An EnKF system for land data assimilation: testing the sensitivity of the analyses to assimilation parameters

Land DA group at NILU:

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SURFEX LDAS at NILU

- Based on the offline version of SURFEX v4.8 and the SURFEX-EKF code provided by Jean-François Mahfouf, Météo-France
- SURFEX- EKF and EnKF test run: 289 x 289 grid over Europe. Forcing data from Météo-France (July 2006)
- Control variables:
  - TG1: Surface temperature (surface quantity), [K]
  - TG2: Mean surface temperature (volume quantity), [K]
  - WG1: Superficial volumetric water content (surface quantity), [m^3/m^3]
  - WG2: Mean volumetric water content of the root zone, [m3/m3]
- SURFEX-EnKF model for Norway
  - Test domain: 25 x 25 grid (4 km resolution) centred in Oslo
  - Atmospheric forcing data from met.no
  - The domain will eventually be extended to larger parts of Scandinavia

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SURFEX LDAS at NILU (2)

- Observations
  - T2m and HU2m from SYNOP: CANARI analysis
  - Soil moisture from EOS AQUA/AMSR-E (July 2006)
  - Soil moisture from SMOS (September- October 2010)

- We use these observations together with the SURFEX model applying:
  - Extended Kalman filter (EKF)
  - Ensemble Kalman filters (EnKF)
    - **1) Square Root EnKF**
    - 2) Deterministic EnKF
  - Particle filters (PF)
    - 1) Standard PF (SIR)
    - 2) Regularized PF (RPF)
    - 3) Auxiliary PF (APF/ASIR)

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SURFEX-EnKF model setup and challenges

- Several EnKF/PF assimilation methods to test
- Many different parameters that should be set correctly (No. of ensemble members, perturbation method, amount of perturbation…..)

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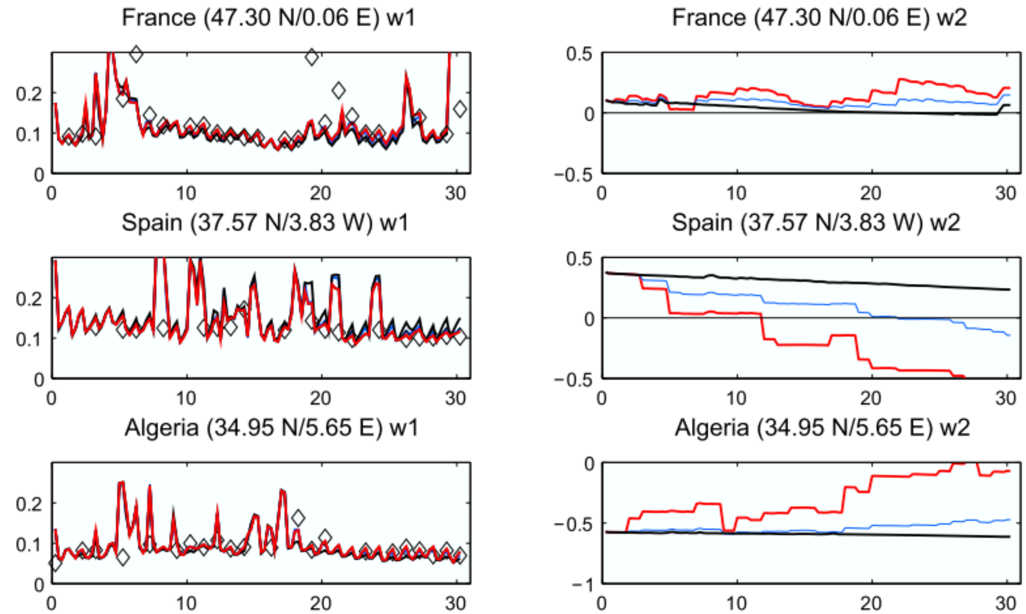
SURFEX-EKF and SEKF for July 2006

