Passive and active observations of clouds and precipitation for model validation and data assimilation

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Many Thanks to :
Liselotte Bach (DWD), Marylis Barreyat (MF), Niels Bormann (ECMWF), Olivier Caumont (MF), Mark Fielding (ECMWF), Alan Geer (ECMWF), Yasutaka Ikuta (JMA), Marta Janiskova (ECMWF), Masahiro Kazumori (JMA), Christina Köpken-Watts (DWD), Philippe Lopez (ECMWF), Rohit Mangla (MF), Kozo Okamoto (MF), Leonhard Scheck (DWD)

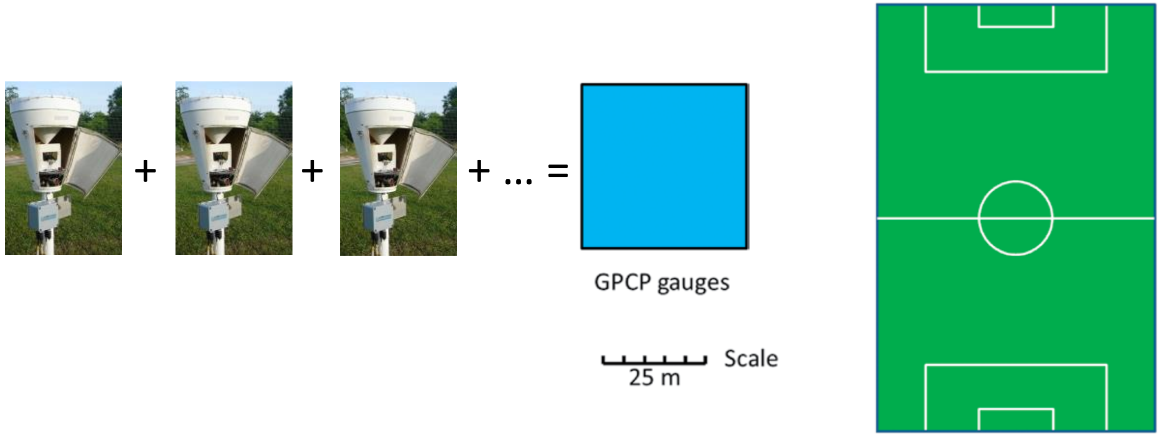
Introduction : precipitation variability

Precipitation – both rain and snow:

- is **highly variable in time and space**;
- has intensities heavily skewed towards zero;
- has **characteristics that vary by location**.

The **ground based network** for precipitation monitoring (e.g. rain gauges) is very heterogenous and only **partially sample rainfall on a global scale**.

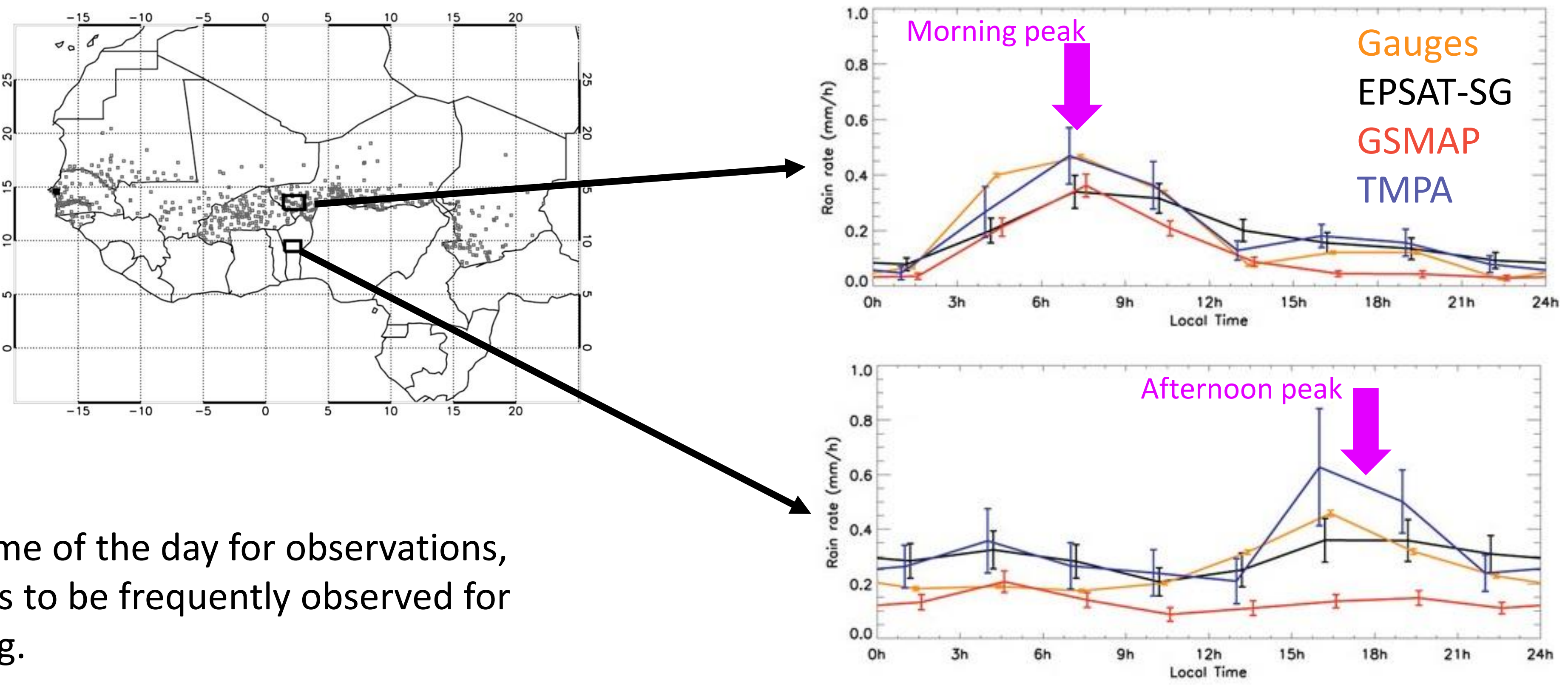
=> **Only satellites can provide the necessary sampling** for precipitation observation on a global scale.



(Kidd, et al., 2017)

Introduction : precipitation variability

Precipitation is characterized by a **diurnal cycle** which can **vary significantly geographically**.

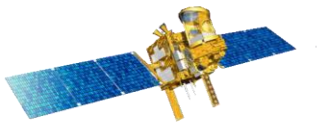


=> No preferred time of the day for observations, precipitation needs to be frequently observed for a global monitoring.

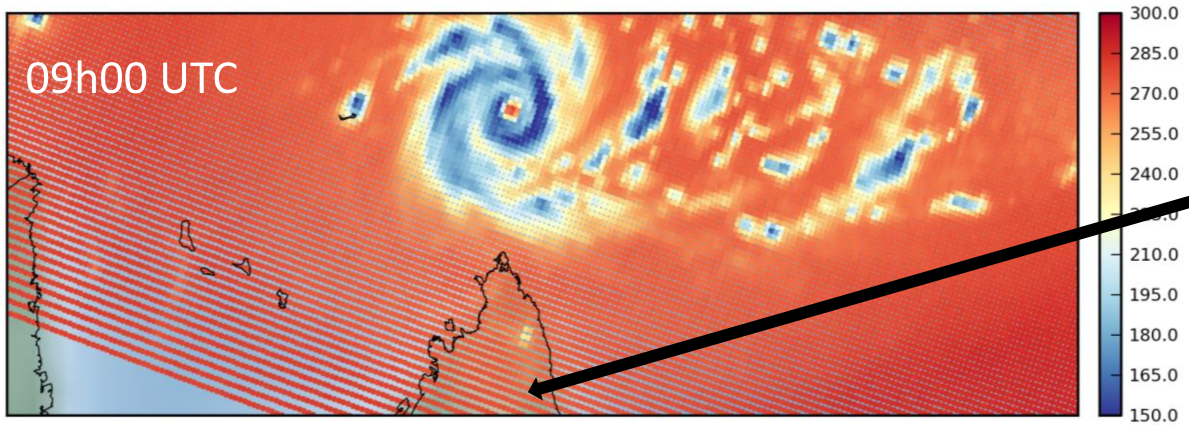
(Roca et al., 2009)

Introduction : precipitation variability

Numerical Prediction Models are becoming more and more capable to forecast realistic clouds and precipitation structures, but need observational constrain to improve their skills.

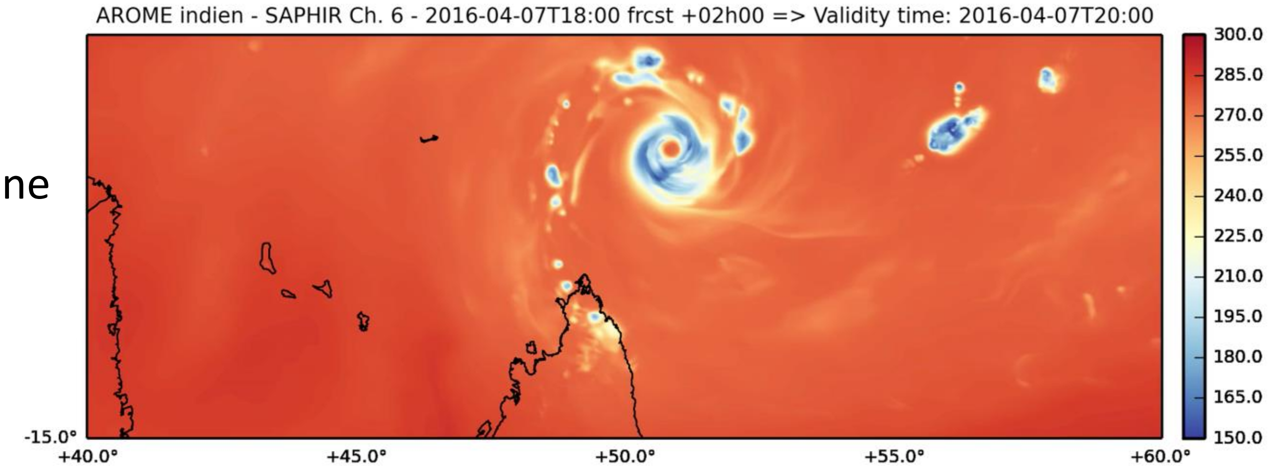


SAPHIR /Megha-Tropiques observations
10km res.

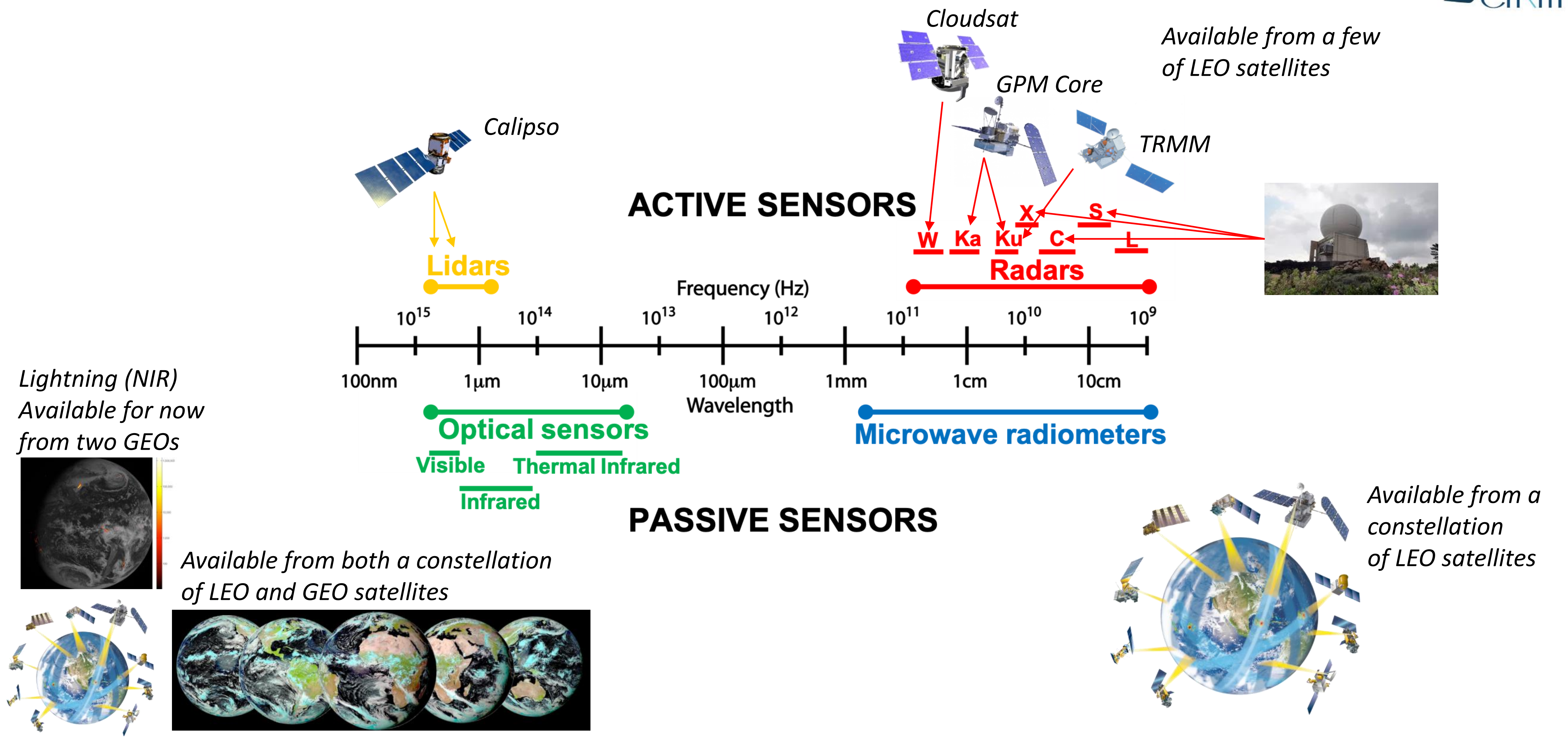


North of Madagascar

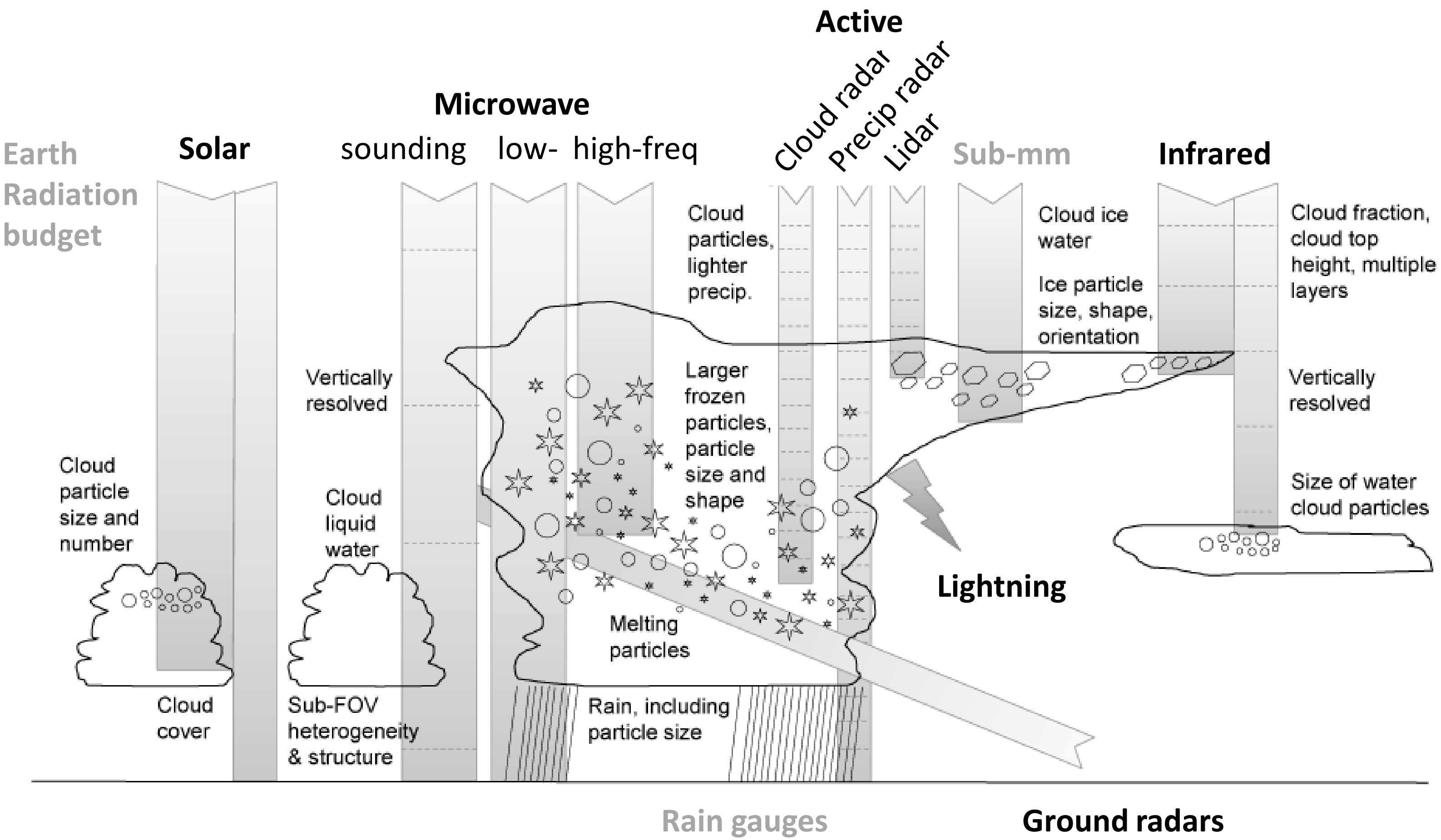
AROME forecast of cyclone Fantala in April, 2016
2.5km res.



Introduction : observing clouds and precipitation

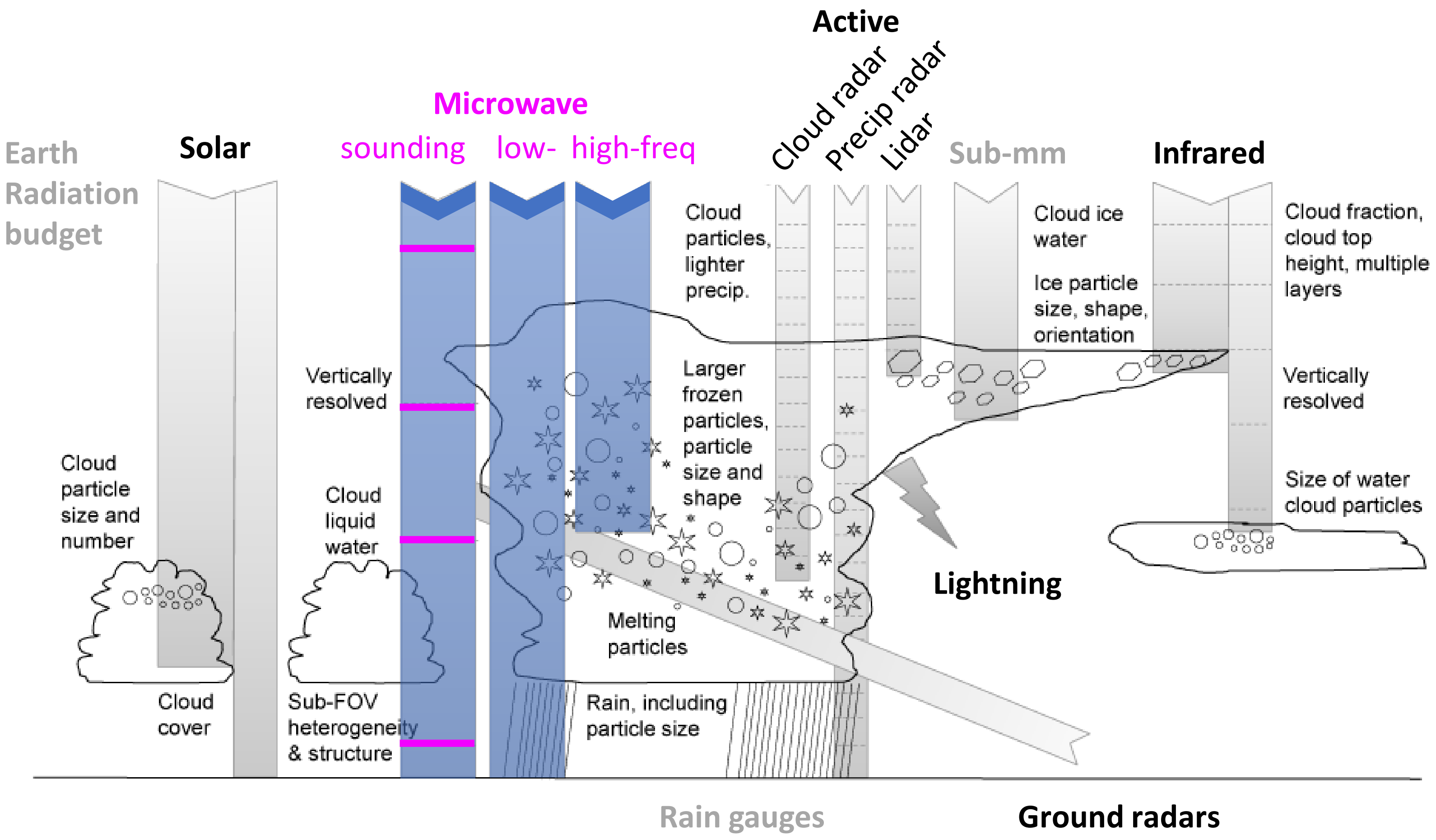


Outline of the presentation



(Courtesy of A. Geer and S. English)

