Inter-model Variability and Biases of the Global Water Cycle in Climate Models*

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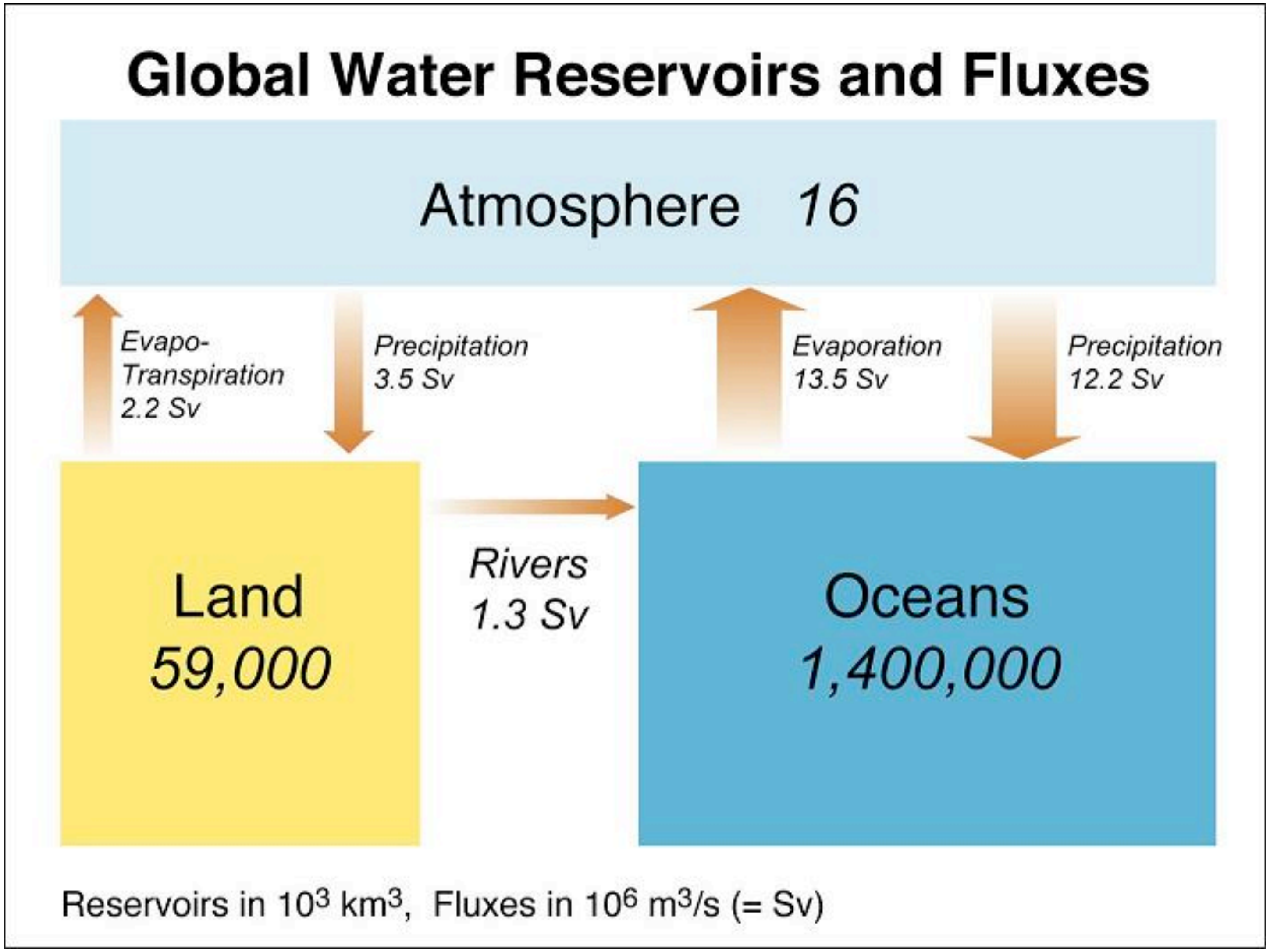
1) **Motivation – Self-consistency of models**
2) **Global atmospheric moisture balance:** Biases and trends
3) **Atmospheric moisture transport from ocean to land:** Inter-model variability and trends
4) **Extension of the dry zones:** Spatial distribution, Inter-model variability and trends
5) **Concluding remarks**



