Cat. 4-5 Landfalling Tropical Cyclones In the Coming Decade

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Image: NASA.

Question: What is the likelihood that within the next decade, a tropical cyclone of Category 4 or 5 will make landfall in a location where more than a million people live at lower elevation than the projected storm surge??

My assessment is that, currently, one cannot give a confident answer to this question.

Question: What is the likelihood that within the next decade, a tropical cyclone of Category 4 or 5 will make landfall in a location where more than a million people live at lower elevation than the projected storm surge??

Risk controlled by three elements:

- Hazard:
  - Storm surge
  - Landfalling TC
- Exposure

Question: What is the likelihood that within the next decade, a tropical cyclone of Category 4 or 5 will make landfall in a location where more than a million people live at lower elevation than the projected storm surge??

Will focus on:

- Baseline risk
- Change in risk

Substantial uncertainties in evaluating each of these

Climatic factors

Factors related to demographics/economics/infrastructure

Question: What is the likelihood that within the next decade, a tropical cyclone of Category 4 or 5 will make landfall in a location where more than a million people live at lower elevation than the projected storm surge??

Tentative answer:

- Baseline risk: probably substantial
- Change in risk

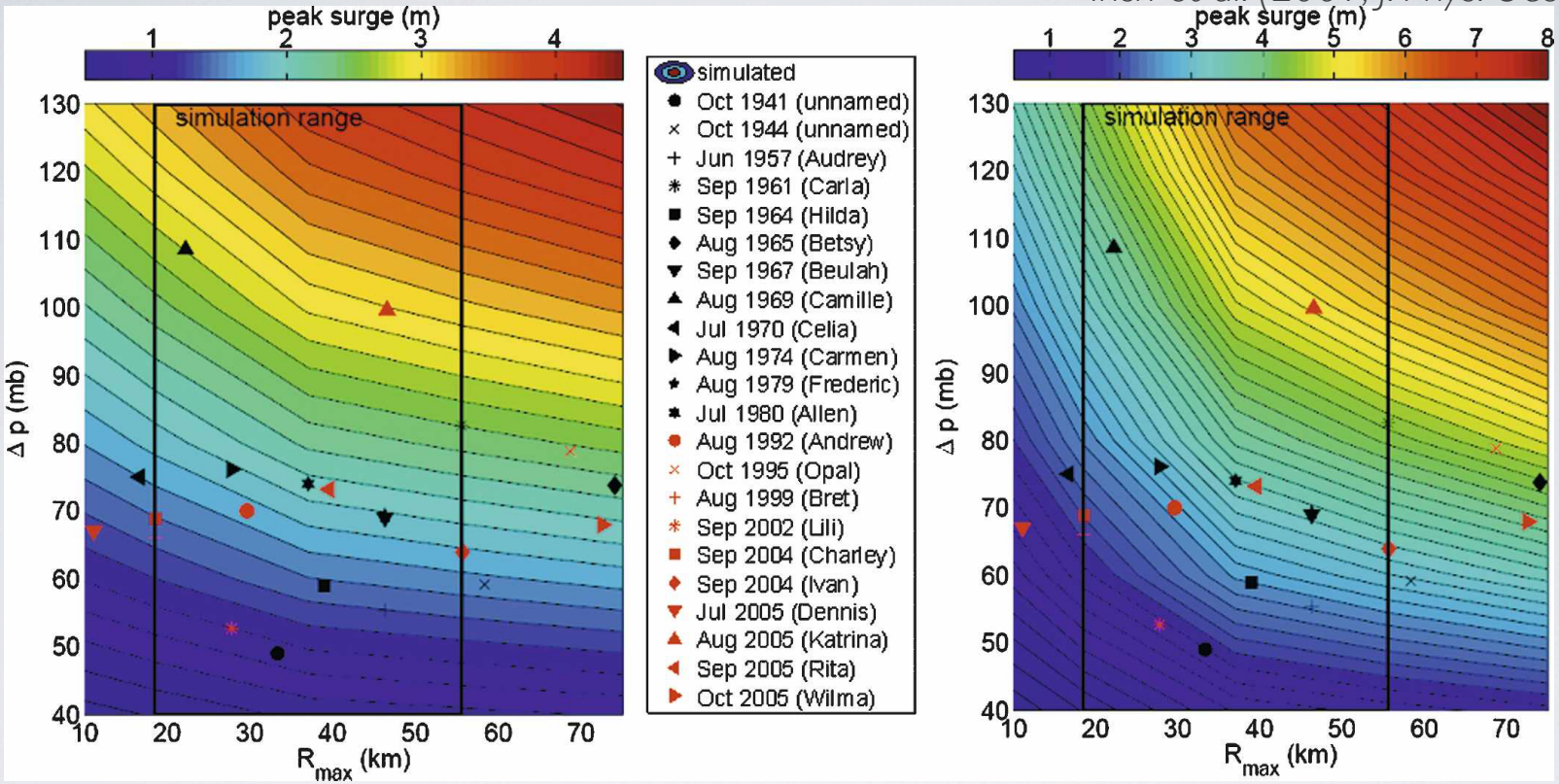
  Climatic factors: even sign is uncertain

  Factors related to demographics/economics/infrastructure:

  likely to increase exposure relative to baseline

Storm surge

Irish et al. (2009, J. Phys. Oceanogr.)



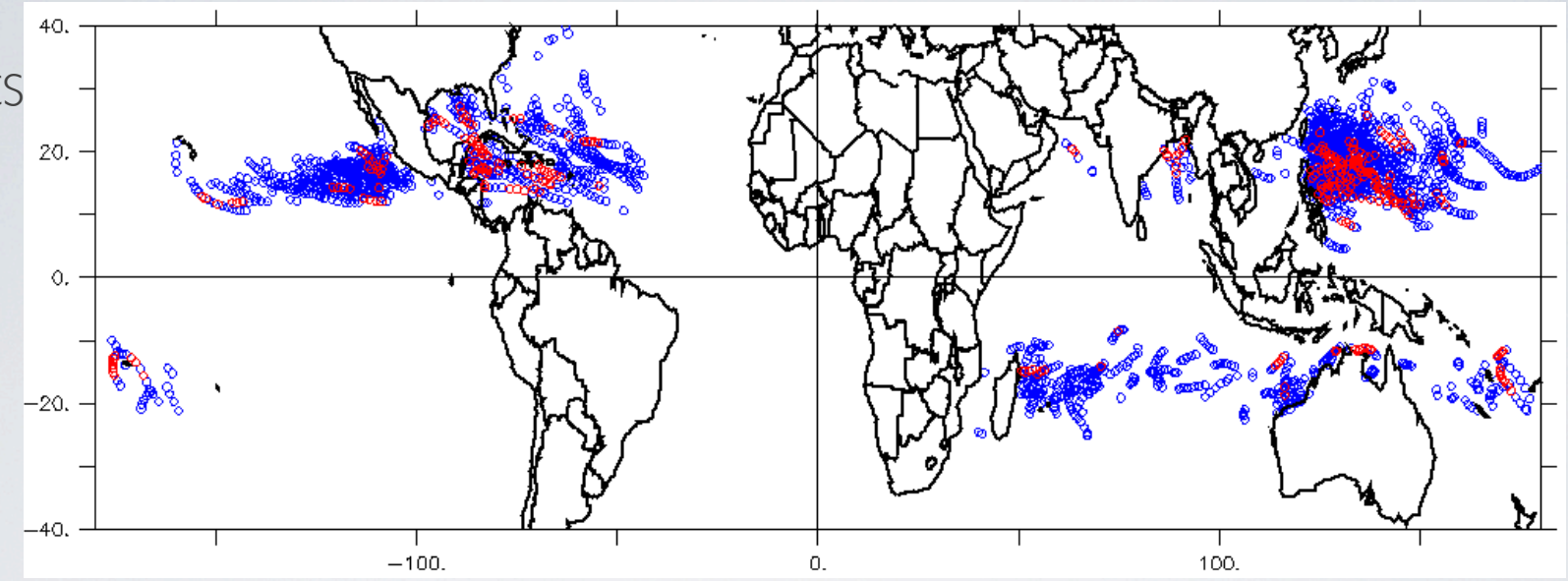
Steep slope

Shallow slope

Depends on: storm intensity, storm size, storm speed, bottom slope, shape of coast…

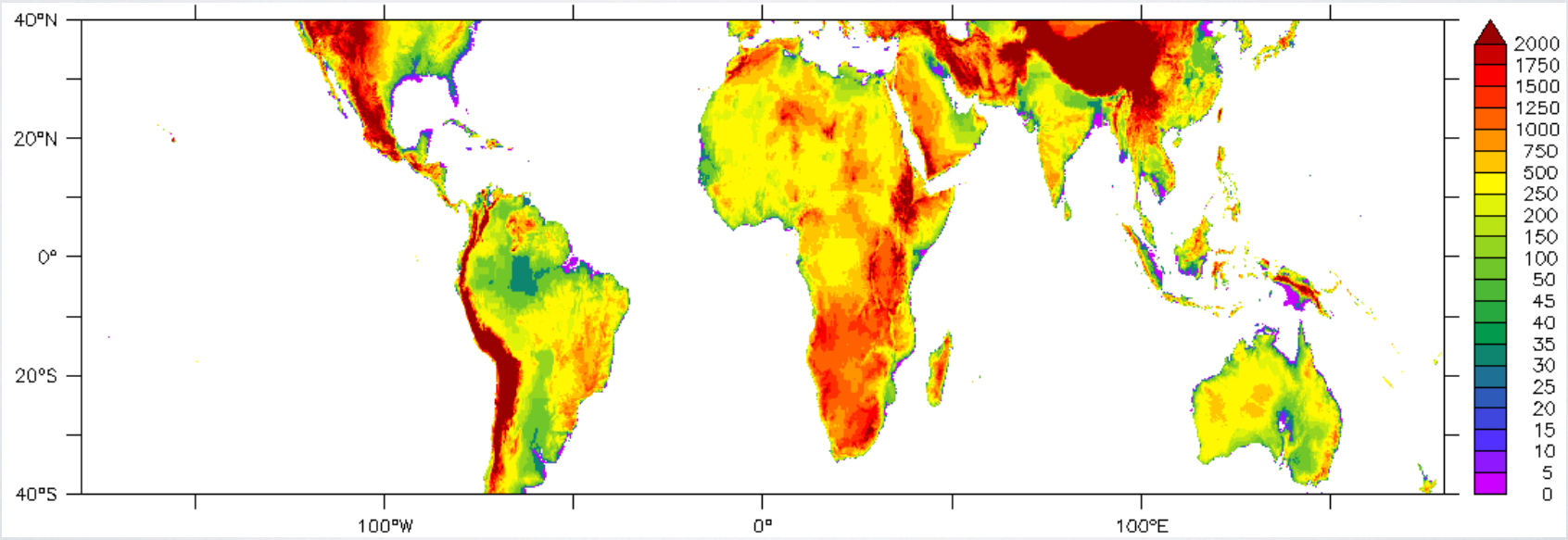
1970-2007 Cat 4-5 TCs & surface elevation

