TC-permitting GCM simulations of hurricane frequency response to SST anomalies projected for the late 21st century

24th Conference on Climate Variability and Change

Jan 21-26, 2012, New Orleans

Ming Zhao

Geophysical Fluid Dynamics Laboratory

Tropical cyclone response to 21st century global warming assessment from IPCC AR4 and WMO TC-expert-team

IPCC AR4 *(WG1, Ch10, Solomon et al. 2007):*

"…, for a future warmer climate, coarse-resolution models show few consistent changes in tropical cyclones (TCs), with results dependent on the model."

WMO TC-expert-team (*Knutson et al. 2010, Nature geoscience*):

"…future projections…consistently indicate that greenhouse warming will cause the globally averaged intensity of TCs to shift towards stronger storms…. Existing modelling studies also consistently project decreases in the globally averaged frequency of TCs… For all cyclone parameters, projected changes for individual basins show large variations between different modelling studies."

- **Uncertainty in regional hurricane projections**
- **Differences in models, forcings, downscaling methods**
- **Uncertainty due to SST warming pattern**

Justification of time-slice downscaling approach using GFDL global High Resolution Atmospheric Model (HiRAM)

Simulation of present-day hurricanes statistics *(Zhao, Held, Lin, Vecchi 2009, J. Climate)*

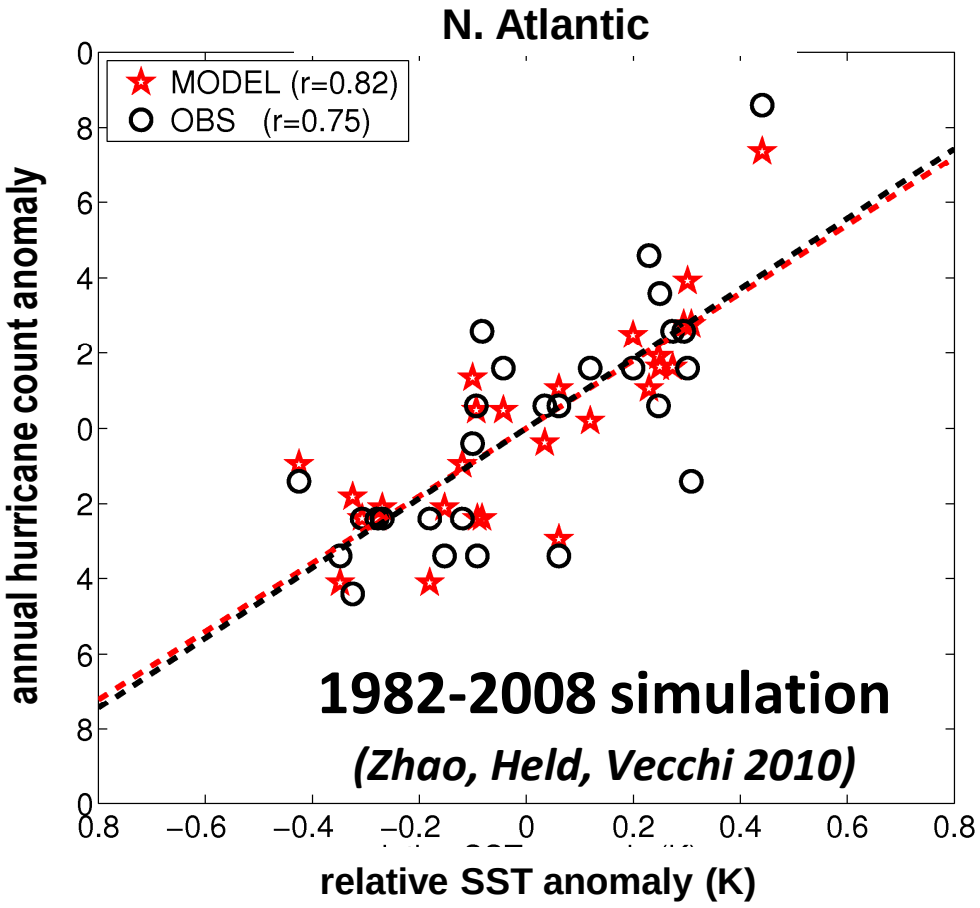
Retrospective forecasts of hurricane season *(Zhao, Held, Vecchi 2010, Mon. Wea. Rev.)*

Statistical-dynamical hurricane prediction system *(Vecchi et al, 2010, Mon. Wea. Rev.)*

Dominant role of SST variability on storm frequency variability

Relative SST: Atlantic MDR SST minus tropical mean SST in the hurricane season ***(Vecchi et al. 2008)***

The quality of the observed SST experiments justify the time-slice approach.



