The Global Water Cycle and Salinity in CMIP5

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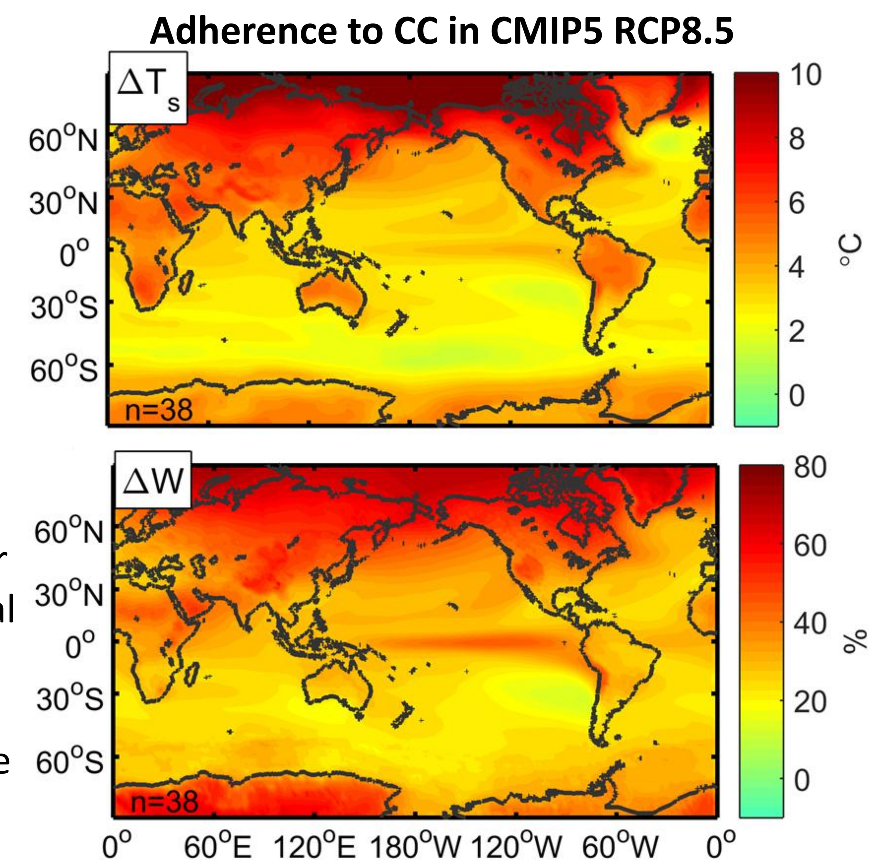
The Global Water Cycle in a Warming Climate

The starting point for relating changes in global temperature to the water cycle is the increased mobility of water molecules at higher temperatures. The Clausius Clapeyron (CC) relation indicates that atmospheric water vapor content (*W*) increases by ~7% K^{-1} at constant relative humidity for earth's mean temperature. In a warming climate, this increase in W amplifies regional divergence and convergence of atmospheric moisture, accelerating moisture transport and producing the so-called 'rich get richer' mechanism (Held & Soden 2006).

Of relevance to ocean circulation, intensification of the water cycle amplifies freshwater fluxes into and out of the oceans in areas of net evaporation (*E*) or precipitation (*P*). Changing surface fluxes alter salinity contrasts both between and within ocean basins. Regional areas of particular interest include the freshening of high latitude deep convection sites, salinification of subtropical salinity maxima, and divergence of *E - P* which gives the meridional freshwater transports and corresponding meridional heat fluxes. Salinity may be a more sensitive indicator of water cycle change than *P* itself (Durack et al. 2012), hence the interest in understanding the behavior of the 'ocean rain gauge'.



