Overview of the assimilation of microwave imagers and humidity sounders observations within clouds and precipitation

4th workshop on assimilating satellite cloud and precipitation observations for NWP / 3-6 February 2020, ECMWF

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Outline of the presentation

1. ***Status of the constellation of microwave sounders and imagers: Which frequencies are we currently using/not using within clouds?***

2. ***What impacts are we getting from these observations?***
   - *On large scale forecasting scores*
   - *On extreme events forecasts*
   - *On precipitation forecasts*

3. ***What are the current limitations and challenges?***
   - *Observation operator and radiative properties of hydrometeors*
   - *Representation and observation of sub-grid cloud variability*
   - *Representation of cloud life cycle within NWP models and possible link with saturation effects*

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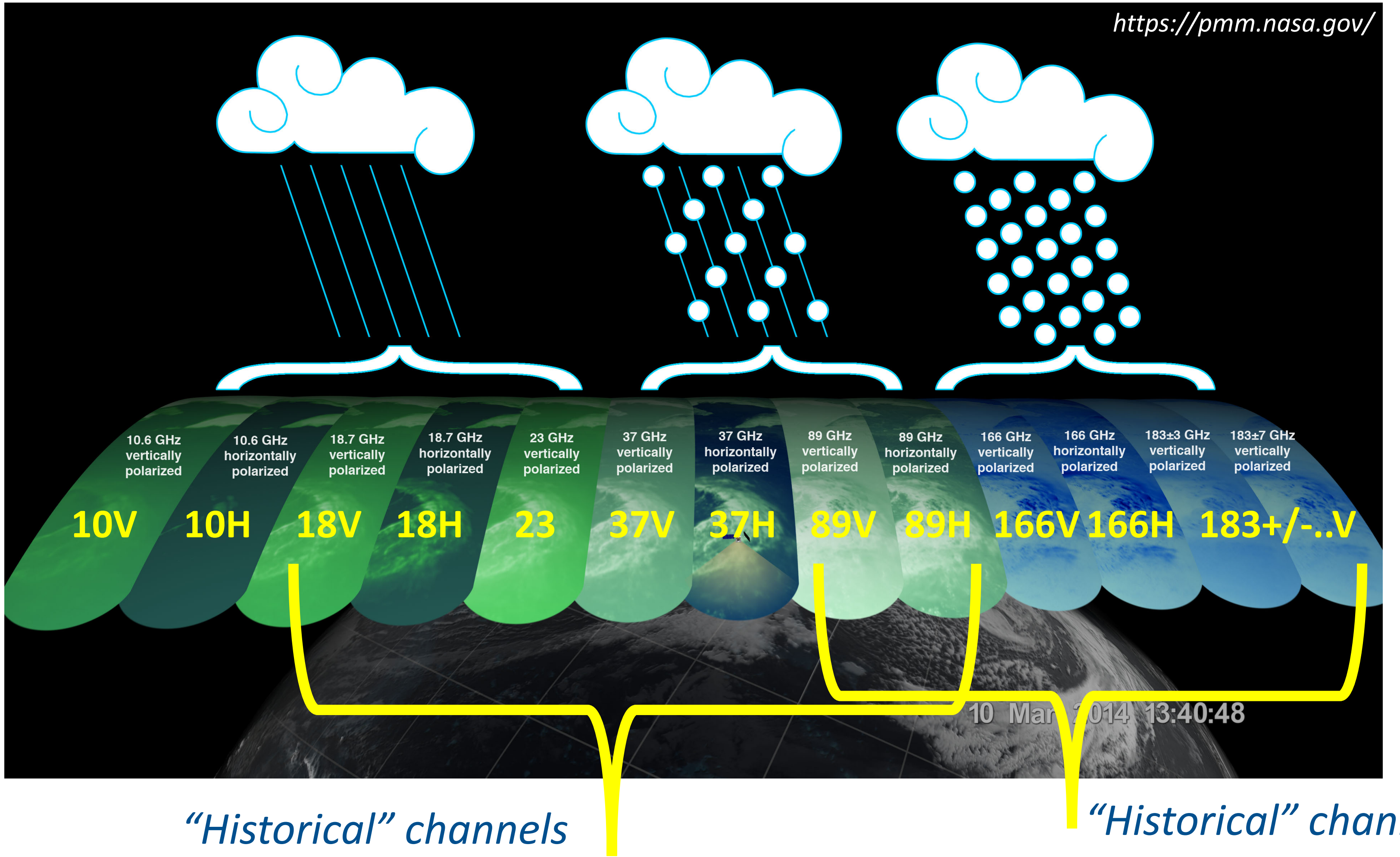

"Historical" channels onboard conical imagers

"Historical" channels onboard humidity cross-track sounders

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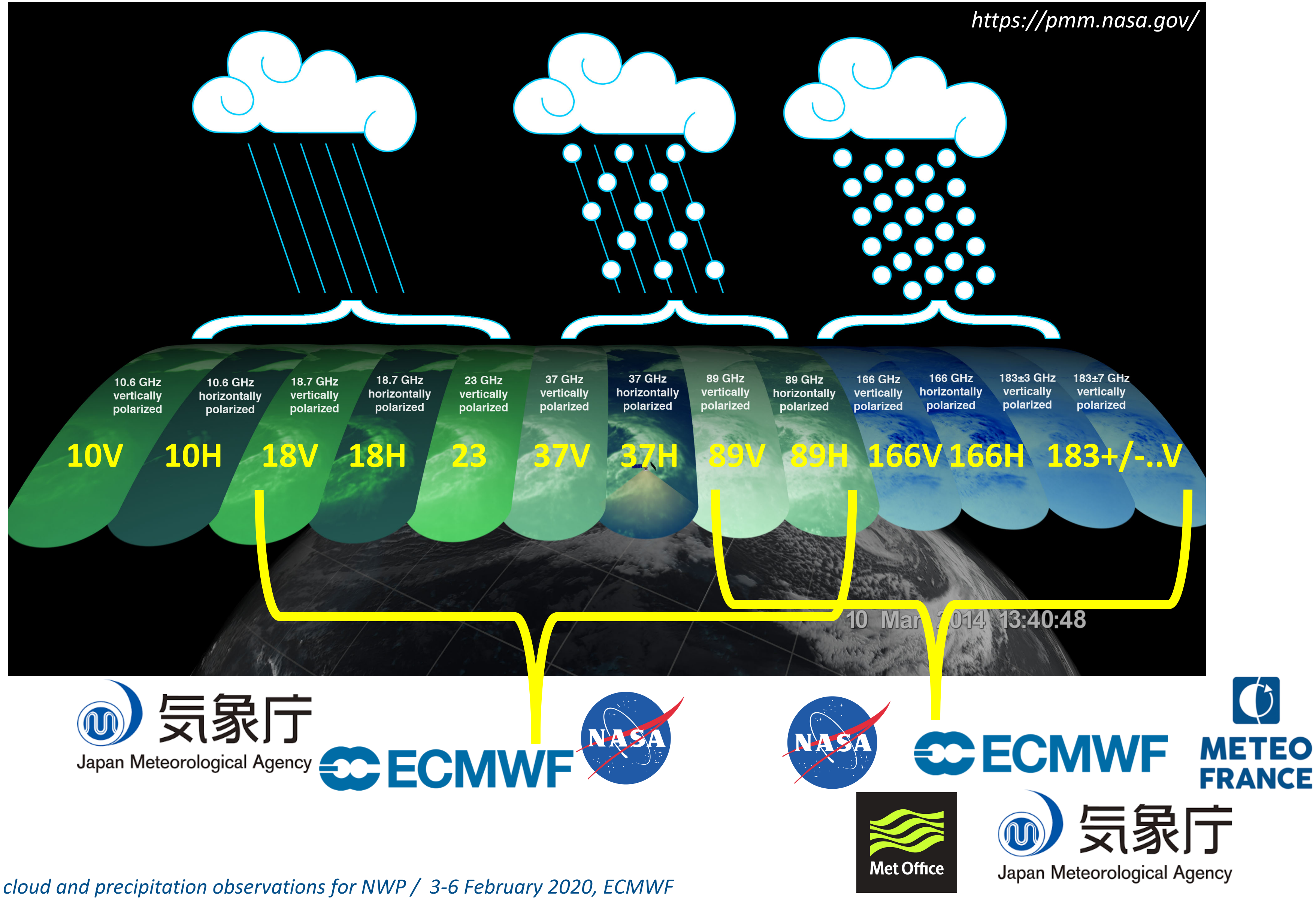

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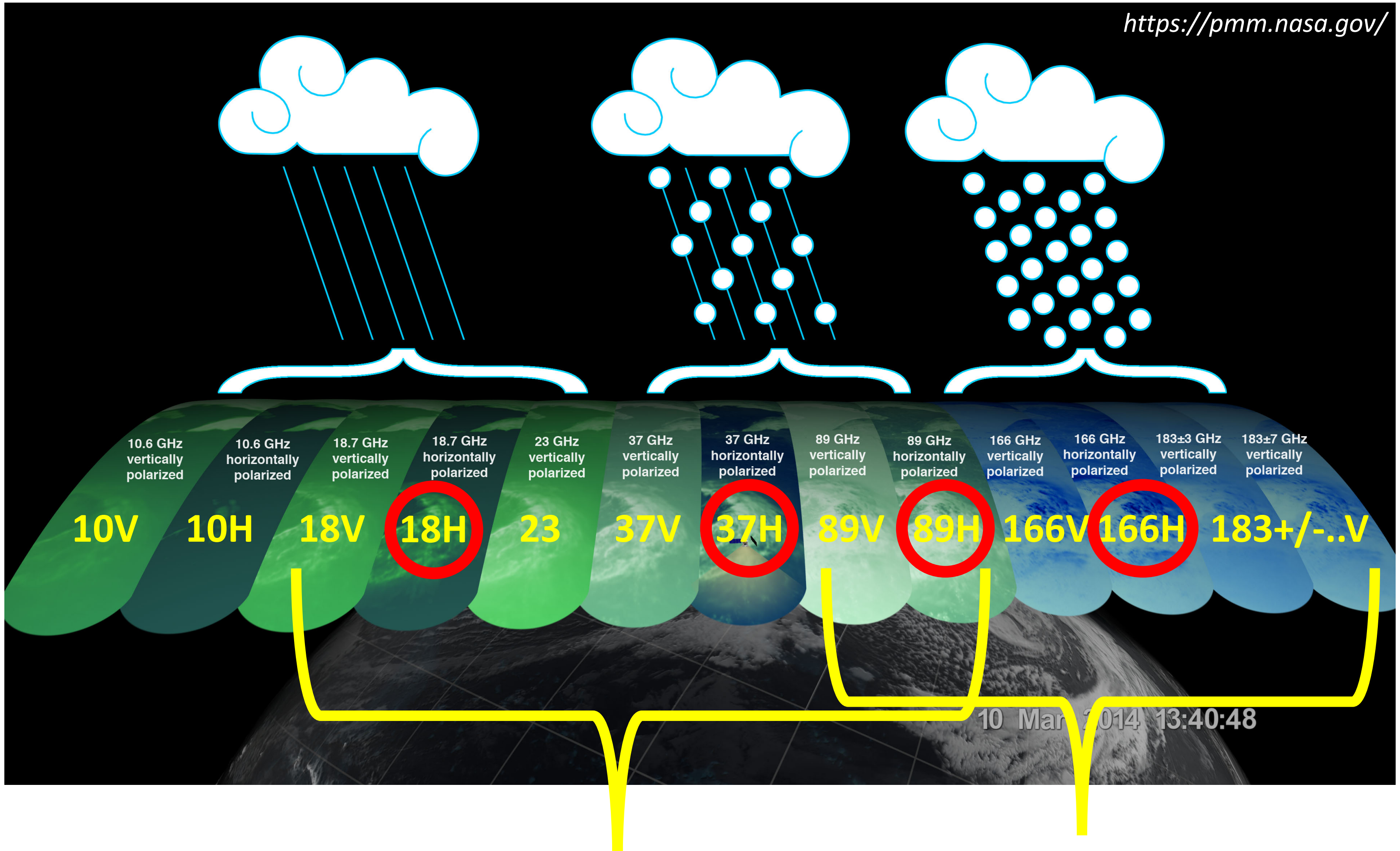
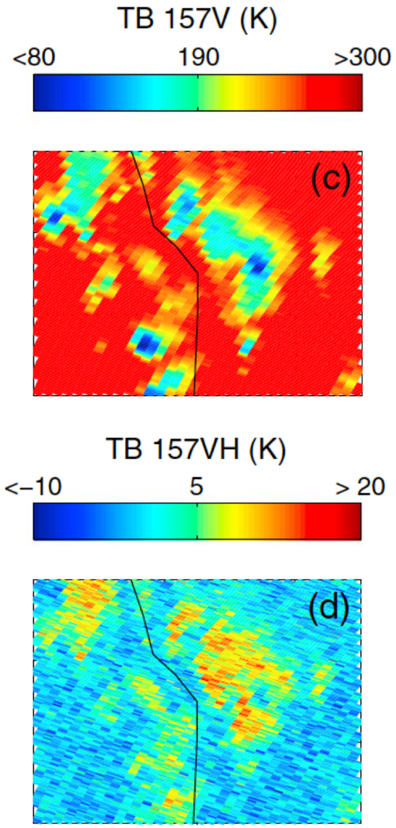


Example of H-V signal with the MADRAS imager (Defer et al., 2014)

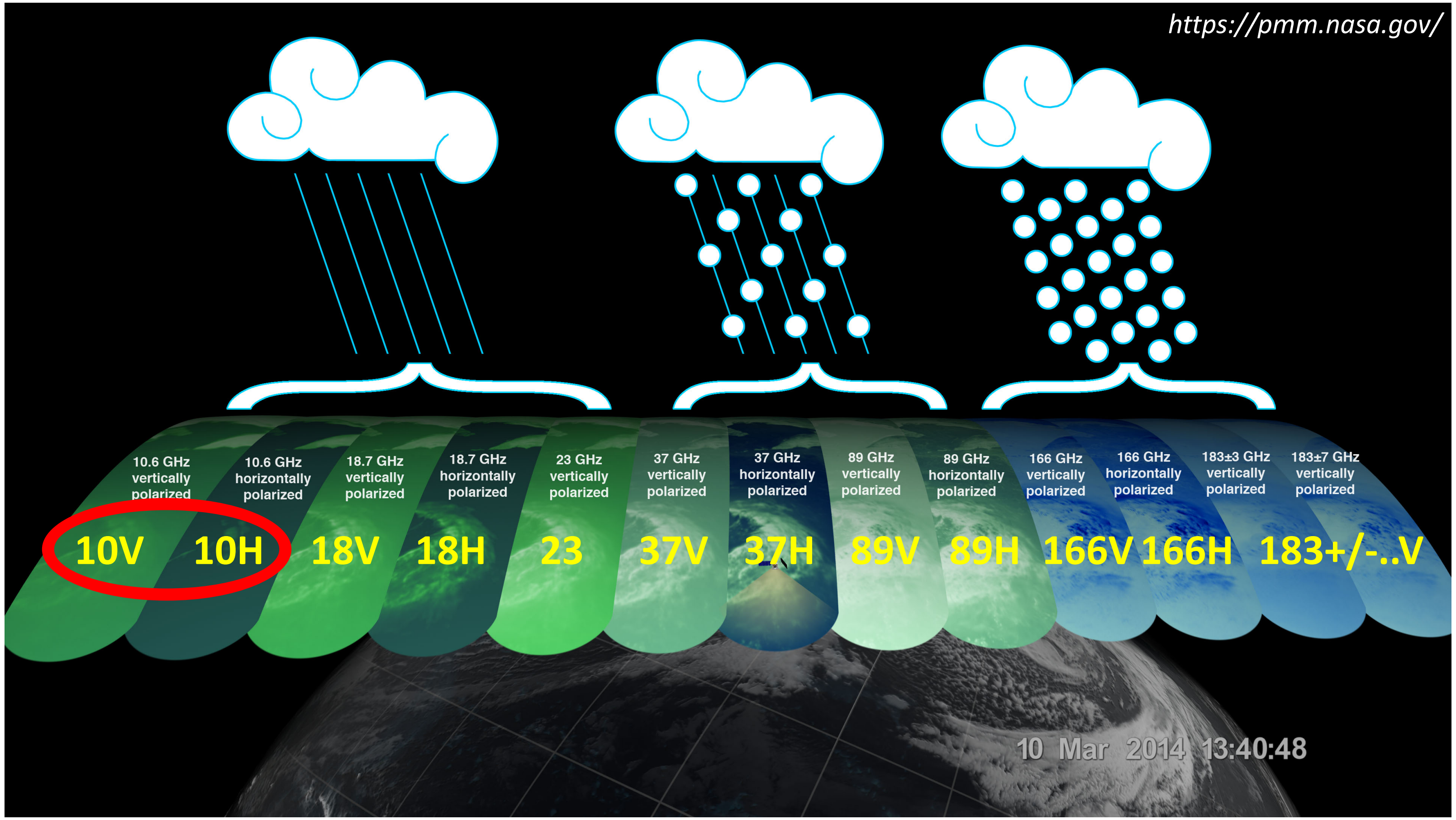


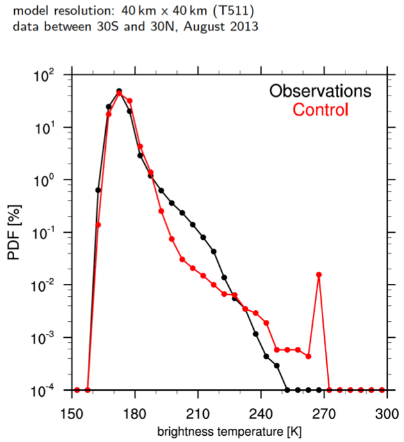
In clear sky, both polarizations are often used,
but within clouds, fully polarized fast radiative transfer models are not yet available and only surface effects are taken into account which mean that the information content of this pairs of channels is currently under used
(but one question is if current NWP models can really take benefit from this H-V signal, ~ related to particle shapes/orientations)

1. Status of the constellation of microwave sounders and imagers: Which frequencies are we currently using/not using within clouds?

Channels not assimilated yet:
- Low resolution (complex beam filling effects)
- Modeling difficulties in precipitation and surface emissivity

=> But research has been done on the 10 GHz !





From Lonitz et al., (e.g. in IPWG 2014)
- Importance of spatial resolution
- Fall speed parametrization
- …

Outline of the presentation

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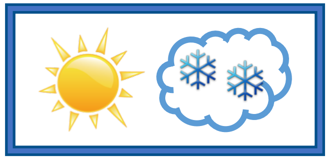
2. What impacts are we getting from these observations?

