Utilization of microwave frequencies for precipitation remote sensing

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CGMS

IPWG International Precipitation Working Group

What is IPWG?

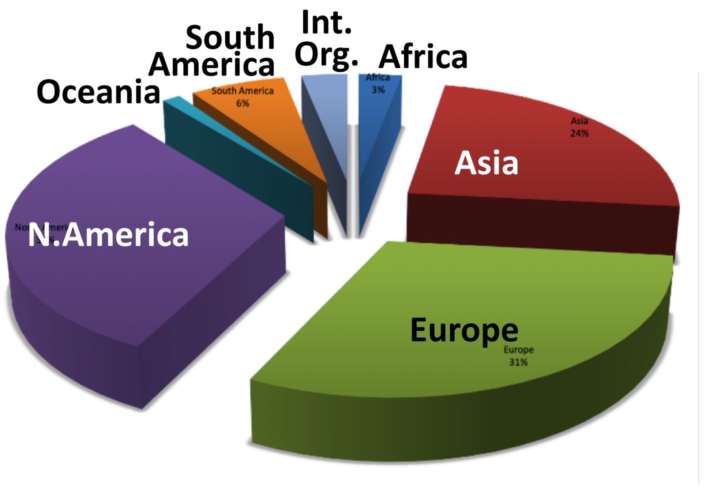
IPWG was established as a permanent Working Group of the Coordination Group for Meteorological Satellites (CGMS) in 2001.

Focused on operational and research satellite based quantitative precipitation measurement issues and challenges.

- Provides a forum for operational and research users of satellite precipitation measurements to exchange information.
- IPWG fosters:
  - Development of better measurements, and improvement of their utilization;
  - Improvement of scientific understanding;
  - Development of international partnerships.

=> IPWG members expertise cover both precipitation retrieval and precipitation assimilation for NWP

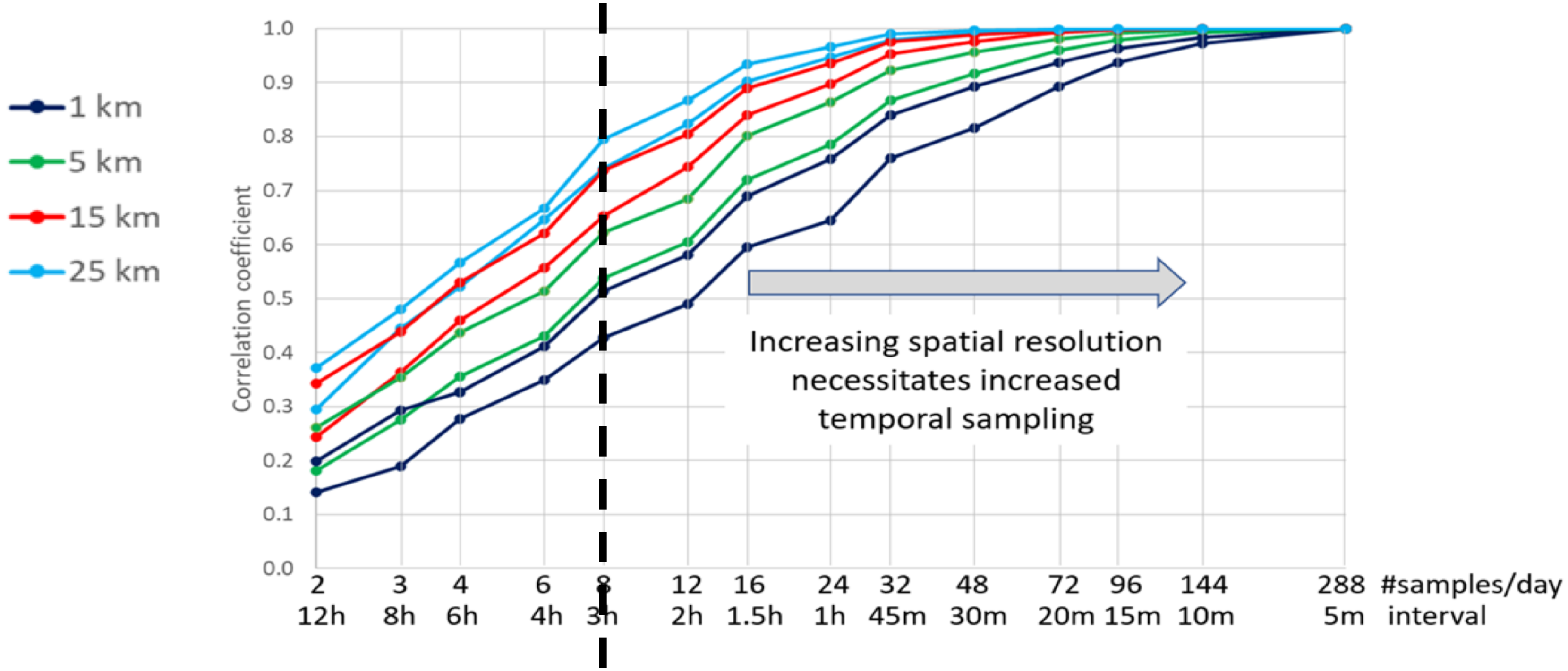
IPWG Membership October 2018



1. Precipitation Variability

Frequently sampling rainfall is critical to accurately estimate accumulations. This is even more important when the estimation is required at fine scale.

Example of correlations between daily ground radar estimations with their full temporal sampling, and daily estimations with sub-sampled radar data for a one year period in the UK :



(Kidd et al., 2021, BAMS)

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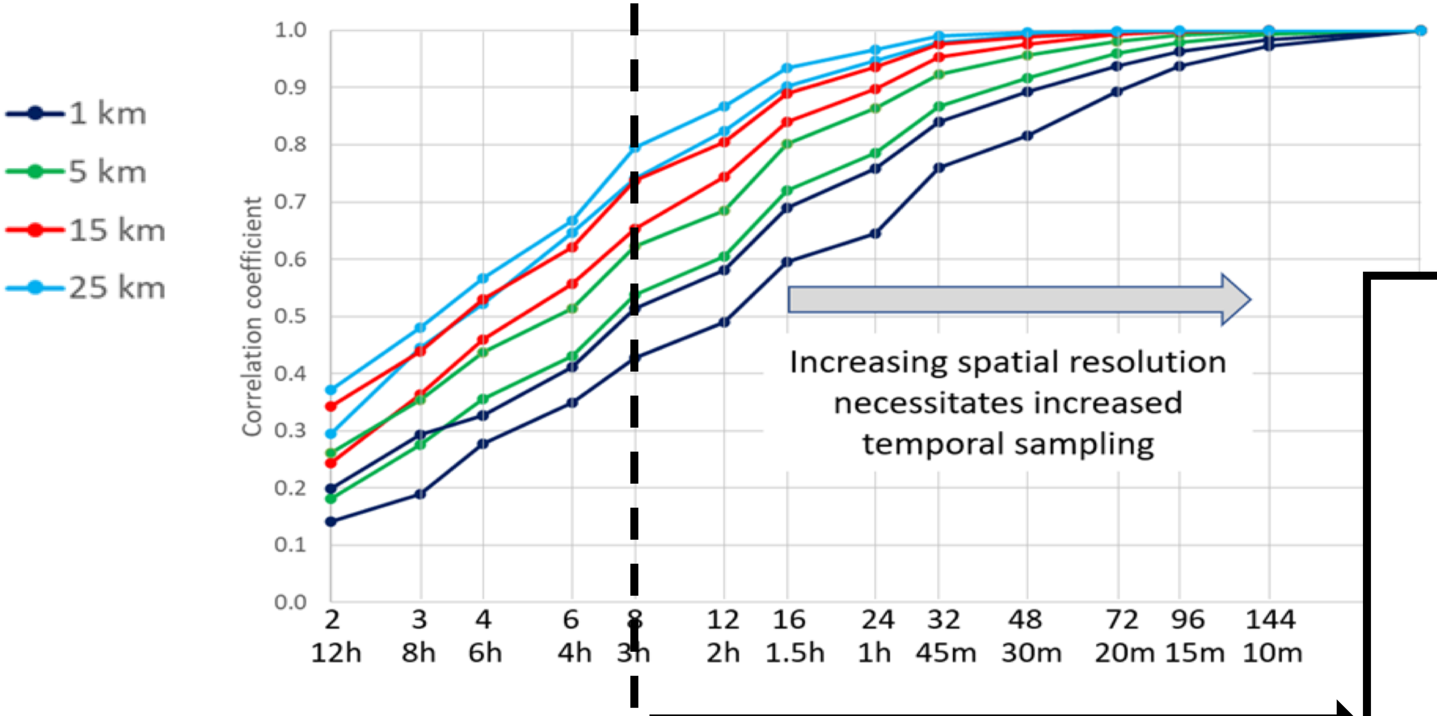
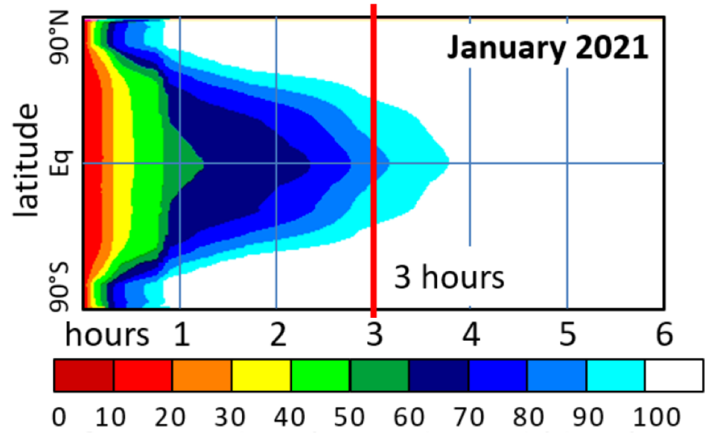


