High-Resolution CESM Simulations of Tropical Cyclones

Past – Present – Future

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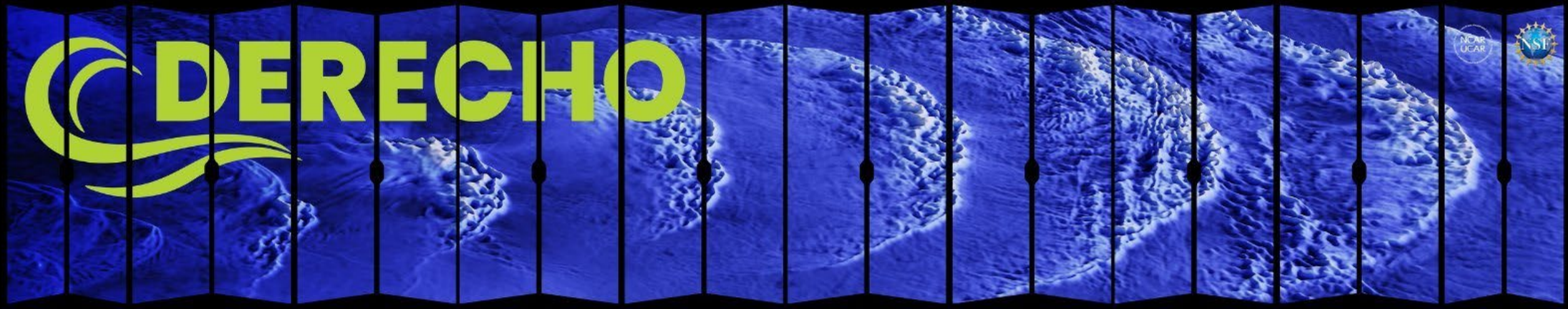
Accelerated Scientific Discovery Project

Extreme Weather Events
Under a Wide Range of Climates in High-Resolution Coupled CESM

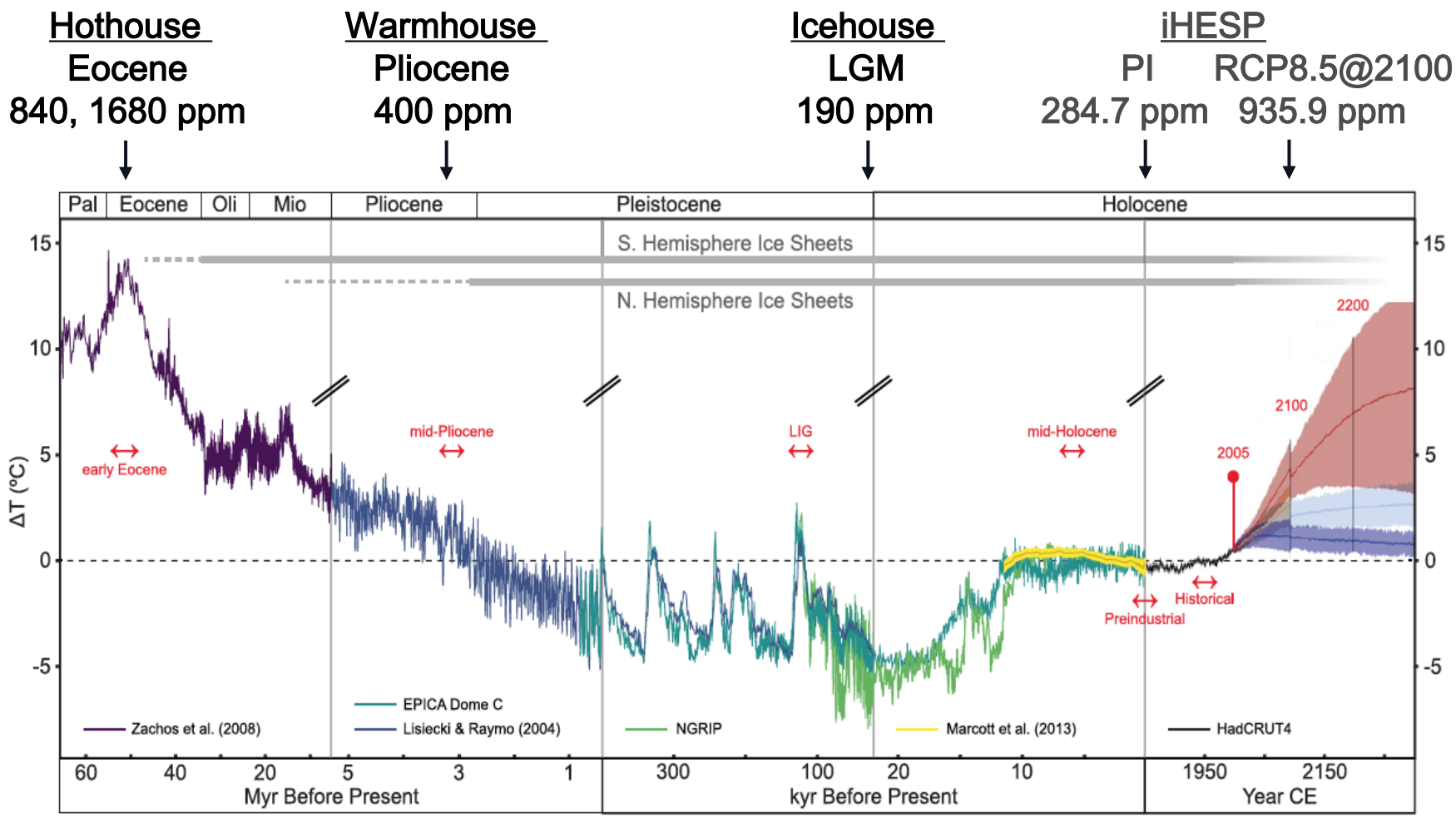


NCAR - Bette Otto-Bliesner, Jiang Zhu, Esther Brady, CJ Sun, Jesse Nusbaumer

UArizona - Jessica Tierney & Andrew Walters

UConnecticut – Ran Feng & Clay Tabor

Setting the Stage



Evolution of temperature for the past 65 Ma and the future.
Adapted from Burke et al., 2018.