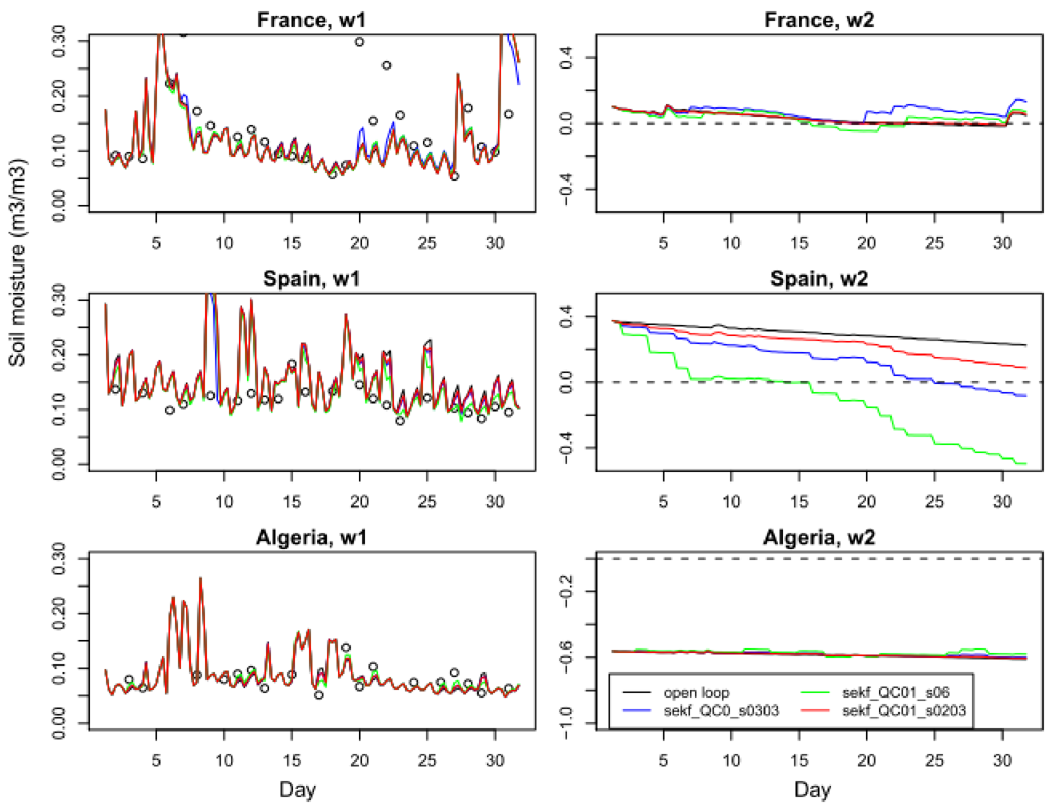


<u>Figure from Draper et al., 2009</u>

Black: Open loop

Red: EKF

Blue: SEKF



<u>SEKF</u>: Simplified EKF; neglects evolution of the background error

<u>QC=0.1:</u> observational data further away than 0.1 m^3/m^3 from the model is discarded

<u>Our "reproduction" of SEKF run</u>:

Black: Open loop

Blue: QC=0, σ(w1)=σ(w2)=0.3

Green: QC=0.1, σ(w1)=σ(w1)=0.6

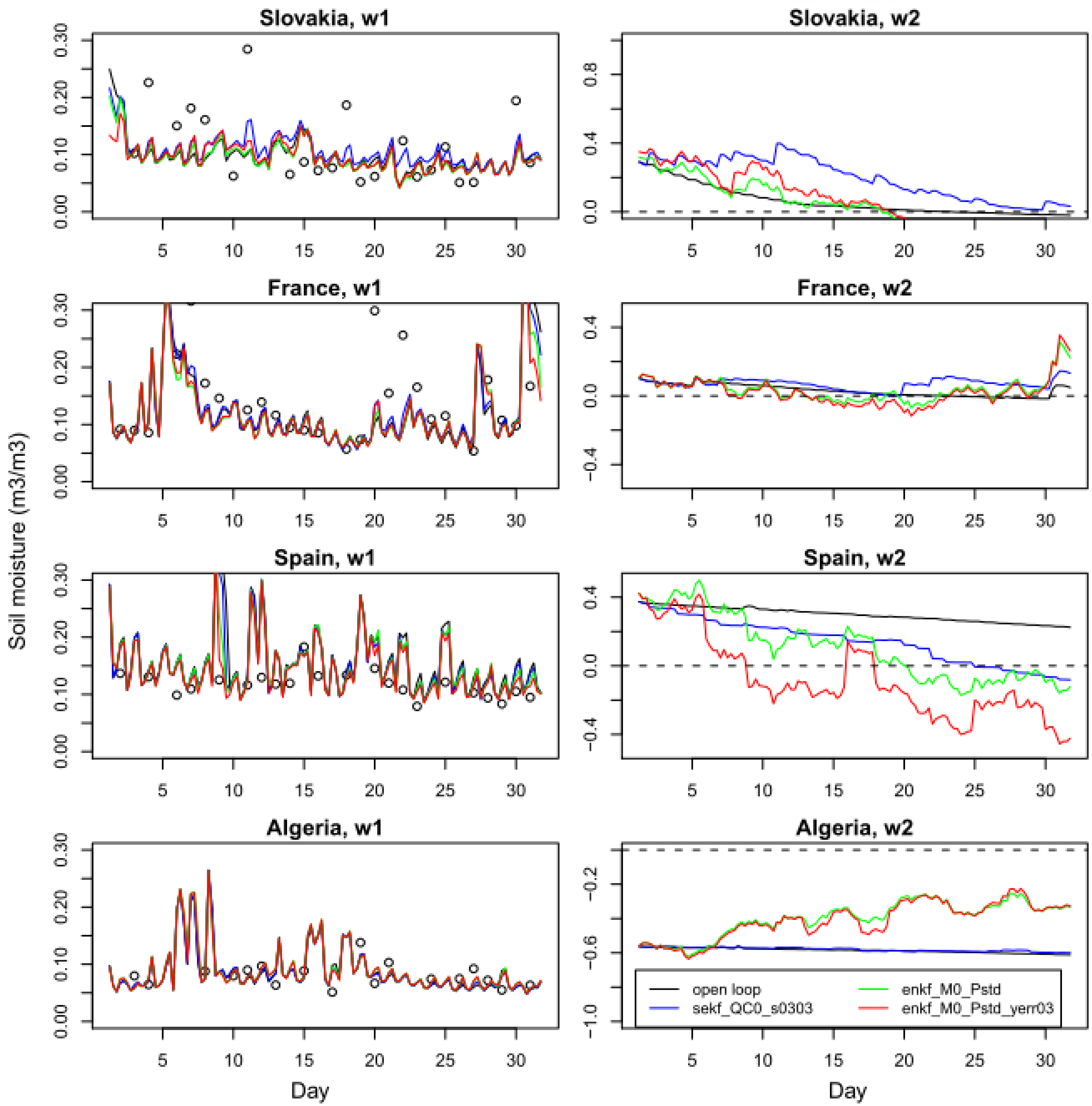
Red: QC=0.1, σ(w1)=0.3, σ(w2)=0.2

2. EKF & EnKF

o AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: M0, QC0, Pstd
- Red: As the green, but obs_err=0.3

