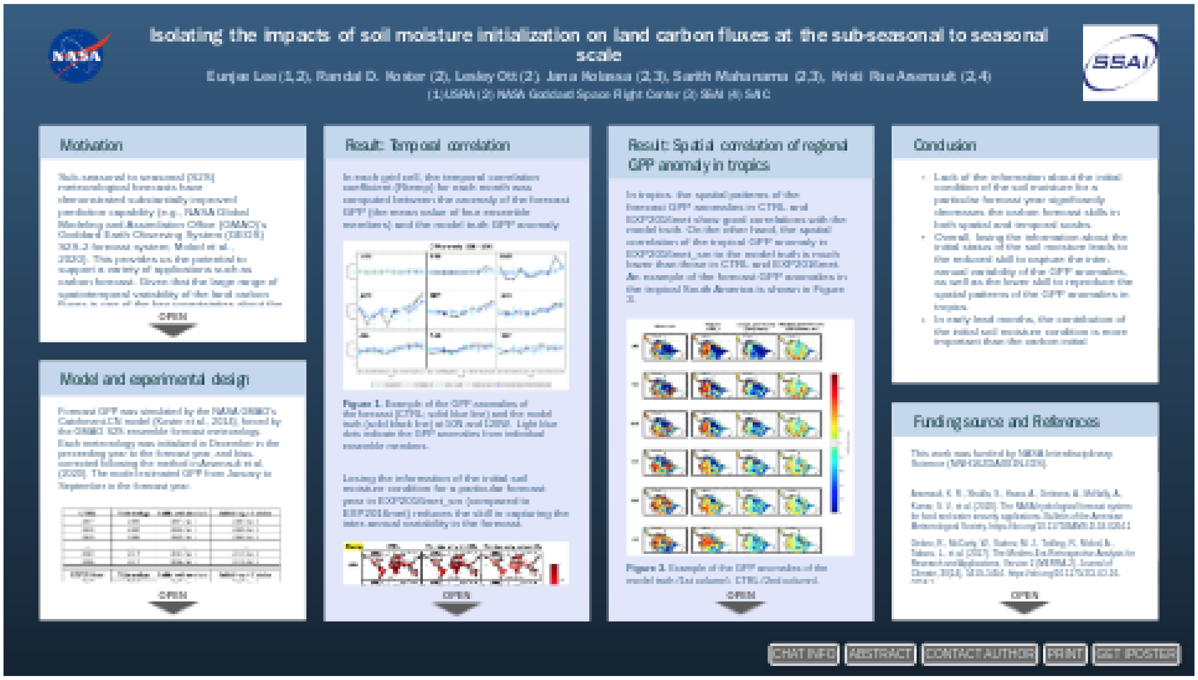
Isolating the impacts of soil moisture initialization on land carbon fluxes at the sub-seasonal to seasonal scale



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MOTIVATION

Sub-seasonal to seasonal (S2S) meteorological forecasts have demonstrated substantially improved prediction capability (e.g., NASA Global Modeling and Assimilation Office (GMAO)'s Goddard Earth Observing System (GEOS) S2S-2 forecast system; Molod et al., 2020). This provides the potential to support a variety of applications such as carbon forecast. Given that the large range of spatiotemporal variability of the land carbon fluxes is one of the key uncertainties about the global carbon budget, it is important to evaluate our current capability of forecasting terrestrial carbon at the S2S scale.

MODEL AND EXPERIMENTAL DESIGN

Forecast Gross Primary Production (GPP) was simulated by the NASA GMAO's Catchment-CN model (Koster et al., 2014), forced with the GMAO S2S ensemble meteorology forecast. Each meteorology was initialized in December of the year preceding the forecast year, and bias-corrected following the method in Arsenault et al. (2020). The model estimated GPP from January to September in the forecast year.

