Data assimilation for NWP at Météo-France: current status and plans towards an increased usage of active instruments

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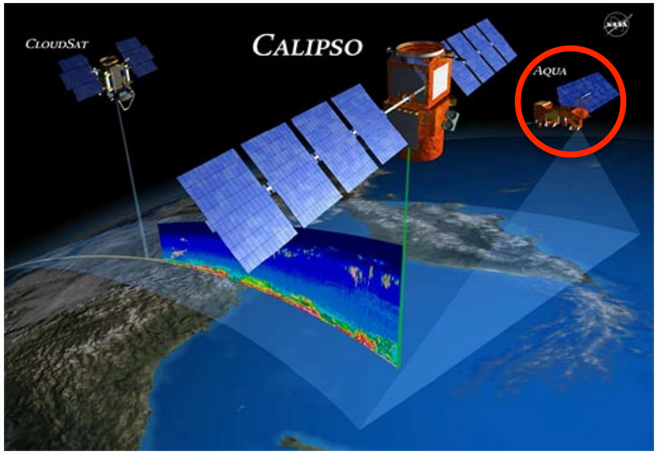
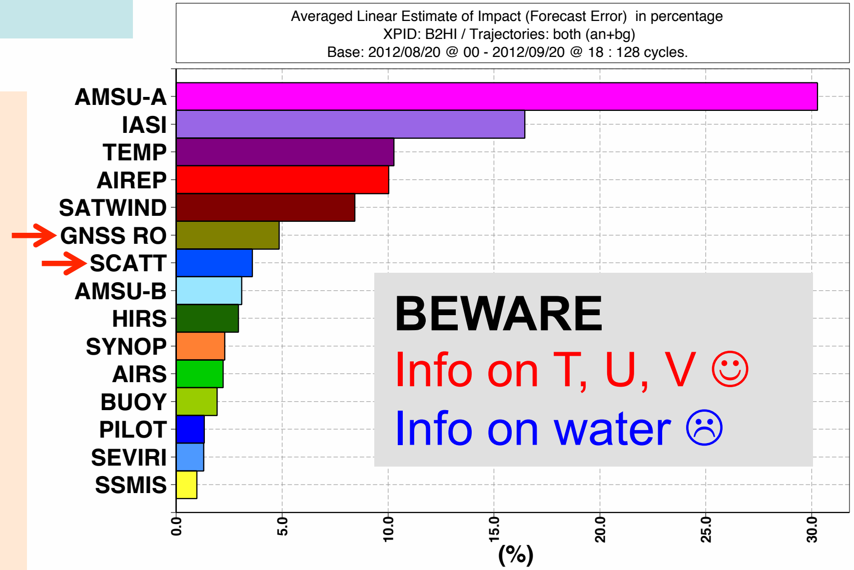
Purpose of this presentation

Explain :
-> the current usage of observations for NWP with an emphasis on satellite data (> 90 % in global systems)
-> why the use of active instruments is currently challenging (visible, IR, MW) in NWP despite providing complementary and valuable information on the atmosphere
-> why rapid progress is expected in the coming years



What are currently the most « useful » observing systems for global NWP ?

-> **AMSU-A**: microwave 55 GHz, several instruments, weakly affected by clouds, low NeΔT, info on T
-> **IASI**: infra-red 15 μm-> 4 μm, many channels (cloud detection), low NeΔT, info on T and WV



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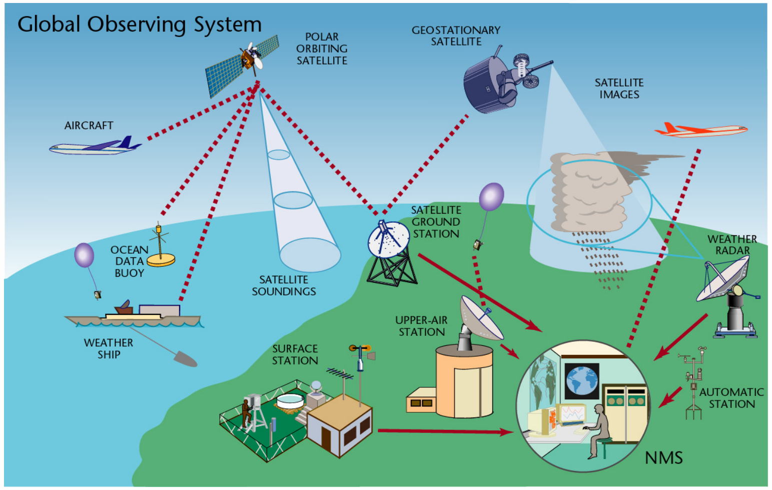
Outline

- Generalities about observations for data assimilation
- On the use of observations for NWP at Météo-France
- Activities on radar data assimilation
- Plans towards increased usage of active instruments

Preamble

- **Observations for NWP**: used to create an accurate model *initial condition* to provide an accurate forecast
- **Data Assimilation**: Statistical optimal combination between available observations and a short-range forecast (background or first-guess)
- **DA important aspects**:
  - Optimality => knowledge of random and systematic errors (biases)
  - Importance of quality controls and model capacity to simulate the observations (observation operator) => reject « useless » observations



