Recent progress in the EnVar data assimilation system for AROME-France

Pierre Brousseau, E. Arbogast, V. Vogt, L. Berre, M. Martet, Y. Michel, T. Montmerle and colleagues,...

ACCORD 1st ASW 13 april 2021.

plan

- Summary and status of OOPS development/validation

- EnVar ongoing works

OOPS : Object -Oriented Programing System

Next major evolution of the MF DA systems : towards Envar schemes

Using OOPS :

- project started in 2009 at ECMWF in collaboration with Météo-France and LAM partners

- renovation of common data assimilation codes in order to enable the development of new algorithms and ease maintenance

- object-oriented design, upper level code in C++

- important refactoring of the IFS-Arpege-LAM FORTRAN codes

- main part of the coding effort now completed

- precursor of the JEDI project at JCSDA (US) also used now at MetOffice

OOPS : MF prototypes (E. Arbogast)

First prototype in cy40t1 (2015) : (limited observation, no varbc)

- first assimilation experiments in 3D/4DVar/EnVar, localization

Second prototype in cy43t1 (2018) : (complete observation set, no varbc, compilation with GMKPACK)

- **3DEnVar :** - first cycled experiments at lower resolution in a 3h cycle and first evaluation over a long period (montmerle et al. 2018)
  - first research works : Scale-dependant localisation (Caron et al. 2019), Hydrometeors in the control variable (M. Destouches PhD)

- **4DEnVa**r : - first cycled experiments at 1,3km in a 1h cycle using 15min observations over some case studies.

- some examples and more informations here : http://srnwp.met.hu/Annual_Meetings/2020/download/wednesday/AM/brousseau_EWGLAM_2020_1.odp.pdf

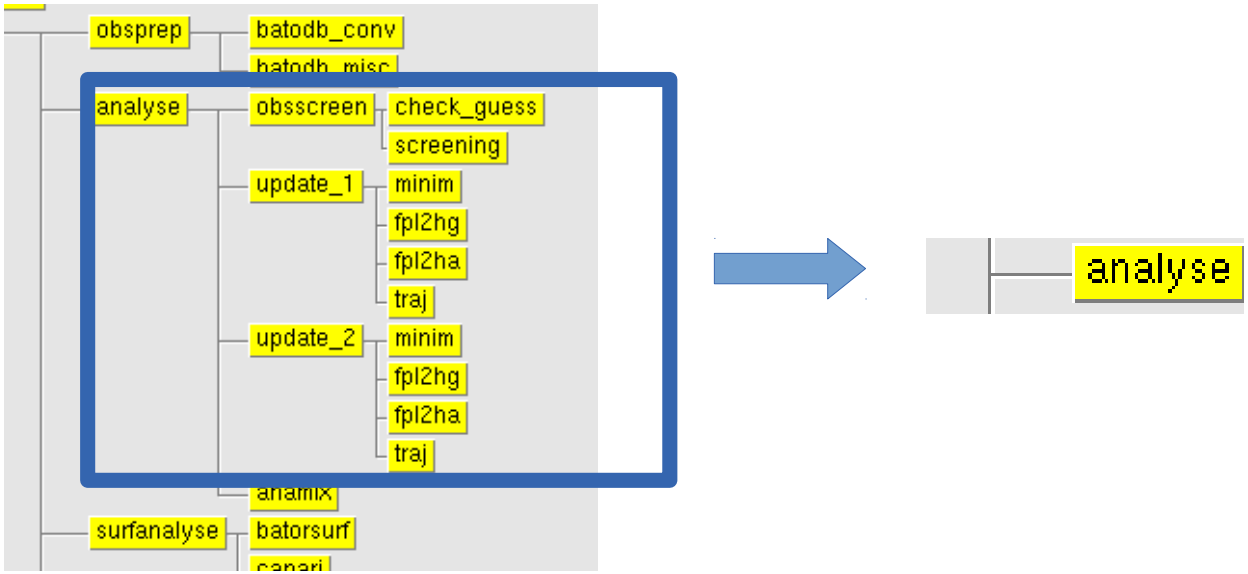
OOPS : MF prototypes (E. Arbogast)

<u>prototype in cy46t1 (2019) :</u> (no varbc) : see after

<u>Cy48t1 (2020) (E. Arbogast) :</u>

- **Varbc, Varqc, jcdfi, incremental dfi**

- full ARPEGE **4DVa**r (screening, minin LR and HR, resolution changes, traj) in a single OOPS execution : scripts and I/O simplification

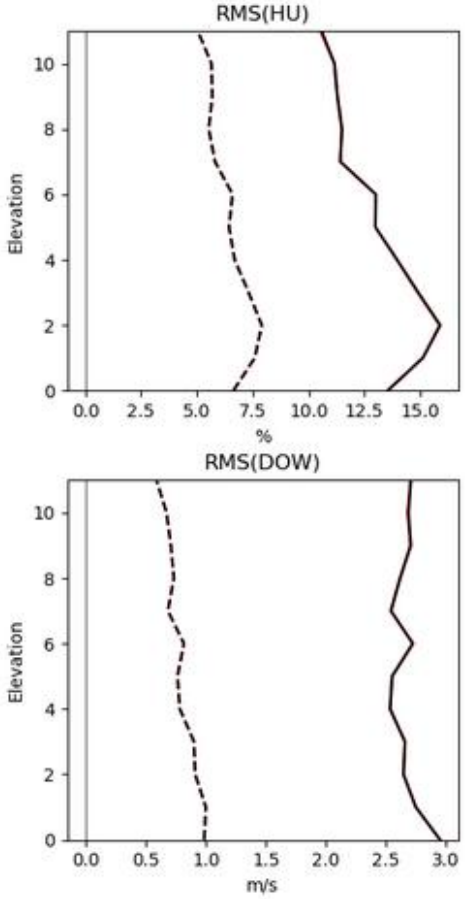


tricky validation : numerical results are changed by the fact that the model fields remain in memory (instead of being written and read in FA file between each tasks)

