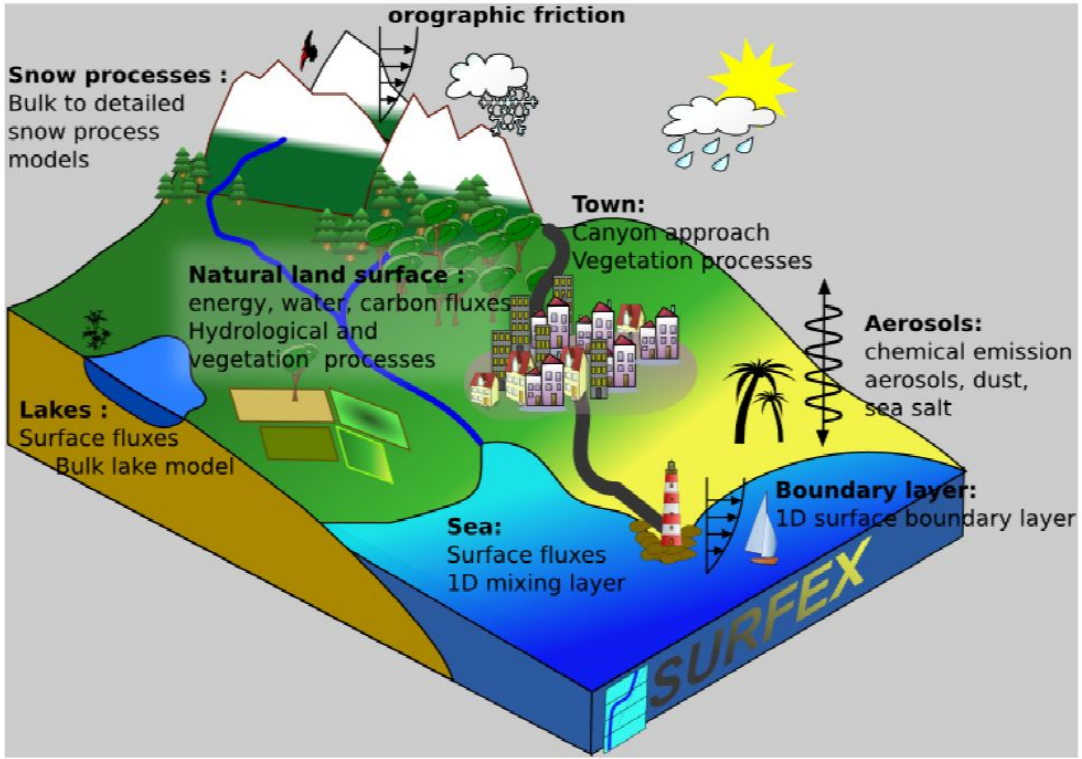
Towards an ensemble approach to surface analysis within the NWP model AROME-France

Sophie Marimbordes, Camille Birman, Nadia Fourrié, Etienne Arbogast, Jean-François Mahfouf
CNRM/GMAP/OBS & CNRM/GMAP/ASSIM

Surface-atmosphere interface



SURFEX coupled with the atmospheric component

=

Importance of an accurate representation of surface-atmosphere coupling

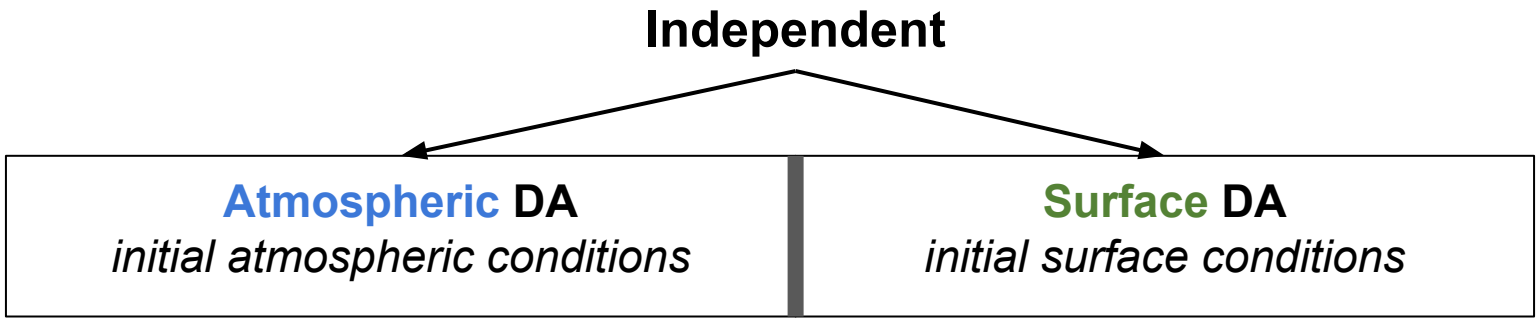
Masson et al. 2013, The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes

Data assimilation process

Numerical Weather Prediction

=

Strong sensitivity to initial conditions



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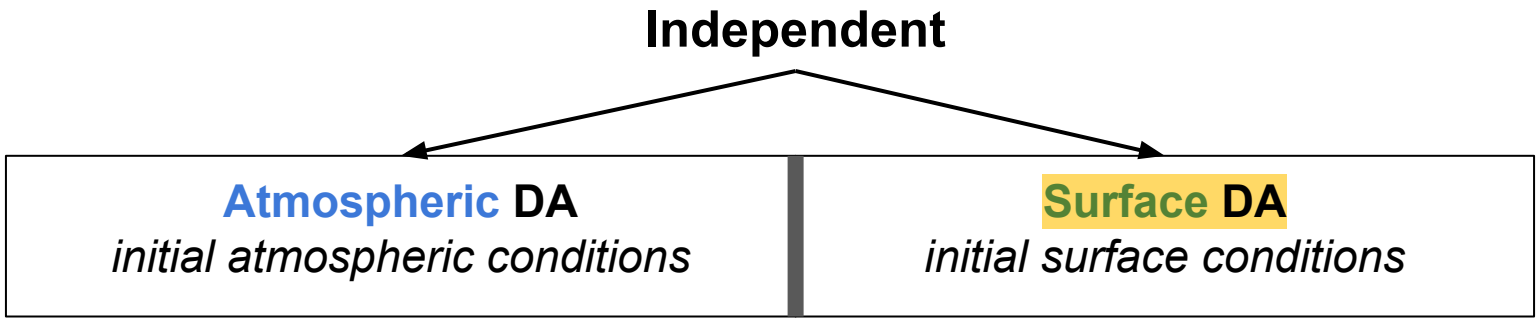

