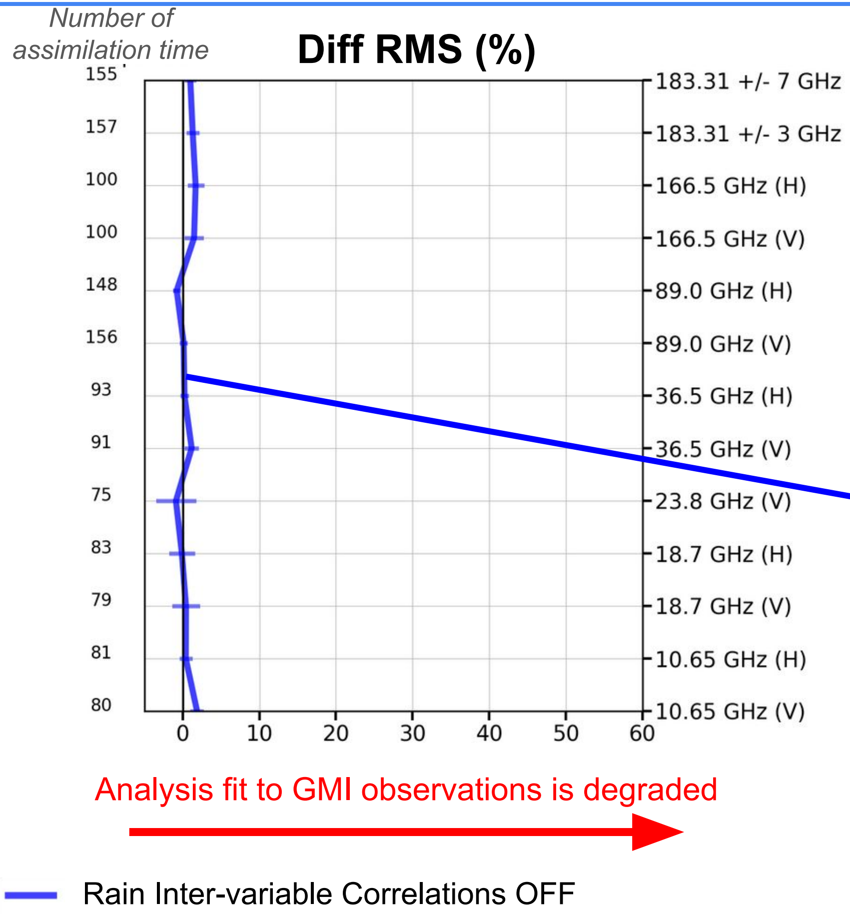
Experiment 2 : RAIN CORR OFF
Rain inter-variable correlations off



$$\begin{bmatrix} \frac{\partial H}{\partial T} \\ \frac{\partial H}{\partial q} \\ \frac{\partial H}{\partial r} \\ \frac{\partial H}{\partial q_s} \\ \frac{\partial H}{\partial q_i} \\ \cdots \end{bmatrix}$$



II. Observation operator & data assimilation 3DEnVar



Relative differences for the RMS with the analysis fit to GMI observations in cloudy areas.

