The International SOFOG3D experiment
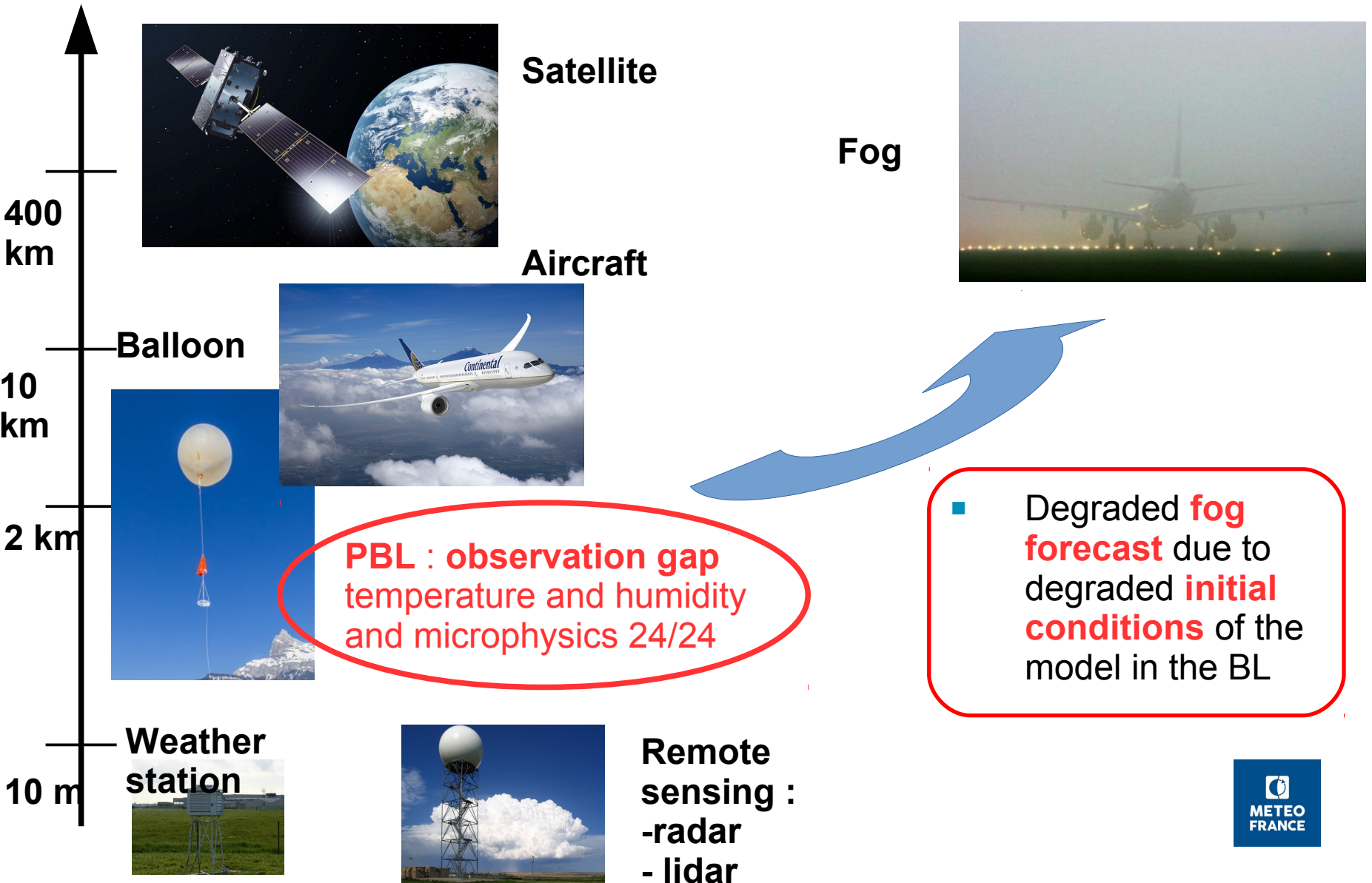
Task5 : Data assimilation and forecast

PI : Pauline Martinet, Nadia Fourrié

The WP5 team members / partners

- CNRM/GMAP : Jean-François Mahfouf, Thibaut Montmerle, Nadia Fourrié

- CNRM/GMME : Olivier Caumont, Benoit Vié

- CNRM/GMEI : Alistair Bell, Vinciane Unger, Gilles André, Jean-Marie Donier, Thierry Douffet

- LATMOS : Julien Delanoe

- University of Cologne : Ulrich Löhnert

- IMAA-CNR, Italy : Domenico Cimini

- MeteoSwiss : Maxime Hervo / Alexander Haefele

- ONERA : Thierry Huet / Xavier Boulanger

- Laboratoire d'Aérologie : Jean-François Géorgis

- RPG : Harald Czekala

- Attex : Mathias Schröder

Motivation of the study

Satellite

Fog

Aircraft

Balloon

400 km

10 km

2 km

Weather station

Remote sensing :
-radar
- lidar

PBL : **observation gap** temperature and humidity and microphysics 24/24

- Degraded **fog forecast** due to degraded **initial conditions** of the model in the BL
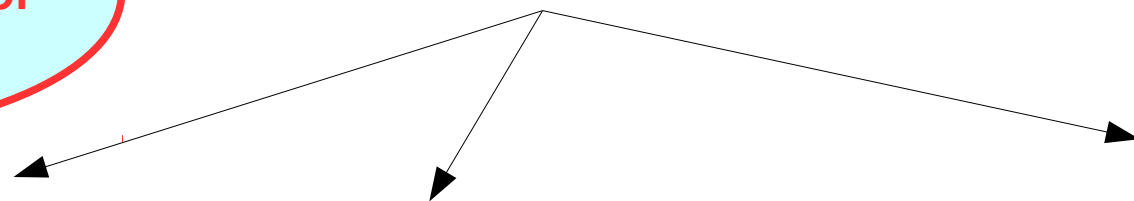
10 m

METEO FRANCE

Ground-based microwave radiometers

Continuous data in all-sky conditions: resolution of seconds to minutes
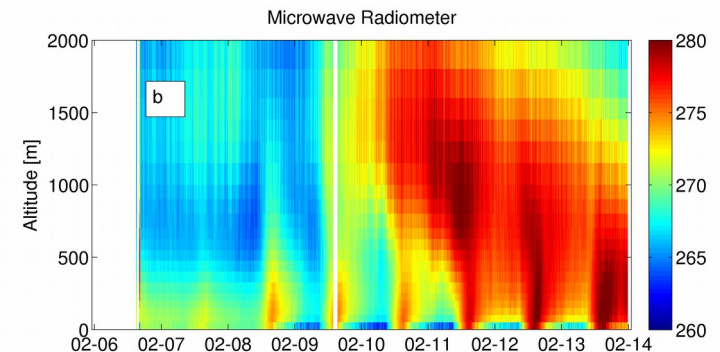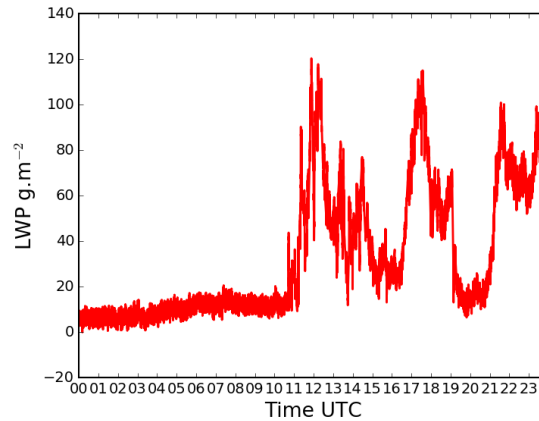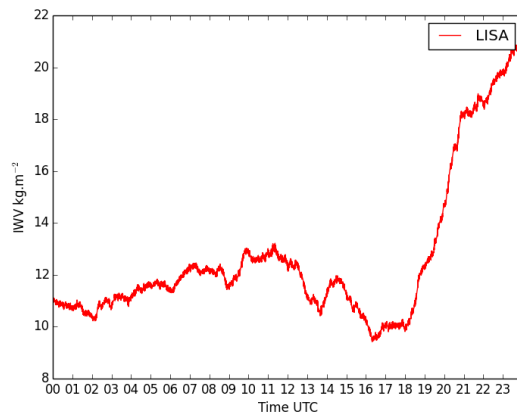
Information mainly residing in the **PBL**
3 main products

low resolution **water vapor profile** but excellent path-integrated values

Path-integrated **liquid water**

Well resolved **temperature** profile in the **PBL**, low resolution above

- LWP : most reliable method but no information on the **cloud vertical distribution**
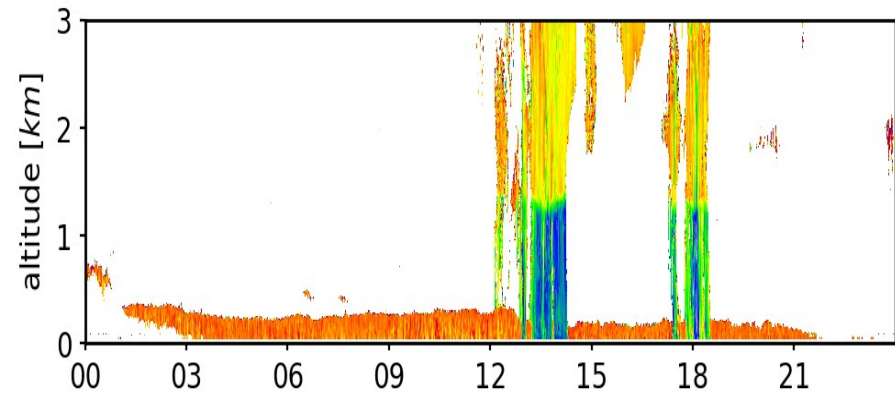
95 GHz cloud-radars