Outline

Model & Obj

AROME-France model + Objective of my Phd

2D-Var

Towards an ensemble variational approach

2D-Var approach to replace the 2D-OI surface analysis

2DEnVar

Implementation of the ensemble variational approach

2DEnVar surface DA scheme using AROME EDA

Optimisation

Optimisation of the ensemble variational approach

Sensitivity tests

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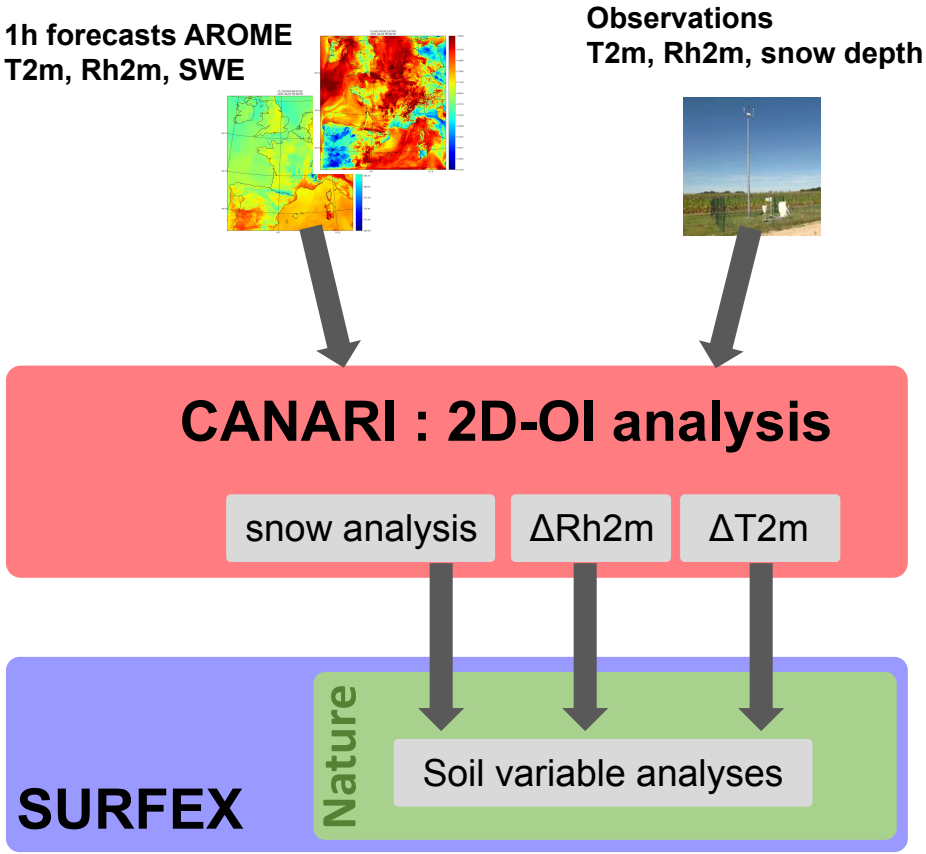
AROME-France surface analysis

Nature tile in SURFEX (ISBA3L)

Assimilation of **2-m temperature, 2-m relative humidity and snow depth observations**

CANARI: **2D-OI analysis** of **2-m temperature, 2-m relative humidity and SWE**

Initialisation of **soil variables** in SURFEX



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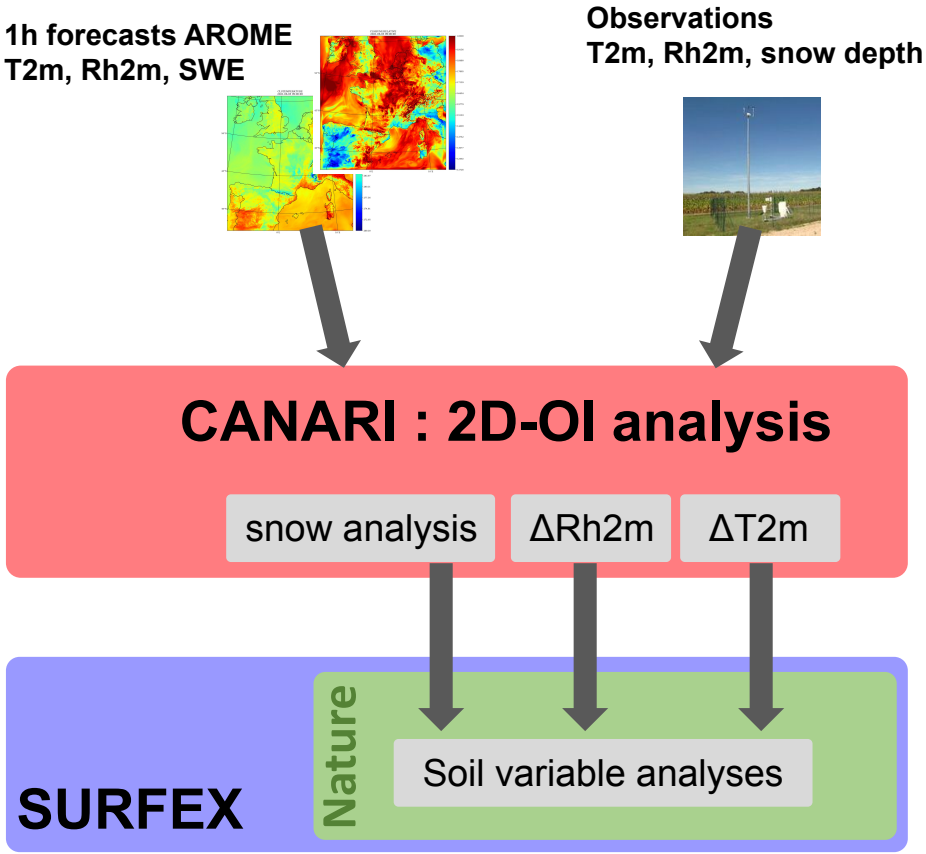


Outdated surface analysis

Implement a system closer to the upper air analysis:
– to **facilitate code maintenance** and evolution
– for future **coupled DA**

AROME-France model

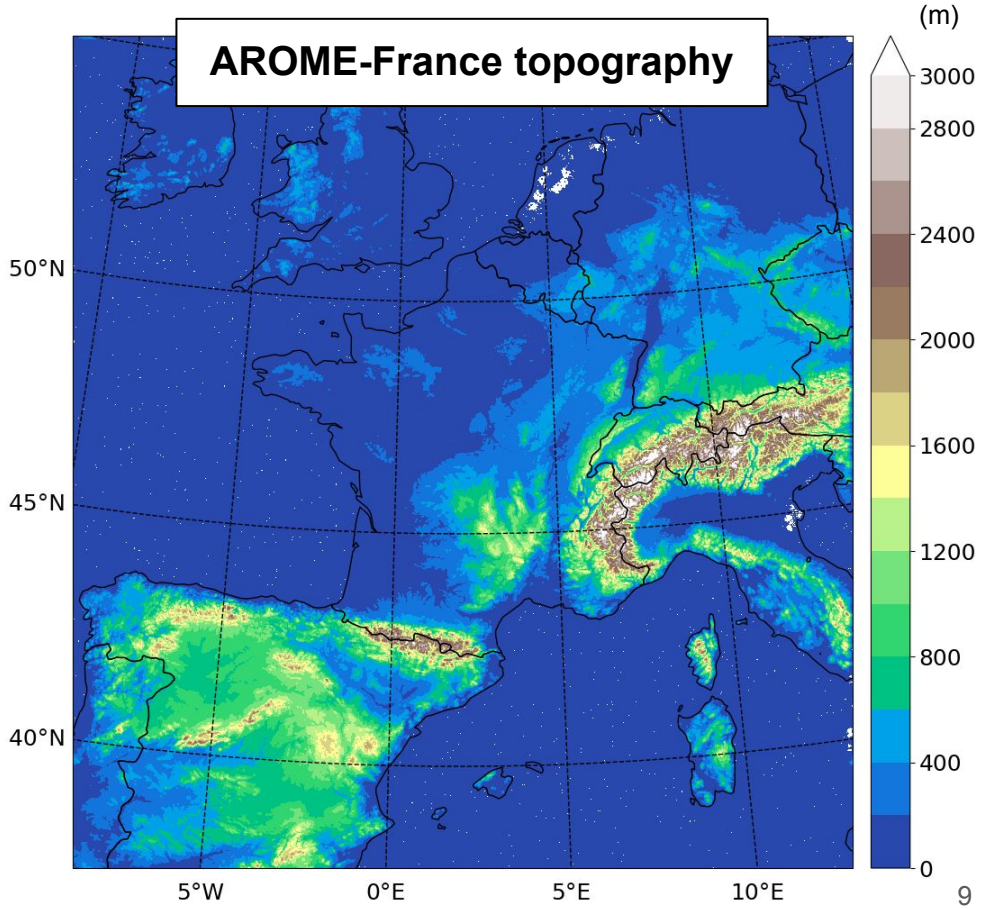
Limited Area Model
Spectral and **Non Hydrostatic model**
Coupled with hourly forecasts from ARPEGE

1.3 km horizontal resolution
90 vertical levels from 5 m to 10 hPa
Forecasts up to +48 h

Surface model SURFEX

Weak coupling
- Coupled forecasts
- Uncoupled analysis

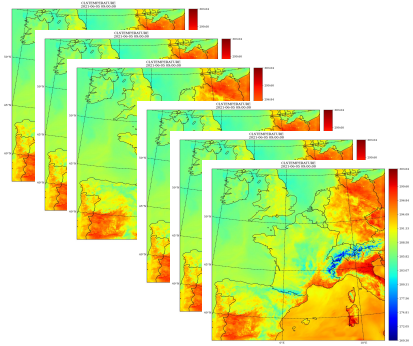
Data Assimilation
- *OI land DA 3-hour cycle*
- ***3DEnVar*** *atmospheric DA 1-hour cycle*



