Extreme weather in a changing climate

ENERGY MODELING FORUM
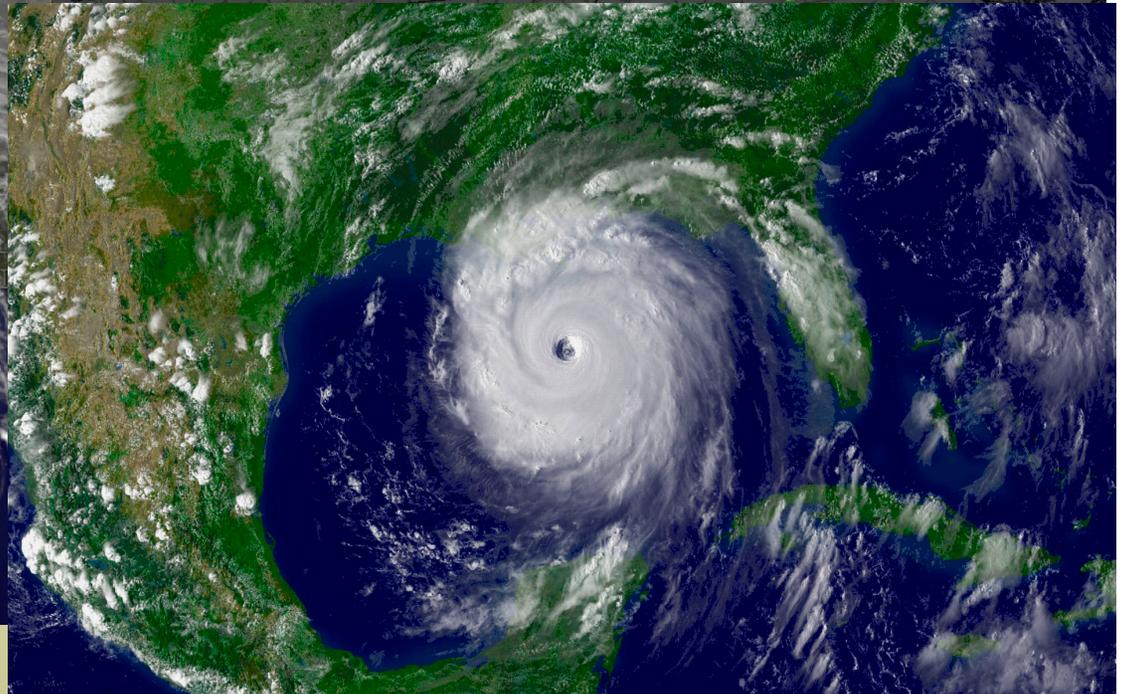Workshop on Climate Change Impacts and Integrated
Assessment (CCI/IA)
Snowmass, Colorado
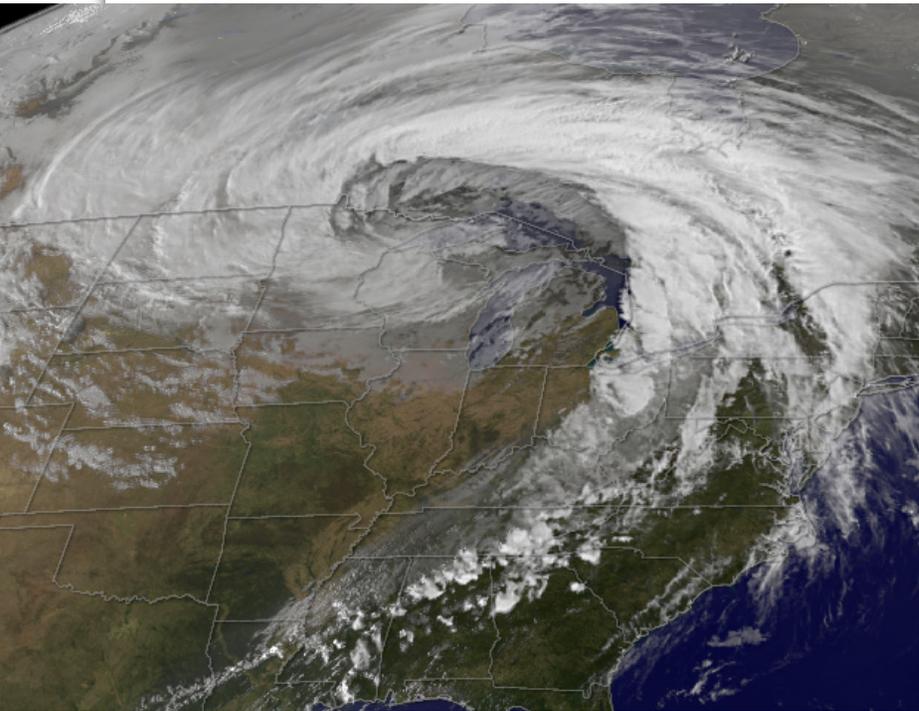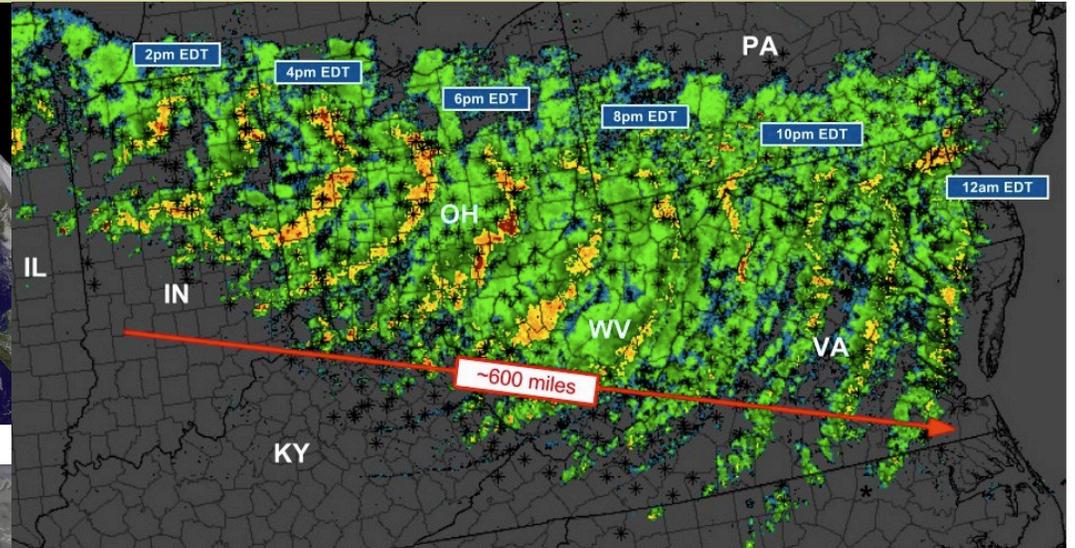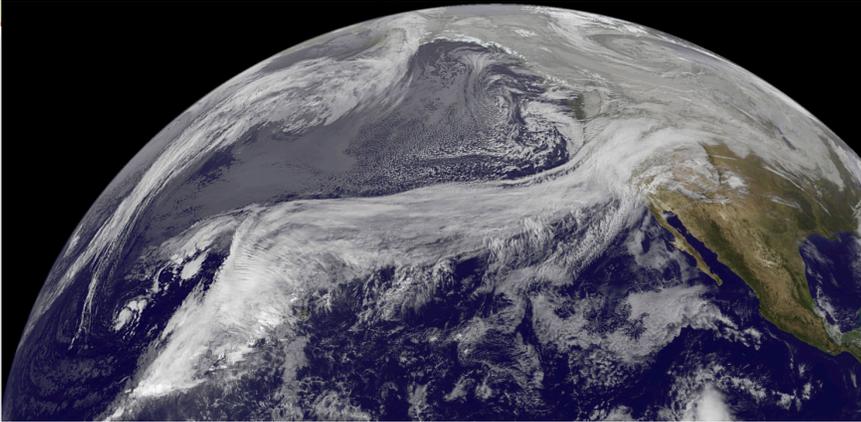July 23, 2014

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Extreme Weather in a changing climate