- Newly industrialized systems

- Sensitive to small **cloud** and **fog droplets**

- Offer new capabilities to access to fog **microphysical** properties

- Complementary information of that of MWR
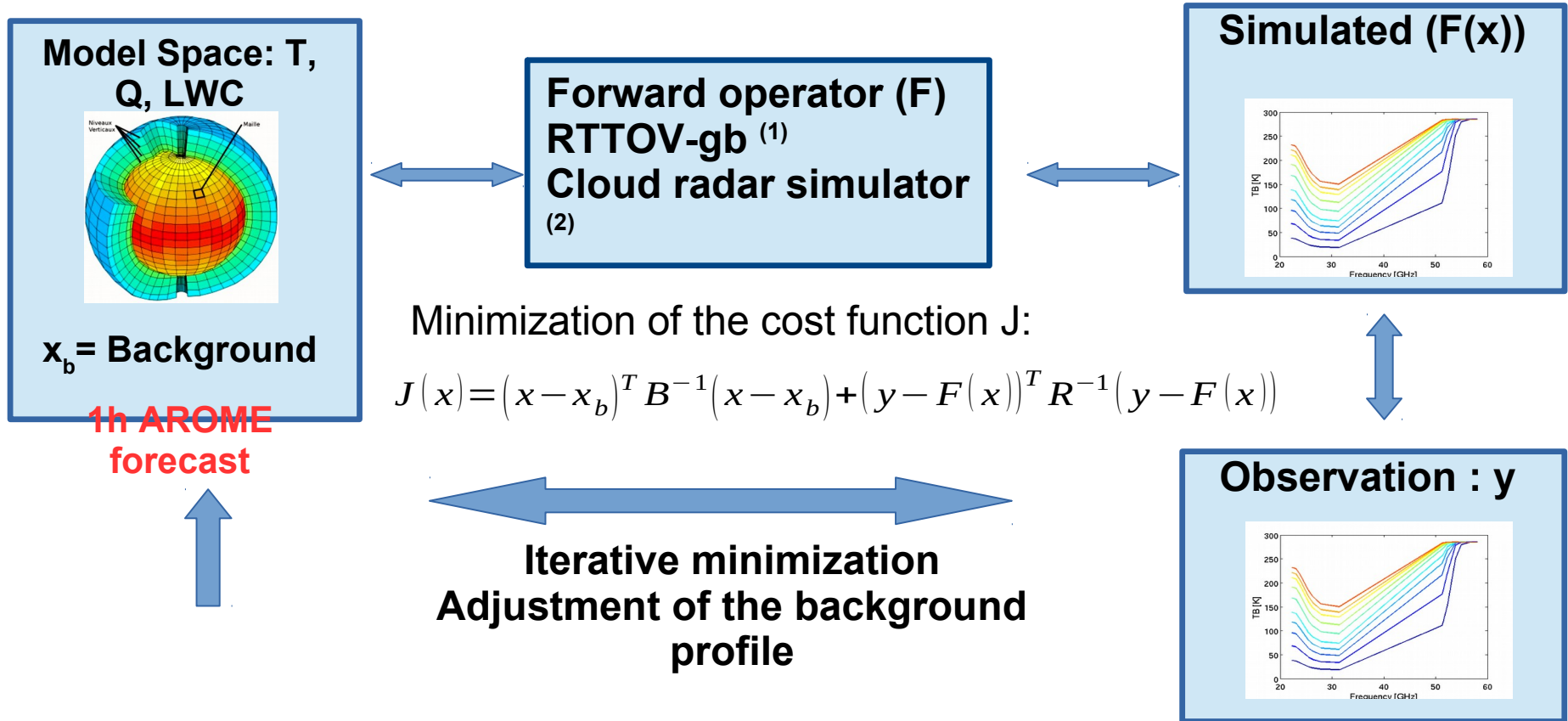
Reflectivity profiles
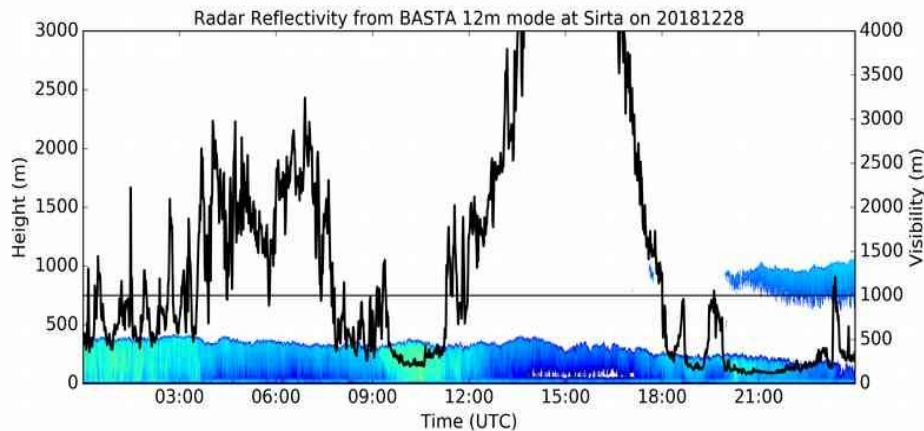
Doppler velocity

- Profiles of LWC

- Droplet number concentration

- Effective radius etc...

- Fog dynamics

How data assimilation works

Model Space: T, Q, LWC

x_b = Background

1h AROME forecast

Forward operator (F) RTTOV-gb [1] **Cloud radar simulator** [2]

Simulated (F(x))

Minimization of the cost function J:

$$J(x) = (x - x_b)^T B^{-1} (x - x_b) + (y - F(x))^T R^{-1} (y - F(x))$$

Iterative minimization Adjustment of the background profile

Observation : y

Minimize the distance both to the background and the observation

Necessary good knowledge of the B and R matrices

(1) De Angelis et al 2016 : RTTOV-gb – adapting the fast radiative transfer model RTTOV for the assimilation of ground-based microwave radiometer observations
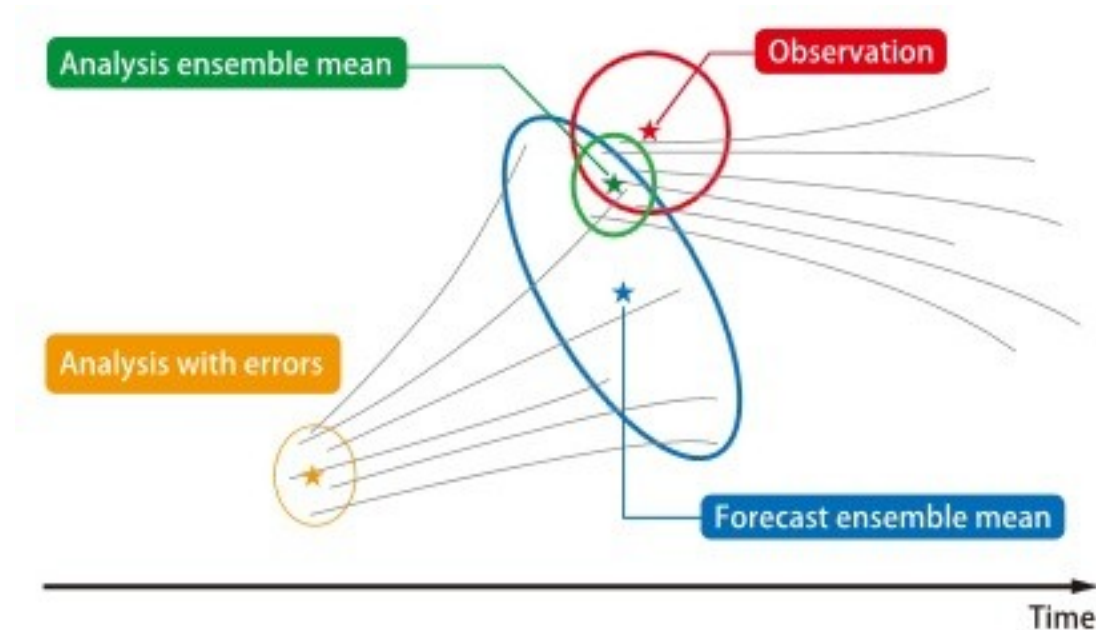*(2) Borderies et al 2017 : Simulation of W-band radar reflectivity for model validation and data assimilation*