Variables of interest:
<u>Current</u>: mass, temperature, wind, water vapour

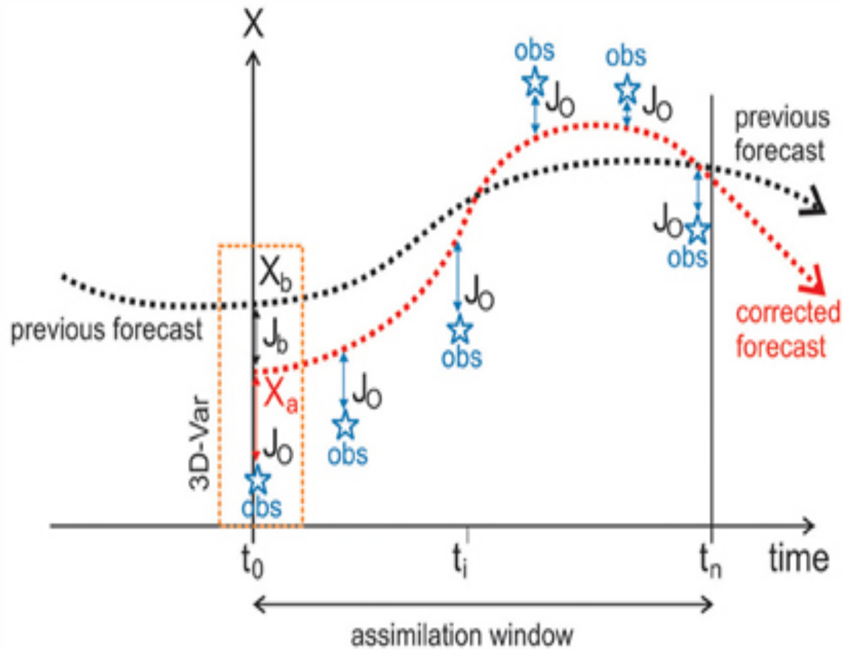
<u>Future</u>: soil moisture, condensed water, atmospheric composition, aerosols, …

Variational data assimilation

Mathermatical formulation: cost-function to minimize

$$J(x)=\frac{1}{2}(x-x_b)^T B^{-1}(x-x_b)+\frac{1}{2}\left[y-H(x)\right]^T R^{-1}\left[y-H(x)\right]$$

- x = state vector (temperature, wind components, surface pressure, water vapour content)
- x_b = background (short-range forecast)
- y = available observations
- H = observation operator
- B = background error covariance matrix
- R = observation error covariance matrix



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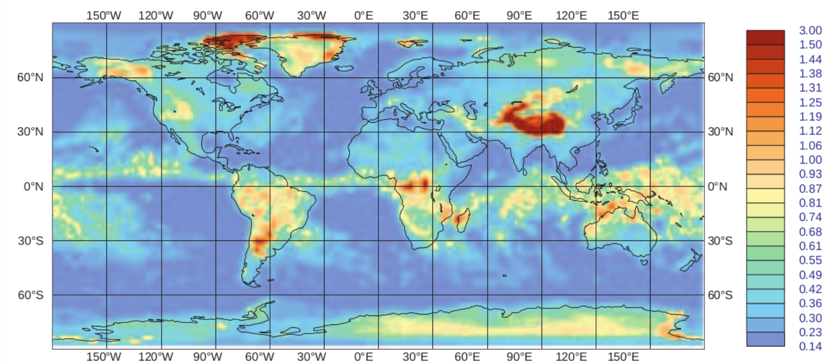
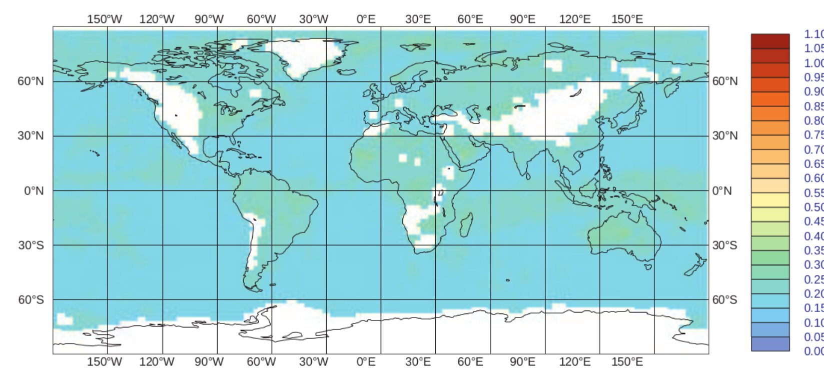
Observations for DA in NWP : requirements

- **Accurate model to simulate (rapidly) the observation**: observation too far from the model => problem either with the observation or with the model – observations closer to the measurement should be favored (L1 vs L2)
- **Accurate and complementary observations**: accurate enough and numerous (in time and/or space) and should complement existing observing systems (reduncancy can be useful for improving resilience)
- **Near-real time availability**: less than 3 hours after the measurement
- **Unbiased and uncorrelated:** bias corrections – data sampling

Observation minus model



All data : AMSU-A Ch5



Data for assimilation

<u>Remark</u> : for AMSU-A in clear sky OmB close to NeΔT (0. 3 K)

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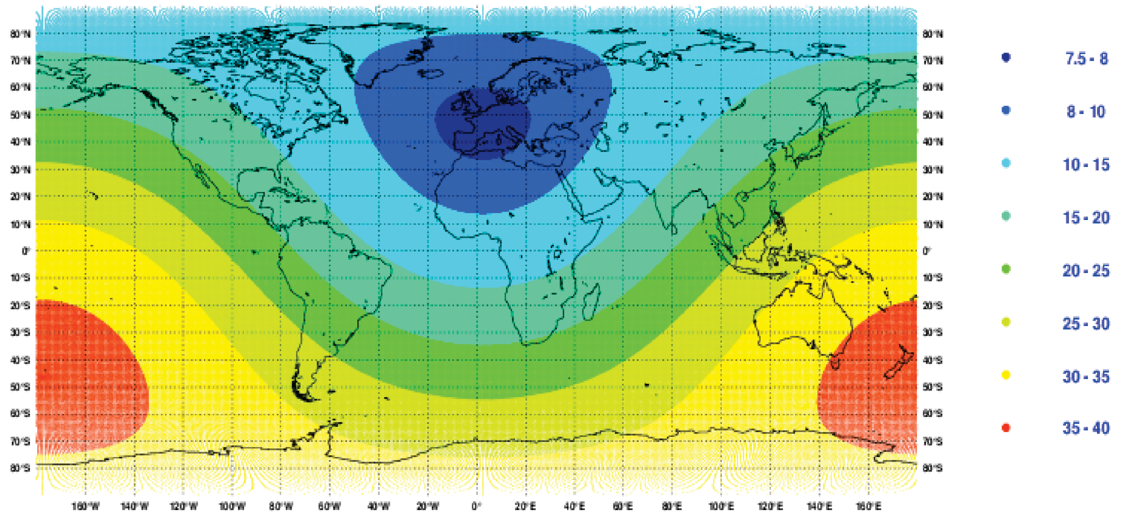
Global model ARPEGE