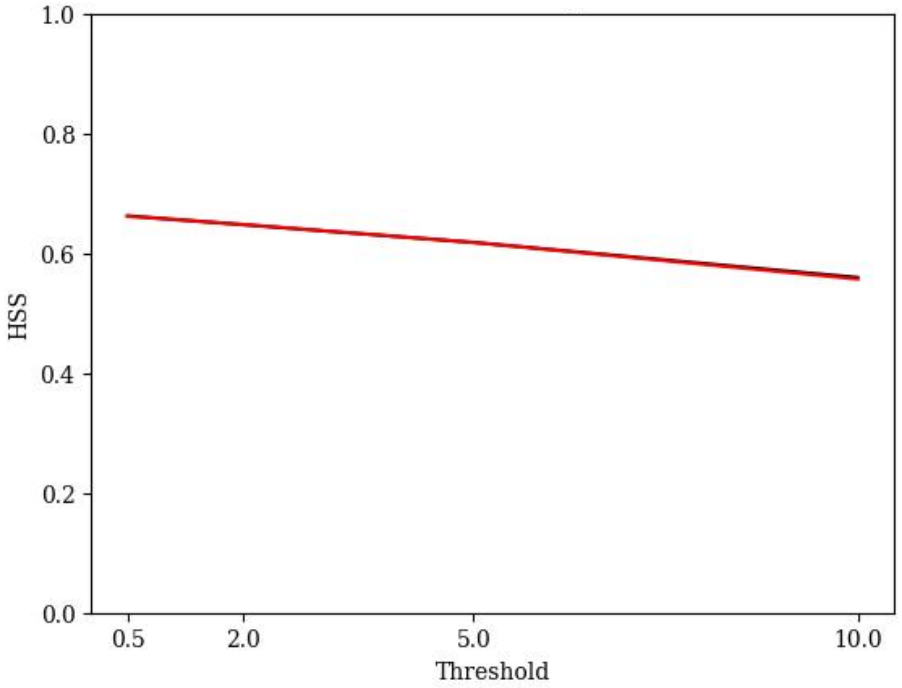
OOPS : 3D-Var Validation in cy46 (V. Vogt)

- Now MASTERODB and OOPS 3DVar **are very close**

RMS of obs-guess (—) and obs-analyse (- - -) for MASTERODB (red) and OOVAR (black)



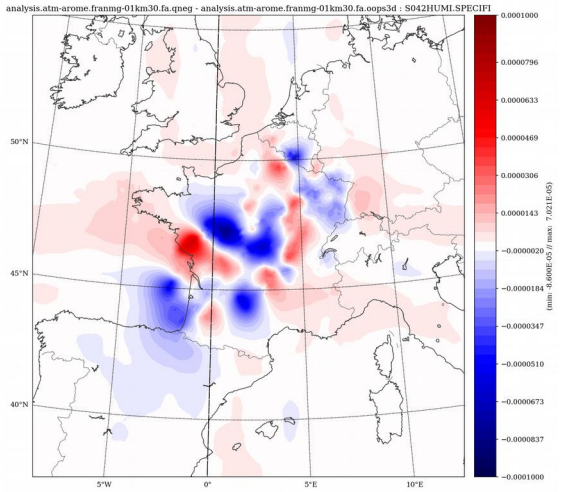
HSS for the 12 cumulated precipitation against radar over a 1 month period

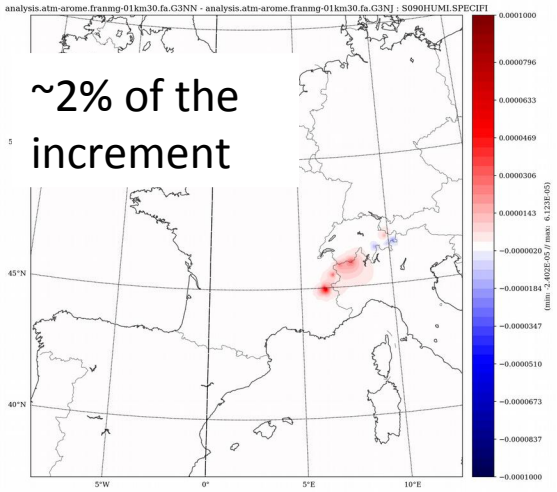


- B. Strajnar (LACE) is also able to run ALARO 3Dvar under OOPS using his own scripts on MF HPC.

OOPS : 3D-Var Validation in cy46 (V. Vogt)

