Biomass and Soil Moisture Simulation and Assimilation over Hungary with the using of Surfex model

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Abstract

In the framework of the ImagineS project a Land Data Assimilation System (LDAS) is applied at the Hungarian Meteorological Service (HMS - OMSZ) to monitor the above ground biomass, surface fluxes (carbon and water) and the associated root-zone soil moisture at the regional scale (spatial resolution of 8km x 8km) in quasi real time. In this system the Surfex (SURFace EXternalisée) 7.3 model is used, which applies the ISBA-A-gs photosynthesis scheme to describe the evolution of vegetation. Surfex is forced using the outputs of the ALADIN numerical weather prediction model run operationally at HMS. First, Surfex was run in open-loop (i.e. no assimilation) mode. Secondly the Extend Kalman Filter (EKF) method was used to assimilate LAI Spot/Vegetation and SWI ASCAT/Metop satellite measurements. The EKF run was compared to the open-loop simulation and to observations (LAI and Soil Moisture satellite measurements) over the whole country and also to a selected site in West-Hungary (Hegyhátsál). A new diffusion soil scheme (ISBA-DIF) was tested and compared to the operational force-restore scheme.

Introduction

Surfex model is used to simulate biomass, carbon and water fluxes. In our experiments the model was run on regular lat-lon grid with 8x8 km resolution over a domain covering Hungary (Fig.1). The model was running in cycling mode and the 24-hour forecast was produced with 6h outputs frequency. Evaluated model outputs are:

- LAI (Leaf Area Index)
- WG2 (Volumetric soil moisture content)
- GPP (Gross Primary Product)
- NEE (Net Ecosystem Exchange)

Surfex model was coupled to ALADIN numerical weather prediction model. Surfex was run in offline mode, this means that the surface fluxes have no influence to the atmospheric fields, but the model needs meteorological data (air temperature, humidity, wind speed, precipitation, long and short wave radiation).

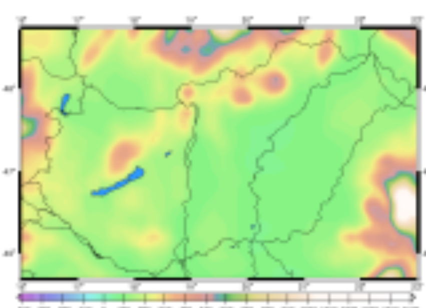

Fig. 1. Domain

Surfex

In Surfex each surface grid point is separated into 4 different tiles: nature, sea, lake and town. The model handles each tiles independently. In our work only the nature tile was treated. The nature tile is further divided into 12 patches according to the vegetation or surface types: bare soil, rock, permanent snow, deciduous tree, coniferous tree, broadleaf evergreen tree, C3 crops, C4 crops, irrigated crops, grassland, tropical grassland, parks and gardens. The model solves the prognostic equations and calculates the surface fluxes separately for the different patches.

The nature tile is simulated with ISBA (Interaction between Soil, Biosphere and Atmosphere) scheme, which contains a photosynthesis model, ISBA-A-gs. This model is suitable to describe the evolution of the vegetation. The biomass is a prognostic variable. Growing of biomass is due to photosynthesis (CO_2 assimilation) while the decline can be due to soil moisture stress or senescence. The model takes into account the soil moisture stress in the photosynthesis. Plants can have two strategies to the stress: draught avoiding and draught tolerant strategy.

The GPP is calculated as the sum of net assimilation and the dark respiration of leaves. NEE determined as a difference of Re (ecosystem respiration) and GPP. In ISBA-A-gs this is parametrized by a simple method depending on surface water content and the surface temperature.

ISBA-3-L

In ISBA 3-layer soil scheme is used (surface 0-1 cm, root zone 0-2 m and deep soil 2-3 m). The soil prognostic variables (temperature, water content and intercepted water content) are calculated with force-restore method. The force terms for temperature are the radiation, latent and sensible heat-flux. The restore term relaxes the temperature to the mean soil temperature. The force terms for soil water content are the precipitation and evaporation. The restoring term describes how the system reaches the equilibrium.