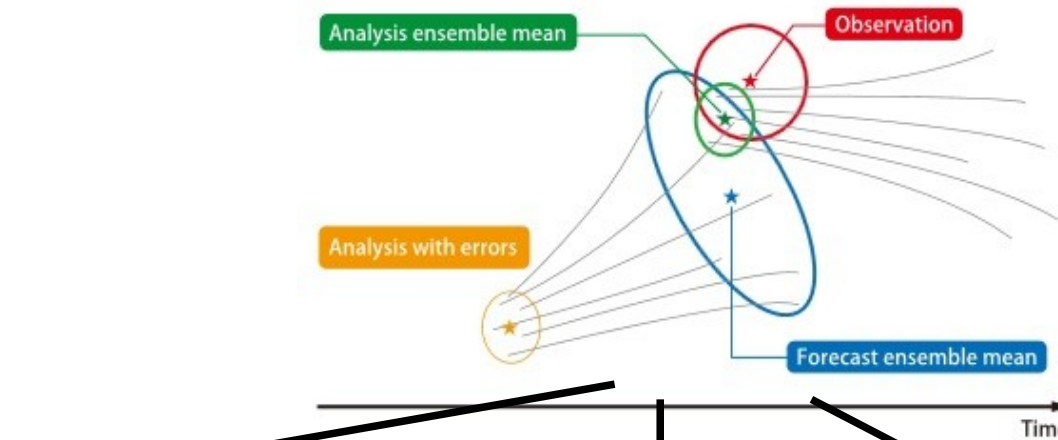# New innovative data assimilation scheme : the EnVar

- Météo-France (GMAP group) has developped for several years a new ensemble based variational assimilation scheme (**EnVar**)

- Prototype already existing and soon operational for the AROME model

N_e membres

$$\epsilon_l^b = \frac{1}{\sqrt{N_e - 1}}(\widetilde{\mathbf{x}}_l^b - \langle \widetilde{\mathbf{x}}^b \rangle) = \widetilde{\mathsf{B}}^{1/2}$$

From Thibaut Montmerle : l'En-Var pour les nuls

What new possibilities thanks to the EnVar

Flow dependent
background-error covariance matrix

Inclusion of **hydrometeors** in the analyzed fields

4D-Var possible (no TL/AD of AROME needed) : obs every **15 min** instead of 1 hour.

Scientific questions

- On what extent, a ground-based microwave radiometer network assimilated in newly developed ensemble variational data assimilation scheme (**EnVar**) can improve fog forecasts ?

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- 8 radiometer units to be deployed

Research laboratories / National Weather Services collaboration :
- Cologne: Ulrich Löhnert (HATPRO) : **T, Q, IWV, LWP**
- MeteoSwiss: Maxime Hervo/Alexander Haeffele (HATPRO, G2) : **T, Q, IWV, LWP**
- Laboratoire d'Aérologie : Jean-François Georgis (HATPRO, G2) : **T, Q, IWV, LWP**
- Météo France : Pauline Martinet/Vinciane Unger (HATPRO G3) : **T, Q, IWV, LWP**
- ONERA:Thierry Huet/ Xavier Boulanger (HATPRO): **T, Q, IWV, LWP**
- Met Office: Jeremy Price (RPG HumPro) : **Q, IWV, LWP**

Industrial Collaboration :
- Attex,MTP-5: Mathias Schroder : **T** (0-1000m)
- RPG HATPRO G5 : Harald Czekala : **T, Q, IWV, LWP**

MWR network instrumental deployment strategy
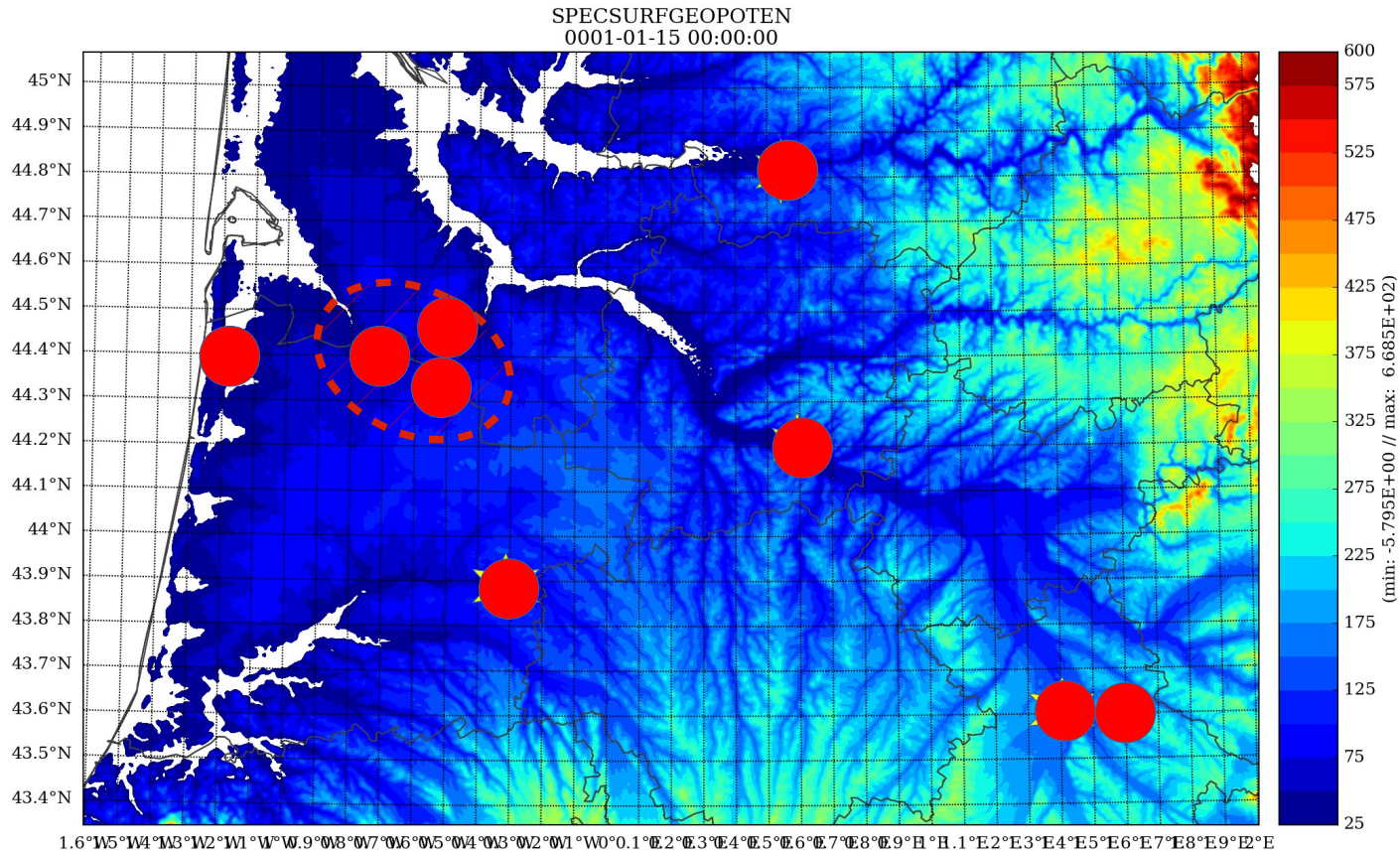
- Strategy based on GMAP team long experience in reanalysis (HyMex) and last conclusions from Hu et al 2017 (OSSE wind profilers) :*an even distribution covering a larger region is more beneficial than a dense network concentrated in a small aread*

- Denser network on the west side to constrain humid air advection from the West /ocean