- example of difficulties encountered during the validation





~2% of the increment

Remaining difference between MASTERODB and OOVAR analysis on specific humidity increment suspected to be due by radar and mountain surface stations obs : diff in the observation operator used for relative humidity ?

```
master (master.F90:189)
  cnt0 (cnt0.F90:211)
    cva1 (cva1.F90:329)
      cva2 (cva2.F90:396)
        L_congrad__331__par_loop4_2_5 (congrad.F90:291)
          sim4d (sim4d.F90:447)
            cnt3ad (cnt3ad.F90:119)
              cnt4ad (cnt4ad.F90:315)
                obsvad (obsvad.F90:87)
                  taskobad (taskobad.F90:122)
                    hop (hop.F90:460)
                      obsop_conv (obsop_conv.F90:379)
                        ppnew (ppnew.F90:470)
```

```
oops::Run::execute (Run.cc:61)
  oops::Variational<ifs::IfsTraits>::execute (Variational.h:84)
    oops::IncrementalAssimilation<ifs::IfsTraits> (IncrementalAssimilation.h:73)
      oops::Minimizer<ifs::IfsTraits>::minimize (Minimizer.h:82)
        oops::PrimalMinimizer<ifs::IfsTraits>::doMinimize (PrimalMinimizer.h:86)
          oops::PLanczosJ<oops::ControlIncrement<ifs::IfsTraits>, oops::HessianM
            oops::HessianMatrix<ifs::IfsTraits>::multiply (HessianMatrix.h:111)
              oops::CostFct3DVar<ifs::IfsTraits>::runADJ (CostFct3DVar.h:164)
                oops::LinearModel<ifs::IfsTraits>::forecastAD (LinearModel.h:182)
                  oops::PostProcessorAD<oops::Increment<ifs::IfsTraits> >::initializ
                    oops::PostBaseAD<oops::Increment<ifs::IfsTraits> >::initializeAD
                      oops::ObserverAD<ifs::IfsTraits, oops::Increment<ifs::IfsTraits>
                        oops::Departures<ifs::IfsTraits>::runObsOperatorAD (Departu