(Kidd et al., 2021, BAMS)



The current "GPM constellation" provides 90% of the time MW observations with time gaps shorter than 3 hours over the globe. => R of 0.8 at 25 km and of 0.55 at 5 km

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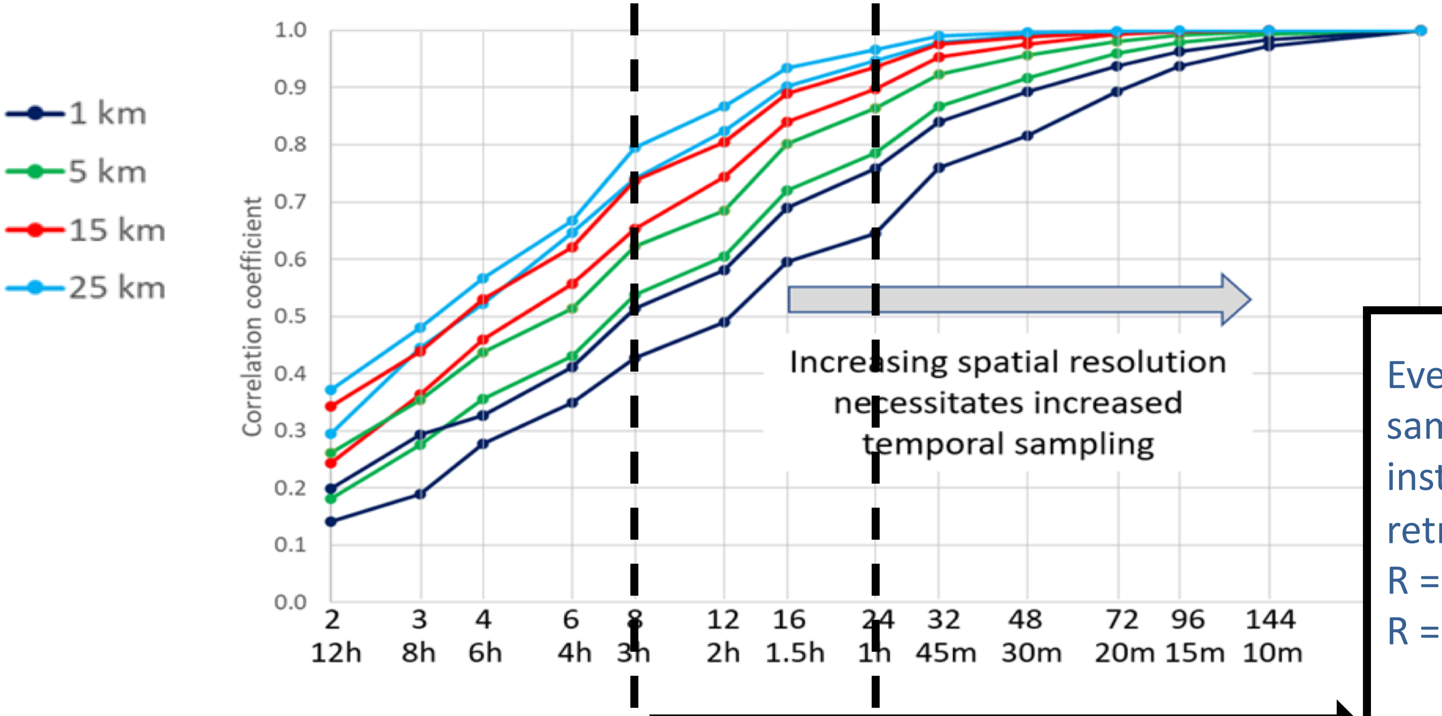


(Kidd et al., 2021, BAMS)

Even at resolutions of 25km, increasing the temporal sampling of precipitation estimation from 3h to for instance 1h would significantly enhance the quality of rain retrievals.

R = 0.8 at 3h

R = 0.95 at 1h

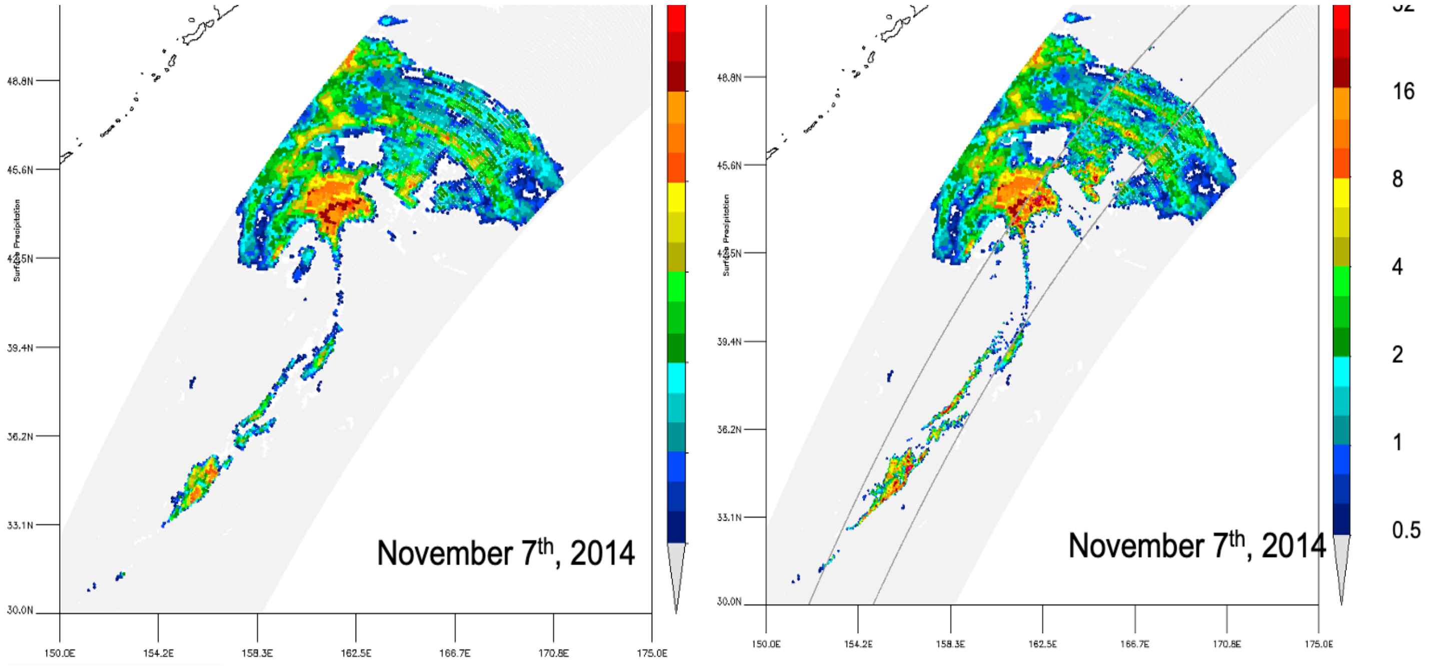
=> **Gain of 26% of explained variance at the daily scale !**

2. What channels are used for precipitation remote sensing ?

- **10 GHz**
- **19 GHz**
- **22 GHz**
- **36 GHz**
- 50-54 GHz
- **89 GHz**
- 118 GHz
- 157/166 GHz
- 183 GHz
- >200 GHz

Historical channels used for precipitation remote sensing from **conical imagers**, both for **rain retrievals** (e.g. Kummerow et al., 1996), and for **assimilation in rainy areas** (e.g. Hou et al. 2000 ; Marécal and Mahfouf, 2002; Geer et al., 2010). Note that the 10 GHz is not yet used in DA (Lonitz et al. 2014).

Use of 10, 19, 22, 36, 89 GHz observations as inputs of a Bayesian algorithm, trained with space radar observations.



(Courtesy of C. Kummerow)

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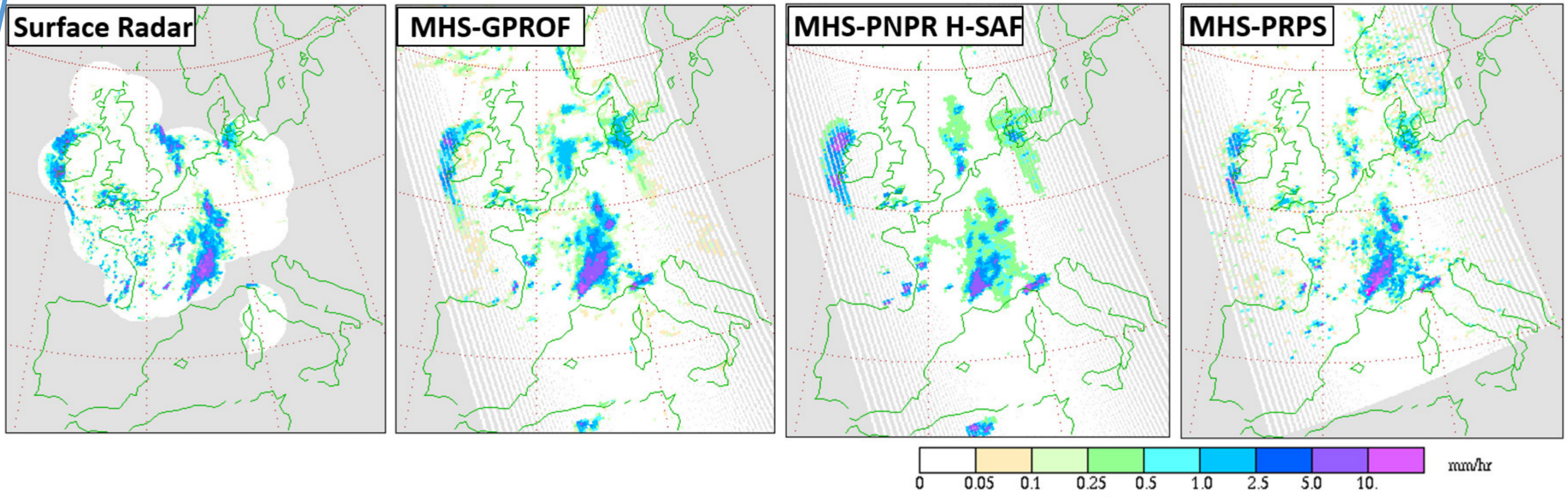
→ Channels used for precipitation remote sensing from **cross-track sounders**, both for **rain retrievals** (e.g. Groddy et al., 1999, Kidd et al., 2021), and for **assimilation in rainy areas** (e.g. Geer et al., 2014)