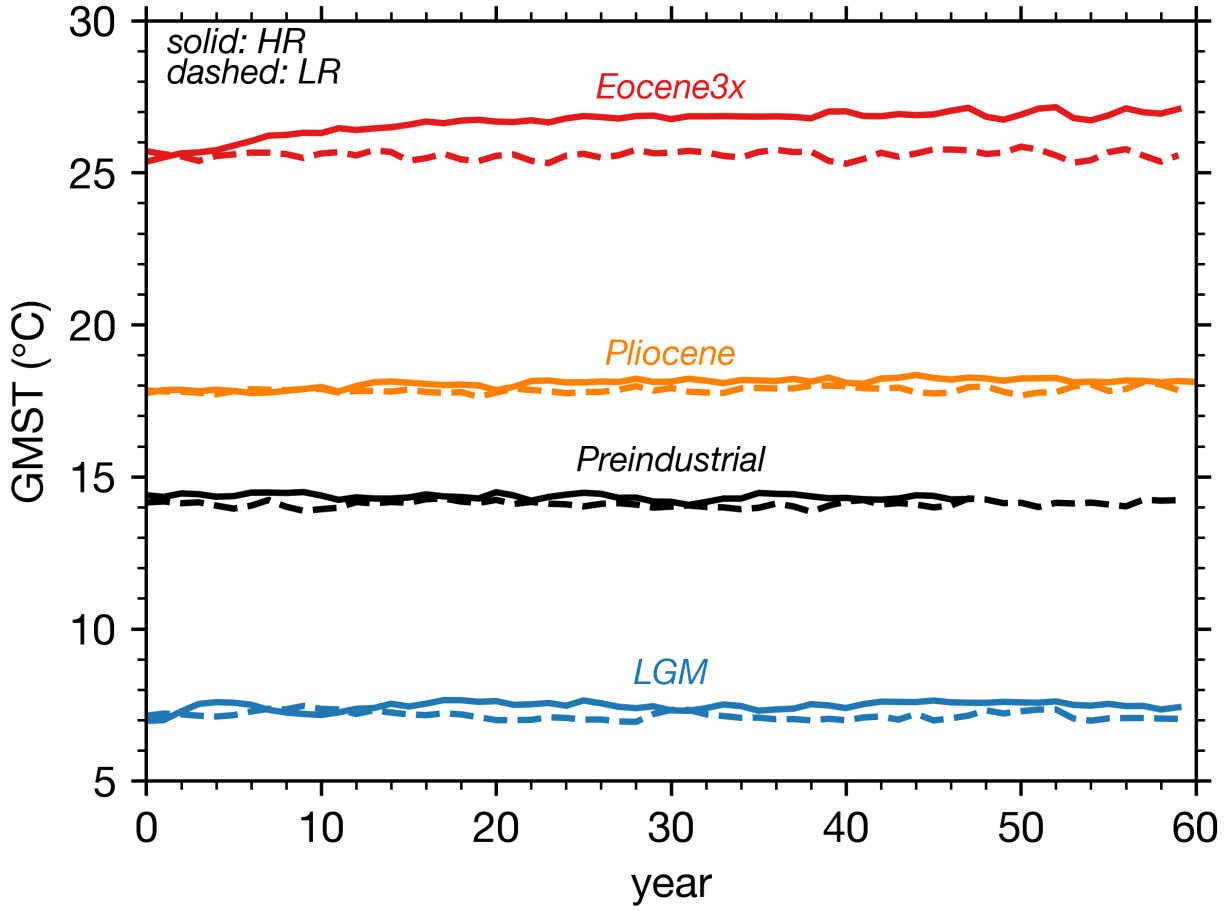
Experimental Setup

Model Configuration:

- **iHESP HR code with CESM1.3 ***
  - 0.25° atmos & land
  - 0.1° ocean & sea ice
  - Multi-century PI, 1920-2015, RCP8.5 to 2100
- **Water isotope capability**
- **Ocean grid**
  - LGM and Pliocene: same horizontal grid as PI. Eocene KMT required shifting the two north poles to satisfy the CFL condition.
  - Paleogeographies from the PMIP4, PlioMIP2, and DeepMIP protocols.
- **HR simulations start from spunup LR simulations**

** Chang et al., JAMES, 2020*

Time Series: GMST



Detection, Attribution & Analysis Framework

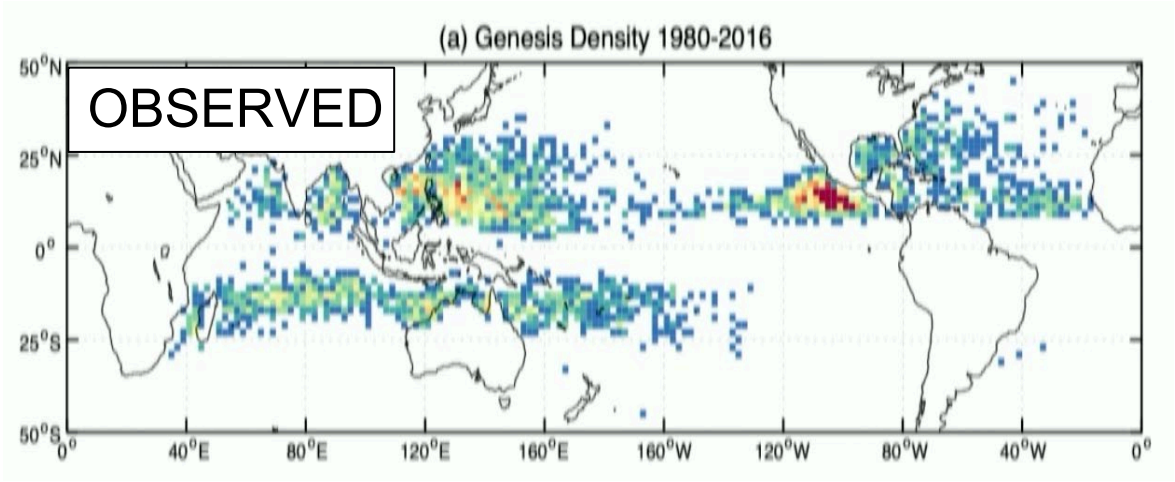
Analysis of 30 years 6 -hourly instantaneous output