                          oops::LinearObsOperator<ifs::IfsTraits>::obsEquivAD (Linea
                            hop (hop.F90:460)
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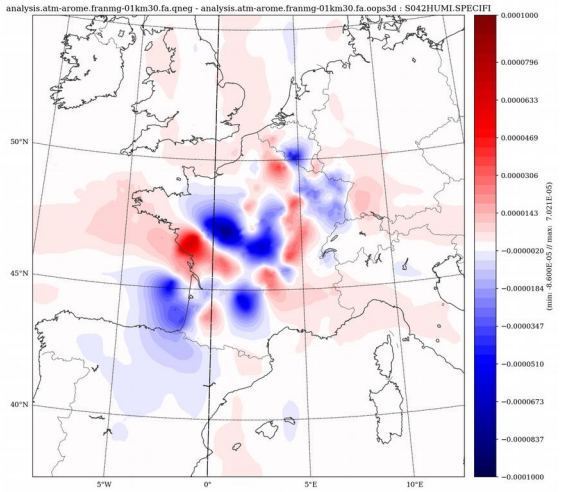

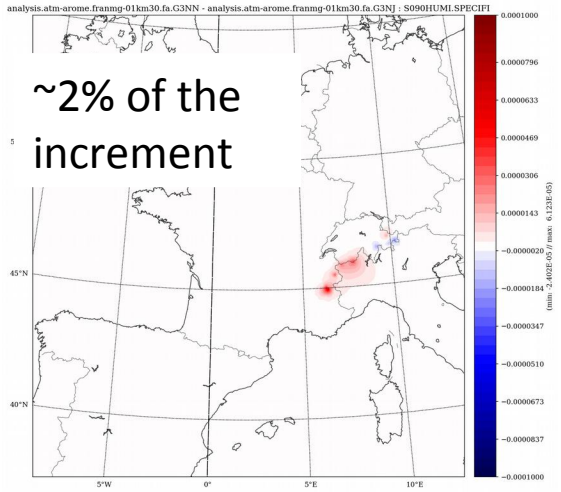

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Su0phy => LNEIGE=.TRUE.

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LNEIGE=.FALSE

RH ↔ qs using only water phase

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RH ↔ qs using water and ice phases

plan

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Envar in operations (3DEnVar e-suite in 2022?)

Operational configuration :1,3km in a hourly cycle, operational observation set, perturbations from the 3,2km operationnal EDA

Important tuning experiment set in the next months:

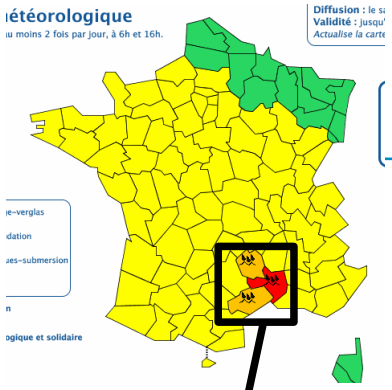
- ensemble size (25, 50 members ?)
- localisation length
- full Envar or hybrid version ?
- spin-up issues ?

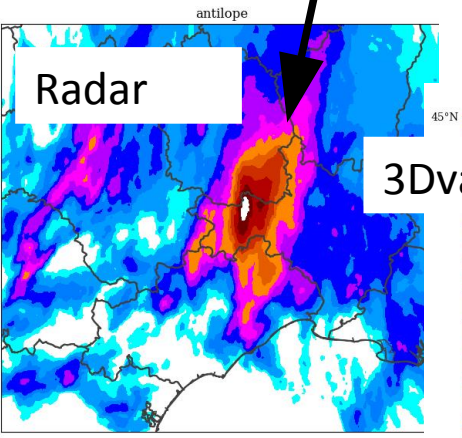
Evaluation over long periods : promising results already exist (Montmerle et al. , Michel et al.) : to be confirmed

Some interesting results on some study cases : example of the 19 September 2020

19 septembre 2020

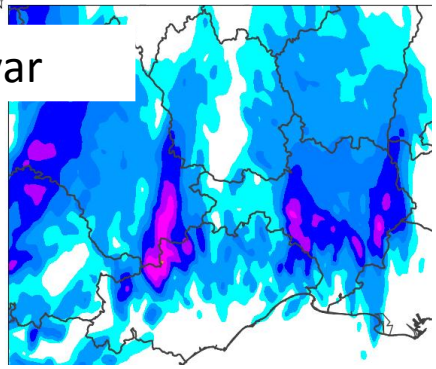
- Red warning over Gard departement
- more than 500 mm from 04 to 15 UTC and important flash-floods
- very low predictability

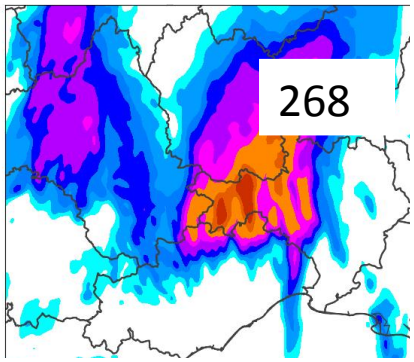


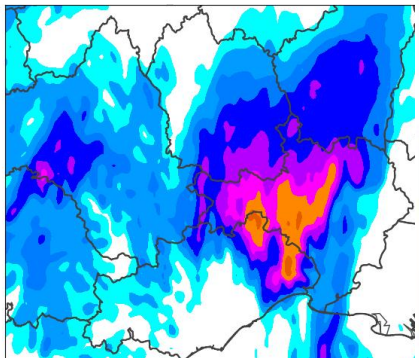


12 UTC 18/09 | 00 UTC 19/09 | 03 UTC 19/09

3Dvar

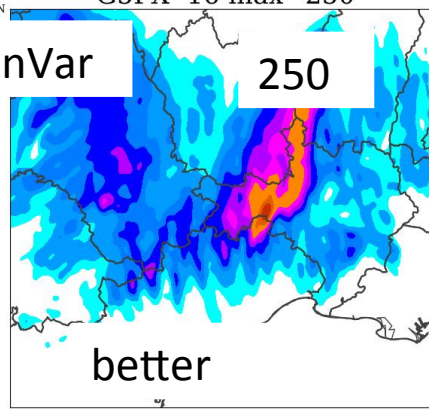


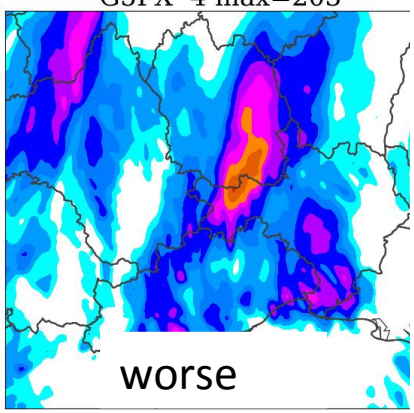


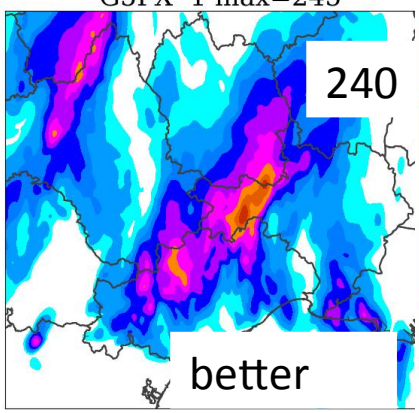


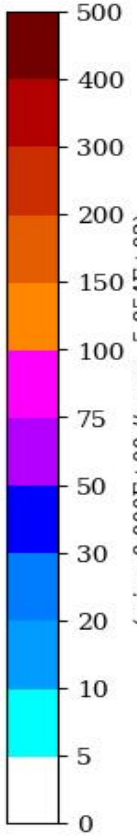
G5PX -16 max=250 | G5PX -4 max=203 | G5PX -1 max=245

3DEnVar

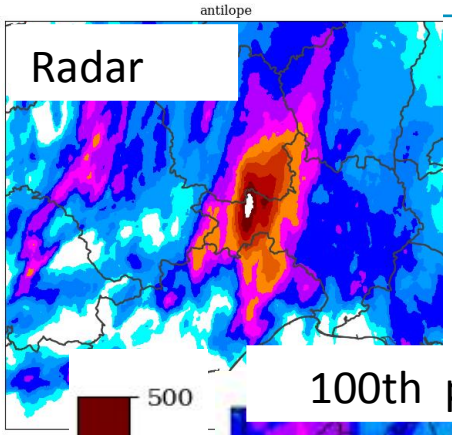