IBTrACS

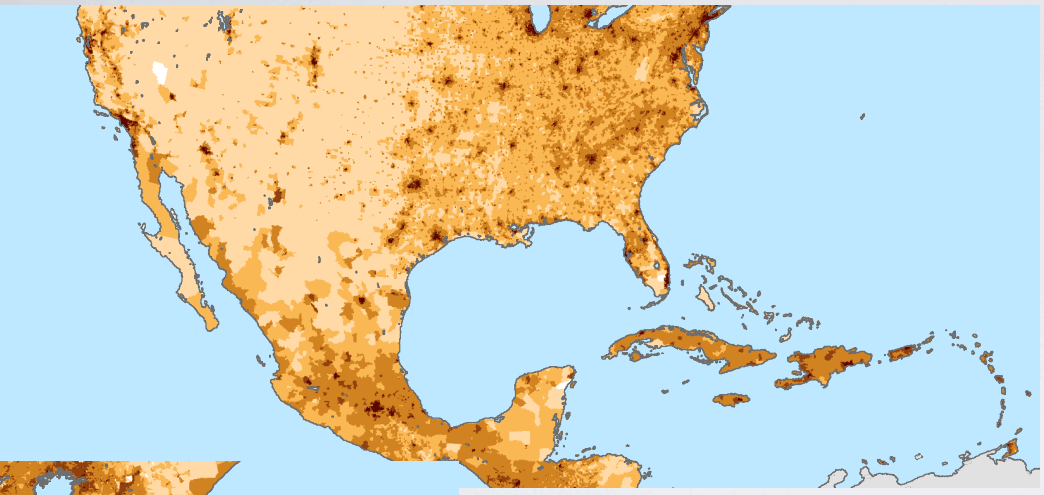


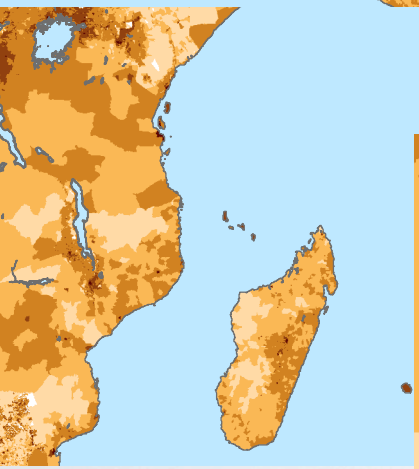
Cat 4

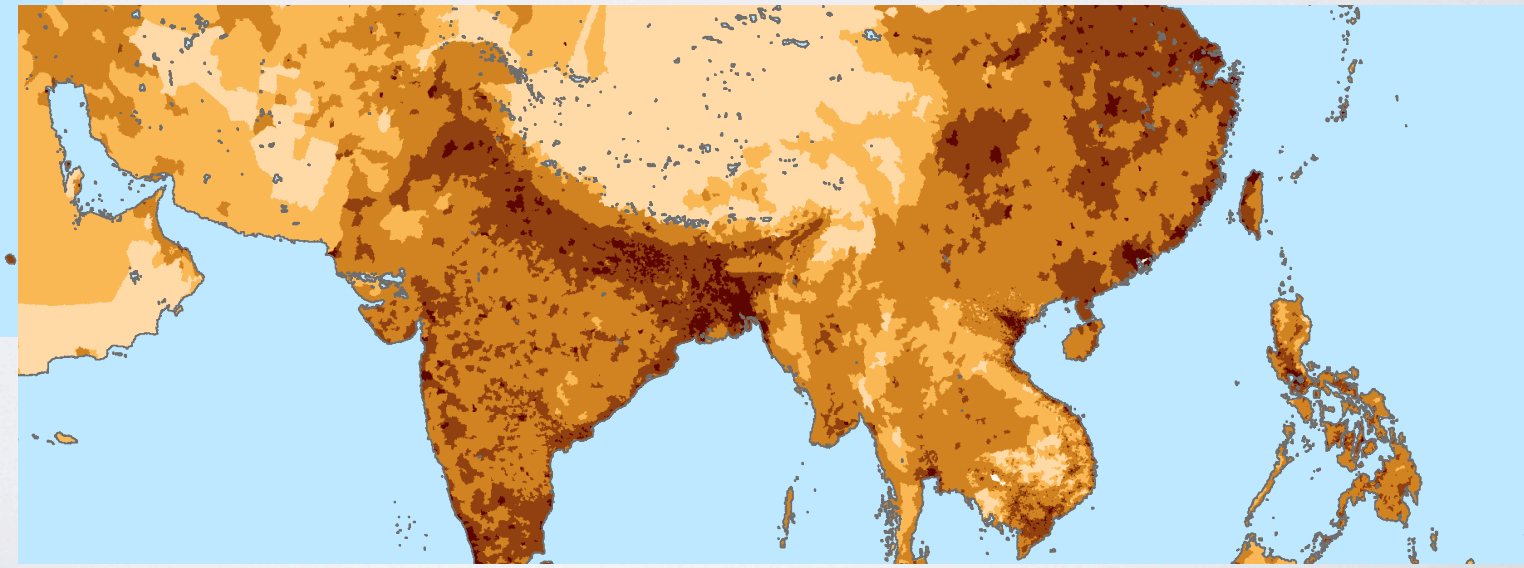
Cat 5



Population density (2000)







GPW [v3]

Gridded Population of the World

Persons per km^2

- 0
- 1 - 4
- 5 - 24
- 25 - 249
- 250 - 999
- 1,000 +

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To first order question is: what is probability of landfalling Cat. 4-5s in northern Bay of Bengal & Arabian Sea?

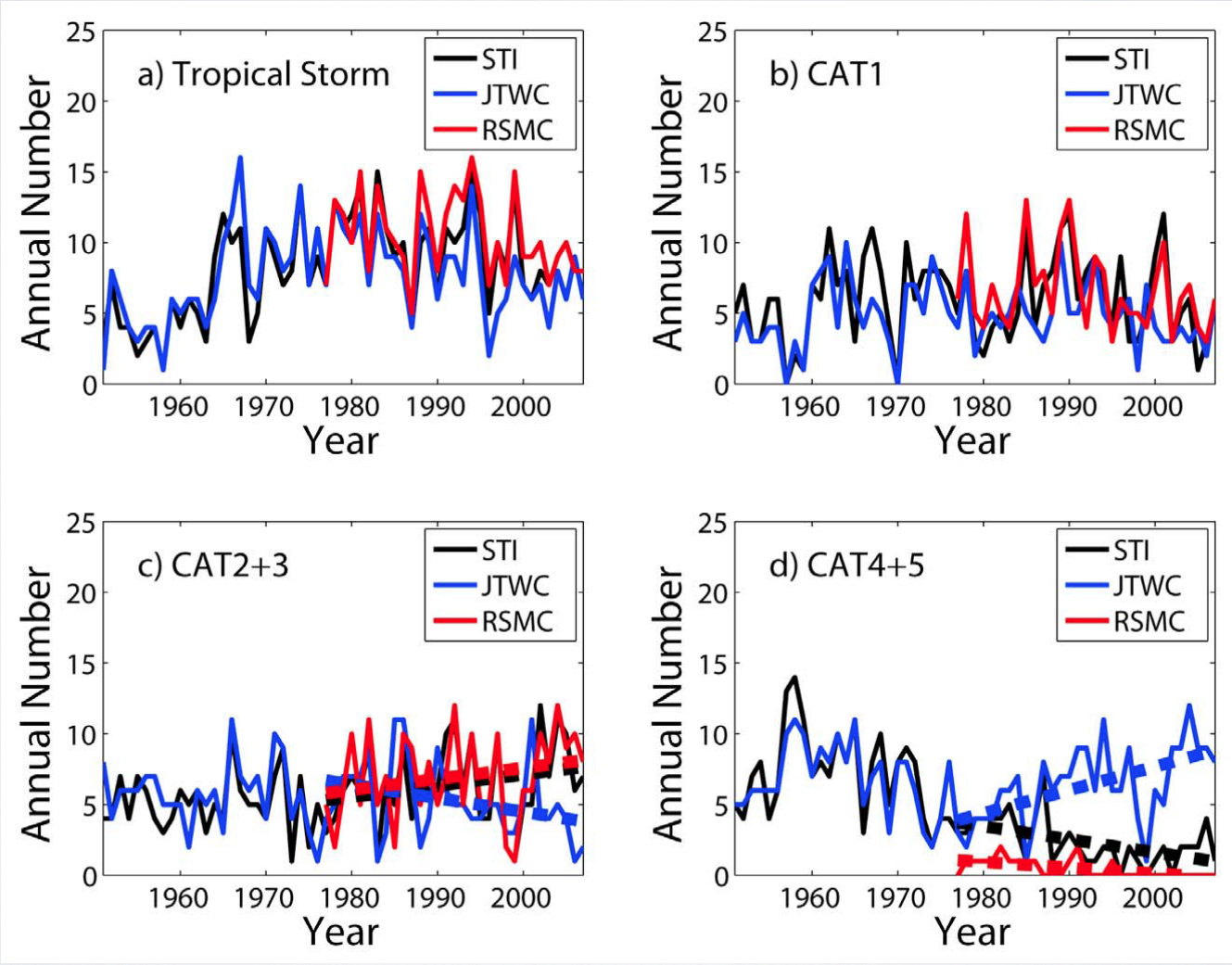
Should we concern ourselves with only Cat. 4-5s? 1970 Bangladesh Cyclone (300,000-500,000 dead) is currently listed as only Cat. 3.

