Response of Downscaled Tropical Cyclones to Climate Forcing: Results and Interpretation

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Program

- Why SST should not be considered a control variable on time scales longer than a few months
- Thermodynamic TC control variables when surface energy balance maintains
- TC activity downscaled from HWG simulations: Results and interpretation

Known TC Control Parameters

- Potential Intensity:

saturation *h* of sea surface

$$V_{pot}^2 = C\frac{T_s - T_o}{T_o}\left(h_0^* - h^*\right),$$

saturation *h* of free troposphere
(assumed equal to PBL *h*)

$$C = F\left(C_k, C_D\right),$$

$$h \equiv c_p T + L_v q + gz \qquad \left(moist\ static\ energy\right)$$

- Normalized mid-troposphere saturation deficit:

actual *h* of middle troposphere

$$\chi \equiv \frac{h^* - h_m}{h_0^* - h^*}$$

- Vertical wind shear
- Absolute vorticity at low levels
- Genesis Potential Index:

$$GPI \equiv |\eta|^3 \chi^{-4/3} MAX\left(\left(V_{pot} - 35\,ms^{-1}\right),0\right)^2 \left(25\,ms^{-1} + V_{shear}\right)^{-4},$$

Low-level absolute vorticity

- Thermodynamic component:

$$GPI\ ;\ \chi^{-4/3} MAX\left(\left(V_{pot} - 35\,ms^{-1}\right),0\right)^2 .$$

Note that both V_{pot} and χ increase under global warming!

Importance of Surface Energy Balance:

$$C_k \rho \,|\mathbf{V}|\left(h_0^* - h^*\right) = F_{net\downarrow} + F_{ocean}$$

surface wind speed

net downward surface radiative flux

Net convergence of ocean heat flux

Combine with expression for potential intensity:

$$V_{pot}{}^2 = \frac{C}{C_D}\,\frac{T_s - T_o}{T_o}\,\frac{F_{net\downarrow} + F_{ocean}}{\rho\,|\mathbf{V}|}$$

Very weak dependence on SST.
SST is a ***cofactor***

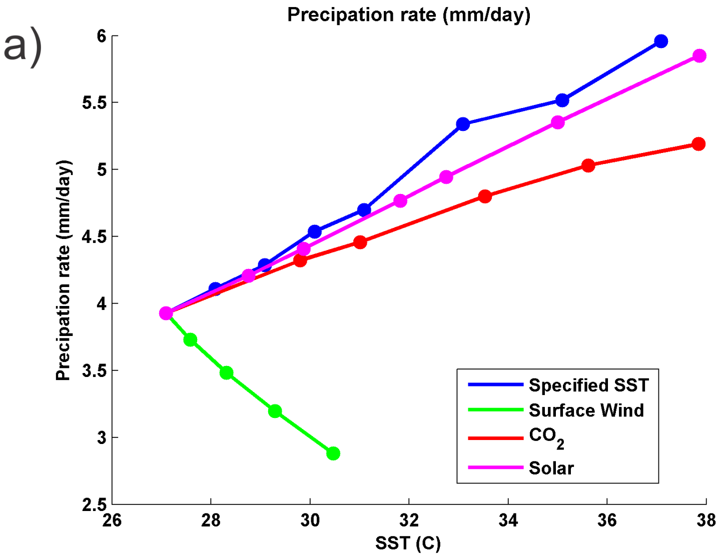
$$V_{pot}{}^{2} = \frac{C}{C_D}\,\frac{T_s - T_o}{T_o}\,\frac{F_{net\downarrow} + F_{ocean}}{\rho\,|\mathbf{V}|}$$

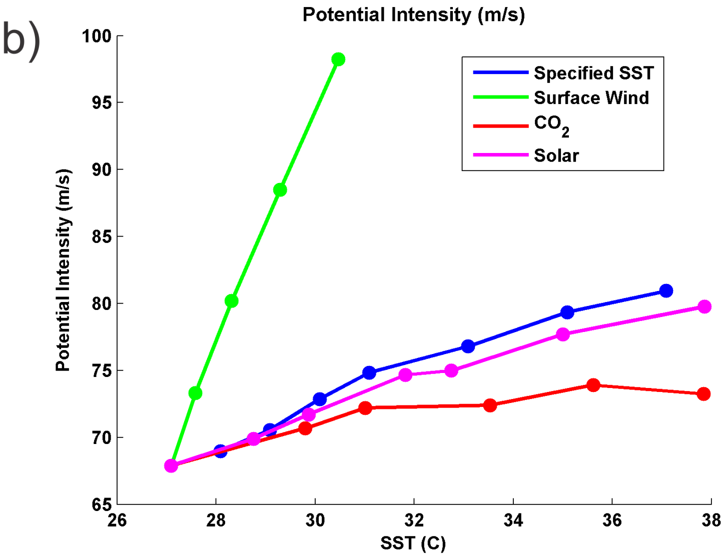
Note that specifying SST is fully equivalent to specifying F_{ocean} above

Single-Column Model Experiments

(Emanuel and Sobel, JAMES 2013, in press)