1. Passive microwave observations



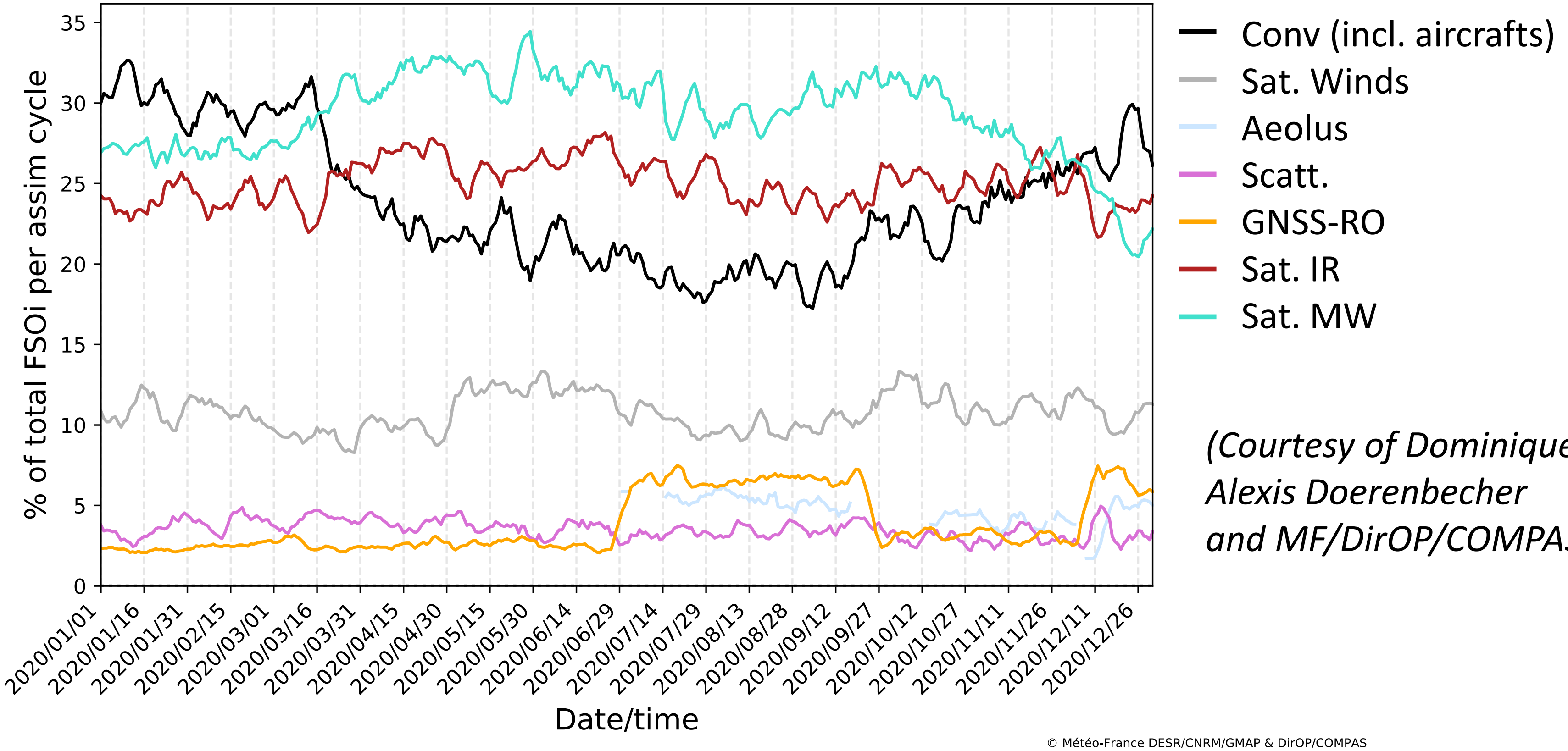
The microwave spectrum offers a unique, **continuous sensitivity,** from the clear sky scenes (water vapour and temperature) to the cloudy and precipitating scenes.

(Courtesy of A. Geer and S. English)

1. Passive microwave observations

The usage of MW observations, **in clear-sky, already provides a significant fraction of total impact (~30%)** (either 1st or 2nd most impacting observing system in MF NWP ARPEGE model).

FSOi per obs group in the ARPEGE 4D-Var
(dry norm, dry adjoint)

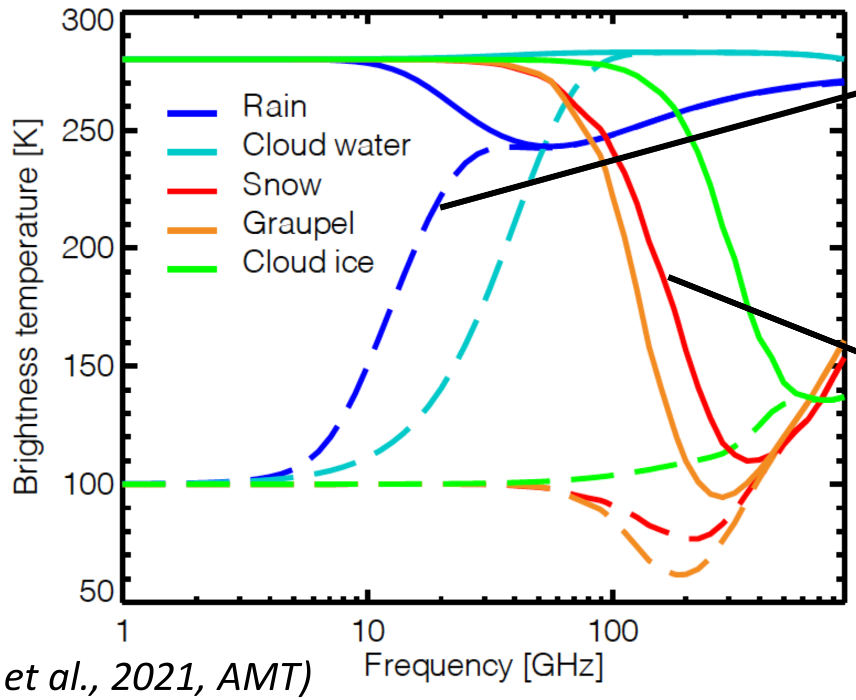


(Courtesy of Dominique Raspaud, Alexis Doerenbecher and MF/DirOP/COMPAS)

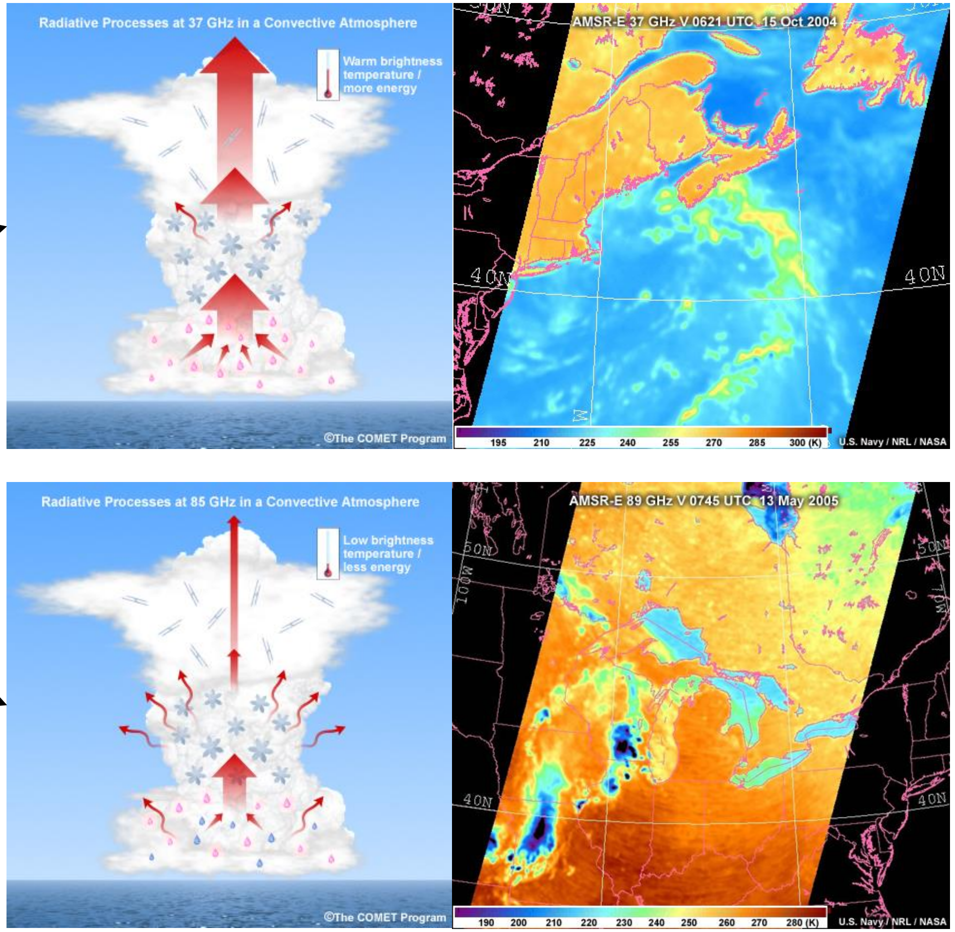
1. Passive microwave observations

This sensitivity is **continuous across the spectrum for condensed water mass** (rain, cloud water, snow, graupel, cloud ice).

Cloud-top TB simulated from uniform slabs composed of one of the default hydrometeor types present in a 2 km thick layer with a water content 10^{-3} kgm^{-3}



(Geer et al., 2021, AMT)



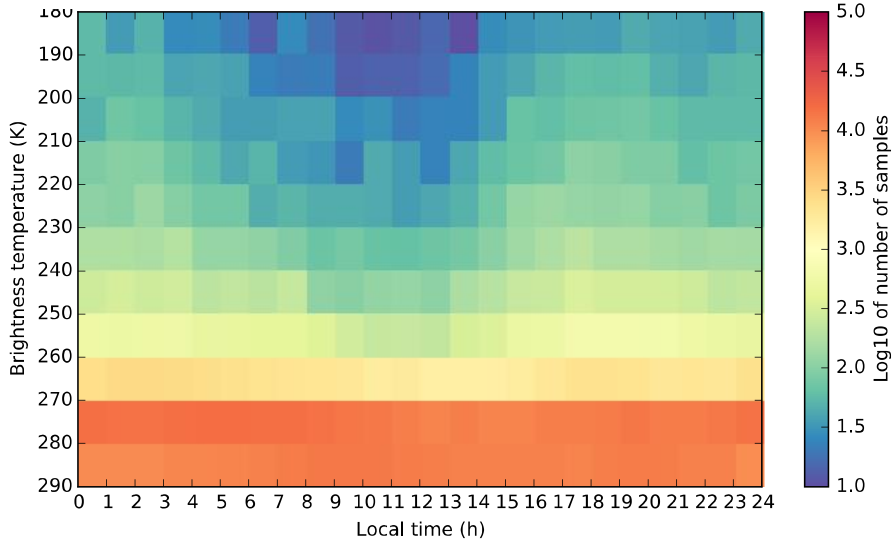
(COMET, UCAR)

1. Passive microwave observations

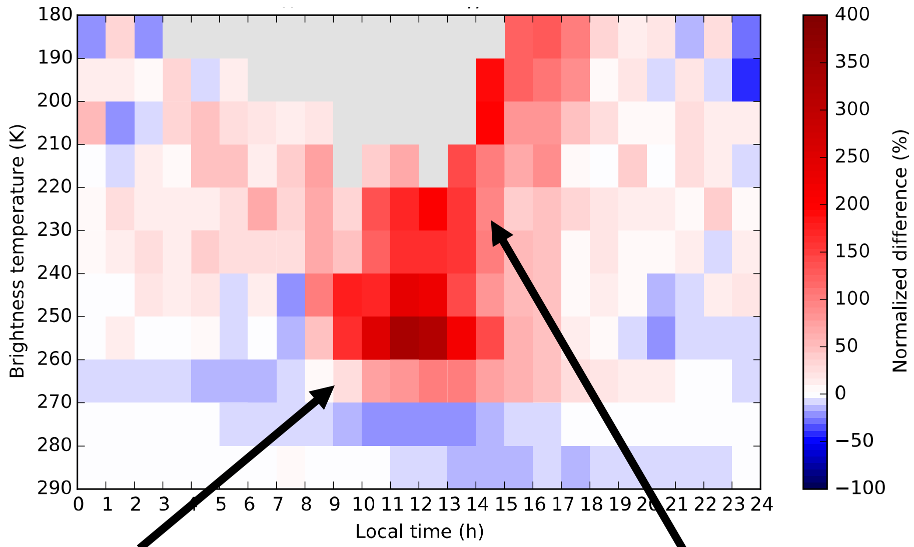
This continuous sensitivity allow to **assess the model representation of water from its vapor state to the condensed state** with a single sensor.

Diurnal cycles of observed and modeled brightness temperatures at 183.31+/-11GHz, over land in the Tropics (cy43r1 11/2015-01/2016)

Megha-Tropiques/SAPHIR observations



Relative difference (IFS model cy43r1 – SAPHIR obs)



Similar shift in the diurnal cycle for water vapour

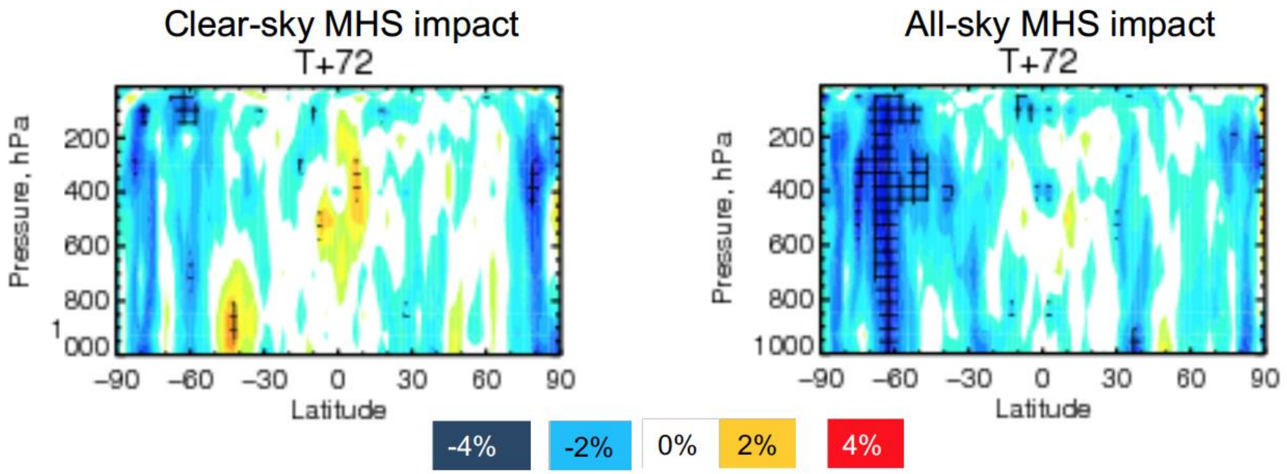
Excess of occurrence of scattering scenes around noon and early afternoon

(Chambon and Geer., 2017, ECMWF Tech Memo 802)

1. Passive microwave observations

Microwave observations have been one of the very first cloudy and rainy observation kinds for which **benefits was demonstrated**. The main mechanism of improvement comes from **the ability of a 4D-variational** (4D-Var) assimilation system to **infer increments to dynamical fields from observations of cloud and precipitation.** The **tracing effect leads to improved wind analysis and subsequent forecasts** when the observations affected by clouds and precipitation are directly assimilation within a 4D-Var :

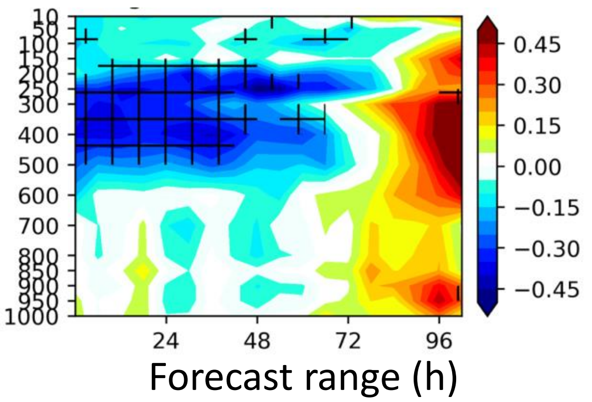
Relative Impact of MHS on T+72 wind forecasts of the IFS

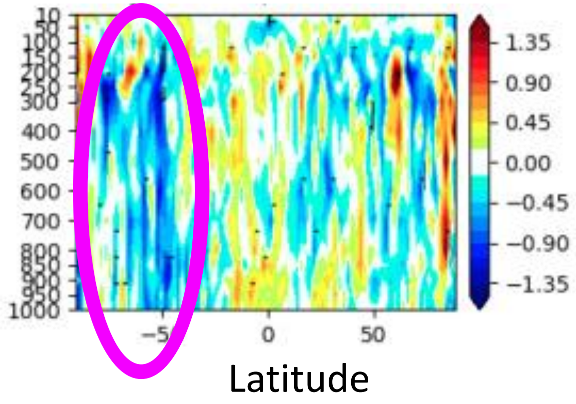


(Courtesy of N. Bormann)

This tracing effect can also be demonstrated even when these observations are assimilated an indirect method (e.g **1D-Bay+4D-Var in the current MF parallel suite**).

Relative Impact of MHS and ATMS cloudy and observations on wind forecasts of the ARPEGE global model with respect to the ECMWF analysis



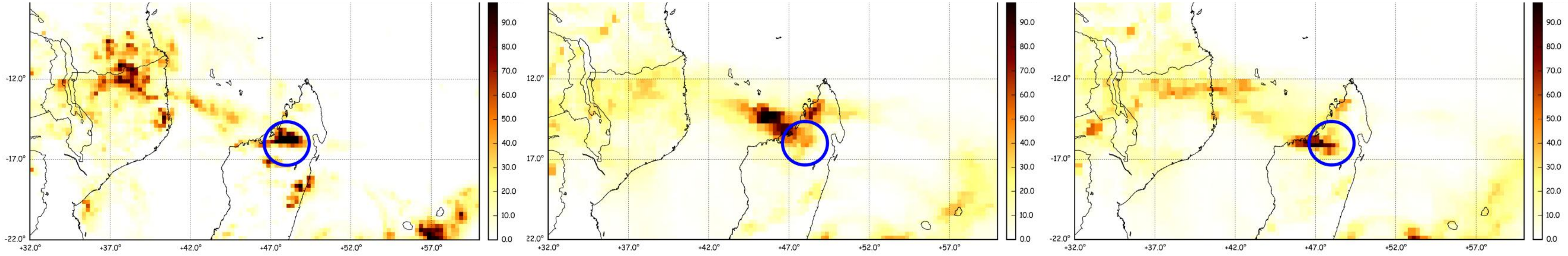


1. Passive microwave observations

With the combined impact of clear and cloudy sky observations, not only the winds, temperature and humidity forecasts are improved but also **the forecasts of clouds and precipitation themselves**.

Comparison of 24h rain accumulations, forecasted with the IFS for a baseline experiment (denial of MHS in the tropics and SAPHIR within the ECMWF all-sky system of 2016) and an experiment including MHS and SAPHIR allsky assimilation.

TRMM 3B42 V7– Jan 18th, 2015 | ***Baseline IFS +36h - +12h forecast*** | ***Baseline IFS + MHS and SAPHIR in all-sky***



(Chambon and Geer, 2017)

1. Passive microwave observations

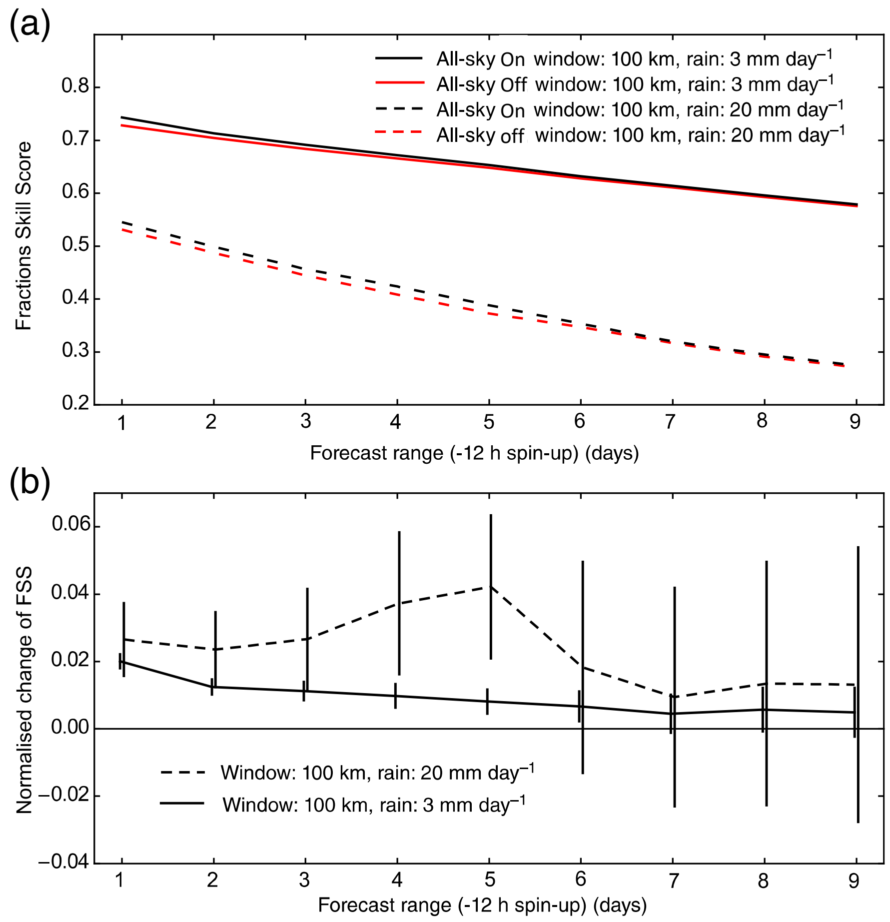
With the combined impact of clear and cloudy sky observations, not only the winds, temperature and humidity forecasts are improved but also **the forecasts of clouds and precipitation themselves**.