Scientific questions

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  - Validation/evaluation strategy by using intensive in-situ observations during IOP, demand on increase RS launchings
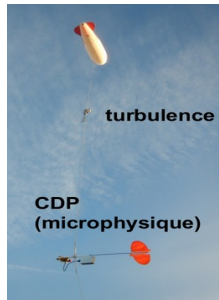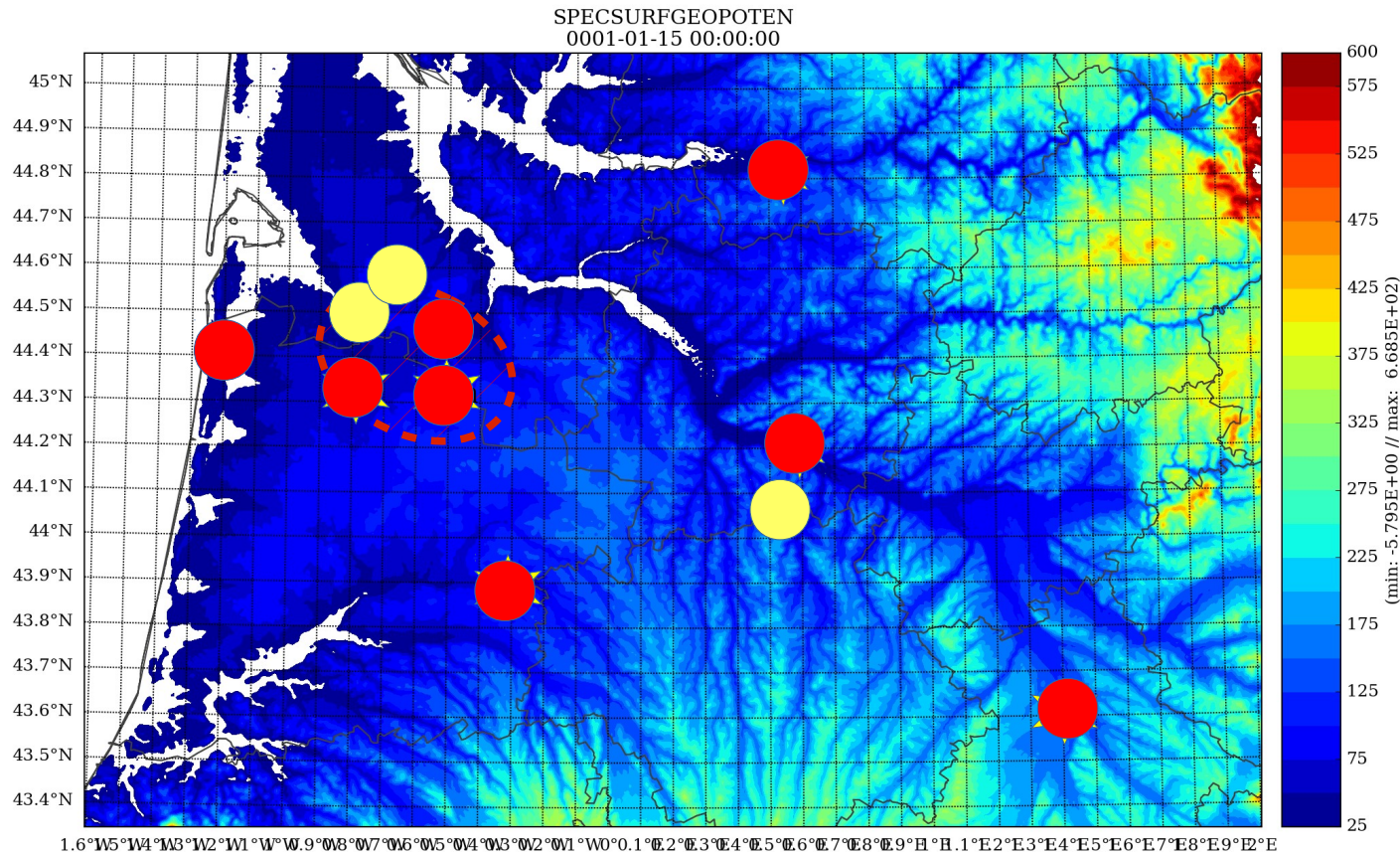

- ~ 100 Radiosonde (every 4 to 6 hours during IOPs)

- Tethered ballons : LWC profiles

- UAVS (spatial heterogeneity, T, Q)

- Towers (T, Humidity, microphysics)
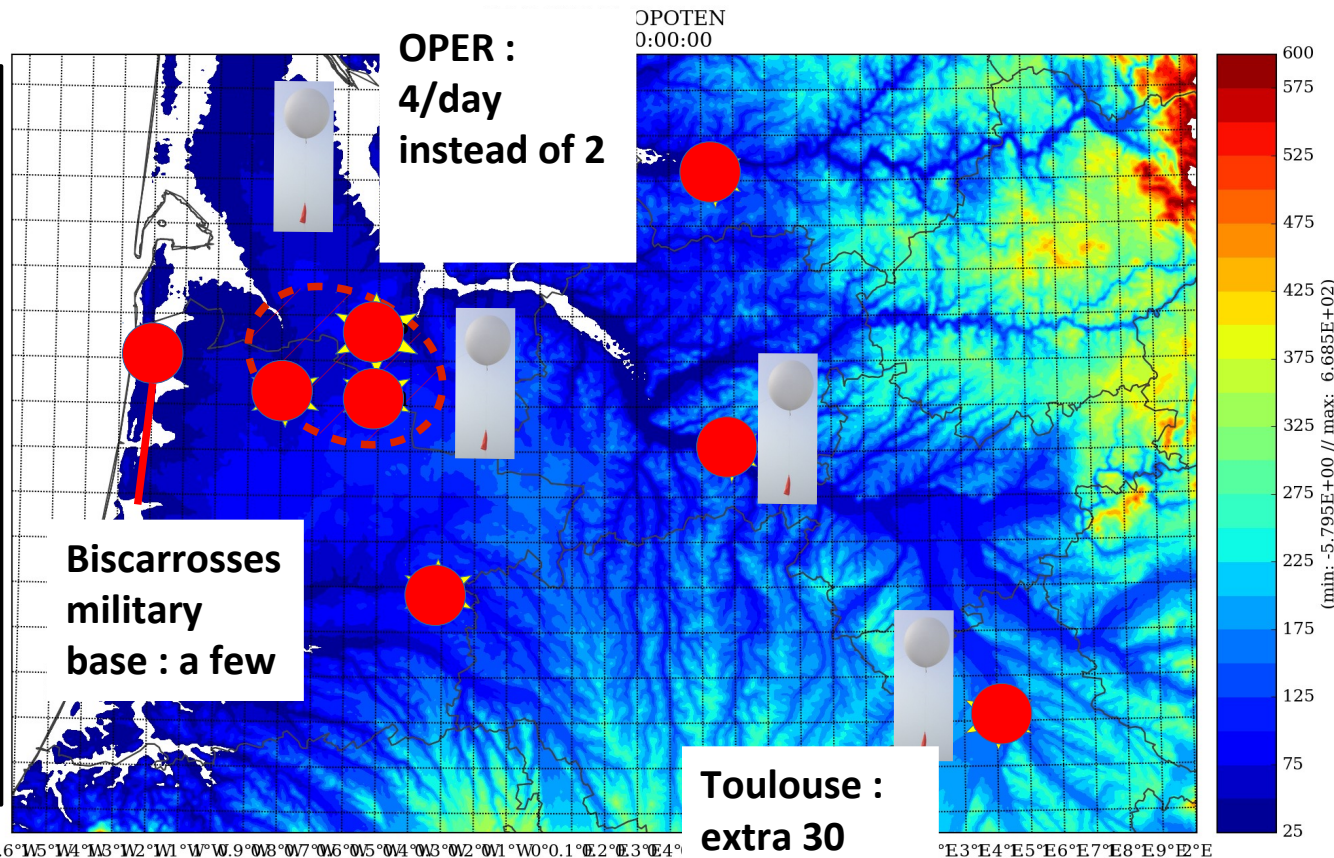
turbulence

CDP (microphysique)

OPER :
4/day
instead of 2

Biscarrosses
military
base : a few

Toulouse :
extra 30

Scientific questions

- What variables/parameters about fog forecasts are improved thanks to the assimilation of a MWR network: fog onset/dissipation times, fog diurnal cycle, vertical depth ?

 - Use of remote-sensing observations for forecast evaluation with a focus on spacial extent

Scientific questions

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MWR

Cloud radar

ceilometer
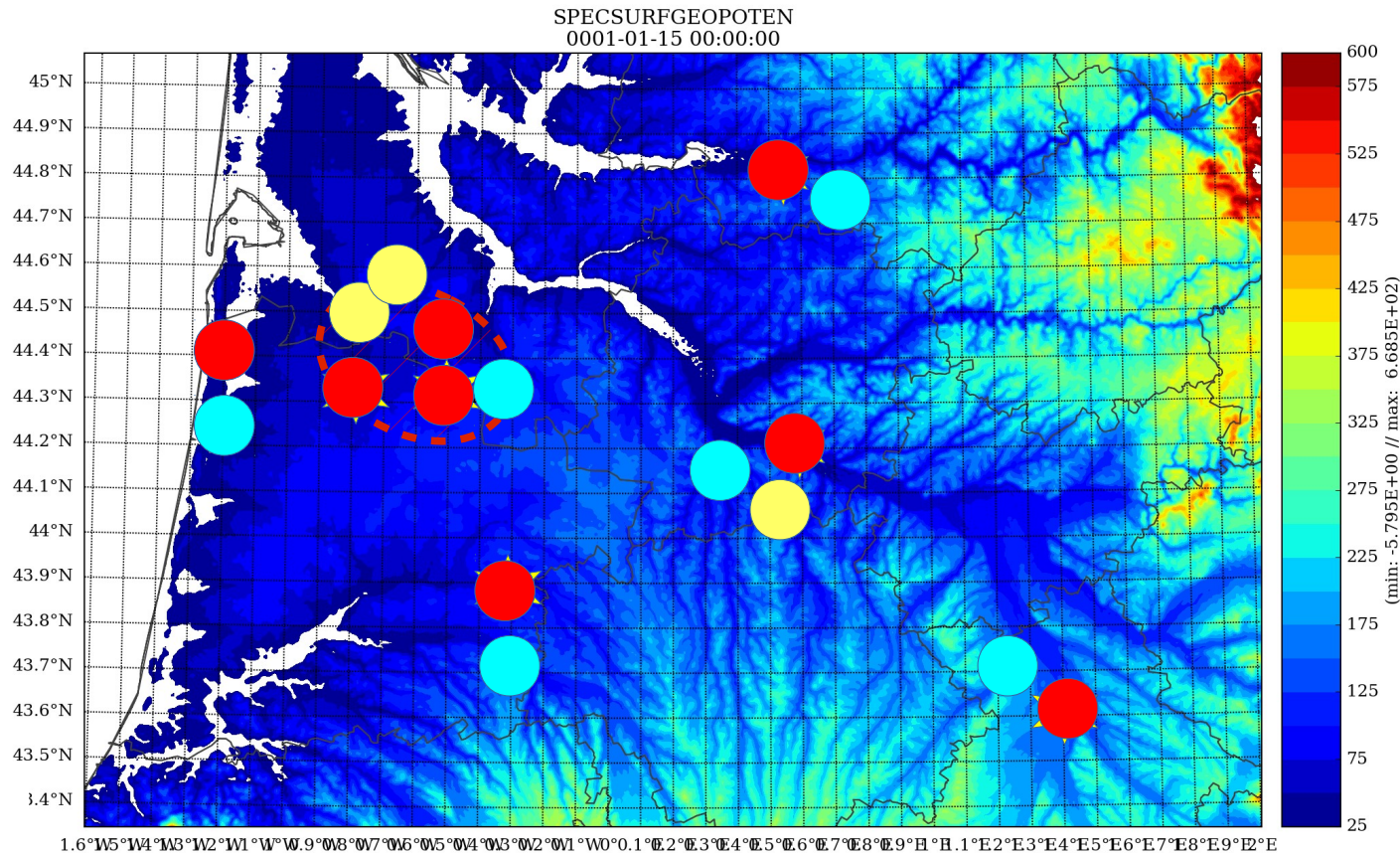
+ use of satellite data
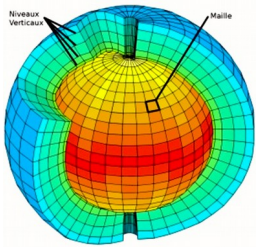
Scientific questions

