Study of the Jacobian of an Extended Kalman Filter for soil analysis in SURFEX

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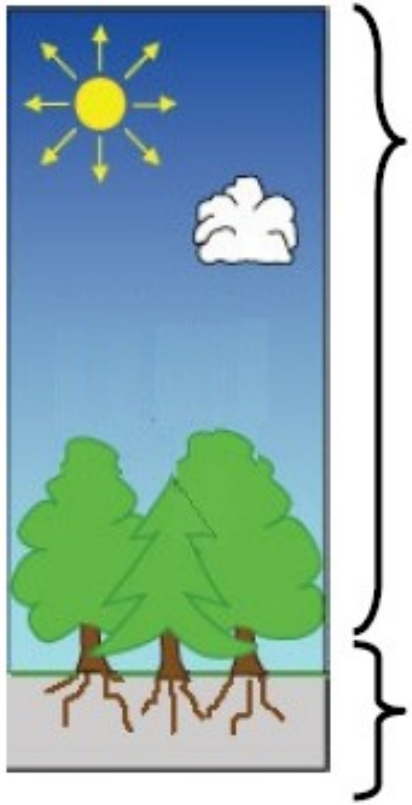
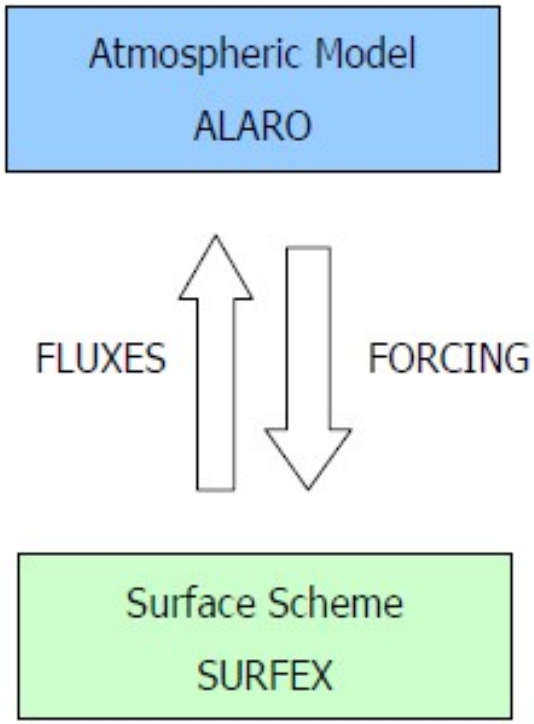
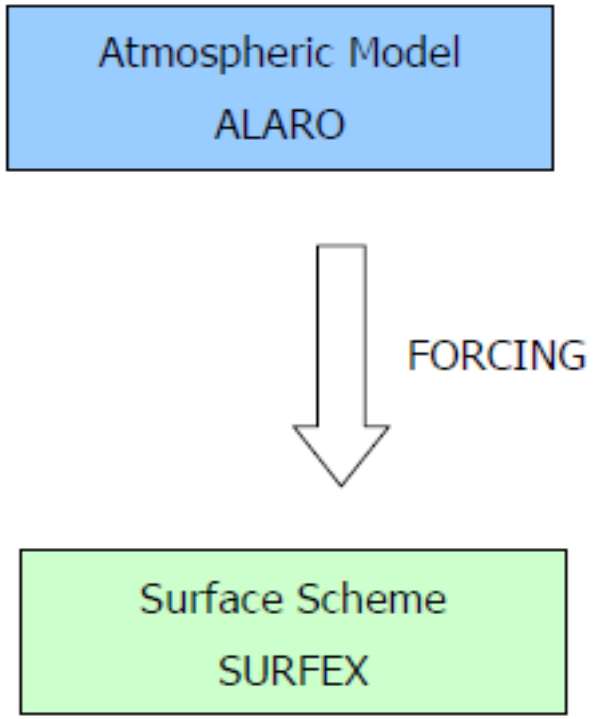
Introduction