There is uncertainty in past records.
Records of decent quality are short.
What about factors affecting storm surge?

If include mudslides, wind and rain damage to concern, probably should add consideration of Philippines, Taiwan, China & Hong Kong + Caribbean Islands (Cuba, Haiti, Rep. Dominicana,…)

Data issues in cyclone records not a thing of the past

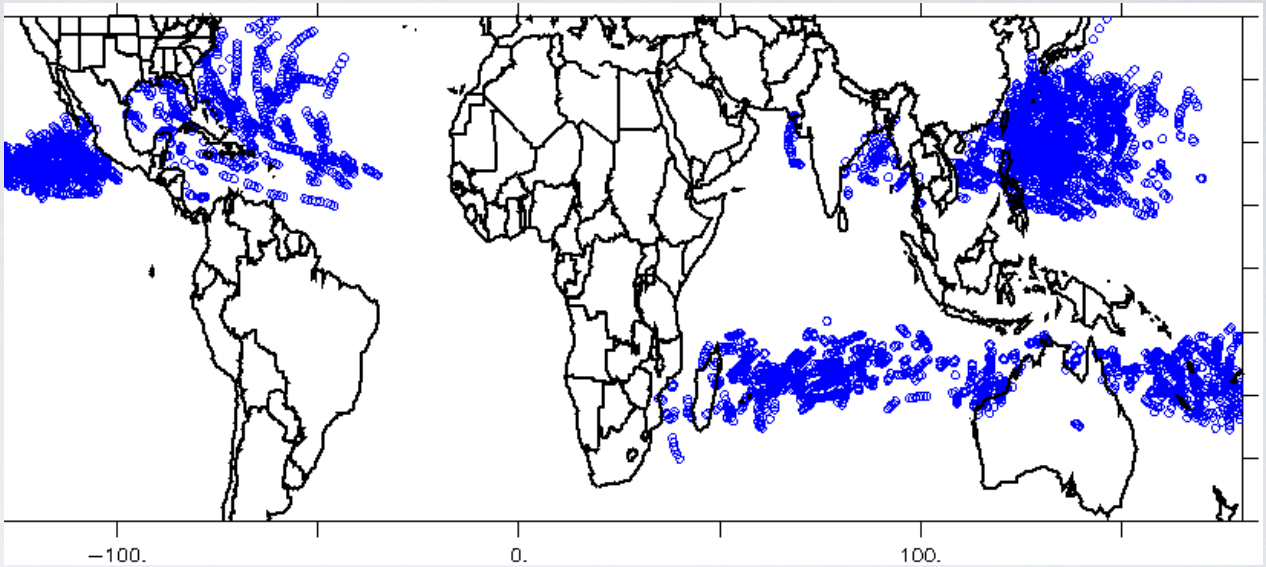
Basinwide West Pacific Typhoon Frequency from Three Sources



Song et al. (2010, JGR)

1982-2006 Major Storms in Homogeneized Database

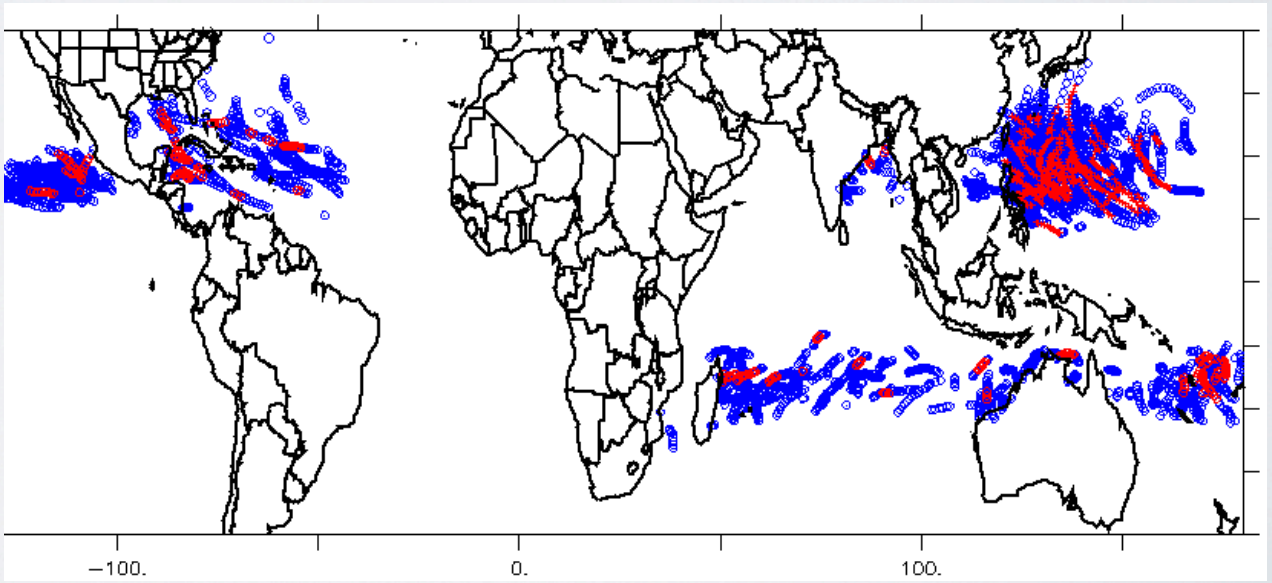
Cat. 3



Kossin et al. (2007, GRL)

Cat 4

Cat 5



Assessing baseline risk from 1982-2006

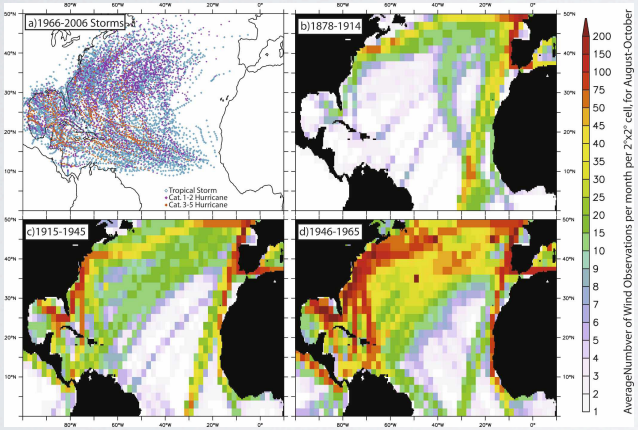
N. Arabian Sea: Pak. & Gujarat Two Cat 3's in 25 Years (1998 &1999)
To Arabian Pen. Two Cat 4's in 25 Years
N. Bay of Bengal: O(10) Cat 4-5s in 25 Years (+ Nargis in 2008)

Madagascar: O(5-10) Cat 4-5s in 25 Years (+ Bingiza 2011)
Southern Mozambique: couple of Cat. 3s

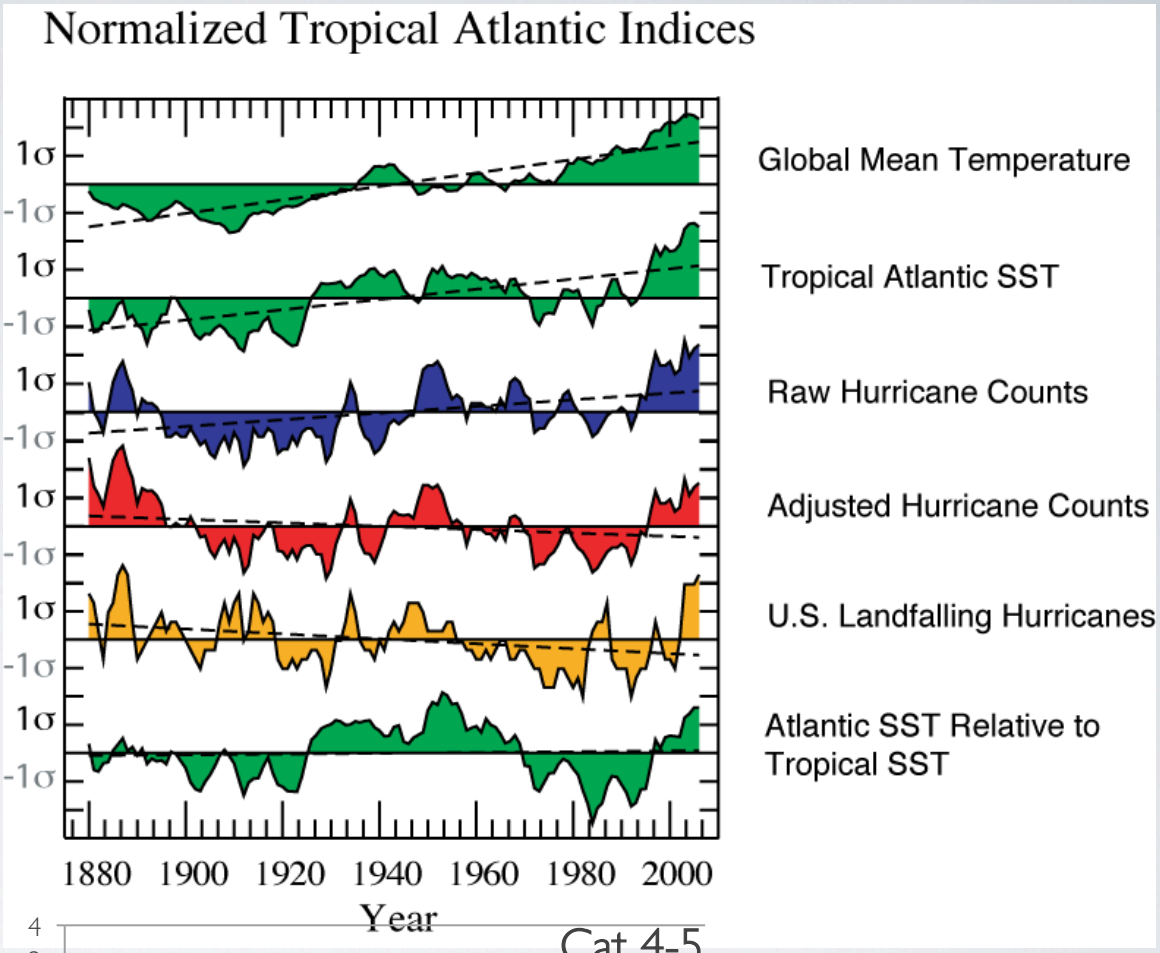
Cat 3's and 4's regularly approach coasts of Vietnam and Southern China