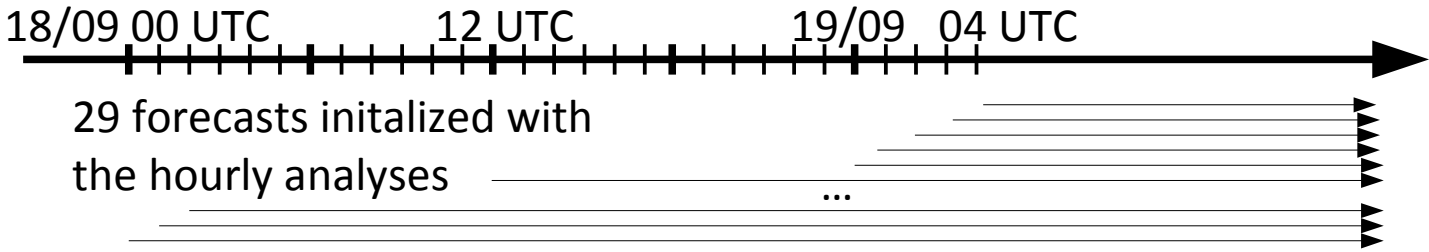


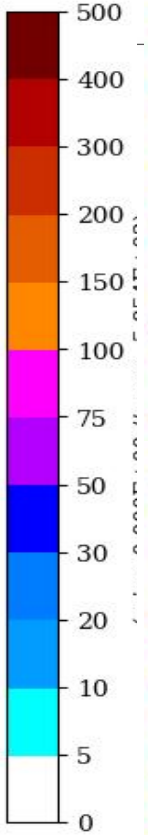




19 septembre 2020 : lagged ensemble verification



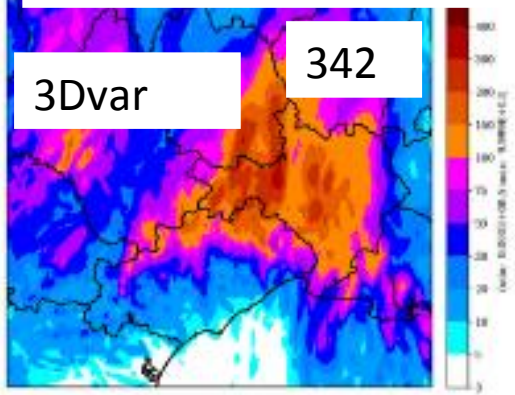


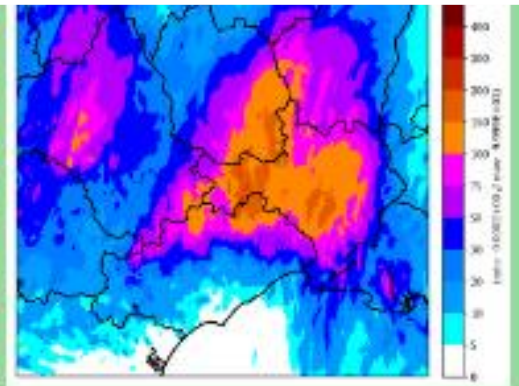


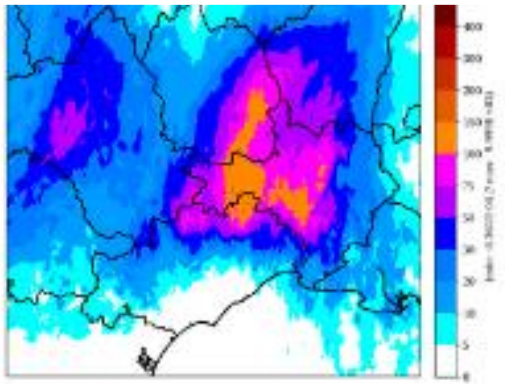
100th percentile

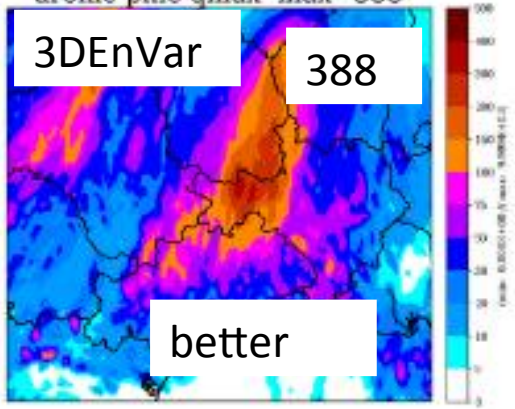
90th perc.

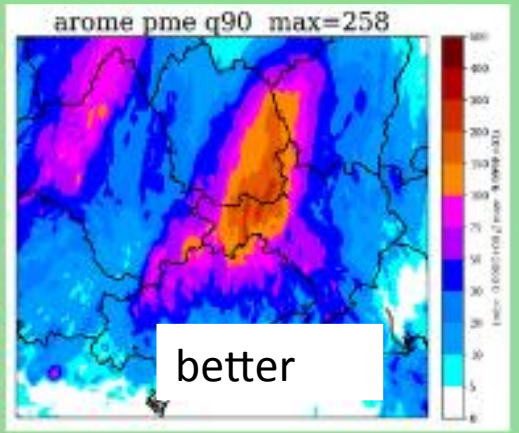
75th perc.

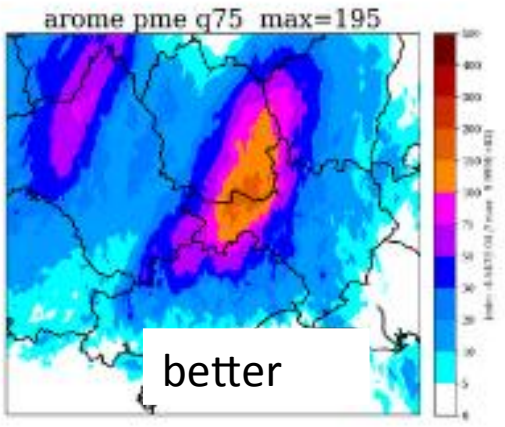












Ongoing works

4DenVar (EWGLAM and ISDA-online talks)

- reminder : only the ALADIN TL/AD (soci et al. 2006) and the ALADIN 4Dvar minimisation exist in the arpege/IFS/LAM code : a **LAM 4Dvar with NH dynamic, and AROME physic (surfex and ICE3 with graupel for instance) is not available.**

- towards a **4DEnVar** system at 1,3km to reduce such inconsistencies : the temporal dimension is managed by the background error temporal cross correlations deduced from an **AROME-EDA** at 3,2km (currently hydrostatic)

Hydrometeors in the control variable and radar assimilation (M.Martet's talk tomorrow)

Non-Hydrostatic variables in the control variable : very preliminary results (just to illustrate why we were right to move to OOPS)

NH variables in the control variable

- Currenty, NH variables (Vertical divergence and pressure departure) are not analyzed but copied from the background

- 3DEnVar allows to obtain background error covariances for these variables if they are present in the used EDA (NH EDA)

Be=**C** o **XX**^{T}
- **C** : localisation
- **X** : perturbation vector from the EDA $[\varepsilon_1 \ldots \varepsilon_n]$

- OOPS allows to easily extend the control variable : no modification needed in the C++ part, a 3 lines modification in the interface routine in fortran … and some help from E. Arbogast ;-)

