Combining the EKF soil analysis with a three dimensional variational upper-air assimilation for ALARO

Rafiq Hamdi, **Annelies Duerinckx,** Alex Deckmyn, Piet Termonia

Original idea by J-F. Mahfouf

1. Introduction

2. Surface assimilation only

3. Combination: surface and upper air assimilation

4. Summary & Future work

Surface Analysis and upper air analysis

- For the time being surface analysis are performed separately from upper air analysis. In theory a single analysis would be better but it is much more difficult to implement:

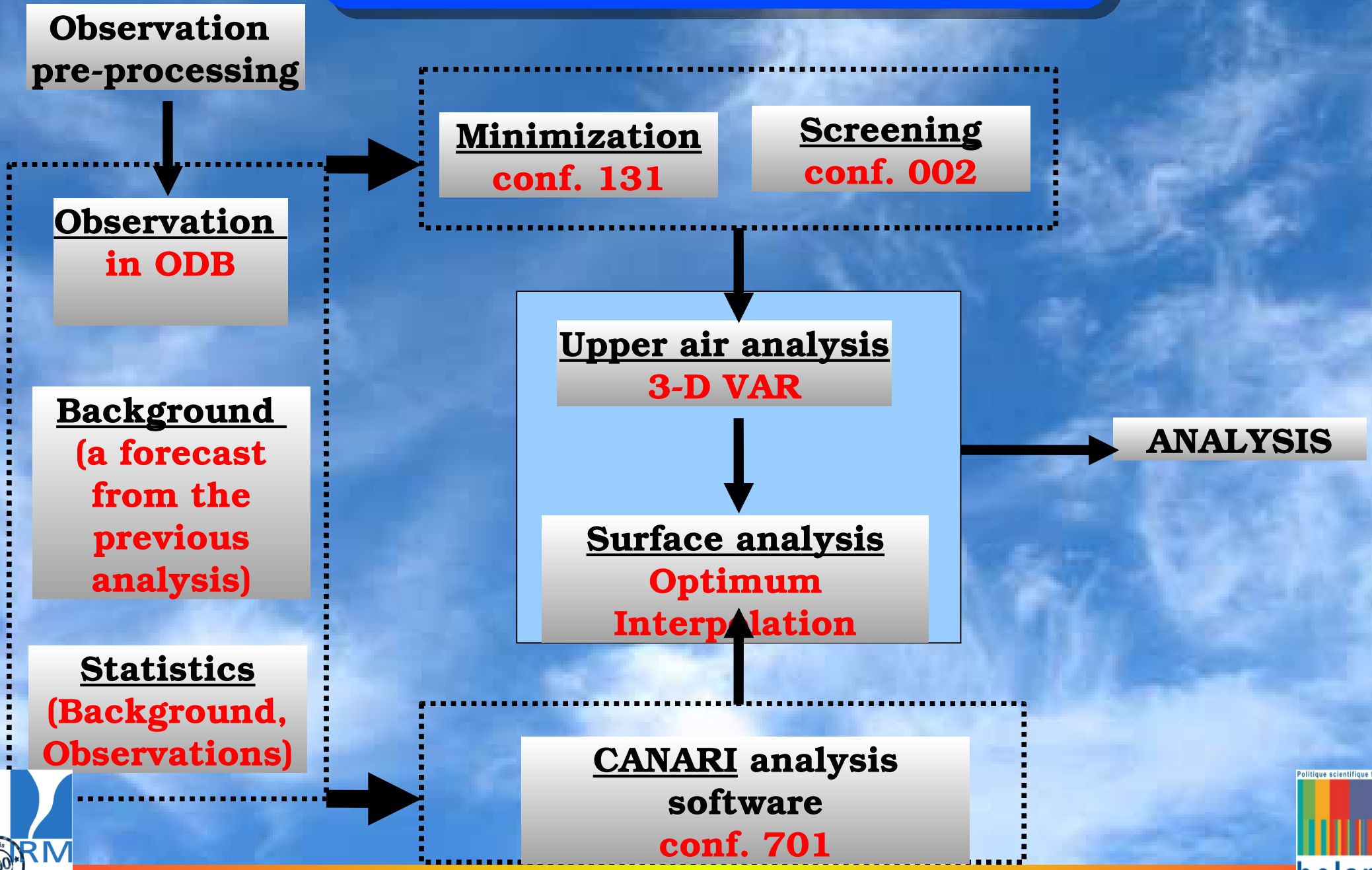
  1) definition of **B** between upper air and surface variables,

  2) time scale evolutions may be different, ...

- For the time being several surface analysis are used for different surface parameters (Soil temperature and Soil moisture, Snow, SST, Sea ice, ...

- Atmospheric analysis and several surface analysis are done separately and combined to provide the final analysis for the forecast.

Surface Analysis and upper air analysis



Surface Analysis and upper air analysis

- Question: Whether combining surface assimilation with upper-air assimilation has an added value compared to using either of them separately?

- Randriamampianina and Storto (2008) → improvement for short forecast range
- Schneider et al. (2009) → results more mixed
- Stanesic (2011) → positive for 2m T, RH and upper air RH
- de Rosnay et al. (2012) → EKF with 4D-Var operationally at ECMWF

- Duerinckx et al. (2016) focuses on **new** combination **EKF+3D-Var** tested with ALARO-0 coupled to SURFEX

Simulation set-up

	Initial Conditions	
	Atmosphere	Soil
Open Loop (OL)	ARPEGE analysis	ARPEGE analysis
Optimum Interpolation (OI)	ARPEGE analysis	OI
Extended Kalman Filter (EKF)	ARPEGE analysis	EKF
3dVar+OL	3dVar	ARPEGE analysis
3dVar+Free run	3dVar	6h fc. from prev. run
3dVar+OI	3dVar	OI
3dVar+EKF	3dVar	EKF
3dVar+OI/EKF	3dVar	OI(soil temp.) + EKF(soil moisture)

Prognostic Variables :

- Soil moisture content : Wg and W2
- Soil temperature : Ts and T2

Observations : T2m and RH2m

- Interpolated to model grid with CANARI

- ALARO-0
- SURFEX/ISBA 2-layer version
- One year run for 2013
- 6-hour assimilation cycle
- Operational ALADIN-Belgium domain 4km resolution
- 181x181 grid point and 46 vertical levels
- OPLACE database for 2m T & RH
- OPLACE conventional observations: wind profiler, radiosonde, aircraft data and surface synoptic observations.

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)

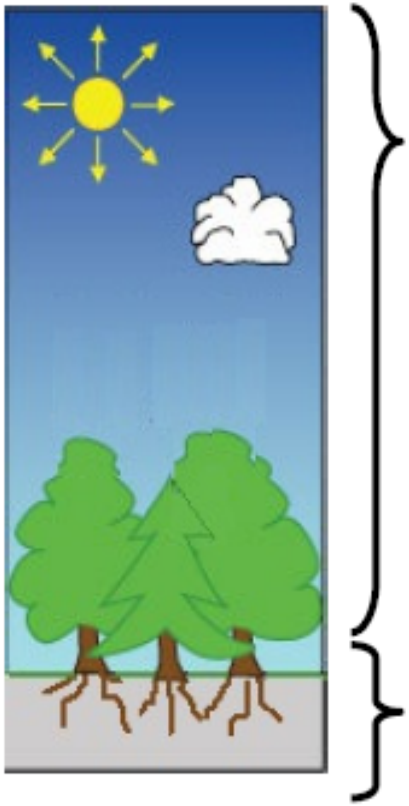
EKF: The Jacobian

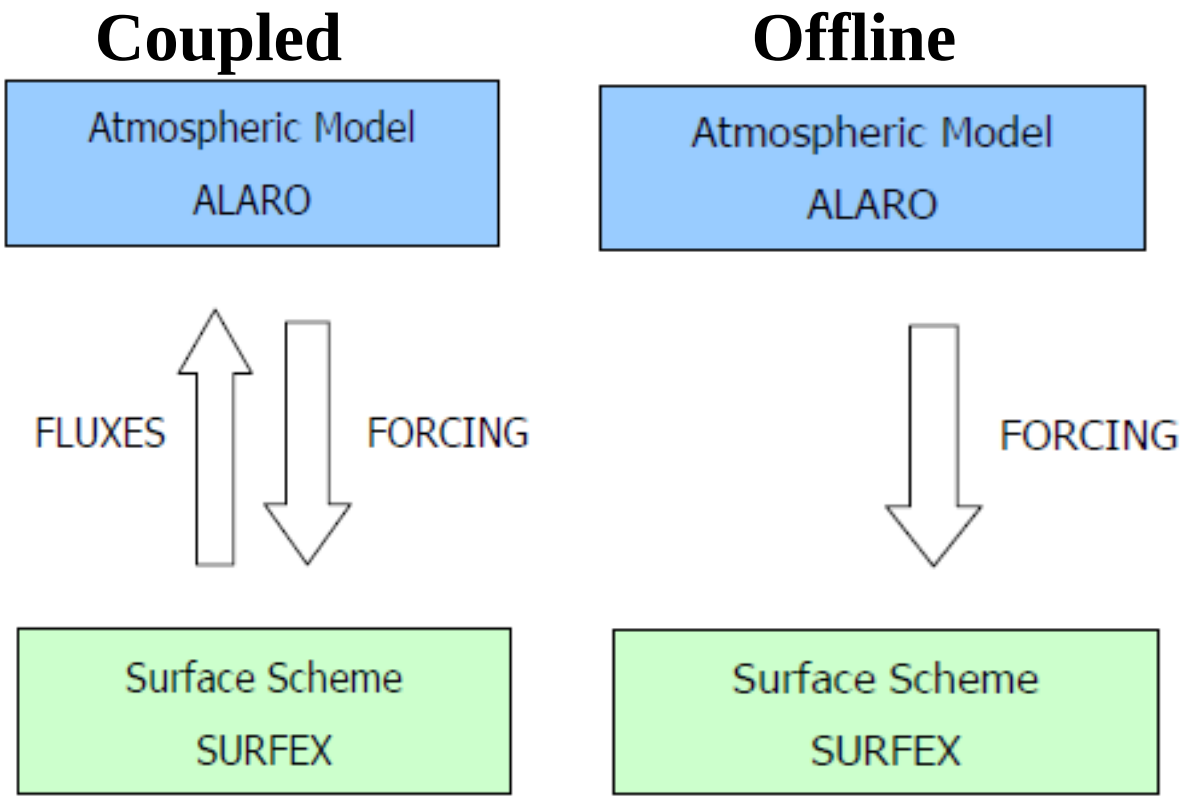
$$\mathbf{x}_t^a = \mathbf{x}_t^b + \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}[\mathbf{y}_t^o - \mathcal{H}(\mathbf{x}_o^b)]$$

