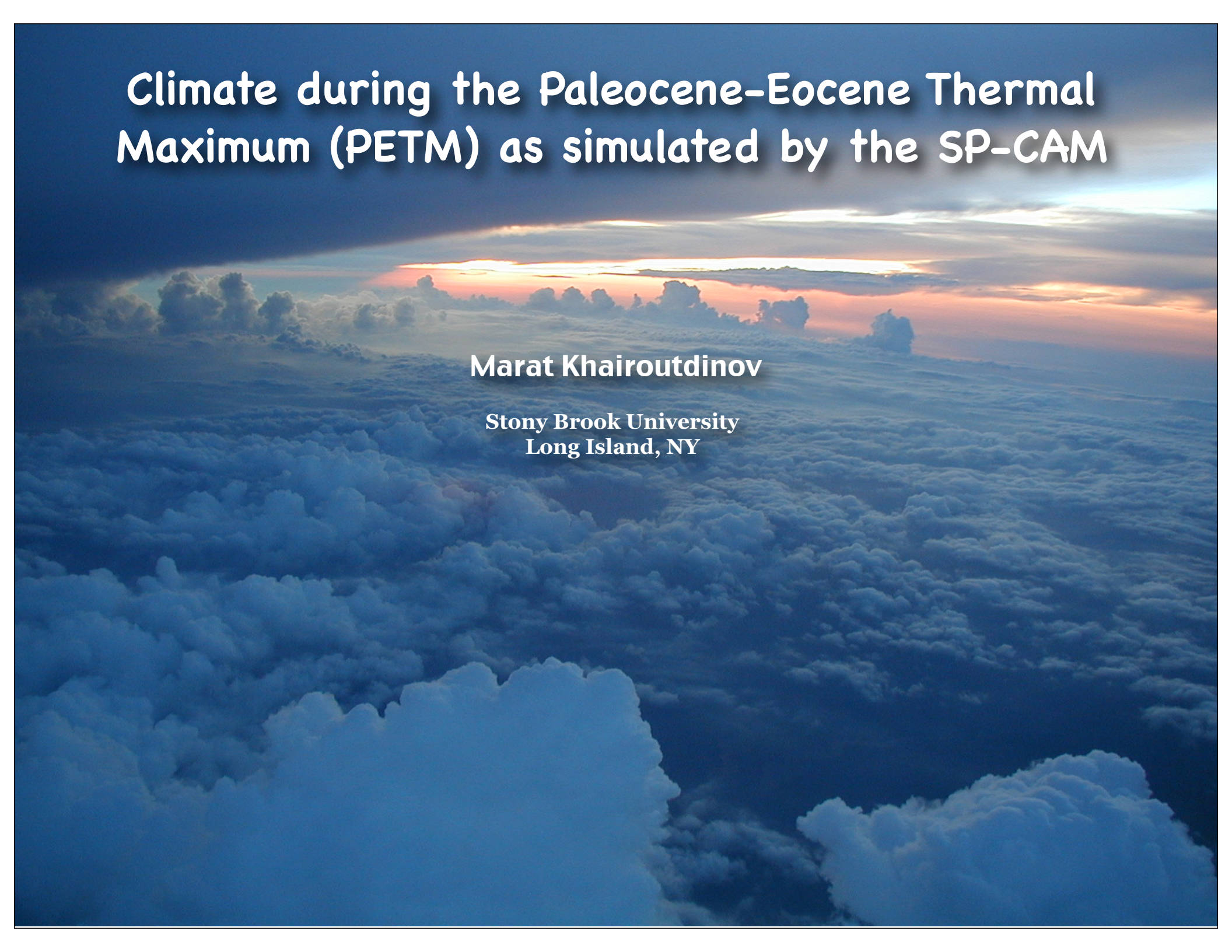


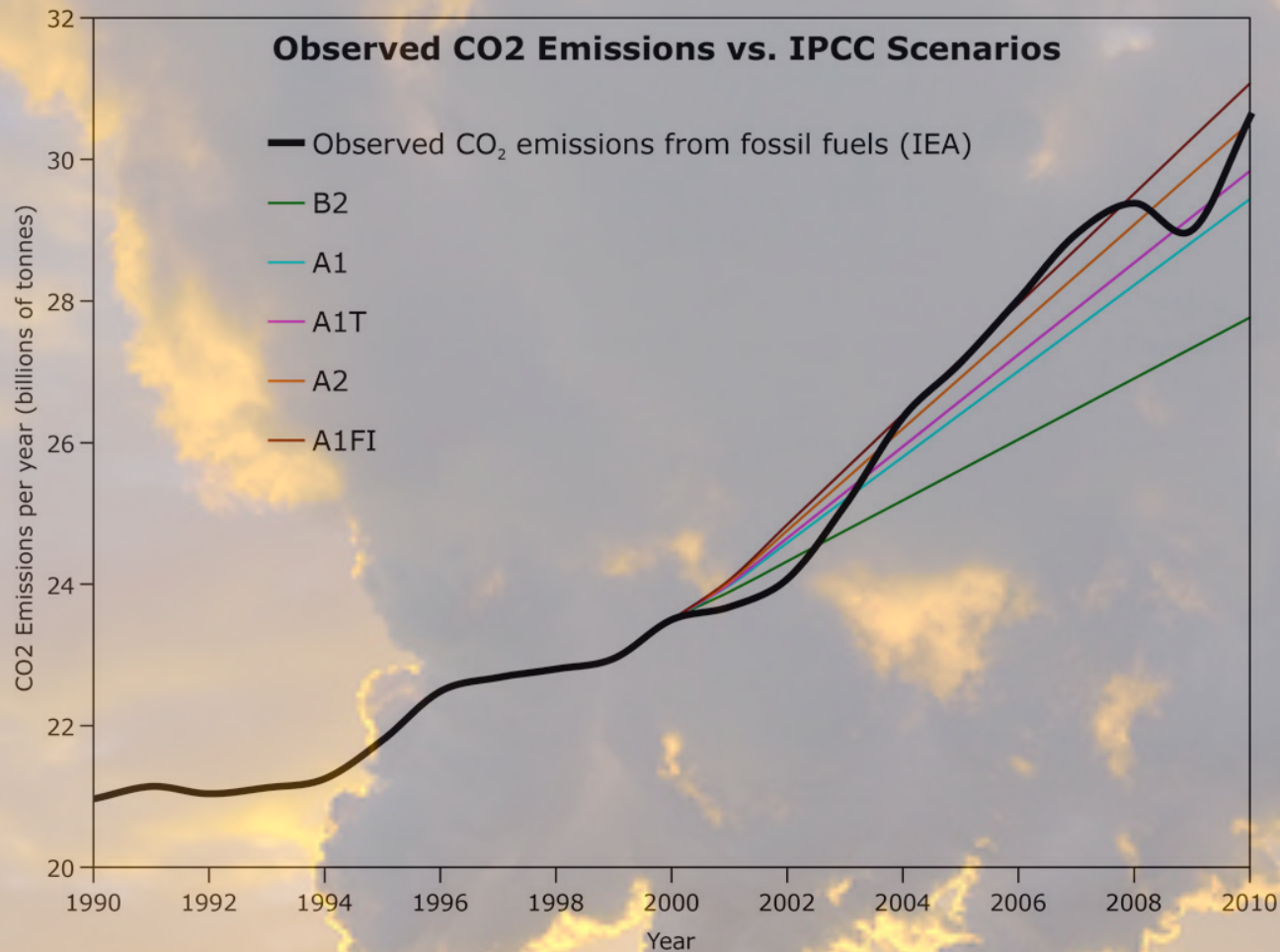
Climate during the Paleocene-Eocene Thermal Maximum (PETM) as simulated by the SP-CAM

Marat Khairoutdinov

**Stony Brook University
Long Island, NY**



The latest figures suggest that we are on track with the worst case scenario of CO₂ emissions from the IPCC AR4

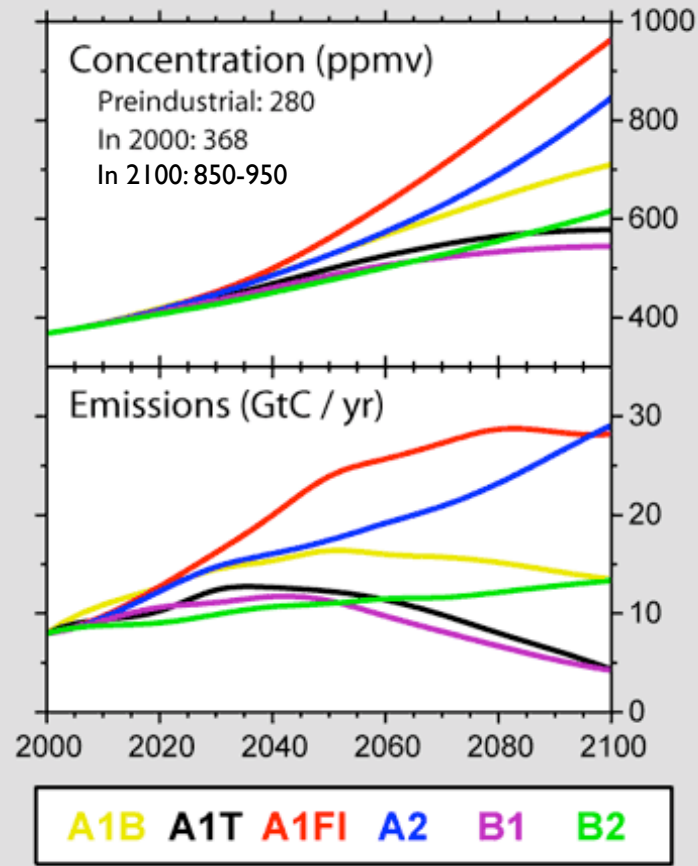


IEA global human CO₂ annual emissions from fossil fuels estimates vs. IPCC SRES scenario projections.

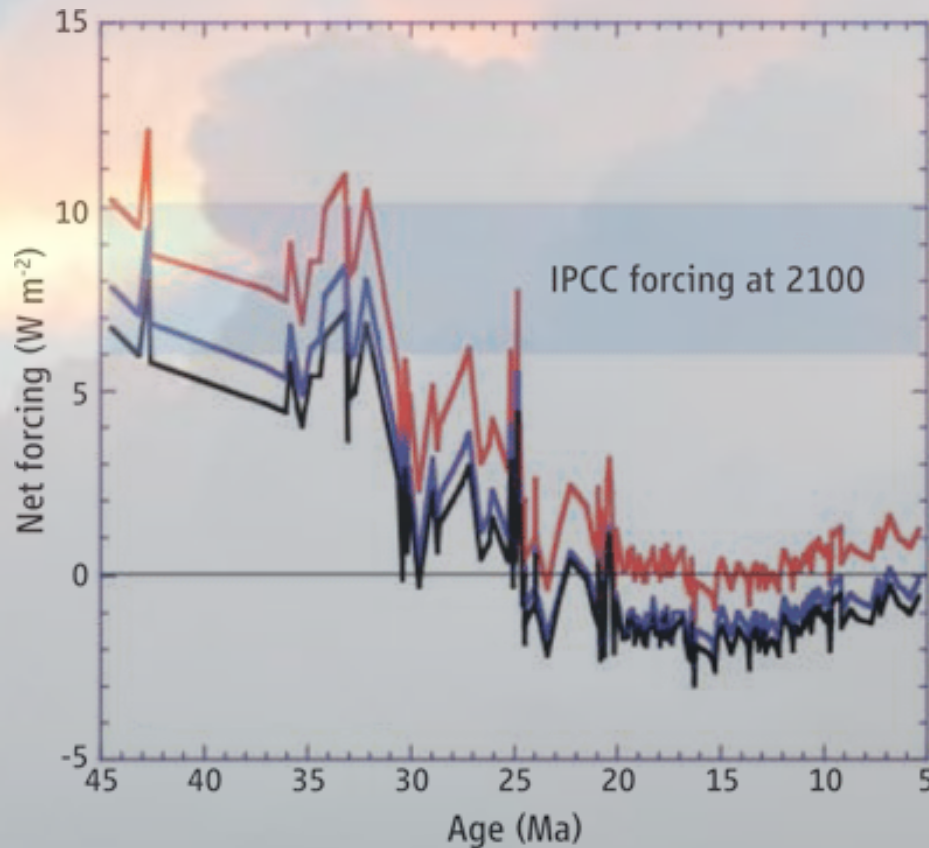
International Energy Agency report, June 2011

At such a 'business-as-usual' rate, the CO₂ concentrations could reach 800 to 1000 ppmv by 2100, which means tripling not doubling CO₂ levels with respect to preindustrial levels.