```
if (lecmwf) then
  allocate(ids(6))
  ids(:)=(/fid%u, fid%v, fid%t, fid%q, fid%o3, fid%sp /)
else
  if ( ivar == 1 ) then
    allocate(ids(5))
    ids(:)=(/fid%u, fid%v, fid%t, fid%q, fid%sp /)
  else if ( ivar == 3 ) then
    allocate(ids(10))
    ids(:)=(/fid%u, fid%v, fid%t, fid%q, fid%sp, fid%l, fid%r, fid%i, fid%s, fid%g /)
  else if ( ivar == 4 ) then
    allocate(ids(7))
    ids(:)=(/fid%u, fid%v, fid%t, fid%pd, fid%vd, fid%q, fid%sp /)

  endif
endif
call variables_create(self, ids)
```

Usual ECMWF with O3

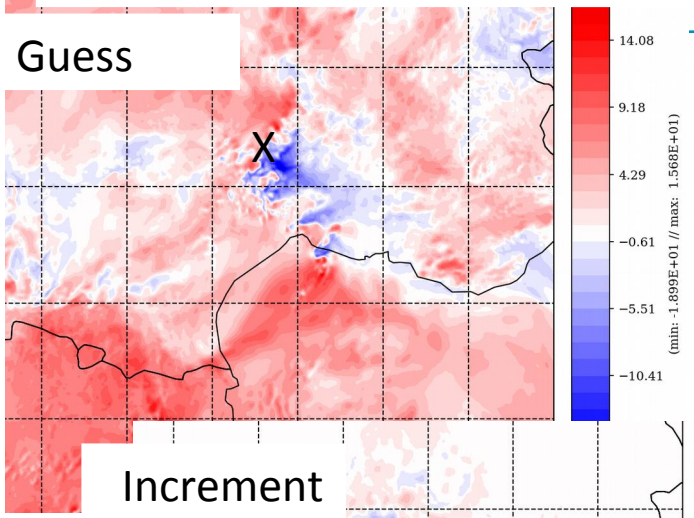
Usual MF

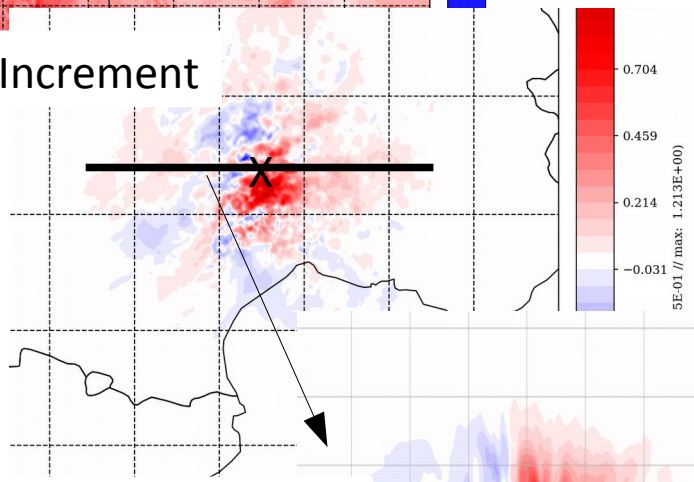
With hydrometeors

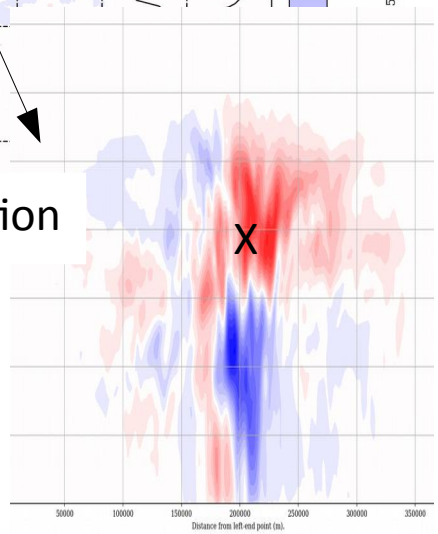
With NH variables

NH variables in the control variable : single Wind observation

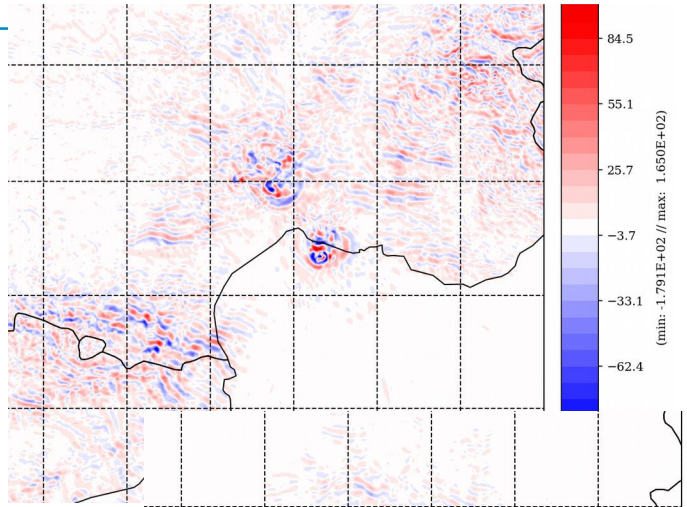
Wind U

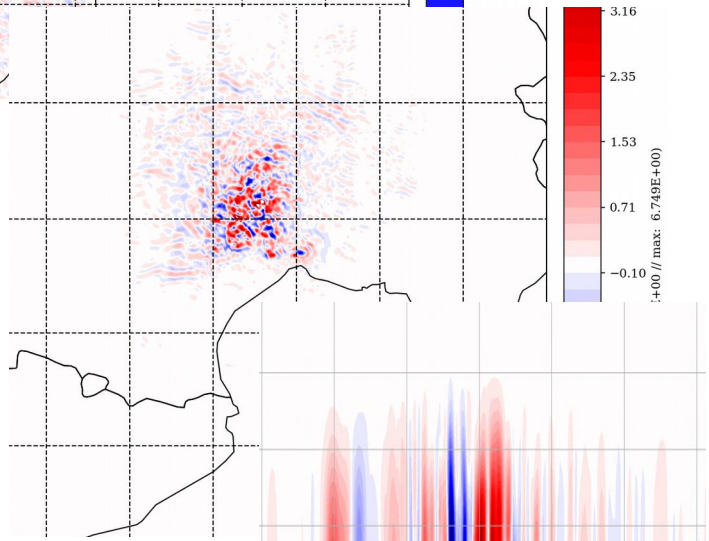


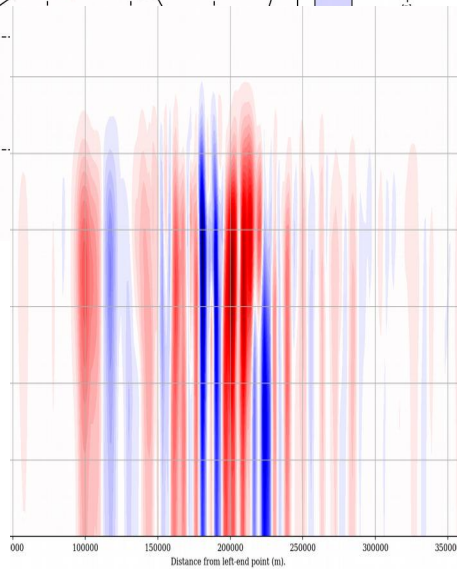




press.dep







Conclusion : towards LAM EnVar systems under OOPS at Météo-France

- towards EnVar (3D and 4D) scheme under OOPS :