Questions explored by the time-slice approach

1. **How much uncertainty in regional hurricane projections may result solely from the variety of future projections of the spatial pattern of SST warming?**

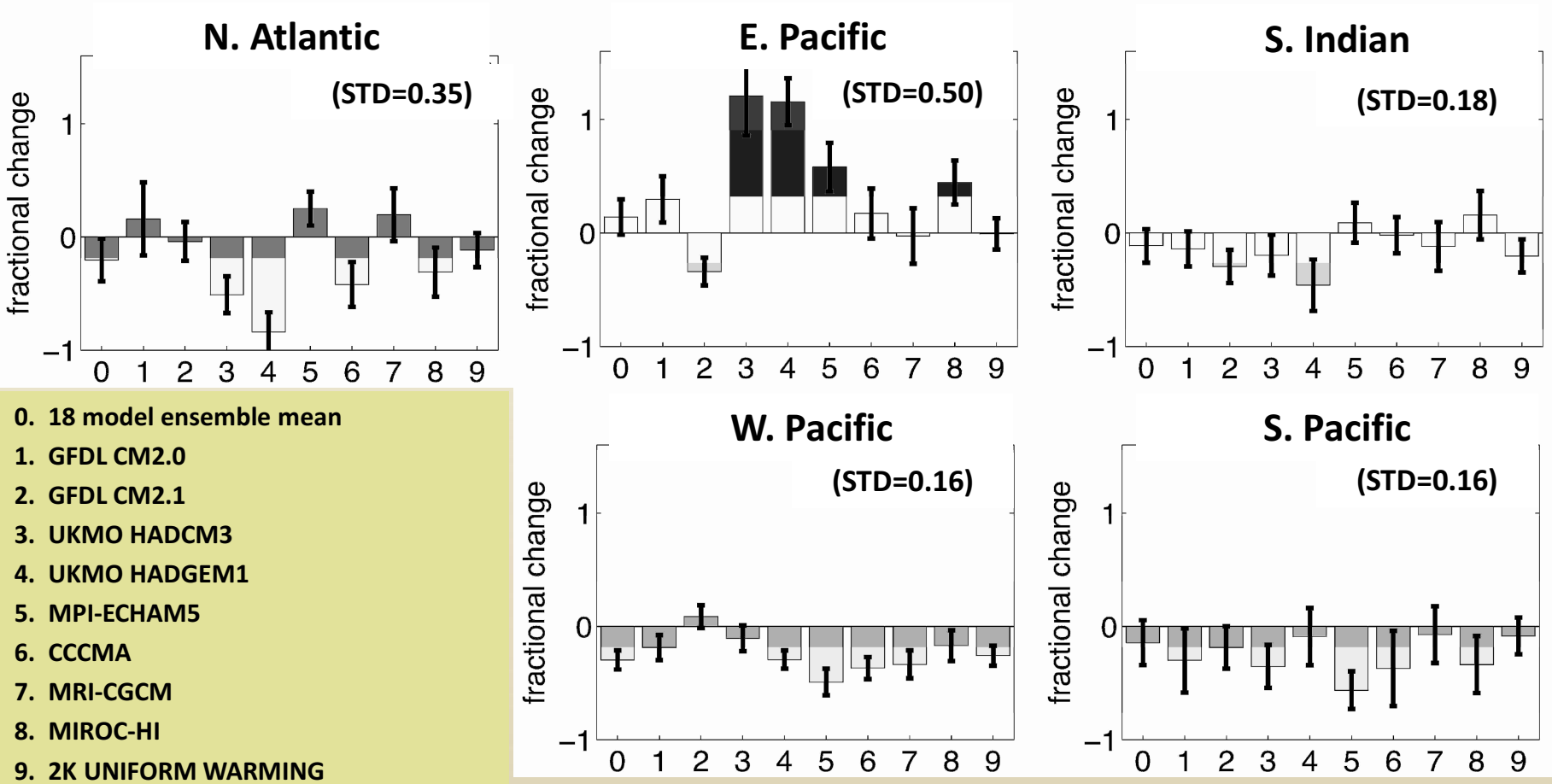
2. **What features of SST distributions are important? To what extent can a simple relative SST index be used to explain the simulated differences in hurricane response in all ocean basins?**

3. **What are the atmospheric mechanisms that translate the SSTs into processes that directly control regional hurricane activity?**

Model: an earlier version of HiRAM at 50km resolution.

