Tropical Cyclone Hazard Assessment: Past, Present, Future

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Outline

1. Tropical Cyclone Climatology
2. Methods for Assessing TC Wind Hazard
3. Baselines for Present and Future TC Wind Hazard
4. Moving from Hazard to Risk: The Hurricane Risk Calculator

1. Tropical Cyclone Climatology

- Definition
- Conditions for genesis
- Distribution (time, space, seasonality)
- Variability (interannual, interdecadal)

WMO Definition of a Tropical Cyclone

"A warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters, with organized deep convection and closed surface wind circulation about a well-defined center."

Breaking down the WMO definition

- *warm-core*
- *non-frontal*
- *synoptic-scale cyclone (low pressure)*
- *originating over tropical or subtropical waters*
- *organized deep convection*
- *closed surface wind circulation about a well-defined center*

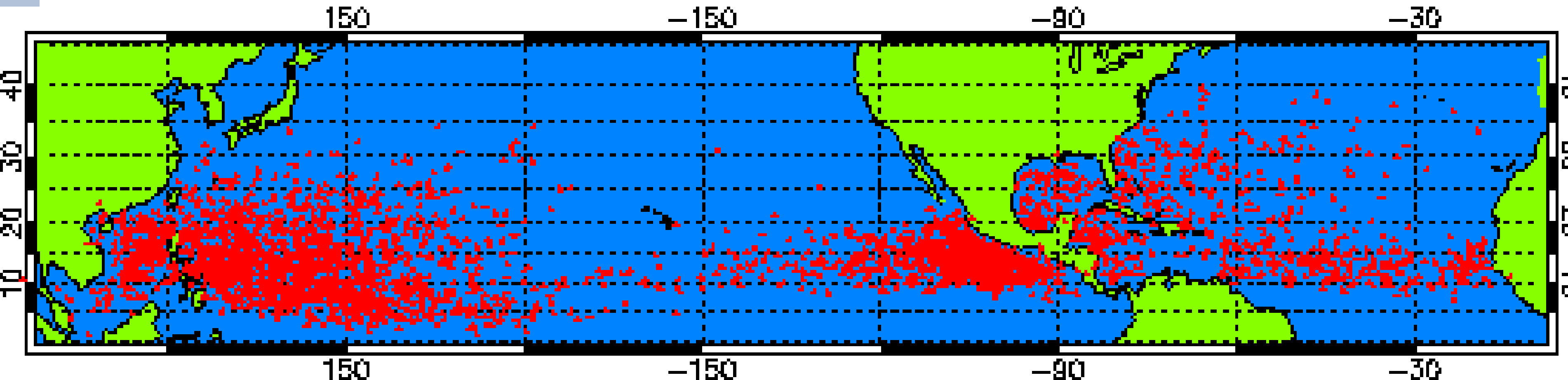
- Notes:
  - No intensity criterion is listed
  - Origination over water is a key, as it implies that the cyclone derives its energy from the surface fluxes.

Conditions for Genesis

- ***"We observe universally that tropical storms form only within pre-existing disturbances…An initial disturbance therefore forms part of the starting mechanism. A weak circulation low pressure and a deep moist layer are present at the beginning. The forecaster need not look into areas which contain no such circulations."***

Herbert Riehl (1954)

Distribution of Genesis



TC genesis locations from 1949-2006 (Northern Hemisphere)

From RAMMB Tropical Cyclone Genesis Project

Large-Scale Conditions and Other Characteristics Associated with TC Formation

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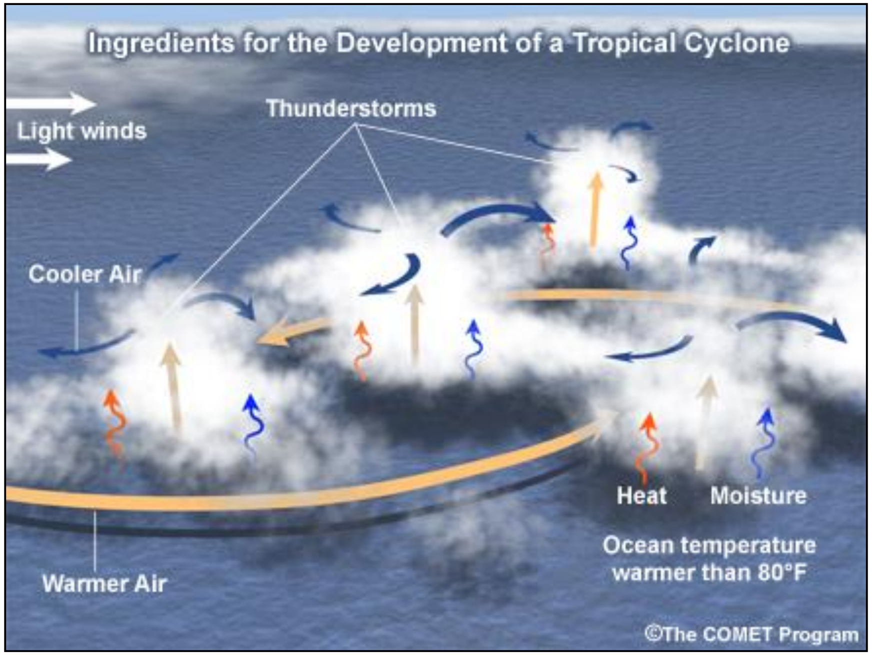
Necessary but not sufficient conditions! (Gray 1968, 1975)

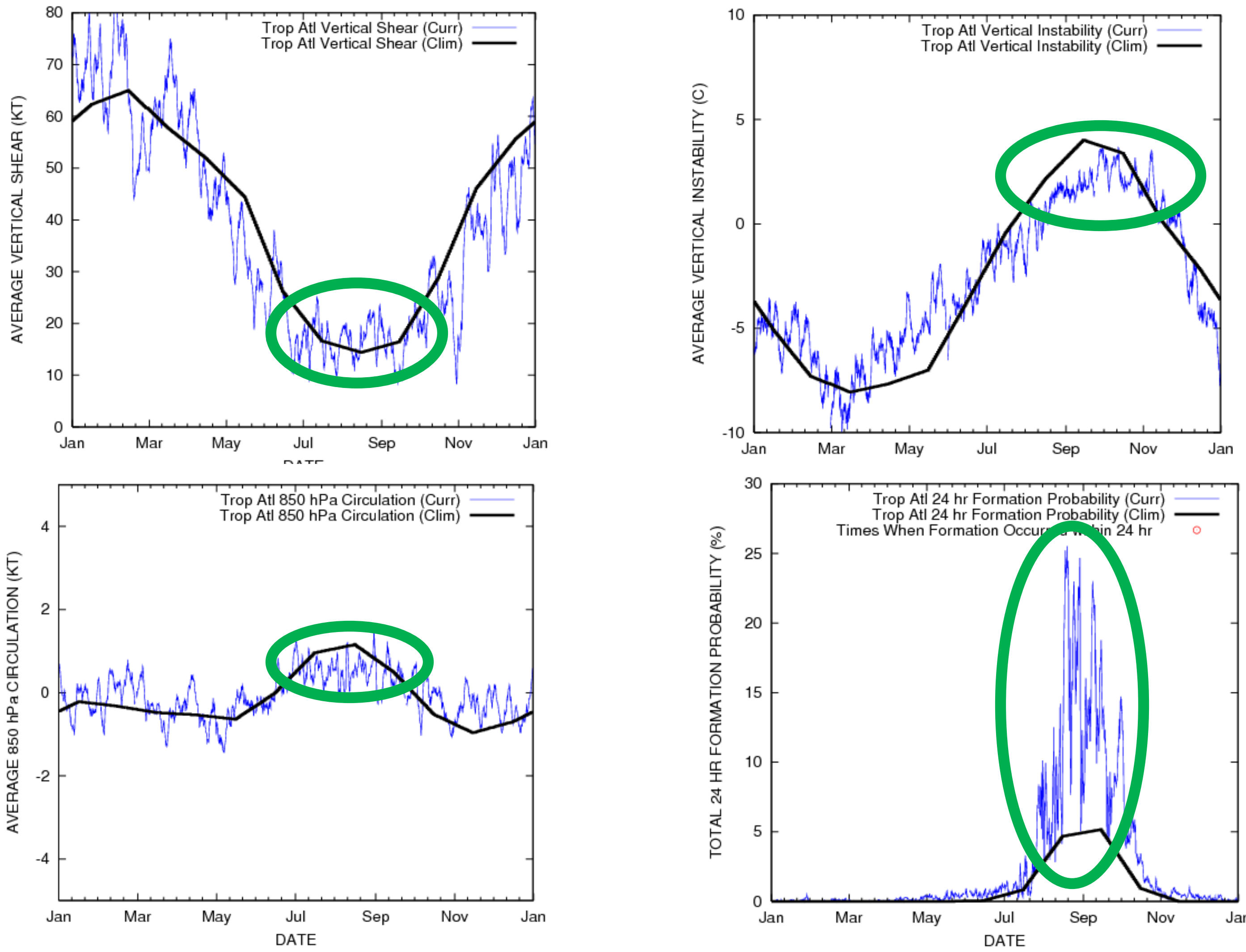
- A pre-existing disturbance containing abundant deep convection
- Latitudes poleward of ~5º
- Adequate ocean thermal energy

  SST > 26ºC extending to a depth of 60 m
- A "sufficiently" conditionally unstable atmosphere
- Enhanced mid-tropospheric relative humidity (700 hPa)
- Weak vertical shear of the horizontal wind

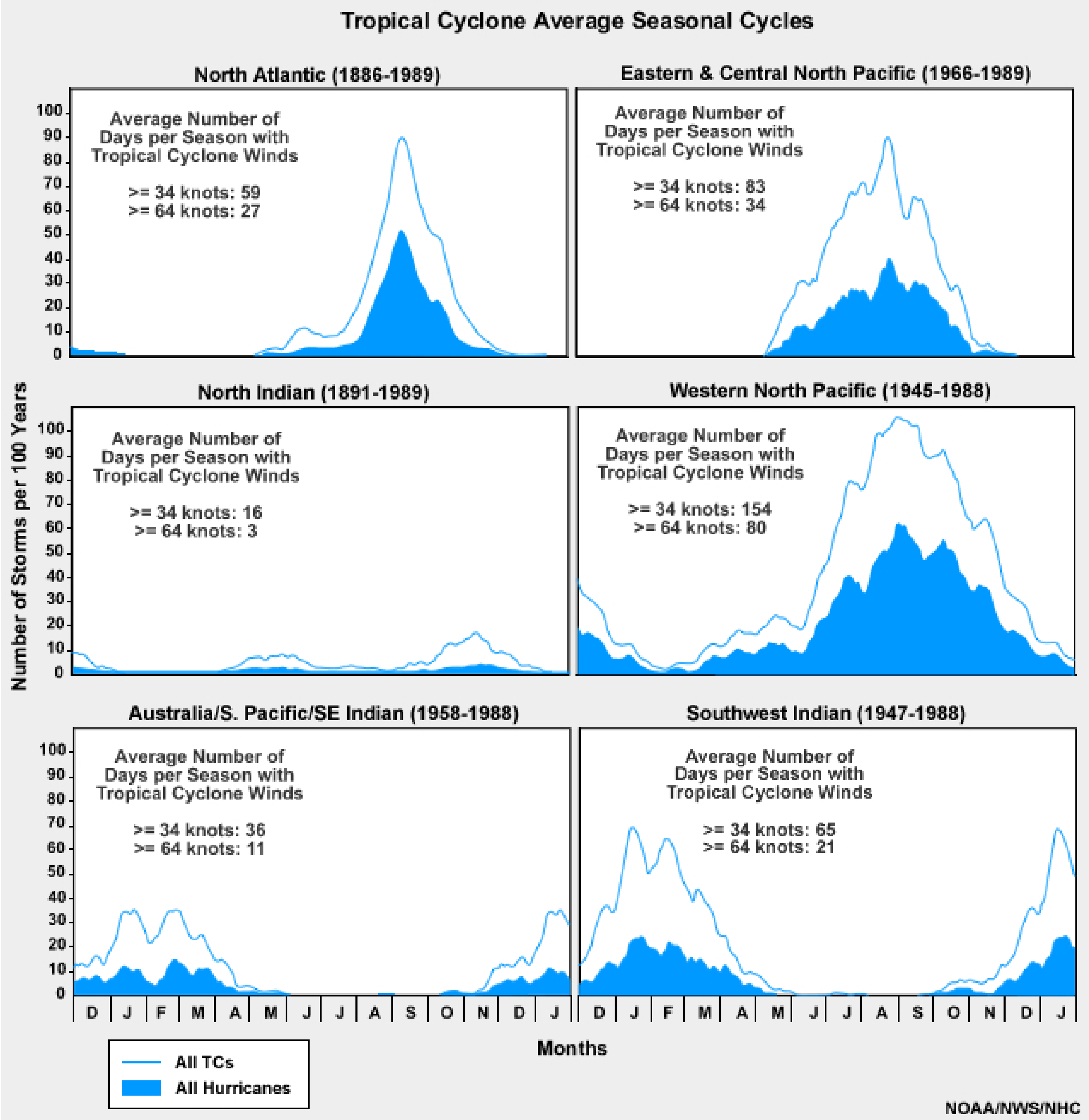


NHC and COMET

Time Series of TC Genesis Parameters (2012)



RAMMB
TC Genesis
Project



Tropical Cyclone Average Seasonal Cycles
North Atlantic (1886-1989)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 59
>= 64 knots: 27
Eastern & Central North Pacific (1966-1989)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 83
>= 64 knots: 34
North Indian (1891-1989)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 16
>= 64 knots: 3
Western North Pacific (1945-1988)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 154
>= 64 knots: 80
Australia/S. Pacific/SE Indian (1958-1988)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 36
>= 64 knots: 11
Southwest Indian (1947-1988)
Average Number of Days per Season with Tropical Cyclone Winds
>= 34 knots: 65
>= 64 knots: 21
Number of Storms per 100 Years
D J F M A M J J A S O N D J
Months
All TCs
All Hurricanes
NOAA/NWS/NHC

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Sources of Disturbances

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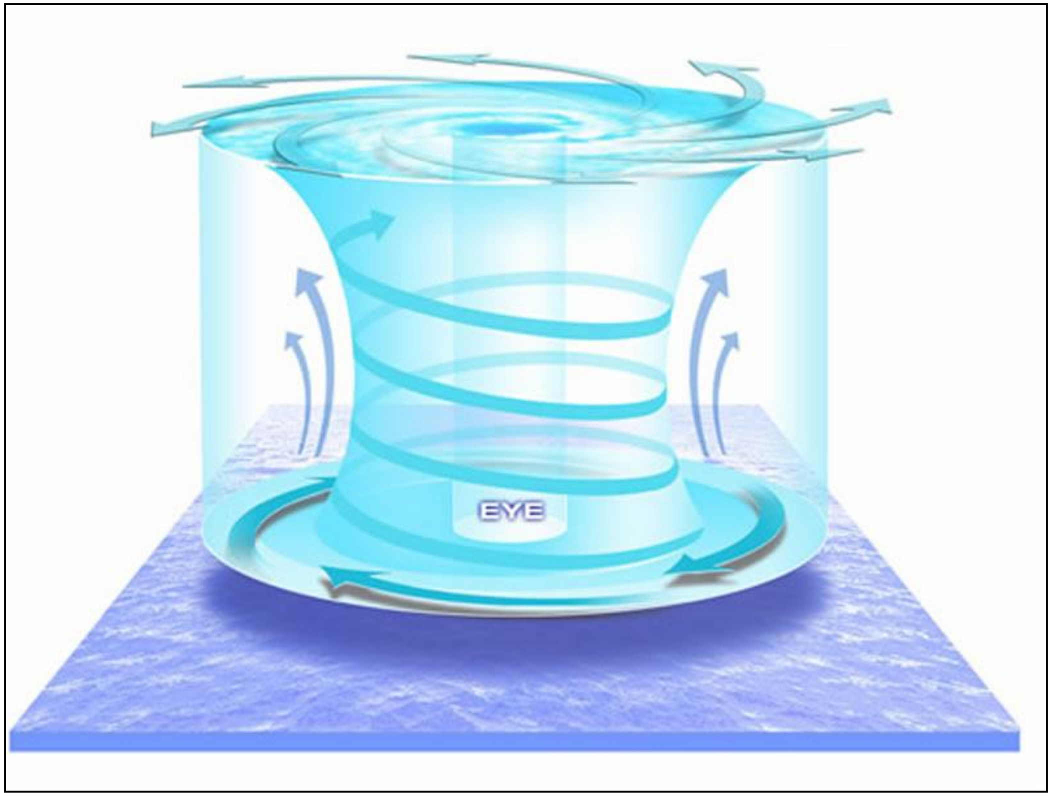
- African Easterly Waves
- Intertropical Convergence Zone (ITCZ)
- Equatorial Waves and Madden Julian Oscillation (MJO)
- Tropical Upper Tropospheric Trough (TUTT)
- Monsoon Trough

Specifics of the disturbance might not be that important.
Genesis may behave like a stochastic process.

Large-Scale Conditions Associated with TC Formation

- **Upper-tropospheric anticyclonic outflow over the area**
- **Enhanced lower tropospheric relative vorticity**
- **Appearance of curved banding features in the deep convection**
- **Falling surface pressure: 24-hour pressure changes (falls) of usually 3 mb or more**



NHC/COMET

Principal Areas of Tropical Cyclones

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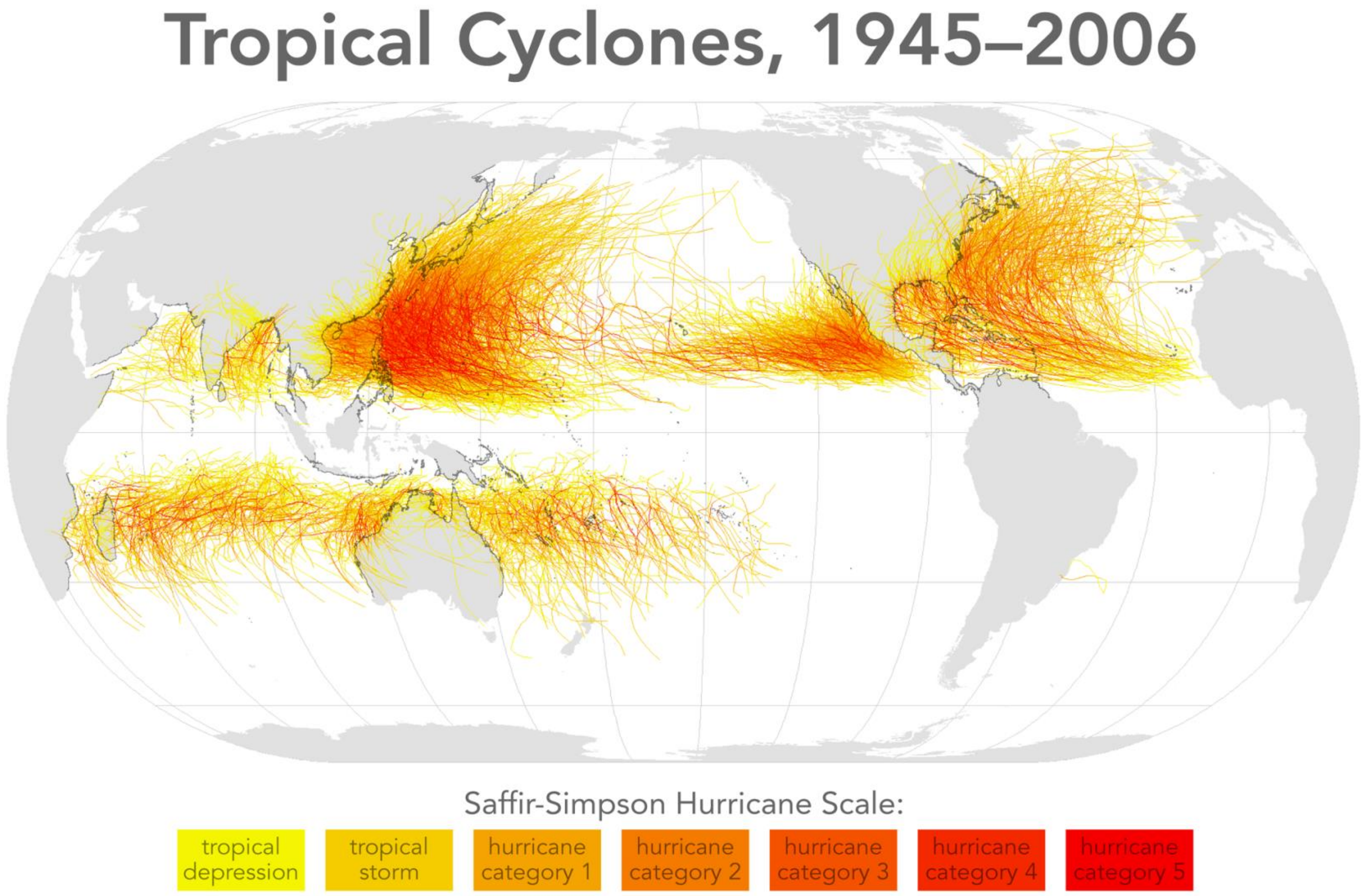
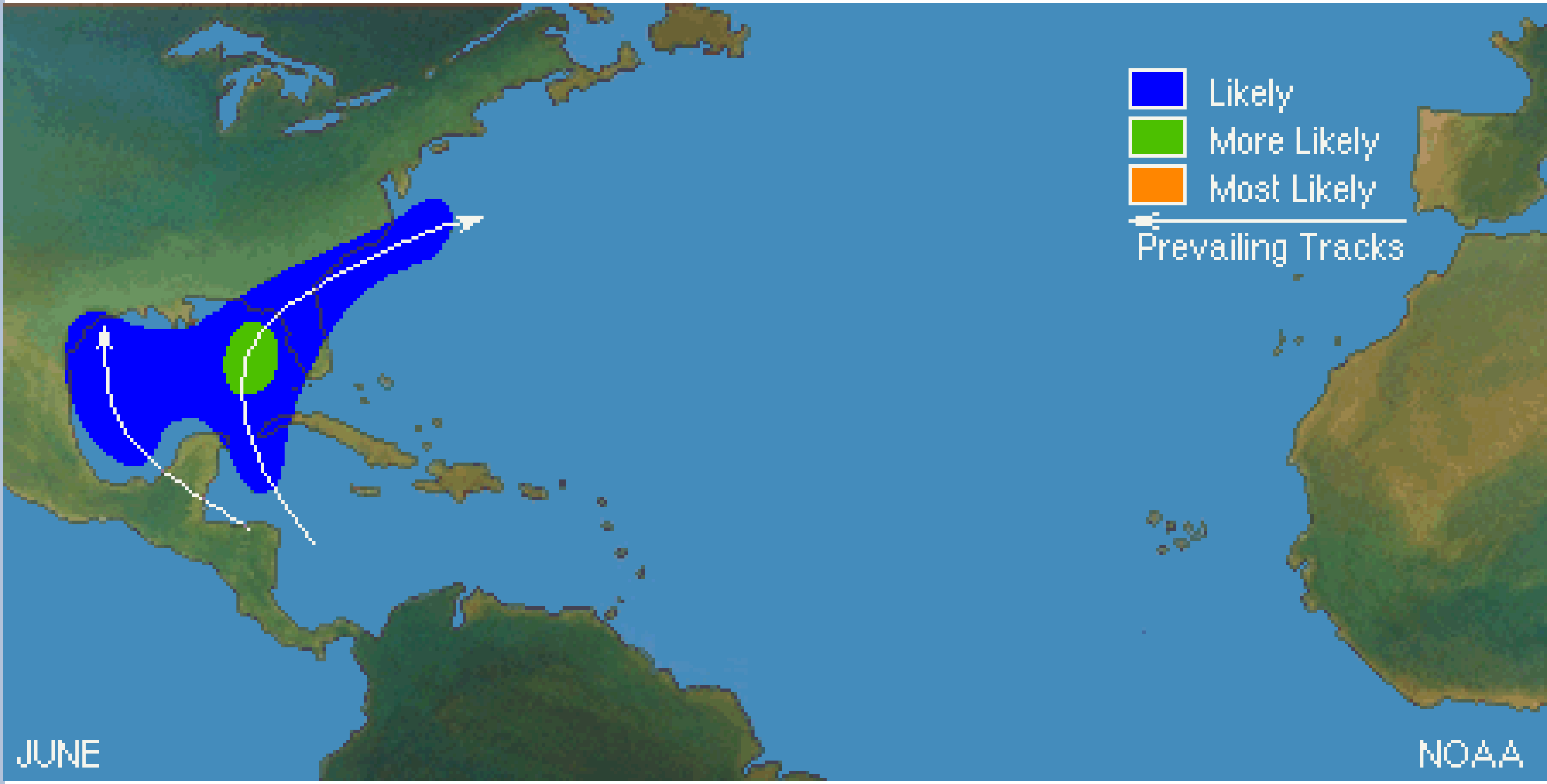
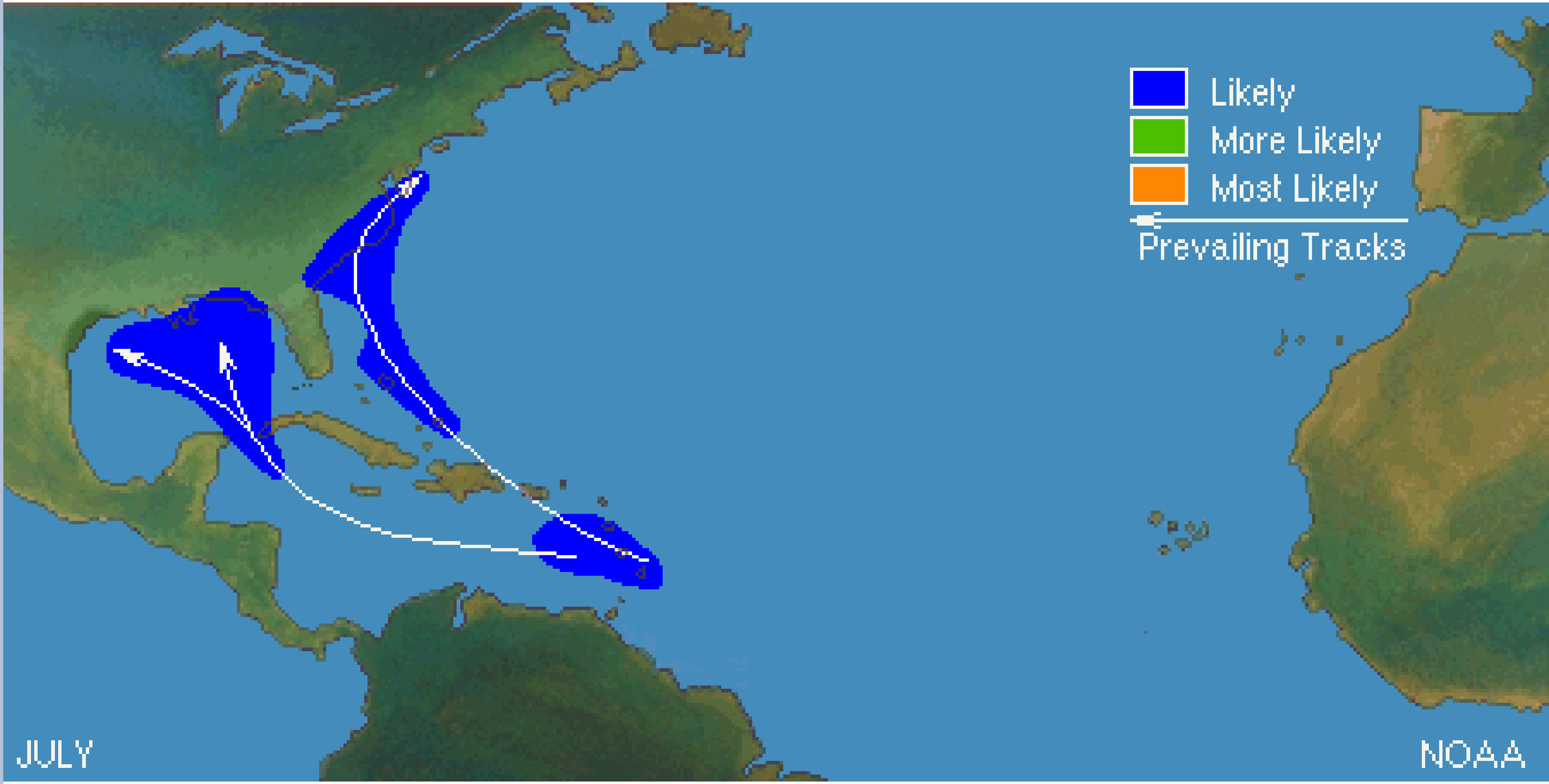