<u>Impacts obtained across NWP centers are not necessarily straightforward to intercompare for several reasons:</u>

- The satellite instruments for which the assimilation of cloudy and rainy observations are not necessarily the same across the experiments, nor periods or verification domains

⇒ *The examples which will be given are illustrations of the achievements of the community for the assimilation of microwave data in all weather conditions, but not meant to be intercompared*

Across the presentation:



⇒ *Impacts of both clear and cloudy sky*

⇒ *Impacts of cloudy sky*

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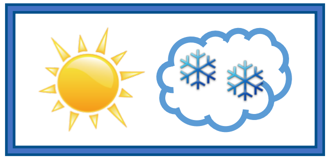
- The impacts of a given sensor in an all-sky context is now often reported as the impact of both clear sky and cloudy sky observations

⇒ *A good sign that assimilating cloudy and rainy observation is becoming more standard*

⇒ *But, does not help to specifically quantify the impact we are deriving from the clouds*

Across the presentation:



⇒ *Impacts of both clear and cloudy sky*

⇒ *Impacts of cloudy sky*

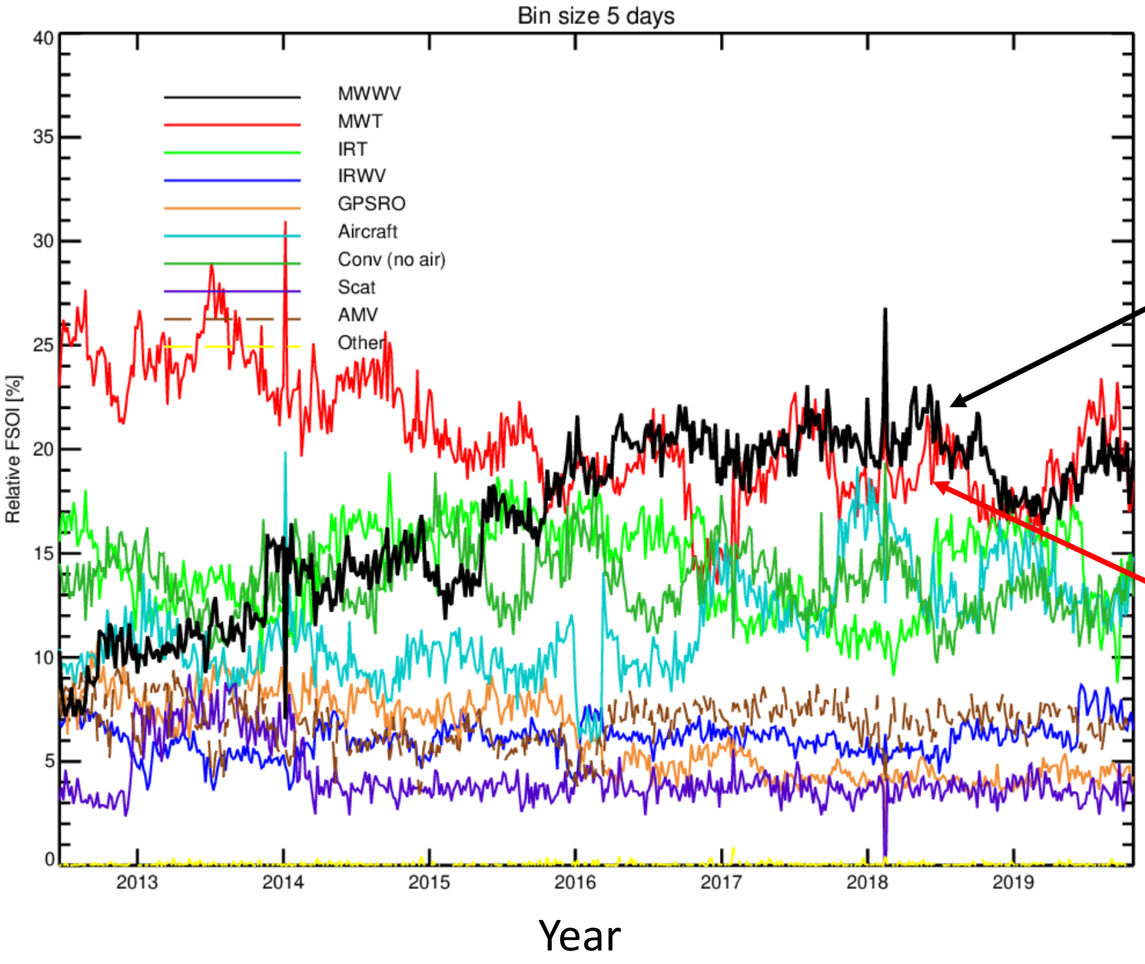
2. What impacts are we getting from these observations?

Context / **On large scale forecasting scores** / On extreme events forecasts / On precipitation forecasts

ECMWF

All-sky radiances sensitive to water vapour, cloud and precipitation are now one of the most important observation types within the ECMWF system

Relative forecast impact at 24h computed by adjoint



Microwave radiances sensitive to water vapour, cloud and precipitation

- 8 sensors assimilated in all-sky conditions
- 3 sensors only in clear-sky

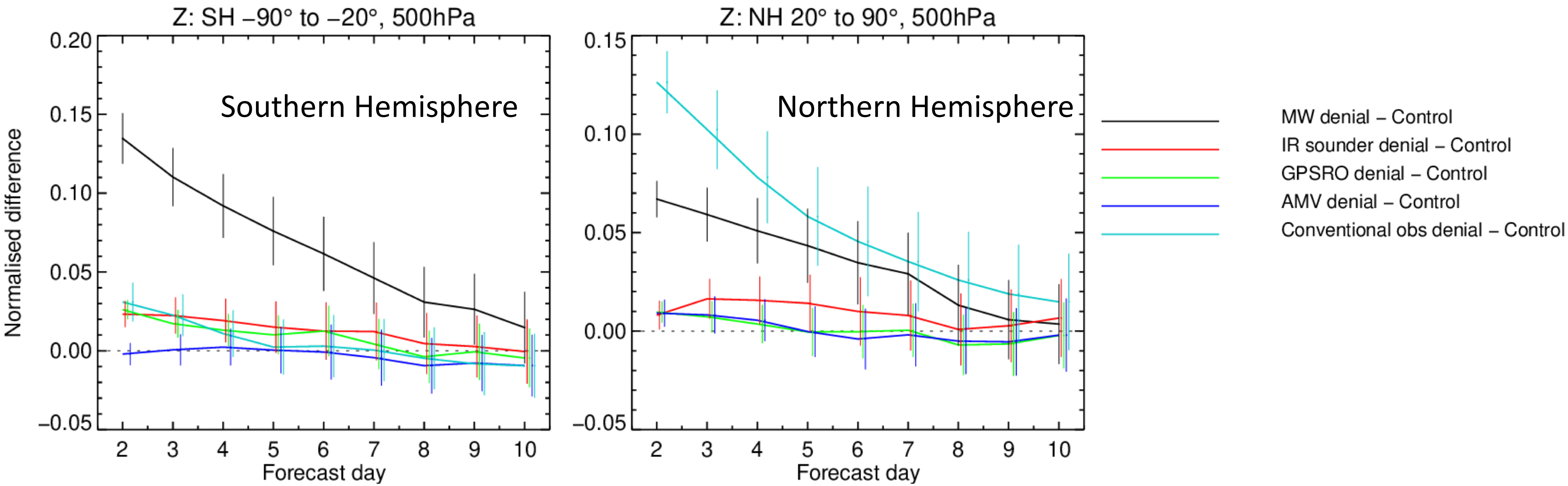
Microwave radiances sensitive to temperature

- assimilated in clear-sky only

(Courtesy of A. Geer)

ECMWF

- Denial experiments compared to a full system for:
  Conventional observations, MW radiances, AMVs, IR sounders, GPSRO
- Periods: 1 June – 30 September 2016; 1 December 2017 – 31 March 2018; (ie 2 x 4 months)



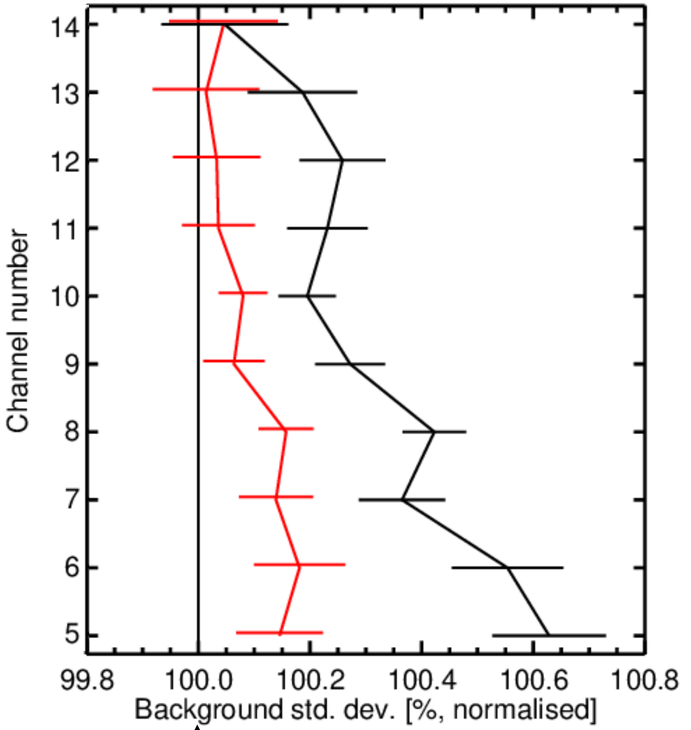
(Courtesy of N. Bormann)

ECMWF

Focus on the impact of observations from 9 instruments affected by clouds and precipitation, in a symmetric way (first guess affected as well as affected obs)

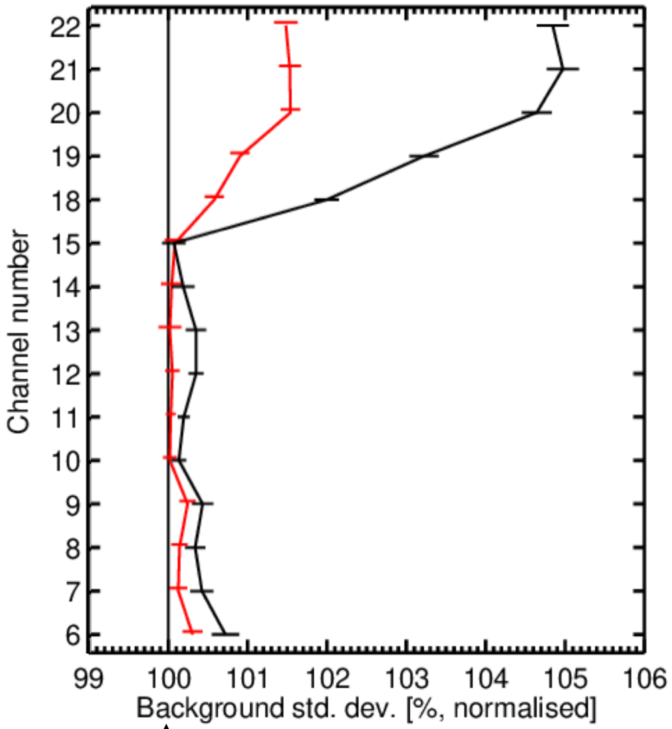
Period:
June 13th
Aug 19th
2019

AMSU-A / South Hemis.



Full system

ATMS / South Hemis.



Full system

Degradation coming from removing all the obs in the all-sky system

Degradation coming from removing only the cloudy/rainy obs in the all-sky system

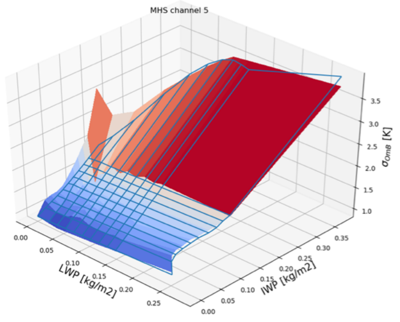
9 instruments:
SSMIS F17, F18
GMI, AMSR2
FY-3C MWHS2
*4 * MHS*

(Courtesy of A. Geer)

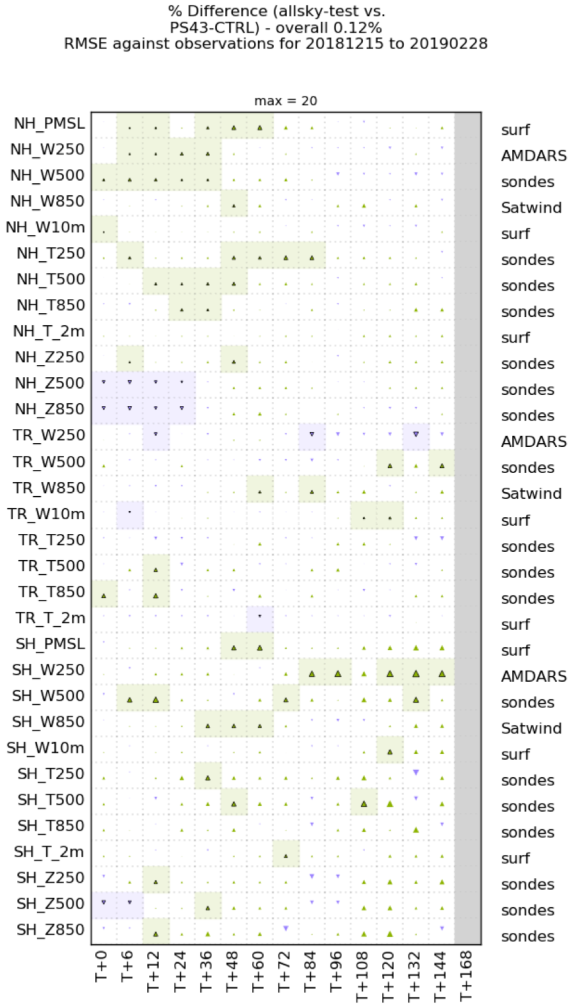
Experiments of MHS all-sky assimilation

- A new augmentation error strategy

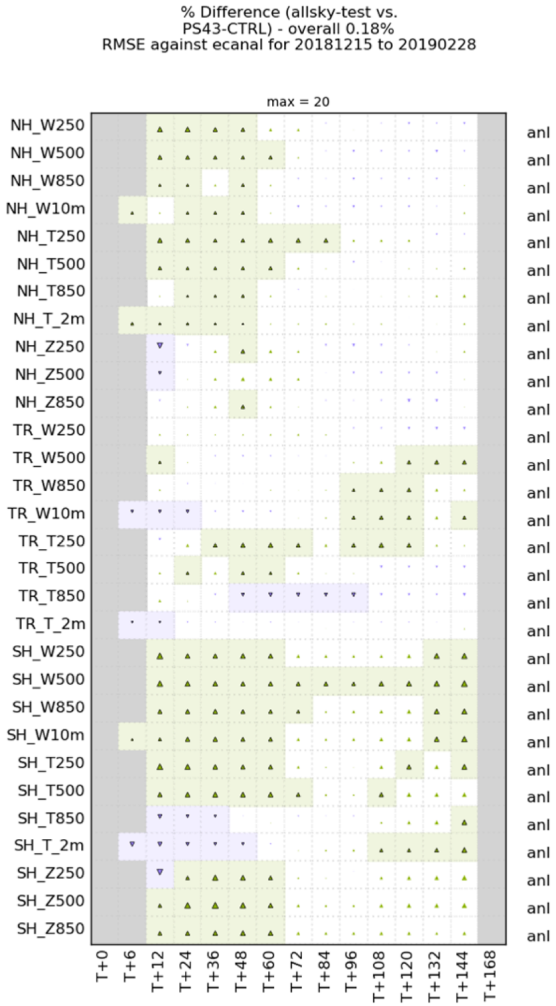
$$\sigma_i = \sigma_i^{clr} + a_i\, LWP + b_i\, IWP$$



- Score card results for a trial experiment in winter 2018-2019. Green (purple) triangles denote improvements (degradations) proportional to their size (maximum size here represents a 20% skill change). Shading denotes statistical significance. data set.
- Overall 0.12% and 0.18% RMSE reduction wrt observations and ECMWF analyses, respectively. Consistent and significant improvements are found particularly in extratropical wind and temperature forecast skill.



REF: observations



REF: ECMWF analysis

(Courtesy of Stefano Migliorini and Brett Candy)

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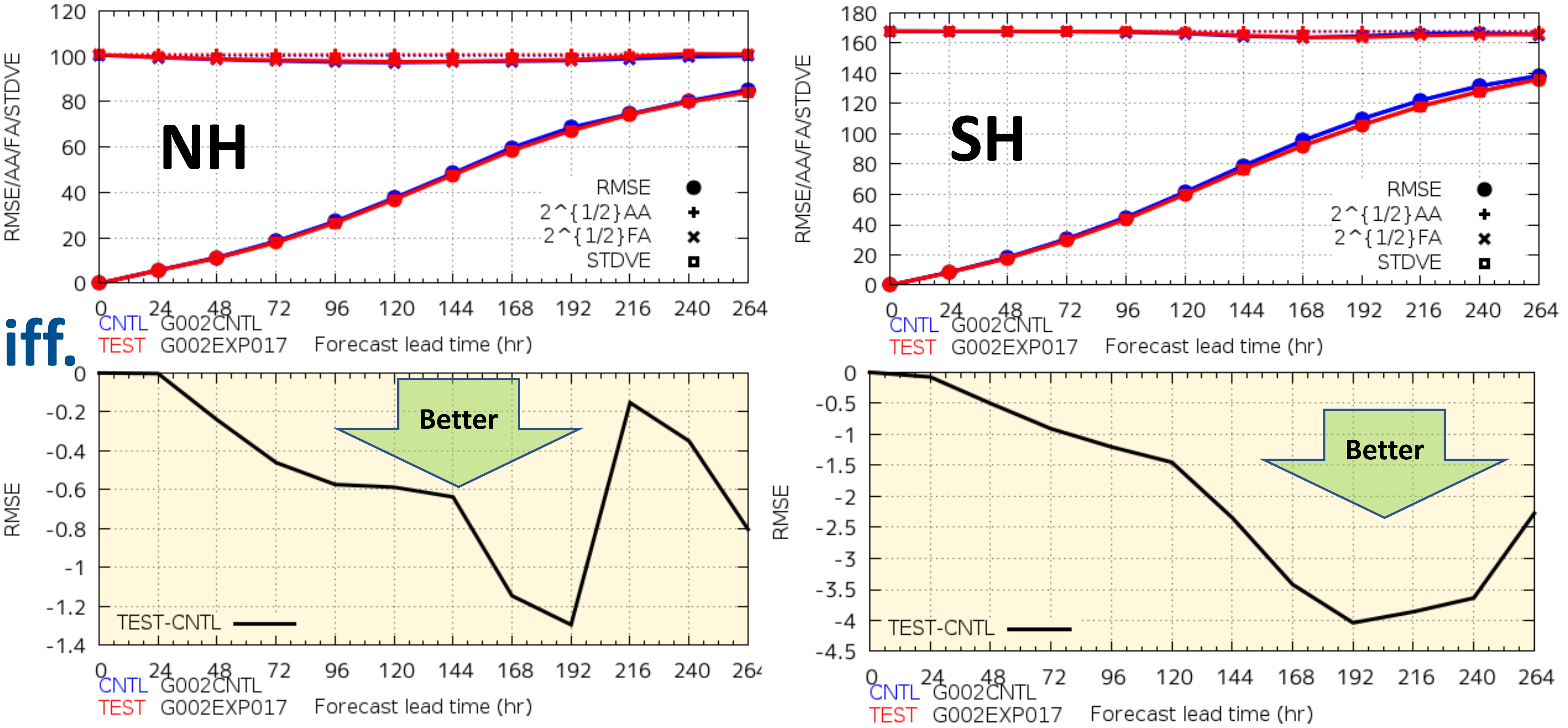
Japan Meteorological Agency

Change of accuracy of 500 hPa geopotential height forecast

From July 1 to September 30, 2017

RMSE

Diff.