Spectral model with variable resolution : T_L1198c2.2L105
(resolution from 7.5 km to 36 km, 105 levels from 10 m to 0.1 hPa)
Forecasts up to 104 hours



Moist physical processes : prognostic large-scale precipitation scheme with explicit microphysics for 4 species (Lopez, 2002) and diagnostic moist convection scheme based on mass-flux (Bougeault, 1985)

Data assimilation system : 4D-Var (6-h window and 30 min time-slots) + ensemble data assimilation system (background error statistics)

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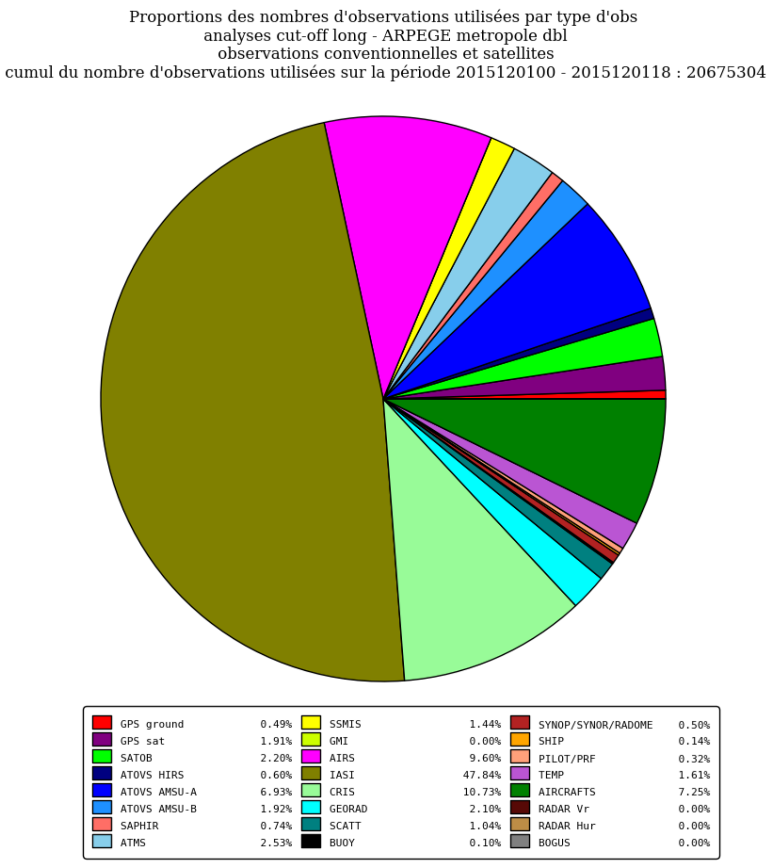
Partition by observation types



ARPEGE Model – 01/12/2015

Total number of daily data assimilated (4 analyses per day) :
20.6 millions

IR sounders -> IASI 48 % + AIRS 10 % + CrIS 11 % => 69 %
MW sounders/imagers : 14 %

GPS- RO : 2 %
SCAT winds : 1 %
SATOB winds : 2 %

Aircraft data : 7 %
TEMP+PILOT : 2 %

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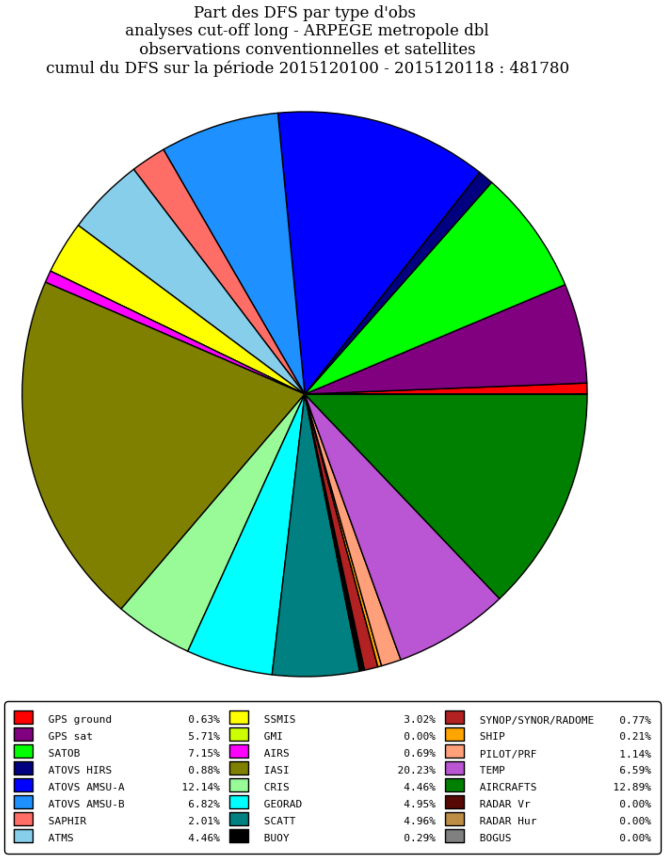
Information content : DFS



DFS : depends upon the number of observations, the observation accuracy, the projection on the variables to analyse (T,q,U,V,Ps)