Example of 3 retrieval algorithms using MHS channels as inputs for a rain event on 13 September 2015



(Kidd et al., 2021, Remote Sensing)

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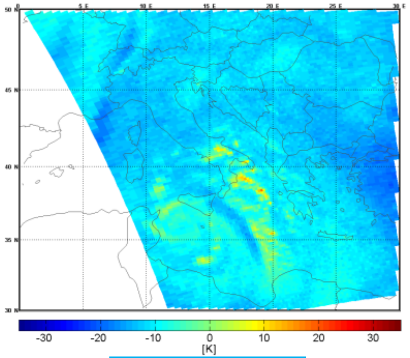
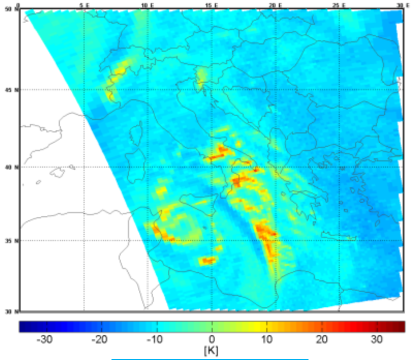
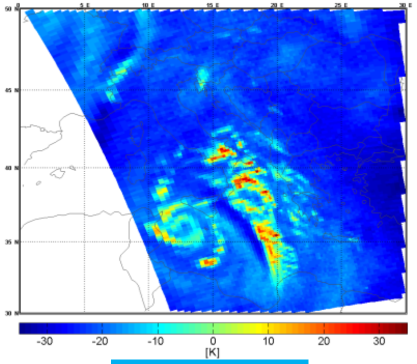
Various strategies have been used in the community to make use of water vapor sounding channels to retrieve precipitation. As an example, having multiple channels at 183.31 GHz allow using **channel differences as predictors of rain rates** :



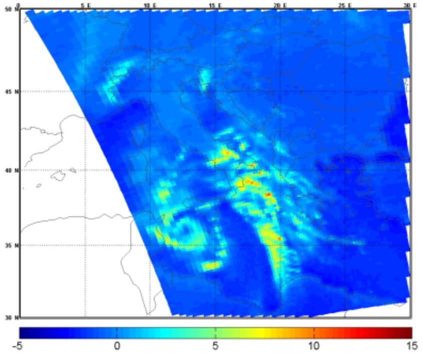
Δ13=183.31±1 - 183.31±3 GHz



Δ37=183.31±3 - 183.31±7 GHz

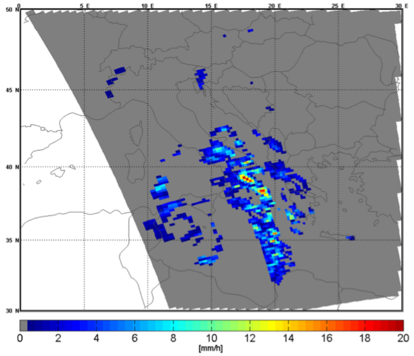


Δ17=183.31±1 - 183.31±7 GHz



Δ24=183.31±1.8 - 183.31±2.4 GHz

PMW Neural-net Precipitation Retrieval (PNPR) Algorithm for ATMS cross-track scanners (H SAF product H18)



(Courtesy of Giulia Panegrossi, Daniele Casella and Paolo Sano)

2. What channels are used for precipitation remote sensing ?

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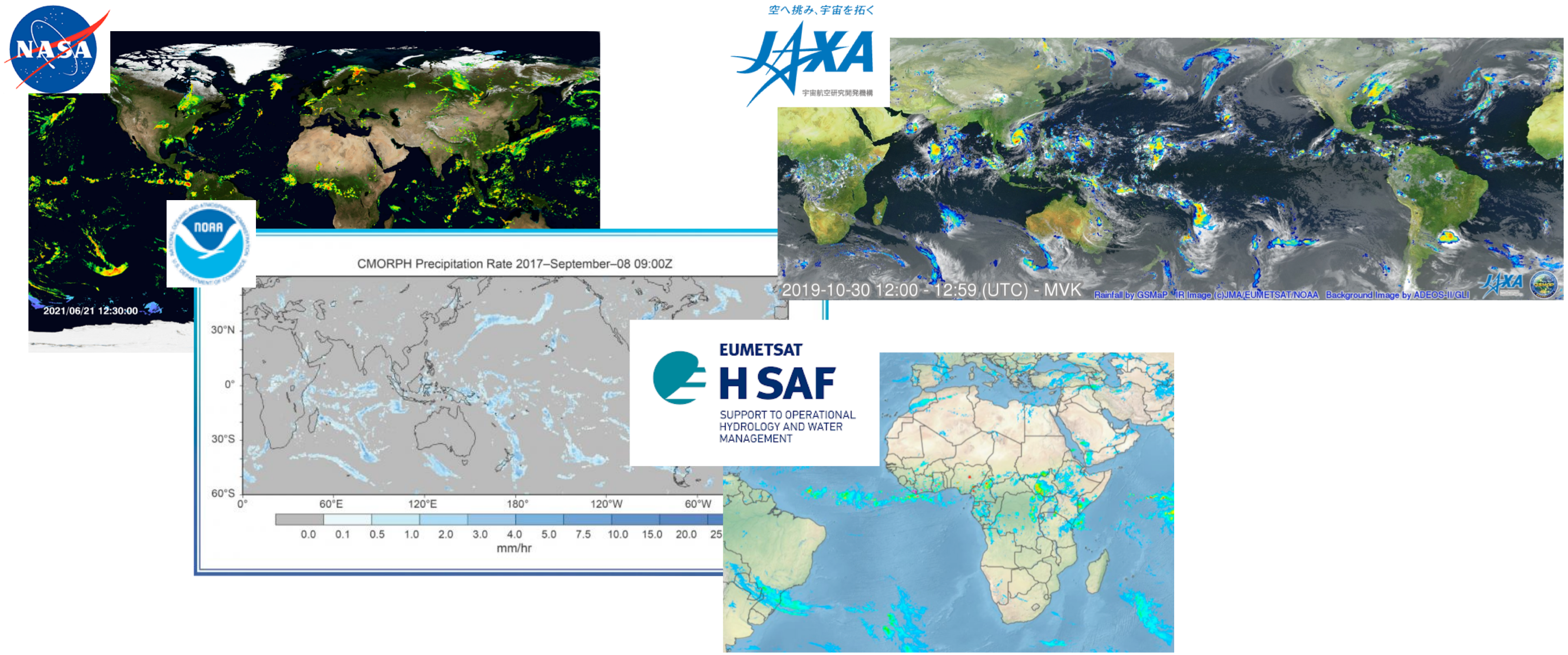
All those channels are **routinely used for generating Level-2 rain rates products** operationally, by various agencies. Those Level-2 products are then often merged together (intercalibration needed) with geostationary data in the IR to produce Level-3 products (global or quasi-global maps of precipitation estimates).



