Geosci. Model Dev. Discuss., 2, C303–C309, 2009
www.geosci-model-dev-discuss.net/2/C303/2009/

Geoscientific
Model Development
Discussions

Interactive comment on "Streamflow data assimilation for soil moisture analysis" *by* K. Warrach-Sagi and V. Wulfmeyer

K. Warrach-Sagi and V. Wulfmeyer

warrach@uni-hohenheim.de

Received and published: 1 October 2009

Thank you very much for the review of our manuscript. We anwer by paragraph.

1. We agree, that the assimilation of the streamflow observations – which are responsible for the EnKF becoming "retrospective" should be extended. We will provide more details on page 558 and add a flow chart (see attached figure). The state vector y includes the timeseries of the streamflow. Streamflow from t=0 to t=m*dt is assimilated to update (or analyze) the soil moisture at t=0. This means, the complete observation time series is assimilated, i.e. e.g. 96 values for Pforzheim. The closer the grid cell is to the gauging station, the shorter is the part of the streamflow time series responsible for its soil moisture. But since streamflow is an integrated quantity over the whole catchment, this is not separated in the EnKF. Less optimal results can be caused in those

grid cells through the assimilation of for this grid cells "too long" assimilation windows. A denser gauging network would help to reduce these effects. So we will re-write that sentence is the following way: "This is due to the following fact: The closer the grid cell is to the gauging station, the shorter is the part of the streamflow time series responsible for its soil moisture. But since streamflow is an integrated quantity over the whole catchment, this is not separated in the EnKF. Less optimal results can be caused in those grid cells through the assimilation of for this grid cells "too long" assimilation windows. A denser gauging network would help to reduce these effects."

2. Yes,the model state vector is x=[soil moisture(i,j,k,n),streamflow in river net gridbox (i,j,n)], i,j = grid cell counter, k= soil layer, n= timestep => depending on the gauging station e.g. 244 grid cells * (6 soil layers + streamflow)* 120 timesteps And the observation vector is y = [streamflow(n)] = timeseries of observed streamflow at gauge

We are not sure, what you refer to with "numerous observations".

a) If you mean observations from multiple gauging catchments at once, then this would not lead to more model states but y would become y = [streamflow(g,n)] = timeseries of n observed streamflow at gauges g, the observation operator matrix would need to be modified towards the sub-catchments between the gauges. But there would not be more model states.

b) If you mean different variables such as soil moisture profiles to be assimilated, this requires different observation operators.

We can add this to the final manuscript to clearify. Since all the necessary mathematics are described in detail by Evensen (2003 and 2004 and 2006) and the code is available from http://enkf.nersc.no we will add a figure with a flow chart of the assimilation in the revised manuscript (see above).

3. The goal of the streamflow data assimilation for soil moisture analysis is to apply the updated soil moisture fields with their error covariance matrix as initial condition in

weather prediction models running in a data assimilation mode. Further the analysis error covariance matrix A is critical information for the interpretation of the results. Further, thanks for the hint for the "tangent linear observation operator matrix", it is correct, we oversaw a miss-formatted symbol. In the text it should be a bold H and not an italic H and it occurs in eq. 4. Of course we do not apply the last term in eq. 4 in the EnKF, but this equation shows the relation between the EnKF and Extended Kalman Filter. This will be explained more in detail in the manuscript.

4. We are focusing on the analysis (see above) and not on forecasts here. So the initial state (t=0) is updated, but the soil moisture at t=0 influences the streamflow during the period from t=0 to t=m*dt (see page 558, line19). This means the streamflow from t=0 to t=m*dt is assimilated to update (or improve) the soil moisture at t=0. This is why we show the figures for t=0. For t=10*dt we would need to assimilate the streamflow from t=10 *dt to t=(m+10) dt. We will explain this more detailed in chapter 3 on page 558 in the revised manuscript.

5. The panel-figures (like figure 6 and 7) for the 6 single layers of TERRA-ML can be added and discussed in the revised version. The percent difference figures look very similar to the total column difference plots. If we add timeseries, then the spatial distribution is lost because we connot display it for all grid cells. I suggest to add the following graphs for the revised manuscript:

a) figure 6 or 7 for for each layer

b) time series of the catchment mean soil moisture of the control, ensemble and add a new simulation running TERRA-ML-routing starting with the soil moisture analysis (t=0)

c) time series of the catchment mean streamflow of the control, ensemble and add a new simulation running TERRA-ML-routing starting with the soil moisture analysis (t=0)

6. In publications of climate model simulations the word “climate” is also used for sea-

sonal prediction and soil moisture influence has been shown for seasonal to interannual climate prediction (e.g. Ni-Meister et al., JGR, 2005; Vinnikov et al., JGR, 1996; Entin et al., 2000, Koster and Suarez, Journal of Hydrometeorology, 2000; Liu and Avissar, Journal of Climate, 1999a & b). So we suggest to change line 22 to “weather prediction and seasonal to intraseasonal climate simulations rely on proper root zone soil moisture initialization"

7. Ok, this will be corrected.

8. Ok. We will delete that sentence and replace it by the following: “If due to the assimilation of screen level variables the model’s soil moisture and soil temperature are changed so that they may not reflect reality, this impacts other parameterizations and sub models that rely on those variables, e.g. runoff and latent and sensible heat flux.”

