Development of a SURFEX EKF for ALADIN and comparison of the offline and coupled version with the OI analysis.

Toulouse, 5th March 2012

Surface Data Assimilation

- Optimum Interpolation (OI)
  - Coefficients are derived using simple assumptions
- Extended Kalman Filter (EKF)
  - dynamical coefficients
  - Formulation: $\mathbf{x}_t^a = \mathbf{x}_t^b + \mathbf{B}\mathbf{H}^T\left(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R}\right)^{-1}\left[\mathbf{y}_t^o - \mathcal{H}\left(\mathbf{x}_0^b\right)\right]$

    $\mathcal{H}$: the observation operator

    includes a model propagation

    H: the Jacobian matrix of the observation operator:

    $$\mathbf{H} = \frac{\partial \mathbf{y}_t}{\partial \mathbf{x}_{t_0}}$$

    H is calculated by a finite difference approach:

    $$H_{ij} = \frac{y_i\left(\mathbf{x} + \delta x_j\right) - y_i(\mathbf{x})}{\delta x_j}$$

Extended Kalman Filter

- Finite difference approach:

$$H_{ij} = \frac{y_i(\mathbf{x} + \delta x_j) - y_i(\mathbf{x})}{\delta x_j}$$

- Calculation of $y_i(\mathbf{x} + \delta x_j)$ and $y_i(\mathbf{x})$:
  - Perturb a component x_j of the control vector **x**
  - Perform run with the perturbed surface field to calculate corresponding y_i

    Offline: surface scheme decoupled from atmospheric model

    the forcing is taken from the lowest model level

    Coupled: surface scheme coupled to atmospheric model

    interaction is possible between atmosphere and surface

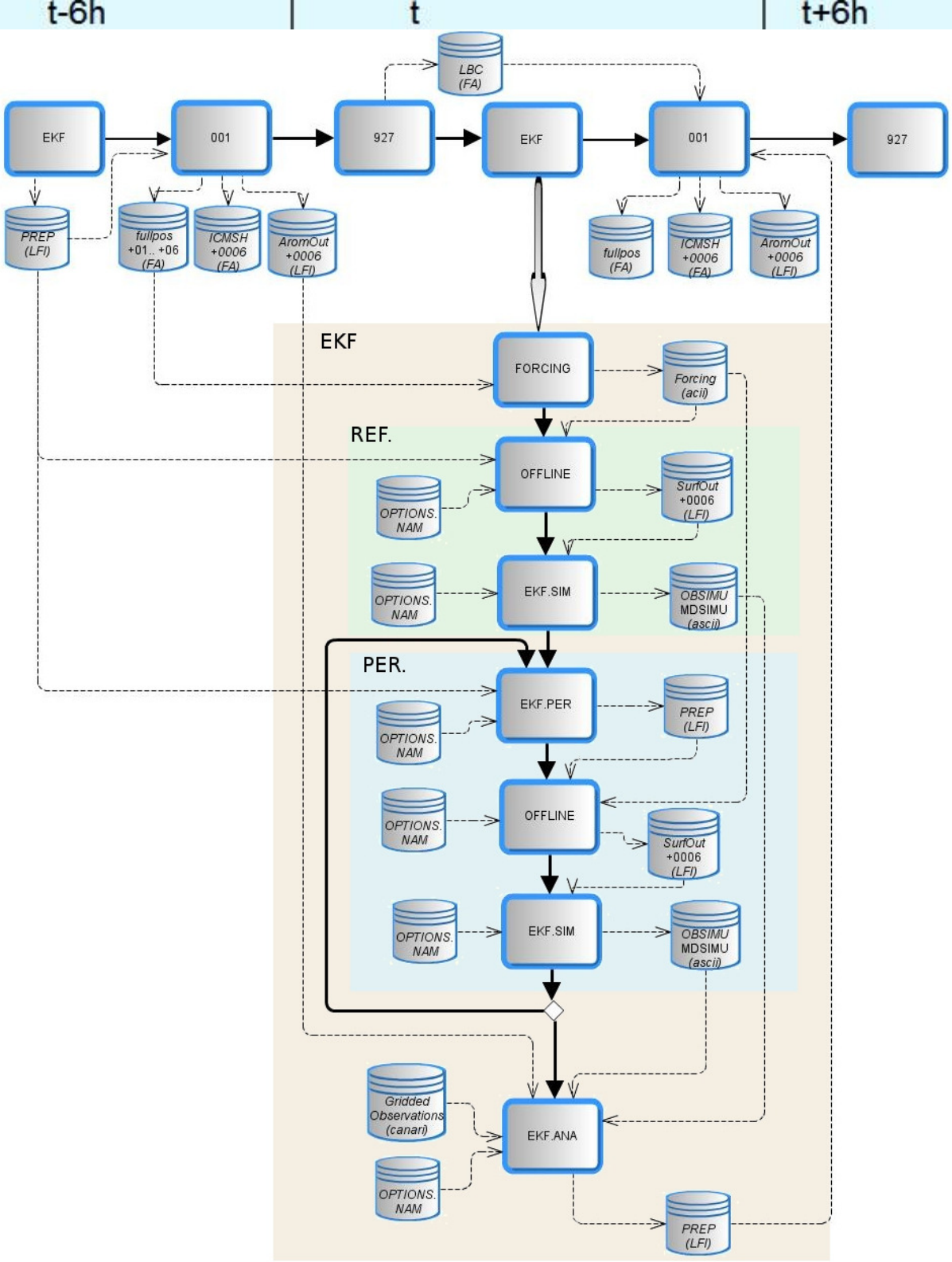
Offline vs. coupled EKF

- In Balsamo et al. (2007,JH), the offline approach is compared to the coupled approach for a single day during the summer with the GEM model. The gain components are found to be smaller for the offline approach but with similar patterns as the coupled approach.
- In Balsamo et al (2004,QJRMS) it is mentioned that for coupled experiments the choice of the perturbation size is important. Small perturbations can lead to a noisy H matrix and inaccurate corrections.
- This presentation:
  - Implementation of offline and coupled SURFEX EKF for ALADIN
  - Comparison between offline and coupled EKF: jacobians, gain, increments
  - Comparison of forecast scores of EKF, OI and runs without assimilation

- Prognostic variables:
  - Superficial water content (wg1)
  - Root zone water content (wg2)
  - Surface temperature (Tg1)
  - Deep soil temperature (Tg2)
- Observations:
  - Screen level temperature (T2m)
  - Screen level relative humidity (RH2m)
- Additional information:
  - LBC data from Aladin France
  - Assimilation interval τ = 6 hours, with assimilation at 00,06,12,18 UTC
  - Forecasts with surfex + alaro and inline fullpos (interval 1 hour)
  - Background error covariance matrix **B** is kept constant (WG set to 0.1,TG set to 2 K)
  - Error covariance matrix **R:** T2m set to 1K, RH2m set to 10%

Flowchart to run EKF

Offline version



EKF-steps:

- Forcing:

  transform fullpos FA to ascii

  needed for the offline runs

- Reference run: $y_i(\mathbf{x})$

  Offline: offline surfex run (6h fc.)

  Ekf.sim: store fields in ascii files

- Perturbed runs: $y_i(\mathbf{x} + \delta x_j)$

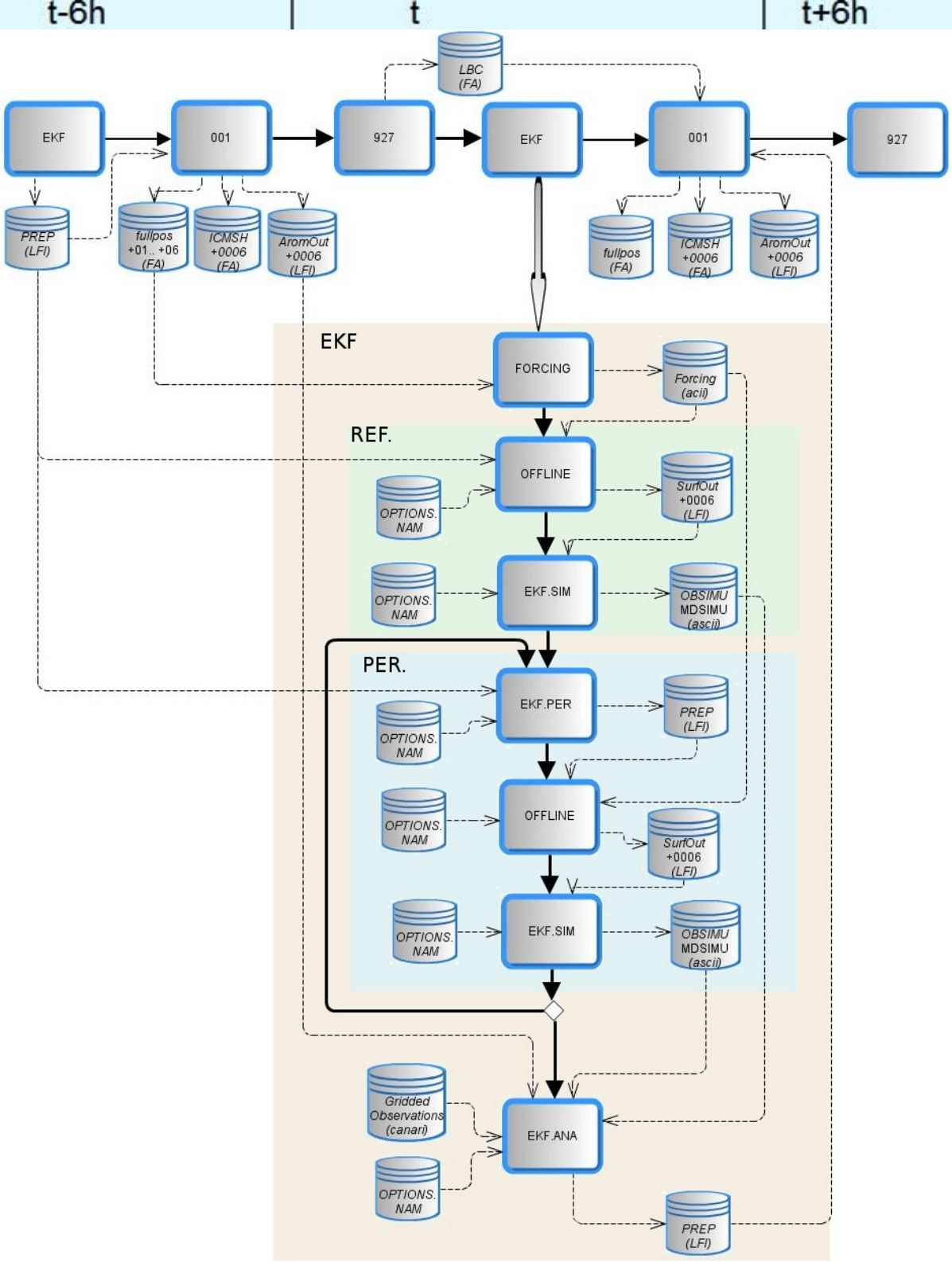
  Ekf.per: perturb surface variable

  Offline: offline surfex run (6h fc.)