June



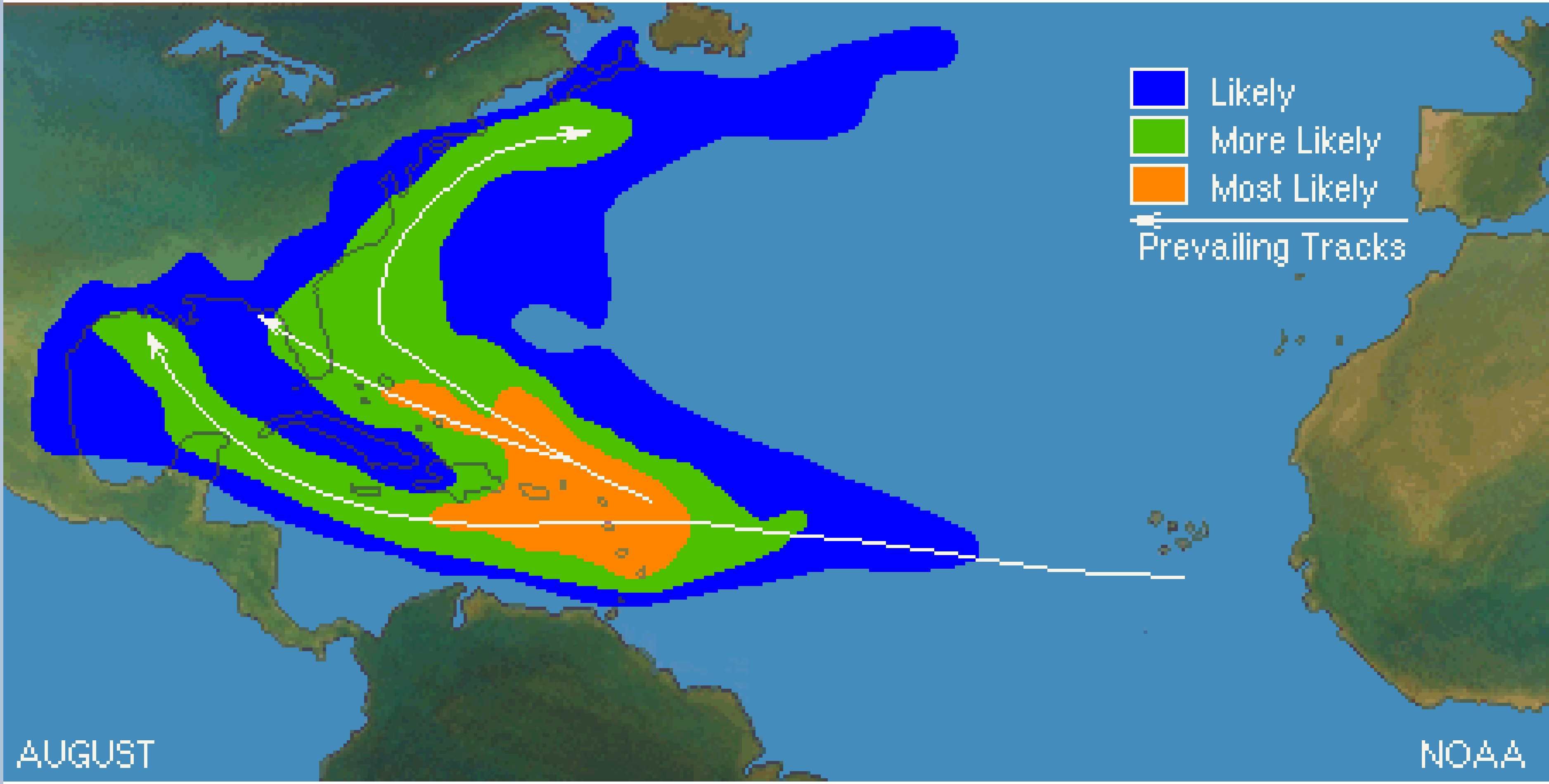
Likely
More Likely
Most Likely
Prevailing Tracks
JUNE
NOAA

July

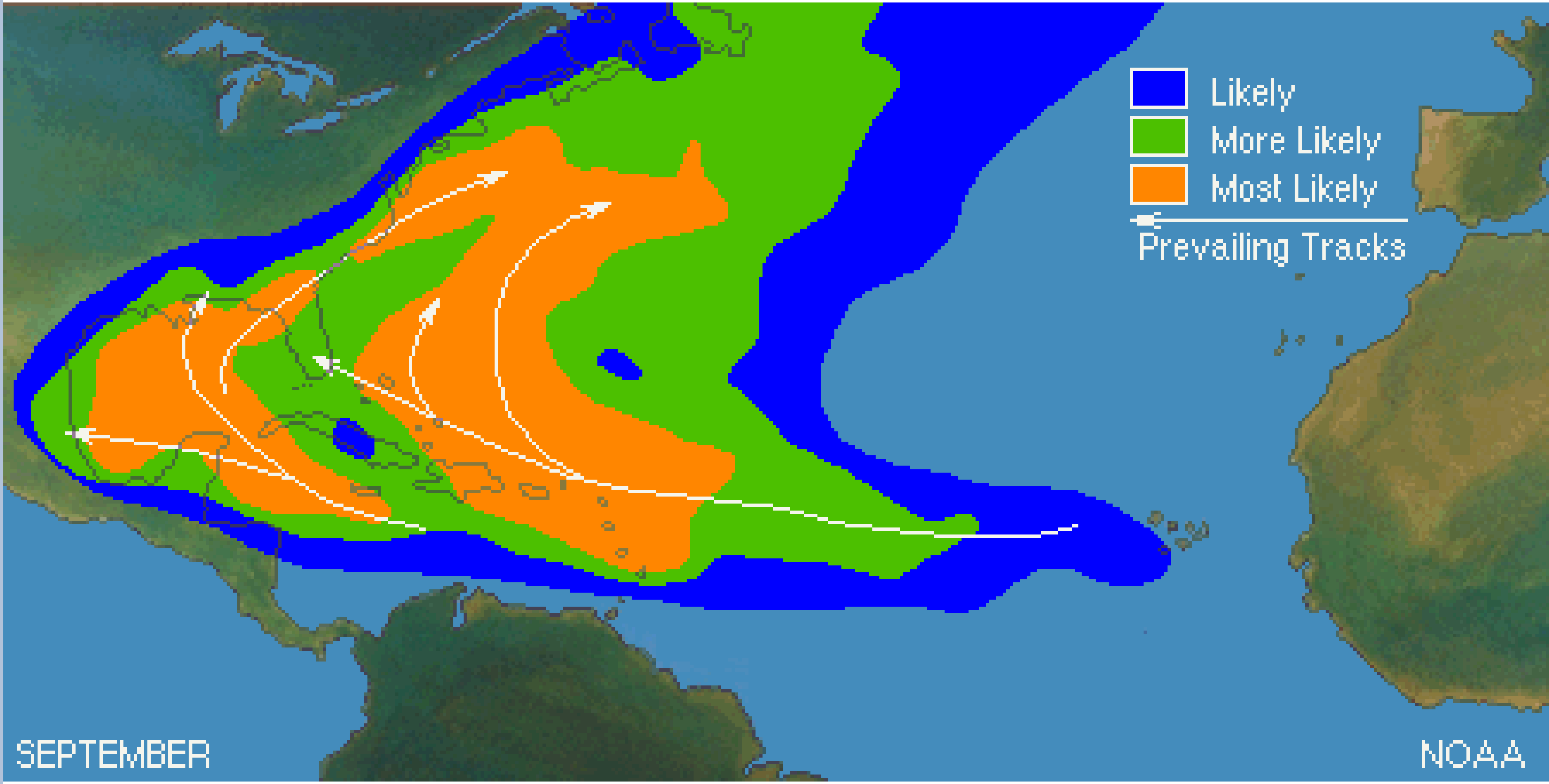


Likely
More Likely
Most Likely
Prevailing Tracks
JULY
NOAA

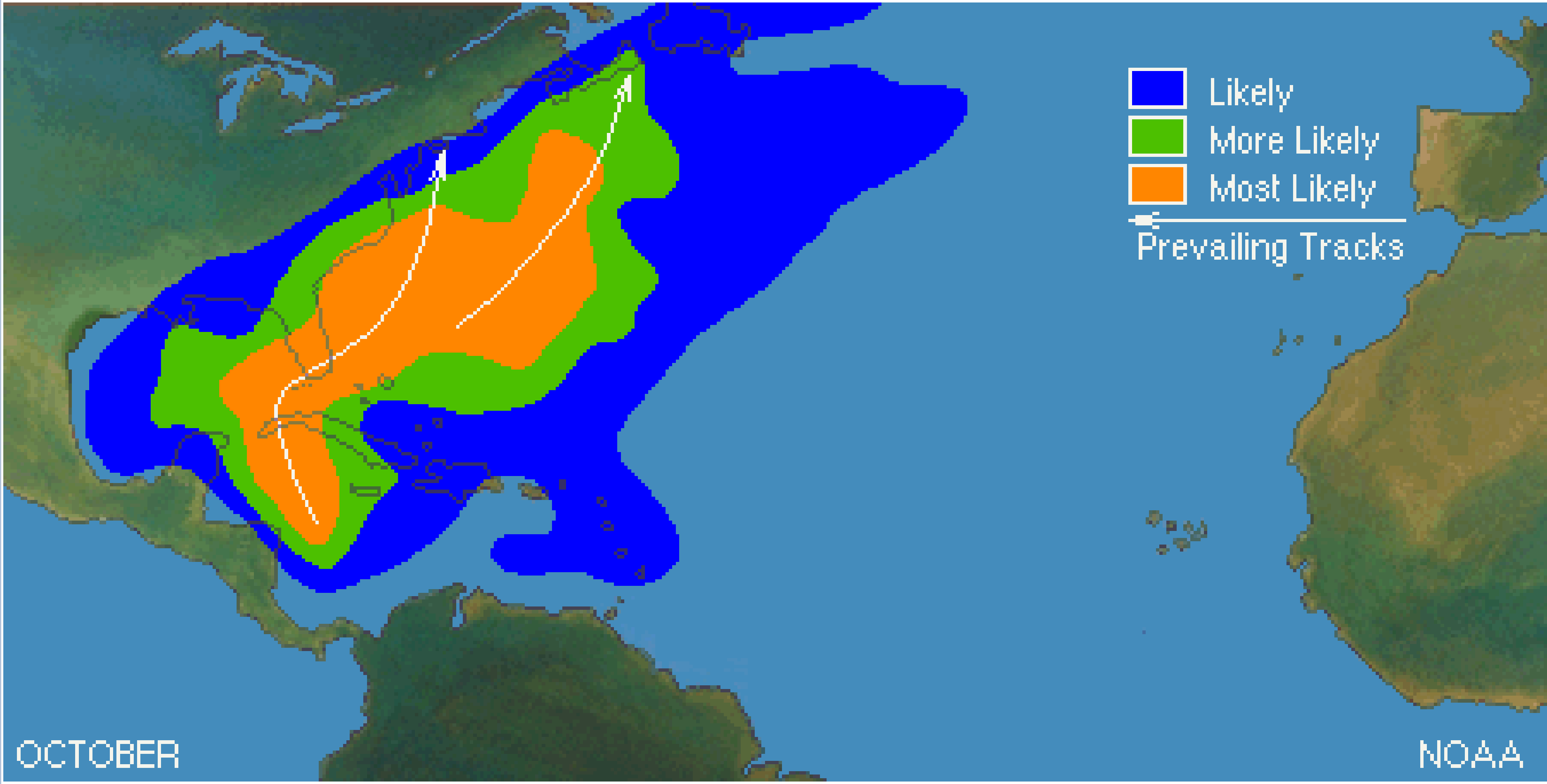
August


Likely
More Likely
Most Likely
Prevailing Tracks
AUGUST
NOAA

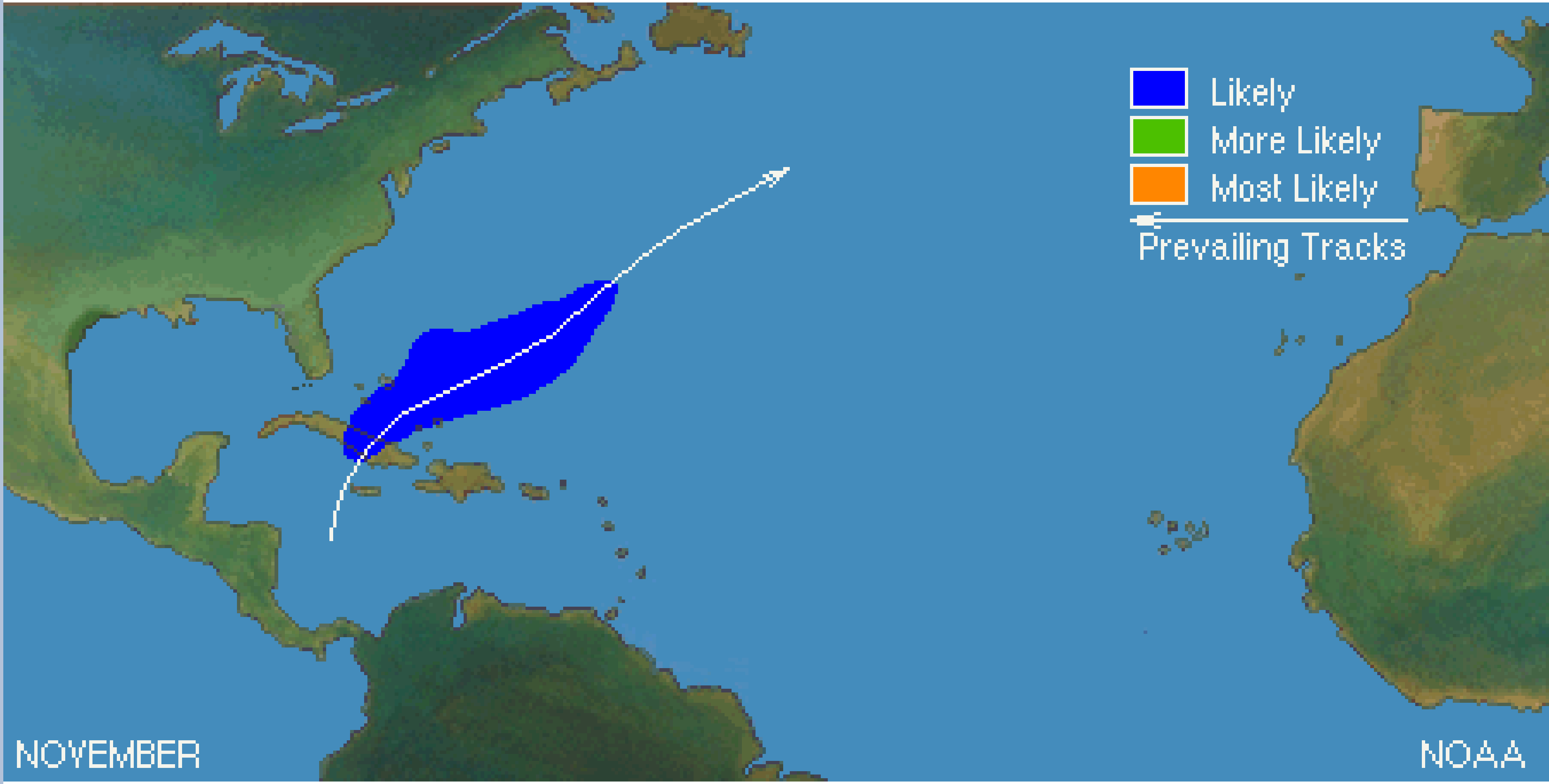
September


Likely
More Likely
Most Likely
Prevailing Tracks
SEPTEMBER
NOAA

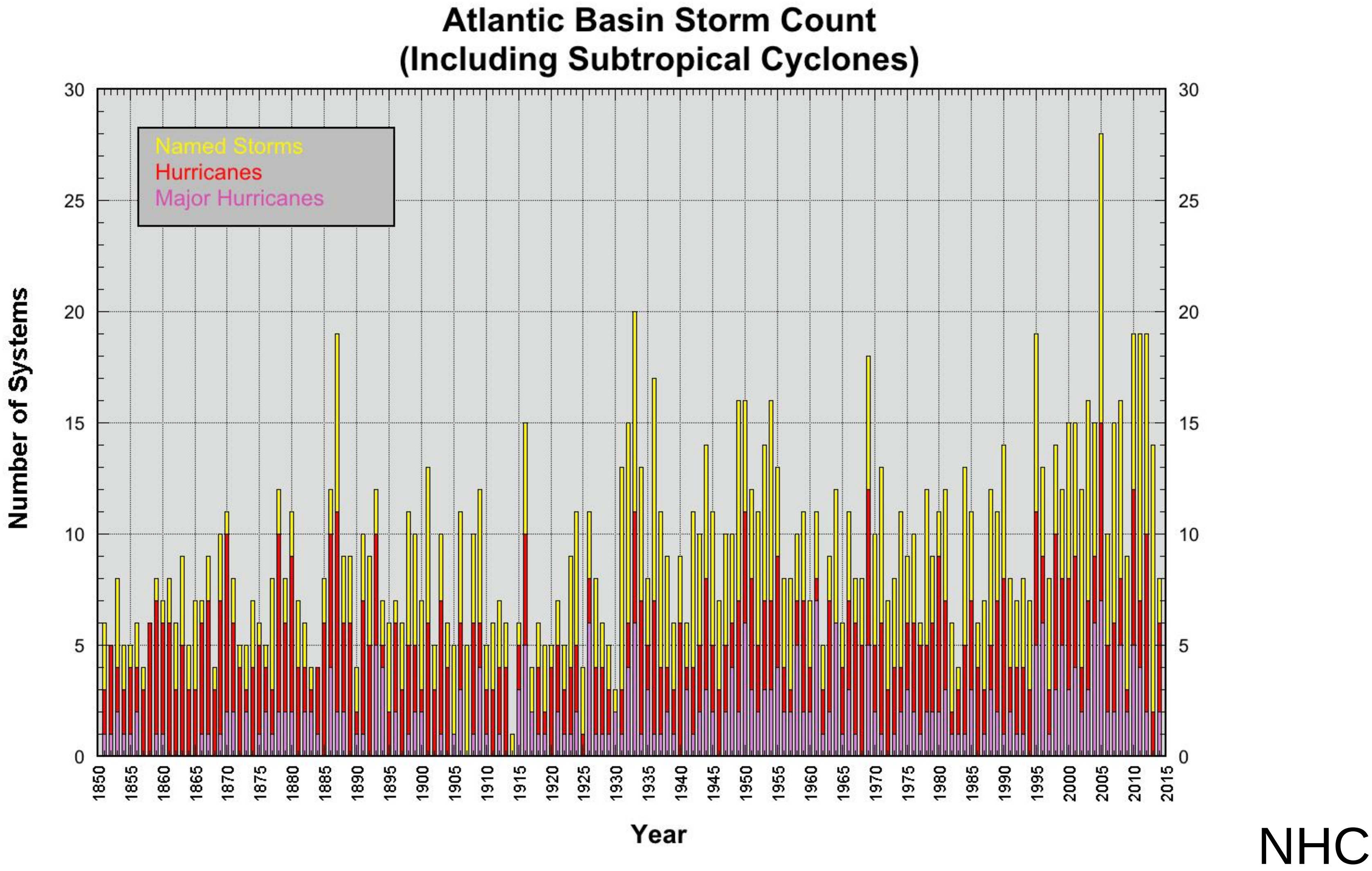
October


Likely
More Likely
Most Likely
Prevailing Tracks
OCTOBER
NOAA

November


Likely
More Likely
Most Likely
Prevailing Tracks
NOVEMBER
NOAA

Long-term Variability



Saffir-Simpson Hurricane Wind Scale

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- A "scale using 1 to 5 categorization based on a hurricane's intensity at the indicated time. The scale provides examples of the type of damage and impacts associated with each indicated intensity. In general, damage rises by a factor of four for every category increase." (NWS 2017; Simpson 1974). The sustained wind thresholds for the categories are as follows for various units:

	mph	knots	$m\ s^{-1}$
• Category 1:	74-95	64-82	33 to 42
• Category 2:	96-110	83-95	43 to 49
• Category 3:	111-129	96-112	50 to 57
• Category 4:	130-156	113-136	58 to 70
• Category 5:	>156	>136	> 70 $m\ s^{-1}$