Coupled



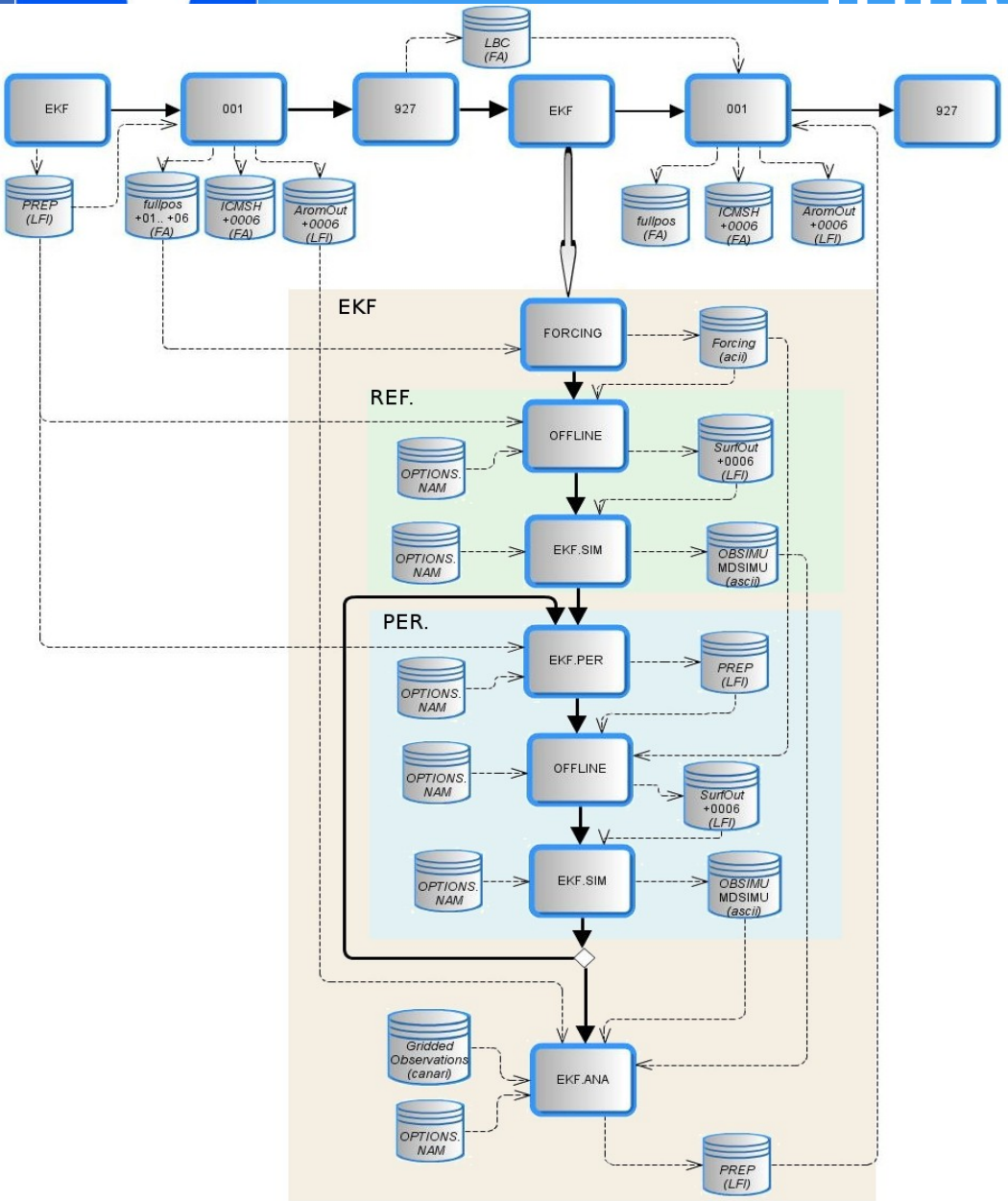
Offline

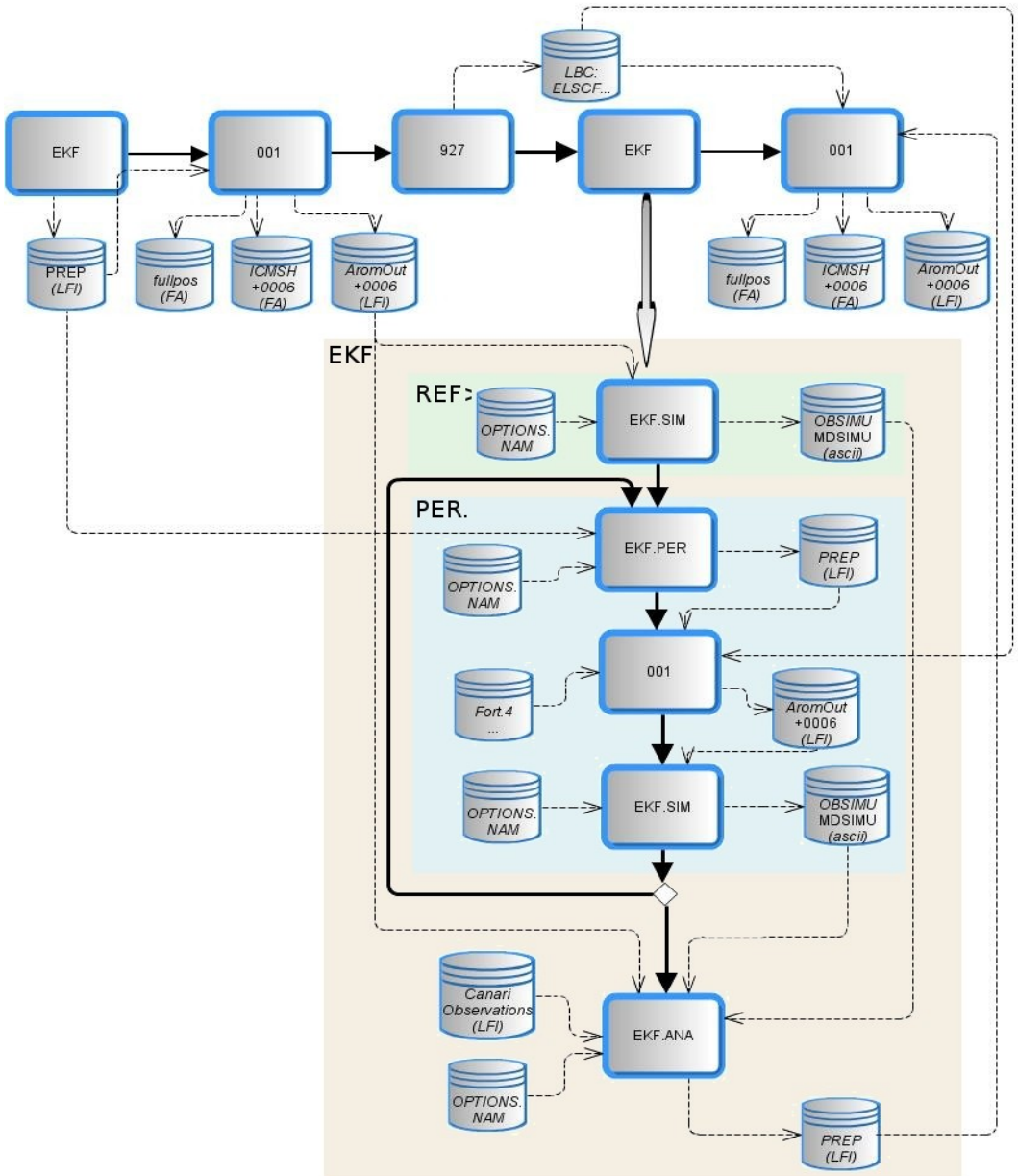


Coupled : used for the forecast

Offline : used in the EKF to calculate the Jacobian

Introduction





An EKF for soil analysis

Background error covariance matrix

Observation error covariance matrix

$$\mathbf{x}_t^a = \mathbf{x}_t^b + \underbrace{\mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}}_{\text{Kalman gain (weight)}}\underbrace{[\mathbf{y}_t^o - \mathcal{H}(\mathbf{x}_o^b)]}_{\text{Departure (error)}}$$

$\mathbf{y}_t^o$ Observations (T2m, RH2m)

$\mathbf{x}_o^b$ Model variables (Wg, W2, Ts, T2)

$\mathcal{H}(\mathbf{x}_o^b)$ Model counterpart of Observations (T2m, RH2m)

EKF : The Jacobian

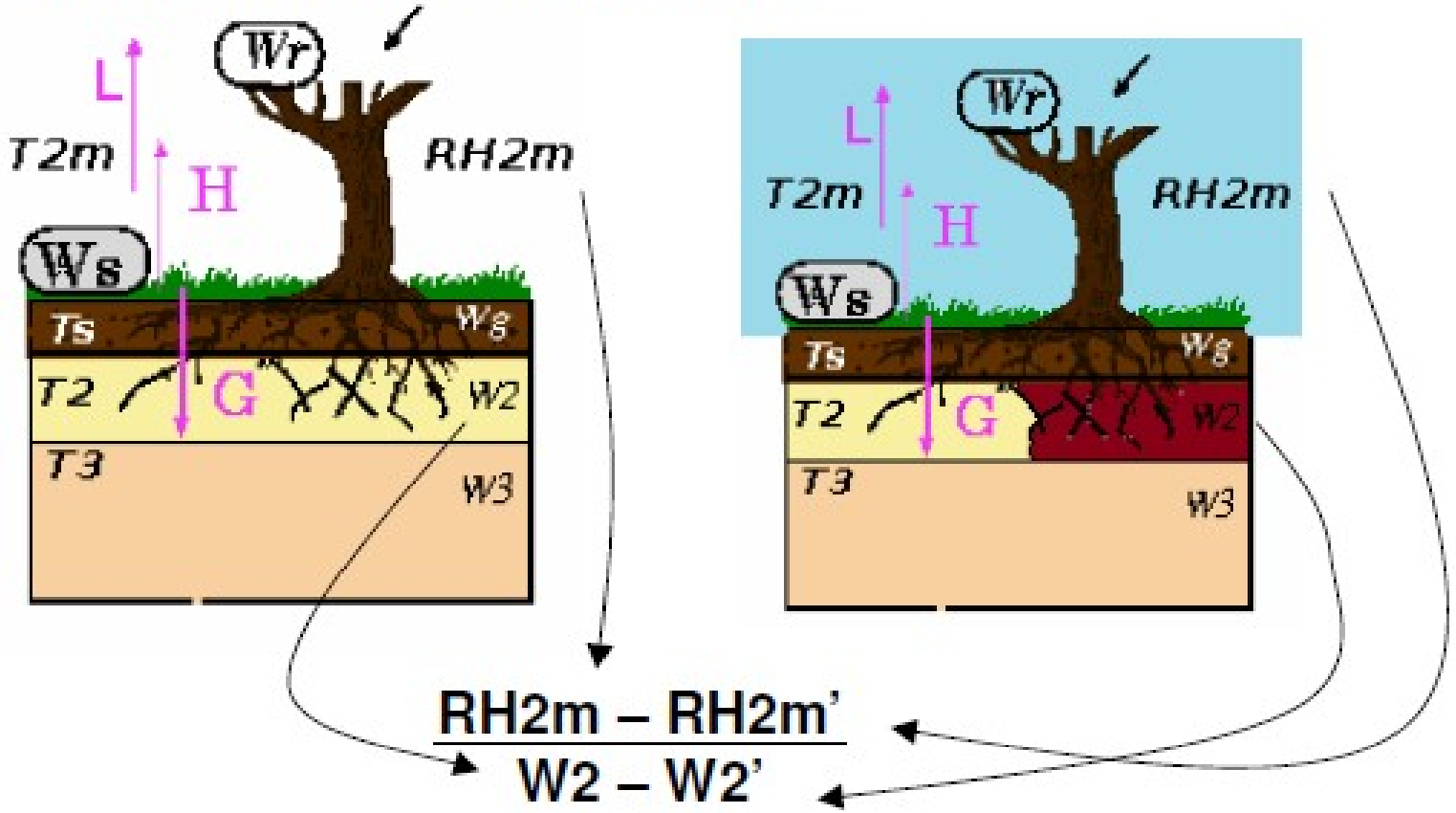
$$\mathbf{x}_t^a = \mathbf{x}_t^b + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}[\mathbf{y}_t^o - \mathcal{H}(\mathbf{x}_o^b)]$$