  Ekf.sim: store fields in ascii files

Flowchart to run EKF

Offline version



EKF-steps:

- Analysis:

  Observations: gridded by canari

  Background: previous forecast

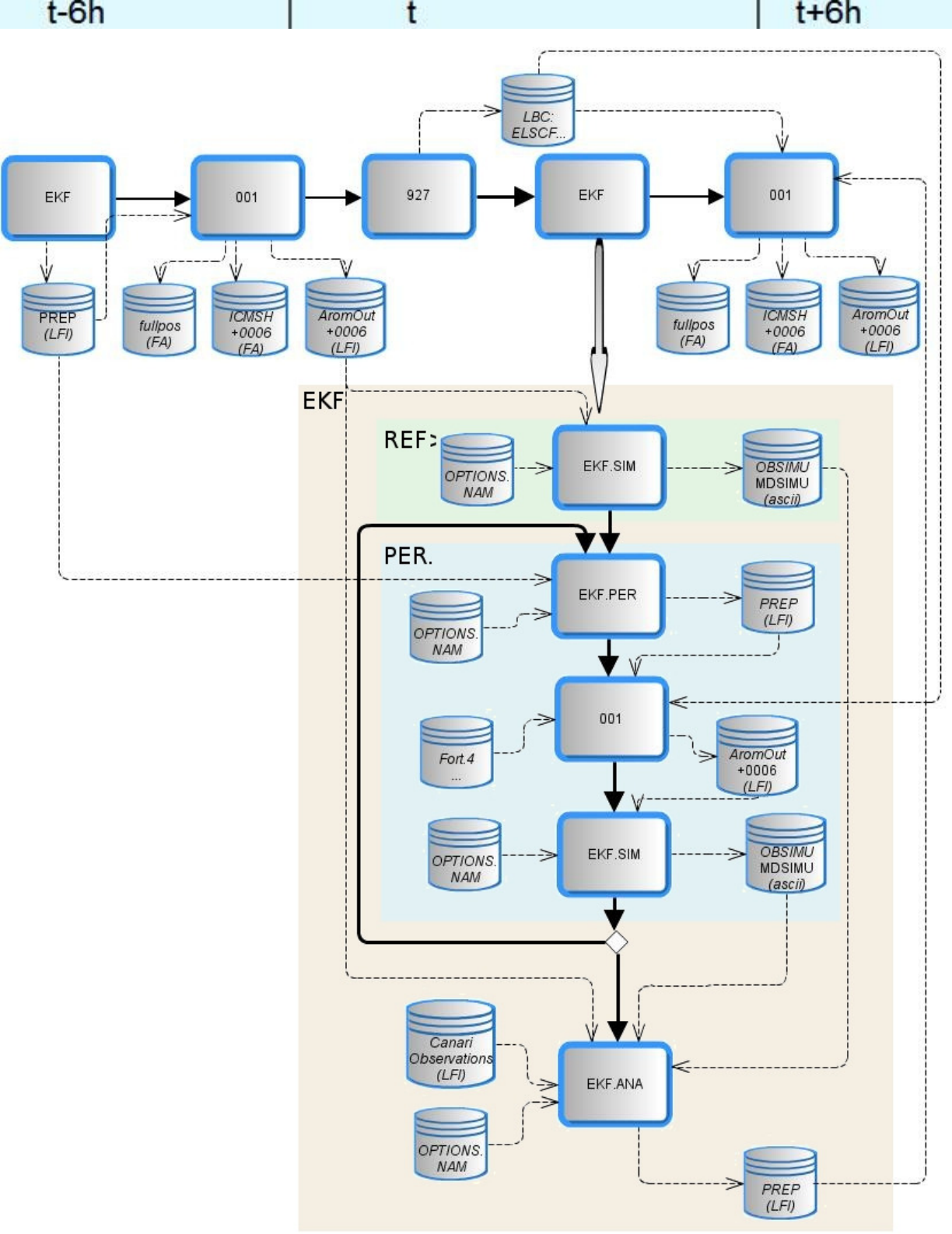
  Jacobians: obsimu/mdsimu files

$$H_{ij} = \frac{y_i(\mathbf{x} + \delta x_j) - y_i(\mathbf{x})}{\delta x_j}$$

- Note: the canari run to make gridded observations is performed with high background errors to limit the effect of the model background.
- Note: B is kept constant

Flowchart to run EKF

Coupled version



EKF-steps:

- Forcing:

  not needed (no offline runs)

- Reference run: $y_i(\mathbf{x})$

  6h forecast surface as reference

  Ekf.sim: store fields in ascii files

- Perturbed runs: $y_i(\mathbf{x} + \delta x_j)$

  Ekf.per: perturb surface variable

  001: coupled 6h forecast

  Ekf.sim: store fields in ascii files

- Analysis

Experimental Setup

Experiments:

- Free run: (no assimilation)

  Surface field from 6h forecast of previous run

- Open loop: (no assimilation)

  Surface is interpolated from Arpege analysis

- Surface Assimilation runs:

  Optimum Interpolation

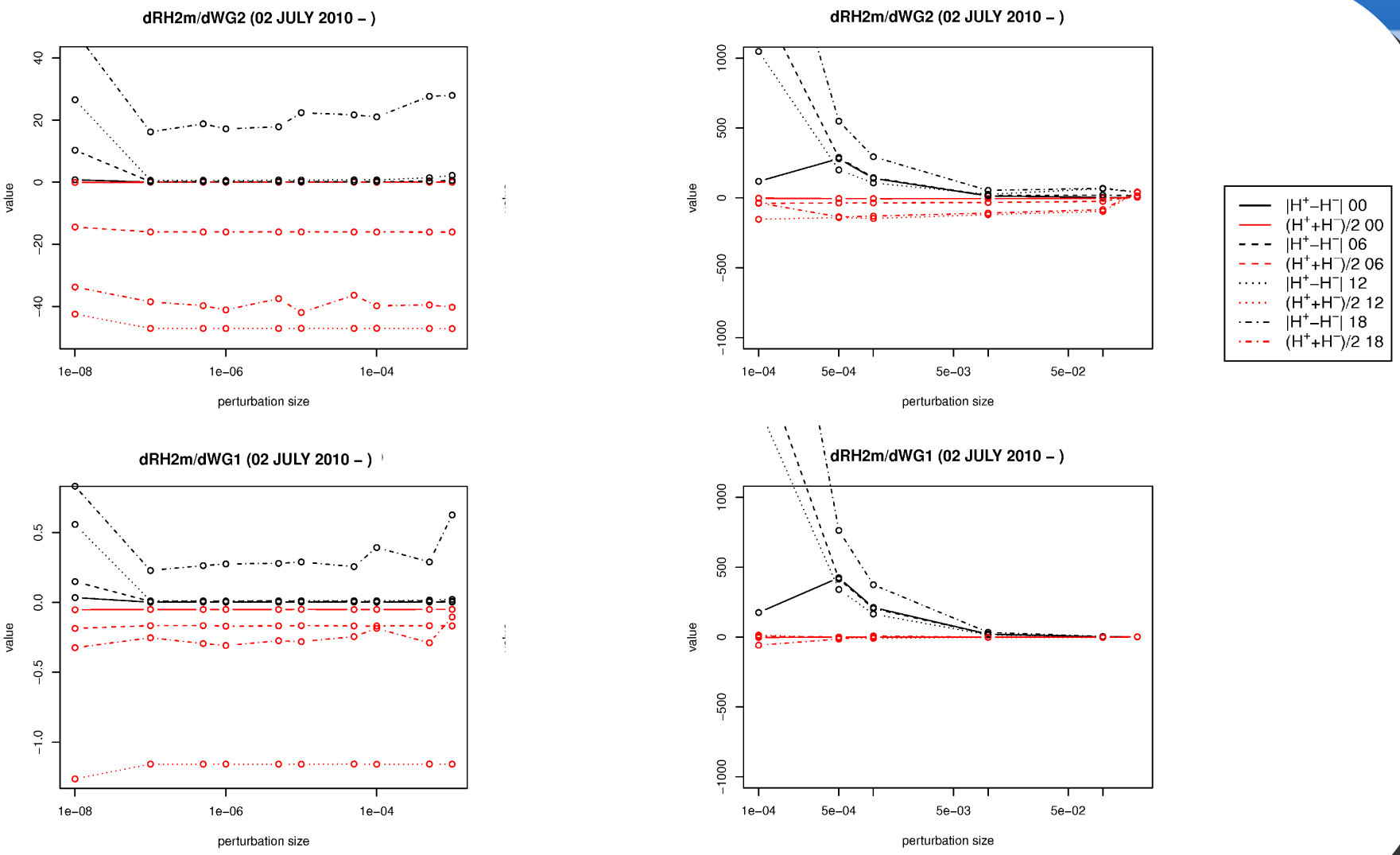
  EKF with offline jacobian calculation

  EKF with coupled jacobian calculation

  → Surface guess for assimilation is taken from 6h forecast of previous run

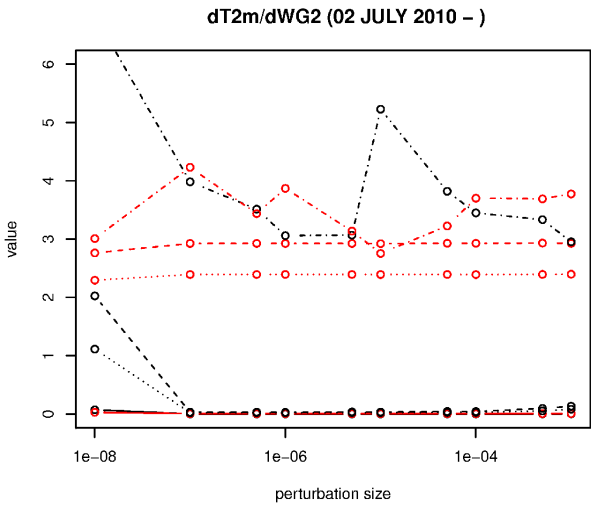
EKF offline

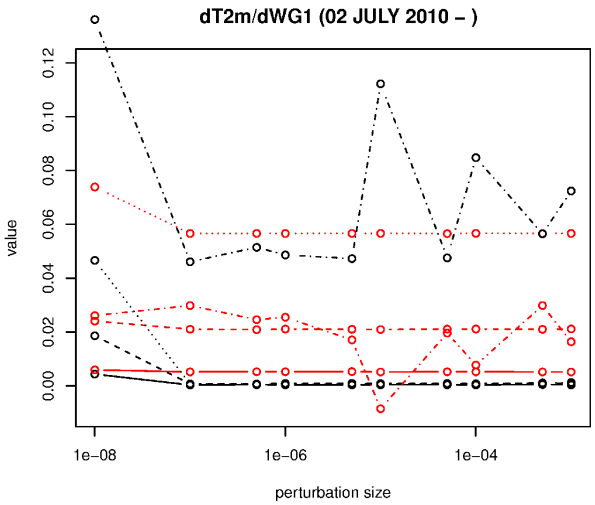
EKF coupled



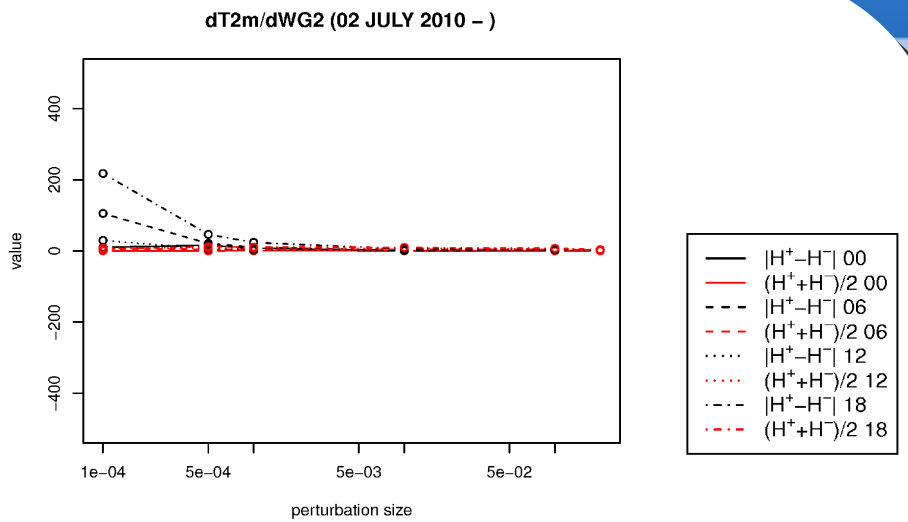
Jacobian Matrix Elements

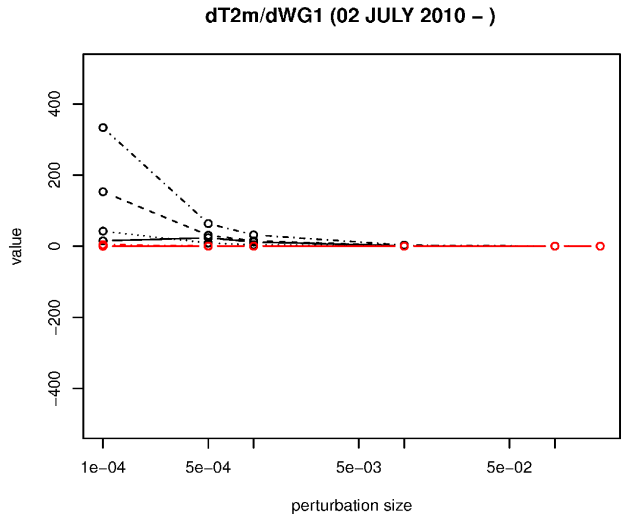
EKF offline





EKF Coupled

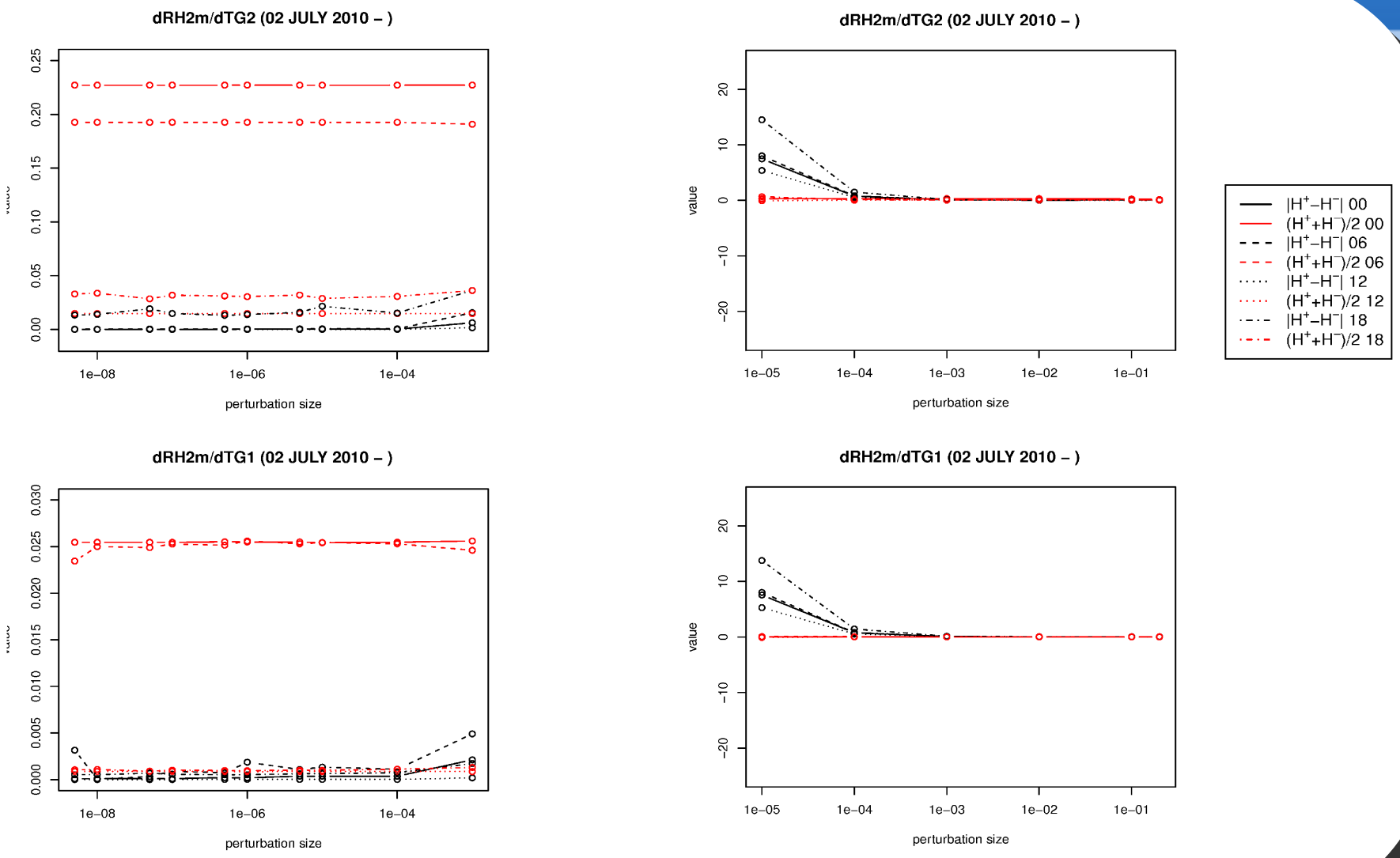




Jacobian Matrix Elements

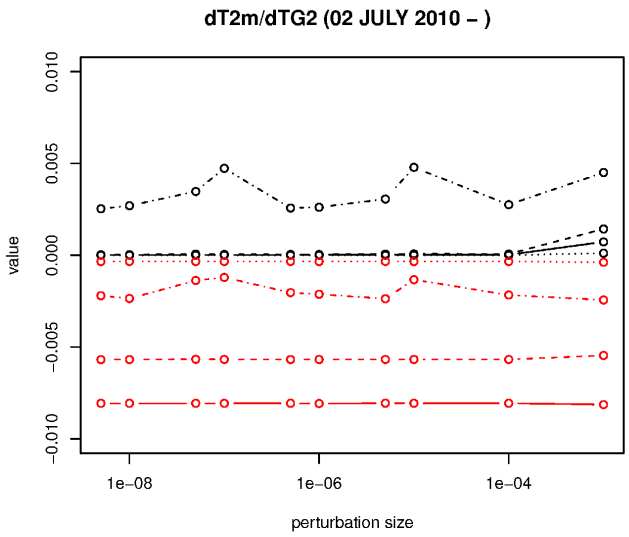
EKF offline

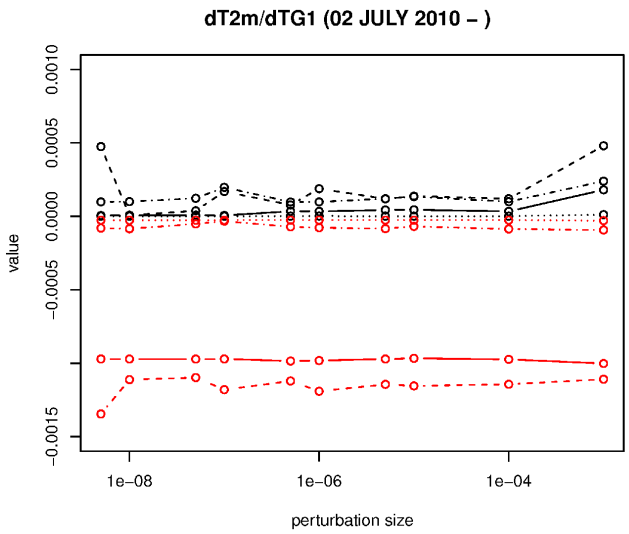
EKF coupled



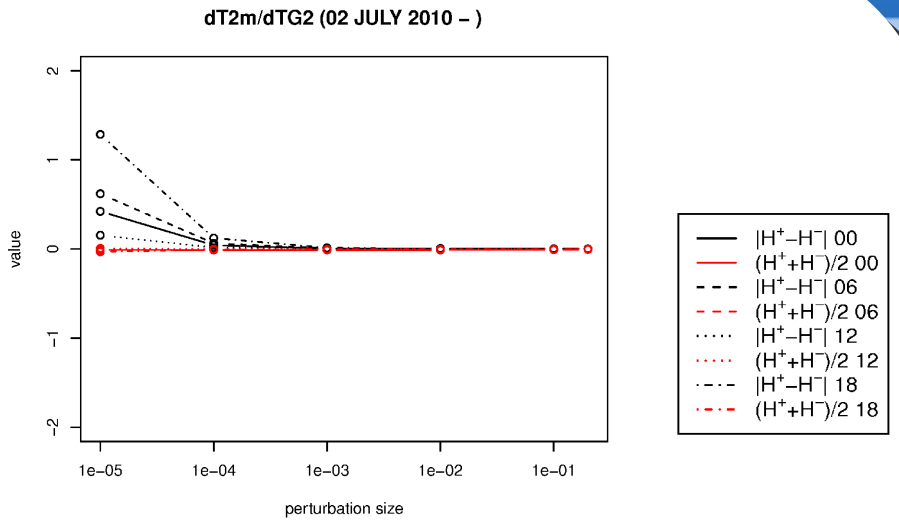