IPCC Emissions Scenarios: Carbon Dioxide

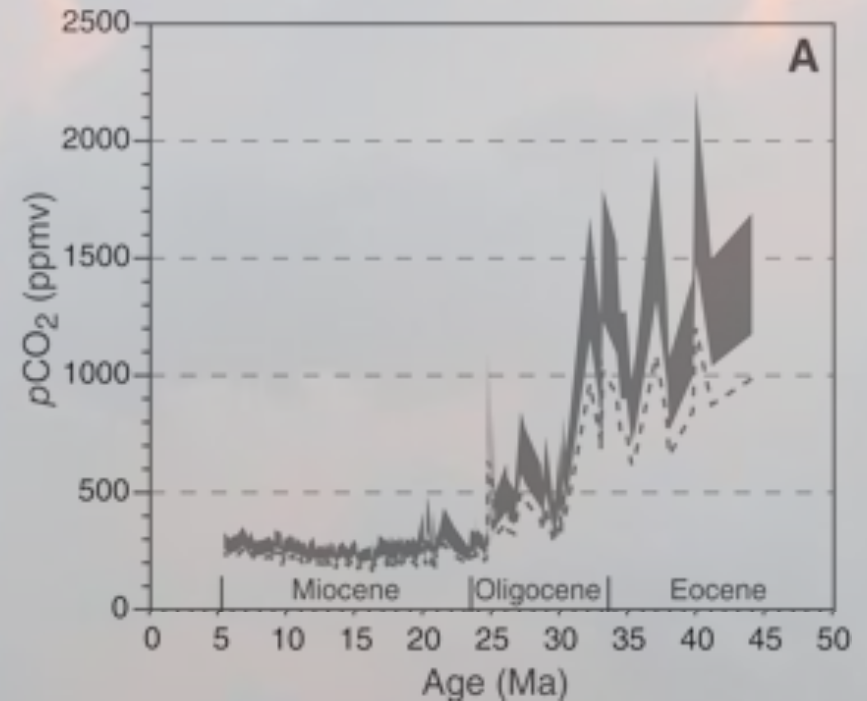


According to paleo reconstructions, it has been tens of millions of years since the Earth had the levels of CO₂ and corresponding radiative forcing that we may experience in just 90 years from now.



The net radiative forcing due to changes in atmospheric CO₂ concentration and total solar irradiance over the past 45 million years.

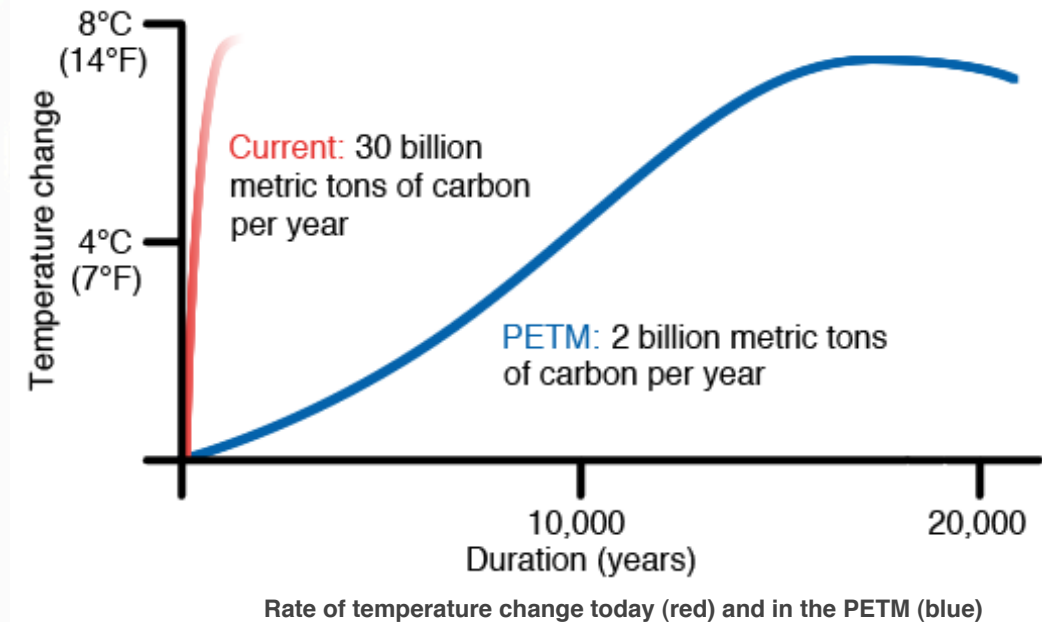
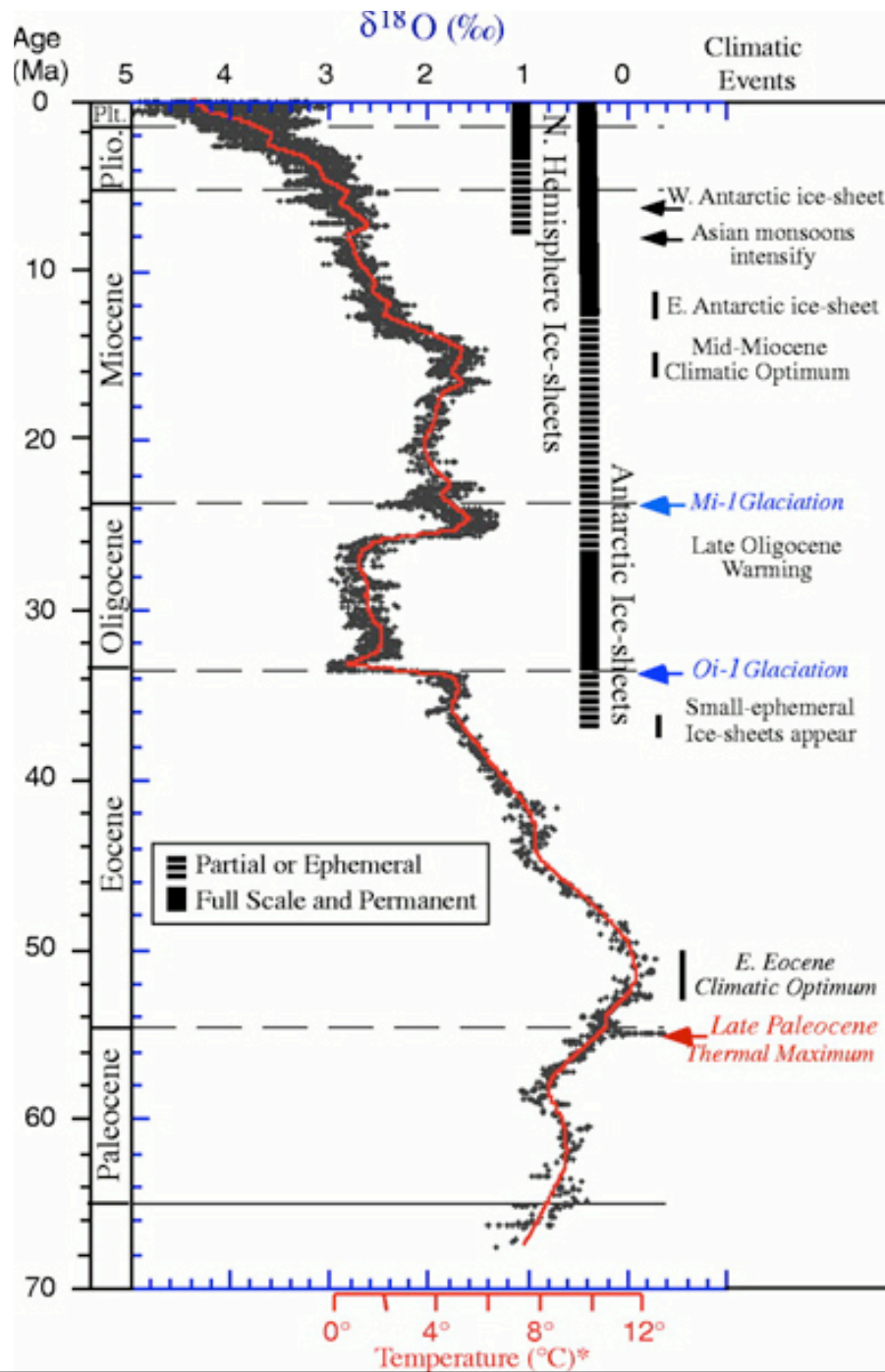
Kiehl (Science, 2011)



Reconstruction of the CO₂ levels over the past 45 million years

Pagani et al (Science, 2005)

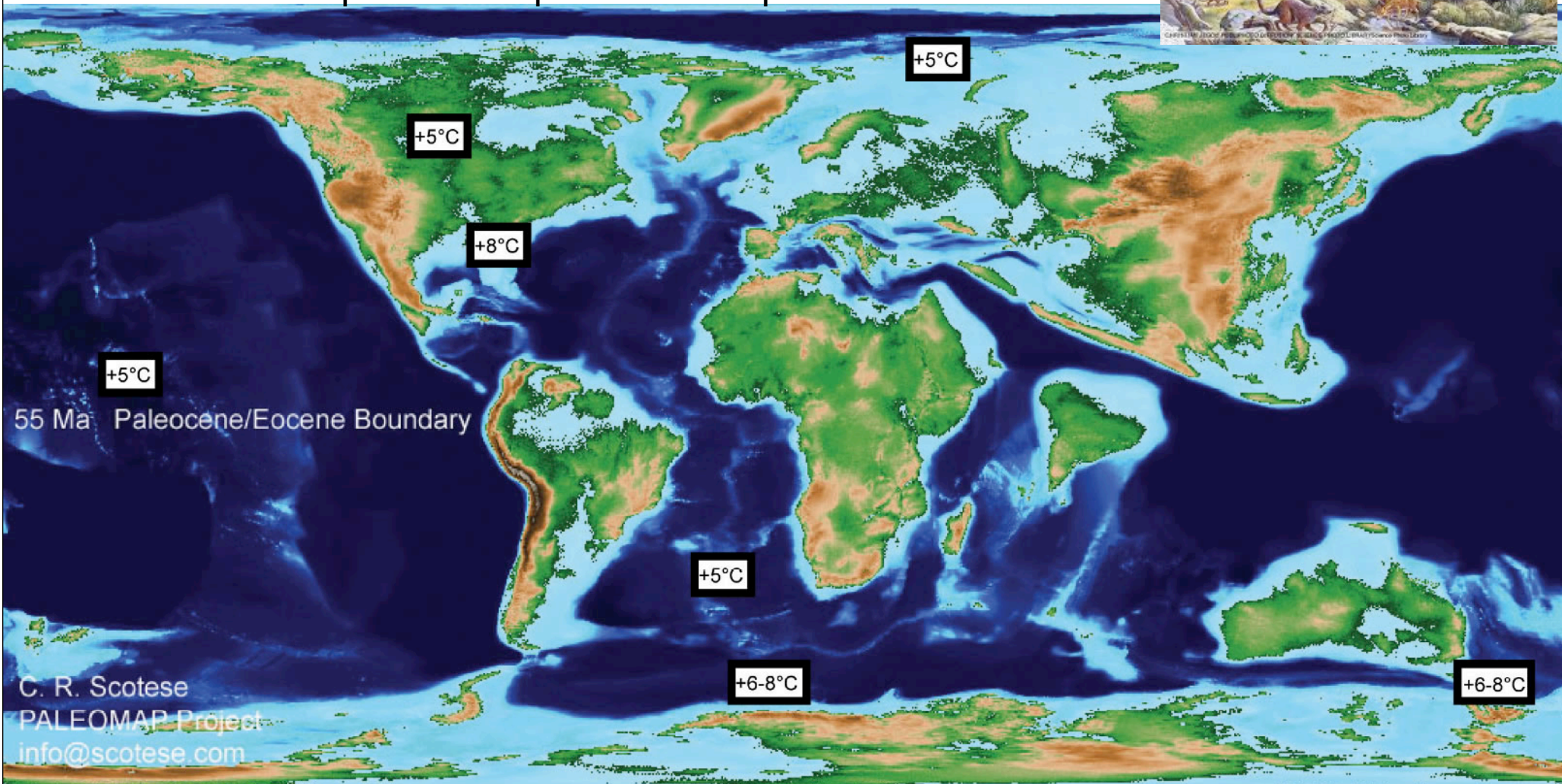
Perhaps we can use the past to tell us what is waiting for us in the future...