- $\mathcal{H}$: observation operator
  includes a model propagation
- **H**: Jacobian of the observation operator
  Calculated with finite differences

$$H_{i,j} = \frac{\delta y_{i,t}}{\delta x_{j,t0}} = \frac{y_i(x + \delta x_j) - y_i(x)}{\delta x_j}$$

EKF : The Jacobian

- **dRH2m/dW2:** how big is the change in RH2m if we introduce a small change in W2?



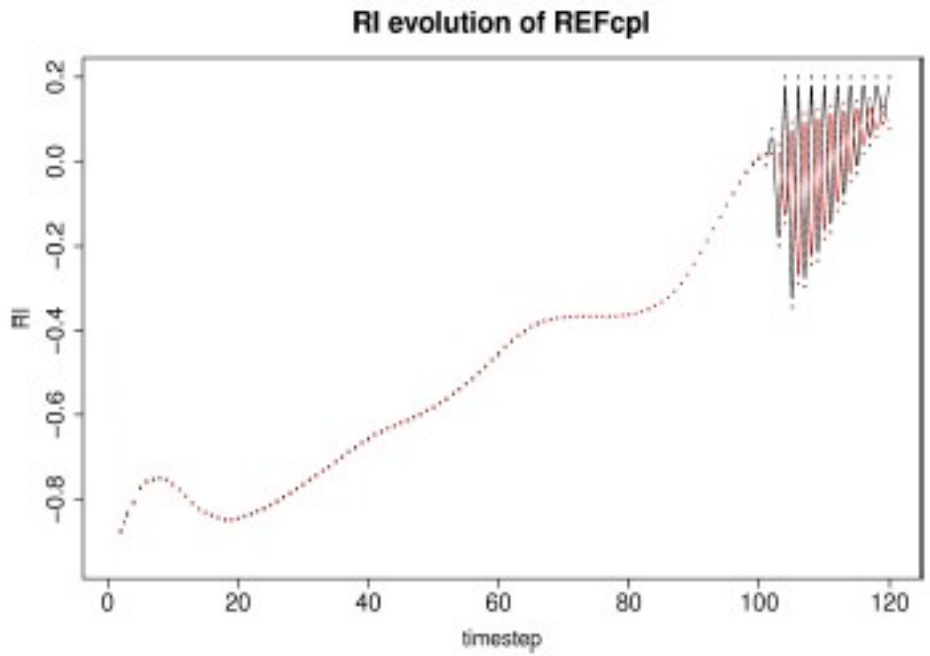
- **Calculation of the Jacobian requires 4 perturbed runs**
  - In offline or coupled mode
  - offline mode is computationally cheaper and allows smaller perturbation sizes

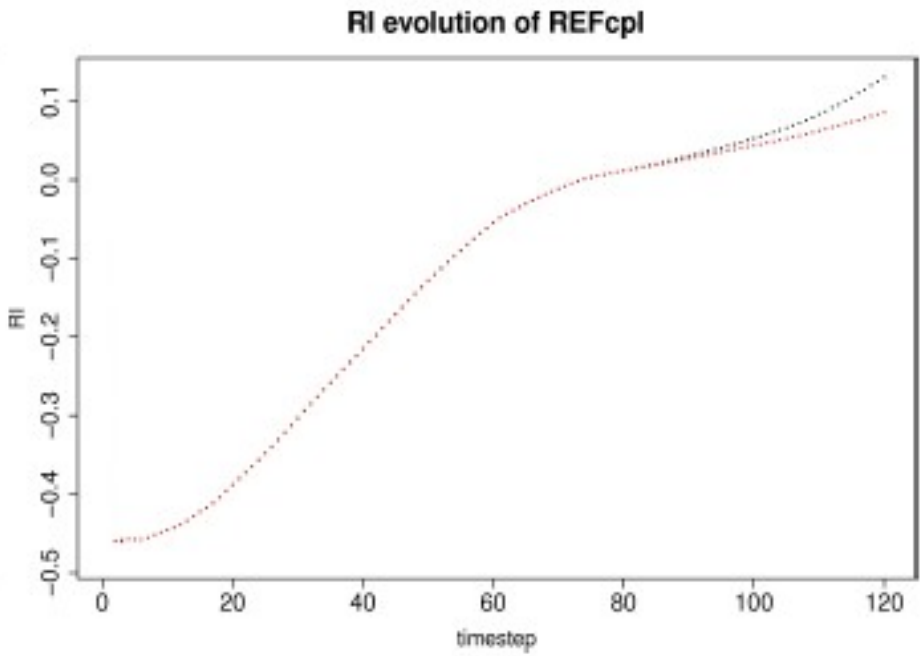
Surfex + Alaro

- Richardson number (RI) plotted every timestep
- 2 July 2010, 6h run from 12 UTC until 18 UTC
- Two different points in the domain, same run
- Black : RI value of SURFEX