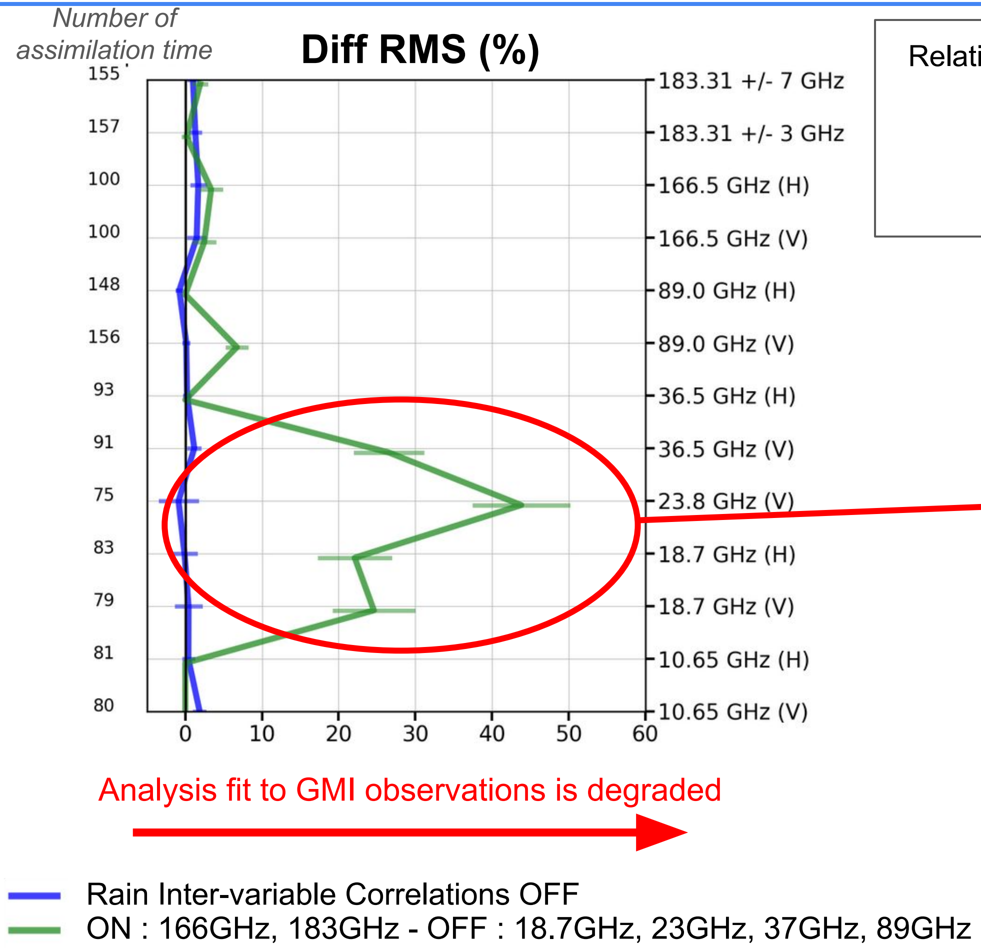
experiment of reference : ***"GMI all-sky"***
Study period of 36 days : 5th May to au 9th June 2023

The lack of inter-variable correlations has only a limited negative impact on high frequencies.
→ ~ 1% of degradation

The analysis of rainfall benefits to the analysis of snow and graupel.

7. *Geer and Bauer, 2010*

II. Observation operator & data assimilation 3DEnVar



Relative differences for the RMS with the analysis fit to GMI observations in cloudy areas.

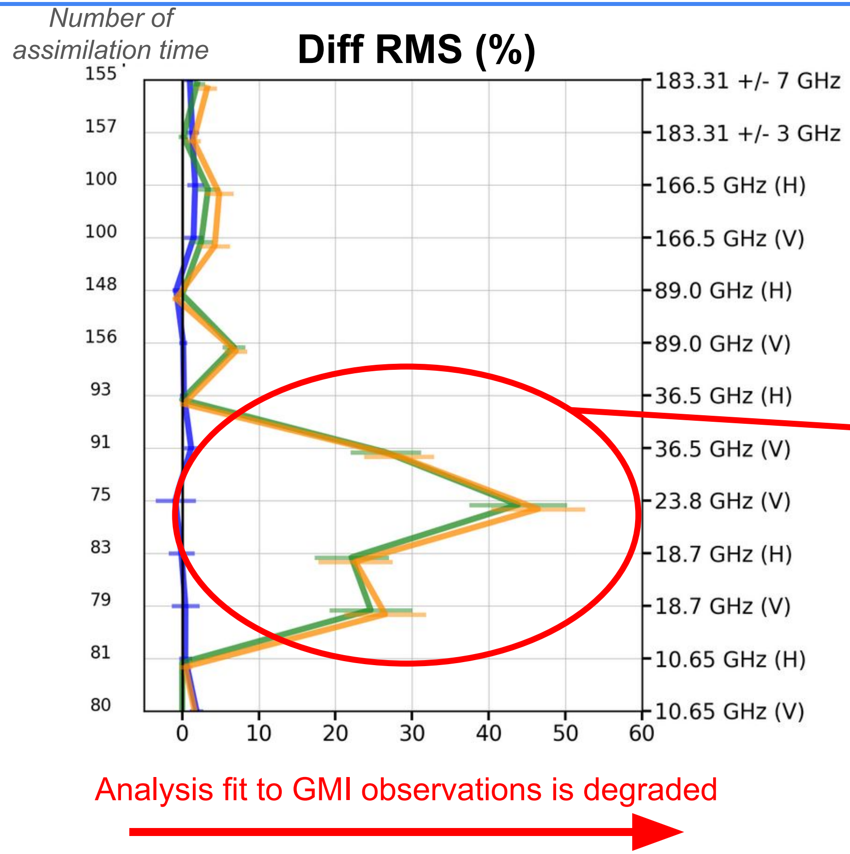
experiment of reference : ***"GMI all-sky"*** [7]
Study period of 36 days : 5th May to au 9th June 2023

Greater degradation of rain-sensitive channels when rain-sensitive channels are deactivated.