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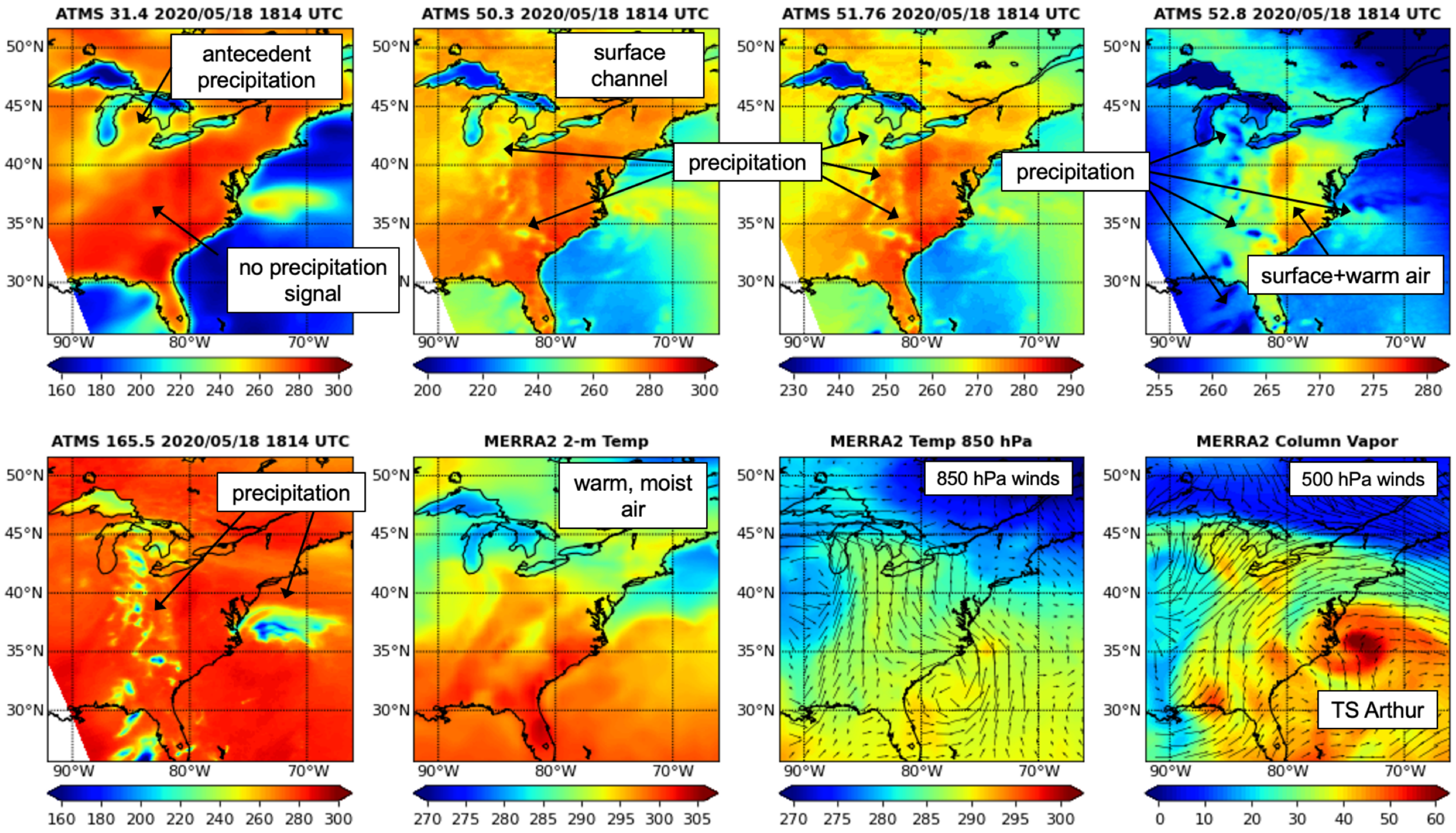
→ **Experimental work** has also been performed in the community to exploit temperature channels for precipitation retrievals.

Michigan flood events in May 20202 => Tb depressions at 52.8 GHz from ATMS



(Courtesy of Joe Turk)

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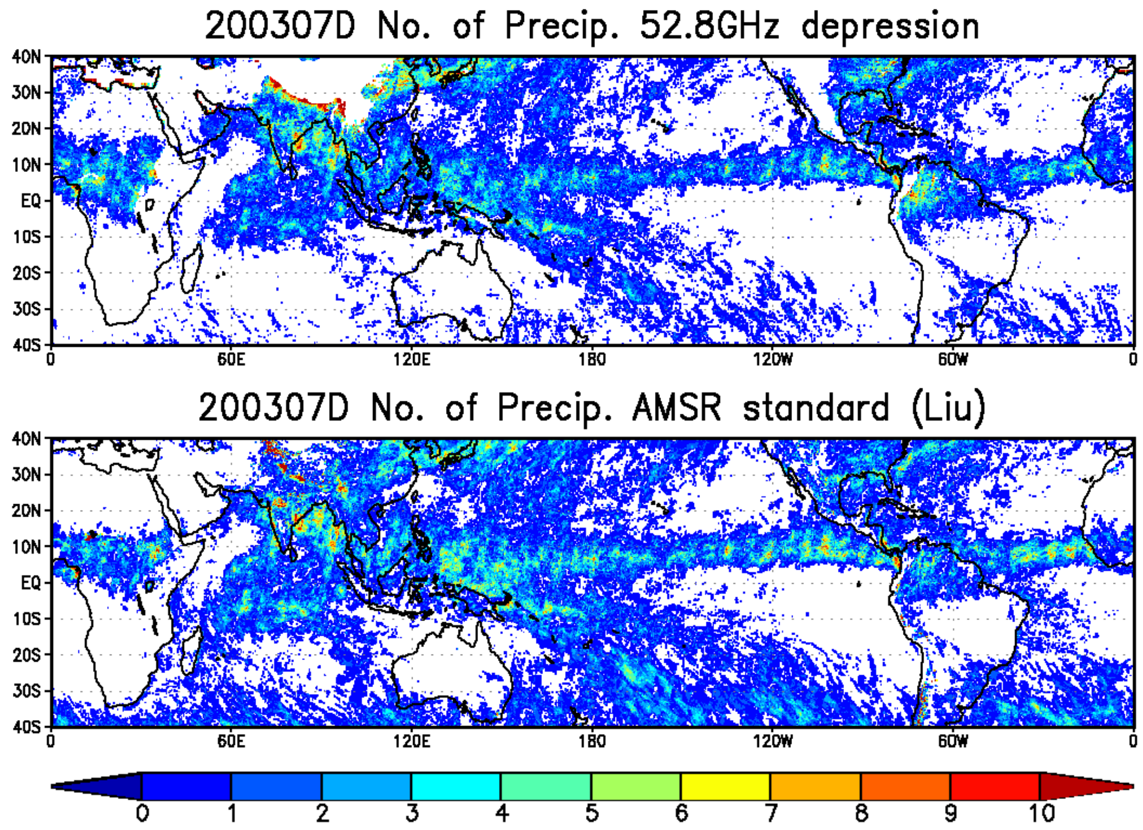
Experimental work has also been performed in the community to exploit temperature channels for precipitation retrievals. As an example, studies were performed by JAXA with the AMSR sensor onboard the ADEOS-II satellite (2002, 2003)

Use of 52.8GHz channel for detecting precipitation:
- Tb depression by precipitation can be uniformly identified over both land and ocean (thanks to the insensitivity of the channel to surface emissivity).
- Although weaker scattering signal than that of 89GHz channels makes it difficult to detect precipitation at higher latitude, combination of 50.3 and 52.8 GHz channels may help improving precipitation algorithm (e.g., cold surface screening, freezing level height estimation).



(Courtesy of Takuji Kubota and Keiji Imaoka)

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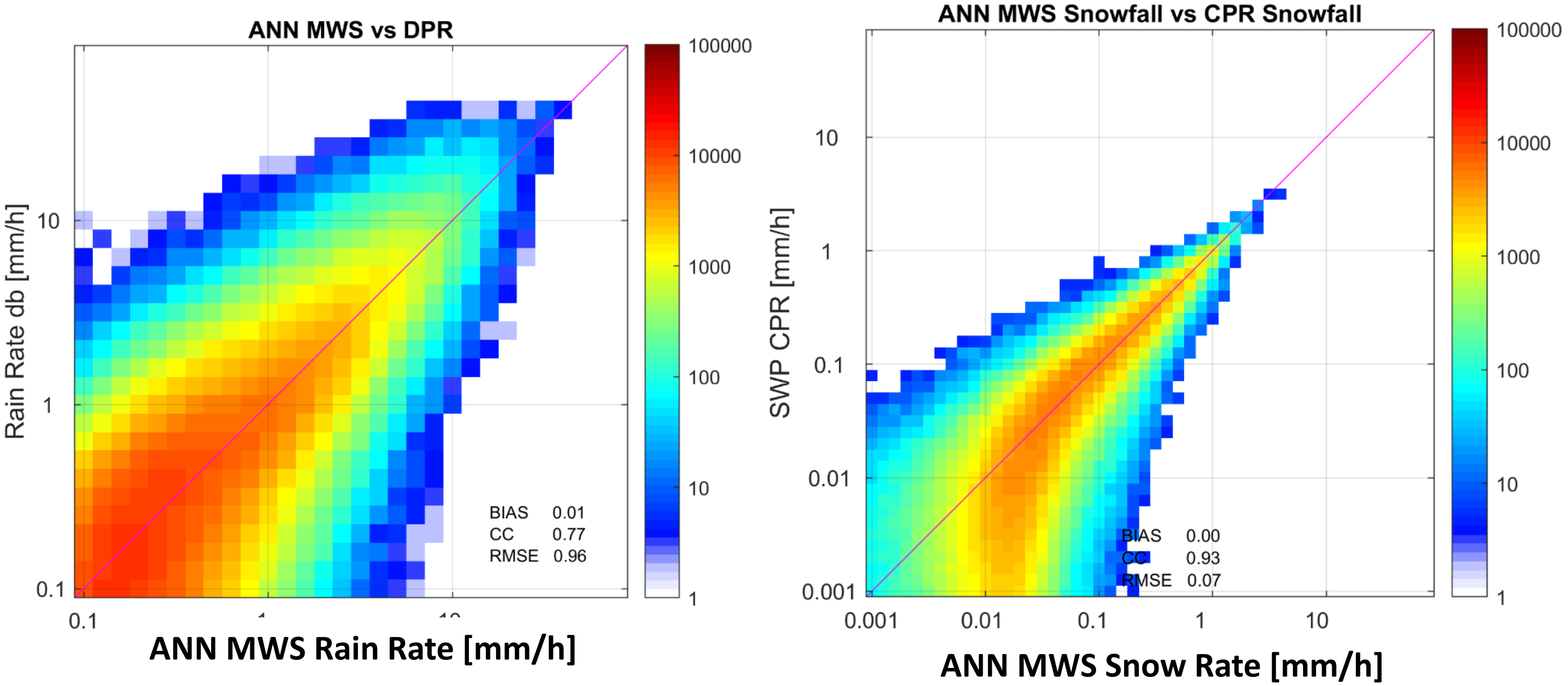
As another example, the EUMETSAT HSAF is preparing for the exploitation of the MWS sounder onboard EPS-SG and will make use of temperature channels to improve the **definition of environmental conditions important for snowfall retrievals.**