  Red : RI at the ground according to Alaro
- Left : oscillation when RI>0

  Right : No oscillation, but divergence between Alaro and SURFEX

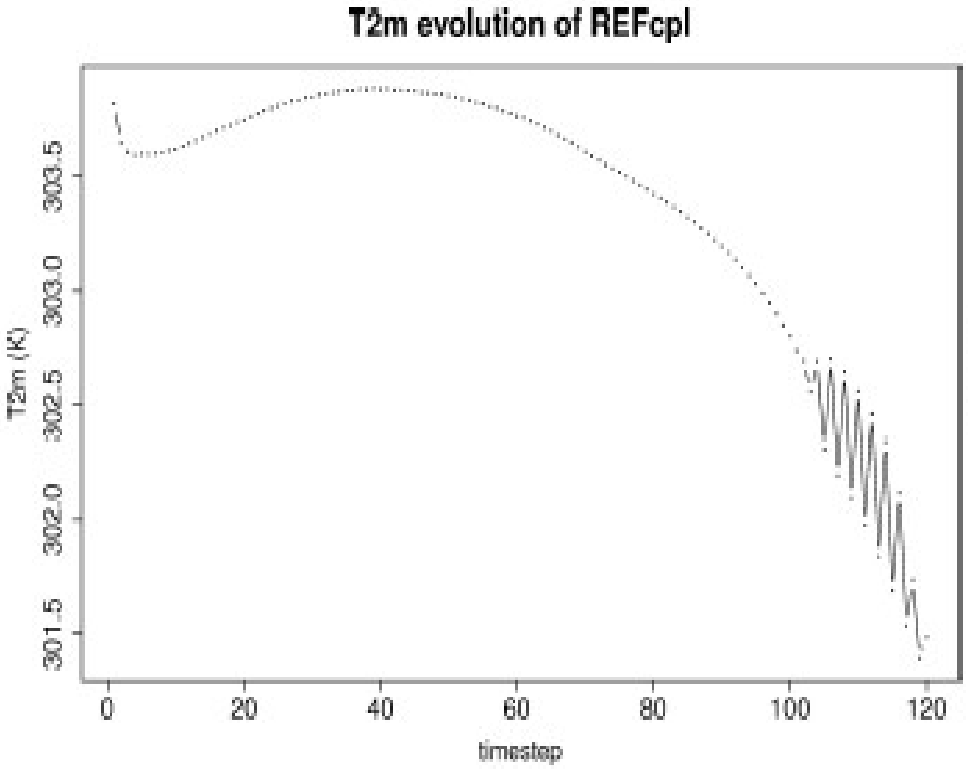


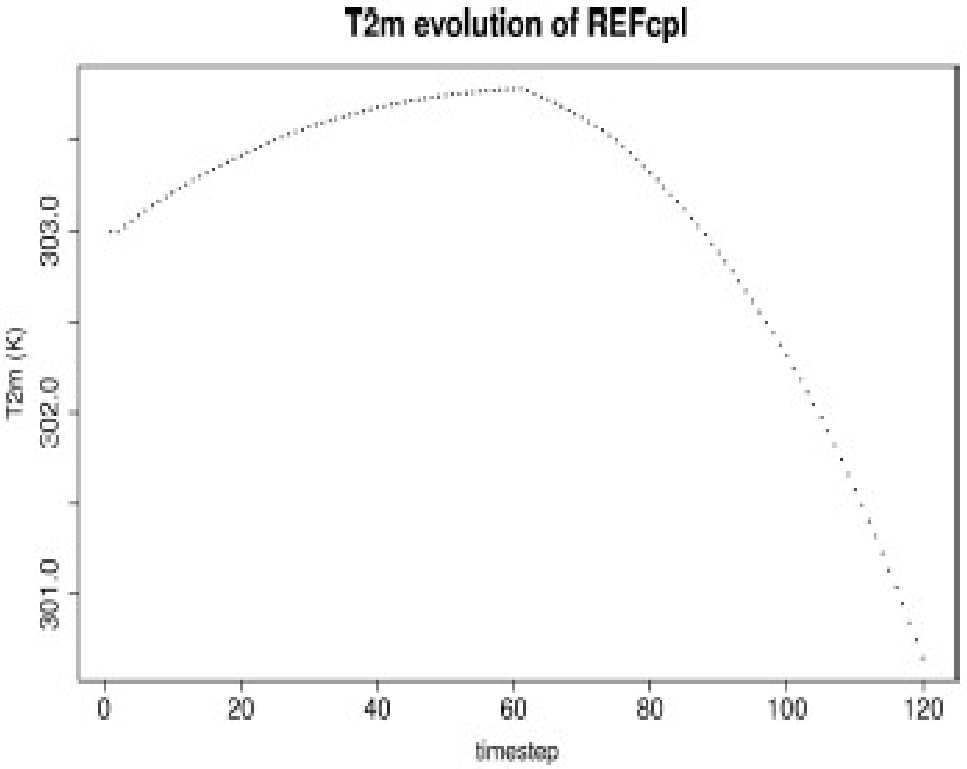


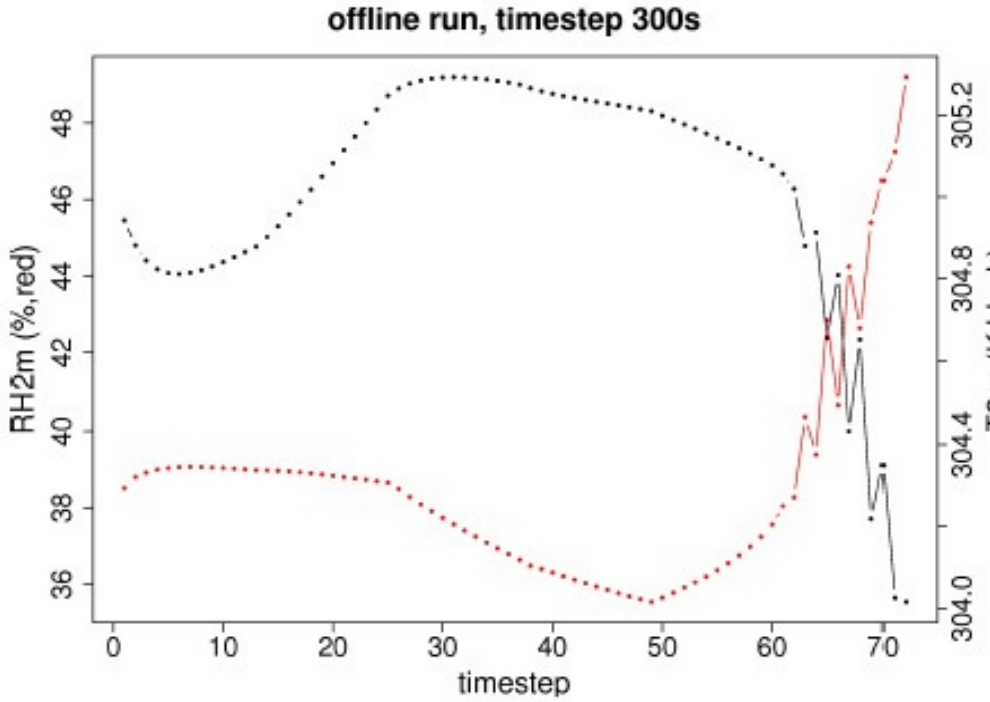
Surfex + Alaro

Effect on T2m in these two points :

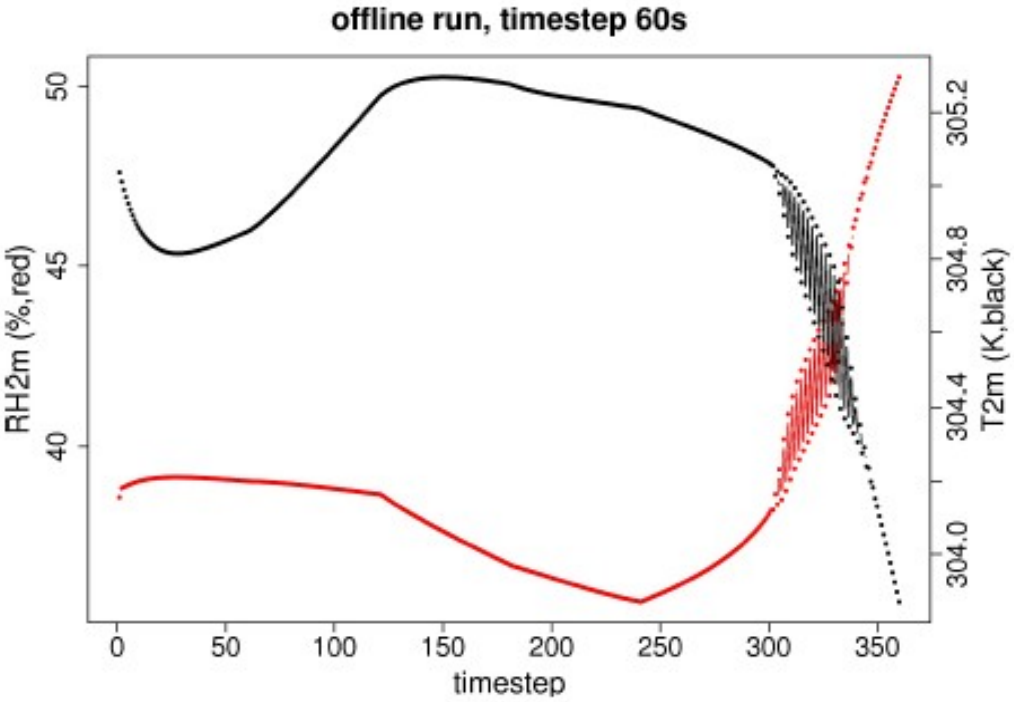
- Remain small, no detrimental effect on model runs
- But ! Cause noisy Jacobian values for the EKF