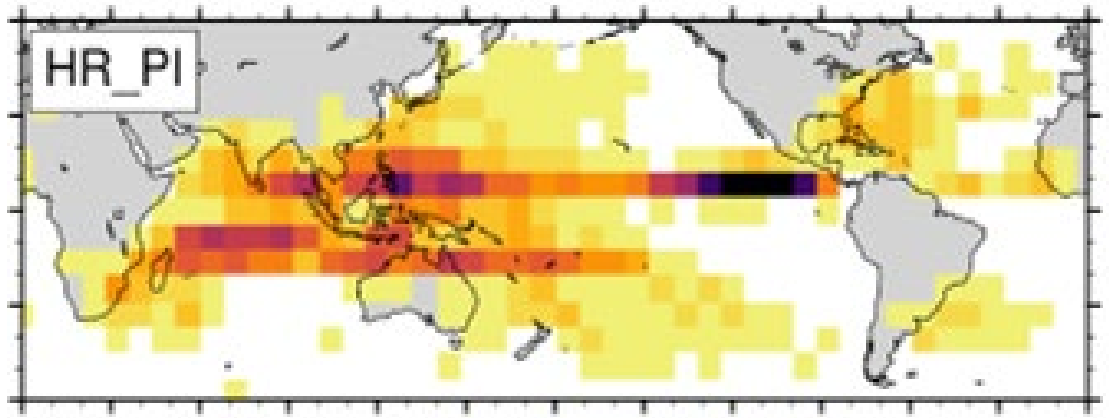
- ASD simulations: after spinup to ~equilibrium of GMST
- RCP 8.5: years 2066-2095

- **TempestExtremes v2.1**
  - Ullrich, et al., GMD 2021
  - DetectNodes
    - Input: 6_hrly instantaneous (PSL, Z250, Z500, U10, PHIS
    - Criteria: Closed contours* around PSL low, with attached geopotential height anomaly (i.,e.,upper level warm core)
    - Output: list of located nodes (PSL, max(U10) within 2 °
  - StitchNodes
    - Input: output Nodes file
    - Builds tracks with criteria: persistence > 54h,
    - Output: trajectory file

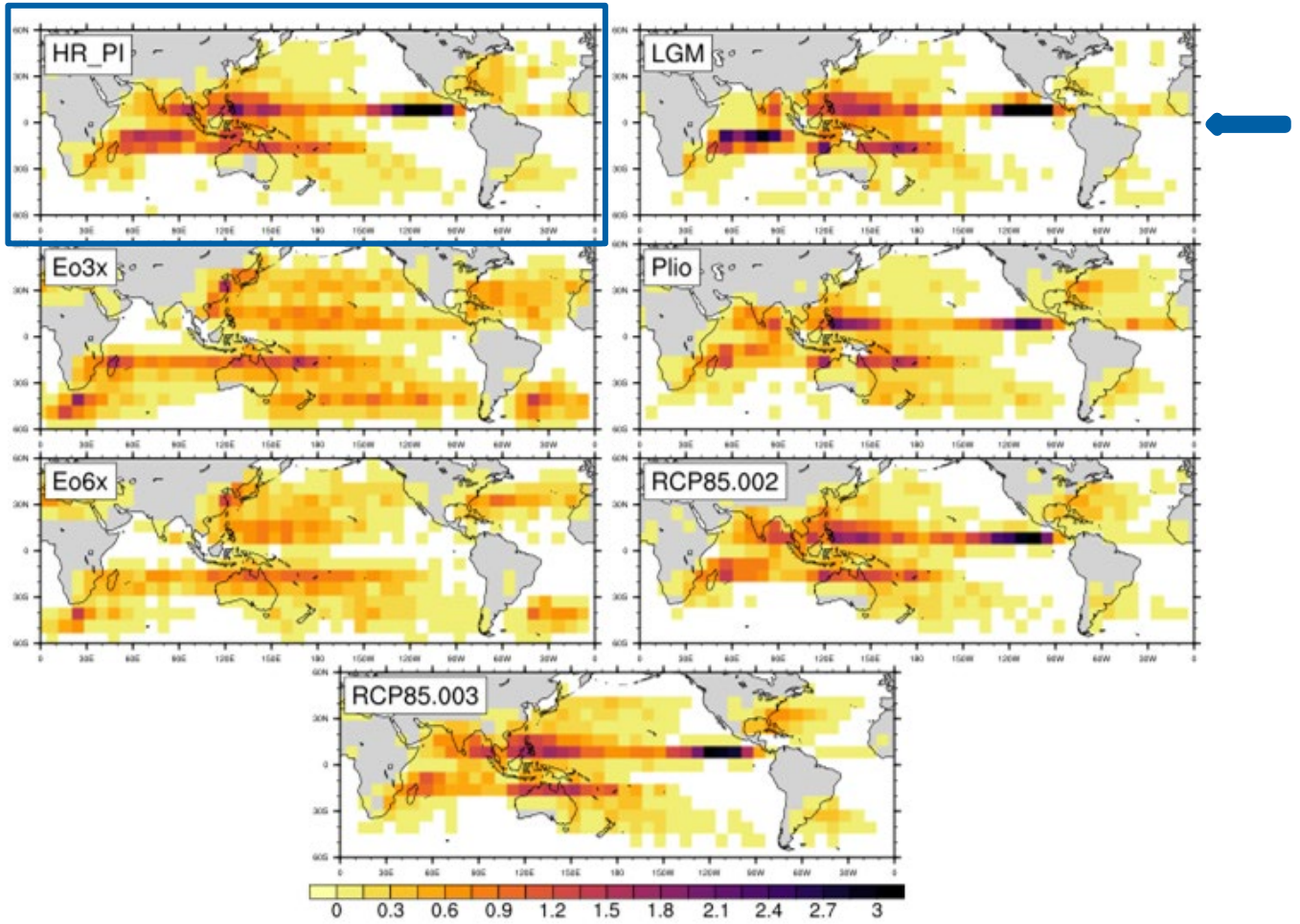
- **CMePs**
  - Zarzycki , et al., JAMC 2021
  - Input: Trajectory file from TempestExtremes
  - Metrics:
    - TCD (storm durations)
    - Storm genesis locations
    - Gridded Minimum PSL, Maximum U10
    - Accumulated Cyclone Energy (f(U10*U10))
    - Statistical comparisons to Reference case
    - Plots (lat-lon gridded metrics, seasonal and interannual timeseries)

