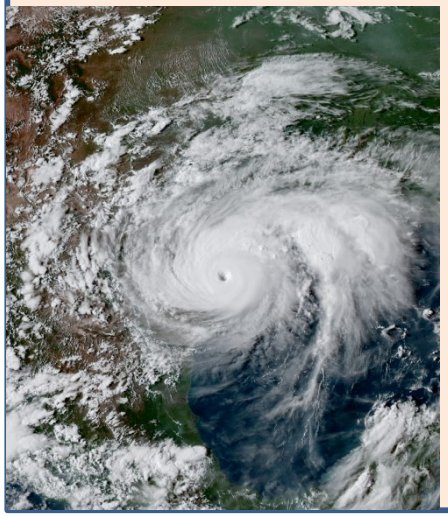
Assessment of Tropical Cyclones and Climate Change

Thomas R. Knutson

NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ

Chair, WMO Task Team on Tropical Cyclones and Climate Change

Sept. 5, 2019



My homepage:
www.gfdl.noaa.gov/tom-knutson-homepage

WMO Task Team on Tropical Cyclones and Climate Change

https://www.wmo.int/pages/prog/arep/wwrp/tmr/tc-panel.html

Team Members: Thomas Knutson[1], Suzana J. Camargo[2], Chang-Hoi Ho[5], Mrutyunjay Mohapatra[7], Masaki Satoh[8], Kevin Walsh[10], Liguang Wu[11]

Emeritus members on Author Team: Johnny C. L. Chan[3], Kerry Emanuel[4], James Kossin[6], Masato Sugi[9]

[1]Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, NJ USA.
[2]Lamont-Doherty Earth Observatory, Columbia University, Pallisades, NY USA
[3]Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong, Kowloon, China
[4]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA
[5]School of Earth and Environmental Sciences, Seoul National University, Seoul, Korea
[6]National Centers for Environmental Information/NOAA, Center for Weather and Climate, Madison, WI USA
[7]India Meteorological Department, New Delhi, India
[8]Atmosphere and Ocean Research Institute, University of Tokyo, Chiba, Japan
[9]Meteorological Research Institute, Tsukuba, Japan
[10]School of Earth Sciences, University of Melbourne, Victoria, Australia
[11]Nanjing University of Information Science and Technology, Nanjing, Jiangsu Province, China

New Reports: **(available at Bull. Amer. Meteorological Society early online release site)**

1. "Tropical Cyclones and Climate Change Assessment: Part I. Detection and Attribution" http://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-18-0189.1

2. "Tropical Cyclones and Climate Change Assessment: Part II. Projected Response to Anthropogenic Warming". https://journals.ametsoc.org/doi/abs/10.1175/BAMS-D-18-0194.1

Type I vs. Type II error: which is worse?

(Ref.: Lloyd and Oreskes, *Earth's Future*, 2018)

<u>Type I error</u> refers to "claiming something that is not the case or overstating an effect, aka a false positive"

<u>Type II error</u> refers to "missing something that is the case or understating an effect, aka a false negative".

In the D&A chapter of CSSR, we used the conventional approach of preferentially avoiding Type I errors (i.e., cautious approach, requiring robust evidence, evaluating significance at p-level = 0.05, etc., to avoid overstating anthropogenic influence).

Alternatively, we could have preferentially sought to avoid Type II errors (i.e., avoid missing or understating anthropogenic influence) by using a much weaker criteria, such as "balance of evidence". This would lead to a number of more speculative attribution statements with substantial potential for false alarms (i.e., overstating anthropogenic influence).

