ENSO diversity and its impact on Terrestrial Water Storage to Sea-Level

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Outline

Part I: Interannual variation of terrestrial water storage from satellites, reanalysis and offline CLM5 simulation
(Coauthors: Dr. Min-Hui Lo, Dr. Yu-Chiao Liang, Dr. Yu-Heng Tseng, Dr. Chia-Wei Hsu)

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Part II: Internal variability and hydroclimate in CESM2
(Ongoing project supervised by Dr. Flavio Lehner, collaborating with Dr. Matt Newman)
Part I: Interannual variation of terrestrial water storage from satellites, reanalysis and offline CLM5 simulation
The sea level rise is accelerated and this is very likely to be related to human activities.

d) Global mean sea level change relative to 1900

Low-likelihood, high-impact storyline, including ice sheet instability processes, under SSP5-8.5.

Ref: IPCC AR6
Data: CU sea level research group, 60-day running mean, seasonality removed

Trend: 3.3mm/year

Global Mean Sea Level 1993 - 2020
The interannual variation of the global mean sea level (GMSL) might obscure its trend.
El Niño-Southern Oscillation (ENSO):
- Dominates the interannual variation of GMSL
- The warm (El Niño) and cold (La Niña) phases of Equatorial Pacific sea surface temperature

El Niño and La Niña diagrams from NOAA, Satellite altimetry data from AVISO+
The peaks of GMSL of the two extreme El Niños differ for $5.28 \pm 0.96$ mm.

**WHY?**

![Graph showing the evolution of Global Mean Sea Level (GMSL) from 1996-1998 and 2014-2016 with ONI values](image)

*Satellite Altimetry Observation from AVISO+*
**Introduction**

**Hydrologic Cycle**

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**Sea-level variations:**

1. **Steric sea-level**

Density variation, controlled by ocean heat content (OHC; major factor) and salinity (saltiness; minor)

\[ \text{steric} = \frac{1}{\rho_0} \int_{-H}^{0} (\rho - \bar{\rho})dz \]

2. **Barystatic sea-level**

Mass variation, the *extra* water mass into the ocean

\[ \Delta M_{\text{ocean}} \approx -\Delta M_{\text{land}} \]
The interannual sea-level difference of the two events is mainly from *barystatic* variation

**Why the barystatic sea-level (ocean mass) increased more in 2015 El Niño?**

ECCO – An Ocean Reanalysis from NASA JPL
Assume the Earth is a closed system:

\[
\Delta M_{\text{ocean}} \approx -\Delta M_{\text{land}} = -\Delta TWS
\]

Terrestrial Water Storage Flux

\[
\Delta TWS = P - E - R
\]

\[
TWS = \int_{1993}^{2016} (P - E - R) dt = -\text{Barystatic}
\]

<table>
<thead>
<tr>
<th>Data sets</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>-TWS</td>
<td>ERA5-land, CLM5 I1850</td>
</tr>
<tr>
<td>-TWS from GL+ANT</td>
<td>RACMO2.3p2</td>
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</table>
1. The barystatic sea-level varies as $-\text{TWS}$
2. Both ERA5-land and CLM5 demonstrate higher $-\text{TWS}$ in DJF of 2015-16

Why there was larger anomalous $-\text{TWS}$ in 2015 El Niño?
RECALL: El Niño

Central-Pacific ENSO (related to subtropical Pacific and A.-A. monsoon)

Eastern-Pacific ENSO (related to tropical atmos-ocean coupling)

El Niño and La Niña diagrams from NOAA; CP/EP figure from Dr. Yu, Jin-Yi in UC Irvine
1997-98 El Niño is a pure EP El Niño

2015-16 El Niño is a mixture of EP and CP El Niño

Calculating the CorrCoef. and regression of barystatic sea-level and –TWS on EPI/CPI
**CP ENSO** drives more interannual -TWS (barystatic) variation

<table>
<thead>
<tr>
<th></th>
<th>ECCOv4r4</th>
<th>ERA5-land</th>
<th>CLM5</th>
<th>GRACE</th>
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<tr>
<td><strong>CPI</strong></td>
<td><strong>CorrCoef</strong></td>
<td>0.45</td>
<td><strong>0.63</strong></td>
<td>0.56</td>
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<tr>
<td></td>
<td><strong>mm/index</strong></td>
<td>1.04±0.90</td>
<td>0.88±0.33</td>
<td>1.50±1.13</td>
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<tr>
<td><strong>EPI</strong></td>
<td><strong>CorrCoef</strong></td>
<td>0.19</td>
<td>-0.12</td>
<td>0.17</td>
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<td><strong>mm/index</strong></td>
<td>0.44±1.21</td>
<td>-0.16±0.62</td>
<td>0.44±2.76</td>
</tr>
</tbody>
</table>
“So far, consistent results of the global mean TWS can be seen from the two models. Further studies about model uncertainties of TWS predictability are necessary.”
– from Conclusion and Discussion of Kuo et al. (2021)
Part II: Internal variability and hydroclimate in CESM2
Introduction

Method & Data

Results

What’s tropical SST’s contribution to such a drying trend in North America?

TWS trend in CESM2-LE:

• Signal: ensemble mean trend over 1980 – 2014
• Noise: standard deviation of trend across ensemble members

1. Overall drying in North America with drying in western coast
2. Trends across ensemble members spread in eastern U.S.
CAM6 Prescribed SST AMIP Ensembles: Tropical Ocean Global Atmosphere (TOGA) simulations

SST trend maps from Climate Variability Diagnostics Package for Large Ensembles (CVDP-LE)

- Prescribed with historical ERSSTv5 (10 ensemble members), LIM66 (10) and LIM94 (10) SSTs in the tropics
- LIM66 and LIM94 SSTs generated from a cyclostationary linear inverse model (Shin et al., 2021)
Drying is stronger compared to the fully coupled CESM2-LE
ERSSTv5, LIM66, LIM94 all show increasing PSL trend (negative PDO like) and overall decreasing precipitation BUT different from CESM2-LE
Thanks for your attentions!

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