Using large ensembles to study changes in terrestrial ecosystems

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Large Ensembles Workshop
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Are land surface models getting better over time?

- Assessment of model performance using ILAMB
- CMIP6 models perform better than CMIP5 models
- Why?
  - Driver variables look to have smaller biases (air temperature, precip.)
  - Improvements in model mechanism (permafrost, nitrogen cycle, fires)

Hoffman et al. (in prep)
Do ESMs accurately represent the strength of land-atmosphere coupling?
Table 1. Remote sensing products used for analysis.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbr.</th>
<th>Data product</th>
<th>Spatial resolution</th>
<th>Temporal resolution</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial water storage</td>
<td>TWS</td>
<td>GRACE Tellus RL05.1</td>
<td>1°</td>
<td>monthly</td>
<td>Landerer and Swenson (2012)</td>
</tr>
<tr>
<td>Vapor pressure deficit</td>
<td>VPD</td>
<td>AIRS AIRX3STM v6</td>
<td>1°</td>
<td>monthly</td>
<td>Susskind et al. (2014)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>PPT</td>
<td>GPCP 1DD v1.2</td>
<td>1°</td>
<td>daily</td>
<td>Huffman et al. (2009)</td>
</tr>
<tr>
<td>Downwelling shortwave radiation</td>
<td>SW↓</td>
<td>CERES EBAF Ed2.8</td>
<td>1°</td>
<td>monthly</td>
<td>Loeb et al. (2009)</td>
</tr>
</tbody>
</table>
Timing of onset, termination, and duration of drawdown interval (dry season)
Example relationships between soil moisture and atmospheric state variables

Forcing metric                     Response metric

(a) VPD forcing metric (GRACE-AIRS) (b) VPD response metric (GRACE-AIRS)

(c) VPD forcing metric (LENS 001)  (d) VPD response metric (LENS 001)

Correlation coefficient
In tropical and temperate regions, the forcing branch of land-atmosphere coupling in CESM1-LENS looks to be too strong.
Land-atmosphere coupling findings

• To evaluate the land-atmosphere moisture feedback, it’s important conceptually to consider both soil moisture forcing of the atmosphere, but also the response of soil moisture to atmospheric forcing.

• Biases in either branch can affect the strength of the land-atmosphere moisture feedback.

• CESM1 and many other CMIP5 models appear to exhibit too strong a land-atmosphere moisture feedback.

• Land-atmosphere coupling likely amplifies and extends terrestrial carbon cycle responses to ENSO forcing in the Amazon and elsewhere.


Climate change impacts on the position of the ITCZ and patterns of tropical precipitation in CESM1-LENS

Probability Distribution of the location of the ITCZ in baseline 1983-2005

May-Oct

Latitude

Nov-Apr

Longitude

PDF

Eastern Pacific bias

Mamalakis, Foufoula-Gergiou et al., In prep.
Changes in the ITCZ show a diverging pattern across Eastern and Western Hemispheres

CESM-LENS
Difference in the distribution of the ITCZ location between 2075-2100 and 1983-2005

Future trends in the location of the ITCZ

Mamalakis, Foufoula-Gergiou et al., In prep.
The effect of daily climate extremes on California wildfires

Data sources: Daily MODIS burned area and daily PRISM

Gutierrez et al.
The effect of daily climate extremes on California wildfires

Gutierrez et al.

a) Jun–Sep FN

Years
1980s 2000s 2020s 2040s

Fires (n y⁻¹)

0 10 20 30 40

b) Jun–Sep BA

Years
1980s 2000s 2020s 2040s

Burned Area (km² y⁻¹)

0 100 300 500 700

LENS
PRISM
FRAP

Gutierrez et al.
Longer term ensembles to 2300 and beyond are needed to quantify the robustness of new climate-driven ecological teleconnections.