AROME-France model

3DEnVar ⇒ background-error covariance ***B-matrix*** **updated**

Fully flow-dependent B-matrix with an Ensemble of Data Assimilation **AROME EDA**



Statistics on

atmospheric fields from AROME EDA

Fully 3DEnVar dynamical

B

matrix

Localization

o **L**

operator

AROME EDA (Ensemble of Data Assimilation)

Hydrostatic core
3.2 km horizontal resolution

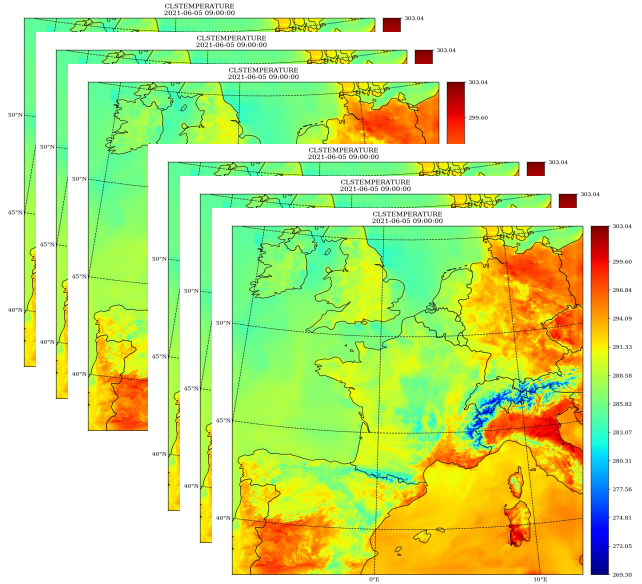
50 members

Short-term forecasts **+3 h**

OI land DA 3-hour cycle
3D-Var atmospheric DA 3-hour cycle

+ Perturbation of observations
+ Perturbation of SST variable
+ SPPT = ***S**tochastically **P**erturbed **P**arametrisation ***T**endencies* scheme **through the atmosphere**

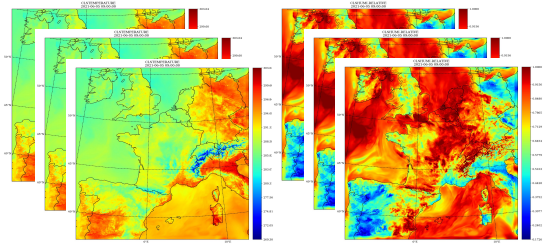
⚠ SPPT not applied **near the surface**



Objective

Can an ensemble-based surface analysis improve forecasts of low-level processes in a coupled SURFACE-ATMOSPHERE system?

2DEnVar approach similar to 3DEnVar



T2m and Rh2m forecasts from AROME EDA

2DEnVar dynamical

B

matrix

Compute T2m and Rh2m increments

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2D-Var: background-error covariances

– **Gaspari & Cohn** function (Gaspari and Cohn, 1999), with Daley length = 25 km
~ Gaussian function which becomes zero at a certain distance

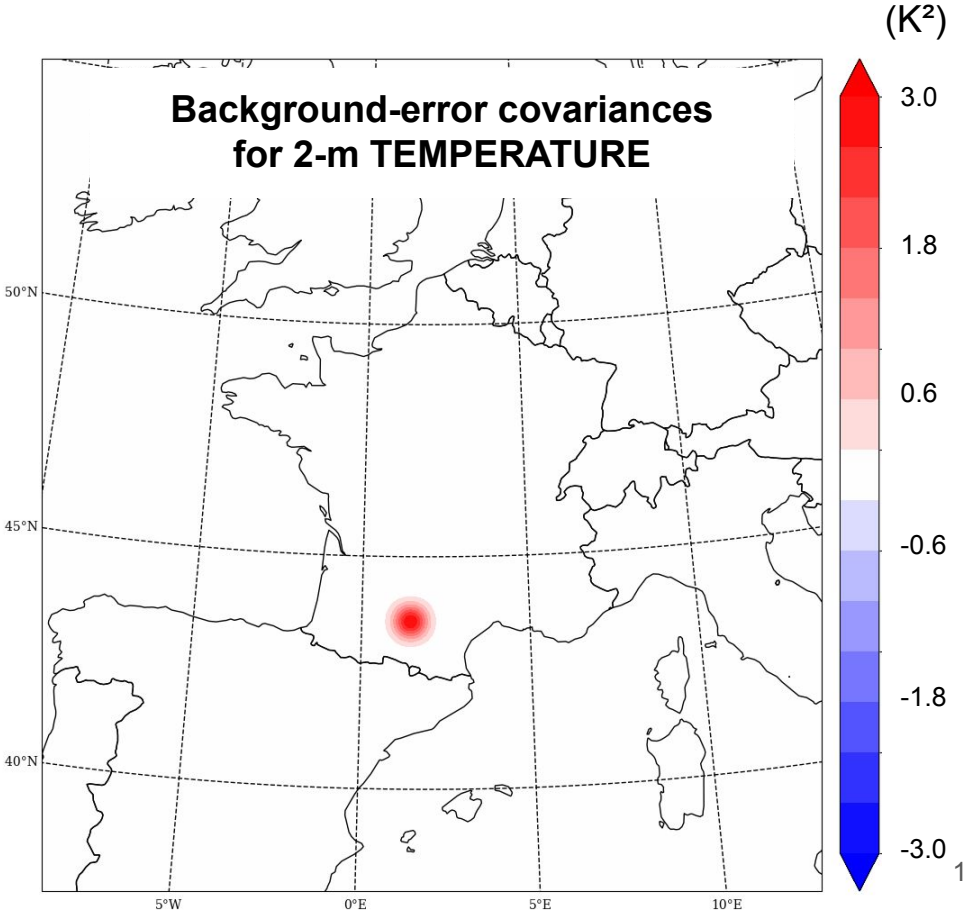
– Univariate, static, homogeneous and isotropic

2-m temperature : $\sigma_b = 1.6\ K$

$$\sigma_b^{\ 2} = 2.56\ K^{\ 2}$$

2-m relative humidity : $\sigma_b = 10\ \%$

– **Similar** to **MESCAN** spatial correlations defined in **CANARI-OI**
(Häggmark et al. 2000)