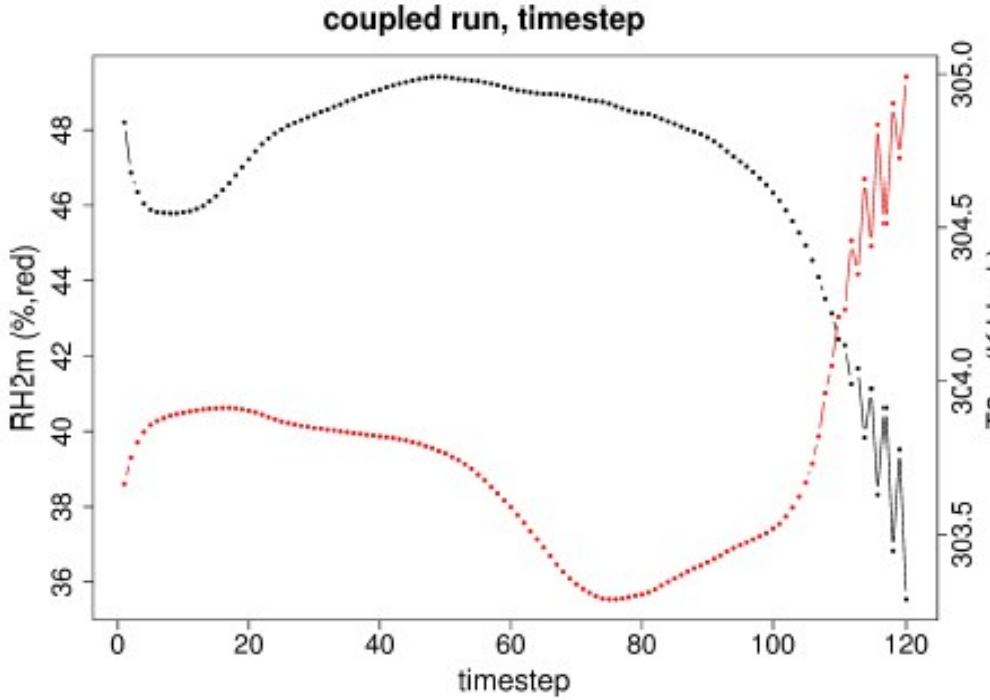


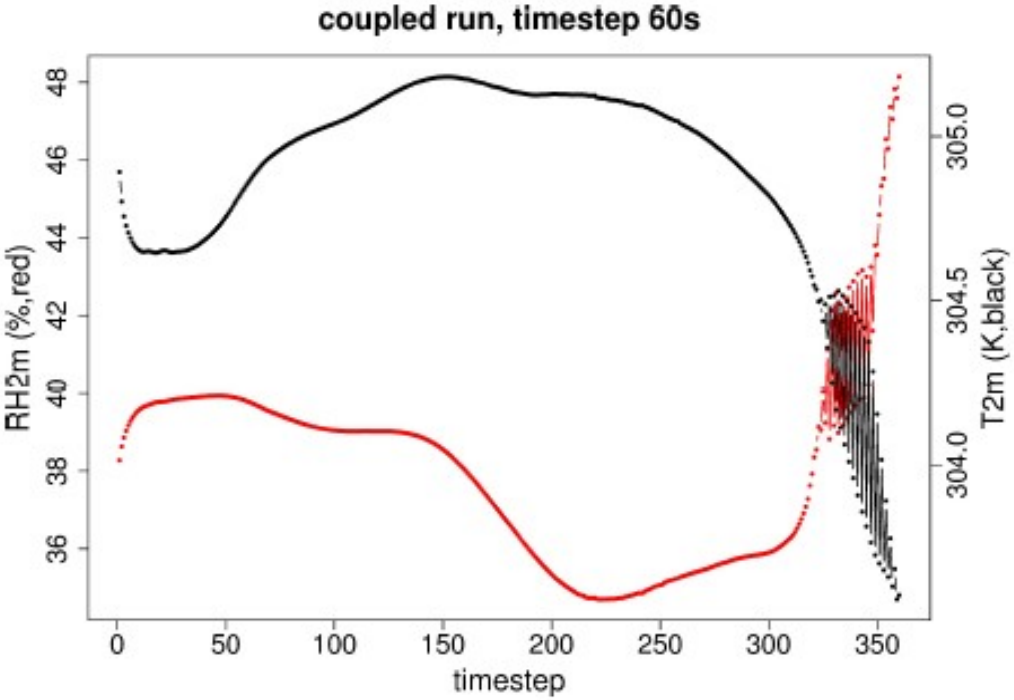

offline run, timestep 300s
RH2m (%,red)
T2m (K,black)
timestep

(a)


offline run, timestep 60s
RH2m (%,red)
T2m (K,black)
timestep

(b)