- $\mathcal{H}$: 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





Coupled : used for the forecast

Offline : used in the EKF to calculate the Jacobian

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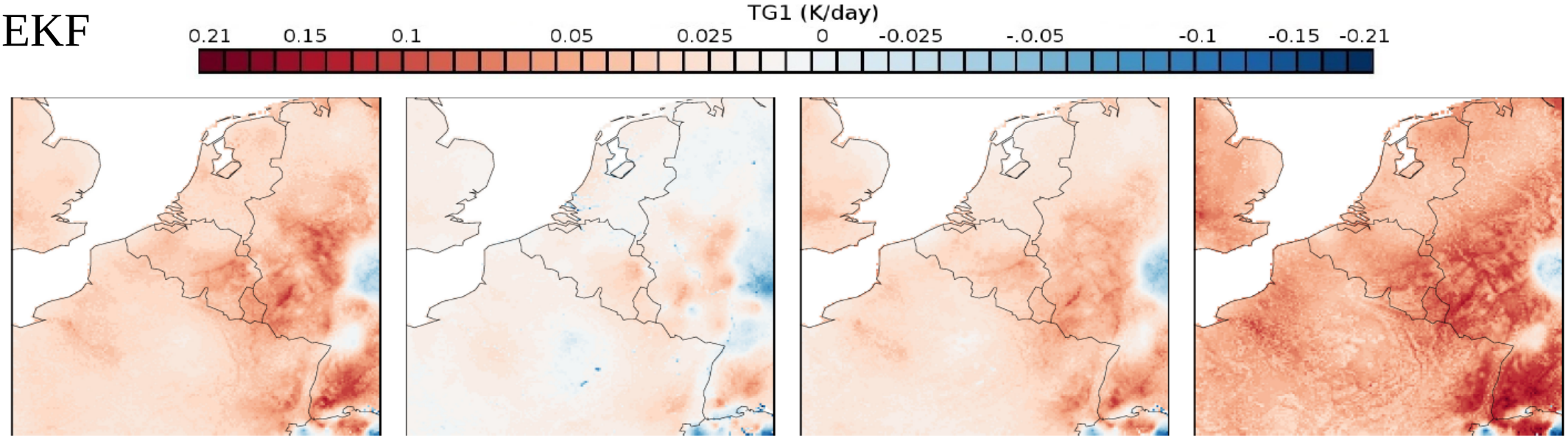
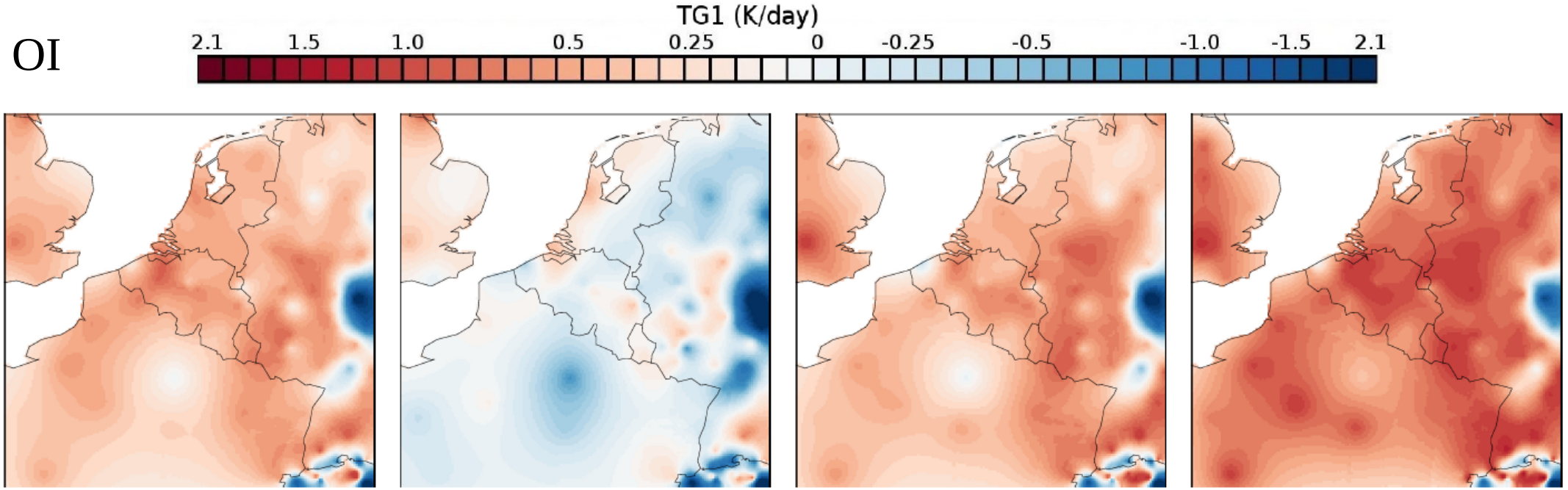
Increments

EKF



(b) TG1, Spring (c) TG1, Summer (d) TG1, Autumn (e) TG1, Winter

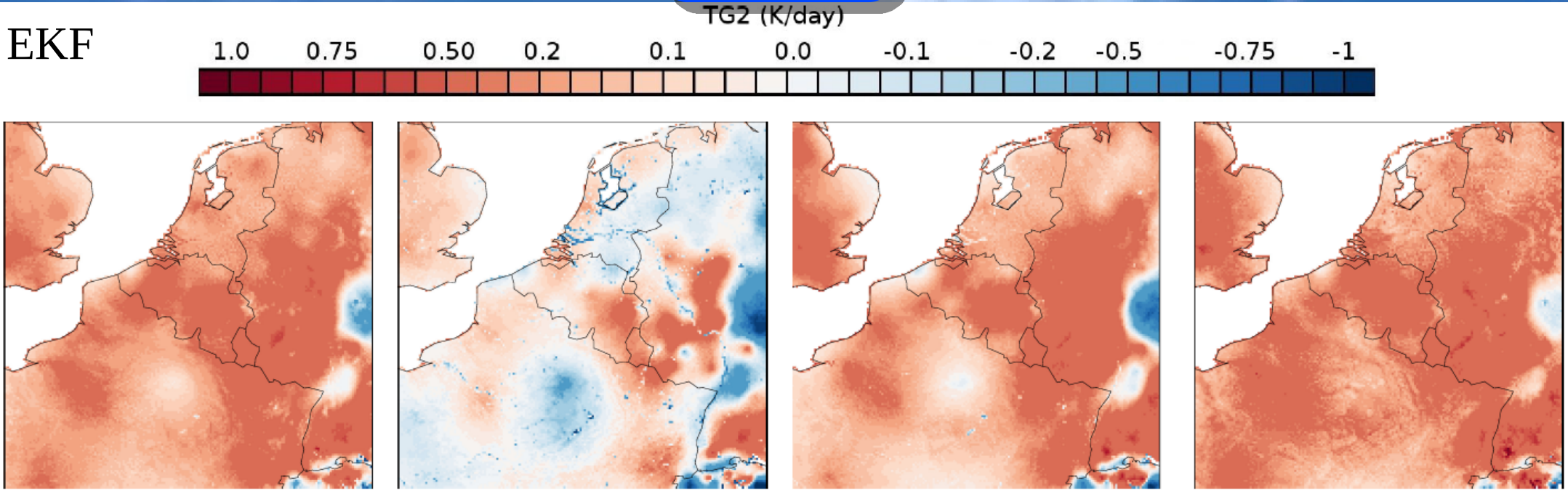
OI



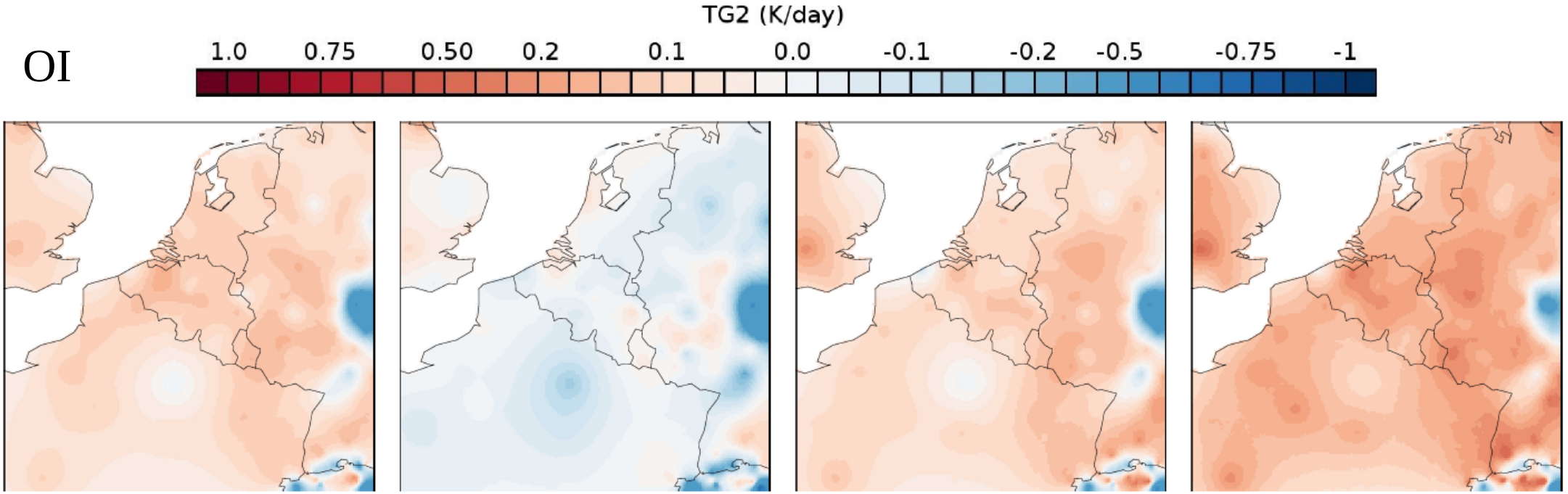
(b) TG1, Spring (c) TG1, Summer (d) TG1, Autumn (e) TG1, Winter