- AR5 ES:
  - It is *virtually certain* that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase
  - Under RCP8.5 it is *likely* that, in most land regions, a current 20-year high temperature event will occur more frequently by the end of the 21st century (at least doubling its frequency, but in many regions becoming an annual or two-year event) and a current 20-year low temperature event will become exceedingly rare.
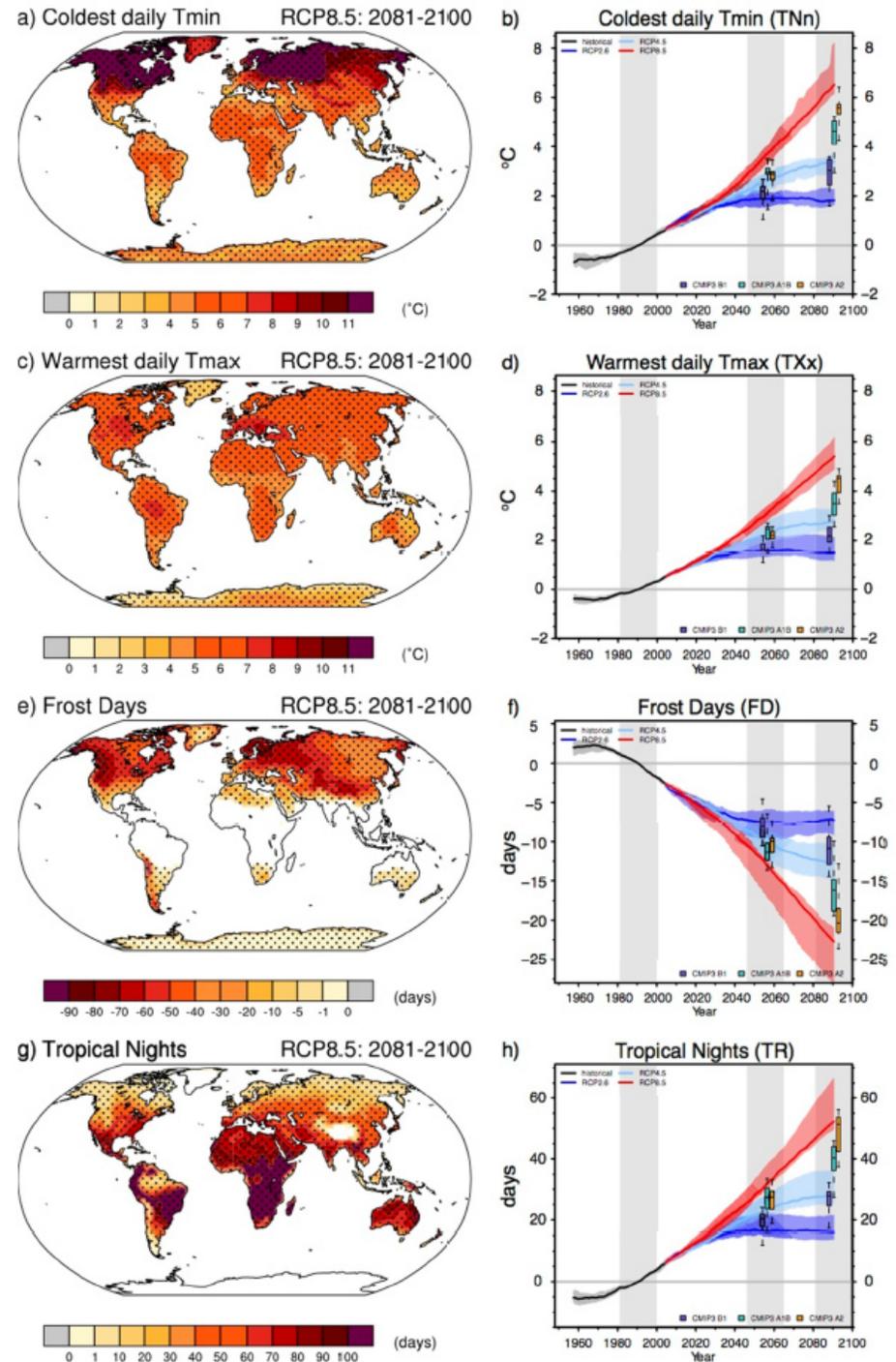
IPCC AR5 AR5 Figure 12.13

- Expert Team on Climate Change Detection and Indices **(ETCCDI)**

- Designed for "detection and attribution".
- Not necessarily relevant to impacts.
- Not very "extreme".
- Multi-model averages.
- Annualized.
- All results presented here are for the end of this century relative to present.

- http://www.cccma.ec.gc.ca/data/climdex/

Sillmann, J., V. V. Kharin, F. W. Zwiers, X. Zhang, and D. Bronaugh, 2013a: Climate extremes indices in the CMIP5 multi-model ensemble. Part 1: Model evaluation in the present climate. *J. Geophys. Res.,* doi:10.1002/jgrd.50203.

Sillmann, J., V. V. Kharin, F. W. Zwiers, X. Zhang, and D. Bronaugh, 2013b: Climate extremes indices in the CMIP5 multi-model ensemble. Part 2: Future projections. *J. Geophys. Res.,* doi:10.1002/jgrd.50188.
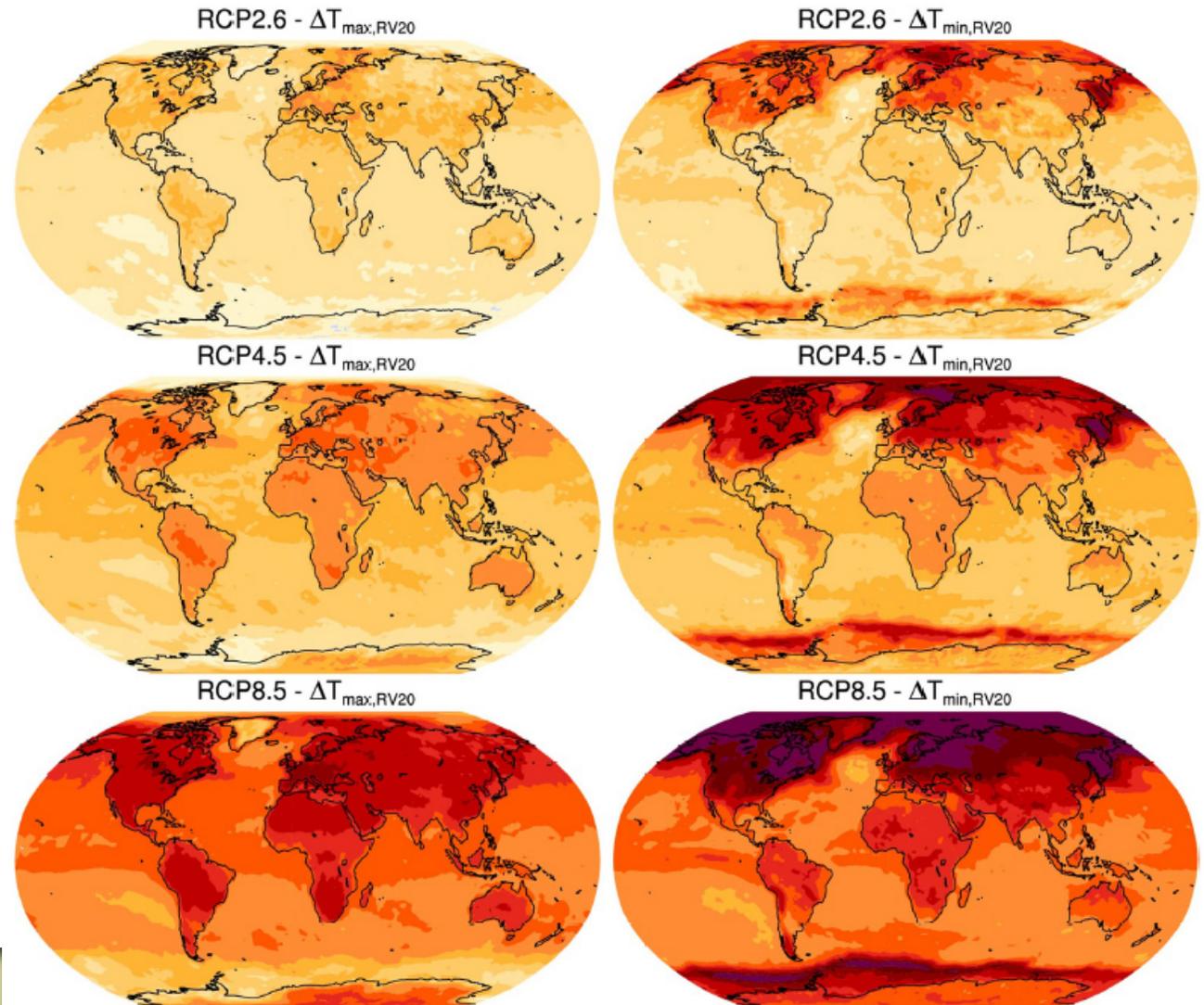
- Changes in 20 year return values of the annual hottest and coldest day.

- "Today's rare hot events become commonplace"

- Cold extremes increase more than hot extremes.

V. V. Kharin, F. W. Zwiers, X. Zhang, M. Wehner (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble, *Climatic Change* **119**, 345-357 10.1007/ s10584-013-0705-8.

Daily surface air temperature 20 year return value change (2081-2100)

Hot — Cold

RCP2.6 - $\Delta T_{max,RV20}$ RCP2.6 - $\Delta T_{min,RV20}$

RCP4.5 - $\Delta T_{max,RV20}$ RCP4.5 - $\Delta T_{min,RV20}$

RCP8.5 - $\Delta T_{max,RV20}$ RCP8.5 - $\Delta T_{min,RV20}$

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 7 9 11 (°C)

3rd US National Climate Assessment: Rare temperature extremes

- Same data as IPCC AR5
  - Kharin et alli (2013)
  - 20 year return values

- RCP2.6 (geoengineering)
  - Increases in hot extremes limited to ~3ºF or less in US