2D-Var: 2-m temperature increments

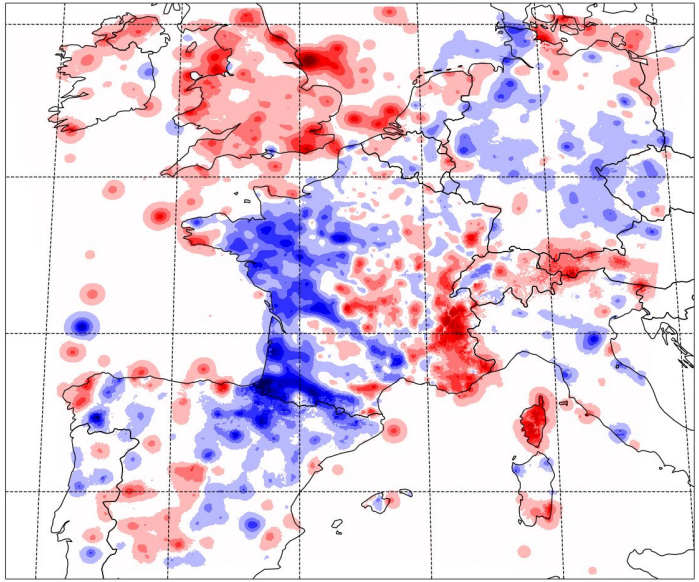
7/09/2021 12h

AROME-France domain

1.3 km resolution

***Similarities**: same patterns at the same places*

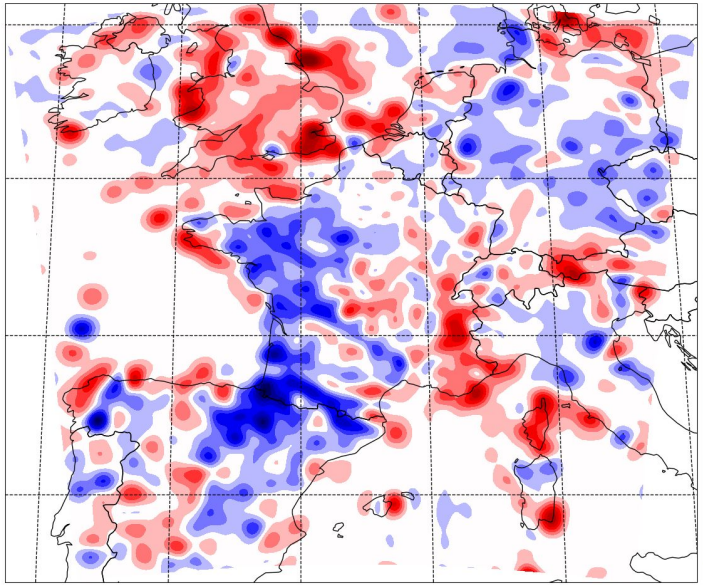
CANARI-OI



MESCAN structure function

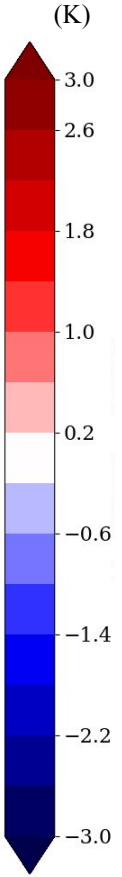
correlation length = **25 km**

2D-Var

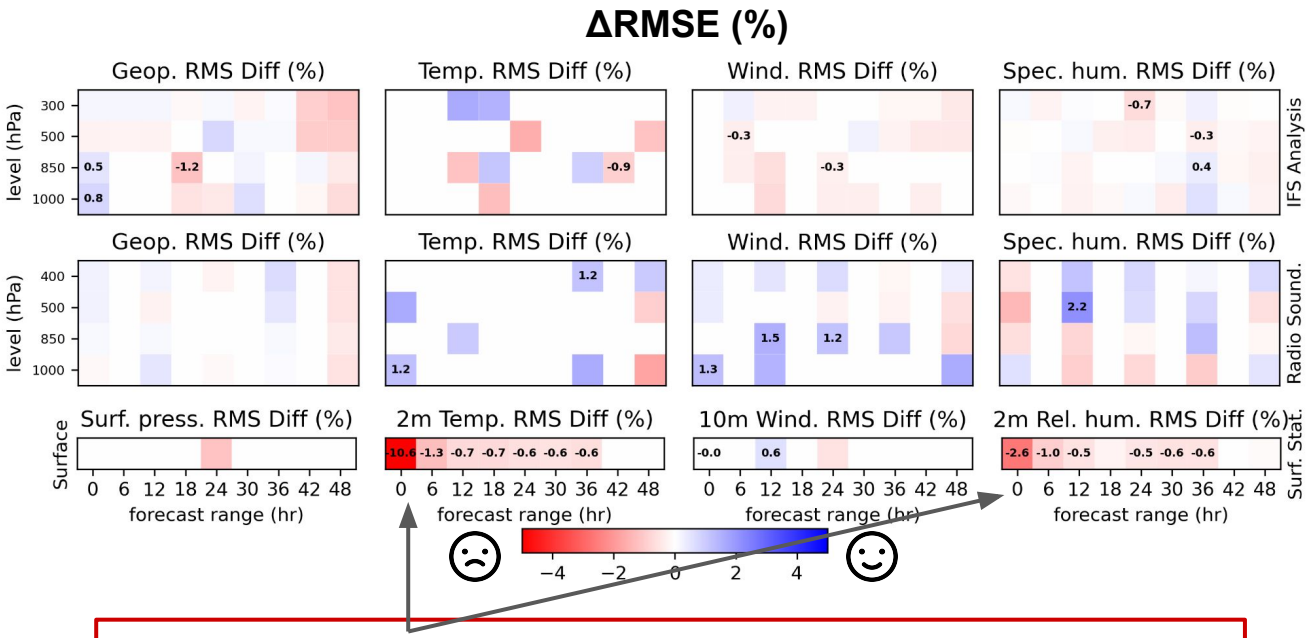


Gaspari & Cohn structure function

correlation length = **25 km** (Daley length)



2D-Var vs. CANARI-OI: forecast scores



Over ***2 months*** *7/09/2021 - 5/11/2021 and over the* ***AROME-France domain***

– **CANARI-OI analysis fits better to observations than 2D-Var**

– **Neutral impact** against **observations** + **ECMWF analysis**

2D-Var close to CANARI-OI ⇒ Baseline to implement 2DEnVar

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2DEnVar: background-error covariances

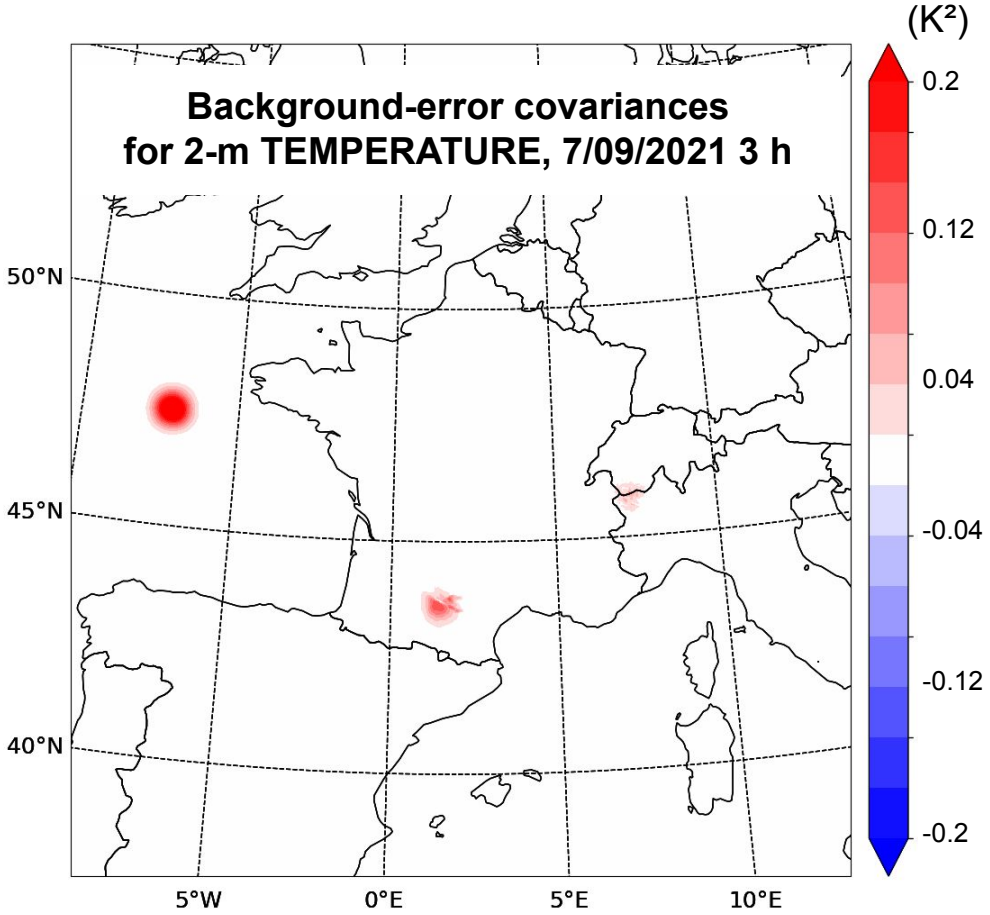
– **AROME EDA** 50 members:
3.2 km resolution, **3-h** range forecasts

– **Fully flow-dependent** B-matrix

multivariate covariances: temperature / relative humidity

heterogeneous and **anisotropic** covariances: different shapes at different locations