Increments

EKF



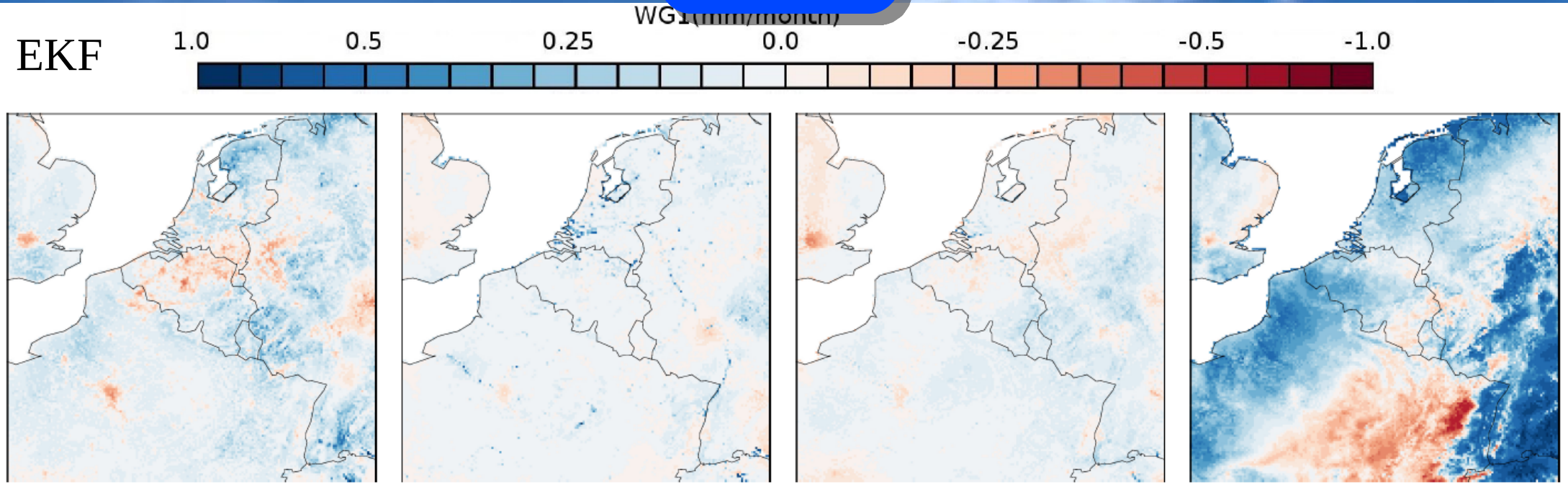
OI



(g) TG2, Spring (h) TG2, Summer (i) TG2, Autumn (j) TG2, Winter

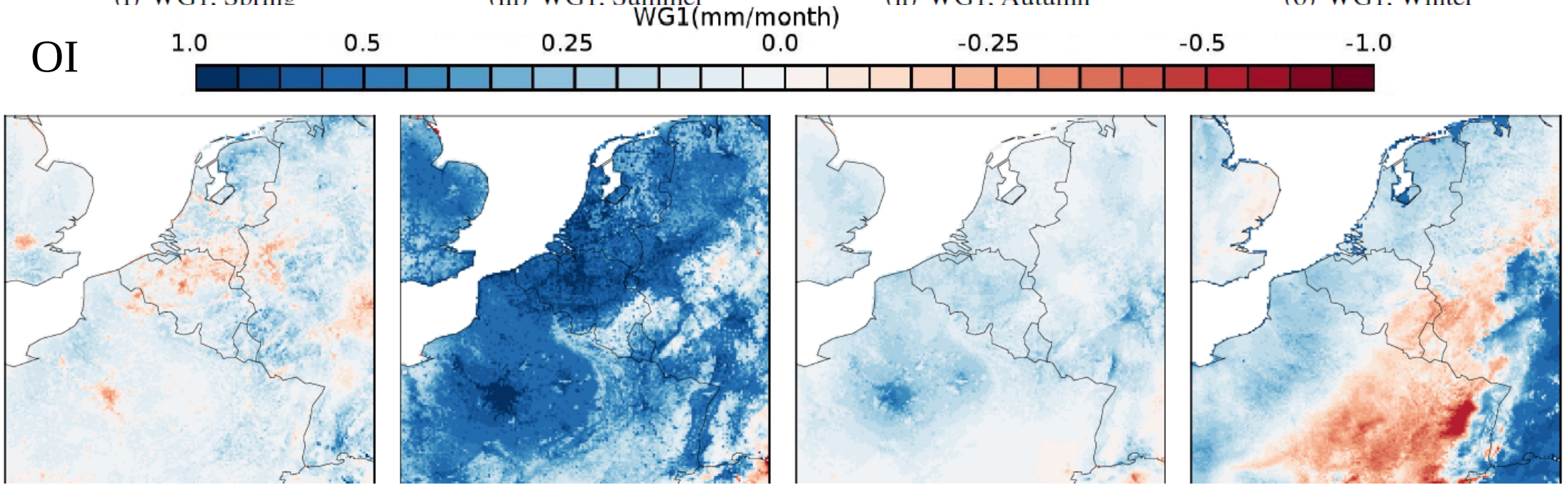
Increments

EKF



(l) WG1, Spring (m) WG1, Summer (n) WG1, Autumn (o) WG1, Winter

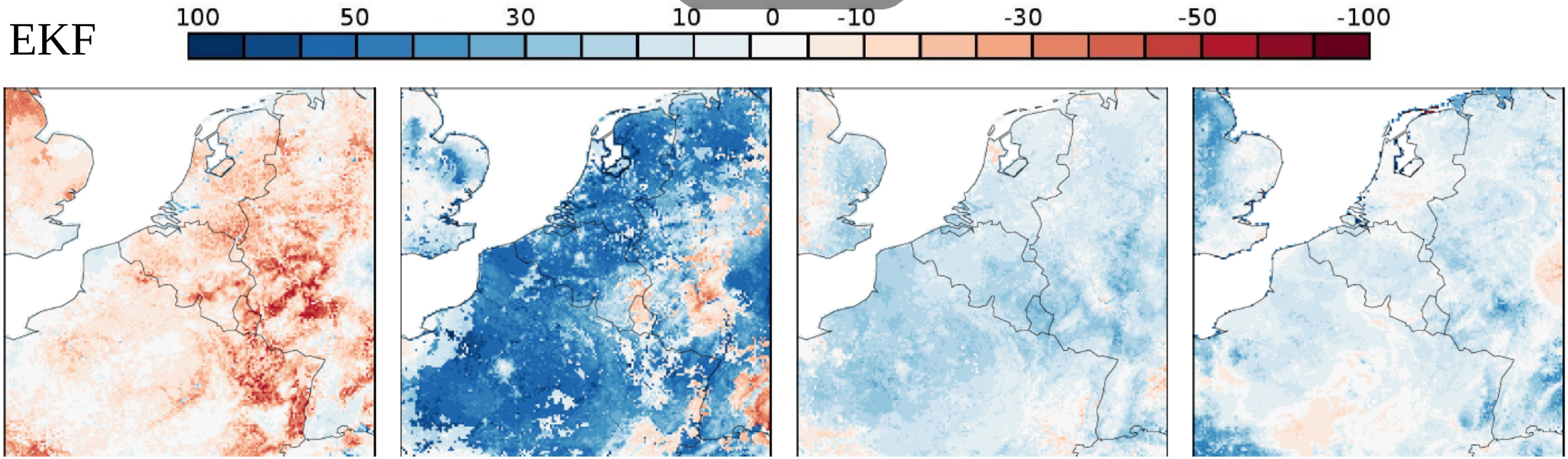
OI



(l) WG1, Spring (m) WG1, Summer (n) WG1, Autumn (o) WG1, Winter

Increments

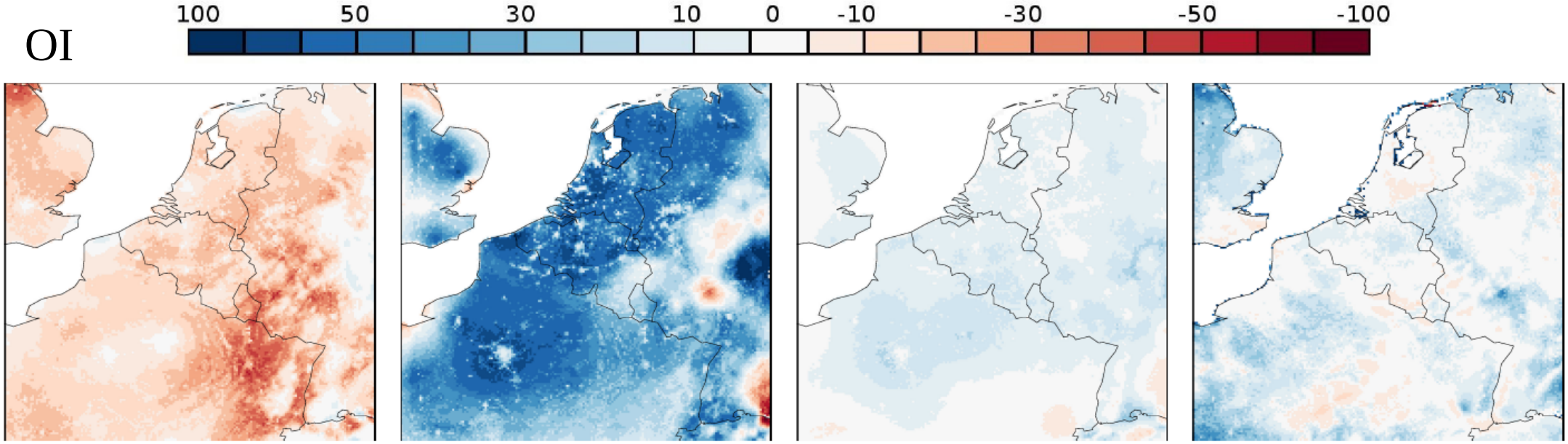
EKF



(q) WG2, Spring (r) WG2, Summer (s) WG2, Autumn (t) WG2, Winter

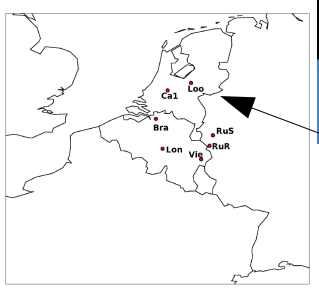
WG2 (mm/month)

