Next Generation Operational Met Office Weather Radars and Products

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Part I: Infrastructure
The European radar network

Currently (EUMETNET/OPERA Database) :

192 radars :
159 C, 32 S, 1 X
187 Doppler
30 dual-pol

A European Data Centre currently under development

We still need ≈ 10 years to arrive at the same level of coordination as in the US

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http://www.chmi.cz/OPERA/
Update: 3.1.2007
Currently: 24 magnetron-equipped weather radars covering about 90% of the French territory ($\approx 1000 \times 1000 \text{ km}^2$).

A “composite” network of radars having:
- different wavelengths (16 C, 8S, soon 4X),
- different ages (between $\approx 20$ and 1 y.o.),
- different manufacturers (THALES / SELEX / …),
- different scanning strategies.

Yet all radars are equipped with the same “home-made” radar processor (named CASTOR2), which guarantees homogeneity of the products.
Design, evolution and operations of the network essentially driven, so far, by hydrological applications

Maps of median daily radar / rain gauge ratio

Daily Rain Gauge Accumulation > 5 mm

Fall 2006

Fall 2007

Fall 2008

Fall 2009
The VCP (Volume Coverage Patterns) of the radars are not uniform and are adapted according to the surrounding topography and the mechanical scanning capabilities.

At best, radars perform $\approx 13$ independent elevation angles every 15 minutes, with the 3 – 4 lower tilts being revisited every 5 minutes to generate 5’ products (such as QPE).

All radars are Doppler and equipped with a staggered triple-PRT (Pulse Repetition Time) scheme that solves the range – folding dilemma and provides radial velocity with no ambiguity up to long ranges ($\approx 250$ km).

The Doppler upgrade

- In 2002: Only one Doppler radar in the network! France: last dinosaur in Europe?

- Beginning of 2008: 15 Doppler radars;

- 2010: 24 Doppler radars;

The upgrade was strongly supported by the NWP community

Radars = A strategic data source for regional, high-resolution models (AROME at the French level).

→ Reflectivity ($Z_H$) and radial velocity ($V_R$) data are currently assimilated operationally in AROME
The triple PRT (Pulse Repetition Time) technique


Current (low) PRFs on C-band radars:
- 379 Hz, 325 (6/7) and 403 Hz (4/5)

Folded velocities [Nyquist velocity: \(\approx 5 \text{ m s}^{-1}\)]

Unfolded velocity
- Extended Nyquist velocity: \(\approx 60 \text{ m s}^{-1}\)
The polarimetric upgrade

Conventional radar

Transmission / Reception of a horizontally polarized wave

Polarimetric radar

Transmission / Reception of a vertically polarized wave

Horizontal reflectivity $Z_H$ (dBZ)

Differential reflectivity $Z_{DR} = Z_H - Z_V$ (dB)

Differential phase $\Phi_{DP}(\degree)$

Correlation coefficient $\rho_{HV}(\theta)$

French C-band Trappes radar

1.5° elevation angle - 18 August 2004 - 12.00 → 13.45 UTC
The network currently comprises 10 polarimetric radars (9 C, 1 S, simultaneous H & V transmit & receive)

All of them were manufactured by SELEX (GEMATRONIK). Digitized I and Q data are fed into the CASTOR2 radars processor, which computes all polarimetric and Doppler moments.

4 more X-band polarimetric SELEX systems (with transmitters and receivers mounted on the antenna) to be deployed over the period 2010 – 2013.

Polarimetry has become the new standard for operational weather radars.
2004 : First polarimetric radar installed in Trappes
Part II:
Products
European radar networks are multi-purpose

- 2D & 3D Mosaicks of Reflectivity and Derived parameters ($Z_{MAX}$, ECHOTOP, VIL, ...) → Nowcasting (aviation-oriented ...);

- Quantitative Precipitation Estimation (QPE) with uncertainties → Hydrology;

- 3D Hydrometeor Classifications (using polarimetry);

- Refractivity products → low-level moisture field;

- Doppler products;
Doppler products (1) : VAD Wind Profiles

Wind profiles are retrieved at each height at the vertical of the radar assuming that the horizontal wind is uniform (linear) in the vicinity of the radar (Browning and Wexler 1968).

A product that has probably become obsolete at the age of:

- Radial velocities assimilation by NWP models and multiple-Doppler 3D wind field reconstructions !!!