Long Term Variability

Interannual influences

- North Atlantic Oscillation (NAO)
- El Niño and La Niña

Interdecadal influences

- Atlantic Multidecadal Oscillation (AMO)
- Pacific Decadal Oscillation (PDO)
- Thermohaline Circulation changes

2. Methods of Assessing TC Wind Hazard

- Local method / statistical modeling
- Synthetic track modeling

Goal is to characterize the long-term hazard posed by tropical cyclones

Local / Statistical Methods

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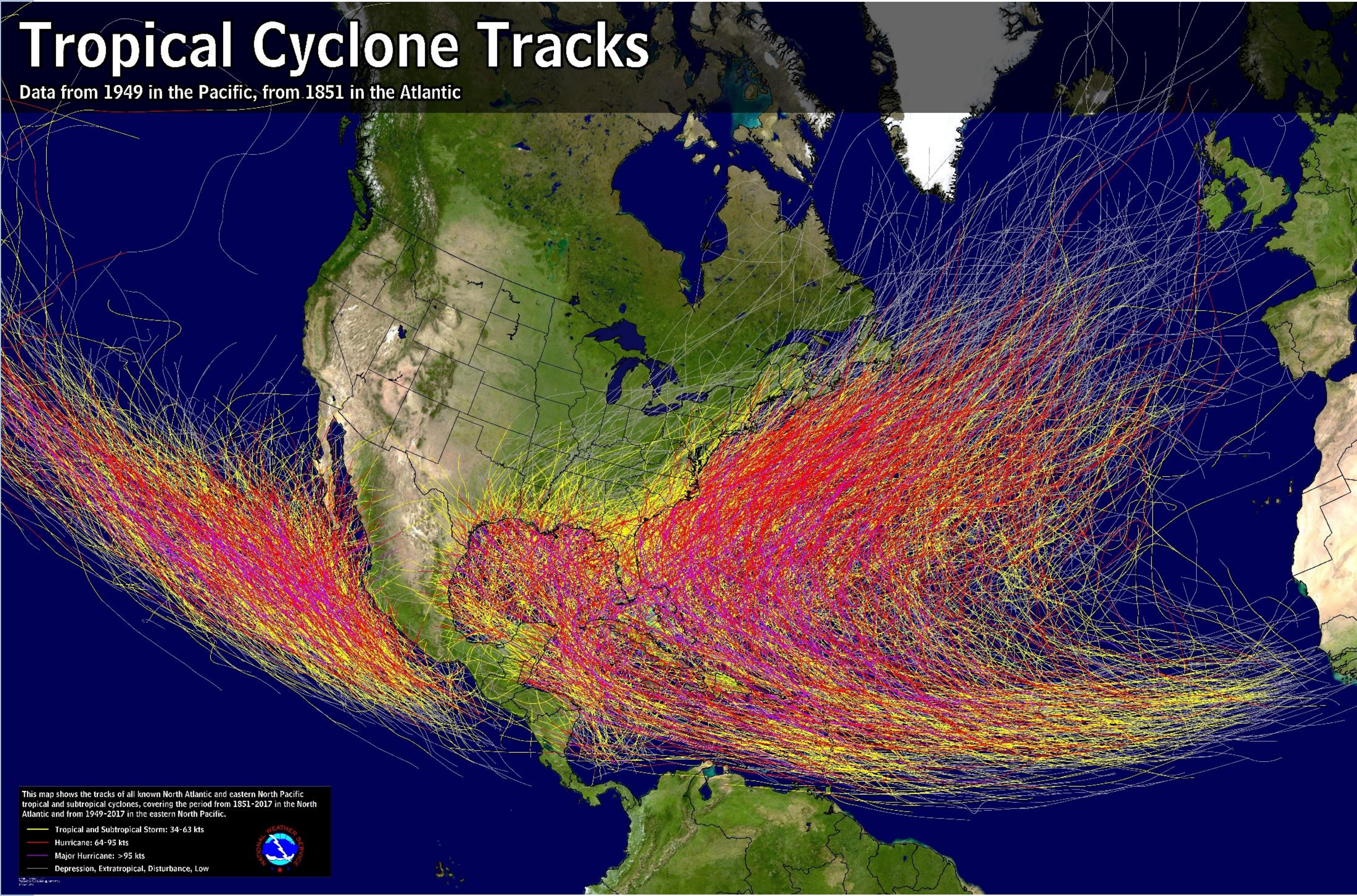
Count # of TCs crossing coast in a particular region, then determine the long-term average

Advantages:

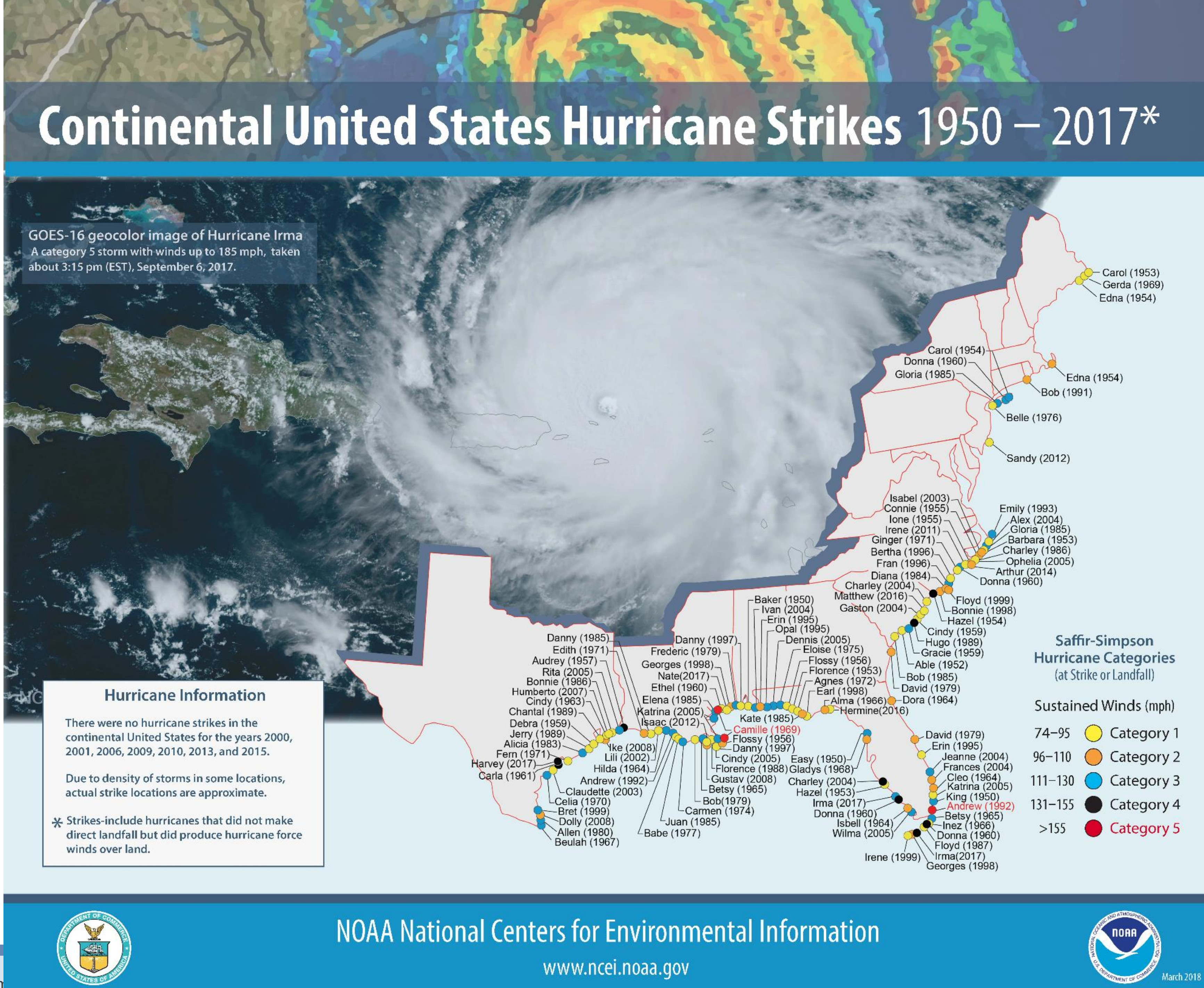
- Can be quite accurate on the large scale when there are sufficient high quality records

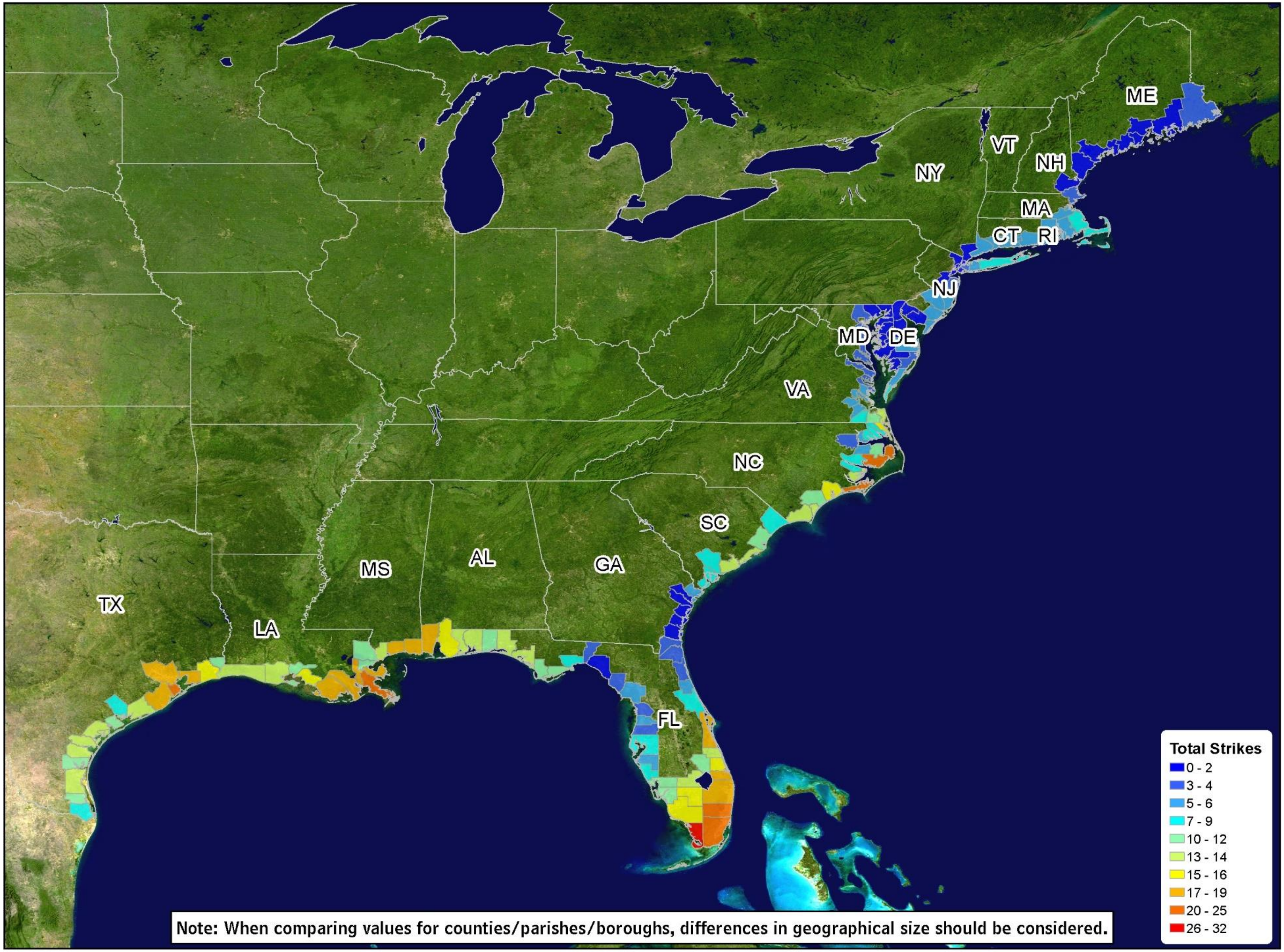
Drawbacks:

- Requires a consistent long-term record
- There may not be any landfalls during the historical period, even though TCs are physically plausible in that region
- Rare events may not be captured
- Sampling errors may result from chance clustering of landfalls, lack of landfalls in other areas



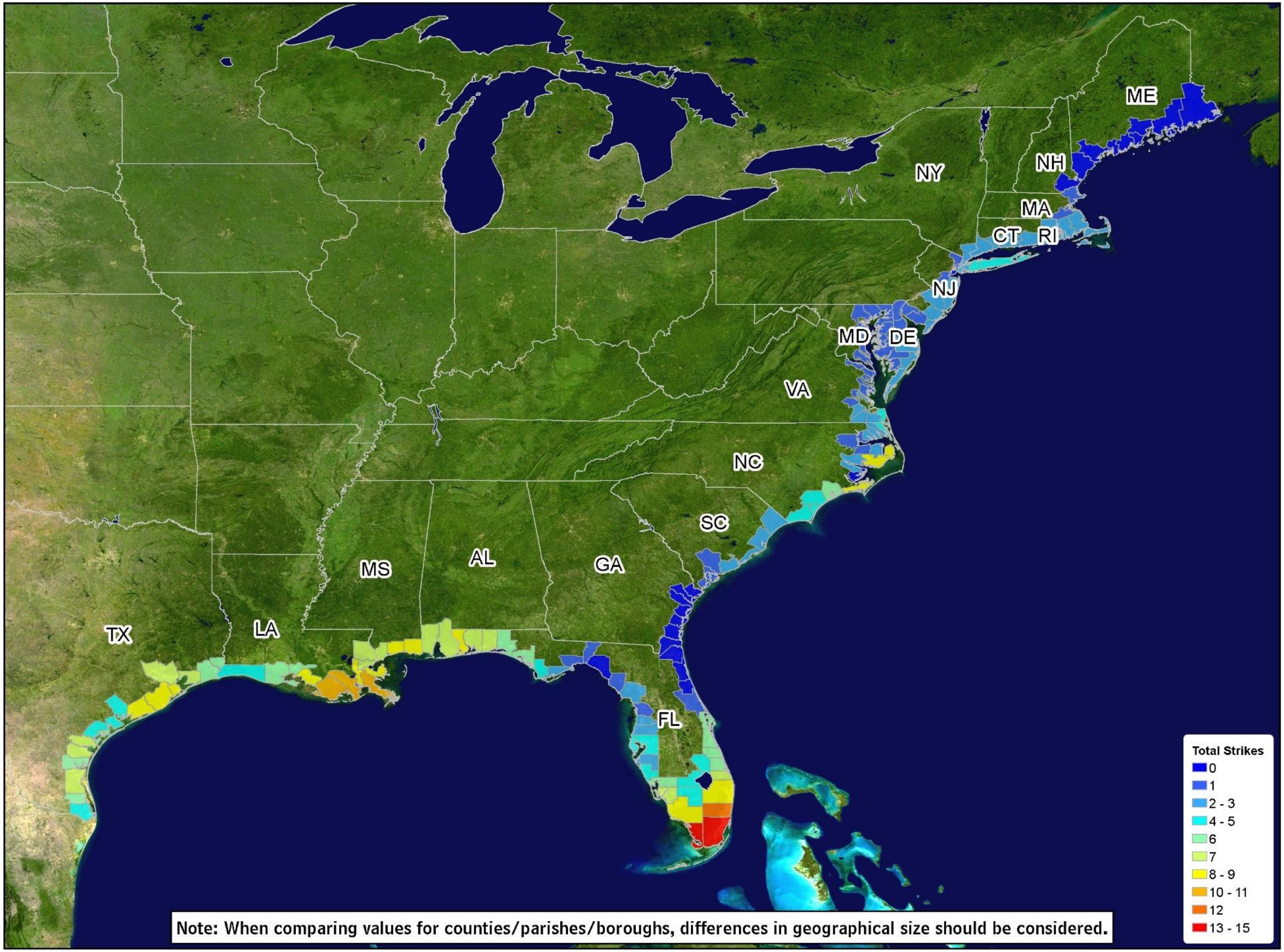
All North Atlantic and Eastern North Pacific tropical cyclones (from Ethan Gibney, NHC/WFO SGX)


Continental United States Hurricane Strikes 1950 – 2017*
GOES-16 geocolor image of Hurricane Irma
A category 5 storm with winds up to 185 mph, taken about 3:15 pm (EST), September 6, 2017.
Hurricane Information
There were no hurricane strikes in the continental United States for the years 2000, 2001, 2006, 2009, 2010, 2013, and 2015.
Due to density of storms in some locations, actual strike locations are approximate.
* Strikes-include hurricanes that did not make direct landfall but did produce hurricane force winds over land.
Saffir-Simpson Hurricane Categories (at Strike or Landfall)
Sustained Winds (mph)
74–95 Category 1
96–110 Category 2
111–130 Category 3
131–155 Category 4
>155 Category 5
Carol (1953)
Gerda (1969)
Edna (1954)
Carol (1954)
Donna (1960)
Gloria (1985)
Edna (1954)
Bob (1991)
Belle (1976)
Sandy (2012)
Isabel (2003)
Connie (1955)
Ione (1955)
Irene (2011)
Ginger (1971)
Bertha (1996)
Fran (1996)
Diana (1984)
Charley (2004)
Matthew (2016)
Gaston (2004)
Emily (1993)
Alex (2004)
Gloria (1985)
Barbara (1953)
Charley (1986)
Ophelia (2005)
Arthur (2014)
Donna (1960)
Floyd (1999)
Bonnie (1998)
Hazel (1954)
Cindy (1959)
Hugo (1989)
Gracie (1959)
Able (1952)
Bob (1985)
David (1979)
Dora (1964)
Baker (1950)
Ivan (2004)
Erin (1995)
Opal (1995)
Dennis (2005)
Eloise (1975)
Flossy (1956)
Florence (1953)
Agnes (1972)
Earl (1998)
Alma (1966)
Hermine(2016)
Danny (1997)
Frederic (1979)
Georges (1998)
Nate(2017)
Ethel (1960)
Elena (1985)
Katrina (2005)
Isaac (2012)
Kate (1985)
Camille (1969)
Flossy (1956)
Danny (1997)
Cindy (2005)
Florence (1988)
Gustav (2008)
Betsy (1965)
Bob(1979)
Carmen (1974)
Juan (1985)
Babe (1977)
Danny (1985)
Edith (1971)
Audrey (1957)
Rita (2005)
Bonnie (1986)
Humberto (2007)
Cindy (1963)
Chantal (1989)
Debra (1959)
Jerry (1989)
Alicia (1983)
Fern (1971)
Harvey (2017)
Carla (1961)
Ike (2008)
Lili (2002)
Hilda (1964)
Andrew (1992)
Claudette (2003)
Celia (1970)
Bret (1999)
Dolly (2008)
Allen (1980)
Beulah (1967)
Easy (1950)
Gladys (1968)
Charley (2004)
Hazel (1953)
Irma (2017)
Donna (1960)
Isbell (1964)
Wilma (2005)
Irene (1999)
David (1979)
Erin (1995)
Jeanne (2004)
Frances (2004)
Cleo (1964)
Katrina (2005)
King (1950)
Andrew (1992)
Betsy (1965)
Inez (1966)
Donna (1960)
Floyd (1987)
Irma(2017)
Georges (1998)
NOAA National Centers for Environmental Information
www.ncei.noaa.gov
March 2018



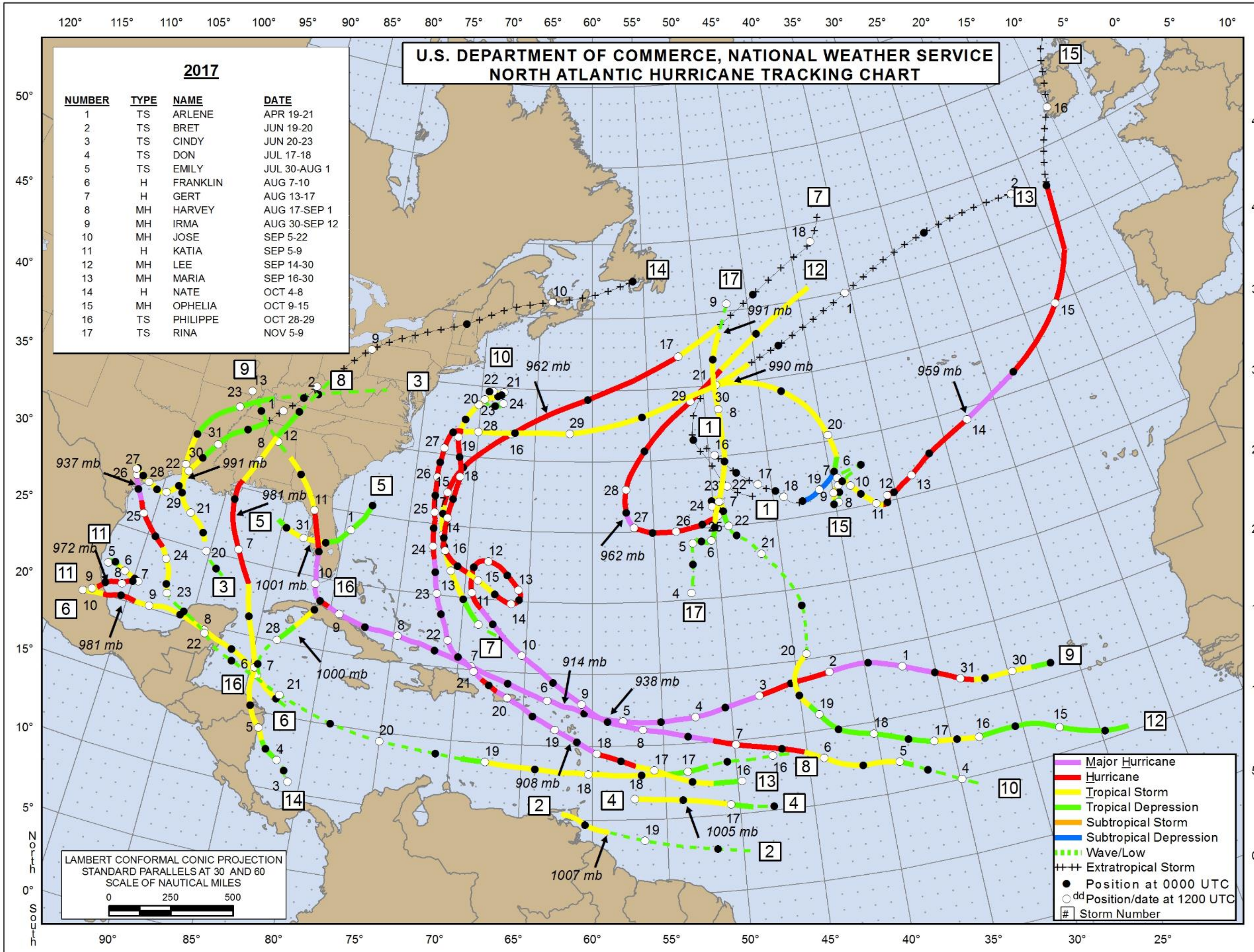
Total number of hurricane strikes by counties/parishes/boroughs, 1900-2010

Data from NWS NHC 46: Hurricane Experience Levels of Coastal County Populations from Texas to Maine. Jerry D. Jarrell, Paul J. Hebert, and Max Mayfield. August, 1992, with updates.