CTRL	**Meteorology**	**Initial soil moisture**	**Initial veg + C status**
2007	2007	2007 Jan 1	2007 Jan 1
2008	2008	2008 Jan 1	2008 Jan 1
2009	2009	2009 Jan 1	2009 Jan 1
…	…	…	…
2015	2015	2015 Jan 1	2015 Jan 1
2016	2016	2016 Jan 1	2016 Jan 1
EXP2016met	**Meteorology**	**Initial soil moisture**	**Initial veg + C status**
2007	2016	2007 Jan 1	2007 Jan 1
2008	2016	2008 Jan 1	2008 Jan 1
2009	2016	2009 Jan 1	2009 Jan 1
…	…	…	…
2015	2016	2015 Jan 1	2015 Jan 1
2016	2016	2016 Jan 1	2016 Jan 1
EXP2016met_sm	**Meteorology**	**Initial soil moisture**	**Initial veg + C status**
2007	2016	2016 Jan 1	2007 Jan 1
2008	2016	2016 Jan 1	2008 Jan 1
2009	2016	2016 Jan 1	2009 Jan 1
…	…	…	…
2015	2016	2016 Jan 1	2015 Jan 1
2016	2016	2016 Jan 1	2016 Jan 1

Table 1. Experimental design. In the CTRL experiment, the simulations used the bias-corrected, forecasted meteorology and land initial conditions appropriate for the forecast year. The simulations in EXP2016met applied the land initial condition appropriate for the forecast year while the 2016 forecast meteorology was applied to all forecast years. The diurnal and monthly variations in the year 2016 meteorology remain in EXP2016met. In EXP2016met_sm, both the meteorology of year 2016 and the soil moisture condition on Jan 1, 2016 were applied to all forecasts, while the initial land condition (except for the soil moisture) appropriate for the forecast year was applied. All are land-only (offline) simulations.

The "model truth" GPP was generated by the Catchment-CN model, forced with the MERRA-2 reanalysis meteorology (Gelaro et al., 2017).

RESULT: TEMPORAL CORRELATION

In each grid cell, the temporal correlation coefficient (Rtemp) for each month was computed between the anomaly of the forecast GPP (the mean value of four ensemble members) and the model truth GPP anomaly.