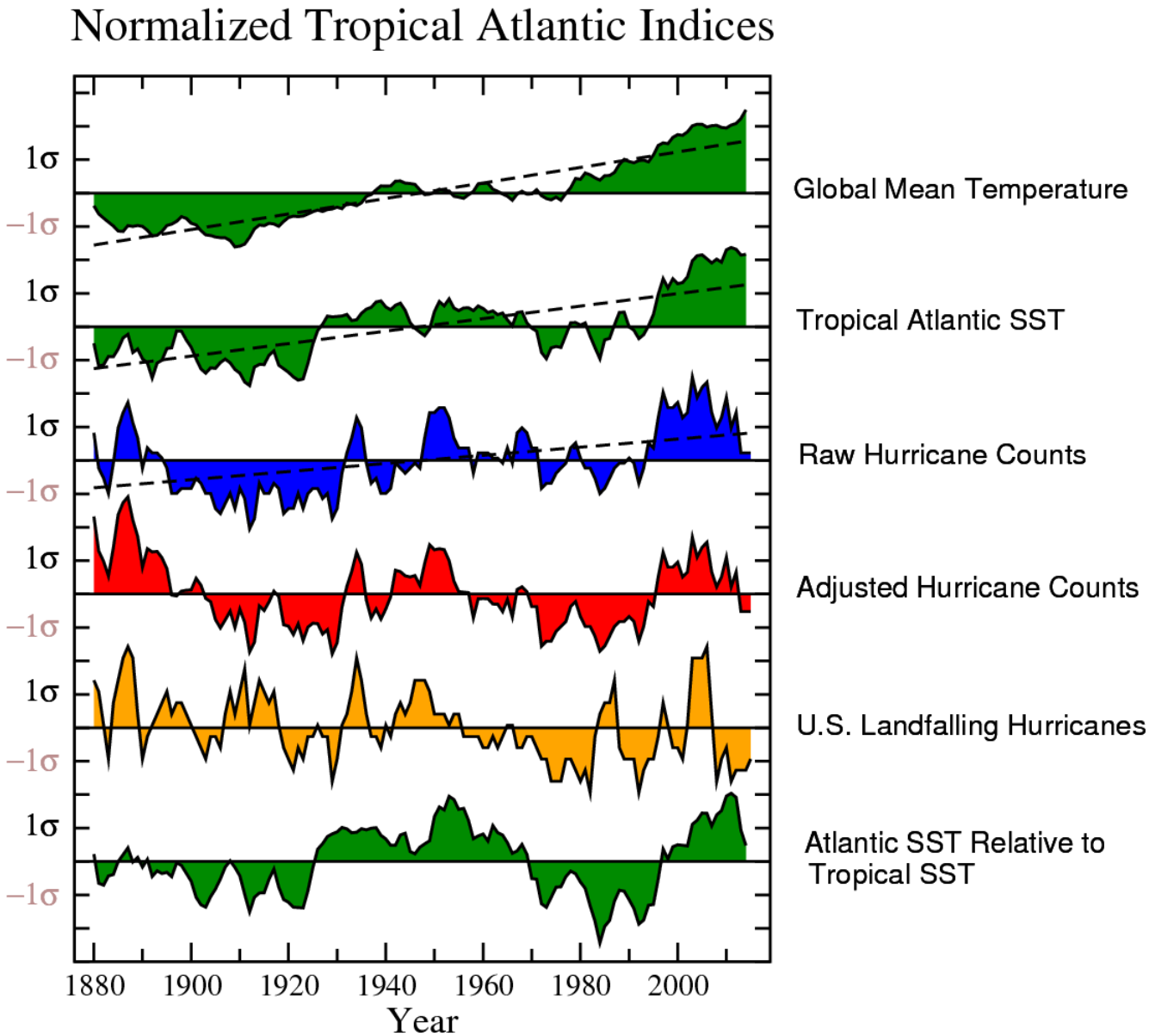
Deciding which approach to use is a policy/audience question.

Summary: Detection and Attribution of TC Changes

1) **<u>Type I error avoidance</u>** (i.e., avoid overstating anthropogenic influence or detection; Lloyd & Oreskes 2016):
   - Observed poleward migration of the latitude of maximum intensity in the western North Pacific is detectable, or highly unusual compared to expected natural variability *(low-to-medium confidence;* 8/11 authors*).*
   - *Low confidence* that any other observed TC changes represent either detectable or attributable anthropogenic changes (majority of authors).