- RCP8.5 (no GHG policies)
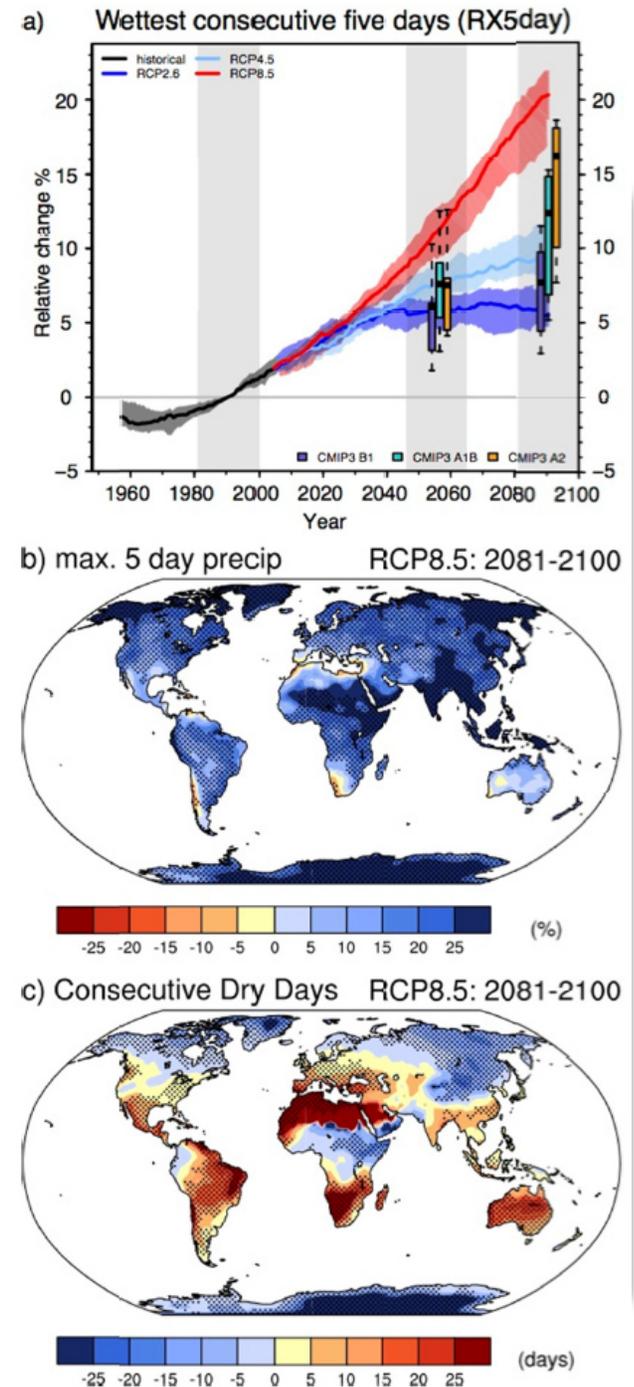 - Increases in hot extremes exceed ~9ºF in US

- AR5 ES:
  - Globally, for short-duration precipitation events, a shift to more intense individual storms and fewer weak storms is *likely* as temperatures increase.
  - Regional to global-scale projected decreases in soil moisture and increased risk of agricultural drought are *likely* in presently dry regions and are projected with *medium confidence* by the end of this century under the RCP8.5 scenario.

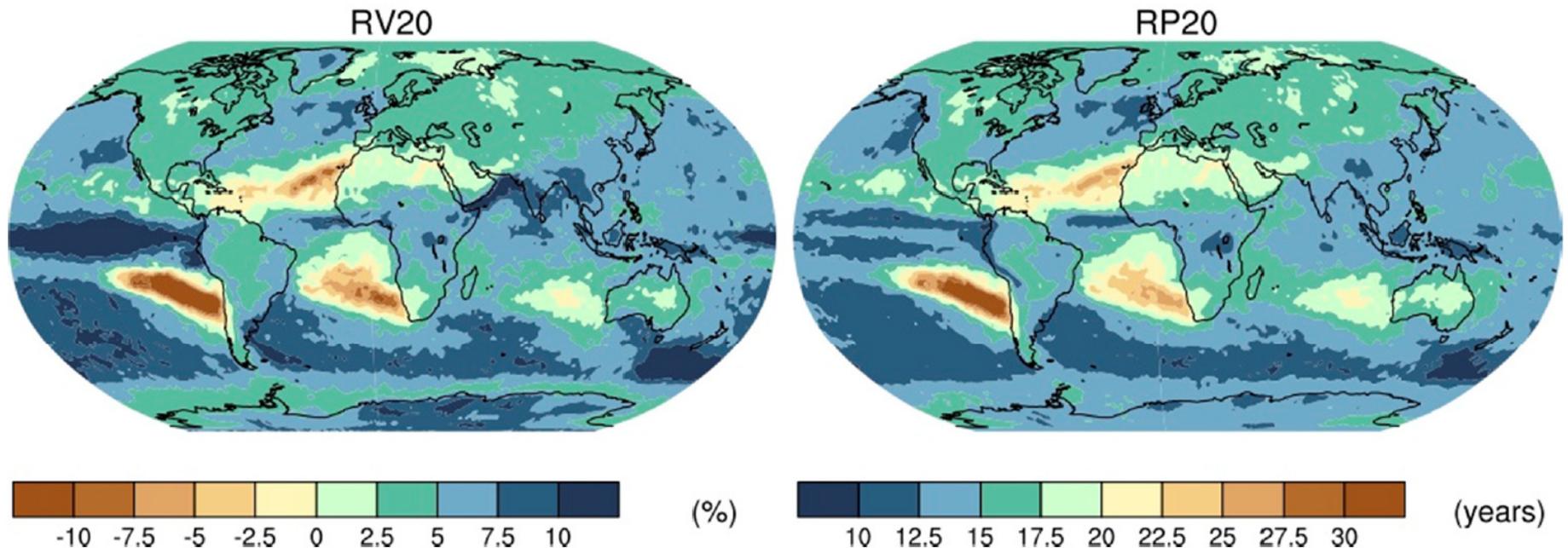# IPCC AR5 Figure 12.26: extreme precipitation

- Expert Team on Climate Change Detection and Indices **(ETCCDI)**

- CMIP5 models are much improved over CMIP3!

- Heavier heavy rainy days in most places.
- Longer dry seasons in dry places.

a) Wettest consecutive five days (RX5day)

b) max. 5 day precip   RCP8.5: 2081-2100

c) Consecutive Dry Days   RCP8.5: 2081-2100

- CMIP5 models are limited by their coarse resolution to reproduce severe storms

- Return value and period expressed as the amount per $^\circ$C local temperature increase rather than give the scenario projections
- A deliberate choice to downplay the attention paid to this figure.

Daily precipitation 20 year return value and return period change (2081-2100)

- "Frequency change multiplier" (aka Risk Ratio)

$$= RP_{2000} / RP_{2100}$$

Projected Change in Heavy Precipitation Events

Rapid Emissions Reductions (RCP 2.6)

Continued Emissions Increases (RCP 8.5)

Future Change Multiplier

1   2   3   4   5   6   7

Office of
Science
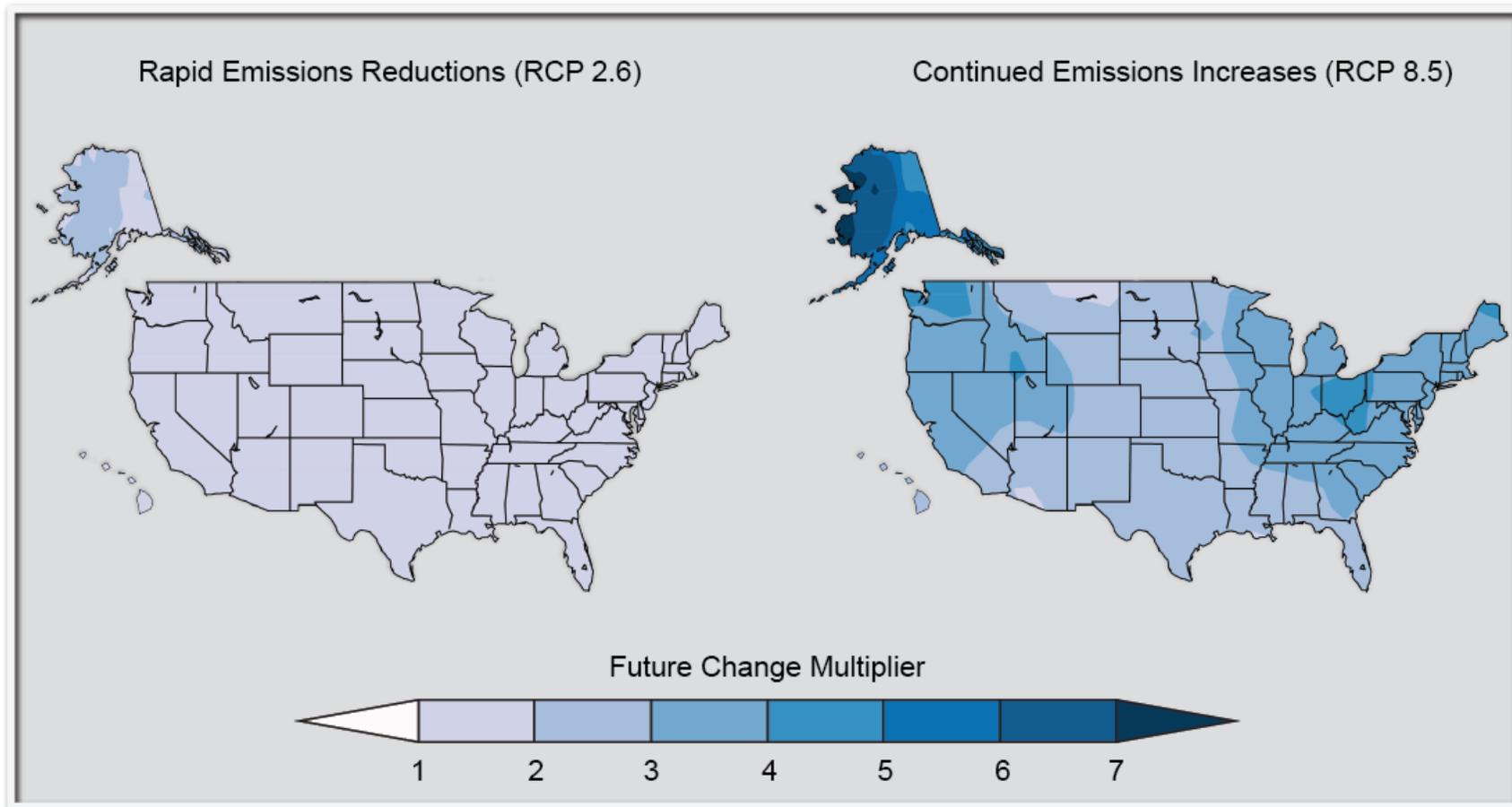
CMIP5 models and extreme weather projections