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)

1. Passive microwave observations

Assimilating microwave clouds and precipitation observations took years of developments by the community, for which ECMWF paved the way on many aspects. Among many developments, this required :

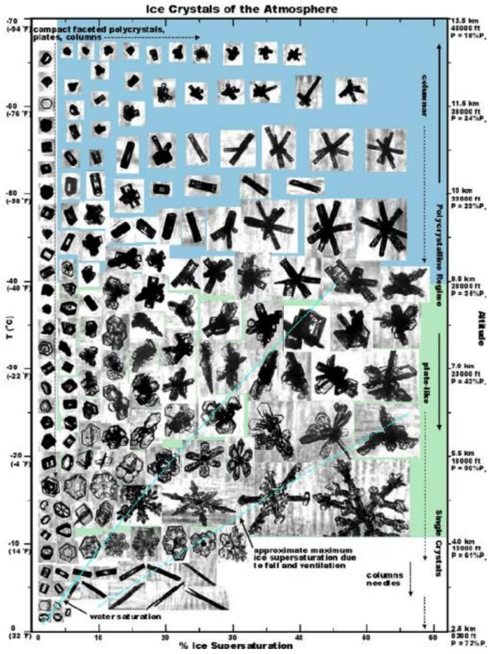
⇒ **Realistic enough but fast radiative transfer modeling across the spectrum** (realistic can mean several things : Model equivalent close to observations ? Assumptions close to what is observed ? Both ?).

Each hydrometeor class requires assumptions for the RT calculations :

- *How one single particle scatters the energy in space.*
- *How the particles are distributed in terms of size.*
- *How the hydrometeor are spread over the model grid box*
- *…*

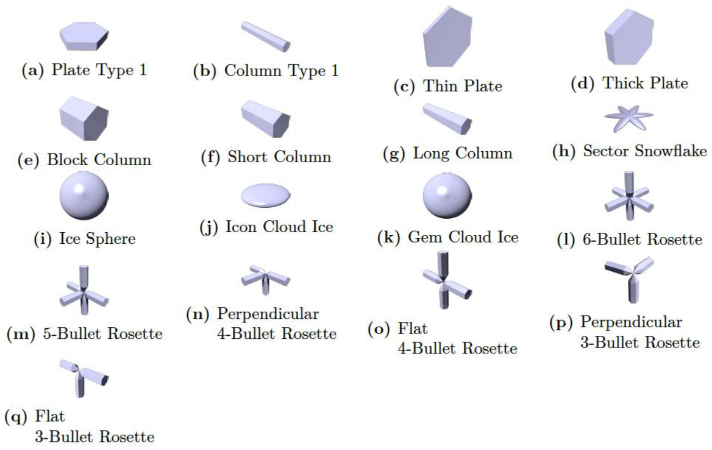
An optimal configuration for the RT calculations is challenging to set up because the problem has many degrees of freedom!

Example of ice crystal shape as a function of formation temperature and supersaturation (Bailey and Hallett, 2009)



Modelling of the Single Scattering Properties of hydrometeors

Single crystal habits from the ARTS database (Ekelund et al., 2018)



⇒ see Patrick Eriksson presentation

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- *…*

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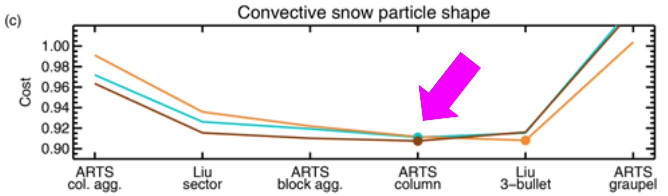
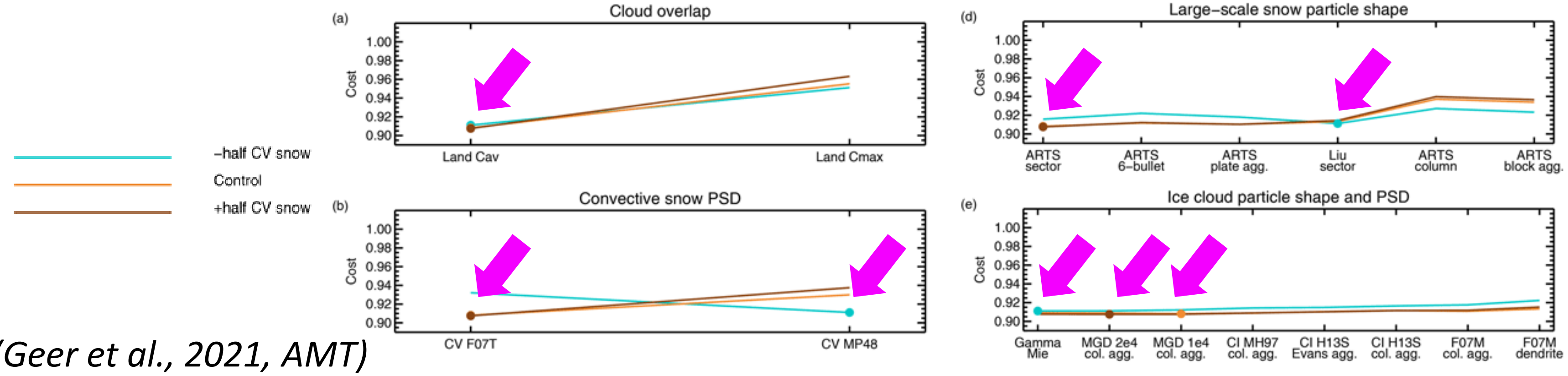
"Finding a reasonable global one-shape-fits-all configuration for all kinds of clouds over the globe has been the approach followed by the community (Geer and Baordo, 2014). The number of available databases of crystal having significantly increased, one approach is to perform a parameter estimation study."

The results of the parameter estimation are robust to changes in the magnitude of hydrometeor contents, which is a good sign that the results do not just reflect tuning to fit the biases of the forecast model used as the reference, and/or the limitations of the radiative transfer model.





(Geer et al., 2021, AMT)

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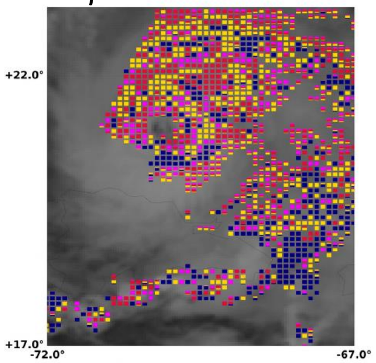
- *…*

An optimal configuration for the RT calculations is challenging to set up because the problem has many degrees of freedom!

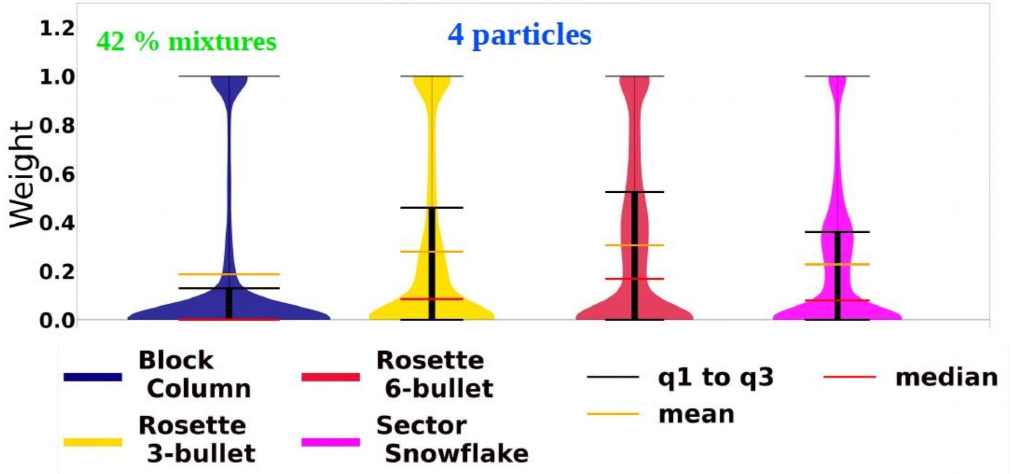
One alternative to define a single set of radiative properties for all clouds over the globe would be to load several potential set of properties and let the assimilation system free to select an optimum.

Experiment for tropical convection (AROME Antilles model), GMI observations, over a 2 month period.
=> Use of single set 58% of the time, and of mixtures 42%.

Hurricane Maria, Sep 2017



Violin plots showing the probability density function of weights



(PhD of Marylis Barreyat, CNRM)

1. Passive microwave observations

Much more to say on microwave data impact… In a nutshell:

⇒ Assimilating cloudy and rainy microwave observations is **becoming almost standard** across NWP centers.

⇒ Among the different kinds of MW sensors (frequencies), **positive impacts have now been demonstrated** for almost all of them.

- **MW imagers**: ECMWF, JMA, GMAO, NCEP
- **MW Humidity sounders** : ECMWF, JMA, UK Met Office, Météo-France, NCEP
- **MW Temperature sounders** : NCEP, UK Met Office, ECMWF, Env. Canada

⇒ All the efforts to achieve today's impact of MW data pave the way for obtaining positive impacts from other observations kinds in clouds and precipitation

1. Passive microwave observations

Room for improvements in many areas:

On the observations side :

⇒ **Enhanced sampling** with more satellite platforms (no saturation effect detected yet ; Duncan et al., 2021 QJRMS) => see Niels Bormann presentation

⇒ New opportunities to constrain models with **future instruments**. E.g. the Ice Cloud Imager (ICI), when it is launched in 2024, will add new frequencies from 243 to 664 GHz, which will better constrain smaller frozen particles.

⇒ …

On the modeling side :

⇒ **Subgrid cloud variability representation**

⇒ **….**

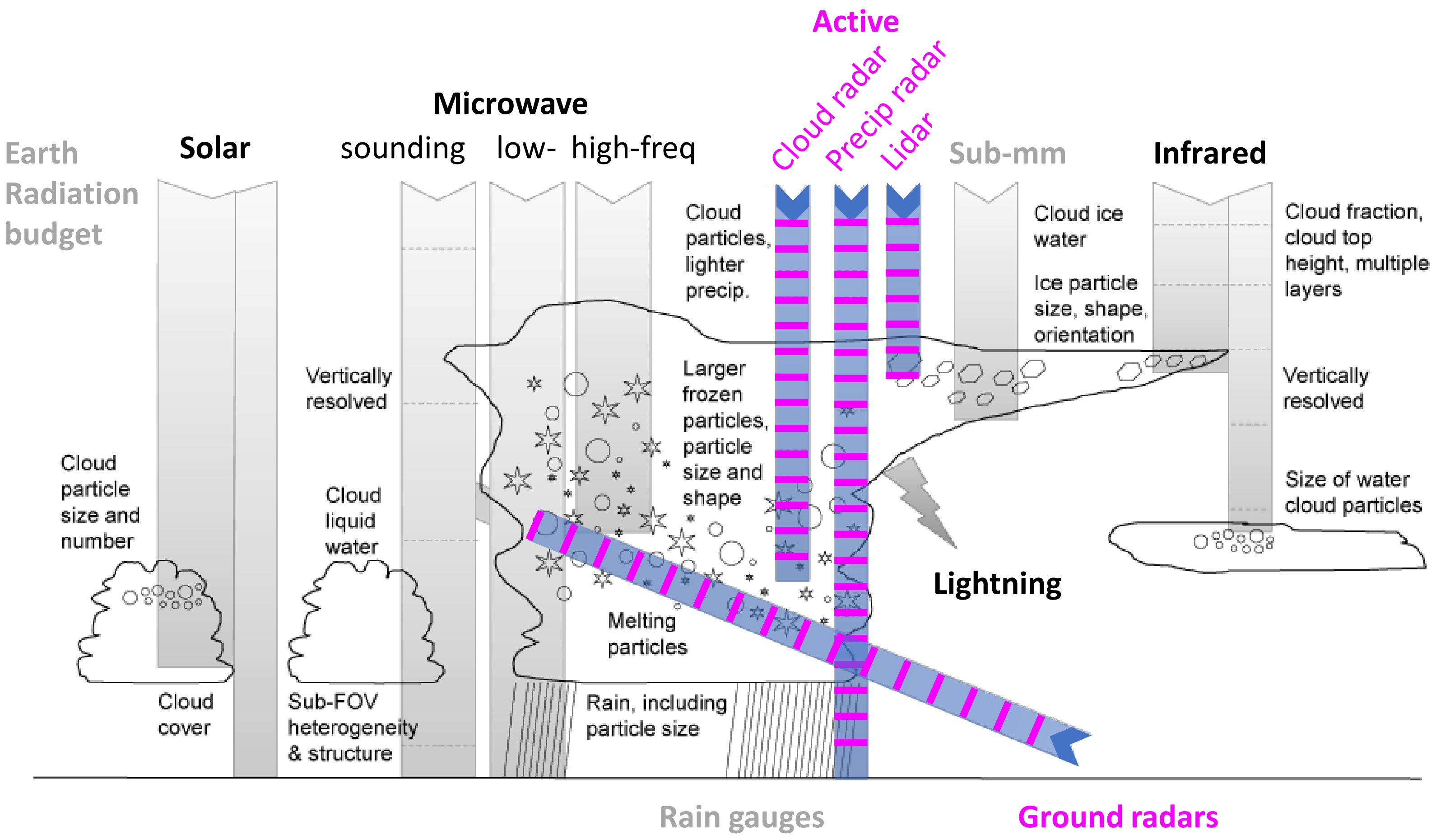
On the algorithmic side :

⇒ **Hydrometeors as a control variable of the DA system**

⇒ **Observation error modeling**: the "Geer and Bauer (2011)" error model is extremely popular! It is still being refined (e.g. Lonitz and Geer, 2020). Overall, this model defines rather high errors in cloudy areas, are there way forward to lower them down and give more weight to cloud and precipitation observations ?

⇒ …

2. Active observations



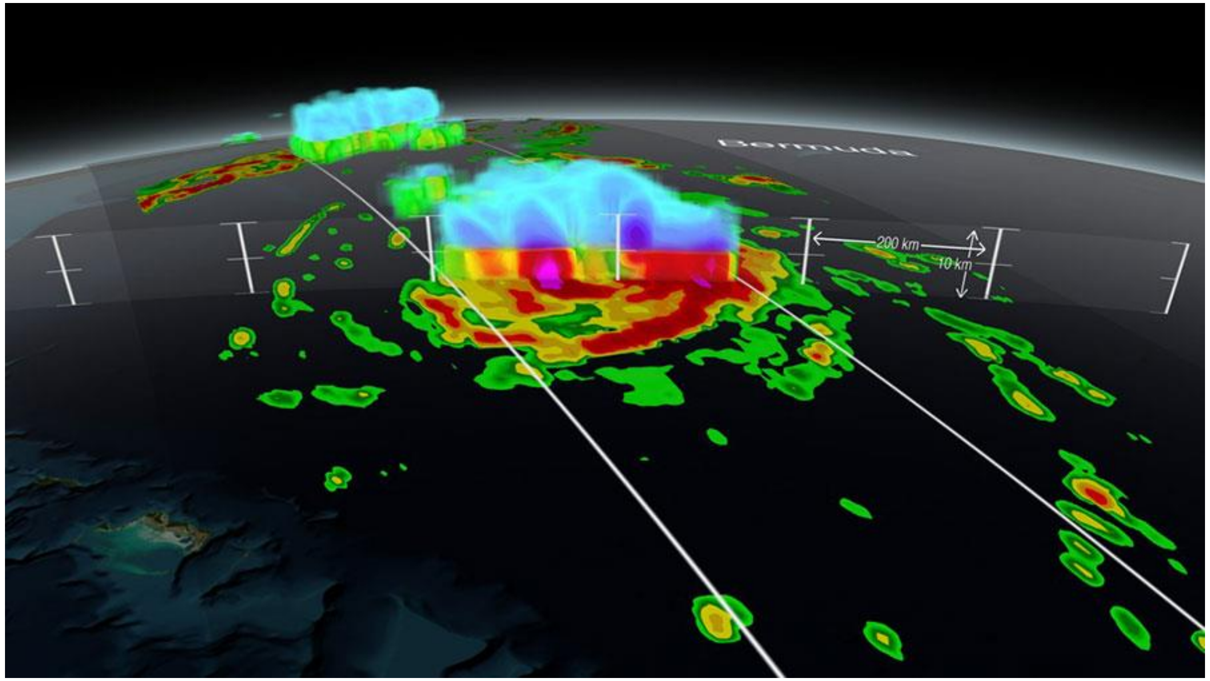
Since the launch of TRMM in 1997 and its follow on, the GPM Core Observatory, in 2014, precipitation radars (Ku and Ka band) have been useful tools which led to **improved knowledge in precipitation science**.

(Courtesy of A. Geer and S. English)

2.1 Precipitation radars

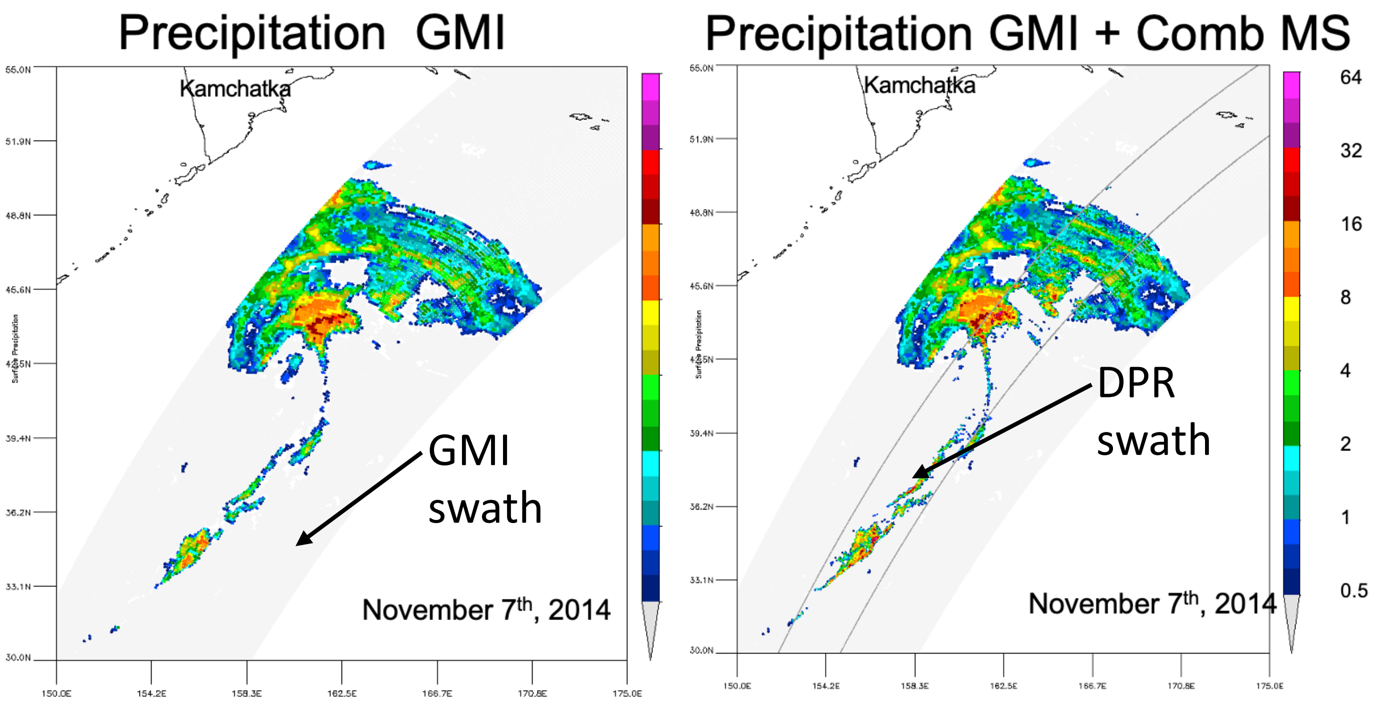
Unlike passive instruments, precipitation radars provide observations of the **three-dimensional structure of rainfall**.