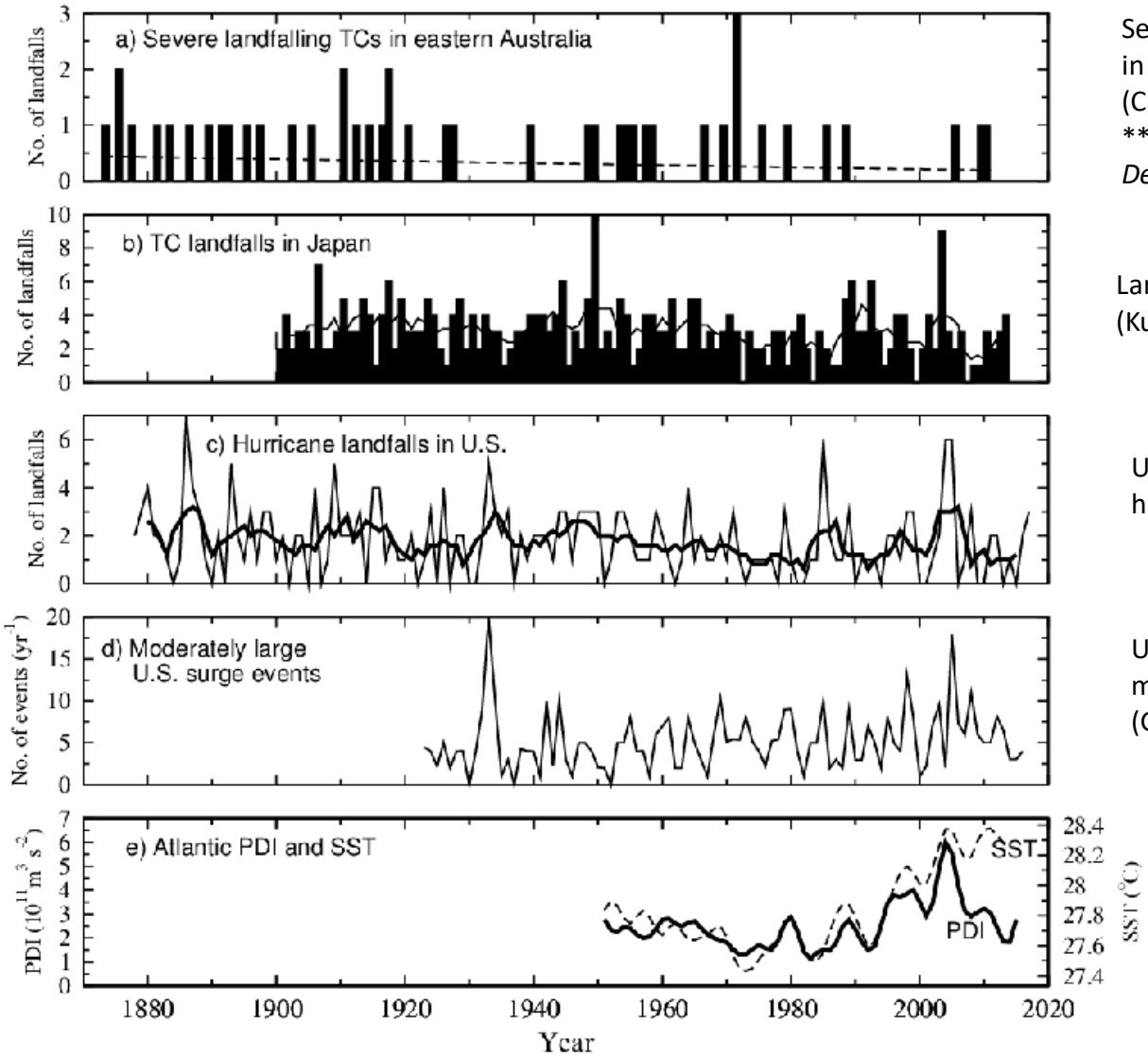
2) **<u>Type II error avoidance</u>** (i.e., avoid understating anthropogenic influence or detection):
   - A balance of evidence suggests an anthropogenic influence on the following detectable changes:
     - poleward migration of the latitude of maximum intensity in the western North Pacific;
     - increased occurrence of extremely severe (post-monsoon season) Arabian Sea TCs;
     - increase of global average intensity of the strongest TCs since early 1980s;
     - increase in global proportion of TCs reaching Category 4 or 5 intensity in recent decades;
     - increased frequency of Hurricane Harvey-like extreme precipitation events in the Texas region.
   - A balance of evidence suggests an anthropogenic influence (without detection) on:
     - unusually high TC frequency near Hawaii in 2014
     - unusually active TC season in the western North Pacific in 2015.
   - A balance of evidence suggests detectable (but not attributable) changes:
     - decreases in frequency of severe landfalling TCs in eastern Australia since the late 1800s;
     - decreased global TC translation speeds since 1949.