PETM

Earth 55 million years ago during Paleocene-Eocene Thermal Maximum (PETM)

- Global mean temperature about 30°C (vs. 14°C today);
- CO₂ range: 1700 to 2250 ppmv (vs. 380 today);
- Lasted 200,000 years; the cause is still a mystery;
- Mammalian abundance; primates and horse orders first appeared.
- GCMs have unexplained 'cold poles' bias compared to reconstructed T



Geographical reconstruction for the PETM from the PALEOMAP Project (www.scotese.com) . Boxes indicate reconstructed surface temperature anomalies for the PETM relative to Paleocene background temperatures

SP-CAM Set-up

- All run-datasets including initial conditions, prescribed monthly SST climatology, orbital parameters, PETM paleogeography, paleotopography, and vegetation reconstruction were courteously provided by Jeff Kiehl and Christina Shields from their PETM multi-millennium simulations with fully coupled CCSM3;
- GCM: SP-CAM T31 L26; CRM: 4km, 32 cols, L25
- 7 years PETM and control (present);

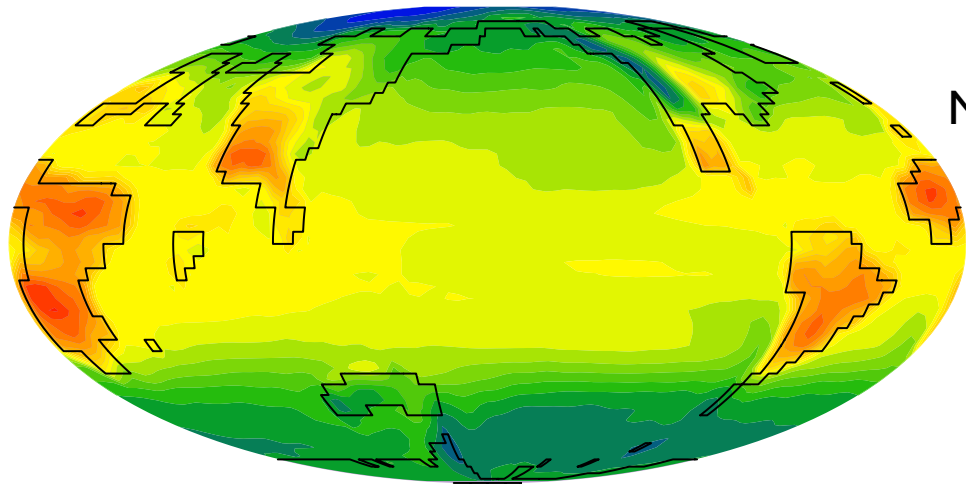
Parameters

	55 MY ago (PETM)	Present
CO ₂ , ppmv	2250	380
CH ₄ , ppmv	16	1.75
N ₂ O, ppmv	0.275	0.3
Solar constant, W/m ²	1355	1365
Eccentricity	0	0.0167
Obliquity	23.5	23.44

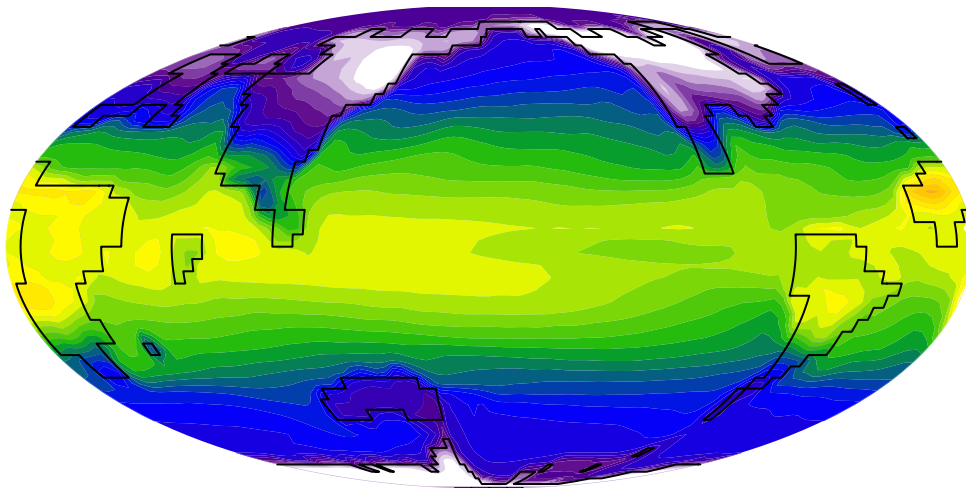
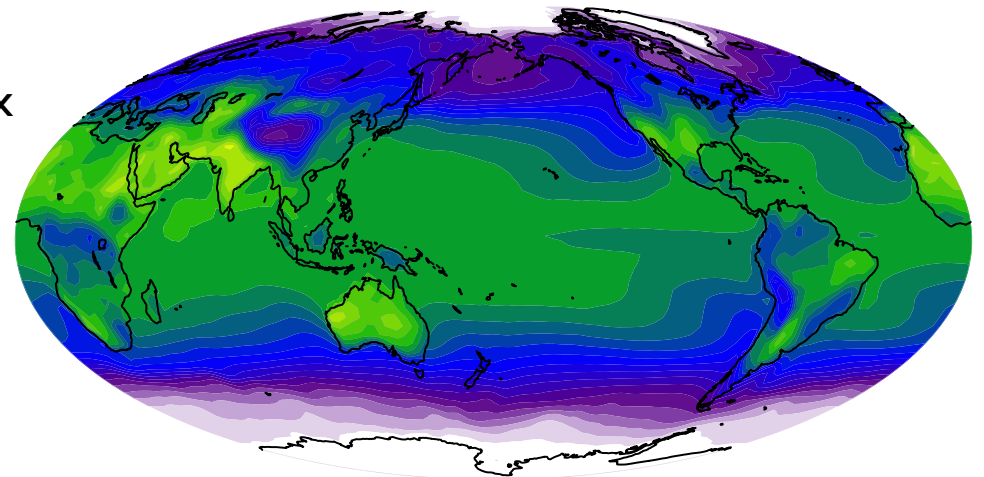
Maximum/Minimum Monthly Surface Temperature, °C

PETM (55.8 MY ago)

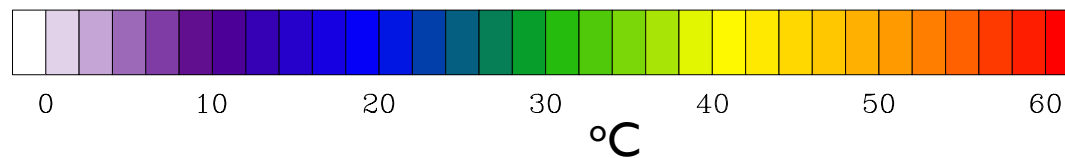
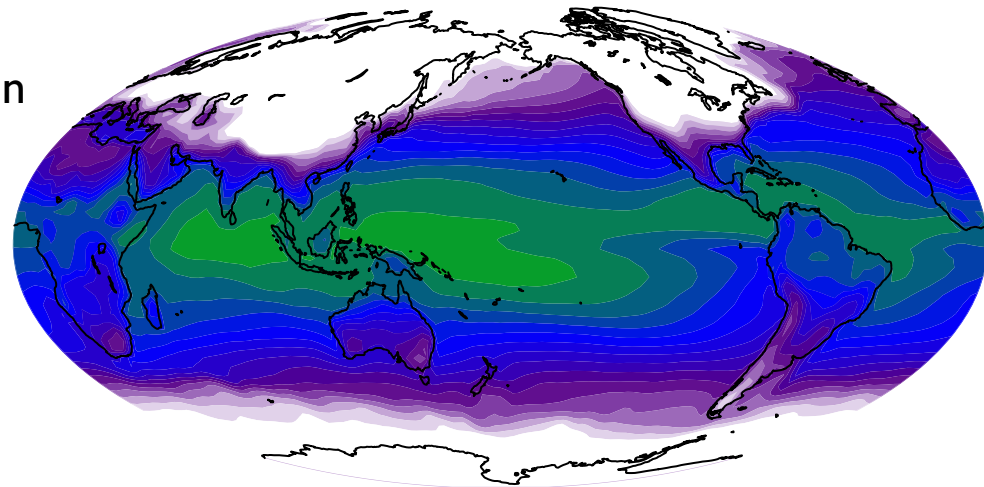
Present



Max

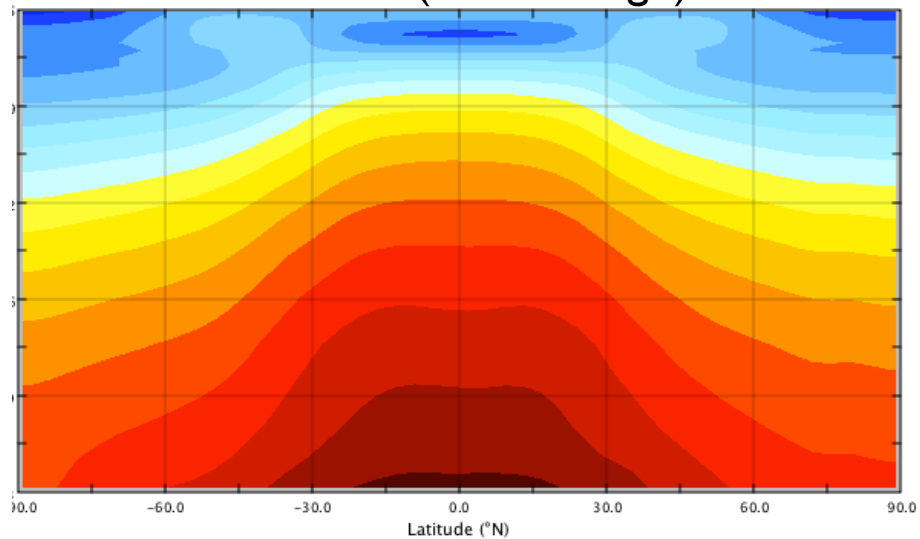


Min

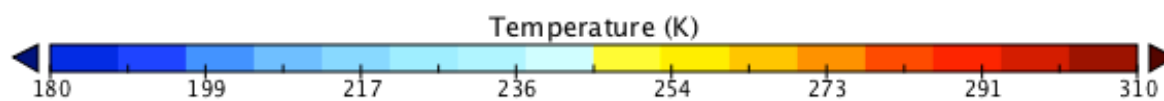
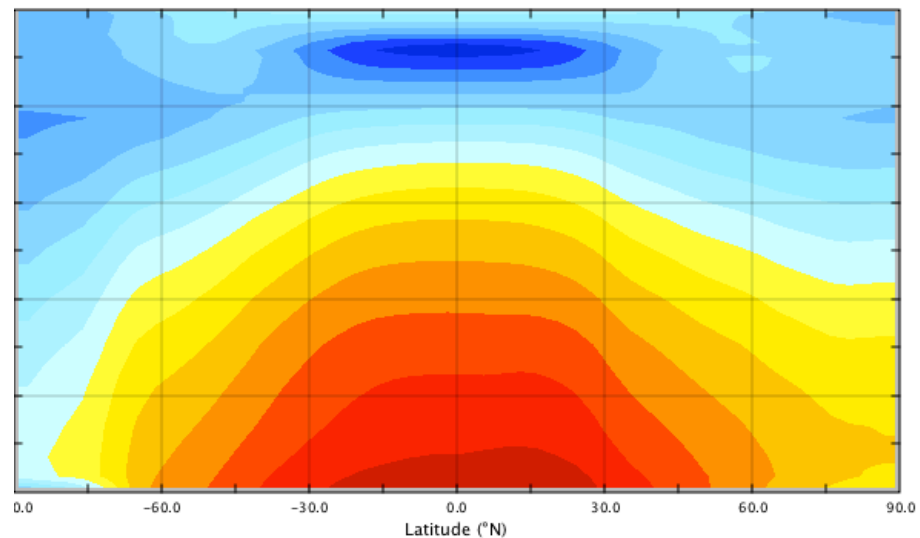