Hurricane Gonzalo approaching Bermuda on October 16, 2014 (pmm.nasa.gov)



2.1 Precipitation radars

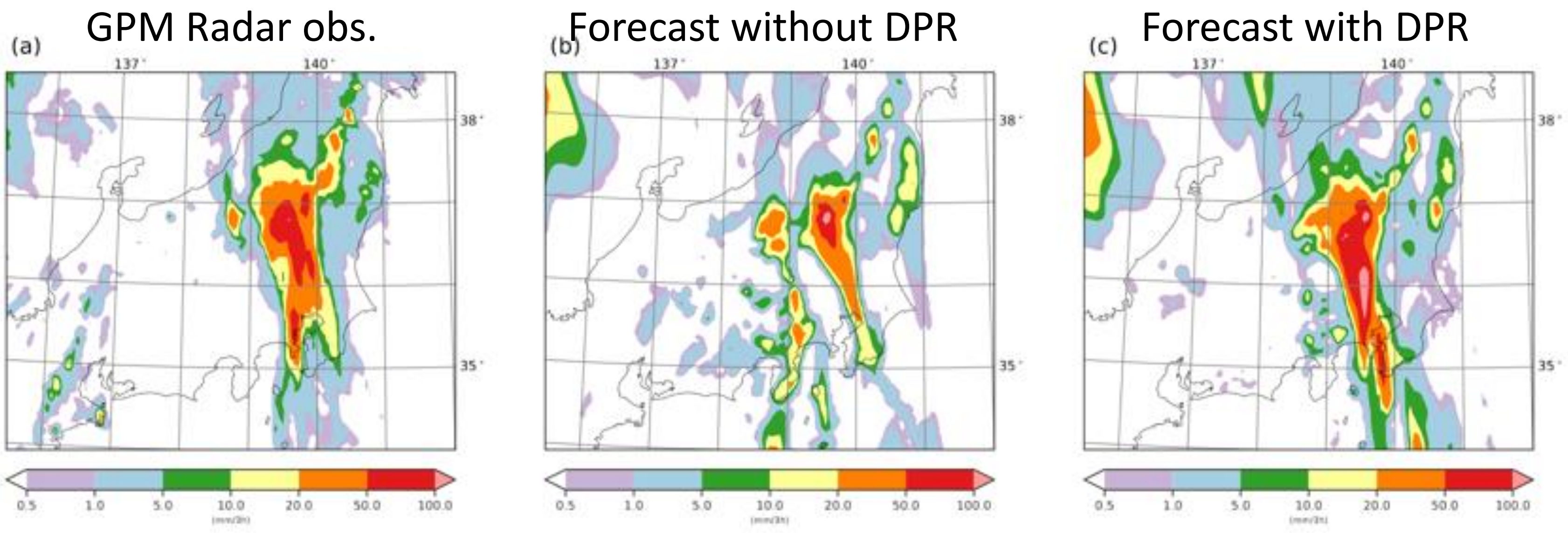
The retrieval community makes a very **mature usage** of precipitation radars which are the **calibrators for retrieving precipitation from passive microwave instruments**



(Courtesy of C. Kummerow)

2.1 Precipitation radars

Since early efforts with TRMM data (e.g. Benedetti et al., 2006), **pioneering work** has been done by **JMA** to assimilate GPM/DPR observations operationally since 2015. Positive impacts have been demonstrated **both on case studies and on long experiments** (Ikuta et al., 2021), even with the narrow swath of the DPR (245 km for Ku, 120 km for Ka).



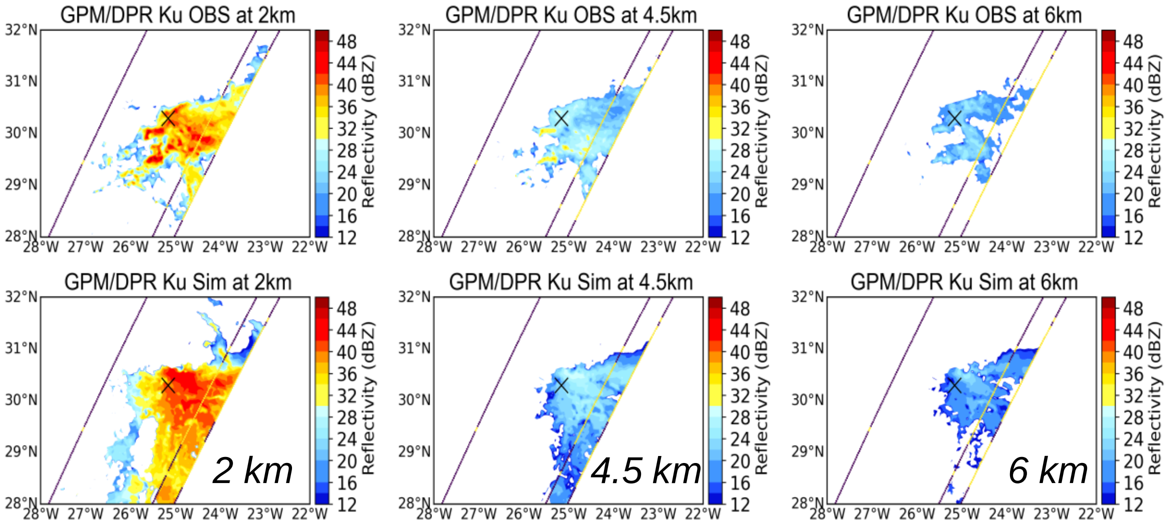
(Courtesy of Yasutaka Ikuta)

2.1 Precipitation radars

The latest version of **RTTOV (V13) now support the simulation of precipitation radars** such as the GPM/DPR which may allow the developments of similar assimilation capabilities than the one JMA developed.

Example of one sub-tropical cloud observed by the DPR on January 2nd, 2021

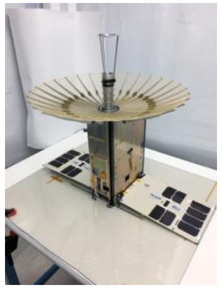
Simulations with RTTOV V13 with the ARPEGE model



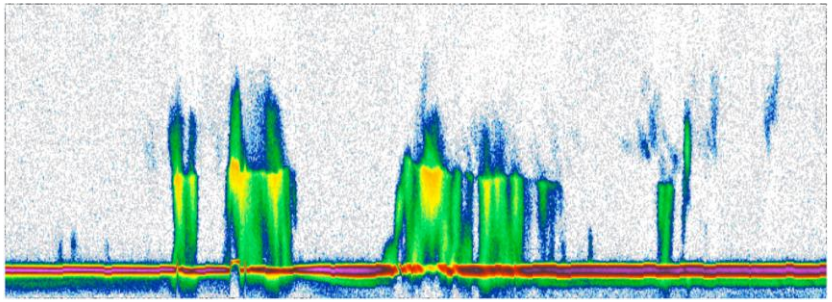
=> See Rohit Mangla poster at the WMO Symposium

Recent technological progresses allow the **miniaturization of precipitation radars**, although with no or limited scanning capabilities. Will this kind of nadir pointing instruments be useful for NWP? In constellation?

Example of the 6U class JPL RainCube at Ka band (https://www.jpl.nasa.gov)



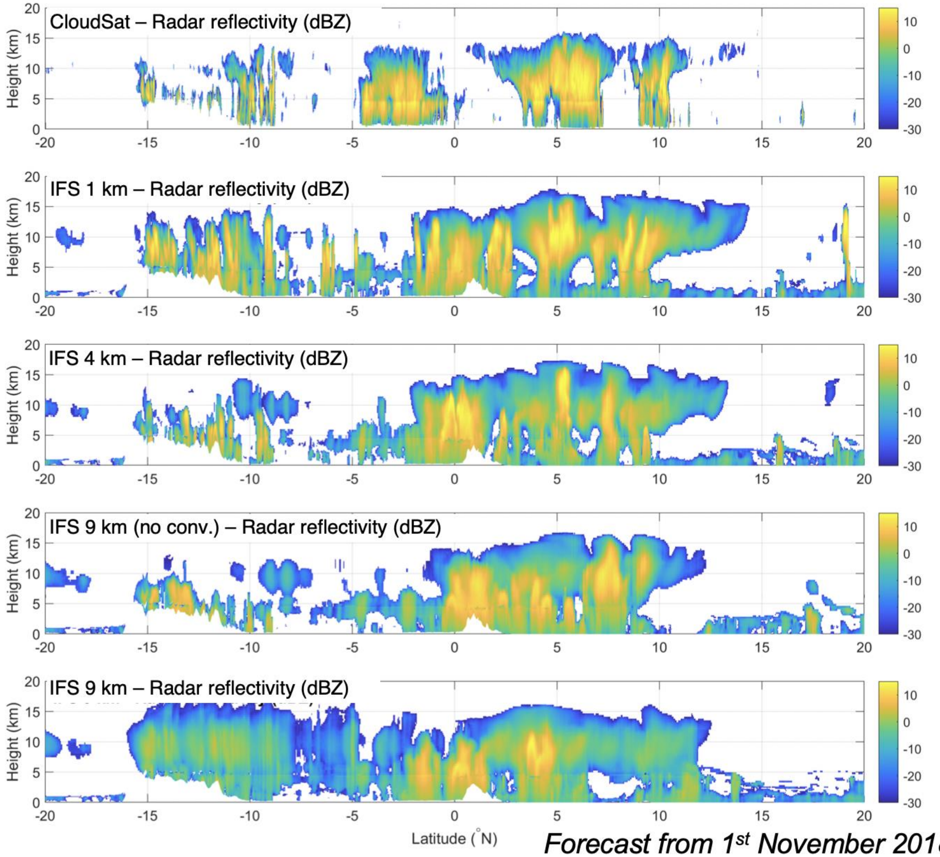
Precipitation profile of Typhoon Trami generated by RainCube on September 28, 2018 (https://science.nasa.gov)



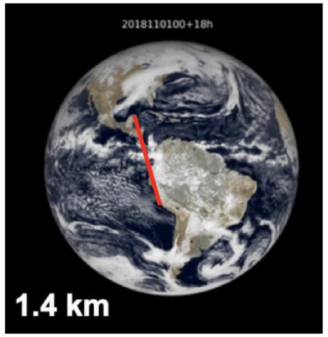
2.2 Cloud and Precipitation radar/lidar

The results obtained by ECMWF in the frame of the **preparation to the assimilation of the EarthCare satellite (radar at 94 GHz sensitive to both suspended and precipitating particles and lidar)** (Janiskova´ et al. 2012; Janiskova´, 2015; Di Michele et al. 2012; … ; Fielding and Janiskova, 2020; Janiskova and Fielding, 2020) showcase several key points :

=> Active instruments provide fine scale data which are **very useful for assessing the model representation of clouds and precipitation.**



Forecast from 1st November 2018



Courtesy: P. Lopez

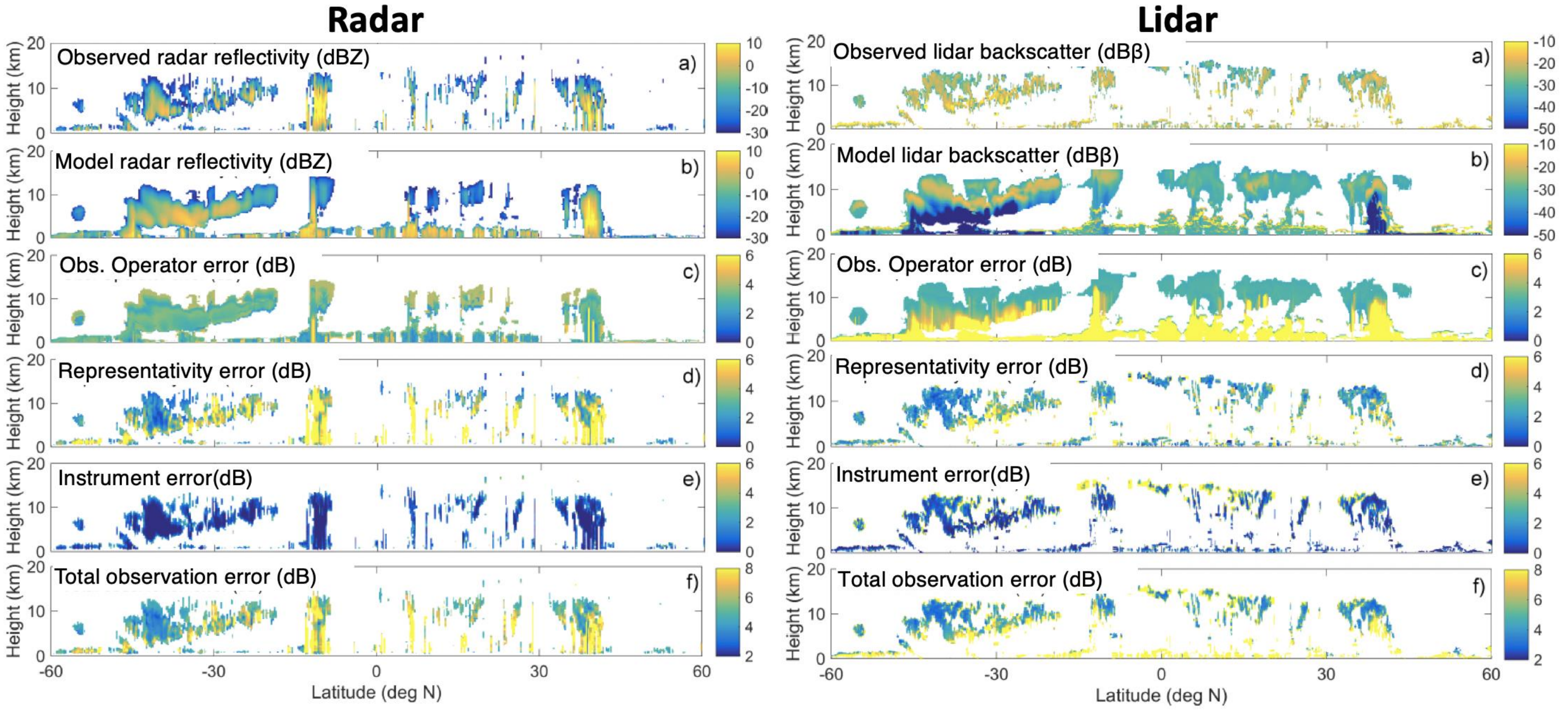
Radar observation operator is highly effective tool for evaluating convection in high-resolution model forecasts

(Courtesy of Mark Fielding and Marta Janiskova)

2.2 Cloud and Precipitation radar/lidar

Assimilating information on the **full vertical structure of hydrometeors** is even more demanding in terms of developments than passive observations, although some aspects are in common and need a consistent approach to lead to a synergistic passive/active assimilation. As an example, the assimilation of Cloudsat and Calispo (proxy data for EarthCare) required **the use of a sophisticated approach for observation errors (Fielding and Janiskova, 2020)**.

Components of observation error



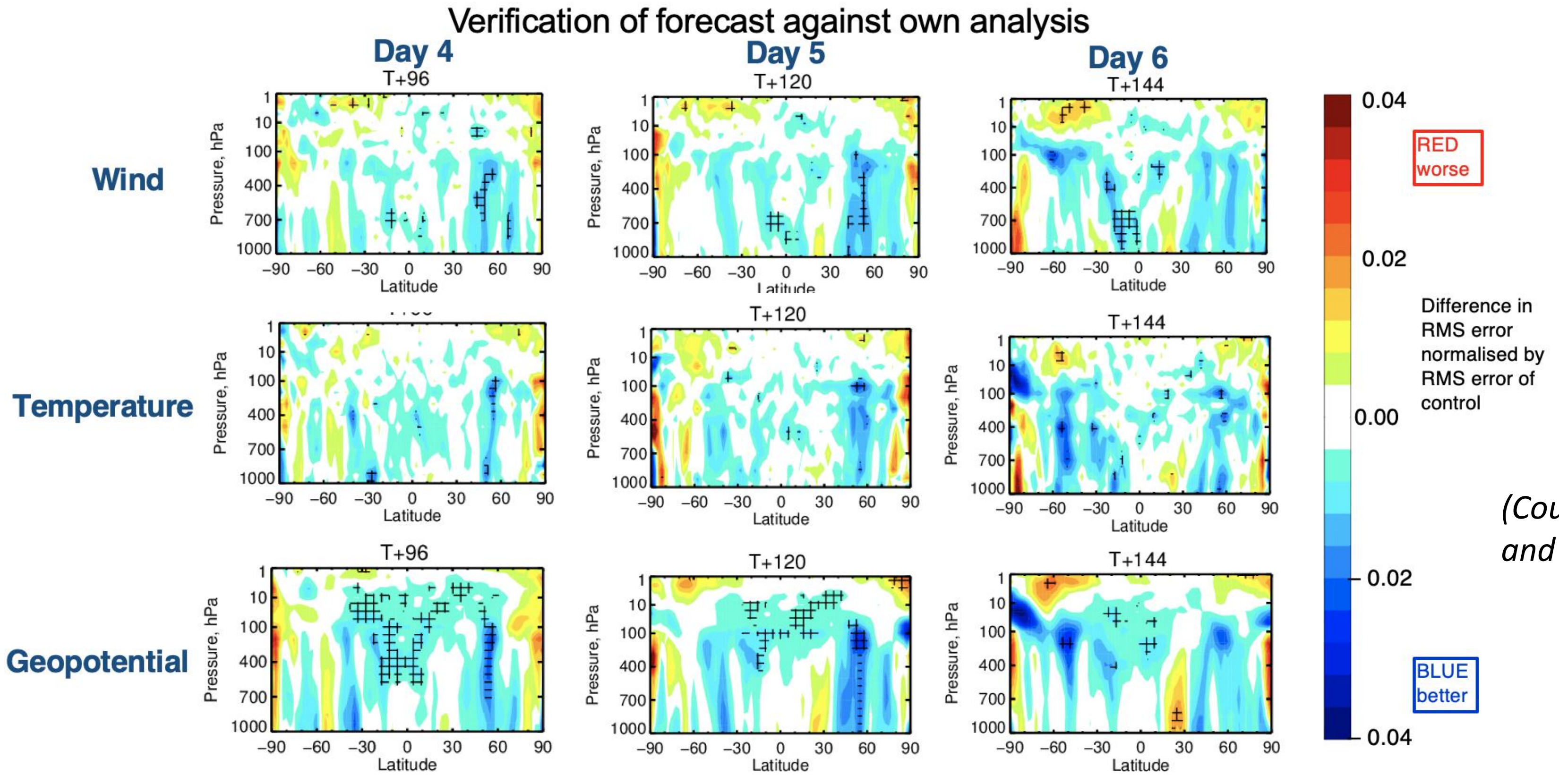
Representativity error dominates total error.

Observation operator error tends to dominate total error.

(Courtesy of Mark Fielding and Marta Janiskova)

2.2 Cloud and Precipitation radar/lidar

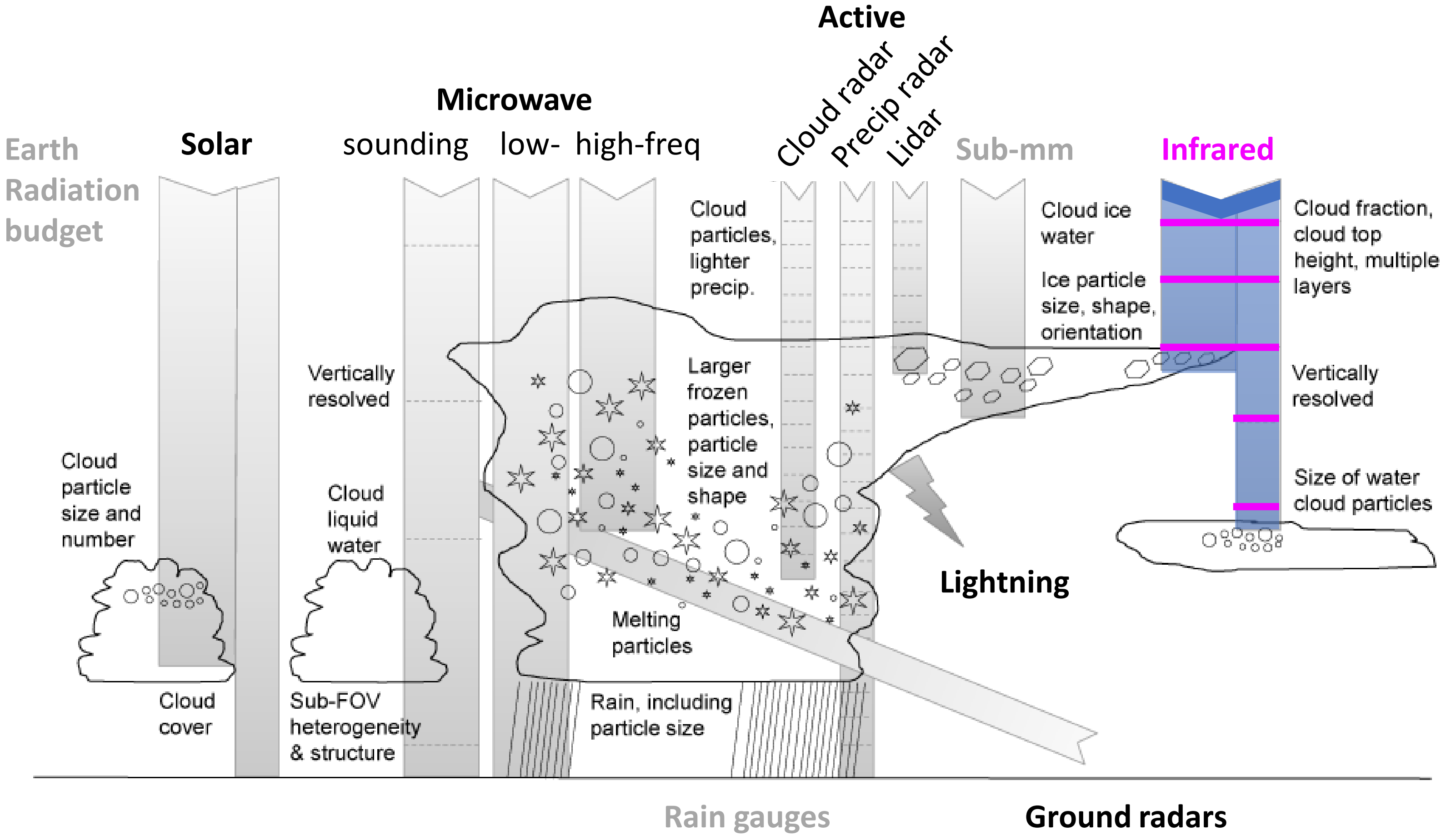
Nadir looking instruments, with very low horizontal sampling, can have **a significant and positive impact on short and medium range forecasts** (which is a good sign that constellations of nadir looking radars may be useful in the future).