OI

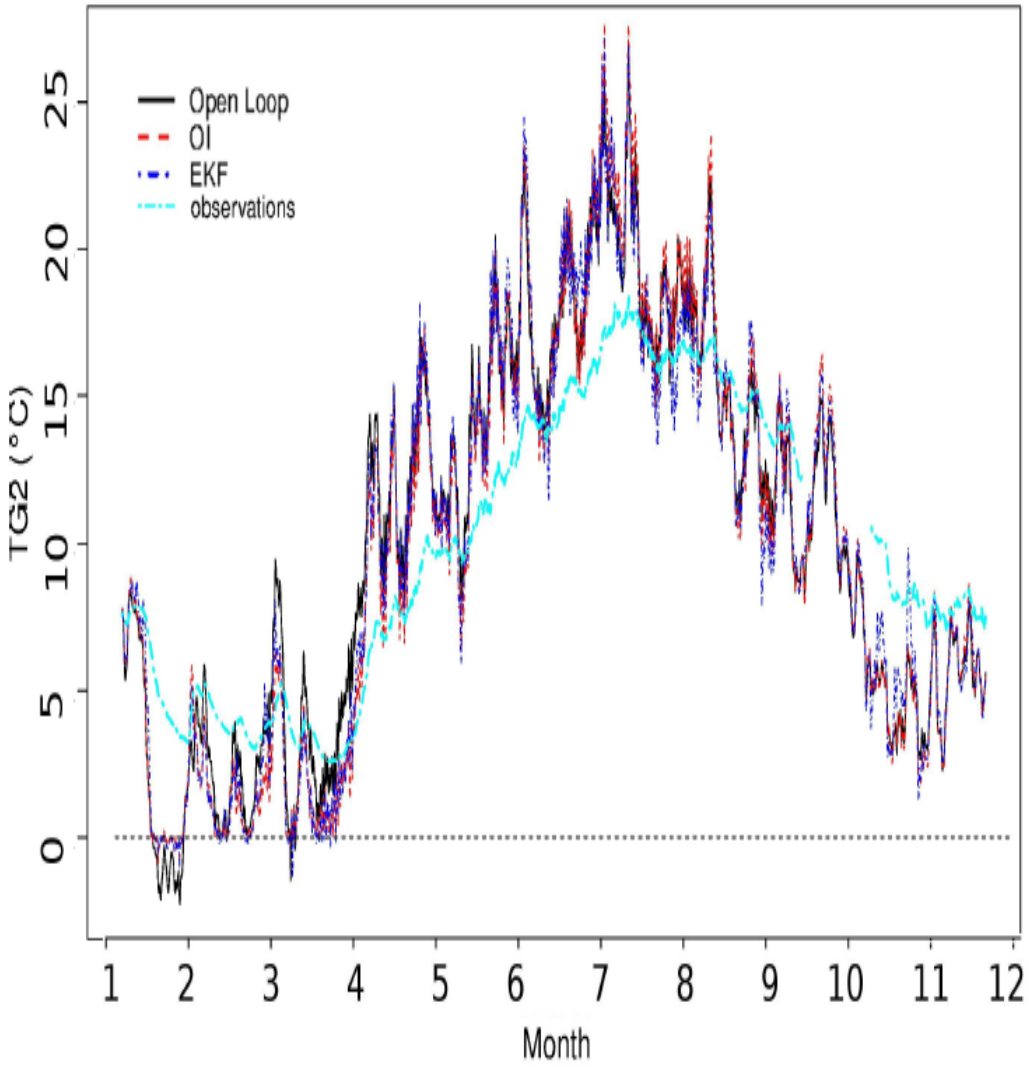


(q) WG2, Spring (r) WG2, Summer (s) WG2, Autumn (t) WG2, Winter

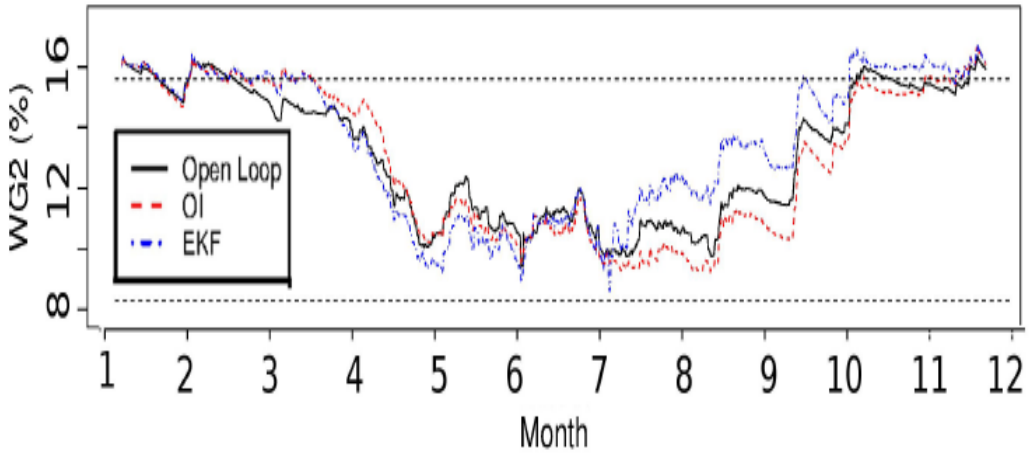
Soil moisture verification



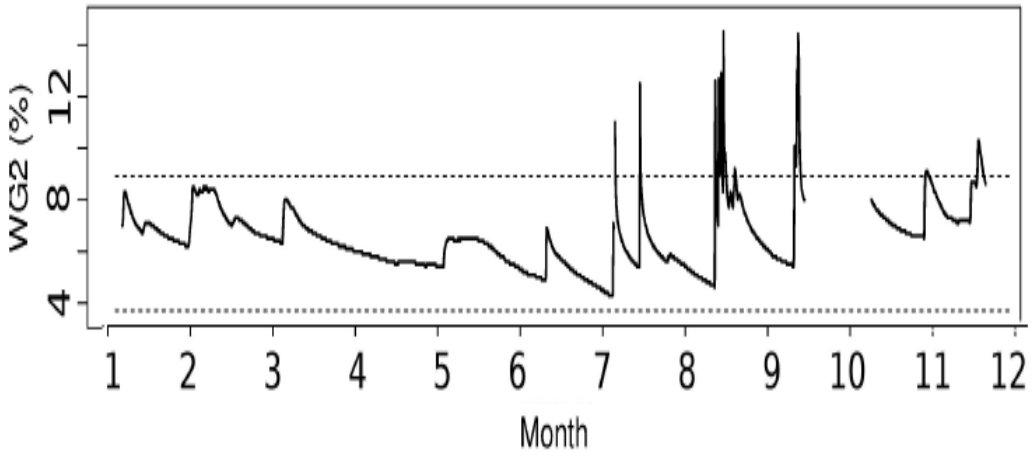
TG2 at Loo

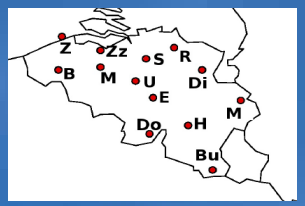


WG2 at Loo



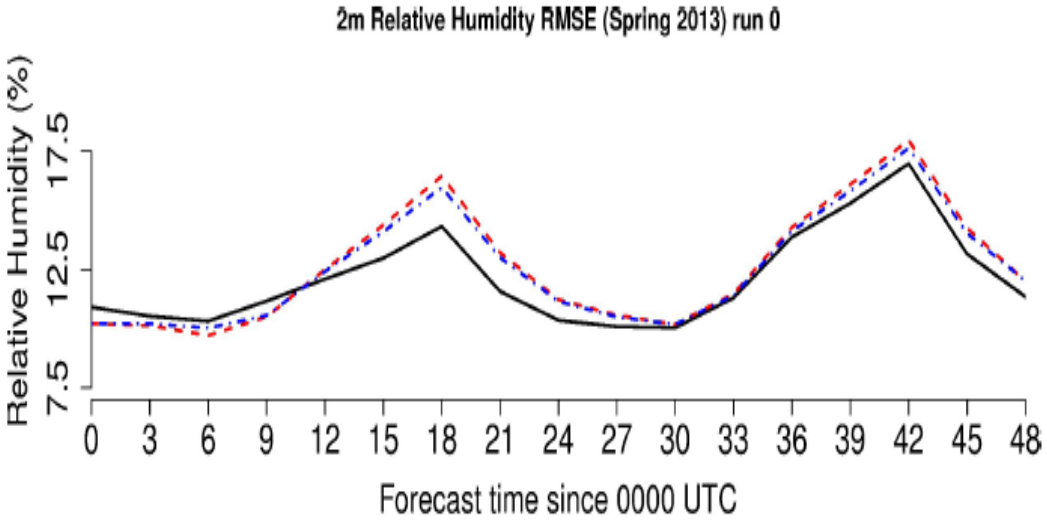
WG2 observations at Loo

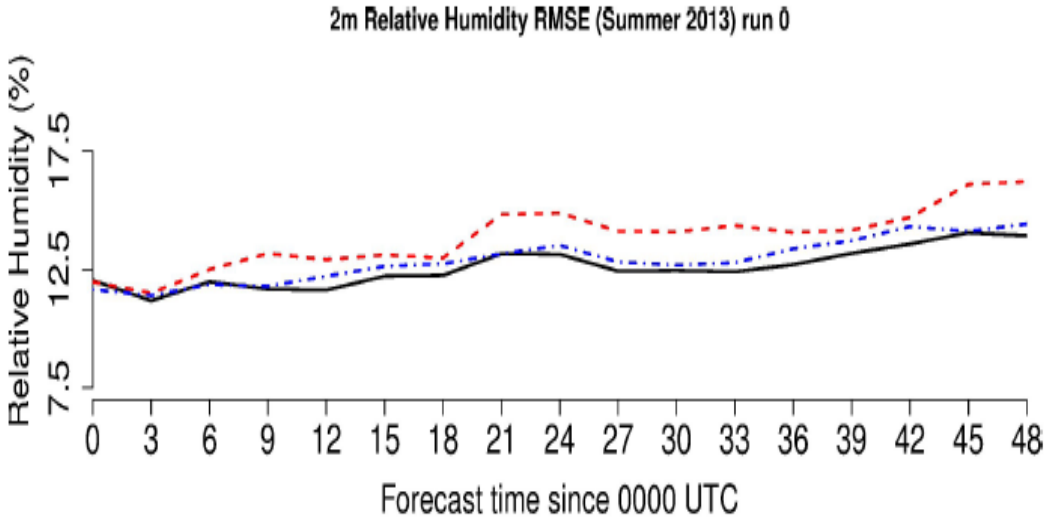


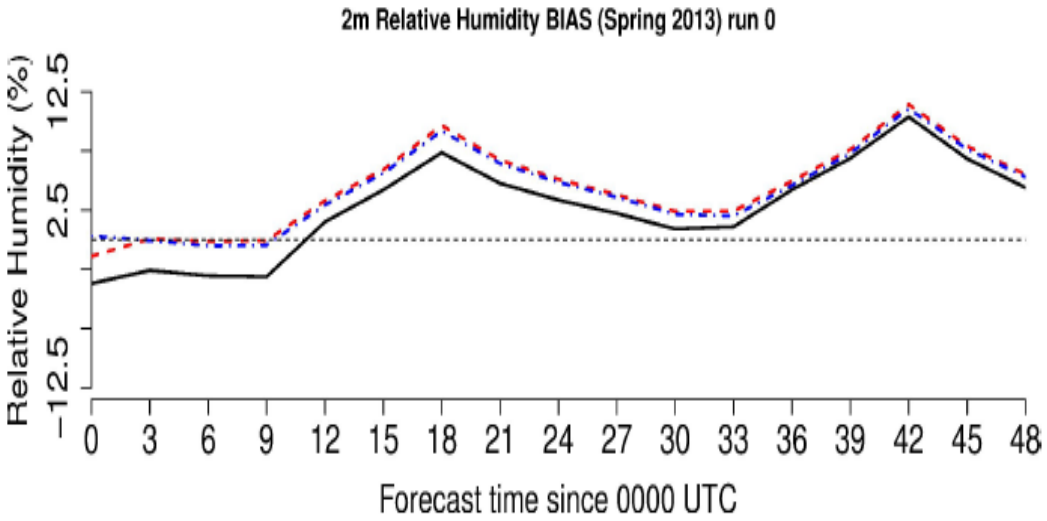


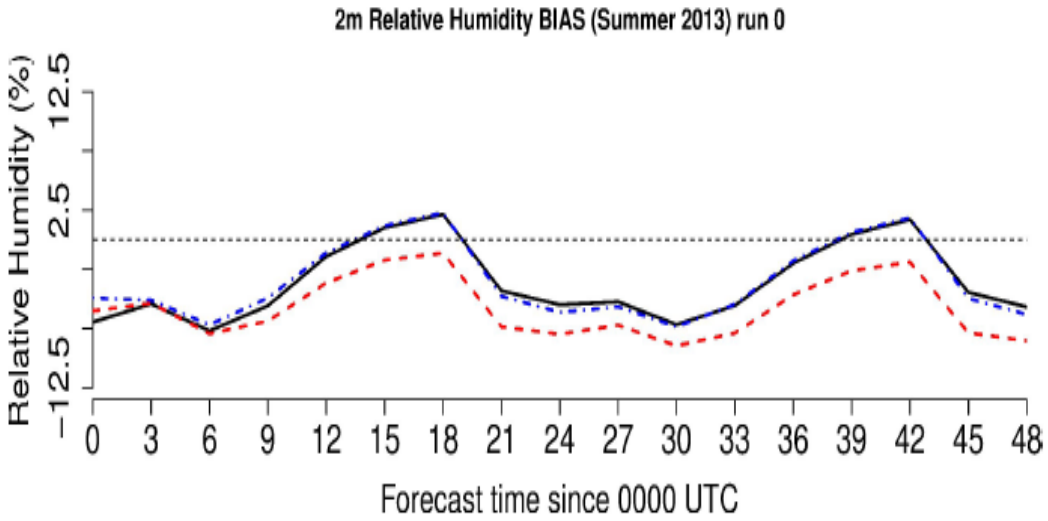
Scores for 2m RH

Open Loop
OI
EKF



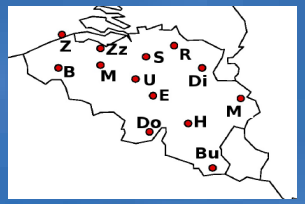






(a) Spring 2013 (MAM)

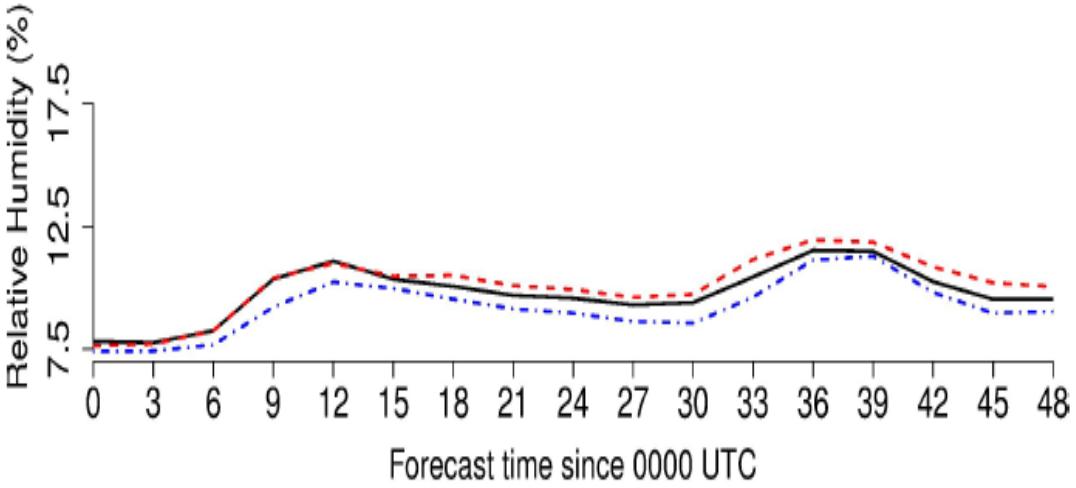
(b) Summer 2013 (JJA)



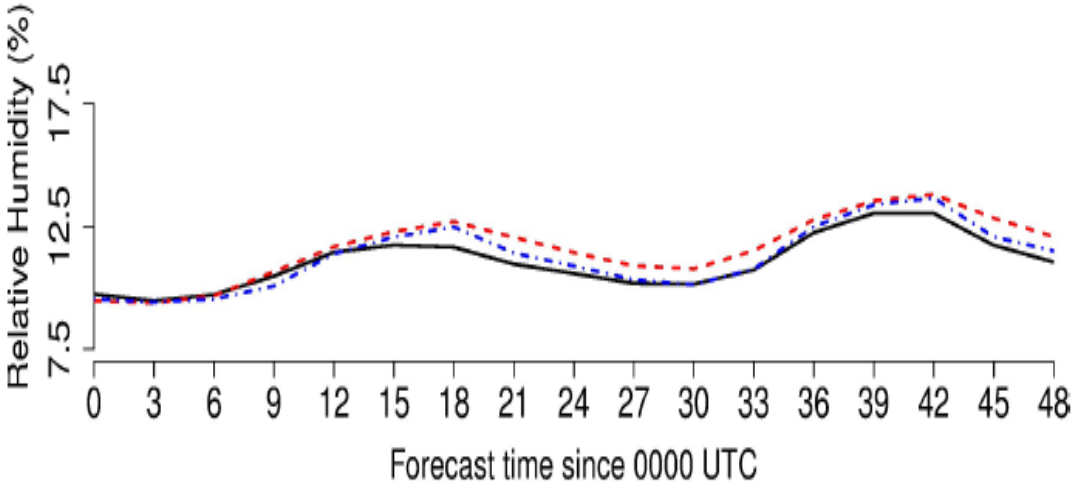
Scores for 2m RH

Open Loop
OI
EKF

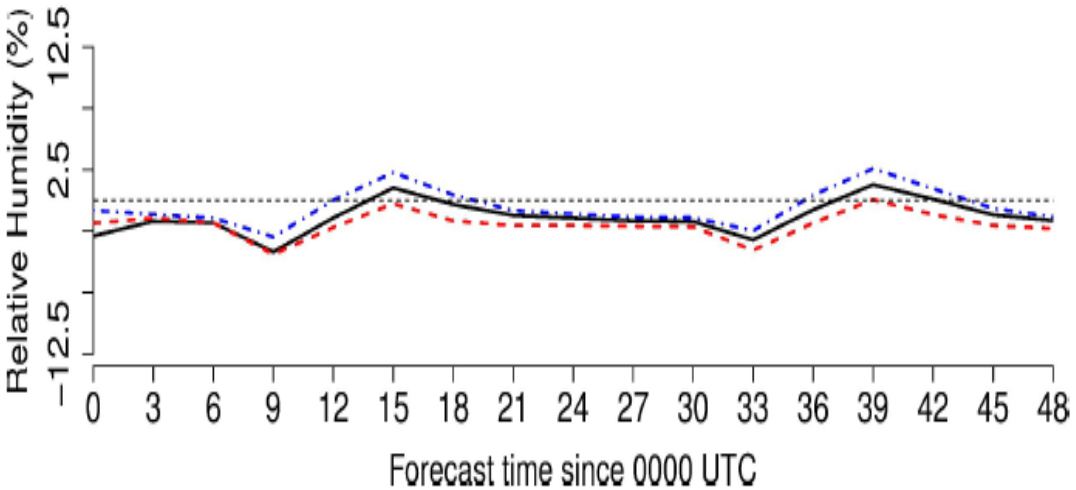
2m Relative Humidity RMSE (Autumn 2013) run 0