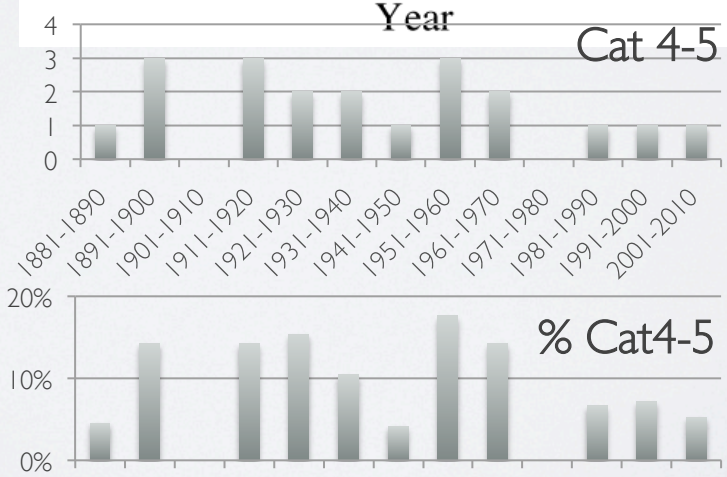
So it would seem that there's a non-trivial chance of Cat. 4-5 making landfall in densely populated area.

Adjustments to storm counts based on ship/storm track locations and density



Vecchi and Knutson (2008, J. Clim.)
Landsea et al. (2009, J. Clim.)
Vecchi and Knutson (2011, J. Clim.)



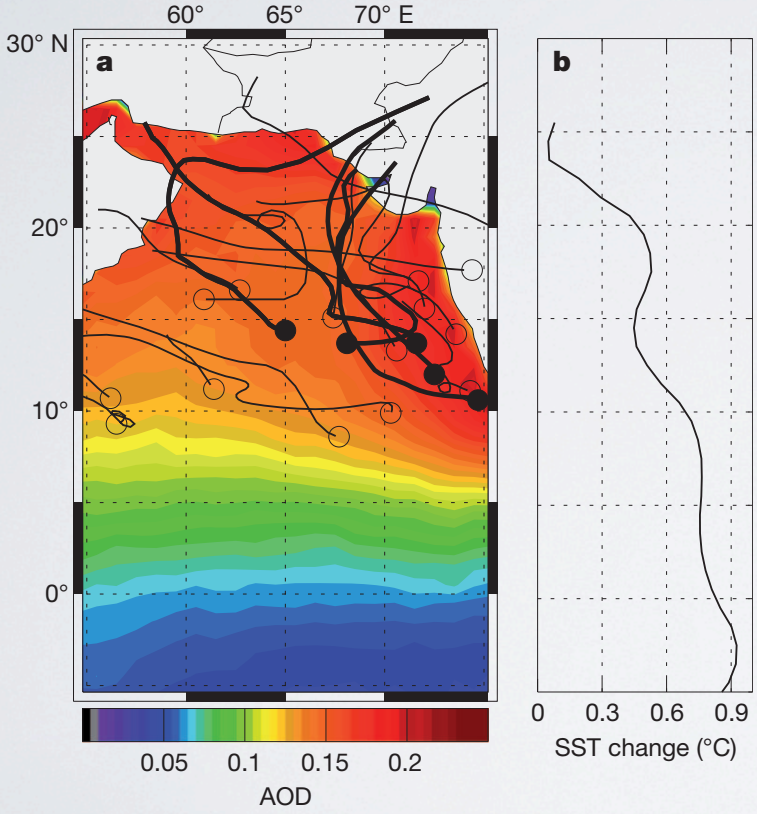


Change in baseline risk due to climate

- Forced climate change
  - Due to greenhouse gases *(e.g., Emanuel et al. 2008 Bull. Amer. Meteorol. Soc., Knutson et al. 2008 Nature Geosci., Zhao et al. 2009 J. Clim., Bender et al. 2010, Science, Villarini et al. 2011 J. Clim.…)* forcing changes slowly (i.e., less uncertain), global impact more well constrained than regional impact, incremental impact over next decade may be smaller than variability. Sea level rise
  - Due to aerosols *(e.g., Mann and Emanuel 2006 EOS, Evan et al. 2011, Nature, Villarini and Vecchi 2012 in prep)* Could be influential, forcing can change rapidly (i.e. uncertain), impact not yet fully understood, spatially heterogeneous.
- Internal climate variability
  - Decadal modes of variation *(e.g., Zhang and Delworth 2006, Smith et al. 2010…)* Ongoing efforts to assess predictability of climate and its impacts – variability, predictability and impacts likely regionally dependent.
  - Rectified extreme interannual events (e.g., 1997-8 El Niño): Current estimates of predictability don't extend beyond a few seasons. *(e.g., Camargo et al. 2009 WMO; Vecchi et al. 2011 Mon. Wea. Rev).*

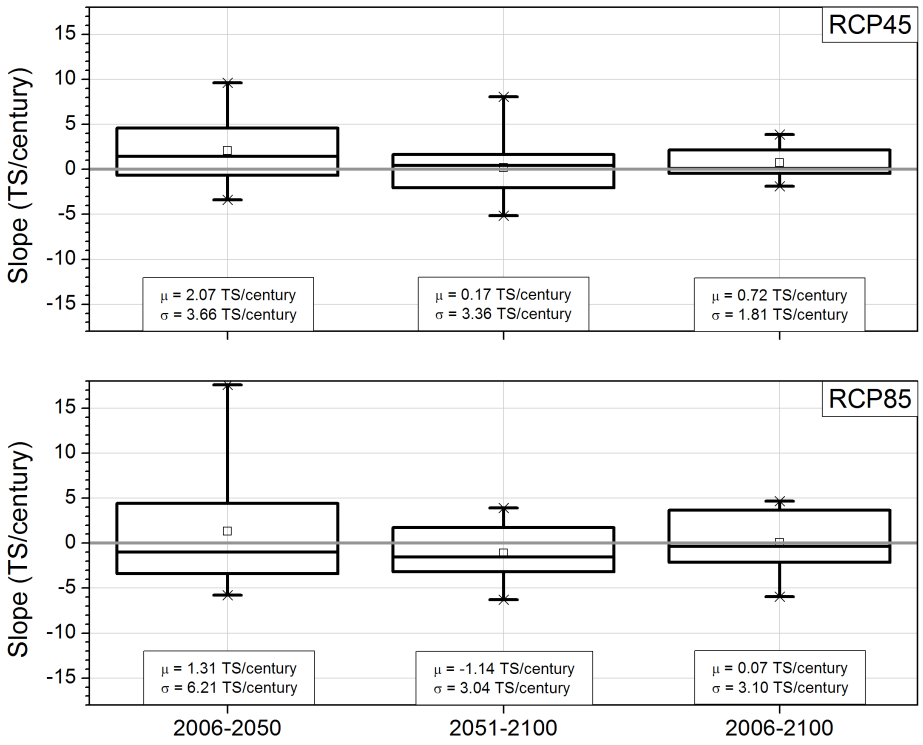
Potential Impact of Aerosols

Black carbon changes suggested as important to increase Arabian Sea TCs through, in part, atmospheric stability



Evan et al. (2011, Nature)

Statistical Natl TS downscale of CMIP5 models indicate largest signal through mid-20th century, and of opposite sign to models' CO2 response.