- Great caution should be taken in the interpretation of projections at smaller scales.
- Why should we expect the CMIP5 ensemble average to resemble the actual world?
  - The real world is one realization in a complex space of possible weather.
  - Internal variability (noise) is large at small space and time scales.
  - CMIP5 is almost always presented as a multi-model average.
    - Better to think of it as an (incomplete) probability distribution.
- Are the observations consistent with this distribution?
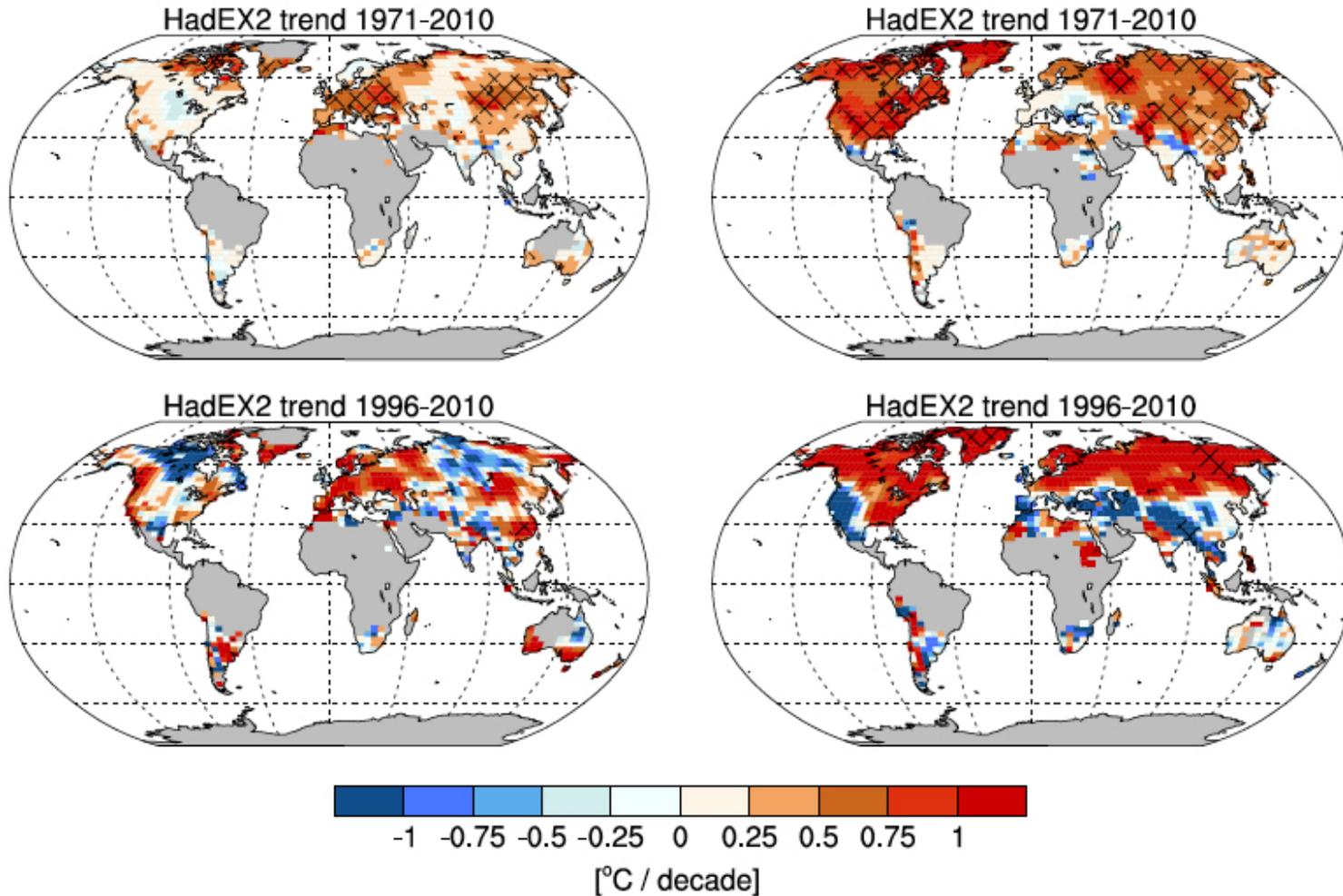- Start thinking like a statistician…

Sillmann J, Donat M G, Fyfe J C and Zwiers F W 2014 Observed and simulated temperature extremes during the recent warming hiatus Envir. Res. Lett. 9 064023

Wehner, M 2014 A temporary hiatus in warming of extreme temperatures is not unusual, nor inconsistent with model simulations of human-induced climate change. To appear as a Perspective in Envir. Res. Lett.

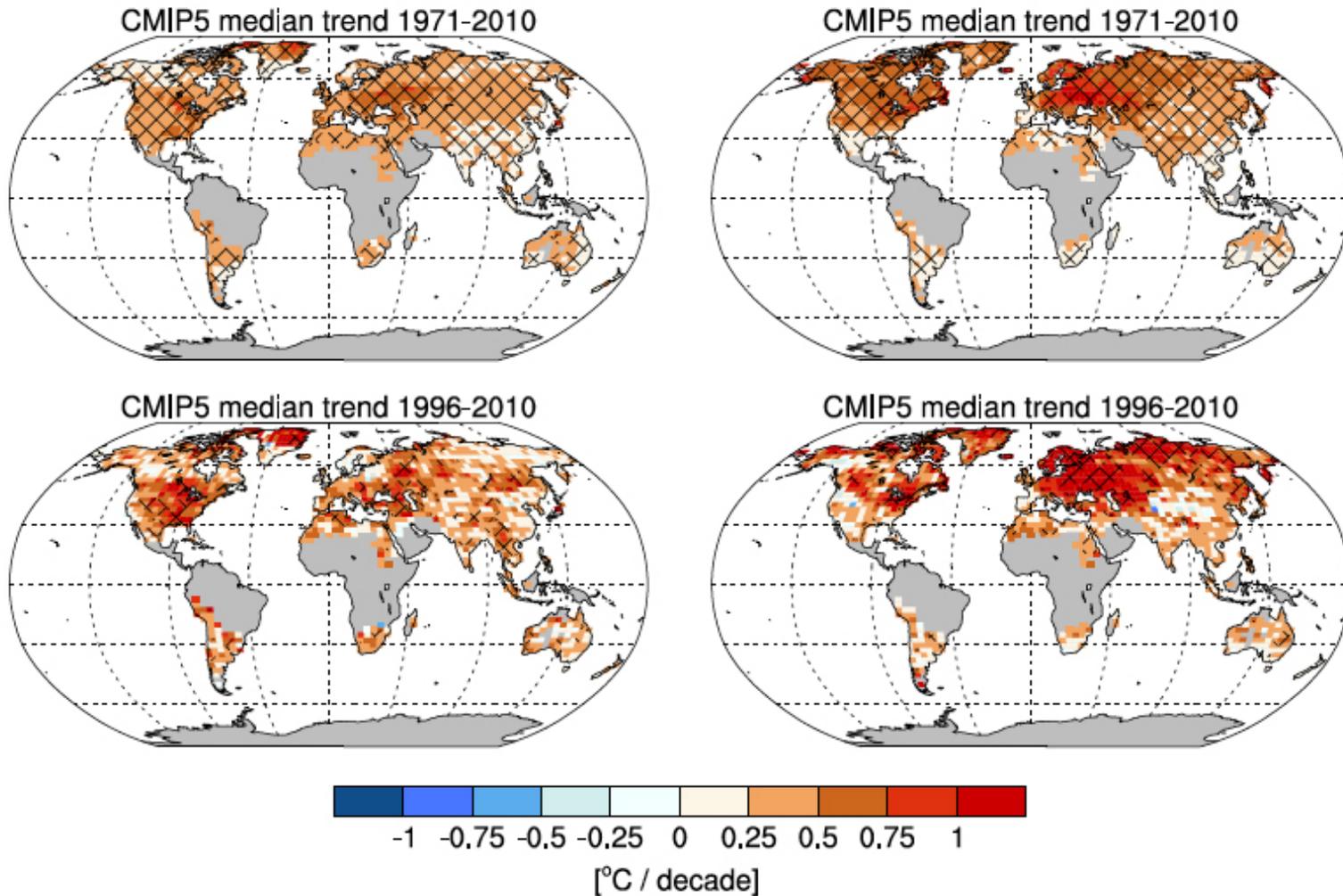# Observed trends

(a) Warmest day [TXx]

HadEX2 trend 1971-2010

HadEX2 trend 1996-2010

(b) Coldest night [TNn]

HadEX2 trend 1971-2010

HadEX2 trend 1996-2010

-1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1

[°C / decade]

CMIP5 multi-model average trends

(a) Warmest day [TXx]

CMIP5 median trend 1971-2010

CMIP5 median trend 1996-2010

(b) Coldest night [TNn]

CMIP5 median trend 1971-2010

CMIP5 median trend 1996-2010

-1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1

[°C / decade]

- The modeled and observed trends in cold and hot extreme temperatures are consistent.
  - Even though the multi-model average is positive everywhere.