<u>M0:</u>
Random w1 and w2 perturbation every grid and time step

<u>Pstd:</u>
5 ensemble members
Prt(w1)=0.15
Prt(w2)=0.025
Obs_err=0.6



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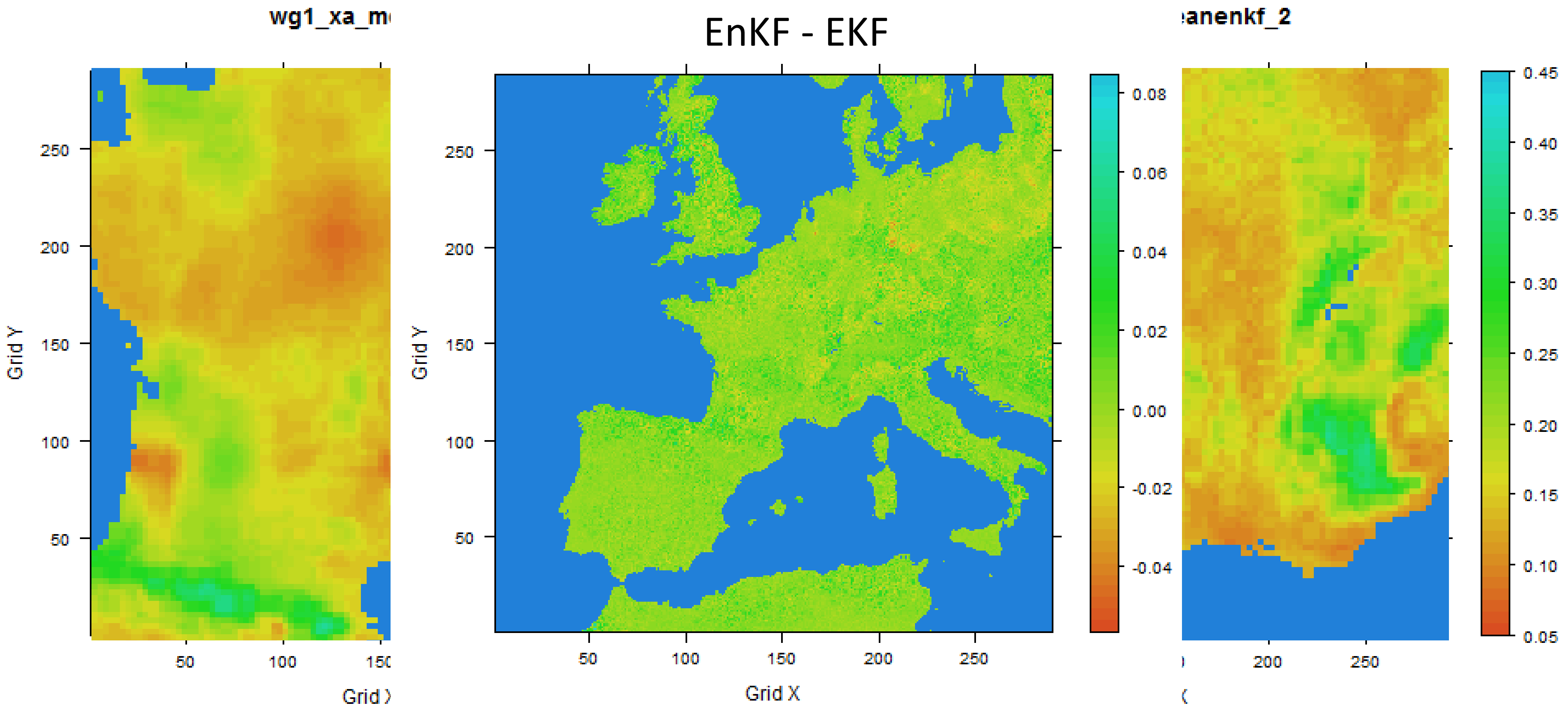
W1 analysis: EKF & EnKF



EnKF:

- Slightly drier
- Some more ”noise”

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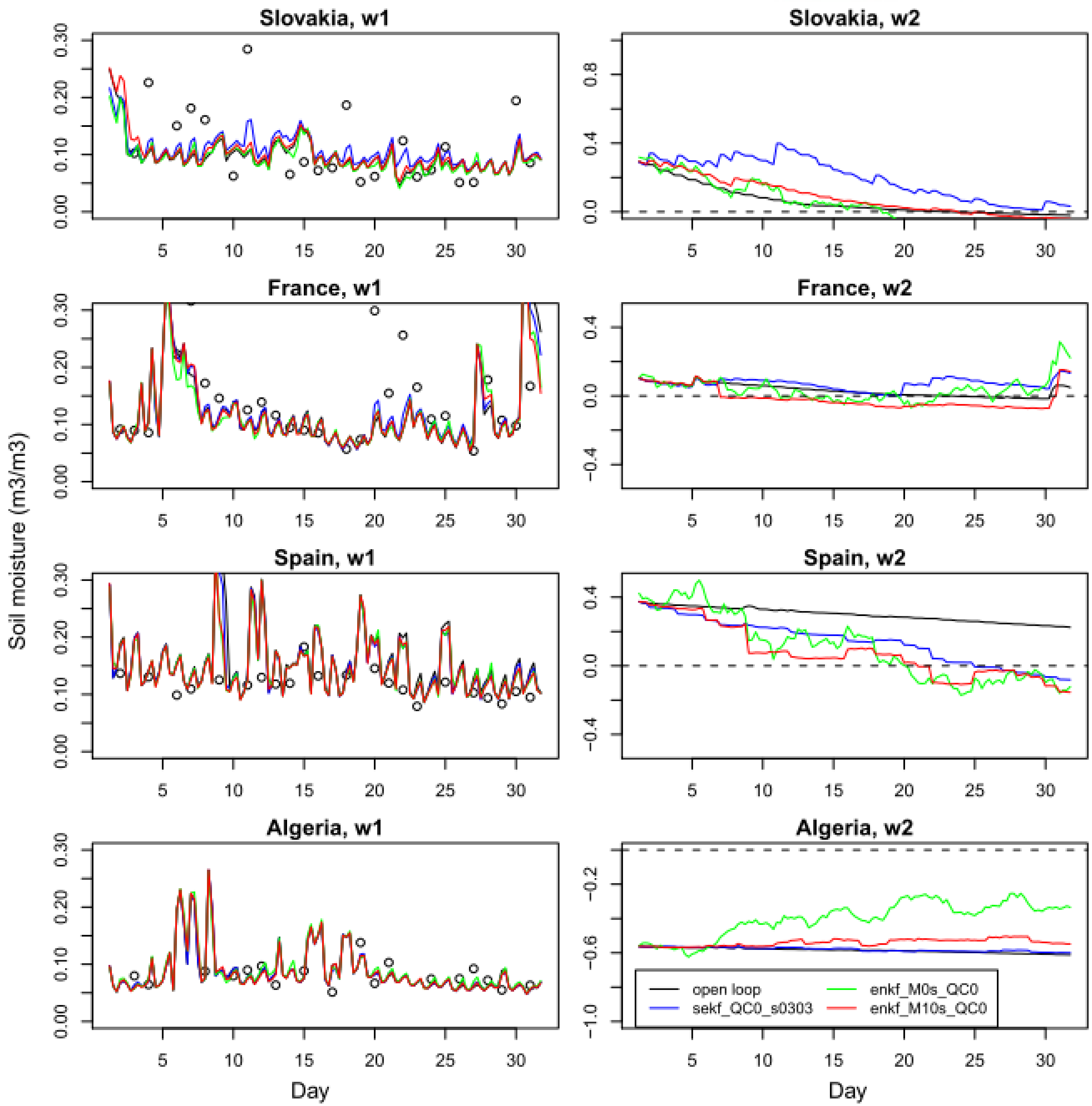
3. EKF & EnKF