The combined use of high frequencies and inter-variable correlations doesn't lead to a rainfall analysis as good as when low frequencies are available.

7. Geer and Bauer, 2010

II. Observation operator & data assimilation 3DEnVar



Relative differences for the RMS with the analysis fit to GMI observations in cloudy areas.

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Study period of 36 days : 5th May to au 9th June 2023

The two sources of information **act in synergy.**

- Rain Inter-variable Correlations OFF
- ON : 166GHz, 183GHz - OFF : 18.7GHz, 23GHz, 37GHz, 89GHz
- Rain Inter-variable Correlations OFF - ON : 166GHz, 183GHz - OFF : 18.7GHz, 23GHz, 37GHz, 89GHz

III. Impact of microwave observations on forecasts

Impact of the all-sky assimilation of a satellite constellation of passive microwave observations within AROME

1 How do interact the observation operator (RTTOV-SCATT) and the AROME-France EnVAR including hydrometeors in the control vector ?

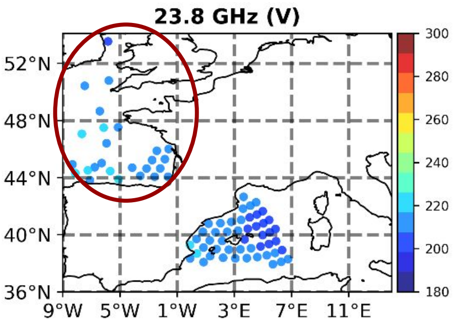
2 **What are the impacts of activating the assimilation within clouds and precipitation onto AROME-France forecasts ?**