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Climate Modeling Data:

- Coupled atmosphere ocean general circulation models (CMIP3) described in IPCC-AR4
- 18 model simulations of the 20th century and 16 model simulations of the 21st century A2 scenario
- Individual runs were analyzed
- Monthly means of surface and column integrated data on model grid provided by model groups

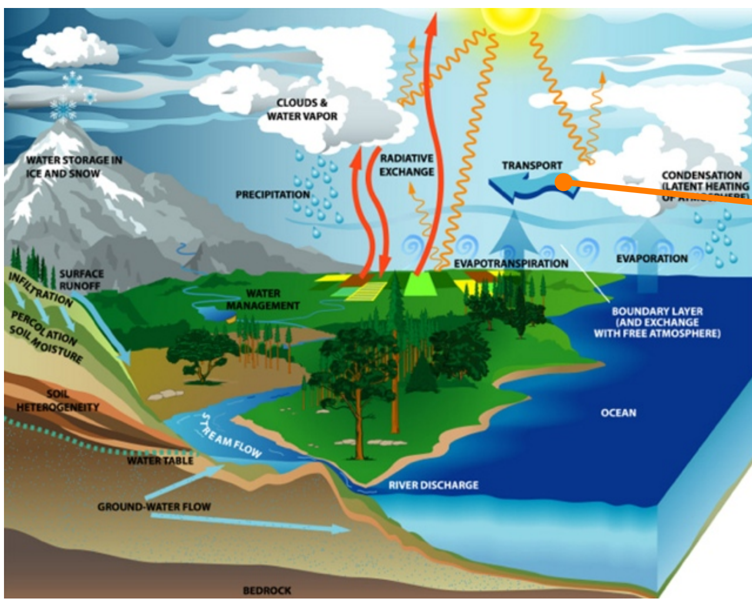
Climate Variables:

- Precipitation: includes liquid and solid, positive and negative (dew and frost) data
- Evaporation: from surface latent heat flux; includes sublimation over sea ice and evapo-transpiration on land
- Atmospheric moisture content: includes water vapor, cloud ice and liquid water

Global atmospheric moisture balance:

$$\frac{\partial W}{\partial t} + \nabla_h \cdot \vec{Q} = E - P \quad \Rightarrow \quad \mathrm{Res}(year) = \left\langle \sum_{i=1}^{12} \left(E_i - P_i \right) \right\rangle - \left\langle W_{12} - W_1 \right\rangle$$