- What is the most important parameter between vertical or temporal resolution to improve fog forecasts ?

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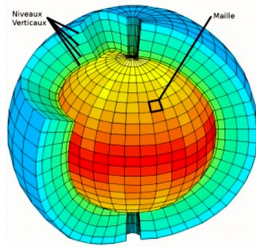   - Data assimilation denial experiments : OSE (Observing System Experiments

3D-EnVar AROME

=

CTRL RUN

Conf 2
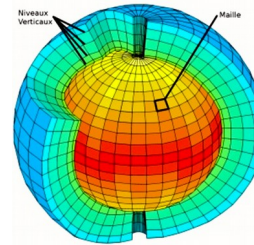
3D-EnVar AROME

+

- Intensive Radiosondes
- UAVs (T, Q profiles) : after validation
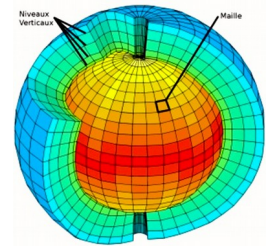
Conf 3

3D-EnVar AROME

+

- MWR retrieved profiles at the same temporal resolution as RS/ UAVs

Conf 4

4D-EnVar AROME

+

- MWR retrieved profiles at high temporal resolution ~ **10min**

Scientific questions

- What are the most relevant meteorological quantities to be initialized (temperature, humidity, hydrometeors) for improving fog forecasts ?

Scientific questions

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  - Retrieval of LWC profiles with cloud radar synergy (A. Bell PhD)

  - OSE experiments : temperature / humidity profiles and temperature / humidity / LWP information

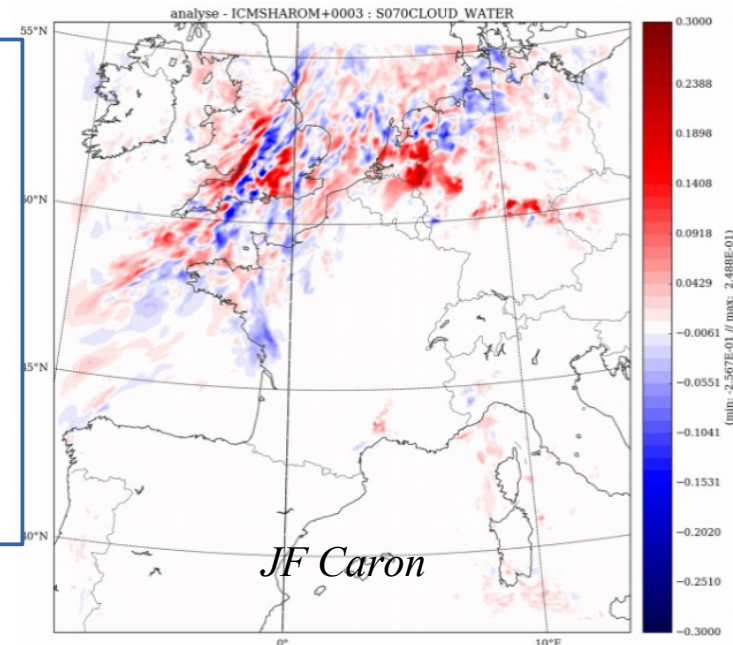 - Possible thanks to the sampling of cross-covariances between T/Q variables and hydrometeors by the En-Var

Combination of MWR and Cloud radar to derive LWC profiles

+

LWC increment in the model withouT assimilation of LWC sensitive obs → Cross-covariances ! GMAP dev (JF Caron courtesy)
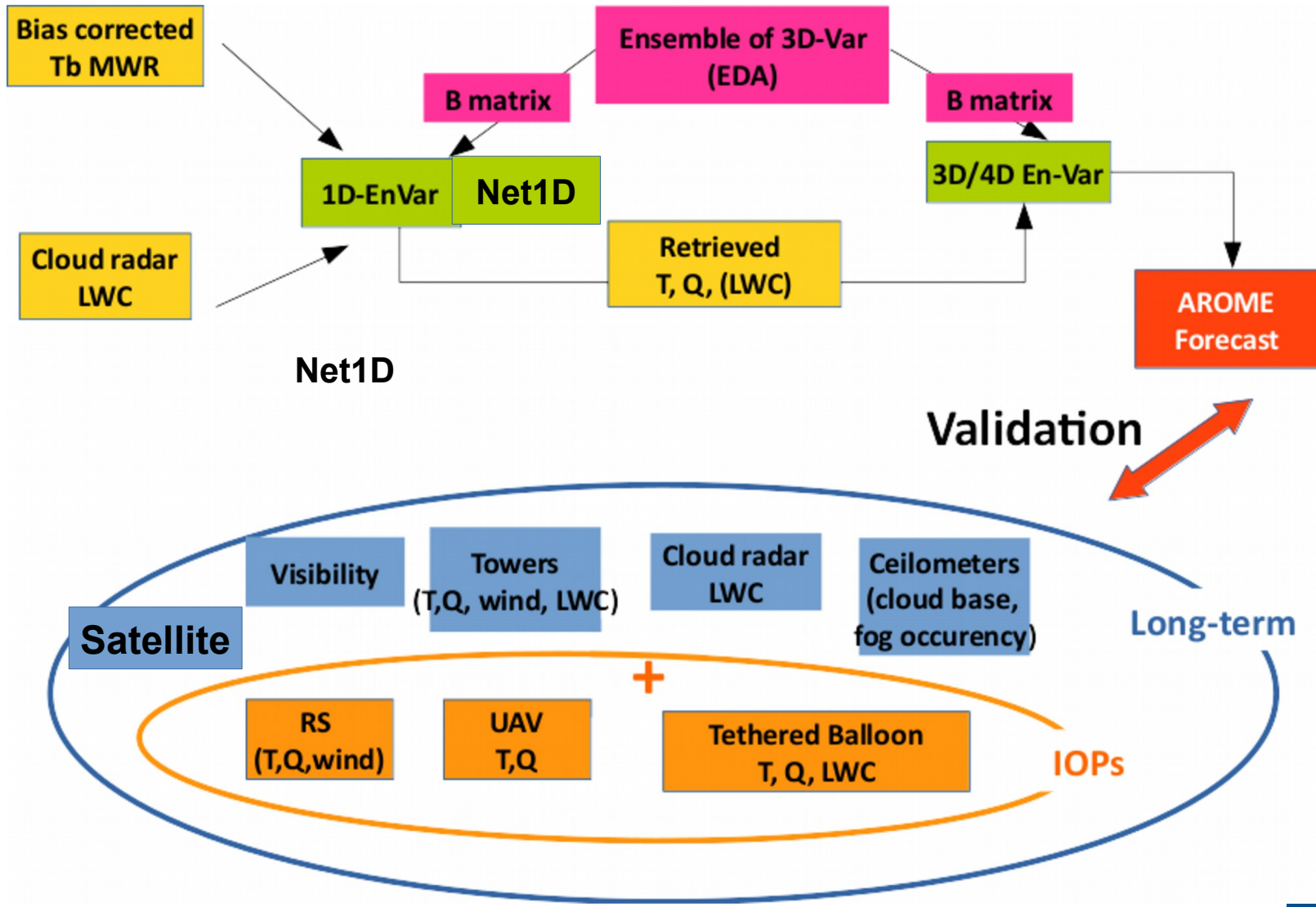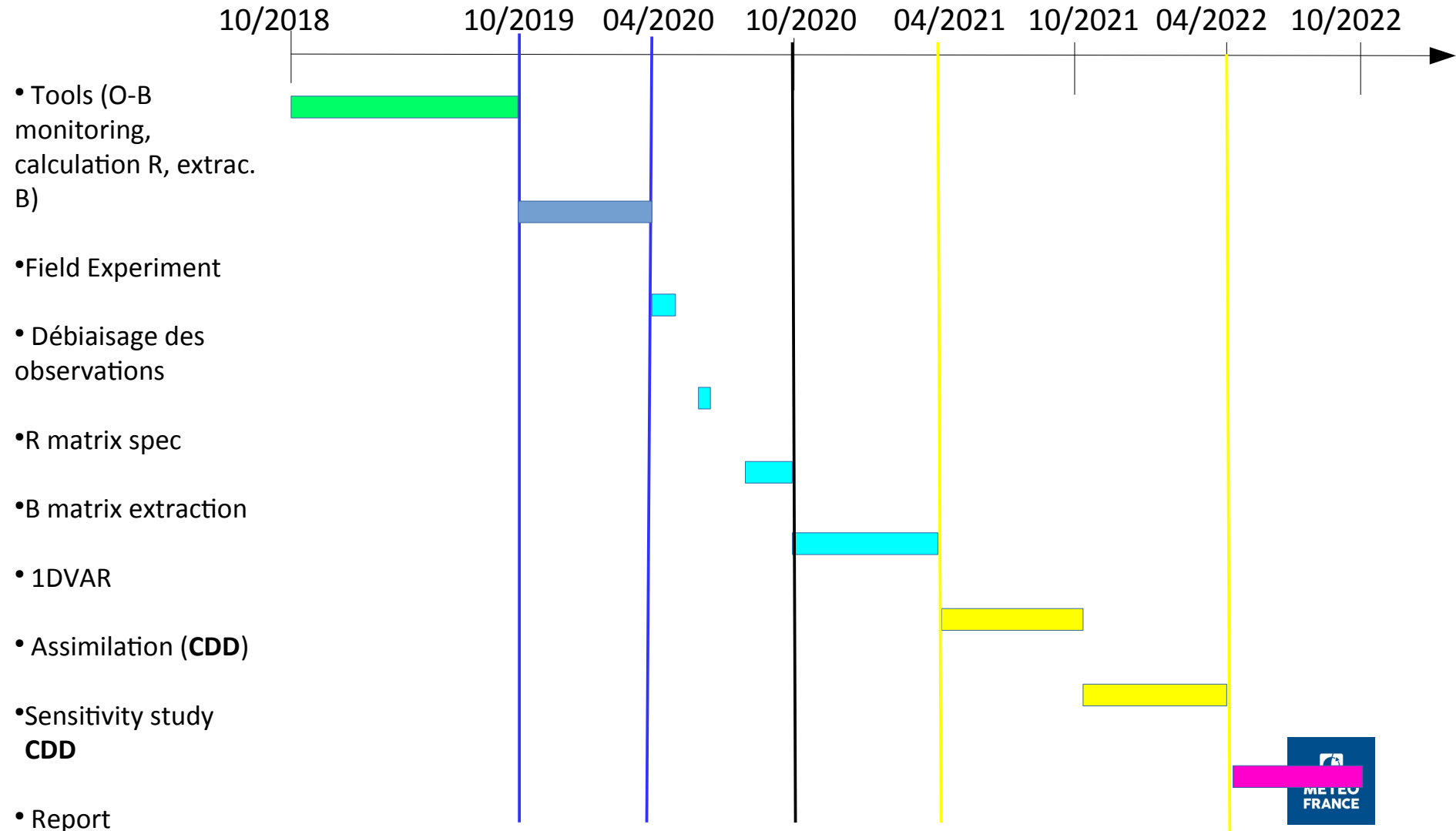
Cloud water (g/kg) @ L70