(Zhao, Held, Lin, Vecchi 2009, J. Climate)

HiRAM simulated hurricane frequency response to 21st century warming projected by IPCC AR4 coupled models



0. 18 model ensemble mean
1. GFDL CM2.0
2. GFDL CM2.1
3. UKMO HADCM3
4. UKMO HADGEM1
5. MPI-ECHAM5
6. CCCMA
7. MRI-CGCM
8. MIROC-HI
9. 2K UNIFORM WARMING

For each basin, there is large inter-model spread in the magnitude and even the sign of the hurricane frequency response. The differences are entirely due to the different SST projections. ***(Zhao and Held, 2012, in press.)***

Indices of SSTs and atmospheric properties relevant to hurricane genesis frequency

SSTs → **atmospheric properties** → **hurricanes**

$RSST\ (m, x, y)$: **relative SST = local – tropical mean SST**

$$\overline{RSST}\ (x, y) = \frac{\sum_m RSST\ (m, x, y) G(m, x, y)}{\sum_m G(m, x, y)}$$

$G(m, x, y)$: climatological storm genesis frequency from the control simulation. m = 1-12, x = lon, y = lat

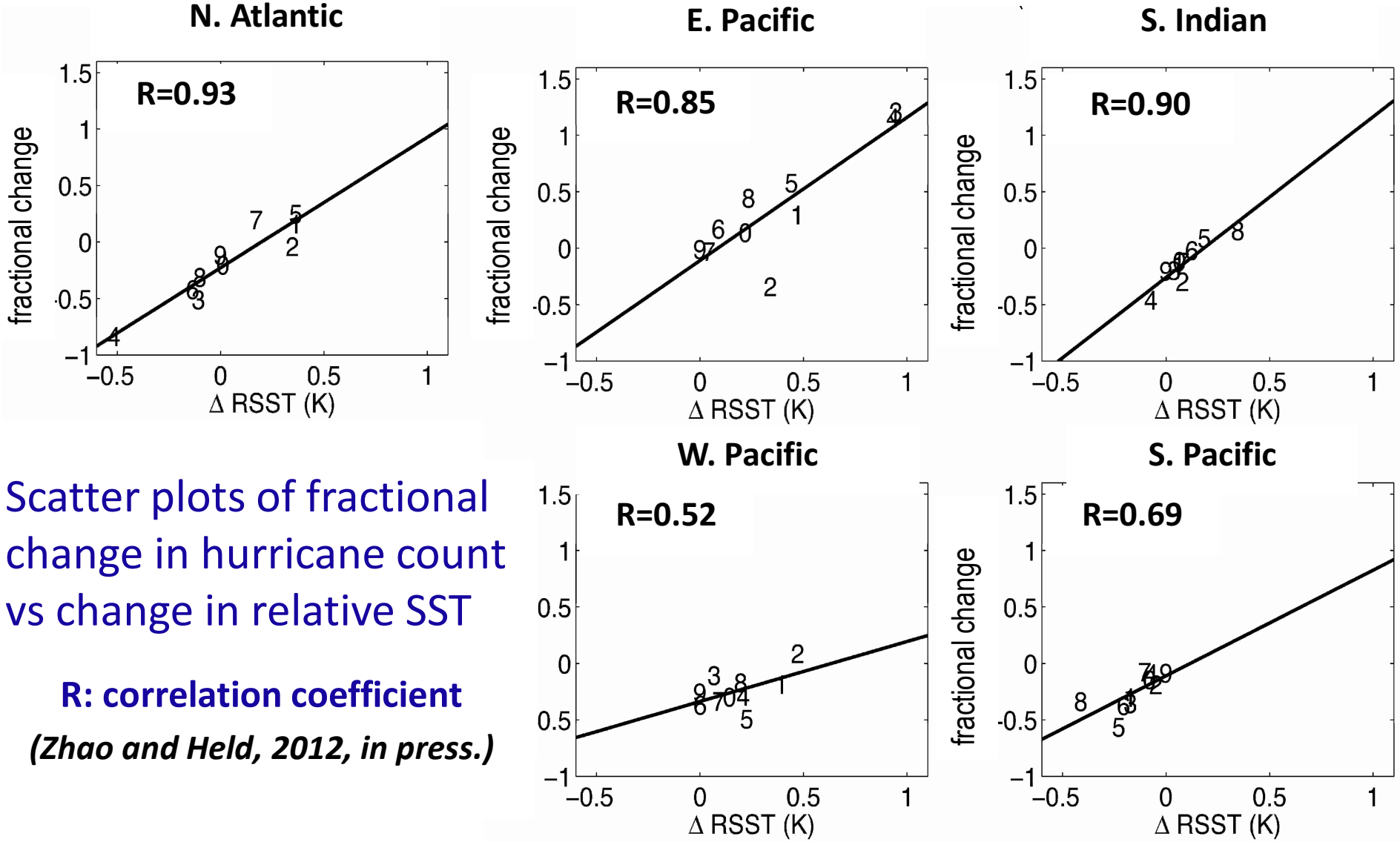
monthly data used for calculating indices