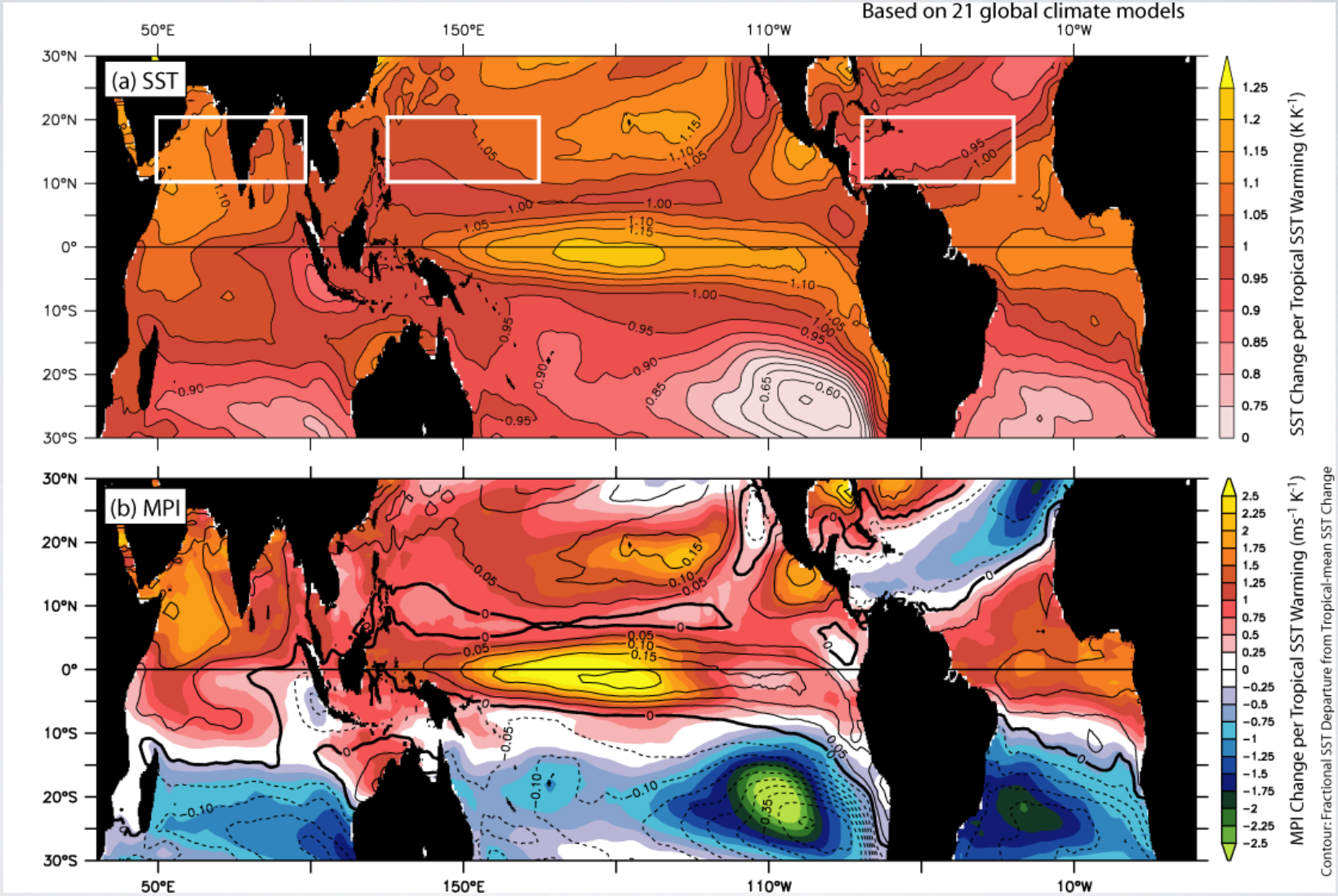


Villarini and Vecchi (2012, in prep.)

GCM Projections of 21st Century Changes

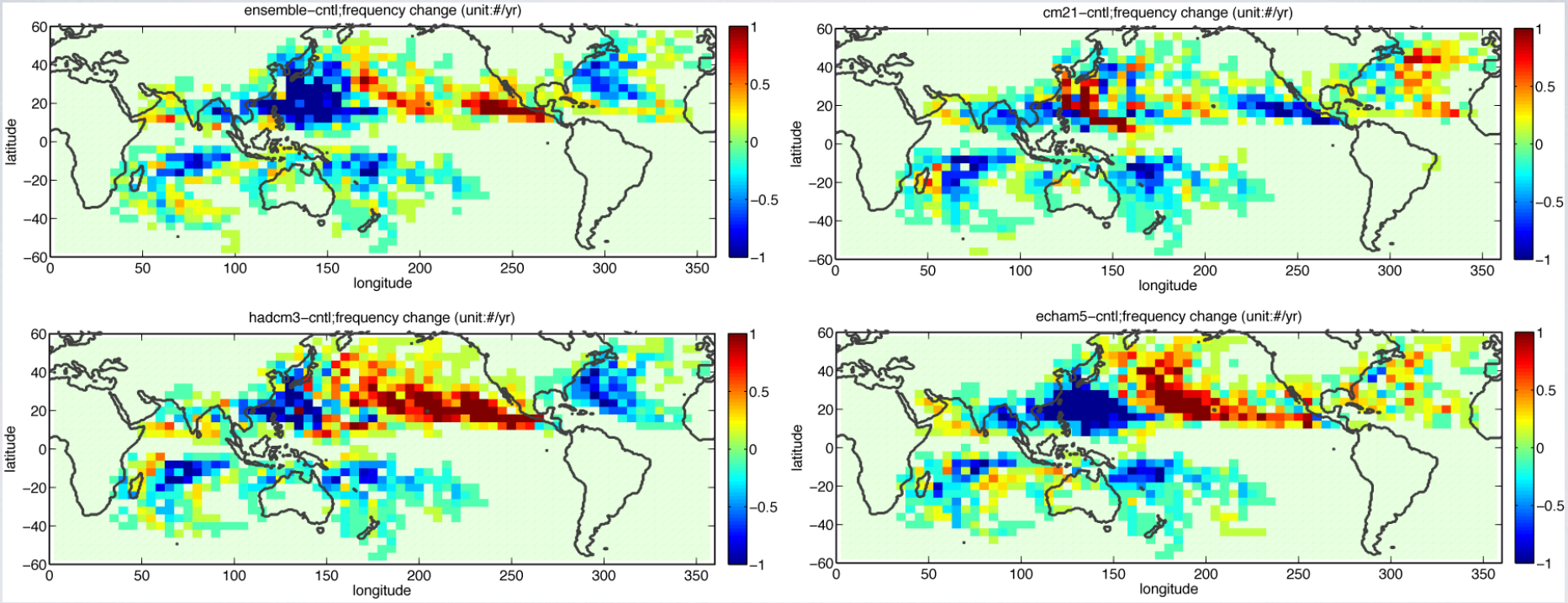
Surface Temp.

Potential Intensity



Vecchi and Soden (2007, Nature)

Response of TC frequency in single 50km global atmospheric model forced by four climate projections for 21st century



Red/yellow = increase
Blue/green = decrease

Adapted from Zhao et al. (2009, J. Climate)

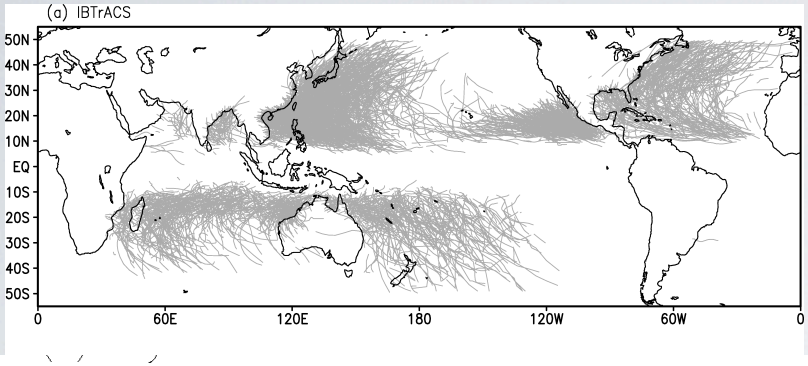
Regional increase/decrease much larger than global-mean.

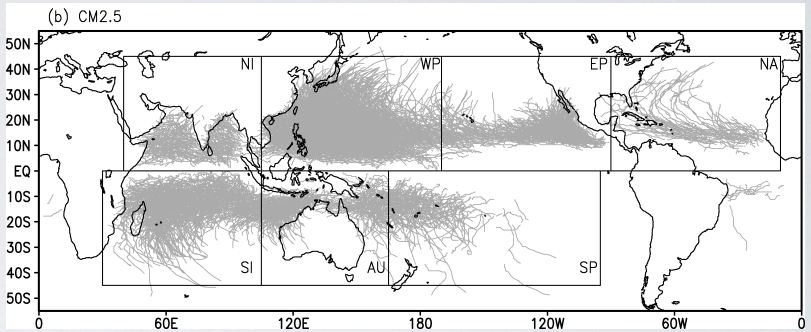
Pattern depends on details of ocean temperature change.

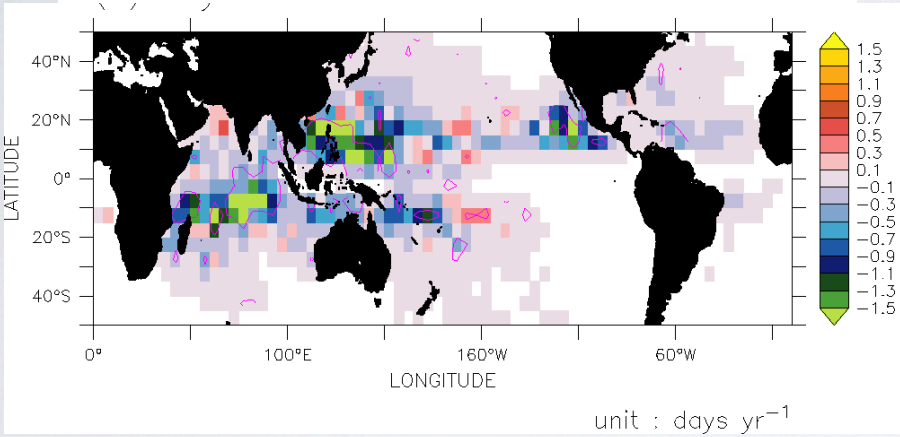
Sensitivity of response seen in many studies

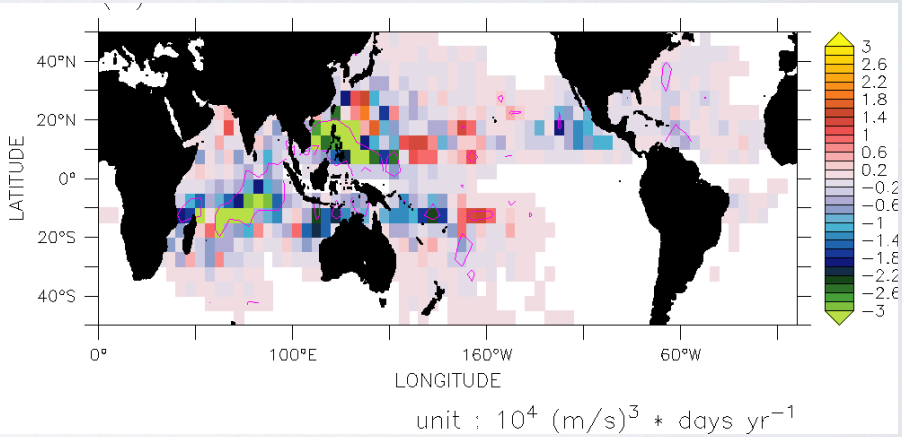
e.g., Emanuel et al 2008, Knutson et al 2008, etc