Total number of major hurricane strikes by counties/parishes/boroughs, 1900-2010

Data from NWS NHC 46: Hurricane Experience Levels of Coastal County Populations from Texas to Maine. Jerry D. Jarrell, Paul J. Hebert, and Max Mayfield. August, 1992, with updates.


U.S. DEPARTMENT OF COMMERCE, NATIONAL WEATHER SERVICE
NORTH ATLANTIC HURRICANE TRACKING CHART
2017
NUMBER TYPE NAME DATE
1 TS ARLENE APR 19-21
2 TS BRET JUN 19-20
3 TS CINDY JUN 20-23
4 TS DON JUL 17-18
5 TS EMILY JUL 30-AUG 1
6 H FRANKLIN AUG 7-10
7 H GERT AUG 13-17
8 MH HARVEY AUG 17-SEP 1
9 MH IRMA AUG 30-SEP 12
10 MH JOSE SEP 5-22
11 H KATIA SEP 5-9
12 MH LEE SEP 14-30
13 MH MARIA SEP 16-30
14 H NATE OCT 4-8
15 MH OPHELIA OCT 9-15
16 TS PHILIPPE OCT 28-29
17 TS RINA NOV 5-9
937 mb
991 mb
981 mb
972 mb
1001 mb
1000 mb
962 mb
990 mb
959 mb
914 mb
938 mb
908 mb
1005 mb
1007 mb
LAMBERT CONFORMAL CONIC PROJECTION
STANDARD PARALLELS AT 30 AND 60
SCALE OF NAUTICAL MILES
0 250 500
Major Hurricane
Hurricane
Tropical Storm
Tropical Depression
Subtropical Storm
Subtropical Depression
Wave/Low
Extratropical Storm
Position at 0000 UTC
Position/date at 1200 UTC
Storm Number

NHC

More sophisticated statistical approaches

- TC landfalls are modeled as a random Poisson process (e.g., Parisi and Lund 2008)
- A model is created using various covariates (e.g., ENSO, NAO)
- When the model can sufficiently represent observed TC landfall rates, it can be used to answer questions about the expected landfall rates at various intensities

Advantages:

- Return periods can be explicitly estimated
  - Expected (average) time that one must wait until a hurricane with *w* or greater wind speed makes landfall in the region of interest

Synthetic track modeling

Historical database is selected

```
AL132017,            KATIA,     18,
20170905, 1200,  , TD, 22.2N,  97.2W,  25, 1010,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
20170905, 1800,  , TD, 22.4N,  97.0W,  30, 1008,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
20170906, 0000,  , TD, 22.4N,  96.7W,  30, 1008,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
20170906, 0600,  , TS, 22.2N,  96.4W,  35, 1006,  40,  40,  20,  20,   0,   0,   0,   0,   0,   0,   0,   0,
20170906, 1200,  , TS, 22.0N,  95.8W,  45, 1004,  40,  40,  20,  20,   0,   0,   0,   0,   0,   0,   0,   0,
20170906, 1800,  , HU, 21.8N,  95.2W,  65,  992,  50,  40,  40,  20,  20,  20,  20,  10,  10,   0,   0,   0,
20170907, 0000,  , HU, 21.7N,  94.9W,  70,  989,  50,  40,  40,  20,  20,  20,  20,  10,  10,  10,  10,   0,
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20170907, 1200,  , HU, 21.6N,  94.6W,  70,  982,  50,  40,  40,  20,  20,  20,  20,  10,  10,  10,  10,   0,
20170907, 1800,  , HU, 21.6N,  94.6W,  70,  982,  50,  40,  40,  30,  20,  20,  20,  10,  10,  10,  10,   0,
20170908, 0000,  , HU, 21.5N,  95.0W,  75,  982,  50,  50,  50,  40,  20,  20,  20,  20,  10,  10,  10,   0,
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20170908, 1200,  , HU, 21.1N,  95.7W,  85,  973,  50,  60,  60,  50,  20,  40,  30,  20,  15,  20,  15,  10,
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20170909, 0000,  , HU, 20.8N,  96.9W,  70,  988,  50,  50,  50,  40,  20,  20,  20,  20,  10,  15,  10,  10,
20170909, 0300, L, HU, 20.6N,  97.1W,  65,  990,  50,  50,  50,  40,  20,  20,  20,  20,  10,  15,  10,  10,
20170909, 0600,  , TS, 20.3N,  97.4W,  35, 1001,  50,  50,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
20170909, 1200,  , TD, 20.1N,  97.7W,  30, 1004,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
```
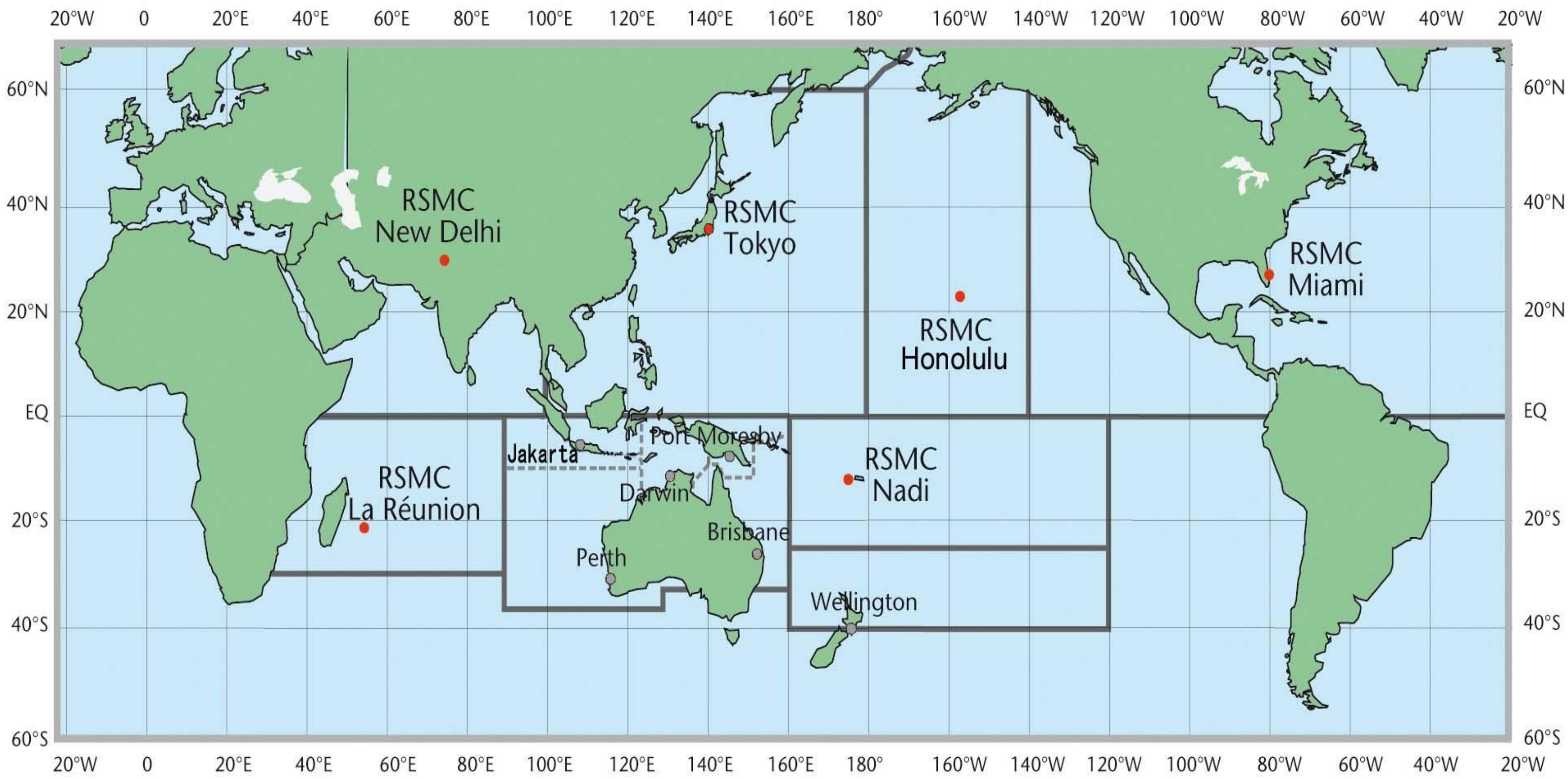

The following parameters are assessed:

- Long-term genesis rates
- Track characteristics (direction, speed)
- Intensity characteristics

Kernel density functions are created to represent the spatial variation of these quantities

Many Different Databases



Kernel density function of genesis

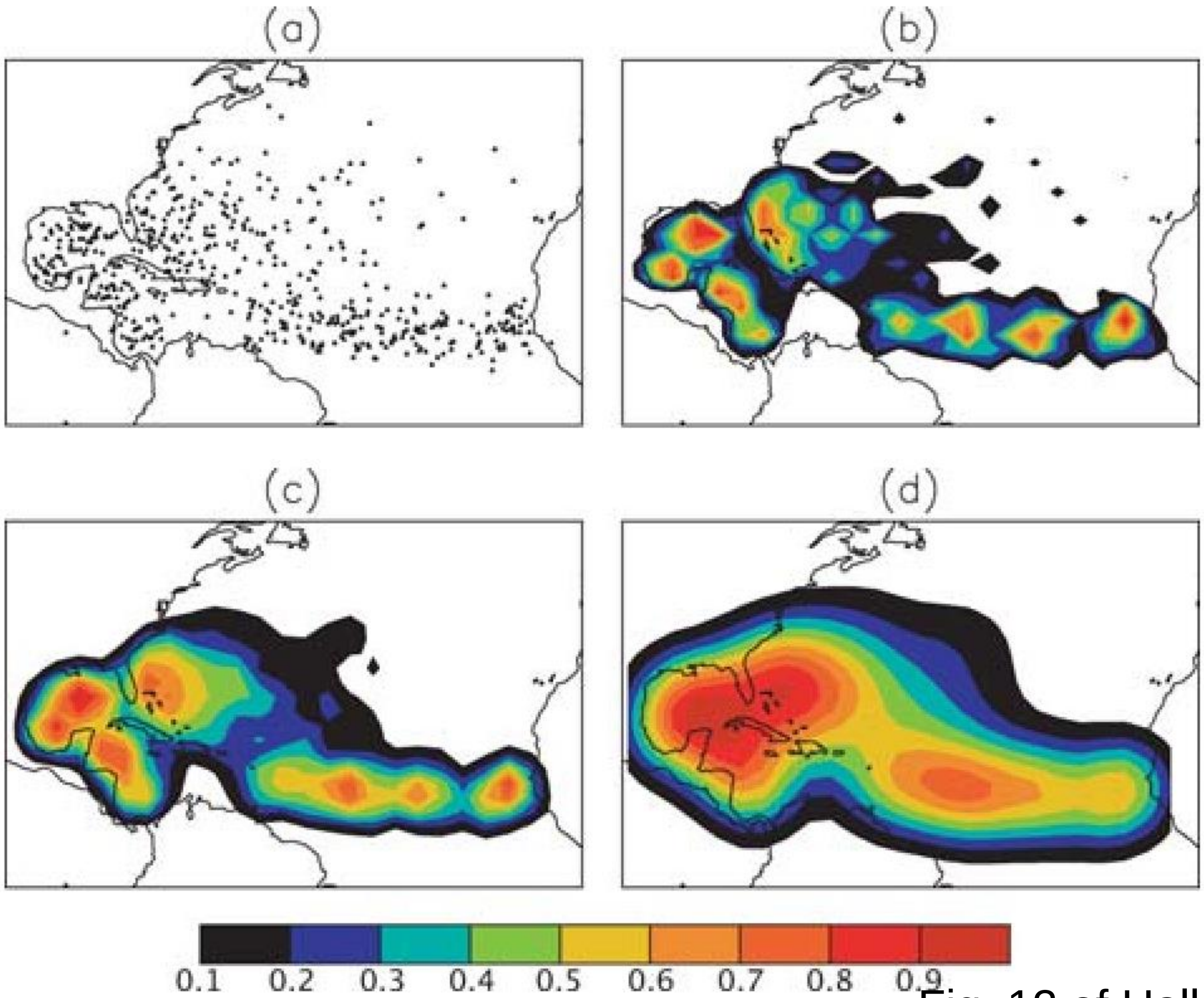


Fig. 12 of Hall and Jewson 2007

Generation of Synthetic Tracks

- The kernel density functions are randomly sampled to draw out the parameters that are used to determine the genesis location

- An auto-regressive (lag-1 autocorrelation) model is typically used
  - statistics of track characteristics (e.g, displacements) are drawn for that region
  - track is constructed using some information about the previous displacement to have some consistency
  - track is usually assumed to be independent of intensity

Comparison of synthetic tracks

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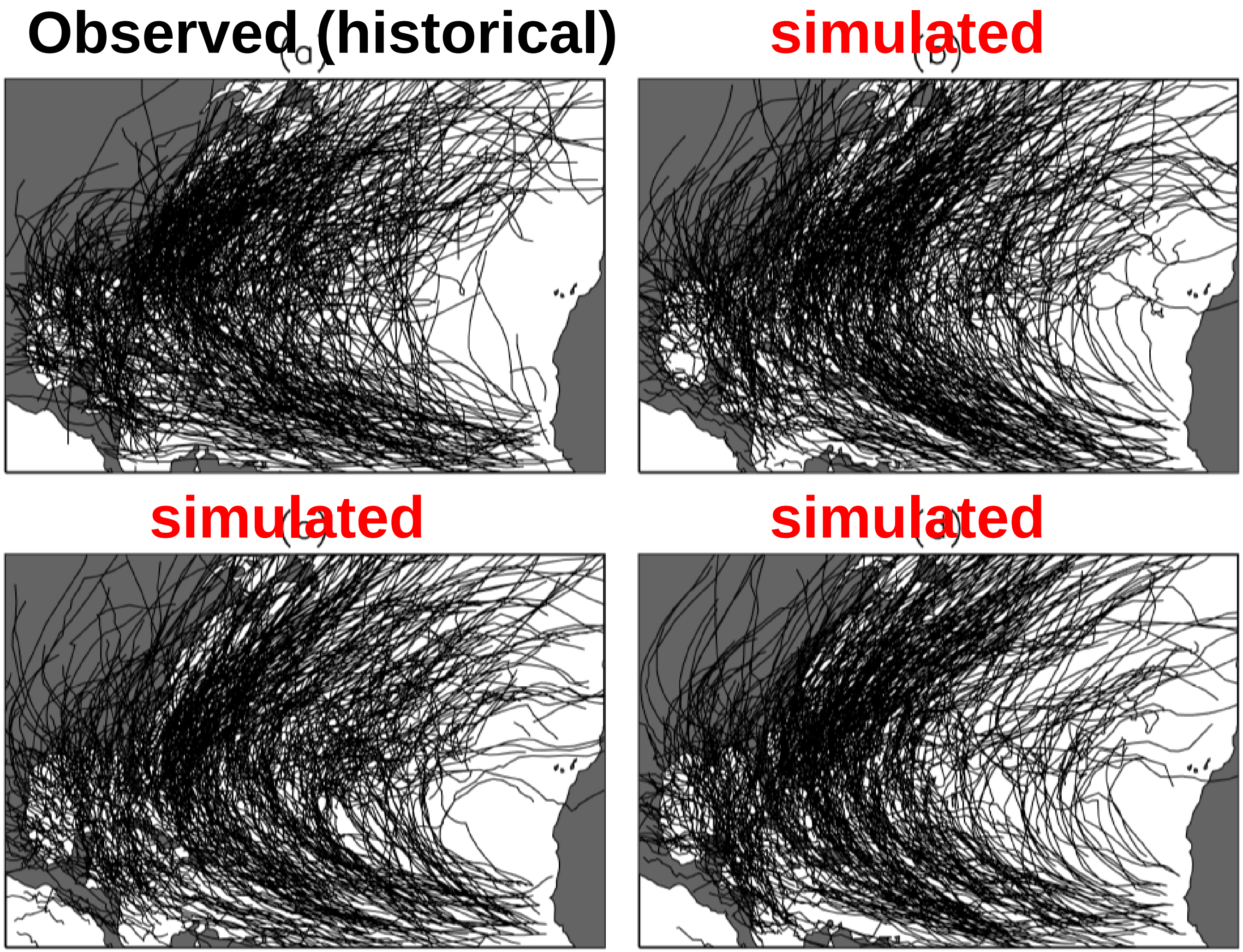


Fig. 14 of Hall and Jewson 2007

Track density

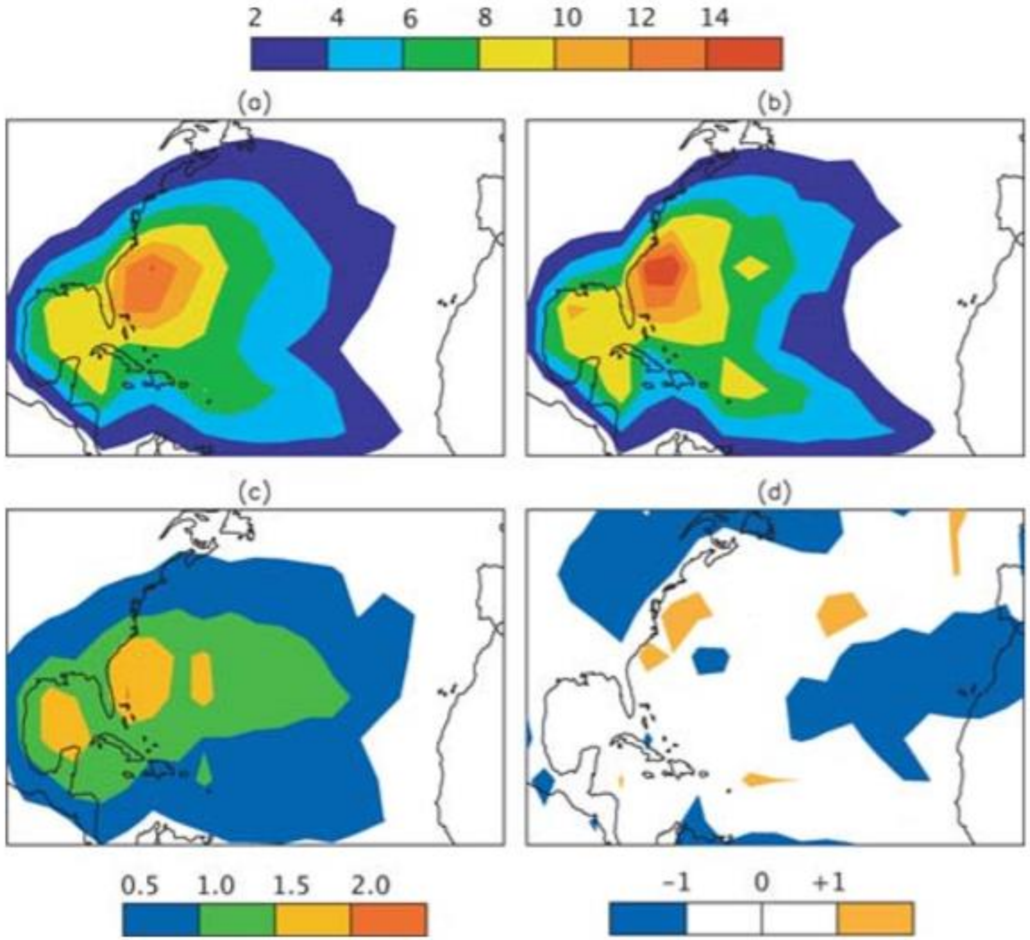


Fig. 15 of Hall and Jewson 2007

Event Sets

- Once a suitable event set has been generated (e.g., 1000, 5000, or even 100,000 simulated years), all sorts of statistics can be computed directly
  - Return periods for a ‘strike’ by a TC of a given intensity in a given period
  - Clustering -- return periods for multiple TCs of a given intensity threshold
  - Crossing rates for a given region

Landfall crossing rates

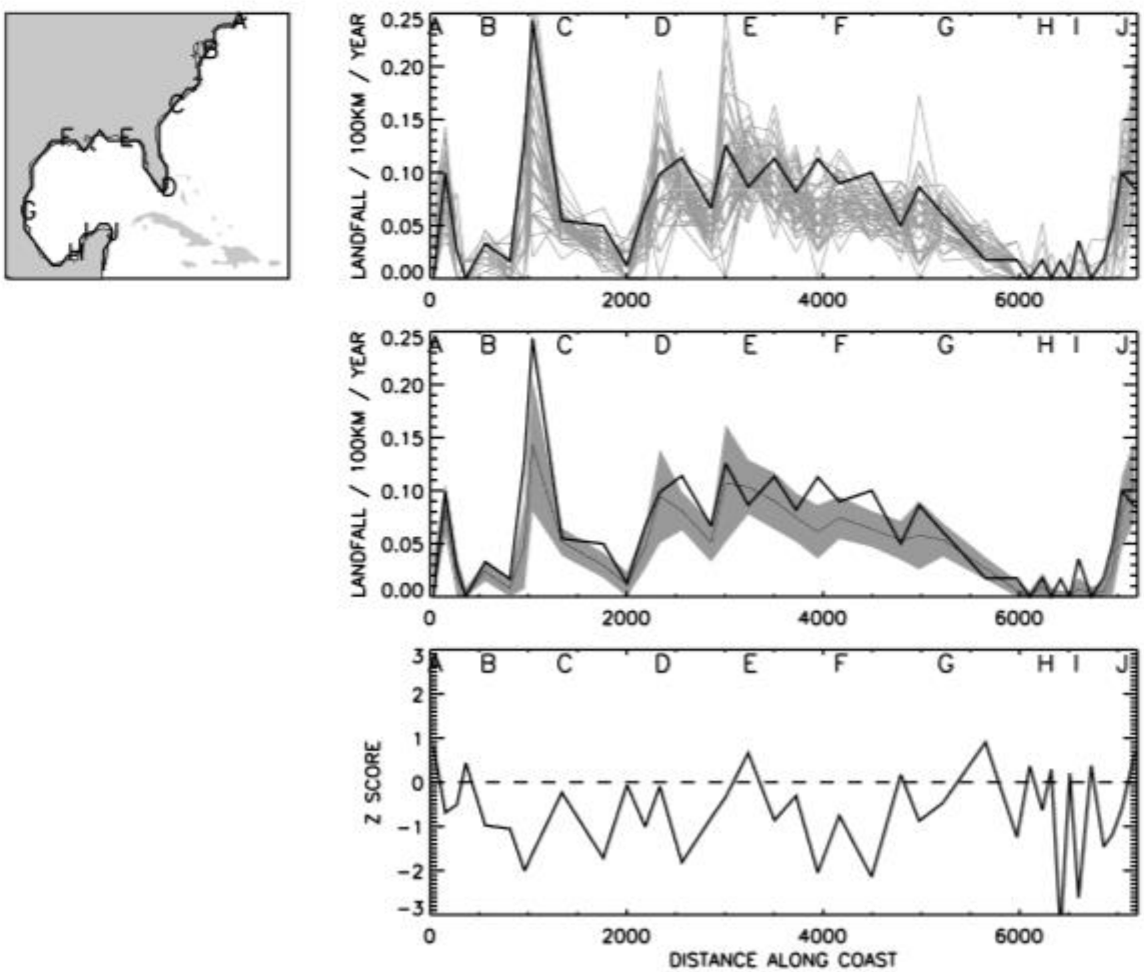
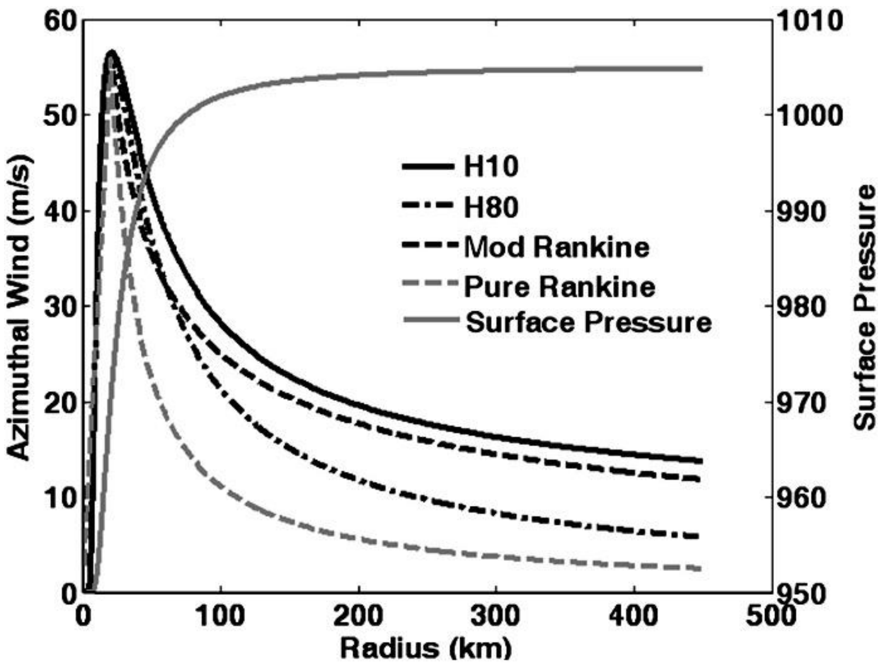