Period : *5th May to 9th June 2023 (36 days)*

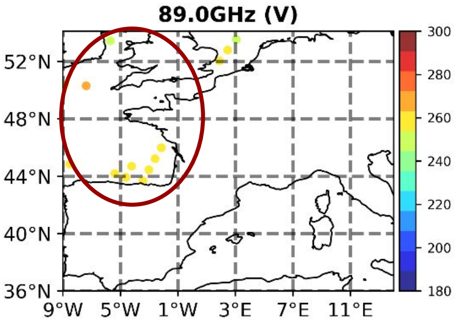
CLEARSKY experiment

The 4 instruments are assimilated in clearsky conditions

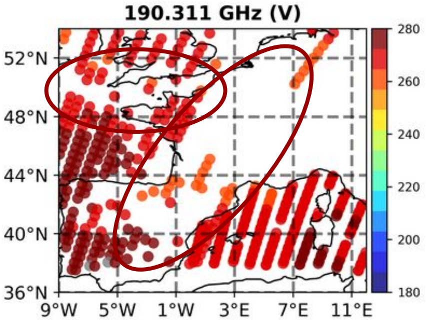
GMI



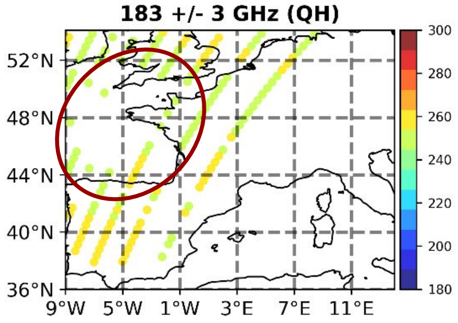
AMSR2



MHS



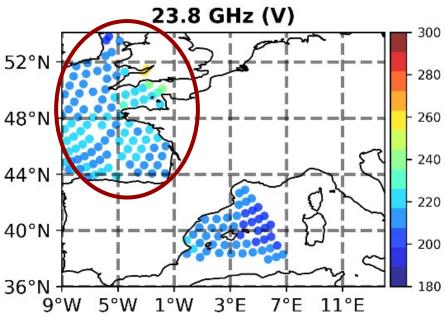
MWHS2



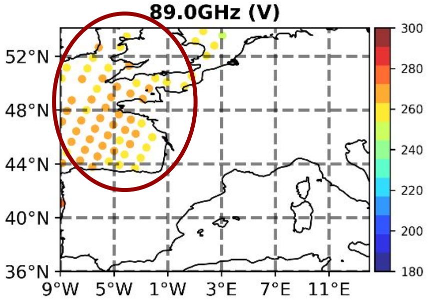
ALL-SKY experiment

The 4 instruments are assimilated in all-sky conditions

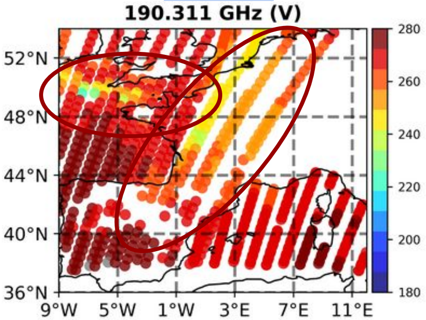
GMI



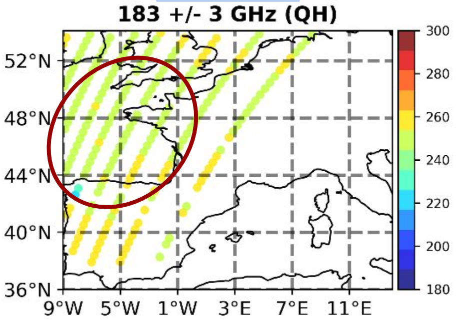
AMSR2



MHS



MWHS2

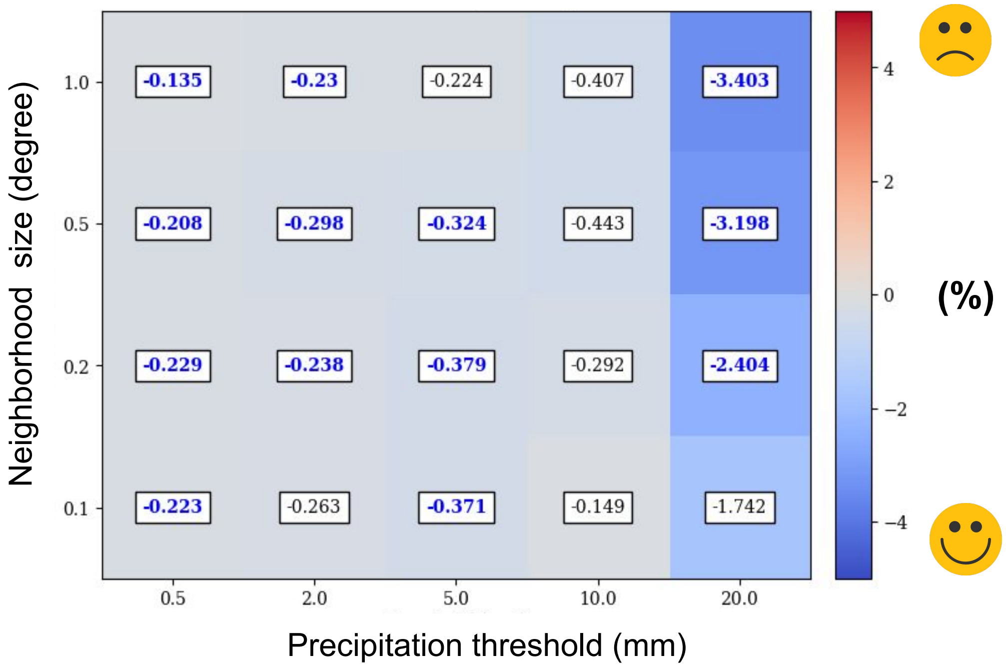


 Period : *5th May to 9th June 2023 (36 days)*

Assessing the quality of rainfall forecasts

- *Based on cumulative 24h of forecasts + 1H*
- *Reference observations used :* ***ground-based radar and rain gauge observations***

