A Simplified Extended Kalman Filter assimilation of soil moisture for SL-AV global medium-range weather forecast model

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Goal: implementation of the Simplified Extended Kalman Filter (SEKF) for deep soil moisture initialization in the SL-AV global atmosphere model

The SL-AV – global operational NWP model (by Tolstykh M. et al)
-- 0.72 x 0.9 ° lat-lon resolution (~ 75 km in mid-latitudes)
-- 28 vertical levels

Input data

- Screen-level temperature (SYNOP)
- Screen-level relative humidity (SYNOP)

Advantages of SEKF

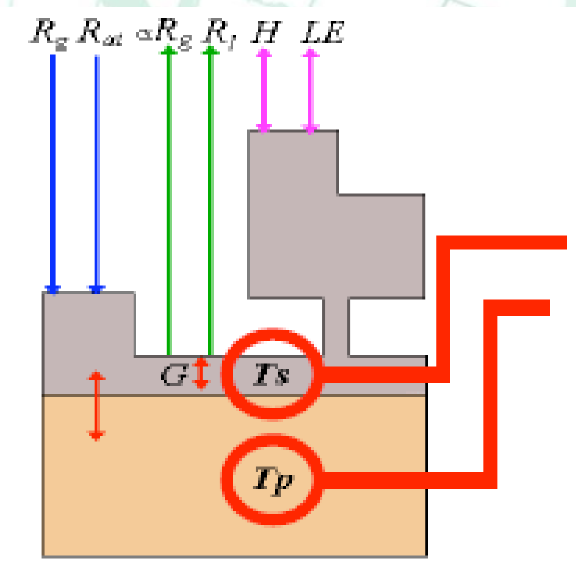
- «cheap» calculations
- elements of Kalman matrix take into consideration meteorological and soil conditions in every grid point implicitly
- potential ability to include satellite data into analysis

The Interaction Soil Biosphere Atmosphere (ISBA) parametrization (J.Noilhan and S.Planton, 1996)

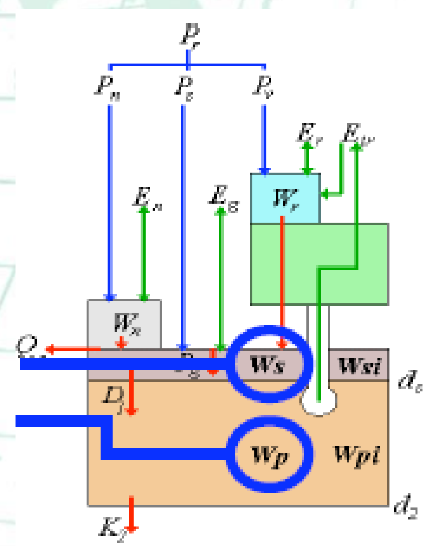
- Scheme has 2 soil layers (depth of superficial layer ~1 cm, depth of deep soil from 0.1 to 10 m)
- Force-restore method (J.W.Deardoff, 1977-1978)
- Coupled with atmosphere
- 8 prognostic variables: the surface temperature (**T_s**), the deep soil temperature (**T_p**), the superficial soil water content in liquid (**W_s**) and in frozen (**W_{si}**) forms , the deep soil water content in liquid (**W_p**) and in ice (**W_{pi}**) forms, the interception water content (**W_l**) and snow water content (**S_n**).

Energy fluxes

Water fluxes



Main analyzed variables



The simplified extended Kalman Filter (SEKF) (Balsamo, 2004 /Hess, 2001)

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Linearization of observation operator is expressed by its first order Taylor expansion with a finite difference approach

$$H(\mathbf{w}+\delta\mathbf{w}) = H(\mathbf{w}) + \mathbf{H}\delta\mathbf{w}$$

$$\mathbf{H} = \frac{H(\mathbf{w}+\delta\mathbf{w}) - H(\mathbf{w})}{\delta\mathbf{w}}$$

$$\mathbf{H} = \frac{\mathbf{H}^{+} + \mathbf{H}^{-}}{2}$$

$\delta\mathbf{w}$ - deep soil moisture perturbations ;

$\delta w = 0.01 м^3 / м^3$

$\mathbf{H}$ - linear estimate of the observation operator.