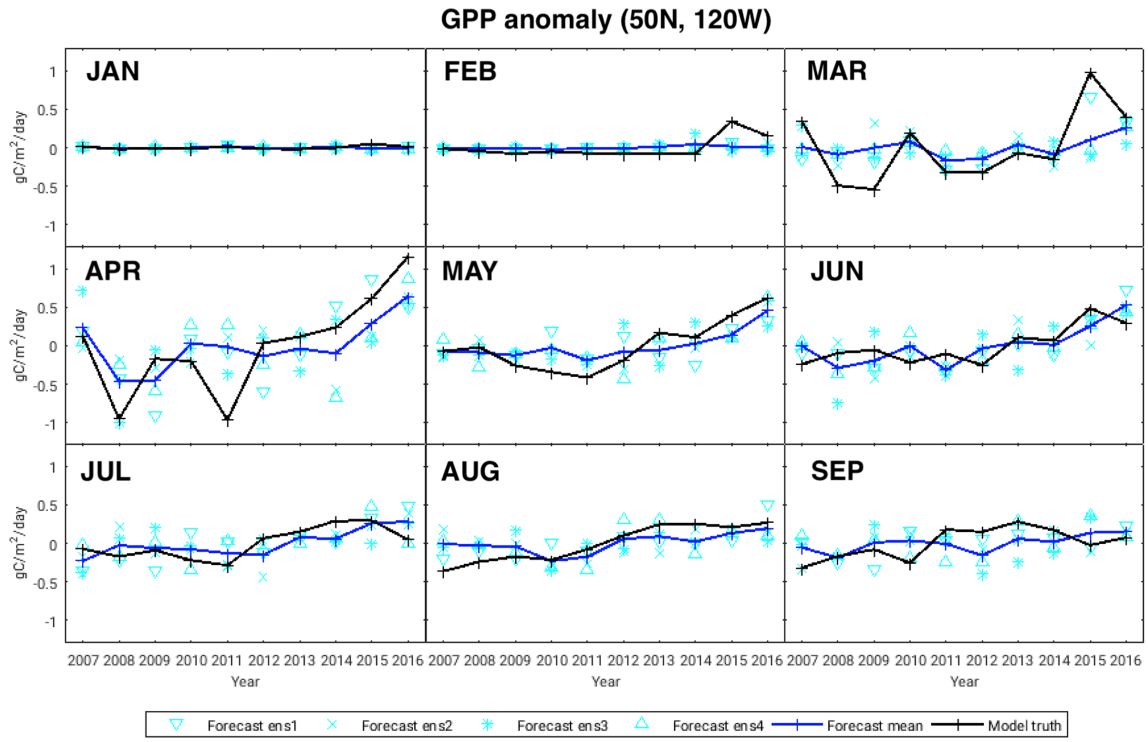

Figure 1. Example of the GPP anomalies of the forecast (CTRL; solid blue line) and the model truth (solid black line) at 50N and 120W. Light blue dots indicate the GPP anomalies from individual ensemble members.

Losing the information of the initial soil moisture condition for a particular forecast year in EXP2016met_sm (compared to EXP2016met) reduces the skill in capturing the inter-annual variability in the forecast.