Relative difference : **FSS CLEARSKY - FSS ALL-SKY**



Improvement of rainfall forecasts, ranging from 0.1 to 3.4 %

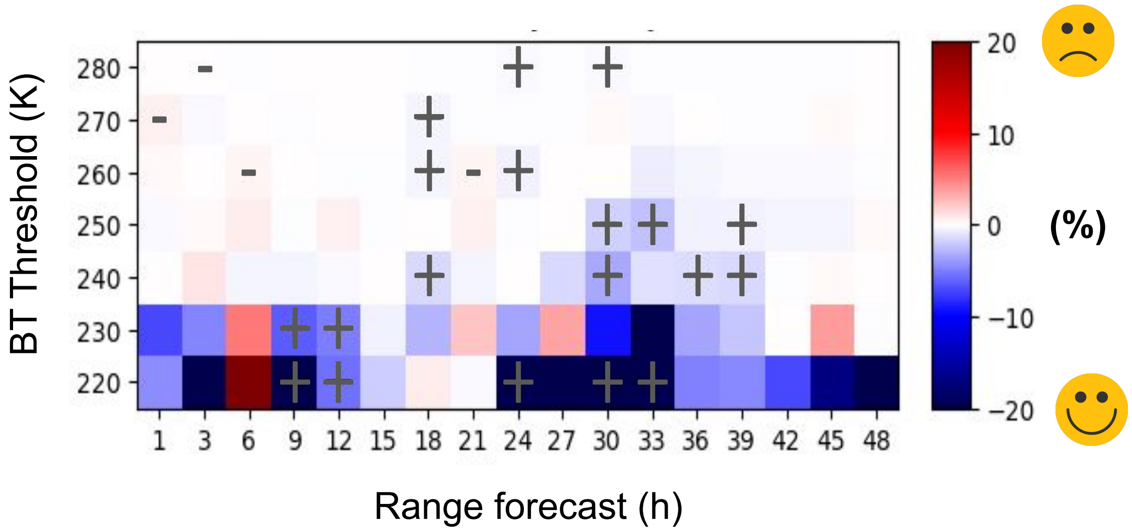
FSS : *Fraction Skill Score*

 Period : *5th May to 9th June 2023 (36 days)*

Assessing the quality of cloud forecasts (Window size 1.0°)

- *Reference observations used :* ***Infrared observations - Imaging Radiometer SEVIRI (Meteosat)***

<u>Relative difference : **FSS CLEARSKY - FSS ALL-SKY**</u>



<u>**Up to 20% improvement in cloud forecasts.**</u>

FSS : *Fraction Skill Score*

Conclusions

- The observation operator (RTTOV-SCATT) and the AROME-France EnVAR including hydrometeors in the control vector **interact in synergy.**
- The loss of rain sensitive channels cannot be compensated by the corrections induced by the assimilation of high-frequency channels and inter-variable correlations.

- The experiment of 4 passive microwave instruments (onboard 8 satellites) in cloudy and precipitations areas **improves rainfall and cloud forecasts.** => Paper in preparation.

Conclusions & perspectives

Conclusions

- The observation operator (RTTOV-SCATT) and the AROME-France EnVAR including hydrometeors in the control vector **interact in synergy.**
- The loss of rain sensitive channels cannot be compensated by the corrections induced by the assimilation of high-frequency channels and inter-variable correlations.