coupled run, timestep
RH2m (%,red)
T2m (K,black)
timestep


coupled run, timestep 60s
RH2m (%,red)
T2m (K,black)
timestep

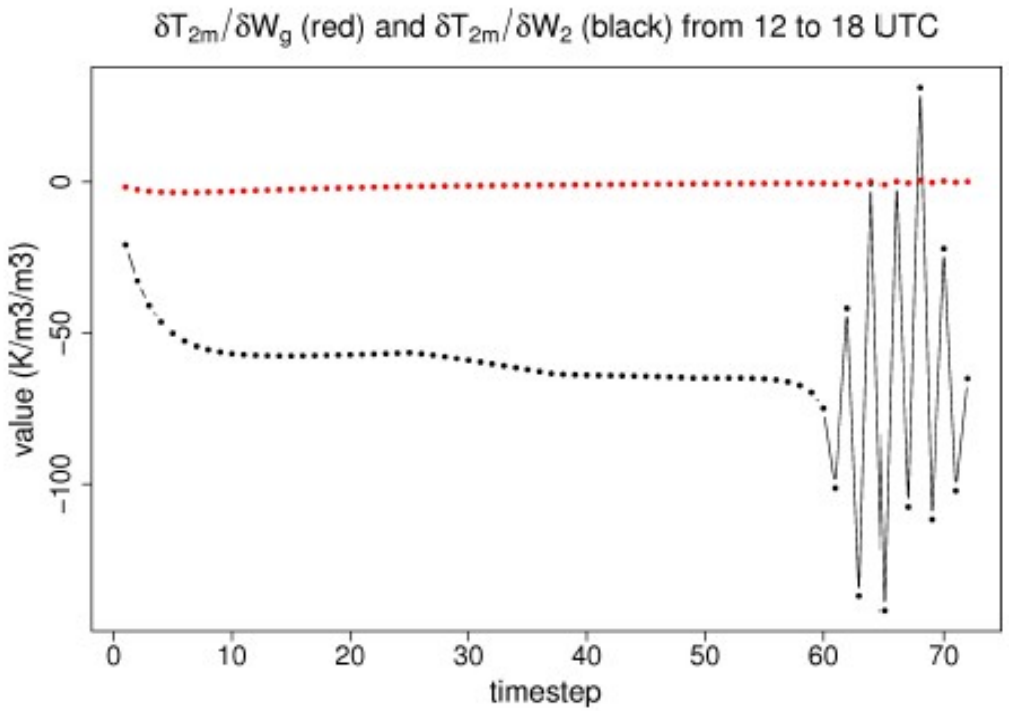
Oscillations

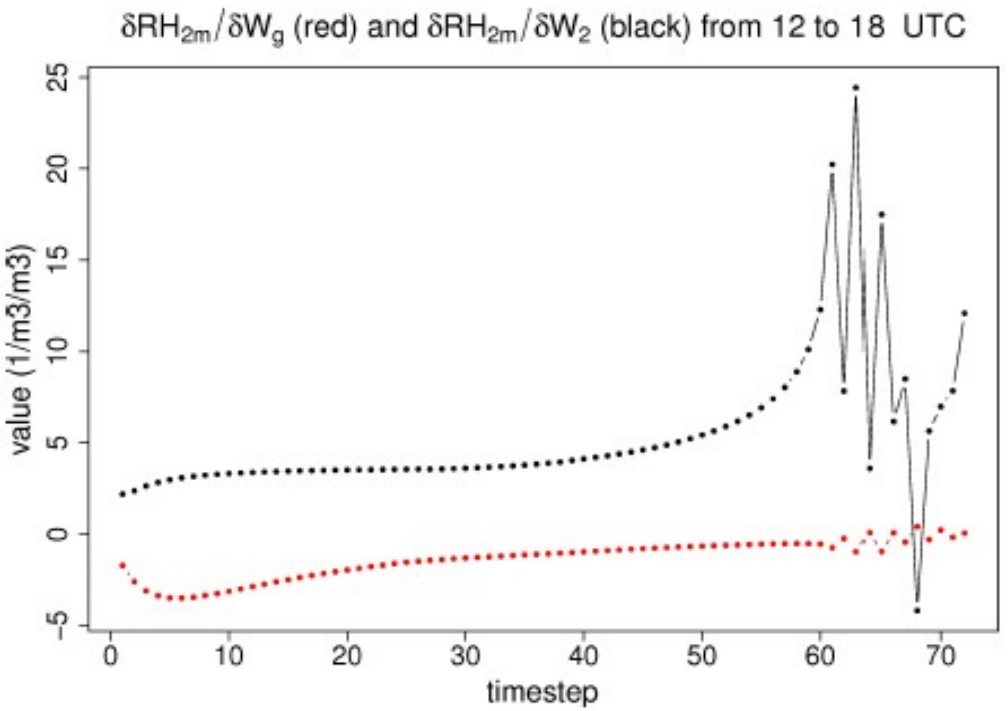
- In coupled and offline runs
- Between 12UTC and 18UTC when RI>0, when stable boundary layer starts to form
- In all surface variables related to fluxes
- $2\Delta t$ oscillations that remain when timestep is decreased from 300s to 60s : artificial !
- No fibrilations, but caused by small inconsistencies in turbulent fluxes between the surface and the atmosphere

Oscillations

Effect on the jacobians :

- Cause noisy Jacobian values for the EKF





Solutions

- SOL1 : Filter out the oscillations

$$x_{filtered} = 0.5 * w * x_{t-1} + (1 - w)x_t + 0.5 * w * x_{t+1}$$

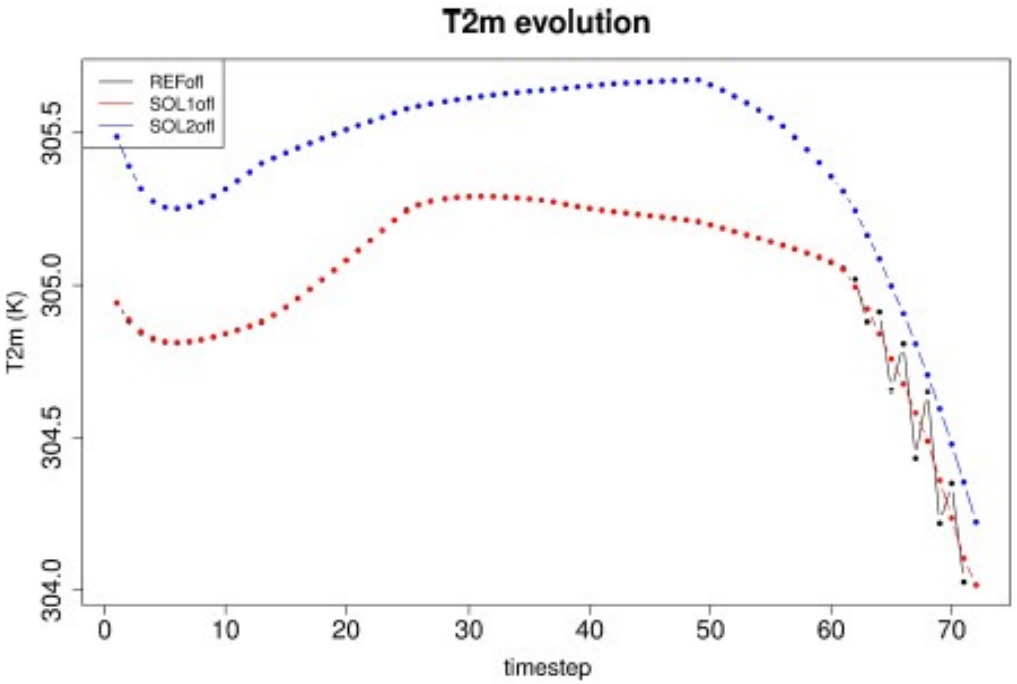
- SOL2 : use a lagged atmosphere
  - Better adjusted to surface
  - Lagged atmosphere only for calculation of the Jacobian, not for the forecasts!

An EKF for soil analysis

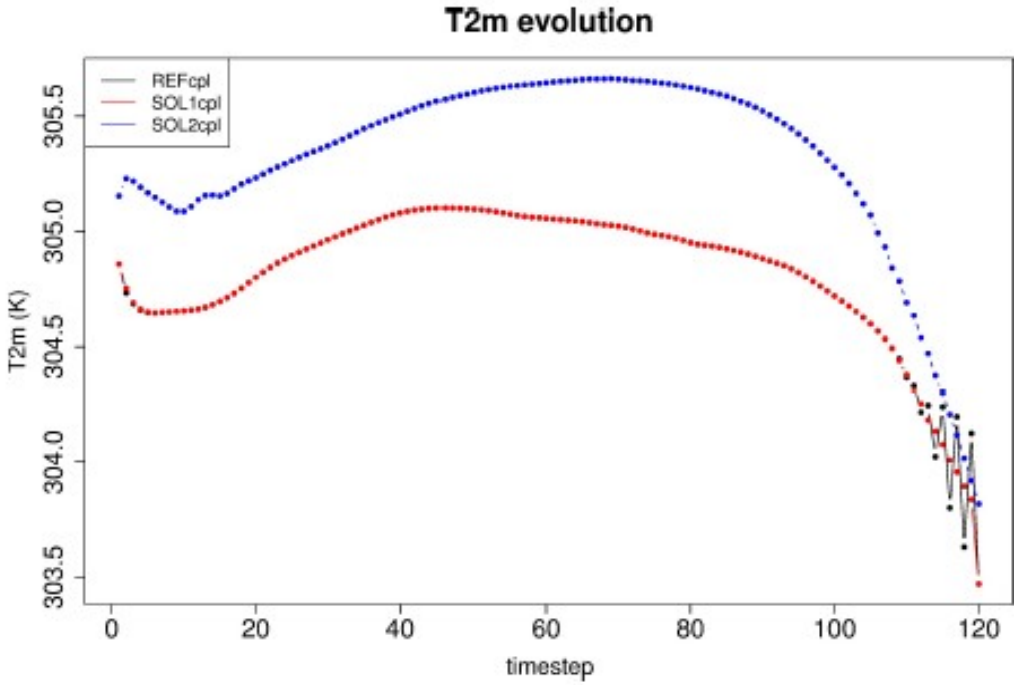
- 6h cycling
- Prognostic Variables :
  - Soil moisture content : Wg and W2
  - Soil temperature : Ts and T2
- Observations : T2m and RH2m
  - Interpolated to model grid with CANARI
- Alaro cy36t1, SURFEX v5

