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JAMES (2022), submitted. (with A. Adcroft, R. Hallberg and O. Sergienko)
Hydrologic cycle

- Fully coupled models with atmosphere, land, and ocean components should approximately conserve water.
- For example, ocean+sea-ice volume in Boussinesq fully coupled models should equilibrate to a constant value, unless glacial mass loss is included.

\[ \int_V Q_t dV = -\int_S T_q \cdot \hat{n} dS + \int_A (E - P) dA, \]
Hydrologic cycle closure in ocean hindcasts

- Ocean hindcasts using atmospheric reanalysis data prescribe precipitation, and either prescribe or diagnose evaporation.
- Globally, this results in non-zero balance between large terms.
- Global imbalance need to be removed - for example in GFDL-based MOM4-6 hindcasts, we diagnose the imbalance at each time-step and adjust the precipitation (and runoff) in order to globally balance net evaporation over the ocean.
- This practice neglects significant seasonal land storage which occurs, for example in the Arctic.
- This clearly biases the fluxes, but we also use virtual salinity fluxes to maintain SSS.
- Reanalysis precipitation uncertainty?
We used the LM3.0 (Milley et al, 2014; github.com/NOAA-GFDL/LM4.git) land model with present-day land use, and a hydraulic network of soil and groundwater, lakes, and rivers.

A spinup procedure was performed in order to bring the land model into approximate balance with the forcing prior to coupling with the ocean.

The integrated surface mass flux (ocean+land) is constrained to zero. This satisfies global mass conservation requirements while allowing for seasonal land storage.
Poleward moisture transport (PMT) constraint

In addition to using a land model, we introduce a climatological mid-latitude PMT constraint.

- This constrains the integrated surface mass balance in the subpolar regions
- Derive climatological PMT constraints, $T_q(40)$, using the CMIP6 historical ensemble (2000-2015)
- $T_n (Sv) : 0.86-0.93 (0.89)$ 5th-95th percentile (mean)
- $T_s (Sv) : 1.03-1.25 (1.11)$ 5th-95th percentile (mean)
Experiment Summary

- Global ¼ degree MOM6 ocean model configuration (Adcroft, 2019)
- Initialized in 1982 with WOA05 data.
- No SSS nudging
- **Exp:M-ref** - A reference simulation forced with MERRA-2, which uses previous global mass closure assumptions which do not account for land storage
- **Exp:M** - MERRA-2 forced with land storage.
- **Exp:M*** - MERRA-2 with the proposed hydrologic closure, which includes both land storage and the climatological PMT constraints
- **Exp:J** - JRA55-do forced with land storage.
- **Exp:J*** - JRA55-do forced with proposed closure including land storage and PMT constraint
- **Exp:M***-88ic - Same as Exp:M*, initialized in 1988 using SODA v3.4.2
### Metrics

<table>
<thead>
<tr>
<th>Experiment</th>
<th>40N PMT (Sv)</th>
<th>40S PMT (Sv)</th>
<th>Atl 40-90N (Sv)</th>
<th>Atl 34S-40N (Sv)</th>
<th>AMOC and linear trend (Sv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp:M-ref</td>
<td>0.7</td>
<td>1.24</td>
<td>0.4</td>
<td>-0.74</td>
<td>19.5</td>
</tr>
<tr>
<td>Exp:M</td>
<td>0.86</td>
<td>1.1</td>
<td>0.47</td>
<td>-0.89</td>
<td>15.9(0)</td>
</tr>
<tr>
<td>Exp:M*</td>
<td>0.87</td>
<td>1.13</td>
<td>0.48</td>
<td>-0.87</td>
<td>15.5(-0.1)</td>
</tr>
<tr>
<td>Exp:J</td>
<td>0.81</td>
<td>0.94</td>
<td>0.38</td>
<td>-0.78</td>
<td>22.9(0)</td>
</tr>
<tr>
<td>Exp:J*</td>
<td>0.86</td>
<td>1.13</td>
<td>0.46</td>
<td>-0.88</td>
<td>22.3(-.05)</td>
</tr>
</tbody>
</table>
JRA55-do : stronger wintertime heat loss in NWAtl
Global Temperature drift from initialization.

- **Cold** drift in control case with traditional FW balancing
- Reduced drift with land closure (Exp:M, Exp:M*, Exp:J, Exp:J*)
- All cases using hybrid Z*-potential density coordinate used in CM4, which is known to uptake less heat relative to z*. Exp:M*-z exhibits excessive warming above 1000m.
Multi-decadal temperature, salinity and potential density drift from initialization
MERRA-2 With Land Storage and PMT constraint vs Without

0-500m

500-1500m
MERRA-2 With Land Storage and PMT constraint vs Without

1500m-2500m

2500m-4500m
MERRA-2 With Land Storage and PMT constraint vs Without North Atlantic

0m-500m

500m-1500m
Initialization sensitivity

0-500m

500-1500m
JRA55-do vs MERRA-2

0-500m

500-1500m
JRA55-do vs MERRA-2

0-500m

500-1500m
Exp: M* 0-700m; Global avg = 0.36 W m⁻²

Exp M-ref: -0.14


Avg: 0.48

0.39
Summary and Future Plans

- We have demonstrated significant improvement in our ocean state estimation by introducing a physically-based closure for the hydrologic cycle.
- This methodology appears to eliminate the need for non-physical SSS restoring forces in our configurations.
- MERRA-2 and JRA55-do forcings both showed similar improvement.
- Large reductions in temperature, salinity and potential density drift from initialization. Improved AMOC representation.

Next Steps:

- Develop a 1/12 ocean configuration with a C348 land component
- Include other reanalyses (ERA5, CFSR, …)