CMIP5 Projections for Atmospheric Water Fluxes

Freshwater Transports and Budgets

The vertically integrated atmospheric moisture transport (***Q***) is given by:

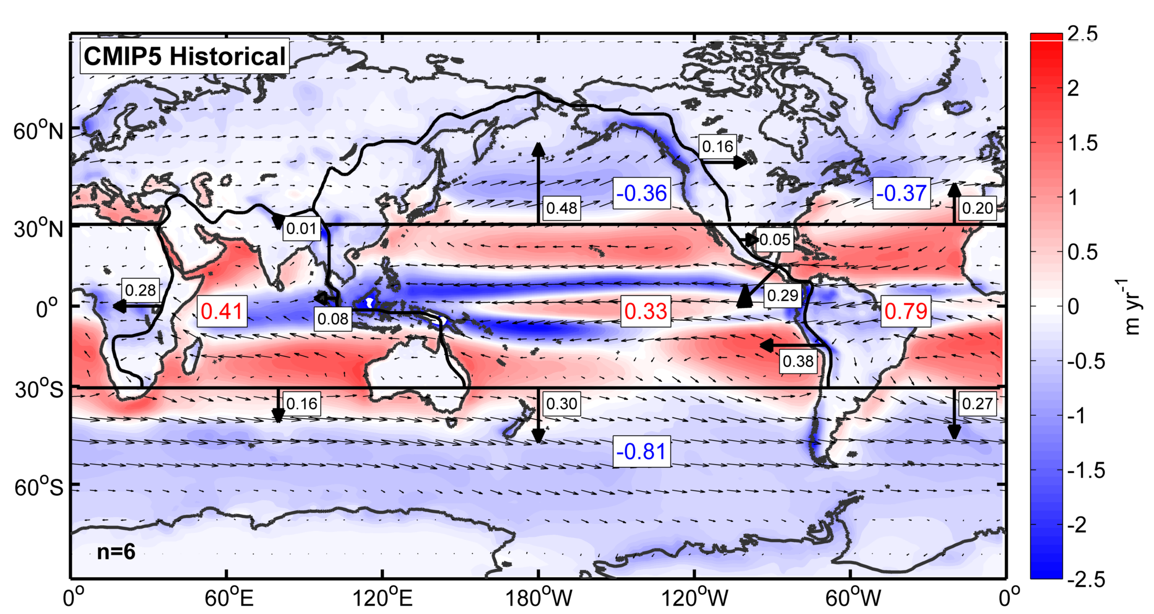
$$\boldsymbol{Q} = \frac{1}{g}\int_{surface}^{top} q\boldsymbol{v}\,dp$$

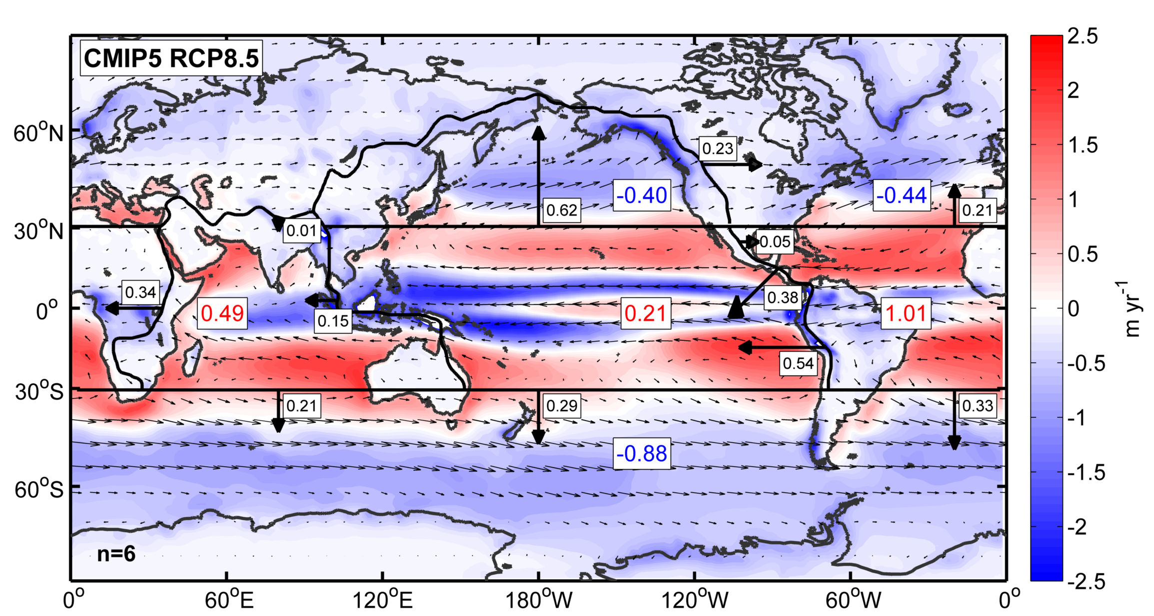
For any region *dA*, convergent or divergent fluxes through boundaries must be balanced by surface fluxes *E - P* (Levang & Schmitt 2015):