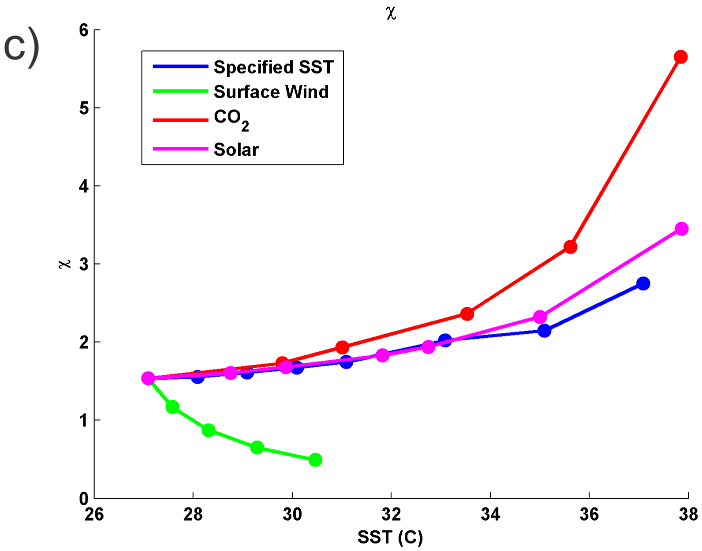
Precip

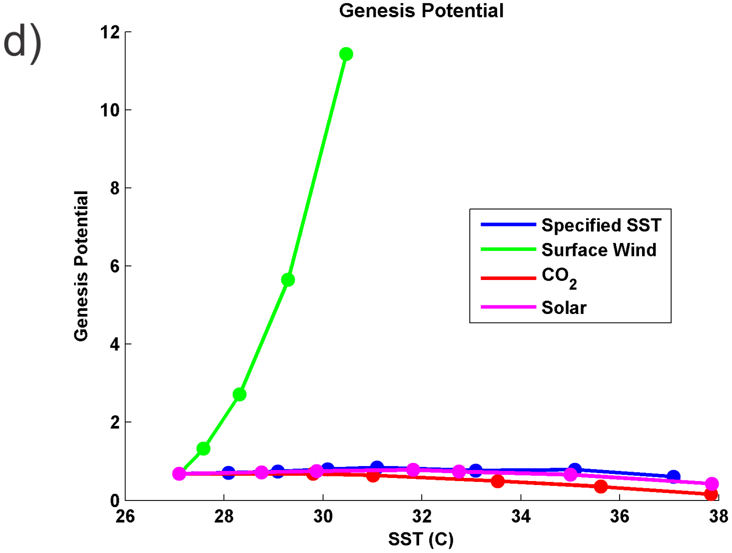




V_{pot}

χ





GPI

HWG Experiments

$$V_{pot}^{\ 2} = \frac{C}{C_D}\,\frac{T_s - T_o}{T_o}\,\frac{F_{net\downarrow} + F_{ocean}}{\rho\,|\,\mathbf{V}\,|}$$

- +2 C increase in SST: Equivalent to increasing F_{ocean} ; increases V_{pot}
- Double CO2: Equivalent to increasing $F_{net\downarrow}$ while decreasing F_{ocean} : indeterminate effect on V_{pot}

Downscaling Approach:

- **Step 1**: Seed each ocean basin with a very large number of weak, randomly located cyclones
- **Step 2**: Cyclones are assumed to move with the large scale atmospheric flow in which they are embedded, plus a correction for beta drift
- **Step 3**: Run the CHIPS model for each cyclone, and note how many achieve at least tropical storm strength
- **Step 4:** Using the small fraction of surviving events, determine storm statistics

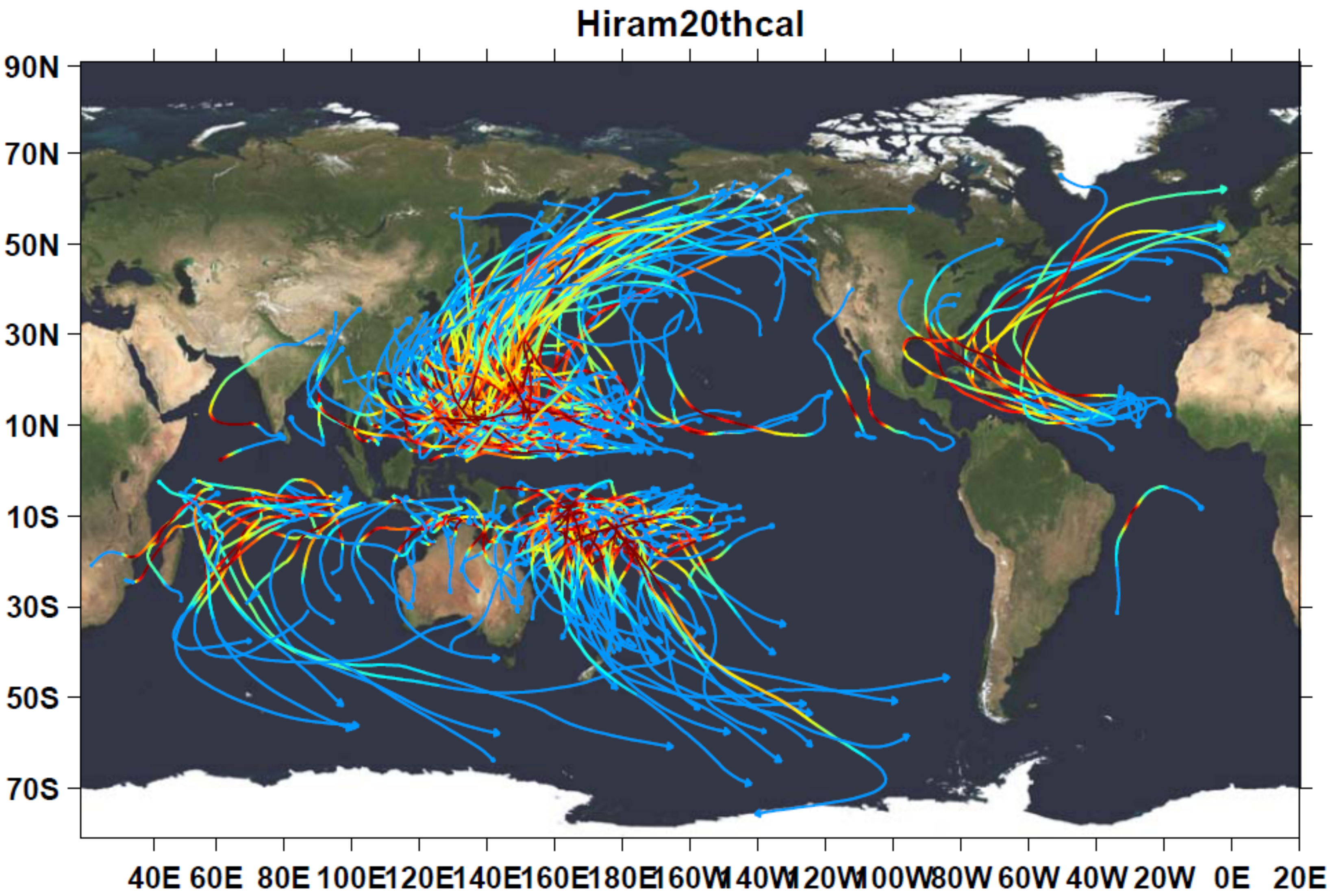
Details: Emanuel et al., *Bull. Amer. Meteor. Soc*, 2008

