Current state of radar data assimilation at Météo-France

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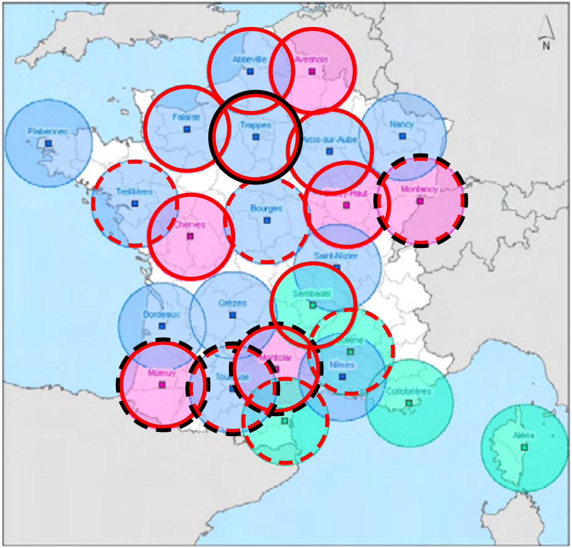
Outline

Introduction

- Large potential of radar data for assimilation in high-resolution NWP models.
- Météo-France is developing its future operational high-resolution NWP model = Arome (planned to be operational by 2008).
- Arome features:
  - nonhydrostatic,
  - high horizontal resolution (ca. 2.5 km),
  - sophisticated microphysical scheme with 6 water species (inherited from Meso-NH),
  - 3DVar assimilation scheme (inherited from Aladin).
- Variational assimilation treats both observational and model uncertainties.

Radar data

French radar network (Aramis)



10 Doppler radars

1 polarimetric radar

Planned by end-2007:

6 Doppler radars

4 polarimetric radars

New format for radar data

For assimilation purposes, Météo-France is defining a new format for radar data complying with OPERA BUFR:

- all fields on 1 km$\times$1 km Cartesian grids,
- 80 levels for reflectivity (-10 to 70 dBZ),
- Doppler winds from -60 to 60 m s^{-1} every 0.5 m s^{-1},
- all volume data in a single file: reflectivity, Doppler winds and quality flags for all elevations.

Additional information is used: static maps of ground clutter and partial masks are computed with the Surfilum software (Delrieu et al., 1995) and accumulated rainfall maps.

Pre-processing of radar data (1/2)

(= before being stored in the observational database)

Spurious and/or bad quality data can have disastrous effects on a weather forecast.
$\rightarrow$ need for a strict pre-processing of data (+ quality control during the assimilation step)

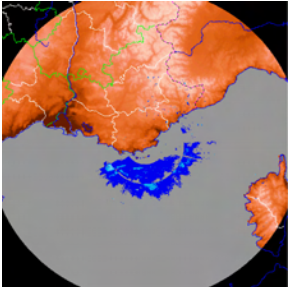
At Météo-France, the general approach is:

- to use as many raw data as possible (only isolated echoes are removed; a corrective factor based on comparisons with raingauge measurements is applied),
- but associate informative quality flags.

Pre-processing of radar data (2/2)

At present, we can detect and flag:

- sea and ground clutter,



Pre-processing of radar data (2/2)

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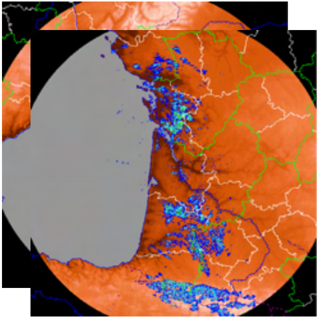

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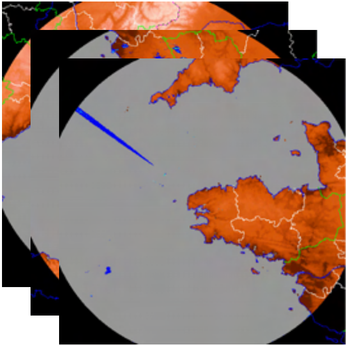

Pre-processing of radar data (2/2)

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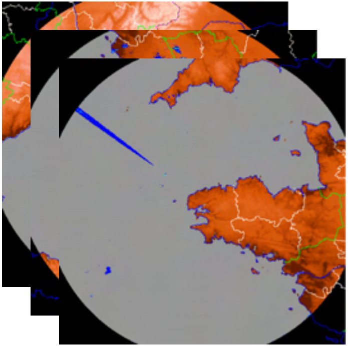

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At present, we can detect and flag:

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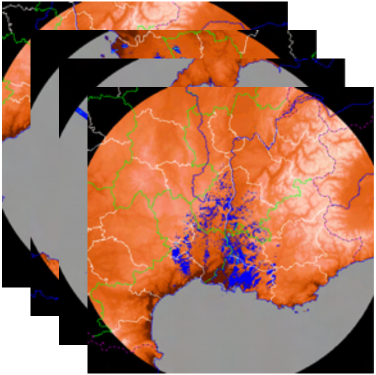
- clear sky echoes (for polarimetric radars only),



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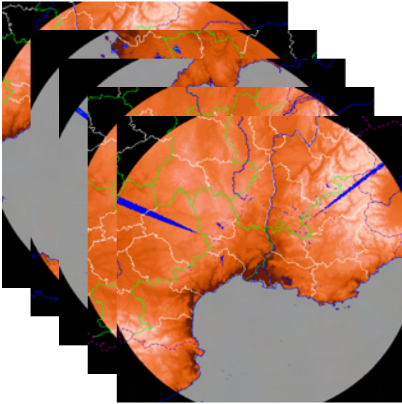

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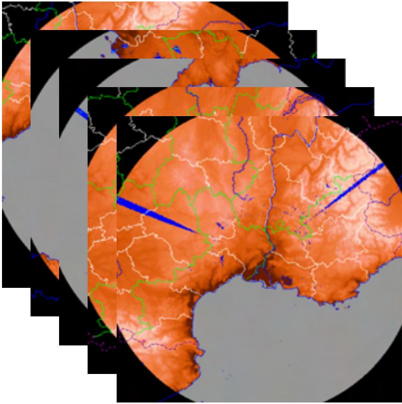
- interferences with other radiative sources,

Pre-processing of radar data (2/2)



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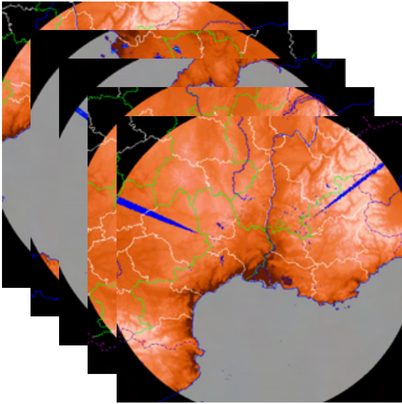

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For Doppler velocities, dealiasing is performed by the "triple-PRT" algorithm (Tabary, 2006).

Radar simulator in Meso-NH

Radar data
- French radar network (Aramis)
- New format
- Pre-processing of radar data

Radar simulator in Meso-NH
- Description of the radar simulator
- Some examples
- Specification of observation operators

Assimilation of reflectivities (+ Doppler velocities)
- Overview
- Assimilation method
- OSSEs for the 1D retrieval only
- Full 1D+3DVar OSSEs
- Assimilation of Doppler radial winds

Introduction

Radar simulator developed for Meso-NH:

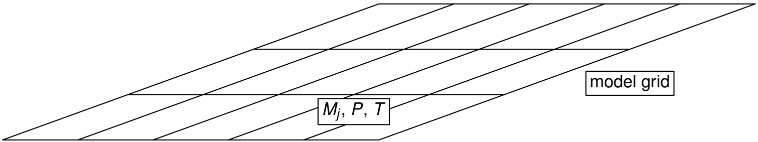
- can emulate reflectivities, Doppler velocities, polarimetric parameters, etc.
- with different complexity levels,

Applications:

- verification of NWP models,
- specification of observation operators.

Description of the radar simulator

Example for reflectivities:



M_j: hydrometeor contents (rainwater, snow, graupel, pristine ice) with distributions following the model ones.

Description of the radar simulator

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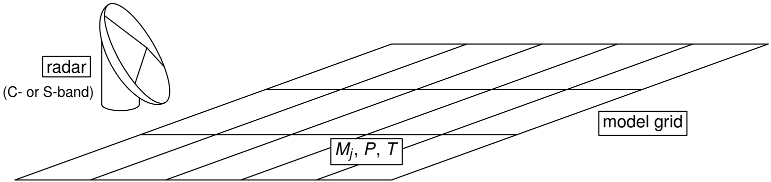

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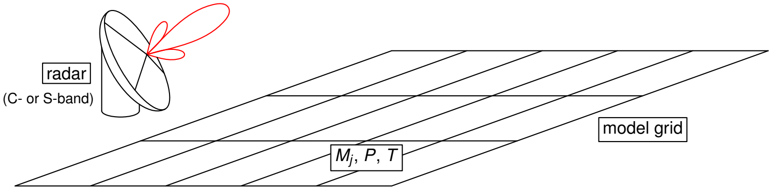
Description of the radar simulator