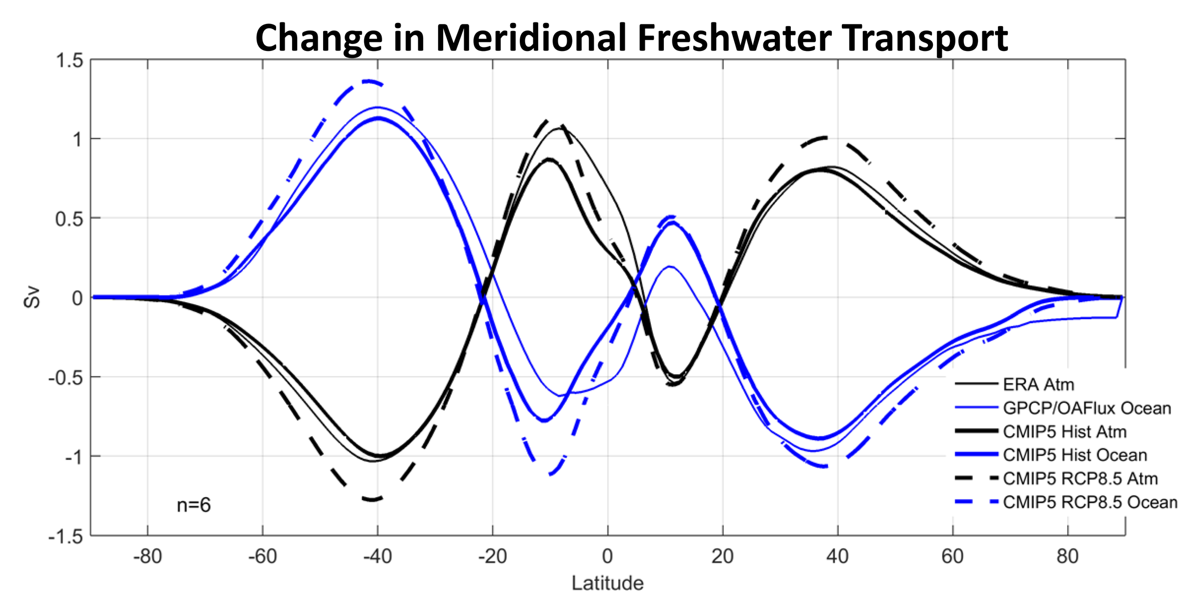
$$\oint \boldsymbol{Q}\cdot dl = \oiint E - P\, dA$$

In the ocean, convergence or divergence of the net surface fluxes must be balanced by a depth integrated transport (Wijffels et al. 1992):