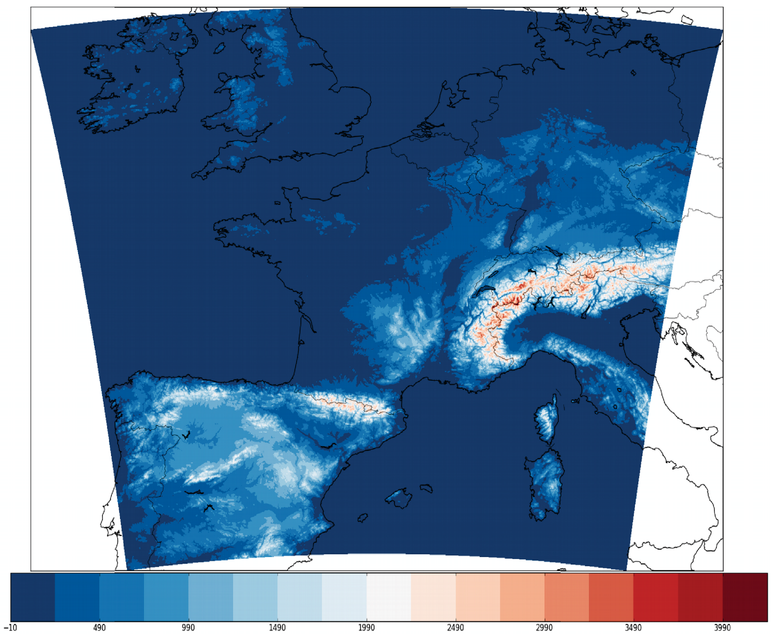
MW imagers/sounders : 28 %
IASI IR sounder : 20 %

Aircraft data: 12 %
TEMP+PILOT : 8 %
GPS- RO : 6 %
SCAT winds : 5 %
SATOB winds : 7 %

DFS (Degree of Freedom for Signal) : capacity of an observing system to reduce the a-priori information

Regional model AROME

- Spectral limited area non-hydrostatic model with explicit moist convection (since 12/2008) => hydrometeors as prognostic variables (mass concentration)
- Horizontal resolution : 1.3 km
- 90 vertical levels (from 5 m up to 10 hPa)
- 3D-Var assimilation (1-h window)
- Observing system : same as ARPEGE (+) 5 SEVIRI/MSG radiances (with Ts inversion) (+) radar DOW and Z (RH)
- Forecast range : up to 42 hours



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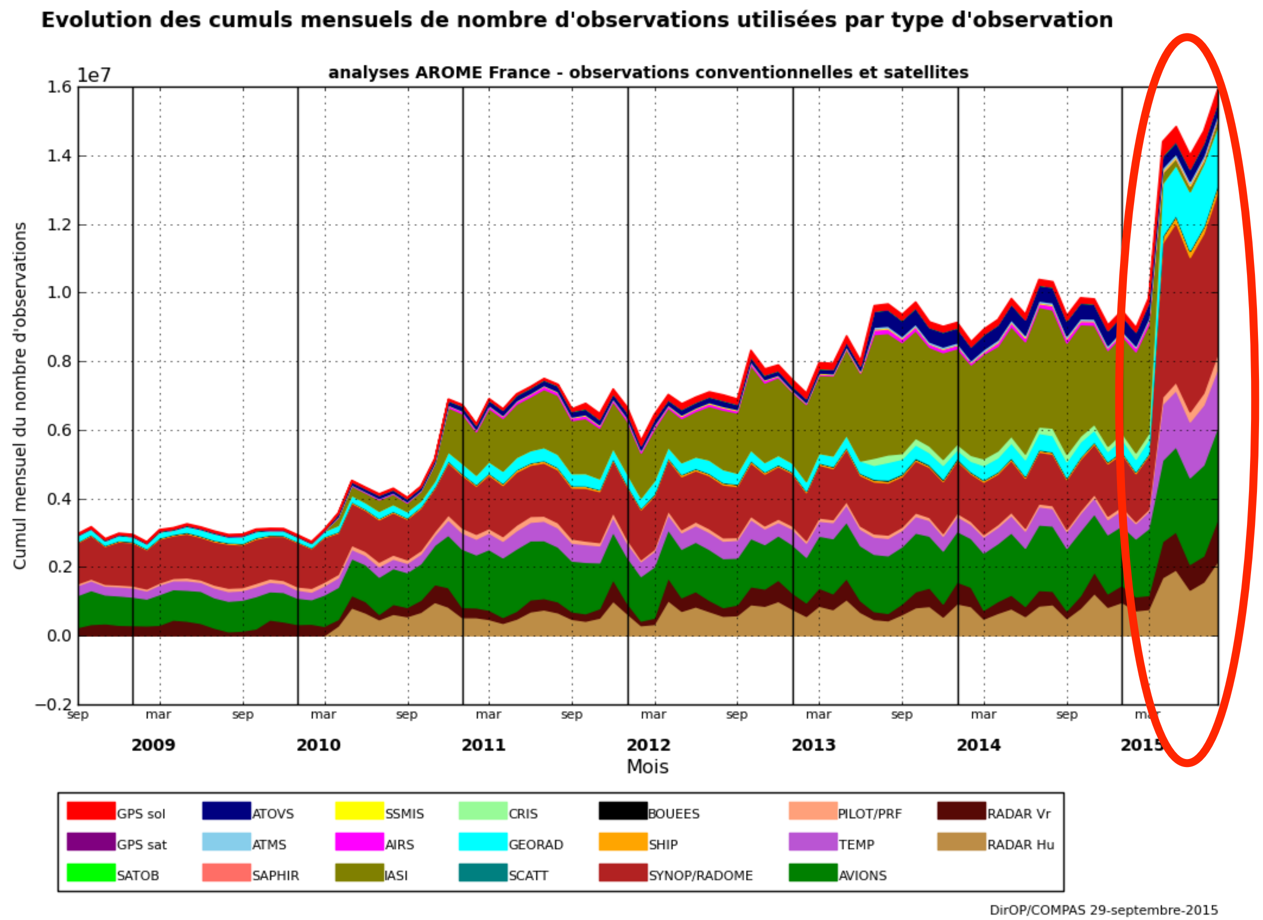
Observations in AROME 3D-Var