Storm Genesis Density Observed vs HR Preindustrial



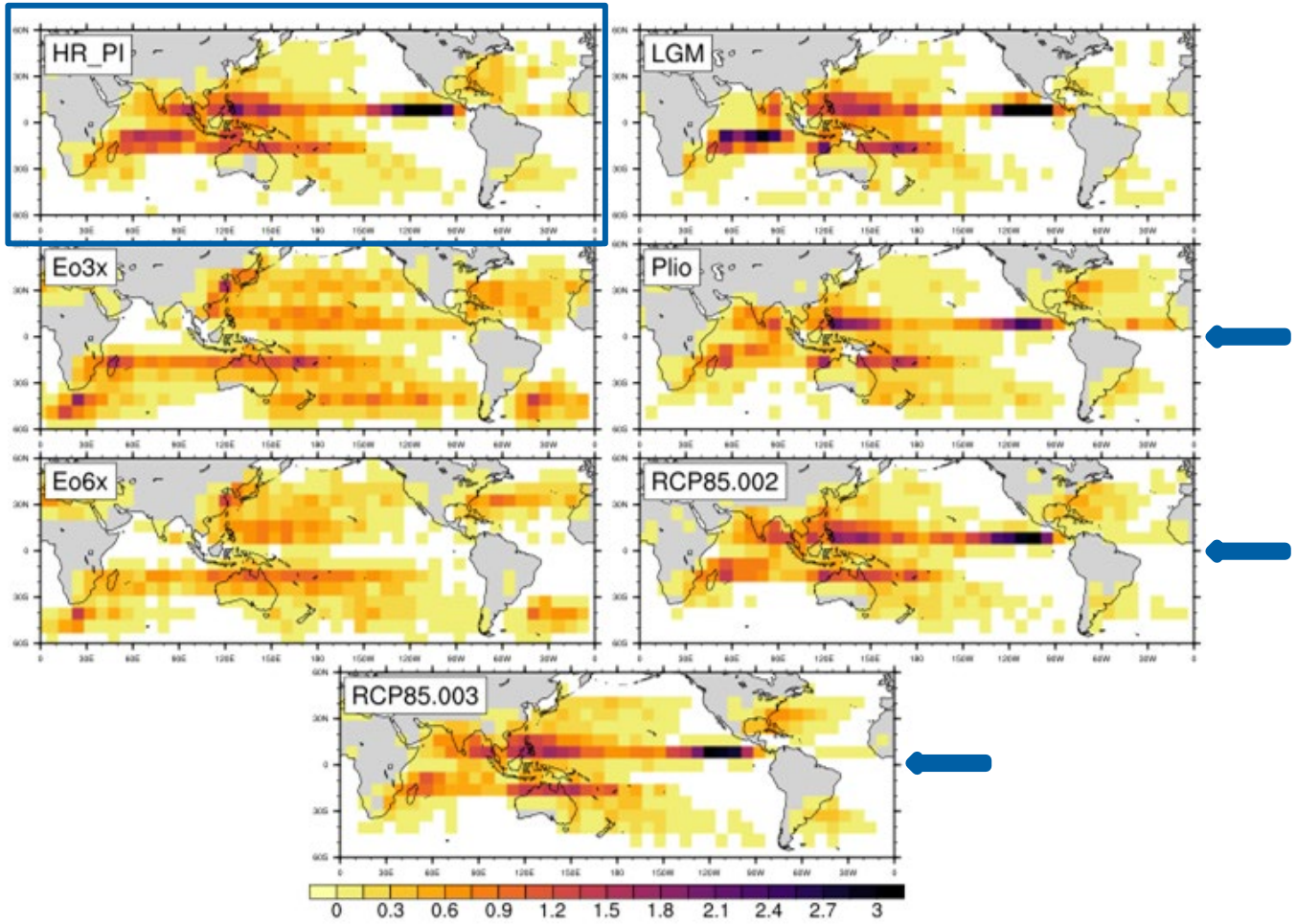


Genesis Density Past – Present – Future



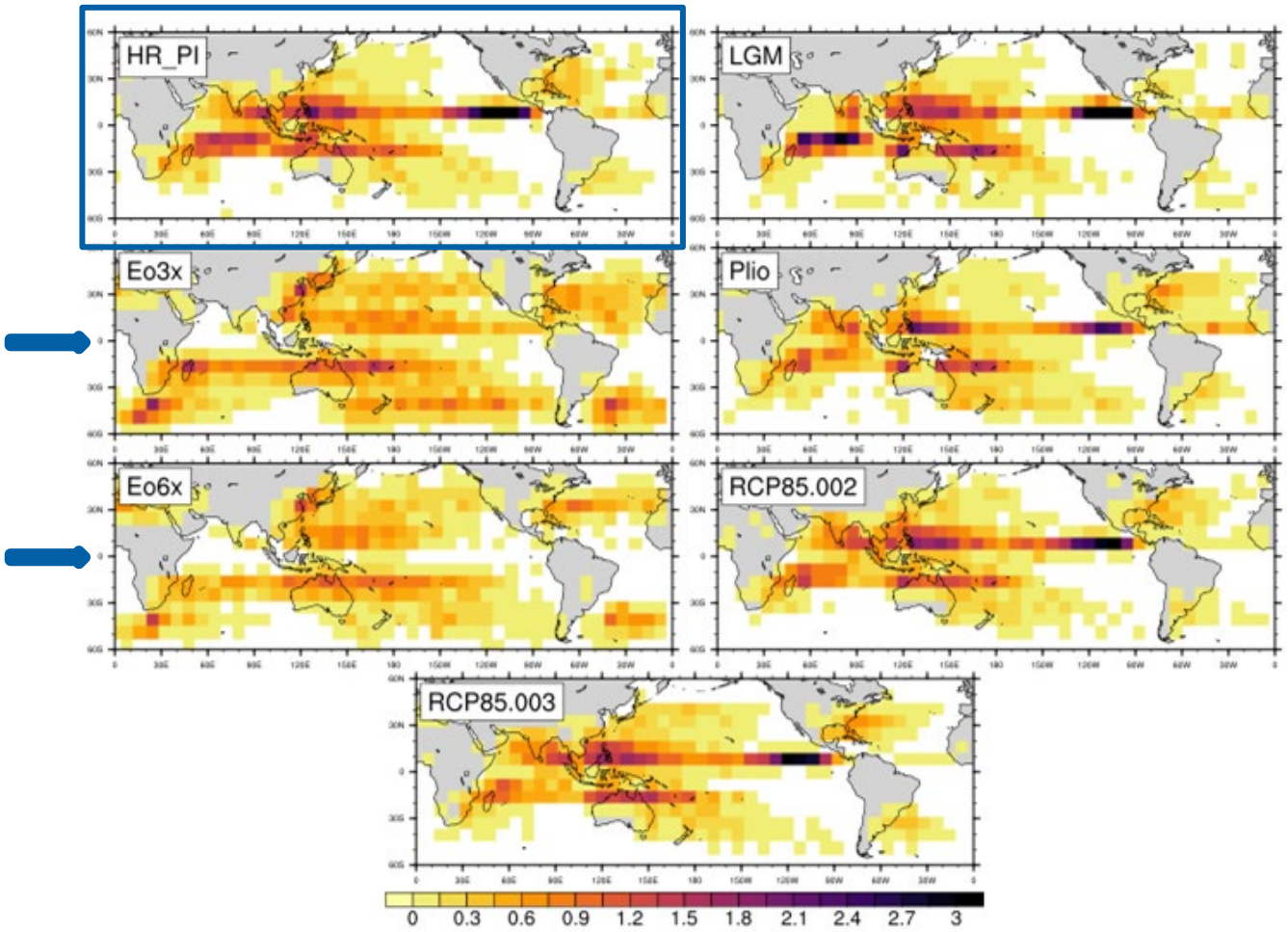
- LGM
  - Decreased in North Atlantic