JF Caron

WP5 : Summary of the work-plan

Schedule of the different tasks

10/2018 10/2019 04/2020 10/2020 04/2021 10/2021 04/2022 10/2022

- Tools (O-B monitoring, calculation R, extrac. B)
- Field Experiment
- Débiaisage des observations
- R matrix spec
- B matrix extraction
- 1DVAR
- Assimilation (**CDD**)
- Sensitivity study **CDD**
- Report

Started work

- 1D-Var sensitivity study to a « fog » B matrix : use of the **Net1D processing chain** (D. Cimini and P. Martinet developments within **TOPROF**)

- O-B monitoring chain (developed within **TOPROF** COST action) : currently tested with three European Units (Lindenberg, SIRTA, Julich) : online at http://gop.meteo.uni-koeln.de/~hatpro/dataBrowser/dataBrowser4.html

- New set of regression coefficients for MWR real-time retrievals : extraction of 1 year database of AROME analyses profiles at each measurement site (soon)

- Inclusion of cloud-radar into 1DVAR : forward operator evaluation (Alistair Bell PhD)

1DVAR B matrix estimation from AROME EDA and BUMP software

- Sensitivity of 1DVAR retrievals to the B matrix

- B matrix diagnosed from en EDA of 25 AROME members with a fog-mask (BUMP, Benjamin Ménétrier, EDA Yann Michel)

- Test for the Bure 2016-2017 experiments : logQ/T cross-covariances

Fog mask

No mask
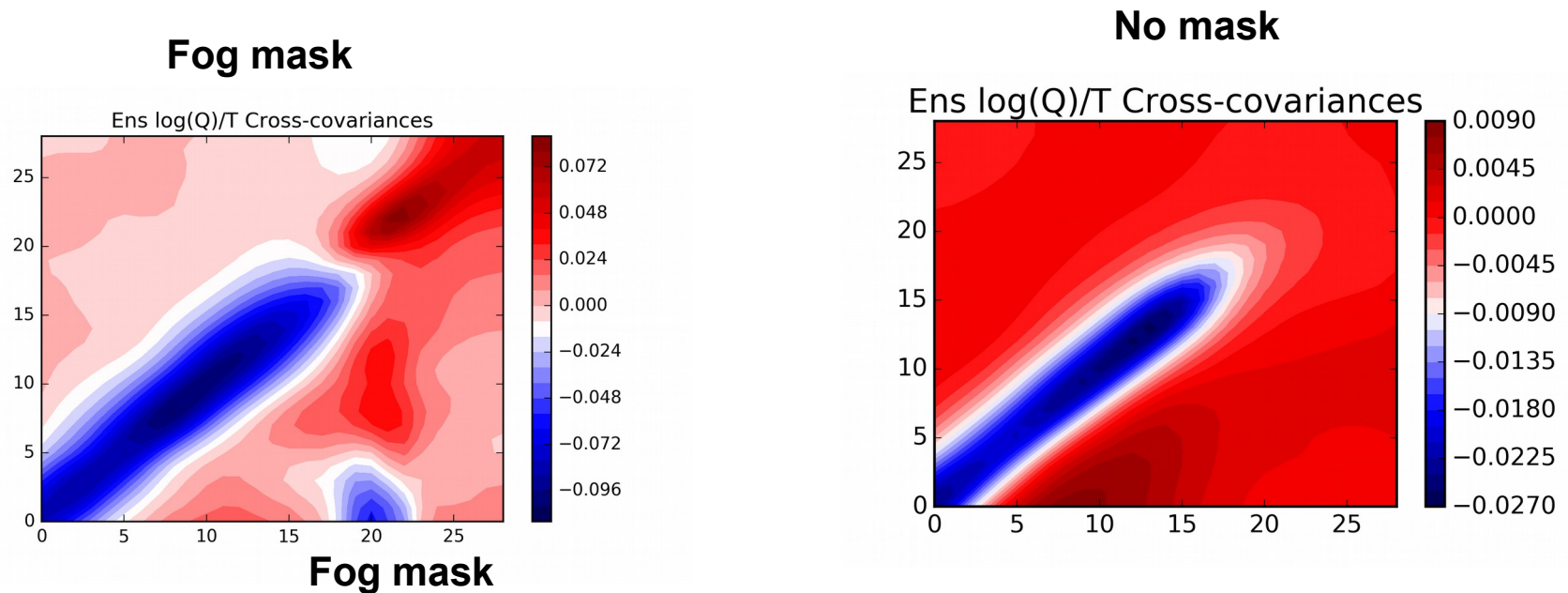
Stronger positive correlation between T/Q in fog

Strong decorrelation beween the fog layers and atmospheric layers above

Improvements in Fog Forecasting through the Instrumental Synergy of Cloud Radar and Microwave Radiometer: Experimental Study and Numerical Simulation

Alistair Bell
Pauline Martinet, Olivier Caumont, Benoît Vie

Project Overview

AROME model output (T, Q, LWC, rain, snow, graupel)