Response of TCs in high-resolution global coupled model (GFDL CM2.5, *Delworth et al. 2012, J. Climate; Kim et al. 2012 in prep.*)

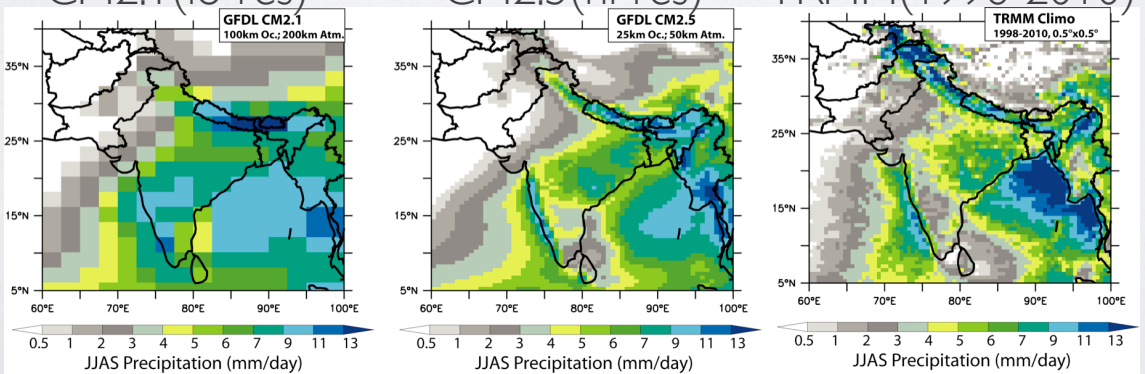






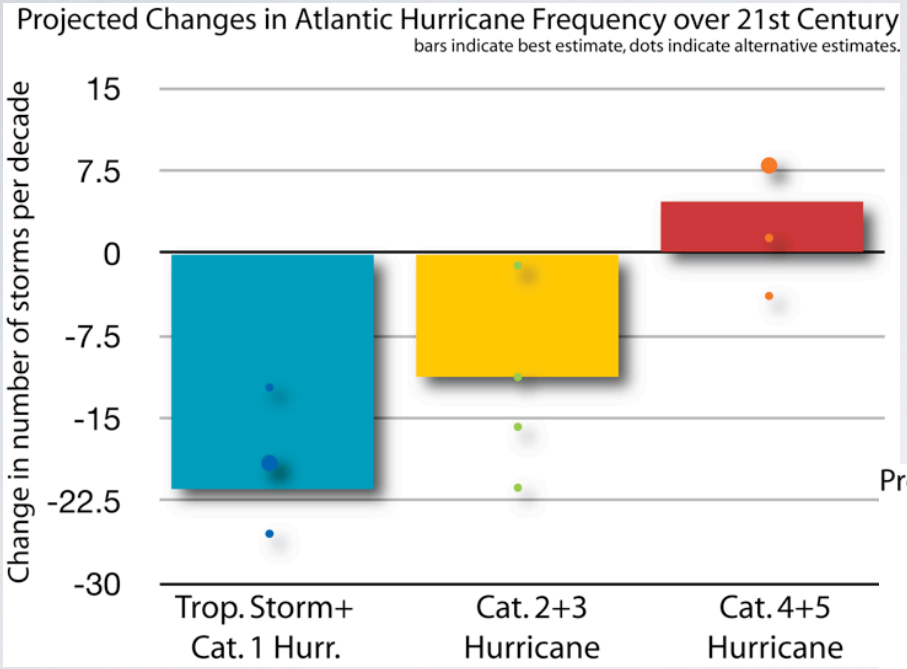


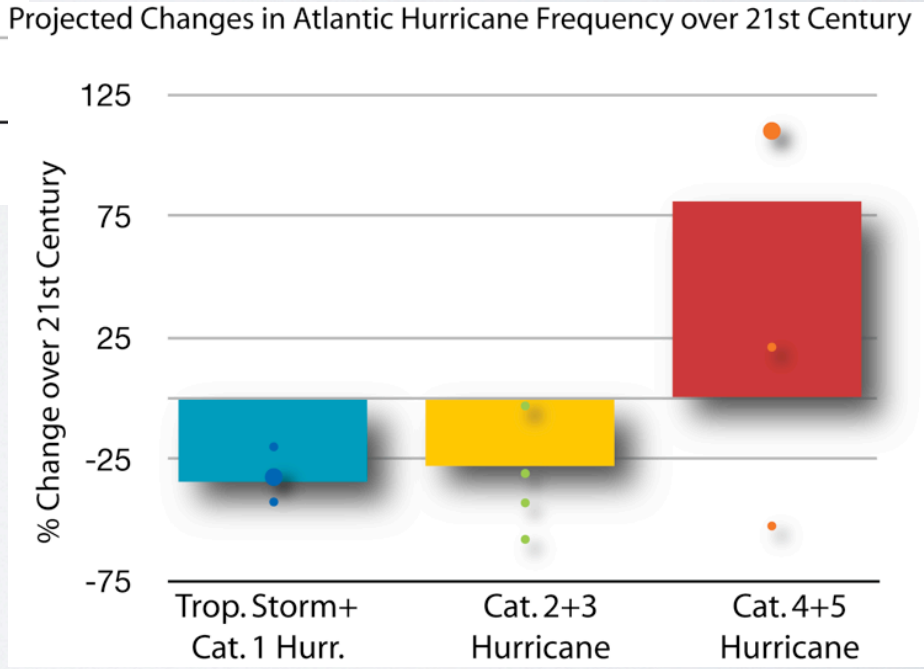
CM2.1(lo-res) CM2.5(hi-res) TRMM(1998-2010)



Resolution improves aspects of IO Climate

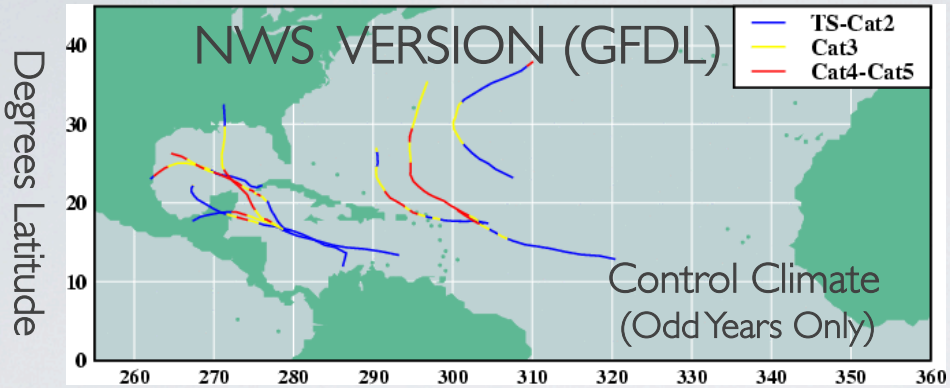
Overall frequency decrease, but strongest storms may become more frequent



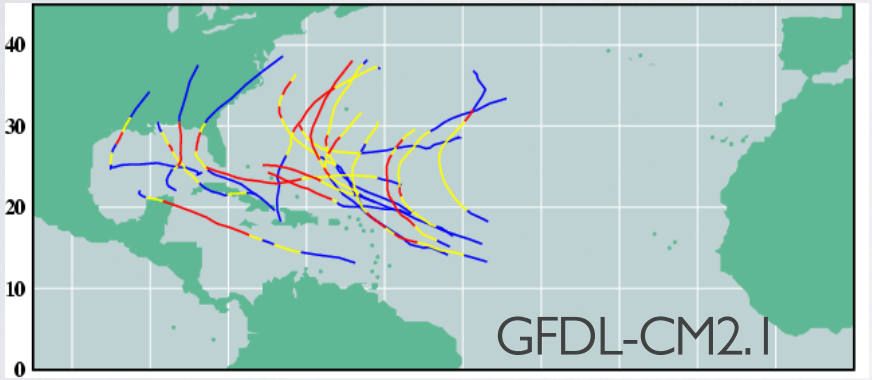


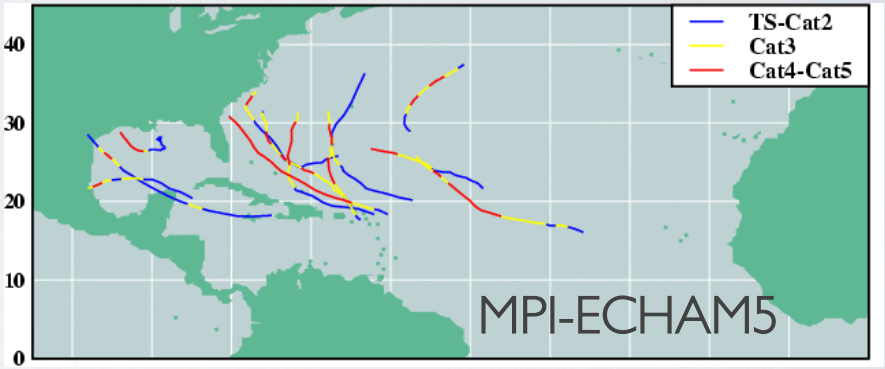
Adapted from Bender et al (2010, Science)