$$\iint E - P - R\, dx\, dy = \iint \rho v\ dx\, dz + T_b$$



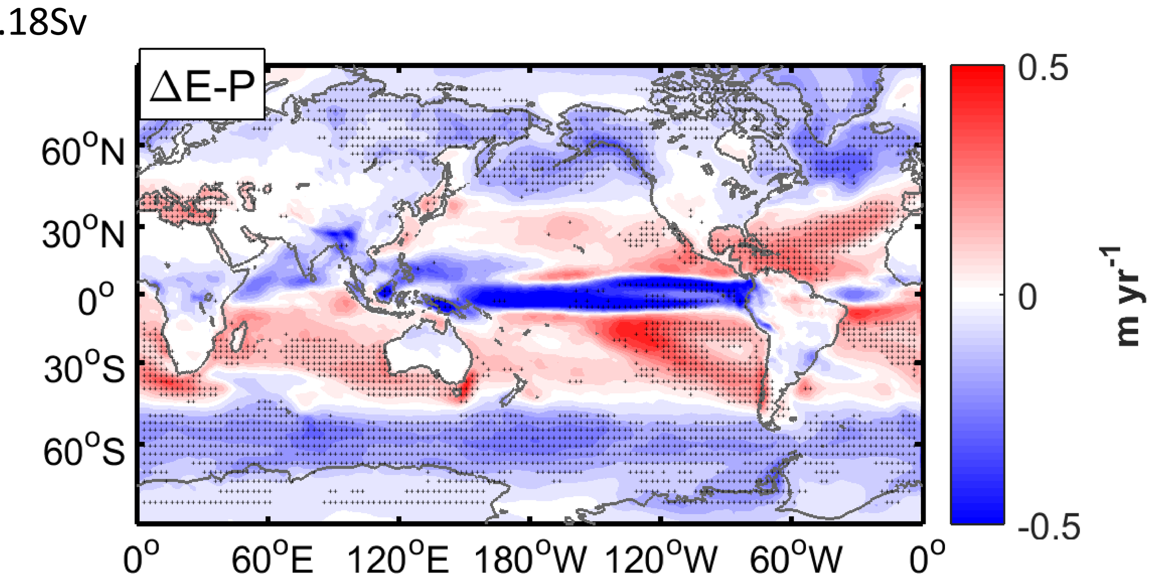




Key Findings from CMIP5

-All figures based on multi-model means from Historical (1990-2000) and RCP8.5 (2090-2100) simulations (Levang & Schmitt 2015)

- Models successfully simulate present-day water cycle with some problem areas (particularly the equatorial pacific)
- Global *W* increases 32% vs 28% predicted from CC scaling
- Global *P* & *E* increase from 17.3Sv to 18.6Sv (8% increase, 2% K^{-1})
- Net *P - E* over land increases from 1.17Sv to 1.31Sv (12% increase, 3% K^{-1})
- The equatorial Pacific becomes 0.12Sv more precipitative and the Atlantic 0.22Sv more evaporative, driven by increased westward moisture fluxes across the Americas
- The total export of freshwater from low to high latitude regions increases by 0.18Sv