ο AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: M0, QC0, Pstd
- Red: M10, QC0, Pstd



M0: Random pert every grid and time step

M10: zero mean random perturbation every grid and time

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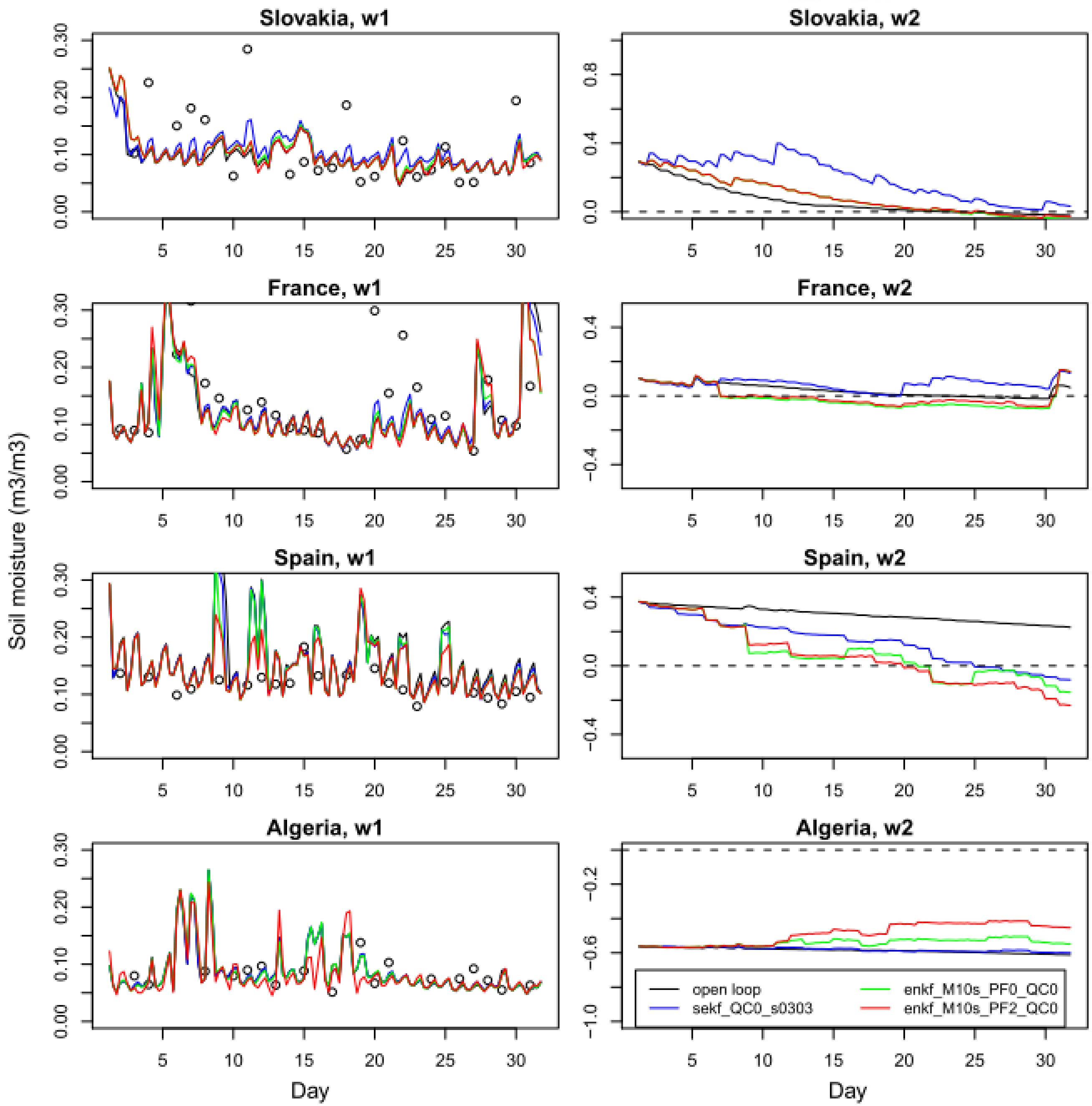
4. EKF & EnKF

o AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: M10, QC0, Pstd
- Red: M10, QC0, Pstd, PF2