IASI
AIRCRAFTS
SURFACE
RADARS
SEVIRI
ATOVS
TEMP



<u>At mesoscale (mid-latitudes)</u>:

ground based
and conventional
obs
>> satellite data

Obs at high temporal availability

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Simulation of polarimetric radar data (1)

One moment cloud scheme : ICE3 with 6 water species (water vapor, cloud water, rain water, graupels, dry snow and pristine ice)

PSD : Exponential for rain, snow and graupel, generalized Gamma for cloud water and pristine ice

Densities are given by mass-diameter relationships $m = aD^b$

What we would like to simulate :

-horizontal reflectivity Z_{hh}

-differential reflectivity Z_{dr}

-differential phase Φ_{dp}

-specific differential phase K_{dp}

-co-polar correlation coefficient ρ_{hv}

What needs to be specified with some level of arbitrariness:

-raindrop shape : axis ratio $r = f(D_{eq})$
-dielectric function for snow and graupels (Maxwell-Garnett)
-dielectric properties for melting graupels

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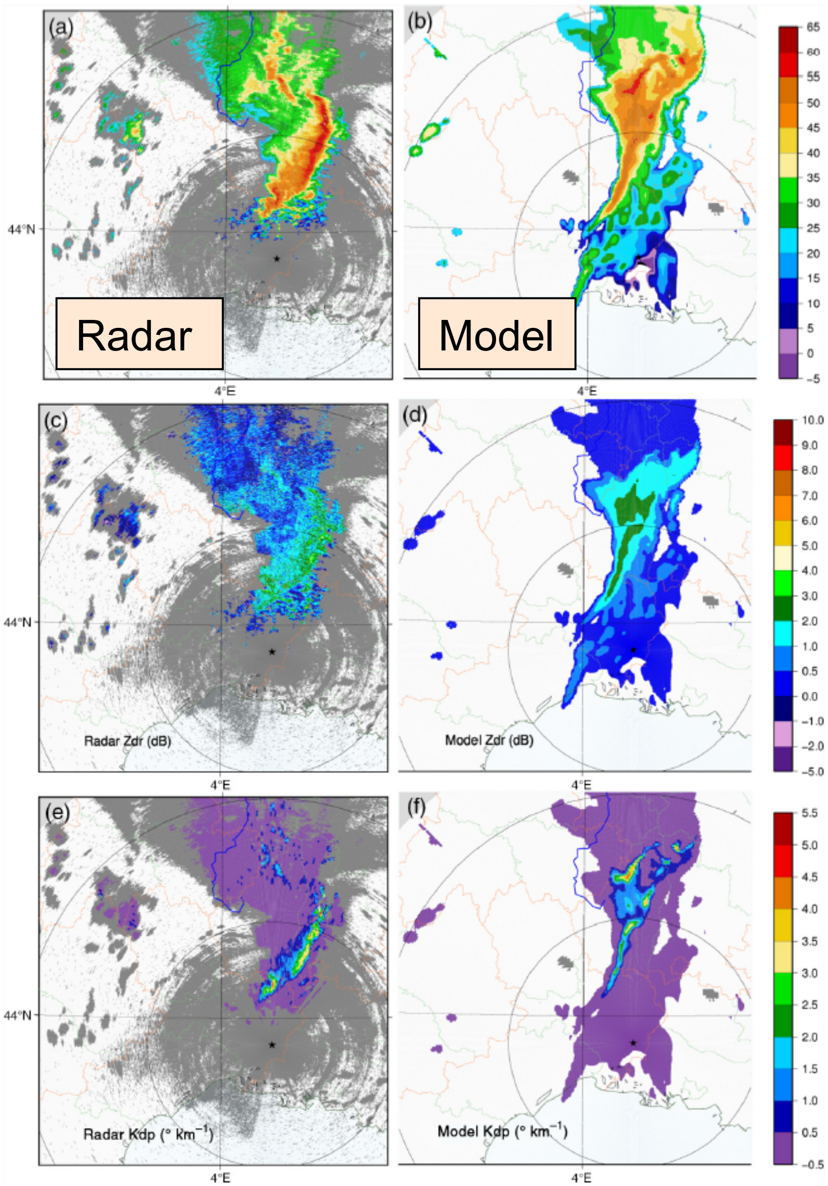
Simulation of polarimetric radar data (2)