No clear evidence for detectable century-scale trend in Atlantic hurricane frequency



Source: Vecchi and Knutson (2011). Five-year running means, updated through 2017.

Long Tropical Cyclone-related Historical Records



Severe landfalling TCs in eastern Australia (Callaghan and Power)
** *Balance of evidence: Detectable decrease*

Landfalling TCs in Japan (Kumazawa et al. 2016)

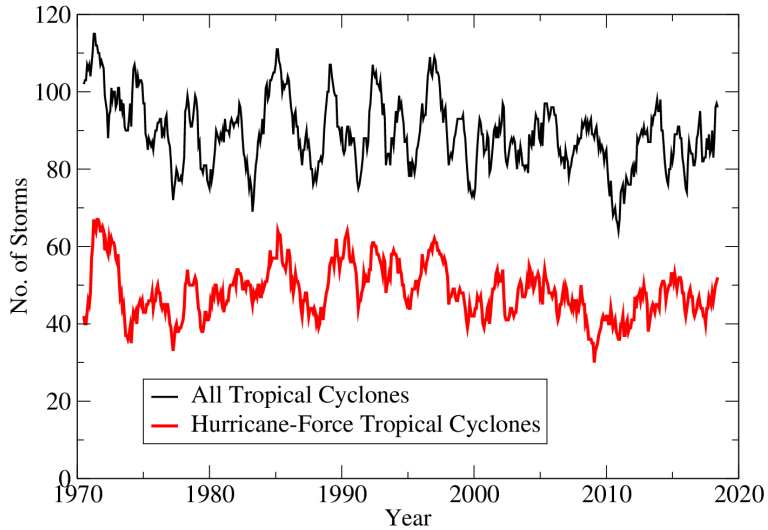
U.S. Landfalling hurricanes (HURDAT)

U.S. Surge index for moderately large events (Grinsted et al)

Atlantic TC Power Dissipation Index and SST (Emanuel)

Sources: See above. Figure in Knutson et al., BAMS, 2019.

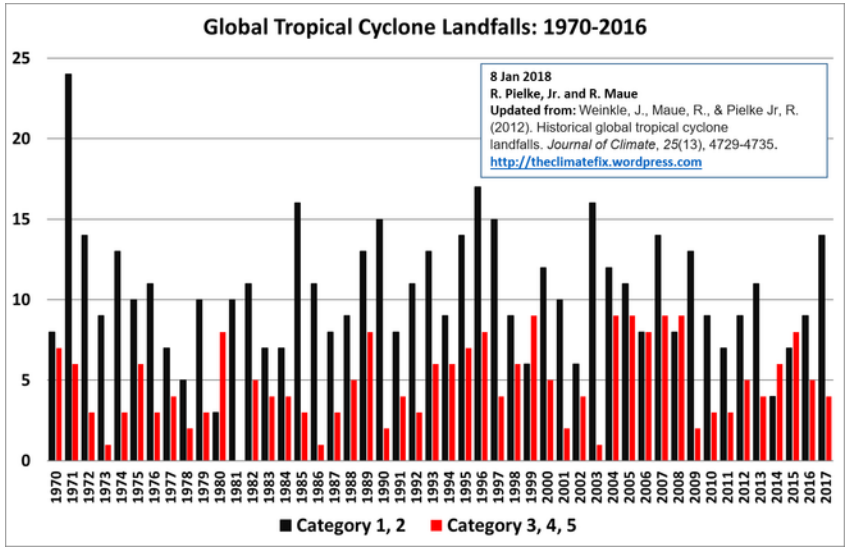
Global tropical cyclone frequency records



Note: TCs here refers to storms of at least tropical storm intensity. Source: R. Maue, GRL (2011), personal communication 2018.