Jacobian Matrix Elements

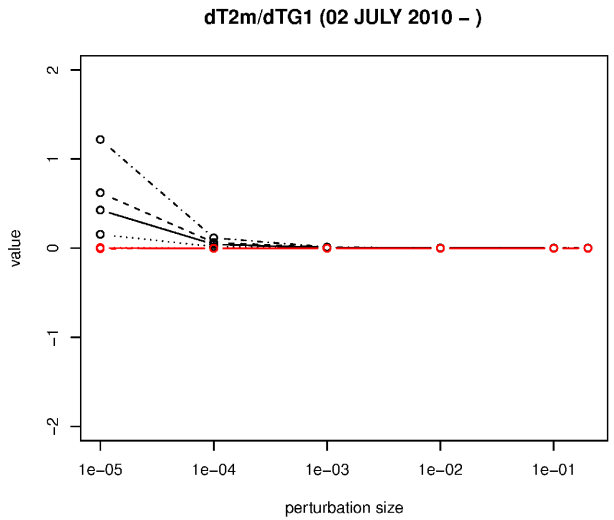
EKF offline





EKF coupled





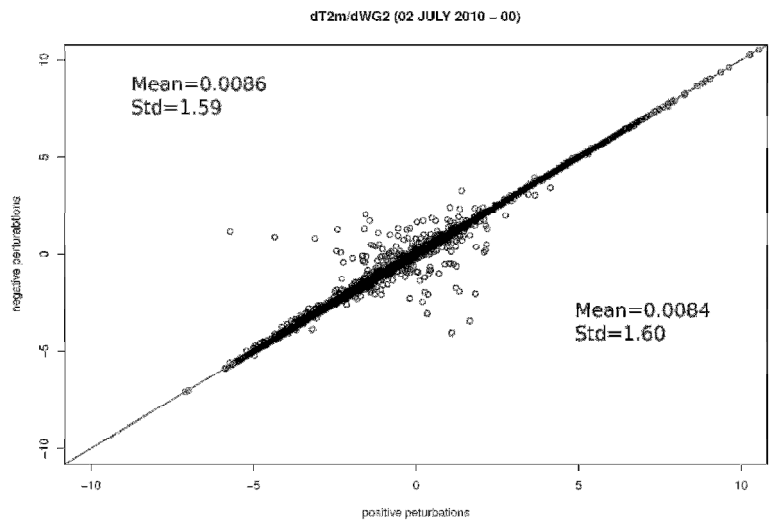
Jacobian Matrix Elements

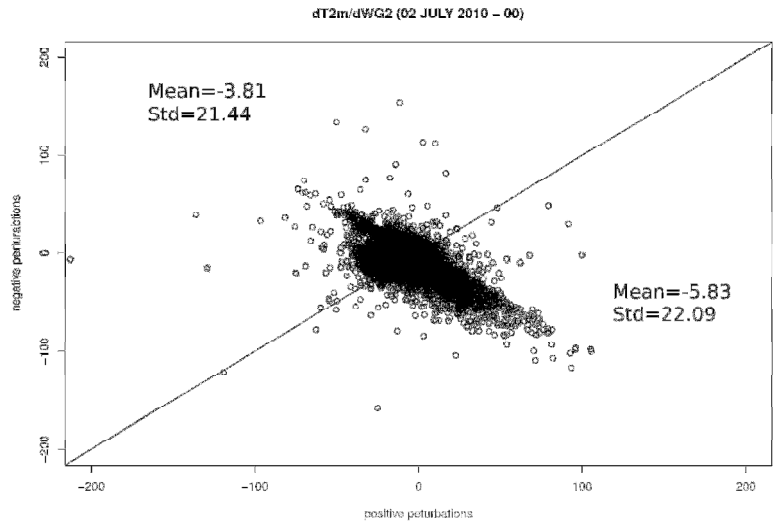
WG2

EKF offline

EKF coupled

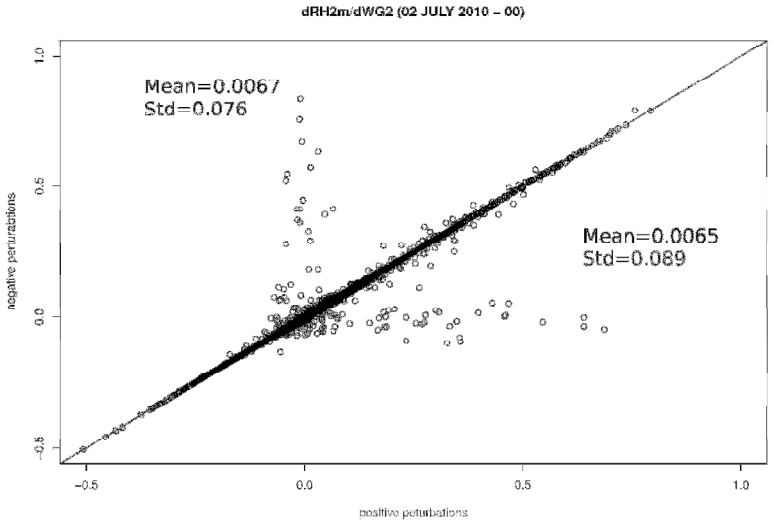
Pert. size: 10^{-4}

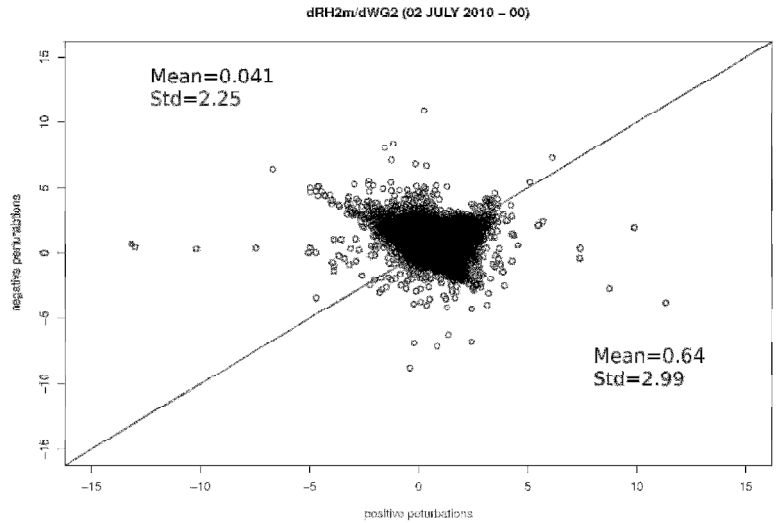




Pert. size: 10^{-1}

Pert. size: 10^{-4}





Pert. size: 10^{-1}

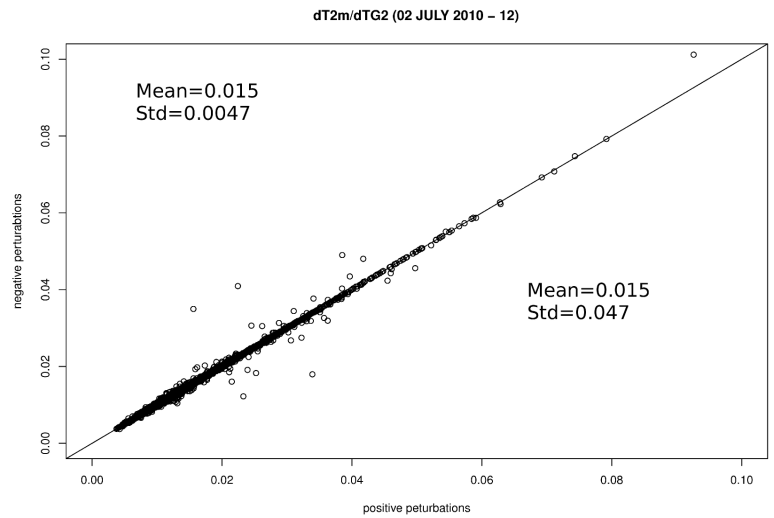
Jacobian Matrix Elements

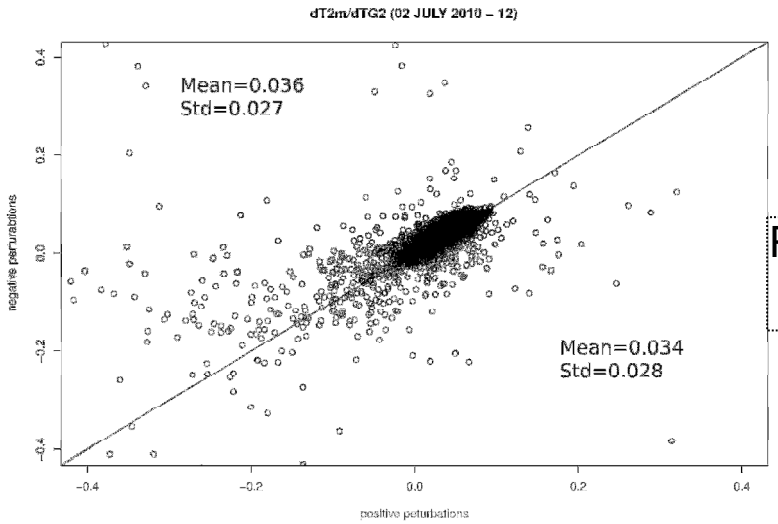
TG2

EKF offline

EKF coupled

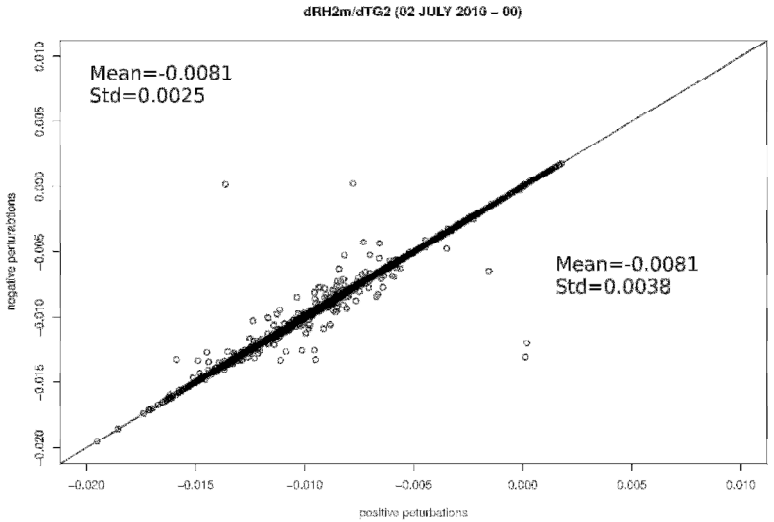
Pert. size: 10^{-6}

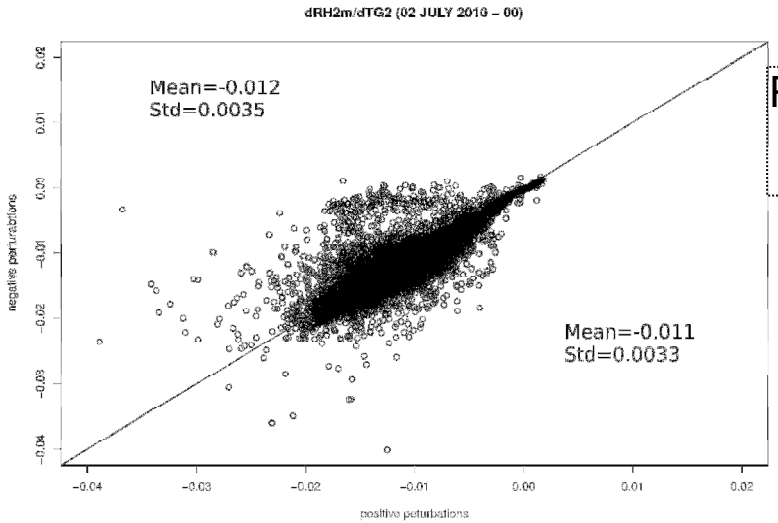




Pert. size: 10^{-1}

Pert. size: 10^{-6}