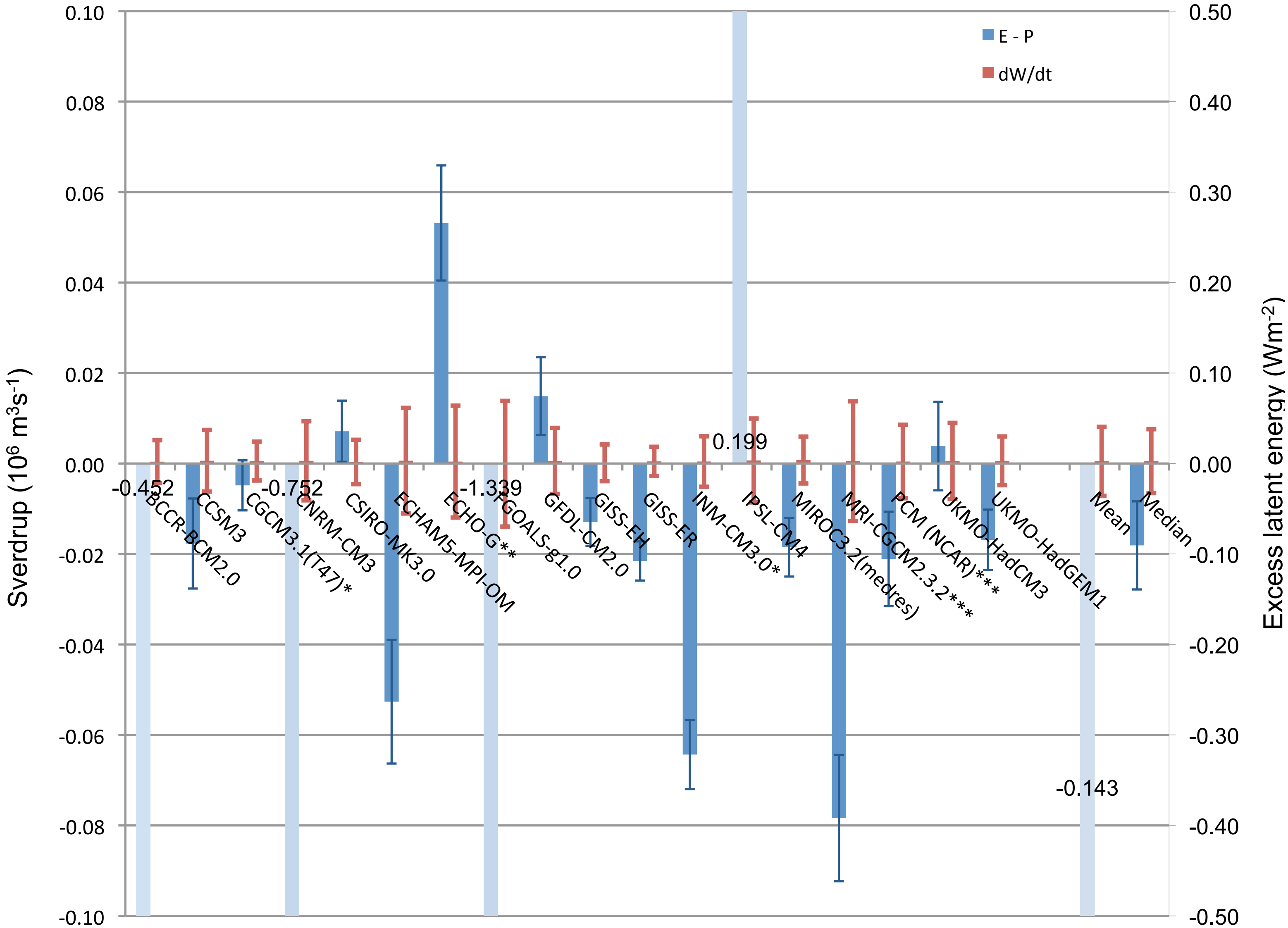
Atmospheric moisture transport from ocean to land:



$$\iint_{\partial Ocean} d\vec{S} \cdot \vec{Q} = \left\langle E - P - \frac{\partial W}{\partial t} \right\rangle_{Ocean}$$