- Jana examined 7 sub-continental regions. Observed trends are contained within the 5-95% range of the modeled trends.
  - For all regions for the 1971-2010 period
  - For all but the strong cold night decrease in south Asia for 1996-2010 period.
    - But 4 of the 74 simulations do have a decrease in south Asia. And one is nearly the same magnitude.

- Projections can be interpreted in a similar manner.

Extreme Event Attribution

- When extreme weather happens, the public wants to know
  - "Is this climate change?"

- Not quite the correct question, better to ask:
  - "How has the risk* of this event changed because of climate change?"
  Or
  - "How did climate change affect the magnitude of this event?"

- We approach these questions in two different ways.
1. Use extreme value statistics and the existing CMIP5 "ensemble of opportunity".
2. Design our own ensembles of climate model simulations tailored to event attribution.
   - Climate of the 20th Century C20C (~50 ensemble members)
   - climateprediction.net (~1000+ ensemble members)
   - Not talking about this now, but this is a major effort for us.

* Note:risk means probability to this community

Extreme event attribution: CMIP statistical analysis

- Consider three different summer heat wave events
  - Europe 2003 (~70,000 excess deaths)
  - Russia 2010 (~50,000 excess deaths, massive fires)
  - Texas 2011 (lots of dead cows, massive drought)

- These are very rare events. We are interested in how the rarity of these events has changed.

- We calculated the change in risk by comparing the extreme value statistics in these regions from realistic historical simulations to those in the pre-industrial simulations and the observations.
  - (Skipping the statistical mumbo jumbo, including normalization)

- Real World: with industrialized humans
- Not Real World: without industrialized humans

$$Risk\_ratio = \frac{P_{real}}{P_{Not\_real}}$$
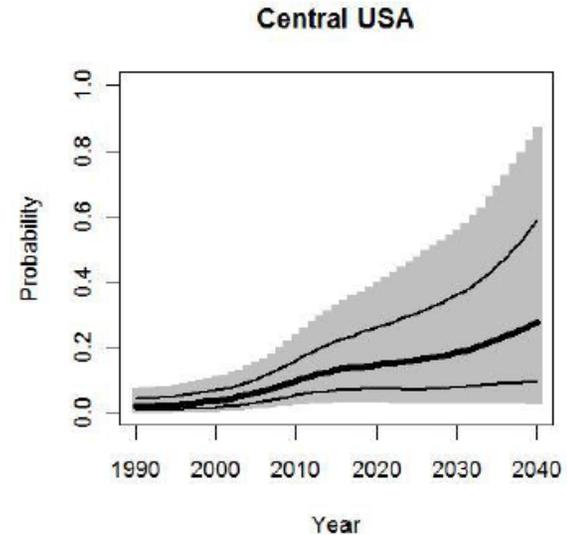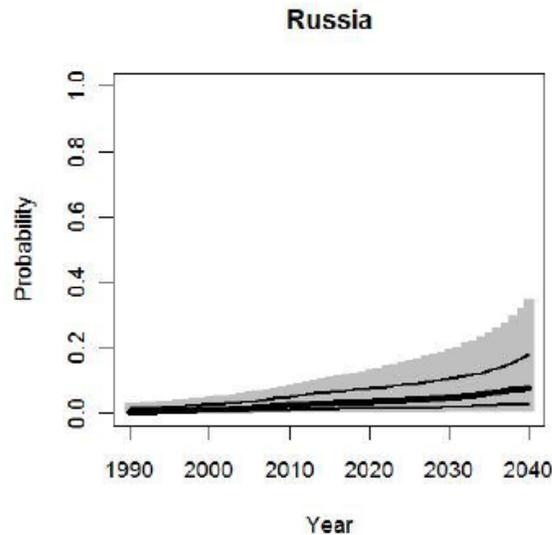
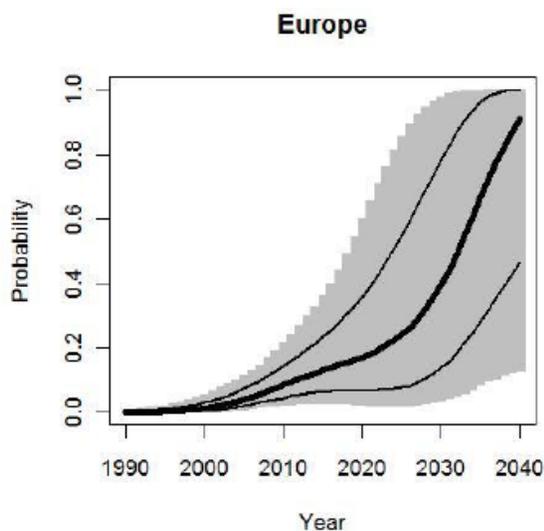$$FAR = 1 - \frac{P_{Not\_real}}{P_{real}}$$

- Fractional attributable risk is often used to determine liability.

The risk of each of these events has least doubled since the preindustrial era

Event	Risk Change at time of event	Change in risk 2023	Change in risk 2040
Europe 2003	~2X	35X	154X
Russia 2010	2-3 X	2.5-4 X	5-8 X
Texas 2011	1.5-4 X	2-5 X	4-10 X
Midwest US 2012	?	?	

Smith & Wehner

High resolution global climate modeling

- The CMIP5 models are far from perfect.
  - The weather is not very realistic. Storm fronts are too broad, diffuse and weak.

- High resolution is required to accurately simulate intense storms.
  - Our aim is to simulate the statistics of extreme weather not forecast actual storms

- ~25km global Community Atmospheric Model (CAM5.1)
  - Able to simulate hurricanes up to Category 5.
  - Far superior extreme precipitation statistics.
  - Circumvents a number of regional modeling issues.
  - Thanks to the large US DOE investment in high performance computing.

  - Our current research focuses on describing the model's ability to simulate extreme weather statistics, assess the changing risk and to project future changes in extreme weather.
  - Model output is available.

CAM5 hi-resolution simulations
(0.25°, prescribed aerosols)

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Lawrence Berkeley National Laboratory

Kevin Reed, University of Michigan

Andrew Gettelman, Julio Bacmeister, Richard Neale
National Center for Atmospheric Research

June 1, 2011

Tropical
Storm

Cat1

Cat2

Cat3

Cat4

Cat5

1979-2005   TD TS H1 H2 H3 H4 H5   iBTrACS Obs.