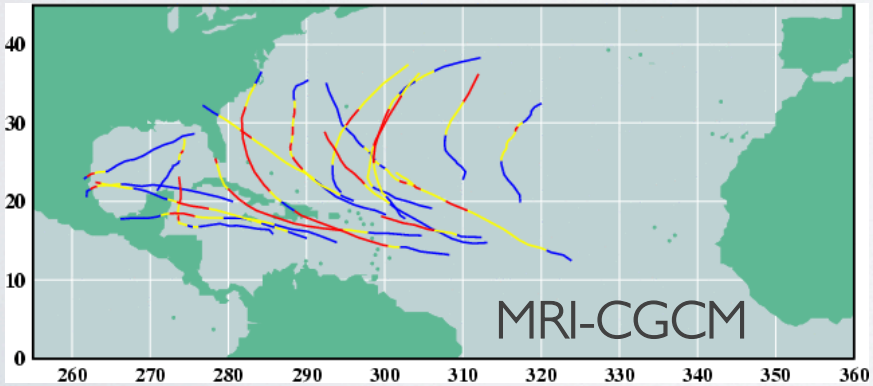
Tracks of Storms that Reached Category 4 or 5 Intensity

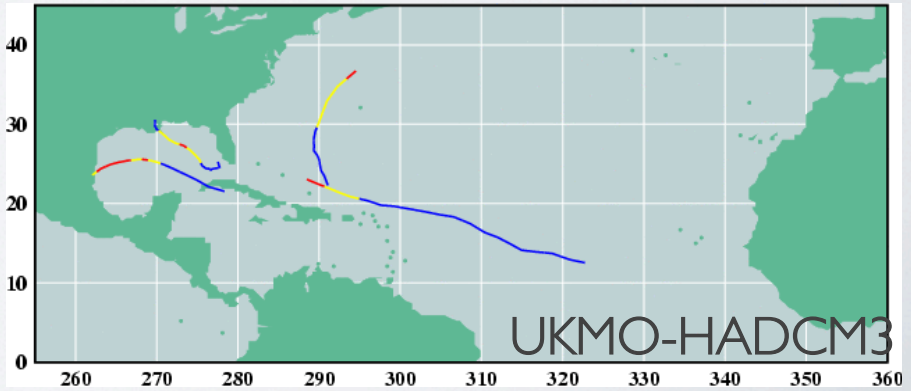


Late 21st Century Warmed Climate Projection based on 4 Individual CMIP3 Climate Models

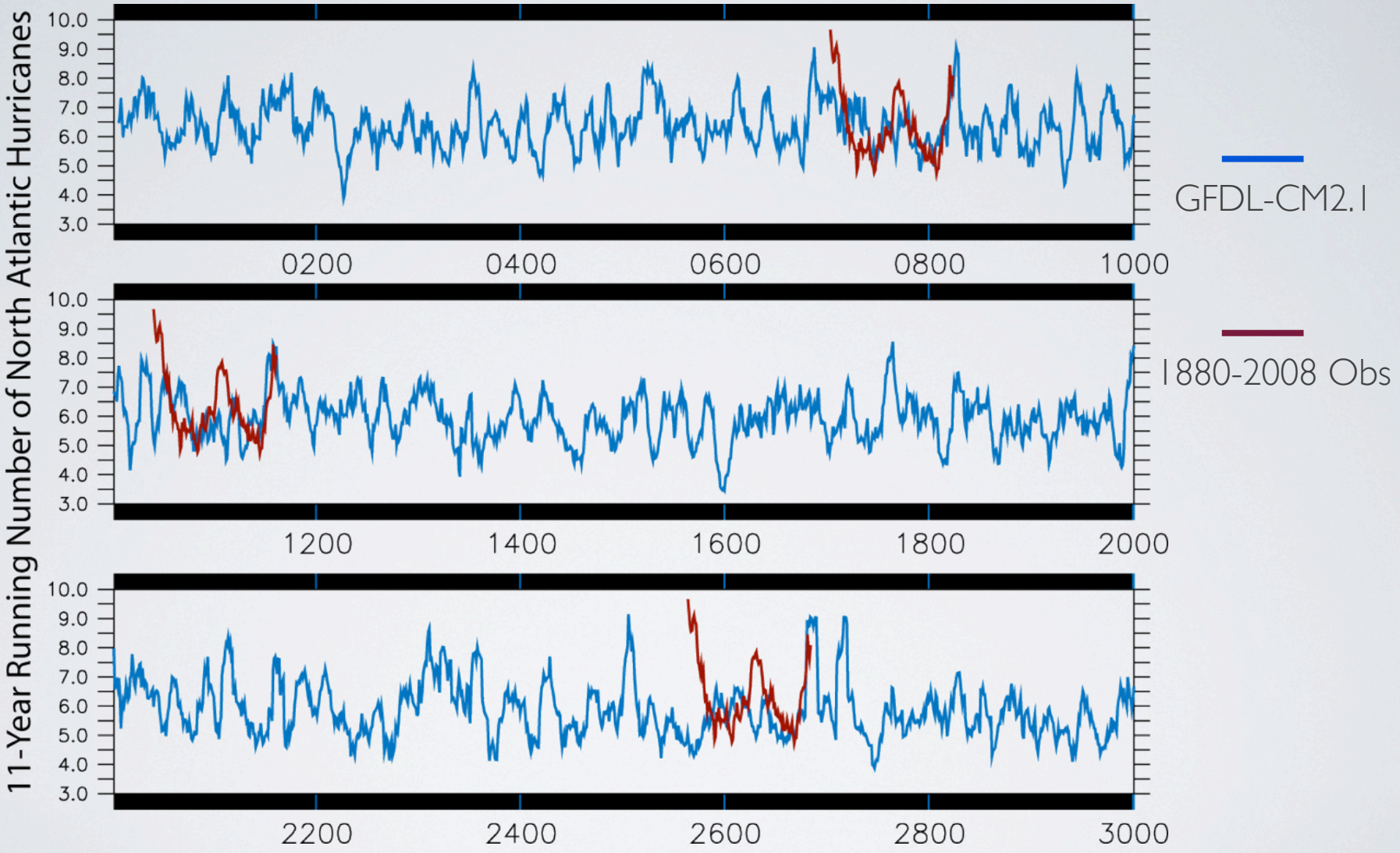








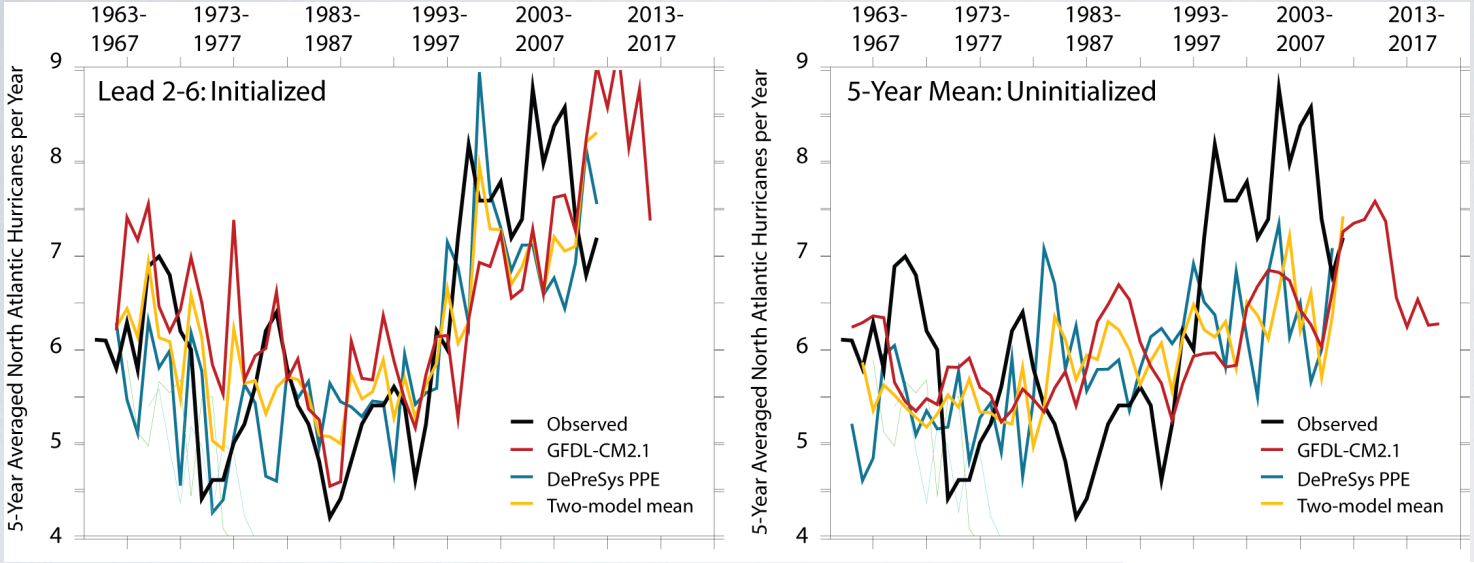
Statistical hurricane counts in GFDL CM2.1 Preindustrial-Control Run



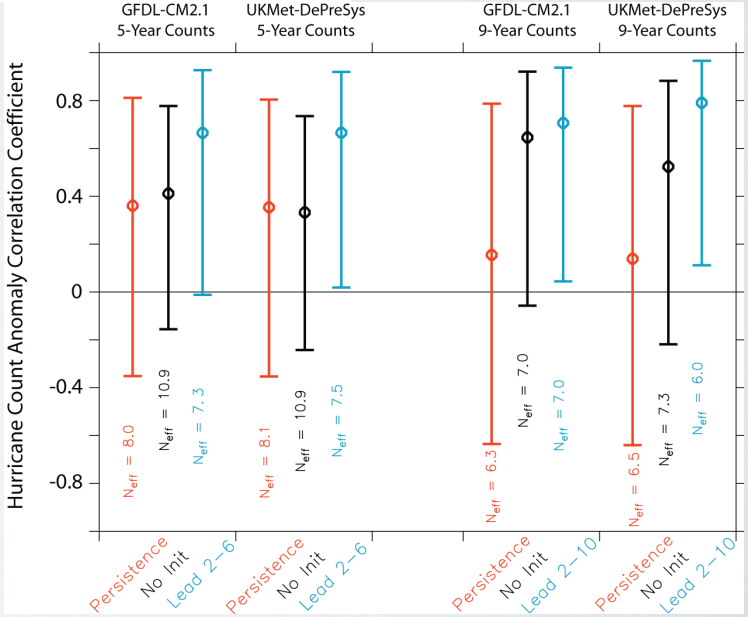
Even in absence of radiative forcing changes, large changes

Experimental decadal predictions

Hybrid system: statistical hurricanes, dynamical decadal climate forecasts



- Retrospective predictions of 1961-2011 decadal NA TS frequency encoraging.
- However, low number of degrees of freedom limit confidence in result, and correl arises more from recognizing 1994-1995 shift than actually predicting it.
- This is for North Atlantic Hurricane frequency only.