Comparison with Rain Rate and Snow Rate independent estimates from DPR and CPR respectively (ANN trained on two-years of global coincident measurements with ATMS)



(Courtesy of Giulia Panegrossi, Daniele Casella and Paolo Sano)

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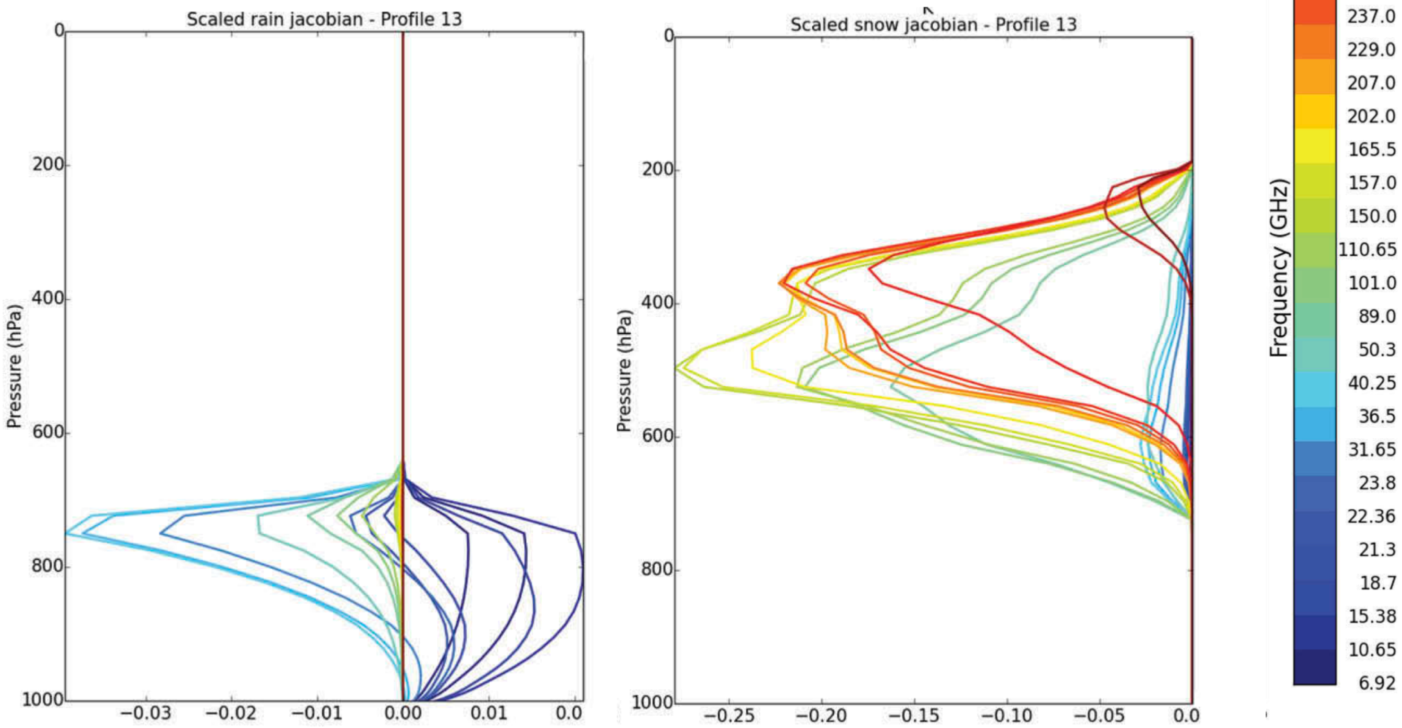
Overall, IPWG has somehow less expertise on the 118 GHz which is only available on MWHS-2 sensors so far. This might change in the future as 118 GHz channels are also present on **TROPICS cubesats**, and will be **on MWI/EPS-SG**. Similar conclusions can be drawn for frequencies above 200 GHz (TROPICS with 204 and **ICI/EPS-SG** with frequencies up to 664 GHz).

Example of rain and snow jacobians for a cloudy situation, for different frequencies

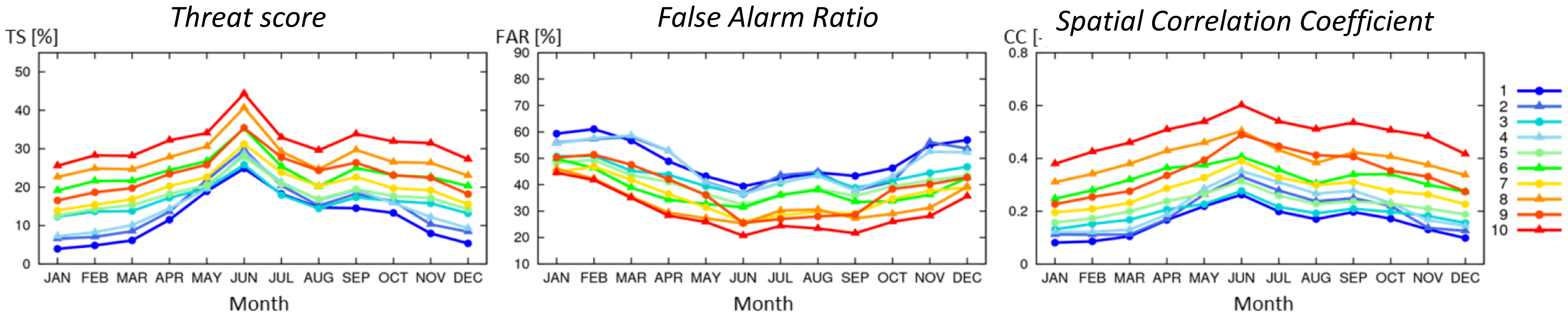


=> Potential of high frequencies for snowfall retrievals (Birman et al., 2017)

3. What is the impact of the channel selection on precipitation remote sensing ?

In order to fill in gaps between MW overpasses, various **gap mitigation strategies** have been developed by the community, making use of IR data in addition to MW, but ultimately precipitation **retrievals perform better when they are directly derived from MW imagers and MW sounders**.

Statistical comparison with 13 years of ground radar data over Japan with the GSMAP algorithm :

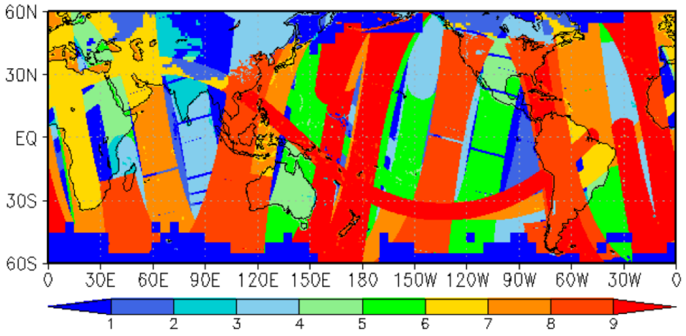


New reliability flag for the GSMAP dataset, based on the source of data, the surface type and the time since the last MW overpass :

Reliability flag 10 => imager with freezing level above 500m

Reliability flag 9 => sounder with freezing level above 500m

Reliability decreases with more increase in time since the last MW overpass



=> The accuracy worsens as the reliability decreases.

(Yamaji et al., 2021, JMSJ)

3. What is the impact of the channel selection on precipitation remote sensing ?

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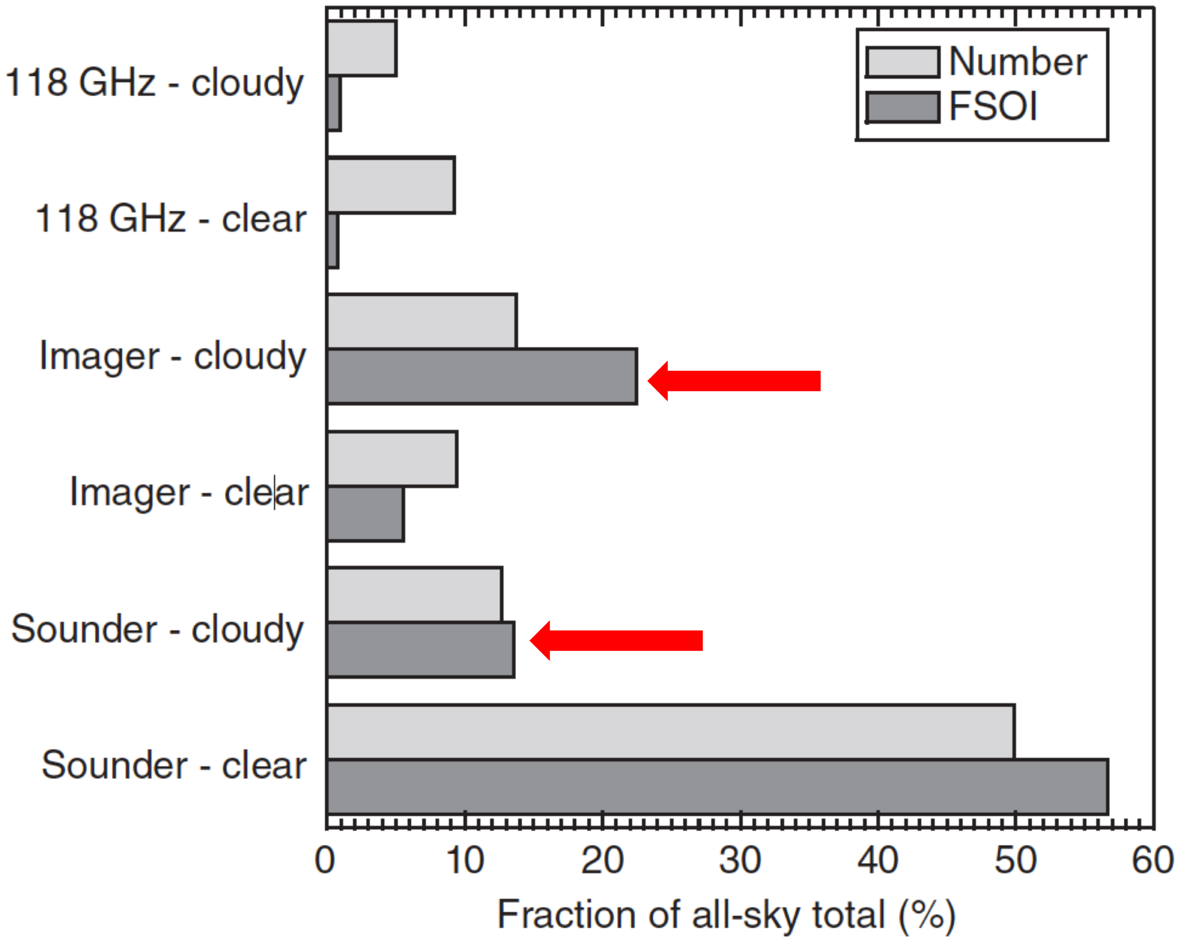
Similarly, the **impact of cloudy observations from imagers is larger** than the impact of cloudy observations from sounders with an all-sky data assimilation system