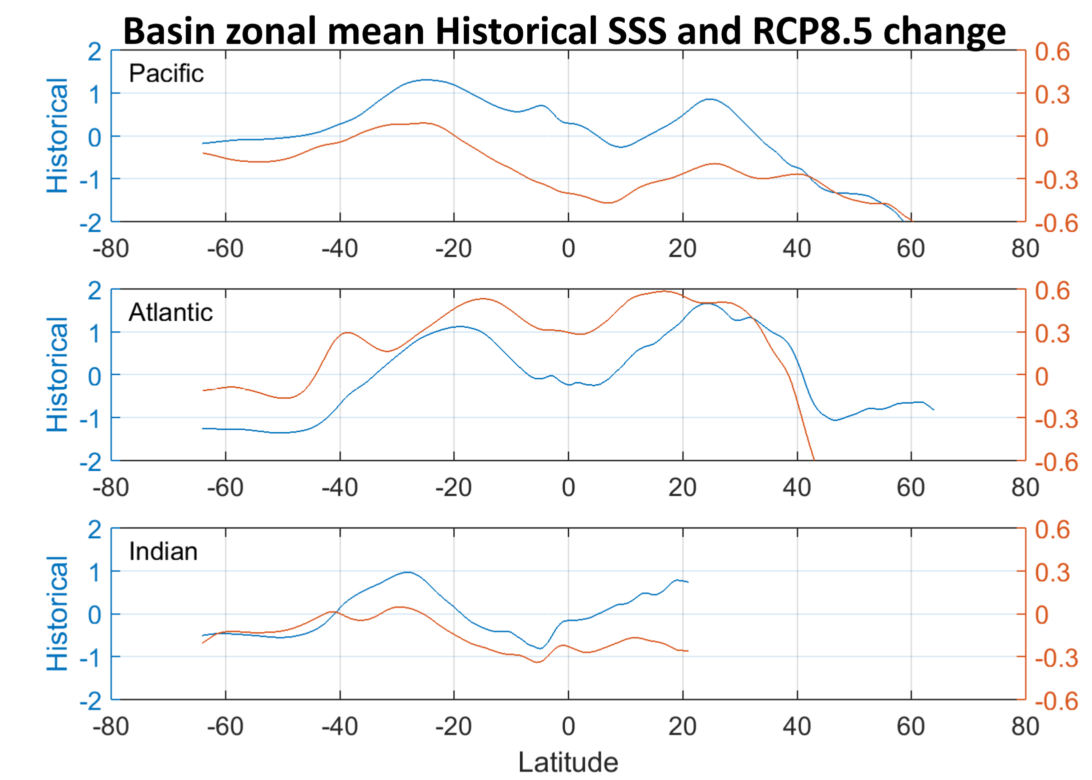
CMIP5 Salinity Projections

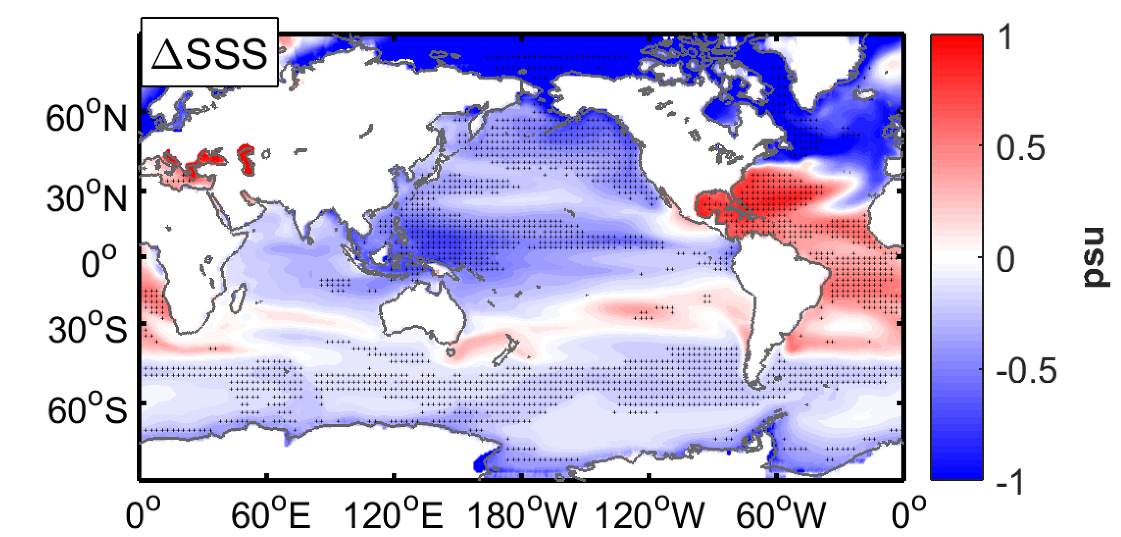
Salinity Signal of Water Cycle Amplification

- Subtropical and tropical Atlantic become saltier, by as much as 0.8psu
- Pacific is freshened, up to 0.6psu
- High latitude North Atlantic and Arctic show large freshening (>1psu)
- Indian is freshened despite increase in E-P, indicating role of advection by the Indonesian Throughflow

Summary

- An intensified water cycle in a warming climate communicates changes in global salinity patterns, particularly the meridional contrast between subtropics and extratropics and the inter-basin contrast between Atlantic and Pacific
- Each basin exhibits SSS pattern amplification, as well as an offset due to changing interbasin transports
- Salinity forcing is relatively well mixed within the subtropical gyres. Perhaps the models are too diffusive?
- Advection and mixing terms are important in transporting surface salinity properties away from forcing locations
- SSS response to changes in $E - P$ forcing on centennial time scales is approximately controlled by the steady state salinity budget

