Added value of assimilating surface pressure observations from personal weather stations in AROME-France

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International Symposium on Data Assimilation – 17 October 2023

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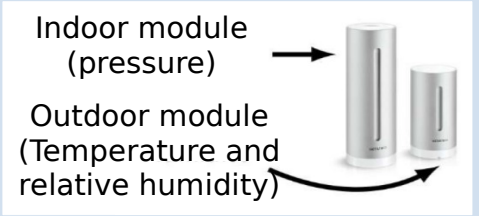
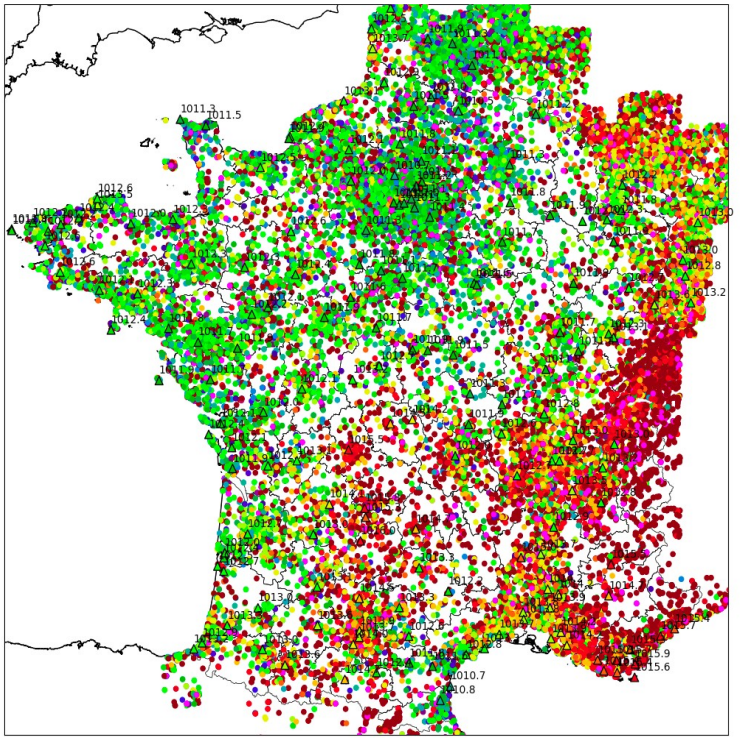
Introduction

- **Standard weather stations (SWSs)**, owned by Météo-France and its partners.

Toulouse-Blagnac station

- **Personal weather stations (PWSs)**, from Netatmo company: ~ 55 000 stations, with heterogeneous quality.
- Absolute accuracy of ±1 hPa.





Raw MSLP observations from SWSs and PWSs on 12 August 2020 at 20 UTC.