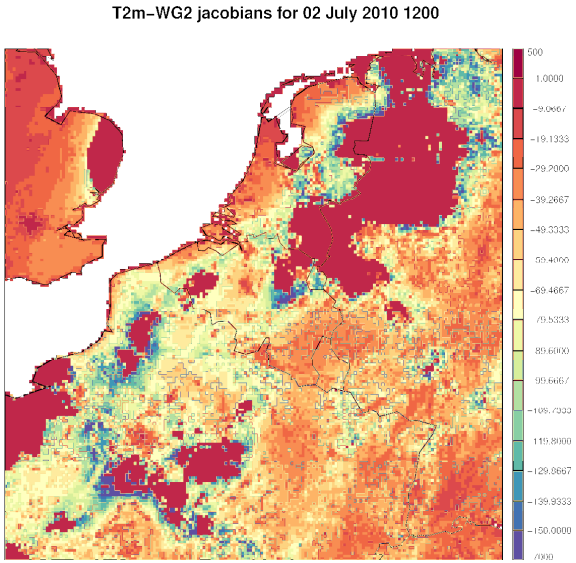
Pert. size: 10^{-1}

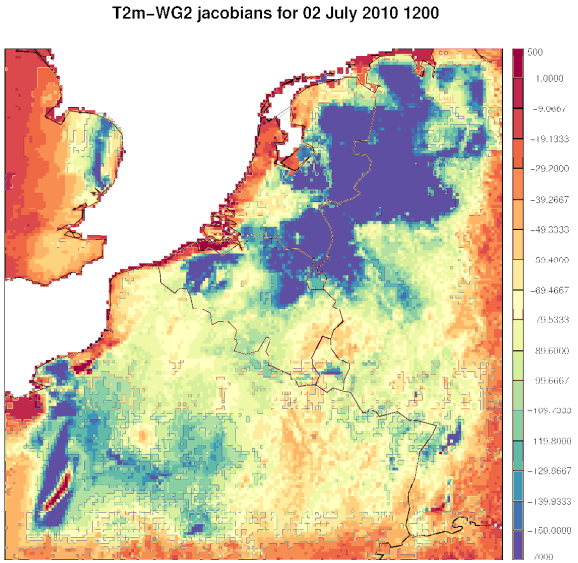
Jacobian Matrix Elements

EKF offline

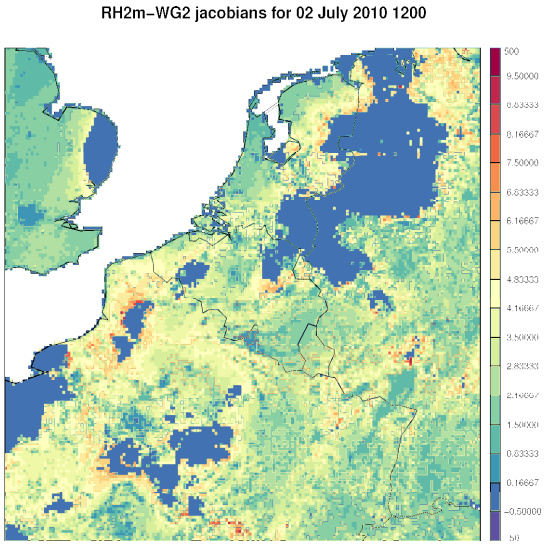
EKF coupled

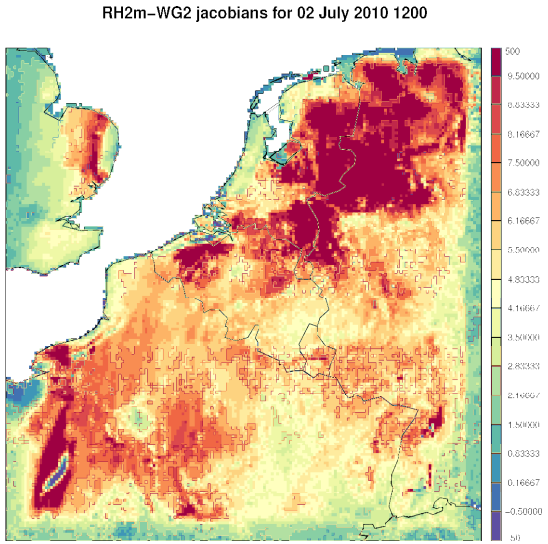
T2m-WG2





RH2m-WG2



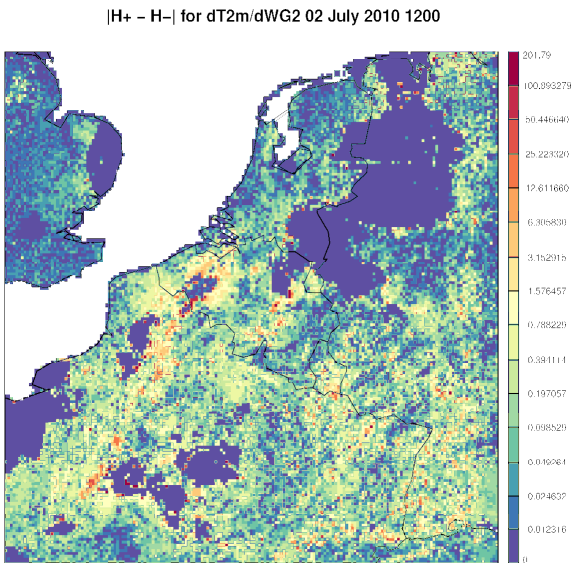


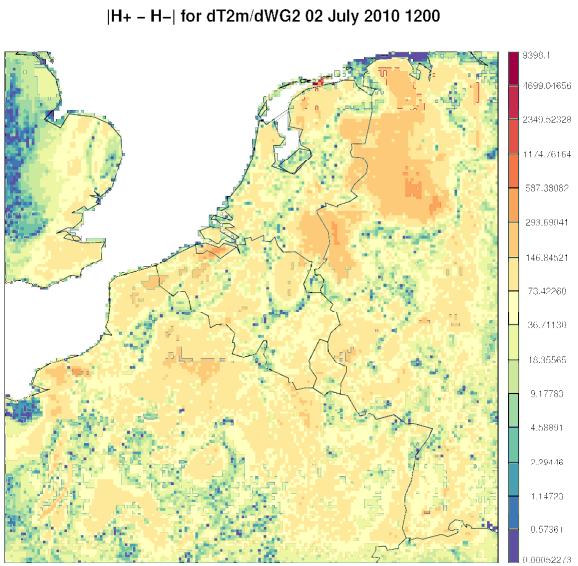
Jacobian Non-linearities

EKF offline

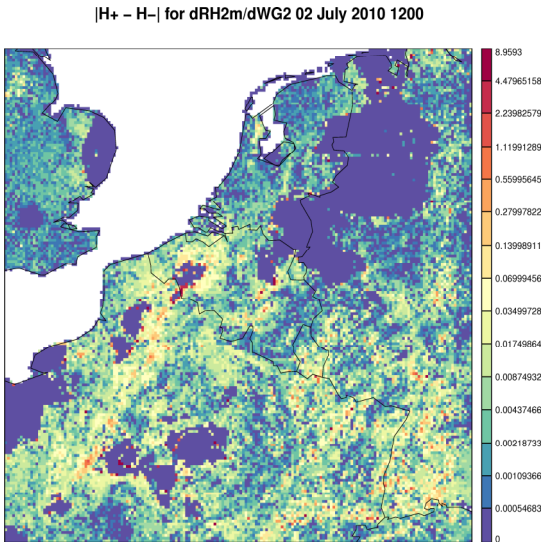
EKF coupled

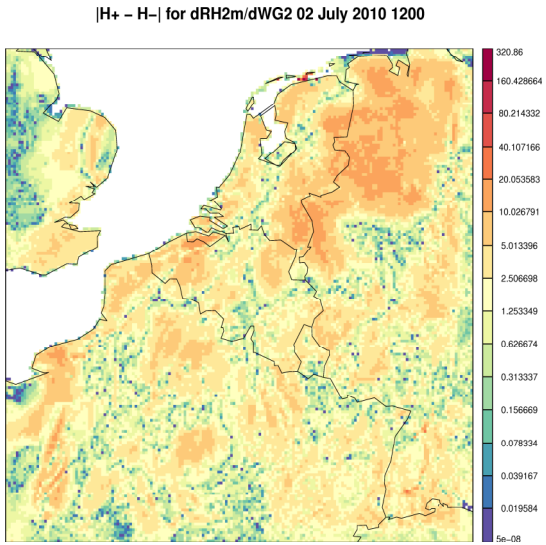
T2m-WG2





RH2m-WG2





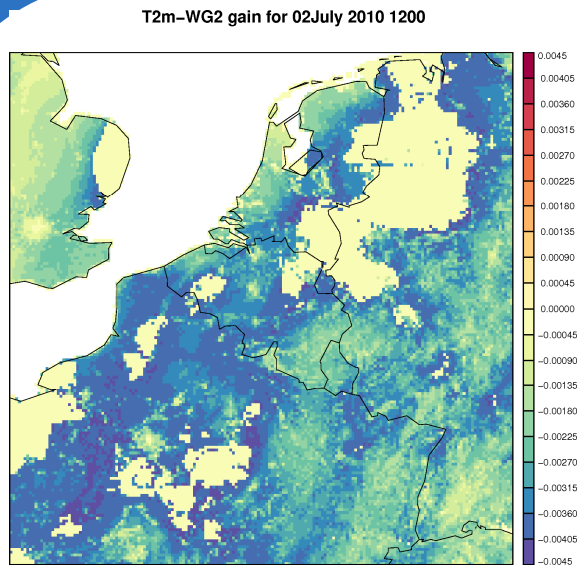
Gain Matrix Elements

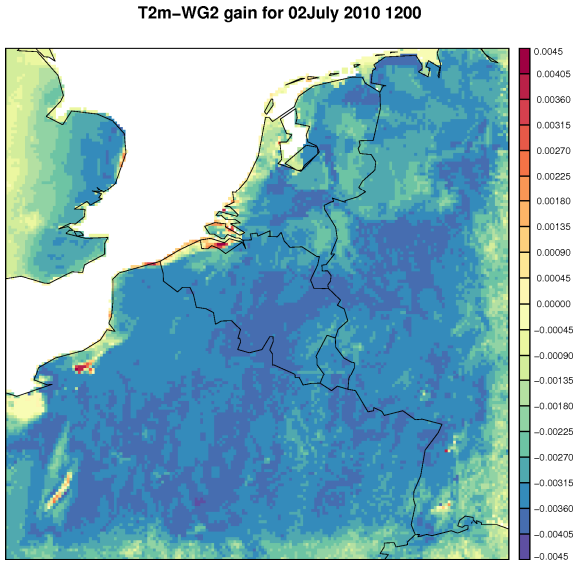
EKF Offline

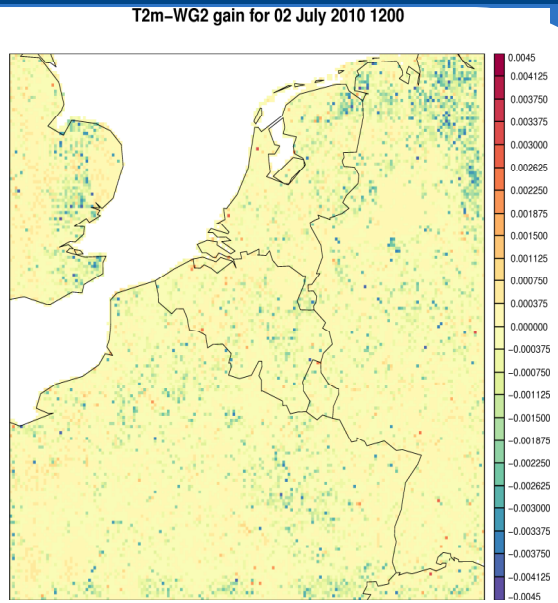
EKF Coupled (large pert.)

EKF Coupled (small pert.)