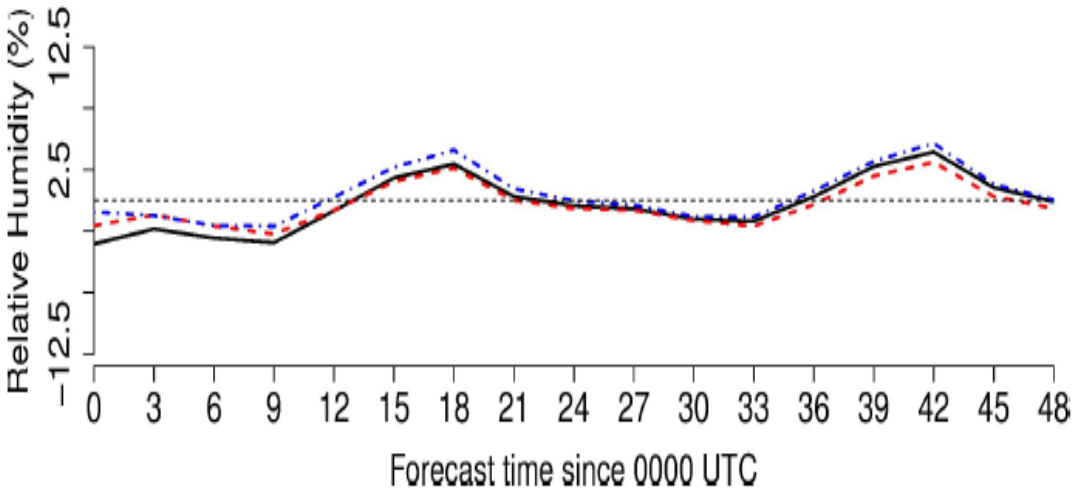
2m Relative Humidity RMSE (Winter 2013) run 0



2m Relative Humidity BIAS (Autumn 2013) run 0



2m Relative Humidity BIAS (Winter 2013) run 0



(c) Autumn 2013 (SON)

(d) Winter 2012-2013 (DJF)

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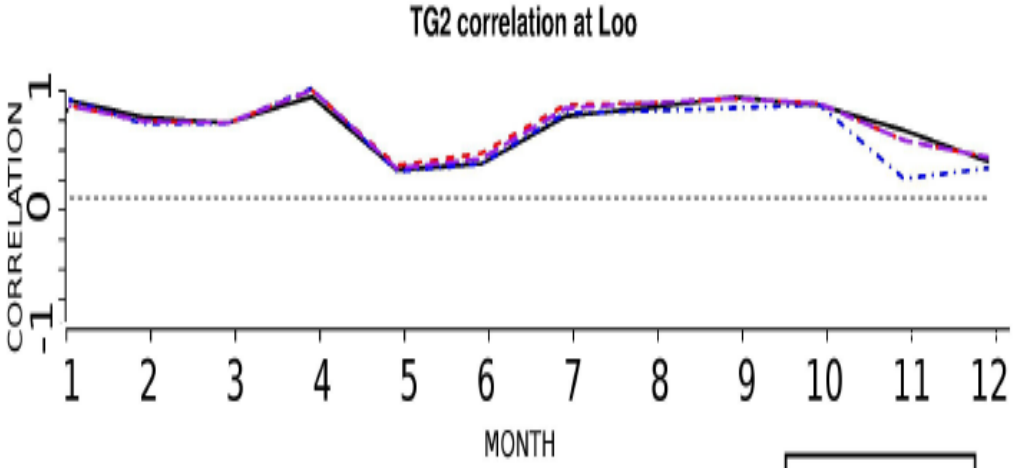
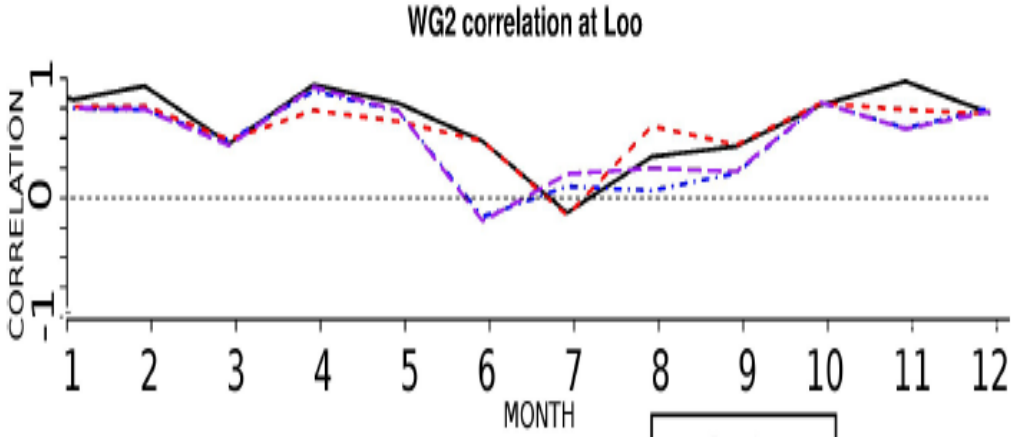
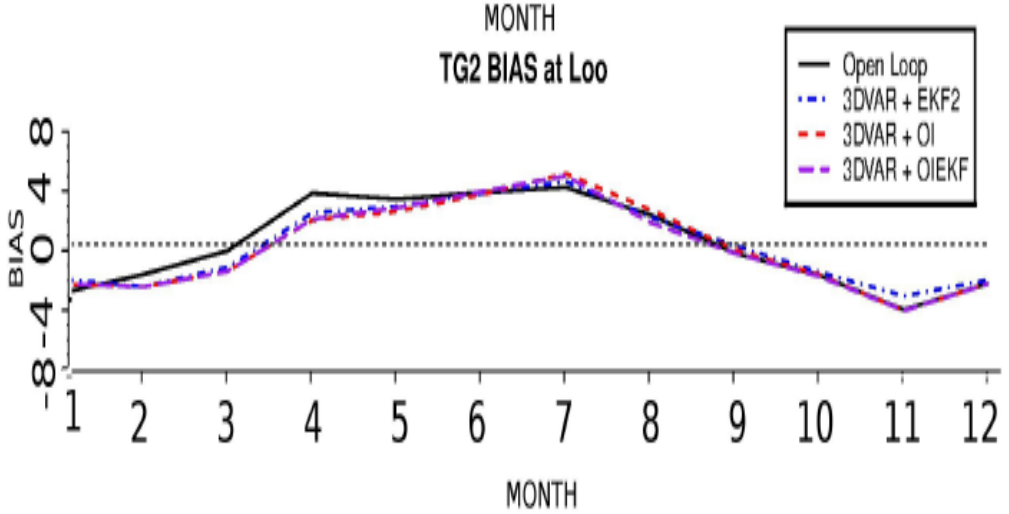
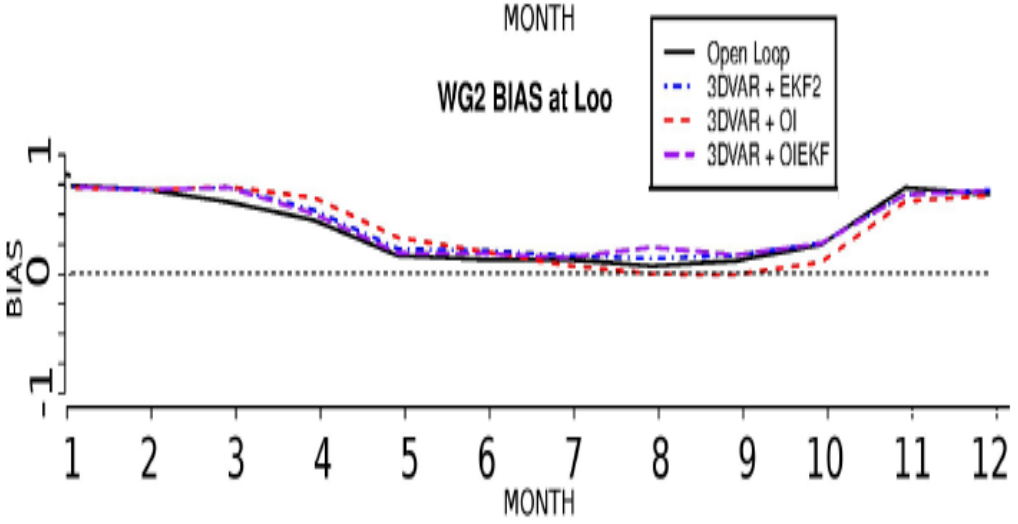
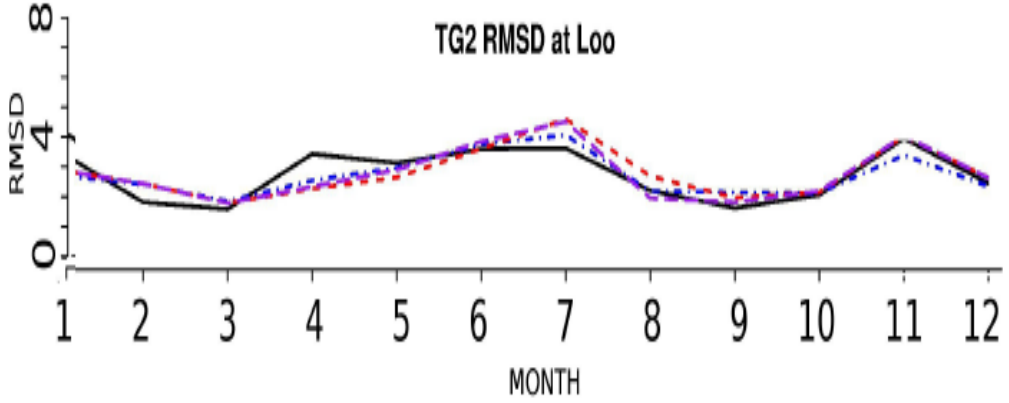
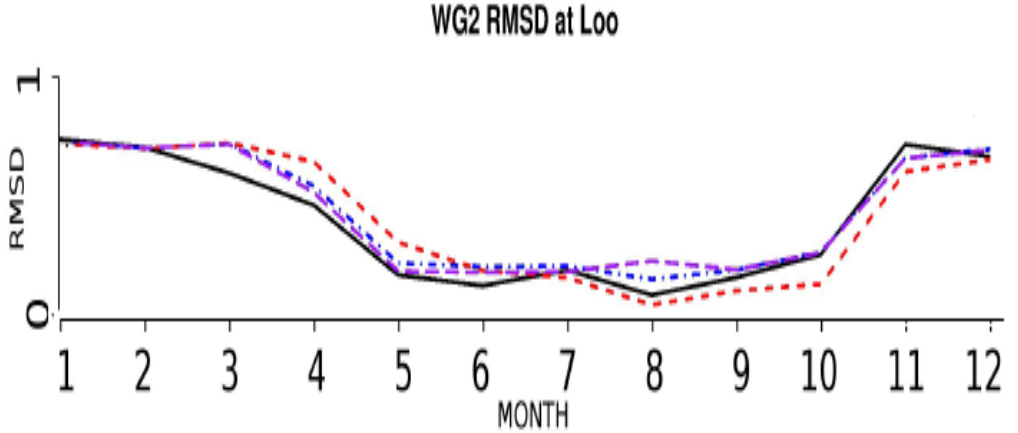