CNTL:clear sky

TEST:all-sky

AMSR2, GMI, SSMIS F17, F18 (19V, 23V, 37V)
GMI, MHS (NOAA, Metop) (183 GHz)
WindSat, MWRI FY-3B, FY-3C

(Courtesy of Masahiro Kazumori)

All-Sky GPM Data in GEOS Weather Forecasts

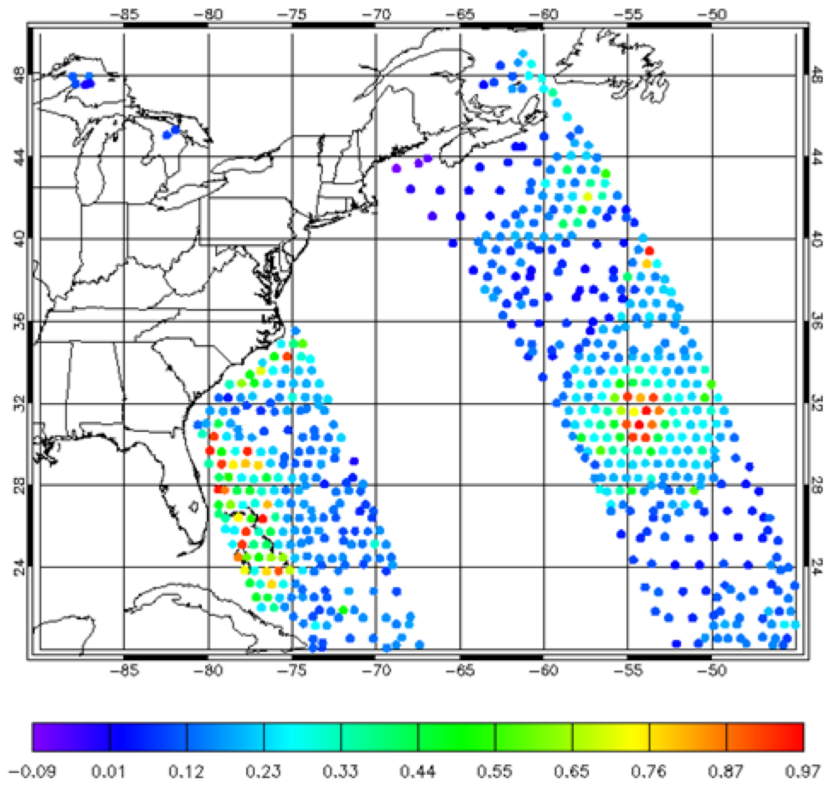
On 11 July 2018, Global Precipitation Mission (GPM) Microwave Imager (GMI) observations were implemented into the GMAO Forward Processing (FP) system

- Assimilation of GMI radiances in near-real-time
- Active assimilation under all-sky situations, eliminating previous limitation to those unaffected by clouds and precipitation

Advanced methods were incorporated to optimize the use of these observations

- Adaptive thinning in the presence of clouds and precipitation (left, where warm colors indicate increased convective activity)
- Advances to underlying radiative transfer algorithm
- Incorporations of ice and liquid clouds and precipitation into the solution

GMI Observations (1-Normalized 37 GHz TB polarization difference)



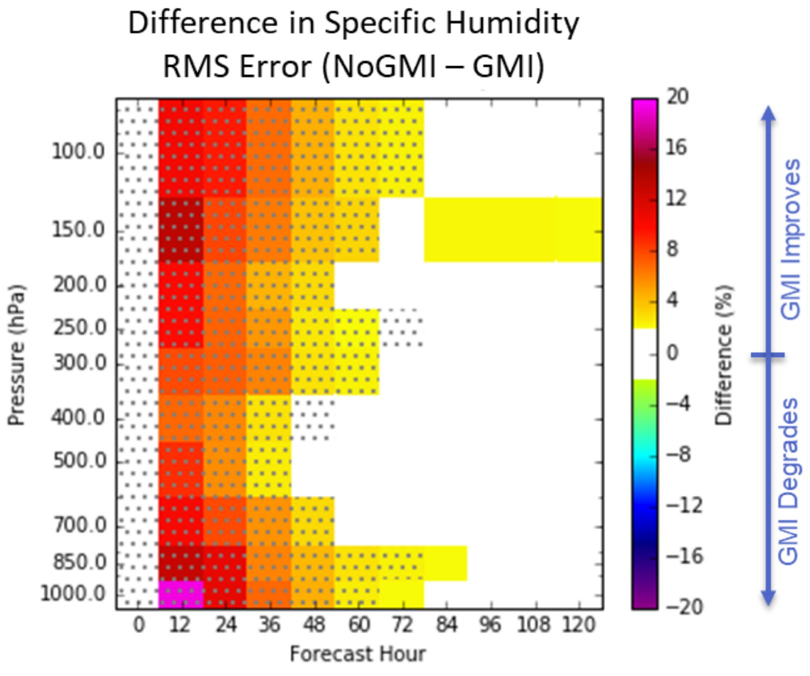
(Courtesy of Min-jeong Kim)

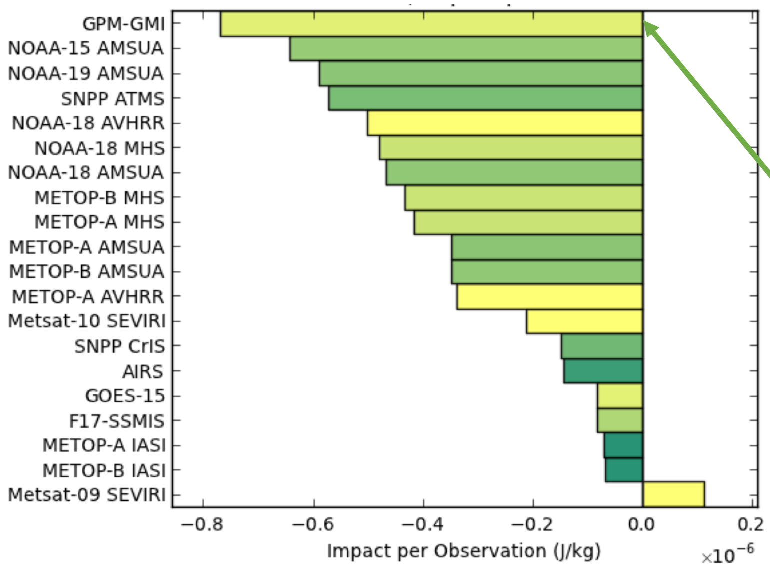
All-Sky GPM Data in GEOS Weather Forecasts

The addition of GMI radiances had the largest impact in the Tropics

- Specific humidity was significantly improved in the short term (0-72 hour) forecasts (right, hatched indicates significance)
- Though not shown, similar improvements were seen in mid and lower tropical tropospheric temperature and winds

Other modeling and initialization improvements included in the FP upgrade retained these improvements into the medium range





The GMI improvement is consistent with results seen via the Forecast Sensitivity to Observation Impact (FSOI) metric

- FSOI is a metric of how each observation contributes to the reduction (negative) or increase (positive) of the 24 hour forecast error
- GMI is seen to have the highest impact per observation of all the radiance observation types

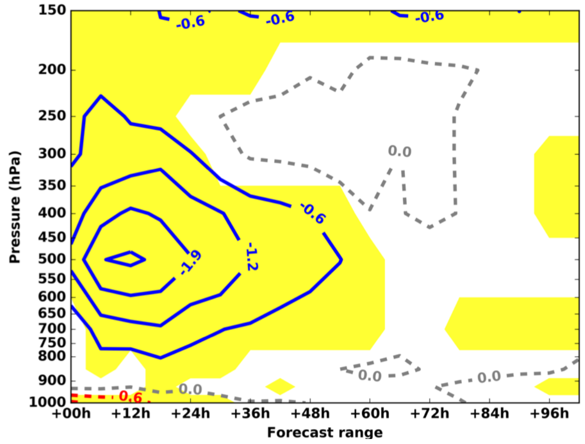
(Courtesy of Min-jeong Kim)

METEO FRANCE

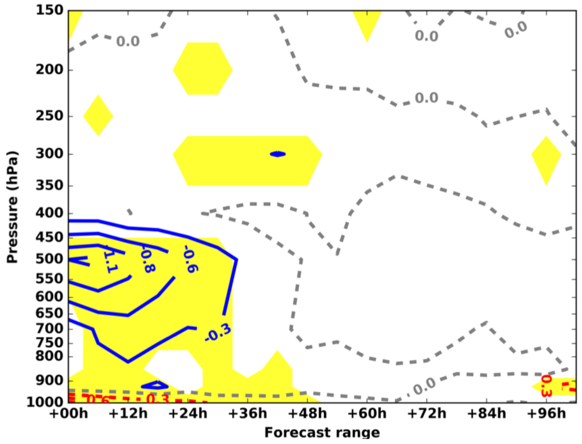
Impacts of assimilating SAPHIR in cloudy and rainy areas with the 1D-Bayesian + 4D-Var technique within ARPEGE over a 4-month period (July to October 2018)

Domain: Tropics
Reference: ECMWF analysis

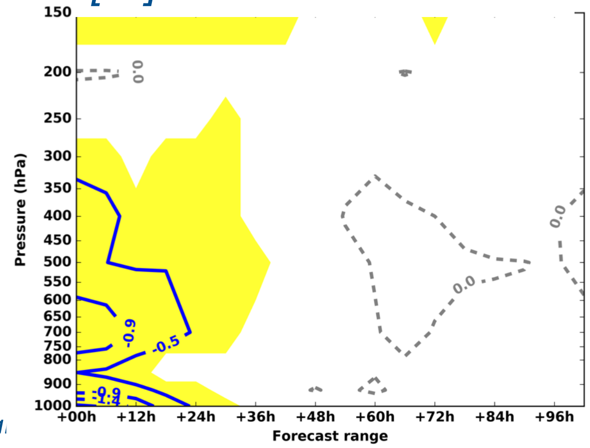
Relative impact on RMSE of Temperature forecasts



[…] of Humidity forecasts

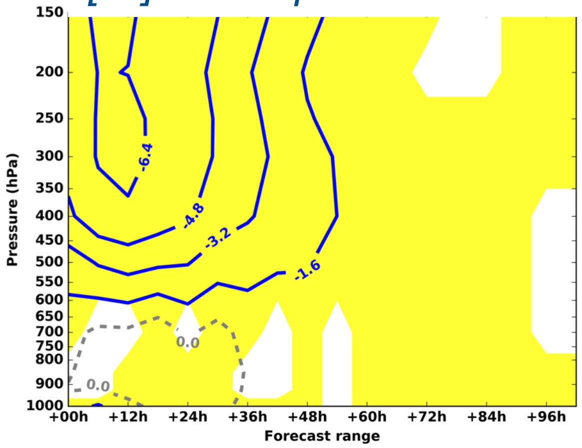


[…] of Wind forecasts



significant at 99%

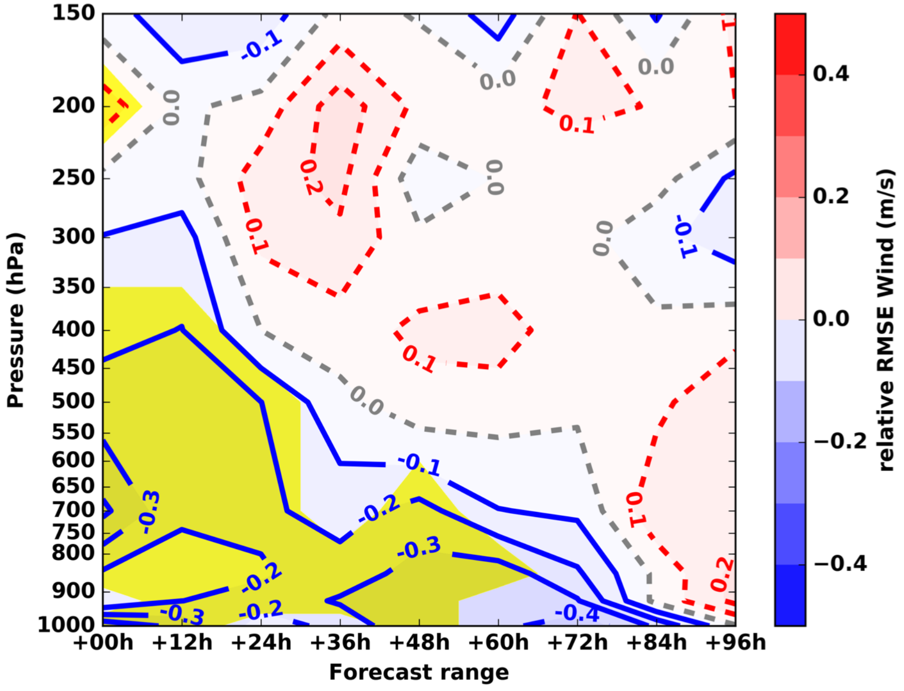
[…] of Geopotential forecasts

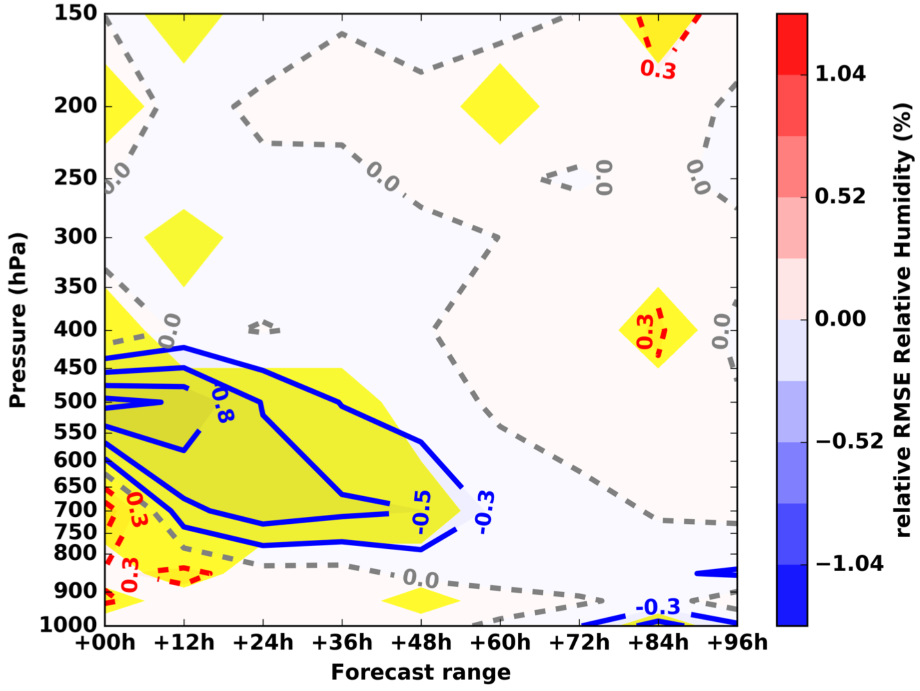


METEO FRANCE

Impacts of assimilating 4 MHS in cloudy and rainy areas with the 1D-Bayesian + 4D-Var technique within ARPEGE up to 60°N over a 3-month period (July to September 2019)

Relative impact on RMSE of Wind forecast for Latitudes >20°





Relative impact on RMSE of Relative Humidity forecast for Latitudes >20°

- Positive impacts of microwave cloudy and rainy observations have been demonstrated within several systems using various methodologies, for both microwave imagers and humidity sounders

- These impacts are significant from the short range and up to 5 to 10 days

=> Can we measure the impact of cloud and precipitation observations onto cloud and precipitation forecasts themselves?

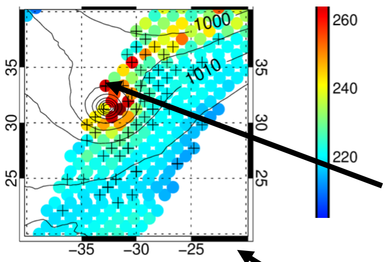
2. What impacts are we getting from these observations?

Context / On large scale forecasting scores / **On extreme events forecasts** / On precipitation forecasts

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

GMI observations at 24 GHz

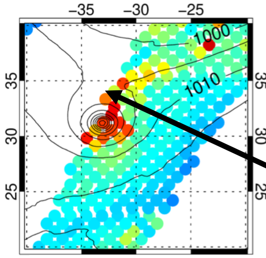
06 UTC, 12-Oct-2018



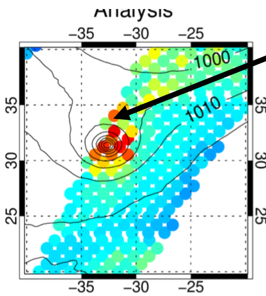
"+" are particularly beneficial observations according to FSOI

Background

simulated from model



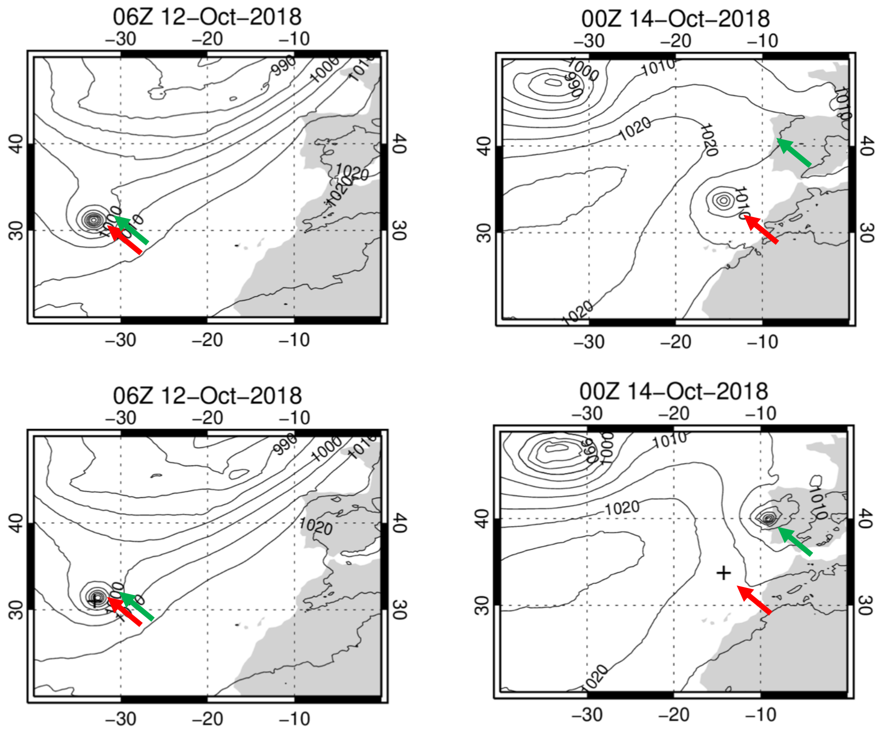
Analysis



Data assimilation shifts the cyclone centre 60 km towards Portugal 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

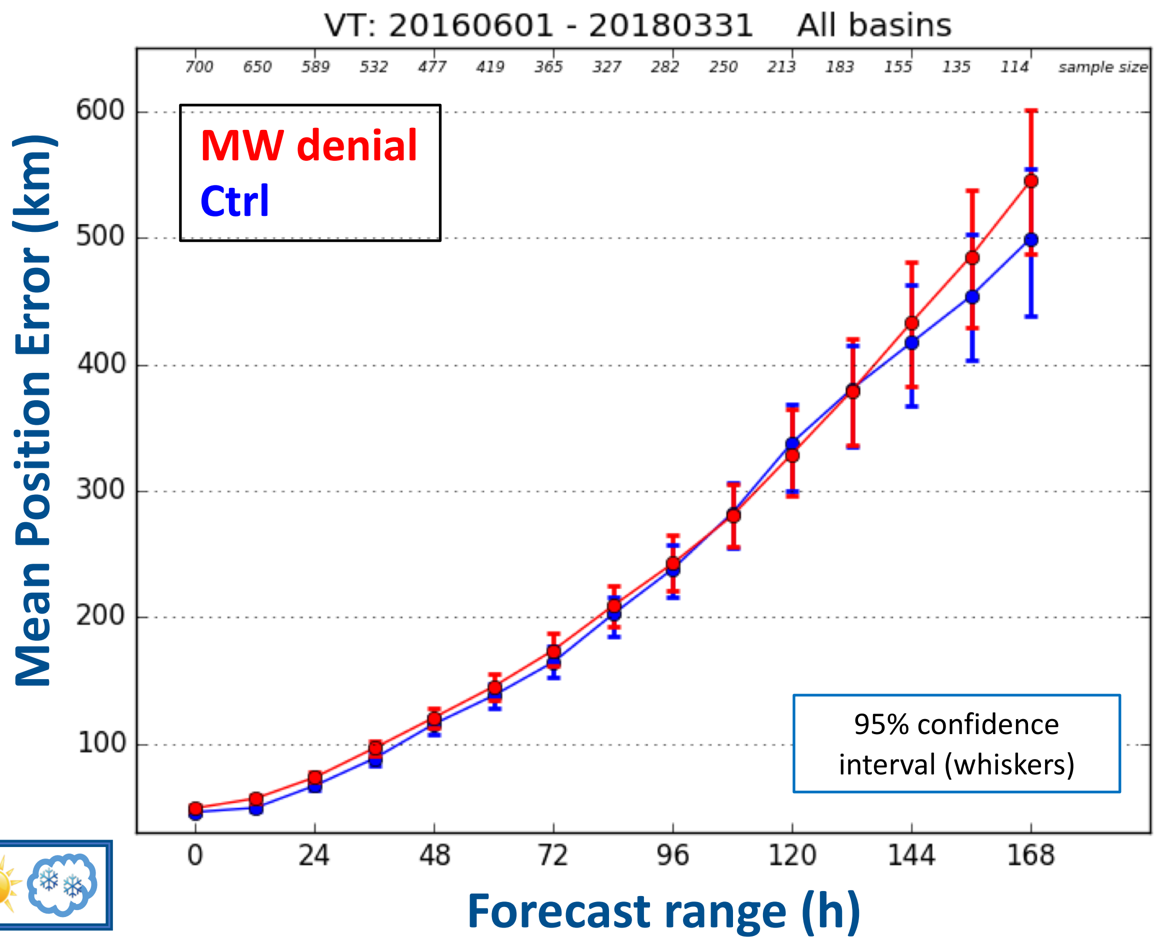


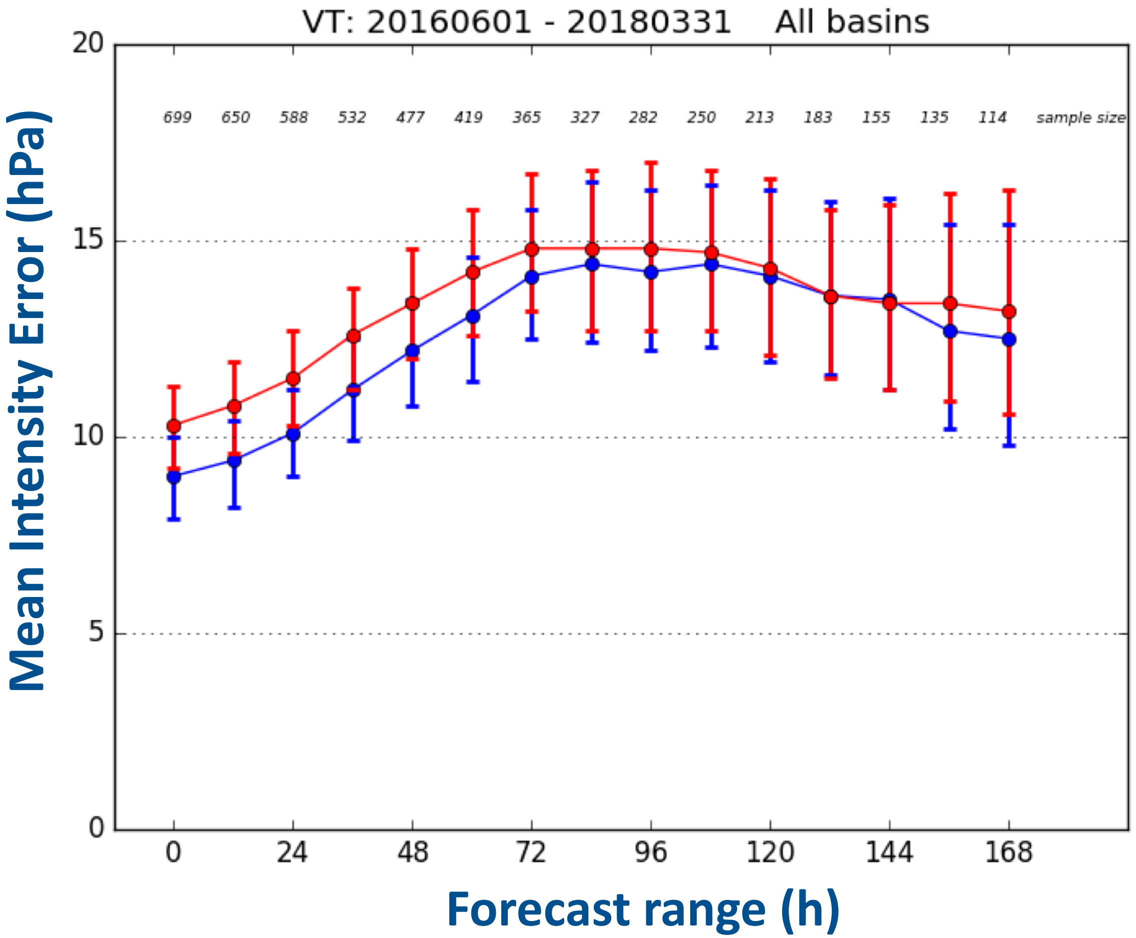
- Forecasting the landfall in Portugal of hurricane Leslie remained challenging 60 hours ahead but the 48 hour forecast began to capture the true evolution of the storm.
- On this occasion, GMI was in the right place to give the biggest satellite contribution to the improved forecast (drifting buoys contributed significantly more, but were the only observation giving more impact than GMI).