Vecchi et al. (2012 in prep.), see also Smith et al. (2010, Science)

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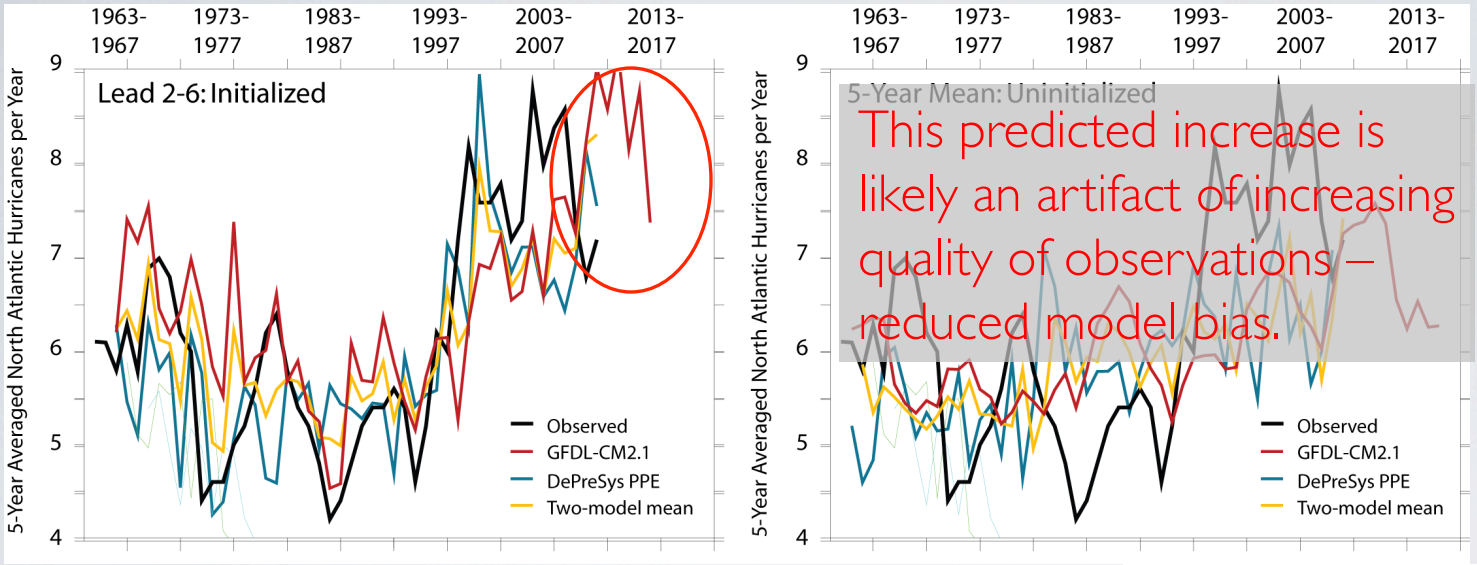

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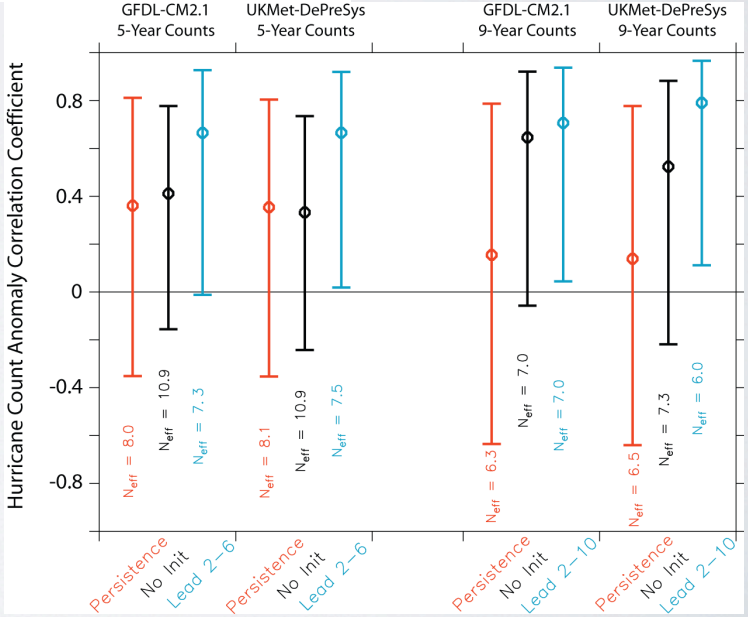

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Demographic factors influencing exposure are important to consider *(e.g., Pielke Jr. 2007QJRMS, Knutson et al. 2010 Nature Geosci, IPCC-SREX 2012…)*

A projection of population density change 2005 to 2015

Not my area of expertise…is this projection sensible? If so, an important contribution to changing risk.

GPW [v3]

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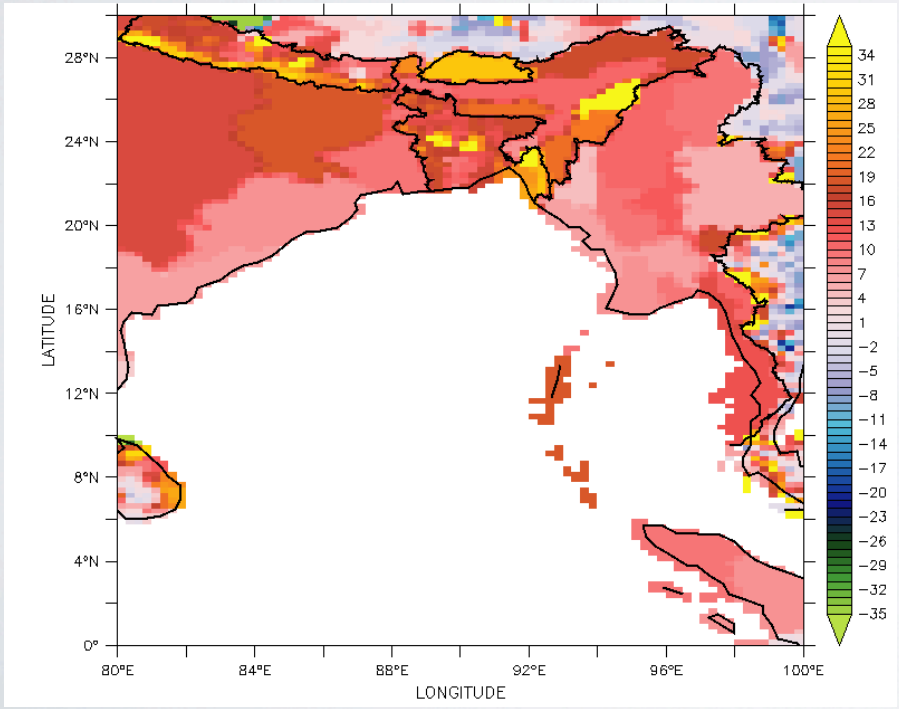

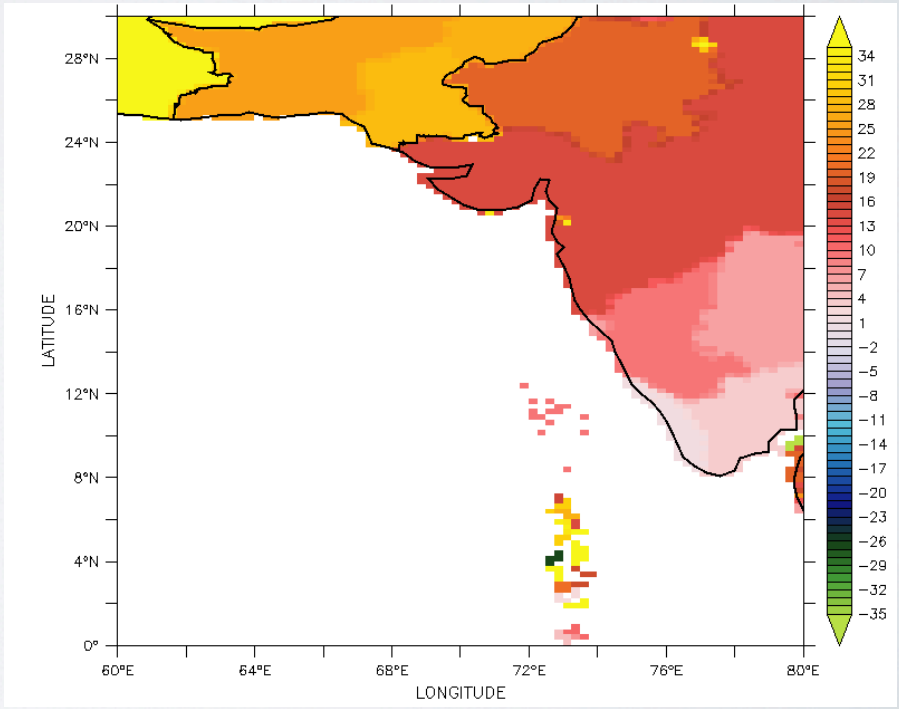

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