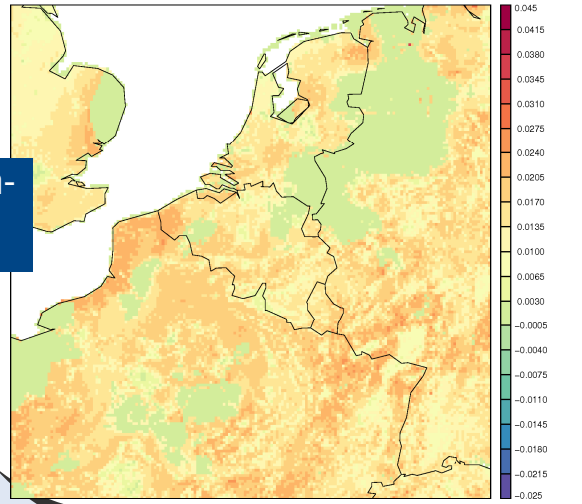
T2m-WG2

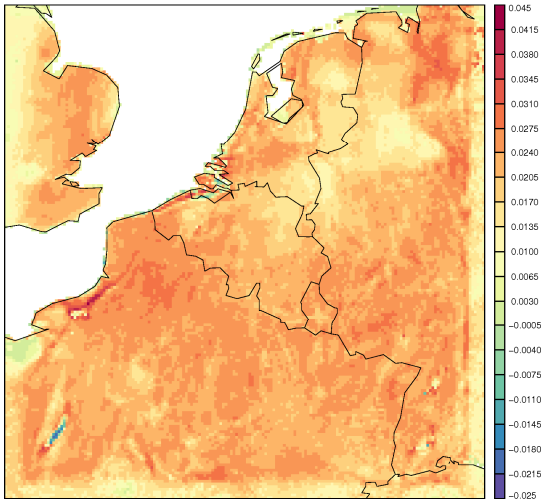


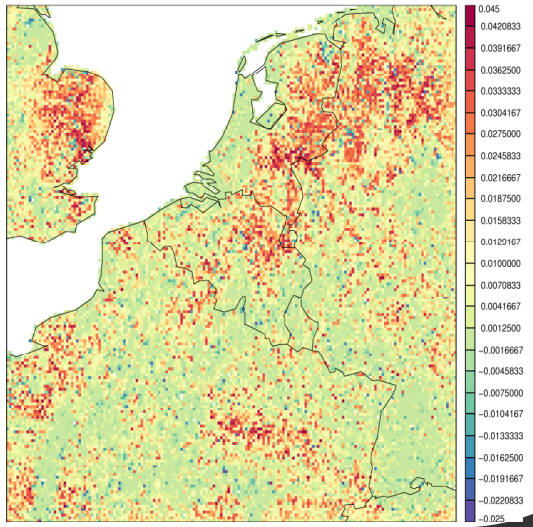




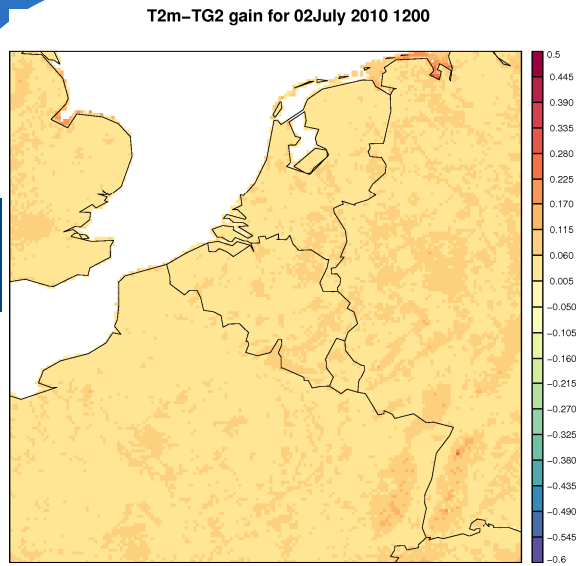
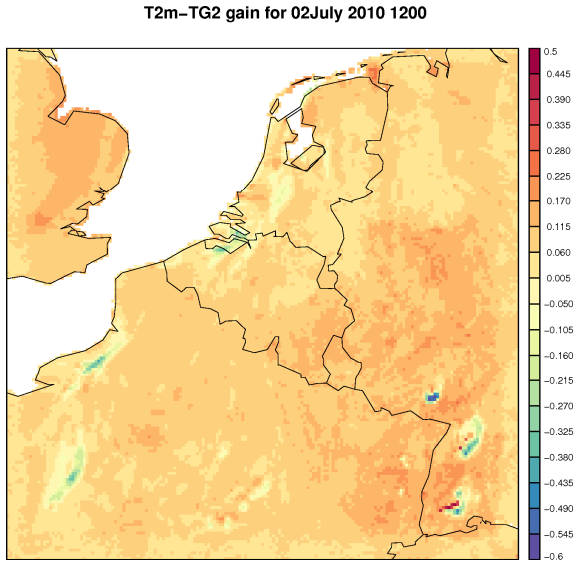
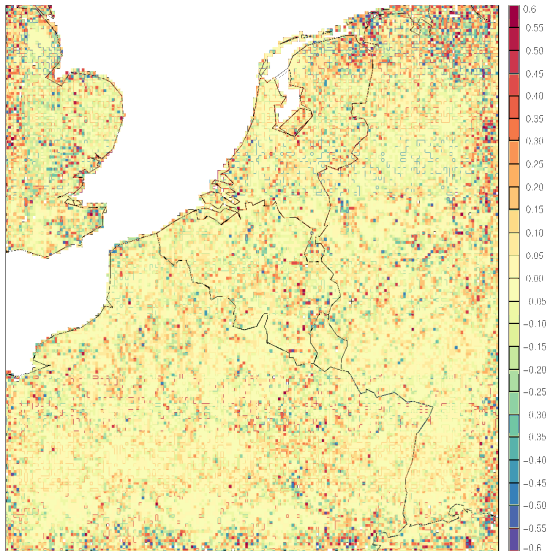
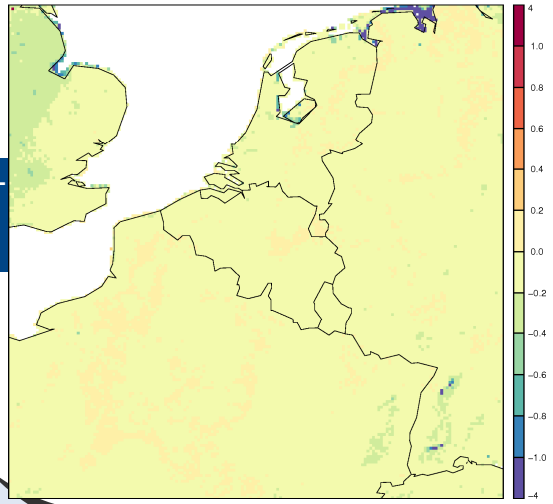
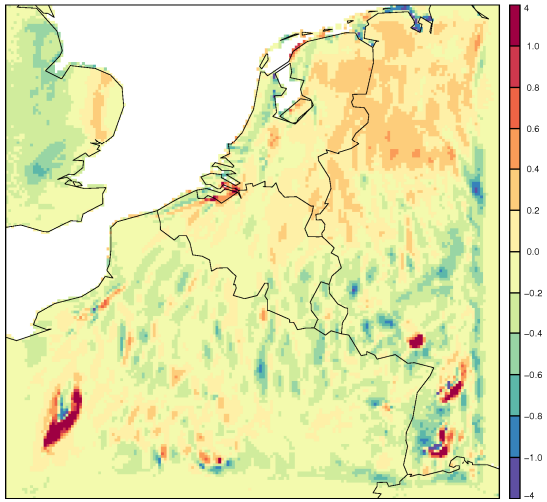
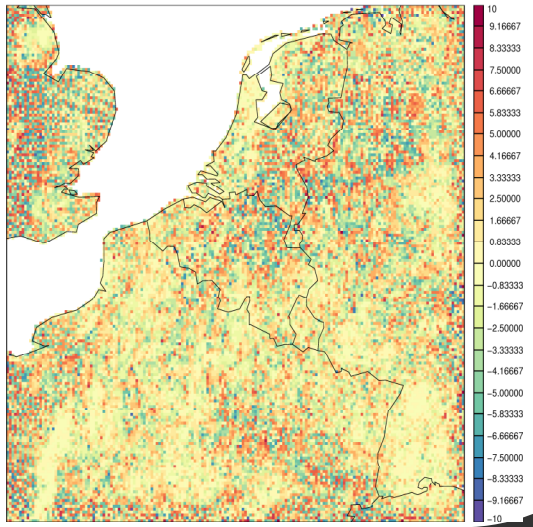
RH2m-WG2



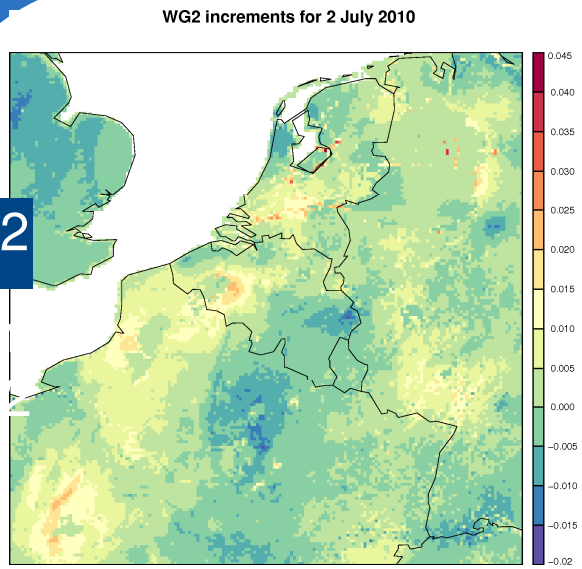
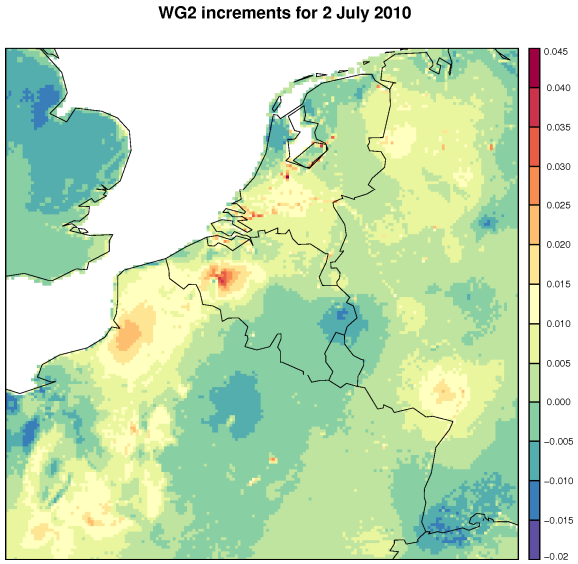
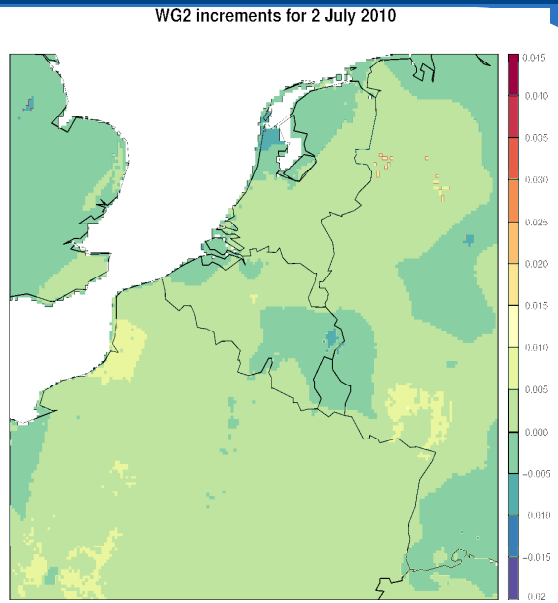
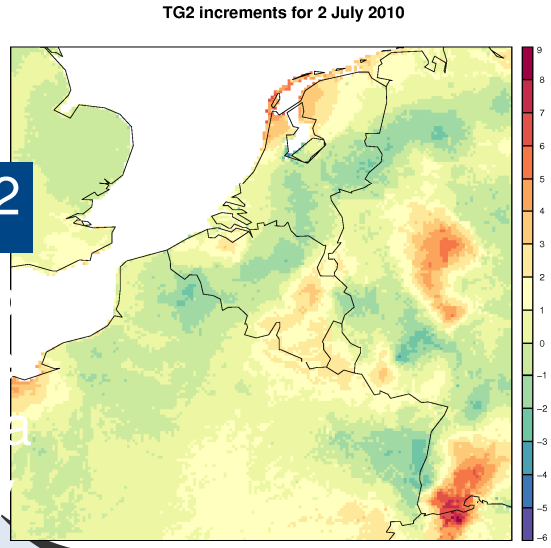
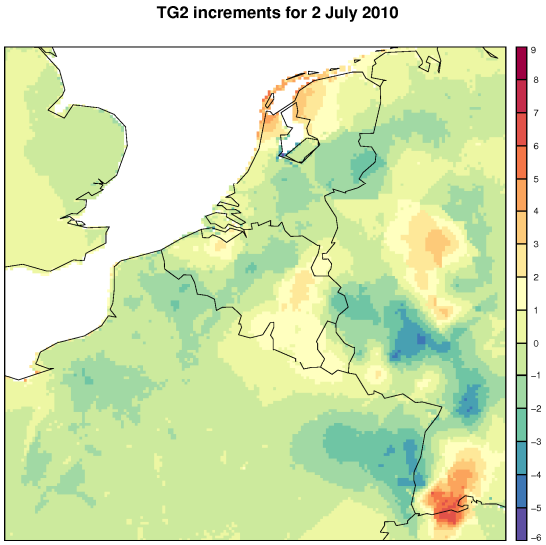
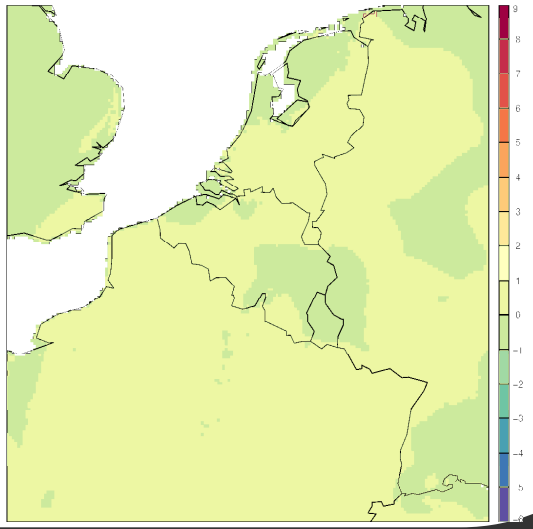