$\omega_{500}(m, x, y)$: **mid-troposphere vertical velocity**

Held and Zhao, J. Climate 2011

Zhao and Held, J. Climate in press

Most inter-model variation can be explained by the simple relative SST index in the N. Atlantic, E. Pacific and S. Indian

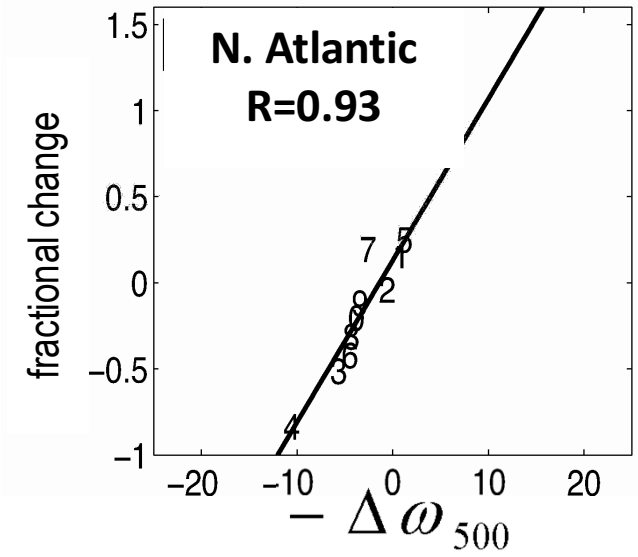


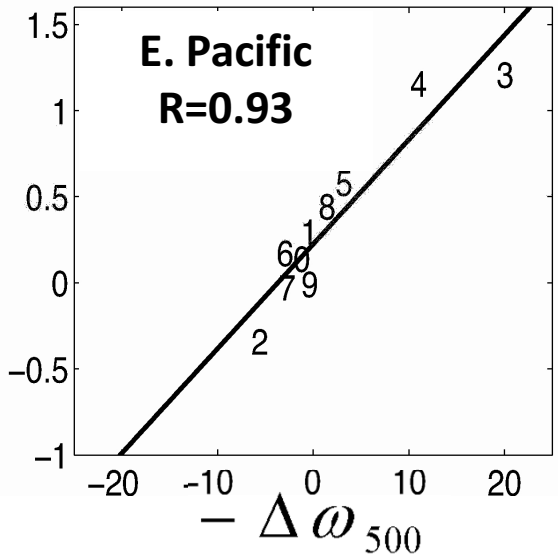
Scatter plots of fractional change in hurricane count vs change in relative SST

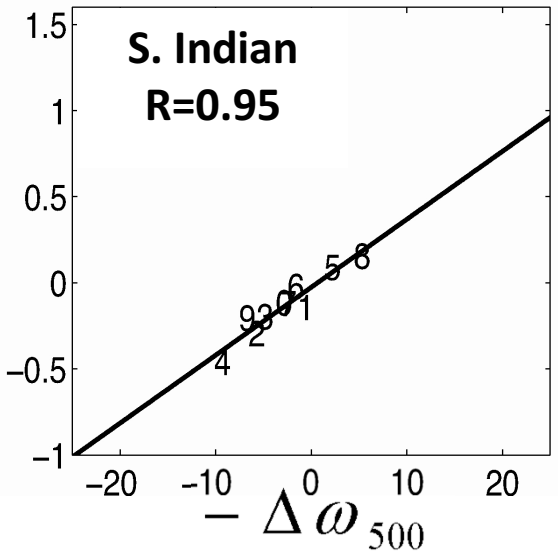
R: correlation coefficient

(Zhao and Held, 2012, in press.)