- Loss of sea ice around Antarctica stimulates a massive phytoplankton bloom after 2100 for RCP8.5
- Nutrients are trapped in the deep Southern Ocean
- Northward water flows into Atlantic and Pacific are depleted in N, P, Si
- Ocean fisheries decrease more than 30% globally north of 40°S, and by nearly 60% in the North Atlantic

Moore et al. (2018) *Science*
Conclusions

• Variability in comparison to benchmarks is much larger across different land surface models than among ensemble members of a single model
• Better metrics are needed for evaluating large ensembles
• More work is needed integrating large ensembles into BGC and land benchmarking systems (and into CMIP7 and beyond)
• Using GRACE observations, there is some evidence that CESM1 (LENS) and many CMIP5 models overestimate the strength of land-atmosphere moisture feedback
• A new frontier is to use large ensembles to explore the robustness of climate-driven ecological teleconnections on longer timescales
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Figure 4. Interannual variability (standard deviation) of VPD$_{di}$ from AIRS (a), PPT$_{di}$ from GPCP (b), SW$_{di}$ from CERES (c) and the equivalent quantities from the LENS ensemble mean (d–f).

Levine et al. (2016) HESS
In tropical and temperate regions, the response branch of land-atmosphere coupling in CESM1-LENS looks to be somewhat stronger than observations.
Future trends in the location of the ITCZ

Mamalakis, Foufoula-Gergiou et al., In prep.
A Global Ecological Teleconnection Driven By Nutrient Trapping

Definition: Global change impact on the biosphere in one region generates a large-scale change in another remote region, as a consequence of changes in transport of energy, water, nutrients, or information.

- Fossil fuels
- Ocean heat uptake
- Loss of sea ice
- Stronger Westerly winds
- A warmer Southern Ocean
- Shoaling mixed layers
- Increases in light availability
- Upwelling on iron-rich shelf

Massive phytoplankton bloom in Southern Ocean

- Lower pre-formed nutrients in surface & intermediate water masses moving north
- Build up of nutrients in deep ocean
- Loss of tropical and northern ocean productivity and flows to higher trophic levels
Ocean warming is stronger at high latitudes, and the southern hemisphere Westerlies shift south, strengthening near the coast of Antarctica.

Moore et al. (2018) Science
Ocean Warming Around Antarctica Decreases Sea Ice

Moore et al. (2018)
The changing climate stimulates a phytoplankton bloom around Antarctica

Particulate sinking carbon flux

Moore et al. (2018) Science
Sinking biological particles in the Southern Ocean carry nutrients with them.

This traps phosphorus and other nutrients in the deep ocean.

Currents that flow into the Pacific and Atlantic Oceans have much lower nutrients than normal (these are Antarctic Intermediate Water (AAIW) and SubAntarctic Mode Waters).

Thus, there is a net transfer of nutrients to the deep ocean and a large decrease in phosphate concentrations in the upper ocean, everywhere to the north of the Southern Ocean (A-C).

The collapse of deep winter mixing in the high latitude North Atlantic, also acts to deplete upper ocean nutrients and increase deep ocean nutrient concentrations (C).

Moore et al. (2018) *Science*
Moore et al. (2018) Science

Nutrient Transfer to Deep Ocean Via the Southern Ocean

Current Era:
- low NPP near Antarctica from:
  - heavy sea ice
  - low light
  - cold ocean
  - slower growth
  - iron-limination

Hothouse Earth:
- higher NPP near Antarctica from:
  - less sea ice
  - more light
  - warmer ocean
  - faster growth
  - more upwelling
  - more nutrients

SAMW: Subantarctic Mode Waters
AAIW: Antarctic Intermediate Water

1990s:
- strong northward nutrient flux

2290s:
- weaker northward nutrient flux
- Decreasing nutrients

Increasing nutrients

Moore et al. (2018) Science
Tropical ocean hypoxic zones contract from loss of productivity in ocean surface waters

Fu et al. (2018) GBC
Salinity in Arctic Ocean declines by nearly 10% by 2300