1979-2005   TD TS H1 H2 H3 H4 H5   25 km CAM 5.1
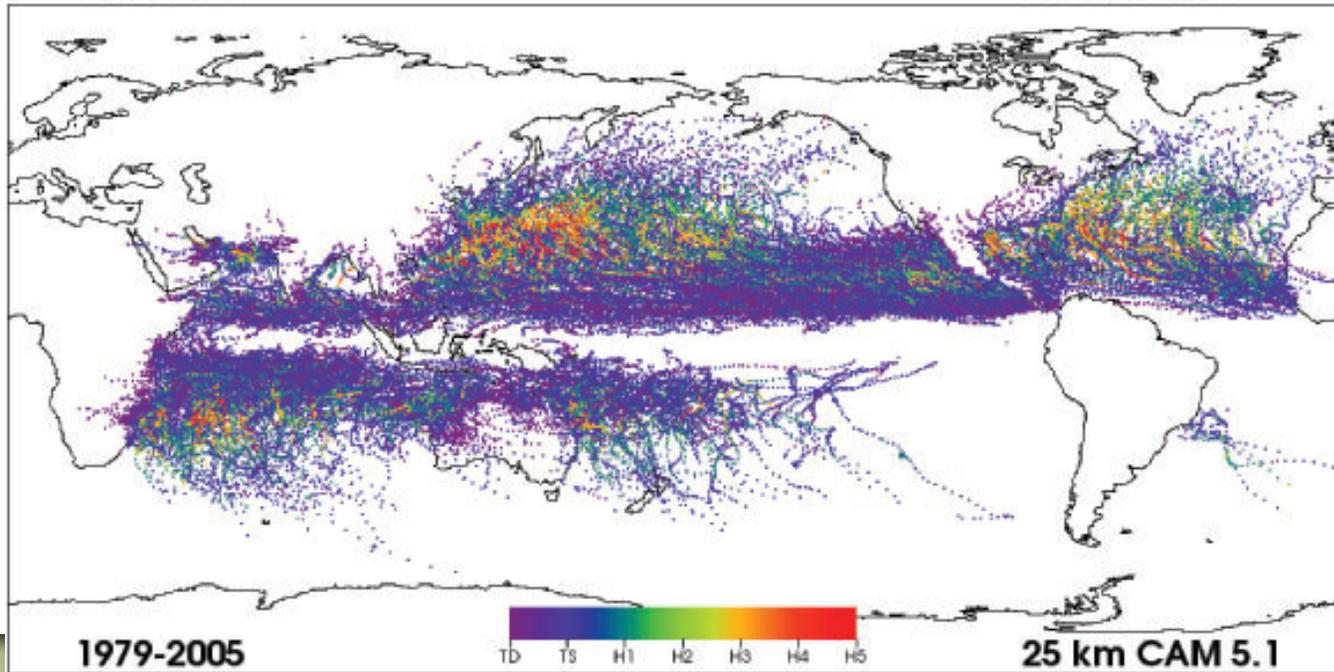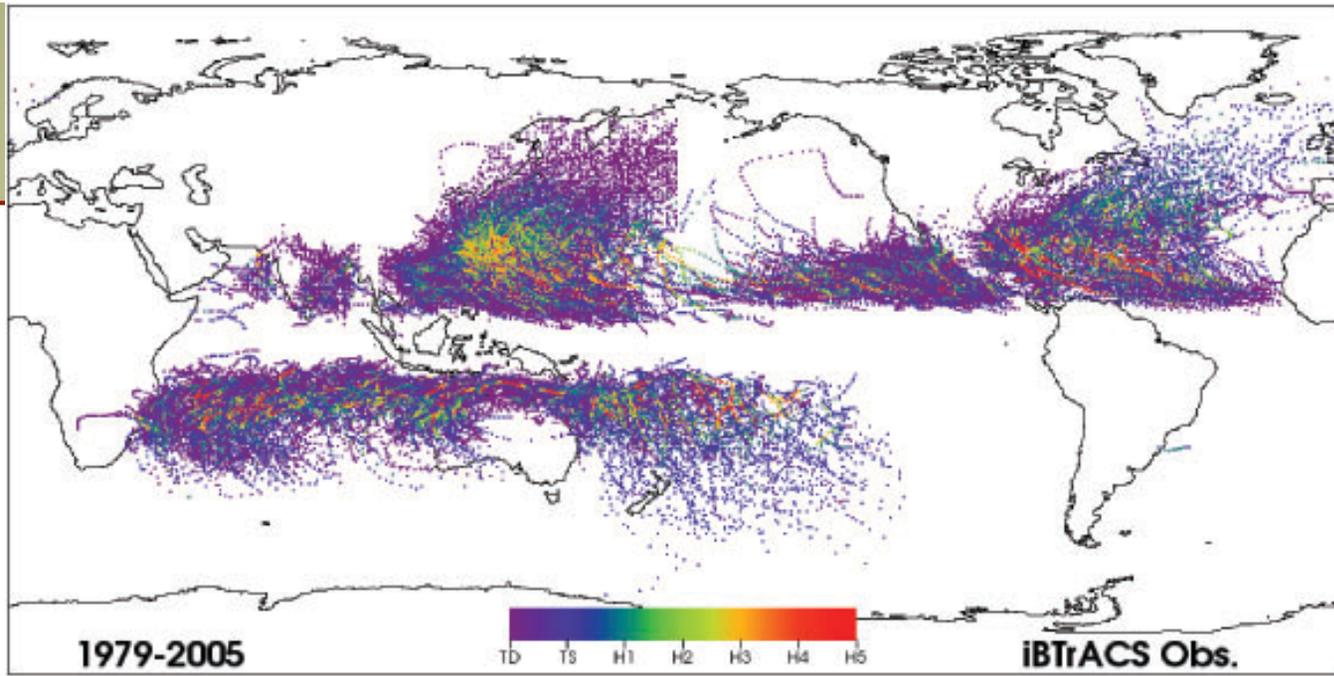
Figures by Prabhat

Cat1

Cat2

Cat3

Cat4

Cat5

1979-2005   TD TS H1 H2 H3 H4 H5   iBTrACS Obs.

1979-2005   TD TS H1 H2 H3 H4 H5   25 km CAM 5.1

Figures by Prabhat

Cat4

Cat5

1979-2005   TD   TS   H1   H2   H3   H4   H5   iBTrACS Obs.

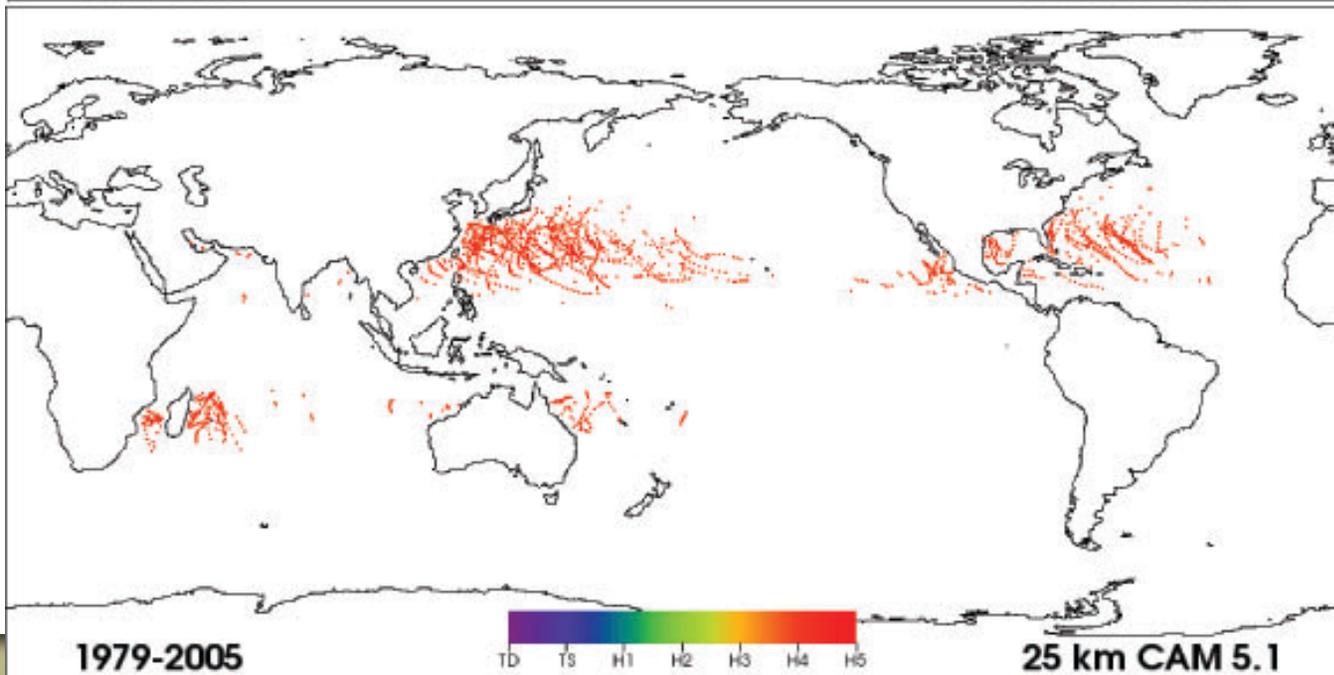1979-2005   TD   TS   H1   H2   H3   H4   H5   25 km CAM 5.1