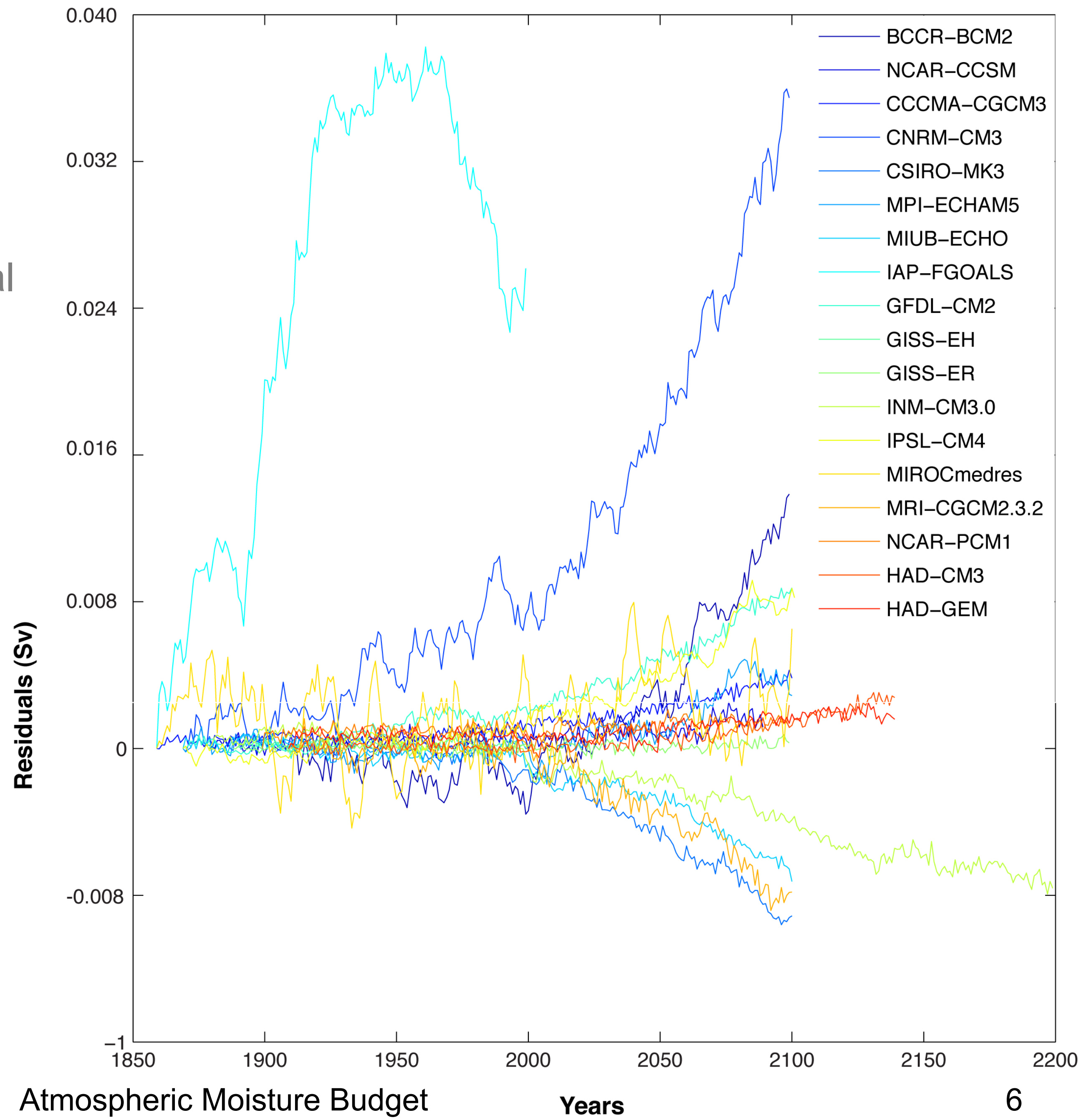
With vertically integrated moisture content and moisture flux: $W = \int \rho q \, dz \quad \vec{Q} = \int \rho q \vec{v} \, dz$

CMIP3 models 20th and 21st century simulations globally integrated *E – P*, *δW/δt* and corresponding latent heating of the atmosphere:

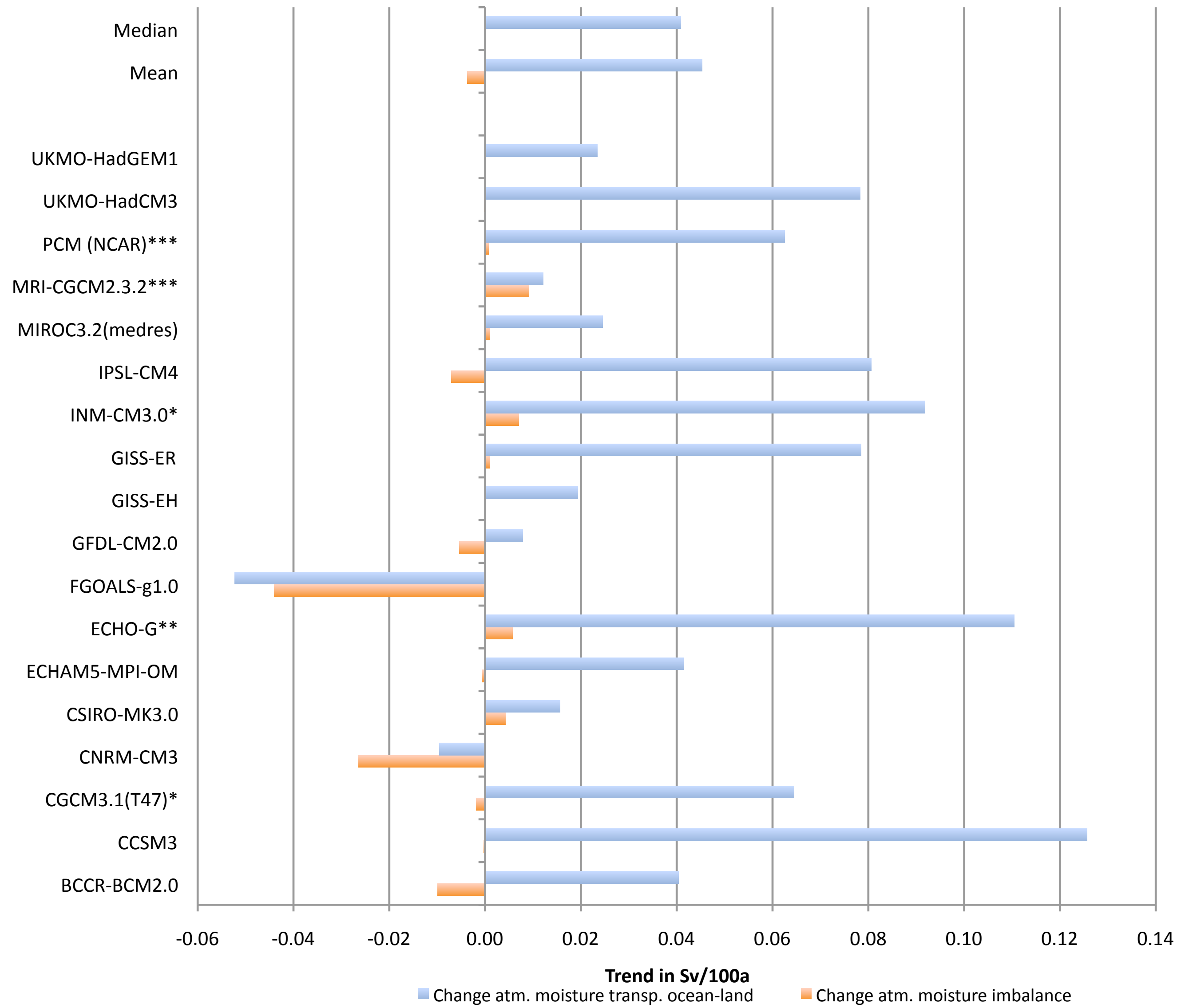


Atmospheric Moisture Balance

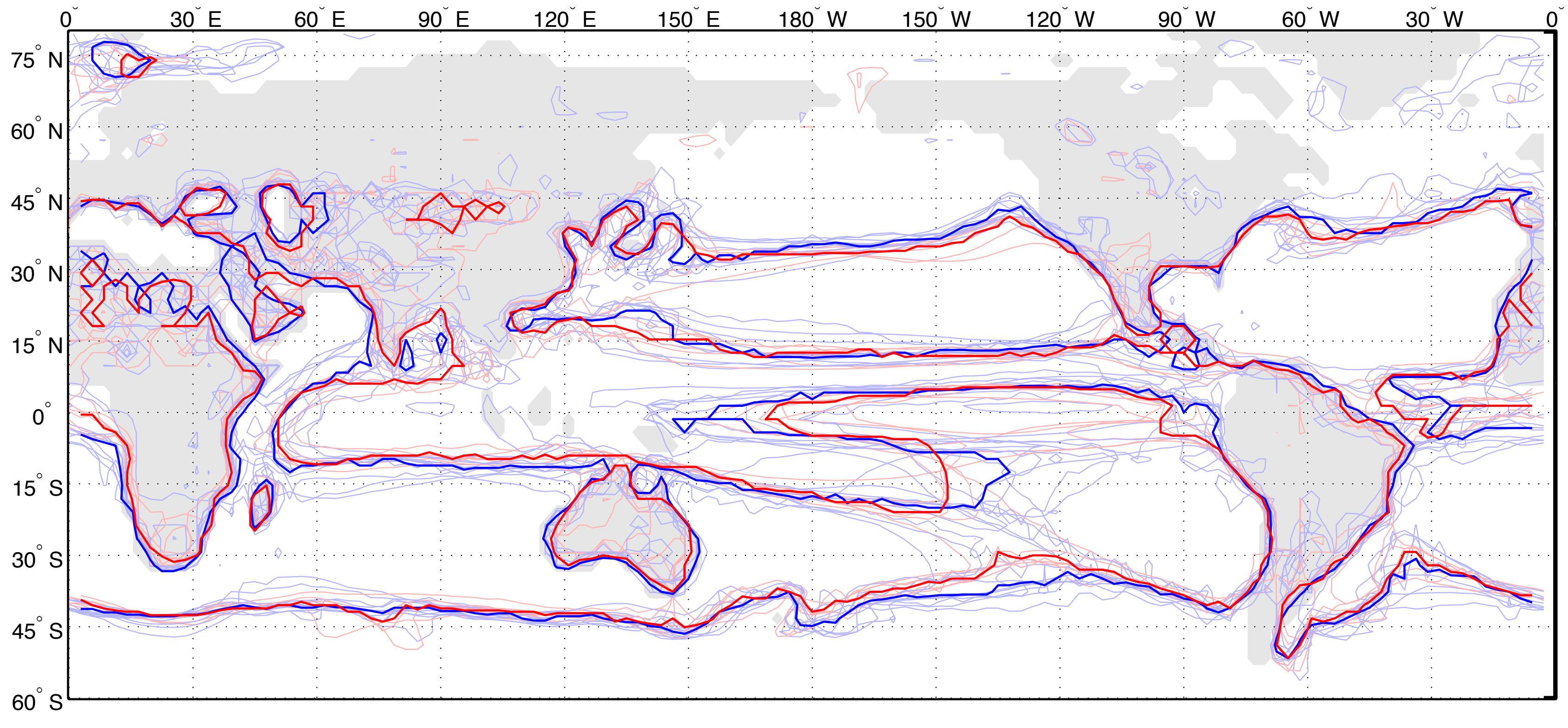
Trends in residuals of global atmospheric moisture budgets in CMIP3 models 20th and 21st C simulations