TG2 correlation at Loo
CORRELATION
-1
0
1
1 2 3 4 5 6 7 8 9 10 11 12
MONTH

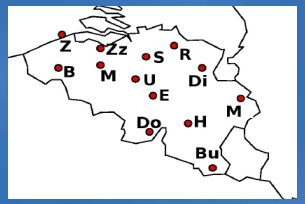

WG2 correlation at Loo
CORRELATION
-1
0
1
1 2 3 4 5 6 7 8 9 10 11 12
MONTH


TG2 BIAS at Loo
Open Loop
3DVAR + EKF2
3DVAR + OI
3DVAR + OIEKF
BIAS
-8 -4 0 4 8
1 2 3 4 5 6 7 8 9 10 11 12
MONTH


WG2 BIAS at Loo
Open Loop
3DVAR + EKF2
3DVAR + OI
3DVAR + OIEKF
BIAS
-1
0
1
1 2 3 4 5 6 7 8 9 10 11 12
MONTH

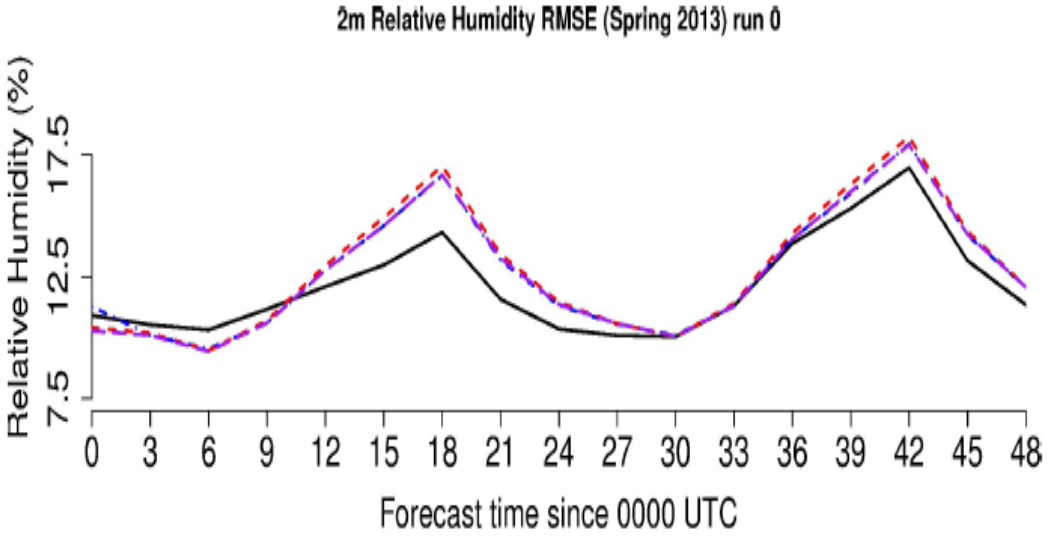

TG2 RMSD at Loo
RMSD
0
4
8
1 2 3 4 5 6 7 8 9 10 11 12
MONTH

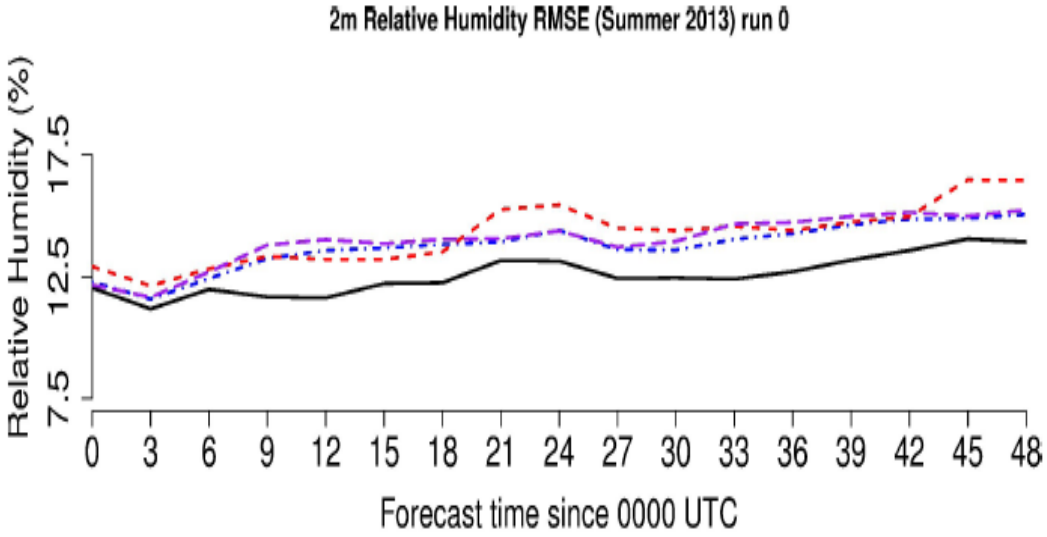

WG2 RMSD at Loo
RMSD
0
1
1 2 3 4 5 6 7 8 9 10 11 12
MONTH

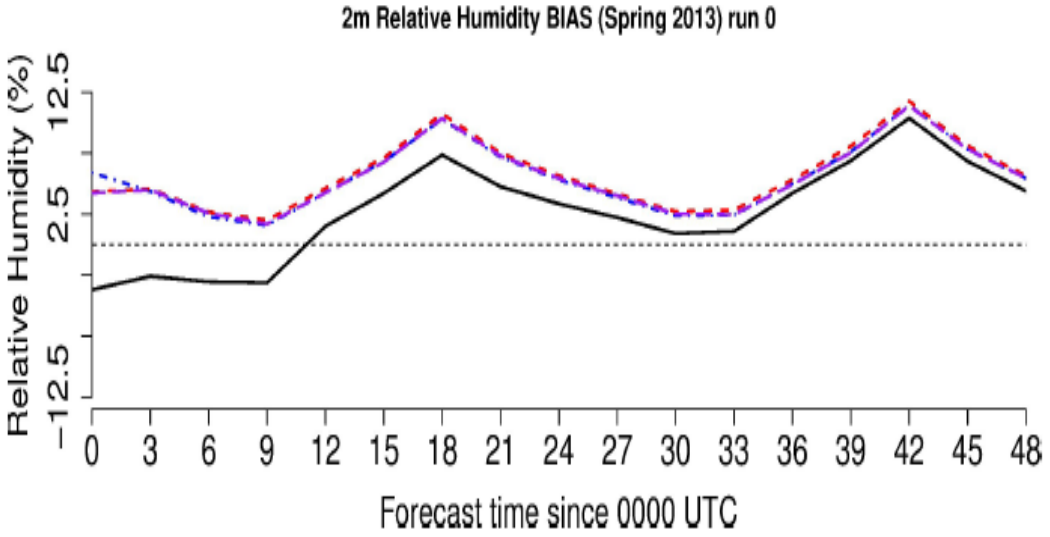


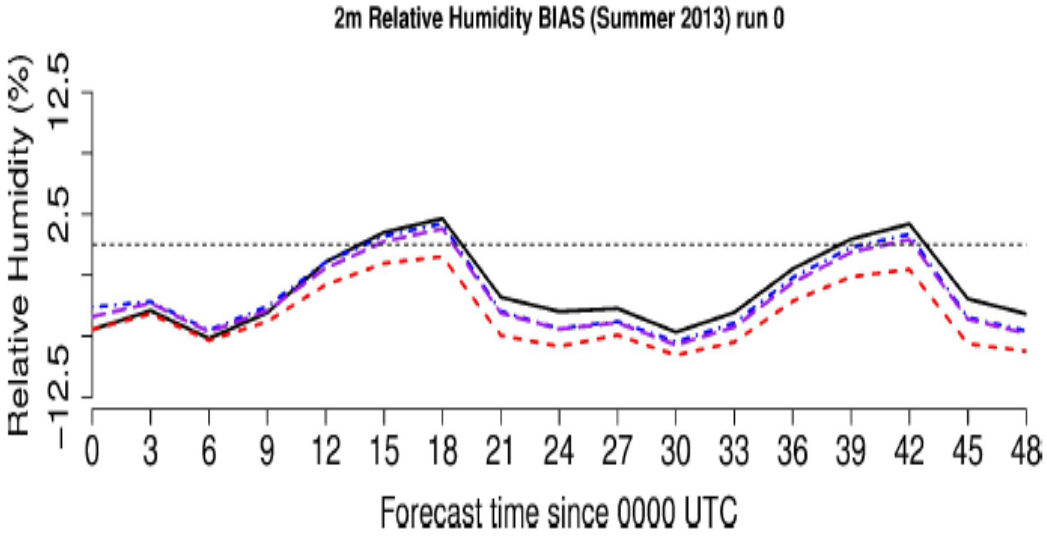
Scores for 2m RH

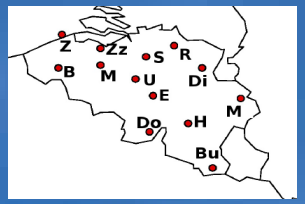
Open Loop
3DVAR + EKF2
3DVAR + OI
3DVAR + OIEKF