FSOi for the ECMWF model over a one-month period (20 July to 20 August 2016) for 9 "all-sky" instruments (F17/F18 SSMIS, NOAA18,19, MetOp-A,B MHS, FY3C/MWHS2, GCOM-W1/AMSR-2, GPM/GMI)



(Geer et al., 2017, QJRMS)

3. What is the impact of the channel selection on precipitation remote sensing ?

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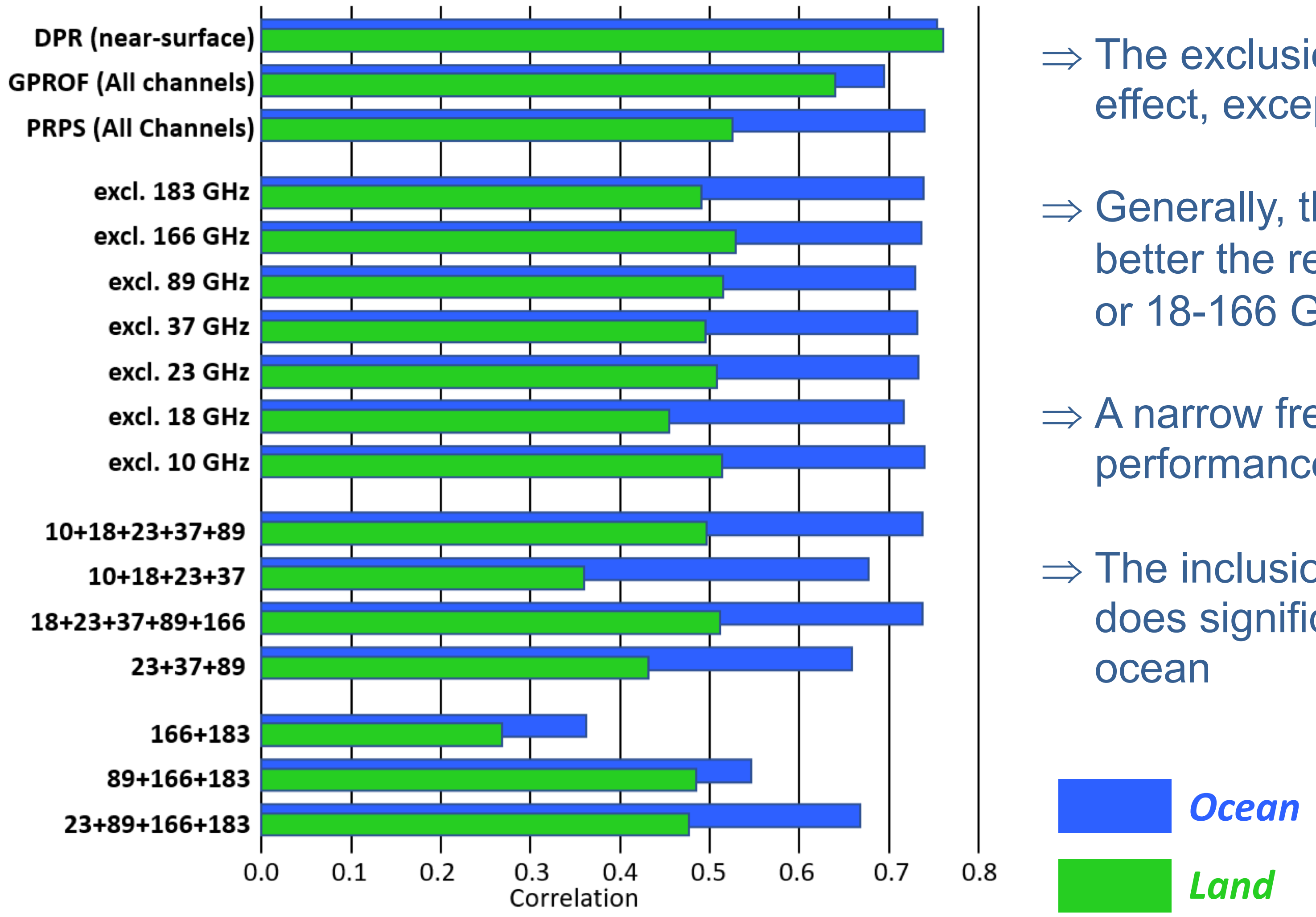
Scenarios used to study the effects of channel loss and channel combinations, based upon instantaneous PRPS retrievals from the 13-channel, 7-frequency GMI sensor, compared with surface radar data over the United Kingdom for 2017



⇒ The exclusion of a single channel has relatively little effect, except for the 18 GHz primarily over land.

⇒ Generally, the more channels that are available, the better the retrieval as seen in the multi-frequency 10-89 or 18-166 GHz retrieval.

⇒ A narrow frequency range results in poorer performance, particularly at high frequency channels,

⇒ The inclusion of a low frequency water vapour channel does significantly improve the performance over the ocean

(Kidd et al., 2021, BAMS)

Conclusions

- Precipitation monitoring (both retrievals and DA) would benefit from additional observations from satellites that would complement the backbone observations because **rainfall and snowfall are highly variable in space and time**.

- The **full range of ATMS/MWS frequencies is potentially interesting for precipitation**, although the IPWG community has more experience on window and water vapor channels (18, 23, 36, 89, 166, 183 GHz) than on temperature and sub-millimetric channels (50, 118, >200 GHz).

- The low frequencies have a significant positive impact on rain retrievals (e.g. **23 GHz can significantly enhance retrievals over oceans => 15% of additional explained variance compared to MHS-like channels**).

- The 50 GHz and > 200 GHz will likely be more used in the future **for improving snowfall retrievals** which need detailed information on environmental conditions (e.g. NOAA new snowfall product).

Thank you !

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Backup slides

GMI contributes to improved forecasts of hurricane / cyclone Leslie (2018)

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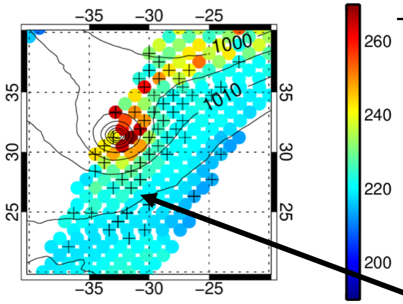
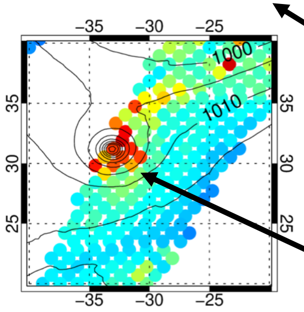
GMI observations at 24 GHz

06 UTC, 12-Oct-2018



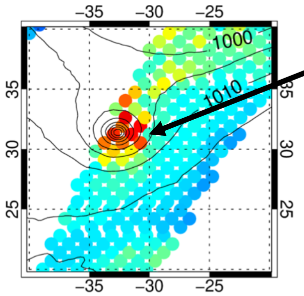
"+" are particularly beneficial observations according to FSOI