  - Broadly similar in other basins

Genesis Density Past – Present – Future



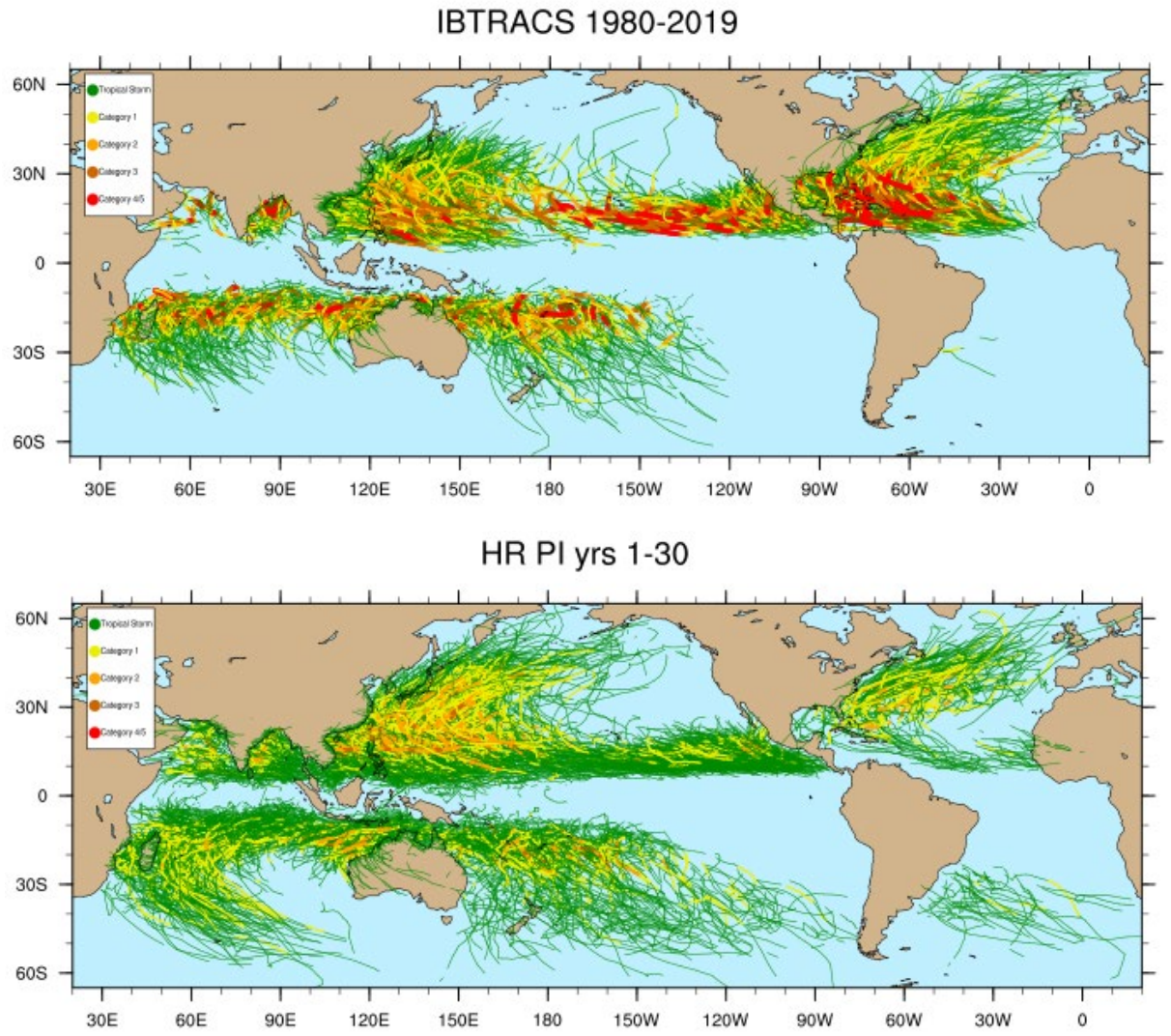
- Pliocene and RCP8.5
  - Increased in North Atlantic
  - Decreased in eastern Pacific and south Indian Ocean