Fig. 14 of Hall and Jewson 2007

Addition of Parametric Wind Models



- A parametric wind model is a simple way to represent the wind field of a TC

$$v_s = \left[\frac{100 b_s \Delta p_s \left(\frac{r_{v_{ms}}}{r} \right)^{b_s}}{\rho_s e^{\left(\frac{r_{v_m}}{r} \right)^{b_s}}} \right]^x \quad \text{or}$$

$$v_s = v_{ms} \left\{ \left(\frac{r_{v_{ms}}}{r} \right)^{b_s} e^{\left[1 - \left(\frac{r_{v_{ms}}}{r} \right)^{b_s} \right]} \right\}^x,$$

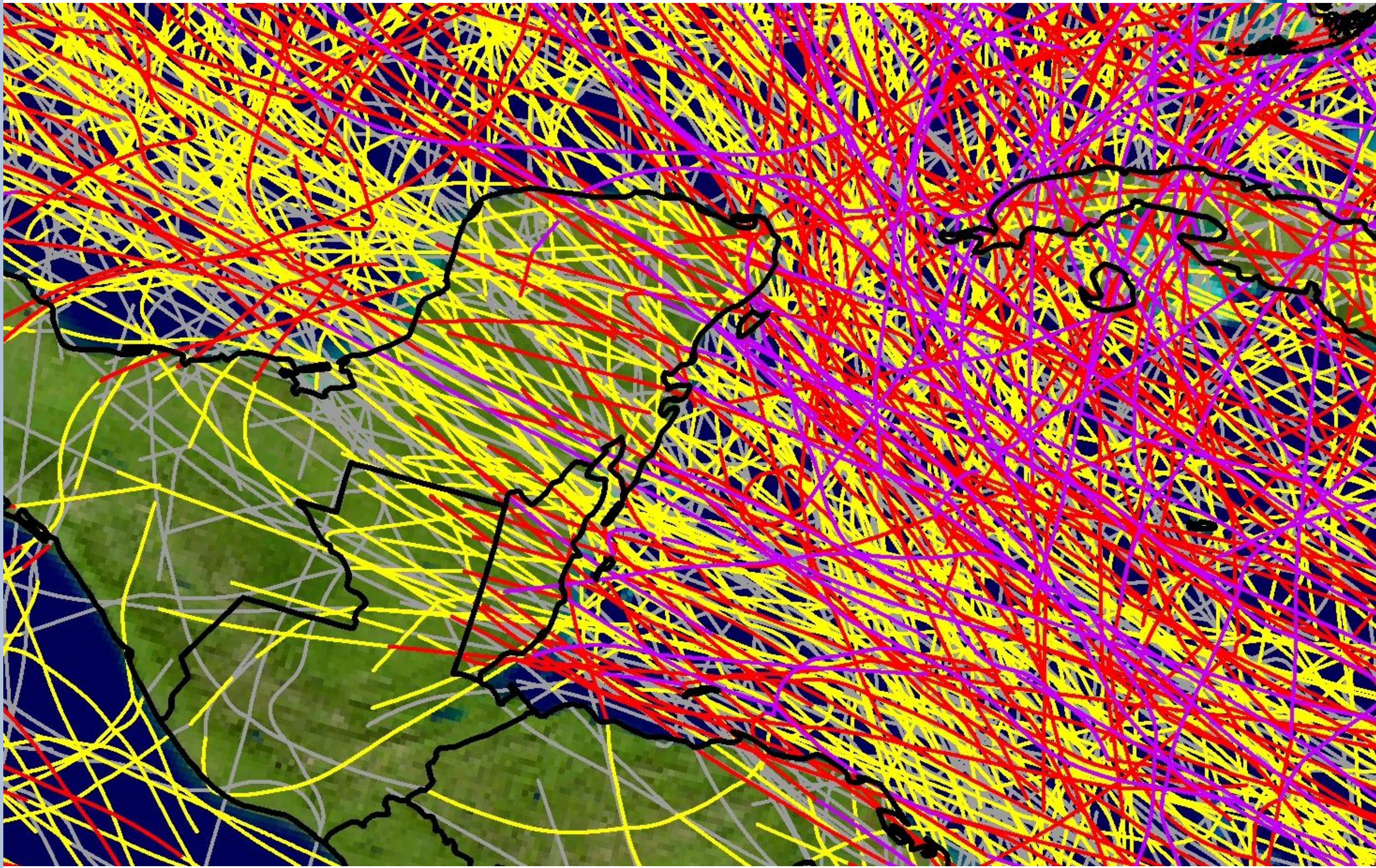
$$b_s = \frac{v_{ms}^2 \rho_{ms} e}{100(p_{ns} - p_{cs})}.$$

Statistical-Parametric Models

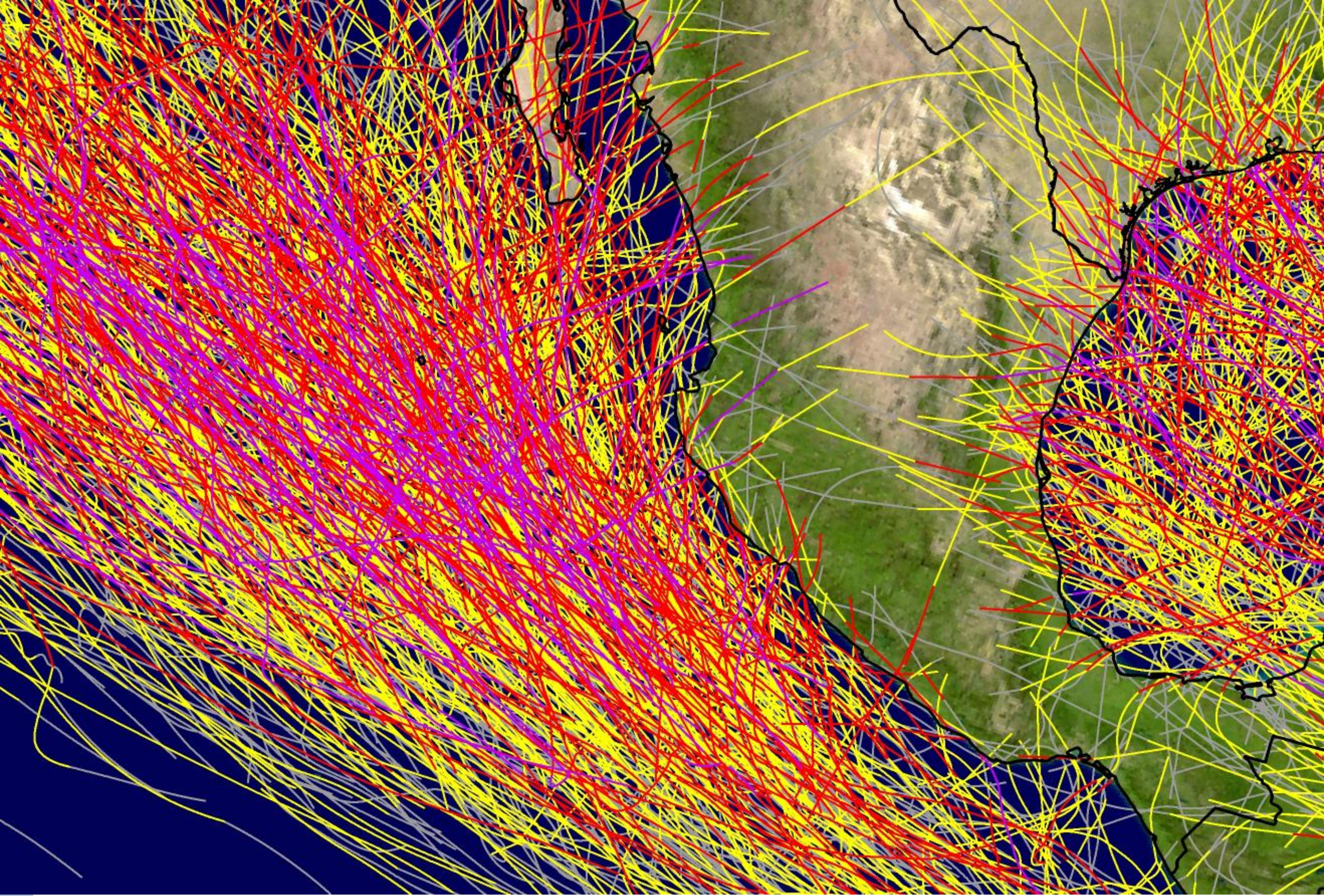
- Use of a parametric wind model with the synthetic track approaches allows one to assess the wind hazard at any given point
- Record maximum winds from each event
- Fit to an extreme value distribution (e.g., Pareto)
- Compute return periods, return levels

Some questions

- How well do the synthetic tracks really do in capturing the local variations in TC tracks?
- Are there other dynamical or environmental effects that are important?
- Is the assumption that intensity is independent of track really a good assumption?
- How do the wind change inland?



All North Atlantic and Eastern North Pacific tropical cyclones (from Ethan Gibney, NHC/WFO SGX)



All North Atlantic and Eastern North Pacific tropical cyclones (from Ethan Gibney, NHC/WFO SGX)

Approaches used to examine future changes

- **Statistical Downscaling**
  - Use Genesis Potential based on large-scale conditions to estimate genesis rates in future climate
  - **Advantages:**
    - Inexpensive
  - **Disadvantages:**
    - Does not say anything about what happens after genesis

Approaches used to examine future changes, cont’d

- **General Circulation Models (GCMs)**
  - GCMs are too coarse to adequately represent TC inner core processes
  - Cannot represent intense TCs
  - Statistical approaches such as quantile-quantile mapping or extreme value analysis may be used, but there are many potential issues
    - SST bias off west coast of Mexico
    - Vertical wind shear bias in tropical Atlantic
- GCMs can still be useful to inform on the large-scale trends such as potential intensity

Approaches used to examine future changes, cont'd

- **Dynamical Downscaling**
  - Involves running a higher resolution full-physics model using the GCM boundary conditions
  - Examples: GFDL hurricane model
  - Tropical channel alternative
  - **Advantages:**
    - Represents inner core dynamics better than any other method
    - Can represent intense TCs
  - **Disadvantages:**
    - Extremely expensive
    - Typically cannot simulate a long climate period
    - Questions about the boundaries

Deterministic Downscaling (Emanuel method)

- Uses a database of synthetic tracks
- Disturbances are “seeded” and a simple axisymmetric intensity model is run
- The disturbances that grow are considered TCs
- **Advantages:**
  - Can represent intense TCs much better than GCMs
  - TC intensities are consistent with the large scale environment simulated by the GCM (potential intensity, vertical shear)
- **Disadvantages:**
  - Still subject to assumptions about the seeding rate of disturbances
  - If actual genesis rate decrases, may overpredict intense TCs

IPCC Statement on TC Intensity

- Global mean TC maximum wind speed is *likely* to increase.
- “Improvements in model resolution and downscaling techniques increase confidence in projections in intense storms, and the frequency of the most intense storms will *more likely than not* increase substantially in some basins.”
- “The available modeling studies that are capable of producing very strong cyclones typically project substantial increases in the frequency of the most intense cyclones and it is *more likely than not* that this increase will be larger than 10% in some basins . . .”

IPCC Statement on TC Frequency

NCAR

- “Based on process understanding and agreement in 21st century projections, it is *likely* that the global frequency of occurrence of tropical cyclones will either decrease or remain essentially unchanged . . . The future influence of climate change on tropical cyclones is *likely* to vary by region, but the specific characteristics of the changes are not yet well quantified and there is *low confidence* in region-specific projections of frequency and intensity.”

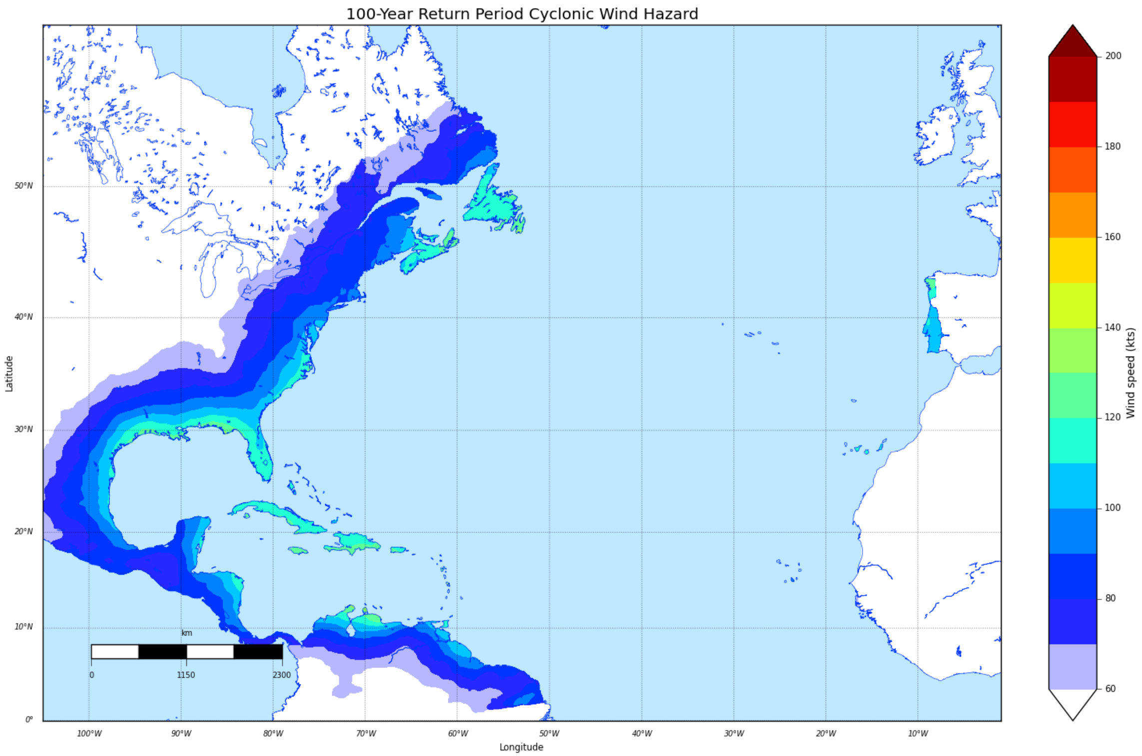
3. Baselines for Present and Future TC Wind Hazard

NCAR

Goal: Quantitatively assess changing wind hazard due to a set assumption on how TC intensity will react to intensity change

Approach:

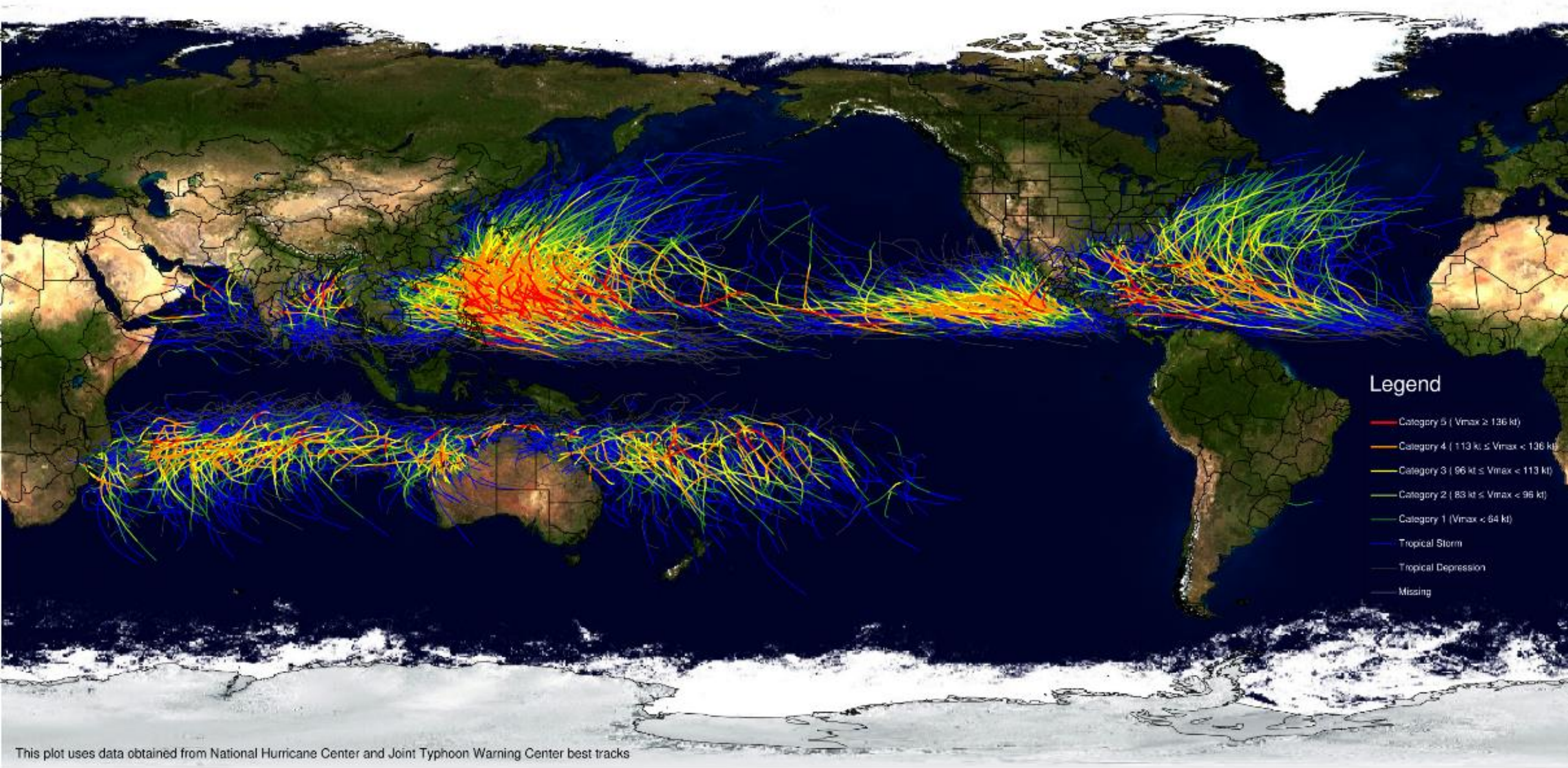
- Use recent 30-year historical records
- Fill in missing central pressures using a wind-pressure relationship
- Run Australia Geoscience Tropical Cyclone Risk Model (TCRM) for current climate (1986-2015)
- Assume that intensity increases 10% across the board for all TCs at all times in the 2071-2100 climate (e.g., RCP8.5)
- Run TCRM for future climate to get new return periods, etc.