Data Assimilation

To improve the accuracy of the initial fields Land Data Assimilation System (LDAS) is used. The analyzed variables are the Leaf Area Index (LAI) and the root-zone soil moisture (WG2). Observations for LAI are derived from SPOT-VGT satellite data. LAI values are produced by a statistical algorithm using two products: SPOT VGT CYCLOPES V3.1) and TERRA/AQUA MODIS collection 5. The product is provided at spatial resolution 1 km and 10 days sampling time in regular latitude/longitude grid. To analyze the root-zone soil moisture, surface soil moisture (SSM) needs to be assimilated which is derived from SWI (Soil Water Index) product. SWI is calculated from MetOp. ASCAT observations using a recursive exponential filter. SWI is provided at 10 km spatial resolution with daily sampling. From SWI information to get SSM value we have to use the following relationship: $SSM=SWI*(w_{max}-w_{min})+w_{min}$, where w_{min} and w_{max} are the minimal and maximal SSM values that the model can take at a given grid point.

Extended Kalman Filter (EKF) assimilation method was performed to analyze LAI and SSM. To determine these values, observations and background (model forecast starting from a previous cycle) information need to take into account. The theory of Kalman Filter assumes that the analysis can be obtained by the following equation:

$$x_a = x_f + K(y_o - H(x_f))$$

Where **x** is the model state vector (a means analysis, f means forecast), **y** is the observation vector, H is the non-linear observation operator, **K** is the Kalman gain.

The analysis equation is solved at each grid point independently, as we assume, there is no correlation between the neighboring grid points.

ISBA-DIF (diffusion soil scheme)

ISBA-DIF is a new ISBA version including a soil multilayer diffusion scheme. With this technique the mass and heat-diffusive equations are solved explicitly. The total soil depth is discredited with several layers, and both moisture and temperature profiles can be explicitly computed according to soil texture properties. This multilayer diffusion scheme is theoretically superior to the simple force-restore scheme. It allows explicit representation of many processes those are more difficult to parameterize in bucket models: e.g. vertical distribution of root profile in the soil, surface capillarity exchanges, soil processes (heat exchange, infiltration, runoff). ISBA-DIF soil hydrology uses the mixed form of he Richard equation to describe the water mass transfer within the soil via Darcy's law.

In our experiment 14 soil layers were considered (0.01, 0.04, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 3.0, 5.0, 8.0 and 12.0 m). Fig. 2. shows the soil discretization used in ISBA-DIF.

2D Validations

Open-loop, Assimilation and Open-loop with ISBA-DIF scheme were performed and compared with satellite observations for year 2013. The observation error was set to 0.2 m^2/m^2 for LAI and 0.04 m^3/m^3 for SSM. The model error was set to 0.2 m^2/m^2 for LAI, 0.5 m^3/m^3 for SSM and 0.2 m^3/m^3 for WG2.

Fig. 3. shows the monthly averaged LAI for the mentioned experiments. Patch averaged LAI values were taken into account. From May-July the simulated LAI fields are closer to the observation in case of assimilation than without it. From August-October the best results were produced by the open-loop simulations as it is presented by the area-mean correlation in Fig. 4.

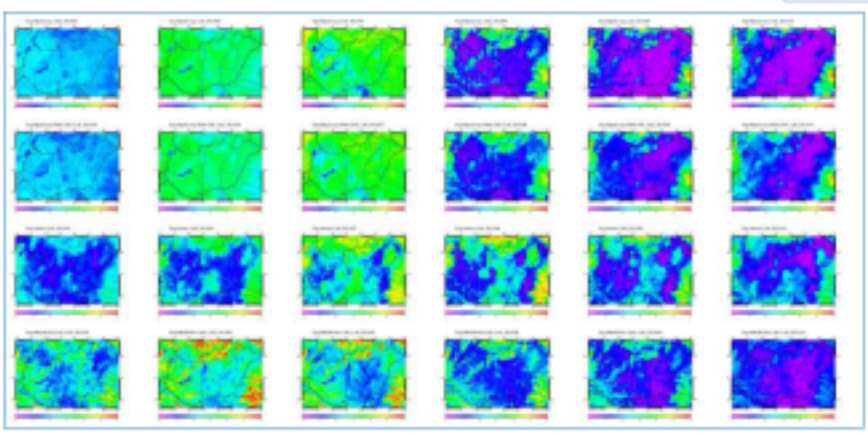

Fig. 3. Validation of LAI, 2013 May-Oct. (first row: Open-loop, second: Open-loop-DIF, third: Assimilation, fourth: satellite obs.)