Mid-tropospheric vertical velocity is skillful in explaining the simulated hurricane response for all basins



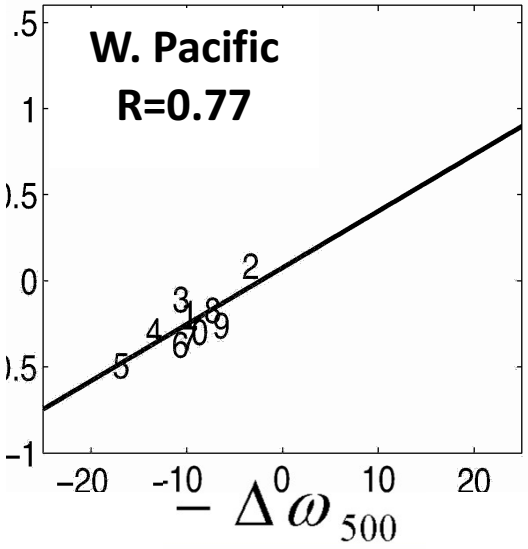


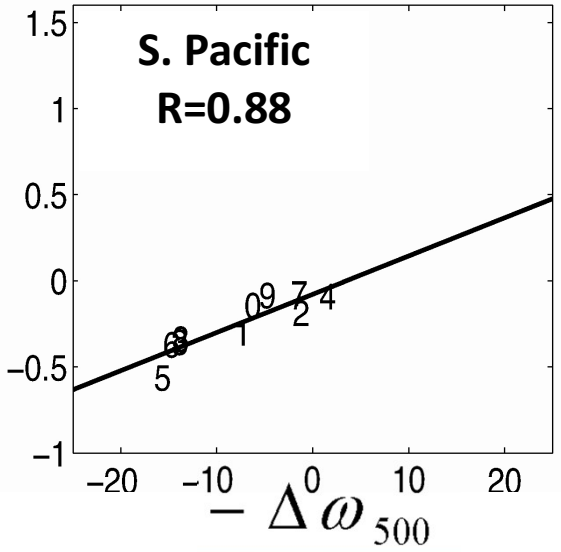


Scatter plots of fractional change in hurricane count vs change in mid-troposphere vertical velocity (hPa/day).