100-Year Return Period Cyclonic Wind Hazard
Latitude
Longitude
50°N
40°N
30°N
20°N
10°N
0°
100°W
90°W
80°W
70°W
60°W
50°W
40°W
30°W
20°W
10°W
km
0
1150
2300
Wind speed (kts)
200
180
160
140
120
100
80
60

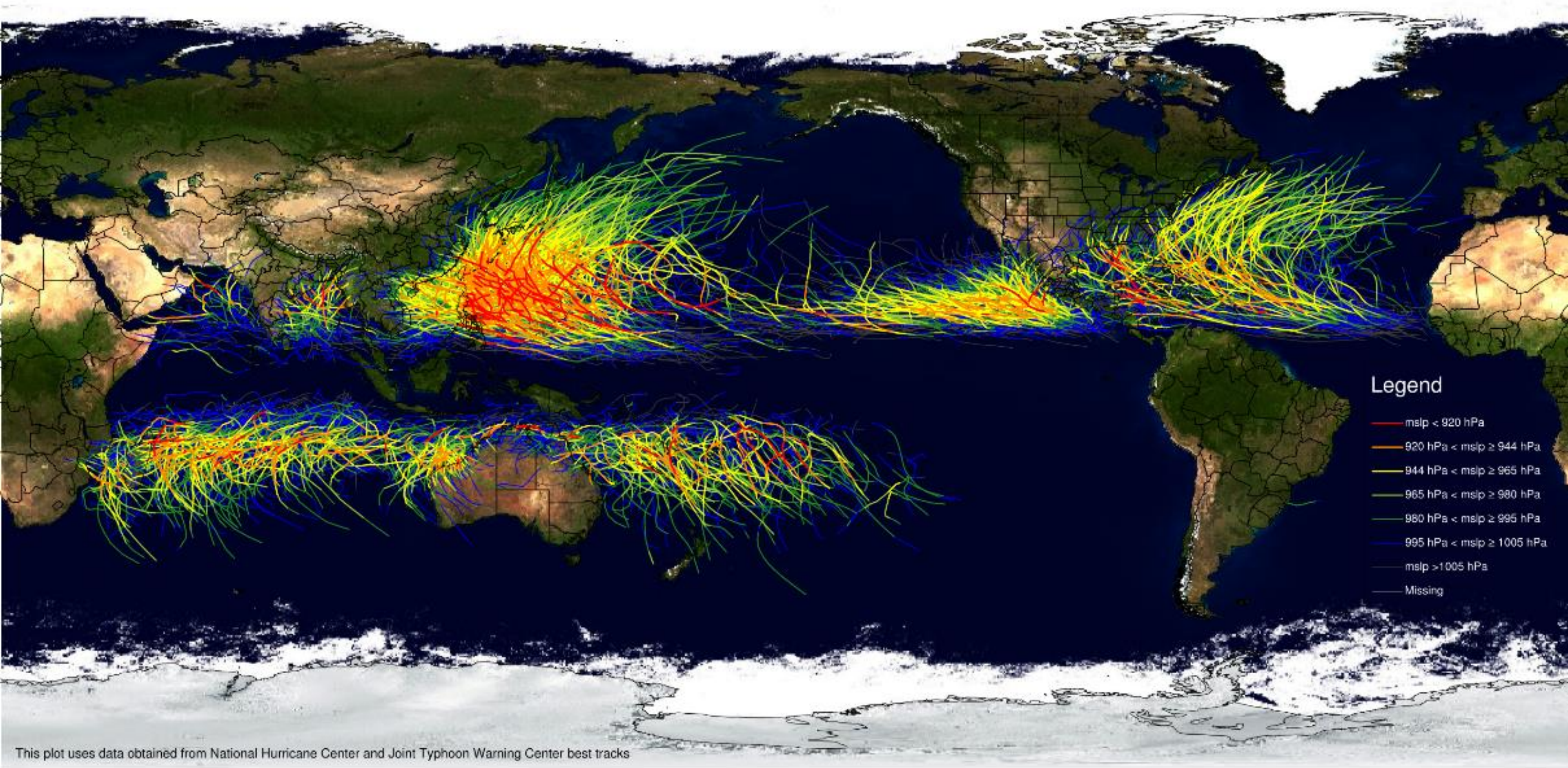
Global Distribution of Tropical Cyclones (1986-2015)

Intensity (maximum 1-minute wind speed) Historical Observations



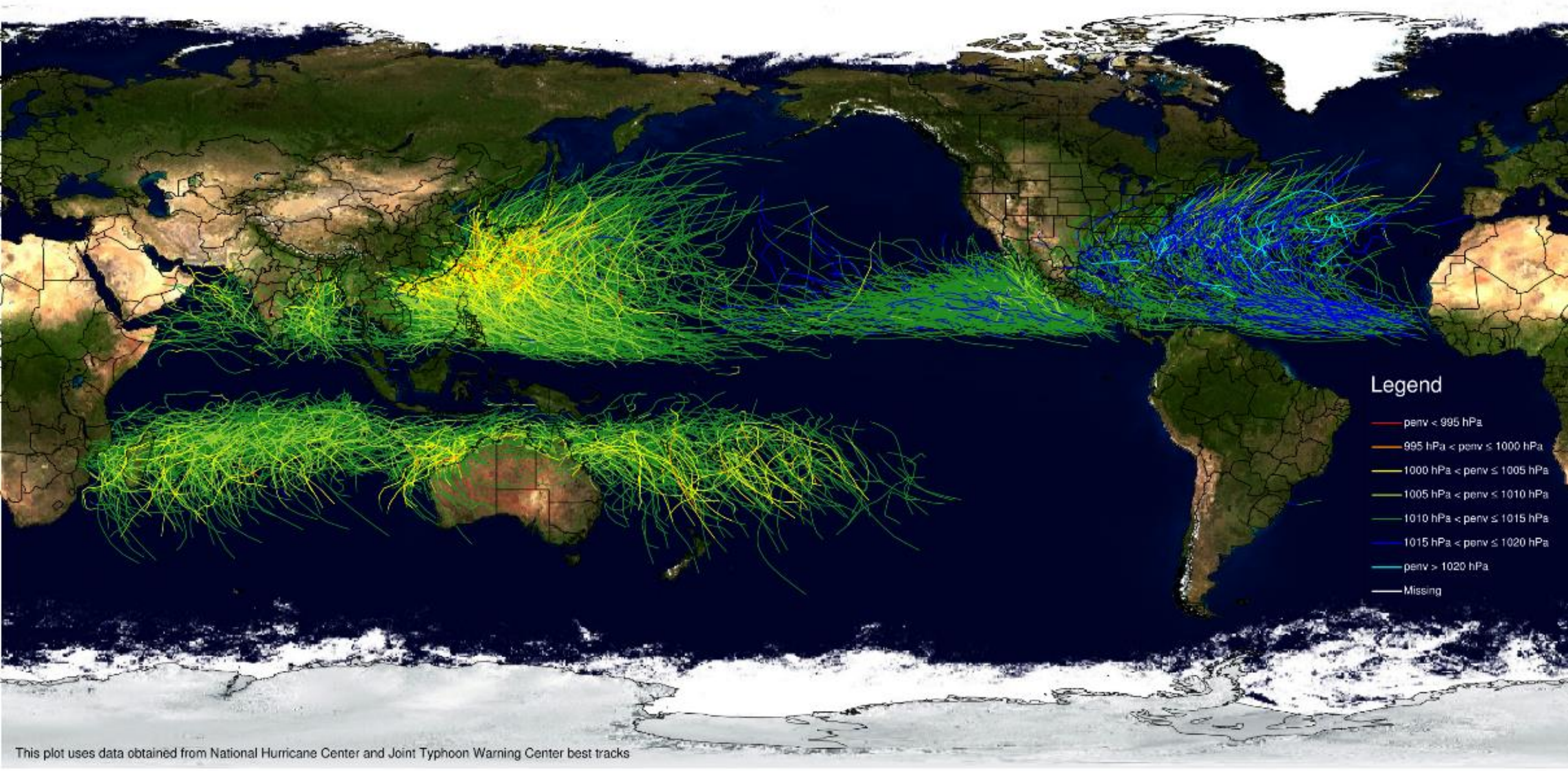
Global Distribution of Tropical Cyclones (1986-2015)

Minimum Sea Level Pressure   Historical Observations



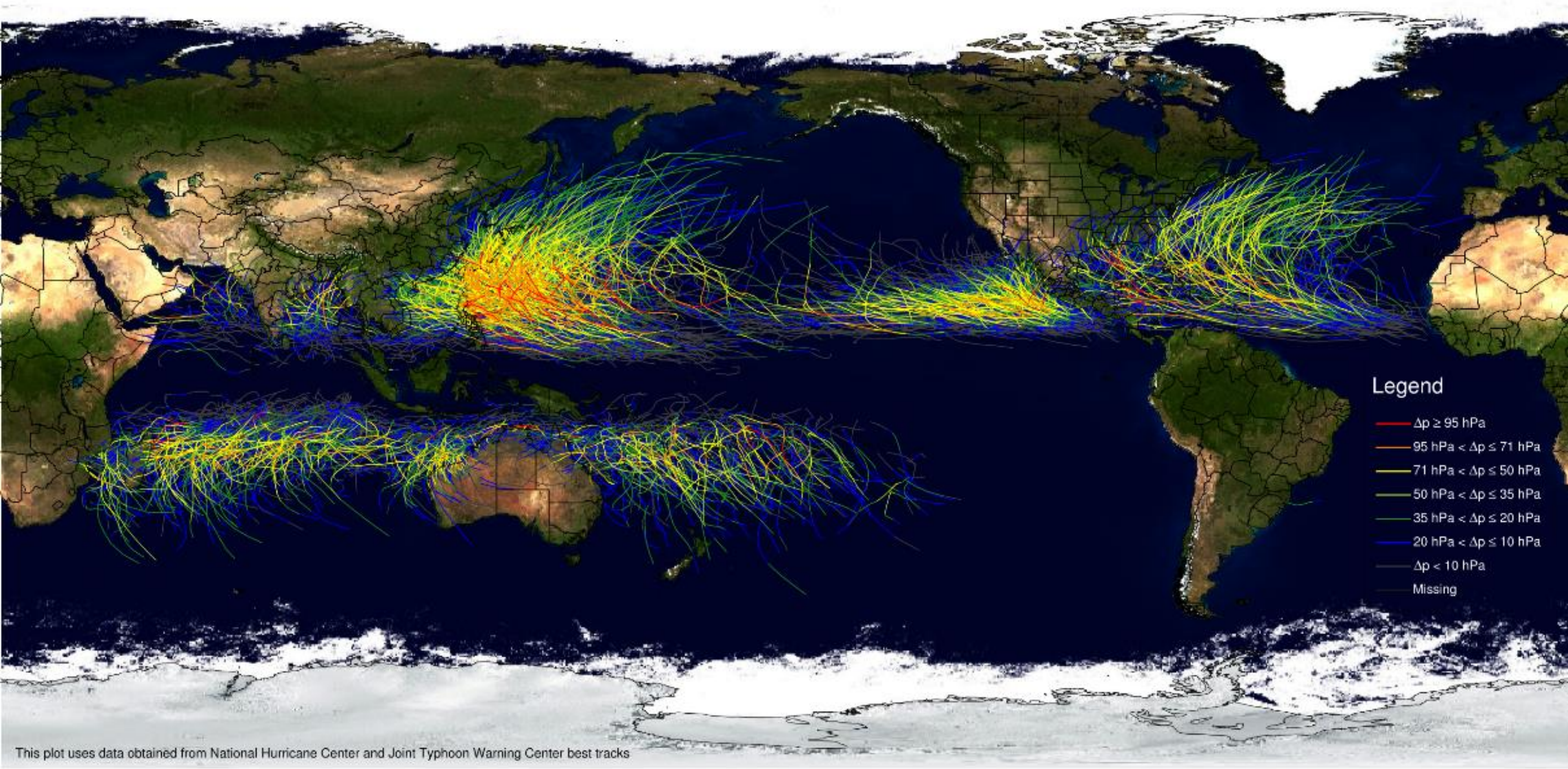
Global Distribution of Tropical Cyclones (1986-2015)

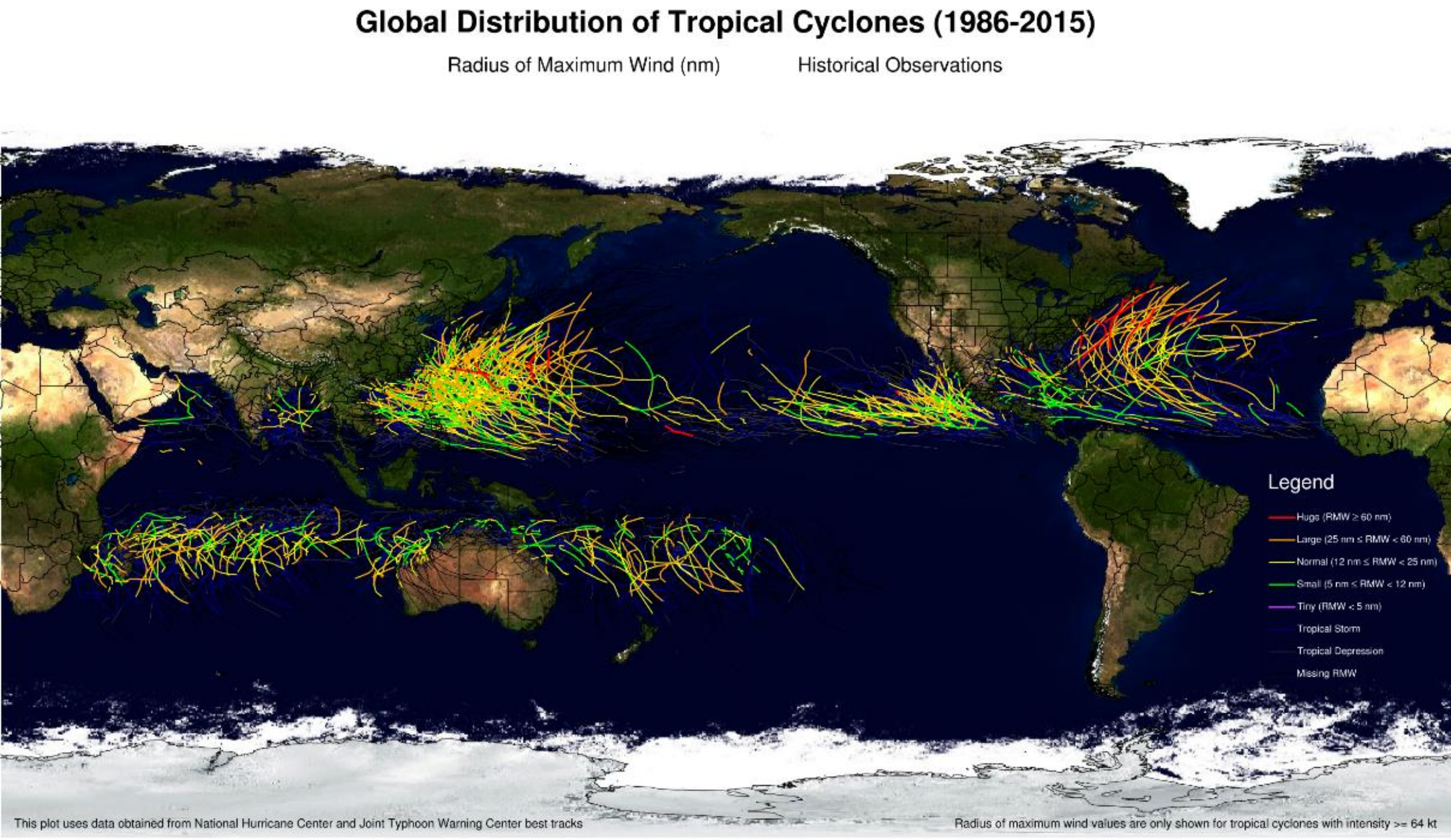
Environmental Pressure Historical Observations



Global Distribution of Tropical Cyclones (1986-2015)

Central Pressure Deficit (Δp) Historical Observations

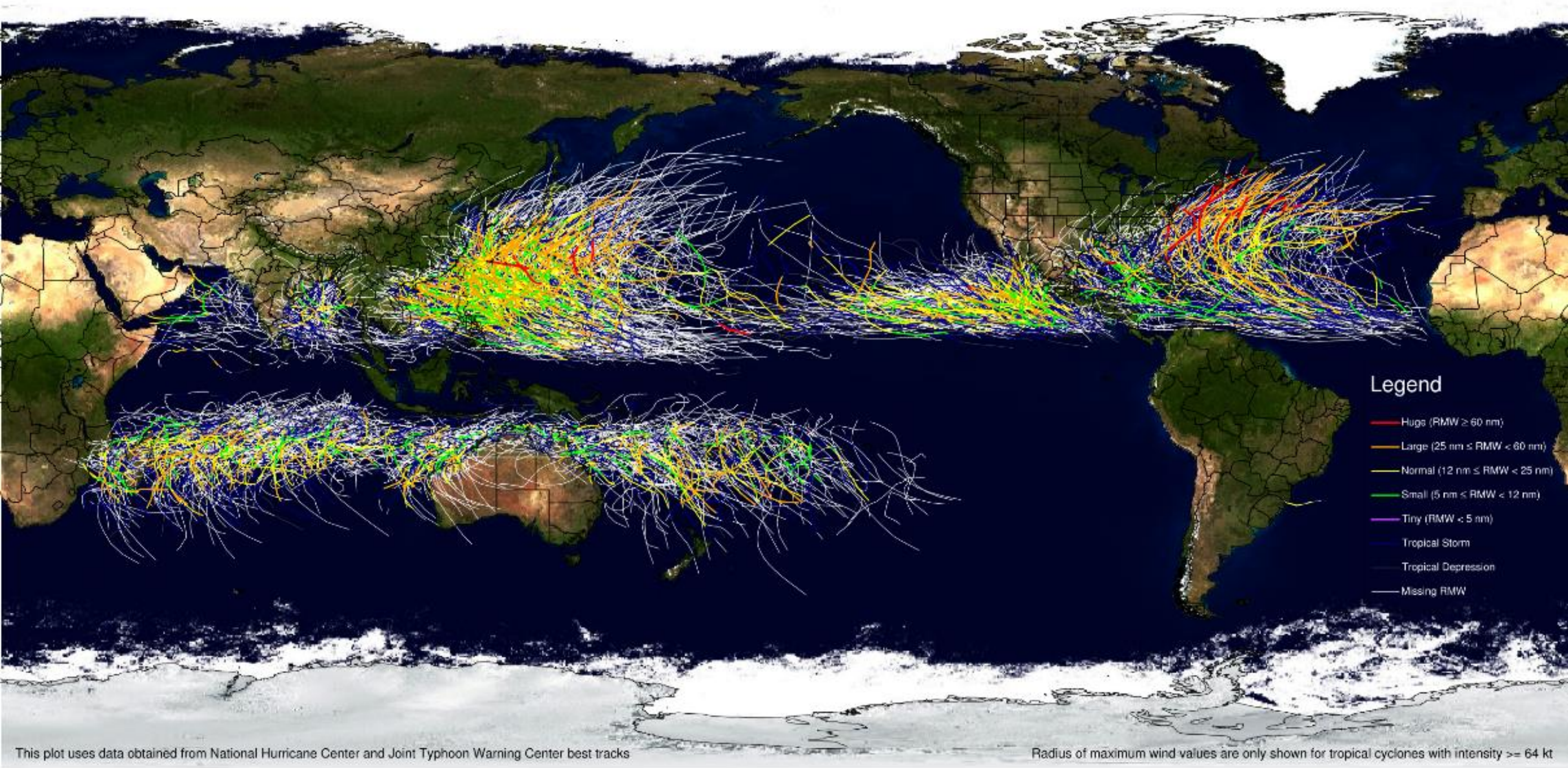




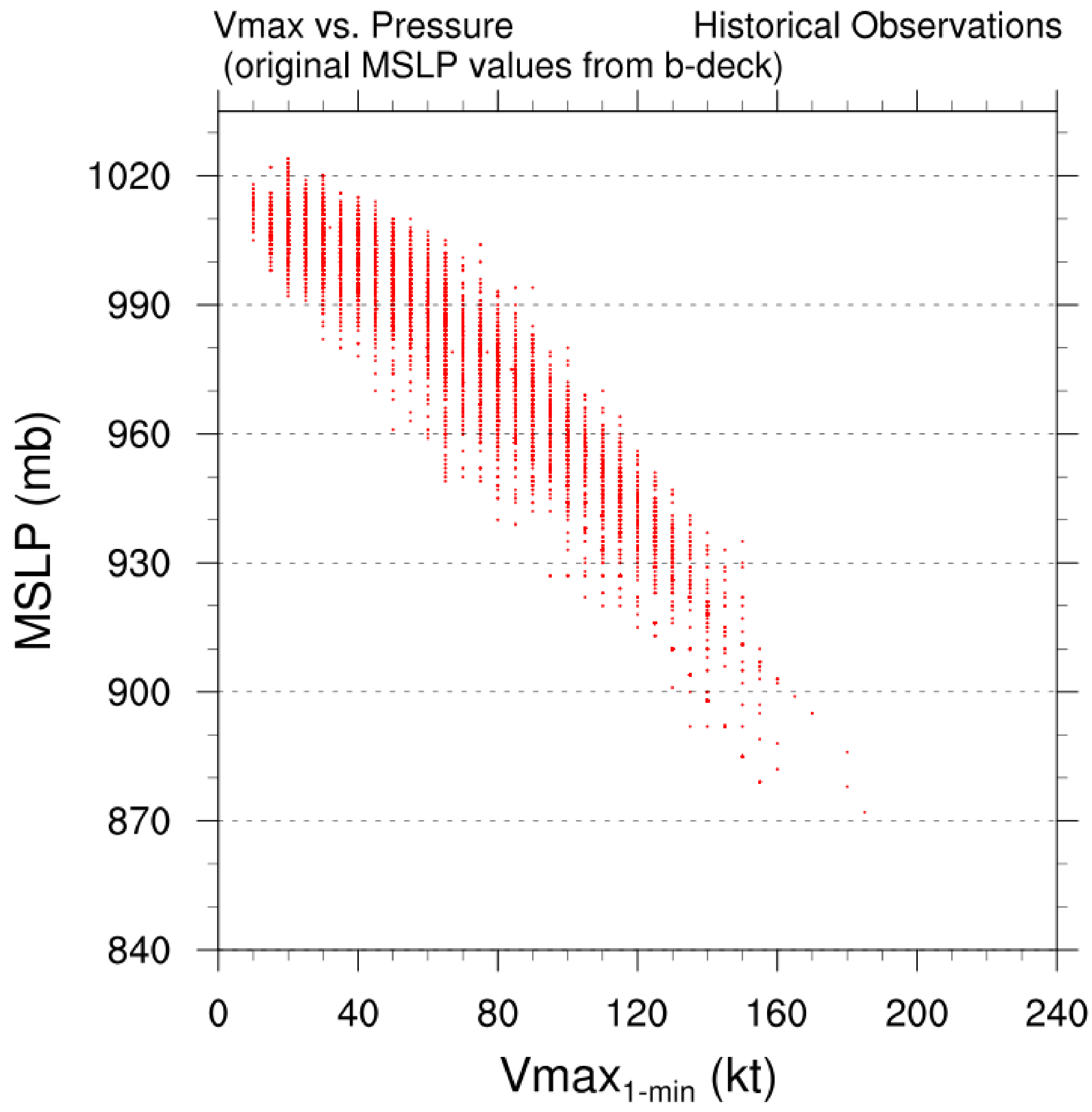
Global Distribution of Tropical Cyclones (1986-2015)
Radius of Maximum Wind (nm)
Historical Observations
Legend
Huge (RMW ≥ 60 nm)
Large (25 nm ≤ RMW < 60 nm)
Normal (12 nm ≤ RMW < 25 nm)
Small (5 nm ≤ RMW < 12 nm)
Tiny (RMW < 5 nm)
Tropical Storm
Tropical Depression
Missing RMW
This plot uses data obtained from National Hurricane Center and Joint Typhoon Warning Center best tracks
Radius of maximum wind values are only shown for tropical cyclones with intensity >= 64 kt

Global Distribution of Tropical Cyclones (1986-2015)

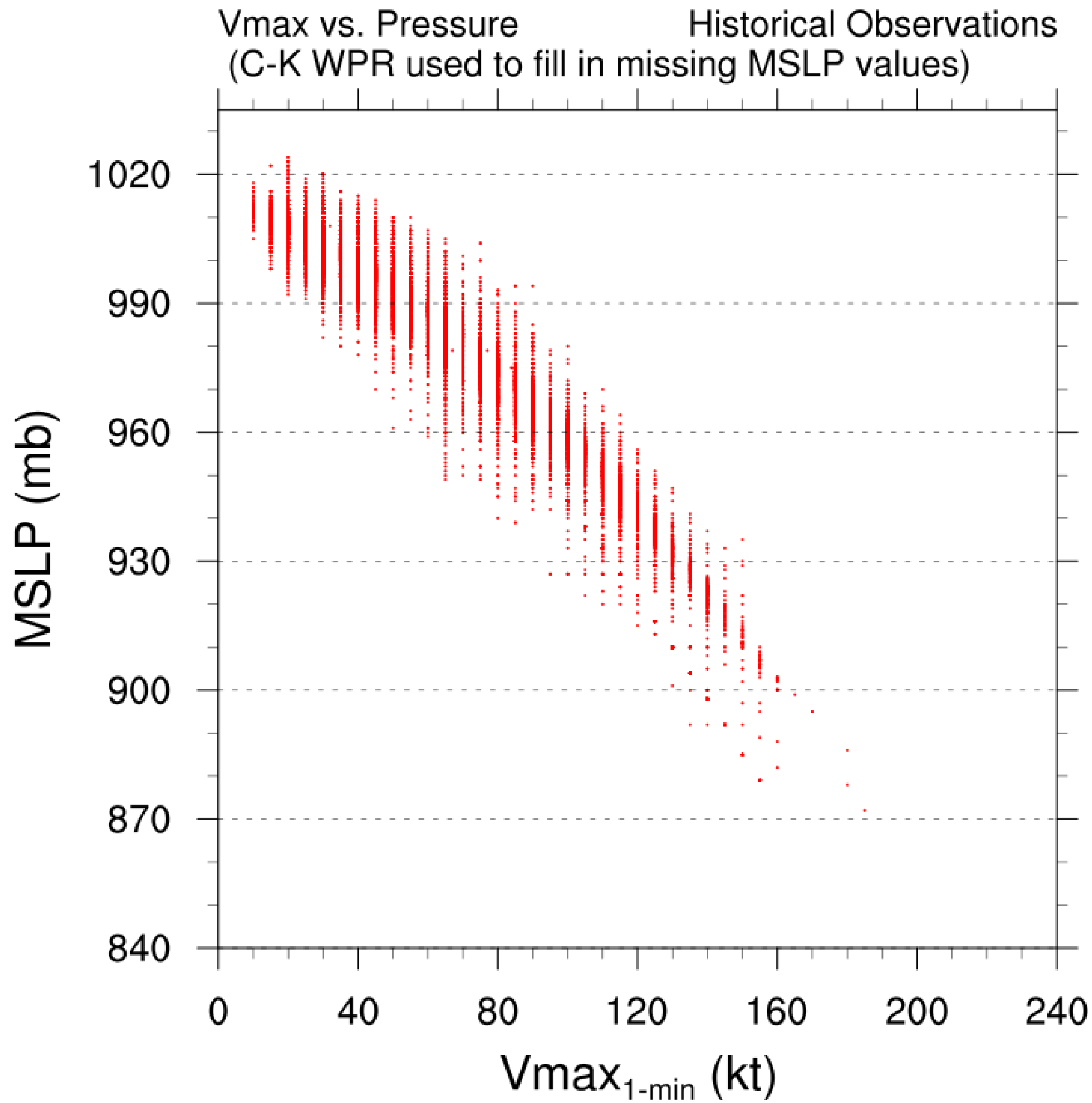
Radius of Maximum Wind (nm) Historical Observations