– **Gaspari & Cohn** localization filter (1999) with Daley length = 25 km



2DEnVar : 2-m temperature increments

7/09/2021 12h

AROME-France domain

1.3 km resolution

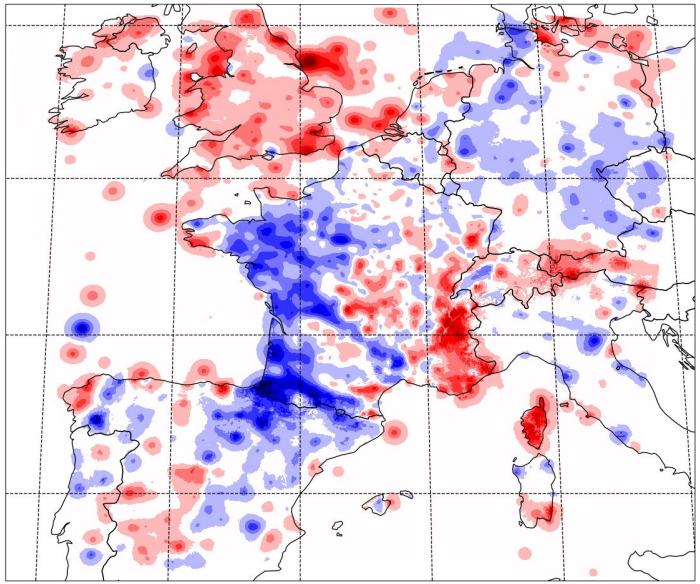
Similar shapes but…

2D-EnVar << CANARI

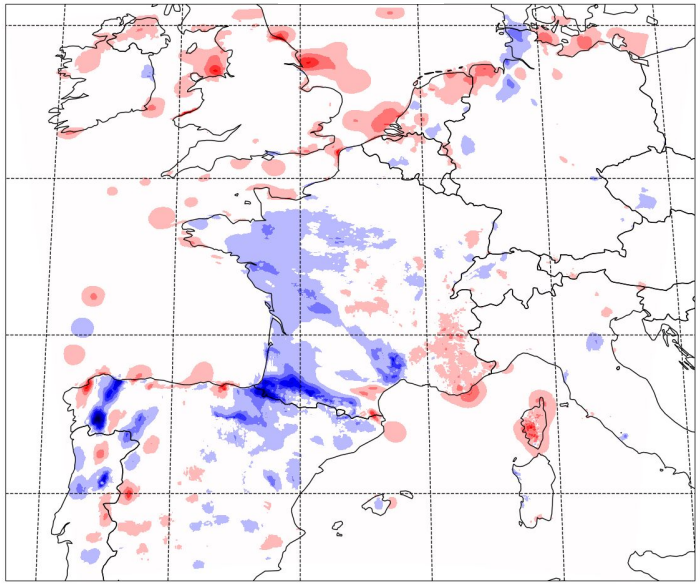
due to low σ_b

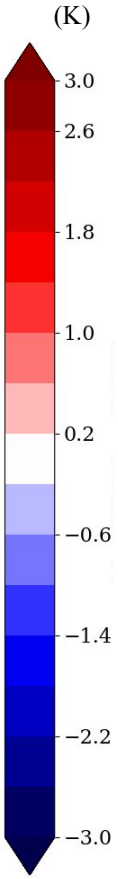
Reminder : SPPT not applied near the surface in EDA

CANARI-OI



2DEnVar

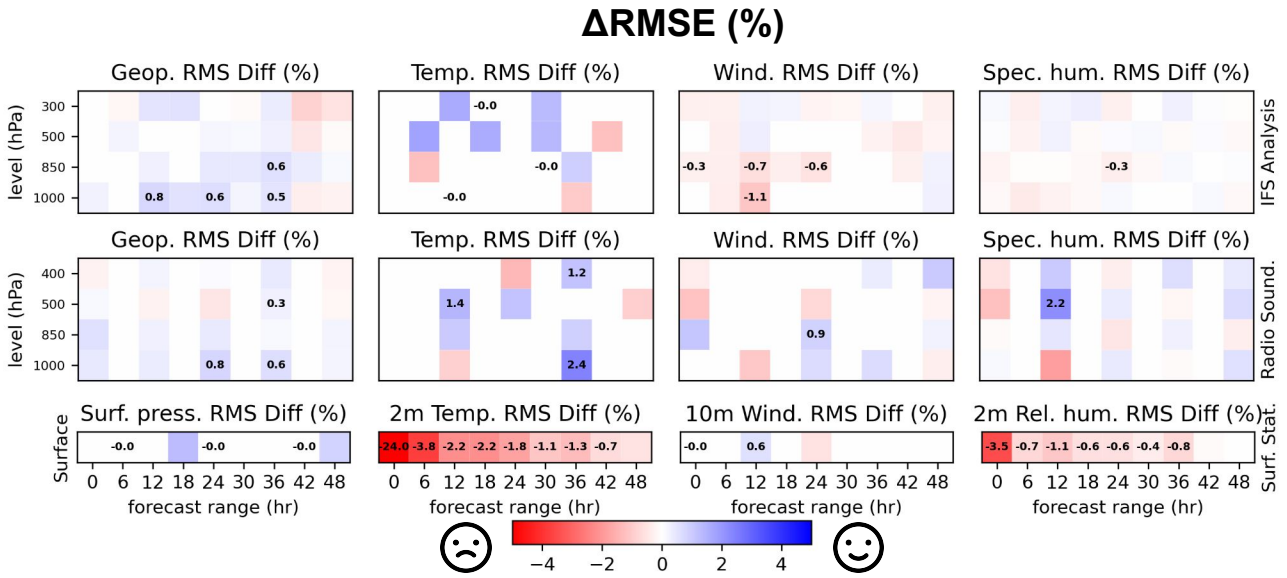




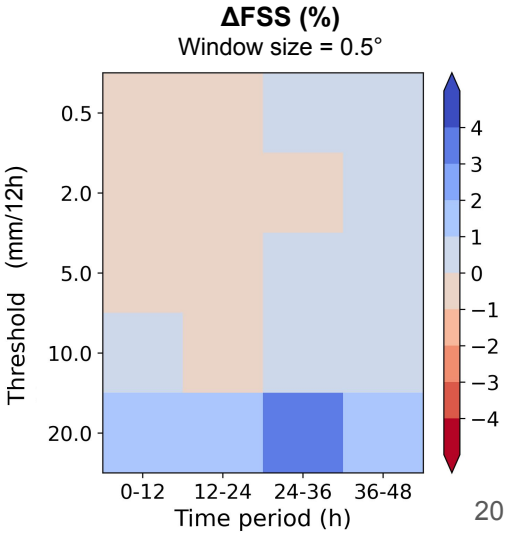
MESCAN function
correlation length = **25 km**

EDA AROME 3.2 km
Gapari & Cohn localization filter
localization length = **25 km**

2DEnVar vs. CANARI-OI: forecast scores



*Over **2 months***
7/09/2021 - 5/11/2021
and over the
AROME-France domain



– **Degradation** for T2m / Rh2m **due to low** σ_b **in 2DEnVar**
10-m Wind + SLP not affected

– **Neutral to positive impact** for T, Rh, Wind, P, Geop against **radiosondes** + **ECMWF analysis**

– **Slight improvement** for RR against **gridded observations** (not significant)

Encouraging results for 2DEnVar

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Sensitivity tests

Sensitivity tests

Initial 2DEnVar

Localisation length = ***25 km***

EDA resolution = ***3.2 km***

Model error near the surface not represented *in EDA*

Sensitivity tests

— **Localisation length**: *50 km, 12.5 km*

— **EDA resolution**: *1.3 km*

— **EDA inflation**: *multiplicative inflation x3 to background perturbations*

Sensitivity tests

Initial 2DEnVar

Localisation length = ***25 km***

EDA resolution = ***3.2 km***

Model error near the surface not represented *in EDA*

Sensitivity tests

— **Localisation length**: *50 km, 12.5 km*

— **EDA resolution**: *1.3 km*

— **EDA inflation**: ***multiplicative inflation x3 to background perturbations***