(Courtesy of A. Geer)

ECMWF

All basins, homogeneous samples,
1 June – 30 September 2016; 1 December 2017 – 31 March 2018; (ie 2 x 4 months)
Note: Spatial resolution TCo399 (~28km) much lower than operations





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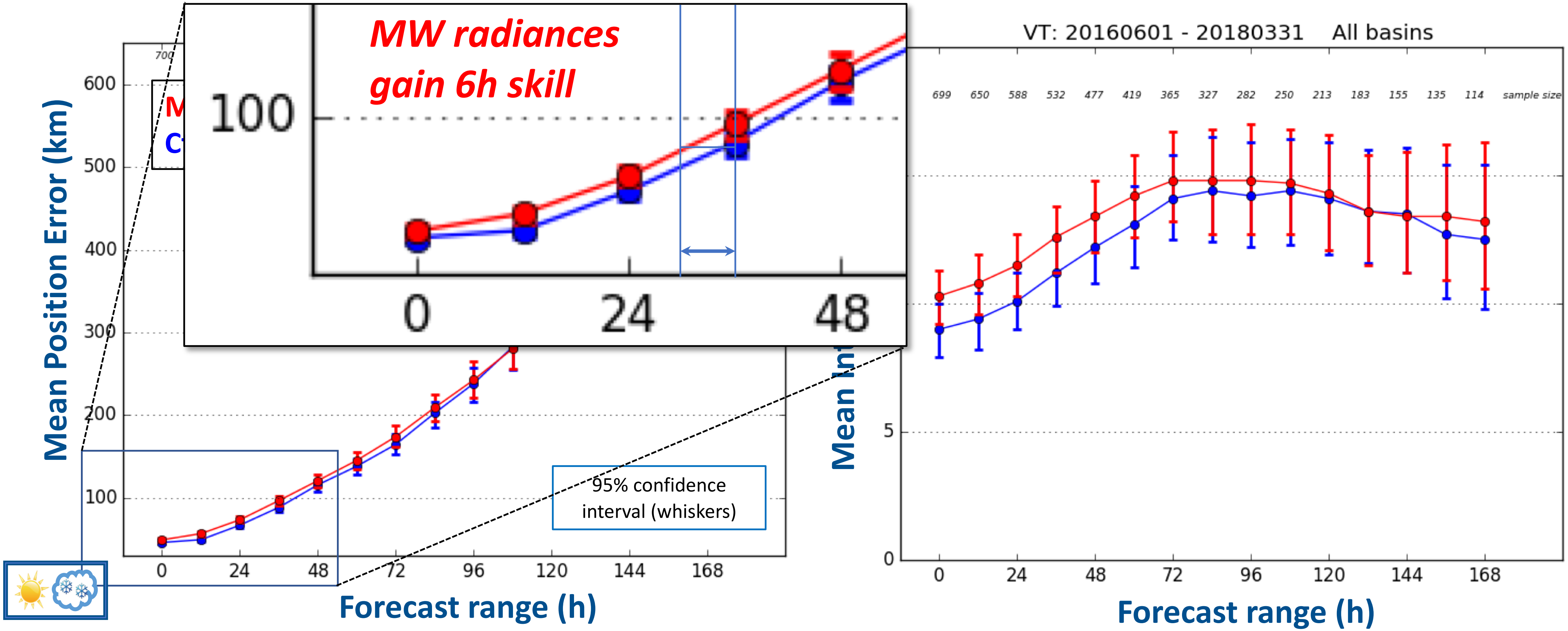

(Courtesy of N. Bormann)

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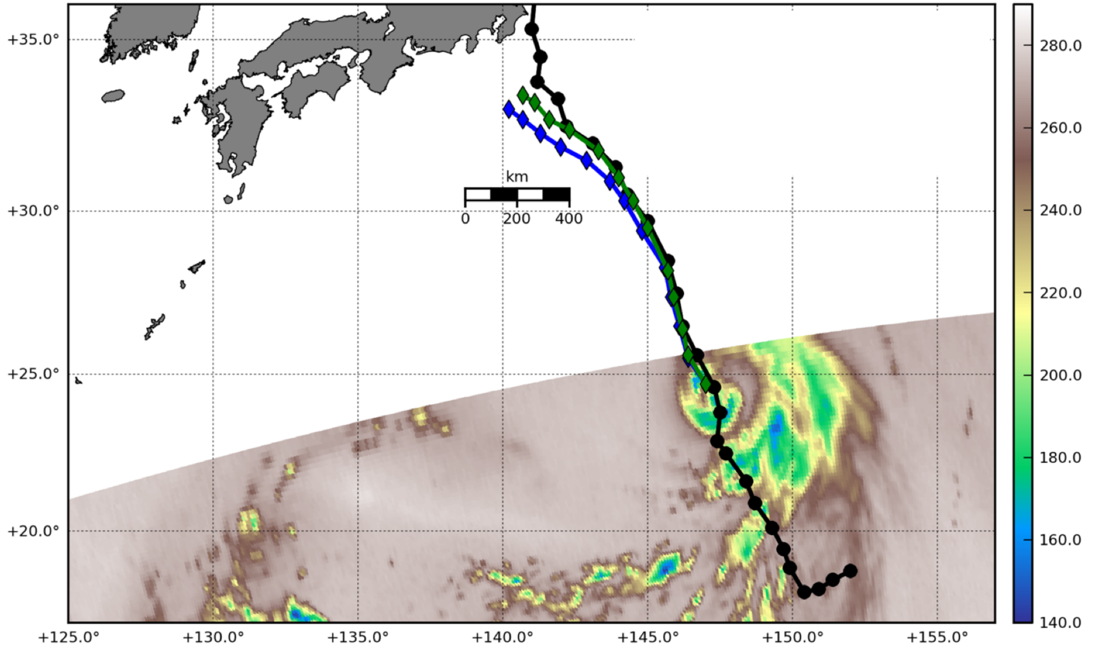
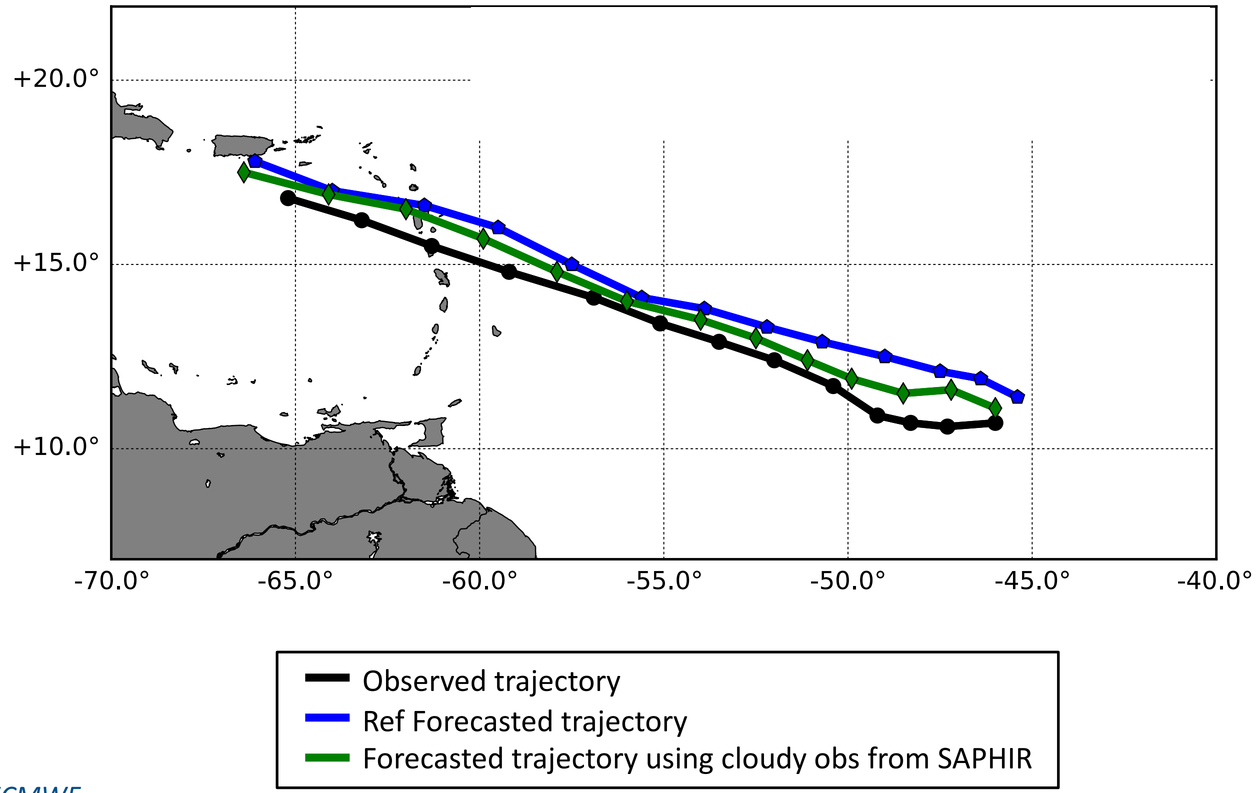
Impact of SAPHIR cloudy radiances on hurricane forecasts:
Examples of Typhoon Shanshan and Hurricane Beryl

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



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

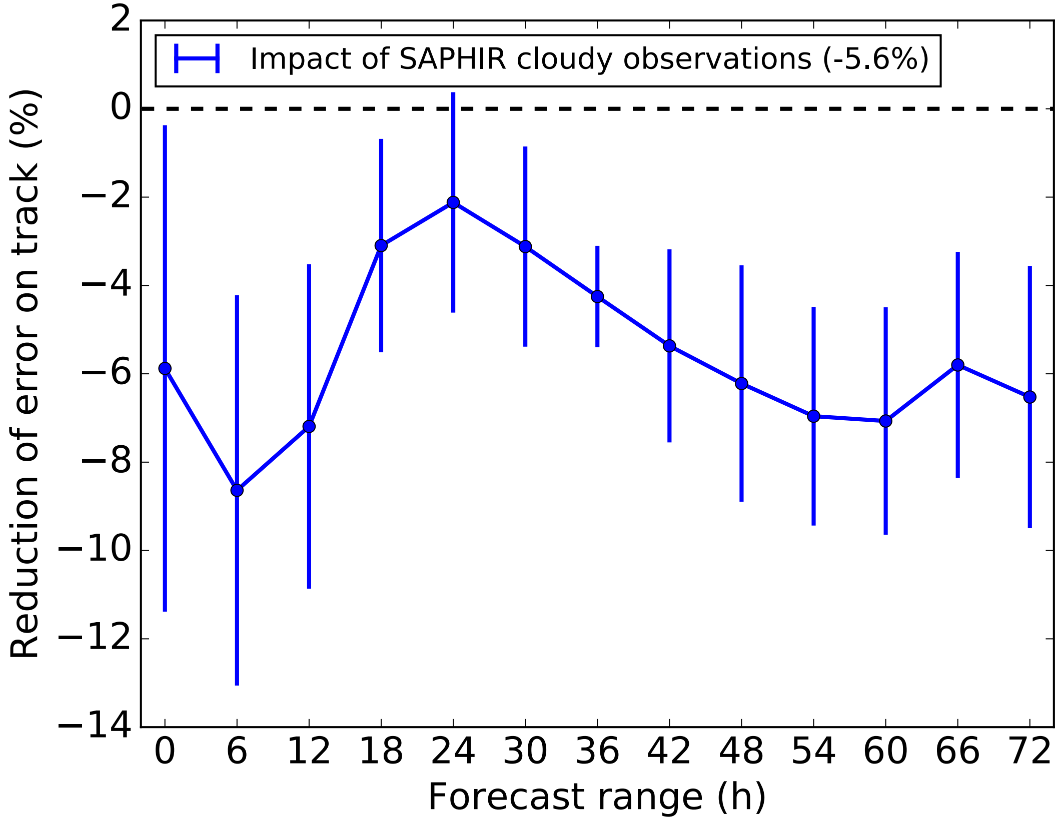


METEO FRANCE

Impact of SAPHIR cloudy radiances on 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)



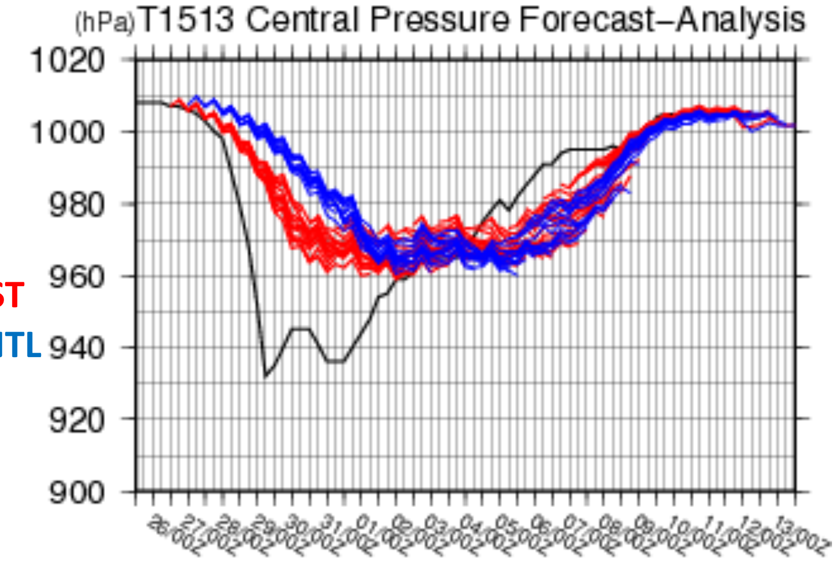
Reduction of error of ~6% in average over the life cycle of the 16 hurricanes.

Japan Meteorological Agency

Improved prediction at TC developing stages

The heat release from water vapor condensation is a source of TC development.
Rapid Intensification* of TC was predicted in the all-sky assimilation experiment.
Water vapor analysis in cloudy conditions would be improved.

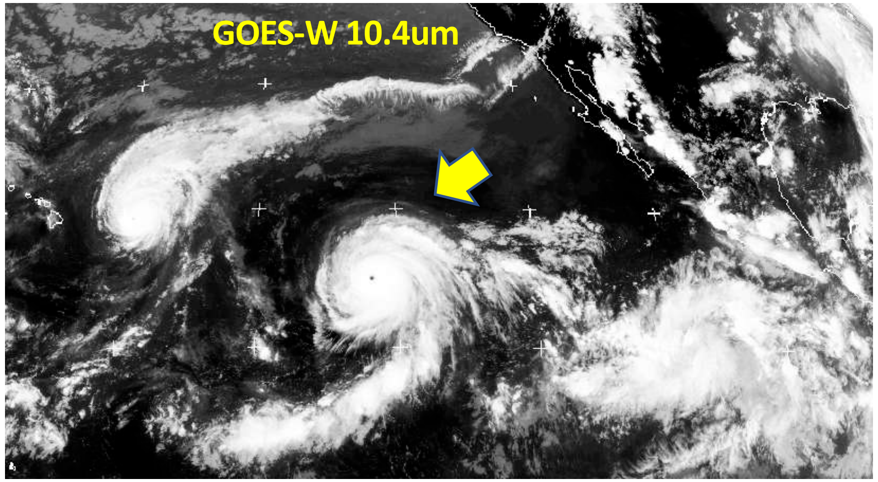
TEST



Red : TEST
Blue : CNTL

00UTC 31 Aug. 2015
Maximum stage

* Decrease in the central pressure of TC at least 30 hPa in a 24-hour period.