Gain Kalman matrix

$$\mathbf{K}_{t-1} = \mathbf{BH}^T \left(\mathbf{HBH}^T + \mathbf{R}\right)^{-1}$$

$\mathbf{R}$ - observation error covariance matrix;

$\mathbf{B}$ - background error covariance matrix;

$$\mathbf{B} = \left(\sigma_{w_b}^2\right)$$

$\sigma_{w_b}^2 = 0.01 м^3 / м^3$

$\sigma_{\mathrm{T_{2M}}}^2 = 1K, \sigma_{\mathrm{RH_{2M}}}^2 = 10\%$

$$\mathbf{R} = \begin{pmatrix} \sigma_{T_{2M}}^2 & 0 \\ 0 & \sigma_{RH_{2M}}^2 \end{pmatrix}$$

The simplified extended Kalman Filter (SEKF) (Hess, 2001)

Forecast step

$$\mathbf{w}_t^b = M_{t-1}\left[\mathbf{w}_{t-1}^a\right]$$

$\mathbf{w}_t^b$ - forecast vector of deep soil moisture

$\mathbf{w}_{t-1}^a$ - previous analysis vector

M_{t-1} - forecast model (ISBA)

Analysis step

$$\mathbf{w}_{t-1}^a = \mathbf{w}_{t-1}^b + \mathbf{K}_{t-1}\left[\mathbf{y}_t^o - H\left(\mathbf{w}_{t-1}^b\right)\right]$$

$\mathbf{y}_{t-1}^o$ - observation vector at moment *t-1*; (screen-level temperature and relative humidity observations at grid point)

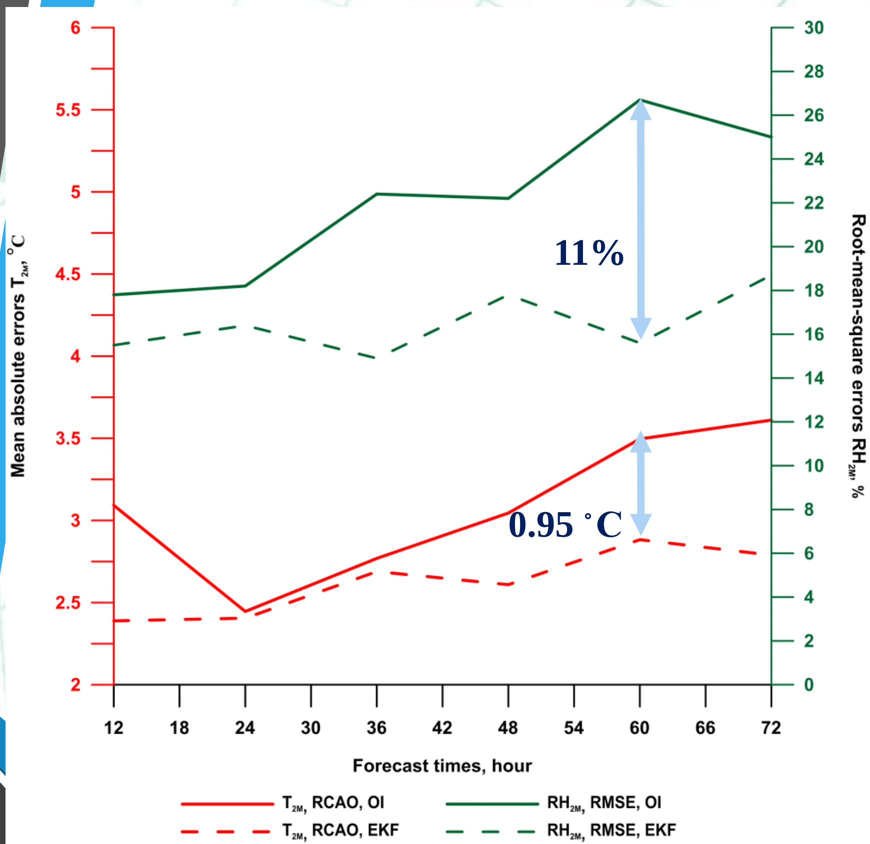
$H\left(\mathbf{w}_{t-1}^b\right)$ - first guess field of screen-level temperature and relative humidity

$\mathbf{K}_{t-1}$ - gain matrix at moment *t-1*;