Genesis Density Past – Present – Future



- Eocene
  - Increased in North Atlantic, though restricted in low lats in 6x
  - Increased in South Atlantic
  - Poleward expansion at mid and high lats in NH and SH
  - Increased in eastern Pacific off North and South America

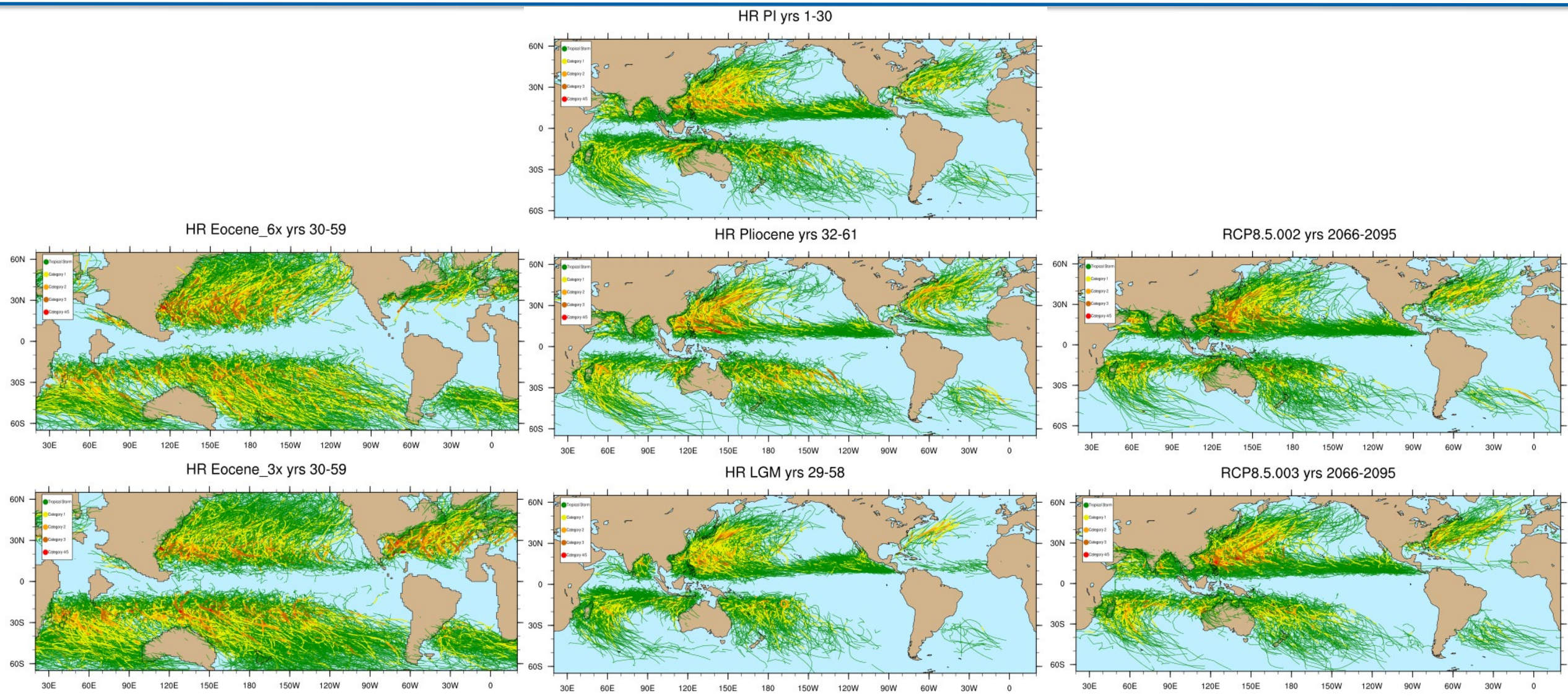
Tropical Cyclone (TC) Tracks – Observed vs HR Preindustrial Run



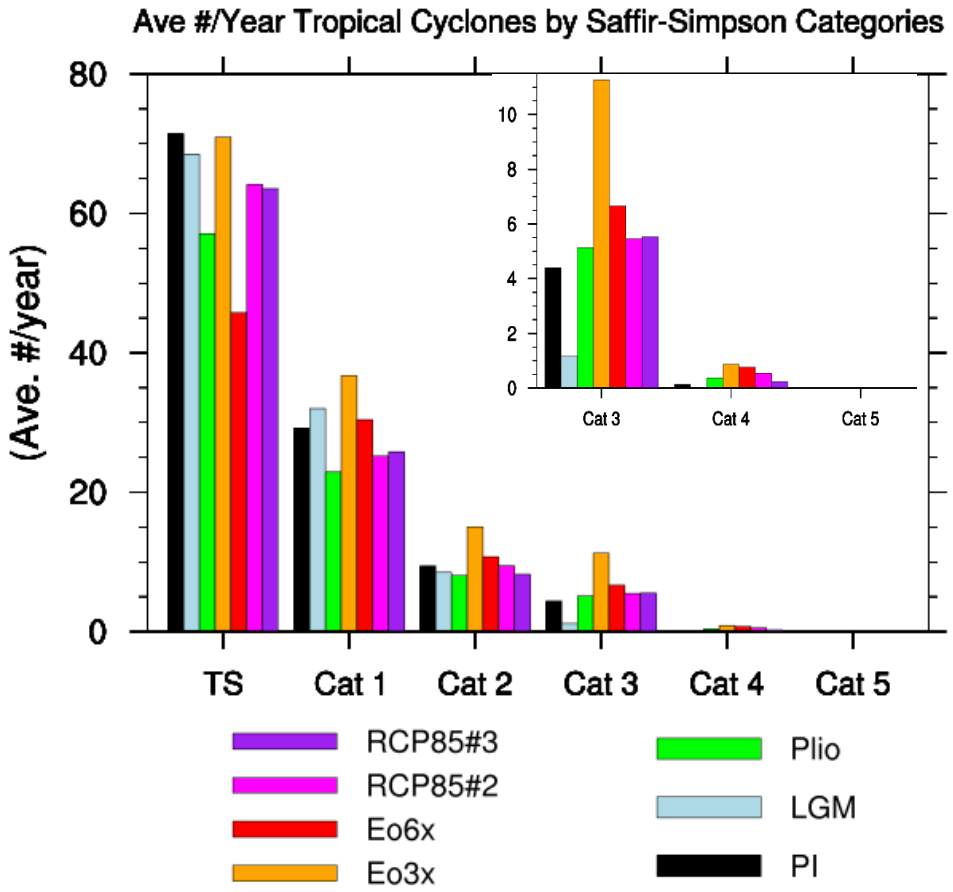
- Global average annual number
  - IBTRACS: 80/year
  - HR PI: 115/year
- CAT 1-5
  - IBTRACS: 41/year
  - HR PI: 43/year
- Strong (CAT4 -5) underestimated in HR PI simulation