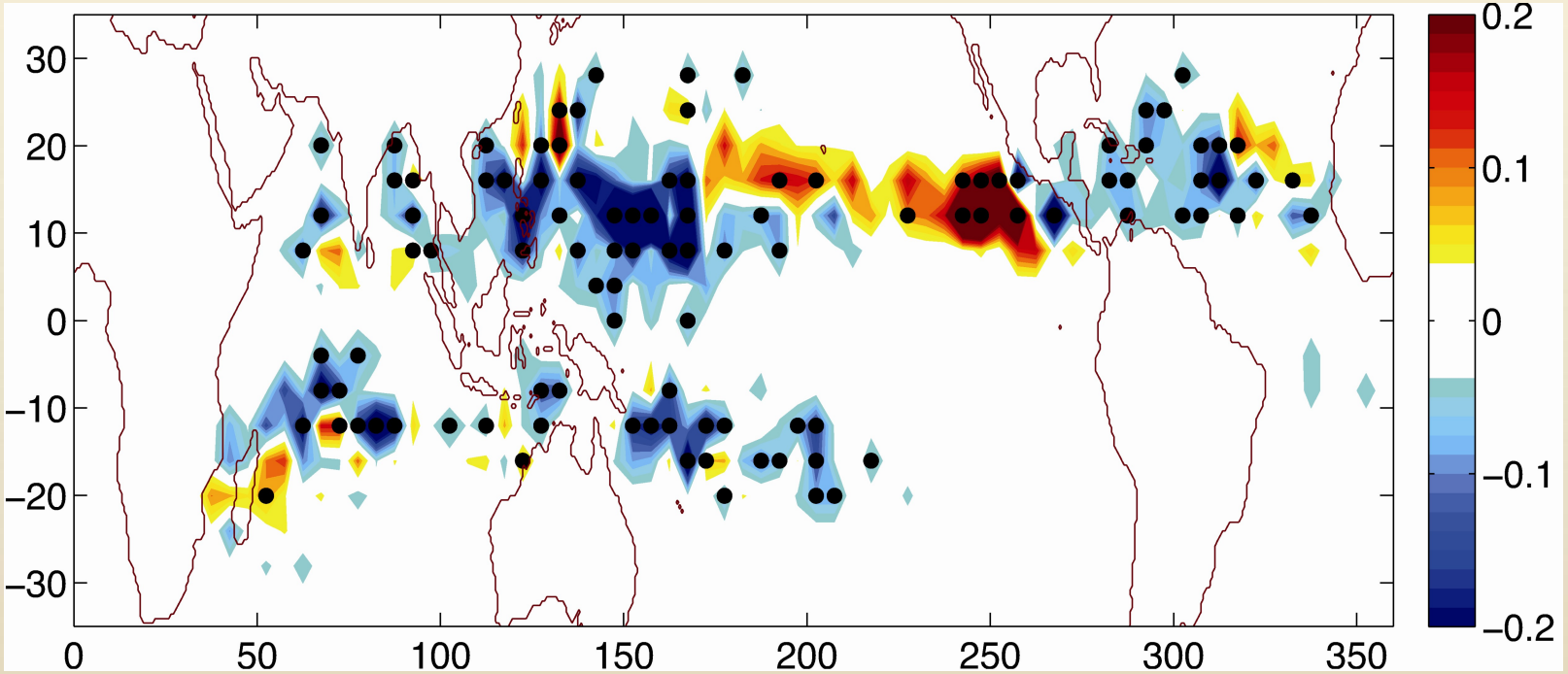
R: correlation coefficient

(Zhao and Held, 2012, in press.)





The simulations exhibit eastward and pole-ward migration of genesis frequency in the N. Pacific and N. Atlantic oceans

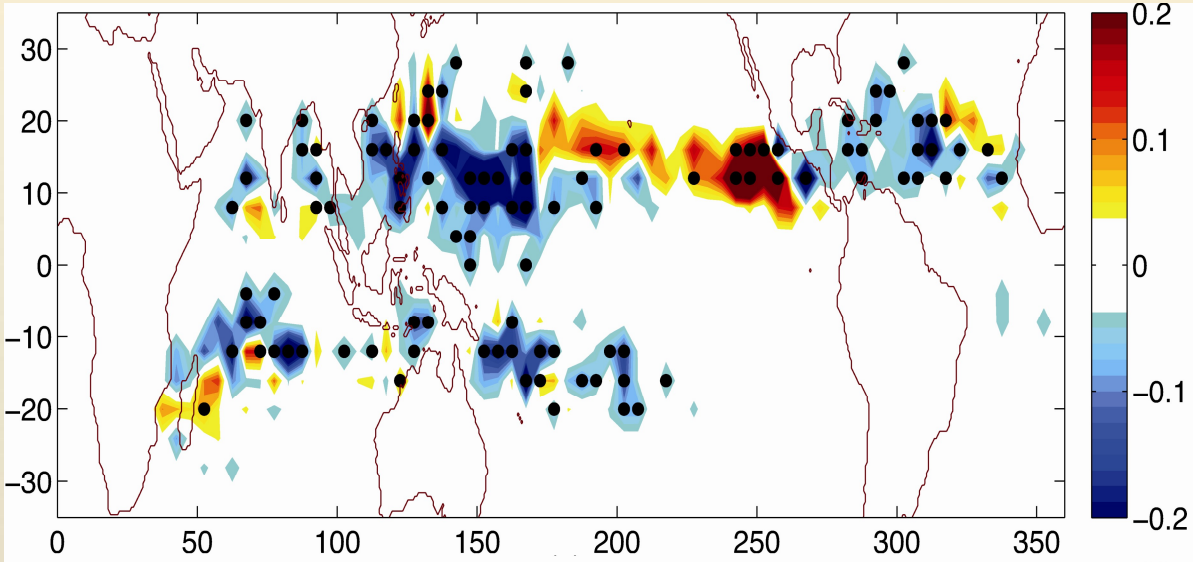


Geographical distribution of changes in annual hurricane genesis frequency. Color: average from 8 individual models' SST anomaly experiments; stipple: area where 6 out of the 8 models agree on the sign of change; unit: #/year/4°x5° ***(Zhao and Held, 2012, in press.)***