The AROME-France NWP system

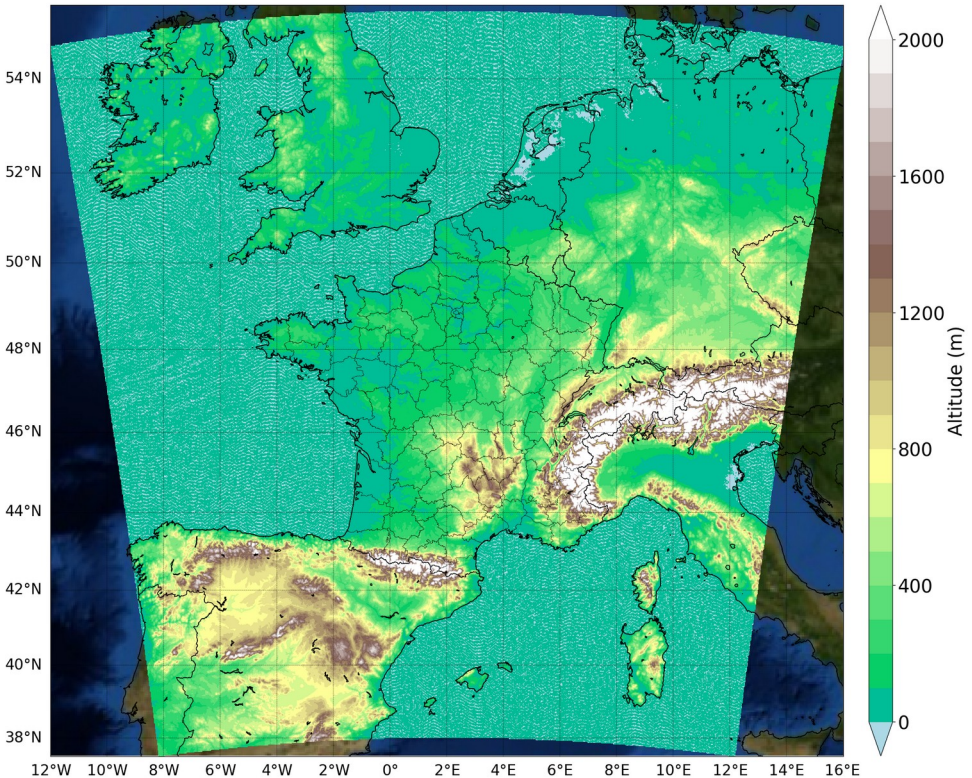
Météo-France limited-area operational model

- Solves Euler fully compressible set of equations;
- 1.3 km horizontal grid spacing (1536 x1440 pts);
- 90 vertical levels from 5 m a.g.l. to 10 hPa, mass-based **hybrid pressure terrain-following** vertical coordinate;
- Coupled to global ARPEGE model;
- 1 h cycle **3D Variational (3DVar)** data assimilation (DA)
- 13 prognostic and 5 control variables, including **hydrostatic surface pressure (Ps)**;
- 8 forecasts per day up to 51 h;

➔ All SWS and PWS surface pressure observations are assimilated as **Geopotential** (product of the station altitude and the gravitational constant) at the **Level of the Observed station Pressure (GLOP)**.

```
   20210906       010000
17  1         14  48.90799     2.24066   'NA000204'   20210906  10000  4.65660E+01
1     1111  100000     1  1.01582E+05  1.70000E+38  4.56654E+02         2064
```

Format of a GLOP PWS observation assimilated by AROME-France.



Orography of the AROME-France domain.

DA scheme: 3DVar vs 3DEnVar

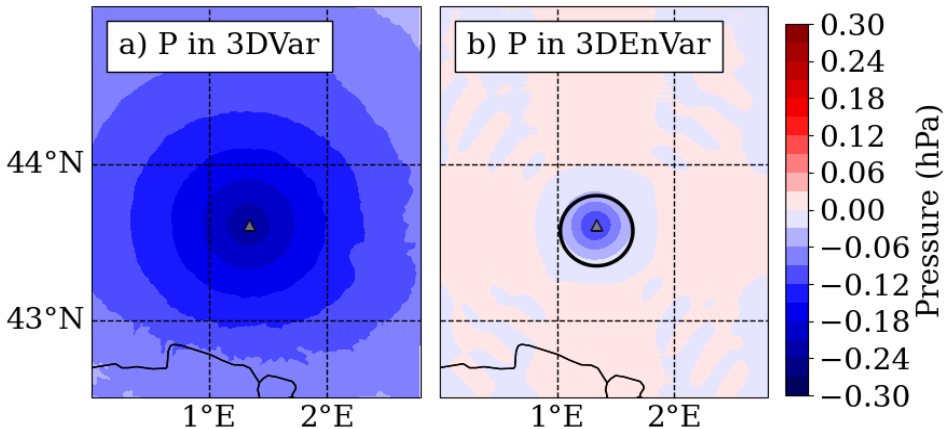
x state of the atmosphere, x_b background state
y_0 observation vector
H non-linear observation operator
B **background error covariance matrix**
R observation error covariance matrix

Minimization of the cost function J:

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

1 h cycle AROME-France DA schemes

- ➔ Operational: **3DVar** DA scheme[1], where B is static;
- ➔ In test: **3D Ensemble Variational** (3DEnVar) DA scheme[2], where B from an EDA (50 members). Localisation of 25 km on the surface.