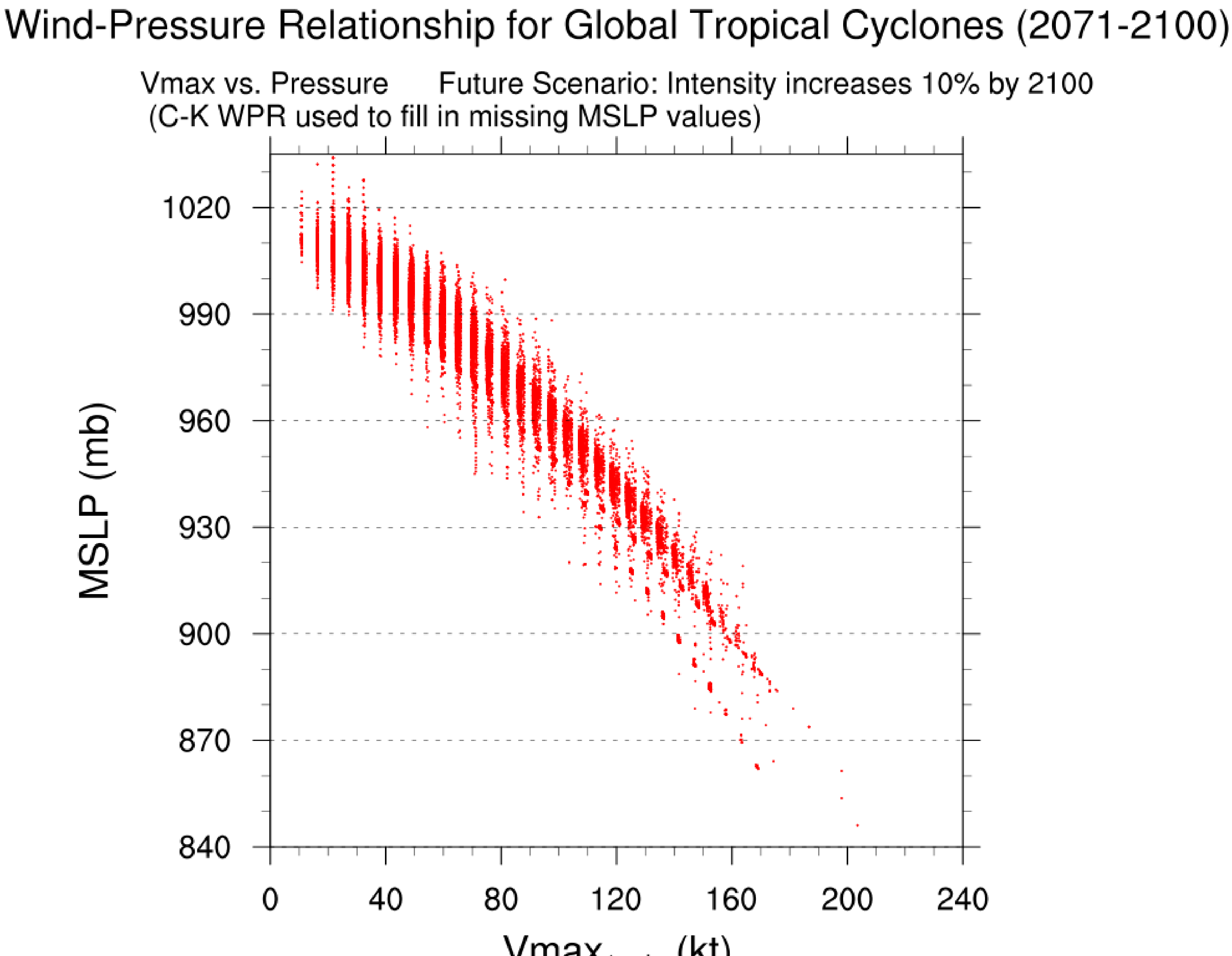


Wind-Pressure Relationship for Global Tropical Cyclones (1986-2015)

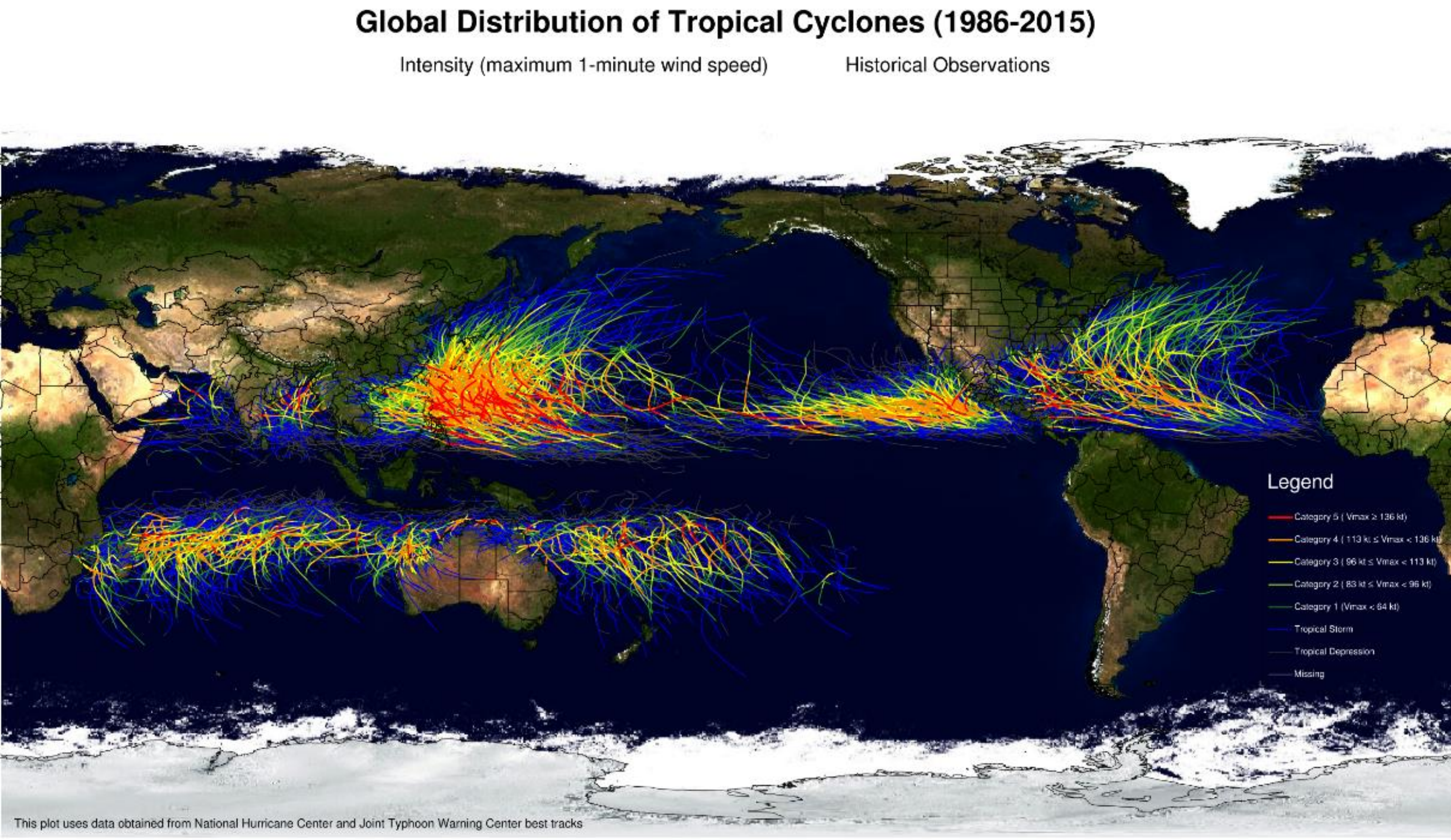


Wind-Pressure Relationship for Global Tropical Cyclones (1986-2015)



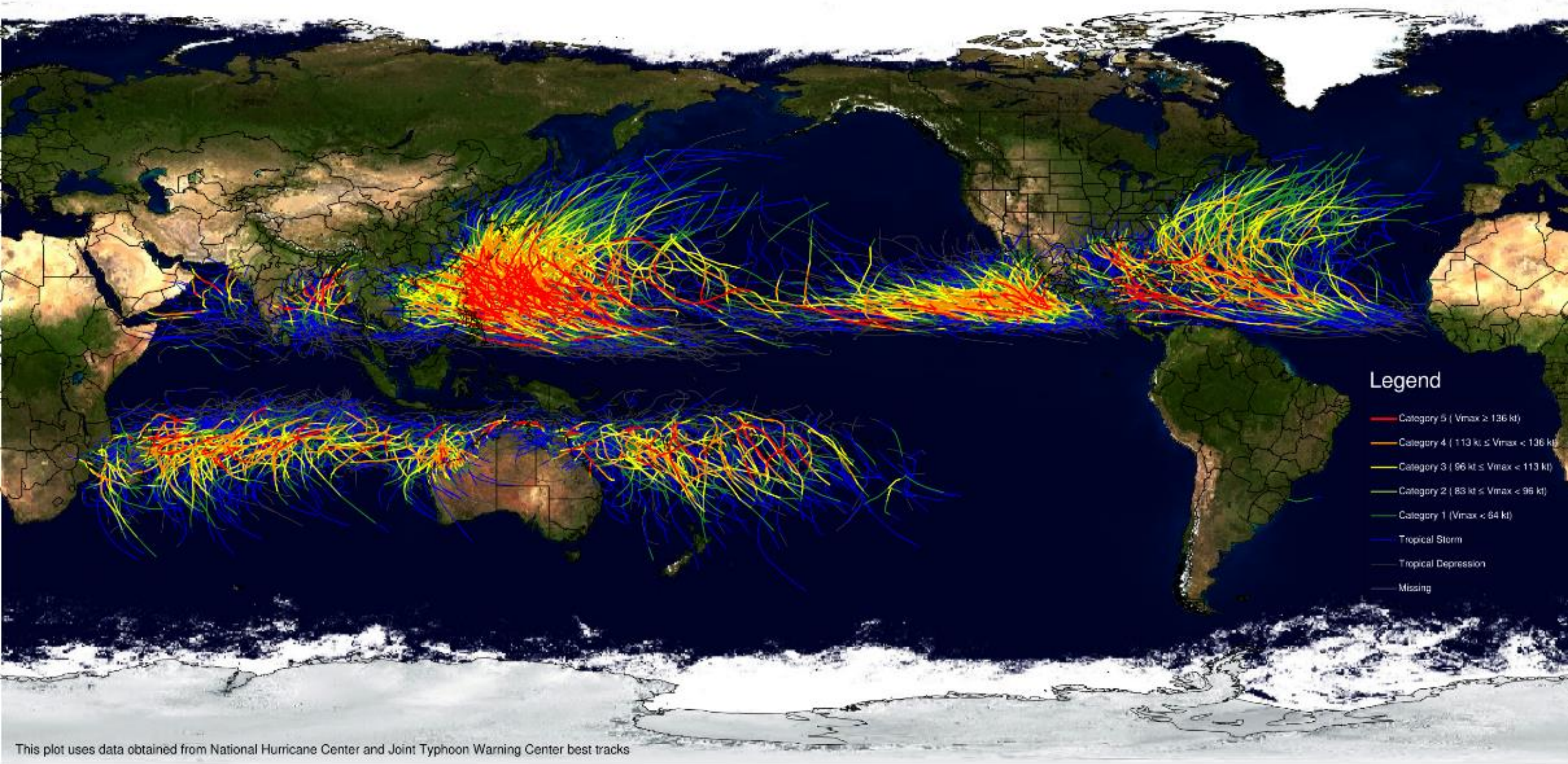


Presented at: *Universidad Nacional Autónoma de México, Instituto de Ingeniería, Laboratorio de Ingeniería y Procesos Costeros*

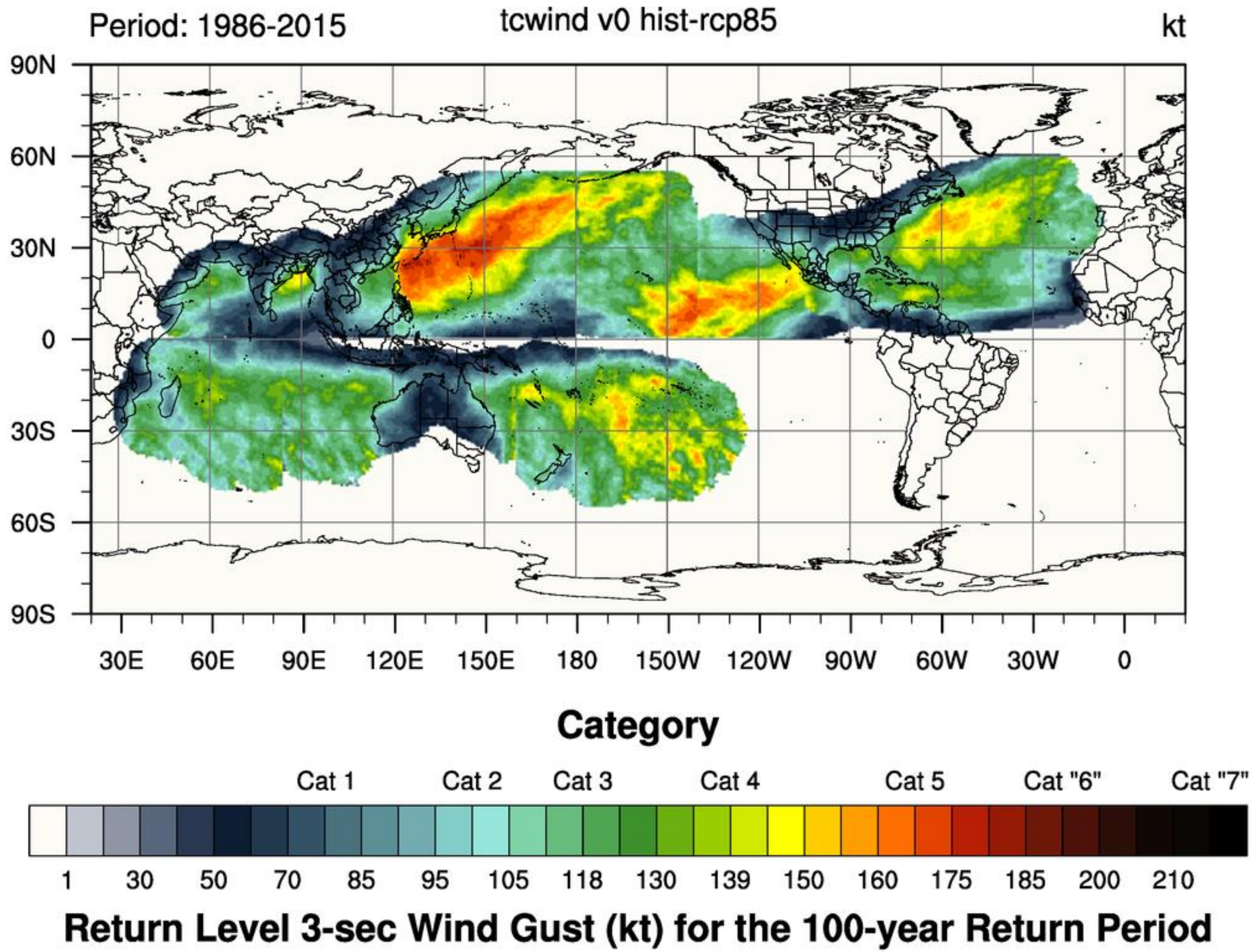

Global Distribution of Tropical Cyclones (1986-2015)
Intensity (maximum 1-minute wind speed)
Historical Observations
Legend
Category 5 (Vmax ≥ 136 kt)
Category 4 (113 kt ≤ Vmax < 136 kt)
Category 3 (96 kt ≤ Vmax < 113 kt)
Category 2 (83 kt ≤ Vmax < 96 kt)
Category 1 (Vmax < 64 kt)
Tropical Storm
Tropical Depression
Missing
This plot uses data obtained from National Hurricane Center and Joint Typhoon Warning Center best tracks

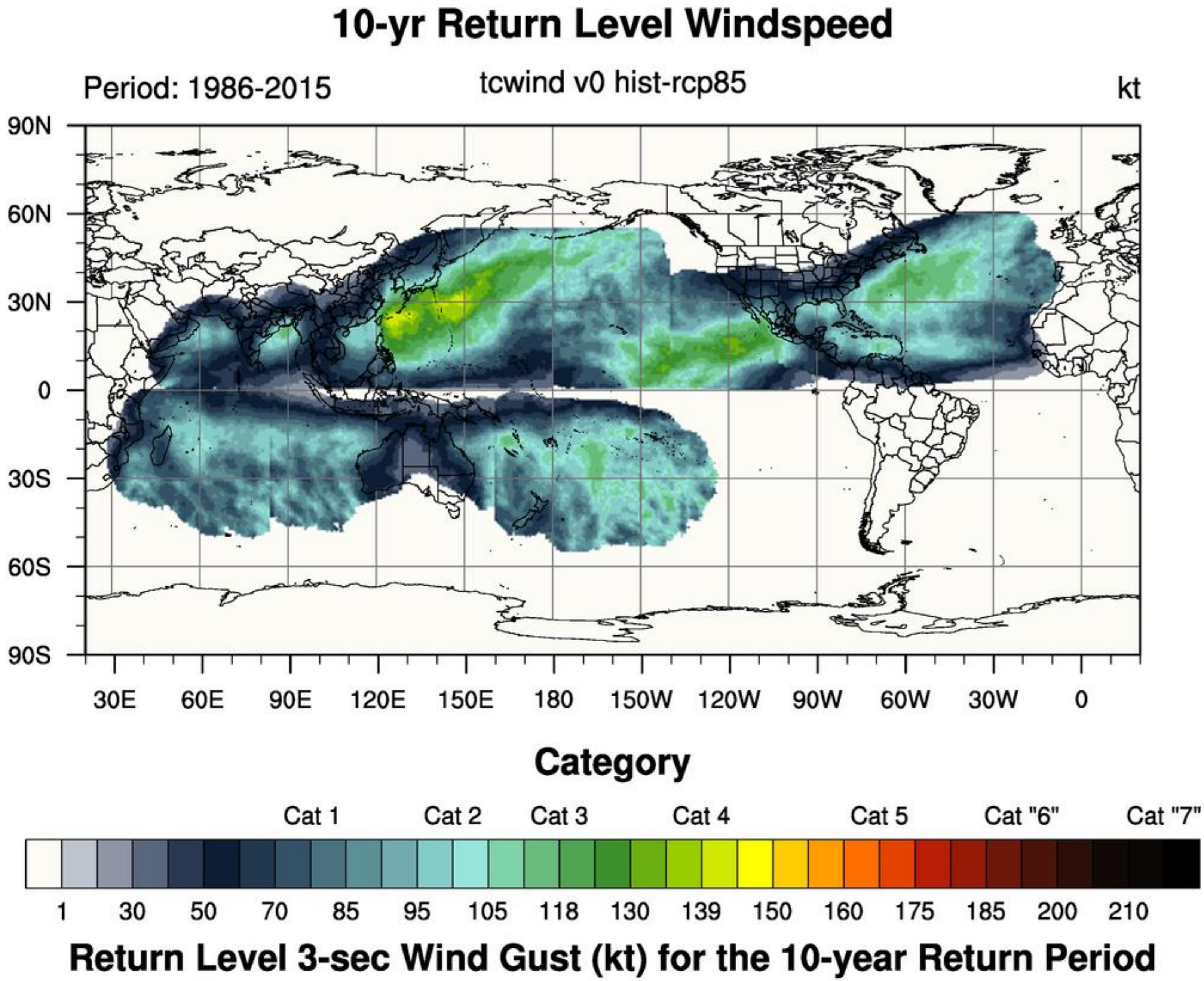
Global Distribution of Tropical Cyclones (2071-2100)

Intensity (maximum 1-minute wind speed)   Future Scenario: Intensity increases 10% by 2100