Downscaling HWG Models

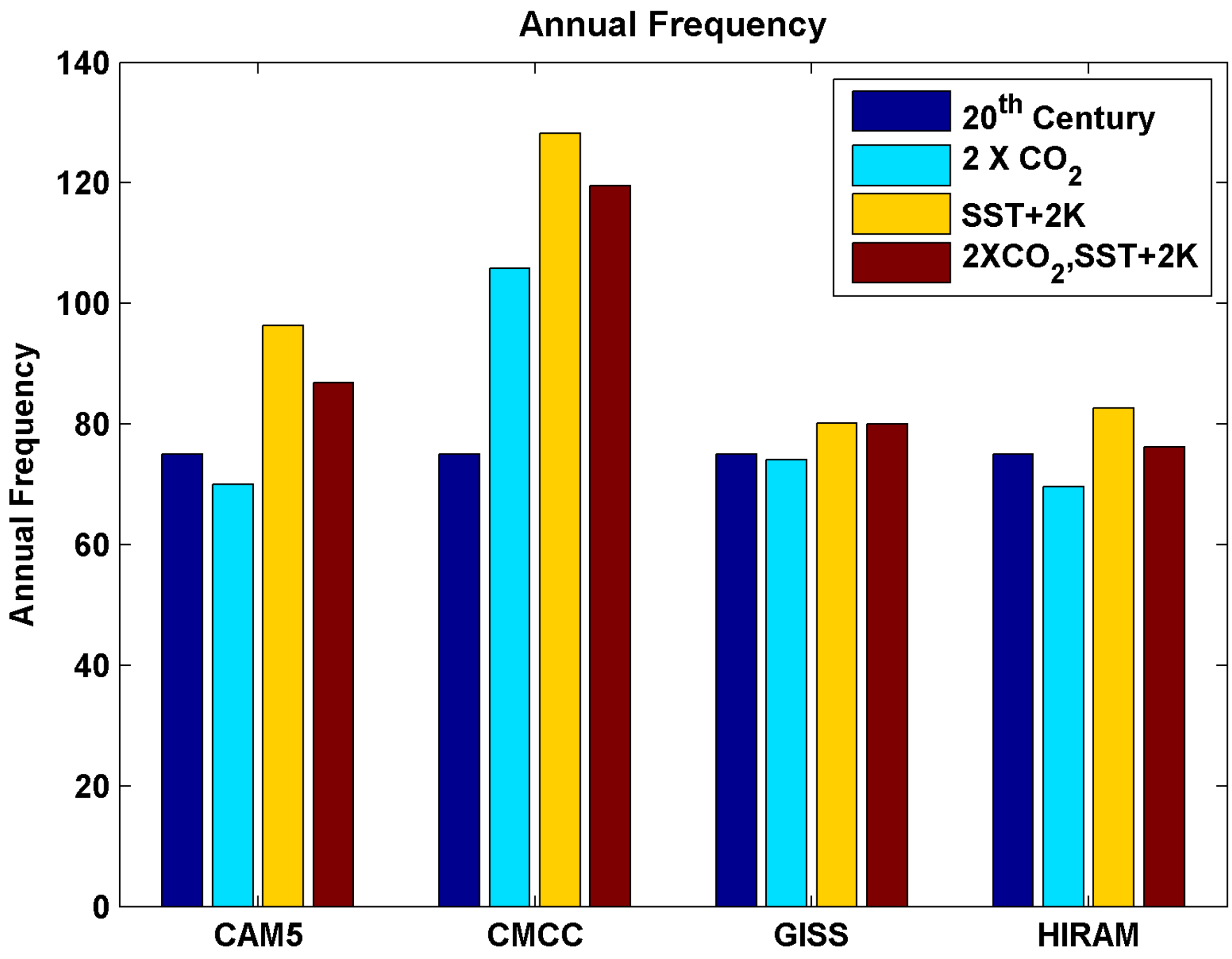
- 10,000 tracks downscaled from each of 4 HWG models: CAM5, CMCC, GISS, and HIRAM, and each of 4 scenarios:
  - 20th Century
  - 2 X CO_2
  - SST + 2K
  - 2 X CO_2, SST + 2K
- Seeding rate calibrated to yield 75 events globally with peak winds > 40 knots, 20th Century simulations