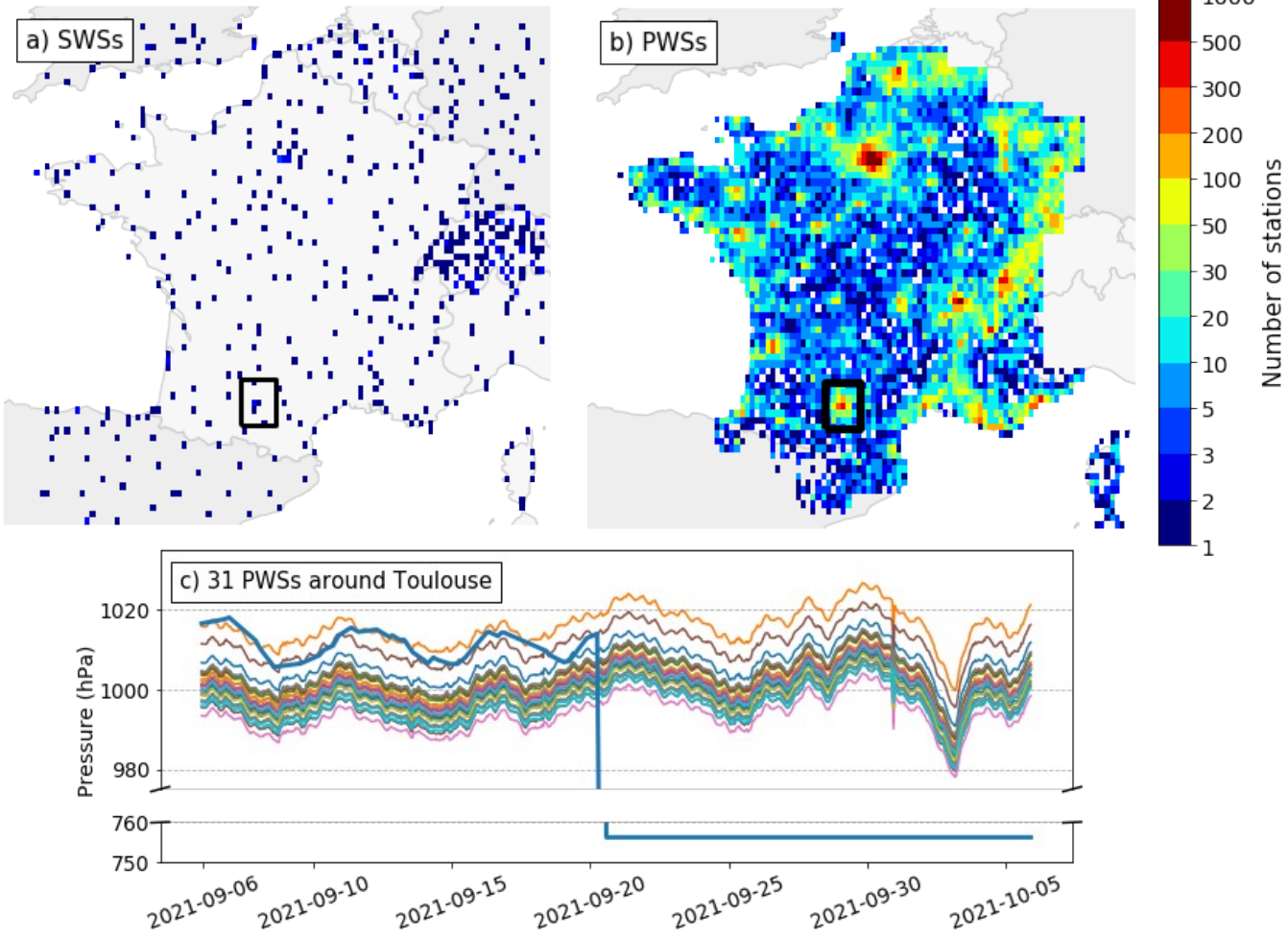
Analysis **increment of P_s** from the assimilation of a single GLOP observation. Starting from the same guess. The black circle indicates a radius of 25 km around the observation.