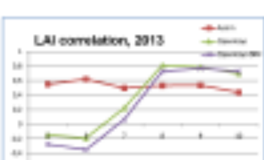

Fig. 4. Area-mean LAI correlation for May-Oct, 2013

Fig. 5. compares the monthly averaged root zone soil moisture. In open-loop simulation more moisture is presented in spring and start of summer. One can see that small differences can be found between the two kind of open-loop experiments.

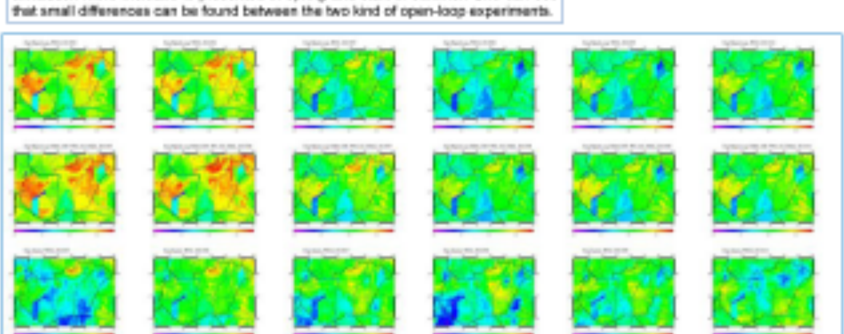

Fig. 5. Validation of WG2, 2013 May-Oct. (first row: Open-loop, second: Open-loop-DIF, third: Assimilation)

Fig. 6. Hegyhátsál is located in West-Hungary

1D Validation

Experiment outputs were validated against in-situ measurements of Hegyhátsál (Fig. 6.). Data are available from two levels:

- 3 m height from a grassland area (valid for only the grassland patch):
  - -LAI (weekly)
  - -Soil Moisture (daily) (derived from 10-30 cm depth)
  - -Carbon fluxes: GPP, Reco and NEE (daily)
  - -Water flux: Latent Heat (LE) (daily)
- 82 m height (valid for the whole grid-point):
  - -Carbon fluxes: GPP and NEE (daily)
  - -Water flux: LE (daily)

Results

LAI is underestimated by the models. Unfortunately the assimilation of LAI and SWI could not improve the results (Fig. 7. and Fig. 8.). The carbon- and water flux forecasts are well represented by the open-loop simulations, but the assimilation run could not reproduce the events at is was in the reality.

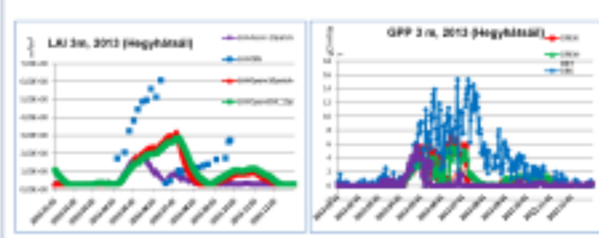

Fig. 7. LAI and GPP over grassland in Hegyhátsál

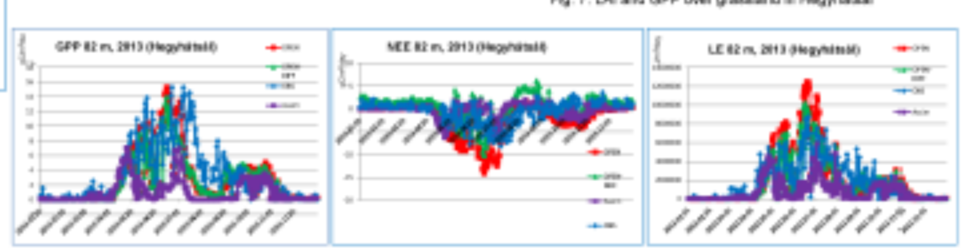

Fig. 8. GPP, NEE and LE over Hegyhátsál