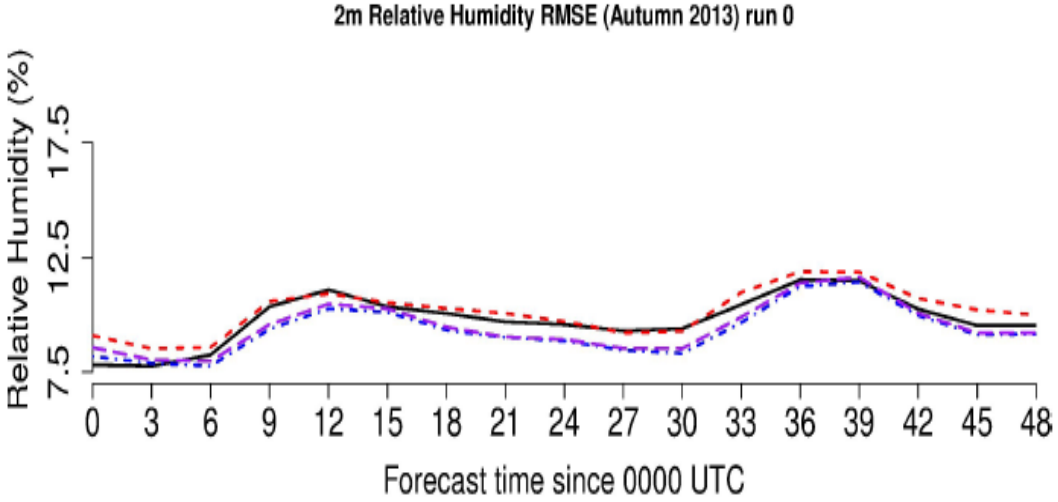


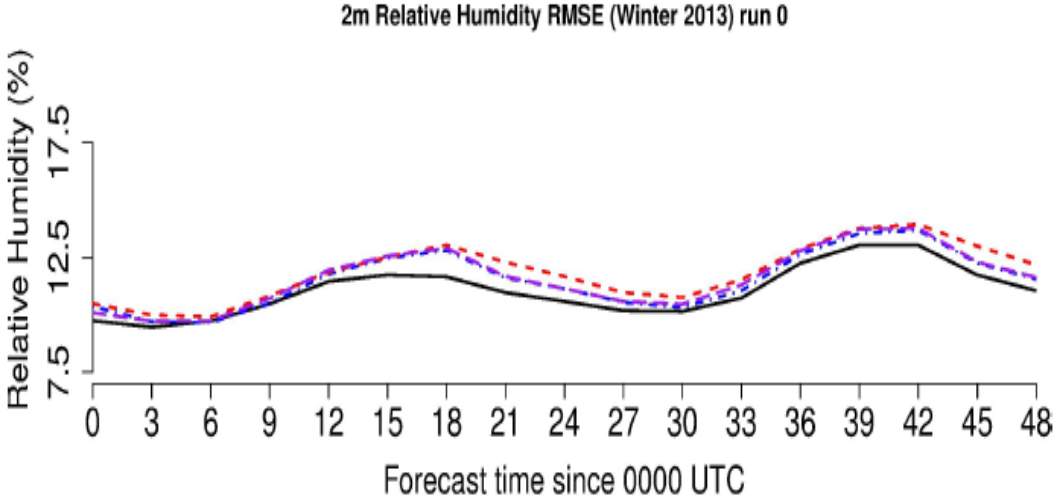


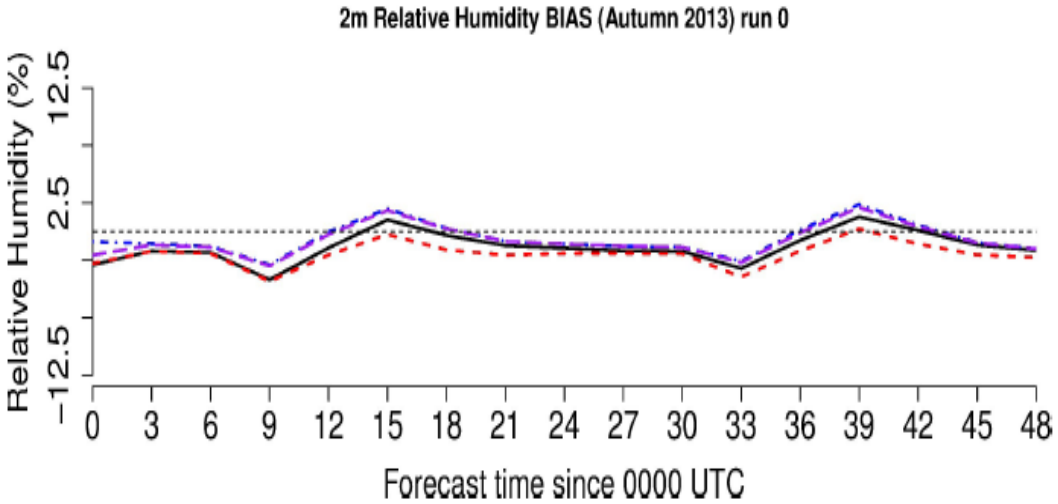


Scores for 2m RH

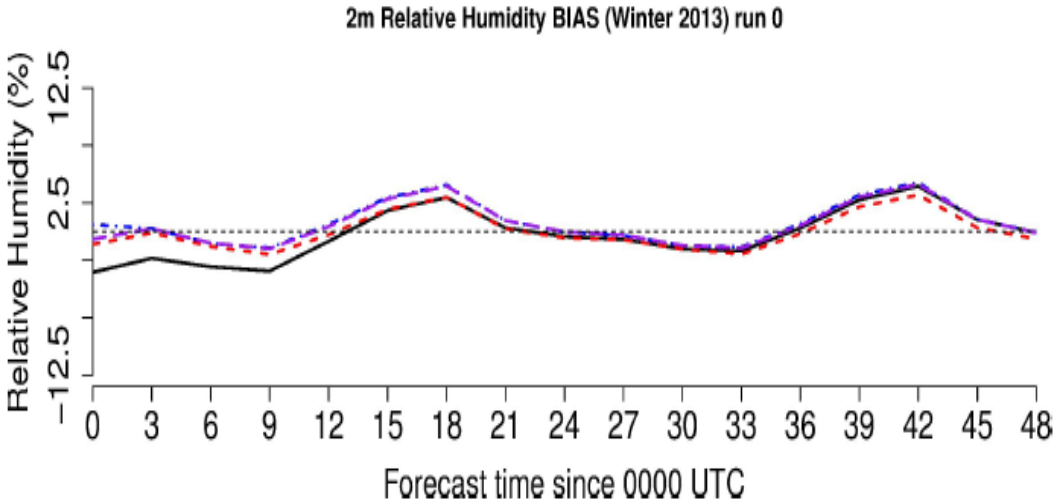
Open Loop
3DVAR + EKF2
3DVAR + OI
3DVAR + OIEKF







(c) Autumn 2013 (SON)



(d) Winter 2012-2013 (DJF)

Scores for precipitation

Winter

	S	A	L
OL	0.266	0.233	0.117
3D-Var+OL	0.267	0.278	0.121
3D-Var+free	0.279	0.281	0.128
3D-Var+OI	0.225	0.257	0.115
3D-Var+EKF	0.250	0.267	0.122
3D-Var+OIEKF	0.241	0.262	0.121
EKF	**0.212**	0.220	**0.114**
OI	0.214	**0.196**	0.115

Summer

	S	A	L
OL	0.407	0.153	0.203
3D-Var+OL	0.427	0.232	**0.189**
3D-Var+free	0.552	0.339	0.226
3D-Var+OI	0.397	0.161	0.191
3D-Var+EKF	0.398	0.201	0.197
3D-Var+OIEKF	0.380	0.193	0.193
EKF	**0.363**	0.097	0.195
OI	0.369	**-0.007**	0.191

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Summary:

1. The EKF runs are more successful in beating the Open Loop than the OI runs.

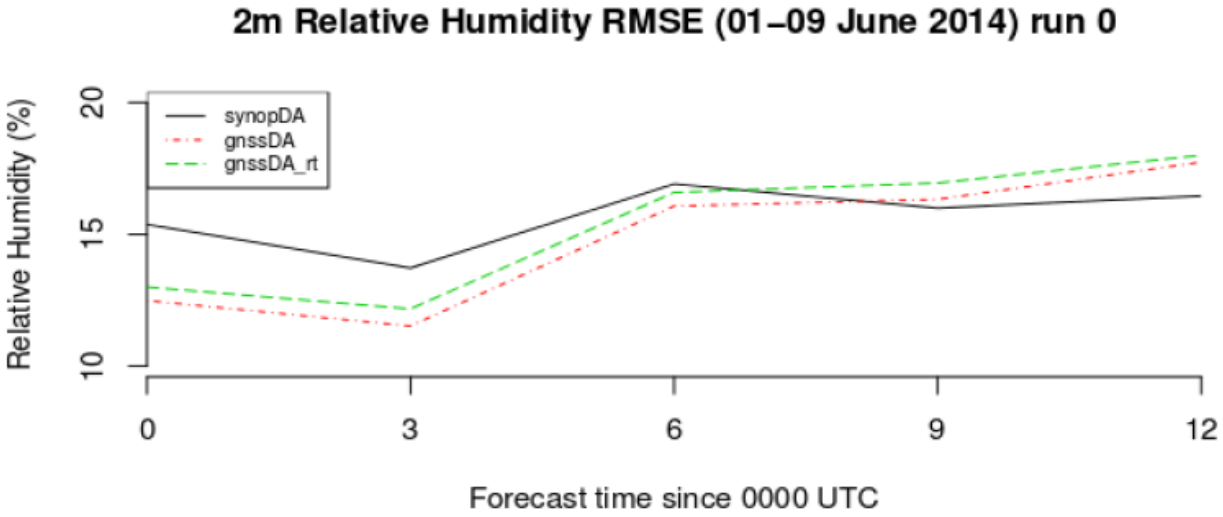
2. 3d-var is able to improve the 2m RH scores during the first 12h compared to Open Loop.

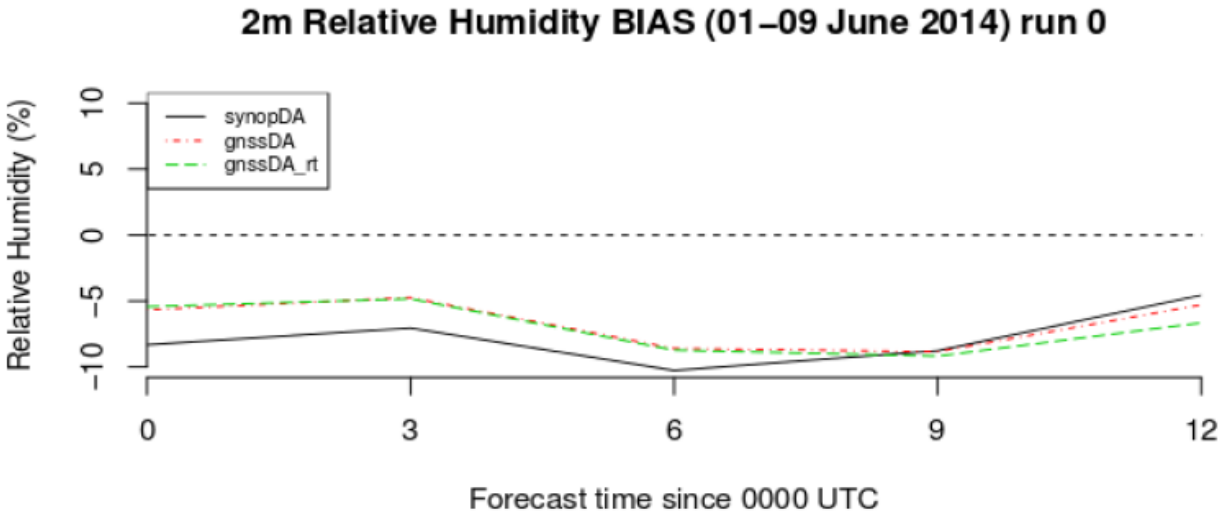
3. During winter, the combination of surface and atmospheric assimilation outperforms the runs with only surface assimilation or only upper-air assimilation.

4. During summer, the runs with only surface assimilation perform better than the runs with a combination of both.

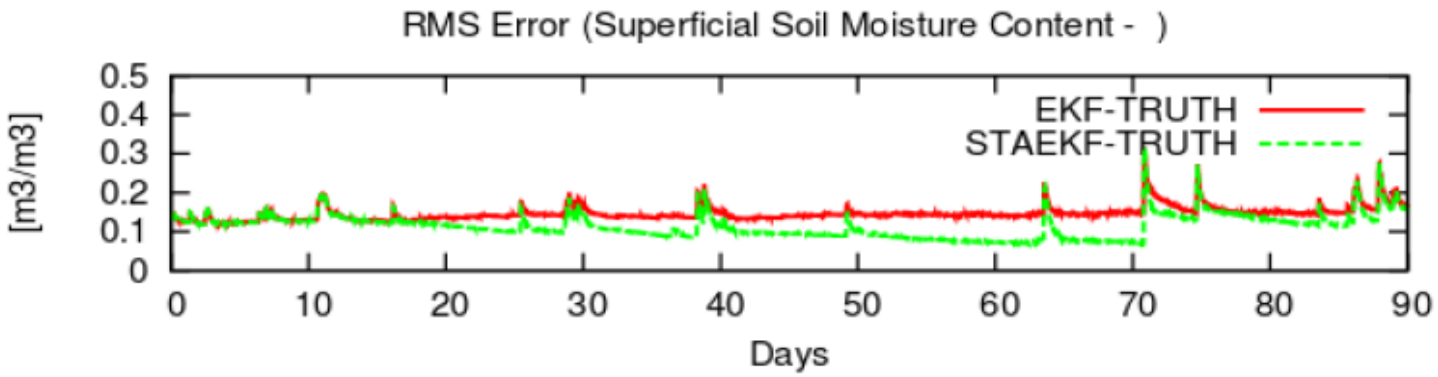
5. upper air scores using sounding indicate that the 3d-var is not able to get an equally well upper-air analysis as the ARPEGE interpolated atmosphere.