[1]Brousseau et al. (2016)
[2]Montmerle et al. (2018), Michel and Brousseau (2021)

Scientific questions

- Does the assimilation of PWS surface pressure observations in the current AROME-France **3DVar DA system** improve weather analyses and forecasts?
- And in the **3DEnVar DA system** currently in test ?
- In particular, are there improvements in analyses and forecasts of **thunderstorms**?

Surface pressure observations assimilated



- AROME-France assimilates 212 pressure observations from SWSs every hour in France (**Fig. a**).
- PWSs are 210 times more numerous, with around 55,000 pressure observations (**Fig. b**).
- The variations in pressure observation time series from nearby PWSs are often similar, although there are sometimes very large variations (**Fig. c**).

DA experiments overview

1. Monitoring non-cycled experiment assimilating raw PWS GLOP ;
2. **Pre-processing** based on **the last rolling month** from the monitoring experiment, for each station:
   - **Bias correction**, by subtracting the average innovations.
   - **Quality control**, rejecting observations when the standard deviation of the innovations exceeds 60 m^2s^{-2}.
   - **Thinning** at 1.3 km and observation error identical to SWS, i.e. 80 m^2s^{-2}.

   ➔ On average, 25 000 PWS GLOP observations remain per hour.
3. OSEs over 1 month (from 6 September to 5 October 2021):

AROME-France DA experiments with operational configuration.

	DA scheme	Assimilation of GLOP pre-processed PWS observations
« 3DVar »	3DVar	
« 3DVarP »	3DVar	✓
« 3DEnVar »	3DEnVar	
« 3DEnVarP »	3DEnVar	✓

Observation minus Background (OmB) scores over 1 month

$$RMS = \sqrt{\sum_{i}^{SWS} (O_i - B_i)^2}$$

$$\Delta RMS = \frac{RMS_{REF} - RMS_{XP}}{RMS_{REF}}$$

ΔRMS OmB from SWSs over the 1 month study period. Positive values of an experiment (XP) w.r.t. another (REF) indicate that 1 h forecast of XP are closer than REF to SWS observations. Significant values are darker.

	Surface pressure		Temperature		Relative humidity		Zonal wind (U)		Meridional wind (V)	
	AROME domain	France	AROME domain	France	AROME domain	France	AROME domain	France	AROME domain	France
3DEnVar w.r.t. 3DVar	−8.0 %	−9.3 %	−2.2 %	−1.2 %	−3.6 %	1.1 %	−2.0 %	−1.1 %	−2.0 %	−1.3 %
3DVarP w.r.t. 3DVar	−0.8 %	−0.7 %	0.0 %	0.8 %	0.0 %	0.0 %	1.4 %	1.6 %	1.4 %	1.5 %
3DEnVarP w.r.t. 3DEnVar	3.0 %	10.3 %	−0.6 %	−0.8 %	−0.8 %	−1.3 %	−0.2 %	0.0 %	0.2 %	0.2 %

- 1 h forecast scores at the ground :
  - 3DEnVar w.r.t. 3DVar, **degradation**;
  - 3DEnVarP w.r.t. 3DEnVar, **improvement** for surface pressure.