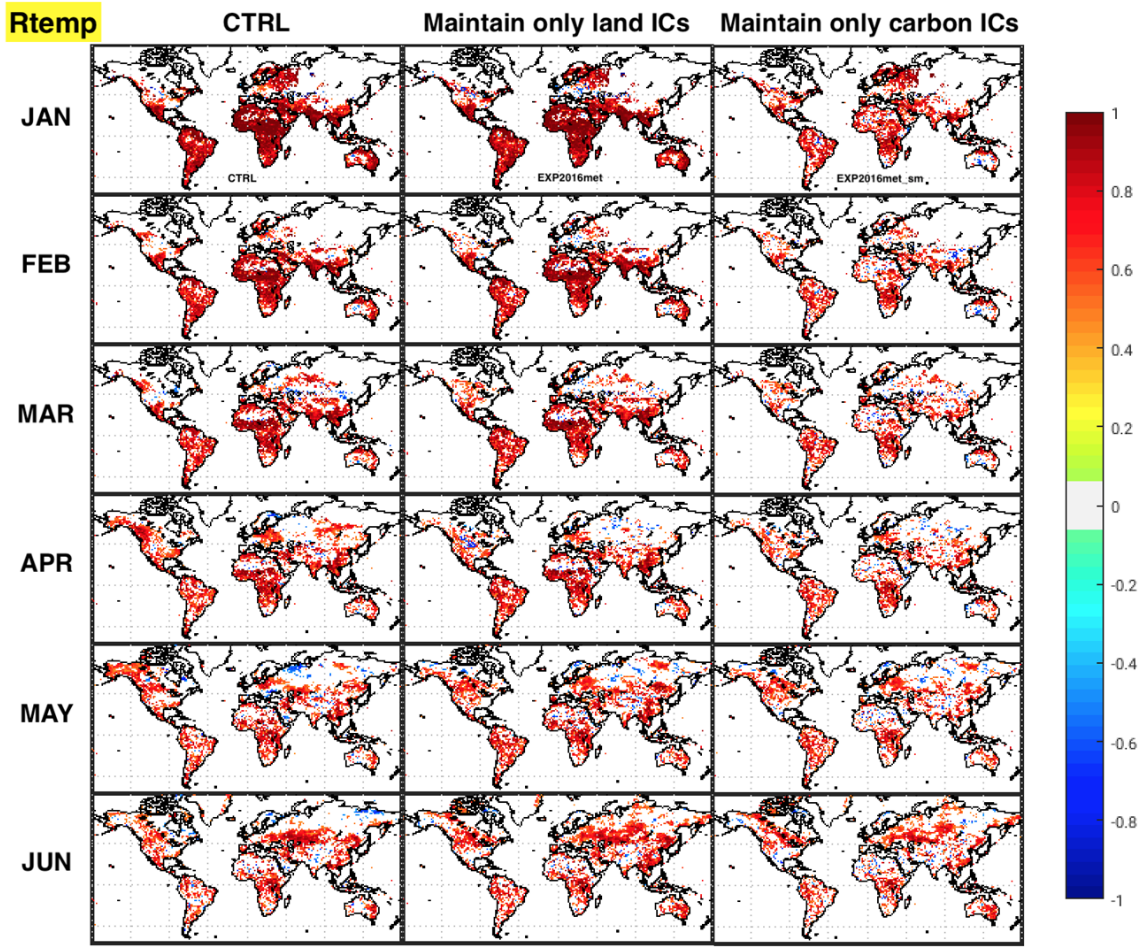

Figure 2. Temporal correlation of the forecast GPP anomalies (CTRL, EXP2016met and EXP2016met_sm) to the model truth GPP anomaly. The confidence interval of 90% has been applied.

RESULT: SPATIAL CORRELATION OF REGIONAL GPP ANOMALY IN THE TROPICS

In the tropics. the spatial patterns of the forecast GPP anomalies in CTRL and EXP2016met show good correlations with the model truth. On the other hand, the spatial correlation of the tropical GPP anomaly in EXP2016met_sm to the model truth is much lower than those in CTRL and EXP2016met. An example of the forecast GPP anomalies in the tropical South America is shown in Figure 3.