Background

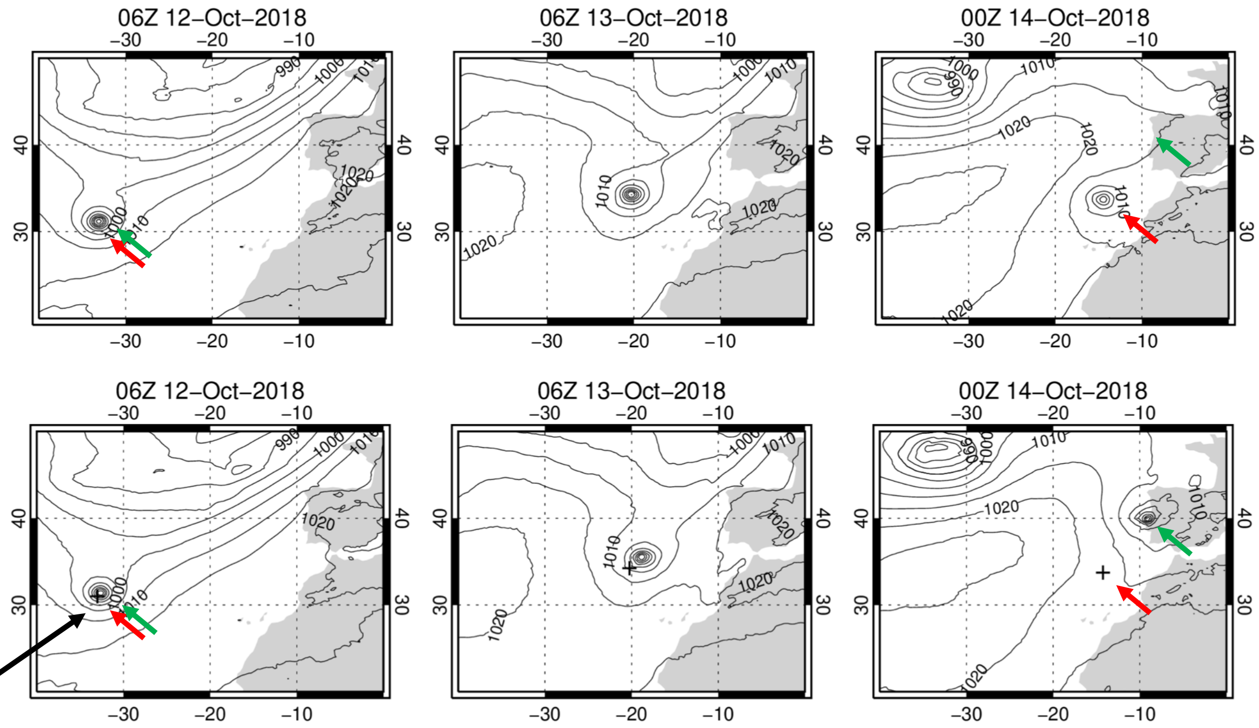


simulated from model

Analysis



Data assimilation shifts the cyclone centre 60 km towards Portugal (almost invisible at this scale), and triggers more rapid and more NE movement of the cyclone



Forecast from 11th October, 12 UTC is incorrect - Leslie's position is around 1000km out

Forecast from 12th October, 00 UTC is correct – Leslie hits Portugal overnight on 13-14th October

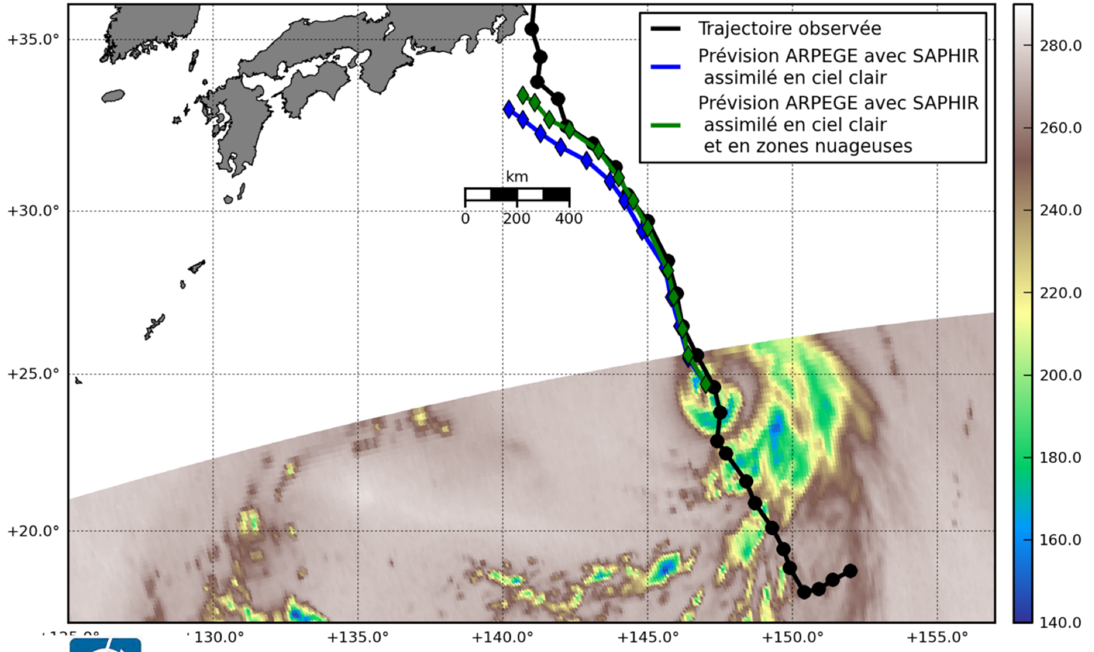
- Long-lived Atlantic hurricane Leslie transitioned to an extratropical storm and brought strong winds, heavy rain and flooding to Portugal, Spain and France.
- Forecasting the landfall in Portugal remained challenging 60 hours ahead but the 48 hour forecast began to capture the true evolution of the storm.
- On this occasion, GMI was in the right place to give the biggest satellite contribution to the improved forecast (drifting buoys contributed significantly more, but were the only observation giving more impact than GMI).
- Forecast Sensitivity to Observation Impact (FSOI) shows GMI on average contributes around 1.3% to the 24h forecast quality at ECMWF. Around 28 satellite radiance sensors are assimilated overall, along with many other types of observation, all of which contribute at one time or another.
- GMI all-sky radiances are assimilated over ocean from channels 19v, 19h, 24v, 37v, 89v, 183±3 and 183±7

ECMWF (Courtesy of Alan Geer)

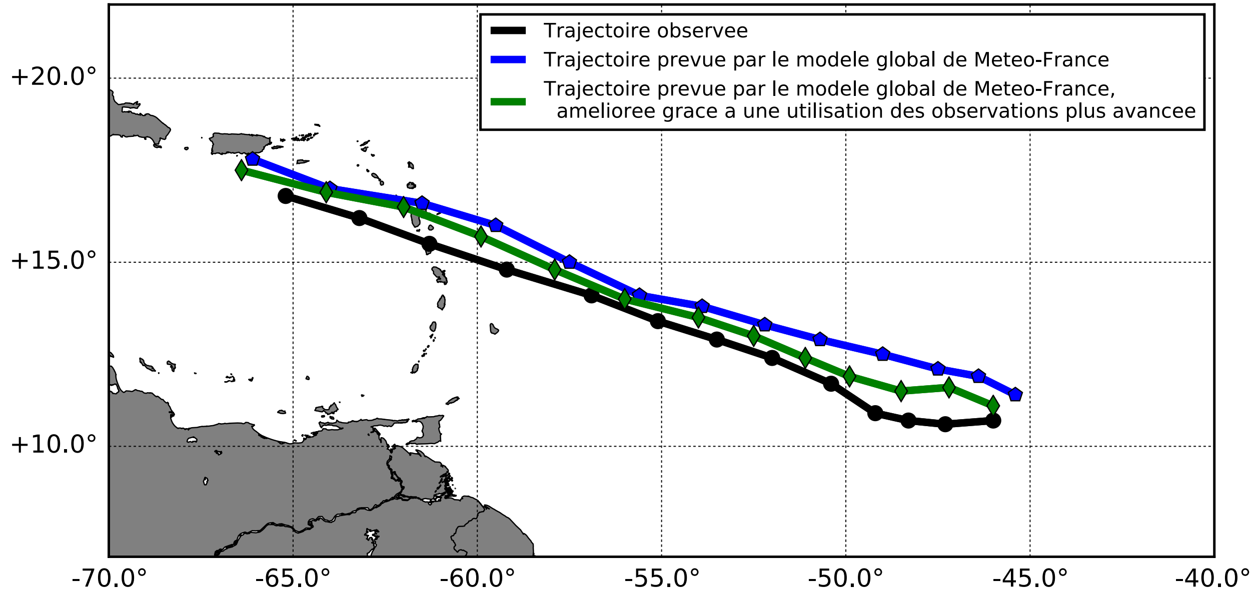
Impact of SAPHIR cloudy radiances on ARPEGE hurricane forecasts:

Examples of Typhoon Shanshan and Hurricane Beryl

North West Pacific basin
+72h forecasts initialized on August 5th, 2018



North Atlantic basin
+72h forecasts initialized on July 7th, 2018



Observed trajectory
Ref Forecasted trajectory
Forecasted trajectory using cloudy obs from SAPHIR

METEO FRANCE

Enhanced sampling at 183 GHz in the Tropics improves hurricane forecasting (2/2)