9. Yes, the reviewer raises critical points which should be discussed in the manuscript. Partly this is addressed in the previous answer. Hess (2001) and Drusch and Viterbo (2007) assimilated screen level variables, not the soil moisture and their assimilated data changed the soil moisture and soil temperature in a way, that the atmospheric state (e.g. 2m-air temperature) would be optimized. This implied that their soil moisture does not necessarily reflect the reality. The intention of Gupta et al. (1999) was to calibrate the model’s parameters within the ranges given in their table 1 to obtain e.g. an optimal soil moisture (their Fig. 4d) Or to calibrate the parameters to obtain the joint optimal results e.g. for sensible heat flux, soil temperature and soil moisture (their Fig. 5d). In the latter case the results for the latent heat flux improved significantly with improved soil moisture. The former case (calibration against soil moisture only) led to the best estimate for soil moisture. But these results were obtained with the automatic calibration and resulted in values for some parameters that are not as important for the soil moisture as they are for the energy balance (e.g. roughness length) and which resulted in too large sensible and too low latent heat fluxes in comparison with observation and the control simulation (see their discussion at the end of section 4.2.3.1). Our philoso-

phy is that an improved soil moisture is the first step in improving the simulation of the water fluxes. We do not expect an immediate positive impact on the simulation of fluxes and atmospheric variables but we are convinced that the optimization of initial fields is the first important step. With the improved soil moisture it will be possible to improve the parameterizations that are responsible for energy balance equations by means of re-analyses. Of course, the golden goal would be the assimilation of streamflow and other soil and atmospheric variables into a coupled atmosphere-land surface model system, e.g., COSMO-TERRA_ML or WRF-NOAH, WRF-CLM. We consider this study a first step towards this direction and should therefore show that it is principally a possible path to follow. We will add these considerations to the revised manuscript.

10. We didn't mean to discard the efforts of Komma et al. (2008), we appreciated their paper. We aimed at expressing, that Komma et al. (2008) had the hydrological forecast as objective while our objective is the soil moisture initialization of atmospheric models. This requires different land surface models. Hydrological land surface models are commonly complex concerning the water fluxes and often include water tables and storages but they tend to be simplified concerning the energy fluxes between the land surface and the atmosphere. Further they often have parameters that can be calibrated to the catchments. Land surface models of atmospheric models are more complex with respect to the energy fluxes and simplify the water fluxes. Since they are applied over large regions, they contain hardly parameters that are subject to calibration. Many land surface models were not applied with hydrological models, so their runoff was not even compared to streamflow. Only during PILPS (e.g. Lohmann et al., 1998) the participating models were checked for their runoff calculations. The snow model in TERRA-ML is based on solving the energy balance equation rather than a degree-day method like in Komma et al. (1998). The evapotranspiration is calculated solving the energy balance equation iteratively and calculating the evapotranspiration after Dickinson (1984). This is by far more complex concerning the energy fluxes. Soil freezing is also included. Time stepping is 15 seconds like in the atmospheric model. Only saturation and air dryness are threshold values. The complete assimilation will

be shown in a flow chart as stated above. So we suggest to change the sentence in the revised manuscript to "However, they use a soil moisture model focusing on the hydrological model application while in this study a land surface model for atmospheric models is applied."

The sentence "go[es] a step further and study the potential of streamflow data assimilation for soil moisture analysis in a catchment, namely for initialisation of numerical weather prediction and climate models." refers not to Komma et al. and Clark et al. but to the previous sentence only, i.e. to Lohmann et al. (2004) and Warrach-Sagi et al. (2008). So we will put a carriage return (break) between "...magnitude or more." and "Streamflow analysis also allows ...." in line 8 on page 555.

11. Thank you for the hint. The units of the streamflow in Figure 3 are not m^3/s as said on the axis, it should read m^3/1800s, so we will correct this.

12. Yes, during the assimilation time the same meteorological data is used, only the initial soil moisture is spatially disturbed (see fig.4). Of course one could change many more variables, namely the quantity and location of precipitation is still a major challenge in the numerical weather prediction, but also the vegetation and soil parameters such as e.g. LAI, root depth, porosity and hydraulic conductivity pose an uncertainty on the soil moisture. Pauwels and DeLannoy (2006) e.g. used a much larger number of ensemble members based on changed parameters and precipitation for their streamflow assimilation study. We limited our OSSE to the perturbation of the initial soil moisture field since our goal was to focus on the uncertainty of initial soil moisture fields for numerical meteorological models and to allow for a clearer interpretation of the results of the OSSE. We can add a figure showing that the areal mean soil water content of the ensemble does not converge to the CONTROL simulation during the assimilation window. But you are right, it would converge more than a month later.

13. The initial condition of the soil moisture is at time t=0, for the atmospheric model we want to improve the initial condition, so the control and analysis panel also show

the soil moisture at t=0. It is obtained assimilating streamflow from t=0 to t=48h. If I am interested in the soil moisture at t=5 h, I would need to assimilate streamflow from t=5h to t=53h. We will clarify this in the revised manuscript.

Please also note the Supplement to this comment.

Interactive comment on Geosci. Model Dev. Discuss., 2, 551, 2009.