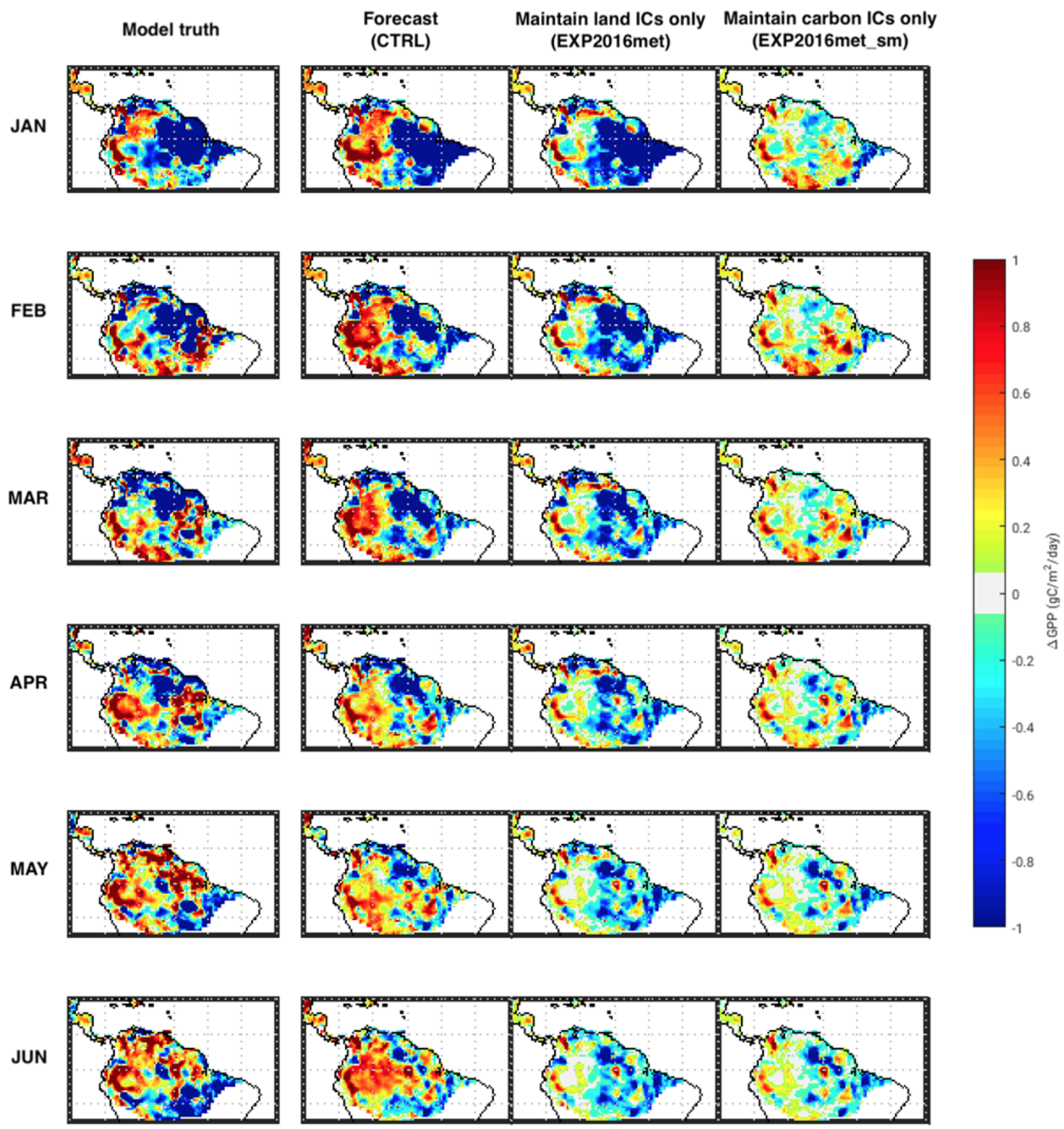

Figure 3. Example of the GPP anomalies of the model truth (1st column), CTRL (2nd column), EXP2016met (3rd column) and EXP2016met_sm (4th column) of the Tropical South America for year 2016.

Moreover, the contribution of the initial soil moisture information is greater in the early lead months (up to 3rd and 4th lead month), when the overall carbon forecast skill is high.