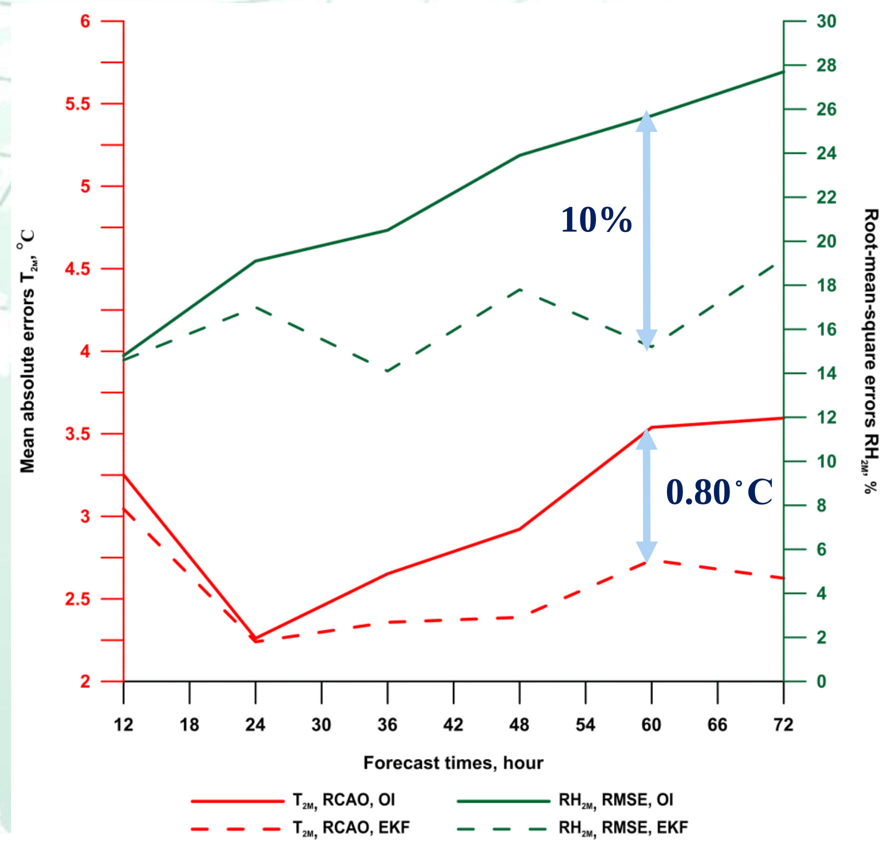
H – non-linear observation operator;

Comparison of the SL-AV forecast errors with SEKF and OI assimilation techniques. July 2014

Europe (0° -50° E, 35° -65° N)



Asia(50° -140° E, 40° -65° N)