- Numerous ingredients already available and validated in the OOPS framework:

- B or B1/2 pre-conditioning
- control variable extending (hydrometeors, non-hydrostatic variables,...)
- spectral/spatial localisation on the horizontal and the vertical
- localisation length-scale depending on the variable, height, scale
- advection of the localisation (4DEnvar)
- resolution changes
- varbc, varqc, jcdfi, inc. dfi, (recent development)

- next steps :

3DEnVar :

- Tuning to be honed and confirmed in the operational configuration (1,3km hourly cycle)
- To be evaluated with the complete system over a long period
- E-suite in 2022 ?

4DEnVar :

- Encouraging results on convective case studies
- Tests over a long period will begin soon (new HPC).

References

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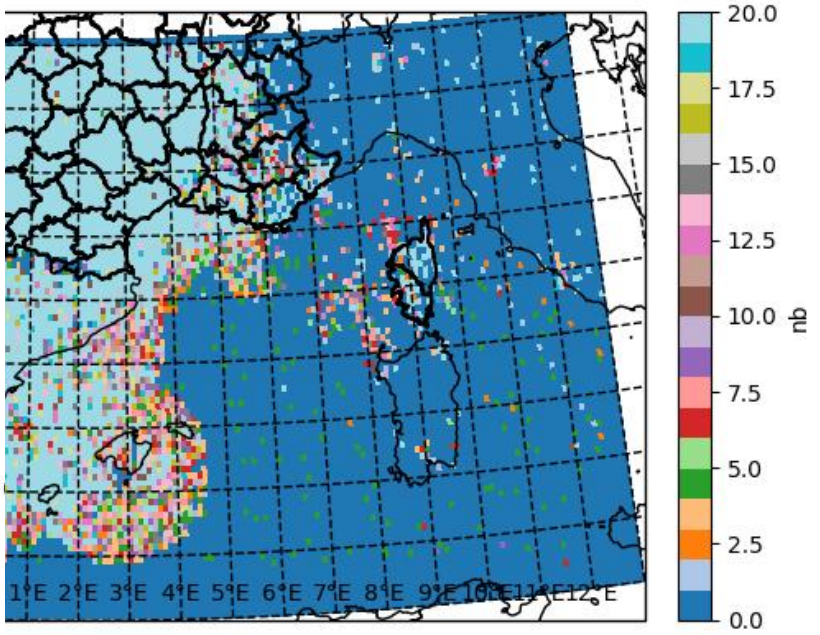
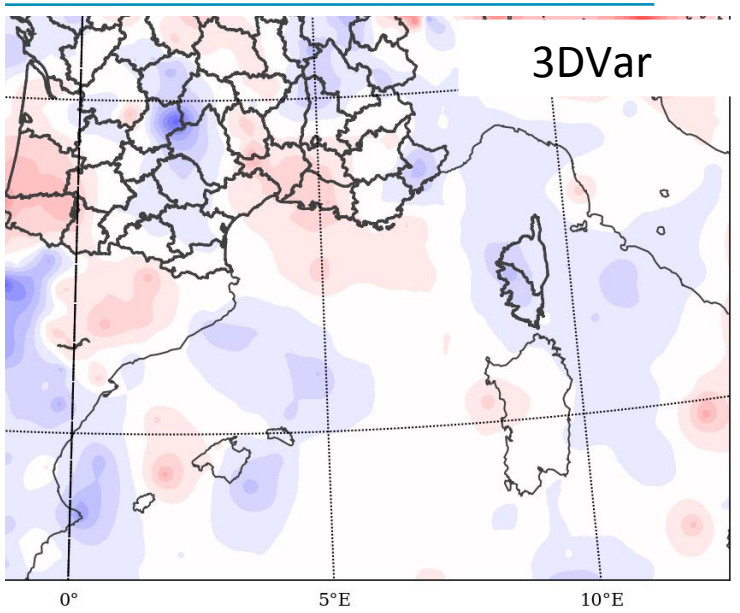
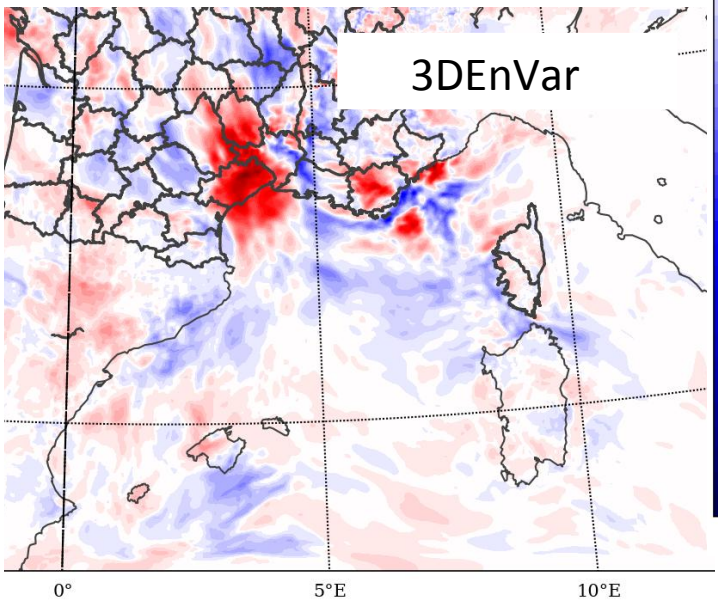
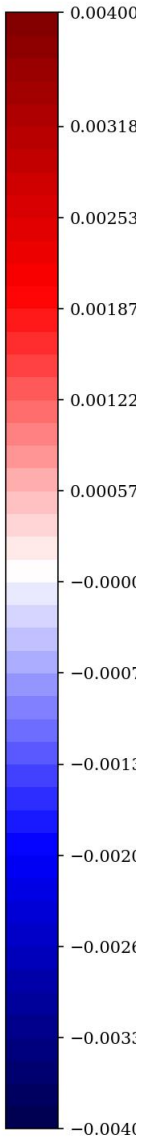