Annual Zonal mean Temperature

PETM (55.8 MY ago)



Present

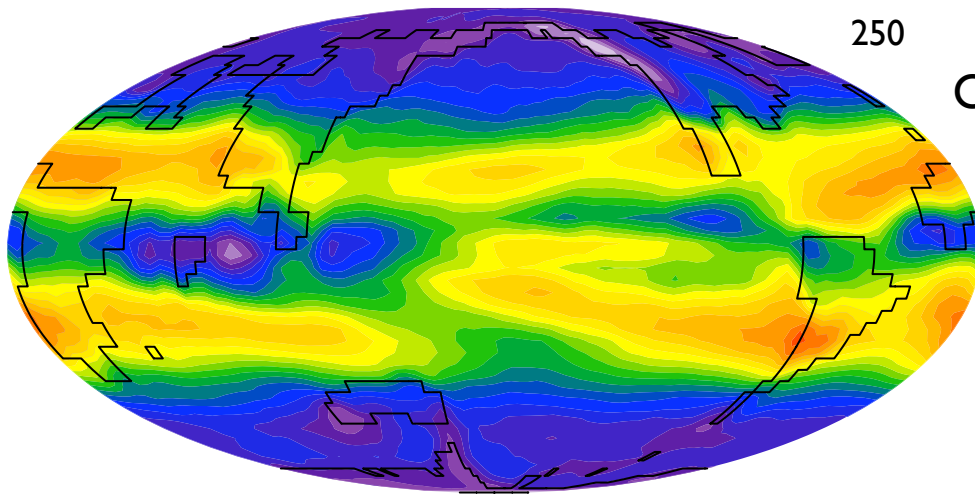


Annual Top-of_Atmosphere Fluxes, W/m^2

- More solar radiation is absorbed in PETM simulation

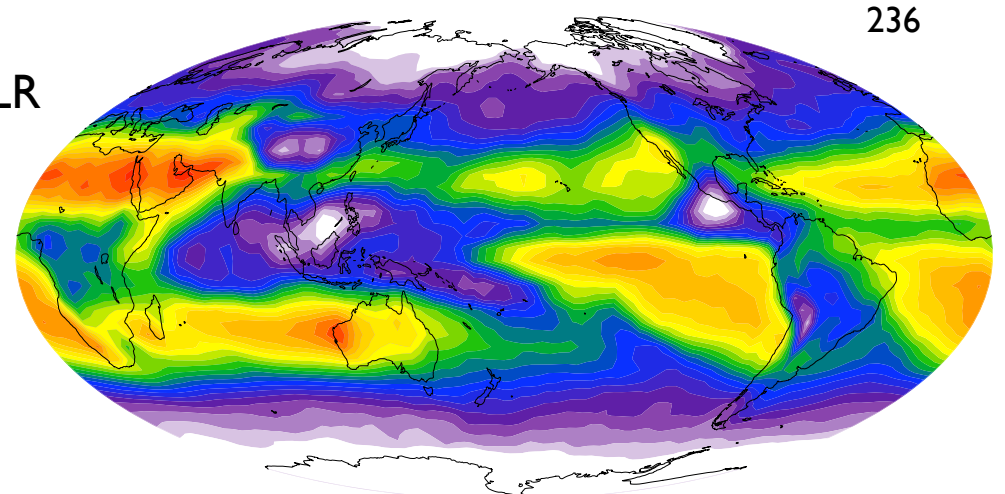
PETM (55.8 MY ago)

Present

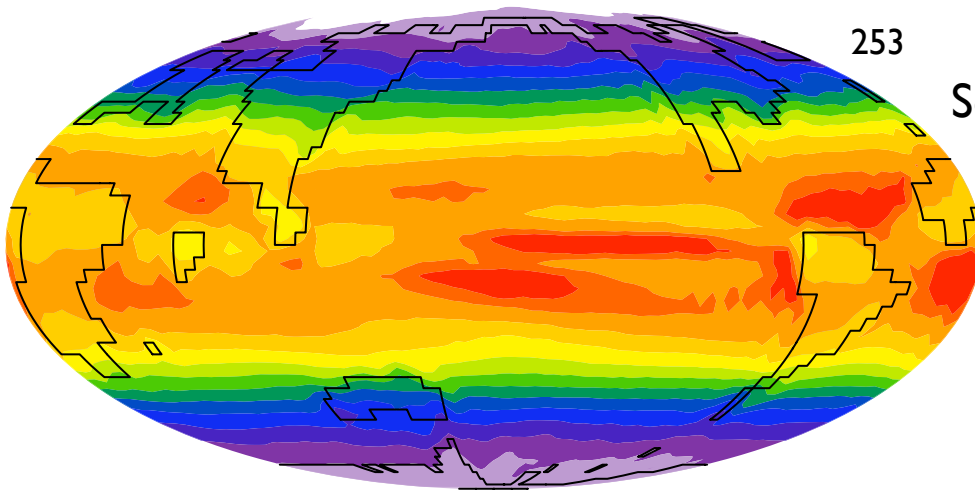
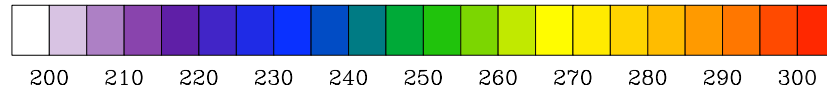


250

OLR

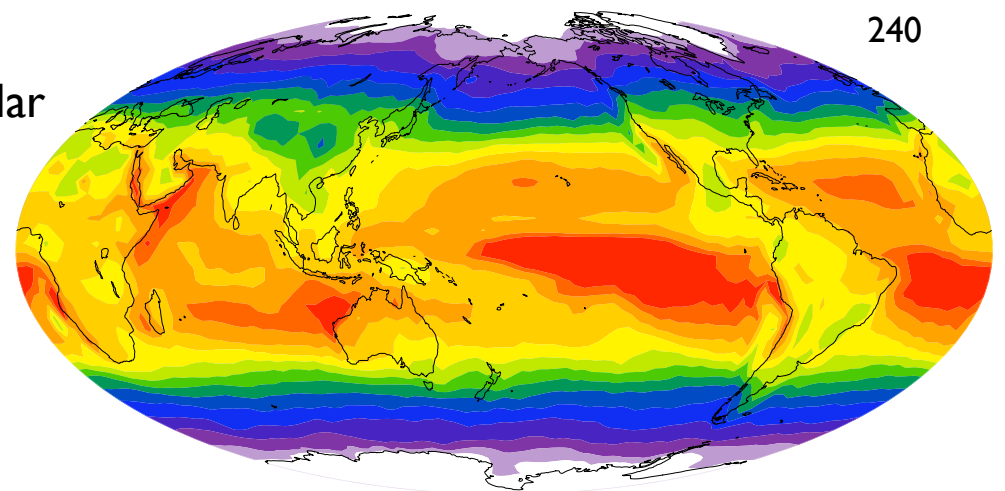


236



253

Solar



240

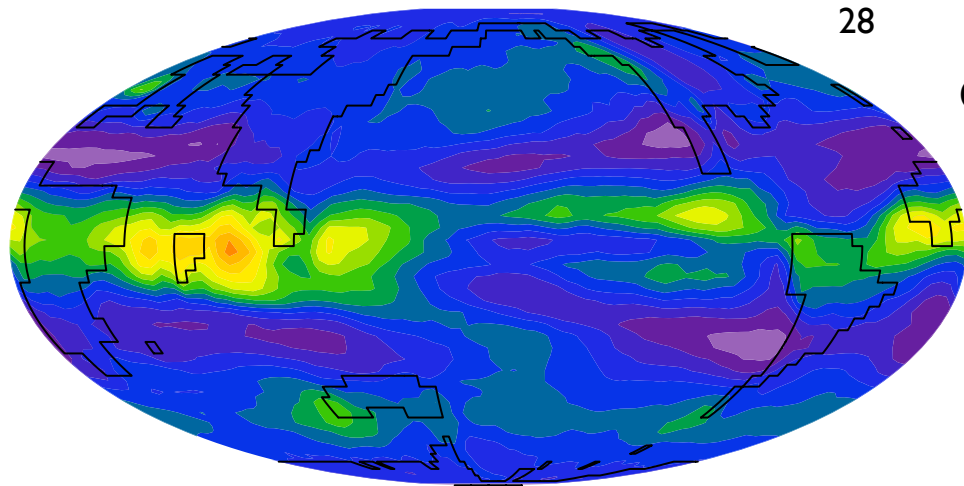


Annual Cloud Forcing, W/m^2

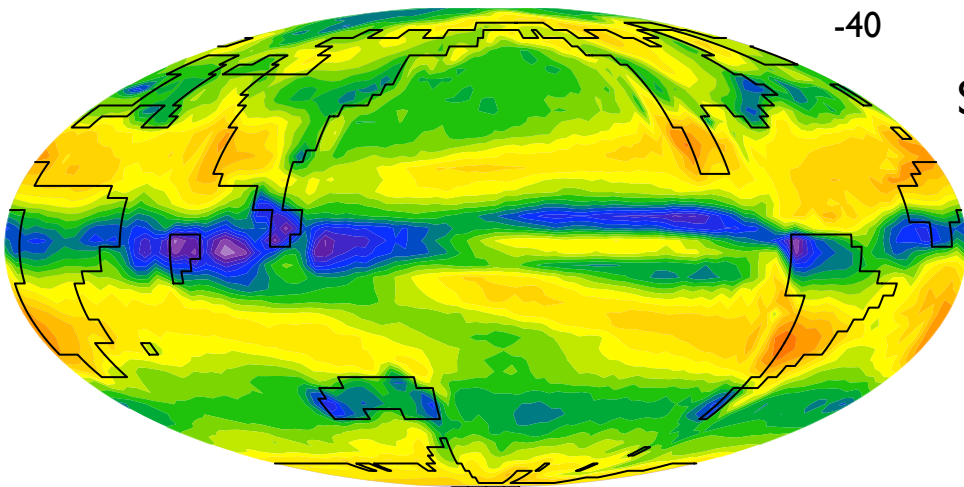
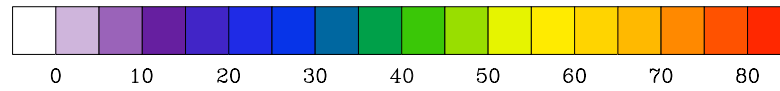
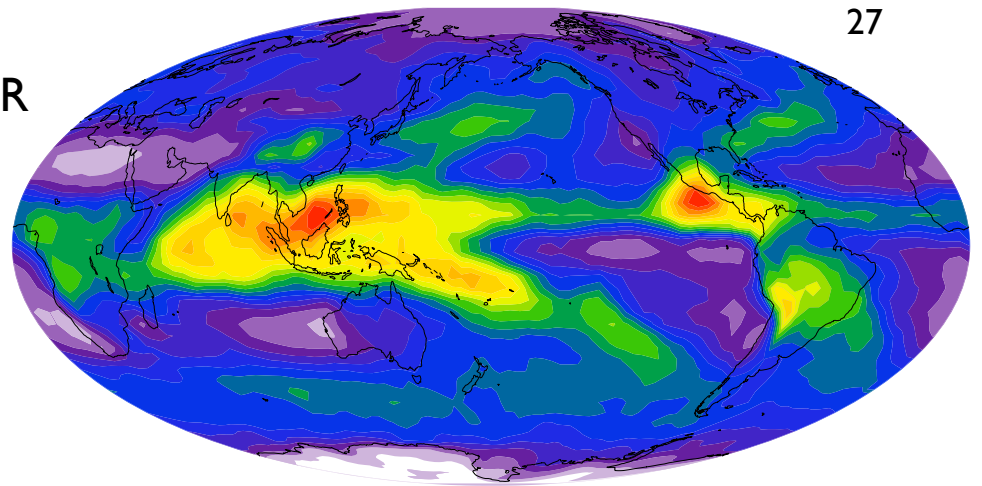
- In PETM, the cooling effect of clouds due to albedo is significantly reduced

PETM (55.8 MY ago)