BASTA radar reflectivity

Microwave Radiometer Brightness Temperatures

1D-VAR

Profiles :
- **Temperature**
- **Humidity**
- **LWC**

Process Studies

3D-VAR Data Assimilation

New Forecast

BASTA LWC profiles

Microwave Radiometer T & Q profiles, LWP

Other Observations : Satellites, Radiosondes, Surface Stations
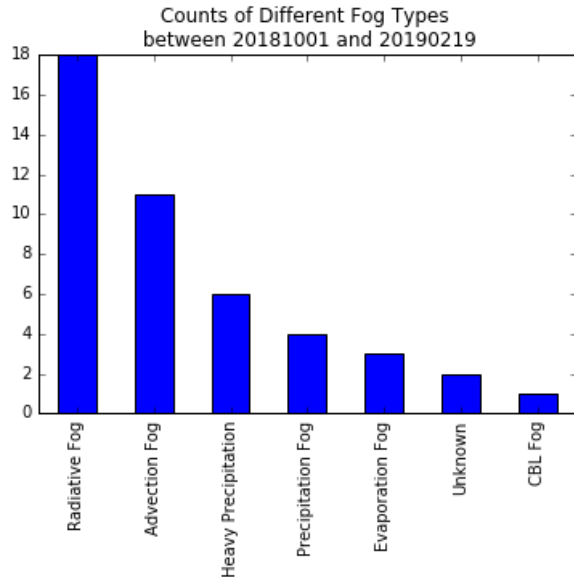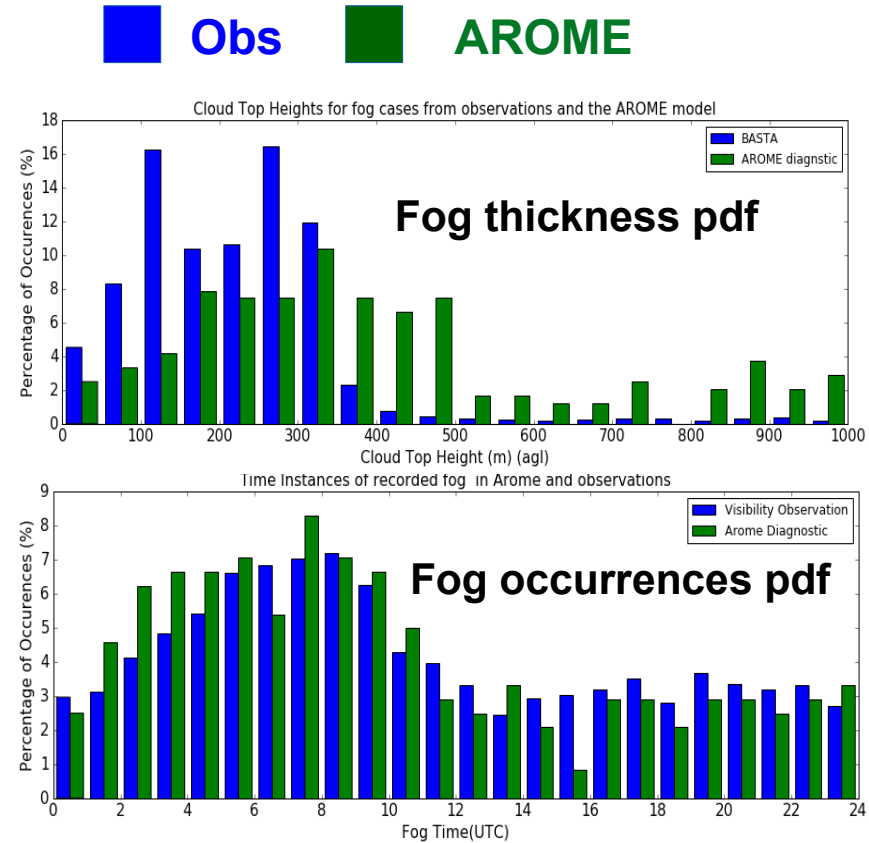
Forecast Verification

METEO FRANCE

Arome Error Analysis

- Optimal use of 1DVAR requires that model and forward operator errors are known

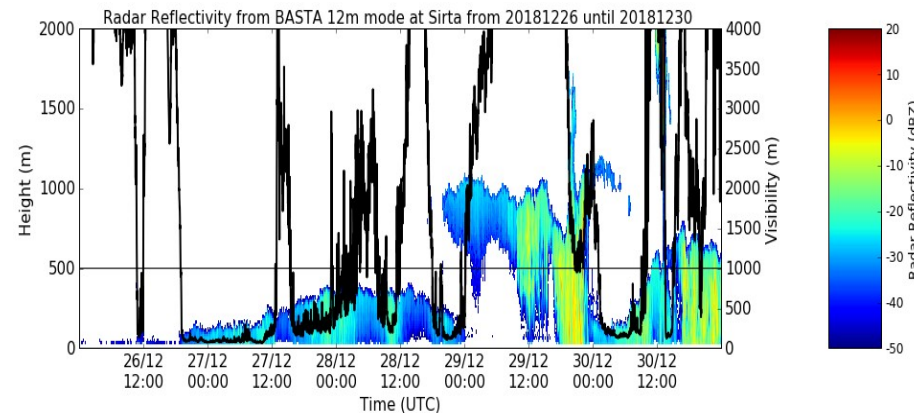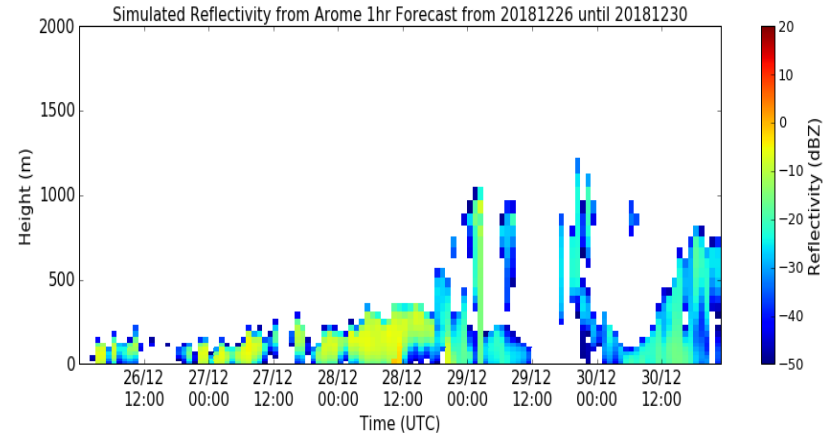- Dataset taken from the SIRTA lab, Paris (winter 2018-2019)

Obs   **AROME**

Fog thickness pdf

Fog classification

- Few stratus lowering (2)

-18 radiative fogs

-11 advective fog

Fog occurrences pdf

- Overestimation of fog thickness in AROME

- Underestimation of fog occurrences during the afternoon, overstimation by night
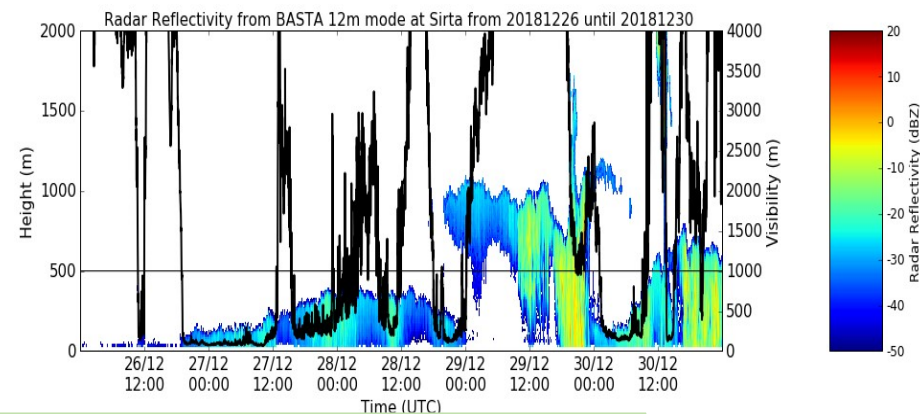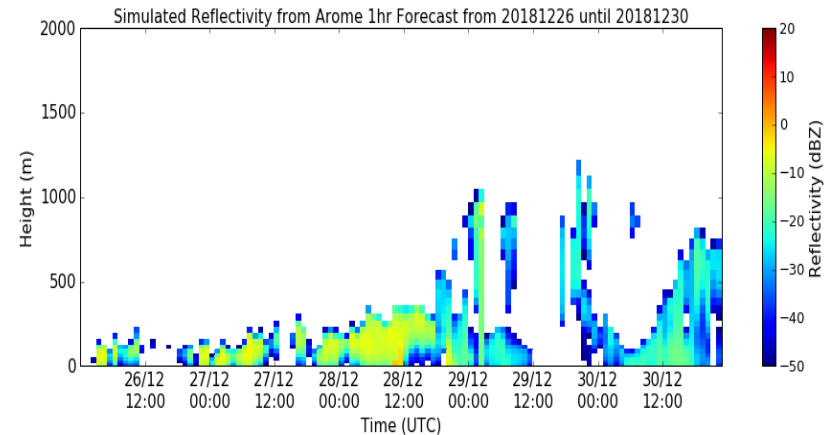
Radar Simulator / Forward Operator

- For 1D-VAR data assimilation, data of the same type must be compared

- Forward operator designed by Borderies et al. downward looking coud radar

- Input : T, Q, rain, graupel, snow, ice

- Size distributions : ICE3 1-moment microphysical scheme

Simulated Reflectivity from Arome 1hr Forecast from 20181226 until 20181230

Radar Reflectivity from BASTA 12m mode at Sirta from 20181226 until 20181230

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Radar Reflectivity from BASTA 12m mode at Sirta from 20181226 until 20181230

Next steps :
- ➔ Error analysis (Observation minus simulated reflectivies)
- ➔ Inclusion of radar forward operator into existing 1DVAR
- ➔ Extention of 1DVAR to LWC retrievals

Thanks for your attention ! Questions ?