** Knapp et al., BAMS, 2010*

Tropical Cyclone (TC Tracks) Past – Present – Future

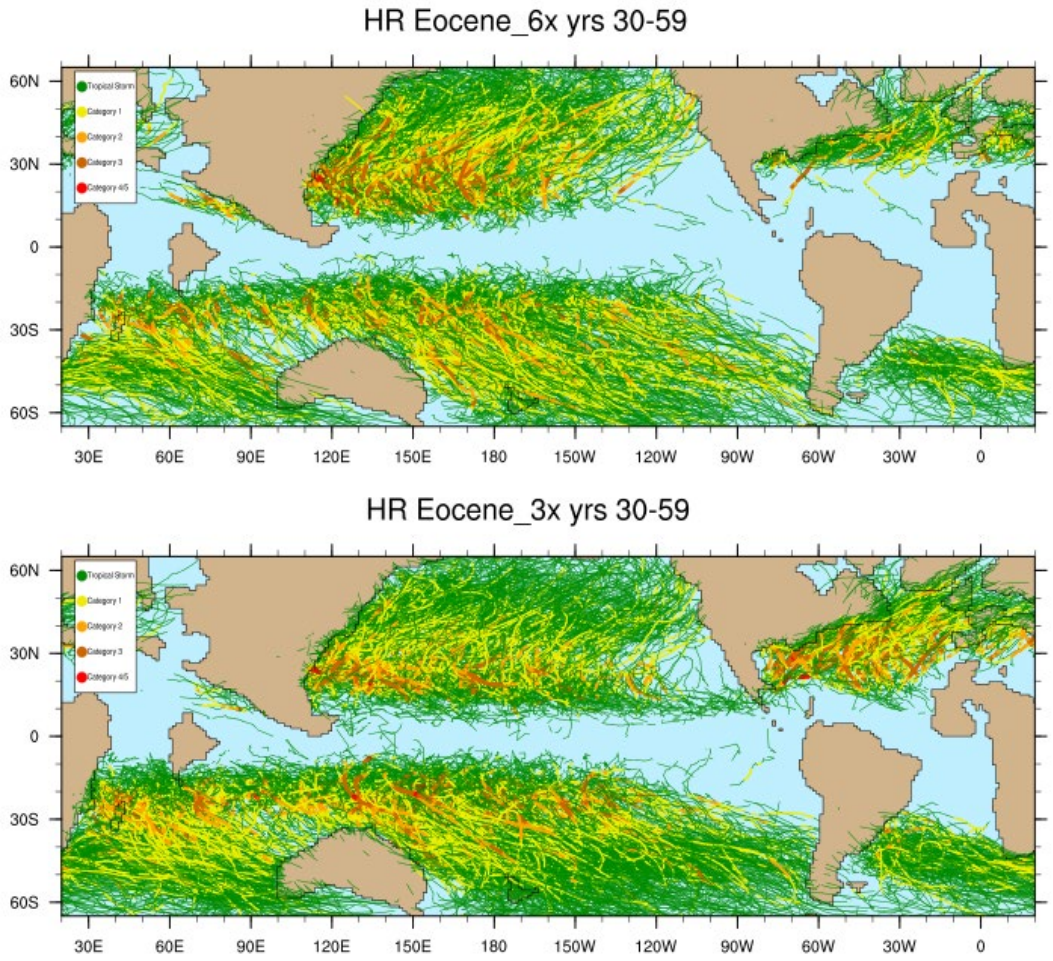


Tropical Cyclone Saffir -Simpson Past – Present – Future



Safir-Simpson Category:w	Hurricane Wind Scale (m/s)
Trop Storm	17 < U < 33
Cat 1	33 < U < 43
Cat 2	43 < U < 49
Cat 3	49 < U < 58
Cat 4	58 < U < 70
Cat 5	U > 70.