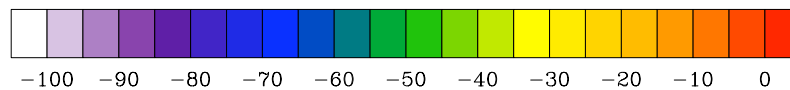
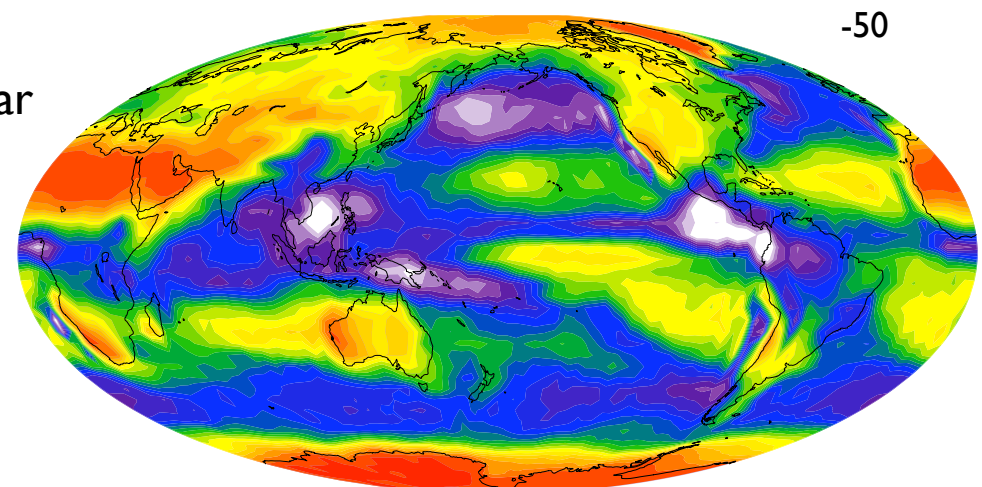
Present



OLR



Solar

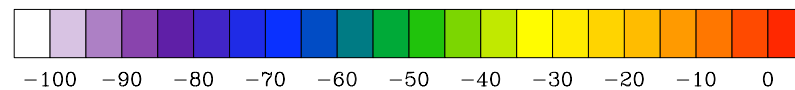
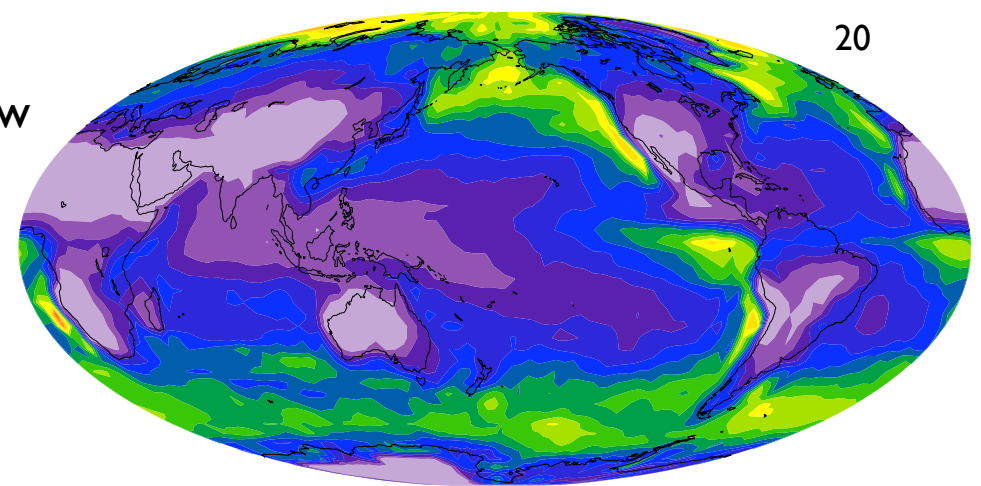
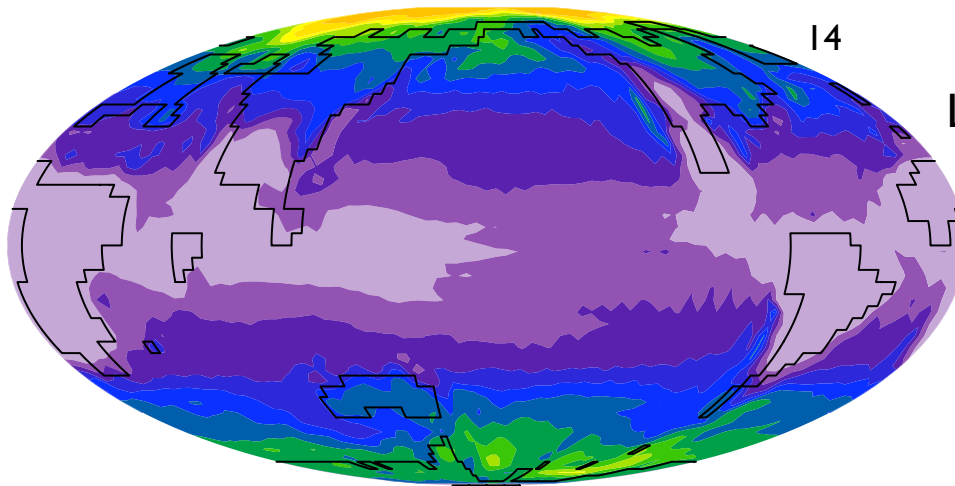
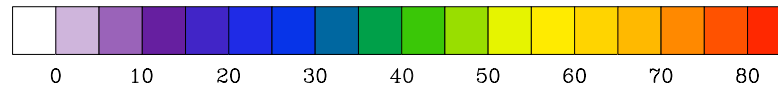
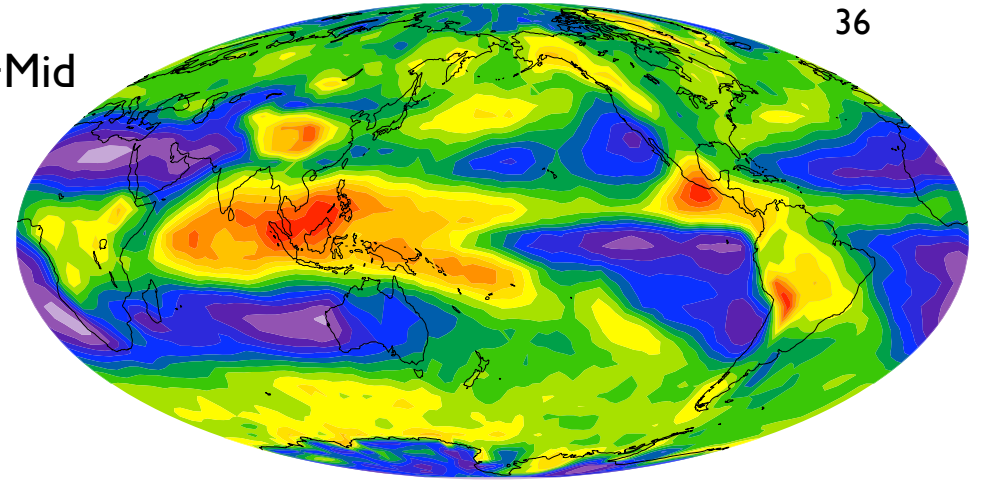
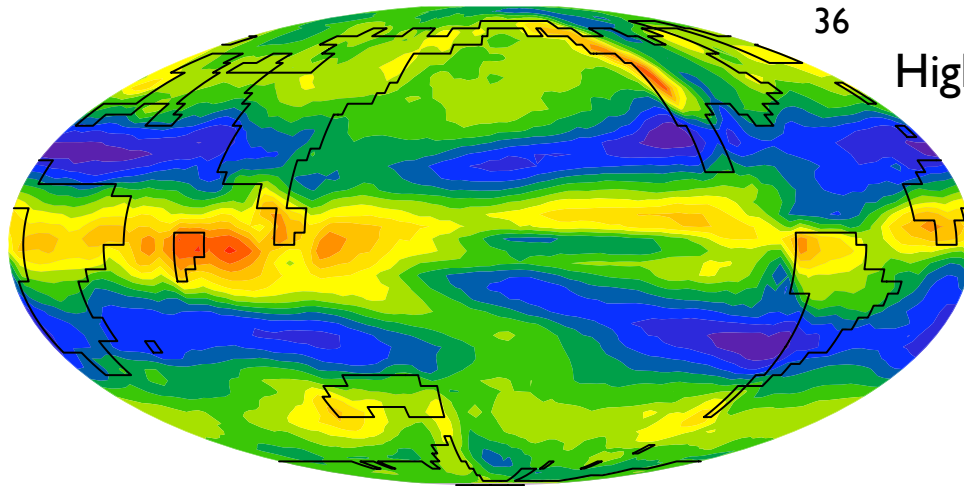


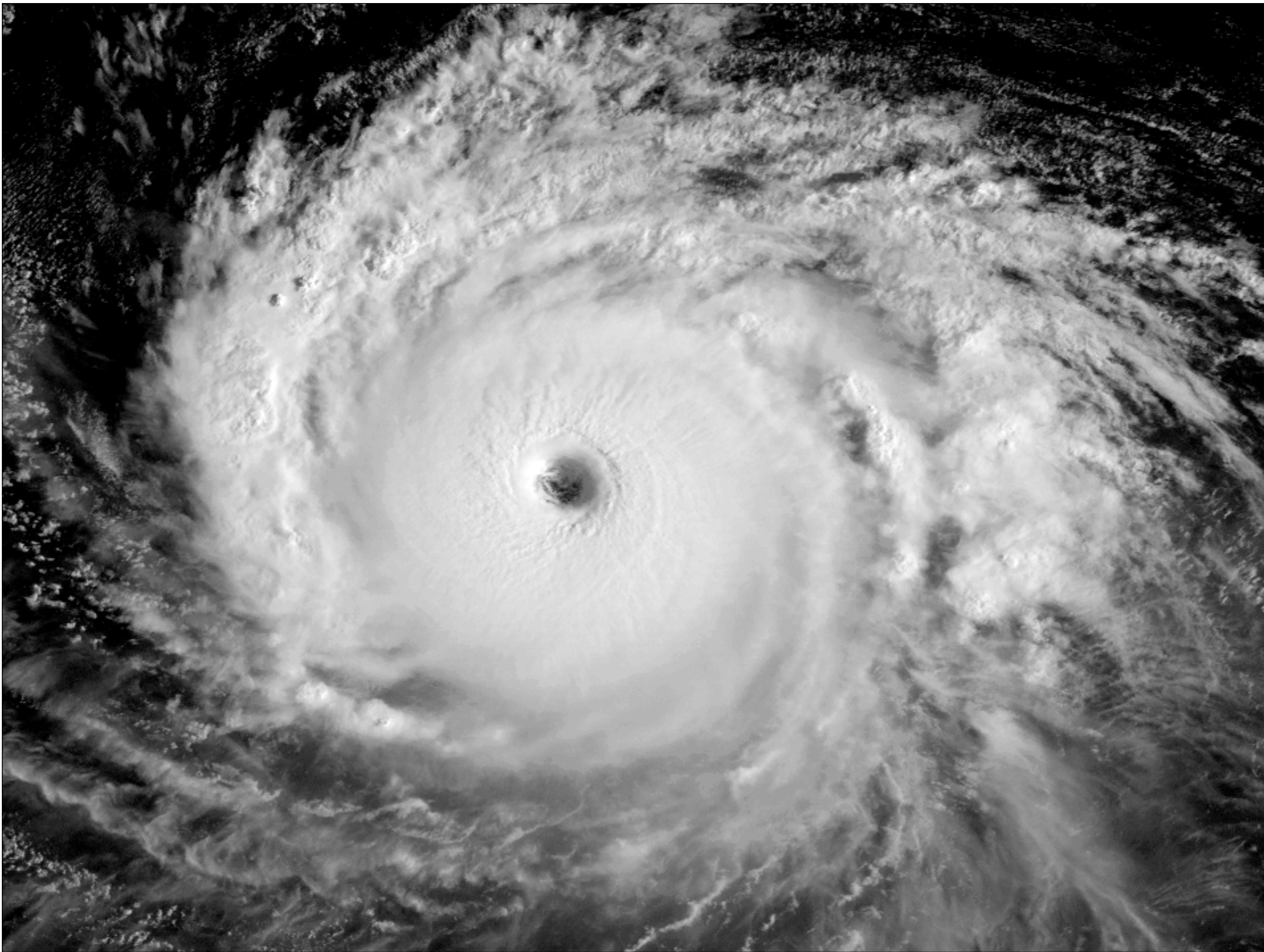
Annual Cloud Cover (ISCCP Sim), W/m^2

- In PETM, the low clouds amount is significantly reduced

PETM (55.8 MY ago)