Note: All track data posted at http://storms.ldeo.columbia.edu/data/downscaled_tracks/

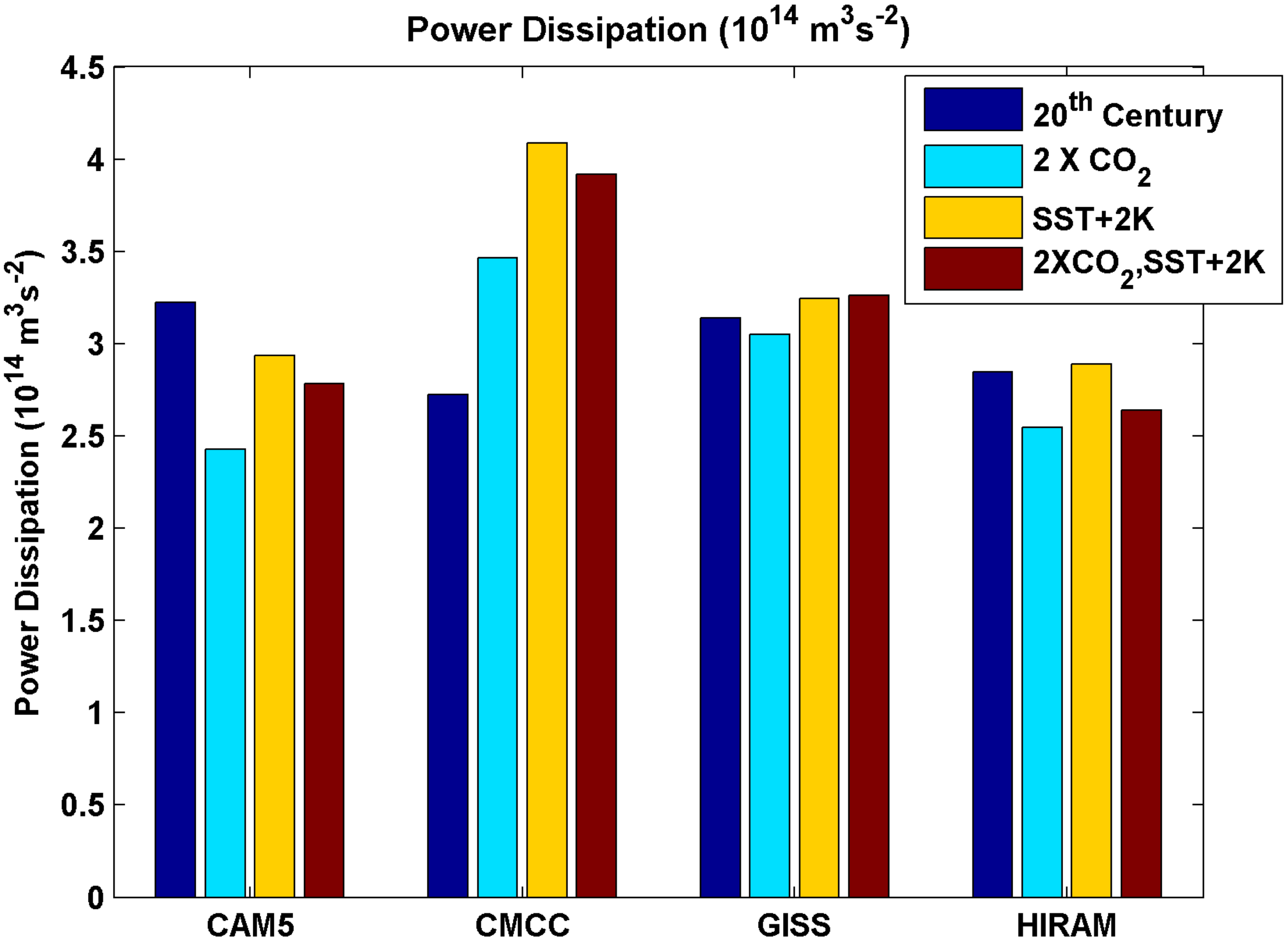
200 HIRAM 20th Century Tracks



Frequency


Annual Frequency
Annual Frequency
140
120
100
80
60
40
20
0
CAM5
CMCC
GISS
HIRAM
20th Century
2 X CO_2
SST+2K
2XCO_2,SST+2K