Solutions

Offline (timestep 300s)



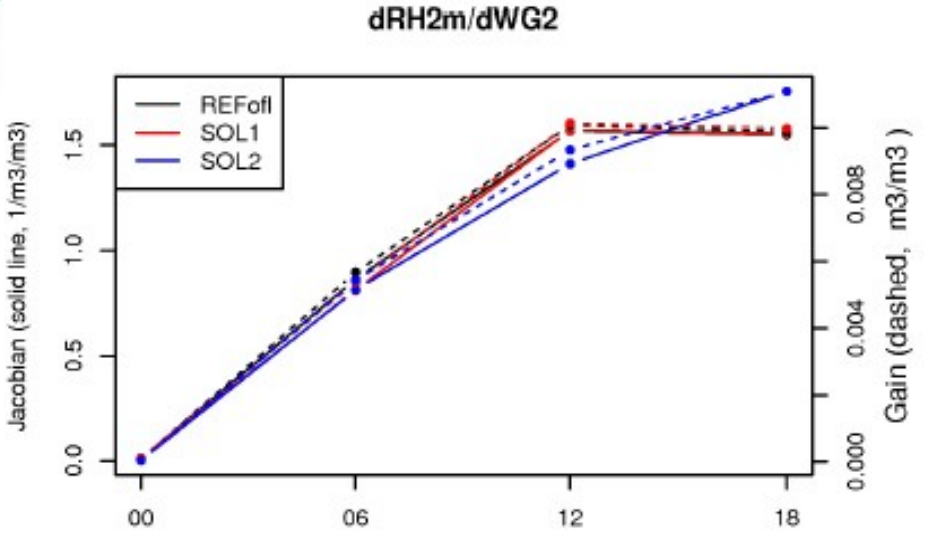
Coupled (timestep 180s)

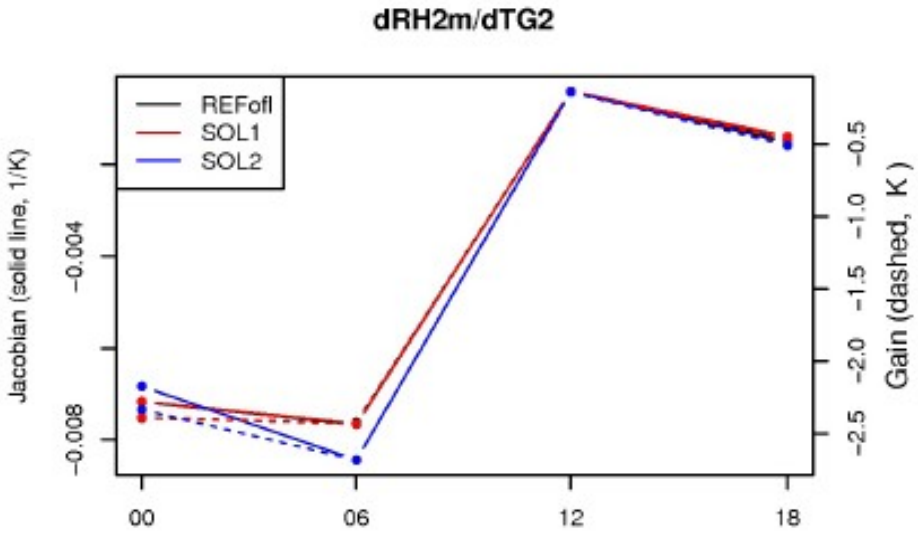


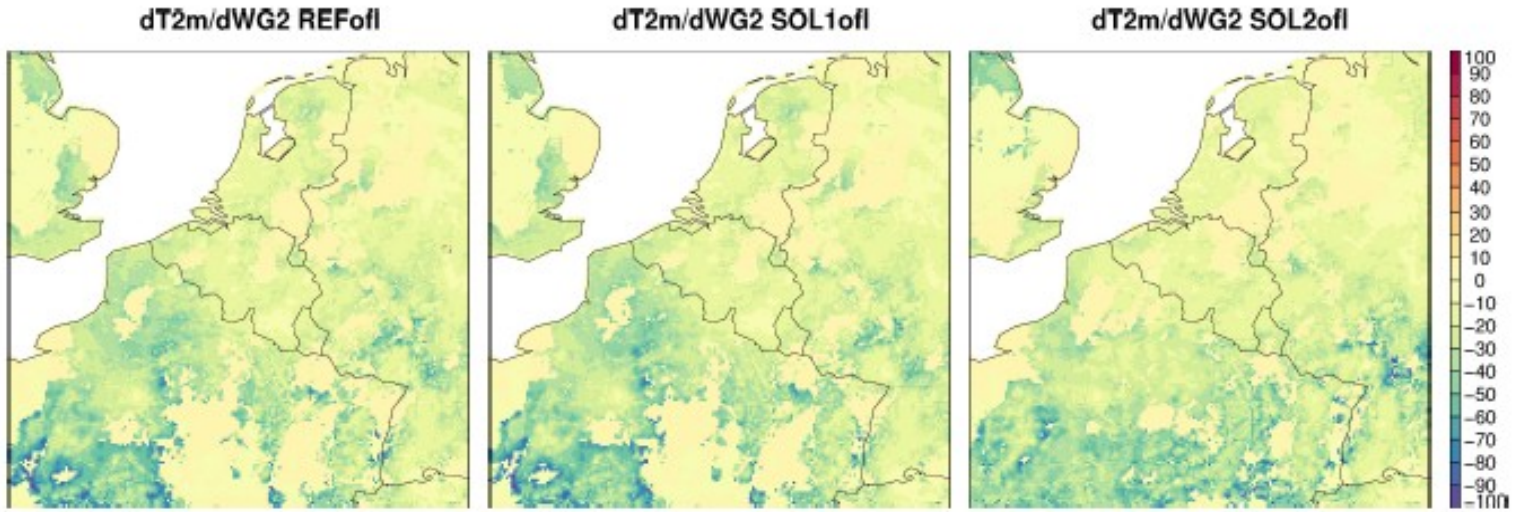
- The Oscillation dissapears for the solutions