PF2: 10% zero mean pert. of precipitation, with spatial correlation



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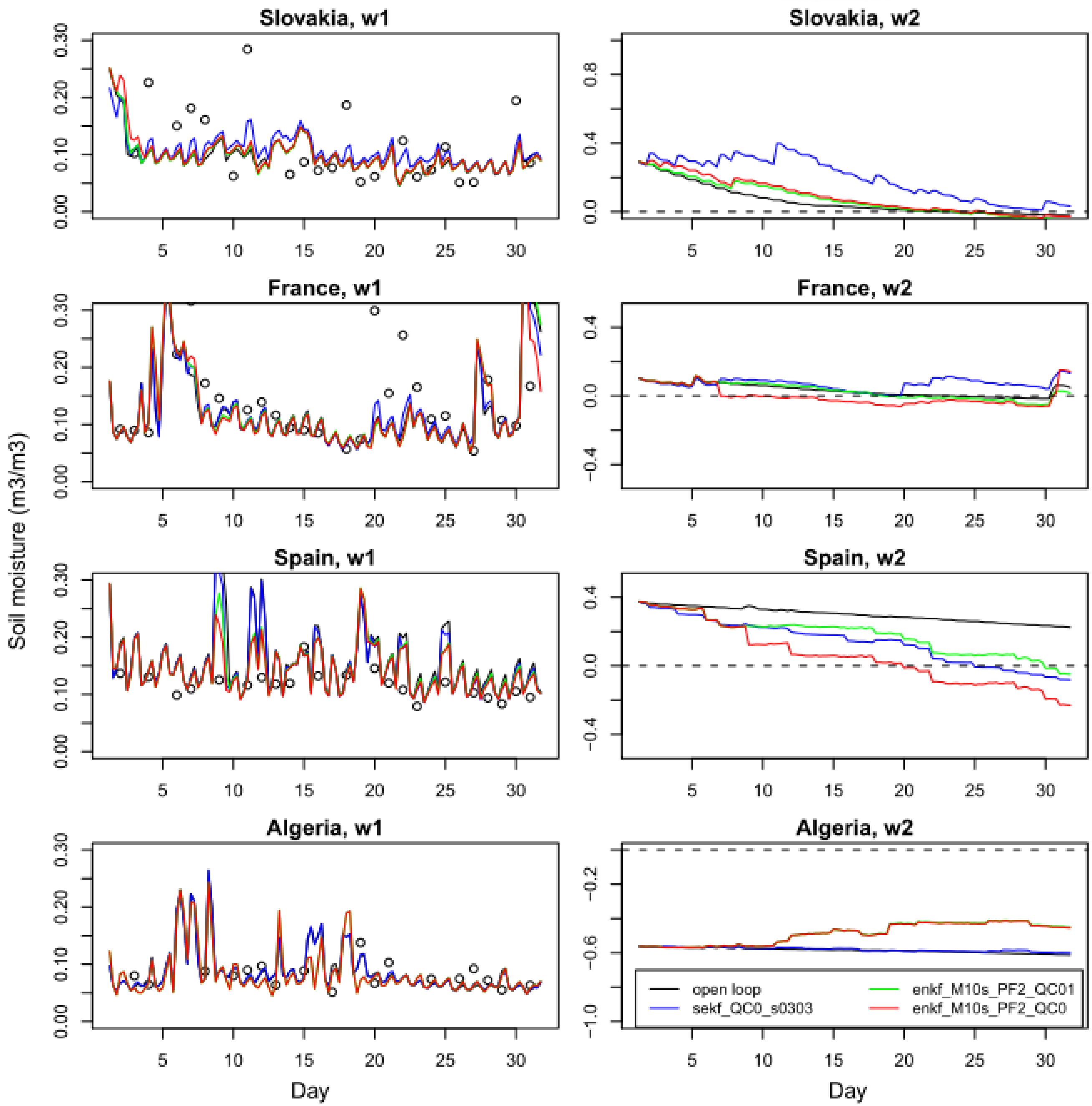
5. EKF & EnKF

o AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: M10, Tstd, QC01, PF2
- Red: M10, Tstd, QC0 PF2

The green line represents our EnKF base run (standard)