(Courtesy of Masahiro Kazumori)

気象庁 Japan Meteorological Agency

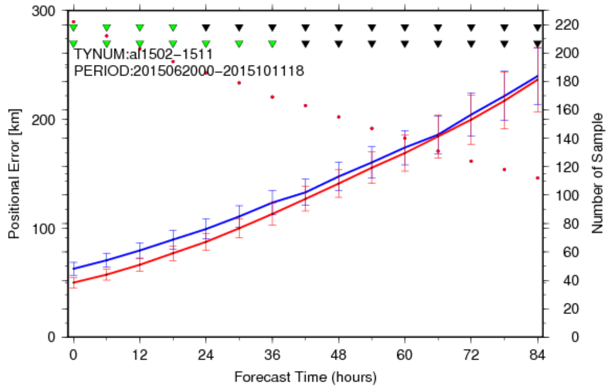
Impacts on TC track predictions 2015 forecasted position error

CNTL:clear sky

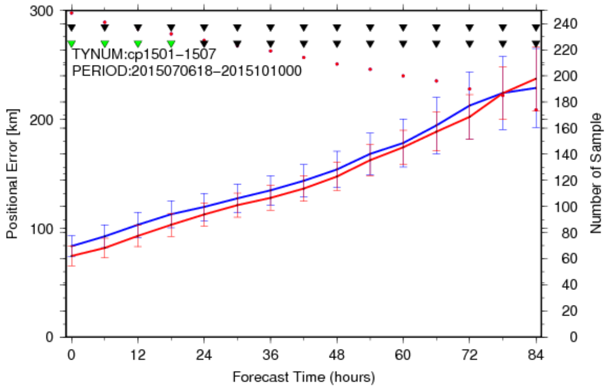
TEST:all-sky

AMSR2, GMI, SSMIS F17, F18 (19V, 23V, 37V)
GMI, MHS (NOAA, Metop) (183 GHz)
WindSat, MWRI FY-3B, FY-3C

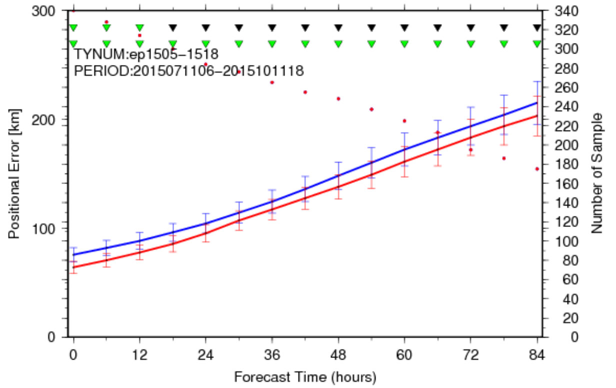
Atlantic Ocean



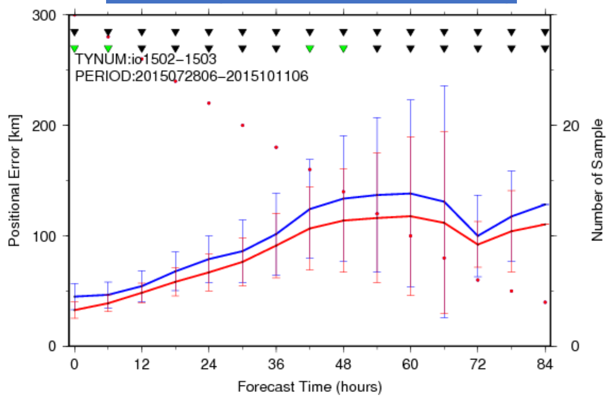
Middle Pacific Ocean



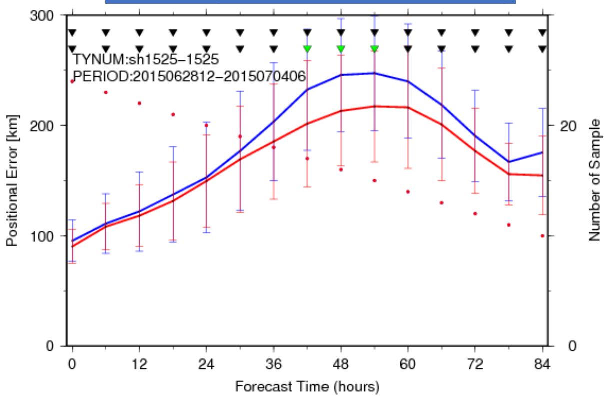
Eastern Pacific Ocean



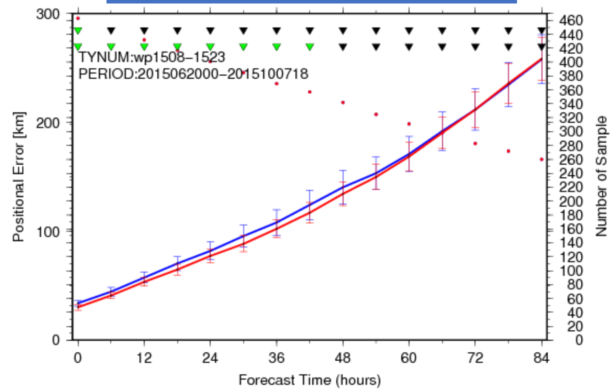
Indian Ocean



Southern Hemisphere



North-Western Pacific



All-sky assimilation improved TC track predictions for all ocean areas.

(Courtesy of Masahiro Kazumori)

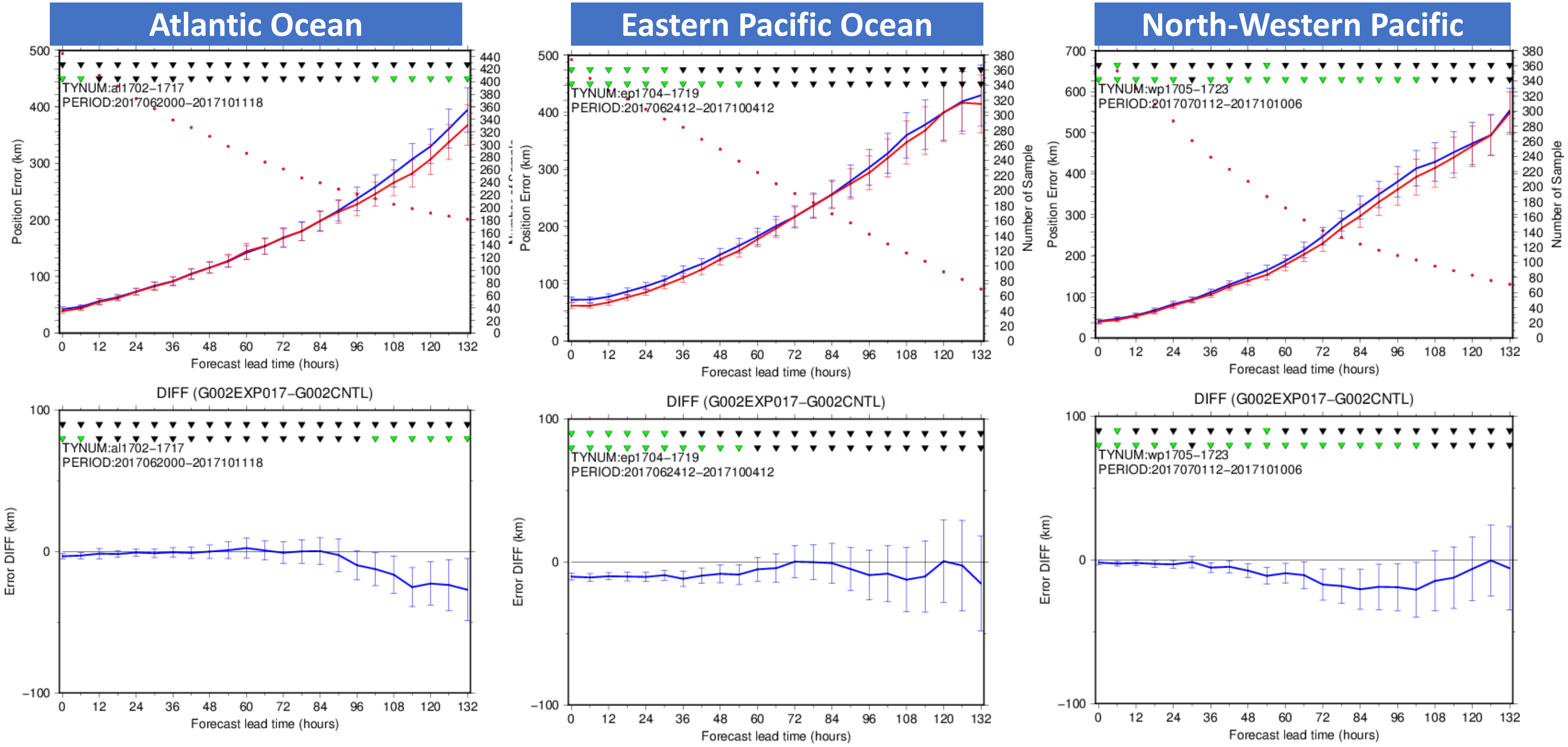
気象庁
Japan Meteorological Agency

Impacts on TC track predictions 2017 forecasted position error

CNTL:clear sky

TEST:all-sky

AMSR2, GMI, SSMIS F17, F18 (19V, 23V, 37V)
GMI, MHS (NOAA, Metop) (183 GHz)
WindSat, MWRI FY-3B, FY-3C



All-sky assimilation improved TC track predictions in 2017

(Courtesy of Masahiro Kazumori)

- Positive impacts of microwave cloudy and rainy observations onto hurricane forecasting have been demonstrated within several systems using various methodologies, for both microwave imagers and humidity sounders

- These impacts are very robust for track forecasting. Some cases of impacts on rapid intensification forecasting have also been reported

=> Do we also see impacts onto precipitation forecasts of smaller scale systems?

2. What impacts are we getting from these observations?

Context / On large scale forecasting scores / On extreme events forecasts / **On precipitation forecasts**

Meteorological Research Institute
Japan Meteorological Agency

CRM

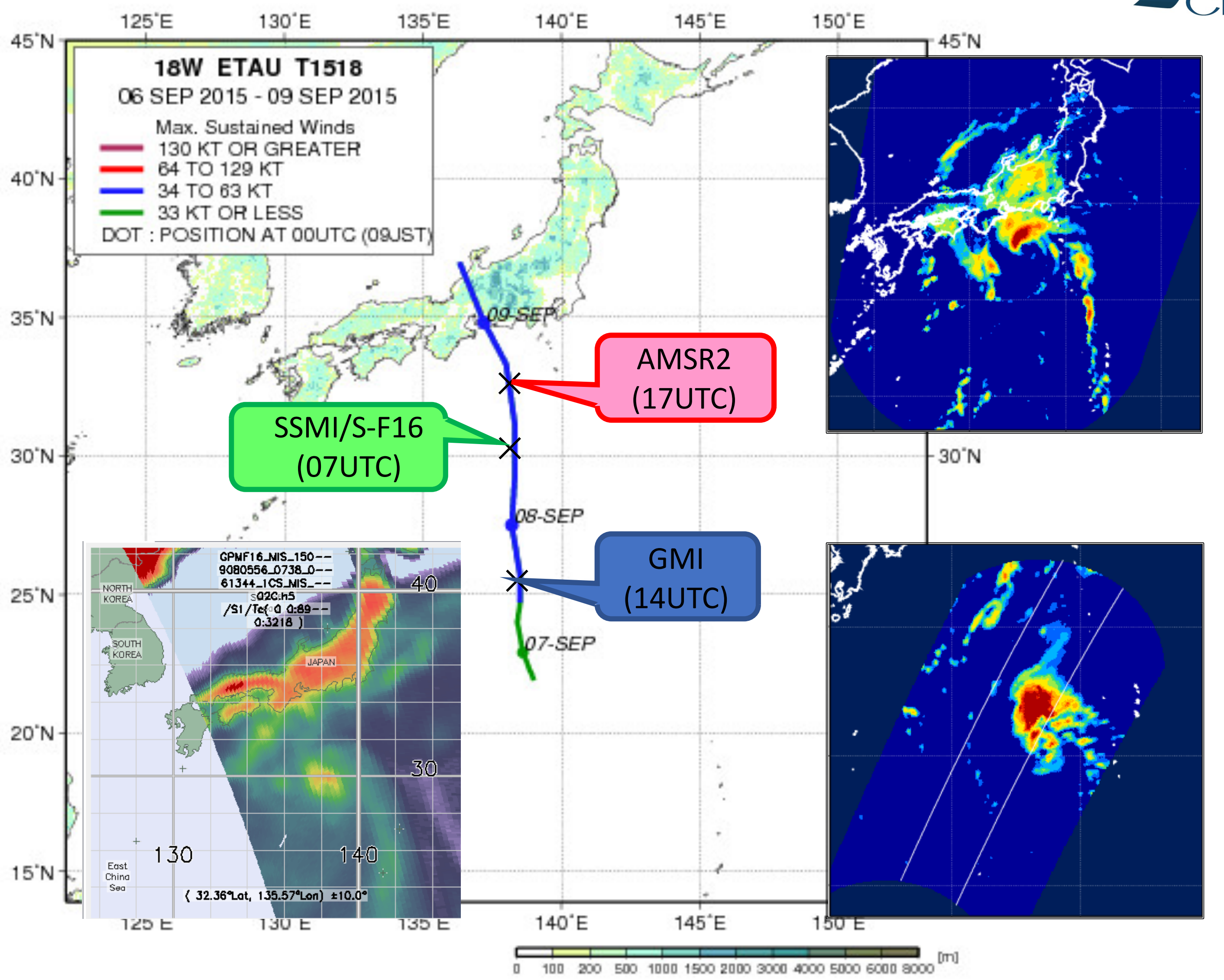
- JMA NHM: 5km, (481x481x50)
- Predicts 6 types of water subsistence

Ensemble forecasts

- Control run starts with initial and boundary data made from GANAL.
- 52 members
- Initial and boundary perturbations are made from the weekly ensemble forecasts (GSM).

EnVAR using the Neighboring Ensemble method

- Hydrometeors and vertical velocities in control variable



(Courtesy of Kazumasa Aonashi)

2. What impacts are we getting from these observations?

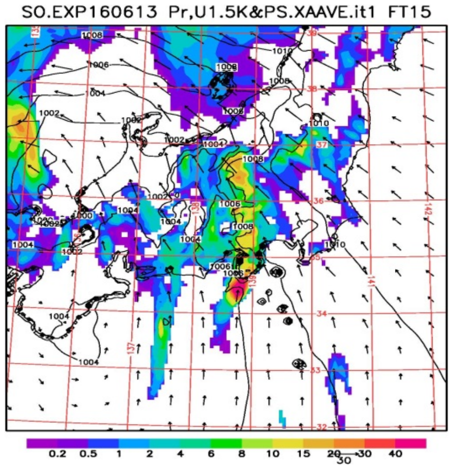
Context / On large scale forecasting scores / On extreme events forecasts / **On precipitation forecasts**

Meteorological Research Institute
Japan Meteorological Agency

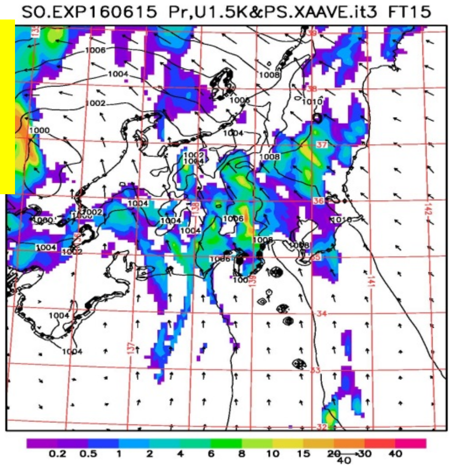
Hourly Precip, Wind@1460m, Ps
FT15 (08 UTC 9th)

The assimilation of rainy TBs improved the CRM precipitation forecast up to 30 hours, in particular, by strengthening and stagnating a rain band over the Kanto Plain.

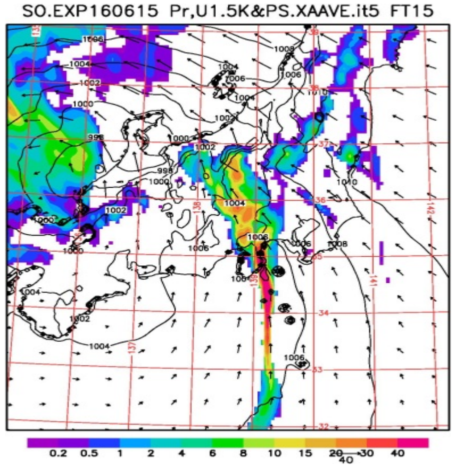
No Assim.



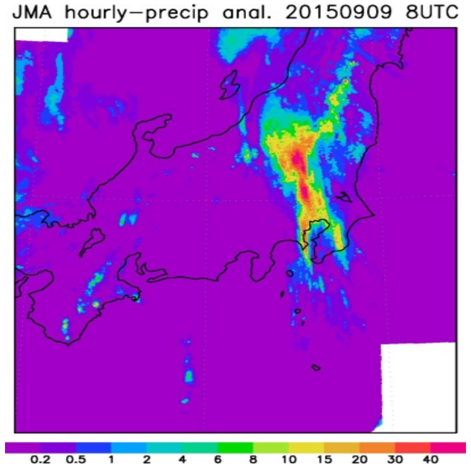
No RainTB Assim.



All-Sky TB Assim.

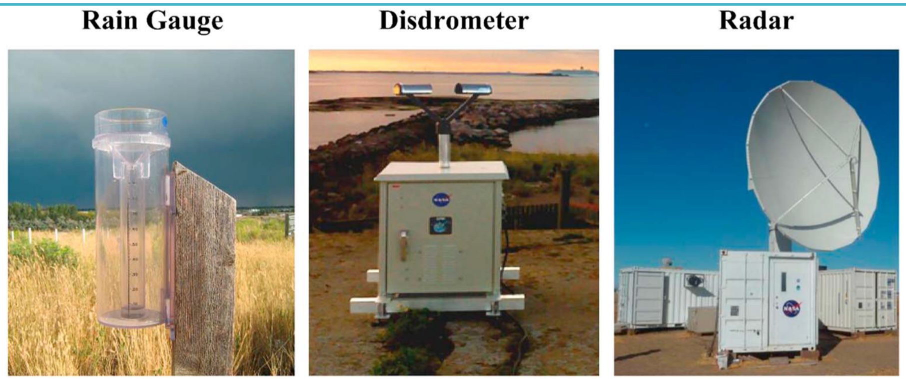


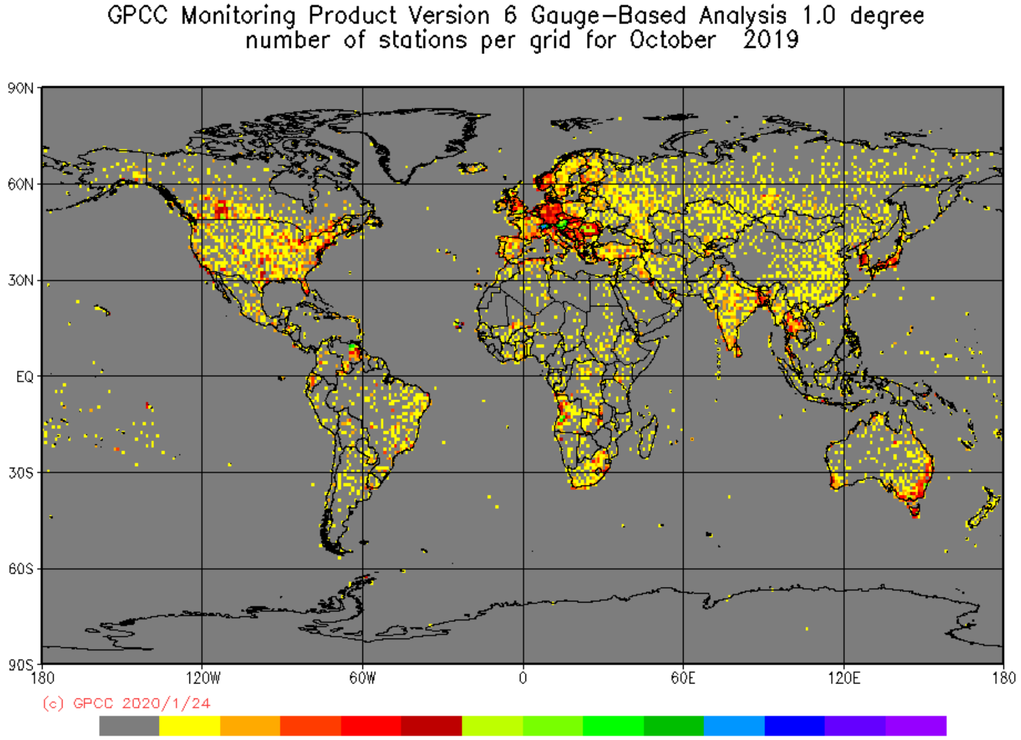
Hourly Precip. Anal



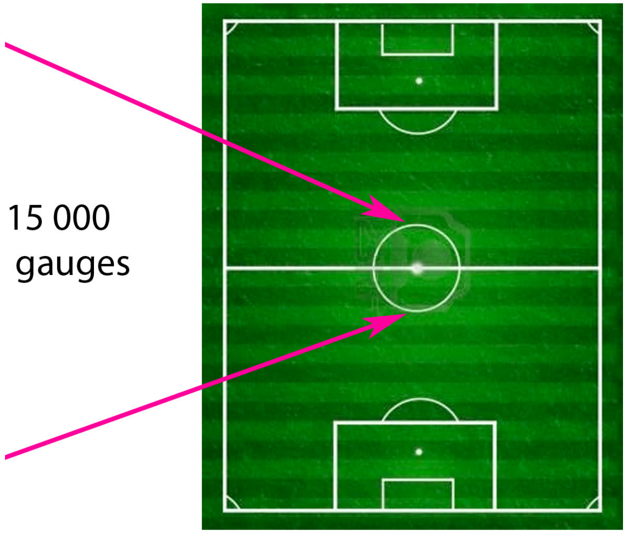
(Courtesy of Kazumasa Aonashi)

For global models and some regional models running over geographical domains where the ground measurement network is sparse, the question of what reference using for validating model forecast arise.