Example for reflectivities:

Antenna's radiation pattern:
- isotropic
- Gaussian (main lobe only)

1. Antenna's radiation pattern



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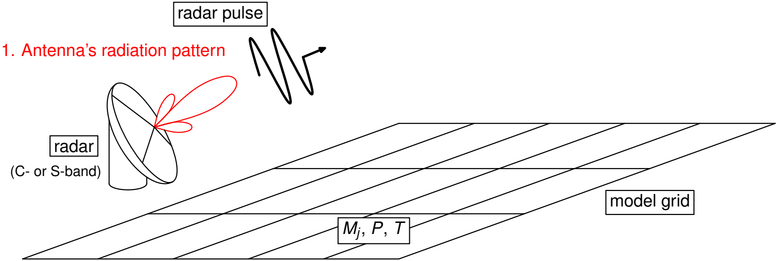

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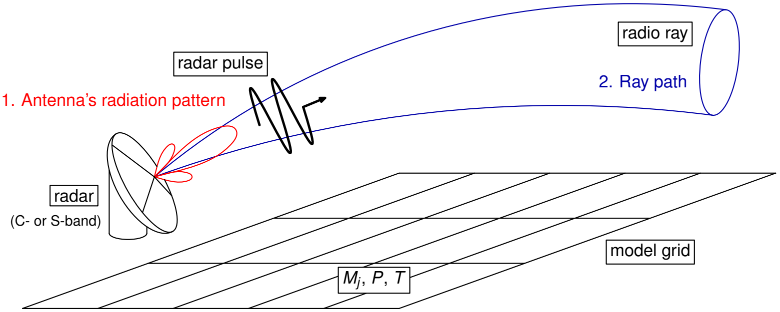
Description of the radar simulator

Example for reflectivities:

Ray path:
- Snell's law
- standard refraction (4/3 Earth's radius)



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Description of the radar simulator

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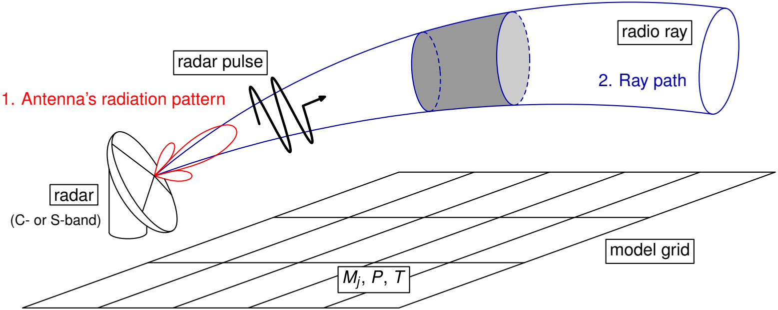

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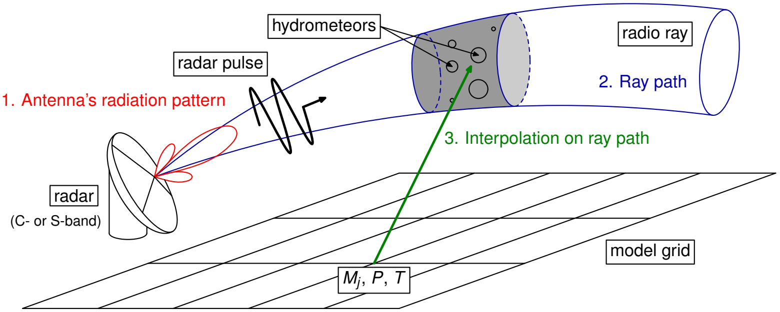
Description of the radar simulator

Example for reflectivities:

Interpolation:
- bilinear



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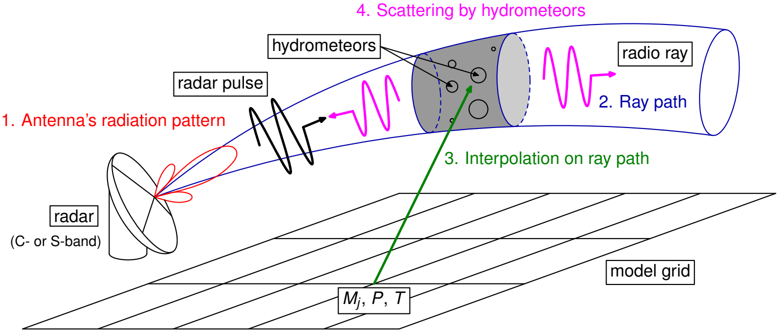
Description of the radar simulator