Present





Maximum Potential Intensity (MPI) Theory

Emanuel (1995), Bister and Emanuel (1998)

upper bound on tropical cyclone wind speed:
$$V_m = \sqrt{\frac{c_k T_s}{c_d T_o} (CAPE_m^* - CAPE_m)}$$

T_s - Sea-surface temperature

T_o - Mean outflow temperature (close to tropopause temperature)

$c_k c_d$ - bulk surface exchange coefficients for heat and momentum

$CAPE_m$ - convective available potential energy of boundary layer air at the radius of maximum wind

$CAPE_m^*$ - convective available potential energy of surface saturated air at the radius of maximum wind

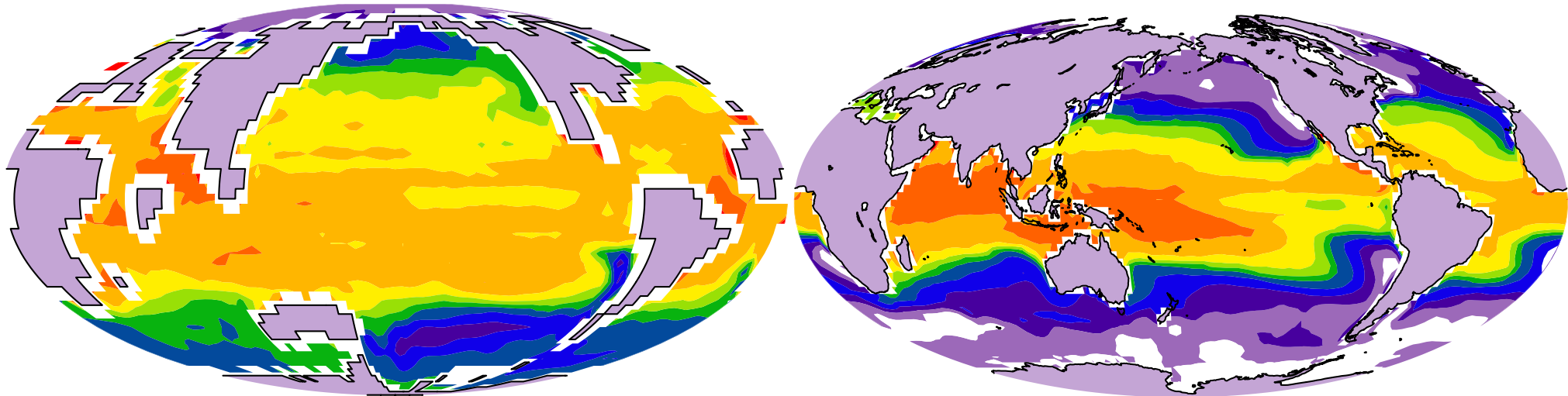
Maximum Monthly Emanuel's Potential Intensity (MPI), m/s

Theoretical estimate of the maximum sustained wind in a developed hurricane

Computed from SP-CAM monthly climatology

PETM (55 MY ago)

Present

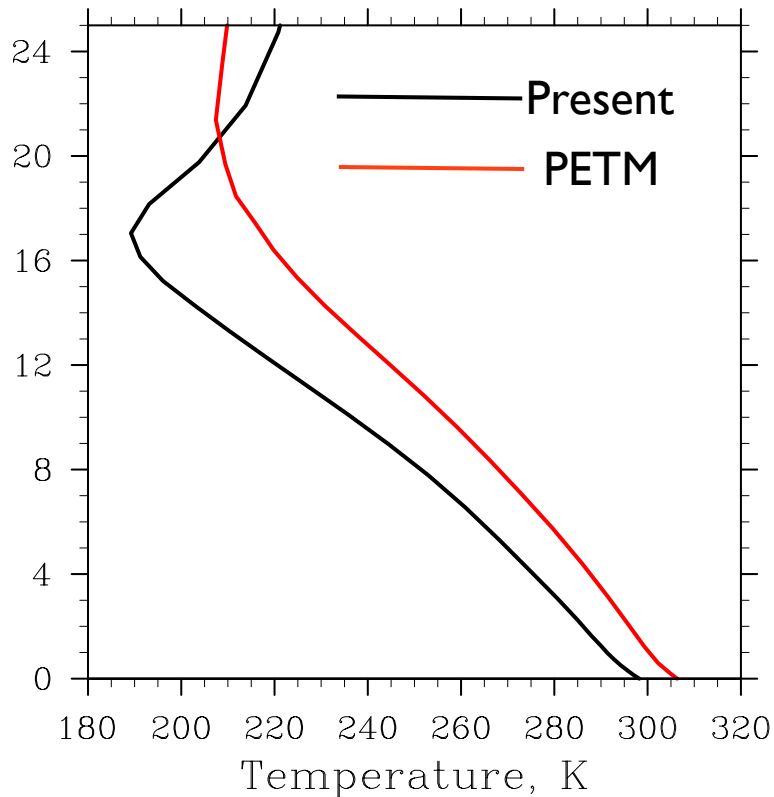


10 20 30 40 50 60 70 80 90 100

m/s

Despite much warmer tropical SSTs (by 10°C!), hurricanes during PETM were probably not stronger than today's hurricanes; maybe even slightly weaker!

Composite mean profiles of temperature simulated by the SP-CAM at the TC genesis regions in Tropics



- In PETM, the tropopause warms up more than twice as much as the surface;
- This tends to reduce efficiency of TCs, and, hence, reduce MPI.
- However, this could be an artifact of coarse model resolution of upper troposphere and low stratosphere;
- Higher vertical-resolution simulations should and will be performed.

Tropical Cyclone Genesis Potential Index (GPI)

Emanuel and Nolan (2004), Camargo et al. (2007)

$$GPI = \left| 10^5 \eta \right|^{3/2} \left[\frac{RH_{700}}{50} \right]^3 \left[\frac{MPI}{70} \right]^3 \left[\frac{1}{1 + 0.1 \left| \vec{V}_{850} - \vec{V}_{200} \right|} \right]^2$$

η - absolute vorticity (1/s) at 850 mb

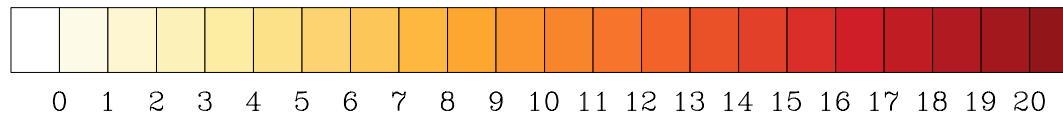
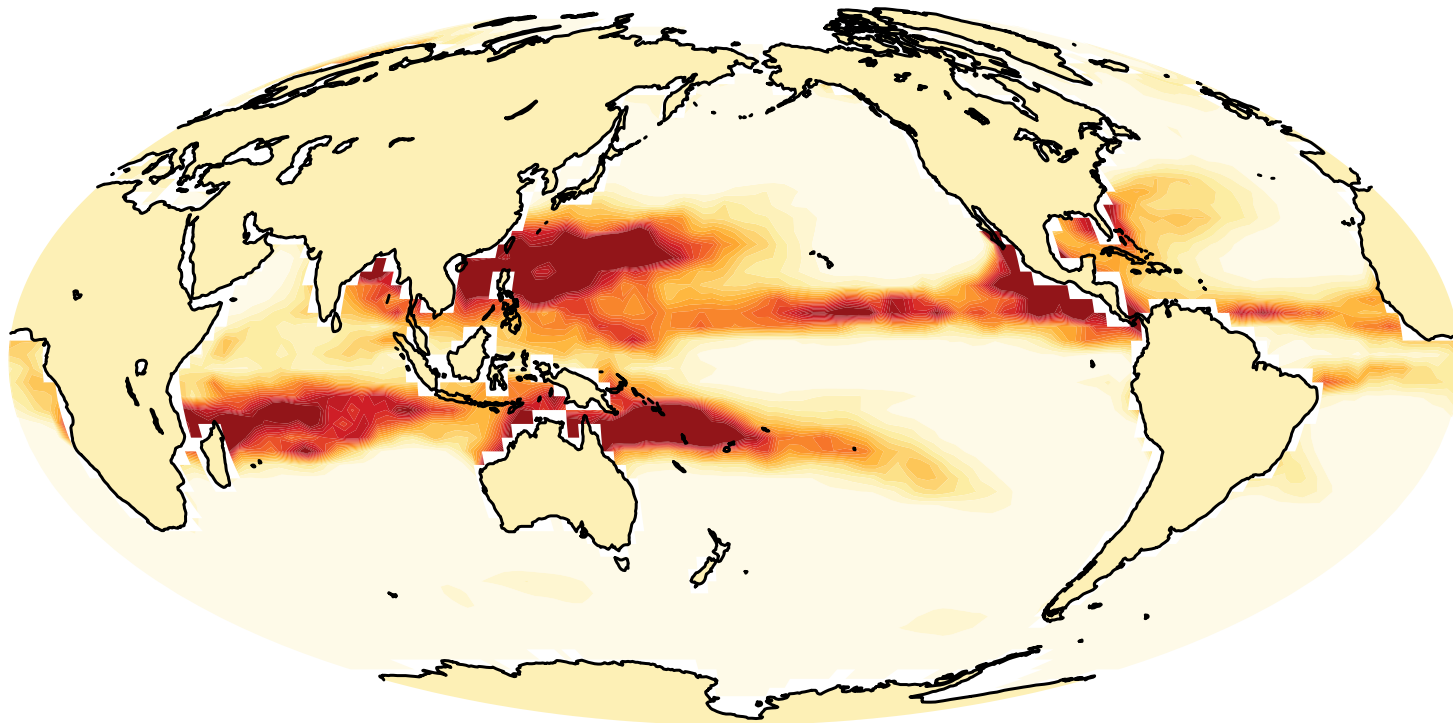
RH_{700} - Relative humidity (%) at 700 mb

MPI - Maximum Potential intensity (m/s)

