Submission Title:

Assimilation of SMAP Observations Over Land Improves the Simulation and Prediction of Tropical Cyclone Idai

Author(s):

Jana Kolassa (NASA 610.1/ SSAI),

Manisha Ganeshan (NASA 613 / MSU),

Erica McGrath-Spangler (NASA 610.1 / MSU),

Oreste Reale (NASA 610.1 / SSAI), and

Rolf Reichle (NASA 610.1)

Abstract

This work is focused on the role of soil moisture in the prediction of tropical cyclones (TCs) approaching land and after landfall. Soil moisture conditions can impact the circulation and structure of an existing tropical cyclone (TC) when part or all of the circulation is over land. For example, dry land surface conditions may lead to faster dissipation of a TC over land (often associated with changes in precipitation structure), whereas very wet conditions may help sustain or in rare cases re-intensify a TC. Moreover, the presence of strong soil moisture gradients may affect the symmetry and development of the TC circulation leading to changes in its over-land track. While the link between soil moisture conditions and TC evolution in proximity to land is relatively well understood in theory, applications of these findings in the context of numerical weather prediction (NWP) have been limited.

Here we present a case study that explores the potential of improving TC predictions through an improved soil moisture initialization in an NWP framework. Specifically, we examine the impact of assimilating observations from the NASA Soil Moisture Active Passive (SMAP) mission into the NASA Goddard Earth Observing System (GEOS) global weather model on the prediction of South-West Indian Ocean TC Idai (2019). SMAP provides accurate L-band (1.4 GHz) brightness temperatures (Tb) observations that are sensitive to soil moisture globally and at high revisit times of 2-3 days. It has previously been shown that the assimilation of SMAP Tb observations significantly improves modeled land surface states. Thus, it is expected that SMAP can be used to constrain land surface initial conditions and potentially benefit TC forecasts. Here we present two sets of retrospective forecasts of TC Idai that are compared in an Observing System Experiment framework at ¼ degree resolution: (i) forecasts initialized from an analysis that is comparable to the GEOS operational analysis (without SMAP Tb assimilation) and (ii) forecasts initialized from an analysis that additionally assimilates SMAP brightness temperature observations over land using a weakly-coupled land analysis.

We find that the assimilation of SMAP meaningfully improves the representation of TC Idai's structure as well as the prediction of its intensity and track. The analyzed TC size, as measured by the wind speed radius, is improved by up to 18% in the analysis with SMAP assimilation relative to the control run. The forecast intensity error, measured against the observed intensity, is reduced by up to 23%. At the 1/4-degree resolution used here, GEOS unavoidably under-estimates TC intensity and over-estimates TC size. The SMAP assimilation therefore corrects the model in the right direction, leading to a storm that is

more energetic and more compact. Furthermore, we find that the along-track forecast error is reduced by up to 34%, indicating a more accurate propagation speed, which is consistent with the fact that TC speed over land is strongly affected by surface processes. The impact of SMAP assimilation on the forecast cross-track error is neutral. Across the TC forecast skill metrics used here, the improvements from SMAP DA are largest at lead times of 36 to 72 hours, suggesting that the predictability of forecasts at shorter lead times may be dominated by short-term convective processes, while the land and its longer memory gains in importance as a source of predictability on a 2-3 day timescale.

We further investigated the underlying mechanisms leading to the skill improvements from SMAP data assimilation by isolating the land areas that directly influence TC Idai using a back trajectory analysis. We find that the assimilation of SMAP leads to wetter soil moisture conditions that cause an increased latent heat flux, which ultimately results in TC analyzed representation that has higher column-integrated total moisture content and total energy compared to the analysis in the control run without SMAP assimilation.

Overall, the results highlight that the assimilation of SMAP observations into a global numerical weather prediction model can lead to pronounced improvements of TC predictions. This is a crucial step towards a better mitigation of the socio-economic impact of landfalling TCs and thus safeguarding human lives. Finally, our study presents an event-based approach that assesses the impact of land data assimilation for a particular weather event rather than by globally averaging differences in skill. We argue that global skill assessments – while necessary – can mute the impact of land data assimilation, because the land's influence on the atmosphere is constrained to certain locations and certain times. Instead, the event-based approach better highlights the true potential of land data assimilation in the context of NWP, especially for extreme events when accurate predictions are critical.