Example for reflectivities:

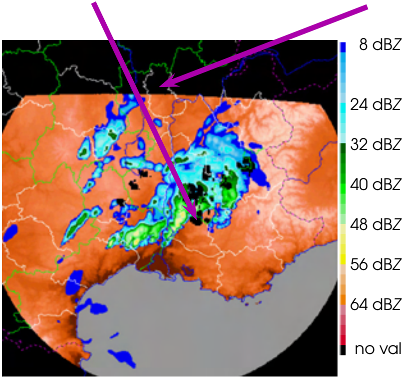
Backscattering and attenuation:
- Rayleigh
- Mie
- Rayleigh-Gans
- T-matrix



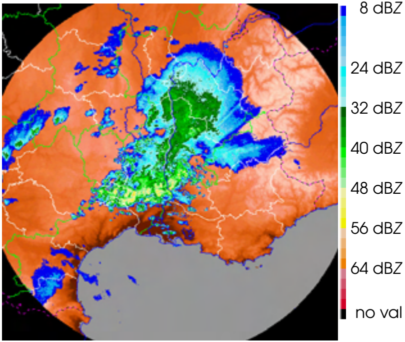
M_j: hydrometeor contents (rainwater, snow, graupel, pristine ice) with distributions following the model ones.

Simulation of reflectivities

Bollène radar, 21 UTC 8 Sep 2002, 1.2°-PPI:



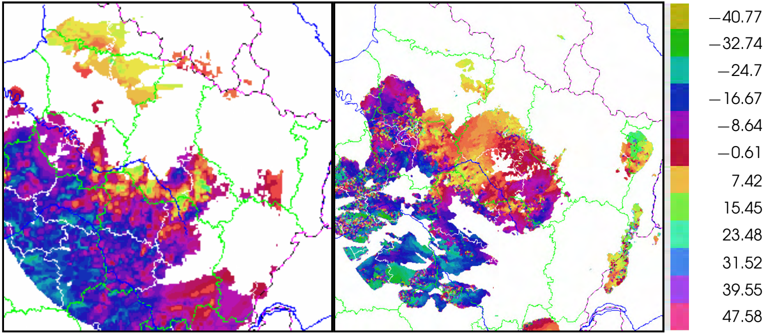
simulated reflectivity



observation

Simulation of Doppler velocities

Radial velocities (in m·s^{-1}) as seen by the Arcis radar on 23 June 2005, at 16 UTC (1.1°-PPI):



Observations *Simulation*

Specification of observation operators

- For reflectivities: Rayleigh scattering, standard beam curvature, beam broadening in the vertical.
- For Doppler velocities: similar to Hirlam's one (Salonen and Järvinen, 2005) but w/ standard beam curvature (due to computational constraints).

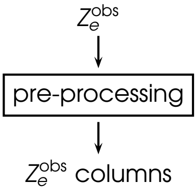
Assimilation of reflectivities

Introduction

Approach for assimilating reflectivities:

- Reflectivity is directly connected with hydrometeor contents,
- But adjusting hydrometeor contents is not expected to significantly improve forecasts (hydrometeors are going to fall quickly)
- Modifying humidity, temperature, vertical velocity, etc. is thought to have much more impact,
- $\Rightarrow$ convert reflectivity columns into columns of humidity, temperature, etc. (1D inversion)
- Then, assimilate these pseudo-observations with the 3DVar assimilation system.

Overview of reflectivity assimilation



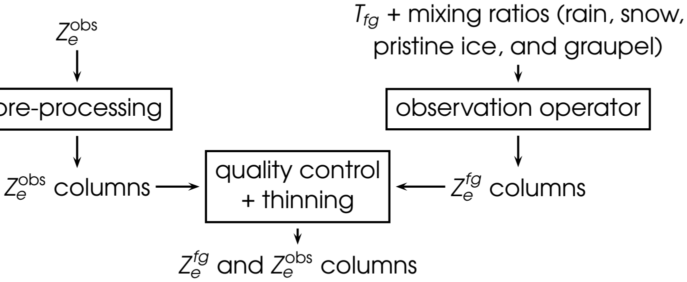
Overview of reflectivity assimilation

Z_e^{obs} → pre-processing → Z_e^{obs} columns

T_{fg} + mixing ratios (rain, snow, pristine ice, and graupel) → observation operator → Z_e^{fg} columns