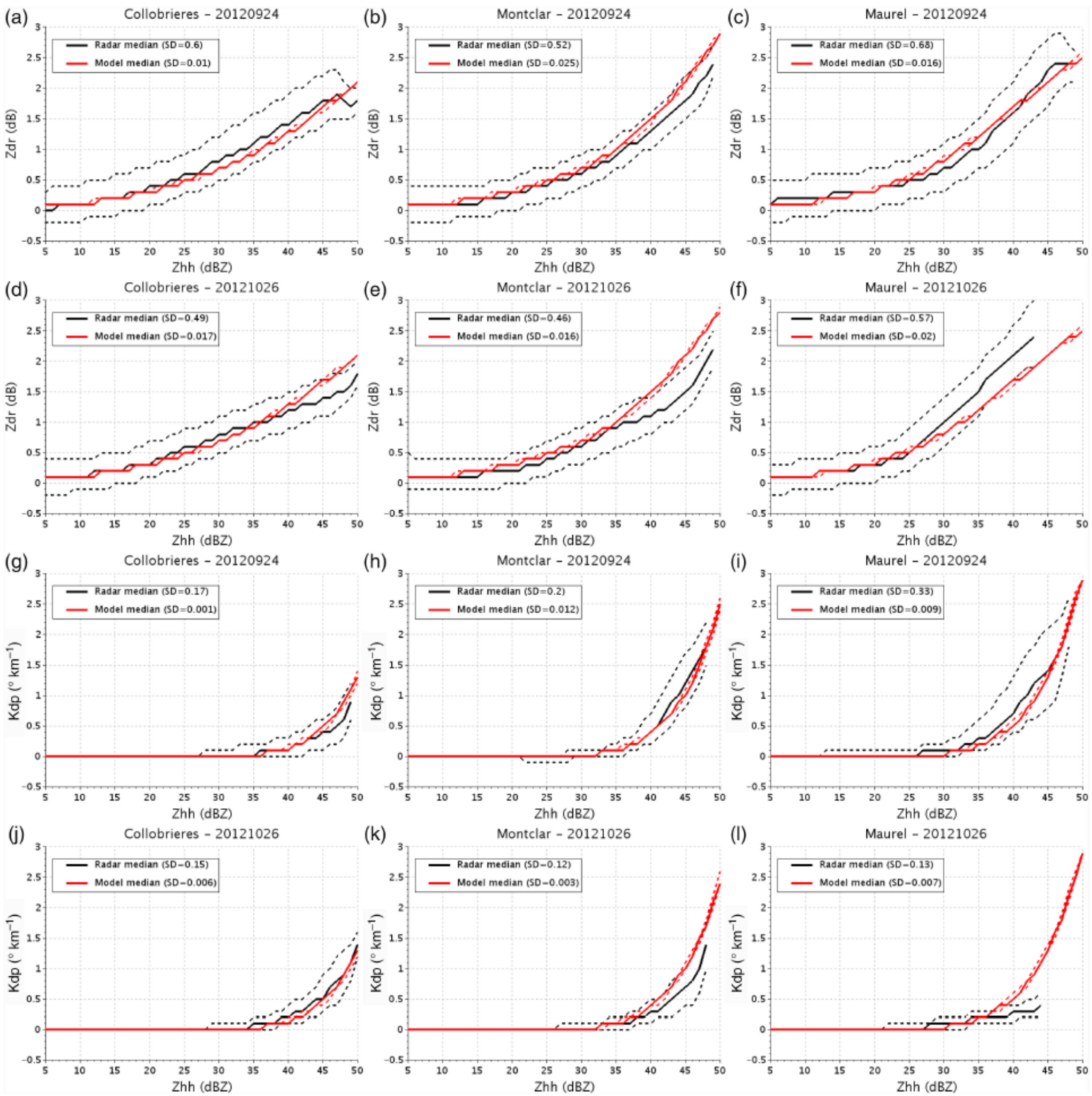
Z_{hh}

Z_{dr}

K_{dp}

Augros et al. (2015) QJRMS

Simulation of polarimetric radar data (3)



$Z_{dr} = f(Z_{hh})$

$K_{dp} = f(Z_{hh})$

MODEL

RADAR

Lack of variability in the model

-> one moment scheme

Augros et al. (2015) QJRMS

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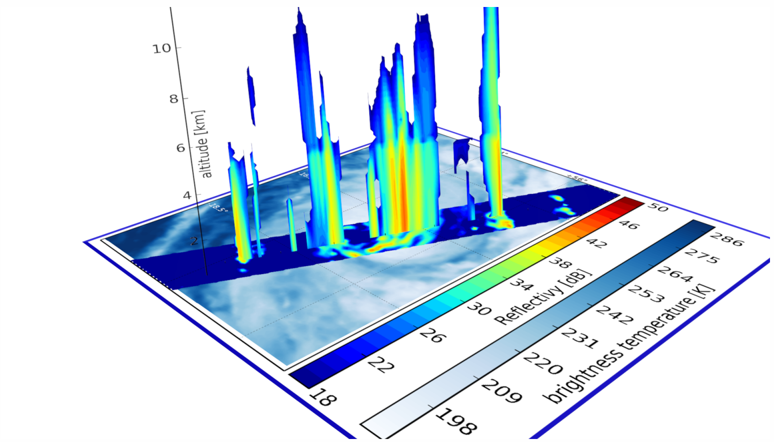
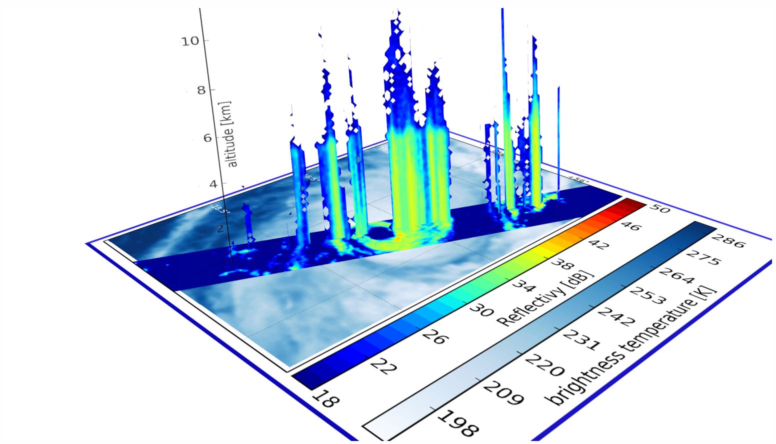
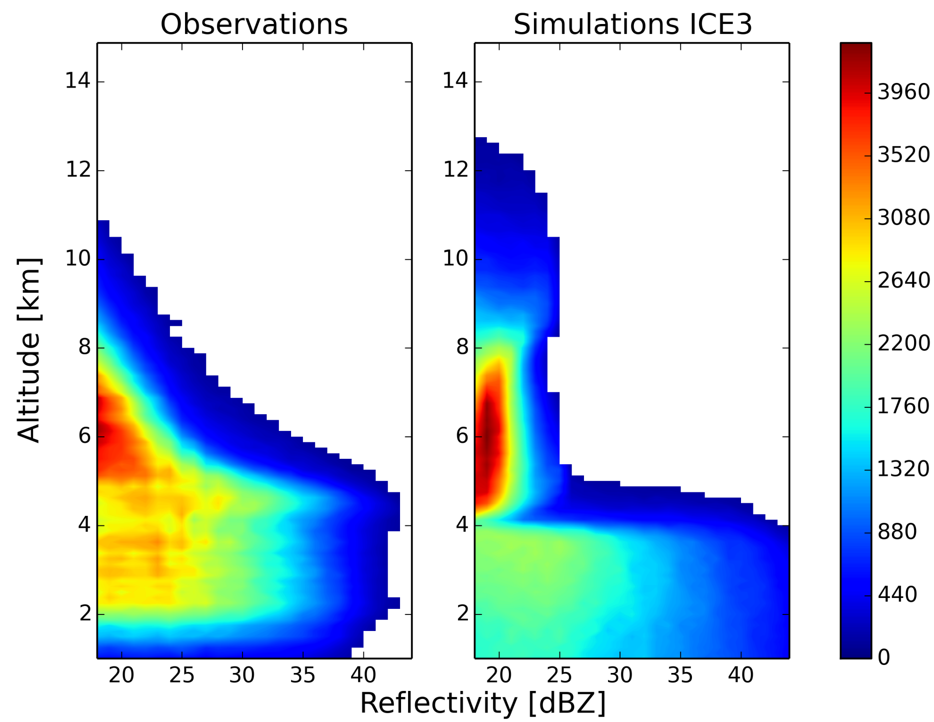
Simulation of GPM DPR with AROME (1)