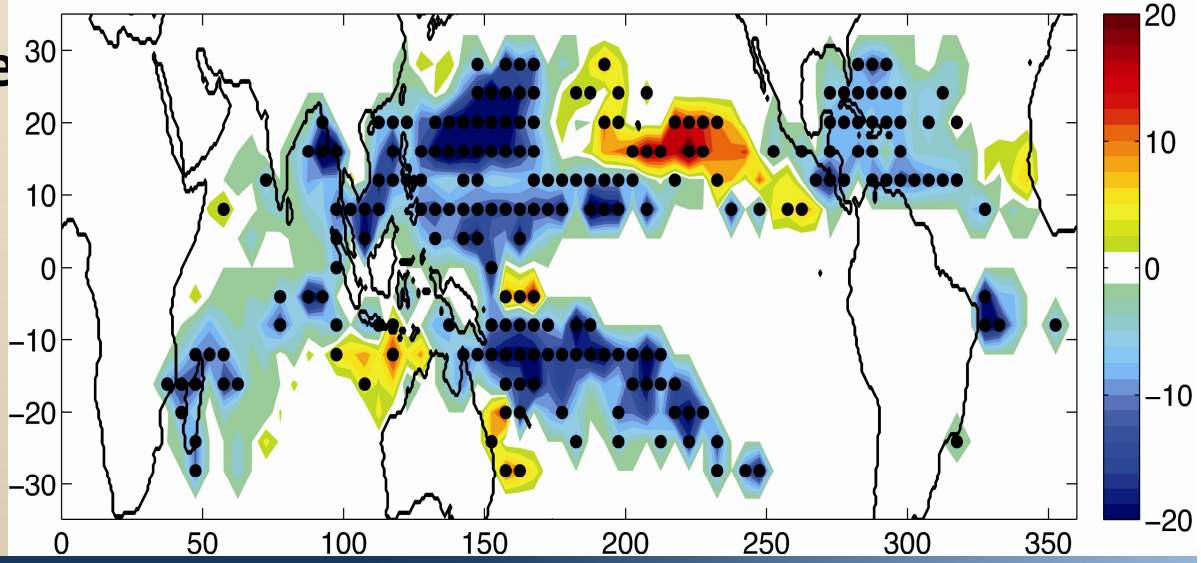
The eastward migration of storm genesis frequency can be explained by changes in mid-troposphere vertical velocity

change in hurricane genesis frequency

(unit: #/year/4°x5°)

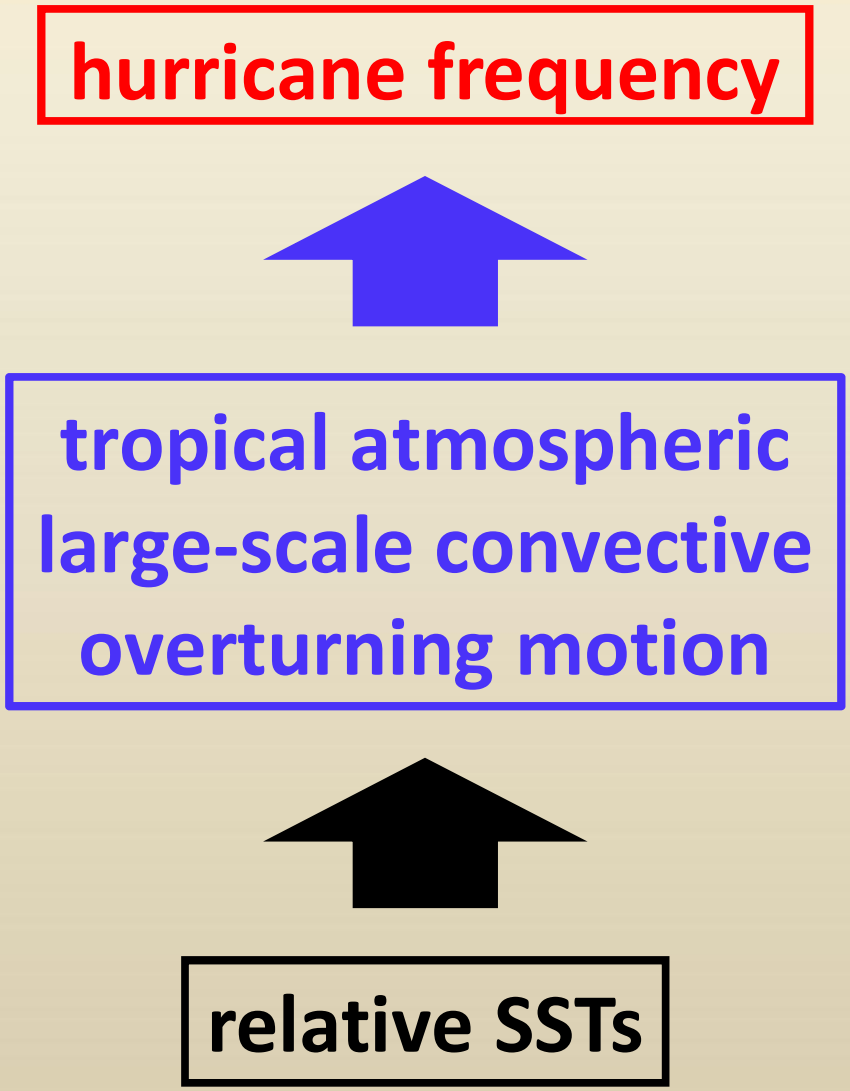


change in mid-troposphere vertical velocity



Color: average from 8 individual models; stipple: area where 6 out of the 8 models agree on the sign of change. (unit: hPa/day)

Improving the quality of regional SST projections in coupled GCMs is a key to reduce uncertainty in hurricane projection