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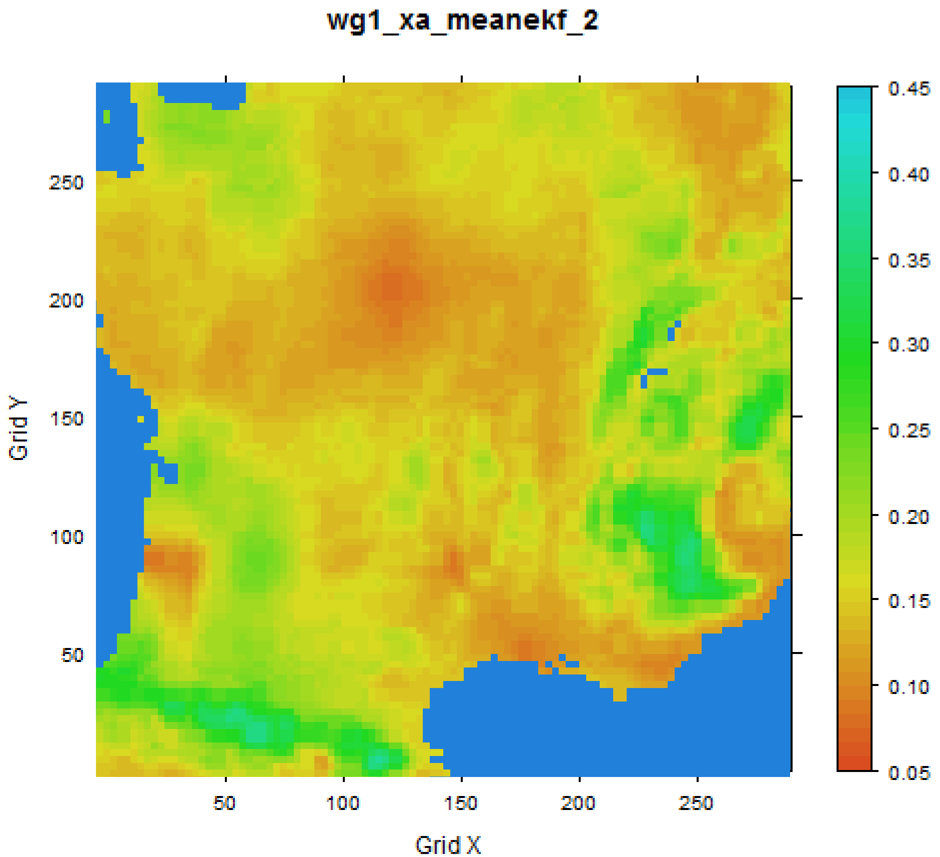
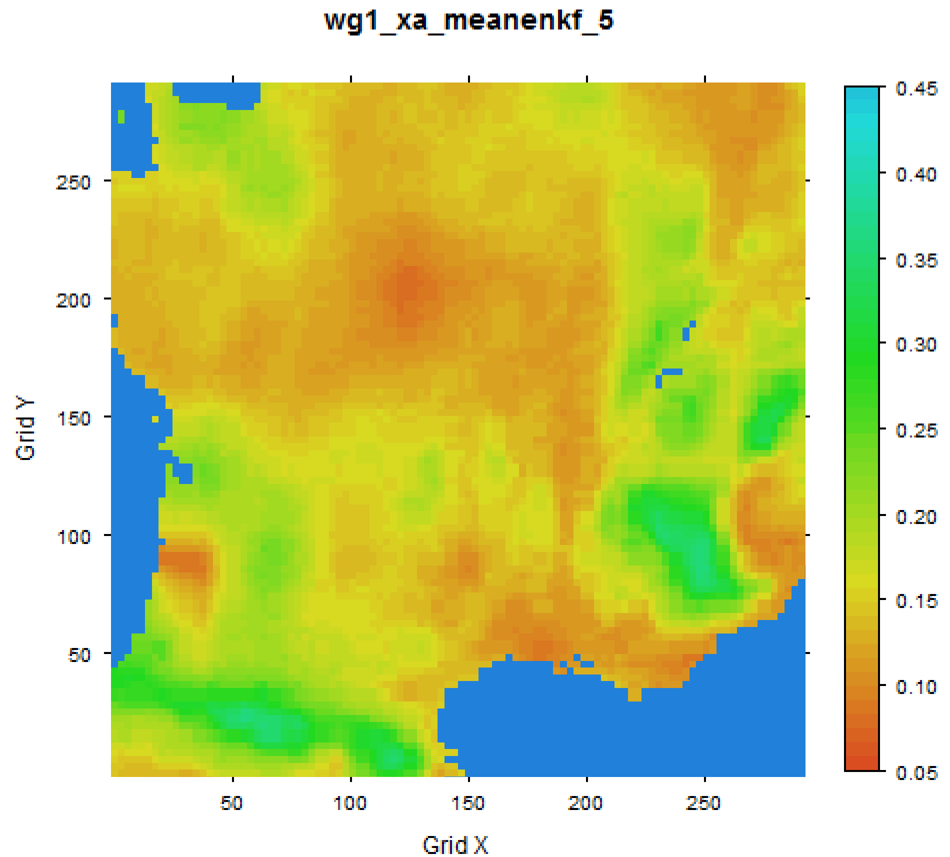
W1 analysis: EKF & EnKF





<u>EnKF:</u>

New perturbation method has less ”noise”