Positive impact with inflation INFx3

2DEnVar INFx3 vs. CANARI-OI

T2m increments

7/09/2021 12h

AROME-France domain

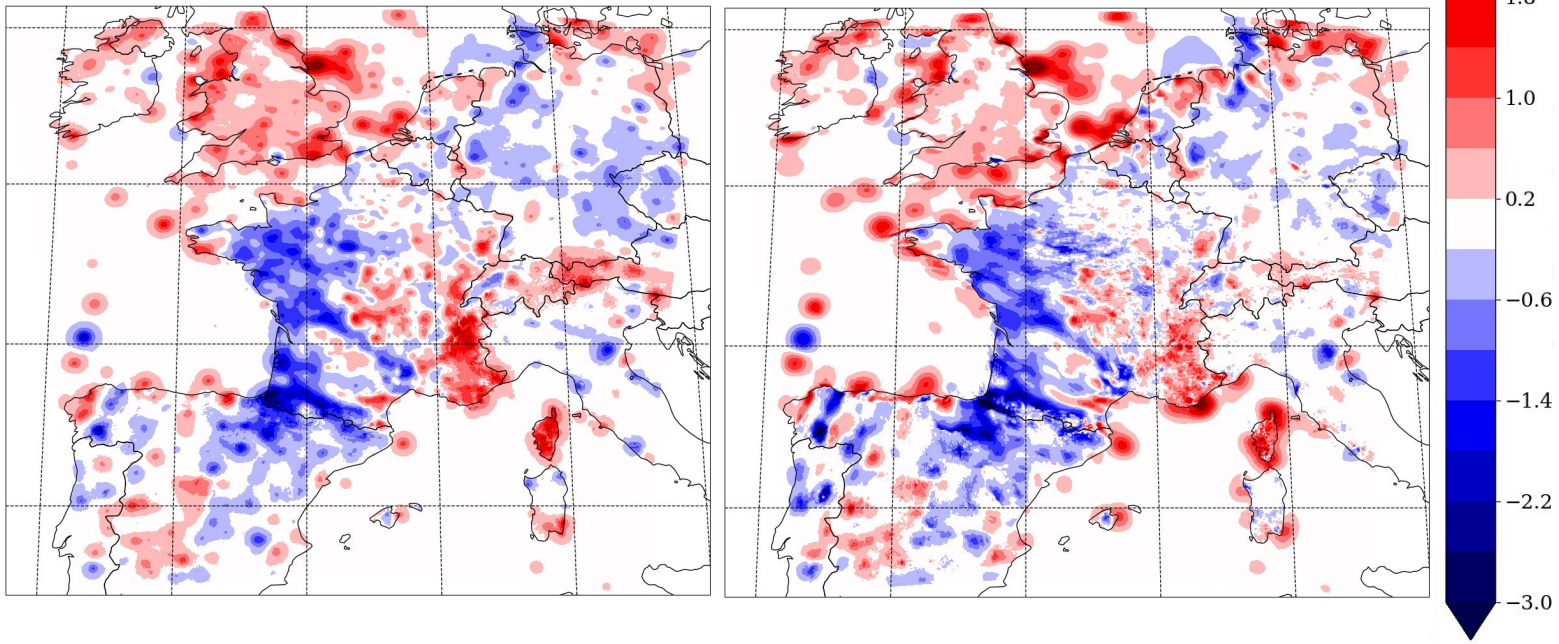
1.3 km resolution

Similar shapes and…

2DEnVar-INFx3 ≈ CANARI-OI

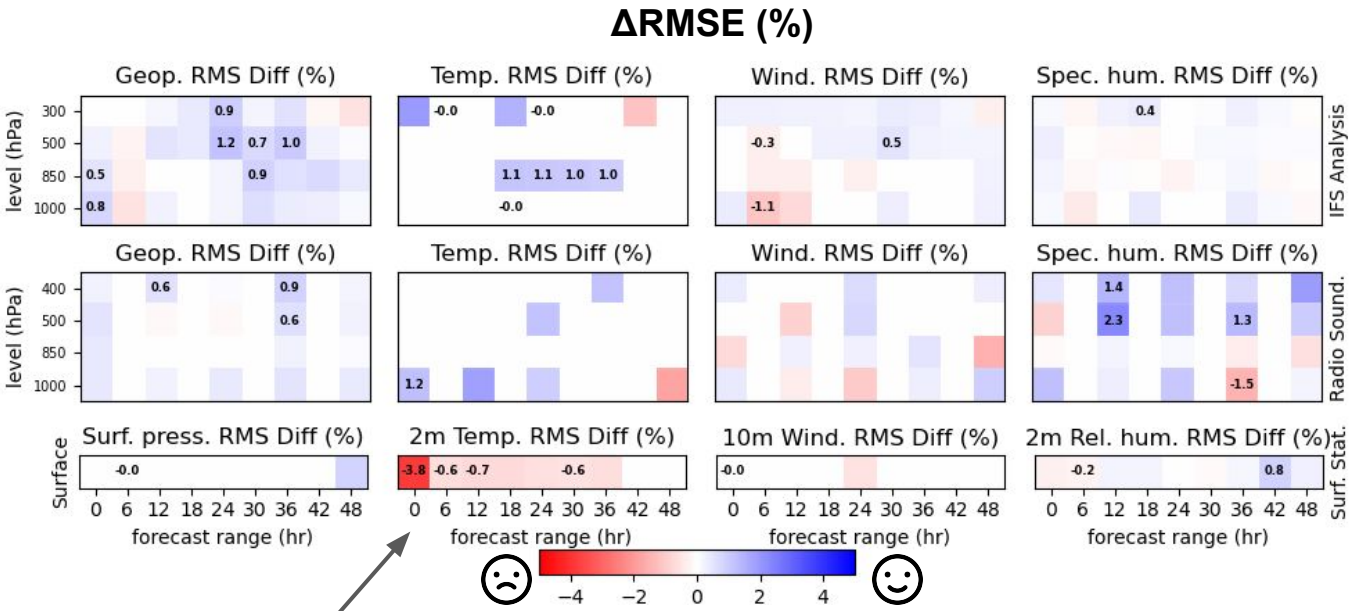
CANARI-OI

2DEnVar-INFx3



Reminder : 2DEnVar << CANARI-OI

2DEnVar INFx3 vs. CANARI-OI: forecast scores



*Over **2 months***
7/09/2021 - 5/11/2021
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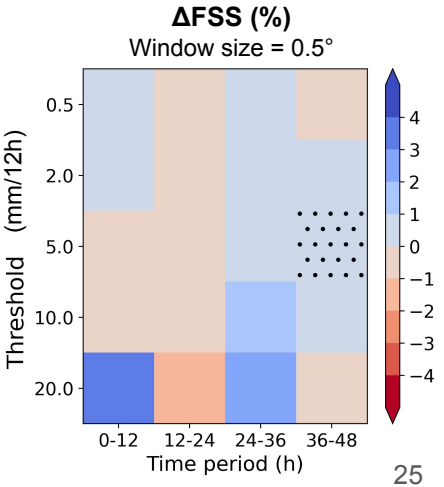
AROME-France domain



- **CANARI-OI analysis still fits better to 2-m temperature observations**
- **Improvement** of forecast scores against **ECMWF analysis and radiosondes**
- **Neutral to positive impact** for RR against **gridded observations**

2DEnVar-INFx3 behave similarly to CANARI-OI

Conclusion

2D-Var

Implementation of **2D-Var**

– ***CANARI-OI fits better to the observations***
– *system close to CANARI-OI →* ***solid base***

2DEnVar

Implementation of **2DEnVar**

– *encouraging results*
– ***but low spread in the EDA near the surface leading to lower forecast scores***

Optimisation

Sensitivity tests in 2DEnVar

– ***positive impact*** *with* ***inflated background perturbations***
– ***2DEnVar-INFx3 behaves similarly to CANARI-OI***

Perspectives

– **Article** in preparation: Marimbordes et al. (2023) - QJRMS

Towards a 2DEnVar surface data assimilation approach within the convective scale numerical weather prediction model AROME-France

– 2DEnVar over **another period** (May-August 2023)