15 000 gauges

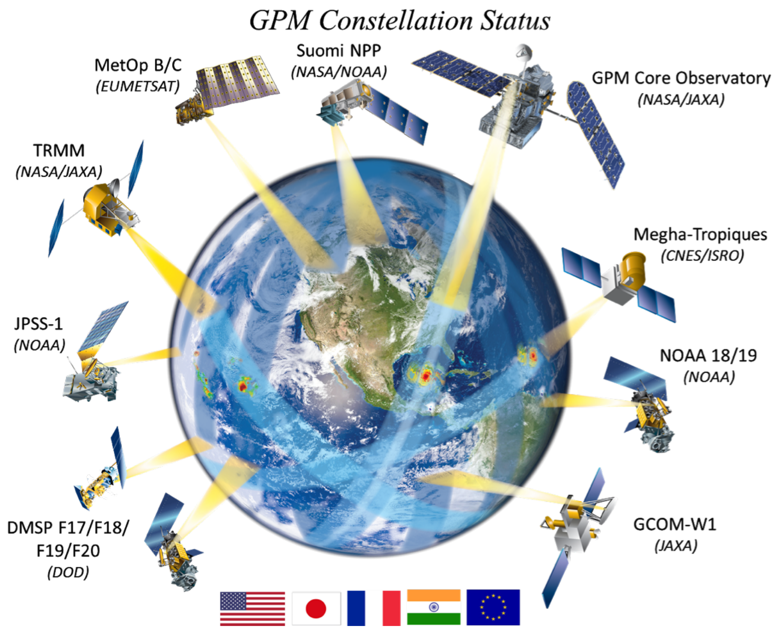


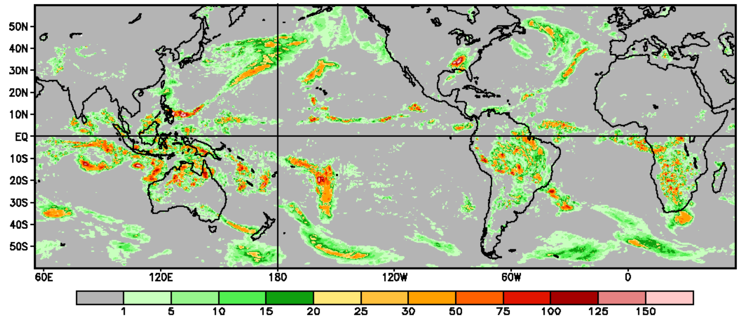
(Courtesy of Chris Kidd)

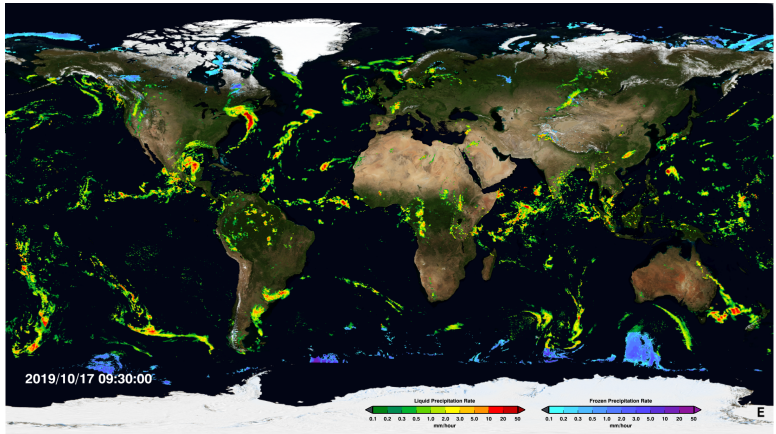
Satellite-based precipitation products haven proven to be useful in the case of lack of good quality ground rainfall estimate

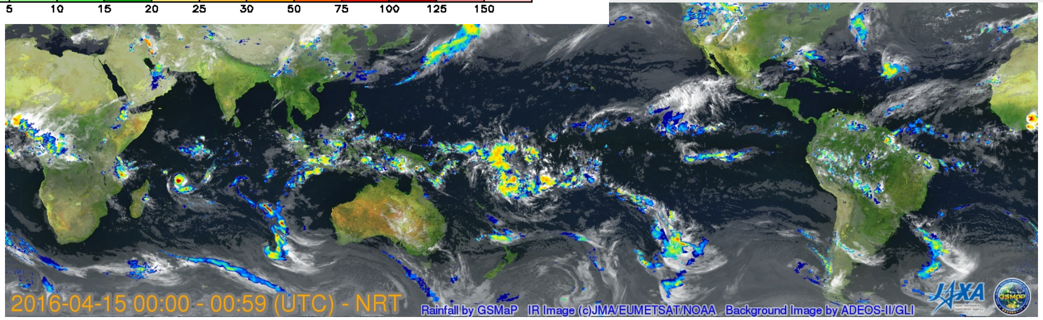
⇒ quite a few different products exist within the community

⇒ IPWG: http://ipwg.isac.cnr.it









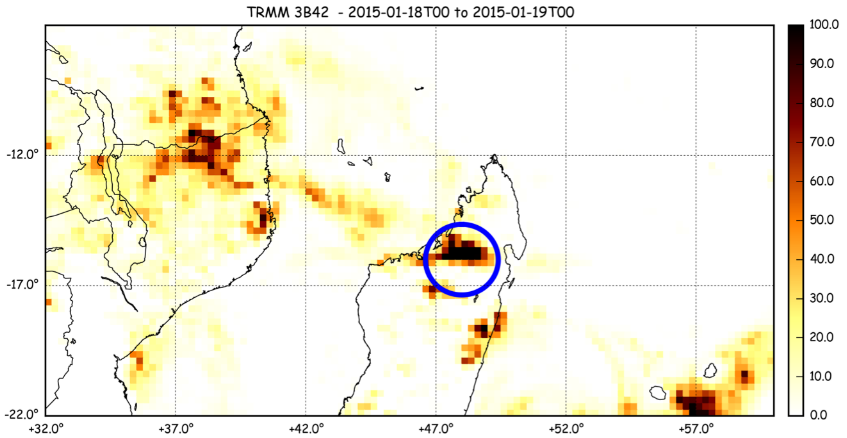
ECMWF

METEO FRANCE

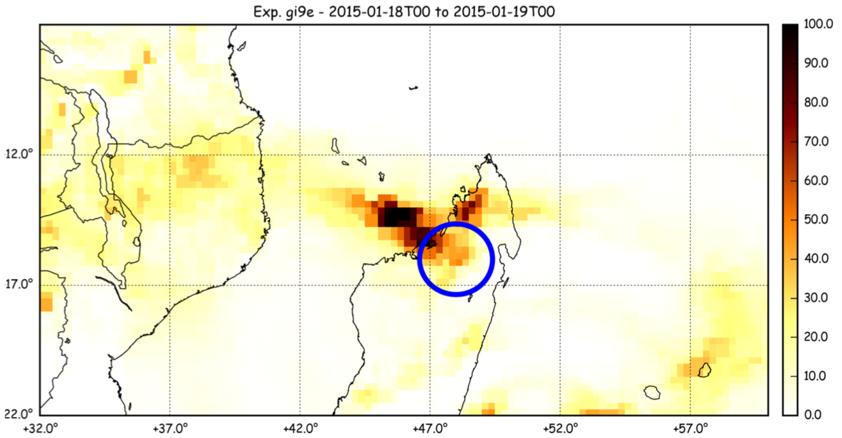
Baseline experiment:

denial of MHS in the tropics and SAPHIR within the ECMWF all-sky system

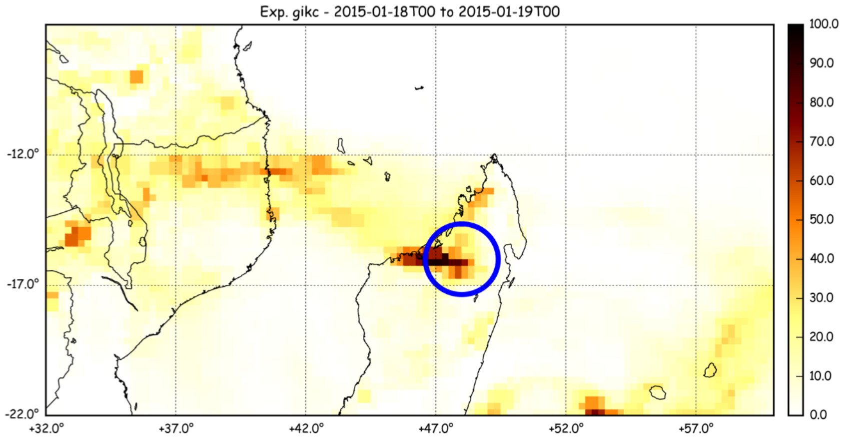
TRMM 3B42 – Jan 18th, 2015



IFS +36h - +12h fcst / Baseline



Baseline + MHS and SAPHIR in all-sky



(Chambon and Geer, 2017)

ECMWF

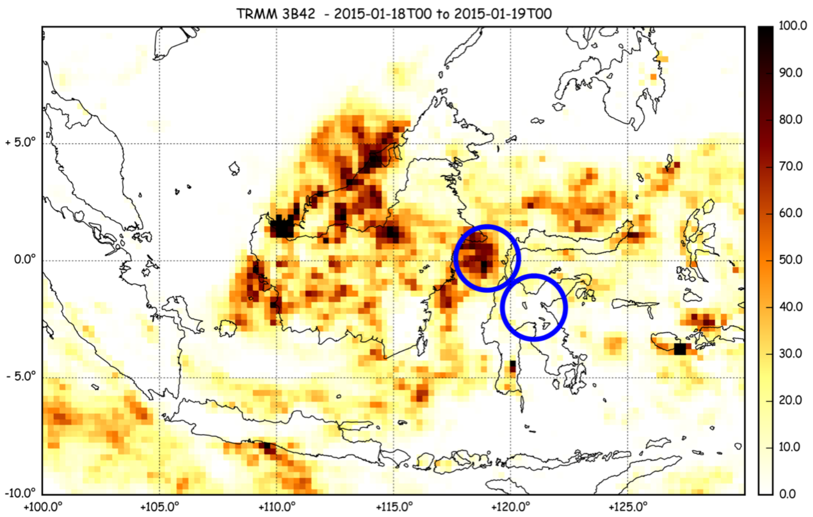
METEO FRANCE

CNRM

Baseline experiment:

denial of MHS in the tropics and SAPHIR within the ECMWF all-sky system

TRMM 3B42 – Jan 18th, 2015



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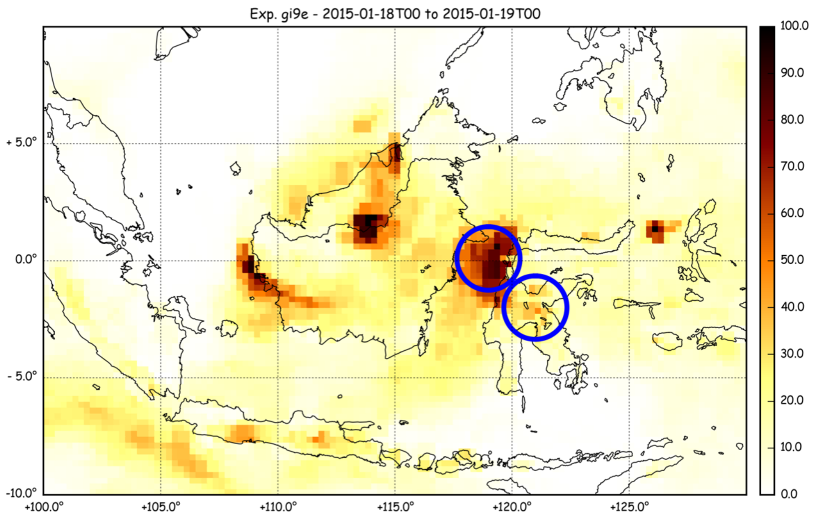
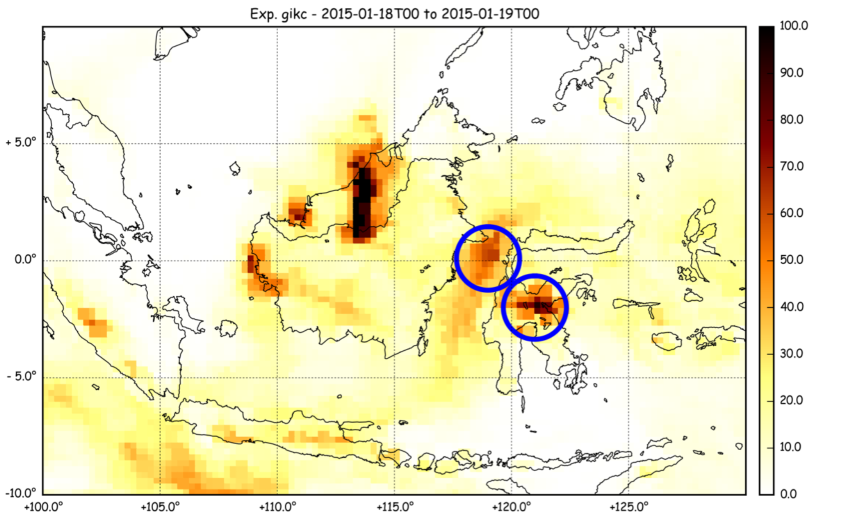


Baseline + MHS and SAPHIR in all-sky



Impact of all-sky data sometimes negative, perhaps for this case due to the complex land/sea mask in this area of the globe

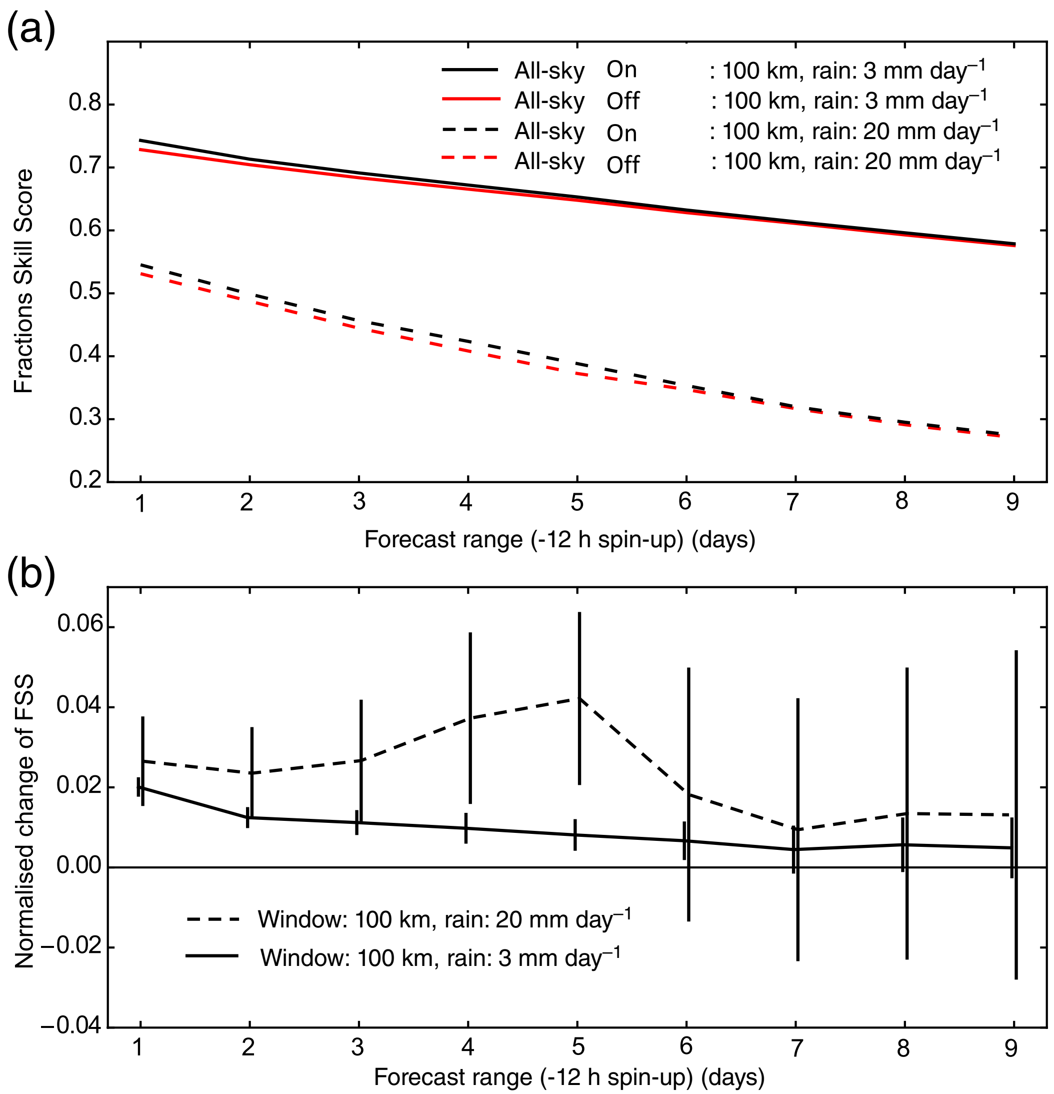
(Chambon and Geer, 2017)

Impact of 9 instruments in all-sky onto tropical ECMWF precipitation forecasts with respect to TRMM 3B42 precipitation estimates

Score: Fractions Skill Score

Period: May to August, 2015

=>In average 2 to 3% improvement of the FSS up to 5 days ahead



(Geer et al., 2018)

Outline of the presentation

1. *Status of the constellation of microwave sounders and imagers: Which frequencies are we currently using/not using within clouds?*

2. *What impacts are we getting from these observations?*
   - *On large scale forecasting scores*
   - *On extreme events forecasts*
   - *On precipitation forecasts*

3. ***What are the current limitations and challenges?***
   - *Observation operator and radiative properties of hydrometeors*
   - *Representation and observation of sub-grid cloud variability*
   - *Representation of cloud life cycle within NWP models and possible link with saturation effects*

3. What are the current limitations and challenges?

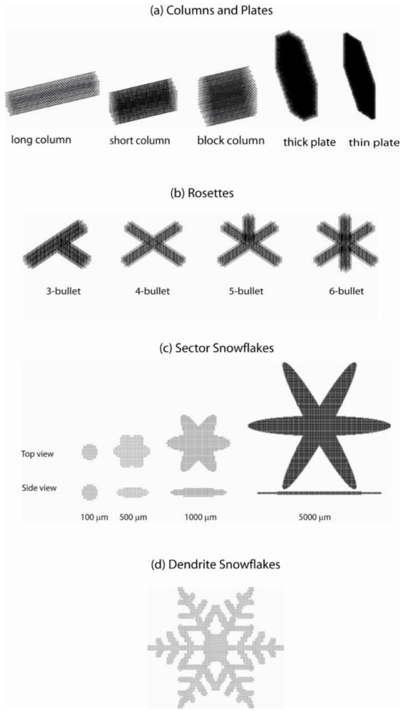
Observation operator / Observation of sub-grid cloud variability / Representation of cloud life cycle

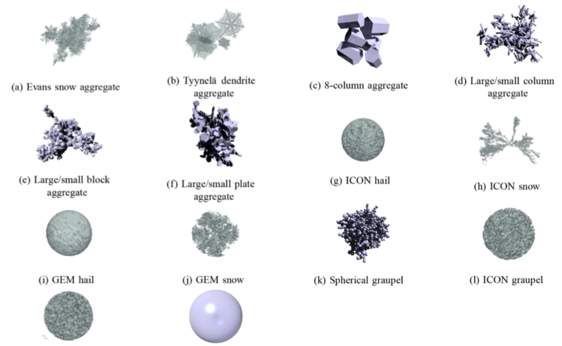
The quality of the obs operator we are using in cloud and precipitation partly rely on the quality of Single Scattering Properties we use

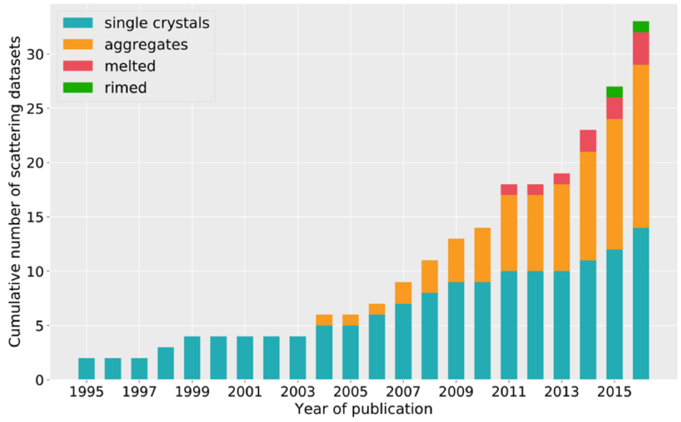
One of the very popular scattering databases, both used within the DA community (in particular thanks to Geer and Boardo, 2014) and within the precipitation retrievals community (Ringerund et al., 2019)