Eocene: Sensitivity to CO_2 concentration



TC-Climate Feedback: TCs depend on

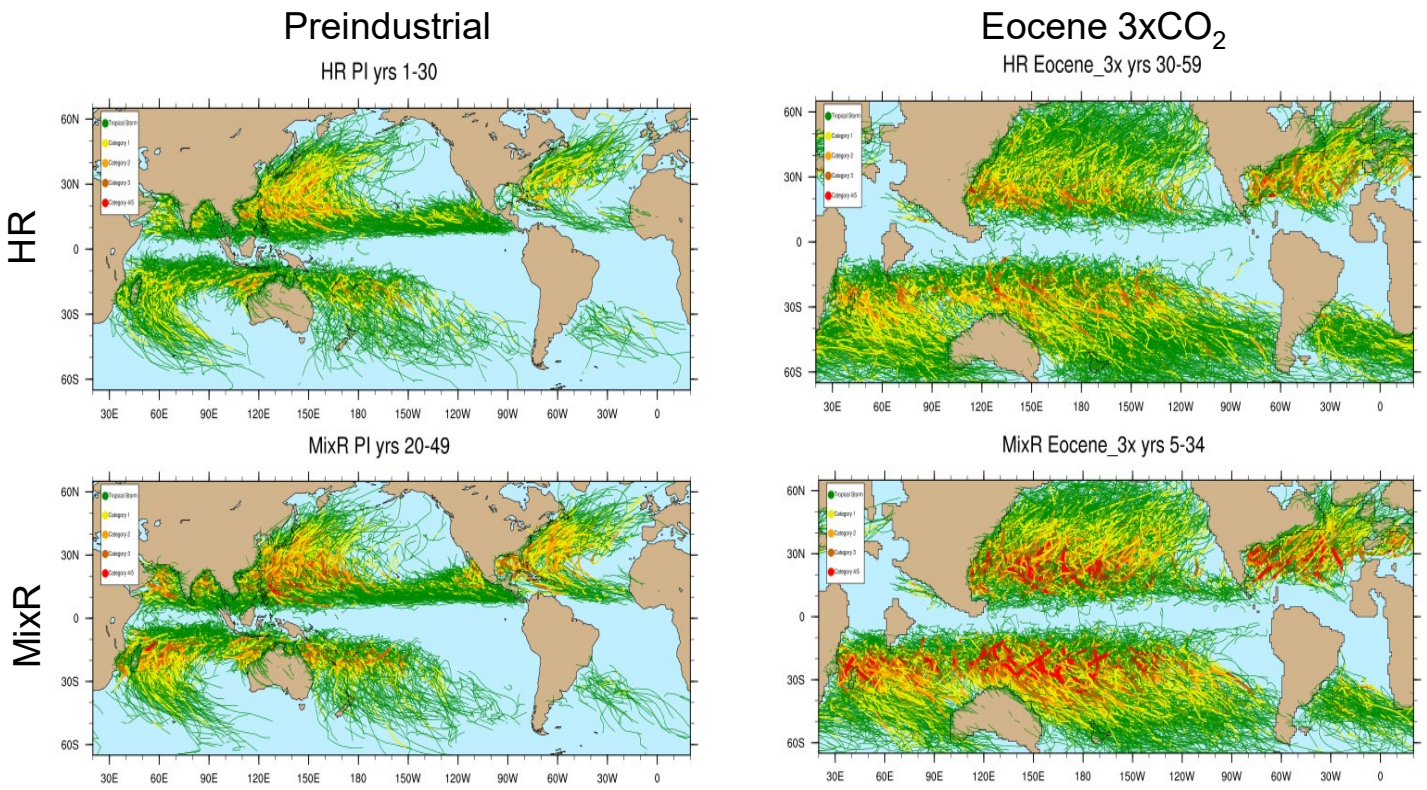
- high potential intensity
- low shear
- humid troposphere

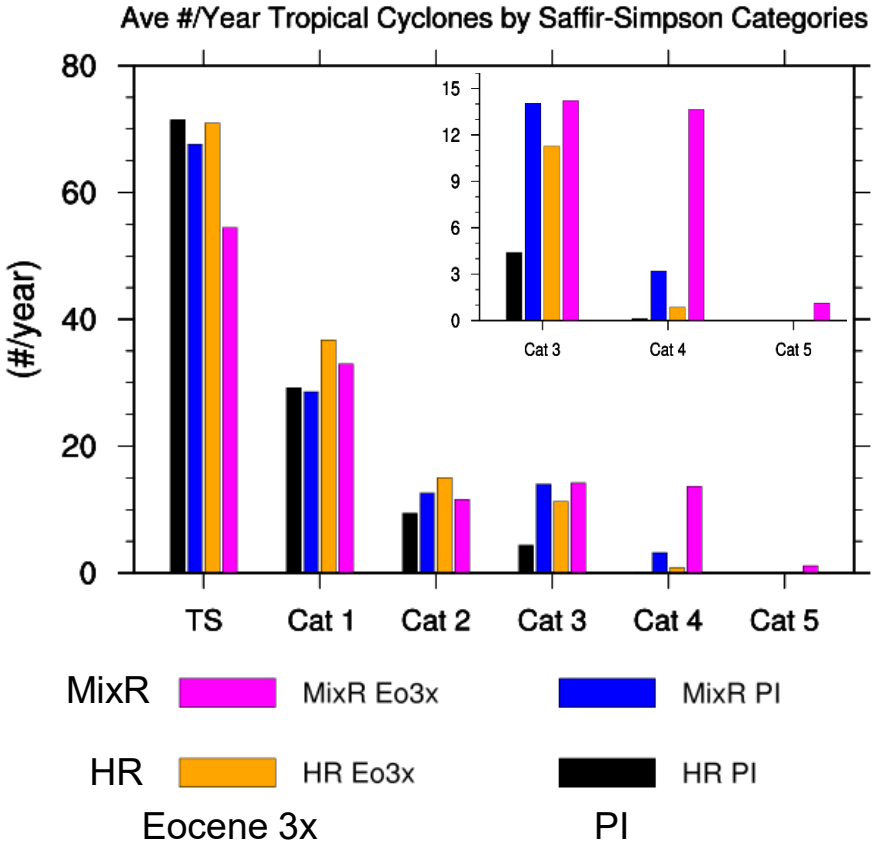
Vertical wind shear which affects the vertical extent of convection to maintain convection (low shear) or inhibit (strong shear) TC formation.

Eocene 3x and Preindustrial: Sensitivity to Ocean Resolution

HR = 0.25° atm/ lnd , 0.1° ocn /seaice
MixR = 0.25° atm/ lnd , 1° ocn /seaice

- **NEXT STEPS**
  - Mixing by mesoscale eddies HR has colder wakes, MixR has weaker cold wakes
  - Mesoscale air-sea interactions might not be as well resolved in MixR
  - Differences in latitudinal SST gradient between HR and MixR experiments





Concluding Remarks

Statistics of tropical cyclones (TCs)

- HR PI compares well in terms of global annual numbers of TCs
  Underestimates CAT4 -5 storms
- Last Glacial Maximum: fewer and less intense TCs in North Atlantic
  Warmer climates (Pliocene, RCP8.5 future scenarios, Eocene): increase in number of intense storms
- Poleward expansion to mid and high latitudes in warmer climates

Next steps … Why and What?

- Why do deep tropics become hostile to TC genesis in the Eocene 6xCO_2?
- Why does the 1 ^{o} ocean (MixR) have more intense TCs than the 0.1 ^{o} ocean (HR)?
- What do tempestites and other sediment data indicate about TCs during the past?