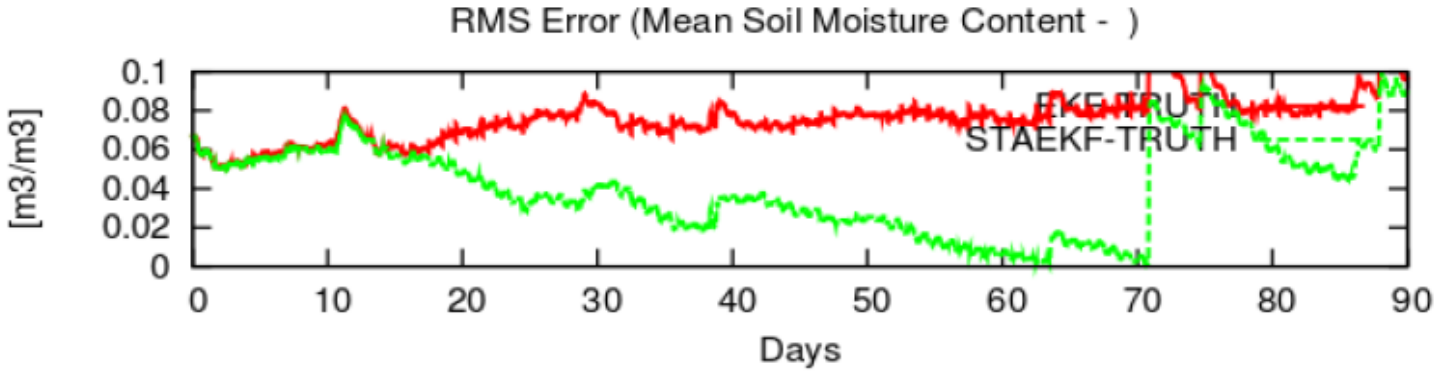
GNSS ZTD assimilation

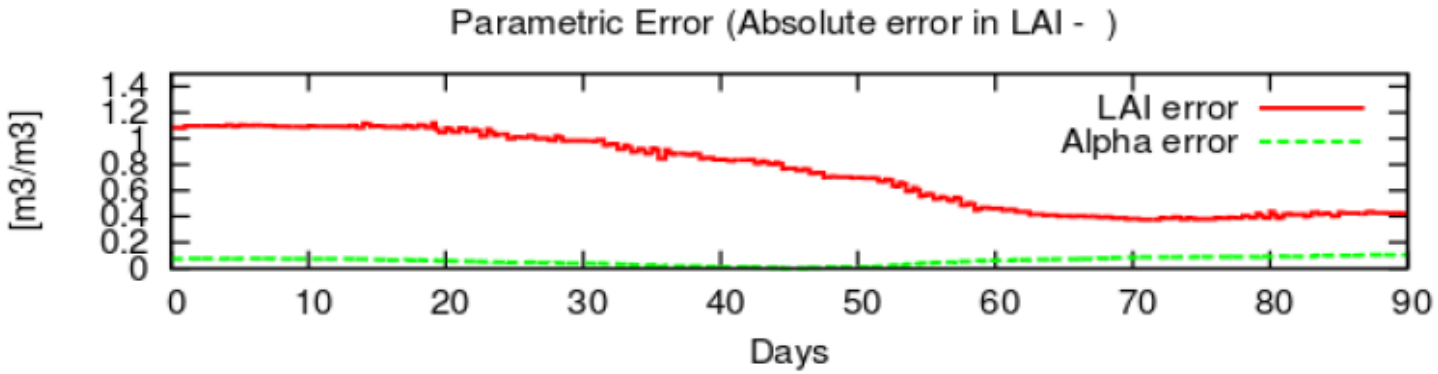


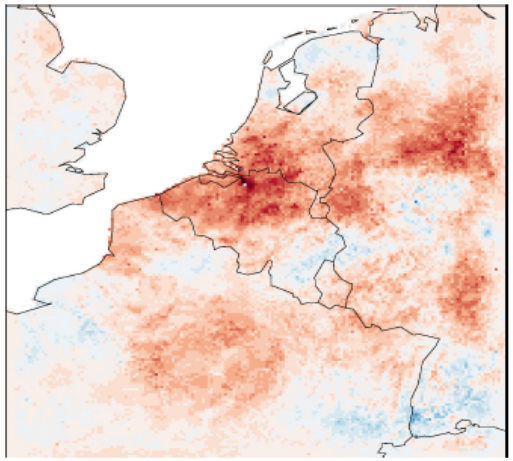


STAEKF

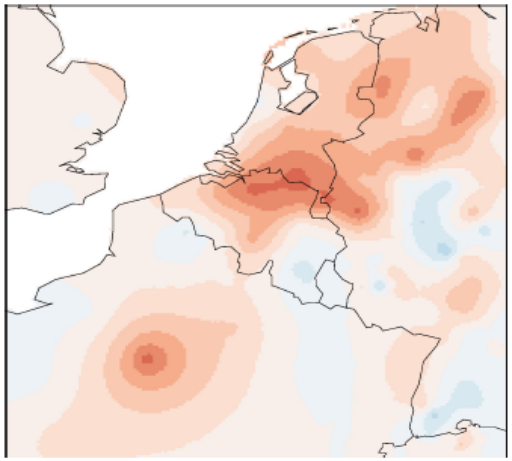

RMS Error (Superficial Soil Moisture Content -)
[m3/m3]
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
Days
EKF-TRUTH
STAEKF-TRUTH


RMS Error (Mean Soil Moisture Content -)
[m3/m3]
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
80
90
Days
EKF-TRUTH
STAEKF-TRUTH

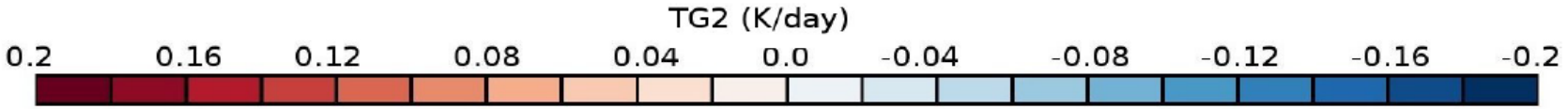

Parametric Error (Absolute error in LAI -)
[m3/m3]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
Days
LAI error
Alpha error

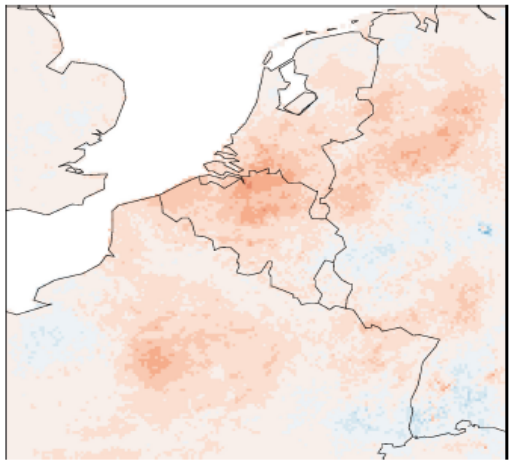


(b) TG1*10, EKF

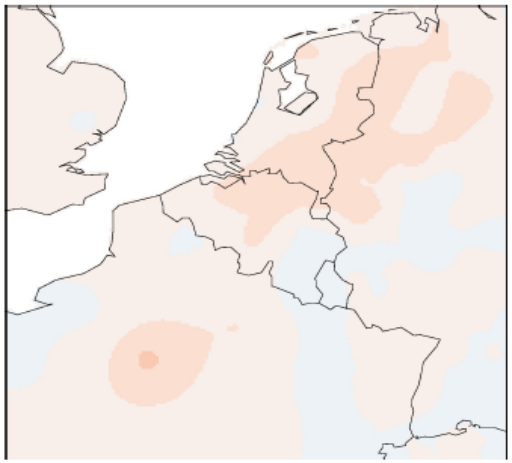


(c) TG1, OI



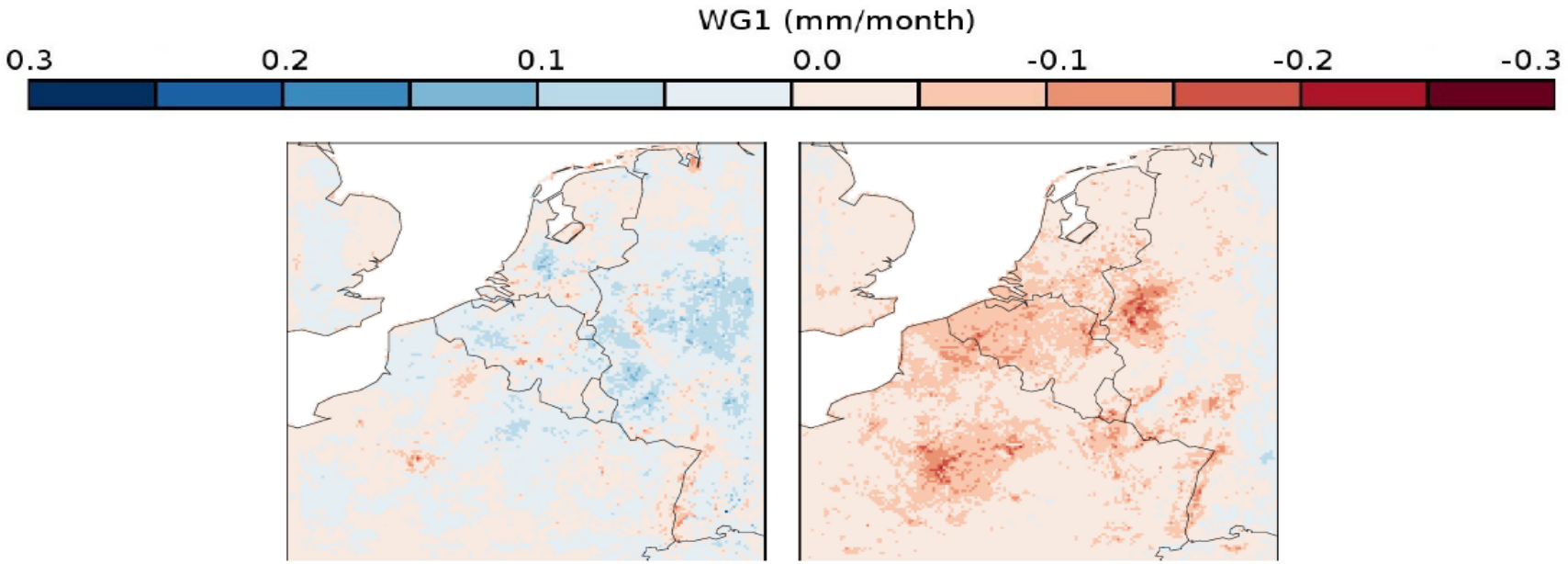


(e) TG2, EKF

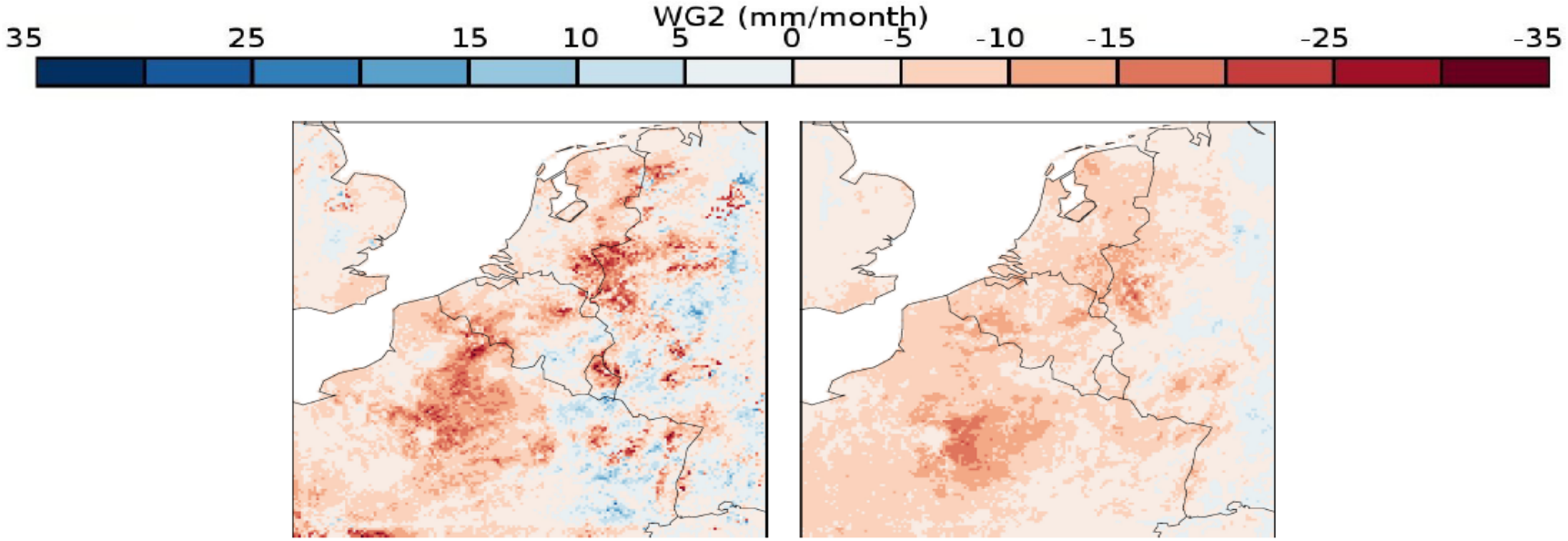


(f) TG2, OI

WG1 (mm/month)



(h) WG1, EKF (i) WG1, OI



(k) WG2, EKF (l) WG2, OI