OSE: 6-month (08.-10. 2007 and 02.-04. 2008) CloudSat and CALIPSO observations in addition to regularly assimilated observations vs control

(Courtesy of Mark Fielding and Marta Janiskova)

3. Infrared observations



IR observations complement well MW observations because they are characterized by **a sensitivity to the smaller suspended particles** that do not affect MW radiations. The cloud top height can be more accurately detected, especially with hyperspectral IR sensors, and its **evolution in time well sampled with geostationary sensors**.

(Courtesy of A. Geer and S. English)

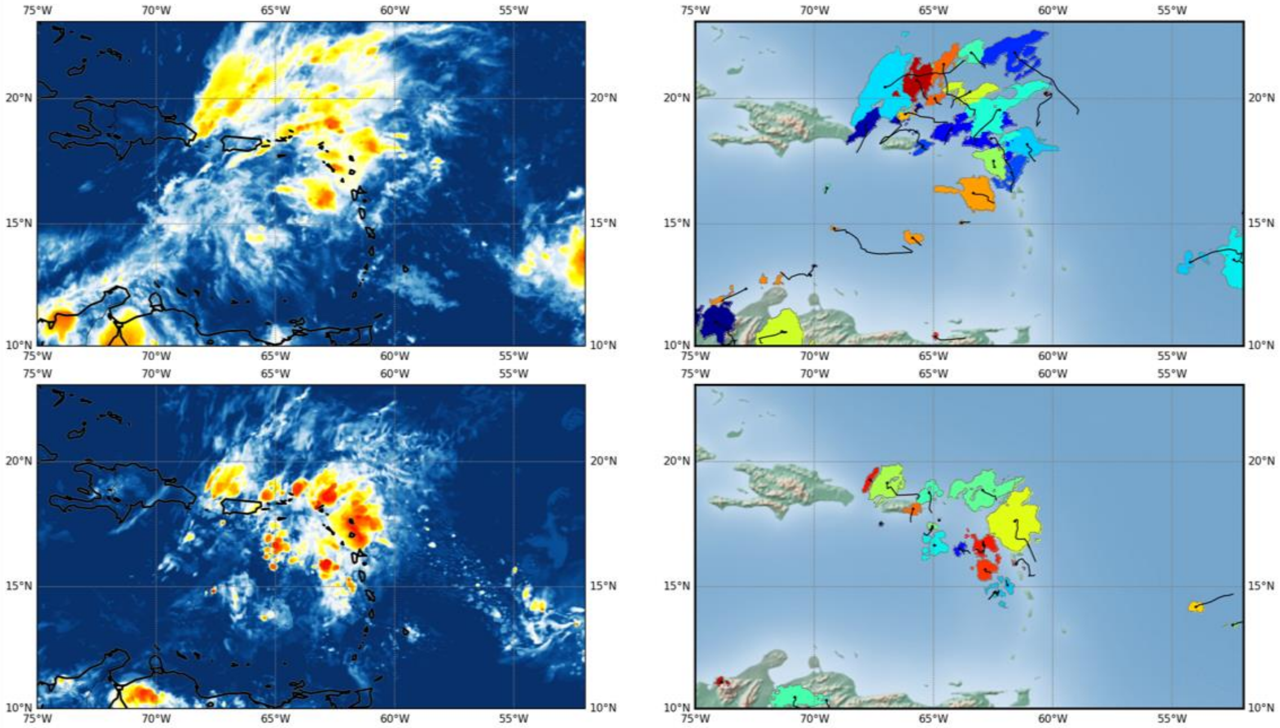
3. Infrared observations

Radiative Transfer simulations have significantly progressed in the past years (e.g. Vidot et al., 2015 for cloud ice optical properties). It allows meaningful comparisons with observations to assess model biases.

August 17th, 2017, Caribbean sea

GOES 13

AROME
RTTOV 12



Use of a cloud tracking algorithm, applied on both the observations and the model (Fiolleau and Roca, 2013)

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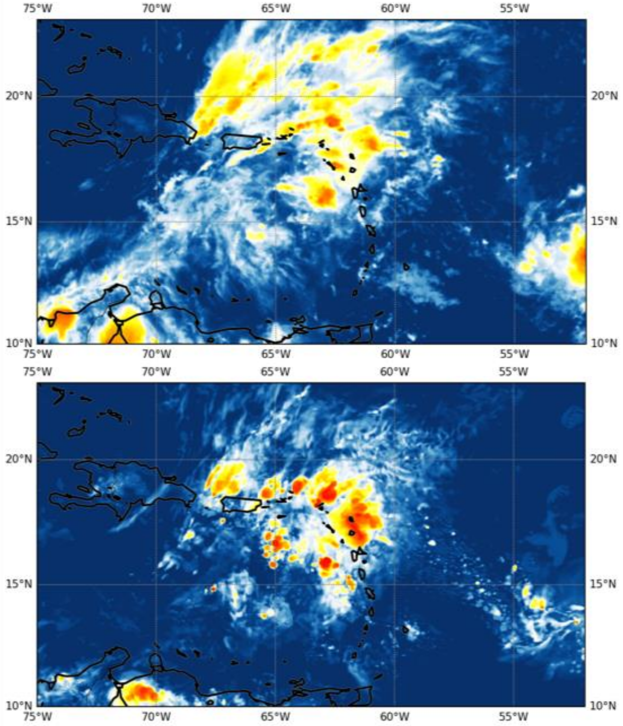
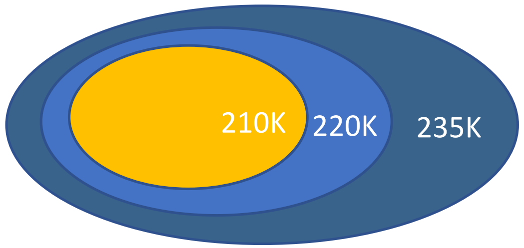
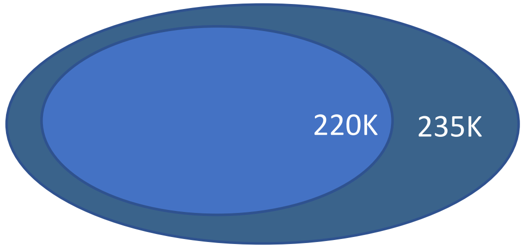
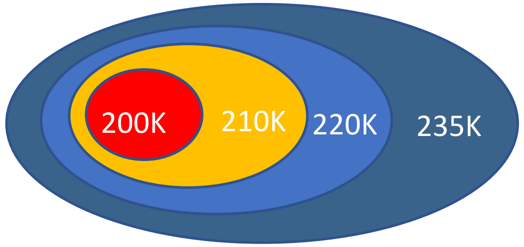
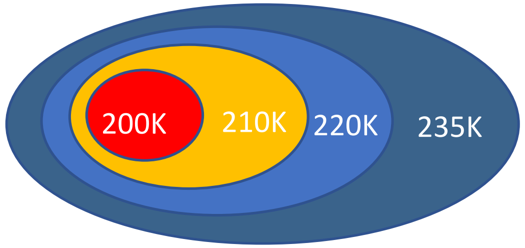
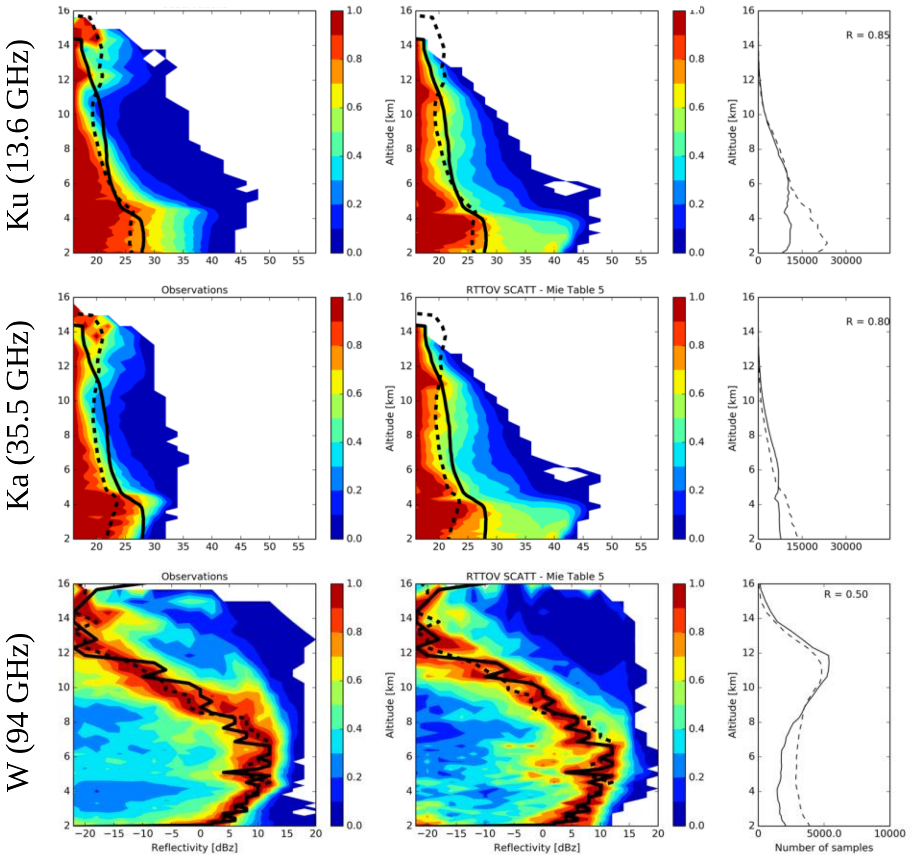


	Clouds lasting ~10h	Clouds lasting ~5h
Most frequently observed clouds		
Most frequently forecasted AROME clouds		

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

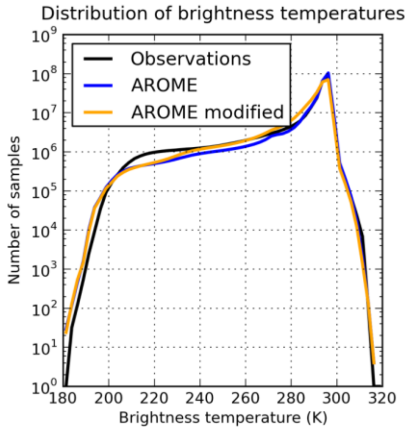
3. Infrared observations

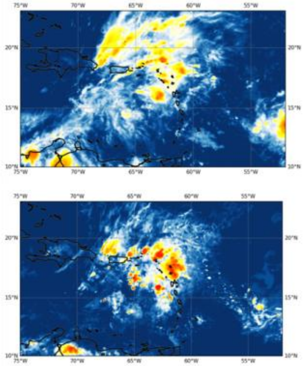
=> Together with MW data, they can be useful to **identify from which processes the model biases originate from**.



Excess of snow in AROME in the Tropics compared to GPM and Cloudsat radars

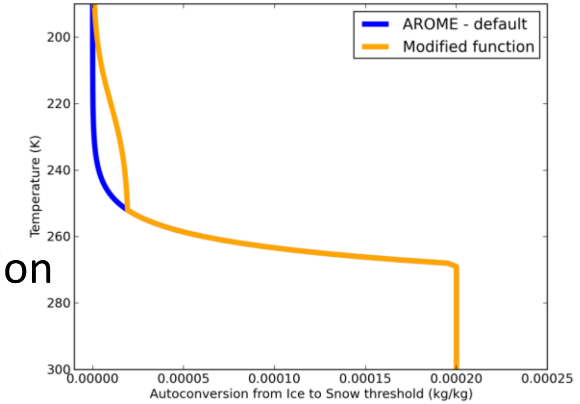
+





Lack of ice compared to TIR GOES data

Tests on the auto-conversion from ice to snow function

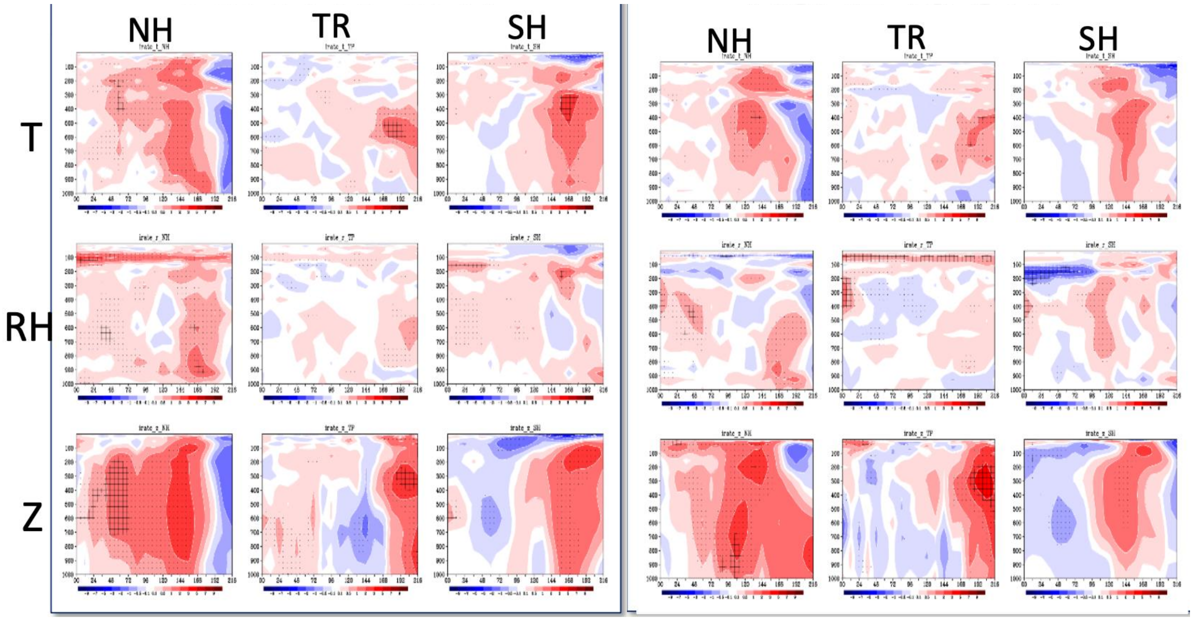


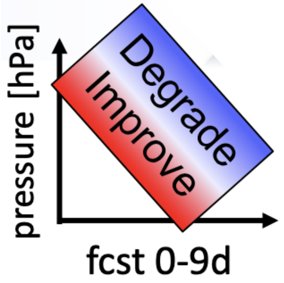
3. Infrared observations

⇒ The latest all-sky IR assimilation experiments performed in the community (ECMWF and JMA) have showed that with a careful and **conservative approach for channel selections** (e.g. 1 Himawari channel, 7 IASI WV channels in Geer et al., 2019), as well as other developments such as **cloud dependent observation error correlation** which seems critical (Geer, 2019), **replication and even slight improvements of all-sky assimilation with respect to clear sky assimilation is feasible**.

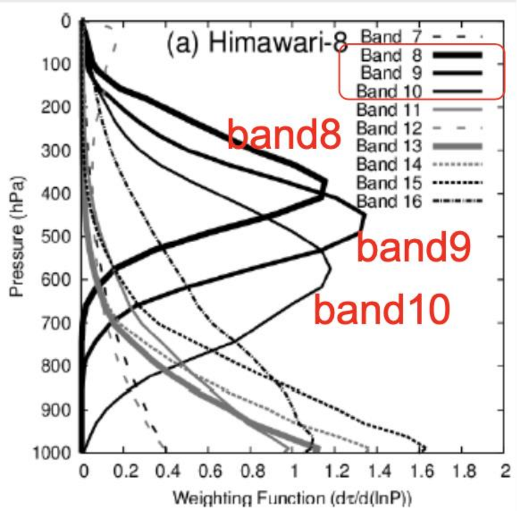
Clear sky assimilation impact of Himawari channel 8

All-sky assimilation impact of Himawari channel 8





(Courtesy of Kozo Okamoto)



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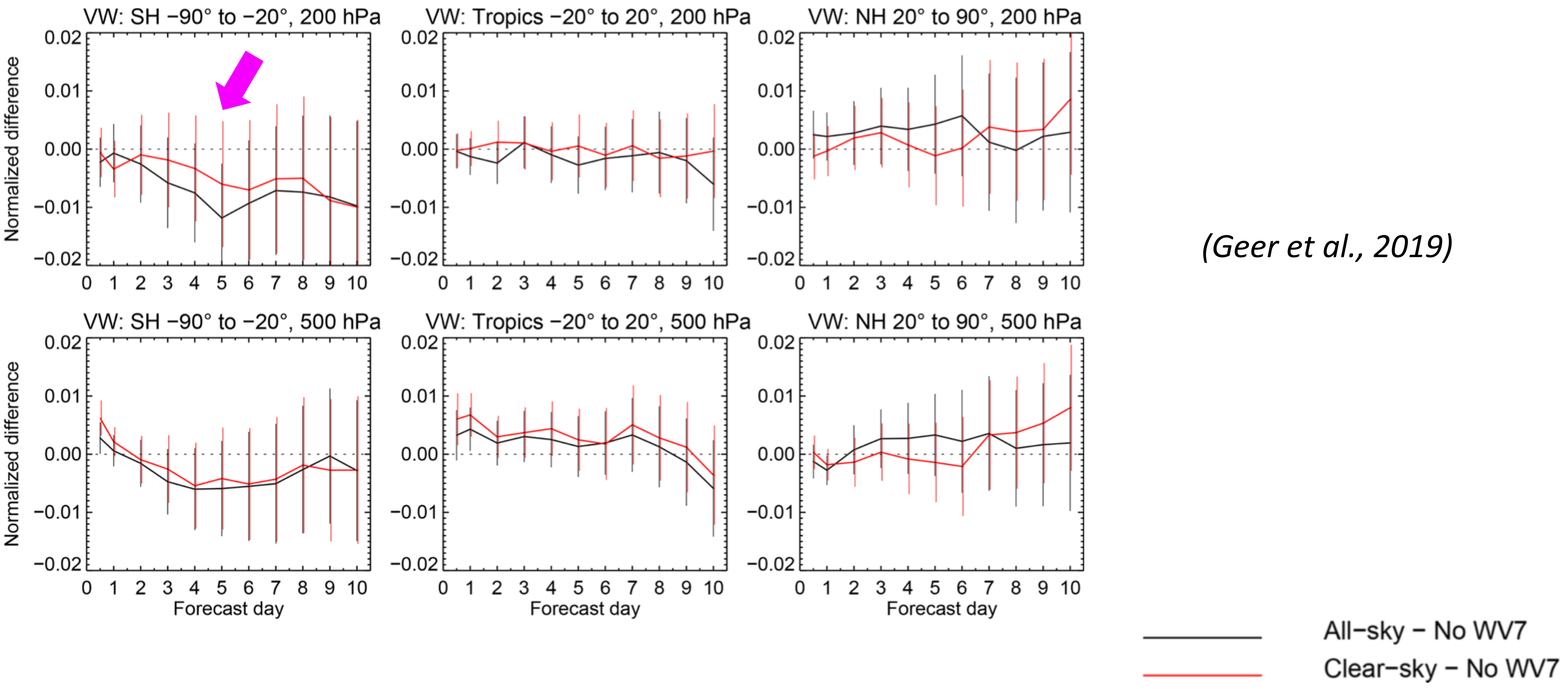
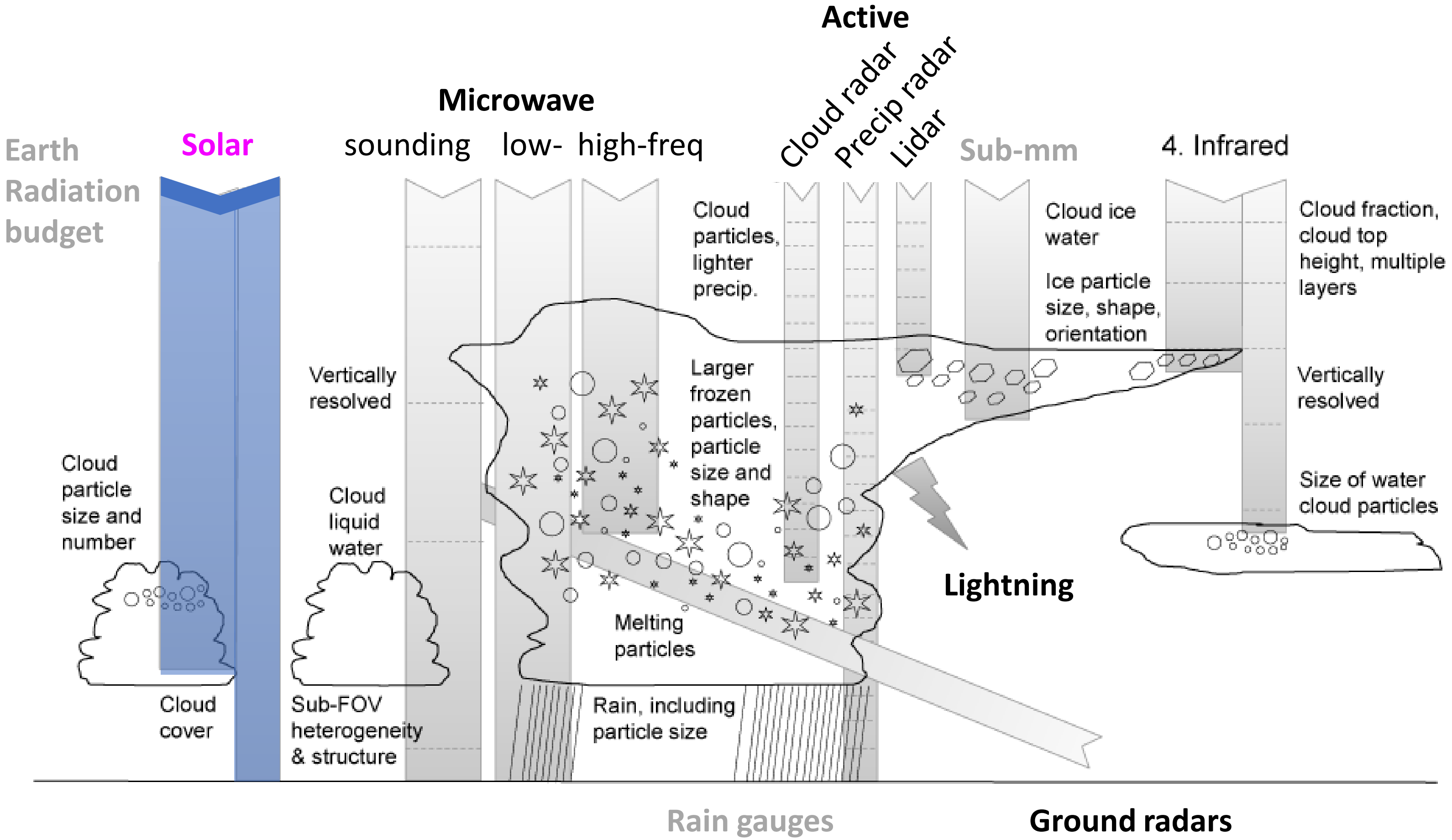
Impact of 7 IASI Water Vapour channels within the IFS model