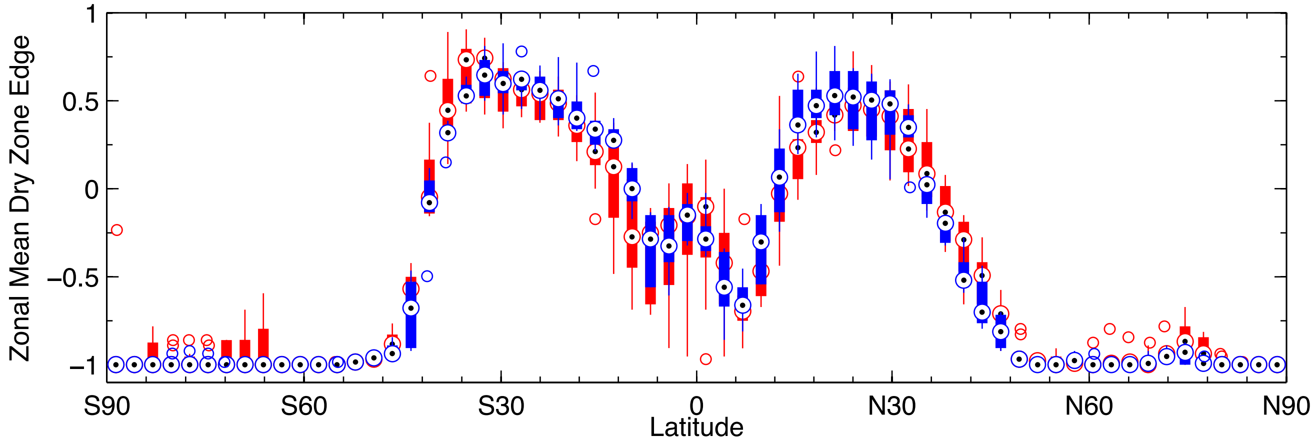
Trends in atmospheric moisture transport from ocean to land areas in CMIP3 models 20^{th} and 21^{st} C simulations compared to residuals of global moisture budgets