Wexler 1968
Doppler products (2) : Specific Product for NWP

- A collection of all PPIs of $Z_H$, $V_R$ and echo type measured by each radar over 15 minutes.

- Input for data assimilation in NWP models. The impact on NWP forecast scores is positive!

- The echo types are currently: ground-clutter, clear-air, sea clutter, noise, sunrise / sunset and precipitation.

- Next step (with dual-pol): document the precipitation type (rain / hail / snow / …) and distinguish between insects and birds.
Impact of radial velocity assimilation in the French operational AROME model
8 November 2007

Analysis of the divergence field at 925 HPa

Convergence line is much better forecasted with radar data assimilation.

RADAR OBSERVATIONS AT THE FORECAST TIME
WITH ASSIMILATION
OF REFLECTIVITIES

WITHOUT ASSIMILATION
OF REFLECTIVITIES

VERIFICATION:
RAIN GAUGES

AROME forecasted 3h
precipitation accumulation w
and w/o radar reflectivity
assimilation
Doppler products (3) : Operational, nationwide, 2.5x2.5x0.5 km$^3$, 15° Multiple-Doppler 3D wind and reflectivity fields

Roadmap on Doppler (2009 – 2012)

- Improve the quality of radial velocities (by increasing the PRF)
- Develop WindShear and Turbulence mosaicks based on spectrum widths and $V_R$ gradients (in range / azimuth)
- Extend 3D wind retrievals to the European scale;
- Develop high-resolution (< 1km², < 5’) multi-Doppler products wherever radar density makes it possible (e.g. airports)
- Introduce spectral filtering techniques on staggered time series to recover weak signals (e.g. clear air and weak rain)
- Distinguish between insects from birds in clear-air data;
- Adapt Doppler schemes and products to X-band systems
- Increase the amount of Doppler data assimilated by the NWP model (AROME) by one order of magnitude;
Increasing the PRF to improve Doppler measurements

Trappes (C) - Radial velocity PPI – 0.8° - 19 January 2009 – 15.00 UTC
High vs. Low PRFs [still using the staggered triple-PRT scheme]

Low PRFs (Mean = 333 Hz) and $V_{NE}=60$ m/s
→ Error rate = 17%  

High PRF (Mean = 471 Hz) and $V_{NE}=44$ m/s
→ Error rate = 5%
Summer of 2010: Real-time Demo of a nation-wide low-level 5', 1 km² WindShear composite

In red: contours of $Z_H > 35$ dBZ
A typical autumn night over France …

(3 September 2006 – 22.00 UTC)
Clear-air measurements: some statistics

Number of clear-air pixels over a 10-day period (in March 2005) over the Grèzes (S) radar

Night: birds
Day: insects

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Clear-air measurements: some statistics

Trappes (C)
Clear-air measurements: refractive index gradients

- Doviak et Zrnic (1993): $Cn^2 = 7.489 \times 10^{-16} \lambda^{-11/3} Z$
  $Cn^2$ turbulence structure parameter in $m^{-2/3}$, $\lambda$ wavelength in m et Z en $mm^6 m^{-3}$
- Typical $Cn^2$ in Nice (from airborne measurements): $10^{-13} m^{-2/3}$

- **Computation:** Maximum detection distance in red (with a sensitivity of 0 dBZ at 100 km)

<table>
<thead>
<tr>
<th>$Cn^2 (m^{-2/3})$</th>
<th>S (10 cm)</th>
<th>C (5 cm)</th>
<th>X (3 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-15}$</td>
<td>-35 dBZ (1 km)</td>
<td>-46 dBZ (0.4 km)</td>
<td>-54 dBZ (0.2 km)</td>
</tr>
<tr>
<td>$10^{-14}$</td>
<td>-25 dBZ (5 km)</td>
<td>-36 dBZ (1.4 km)</td>
<td>-44 dBZ (0.5 km)</td>
</tr>
<tr>
<td>$10^{-13}$</td>
<td>-15 dBZ (15 km)</td>
<td>-26 dBZ (4.4 km)</td>
<td>-34 dBZ (1.9 km)</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>-5 dBZ (45 km)</td>
<td>-16 dBZ (14 km)</td>
<td>-24 dBZ (5.6 km)</td>
</tr>
</tbody>
</table>

**Assumption**: $1/2$ wavelength in the inertial range !!!

**Typical Taylor scale**: 5 – 15 cm → higher wavelength (S) better but then aggressive ground-clutter filtering is needed …!
Thank you!