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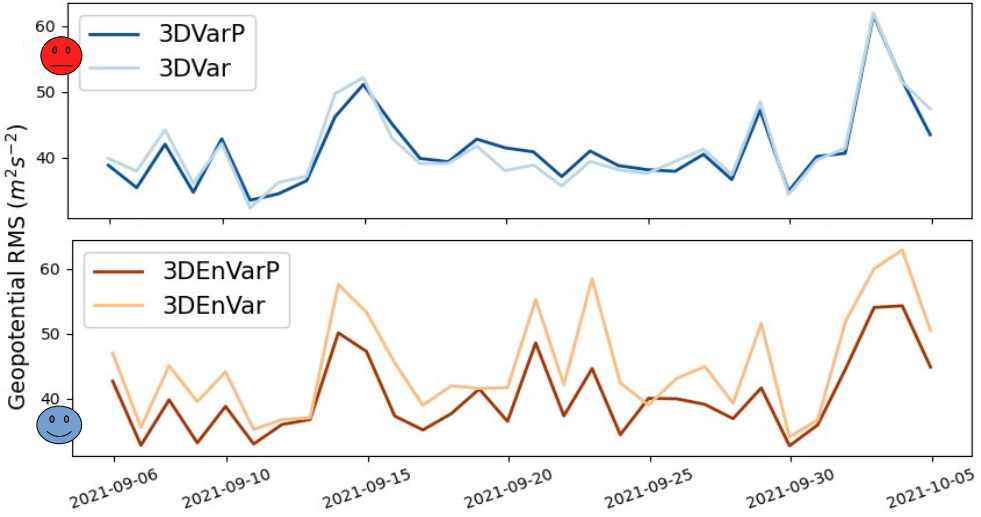
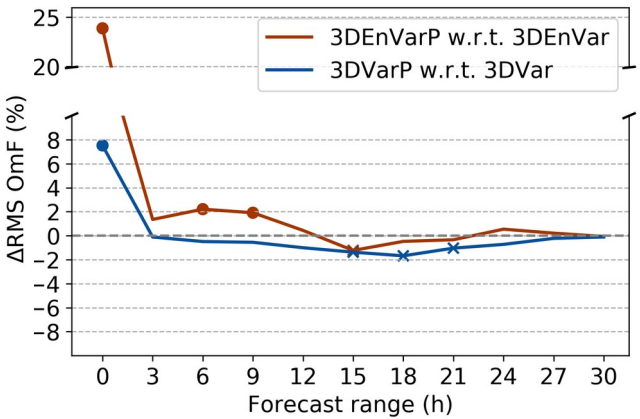


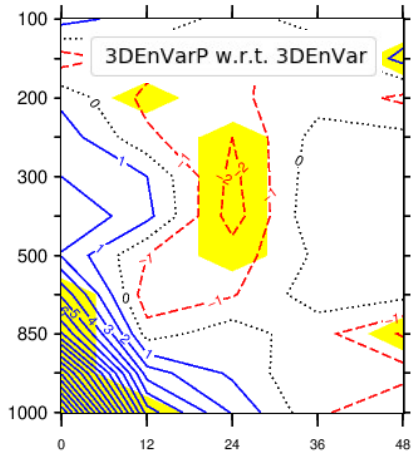
Daily average geopotential RMS of OmB for SWS observations.

- 3DVarP w.r.t. 3DVar, **neutral**;
- 3DEnVarP w.r.t. 3DEnVar, **systematic improvement** of the GLOP 1 h forecast over the one month period.