– Impact of **cross-correlations**

– Impact on **soil variables**

MTG satellite, FCI radiometer

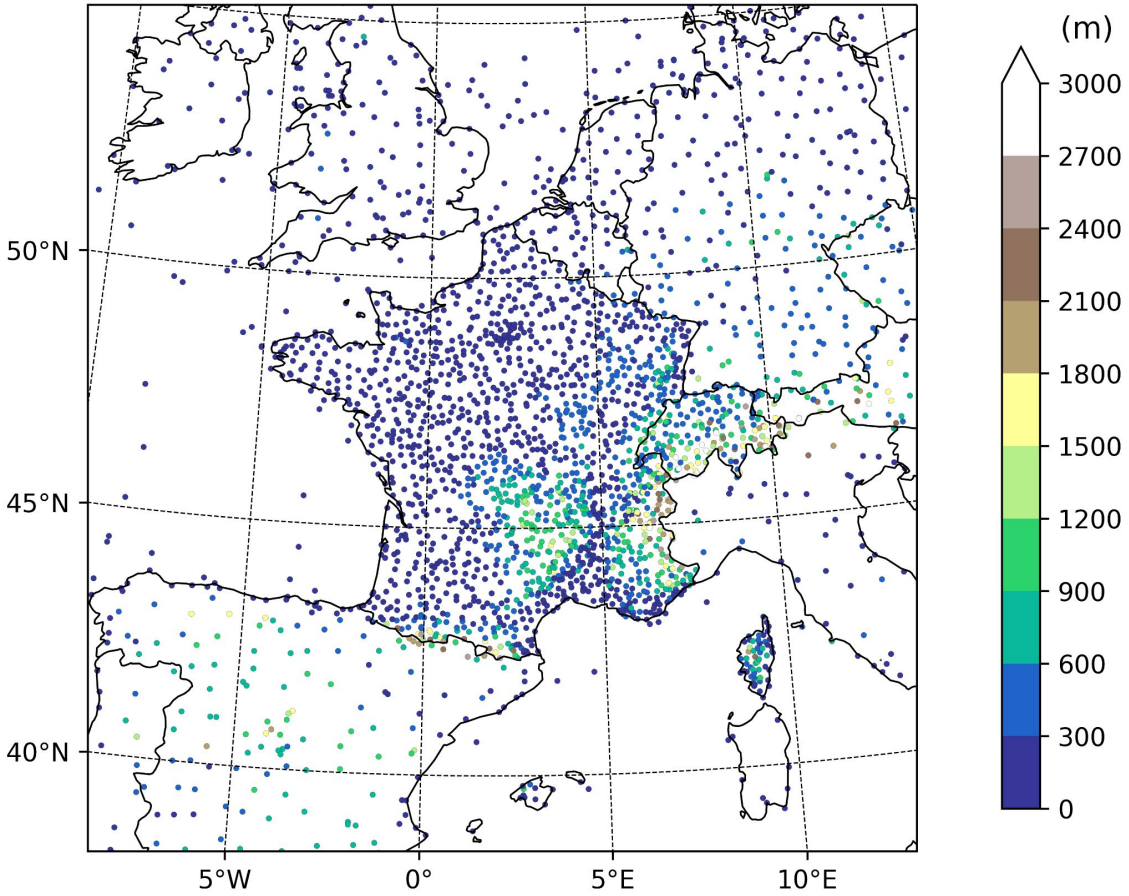
– Assimilation of a new variable in 2DEnVar

Land Surface Temperature *(LST)*

– Extend 2DEnVar to **snow** and **SST analyses** (CANARI variables)

Thank you

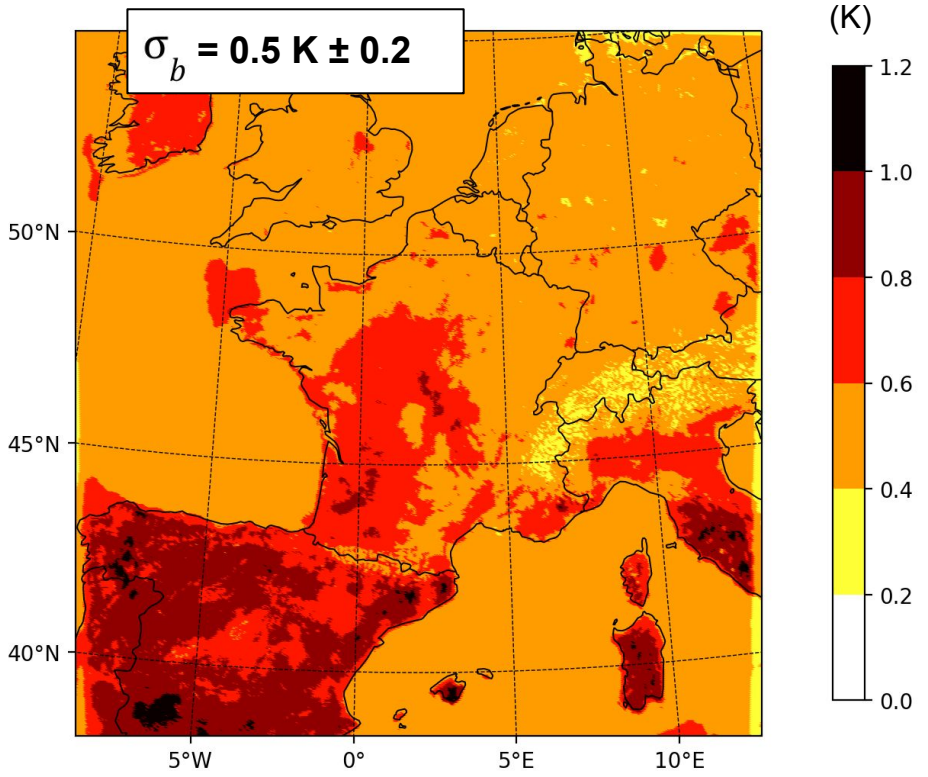
Density and altitude (m) of 2-m temperature observation stations which are assimilated in CANARI
(September 7, 2021 at 1200 UTC)



Sensitivity tests : EDA inflation

Error standard-deviation diagnostics *from short-term forecasts (+3 h) AROME EDA, 50 members, 3.2 km*

2-m temperature mean σ_b [7/09/2021 to 5/11/2021] **12 h**



CANARI-OI

Fixed background-error standard-deviation

For 2-m temperature :

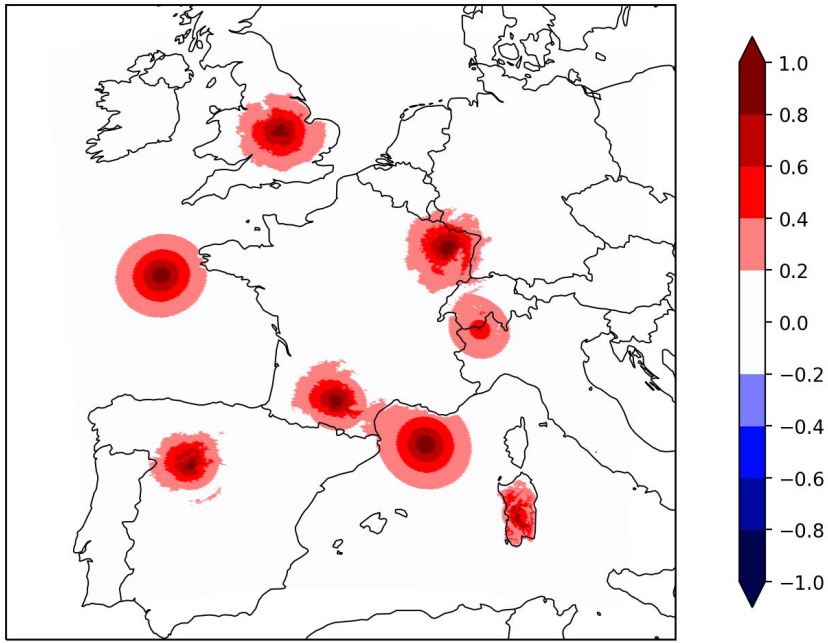
$$\sigma_b = 1.6 \text{ K}$$

Factor x3

Error correlations in CANARI-OI

CANARI-OI : MESCAN function

2-m T error correlations



MESCAN function formula

Land/sea mask **Topography**

$$(1 - min(0.5\,;\, 0.4 * \Delta lsm)) * (1 - min(0.5\,;\, 0.002 * \Delta alti))$$
$$* 0.5 * (e^{-\frac{dist}{L}} + (1 + 2 * \frac{dist}{L}) * e^{-\frac{2*dist}{L}})$$

