EGU24-20049, updated on 25 Apr 2024
https://doi.org/10.5194/egusphere-egu24-20049
EGU General Assembly 2024

Impact of soil moisture data assimilation on short-term numerical weather prediction

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Land-atmosphere (LA) coupling describes the dynamic interaction between the Earth's land surface and (the bottom of) the atmosphere. This coupling involves the exchange of energy, water, and momentum between the two systems and its strength varies depending on several factors (e.g., season, land cover, topography, and climate zone). Several metrics that quantify the strength of the LA coupling, both physical and statistical, have been developed and explored extensively in the literature.

Coupled systems that model the atmosphere, the land surface, and their interaction require an initialization of both the atmospheric and the land components. For the latter, a land surface model (LSM) is typically spun up in a so-called 'offline' manner, i.e., not coupled to the atmospheric model but forced by an atmospheric reanalysis product. So far, little research has focused on the potential impact of satellite-based soil moisture data assimilation (DA) during this spin-up period on the subsequent forecast by the coupled system. However, several studies in the land surface modeling community have demonstrated the potential benefit of soil moisture DA to improve estimates of hydrological variables and land surface fluxes in offline simulations.

In this study, soil moisture retrievals from the 36 km Soil Moisture Active/Passive (SMAP) Level 2 product are assimilated into the Noah-MP LSM with dynamic vegetation, forced by the MERRA-2 atmospheric reanalysis. This is done using a one-dimensional Ensemble Kalman Filter (EnKF) within the NASA Land Information System (LIS). The DA updates the moisture in each of the four soil layers of the LSM. The resulting land reanalysis provides consistent estimates of land surface variables and fluxes from 1 January 2016 through 31 December 2020 on an 18 km grid over the contiguous United States.

This land reanalysis is subsequently used to initialize the land component of an experiment where the Noah-MP LSM and the Weather Research & Forecasting (WRF) atmospheric model are coupled within the NASA Unified WRF (NU-WRF) framework. The atmospheric component is initialized with MERRA-2, which also serves as the boundary condition for the atmospheric model. We compare the results in terms of short-term atmospheric estimates (e.g., of evaporative fraction, growth of the planetary boundary layer, screen-level temperature and humidity) with an initialization that uses a purely model-based land spin-up.

Our study allows the quantification of land DA impact during spin-up and the assessment of its relationship with the LA coupling strength. The results will provide important insights into where and when short-term atmospheric forecasts may benefit from assimilating satellite-based soil moisture retrievals.