All Tropical Cyclones

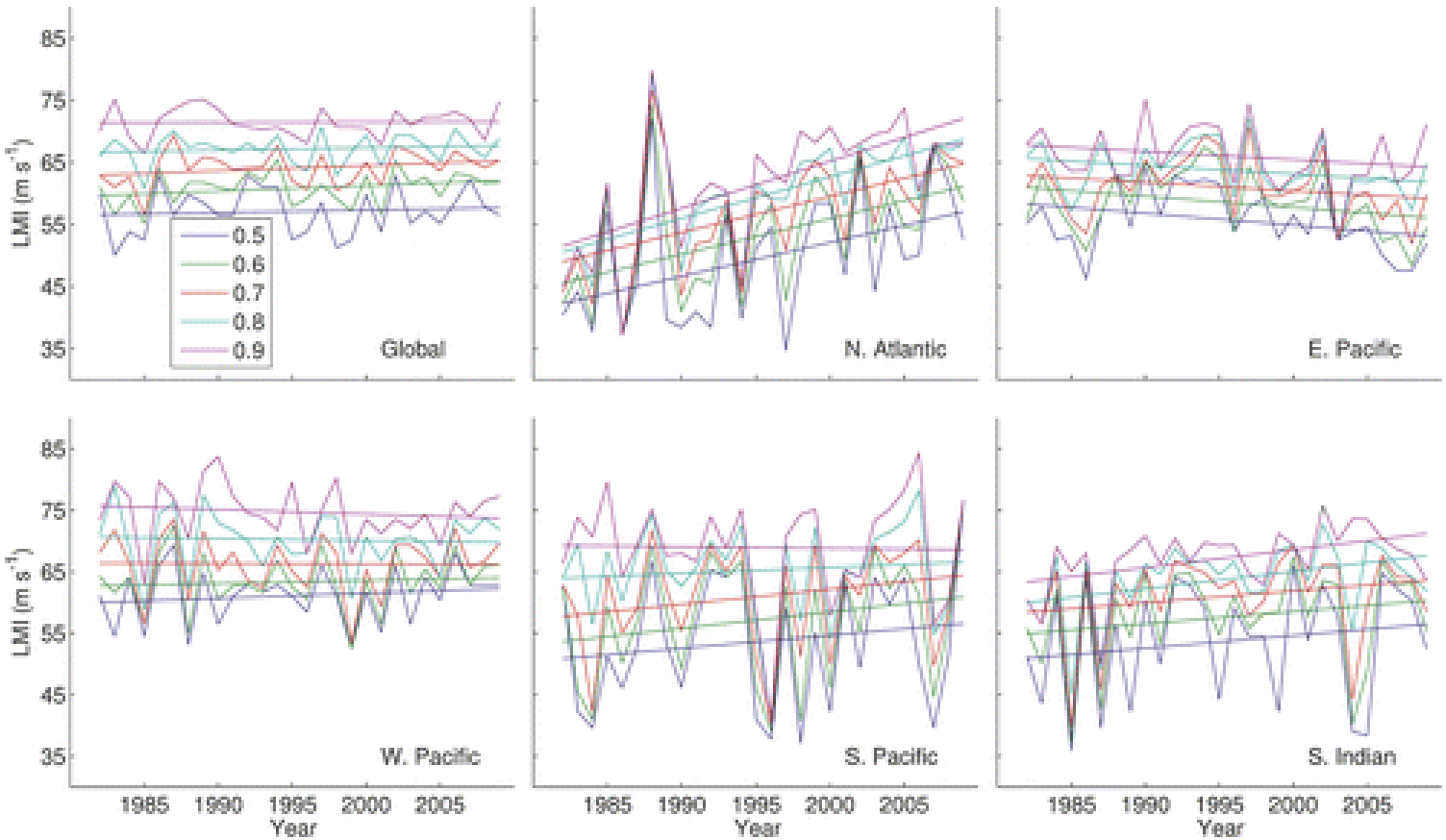
12-month running sums (1970-May 2018).
Data provided by R. Maue,
Updated from Maue, *GRL*, 2011



Landfalling TCs only

Update of Weinkle et al. J. Climate 2012 provided by R. Pielke, Jr. and R. Maue

TC maximum intensity trends by quantile from ADT-HURSAT



- Global: Marginally significant trend (p = 0.1) in LMI of relatively strong (> 60 m/s) TCs
- N. Atlantic: Strong upward trend, but record is short compared to multidecadal variability there.
- Increase is consistent with expected sign of response to greenhouse warming
- ** *Balance of evidence: global detectable anthropogenic increase for strongest TCs*