2D histograms (10 days) of DPR reflectivities in Ku band using microphysics consistent with ICE 3 in SDSU radar simulator

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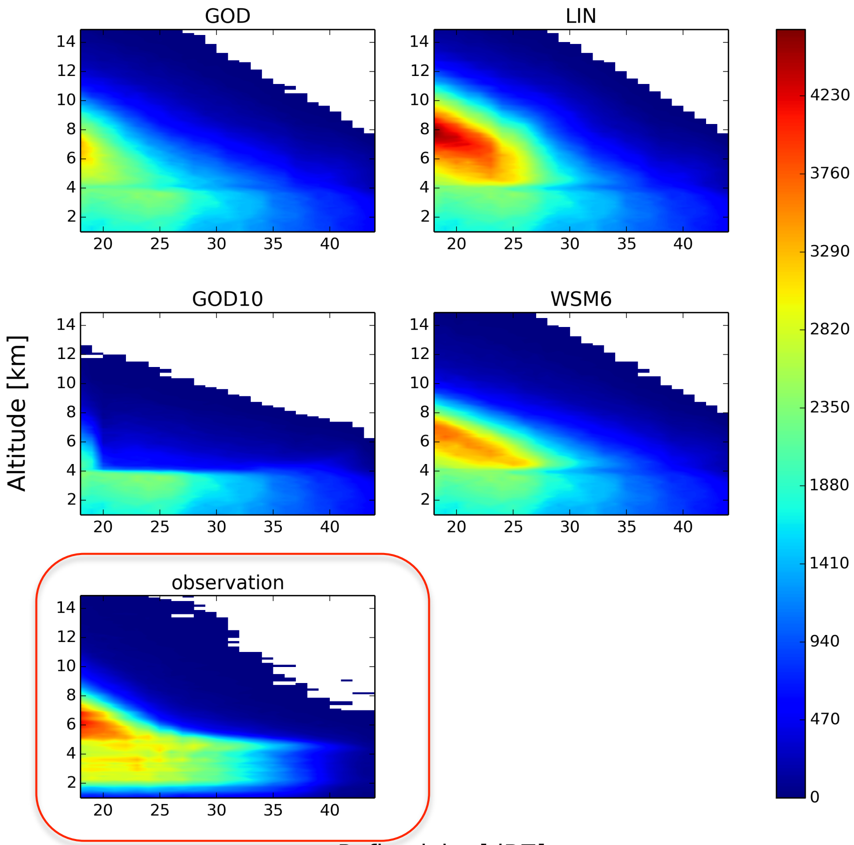
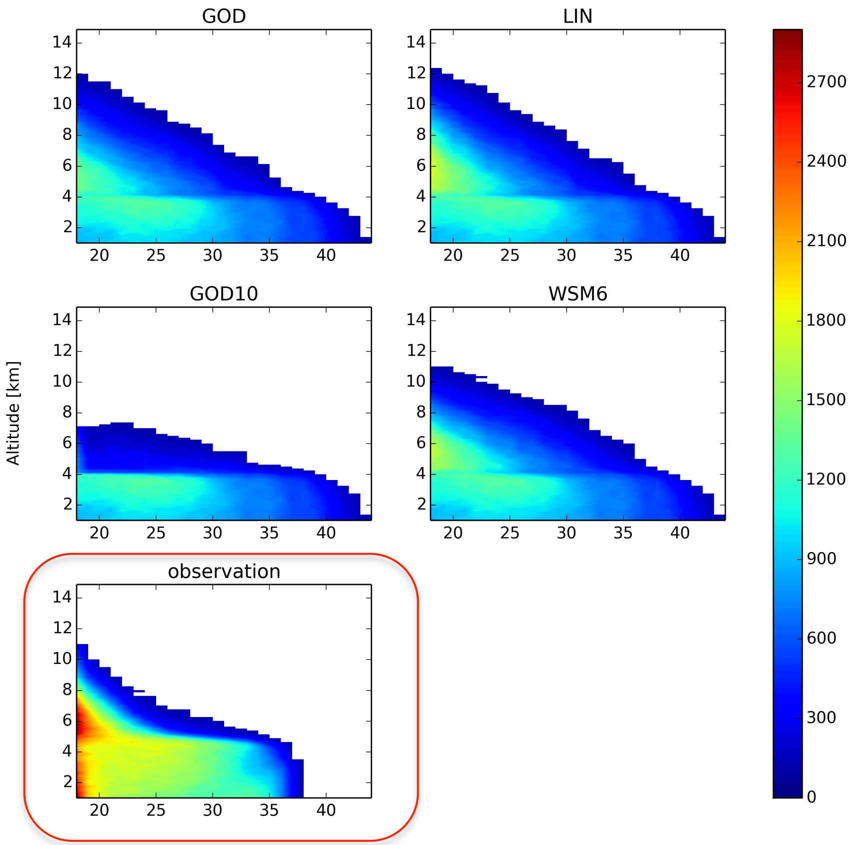
Simulation of GPM DPR with AROME (2)