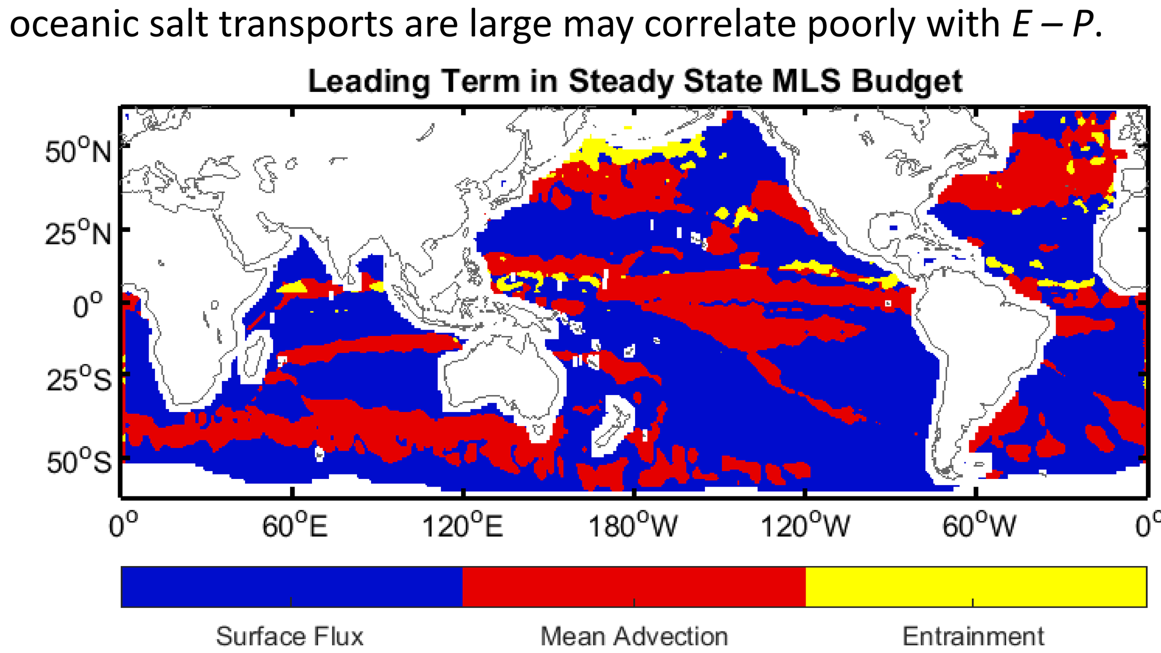




Steady State Salinity in the Present-Day Ocean

One method to further explore the realism of the model salinity response is to take the climate perturbations we are considering to be small in an absolute sense and assume the steady state salinity balance in the upper ocean will not change drastically. Given this, we expect the response in regions where surface fluxes presently dominate the steady state salt budget to closely match the local change in $E - P$, while regions where oceanic salt transports are large may correlate poorly with $E - P$.

$$\frac{\overline{\partial S}}{\partial t} = \frac{\bar{S}(E-P)}{h} - \overline{\boldsymbol{U}}\cdot\nabla\bar{S} - \frac{w_E\left(\overline{S - S_{-h}}\right)}{h} + \kappa_H\nabla^2\bar{S} \approx 0$$



This budget can be assessed from climatological observations, and a preliminary version is presented here, including the surface flux, advection, and entrainment terms. A similar budget has been performed for seasonal MLS anomalies by Yu (2011), which found Ekman advection to be dominant over much of the world oceans. In the steady state, $E - P$ is the most prevalent leading term, especially in the subtropics. However, advection is leading order in the equatorial rain bands and western boundary currents, lending credence to the CMIP5 results that SSS changes become well mixed across the equator. The addition of down-gradient mixing terms would further increase the size of oceanic terms.

References

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