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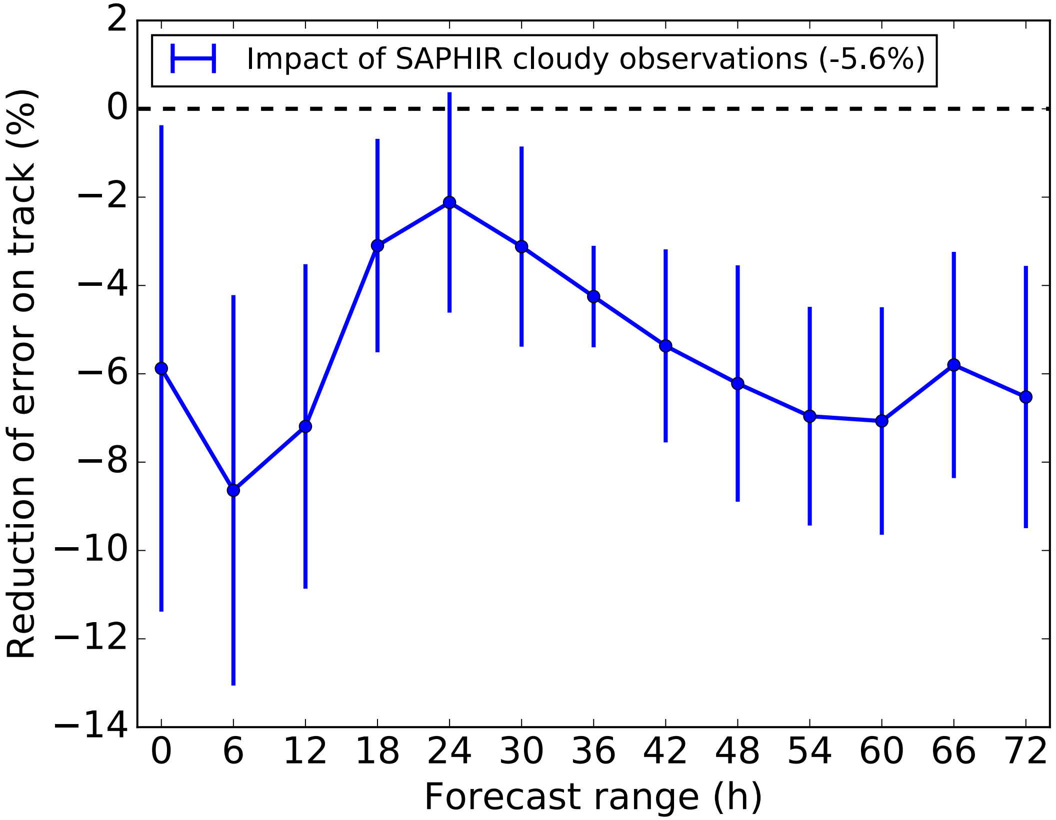
Impact of SAPHIR cloudy radiances on ARPEGE hurricane forecasts:

Impact for 16 hurricanes over several basins for a sample of 432 hurricane forecasts

(c) Reduction of error on track for hurricanes: Beryl (ATL), Chris (ATL), Maria (NWP), Fabio (NEP), Ampil (NWP), Wukong (NWP), Shanshan (NWP), Jongdari (NWP),Hector (NEP), John (NEP), Florence (ATL), Helene (ATL), Isaac (ATL), Kirk (ATL), Michael (ATL), Jebi (NWP)
(16 hurricanes - 432 forecasts)



Reduction of error of ~6% in average over the life cycle of the 16 hurricanes.

METEO FRANCE

Analyze an ensemble of Convection Permitting Simulations

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Analyze an ensemble of Convection Permitting Simulations

- different initial conditions leading to **deep convection**
- innermost horizontal resolution between 148m and 250m
- used different microphysical schemes
- brightness temperatures calculated from radiative transfer model with different scattering assumptions (convolved with hypothetical antenna pattern giving ~ 15km x 15km resolution)

2 Goals:

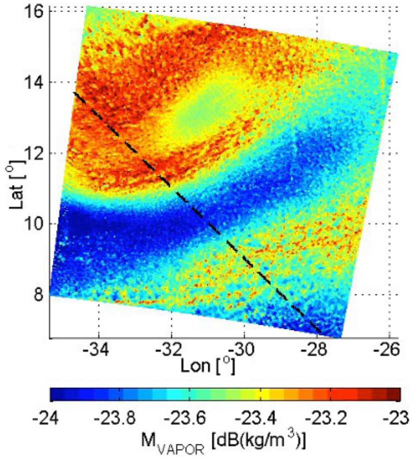
- Establish sensitivity of passive microwave to “vertical structure”
- Quantify dependence of retrieval uncertainty on channel combination

Vertical structure represented by 6 quantities related to “opaqueness”:

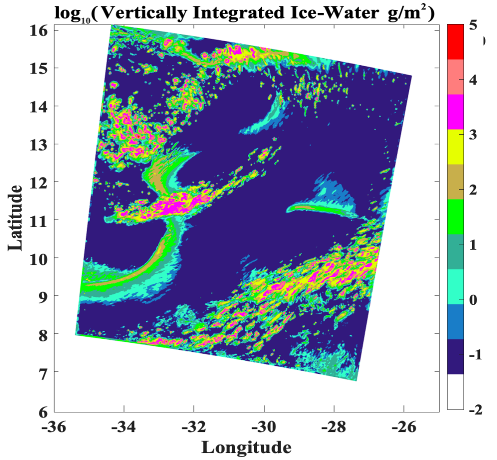
1) $H_{0.05}$ = maximum height reached by condensed water Q > 0.05 g/m^3
2) $H_{0.2}$ = maximum height reached by condensed water Q > 0.2 g/m^3
3) Liquid Water Path
4) Ice Water Path
5) IWP’ = integral of condensed water between $H_{0.05}$ and next height where Q drops below 0.05 (i.e. “top layer” in multi-layer cloud)
6) D_{500} = Depth from $H_{0.05}$ where integral of Q first exceeds 500 g/m^2

tropical storm Isabel
(24 bours before reaching TC intensity and organization, simulated with 5 nested grid, innermost resolution 148m)

TPW



IWP



Credit: Ziad S. Haddad and Sai Prashanth, Jet Propulsion Laboratory, California Institute of Technology

Analyze an ensemble of Convection Permitting Simulations

Method:

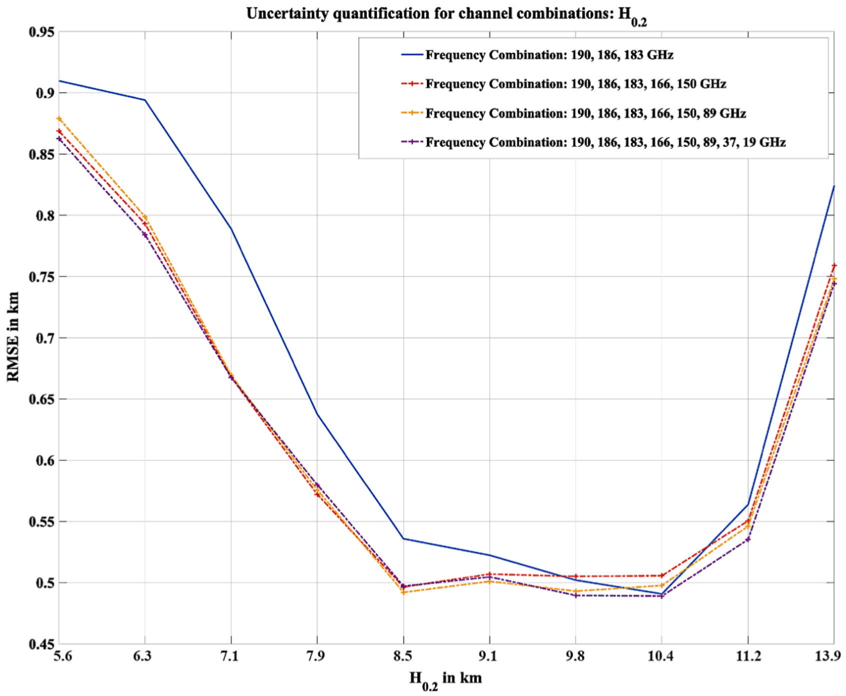
- For each variable, determined its histogram from simulations, and divided the range into deciles (10%)
- Determined the joint probability distribution of the brightness temperature in each decile
- Performed Bayesian retrieval, and compiled error statistics as a function of true (mean) decile value

Channel combos considered: 190, 186, 183, 166, 150, 90, 37, 19 GHz

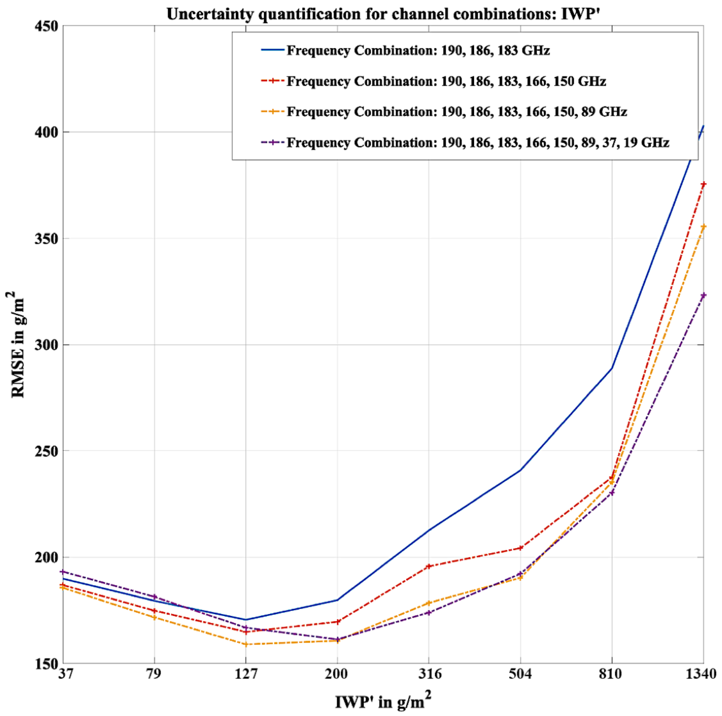
Main conclusion: {190, 186, 183} generically does significantly worse than combos including lower frequencies, but it can do better at the lowest end of the spectrum (low Q) for some variables – and adding channels to {190, 186, 183, 166, 150} does improve IWP' but not significantly improve other variables

Examples:

$H_{0.2}$



IWP'



Credit: Ziad S. Haddad and Sai Prashanth, Jet Propulsion Laboratory, California Institute of Technology