MESAN function (Häggmark et al. 2000)

with correlation length L = 100 km (oper),
fixed to 25 km in our experiment

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T2m increments

7/09/2021 12h

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1.3 km resolution

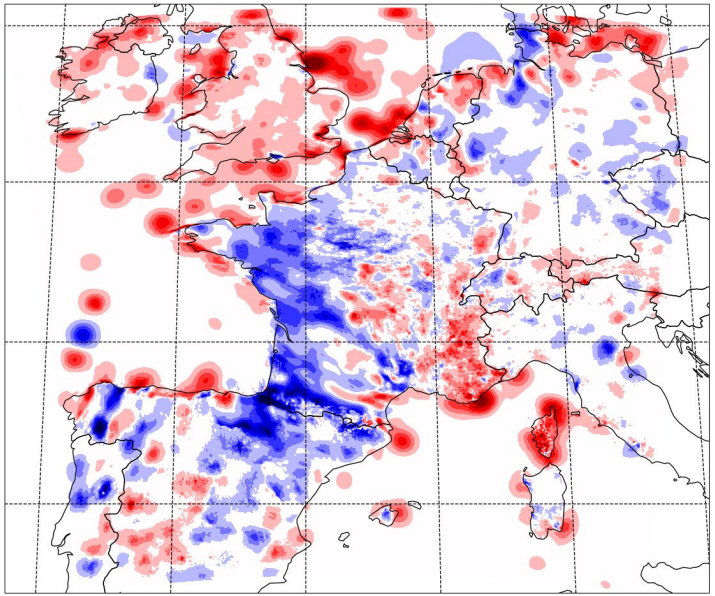
Similar shapes and…

INFx3

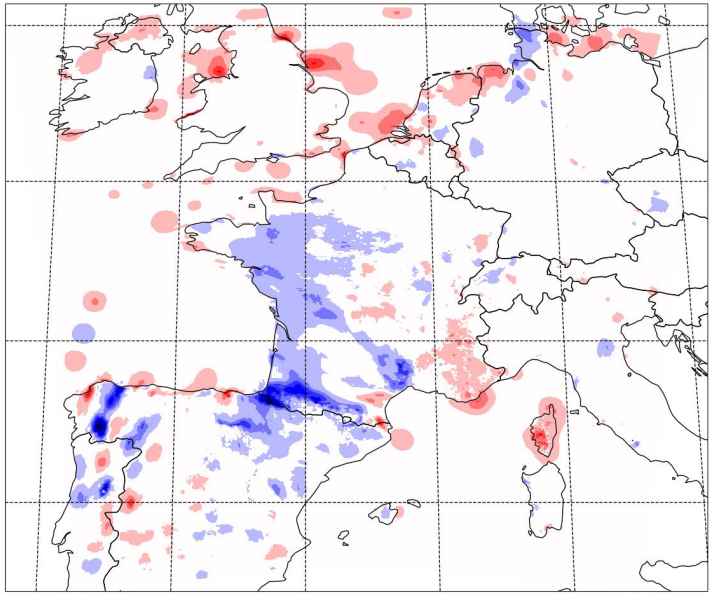
>> NO-INF

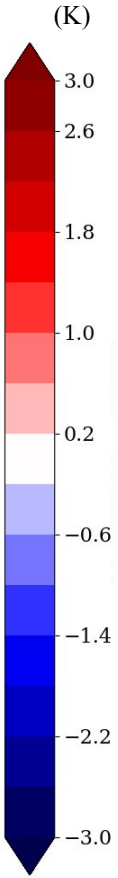
≈ CANARI-OI

2DEnVar EDA 3.2 km
Inflation x3



2DEnVar EDA 3.2 km
No inflation





Gapari & Cohn localization filter : L = **25 km**

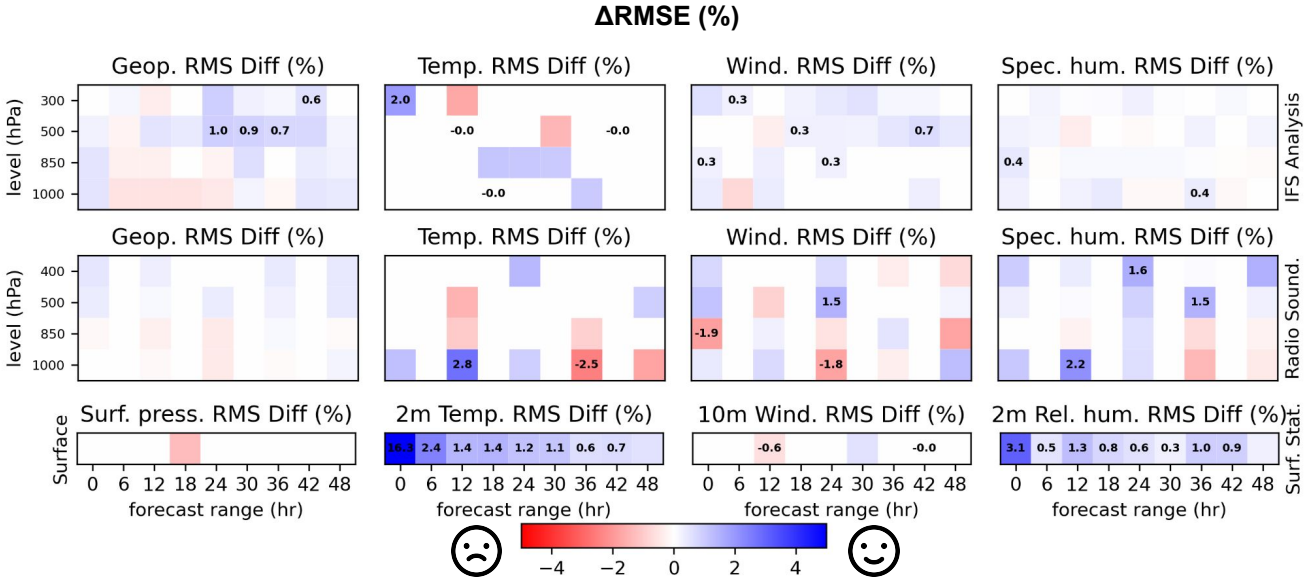
Sensitivity tests : EDA inflation

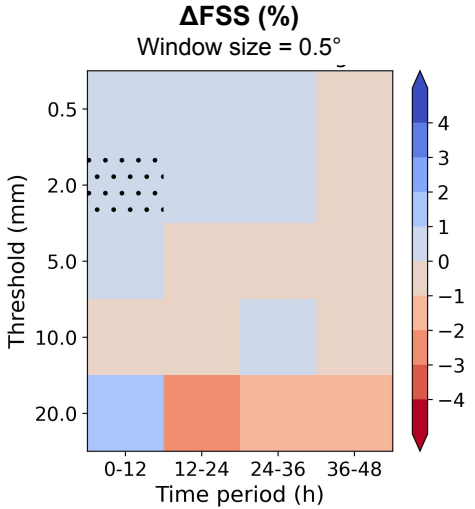
Forecast scores over 2 months (autumn 2021) : 2DEnVar-INFx3 vs. 2DEnVar

– **Positive impact** for T2m and Rh2m against **surface station observations**

– **Neutral scores** for Wind, P, Geop against **surface station observations** + **ECMWF analysis** + **radiosondes**

– **Neutral impact** for RR against **gridded observations**





Positive impact with inflation : INFx3 better than NO-INF

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Spectral and **Non Hydrostatic model**
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- Uncoupled analysis

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AROME-France EDA

Research experiment

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3.2 km horizontal resolution

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+ Perturbation of observations
+ Perturbation of SST variable
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