Observations minus Forecast (OmF) scores over 1 month

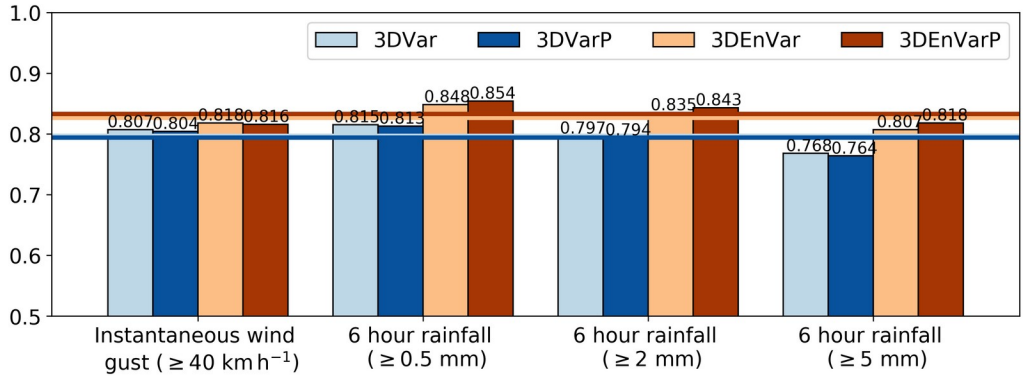


ΔRMS OmF of MSLP from 0 to 30 h of forecast for SWSs over France.
Points (respectively crosses) indicate improvement (resp. degradation) at 90 % statistical significance level.
4 forecasts per day.



ΔRMS OmF of geopotential from 0 to 48 h of forecast against radiosoundings.
Blue (resp. red) for improvement (resp. degradation). Yellow background corresponds to significant results at 95 %.
One forecast per day.

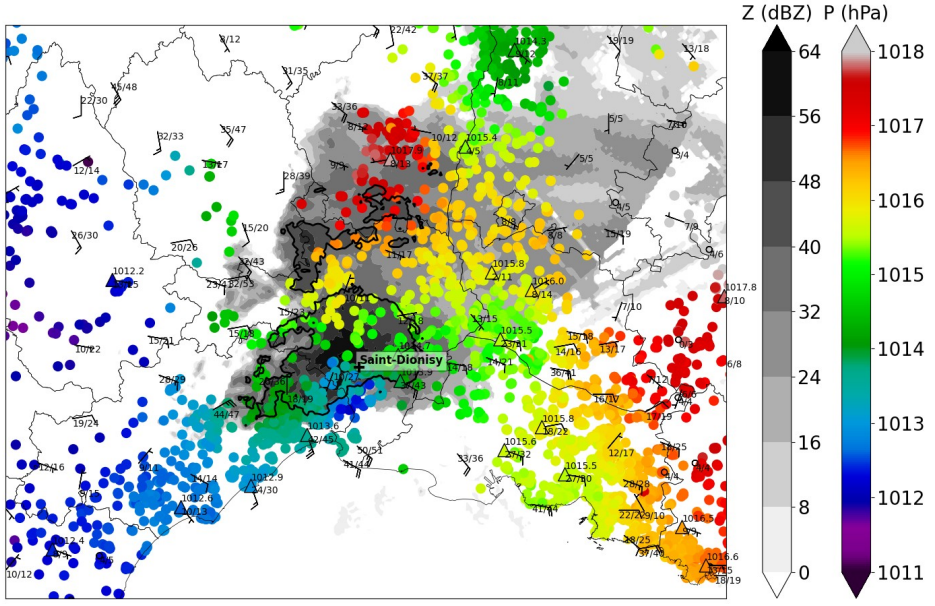
- Improvement of the geopotential until 9 h of forecast in the boundary layer. Degradation in upper troposphere at 24 h of forecast.
- Forecast scores ranking:
  3DVarP < 3DVar < 3DEnVar < 3DEnVarP