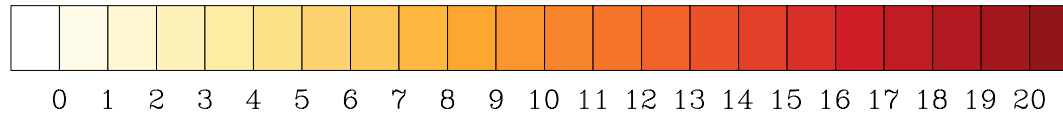
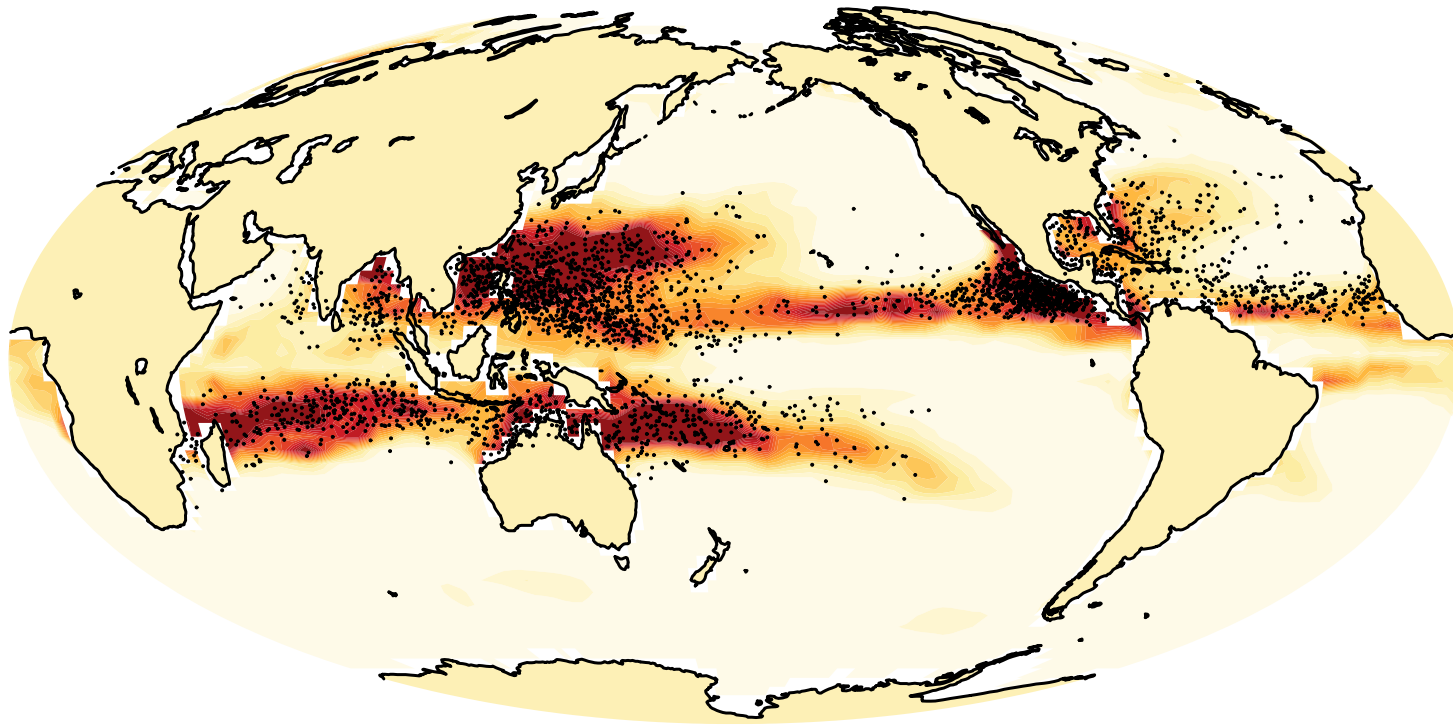
$\left| \vec{V}_{850} - \vec{V}_{200} \right|$ - wind shear between 850 and 200 mb

Maximum Monthly TC Genesis Potential Index based on SP-CAM monthly climatology

Present



Maximum Monthly TC Genesis Potential Index
based on SP-CAM monthly climatology
and observed TC/TS genesis locations from the BestTrack dataset
for 1970-2010

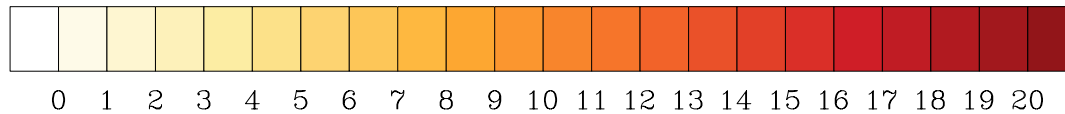
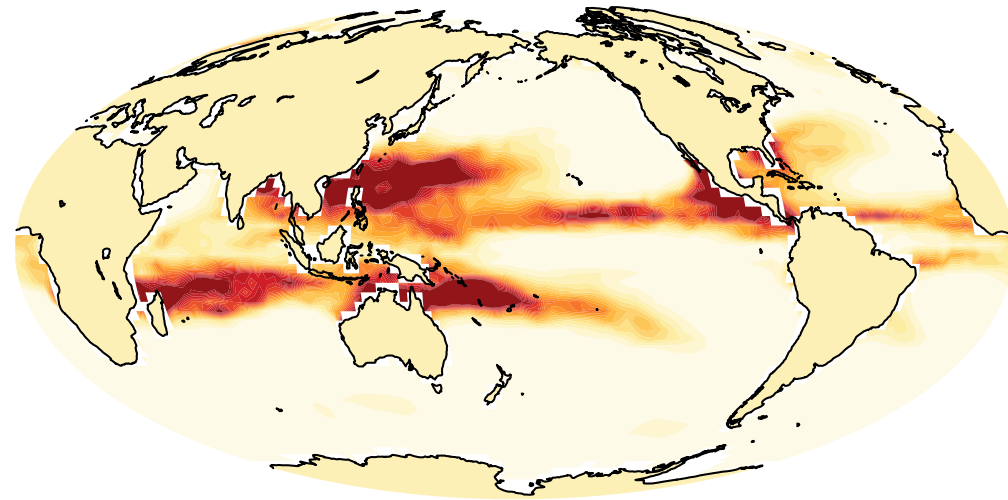
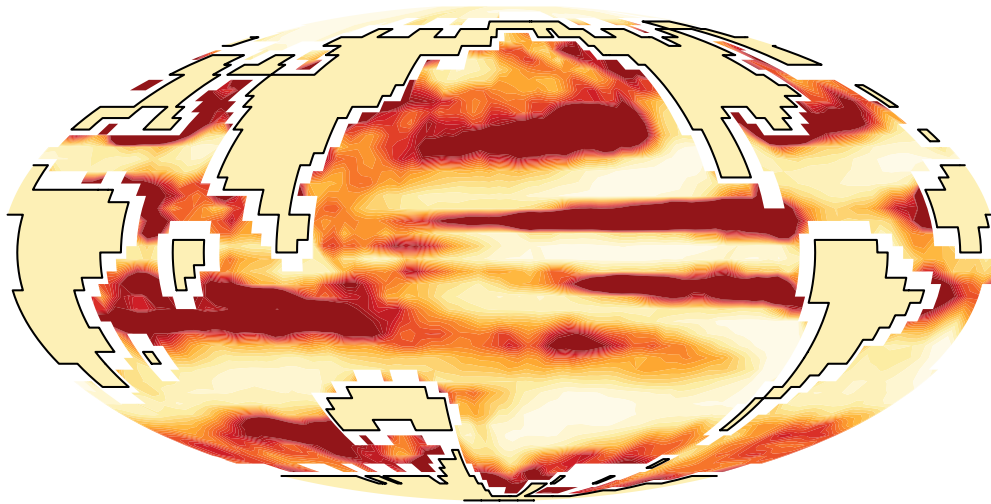


Maximum Monthly TC Genesis Potential Index based on SP-CAM monthly climatology

There is active subtropical cyclogenesis in the PETM!

PETM (55 MY ago)

Present

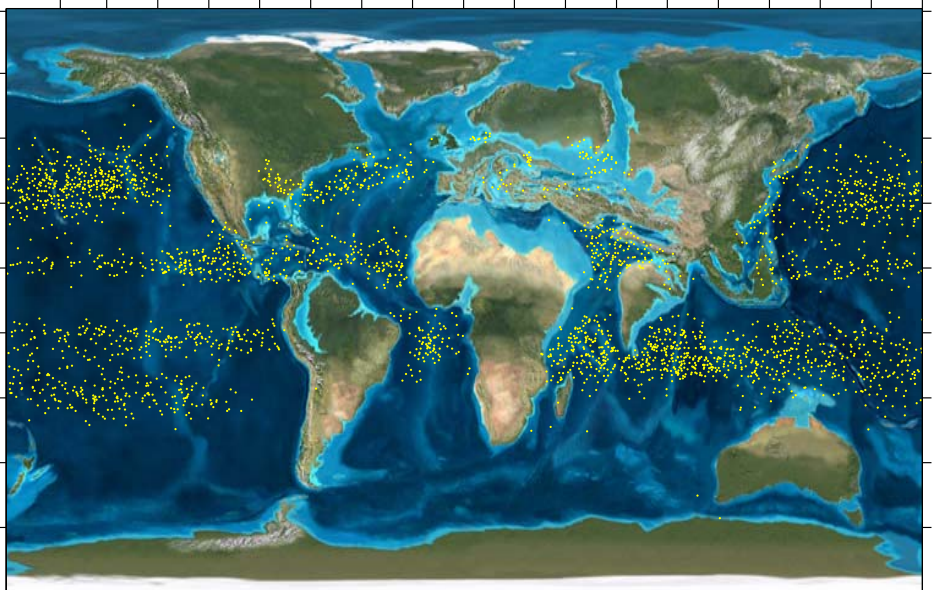


Kerry Emanuel's Downscaled Hurricane Climatology

TC genesis positions (independent from GPI)

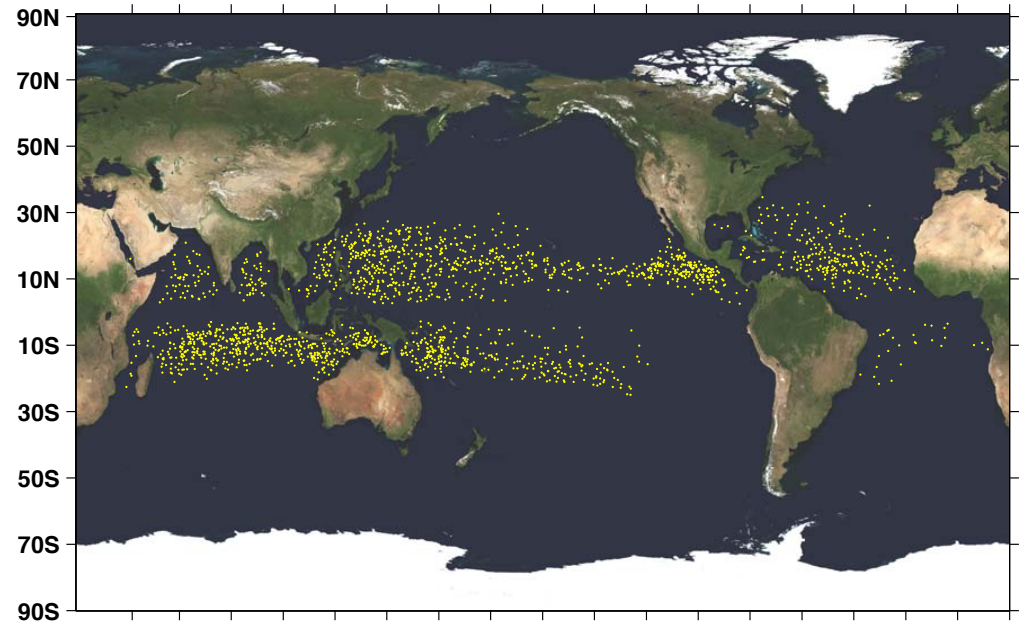
based on SP-CAM monthly climatology

Genesis points, PETM

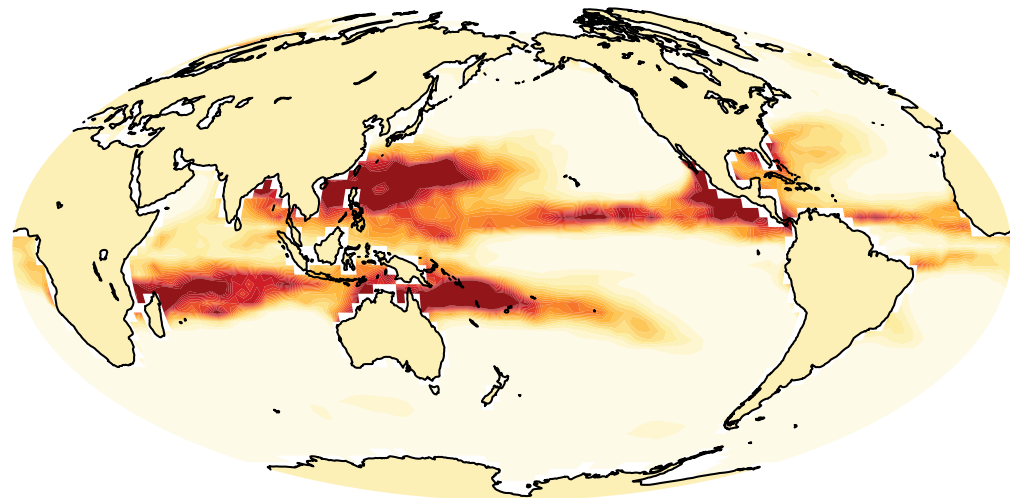
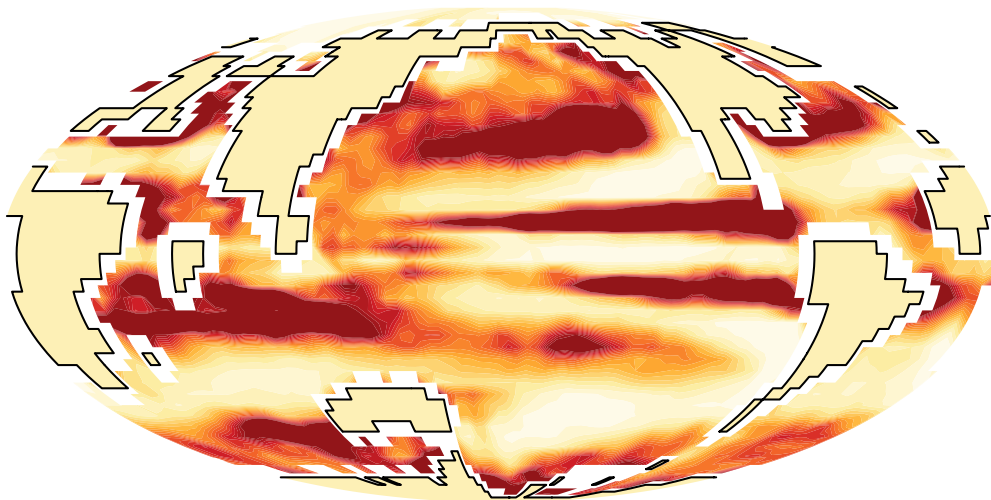