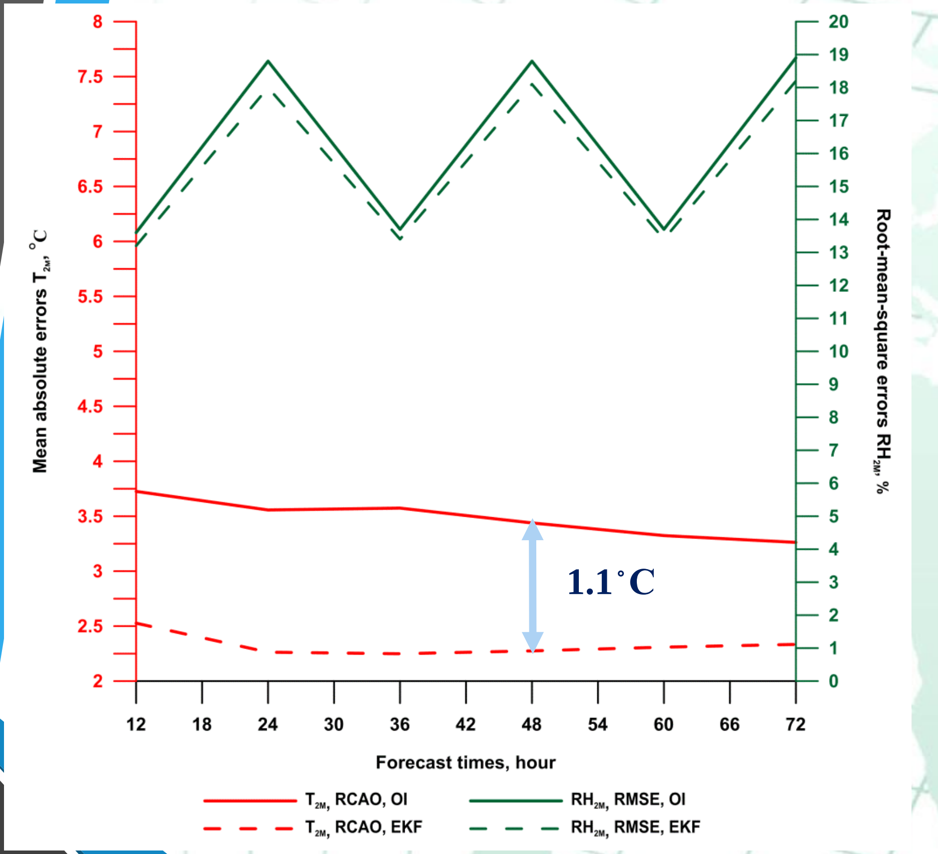


--sequential assimilation every 6 hours

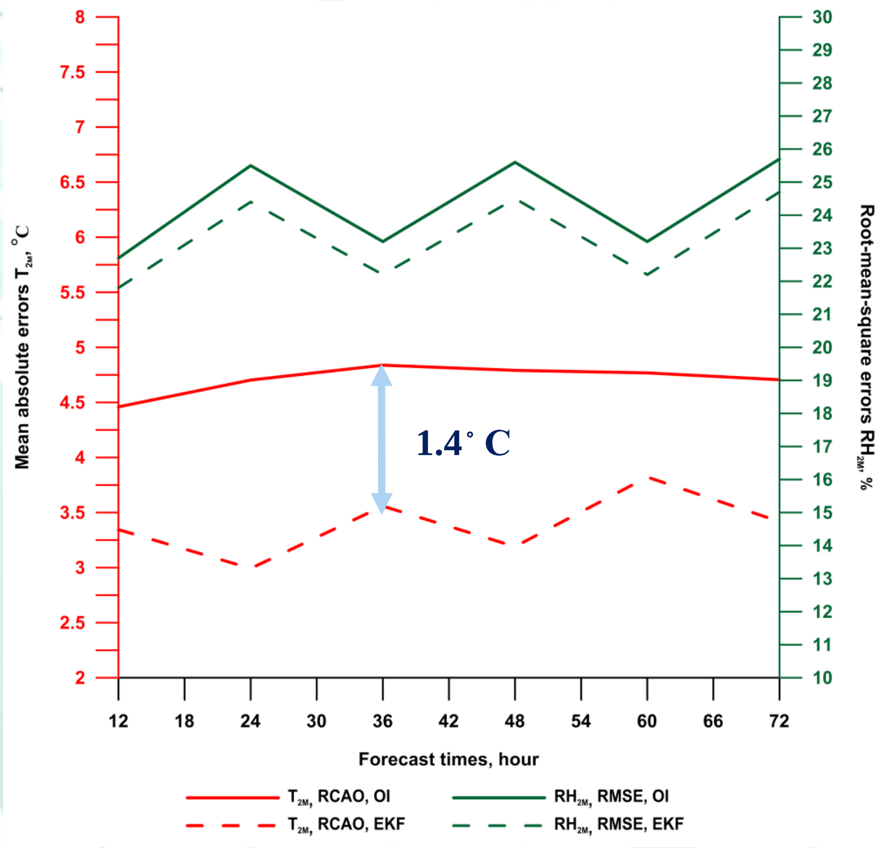
-- start at 12 UTC daily

Comparison of the SL-AV forecast errors with SEKF and OI assimilation techniques. January 2015

Europe (0° -50 ° E, 35° -65 ° N)



Asia(50° -140 ° E 40° -65 ° N)



--sequential assimilation every 6 hours

-- forecast start at 12 UTC daily

Conclusions

- The Simplified Extended Kalman Filter (SEKF) has been implemented for deep soil moisture initialization in the SL-AV global atmosphere model instead of OI method.
- Analysis of monthly averaged absolute (RCOA) and root-mean square errors (RMSE) of daily T_{2M} and RH_{2M} forecasts in July 2014 and January 2015 shows error decrease, more notable in July.
- Implementation of the SEKF essentially improves quality for screen-level temperature and humidity 3-days forecasts by the SL-AV over both assessed regions.

Thank you for attention!