Results : Jacobians

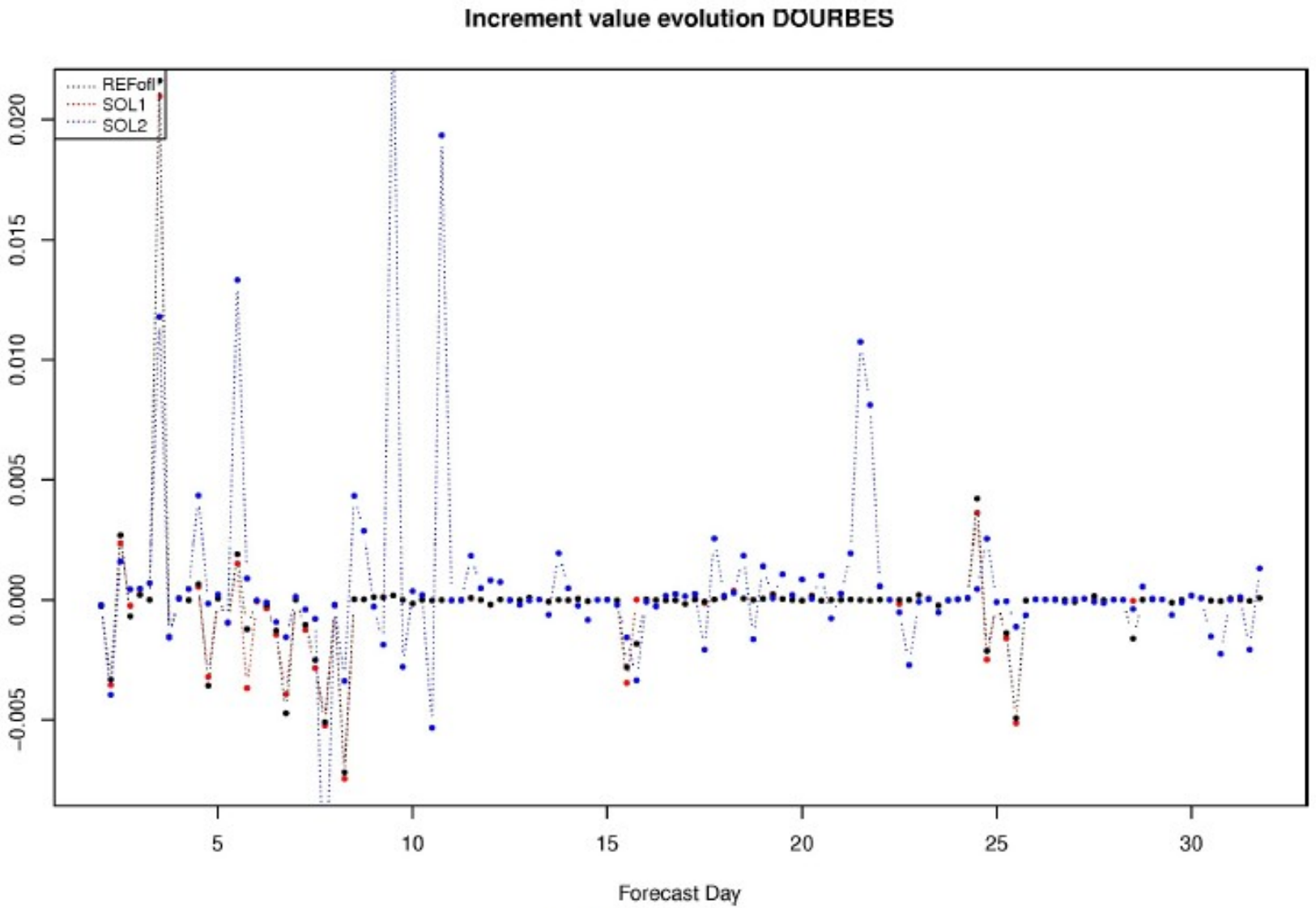
- Optimal perturbation size and average values of the Jacobians are similar for REF, SOL1 and SOL2





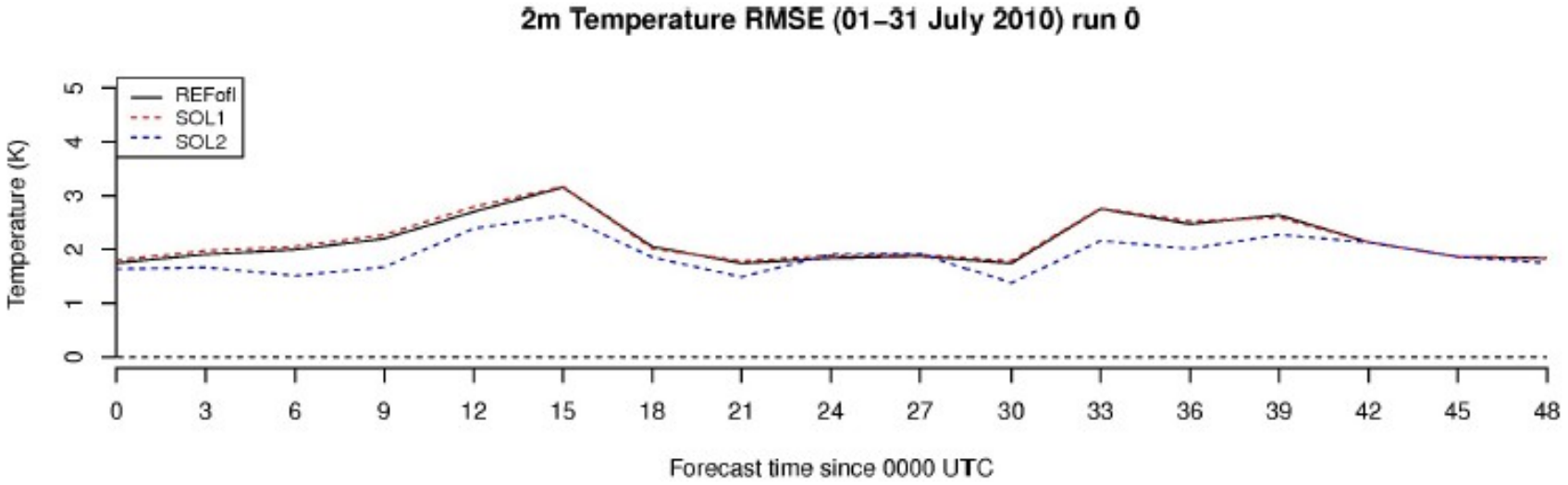


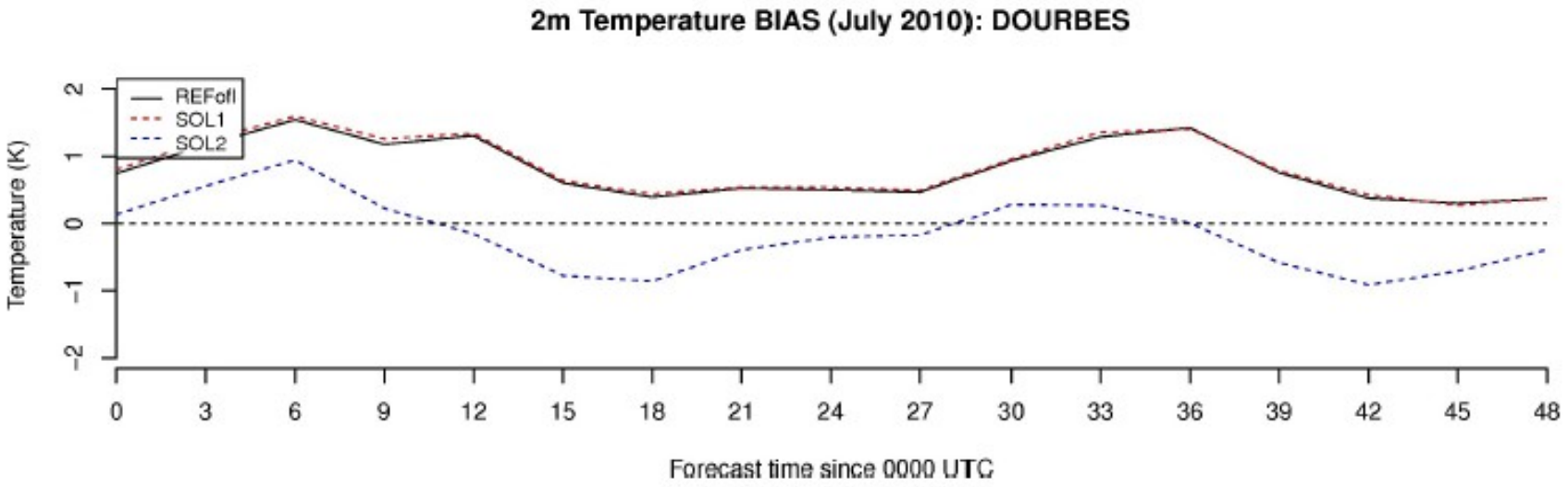
Results : Increments



(a) W_2 increments

Results : scores





Conclusion

- Small inconsistencies between the surface and the atmosphere cause oscillations in coupled and offline SURFEX runs when RI>0
- No problem for model runs, but important effect on Jacobian values of the EKF in certain locations
- Solutions :
  - Use a filter to remove oscillations
  - Use a lagged atmosphere
- Results :
  - Oscillations dissapear with solutions
  - Better forecast scores for lagged atmosphere