What benefit from ground-based microwave radiometers to better forecast fog events?

P. Martinet\textsuperscript{1}, F. Burnet\textsuperscript{1}, D. Cimini\textsuperscript{2}, G. Cayez\textsuperscript{1}, B. Ménétrier\textsuperscript{1}, Y. Michel\textsuperscript{1}
And many others (for technical deployment)

1 : Météo-France, CNRM (GMEI/GMAP)
2 : CNR-IMAA

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Motivation of the study

- Weather station
- Balloon
- Aircraft
- Remote sensing:
  - Radar
  - Lidar
  - Fog

Degraded fog forecast due to degraded initial conditions of the model in the BL

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

What can we expect from the assimilation of MWR observations to improve fog forecasting?
The Bure field experiment: winter 2016-2017

- Continental site (388 m altitude) in the North-East of France
  - 120 m instrumented tower for microphysical measurements (cloud particle counter, liquid water content (PVM100), cloud particle spectrometer (Welas)) + visibility + meteorological parameters (T, Q, winds) at 120m, 50m and 10 m

- UAVs: Xeno (high temporal frequency T, Q measurements)

- 2 IOPs with tethered balloon (turbulence and CDP measurements) + 21 RS

Ceilometer and microwave radiometer
Methodology: 1D-Var retrievals

Model Space: T, Q, LWC

Radiative Transfer (F)
RTTOV-gb

x_b = Background

1h AROME forecast

Minimization of the cost function J:

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

Observation: y

BT simulation (F(x))

Iterative minimization
Adjustment of the background profile

1 F. De Angelis et al 2016: RTTOV-gb - Adapting the fast radiative transfer model RTTOV for the assimilation of ground-based microwave radiometer observations, GMD, doi:10.5194/gmd-9-2721-2016
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Iterative minimization

Adjustment of the background profile

- Strong positive correlations between temperature and humidity background errors derived with an ensemble of 25 AROME 3D-Var analyses

\[ x_b = \text{Background} \]

1h AROME forecast

BT simulation (F(x))

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Methodology: 1D-Var retrievals

Model Space: T, Q, LWC

Radiative Transfer (F)
RTTOV-gb

BT simulation (F(x))

Observation: y

\[ J(x) = (x - x_b)T_B - 1(x - x_b) + (y - F(x))T_R - 1(y - F(x)) \]

Minimization of the cost function J:

Iterative minimization
Adjustment of the background profile

POSTER: Towards data assimilation of a European network of ground-based microwave radiometers into numerical weather prediction

- Strong positive correlations between temperature and humidity background errors derived with an ensemble of 25 AROME 3D-Var analyses

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Very thin radiative fog: 28102016

Ceilometer cloud base

Thin Fog 5 to 9 UTC  Stratus

Liquid water content AROME

- Temporal errors
- Large overestimation of the fog thickness
- Wrong dissipation of the stratus cloud in the afternoon

False alarm  Too thick fog  Missing stratus
Temperature profile retrievals

AROME 1h forecast = background

1DVAR

+ MWR
Temperature profile retrievals

- **Warming** up to 5 K **before** and **during** the fog event
- **Cooling up** to 2 K above 500m and at surface during stratus lowering
Temperature profile retrievals: validation with in-situ measurements

Comparison of temperature diurnal evolution at two levels (50 and 120m)

- **ARO**
- **Tower**
- **1DVAR**

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- **ARO**
- **Tower**
- **1DVAR**

Scatterplot between tower measurements at 120m and AROME forecast or 1DVAR. For all fog cases from 01/10/2016 to 31/03/2017.

- Large **improvement** of the temperature diurnal cycle in the 1DVAR compared to AROME 1h forecasts.
- Correlation coefficients increased from **0.87** to **0.94** (all fog cases compared with tower measurements).
Specific humidity retrievals

- Humidity increments less significant compared to temperature.
- Humidity increase during fog events: **impact of positive cross-correlations**
- Neutral impact statistically.
Relative Humidity retrievals: validation with in-situ measurements

Comparison of relative humidity diurnal evolution at two levels (50 and 120m)

- ARO
- Tower
- 1DVAR

50 m

120 m
Relative Humidity retrievals: validation with in-situ measurements

- Overall improvement of the diurnal cycle in relative humidity
- Decrease from saturated values to unsaturated (~80%): would impact the fog thickness
- Correlation coefficients increased from 0.62 to 0.83 (all fog cases)
LWP MWR (regression)
AROME
1DVAR

Comparison of LWP diurnal evolution

- Large decrease of LWP values before and during the fog event (in agreement with in-situ CDP measurements)
- Large increase during missing stratus
Liquid water path retrievals

- LWP MWR (regression)
- AROME
- 1DVAR

Comparison of LWP diurnal evolution

- Large decrease of LWP values before and during the fog event (in agreement with in-situ CDP measurements)
- Large increase during missing stratus

Scatterplot between MWR LWP retrieved by regressions and AROME forecasts or 1DVAR
For all fog cases from 01/10/2016 to 31/03/2017

- Large increase of the correlation coefficients during fog from 0.62 to 0.96
A regional scale ground-based MWR network to study potential fog forecast improvement (SOFOG3D field experiment winter 2019-2020)

- Improve our understanding of fog **processes**, **modelling** and **forecasts**: deployment of a large set of instruments including new and innovative instrumentation (in-situ and remote sensing)
- Opportunity for data assimilation trials (3D-EnVar) by building a regional scale MWR network

8 MWR (Météo-France, ONERA, LA, University of Cologne, MeteoSwiss, ATTEX, RPG)

- ~ 100 Radiosonde (every 4 to 6 hours during IOPs)
- Tethered balloon: microphysics profiles, aerosols, CCN, T/Q, turbulence
- UAVS (spatial heterogeneity, T, Q, aerosols, extinction)
- Towers (T, Humidity, microphysics)

3 cloud radars BASTA (scanning and vertically pointing)

+ ceilometer + Doppler lidars + aerosol lidar etc.
Conclusions

Main Results

- Significant improvement in the temperature profile analysis is expected during fog events (differences up to 5K, RMSE decrease from 2.1 K to 0.5 K)
- Temperature diurnal evolution at 50 and 120 m significantly improved after the 1DVAR (5K increment on 20161028)
- Most of the impact in specific humidity comes from the correlation in the background error covariance matrix
- Relative humidity: large improvement in the correlation with respect to in-situ tower measurements
- Significant improvement in the LWP initial state

Future Prospects

- Validation of the LWP with cloud particler counter profiles of liquid water content inside the fog layer (tethered balloon)
- Synergy with the 94 GHz cloud radar BASTA to retrieve the liquid water content profile (A. Bell poster)
- Data assimilation studies in the context of the SOFOG3D experiment and validation with in-situ/remote sensing and satellite observations.