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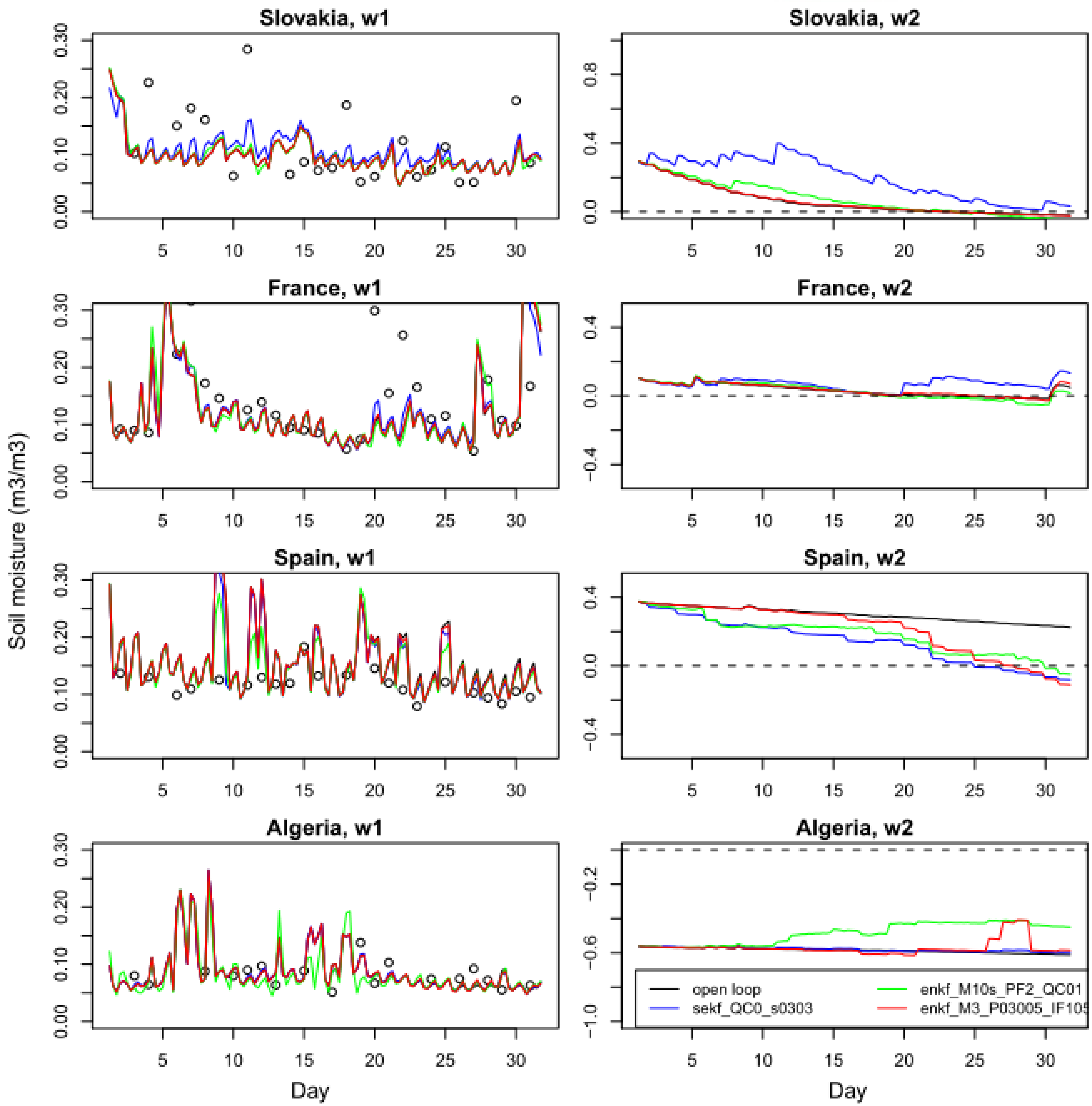
6. EnKF test

- o AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: EnKF base
- Red: EnKF inflation method (M3)

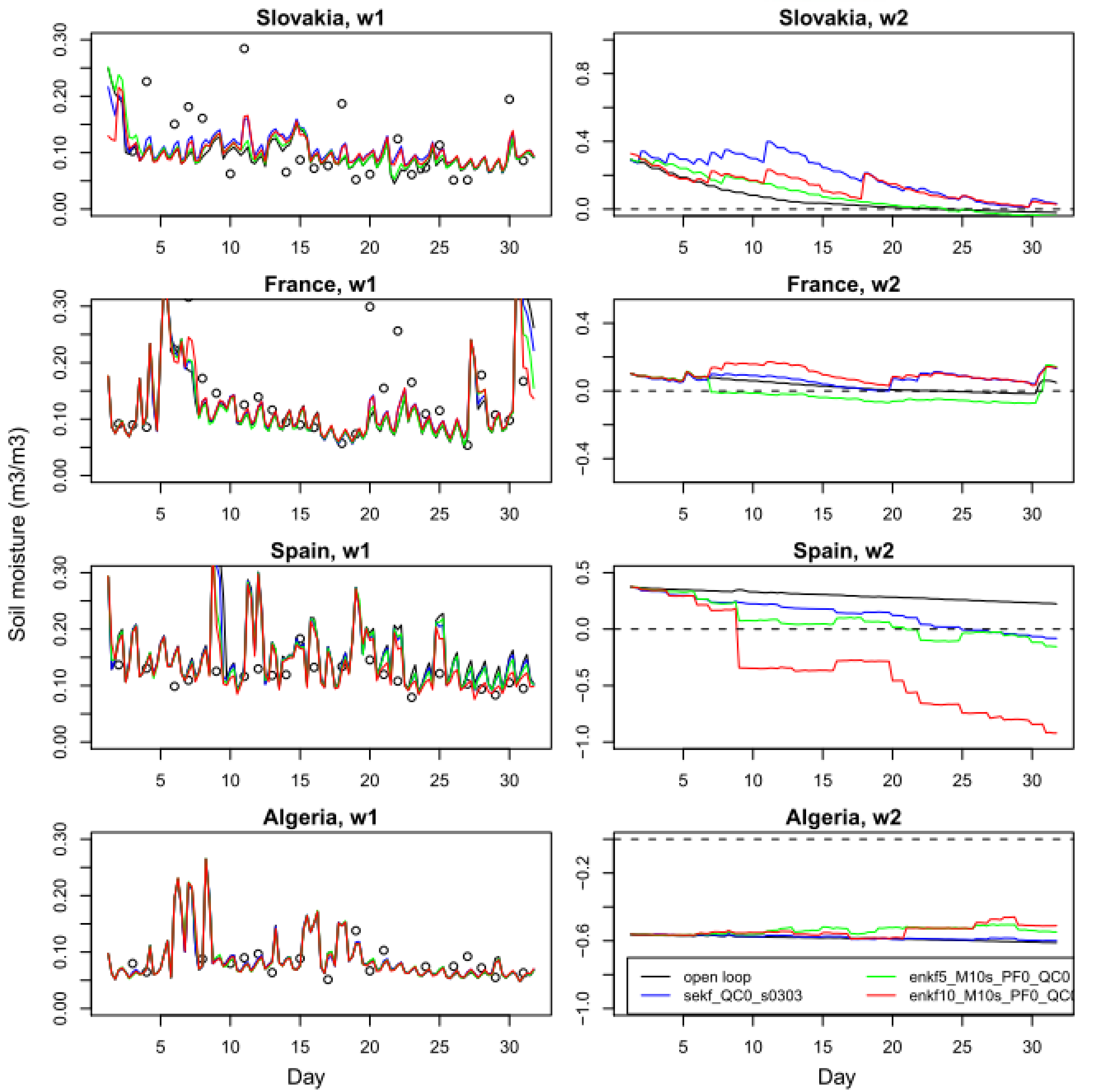


<u>EnKF inflation method</u>: Initial perturbation of B-matrix, spread by inflation.