04UTC Specific humidity increment at 950 hPa







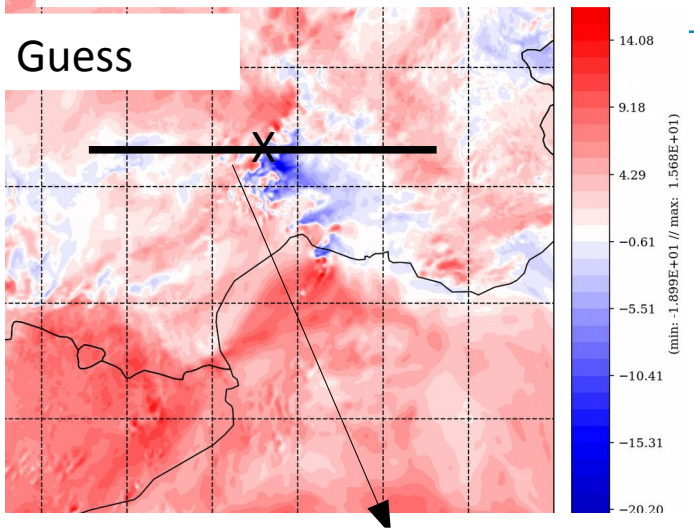


Number of assimilated observations during the 18 of september providing information below 850 hPa

3DEnVar seems to benefit from the observations informative on the incoming low -layer flow thanks to the flow-dependent background error covariances

NH variables in the control variable : single obs assimilation

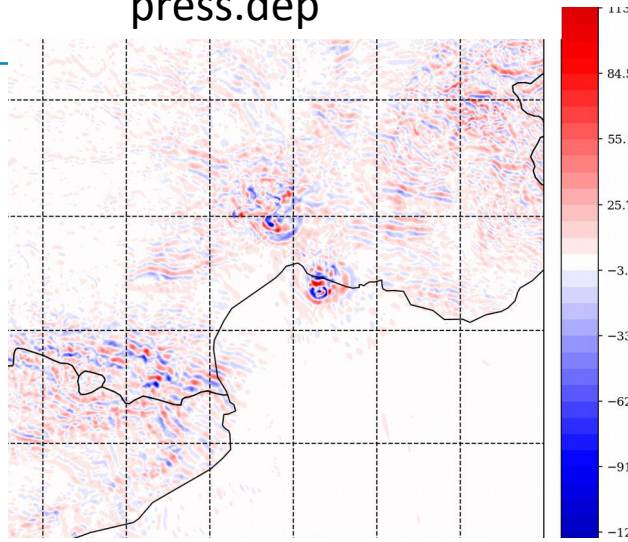
Wind U



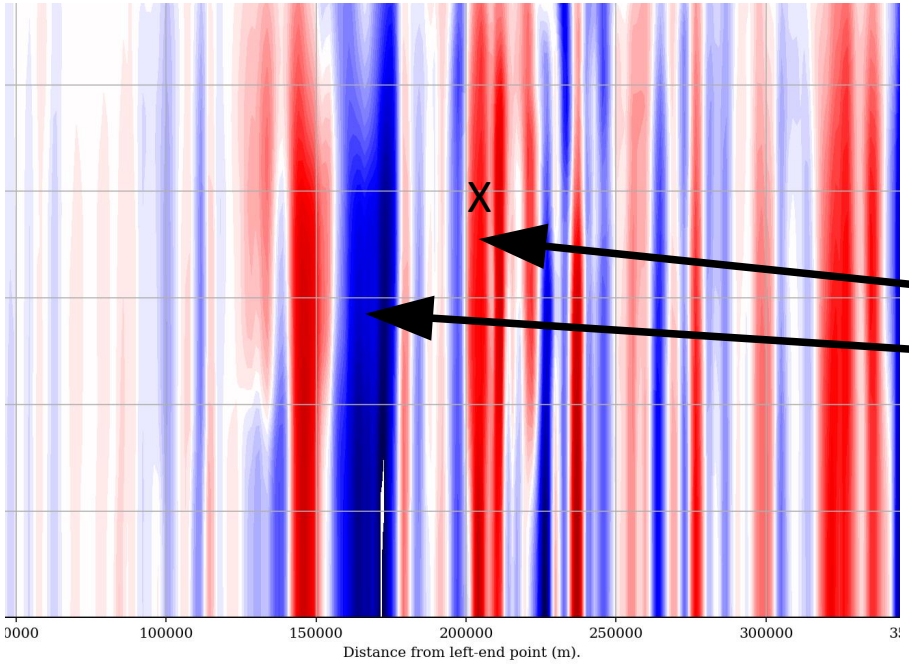
Be=**C** o **XX**^{T}

- **C** : localisation
- **X** : perturbation vector from the EDA $[\varepsilon_1 \ldots \varepsilon_n]$

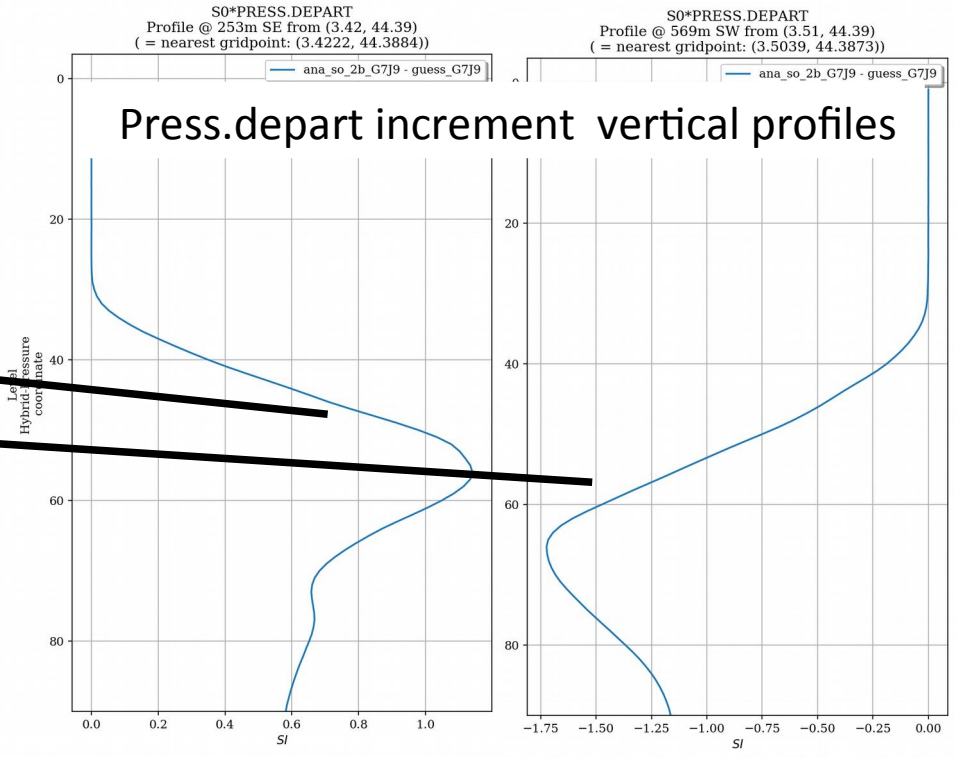
press.dep



Press.depart guess vertical section



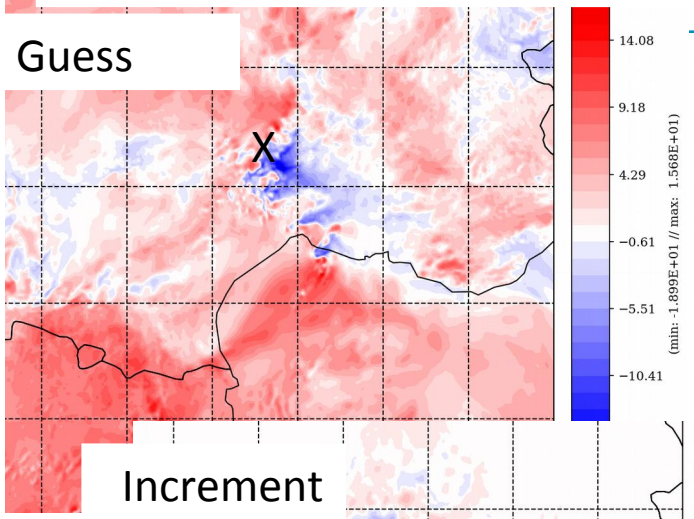
Press.depart increment vertical profiles



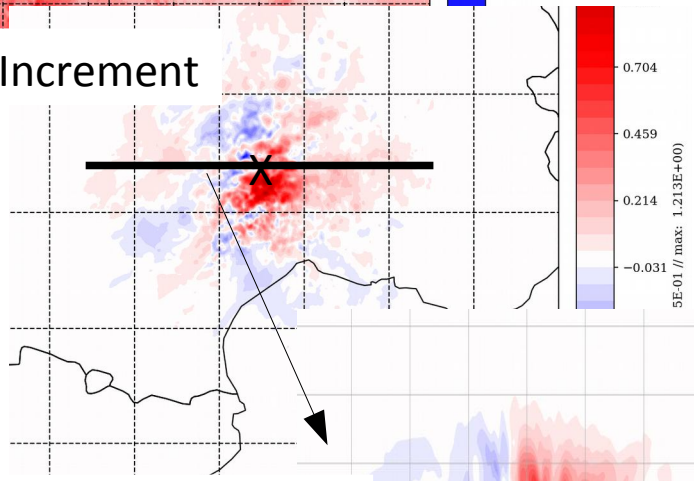
NH variables in the control variable : single Wind observation

Wind U

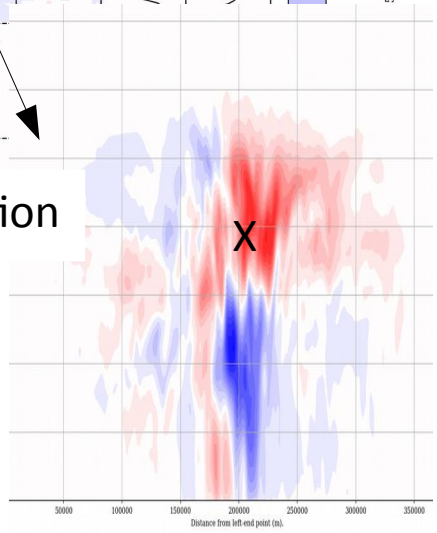
Guess



Increment



Inc. Vert. section



vertical divergence