fg: *first guess*

Overview of reflectivity assimilation



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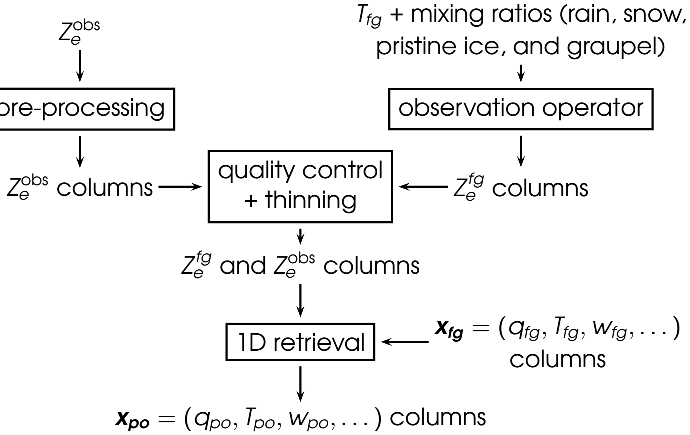
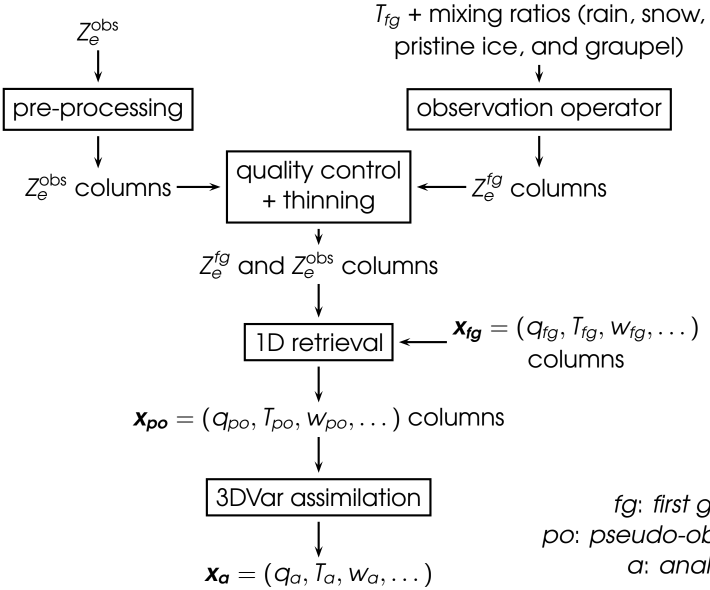


fg: *first guess*
po: *pseudo-observations*

Overview of reflectivity assimilation



fg: *first guess*
po: *pseudo-observations*
a: *analysis*

1D retrieval: theory

Bayesian method for each column:

$$\boldsymbol{x_{po}} = \boldsymbol{E}(\boldsymbol{x}) = \int \boldsymbol{x}\,\mathrm{P}(\boldsymbol{x})\mathrm{d}\boldsymbol{x} \simeq \sum_i \boldsymbol{x}_i^{fg} \frac{\exp\left(-\frac{1}{2}J\left(\boldsymbol{x}_i^{fg}\right)\right)}{\sum_j \exp\left(-\frac{1}{2}J\left(\boldsymbol{x}_j^{fg}\right)\right)}$$

where

$$J(\boldsymbol{x}) \doteq (\boldsymbol{y_Z} - \boldsymbol{H_Z}(\boldsymbol{x}))^{\mathrm{T}}\mathbf{R_Z}^{-1}(\boldsymbol{y_Z} - \boldsymbol{H_Z}(\boldsymbol{x}))$$

$\boldsymbol{y_Z}$: column of observed reflectivities,
$\boldsymbol{x} = (q, T, w \ldots)$: column of model variables,
$\boldsymbol{H_Z}$: observation operator,
$\mathbf{R_Z}$: error matrix for observed reflectivities and observation operator.

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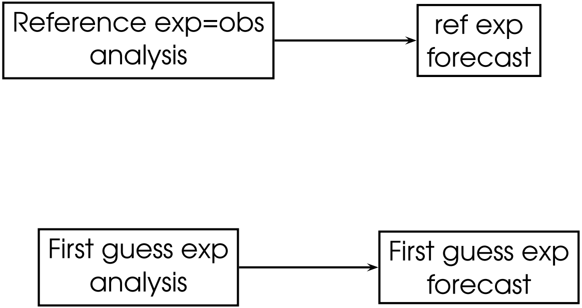
Method unable to adjust q when observed $Z_e > 0$ dBZ and none simulated $\Rightarrow$ in this case we saturate levels above the model condensation level.