⇒ Liu, 2008 (BAMS)

⇒ Frequencies covered from 13.4 to 340 GHz







New databases available:

⇒ ARTS, Eriksson et al., 2018

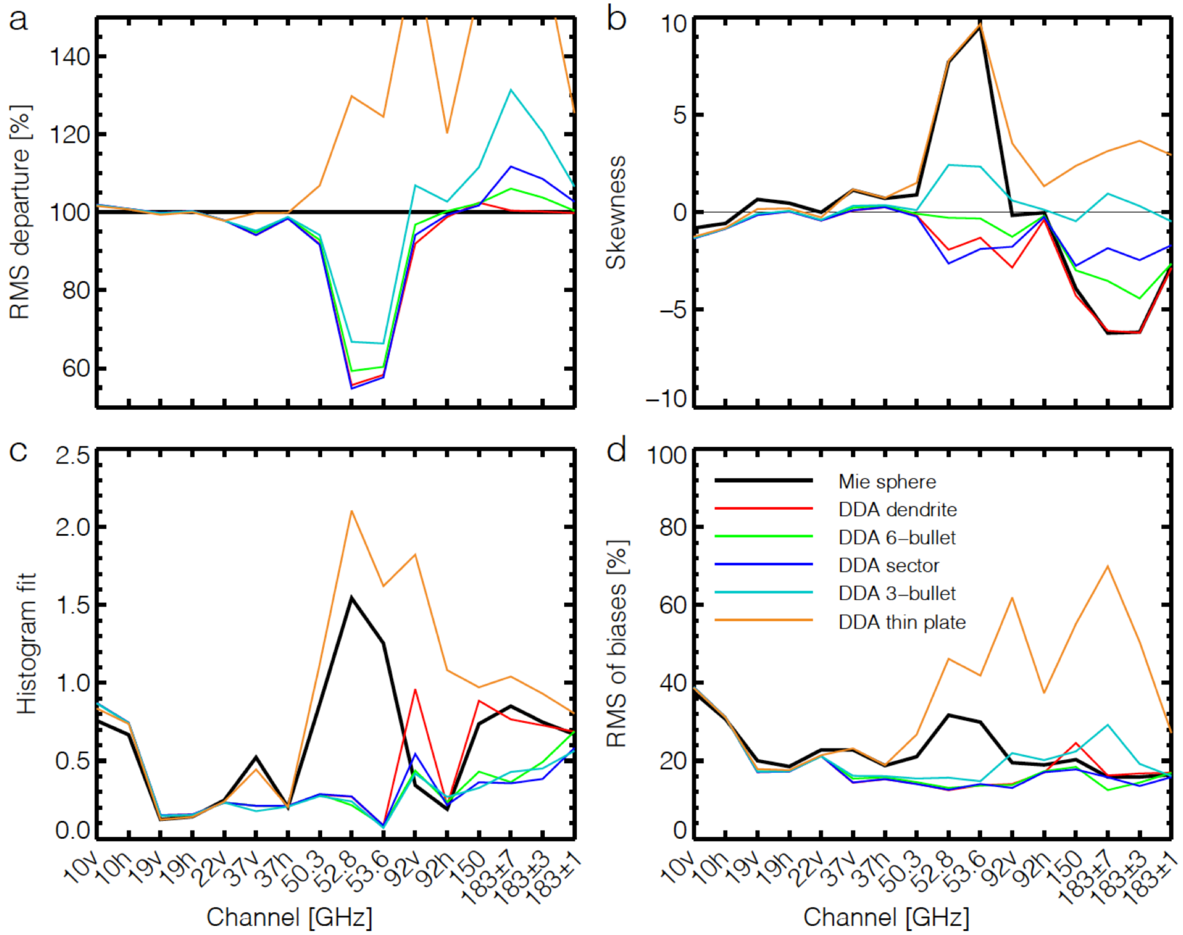
⇒ Frequencies covered 1 to 886 GHz

⇒ 32 shapes including aggregates

Since the mid 90s and the first scattering databases available for the community, the number of databases has significantly increased.

A coordination effort is ongoing within the IWSSM/IPWG community to standardize the databases (both scientifically and technically)

(Kneifel et al., 2017, BAMS)



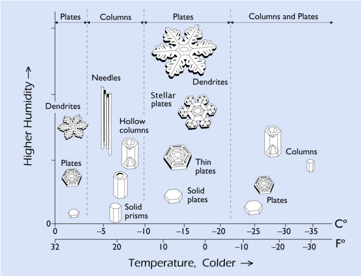
(Geer and Baordo, 2014)

Looking for the best fit of a given combination of particle shape/particle size distribution for a large range of channels like in the study by Geer and Board in 2014 may become "a nightmare" in the next years with this increase of number of scattering database

=> Need for new strategies?

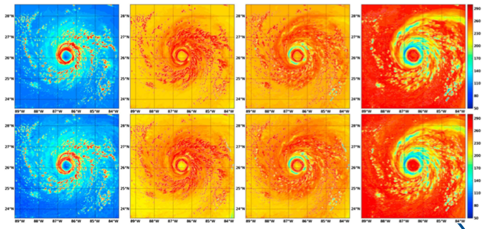
Many possibilities to move forward :

Mixture of crystals like in some databases for InfraRed simulations (Vidot et al. 2015 ; Baran and Labonnote [2007]) ?

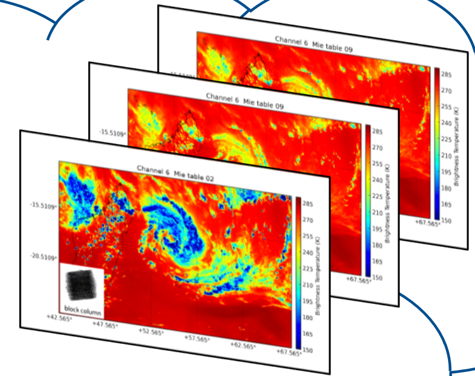


Online choice of optimal particle shape within the DA ?
eg: computation of "hydrotables" online for RTTOV-SCATT

Offline training of observation operators onto ensembles of simulations?
(Haddad et al., 2015)



Using ensemble of forward simulations with various radiative properties directly within DA



(PhD thesis of Marylis Barreyat, 2020 - 2023)

... ?

3. What are the current limitations and challenges?

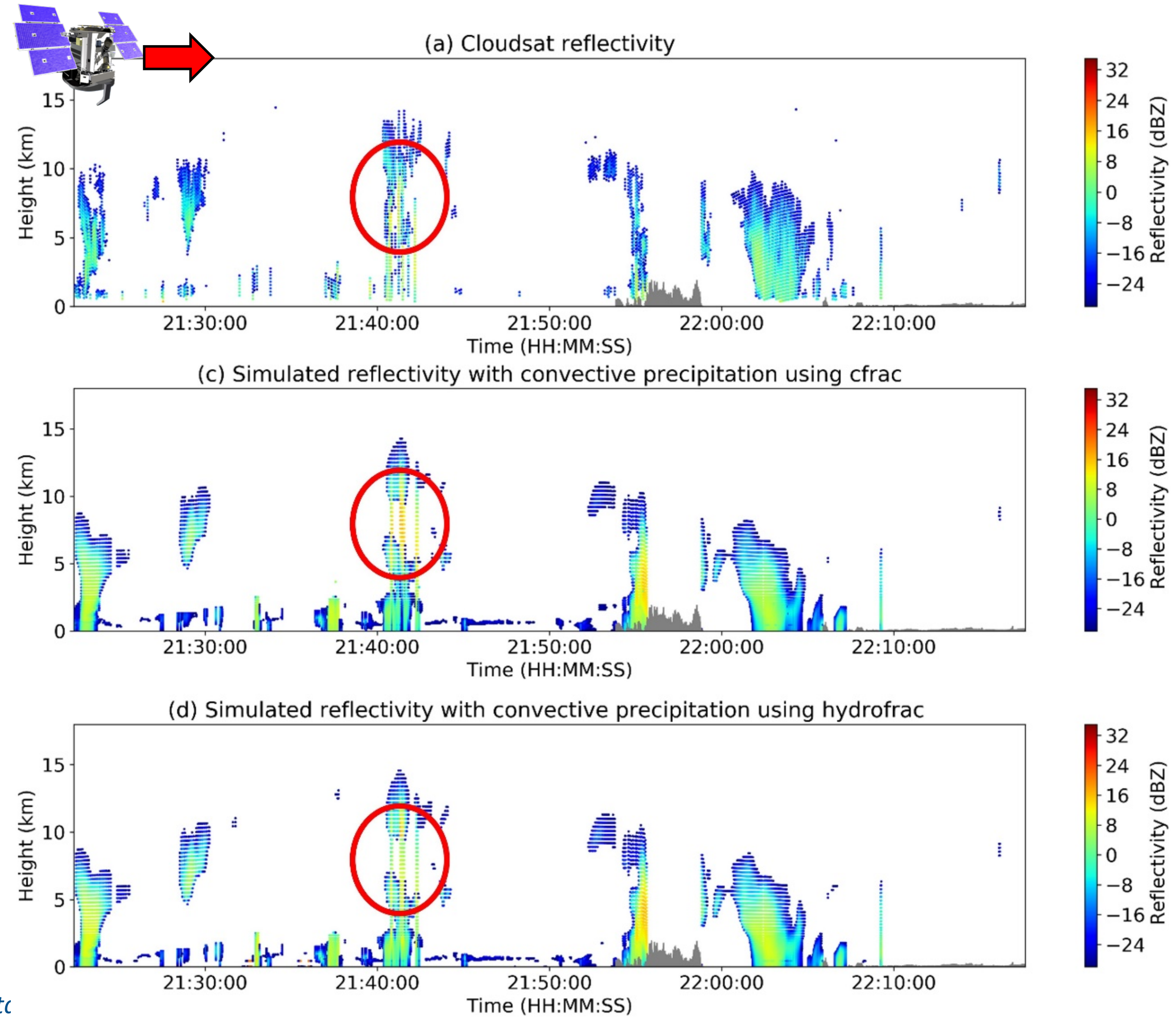
Observation operator / **Observation of sub-grid cloud variability** / Representation of cloud life cycle

A fine modeling of sub-grid cloud variability is usually required to well simulate brightness temperatures

⟹ Easier to spot with space radars and their vertical discretization

Cloudsat observations

Simulations with the ARPEGE global model and the new active sensor module within RTTOV-SCATT



Overestimation of 94GHz reflectivity simulations when using the effective cloud fraction approach of Geer et al. (2009)

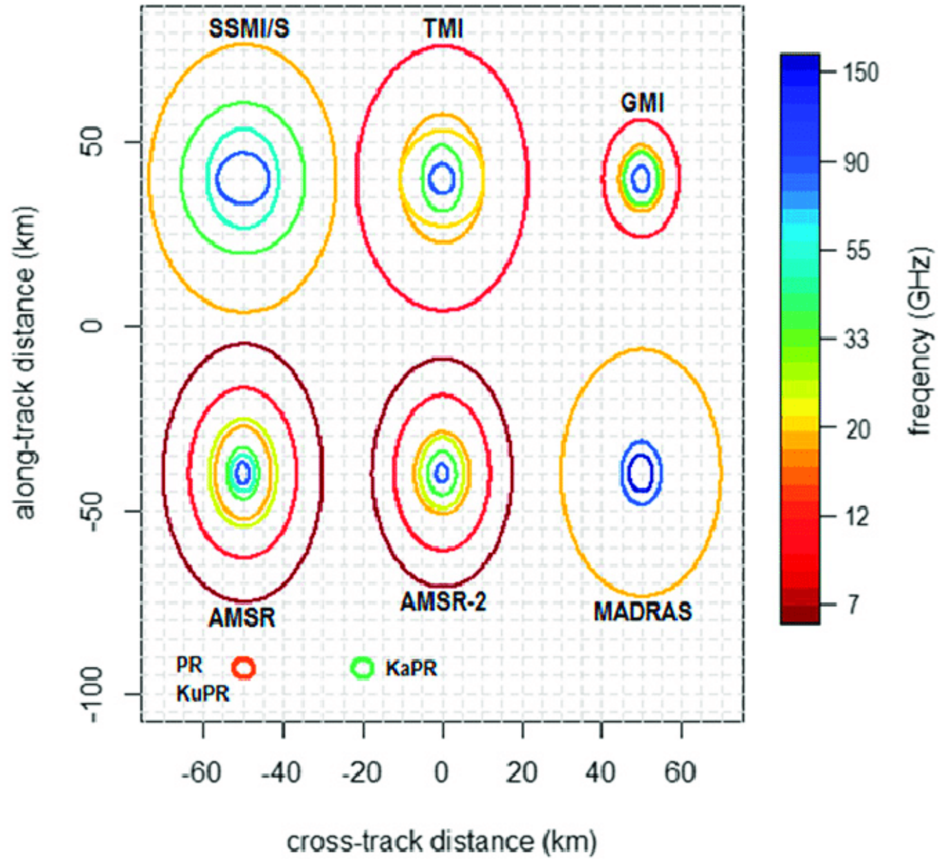
More realistic simulations when using a full profile of precipitation fraction within the calculations

(PhD thesis of Rohit Mangla)

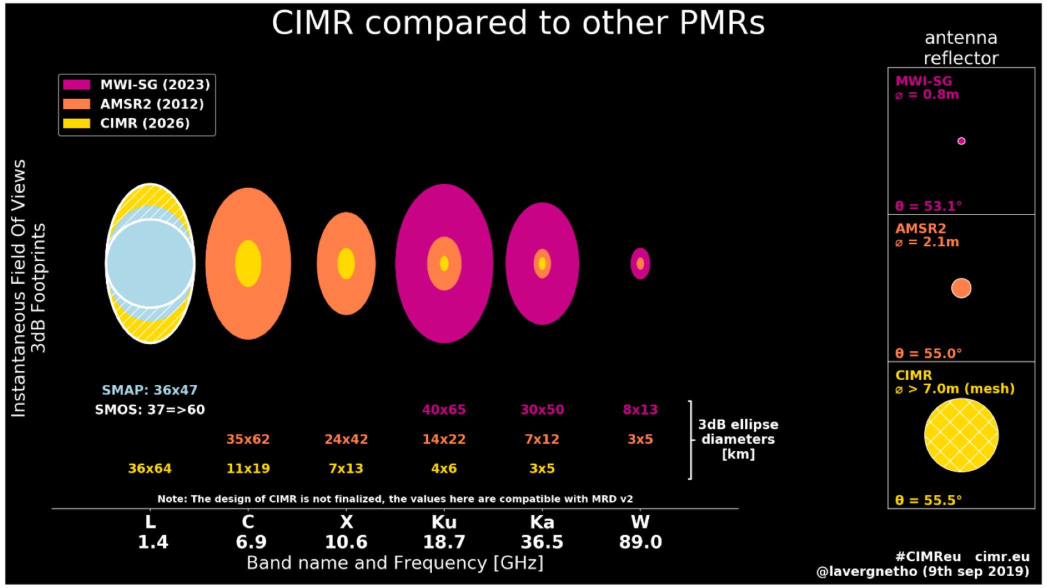
3. What are the current limitations and challenges?

Observation operator / Observation of sub-grid cloud variability / Representation of cloud life cycle

The inconsistency of horizontal resolutions across channels remains a challenge to fully exploit current and future sensors



(Guilloteau et al., 2017)

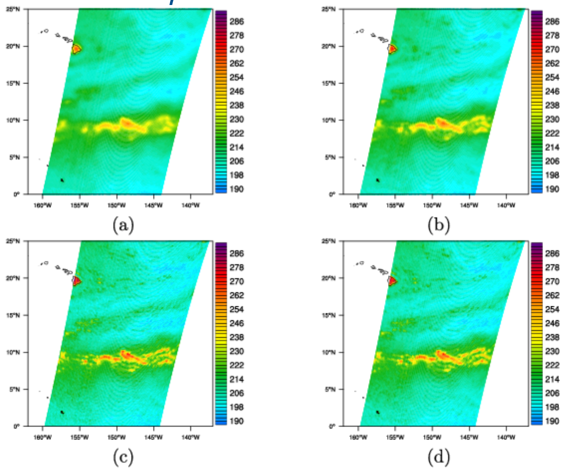


CIMR: Copernicus Imaging Microwave Radiometer
Copernicus High Priority Candidates
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates

3. What are the current limitations and challenges?

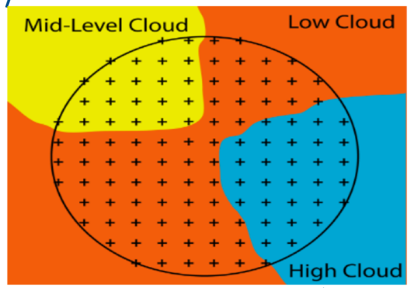
Observation operator / Observation of sub-grid cloud variability / Representation of cloud life cycle

Superobbing of observations at the lowest resolution across channels is still a very relevant strategy, but will we need a need strategy in the next years with the increase in resolution of NWP systems?



Deconvolution of observations across channels?
Steward, Haddad et al., 2019

In the IR, high resolution imagers are often used to evaluate the non uniform beam filling (eg. IASI and AVHRR, Farouk et al., 2019)



Would using high resolution imager information be useful as well for better exploiting microwave observations within clouds?

3. What are the current limitations and challenges?

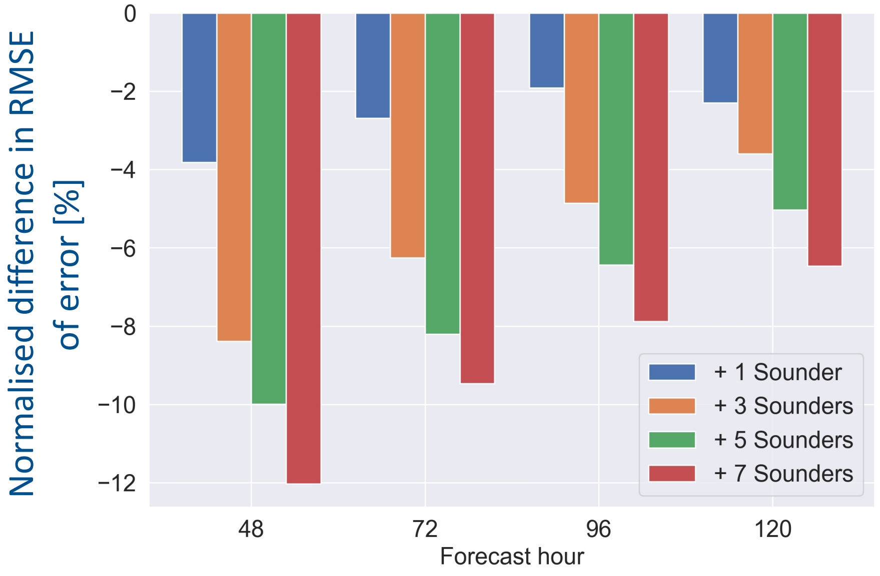
Observation operator / Observation of sub-grid cloud variability / Representation of cloud life cycle

- It is likely that a model forecast can benefit of frequent and high resolution cloud and precipitation observations through Data assimilation only if the model forecast itself can resolve the scales and reproduce the variability of observations in space and time.

- Some saturation in terms of number of microwave imagers that can be assimilated has been reported in the past, was it related somehow to the representation of cloud life cycle?

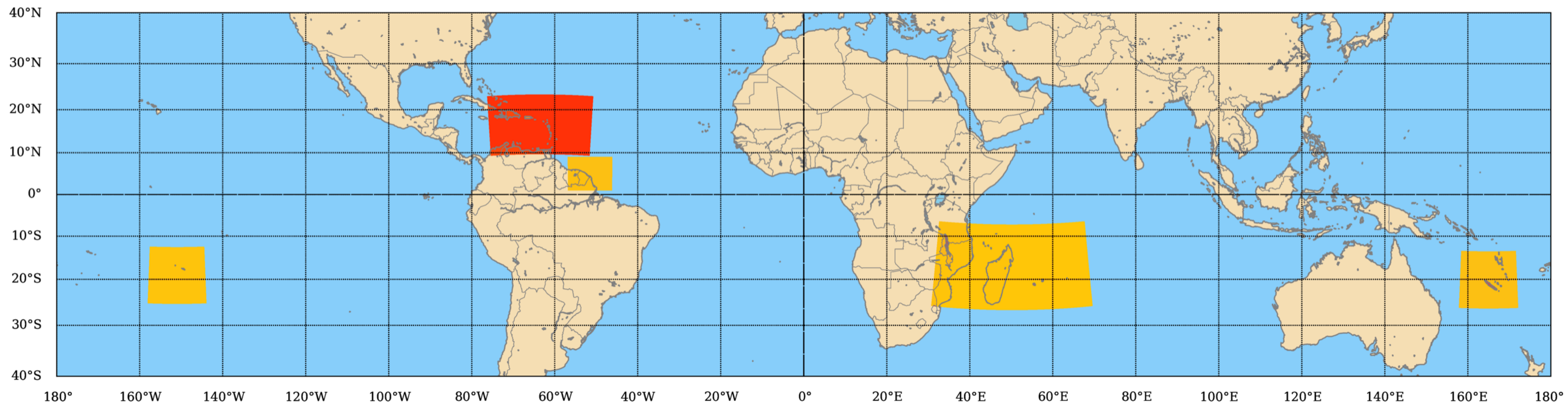
- It does not seem to be the case for sounders and an all-sky approach, but is it really the case for cloudy observations?