Figures by Prabhat

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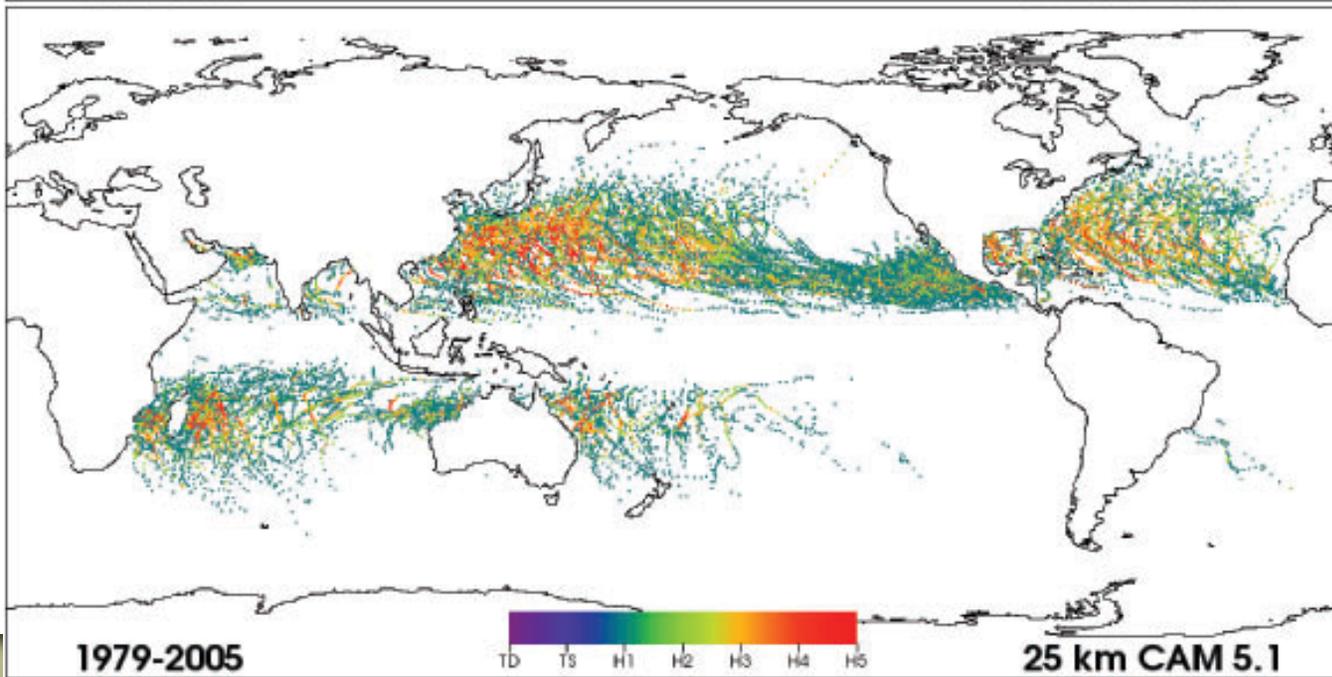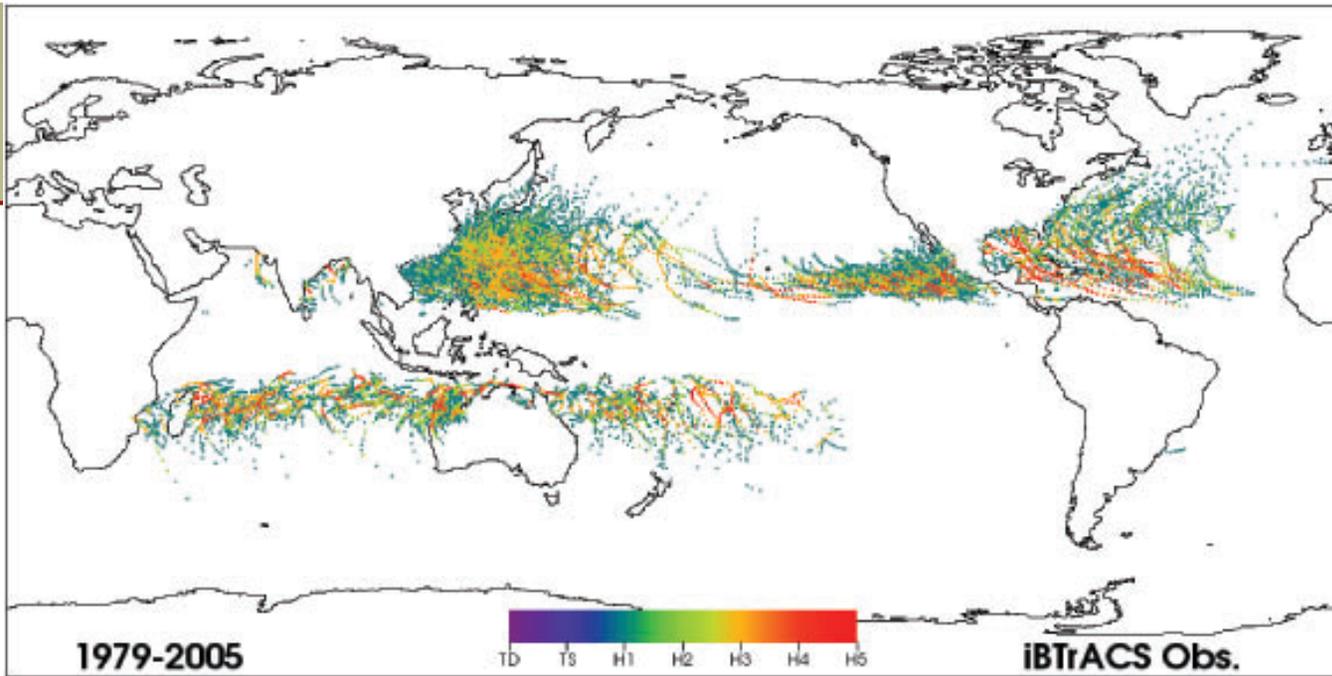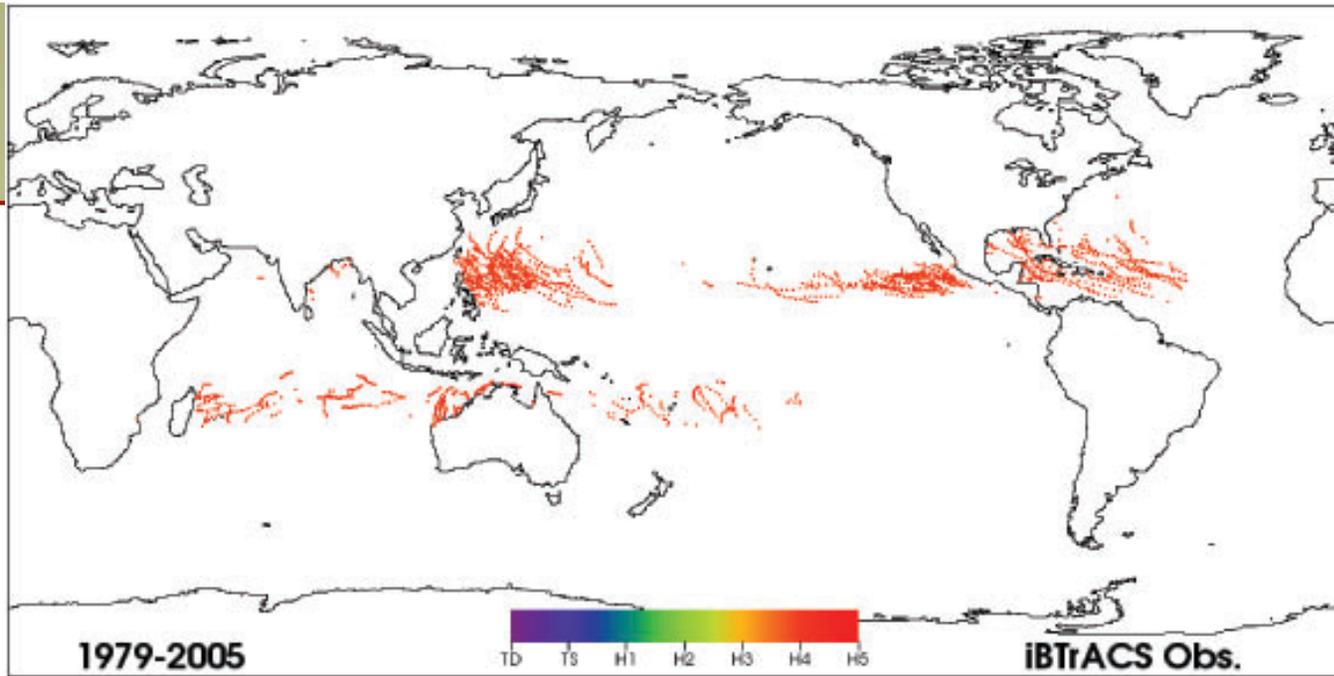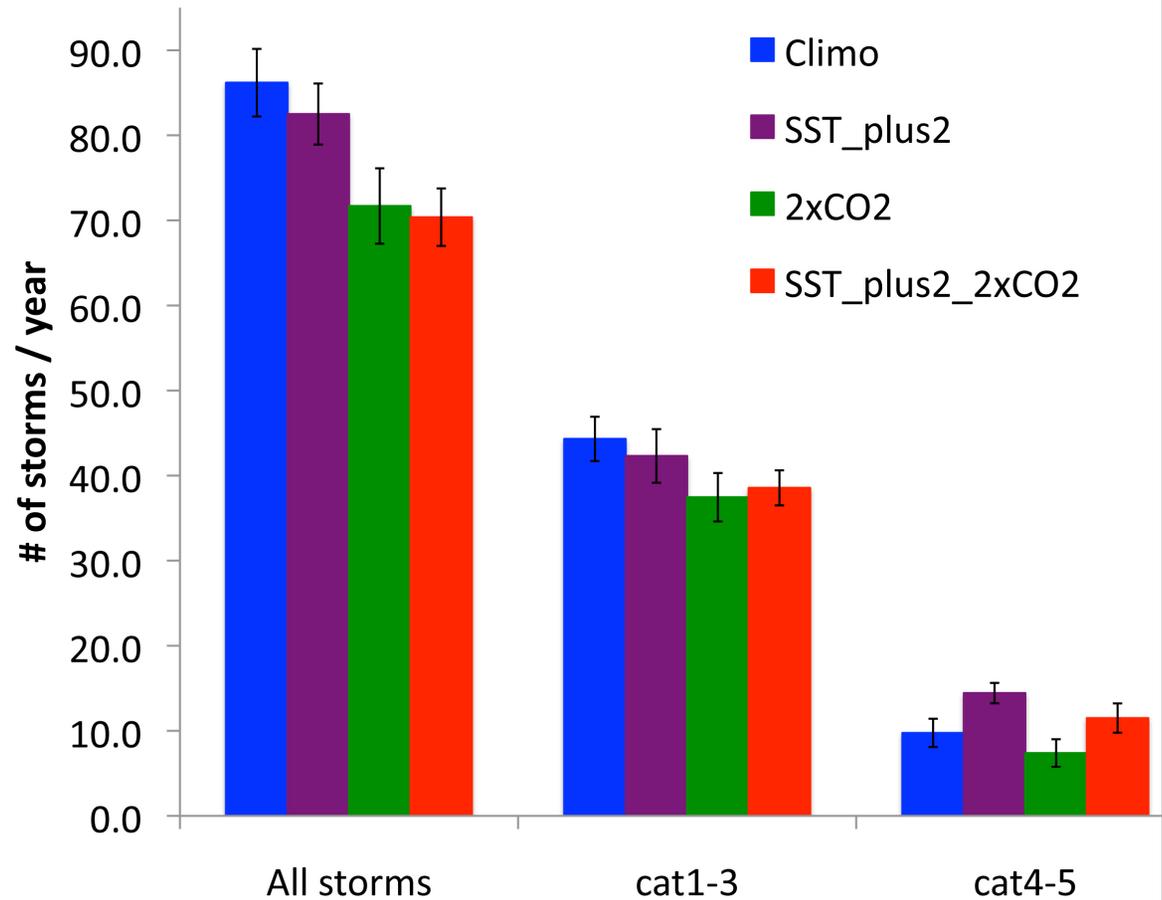
Future global tropical cyclone activity