Ku band



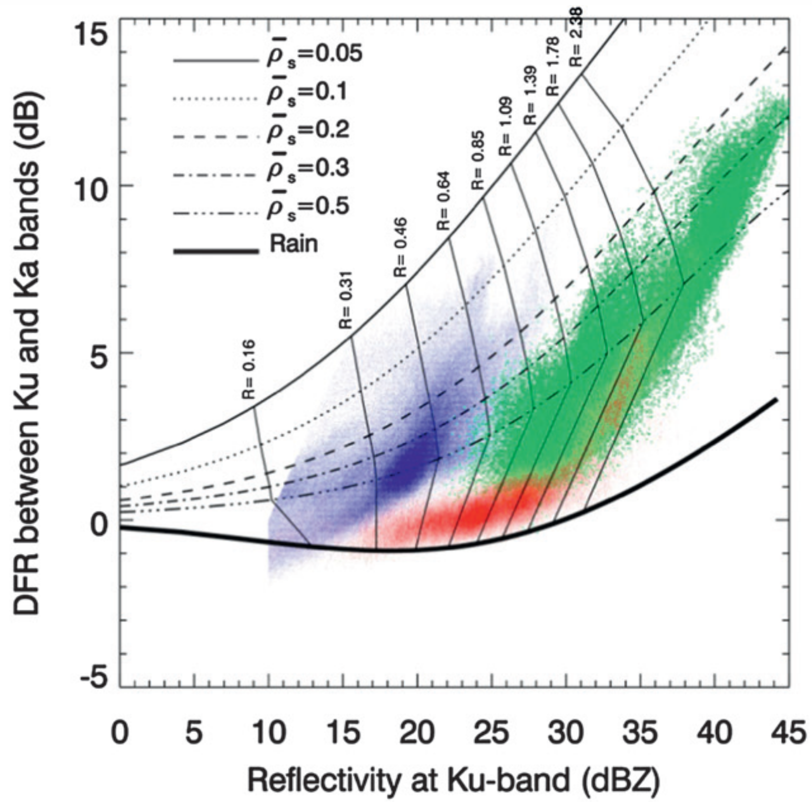
Ka band

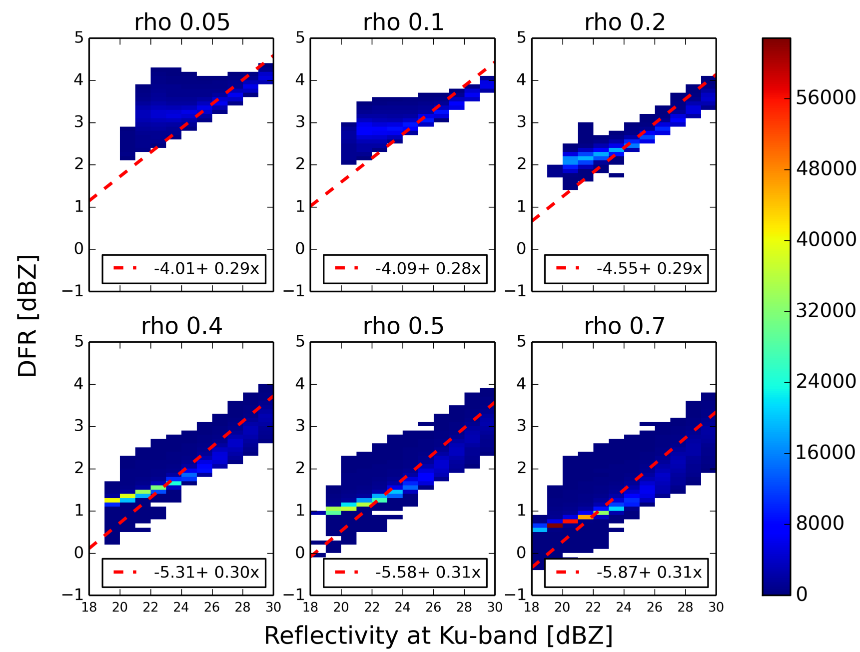


GOD : Tao (2003)
GOD10 : improved GOD

LIN : Lin et al. (1983)
WSM6: Hong et al. (2004)

Simulation of GPM DPR with AROME (3)





Use of the Dual Frequency Ratio to constrain the snow density specification in the radar simulator

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Data assimilation of active sensors

- **Current status**: spaceborne (scatterometers : C and Ku band radars; GNSS-RO : L-band signals) + ground based (weather radars : C, S and X band; wind profilers)
- **Drawbacks**: the raw signal (backscatter coefficient, reflectivity) is converted into a meteorological quantity before assimilation
- **Explanation**: Lack of knowledge in the NWP model on the physical content of the signal (cloud microphysics, sea state) => observation operator
- **Future spaceborne instruments** : ADM-AEOLUS (Doppler wind lidar ; use of L2 products), EarthCare (cloud radar and lidar ; 1D +4D-Var at ECMWF)
- **Difficulties for DA**: polar orbiting satellites with nadir viewing, rather crude description of clouds and aerosols to simulate observations (regional vs. global systems) – but still very useful for model validation (preliminary step before DA)

Conclusion and future activities

- **Interest:** detailed vertical structure on complementary meteorological variables + high temporal frequency of ground based instruments (convective scale DA – nowcasting)
- **Expected model and data assimilation improvements** :
  - More realistic description of cloud microphysics (2 moment schemes) with aerosol interactions (nucleation, scavenging, …)
  - Coupled modelling systems with atmosphere, ocean, land surface, sea state, chemistry, …
  - Development of ensemble data assimilation including new prognostic variables (clouds, precipitation, atmospheric composition) with associated background error statistics
- **Requirements** :
  - Development of accurate and efficient observation operators - need to explore the short-wave spectrum (IR + solar)
  - Improved handling of model and observation errors (biases, …)
  - Space based instruments with a wide swath ?

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Thank you for your attention !

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