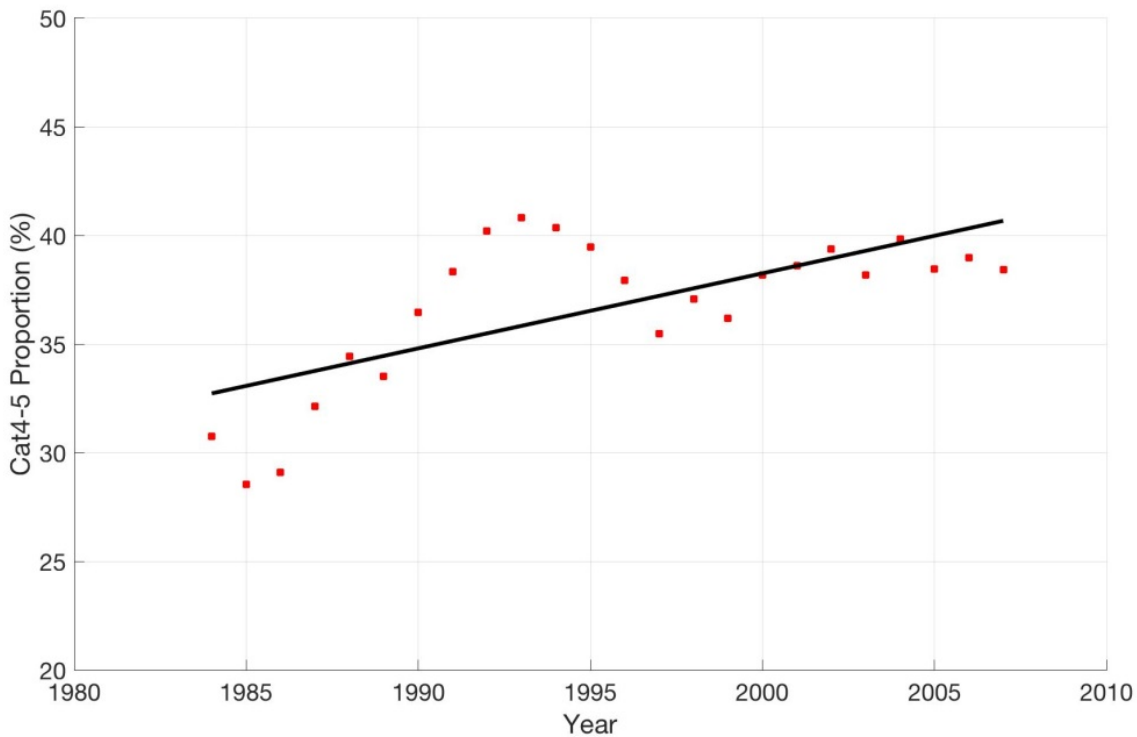
Source: Kossin et al., J. Climate (2013)

Global proportion of TCs reaching Cat 4-5 levels has increased significantly in both best track and ADT-HURSAT, consistent in sign with expected responses to greenhouse warming…

Notes:

- Cat 4-5 proportion at landfall in Weinkle et al. (2012) has increased significantly with ACCI since 1975 (H & B 2014).
- No direct assessment Cat 4-5 proportion using historical forcing climate model runs.
- *** Balance of evidence: global detectable anthropogenic increase*