(Geer et al., 2019)

4. Visible observations



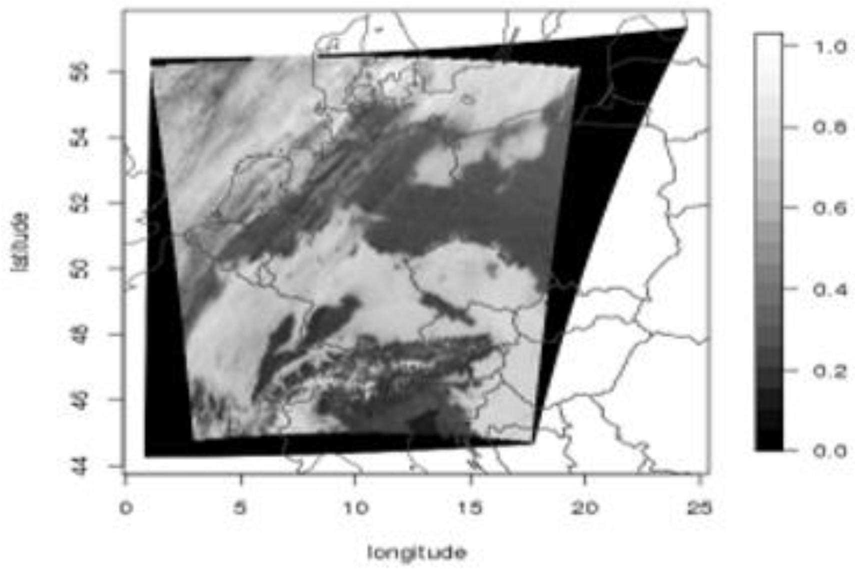
Visible data are characterized by a **sensitivity to low clouds and a wide range of IWP and LWP** which well complement IR and MW data.

(Courtesy of A. Geer and S. English)

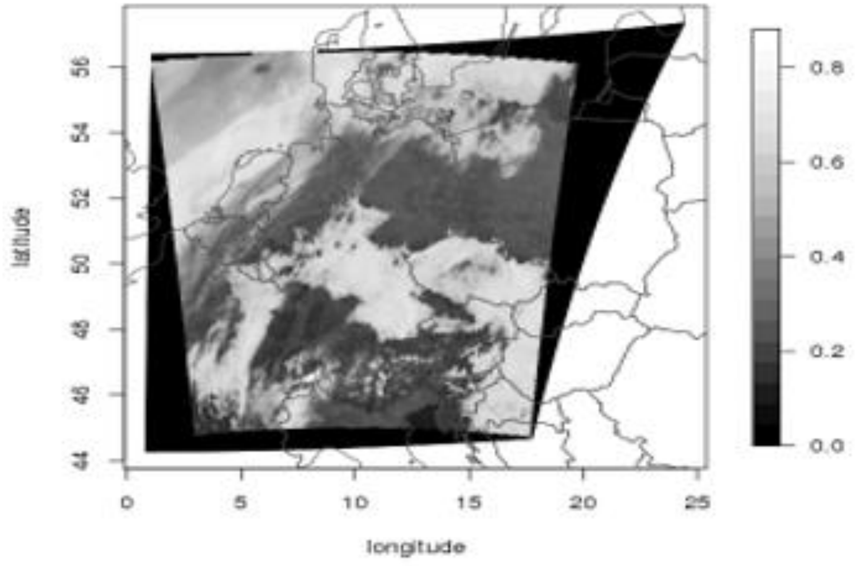
4. Visible observations

The assimilation of Visible data (e.g. 0.6 µm channel of SEVIRI / MSG) requires an advanced radiative transfer model that can **replicate the complex effects of solar reflections on clouds as function of the position of the sun** (Scheck et al., 2016).

Observations



MFASIS simulations with the ICON-D2 model



(Courtesy of Liselotte Bach, Leonhard Scheck and Christina Köpken-Watts)

4. Visible observations

Demonstration of positive impacts of Visible data has been accomplished **at mesoscale in the short range**.

Results from experiments in the ICON-D2 model (convective-scale at 2 km grid resolution) model including conventional data, radar reflectivitiy, radial winds (all reference)
plus SEVIRI 0.6 micron

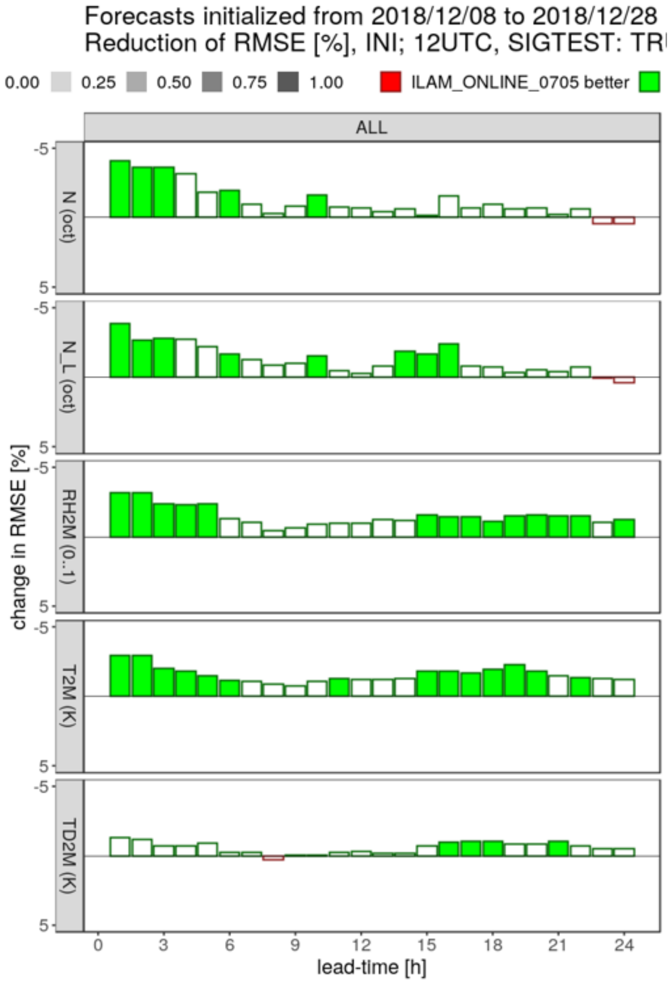
Total cloud cover

Low cloud cover

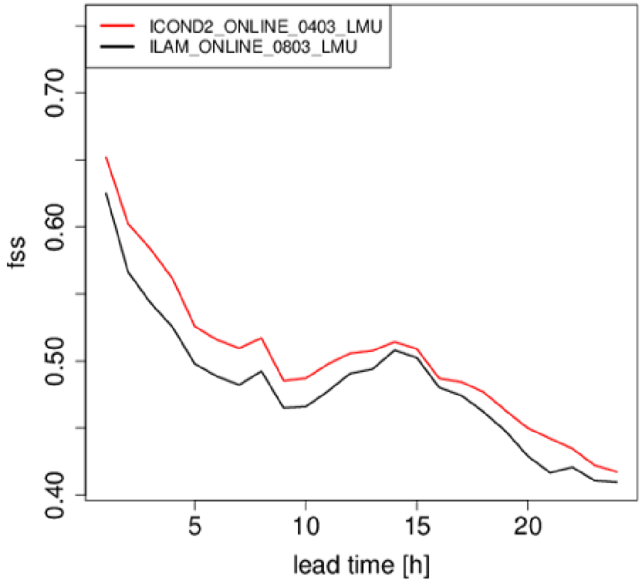
T2m

RH2m

TD2M (dew point)

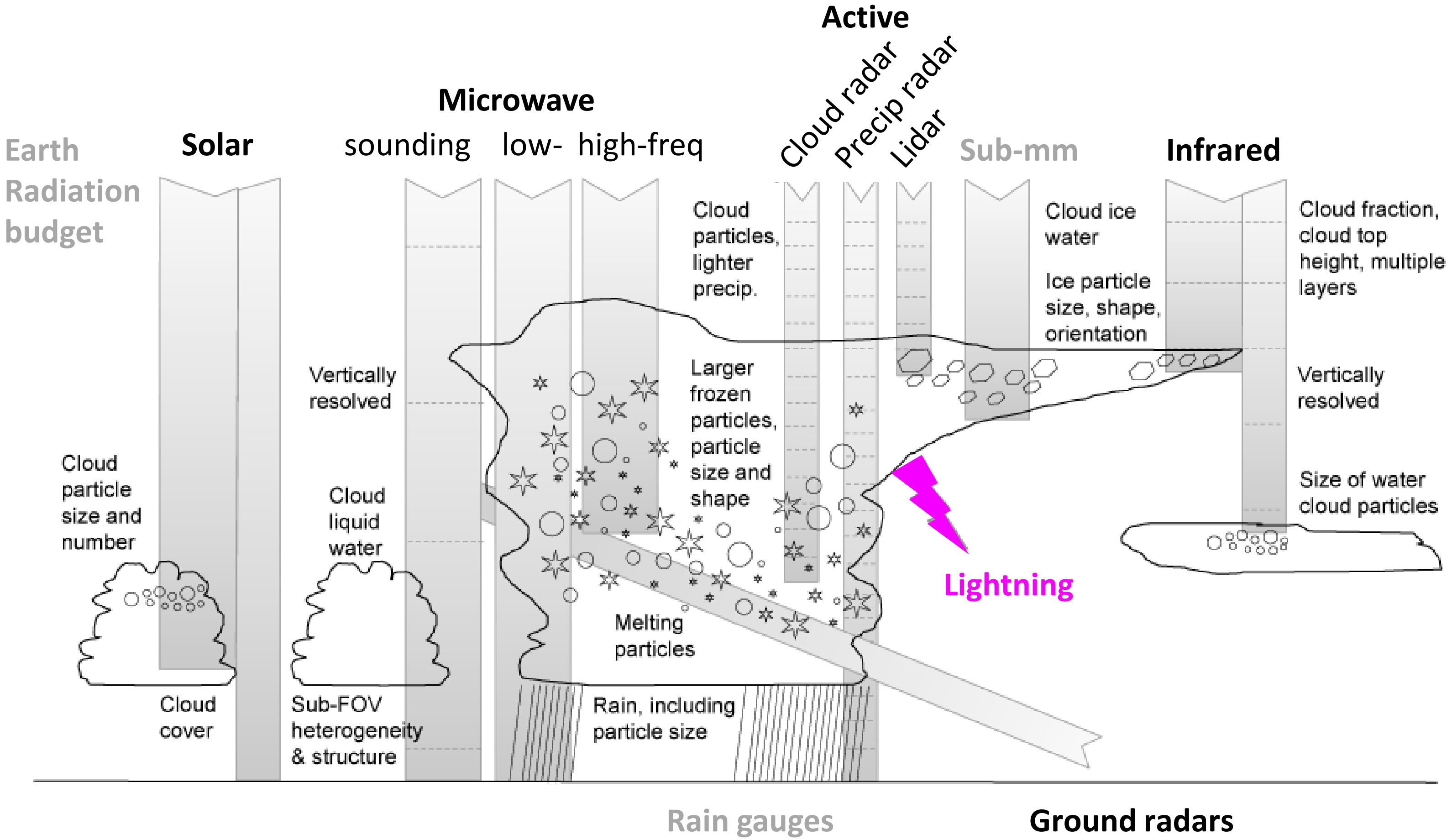


Fraction skill score of precipitation rate at a scale of 11 grid points (~22km) for a threshold of > 0.1mm/h



(Courtesy of Liselotte Bach, Leonhard Scheck and Christina Köpken-Watts)

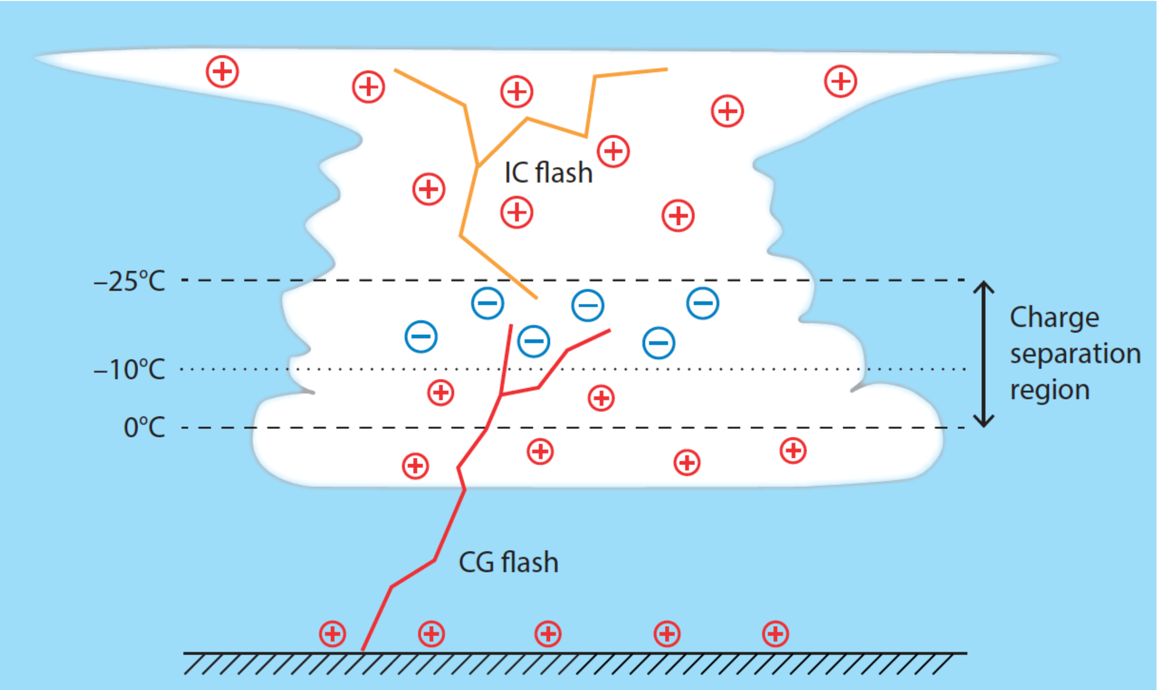
5. Lightning



Lightning observations provide a **combined measure of hydrometeors and the dynamic within the clouds**. Lightning discharges occur in response to a local build-up of an atmospheric electric field.

(Courtesy of A. Geer and S. English)

5. Lightning



IC : intra-cloud lightning flashes
CG : cloud-to-ground lightning flashes

« The typical electric charge distribution is the result of charge separation. Charges are separated during **collisions between various types of hydrometeors with very different fall speeds, especially graupel or hail particles on the one hand and lighter ice particles** or liquid water droplets on the other… Depending on whether the ambient temperature is higher or lower than about –10°C, graupel/hail particles involved in such collisions become positively or negatively charged, respectively.
… »

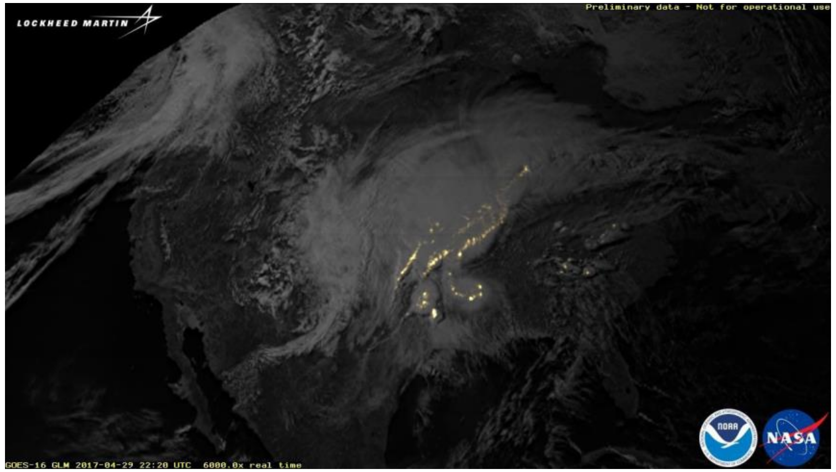
(Lopez P., 2018, ECMWF Newsletter No. 155)

5. Lightning

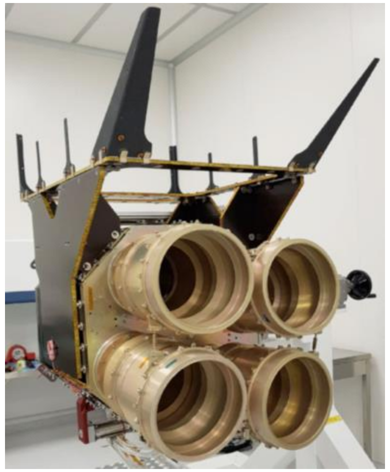
The recent availability of **frequent lightning observations** from the geostationary orbit (GLM instrument onboard GOES-16 and GOES-17) over North America, and soon-to-be over Europe and Africa with MTG/LI, motivates research to use the data for better constraining cloud and precipitation forecasts.

Geostationary Lightning Mapper (GLM)
https://www.goes-r.gov/

GOES-16 Lightning Imagery from Severe Storms
April 28-29, 2017



Meteosat Third Generation Lightning Imager
https://www.esa.int



=> This kind of data have received less attention than others in the past because they were only available from a few platforms like TRMM. Many aspects needed for reaching the ultimate goal of data assimilation have to be tackled first. This includes **building a realistic observation operator** (=> need a proxy for lightning) and an **efficient quality control**.