160W 40W 20W 00W 80W 60W 40W 20W 0E 20E 40E 60E 80E 100E 120E 140E 160E 180

Genesis points, Control



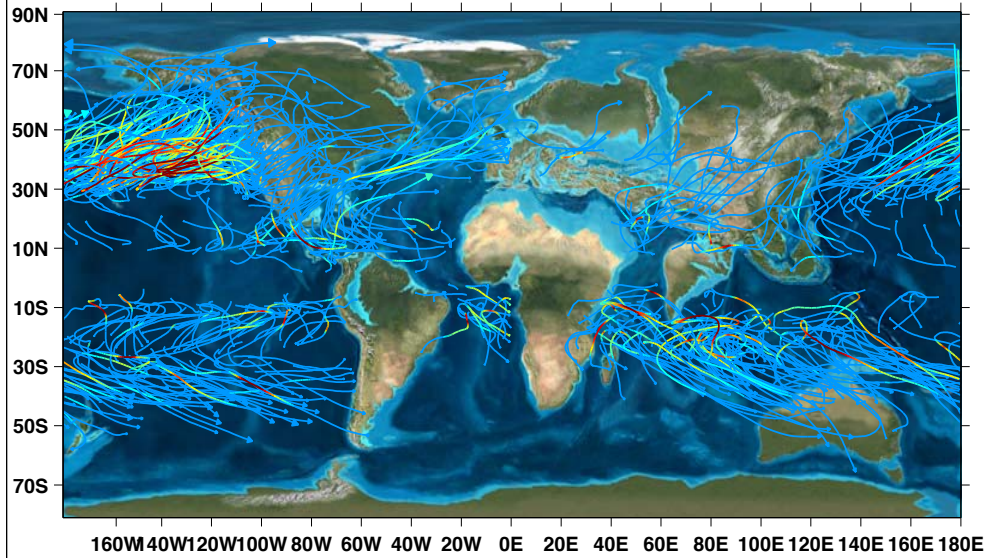
90N 70N 50N 30N 10N 10S 30S 50S 70S 90S
40E 60E 80E 100E 120E 140E 160E 180E 160W 40W 20W 00W 80W 60W 40W 20W 0E 20E



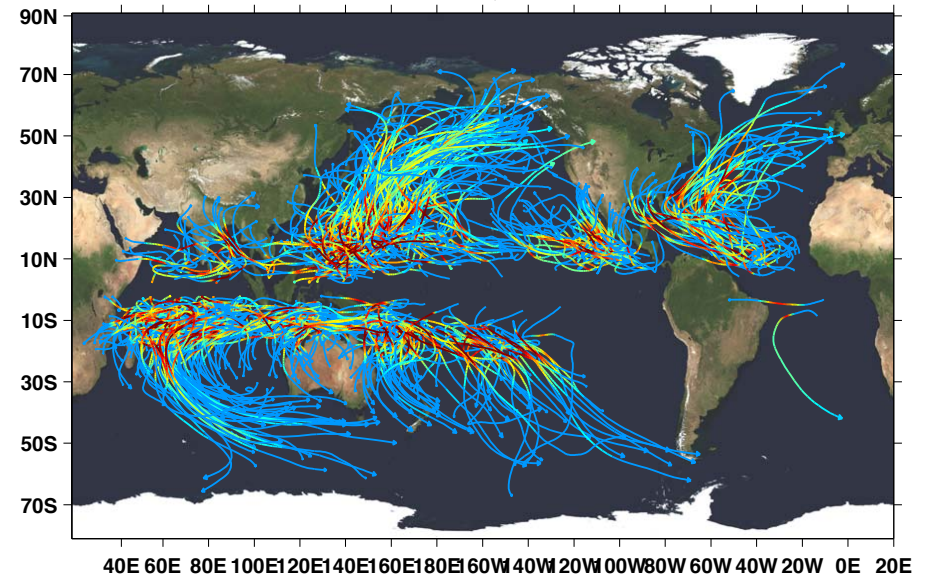
Kerry Emanuel's Downscaled Hurricane Climatology

TC possible tracks

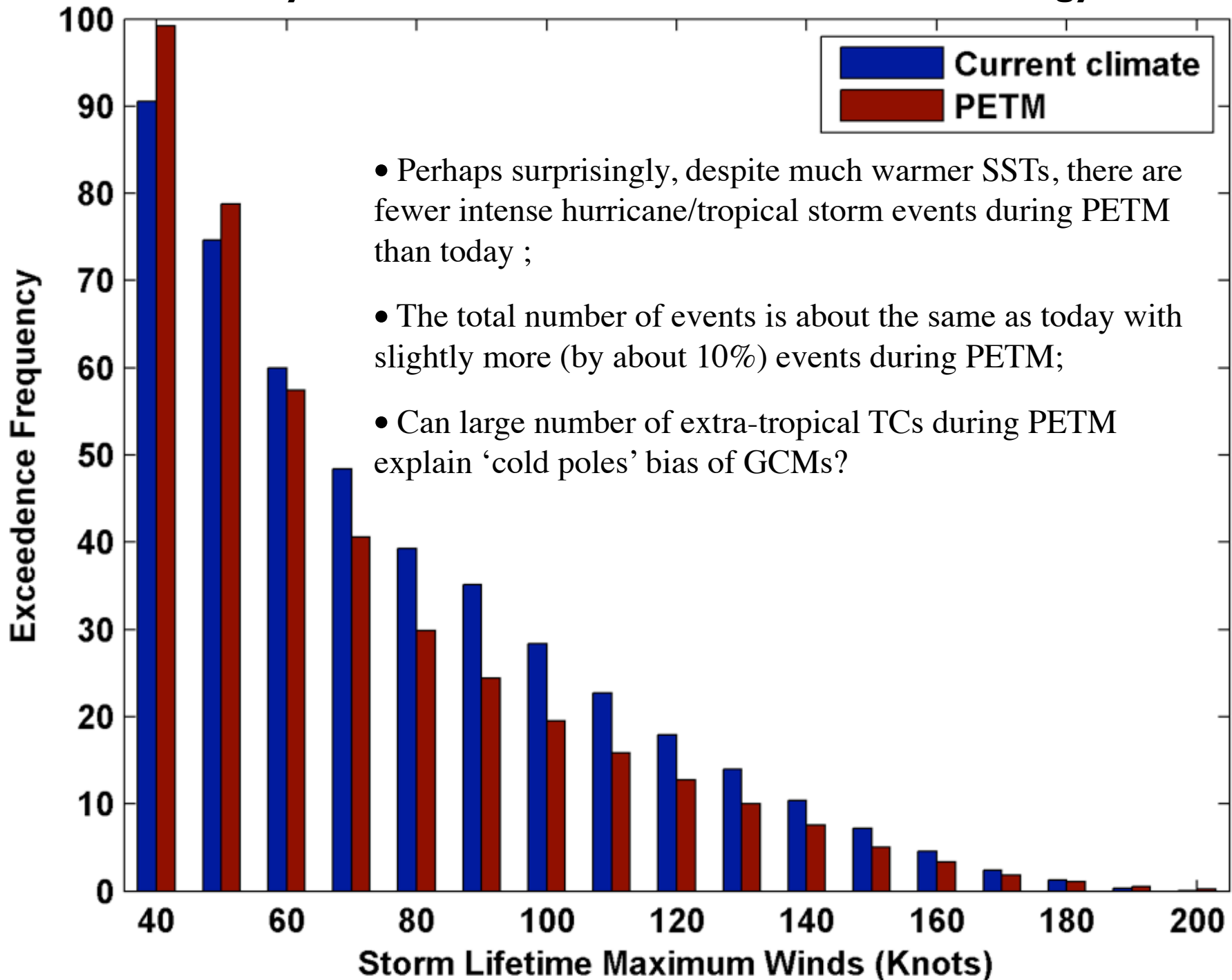
500 PETM tracks



500 tracks, Control

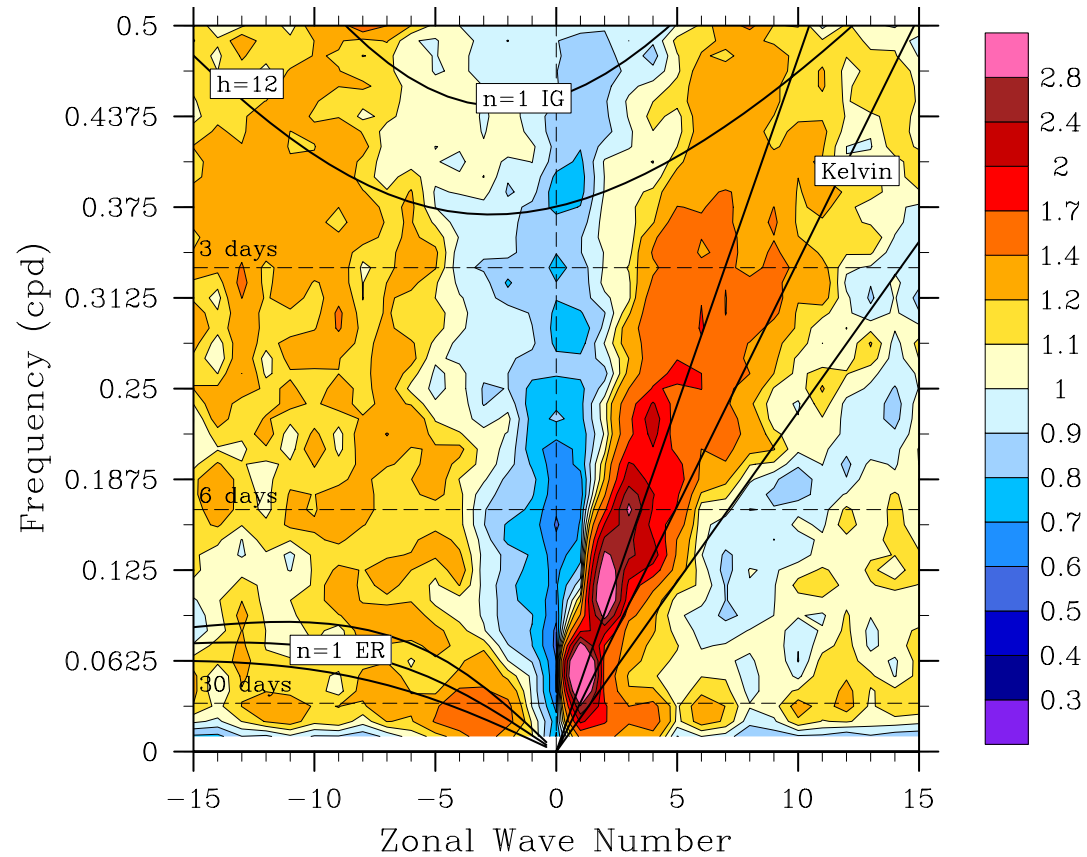


Kerry Emanuel's Downscaled Hurricane Climatology



Intraseasonal variability during PETM

Preliminary look



- Twice as fast Kelvin waves and MJO?