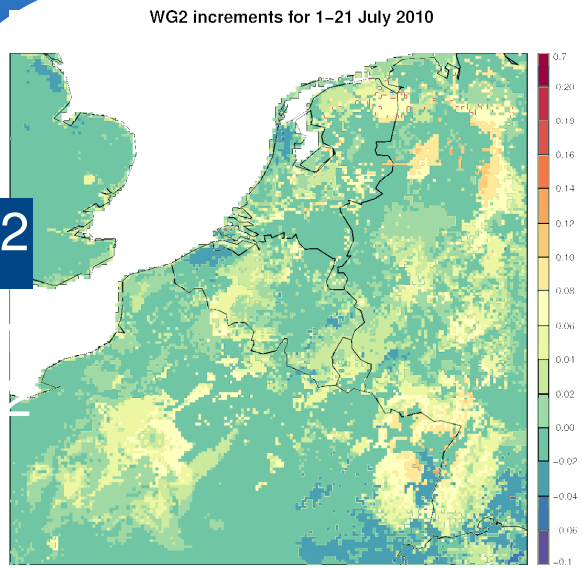
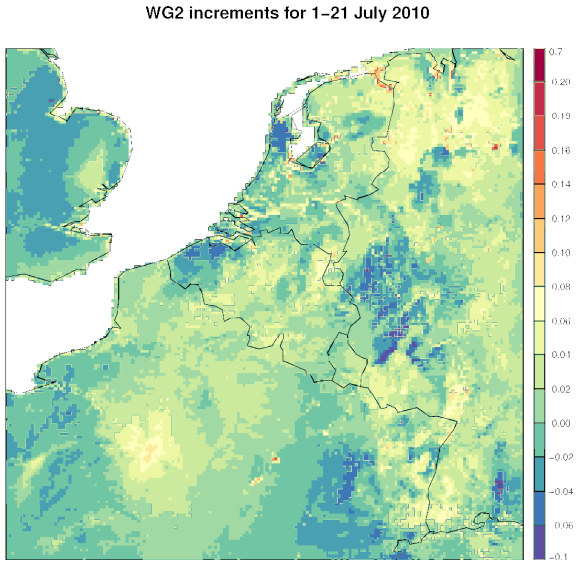
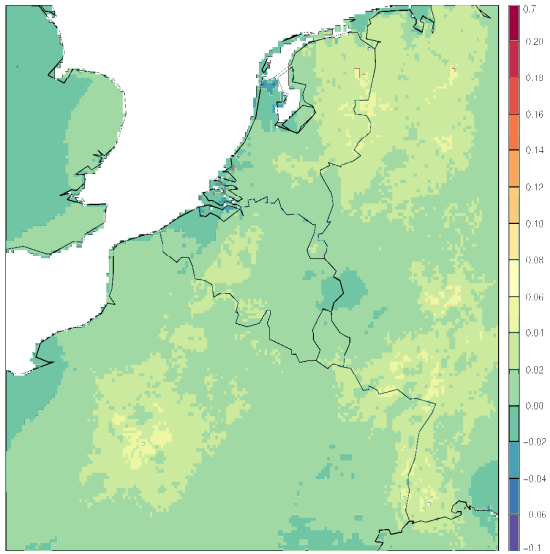
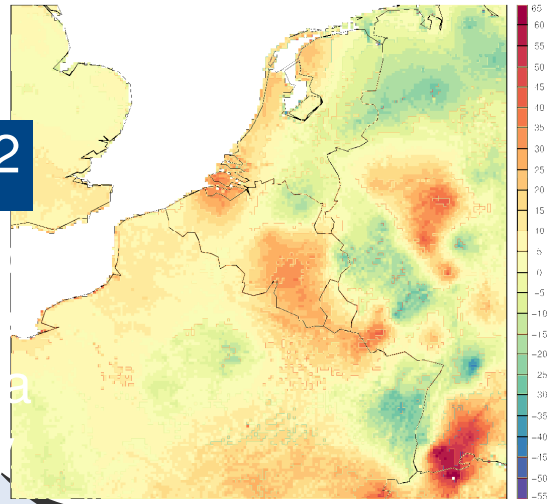
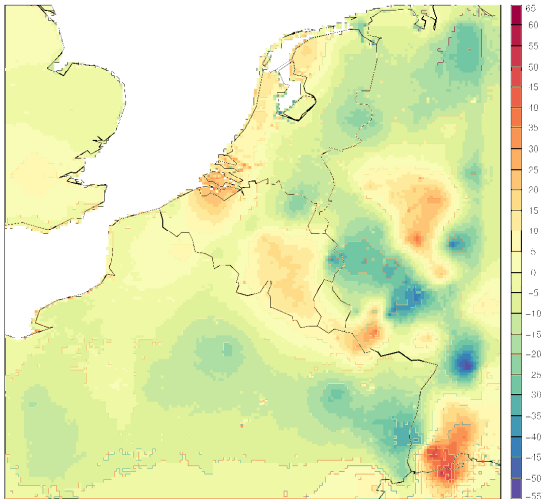
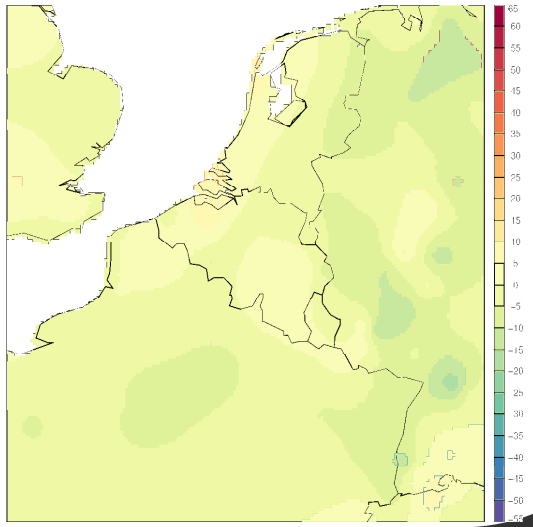
Gain Matrix Elements

	EKF Offline	EKF Coupled (large pert.)	EKF Coupled (small pert.)
T2m-TG2			
RH2m-TG2			

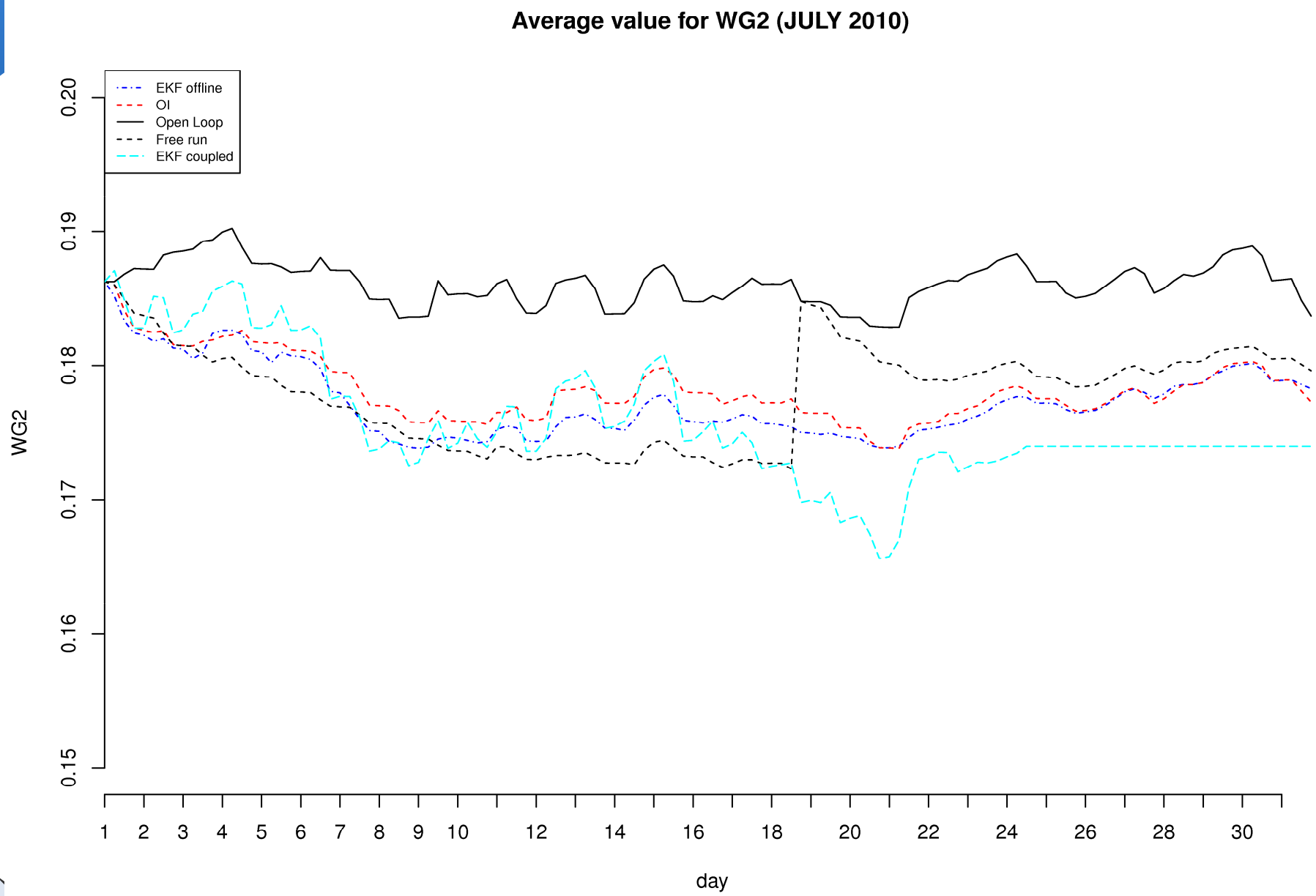
Increments (single day)

	EKF Offline	EKF Coupled (large pert.)	OI
WG2			
TG2			

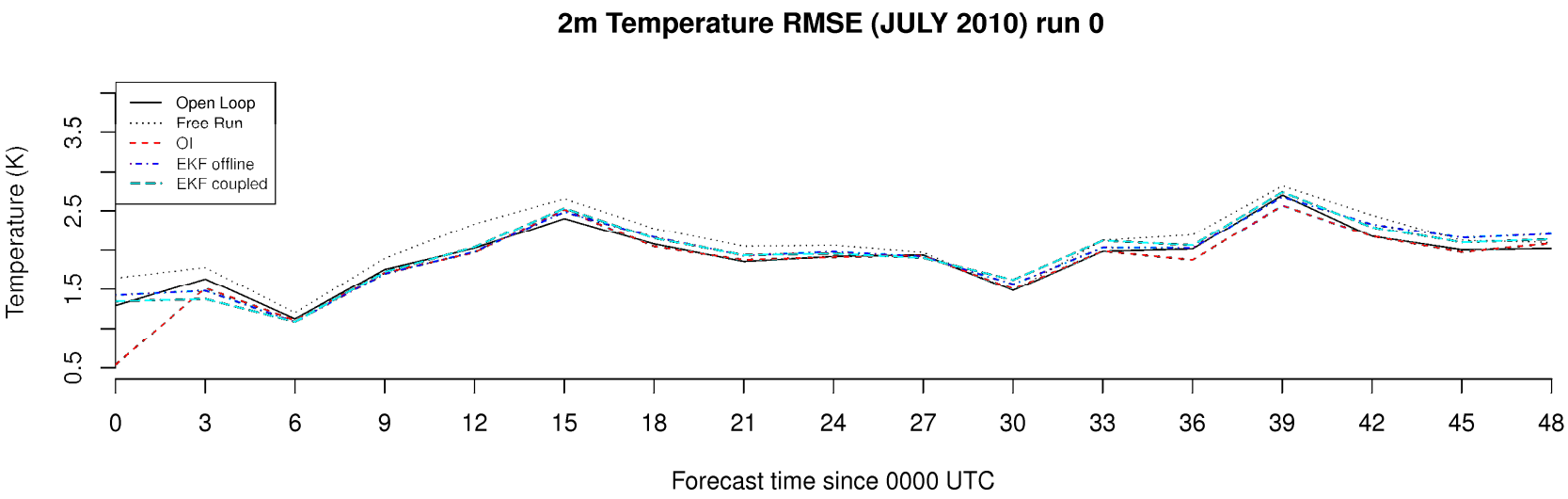
Cummulative Increments (1-21 july 2010)

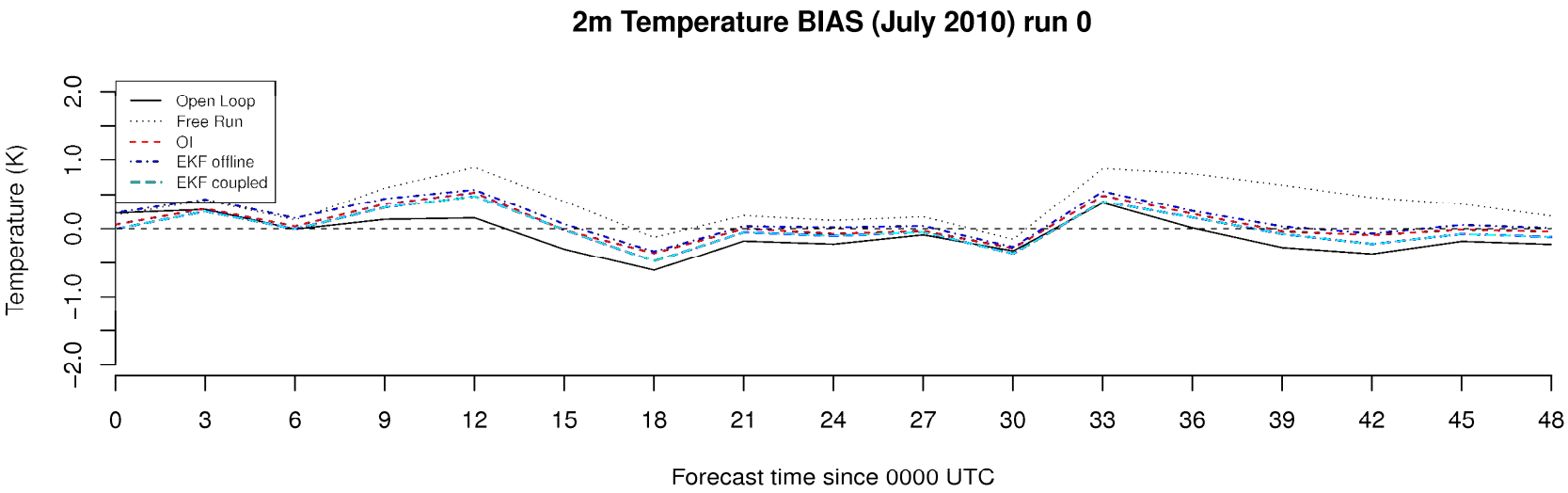
	EKF Offline	EKF Coupled (large pert.)	OI
WG2			
TG2			