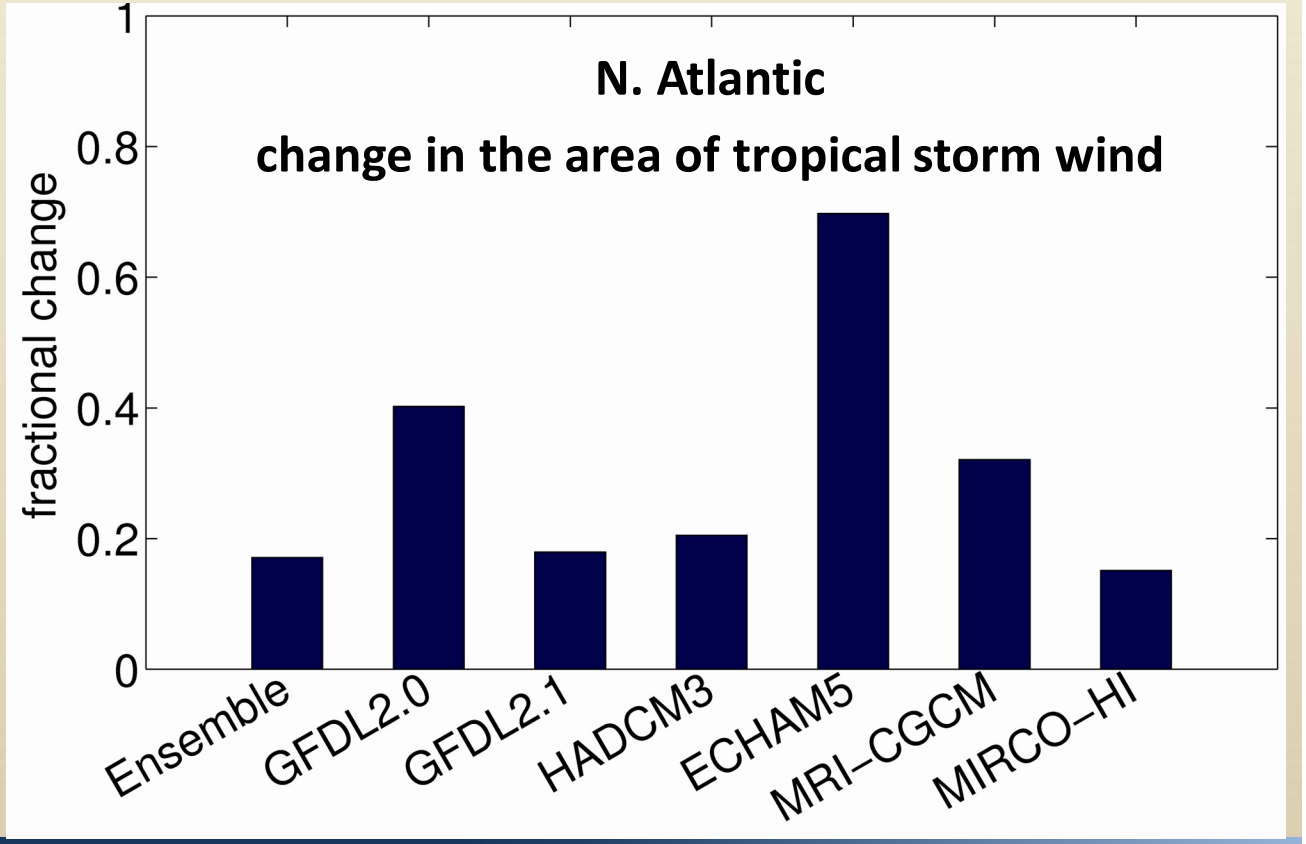
Response of tropical cyclone intensity and size to future warming

A statistical downscaling approach for studying TC intensity change

(Zhao and Held 2010, J. Climate)

On-going research:

response of storm size, destructive power and precipitation



Summary

- **A TC-permitting GCM is used to explore hurricane frequency response to SST anomalies generated by coupled models for the late 21st century.**
- **For each basin, there exists large inter-model spread in the magnitude and even the sign of the frequency response among the different SST projections.**
- **In N. Atlantic, E. Pacific and S. Indian basins, most of the inter-model variation in storm frequency response can be explained by a simple relative SST index.**
- **An atmospheric parameter measuring mid-tropospheric vertical velocity is skillful in explaining the simulated differences in hurricane frequency response for all basins.**
- **Other aspects of tropical cyclone response such as intensity, size, destructive power and precipitation are currently being explored.**