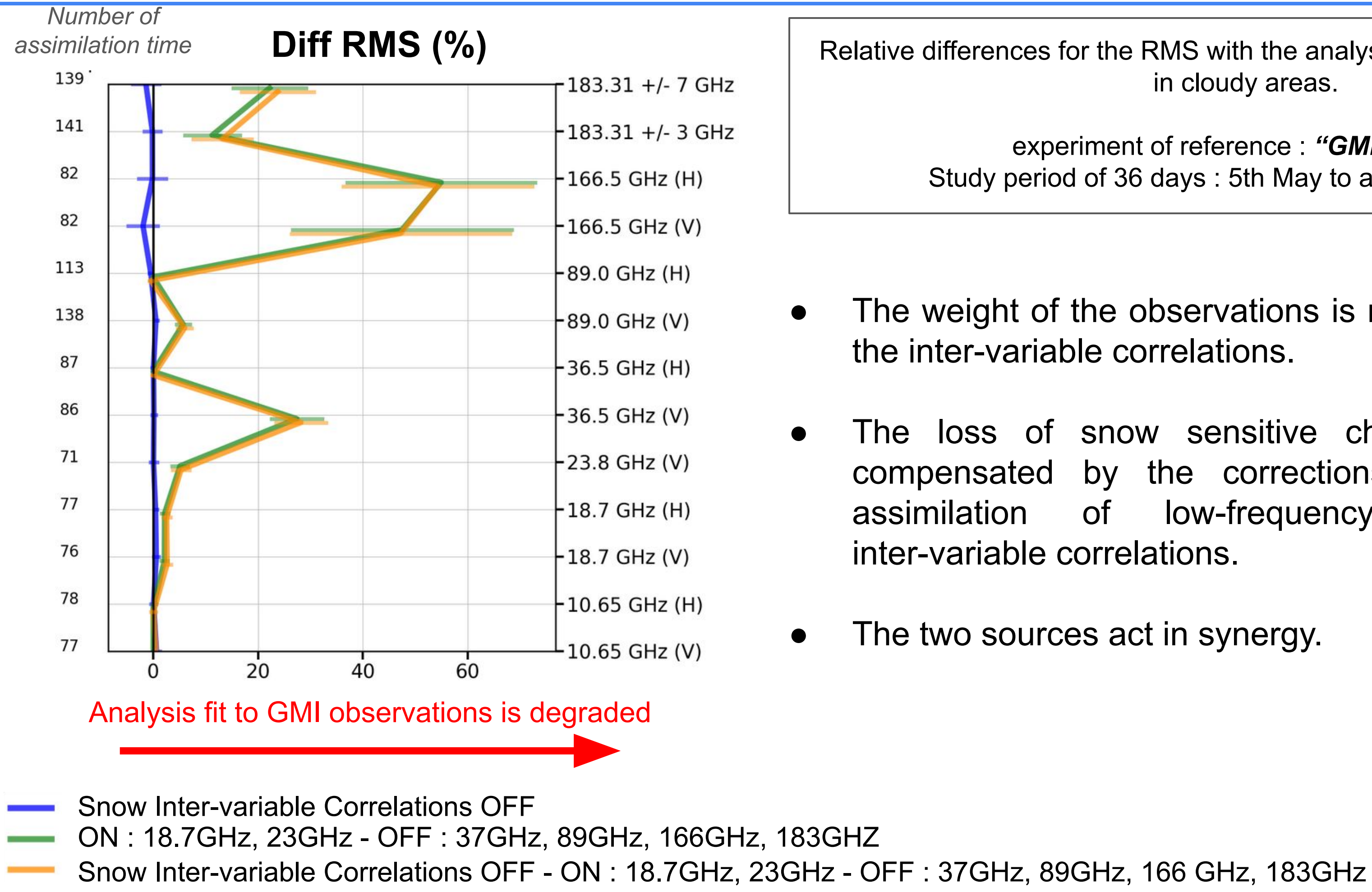
- The experiment of 4 passive microwave instruments (onboard 8 satellites) in cloudy and precipitations areas **improves rainfall and cloud forecasts.** => Paper in preparation.

Perspectives

- An impact experiment is ongoing on another period during winter.
- Identify ways to enhance the positive impact (e.g : observation error models, take into account more sounders (FY-3E, AWS, AMSU-A)).

Thank you for your attention !

Appendix - Observation operator & data assimilation 3DEnVar - SNOW



Relative differences for the RMS with the analysis fit to GMI observations in cloudy areas.

experiment of reference : ***"GMI all-sky"***
Study period of 36 days : 5th May to au 9th June 2023

- The weight of the observations is more important than the inter-variable correlations.
- The loss of snow sensitive channels cannot be compensated by the corrections induced by the assimilation of low-frequency channels and inter-variable correlations.
- The two sources act in synergy.

Appendix - Cloud Predictor (CP) [7]

It is defined as :

$$\begin{cases} P37_{FG} = \dfrac{BT^{v}_{FG} - BT^{h}_{FG}}{BT^{v_{clear}}_{FG} - BT^{h_{clear}}_{FG}} \\[2ex] P37_{OBS} = \dfrac{BT^{v}_{OBS} - BT^{h}_{OBS}}{BT^{v_{clear}}_{OBS} - BT^{h_{clear}}_{OBS}} \end{cases}$$

With ***BT*** the brightness temperature, ***FG*** the first guess, ***OBS*** the observation at 37 GHz vertically ***v*** or horizontally ***h*** polarized. ***P37*** is the predictor for this window channel. Then :

$$\begin{cases} C37_{FG} = 1 - P37_{FG} \\ \boxed{C37_{OBS} = 1 - P37_{OBS}} \end{cases}$$

→ CP used for the study on GMI (part I).

We can after determine the Symmetric Cloud Prediction (SCP) :

$$SCP = \frac{C37_{FG} + C37_{OBS}}{2}$$

7. *Geer and Bauer, 2010*

Appendix - Error Model & Cloud Predictor (CP)