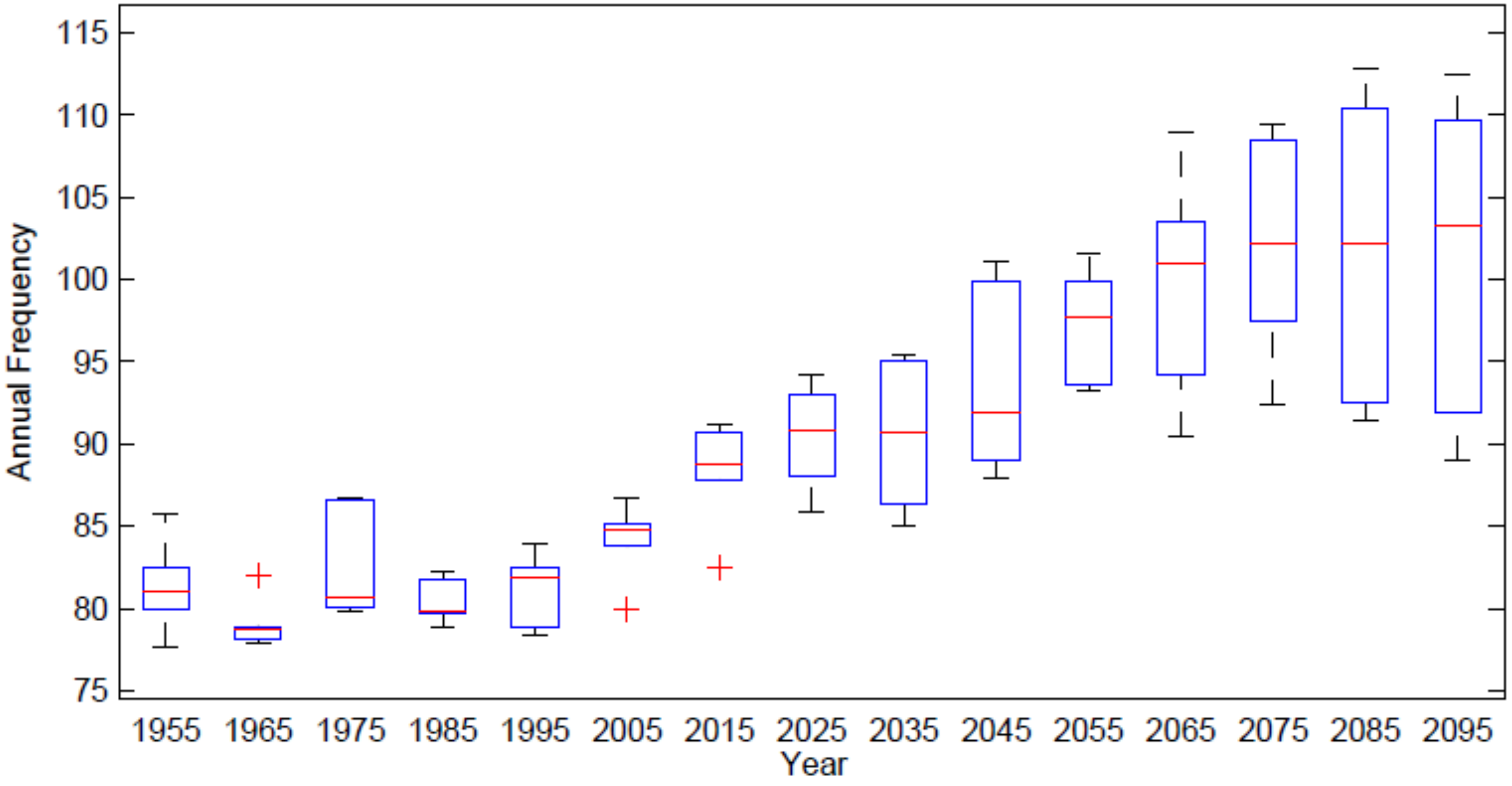
Power Dissipation



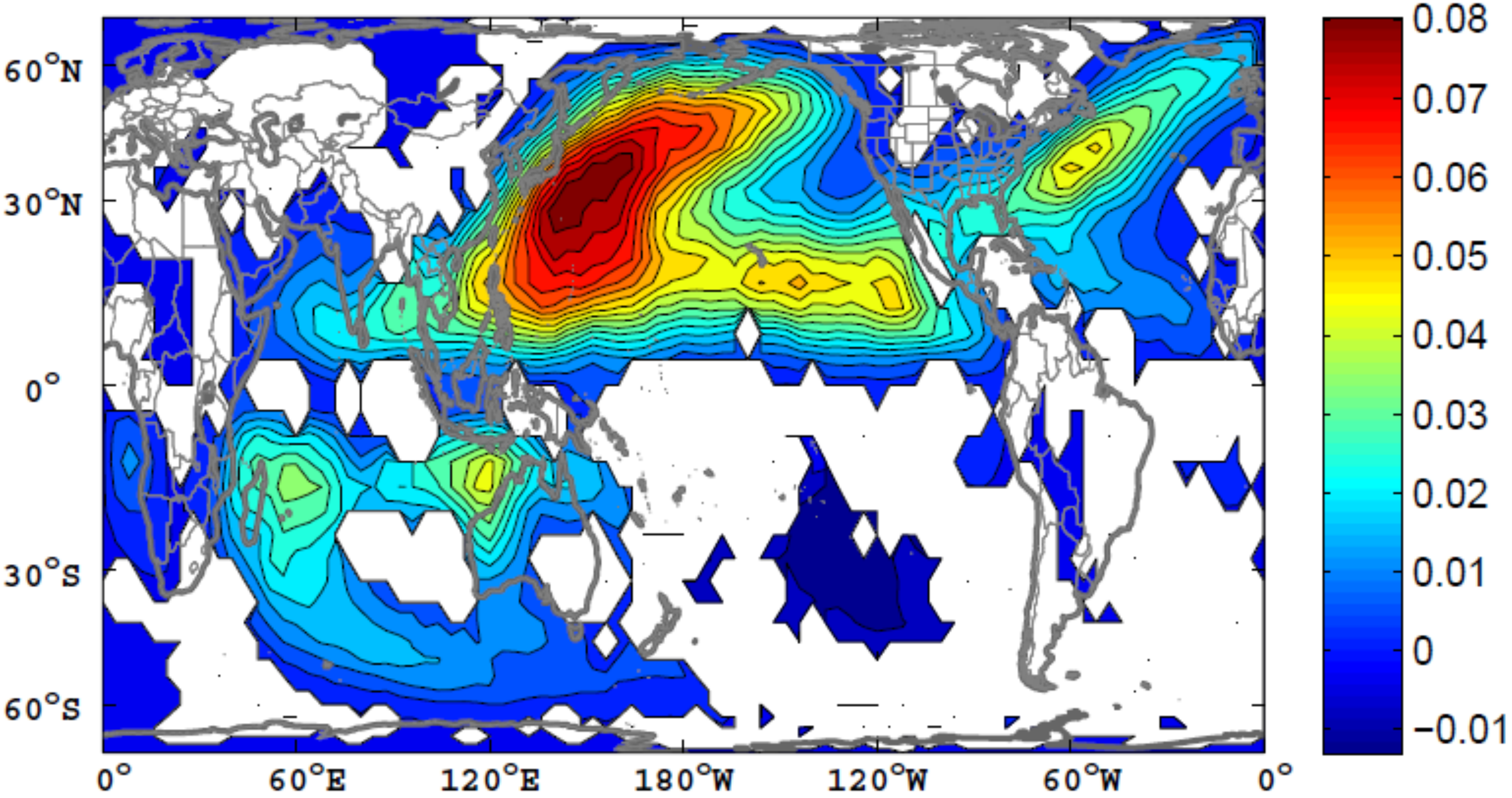
CMIP5 Models

Modeling Center	**Institute ID**	**Model Name**	**Average Horizontal Resolution**
National Center for Atmospheric Research	NCAR	CCSM4	1.25° X 0.94°
NOAA Geophysical Fluid Dynamics Laboratory	GFDL	CM3	2.5 ° X 2.0 °
Met Office Hadley Center	MOHC	HADGEM2-ES	1.875 ° X 1.25 °
Max Planck Institute for Meteorology	MPI	MPI-ESM-MR	1.875 ° X 1.865 °
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	MIROC5	1.41 ° X 1.40 °
Meteorological Research Institute	MRI	MRI-CGCM3	2.81 ° X 2.79 °