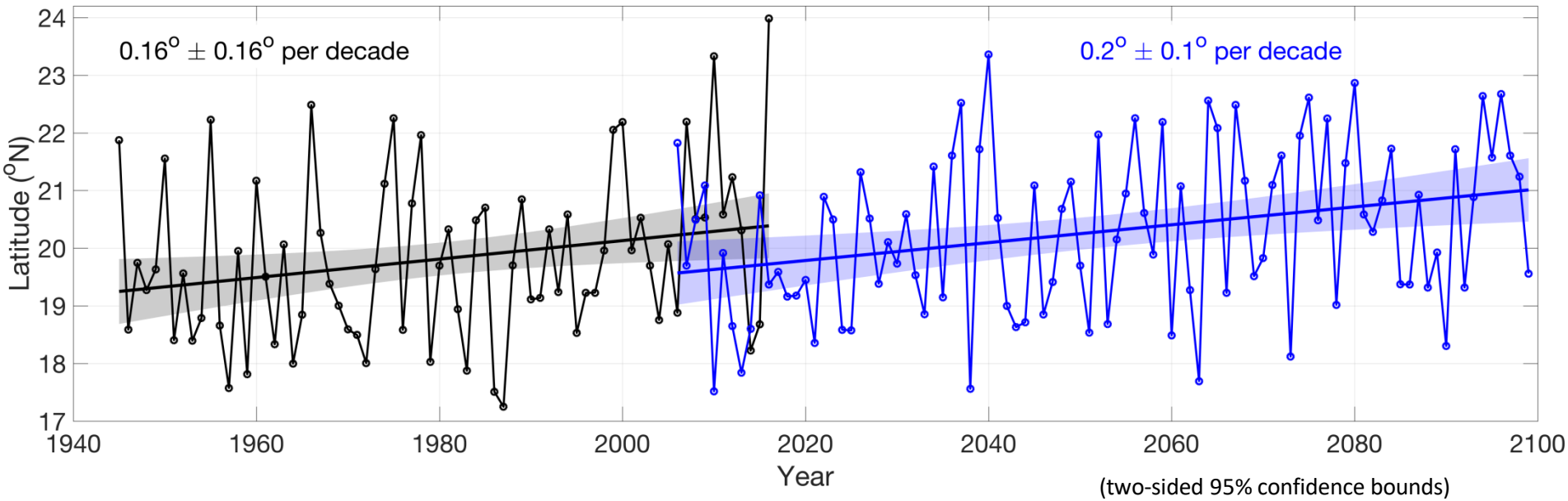
Cat 4-5 proportion: ADT-HURSAT data



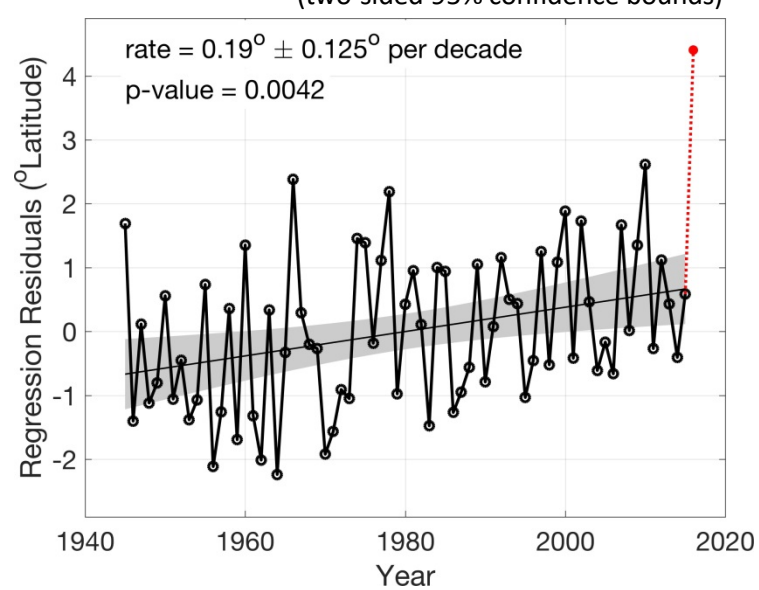
Source: Jim Kossin personal communication; Holland and Bruyere (2014) Climate Dynamics.

Long-term trends in the latitude of maximum intensity: western North Pacific

Ensemble of CMIP-5 (RCP8.5) projections



(two-sided 95% confidence bounds)



Are changes detectable? That is, can we separate part of them from internal variability?

Western North Pacific known dominant modes of (ostensibly) internal variability:
ENSO (inter-annual)
PDO (decadal)