WG2 Evolution during July 2010

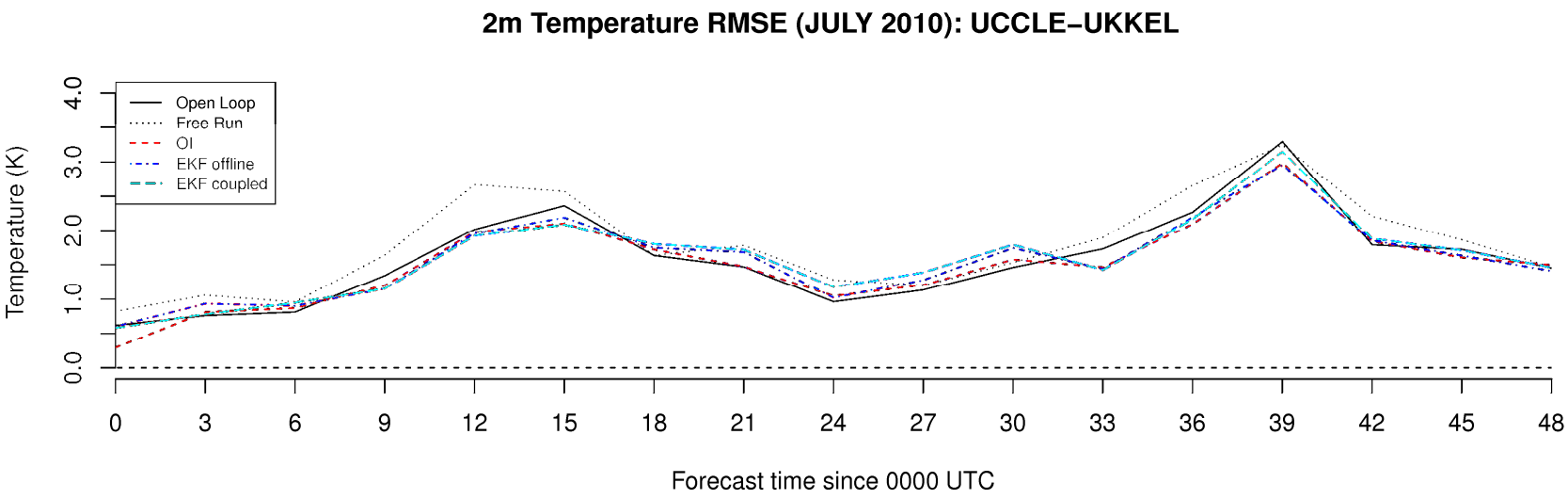


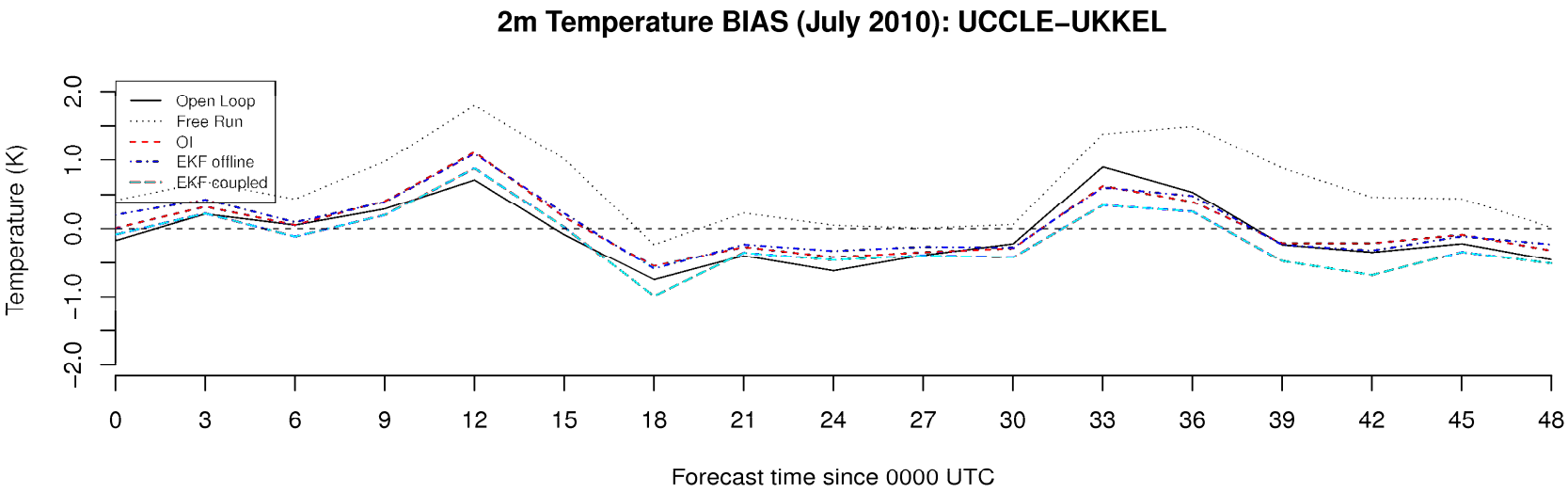
Scores


2m Temperature RMSE (JULY 2010) run 0
Open Loop
Free Run
OI
EKF offline
EKF coupled
Temperature (K)
0.5
1.5
2.5
3.5
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC

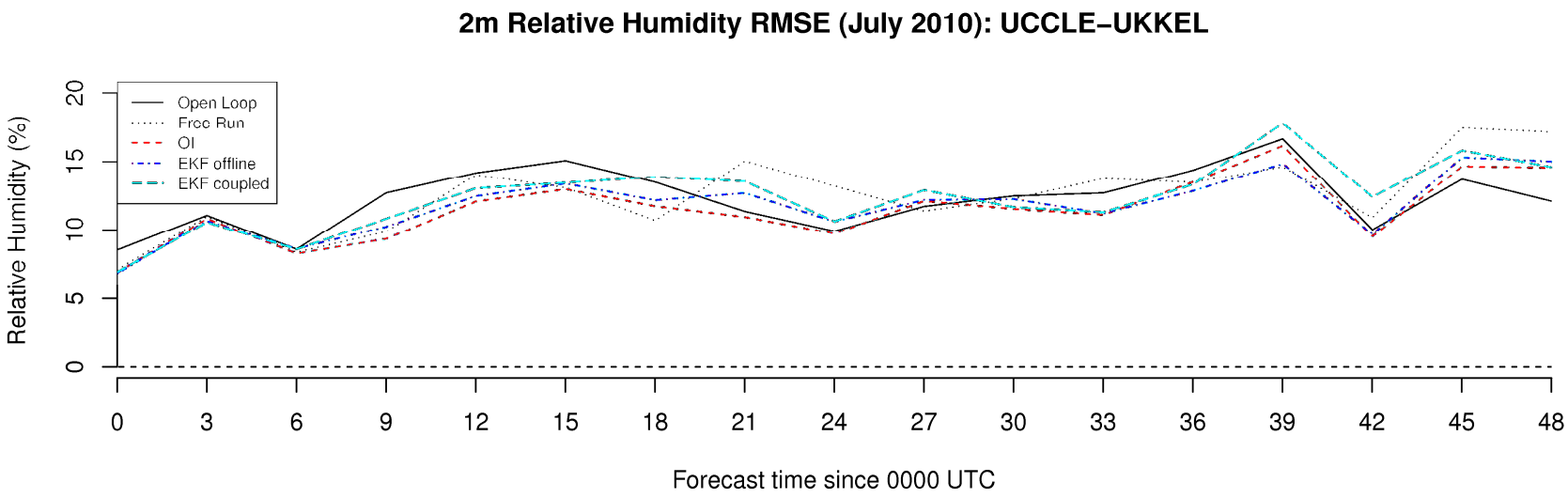

2m Temperature BIAS (July 2010) run 0
Open Loop
Free Run
OI
EKF offline
EKF coupled
Temperature (K)
−2.0
−1.0
0.0
1.0
2.0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC

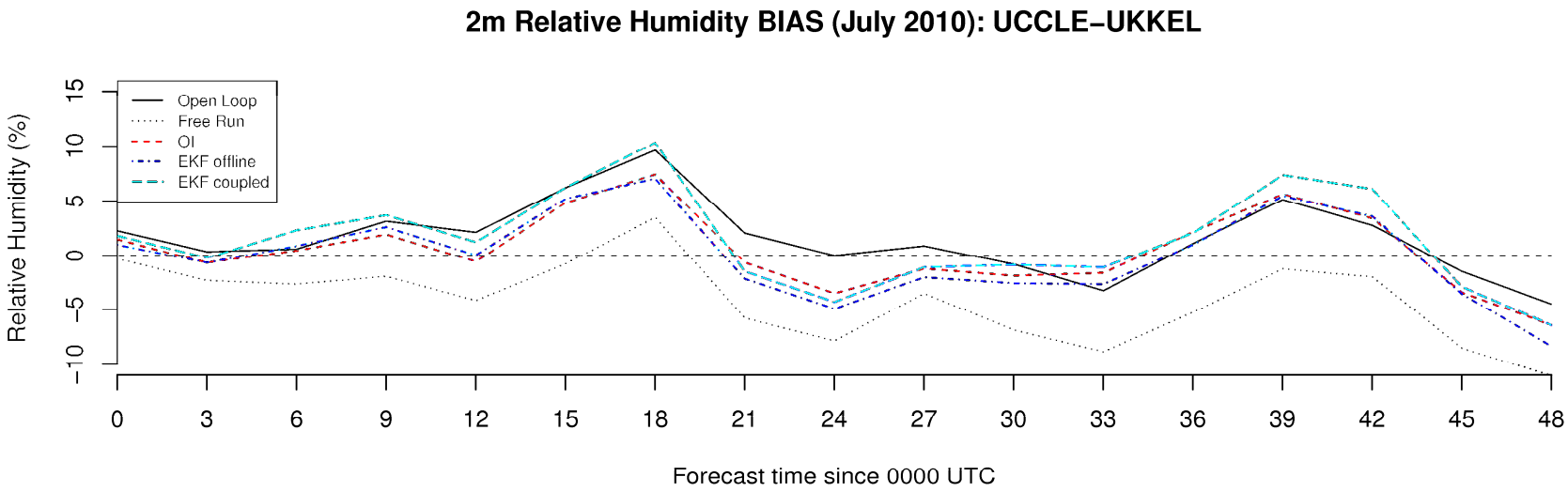
Scores


2m Temperature RMSE (JULY 2010): UCCLE–UKKEL
Open Loop
Free Run
OI
EKF offline
EKF coupled
Temperature (K)
0.0
1.0
2.0
3.0
4.0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC


2m Temperature BIAS (July 2010): UCCLE–UKKEL
Open Loop
Free Run
OI
EKF offline
EKF coupled
Temperature (K)
−2.0
−1.0
0.0
1.0
2.0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC

Scores


2m Relative Humidity RMSE (July 2010): UCCLE–UKKEL
Open Loop
Free Run
OI
EKF offline
EKF coupled
Relative Humidity (%)
0
5
10
15
20
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC


2m Relative Humidity BIAS (July 2010): UCCLE–UKKEL
Open Loop
Free Run
OI
EKF offline
EKF coupled
Relative Humidity (%)
−10
−5
0
5
10
15
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
Forecast time since 0000 UTC

- Comparison offline and coupled EKF:
  - Similar spatial structures for jacobians, gain and increments
  - Some differences for WG2, but limited effect on the scores
  - Differences

    coupled: more sensitive to perturbation size.
    - Too small: noisy H-matrix
    - Too large: not linear

    offline: less sensitive to perturbation size.
    - Allows for a smaller perturbation size → the jacobians are more linear
    - Smaller gain and increments
  - Computing time: 6 min. offline vs. 44 min. coupled

- Effect on the scores:
  - OI, offline EKF and coupled EKF scores lie close together
  - Offline run: the perturbation size has limited effect on scores
  - Winter: data assimilation has no effect on the scores

- Future Plans:
  - Combine surface assimilation with 3DVAR

Bibliography:

G. Balsamo, J.-F. Mahfouf, S. Bélair, G. Deblonde, 2007: A Land Data Assimilation System for soil moisture and temperature: An information content study. J. Hydromet., 8, 1225-1242

G. Balsamo, F. Bouyssel and J. Noilhan, 2004: A simplified bi-dimensional variational analysis of soil moisture from screen-level observations in a mesoscale numerical weather prediction model, Quart. J. Roy. Meteor. Soc., 130, 895-915.