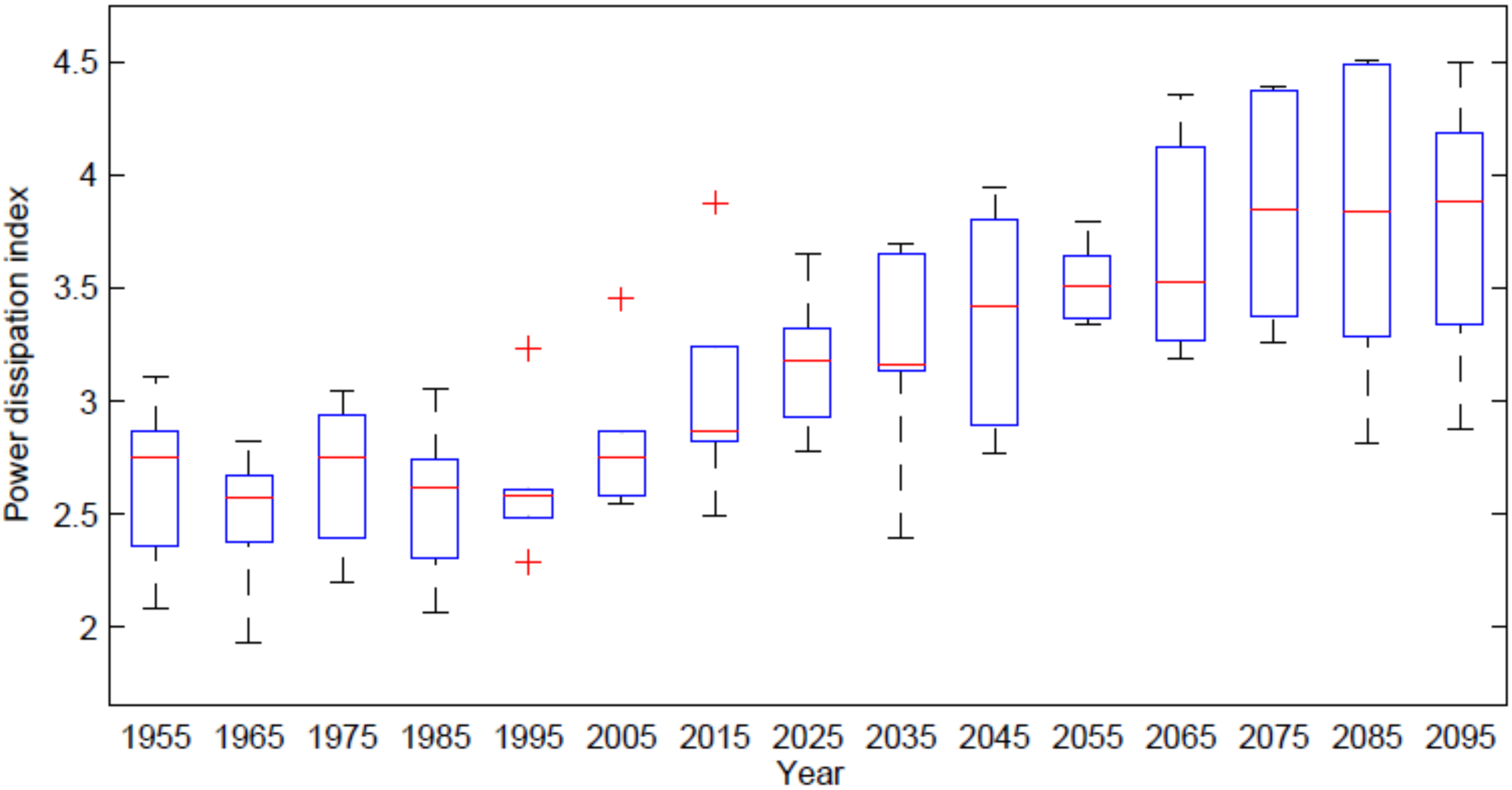
Global Frequency



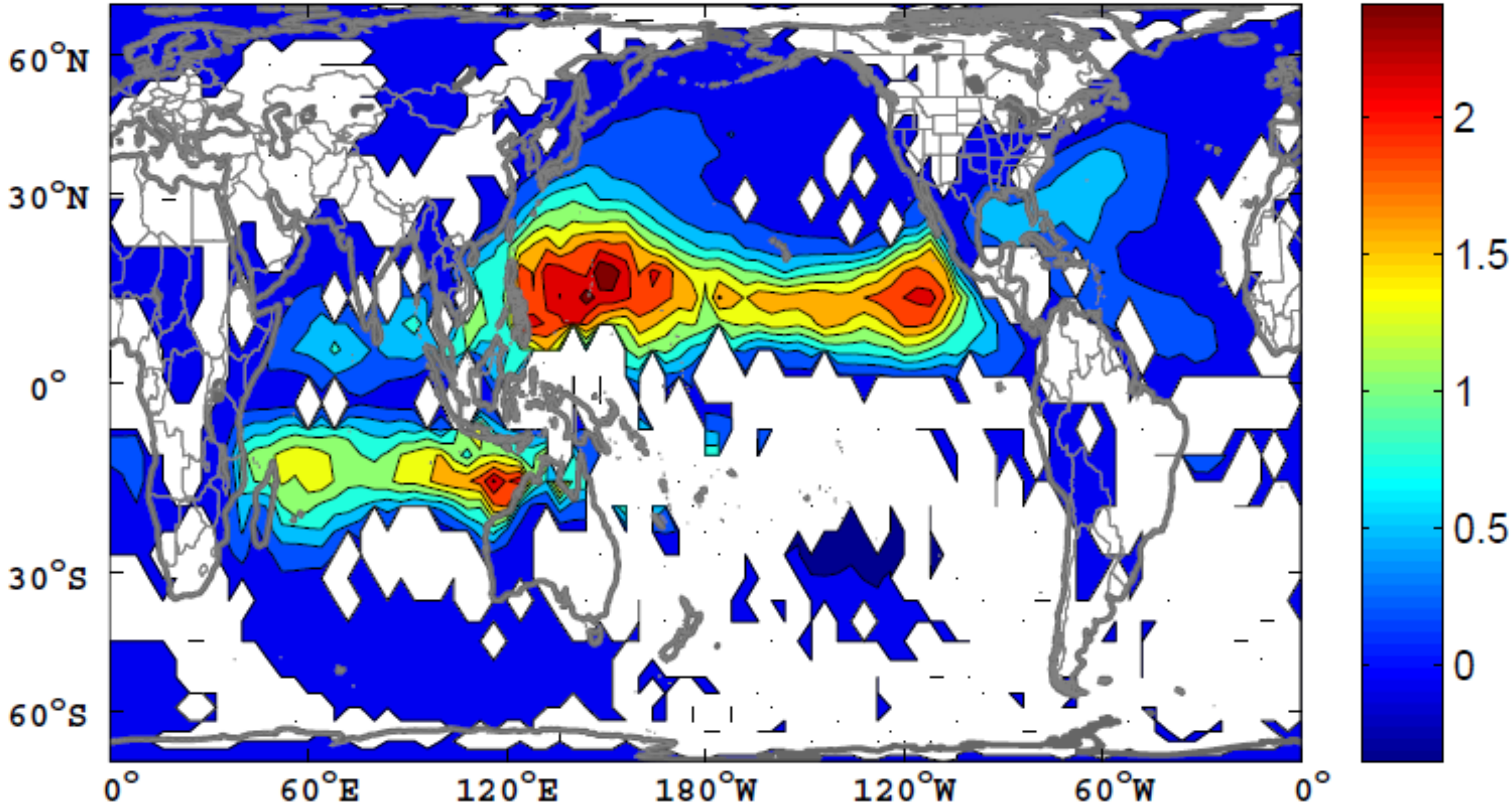
Change in Track Density

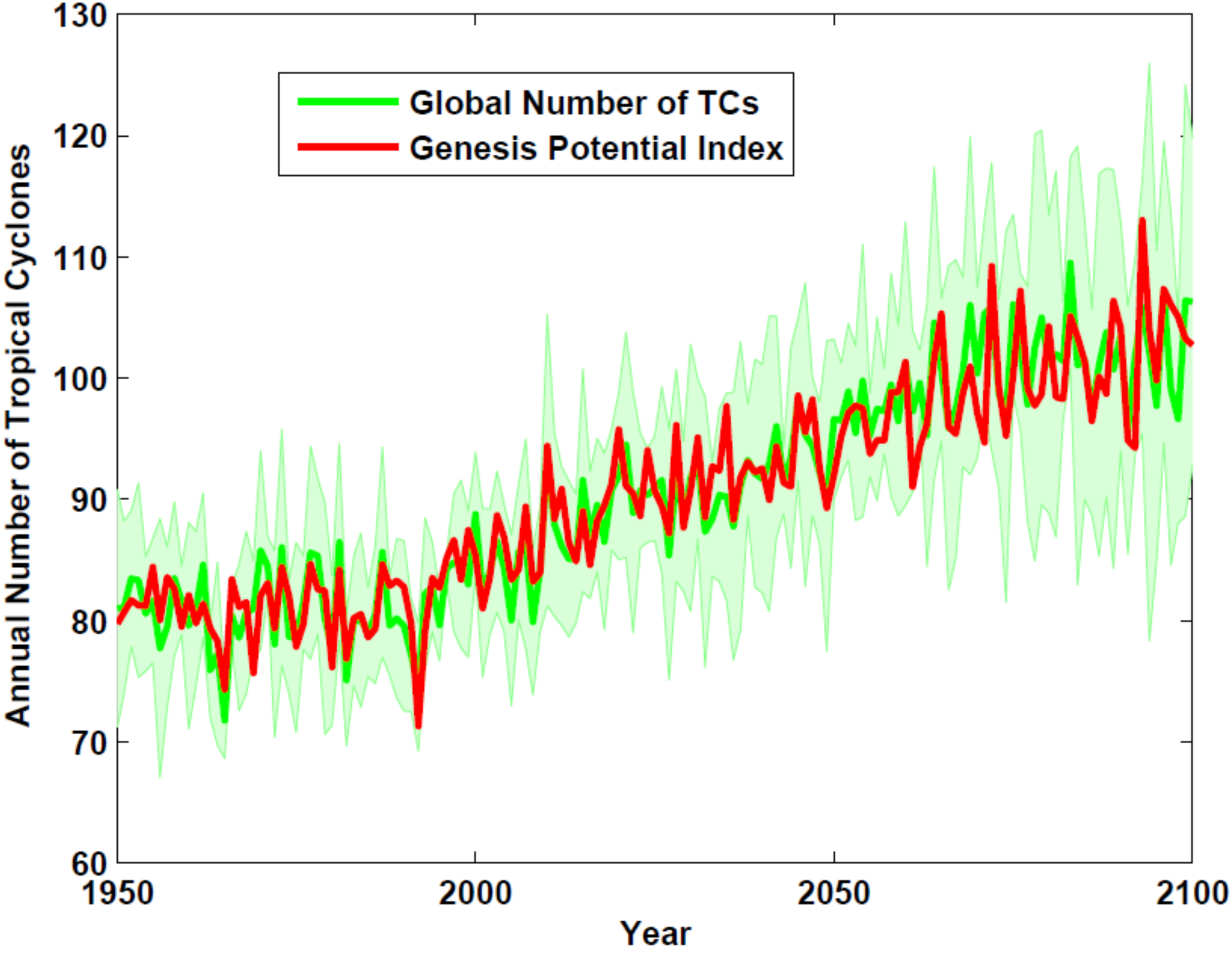


Global Power Dissipation



Change in Power Dissipation




Global Number of TCs
Genesis Potential Index
Annual Number of Tropical Cyclones
130
120
110
100
90
80
70
60
1950
2000
2050
2100
Year

CMIP3 – CMIP5 Comparison

Institute ID	CMIP3 Model	CMIP5 Model	CMIP3 change in global TC frequency	CMIP5 change in global TC frequency	CMIP3 change in global power dissipation	CMIP5 change in global power dissipation
NCAR	CCSM3	CCSM4	-3%	+11%	+5%	+8%
GFDL	CM2.0	CM3	-13%	+41%	+2%	+72%
MOHC		HADGEM2-ES		+22%		+31%
MPI	ECHAM5	MPI-ESM-MR	-11%	+29%	+4%	+57%
MIROC	MIROC3.2	MIROC5	-12%	+38%	+8%	+80%
MRI	MRI-CGCM2.3.2a	MRI-CGCM3	+2%	+13%	+22%	+26%

CMIP3: Change from 1981-2000 to 2181-2200, Emissions Scenario A1b
CMIP5: Change from 1950-2005 to 2006-2100, Scenario RCP8.5

Summary

- On time scale longer than a few months, SST should not be considered an external condition
- Physically based TC predictors such as potential intensity and normalized saturation deficit respond primarily to changing surface radiation, ocean heat flux, and especially mean surface wind speed. SST also varies with these, but in differing ways

- Therefore, relationship between SST and TC predictors differs according to how SST is forced... no unique relationship between TC metric and SST even when kinematic environment is neglected
- HWG experiments valuable for comparing models, but not for understanding climate influences on TCs
- Downscaling CMIP5 models shows global increases in TC metrics under RCP 8.5, in contrast to CMIP3. The are consistent with GPI changes. Variations in surface wind speed likely culprit.