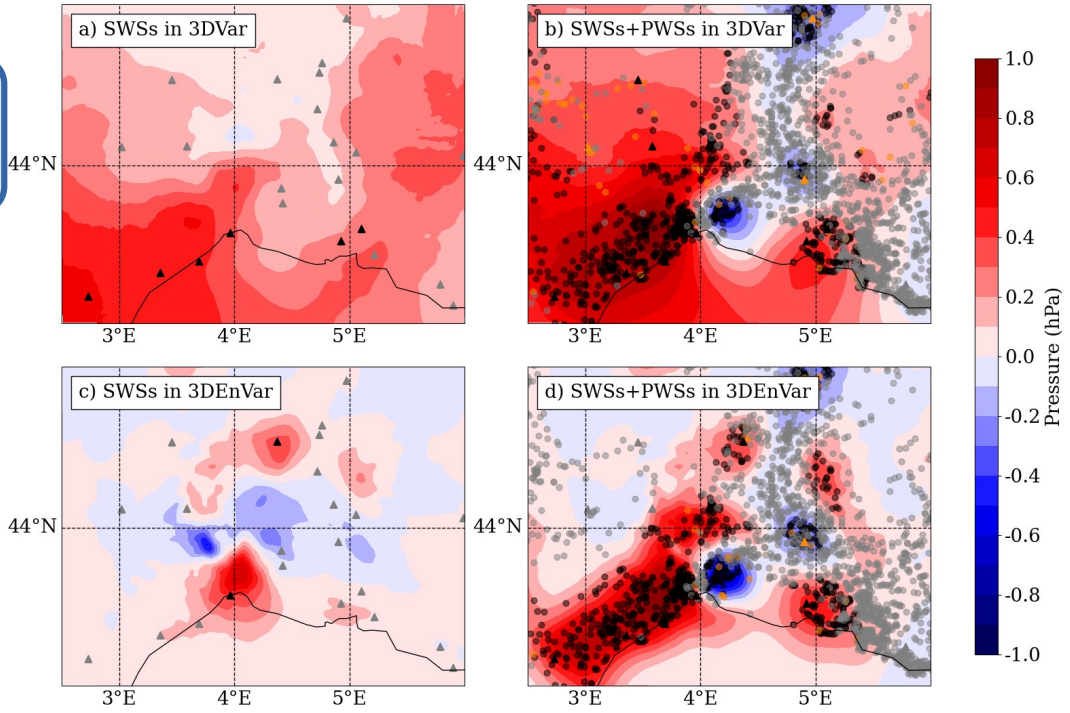
Brier skill score of forecasts during the 1 month, averaged over 4 forecast times (6 h, 12 h, 18 h, 24 h).
One forecast per day.

Case study: Mesoscale Convective System (MCS)

Mediterranean heavy-precipitation event, quasi-stationary MCS **dumping 260 mm of rain in 3 h** at Saint-Dionisy (Gard)



MSLP observations of SWS and PWS networks at 07:00 UTC on 14 September 2021. The triangles (resp. points) represent the SWSs (resp. PWSs). Base reflectivity (Z) in grey colours indicates thunderstorm activity and location.



Analysis increments of surface pressure at 7 UTC on 14 Sept 2021 **starting with identical 3DVar background**.

|obs − analysis| > |obs − guess| in orange (and the reverse in black). The neutral in grey is defined at ±0.2 hPa.

- The strongest increments come from the 3DEnVarP experiment.

Takeaway results

Conclusion

- A simple pre-processing method is applied, removing the long term individual bias and incoherent observations; a thinning at 1.3 km is used.
- After the pre-processing, the GLOP observations rise from 212 (SWSs) to ~25000 (SWSs+PWSs) in France.
  - The **3DVar DA scheme** performs poorly in assimilating additional PWS observations.
  - The **3DEnVar DA scheme** shows positive forecast results **for the boundary layer geopotential up to 9 hours of forecast**. Overall **improvement in 6 h rainfall forecasts** up to 24 h.

Article submitted to *NHESS (Demortier et al.)*. Pre print available: https://doi.org/10.5194/nhess-2023-103

Future work

- Assimilation with 3DEnVar DA scheme for other case studies;
- **Sensitivity studies:** different QC, scale of the thinning/observation error;
- Coding the VarBC method for operational use;
- Assimilation of **temperature** and **relative humidity** observations from PWSs.