- Blue = idealized now

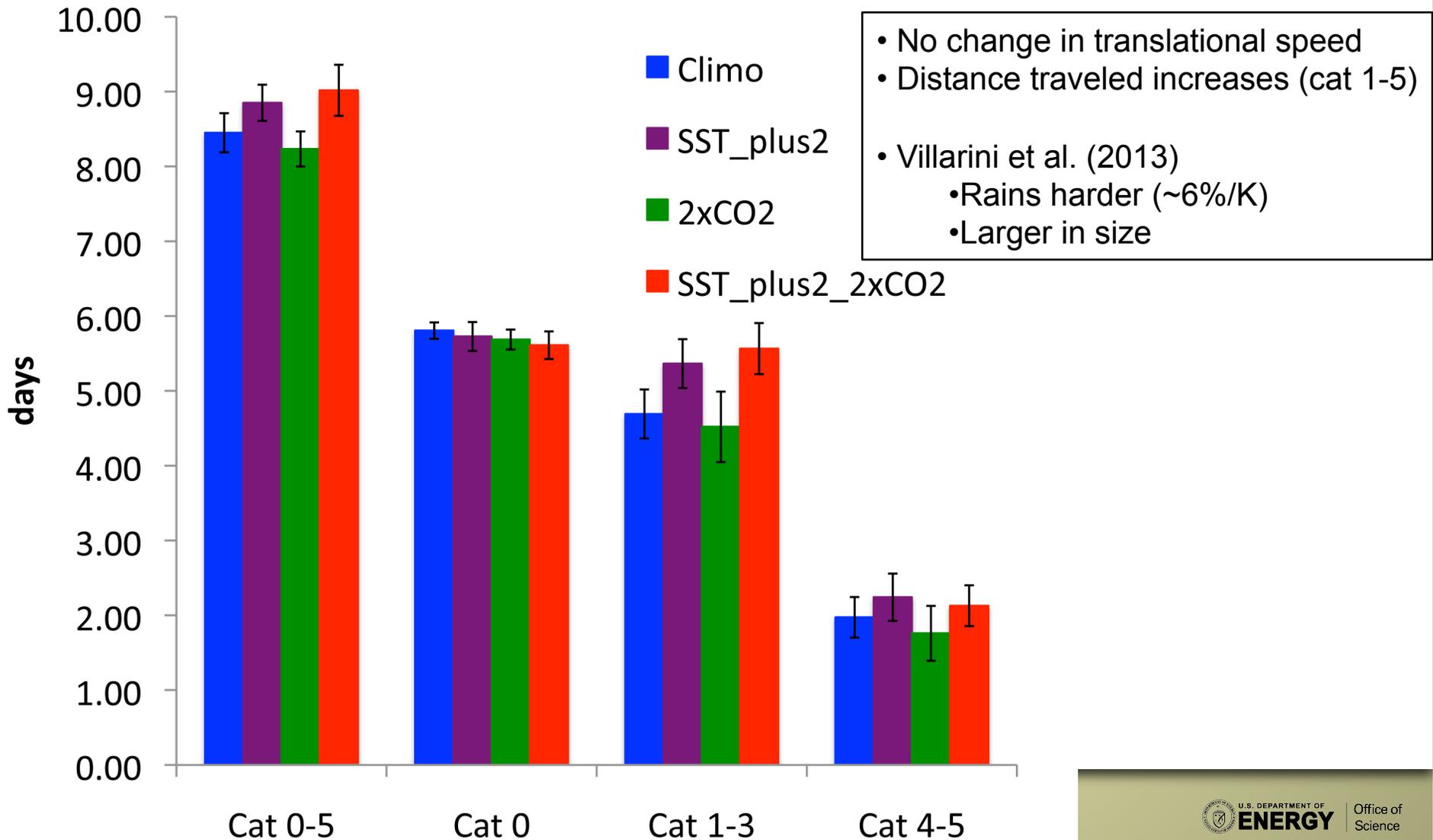- Red = idealized 2° warmer future (aggressive mitigation)

- Fewer total # of tropical cyclone
  - Fewer weak storms
  - More intense storms

TCs last longer in a warmer world

Average Storm duration

Legend:
- Climo (blue)
- SST_plus2 (purple)
- 2xCO2 (green)
- SST_plus2_2xCO2 (red)

- No change in translational speed
- Distance traveled increases (cat 1-5)

- Villarini et al. (2013)
  - Rains harder (~6%/K)
  - Larger in size

X-axis categories: Cat 0-5, Cat 0, Cat 1-3, Cat 4-5
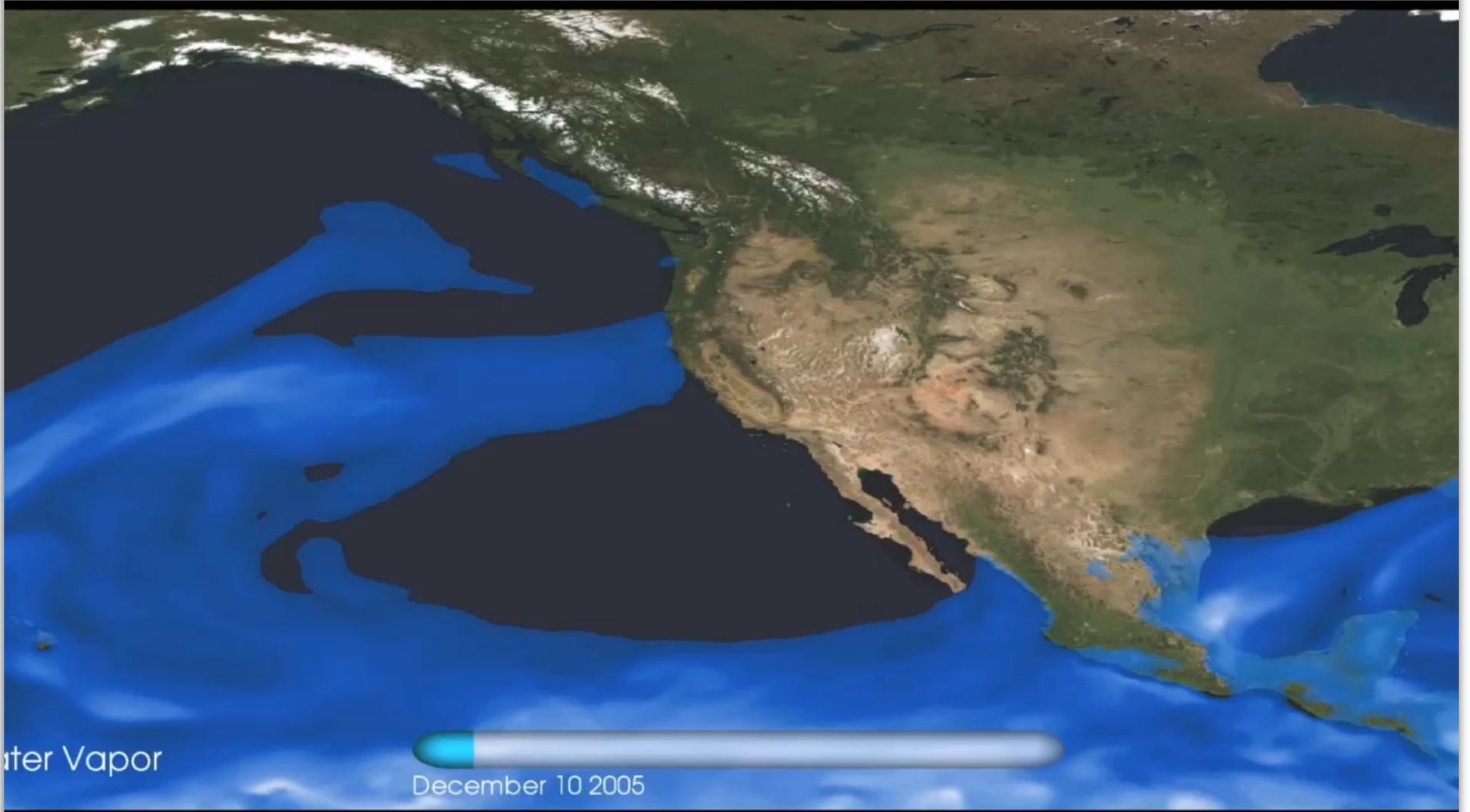
Y-axis: days (0.00 to 10.00)

Multivariate extremes

- Real world systems are multivariate.

- Impacts can depend on the combinations
  - Hot, dry, windy → wildfires
  - Hot, moist, stagnant → human health

- Past and future statistics also depends on the combinations.
  - Mechanisms of changes vary.

- A current project brings climate analysts, impacts scientists and statisticians together
  - Impacts scientists help us define what is "extreme".
  - Statisticians are developing non-asymptotic methods.
  - Climate analysts design targeted numerical experiments

Conclusions

- How could the climate change impacts community use this type of work?
  - Risk of extreme weather.
  - Define impact relevant thresholds.

- The risk of extreme weather is changing and attributable to humans.
- The change in risk of an individual extreme event due to humans can be estimated both now and into the future.
- If impacts can be expressed in terms of thresholds, future changes in risk and its uncertainty can be projected.

- Scale is critical. Global models are fast approaching scales relevant to extreme storms.
  - Projected extreme weather becomes more credible.
  - But regional projections must still be interpreted very carefully.

ater Vapor

December 10 2005

Thank you!
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