OSSEs: Principle



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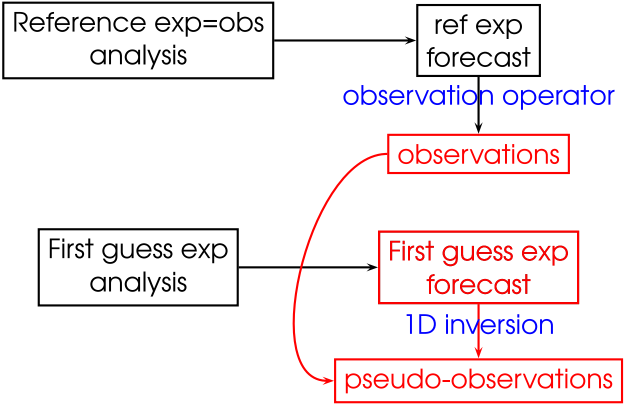

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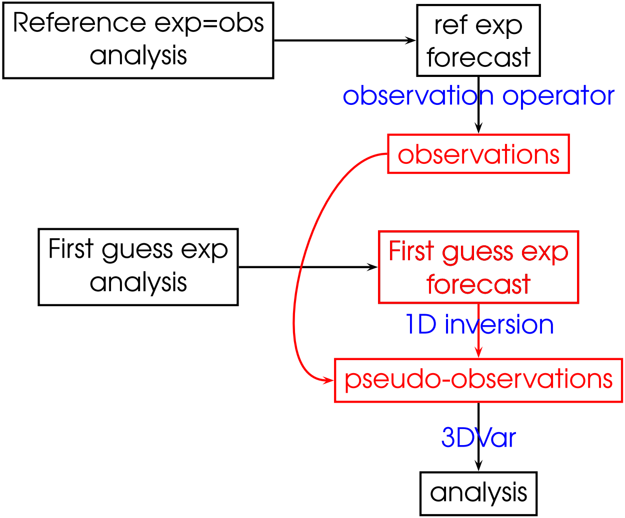

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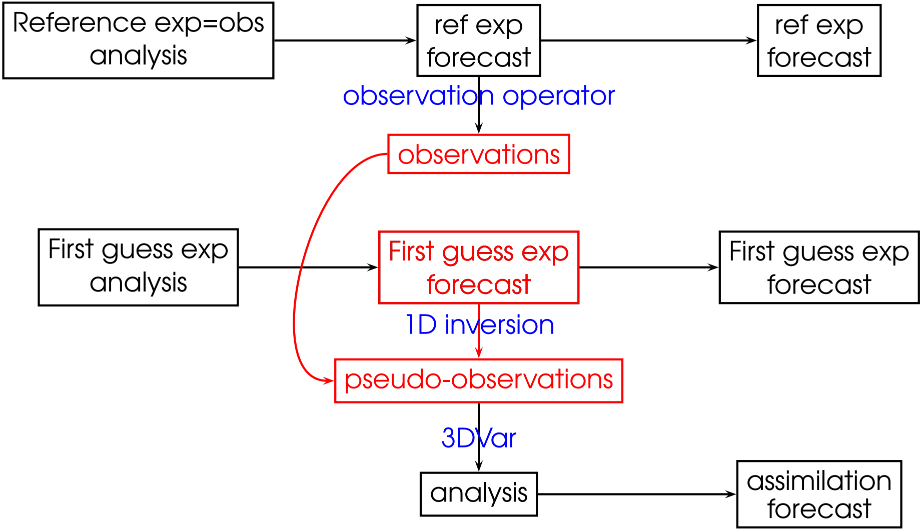

1D retrieval: OSSE with Meso-NH (1/2)

Case study #1: thunderstorm on plain on 9 Oct 2004.

- Ref exp (= observations): starting from a mesoscale data surface initialisation applied to Arpege analysis valid at 12 UTC,
- First guess exp: starting from Arpege analysis at 12 UTC alone.

1D retrieval: OSSE with Meso-NH (1/2)

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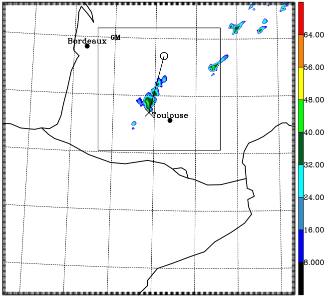
Reflectivities at 1615 UTC:



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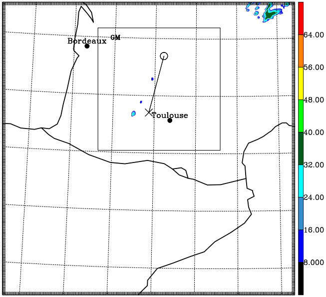
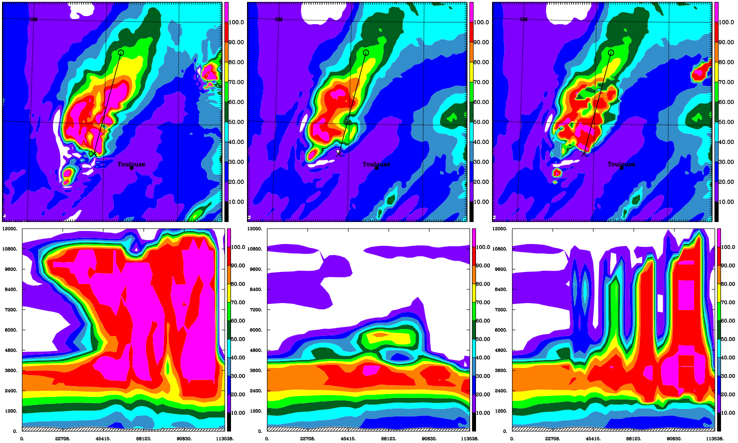


First guess

1D retrieval: OSSE with Meso-NH (2/2)

Relative humidity (%) at 1615 UTC:



alt 4 km

vertical cross-section

Reference=obs *First guess* *1D retrieval*

Full 1D+3DVar OSSEs with Meso-NH/Aladin (1/2)

Case study #2: MCS on 8 Sep 2002.

- Ref exp (=obs):
- First guess:

} Same as for case study #1

Full 1D+3DVar OSSEs with Meso-NH/Aladin (1/2)

Case study #2: MCS on 8 Sep 2002.

- Ref exp (=obs):
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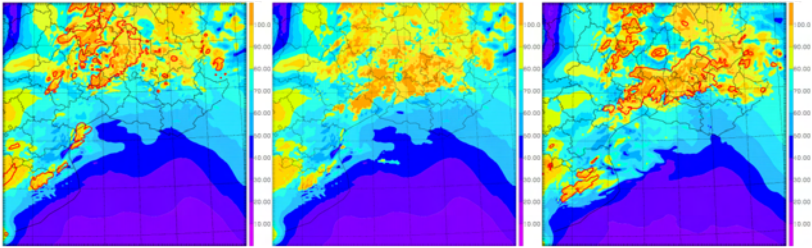
1st step: 1D retrieval at 18 UTC (Bollène radar w/ 13 elev.):

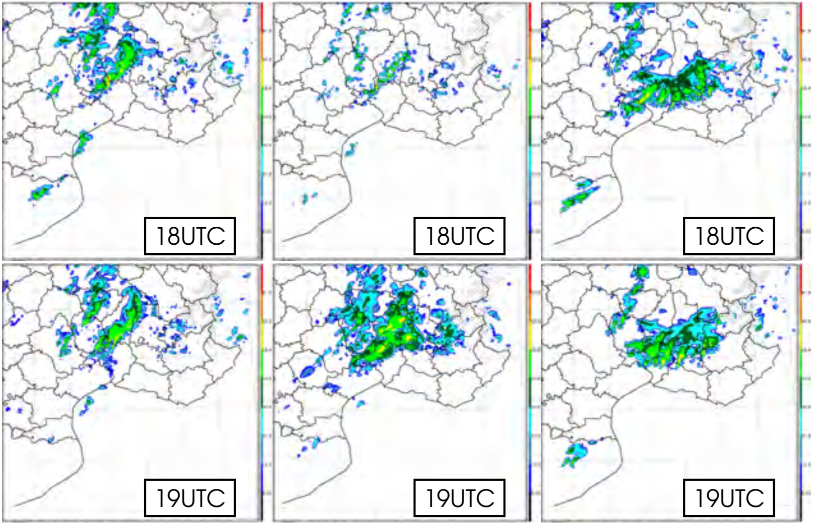


first guess *1D retrieval* *observations*

10-dBZ reflectivity contour (in red) superimposed on relative humidity (%)

Full 1D+3DVar OSSEs with Meso-NH/Aladin (2/2)

2nd step: 3DVar hybrid assimilation of pseudo-observed humidity:



first guess *1D+3DVar analysis* *observations*

Full 1D+3DVar OSSEs with Meso-NH/Aladin (2/2)