Scientific questions

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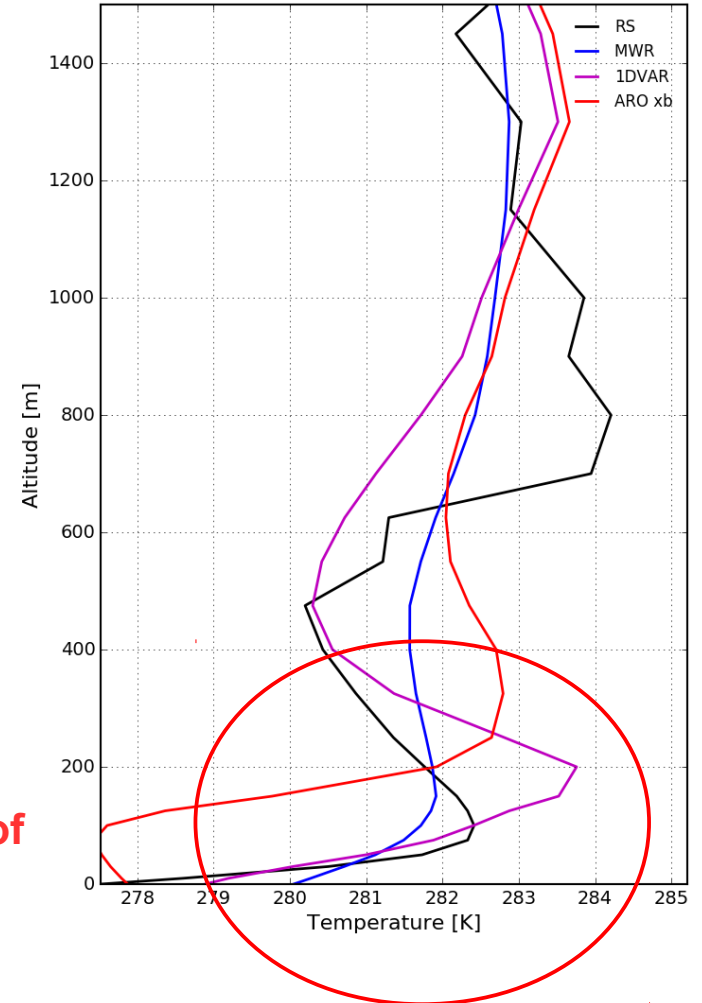# 1D-Var sensitivity to B matrix : Temperature profile

1DVAR   ARO RS
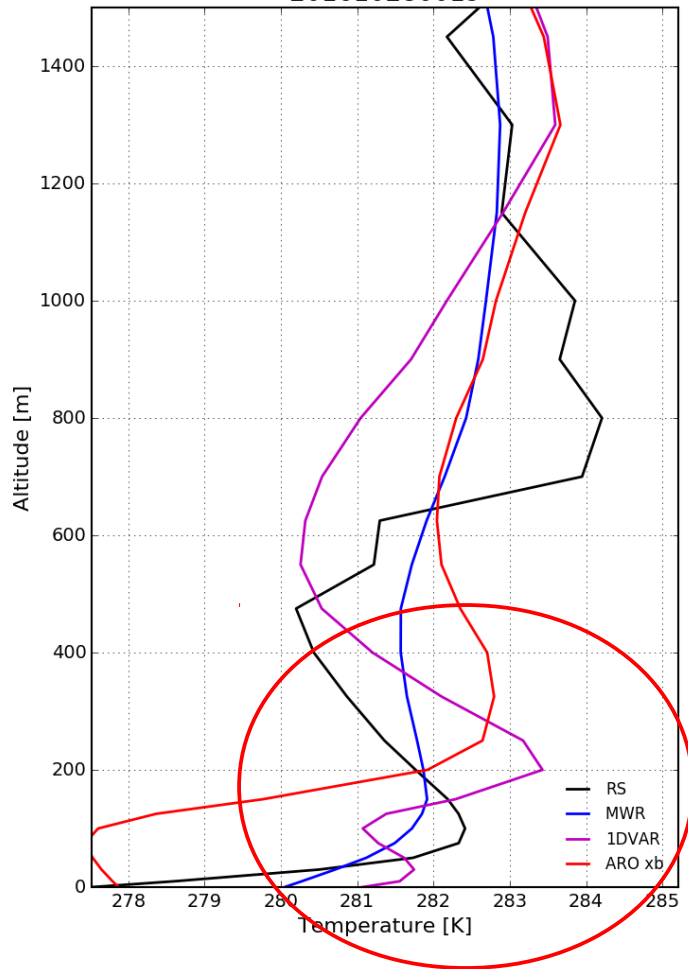
B No mask

B Fog mask

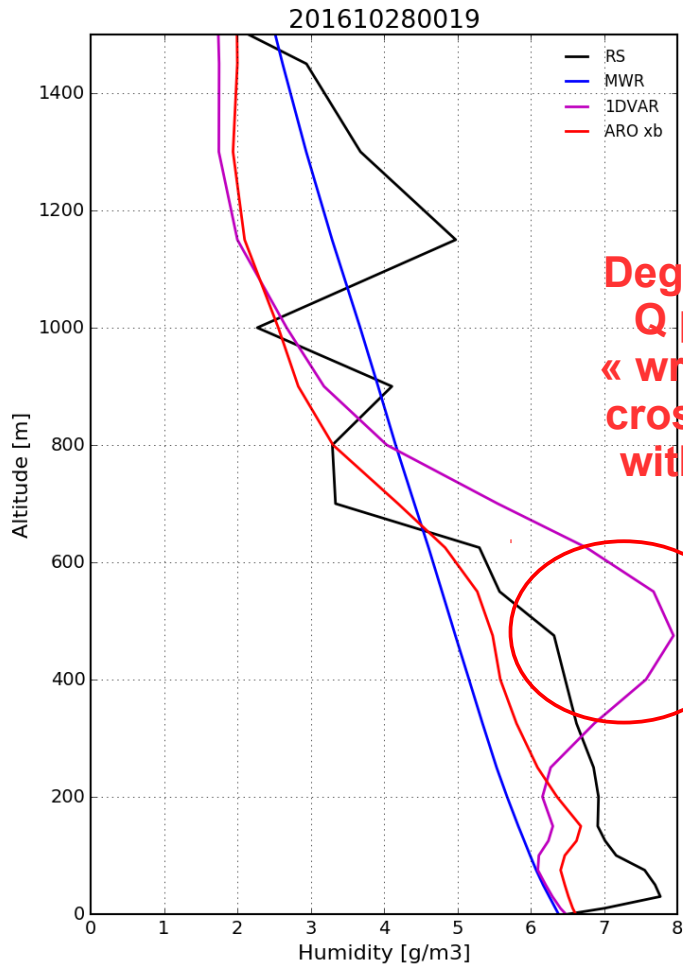**Significant improvement in vertical structure of the temperature inversion**
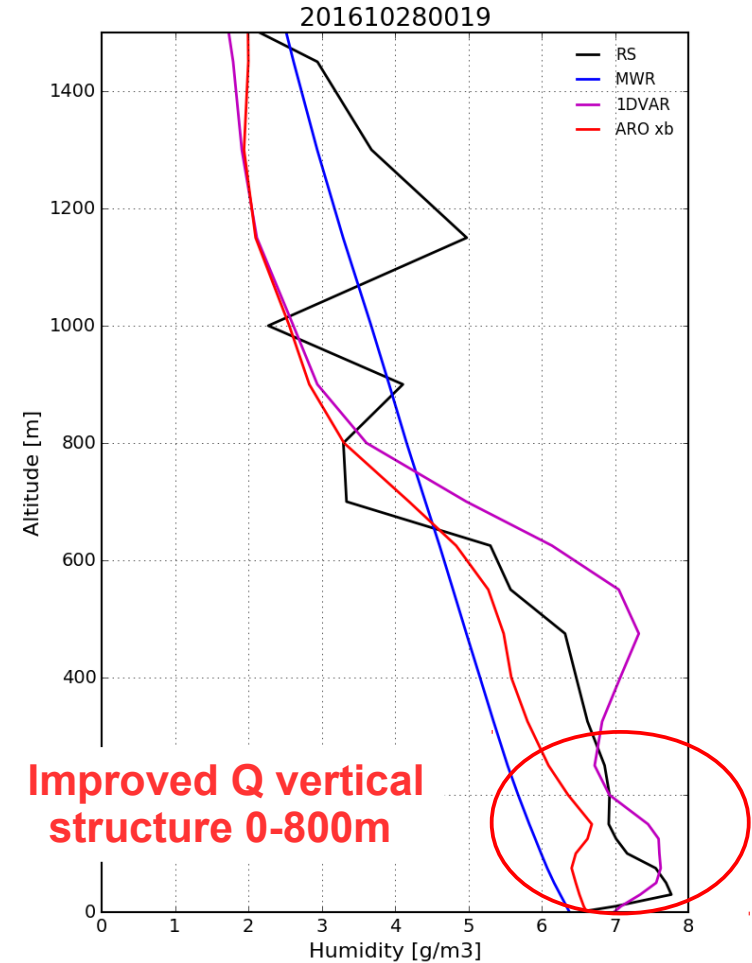
1D-Var sensitivity to B matrix : Humidity profile

1DVAR   ARO   RS

B No mask

B Fog mask

Degradation of the Q profile due to « wrong » negative cross-correlations with temperature

Improved Q vertical structure 0-800m