Z500 - Southern Hemisphere



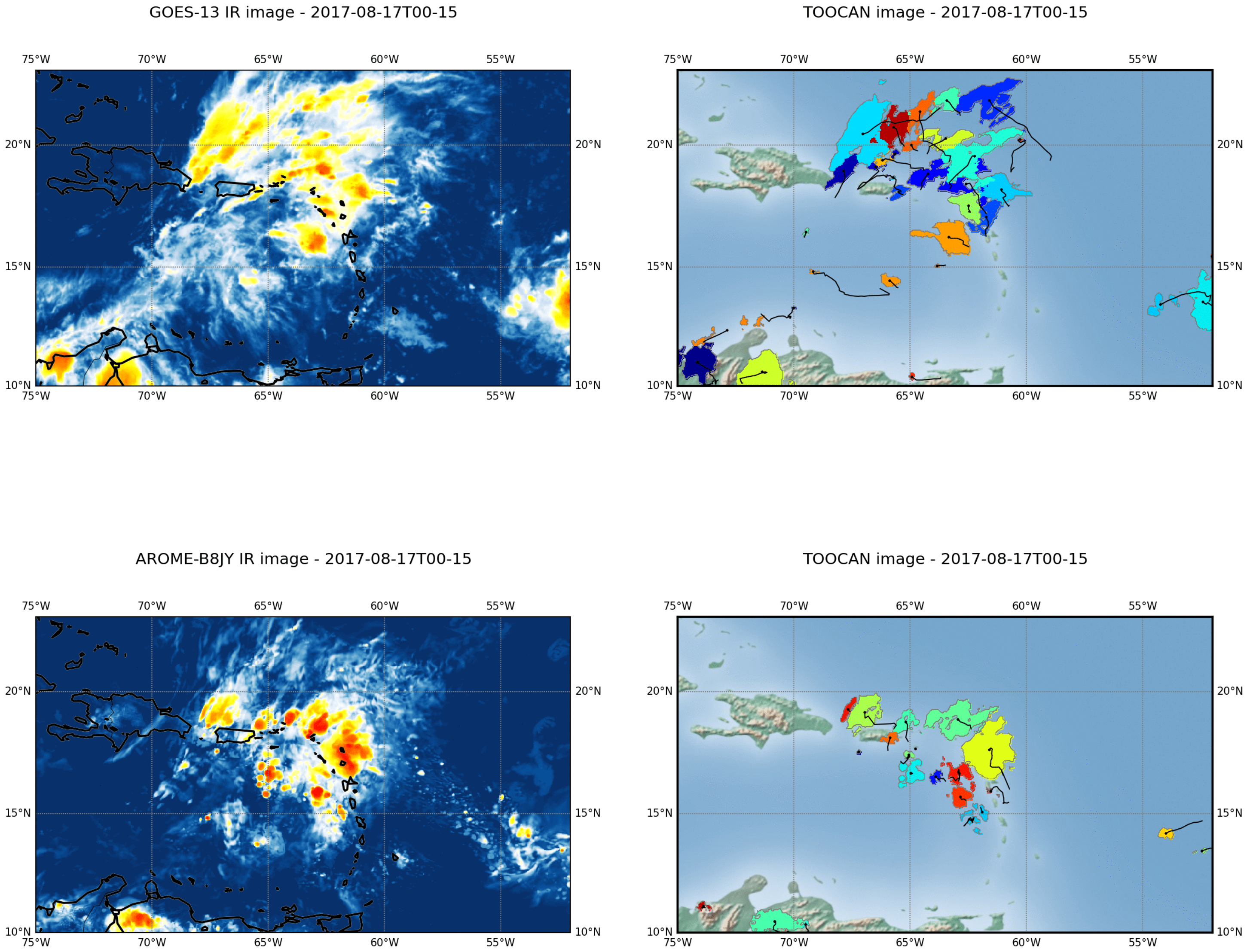
(Courtesy of N. Bormannn)

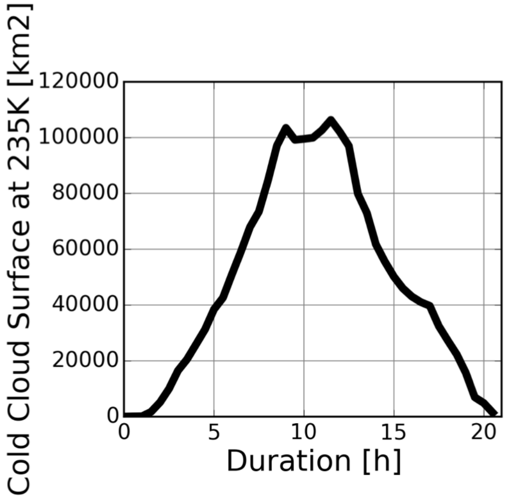
One study was performed in collaboration between Météo-France and LEGOS/CNRS to evaluate the representation of cloud life cycle with the AROME OM (Faure et al., 2020), focusing on tropical convection from an IR perspective. The study uses a cloud tracking algorithm called TOOCAN (Fiolleau and Roca, 2013)



AROME Overseas geographical domains in orange/red

Period: August 1st, 2017 – October 10th, 2017
Domain: Caribbean's
Observations: GOES-13 TIR
Model simulations: 30 minutes images from +3h forecasts from an AROME 3D-Var with 3h cycles
Radiative transfer: RTTOV V12- Vidot/Baran ice cloud parametrization



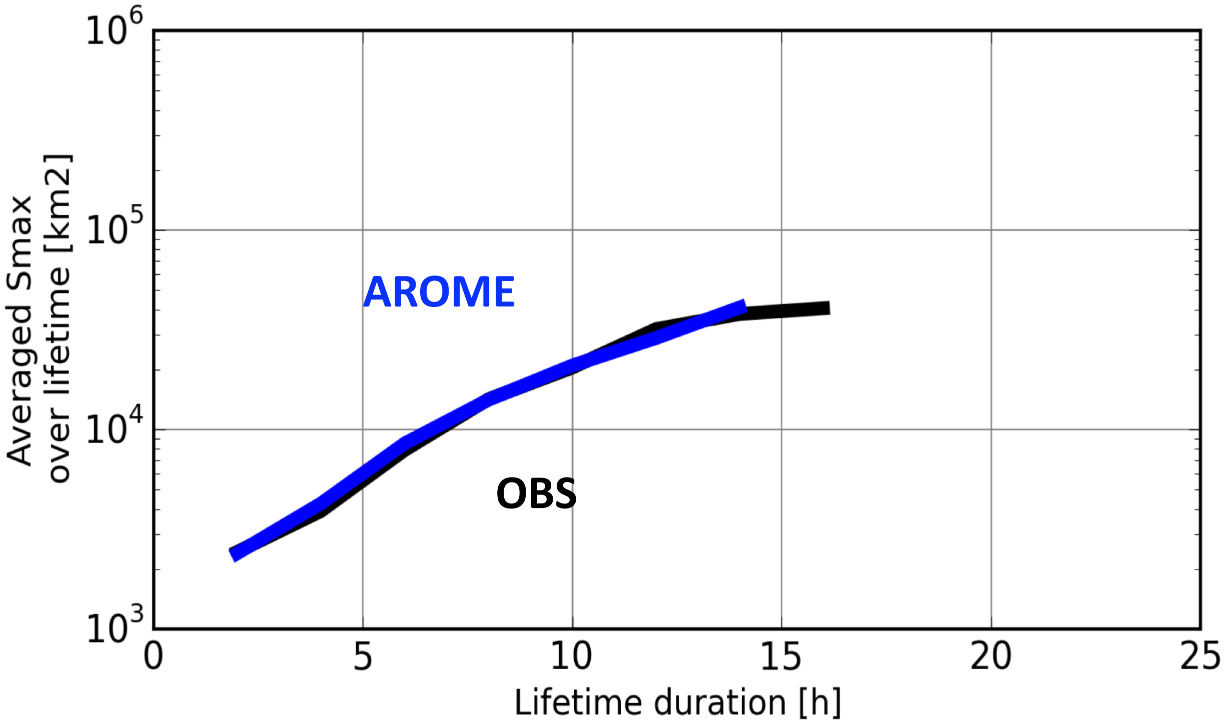


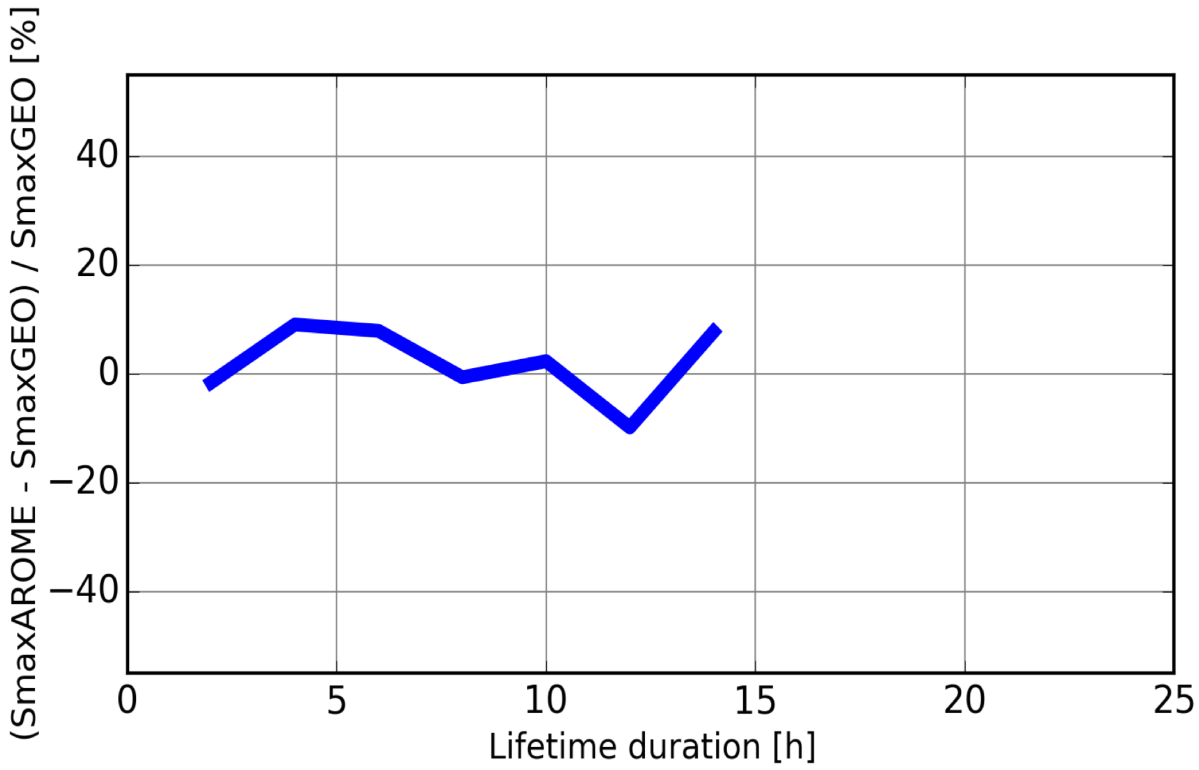
Duration: 21h
Smax: 106.352 km²
Tbmin: 180K
Distance: 329.65 km

(Courtesy of Thomas Fiolleau)

3. What are the current limitations and challenges?

Observation operator / Observation of sub-grid cloud variability / **Representation of cloud life cycle**

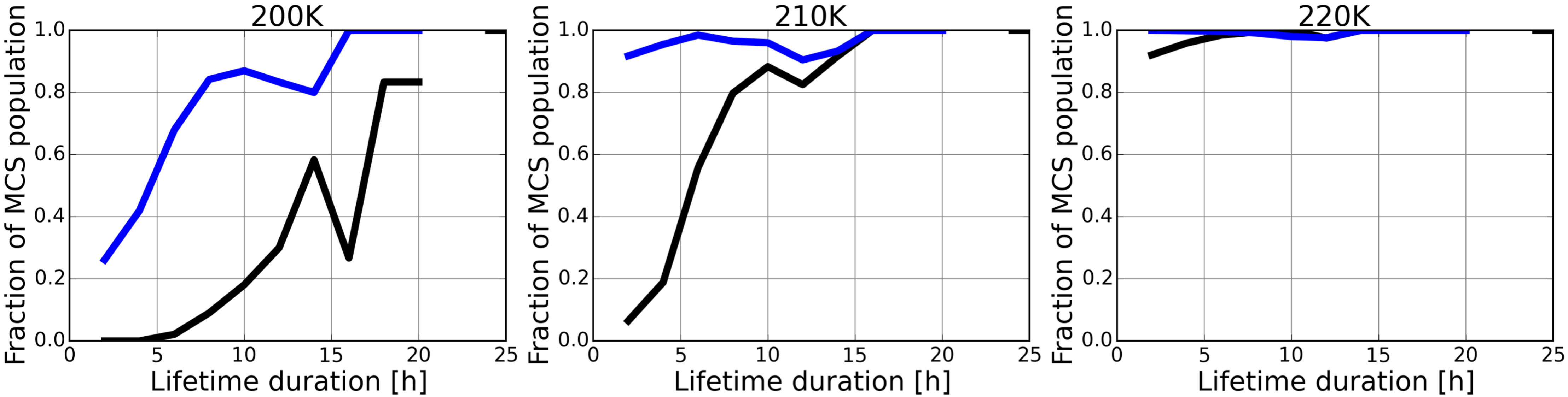




- Similar evolution of the relation lifetime duration vs Maximum size between AROME and observations
- Bias of maximum size ranging between -10 and +10%

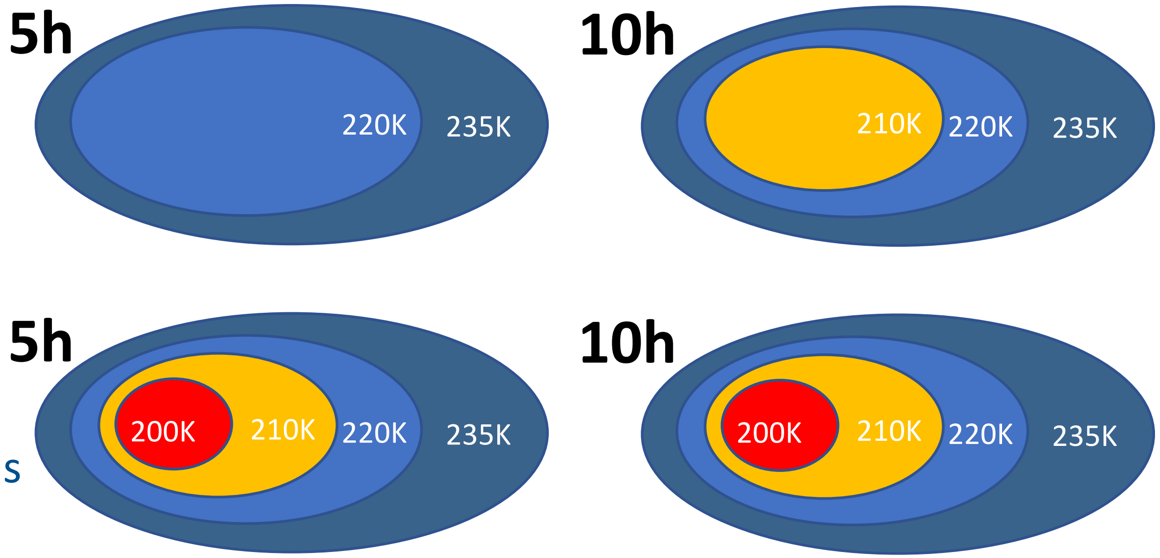
(Courtesy of Thomas Fiolleau)

Observation operator / Observation of sub-grid cloud variability / Representation of cloud life cycle



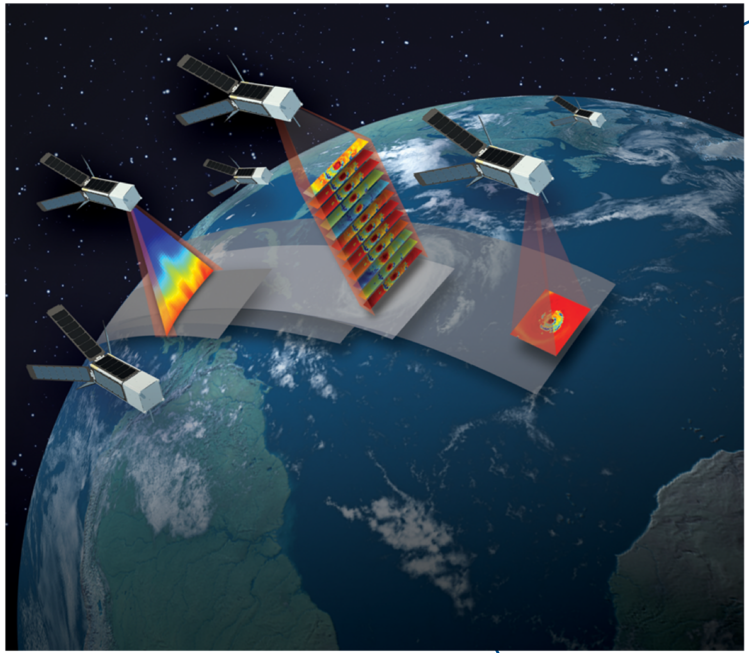
Most frequently observed clouds

Most frequently forecasted AROME clouds



While producing clouds with highly realistic characteristics, AROME tends to produce very cold TIR brightness temperatures independently of the lifetime duration of convection

(Courtesy of Thomas Fiolleau)



(https://tropics.ll.mit.edu)

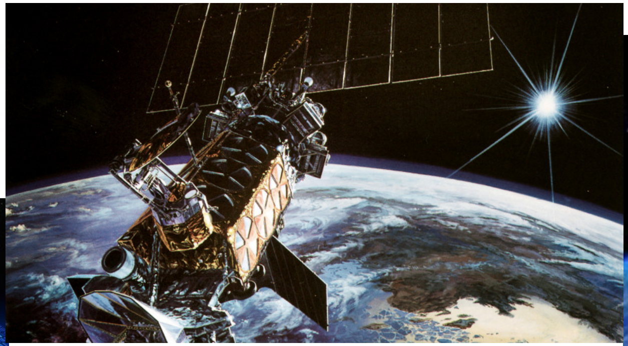
Future constellation of cubesats with microwave sounders may significantly increase the density of observations, in space and time.

Are our model physics ready to ingest and be constrained very frequently within cloud and precipitation?

If not yet, can we estimate at what stage we currently stand?

Thank you !

DMSP ..

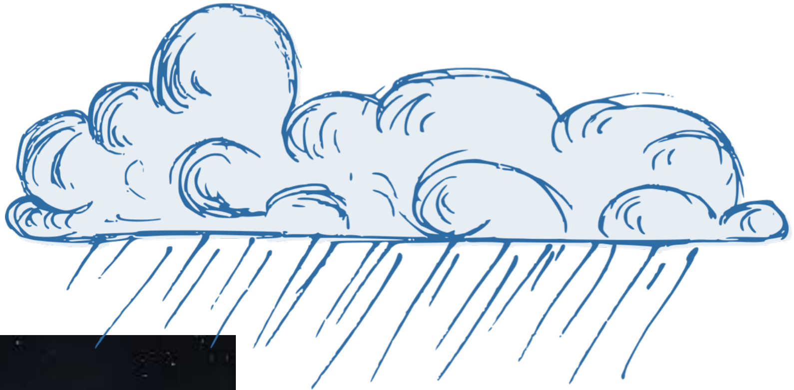


GCOM-W1

GPM Core Observatory

Megha-Tropiques

NOAA ..



TRMM

JPSS

MetOp ..

FY3 ..