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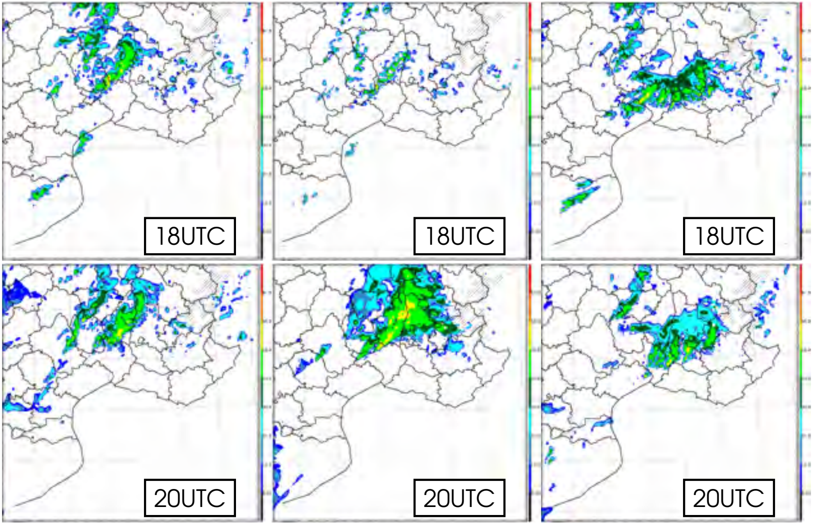


first guess *1D+3DVar analysis* *observations*

Assimilation of reflectivities: Conclusions & Outlook

Conclusions:

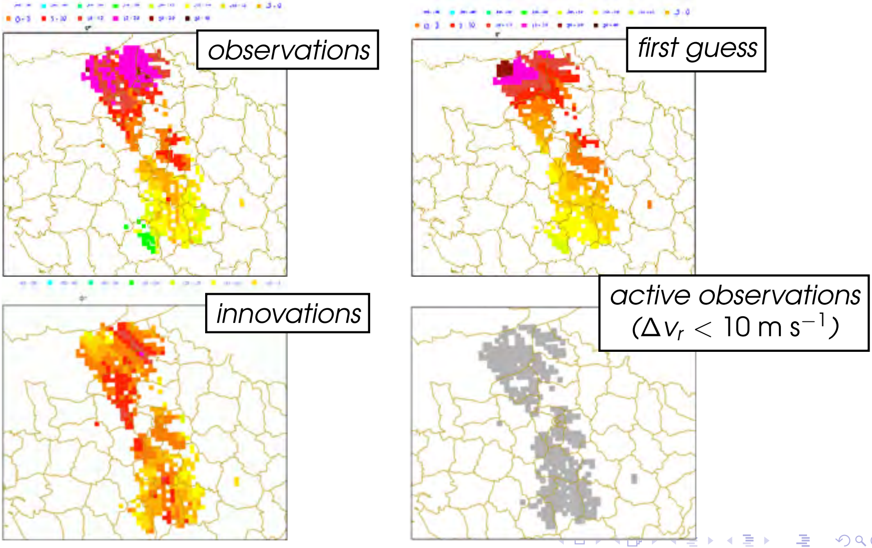
- 1D retrieval able to add and remove humidity according to observed reflectivities,
- 1D+3DVar assimilation exps do not blow up numerically,
- for the 8 Sep 2002 case, need for a good low-level initialisation to improve the analysis.

Future work:

- perform 1D+3DVar assimilation exps with real data using a first guess that takes surface obs into consideration.

Assimilation of Doppler radial winds

Screening: Innovations for 1 elev. (w/o thinning).
Case #3: 10 Aug 2004 at 3 UTC (Trappes radar).



Summary & Outlook

- active research undertaken to characterize radar data quality;
- the 1D+3DVar algorithm is functional (for Meso-NH/Aladin); further tests needed to tune quality flag and 1D inversion thresholds; technical implementation for Arome needs to be done;
- Doppler wind assimilation just started; coding of tangent linear and adjoint codes of the observation operator for Doppler velocities under way; thinning ($\approx$ superobservations) to be done; run assimilation experiments. . . .

References

Delrieu, G., J.-D. Creutin, and H. Andrieu, 1995: Simulation of radar mountain returns using a digitized terrain model. *J. Atmos. Oceanic Technol.*, **12**, 1038–1049.

Salonen, K., and H. Järvinen, 2005: Impact of using Doppler radar radial wind data in a winter cyclone period. *Preprints, Joint 32nd Conf. on Radar Meteorology and 11th Conf. on Mesoscale Processes*, Albuquerque, New-Mexico, Amer. Meteor. Soc. Paper no. JP1J.8.

Tabary, P., 2006: Quantitative assessment of an operational triple-PRT Doppler scheme. *J. Atmos. Oceanic Technol.* Submitted.