5. Lightning

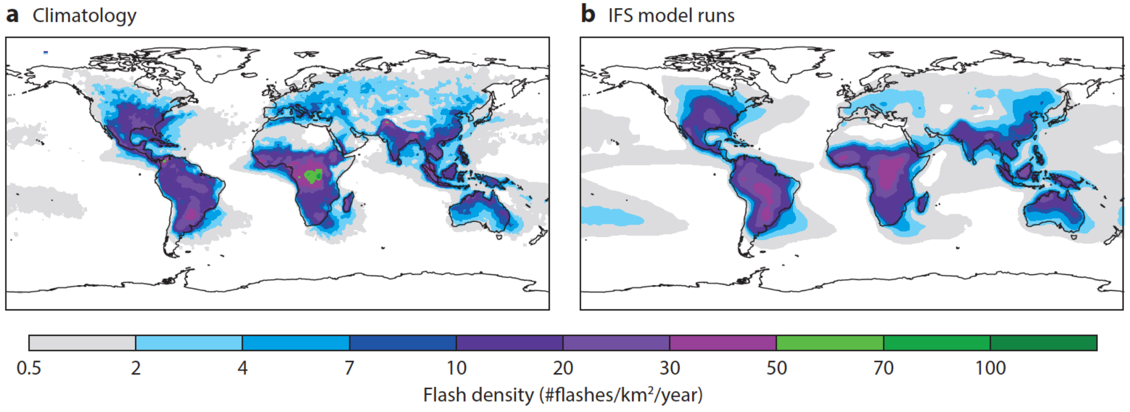
A good **proxy** needs to be found for the observation operator for lightning.

$$Q_R = \int_{z(0°C)}^{z(-25°C)} q_{graup}\,(q_{cond} + q_{snow})\rho(z)\,dz$$

convective cloud base

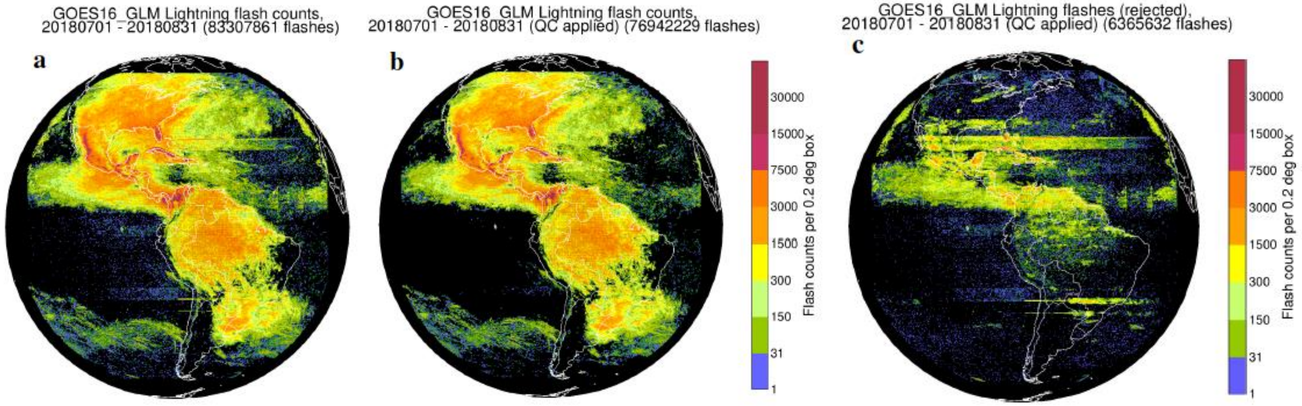
$$f_T = \alpha\, Q_R\, \sqrt{CAPE}\, [\min(z_{base}, 1.8)]^2$$

flash density f_T (in flashes/km^2/day)



(Lopez P., 2018, ECMWF Newsletter No. 155)

$\Rightarrow$ Usage of lightning observations require a **strict quality control** (Lopez, 2020) (flashes contaminated by sunglint over the oceans, sunglint during the eclipse season, sunlight reflection inside the instrument, flashes due to thermal noise …)



ALL FLASHES FLASHES AFTER QC REMOVED FLASHES

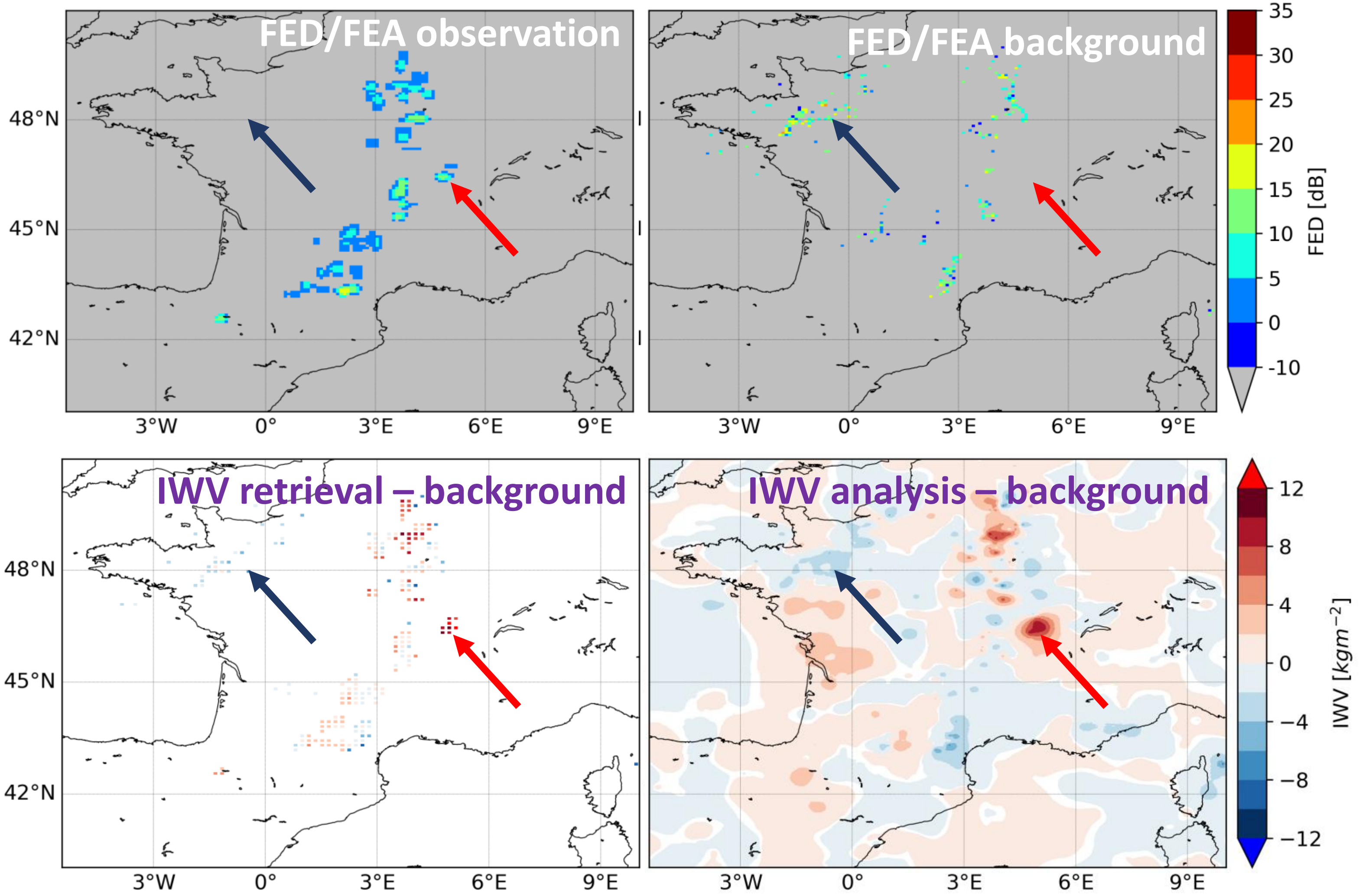
(Lopez P., 2020. ECMWF Tech. Mem. 872)

5. Lightning

⇒ Assimilation experiments with **simulated MTG/LI** results gives promising results for lighting DA.

(Courtesy of Olivier Caumont)

- **Lightning data:** Pseudo-observations of 7 km x 7 km Flash Extent Density or Accumulation (FED or FEA) generated from ground-based low-frequency Météorage network (Erdmann et al. in revision for *JTECH*)
- **Observation operator:** obtained via linear regression on vertically-integrated graupel mass (Deierling et al. 2008). Sensitivity study underway.
- **Assimilation strategy:** 1D Bayesian retrieval of relative humidity + 3DVar (analogous to Duruisseau et al. 2019)



*Example of impact of FED (and other operational observations) on integrated water vapour (IWV) analysis: 6 Oct. 2018 19:00 UTC. Arrows show **drying** and **moistening**. (from Erdmann 2020)*

5. Lightning

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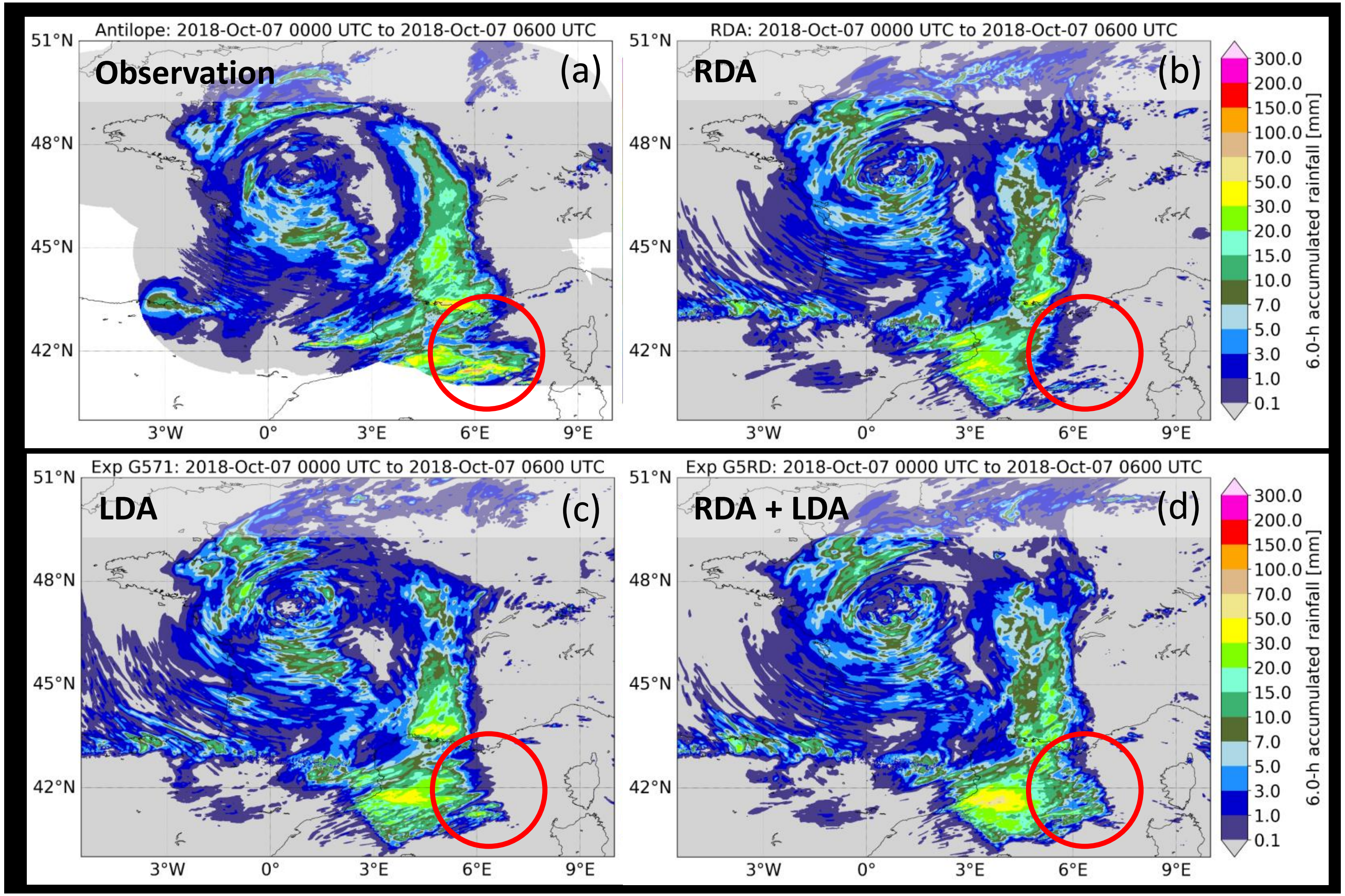
(Courtesy of Olivier Caumont)



=> Impact on precipitation forecasts:

Conclusions for this case study:

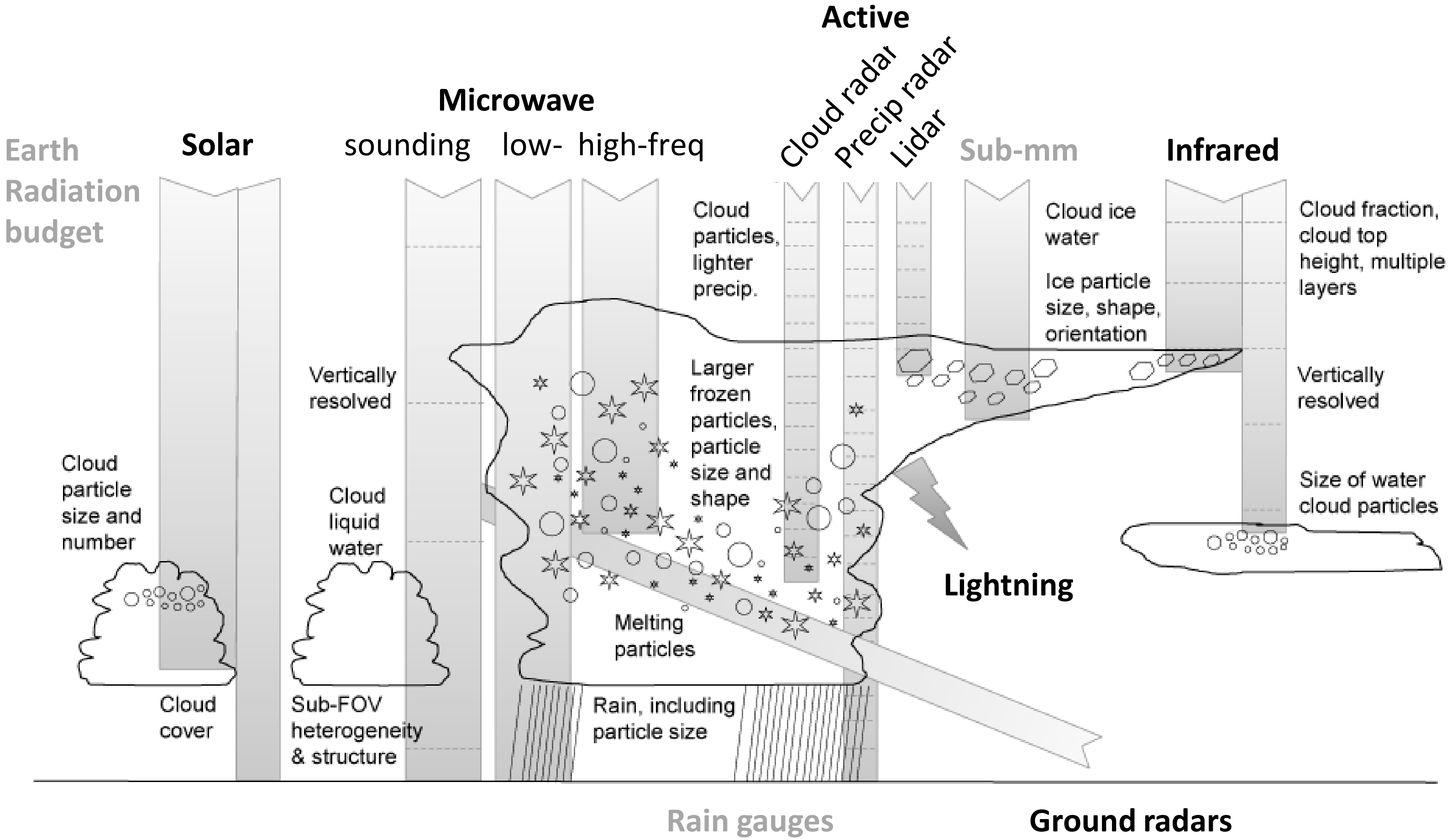
- Performance of lightning data assimilation similar to radar data assimilation (benefit up to 9–12 h); would need to be confirmed on longer periods.

Perspectives (PhD Pauline Combarnous):

- Improve observation operator (next slide)
- Move to direct assimilation via EnVar

Example of impact on precipitation forecasts: 7 Oct. 2018 00:00–06:00 UTC. RDA: operational + radar data assimilation (DA); LDA : operational + lightning DA; RDA+LDA: operational + radar +lightning DA (from Erdmann 2020)

Conclusion and perspective

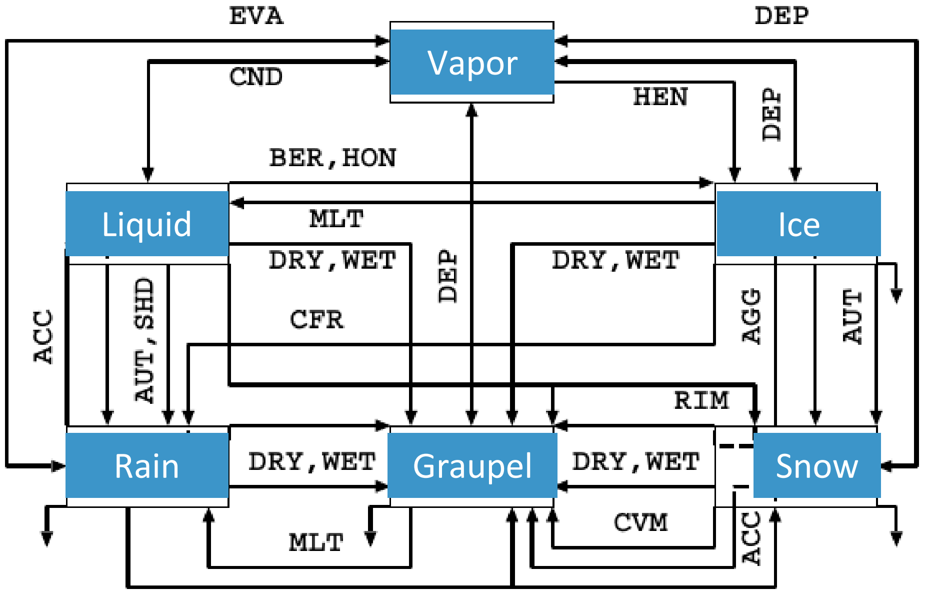


(Courtesy of A. Geer and S. English)

Conclusion and perspective

⇒ While some **observation kinds of clouds and precipitation** are now used with more maturity than others (e.g. microwave data), all observation kinds of clouds and precipitation are **potentially useful for NWP** (but it takes time to reach this point !).

⇒ « …, such a range of microphysical sensitivities available from the global observing system can also support efforts to improve the forecast model, to **reach a point of 'microphysical closure'** where the source of errors in the forecast model is made obvious through the overlapping sensitivities of different observation types. » (Geer et al., 2019, ECMWF Newsletter 161).



⇒ Observation operators are not necessarily using **consistent assumptions across the spectrum** on various aspects (single scattering properties, cloud overlap, …). Are those inconsistencies problematic to reach this point of microphysical closure or minor sources of errors compared to uncertainties in the model parametrizations ?

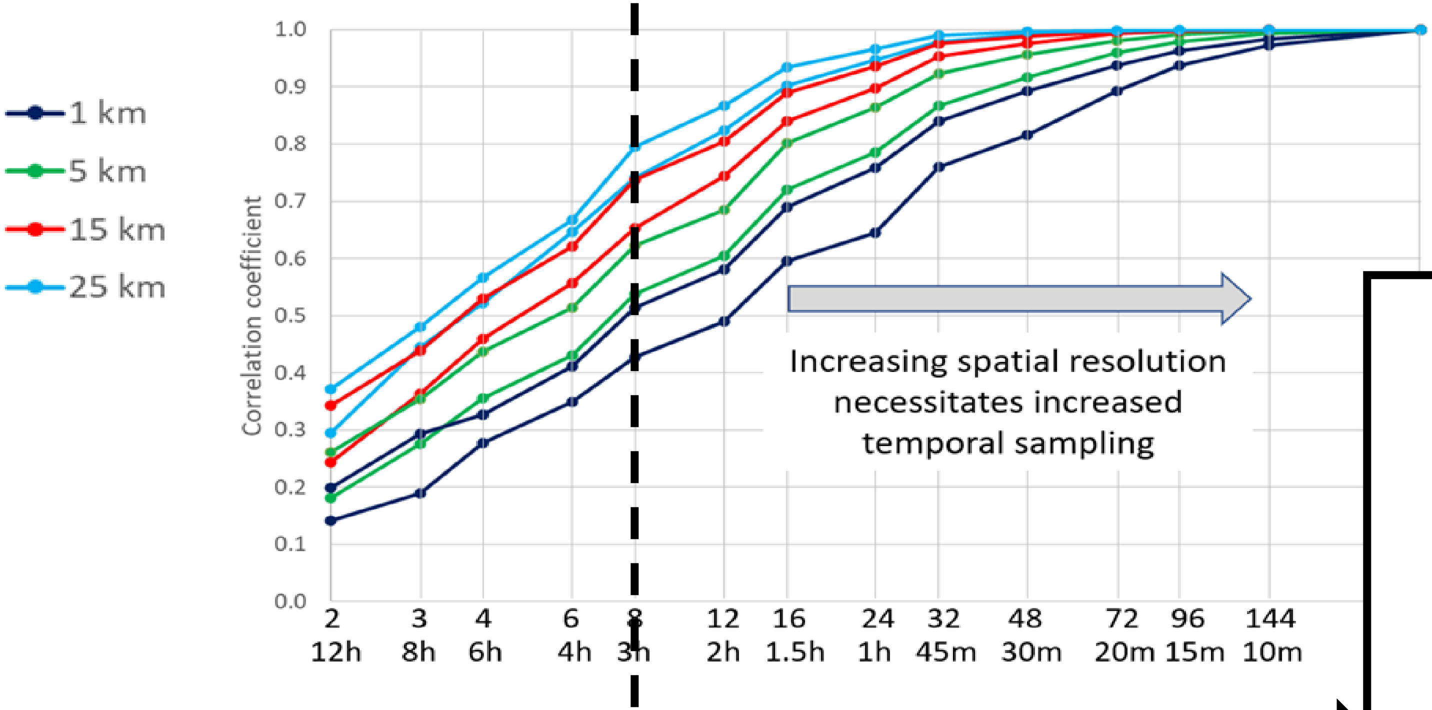
Thank you for your attention !