7. EnKF test

- o AMSR-E observations
- Black: Open loop
- Blue: SEKF
- Green: M10, QC0, Tstd, 5 ens.memb.
-Red: M10, QC0, Tstd 10 ens.memb

<u>Sensitivity run</u>: Effect of increasing the number of ensemble members



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Final remarks and questions

- Many combinations of EnKF parameters
- Have we used the optimal perturbation of control variables and number of ensemble members?
- Should we include spatial correlated w1 and w2 perturbation? Inflation method?
- Perturbed precipitation: Zero mean spatial correlated method. Need more testing/development.
- Perturbed LW, SW forcing: Perturbed randomly in present EnKF. Should they be correlated to precipitation?

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Future plans

- Continue testing with Surfex-EnKF and AMSR-E (ensemble set up, errors)
- Run the SURFEX-EnKF model for Scandinavia
- Test benefit of SMOS soil moisture for Northern Areas (New PostDoc)
- Hybrid EnKF/PF (potential benefits): EnKF sets up ensemble, PF resolves non-linearity/non-Gaussianity

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Thanks!

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Advantages of EnKF vs EKF (1)

- Some major problems associated with using the EKF in connection with (larger) nonlinear models:
  - Inaccuracy in the evolution of the model error covariance matrix and huge computational requirements associated with the storage and forward integration of this matrix
  - Use of the central forecast as the estimate of the state. For non-linear dynamics the central forecast is not equal to the mean or expected value

- The EnKF was designed to resolve the points above. It has gained in popularity due to its simple conceptual framework and relative ease of implementation
  - No derivation of a tangent linear operator
  - Model error covariance implicitly defined through maintaining a set of model states in the form of an ensemble
  - The mean of the ensemble representing the estimated state

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Advantages of EnKF vs EKF (2)

- In EnKFs (and particle filters) each ensemble member is run forward in time through the model
- Uncertainty (or spread in the ensemble) is introduced by stochastic model dynamics (stochastic physics) when integrating each ensemble member forward in time
- In the EKF uncertainty in the estimated state is introduced in the update of the B-matrix (background error covariance) and in the added Q-matrix
- However, both are optimal and correct strictly speaking only when the underlying PDFs (prior and posterior to the observations) are Gaussian

Current DA work at NILU

Test new algorithms (EnKF/PF) vs EKF for soil moisture (Draper et al. 2009). Observations from AMSR-E

Issue: How to create the ensemble

A)Random variable N(0,X) is added to the SURFEX model value every time step. Independent perturbations for all grid cells and ensemble members.

- Too much noise?

B) Random variable N(0,1) is multiplied by the initial B-matrix (from EKF) and added to the SURFEX initial model state. Perturbation through inflation for next time steps.

- Correlation between neighboring grids, less noise

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The SURFEX model includes following elements

Soil and vegetation scheme (ISBA, Interface Soil-Biosphere-Atmosphere, and ISBA-A-gs): Simulates exchange of energy & water fluxes between land surface & atmosphere;

Water surface scheme (COARE/ECUME – for the sea; FLAKE – for inland water): Simulates various features of water surface: turbulent fluxes, temperature, salinity, heat budget, & mixed layer depth; & ice & snow cover for inland water;

Urban and artificial areas (Town Energy Balance, TEB, model): TEB model simulates exchange of fluxes between a town/urban area & atmosphere. Town/urban area represented, e.g., by roofs, roads & facing walls;

Surface boundary layer (SBL) scheme: Accounts for way vegetation canopy modifies interaction between land & atmosphere. Incorporates SBL equations into a surface scheme with implicit coupling to atmosphere;

Chemistry and aerosols: Takes account of contribution of dust aerosols, sea salt emission, dry deposition of aerosols & gaseous species, & biogenic VOCs (volatile organic compounds) to: (i) surface fluxes (information from land surface to atmosphere), and/or (ii) atmospheric forcing (information from atmosphere to land surface);

Land use database (ECOCLIMAP): ECOCLIMAP a global database of land surface parameters @ 1 km horizontal resol. combining land cover maps with satellite info. Provides detailed description of surface conditions: vegetation types, sea/lake, & town;

Land surface analysis: Uses DA scheme (e.g. EKF at Météo-France) to update SURFEX model state variables by assimilation of various in situ & satellite obs. NILU effort extends Météo-France land surface analysis to include variants of EnKF & PF.

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EnKF versions at NILU

- Ensemble Square Root Kalman filter (ESRKF) using a symmetric Ensemble Transform Matrix (ETM)
  - Sakov and Oke: "*Implications of the form of the ensemble transformation in the ensemble square root filters*", submitted to Monthly Weather Review on Sep 4, 2006, last modified Aug 22, 2007

- Deterministic Ensemble Kalman Filter (DEnKF) using a linear approximation to the Ensemble Square Root Filter (ESRF) update matrix
  - Sakov and Oke: "*A deterministic formulation of the ensemble Kalman filter: an alternative to ensemble square root filters*", submitted to Tellus on Mar 6, 2007, printed Nov 6, 2007

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Flowchart of SURFEX-EnKF

OBSERVATIONS

Flowchart similar to the one used for the EKF at Météo-France (Mahfouf et al., 2009).

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