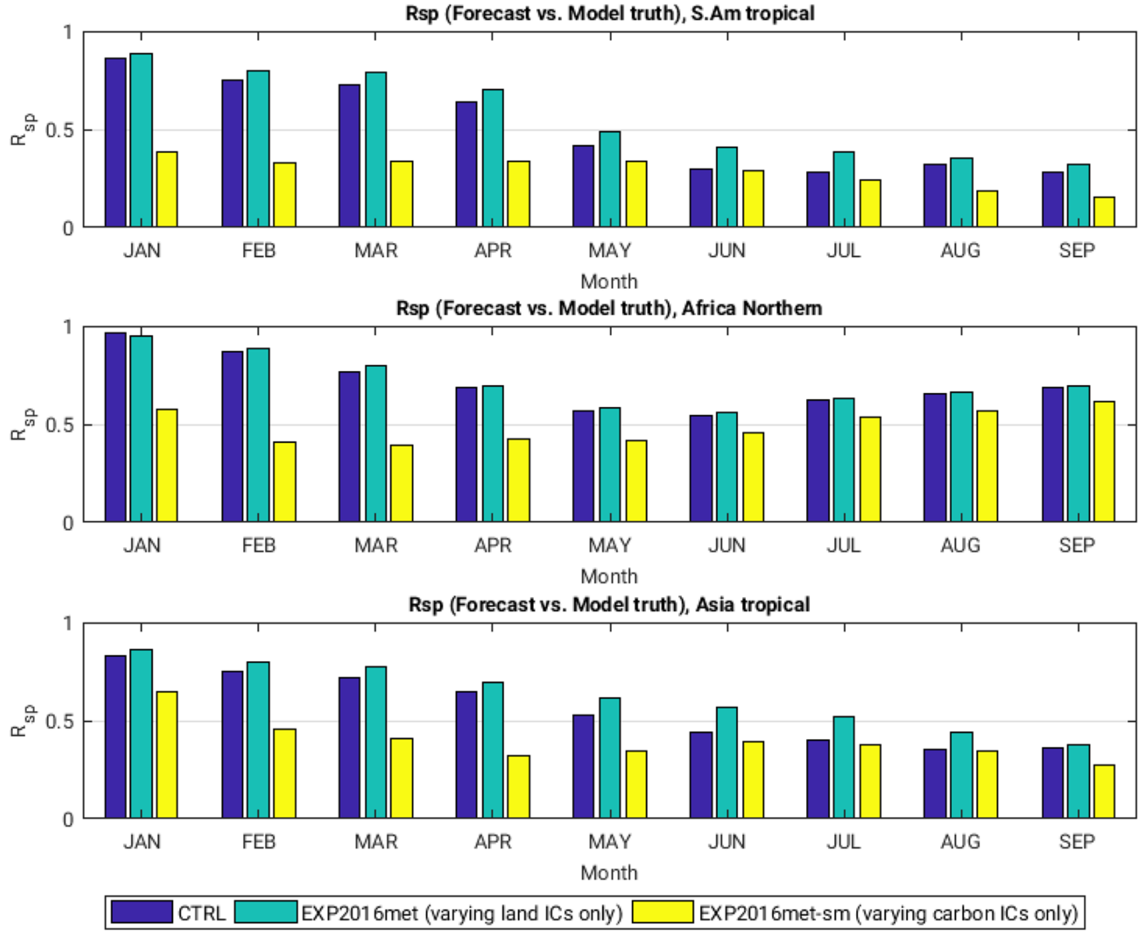

Figure 4. Spatial correlation coefficients (Rsp) of the regional GPP anomalies between the forecast and the model truth: (a) Tropical South America, (b) Africa Northern, and (c) Tropical Asia. The regional boundary adopts the TransCom classification (TransCom (https://www.transcom.com/en/tags/transcom-region)).

CONCLUSION

- Lack of the information about the soil moisture initial condition for a particular forecast year significantly decreases the carbon forecast skills in both spatial and temporal scales.
- Overall, the removal of the information on soil moisture initial conditions leads to a reduced skill at capturing the inter-annual variability of the GPP anomalies as well as a reduced skill in reproducing the spatial patterns of the GPP anomalies in the tropics.
- In the early lead months, the contribution of the initial soil moisture condition is more important than the carbon initial conditions.

FUNDING SOURCE AND REFERENCES

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ABSTRACT

Soil moisture, through its impact on transpiration, plays a significant role in controlling the productivity of terrestrial vegetation. Initial soil moisture conditions in a seasonal forecast may therefore affect the forecast of land carbon uptake. Here we investigate the relative impacts of soil moisture initialization and carbon reservoir initialization on forecasts of land carbon fluxes at the sub-seasonal to seasonal (S2S) scale. The bias-corrected, retrospective meteorology of NASA Global Modeling and Assimilation Office (GMAO)'s S2S ensemble forecast was used to force the stand-alone Catchment-CN model and thereby estimate terrestrial carbon responses out to nine lead months. Our results show that soil moisture initialization is a major contributor (approximately 44%) to the high global carbon uptake forecast skill seen during the first three lead months. The carbon reservoir initialization explains roughly another half of the monthly carbon forecast skill during this period and becomes relatively more important at longer leads (while the overall forecast skill decreases after the 3rd lead month), suggesting a slower but longer-lasting influence of carbon reservoir initialization on carbon fluxes. Our results highlight the significance of a good soil moisture initialization for improved forecasts of carbon fluxes at leads of several months, further support for the usefulness of assimilating the satellite-based soil moisture information into terrestrial biosphere models and of a short term carbon forecast to understand current events with often a lag in the availability of flux estimates.