Backup slides

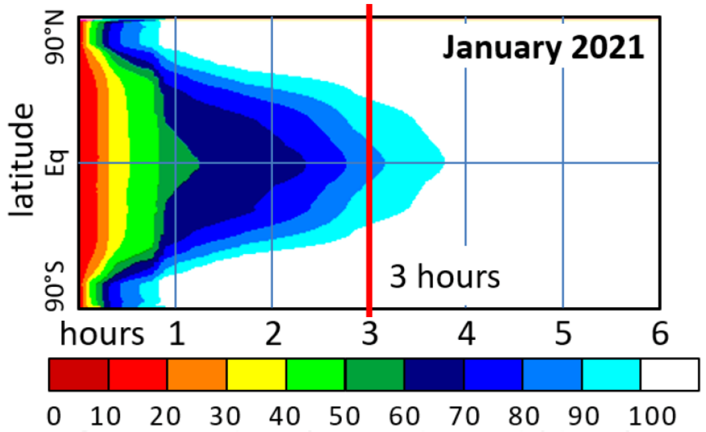
Introduction : precipitation variability

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)



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

Introduction : precipitation variability

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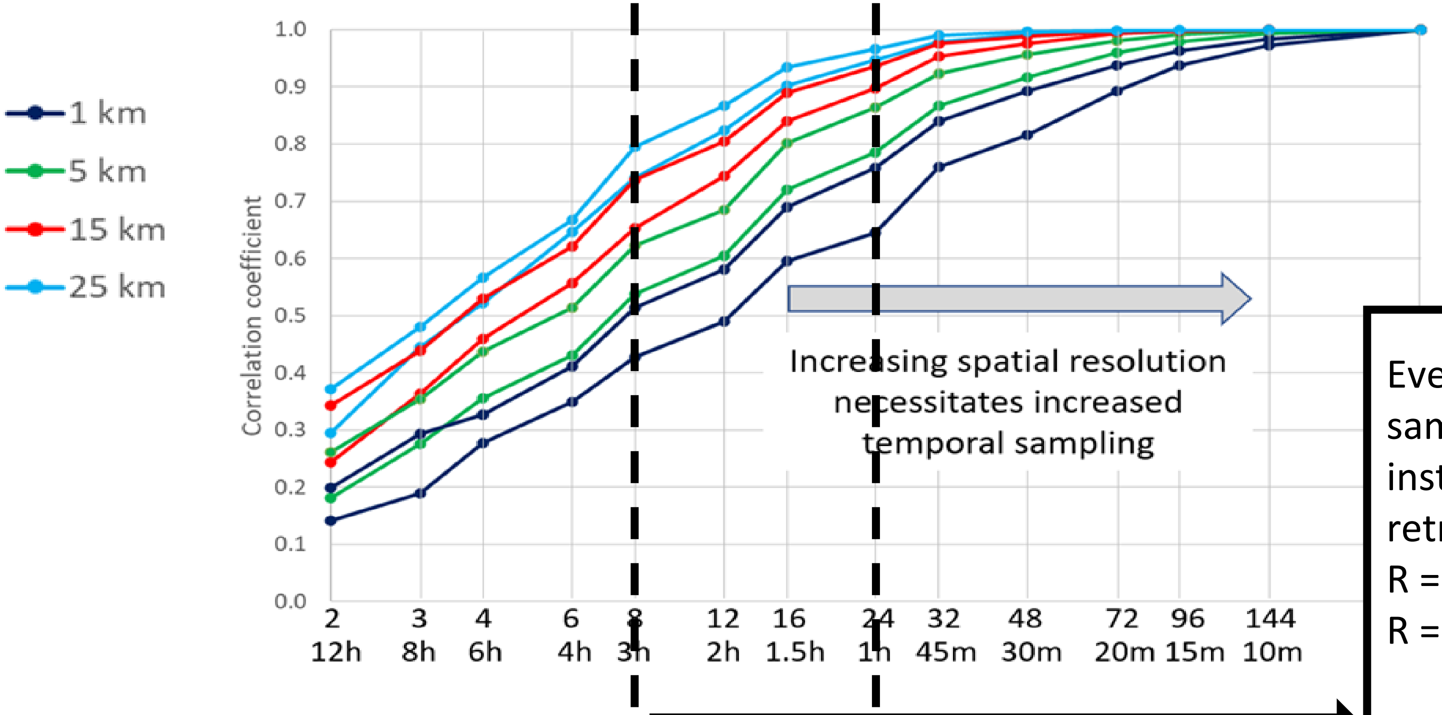


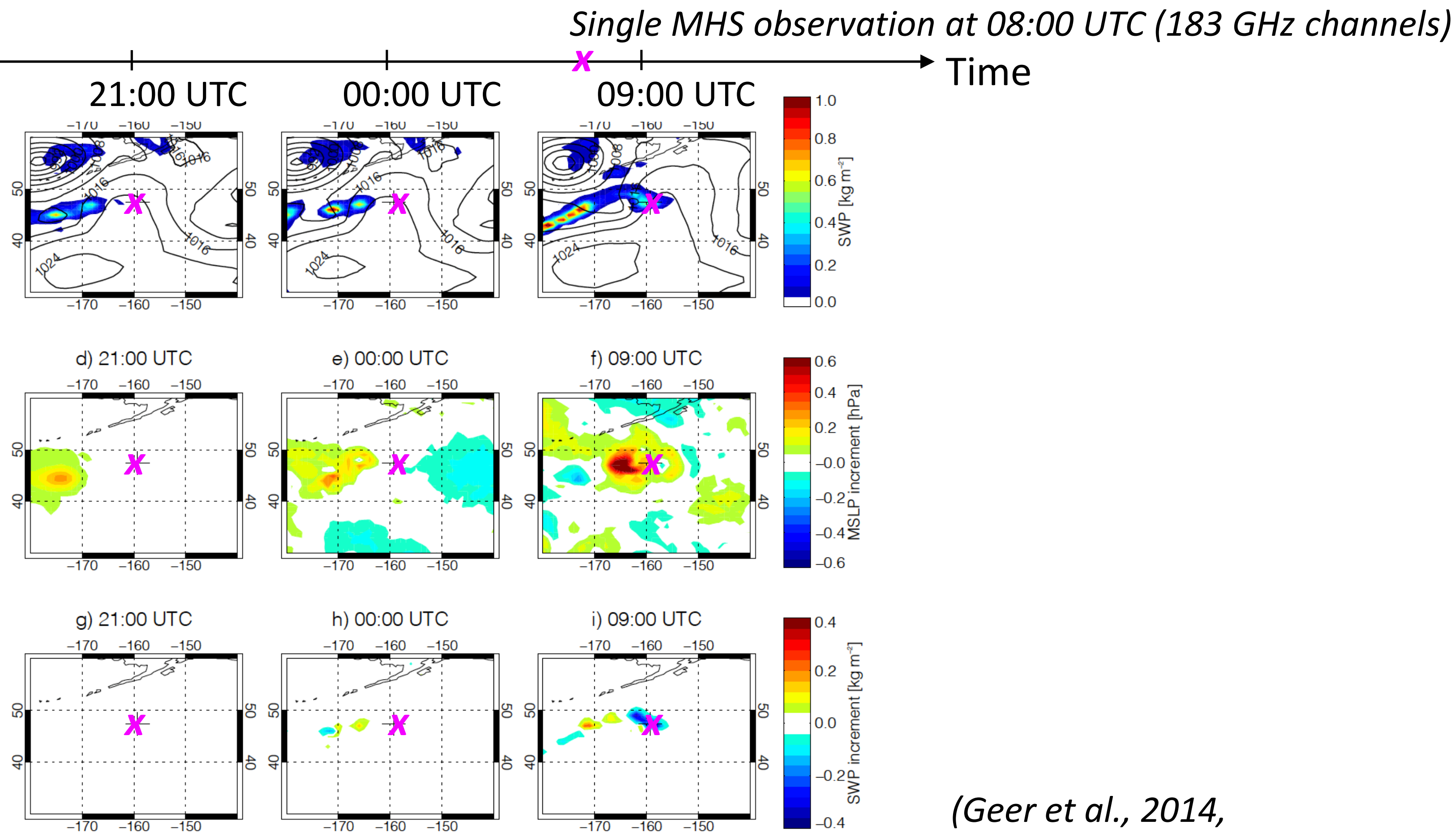
(Kidd et al., 2021, BAMS)

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 !**

1. Passive microwave observations

Microwave observations have been one of the very first cloudy and rainy observation kinds for which **benefits was demonstrated**. The main mechanism of improvement comes from **the ability of a 4D-variational** (4D-Var) assimilation system to **infer increments to dynamical fields from observations of cloud and precipitation.**



First guess mean sea-level pressure (line contours, in hPa) and snow water path (filled contours)

Increments in mean sea-level pressure

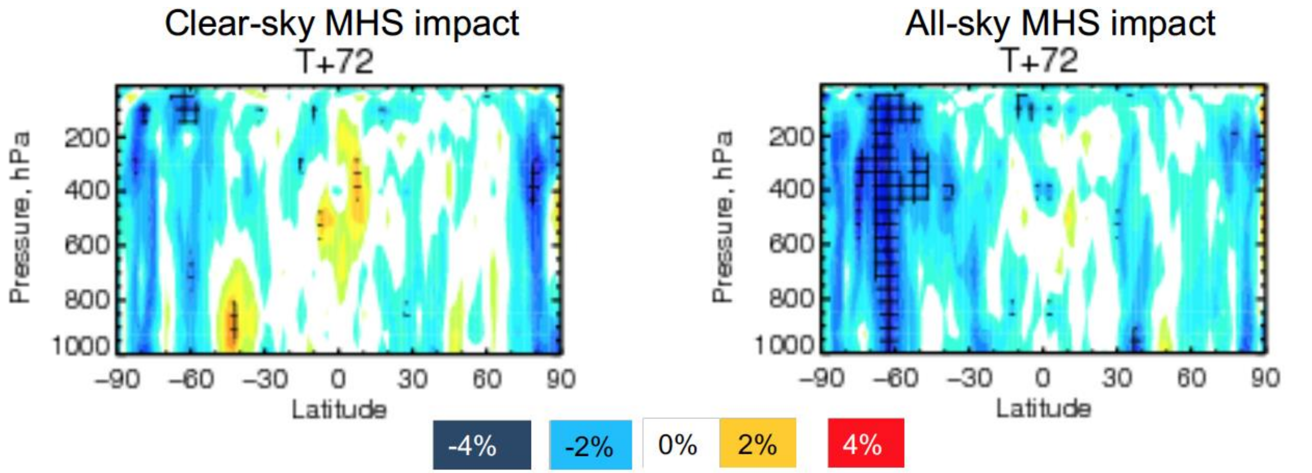
Increments in Snow water path

(Geer et al., 2014, ECMWF Tech Memo 741)

1. Passive microwave observations

The **tracing effect leads to improved wind analysis and subsequent forecasts** when the observations affected by clouds and precipitation are directly assimilation within a 4D-Var :

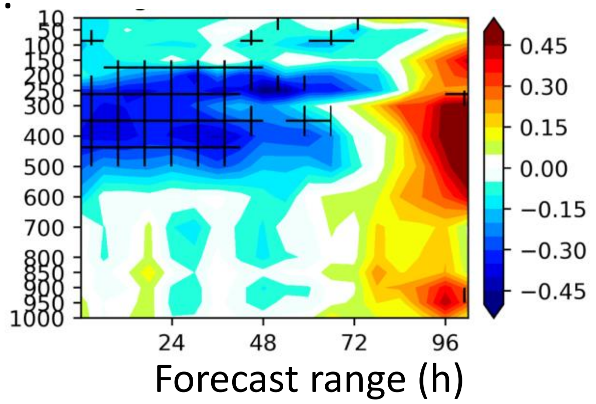
Relative Impact of MHS on T+72 wind forecasts of the IFS

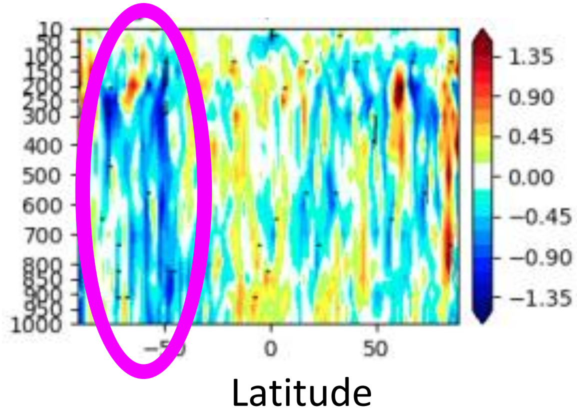


(Courtesy of N. Bormann)

This tracing effect can also be demonstrated even when these observations are assimilated an indirect method (e.g **1D-Bay+4D-Var in the current MF parallel suite**).

Relative Impact of MHS and ATMS cloudy and observations on wind forecasts of the ARPEGE global model with respect to the ECMWF analysis





1. Passive microwave observations

With the combined impact of clear and cloudy sky observations, not only the winds, temperature and humidity forecasts are improved but also **the forecasts of clouds and precipitation themselves**.

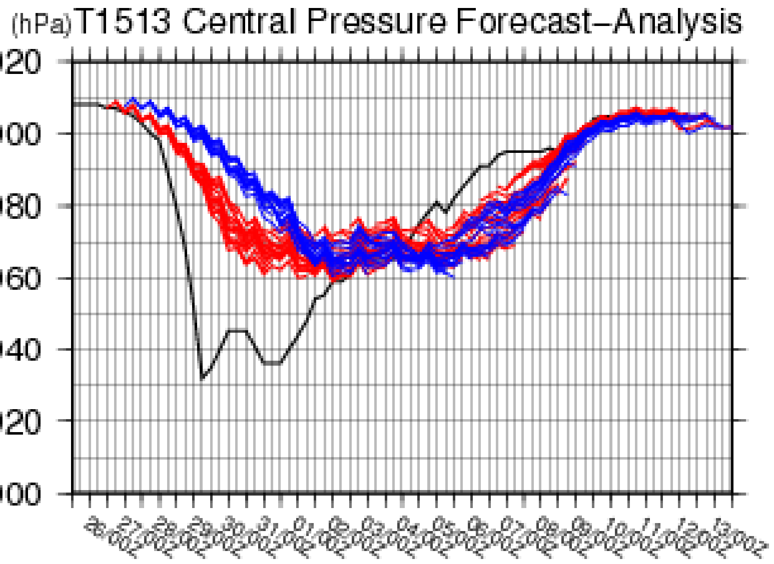
Improved prediction at TC developing stages

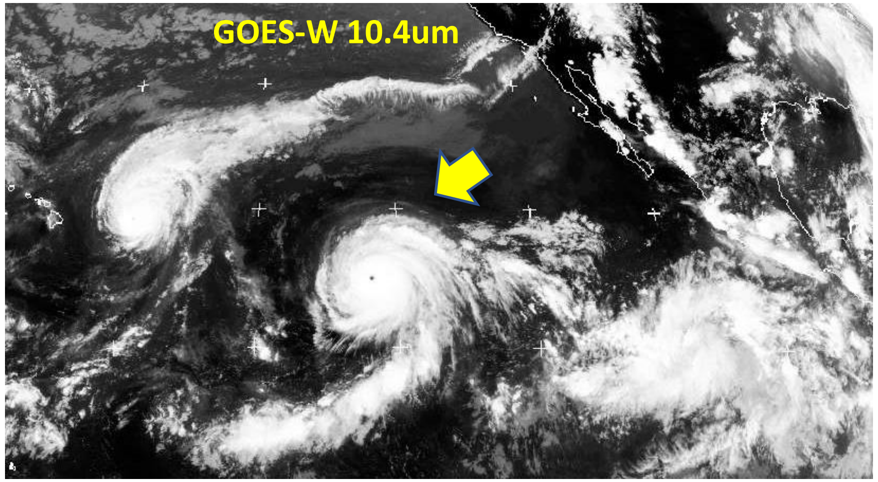
The heat release from water vapor condensation is a source of TC development. ***Rapid Intensification**** *of TC was predicted in the all-sky assimilation experiment. Water vapor analysis in cloudy conditions would be improved.*

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





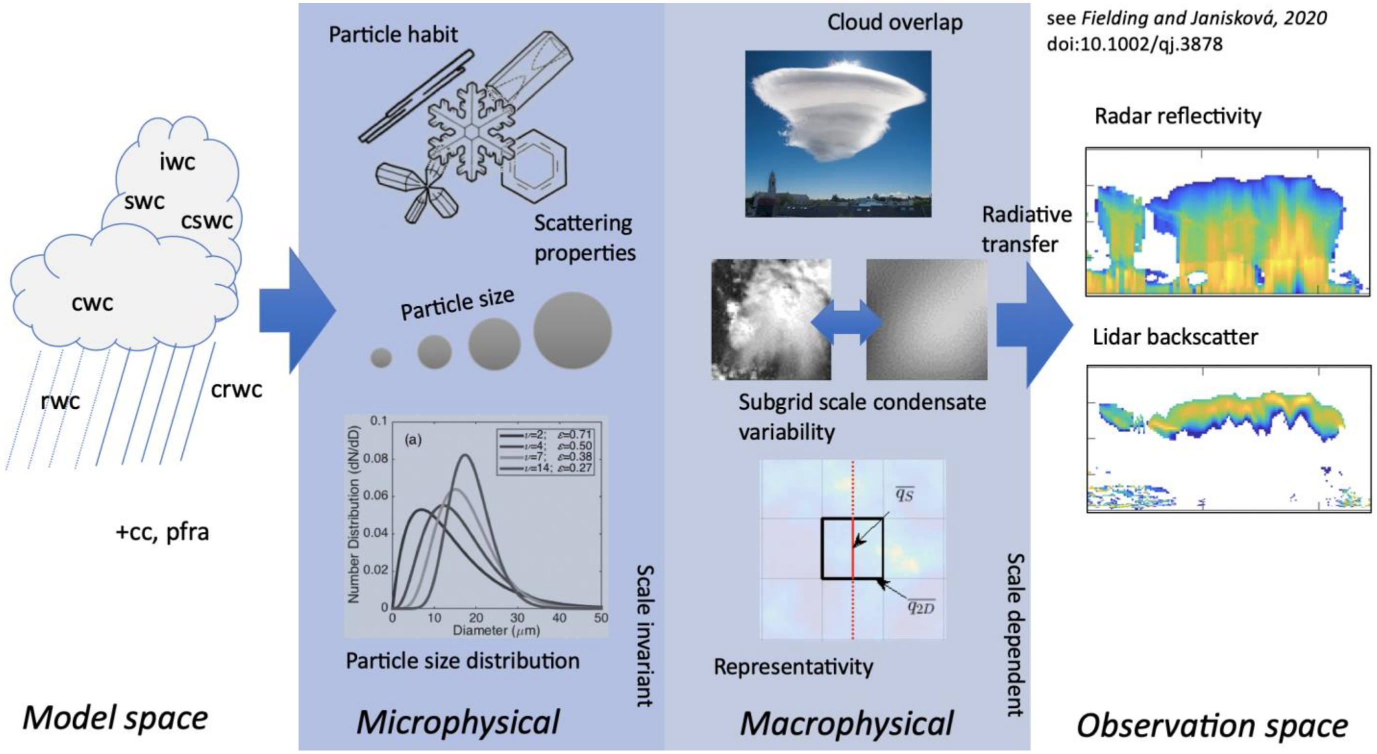
00UTC 31 Aug. 2015
Maximum stage

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

(Courtesy of Masahiro Kazumori, JMA)

2.2 Cloud and Precipitation radar/lidar

Assimilating information on the **full vertical structure of hydrometeors** is even more demanding in terms of developments than passive observations, although some aspects are in common and need a consistent approach to lead to a synergistic passive/active assimilation.



see *Fielding and Janisková, 2020*
doi:10.1002/qj.3878

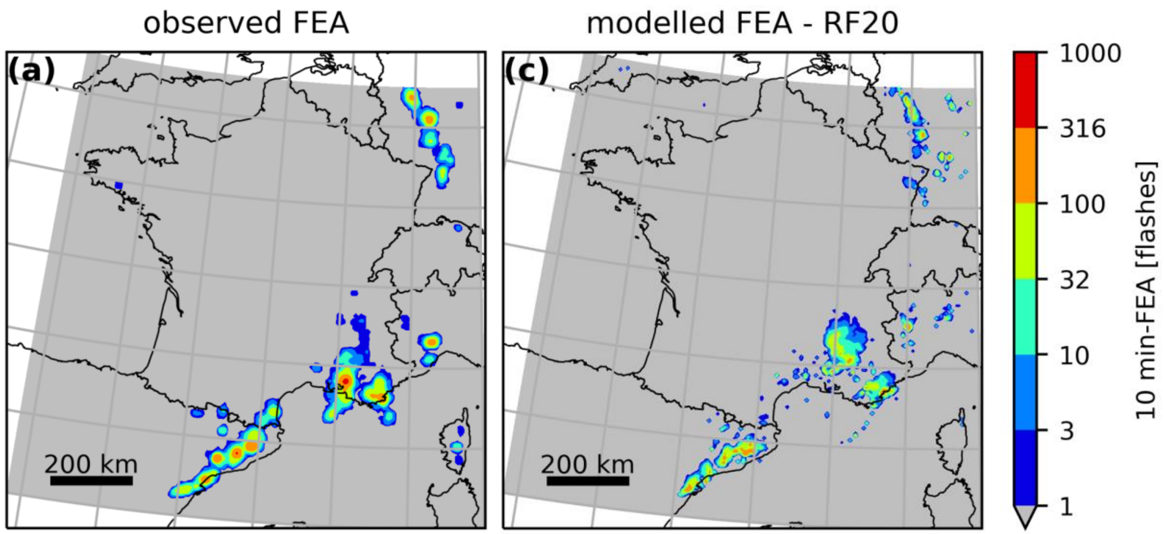
(Courtesy of Mark Fielding and Marta Janiskova)

5. Lightning

- **Lightning data:** Same as in previous slides (44+3 validation days)
- **Methodology:**
  - Distribution matching to overcome time-space errors
  - 8 proxies tested (alone or combined)
  - 4 machine-learning algorithms tested: linear regression, linear support vector machine, perceptron with 20 layers, random forest with 20 trees (RF20)
  - Various accumulation times (10 min to 30 min) tested
  - Validation: R^2 and MAE for distributions; FSS for values

- **Results:**

Example of observed FEA/FED and model equivalent computed from graupel mass above –5 °C with random forest on 9 Aug. 2018 13:00 UTC. (PhD Pauline Combarnous)



- **Conclusions (not shown):**
  - Microphysical proxies perform better than those involving vertical velocity.
  - Random forest and multilayer perceptron perform best.
  - No additional performance gained from combinations of proxies.
  - Very low sensitivity to accumulation time.

(Courtesy of Olivier Caumont)