*** Low-to-medium confidence in a detectable increase*

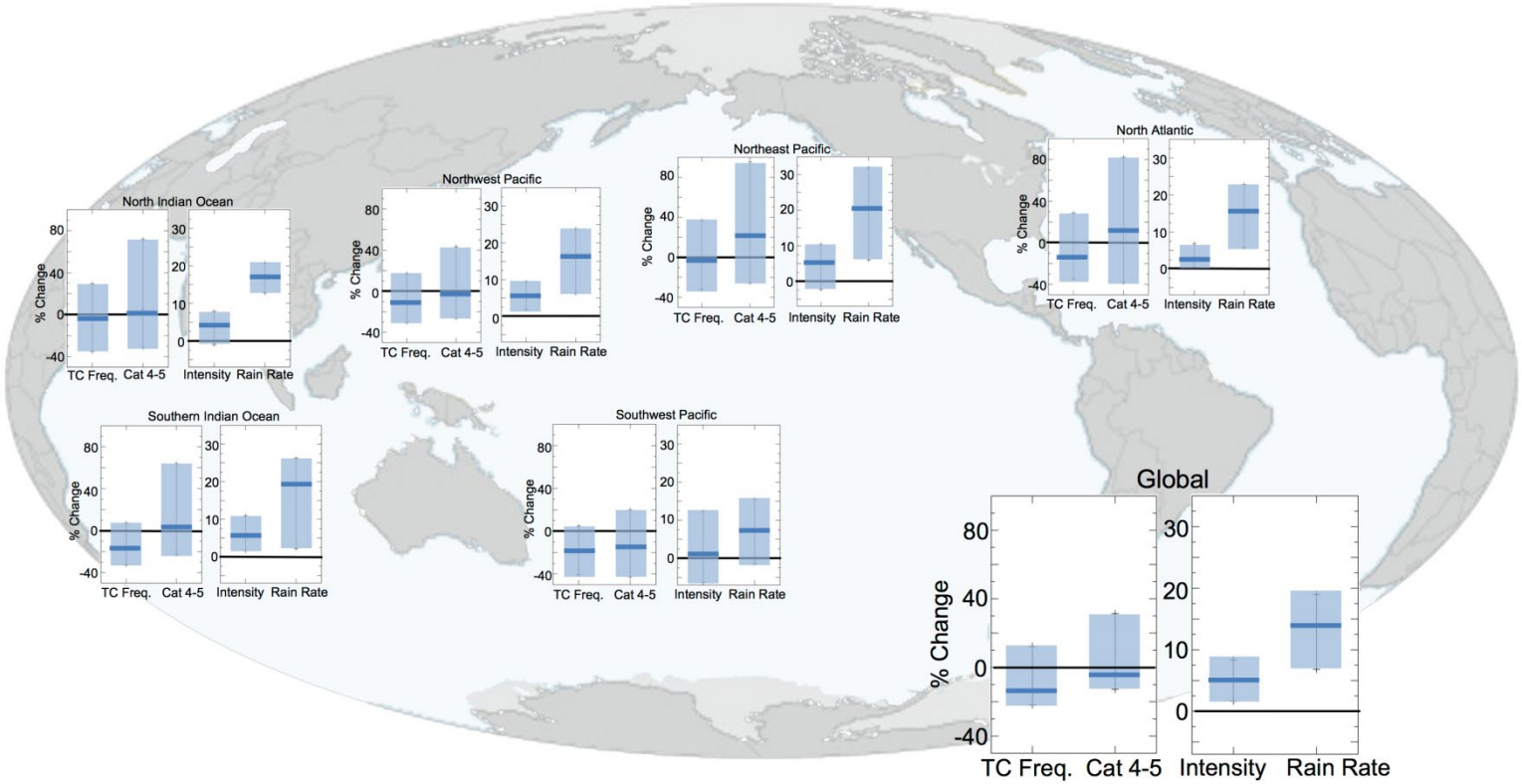
Source: Jim Kossin, NCEI/NOAA

Summary and Conclusions –

TC Projections for a 2°C global warming

1) **Storm Surge**: sea level rise will lead to higher storm inundation levels on average for TCs that occur, assuming all other factors are unchanged. (Not yet detected.)
2) **TC precipitation rates**: at least *medium-to-high* confidence in an increase at the global scale. About +14% for a 2°C global warming, or close to the rate of tropical water vapor increase expected for warming at constant relative humidity. (No detection.)
3) **TC intensity**: at least *medium-to-high confidence* in an increase at the global scale (10/11 authors). Magnitude about 5% (range 1 to 10%) for a 2°C global warming.
4) **Proportion of TCs that reach very intense (Category 4-5) levels:** at least *medium-to-high confidence* in an increase at the global scale. Median projection: +13%
5) **Poleward expansion of the latitude of maximum intensity in the western North Pacific?** (Mixed author opinion on projection; *low-to-medium confidence* in detection of past increase*)*
6) **TC frequency?** Mixed author opinion. 7 of 11 authors had *low-to-medium confidence* in a global decrease. Most modeling studies project a decrease, though mechanism not well known. Median estimate about -13% for 2°C global warming.
7) **Very intense TC frequency (Category 4-5**)? Mixed author opinion on whether this will increase globally or not

Tropical Cyclone Projections (2°C Global Warming)



Source: Knutson et al. (2019). Bulletin of the American Meteorological Society (in press)