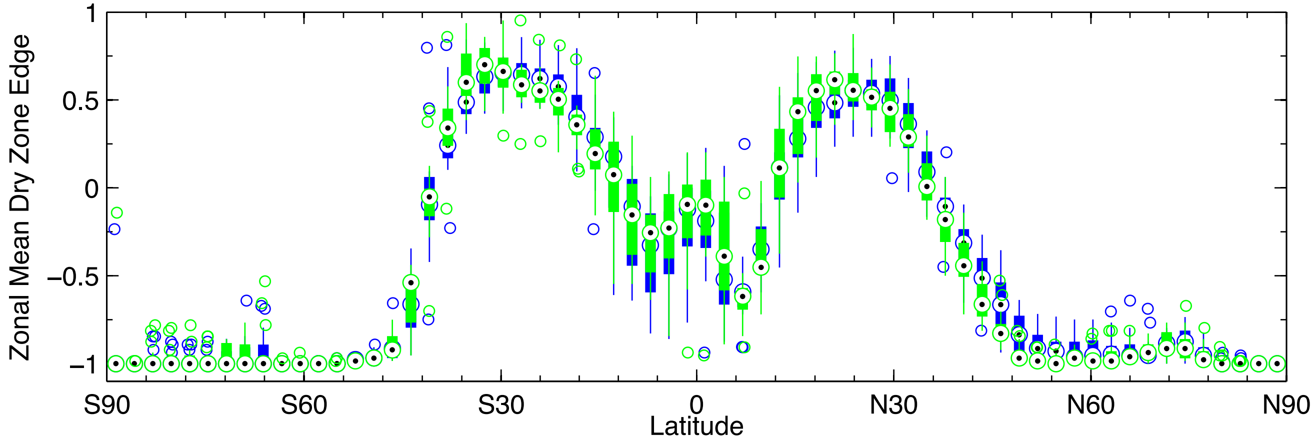


Inter-model Variability: *E - P - dW/dt = 0* contour of 16 CMIP3 models with negative and positive global imbalances



Inter-model Variability and trend: Zonal mean dry zone edges of CMIP3 models for negative and positive global imbalances and the first and the last 2 decades of 21st C





In CMIP3 model simulations of 20th and 21st C:

- **Inter-model variability of atmospheric moisture transport from oceans to land:** 0.26 to 1.78 Sv; expected average increase 4% or 0.08 Sv in 21st C
- Large model-to-model variability of dry zone extension
  - ➢ $E - P$ fields should be used with caution
- **Global atmospheric moisture budgets out of balance** by -0.14 Sv and -0.02 Sv for multi-model mean and median with variability huge amongst models: -1.34 to 0.20 Sv
  - ➢ Use multi-model median
- Biases not constant over time: positive and negative trends from less than a tenth to up to 200% of simulated global precipitation trends detected
  - ➢ Exclusion of models with water imbalances
- Discrepancies between simulated dW/dt *and* $E - P$ implies unphysical, “ghost” source of moisture
- **Atmospheric energy perturbation or non-radiative “ghost” forcing: -1 to +6 W/m^2** (small multi-model median of +0.1 W/m^2)