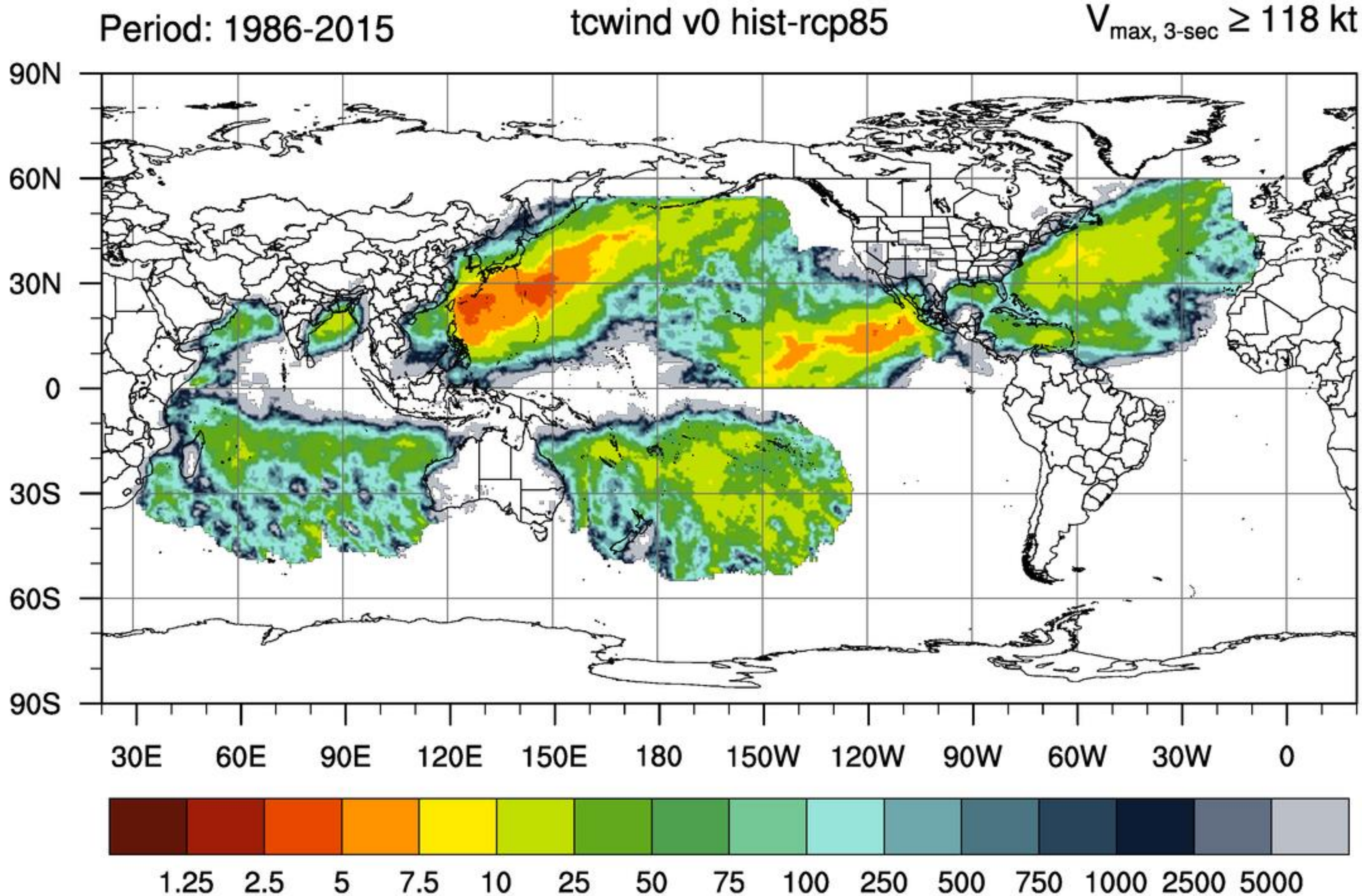


100-yr Return Level Windspeed

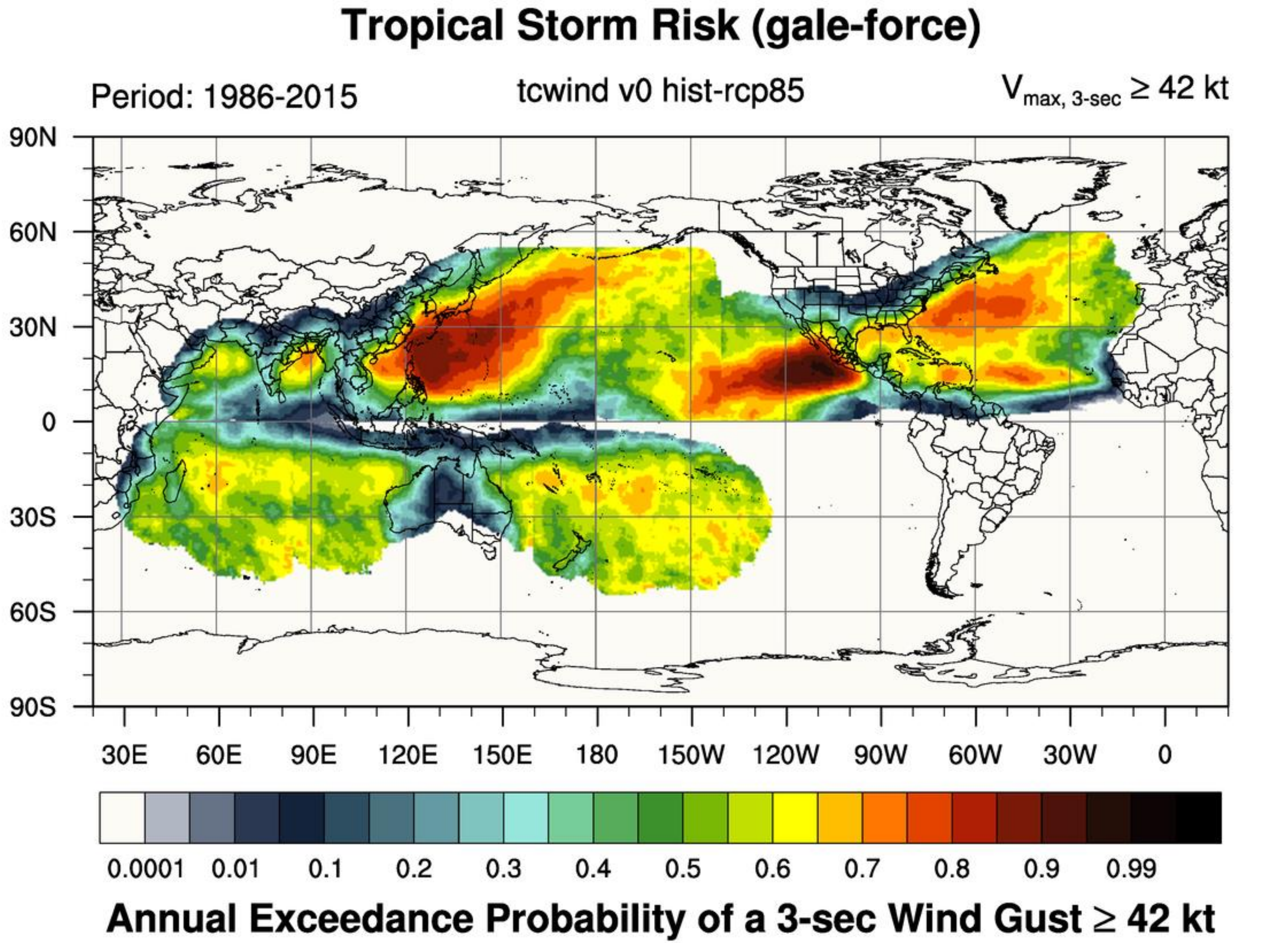



10-yr Return Level Windspeed
Period: 1986-2015
tcwind v0 hist-rcp85
kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
Category
Cat 1
Cat 2
Cat 3
Cat 4
Cat 5
Cat "6"
Cat "7"
1
30
50
70
85
95
105
118
130
139
150
160
175
185
200
210
Return Level 3-sec Wind Gust (kt) for the 10-year Return Period

Category 3 Risk

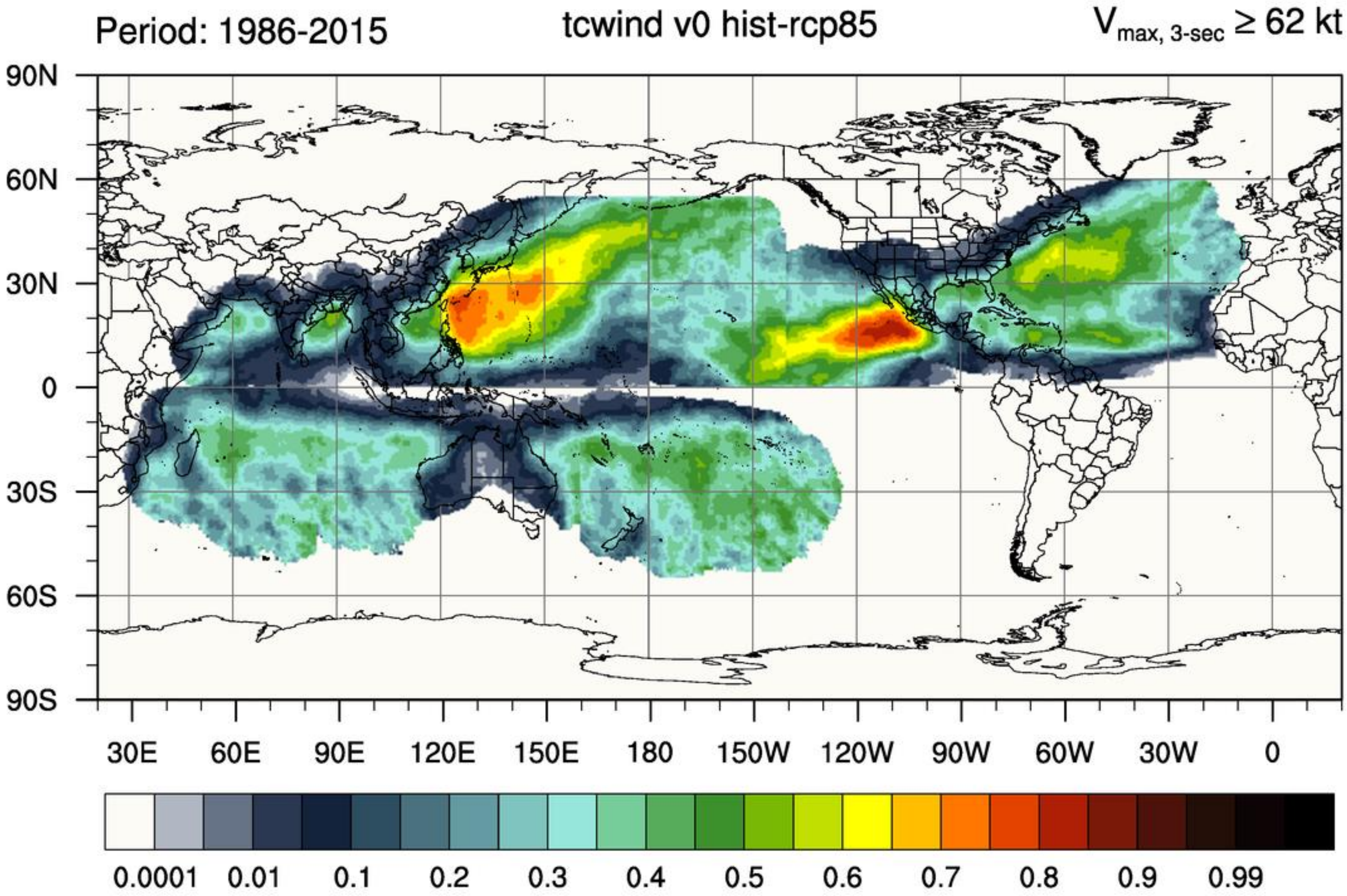


Return Period of a 3-sec Wind Gust ≥ 118 kt

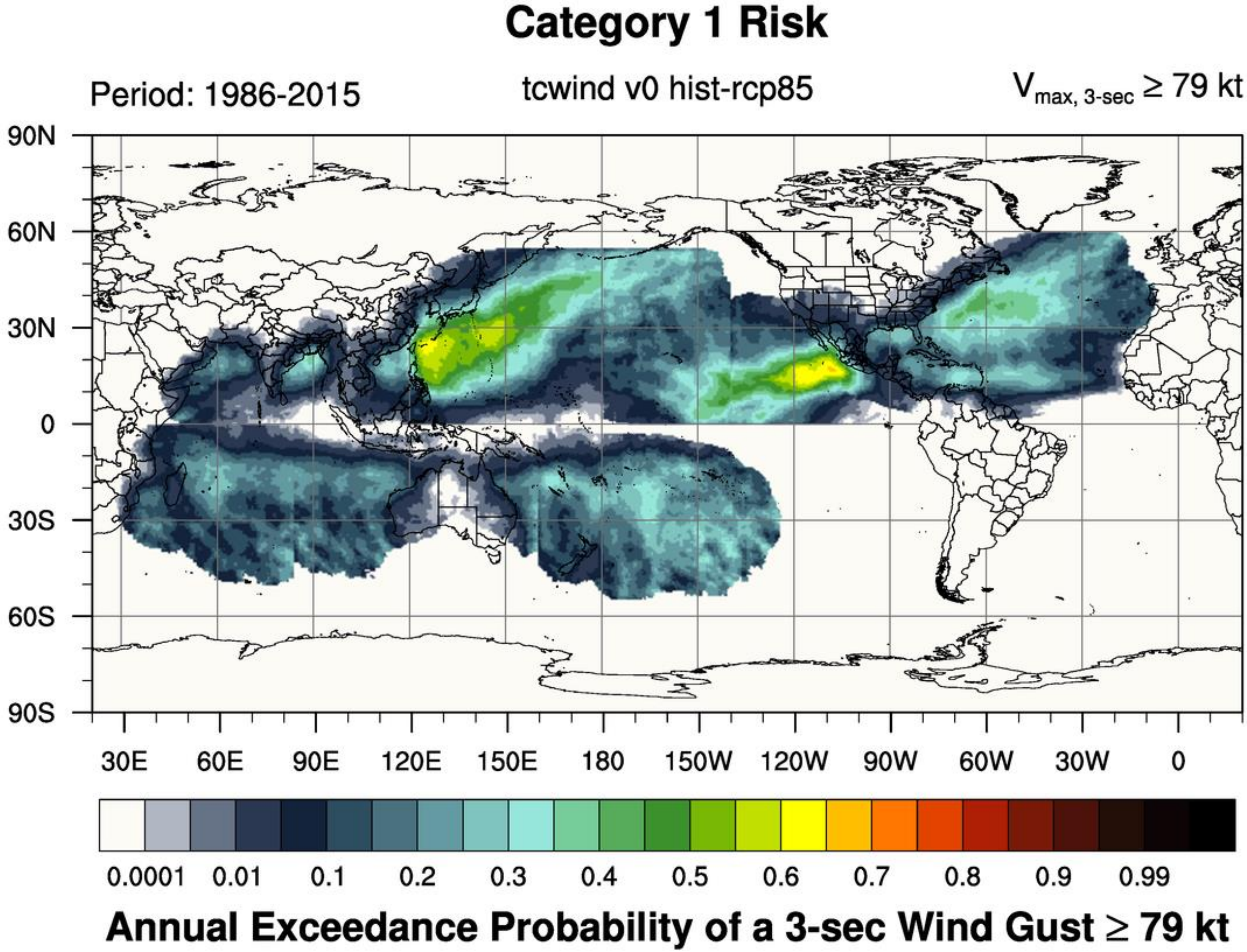

Tropical Storm Risk (gale-force)
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max, 3\text{-}sec} \geq 42$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 42 kt

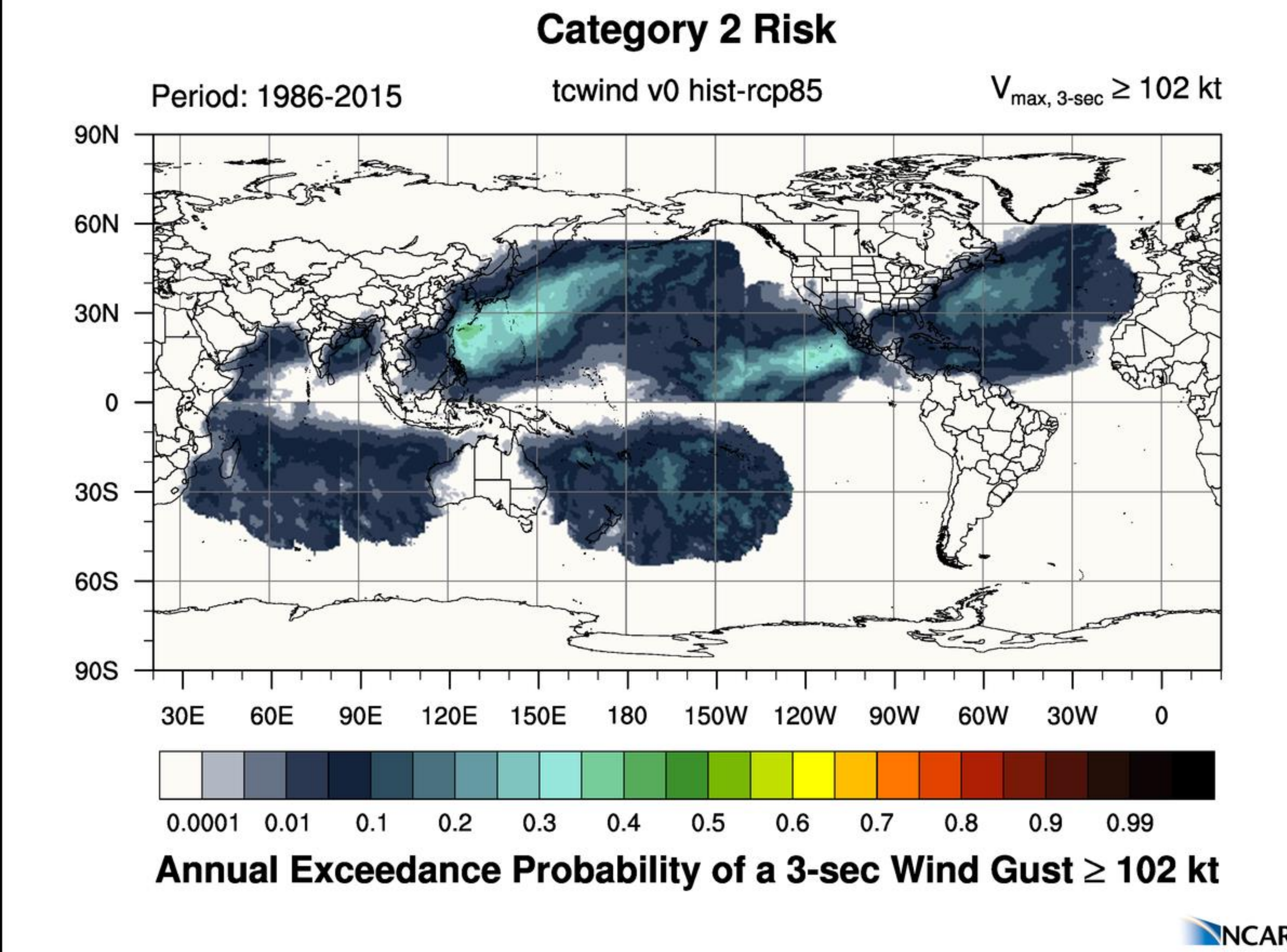
NCAR

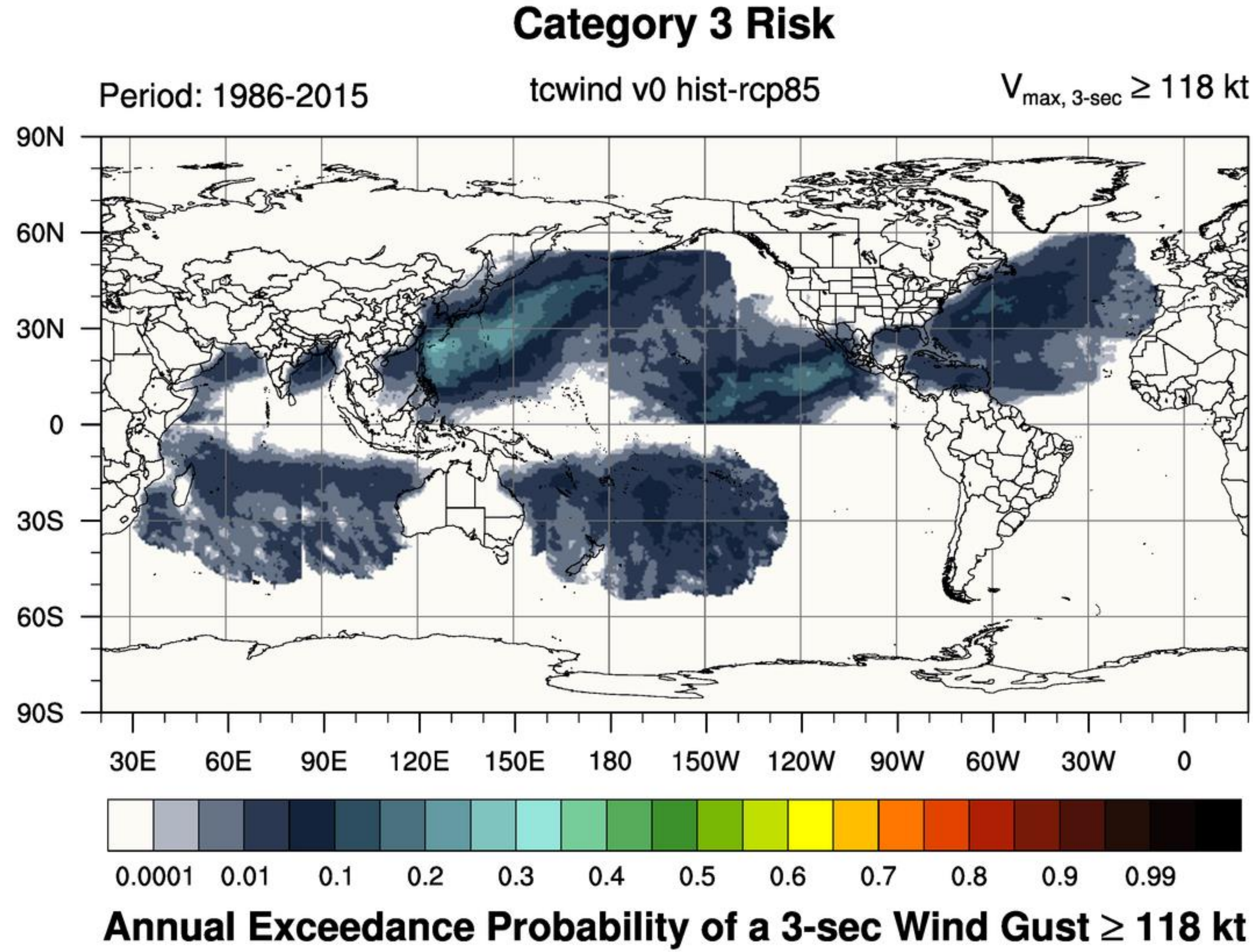
Tropical Storm Risk (storm-force)

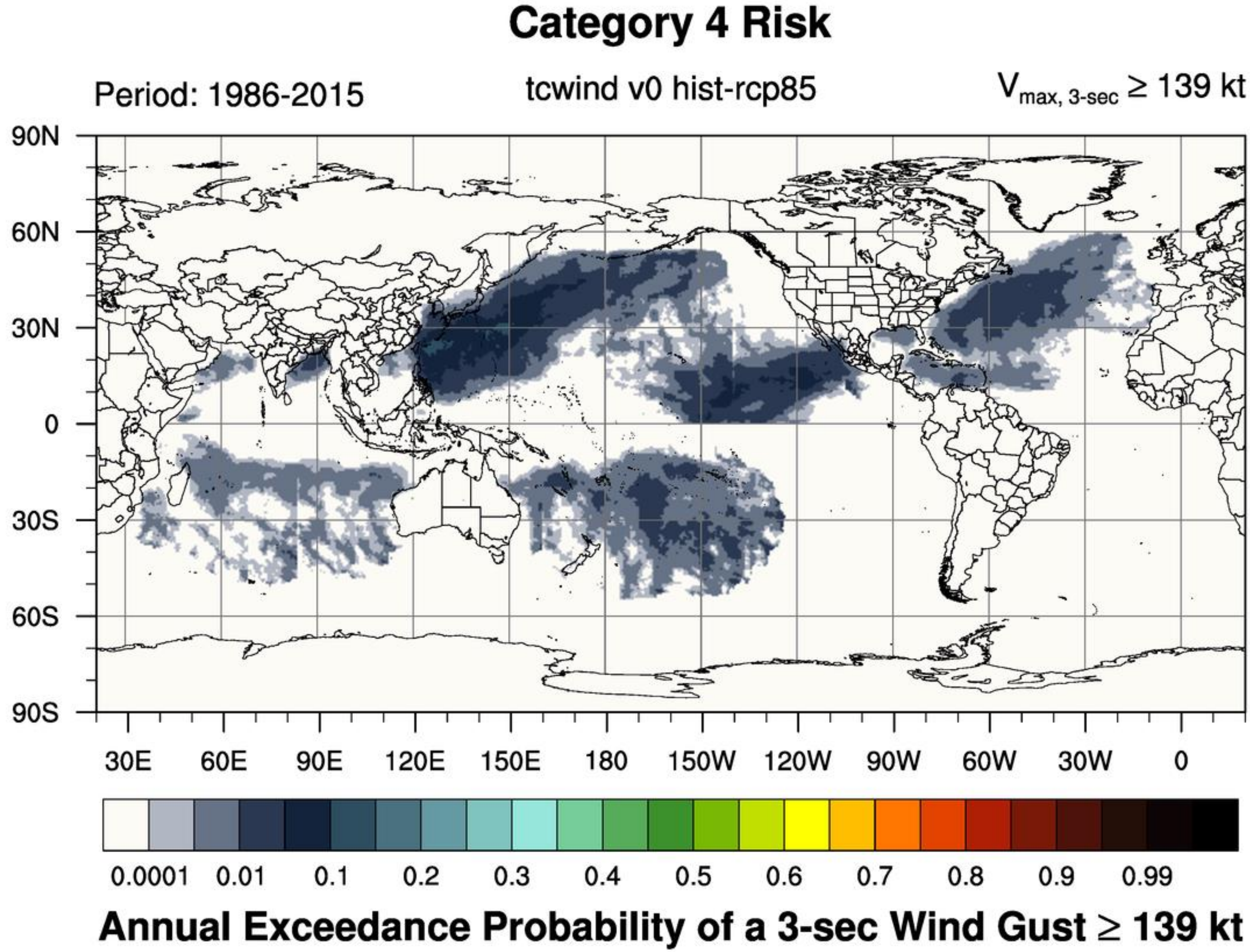


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 62 kt


Category 1 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max,\ 3\text{-}sec} \geq 79$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 79 kt

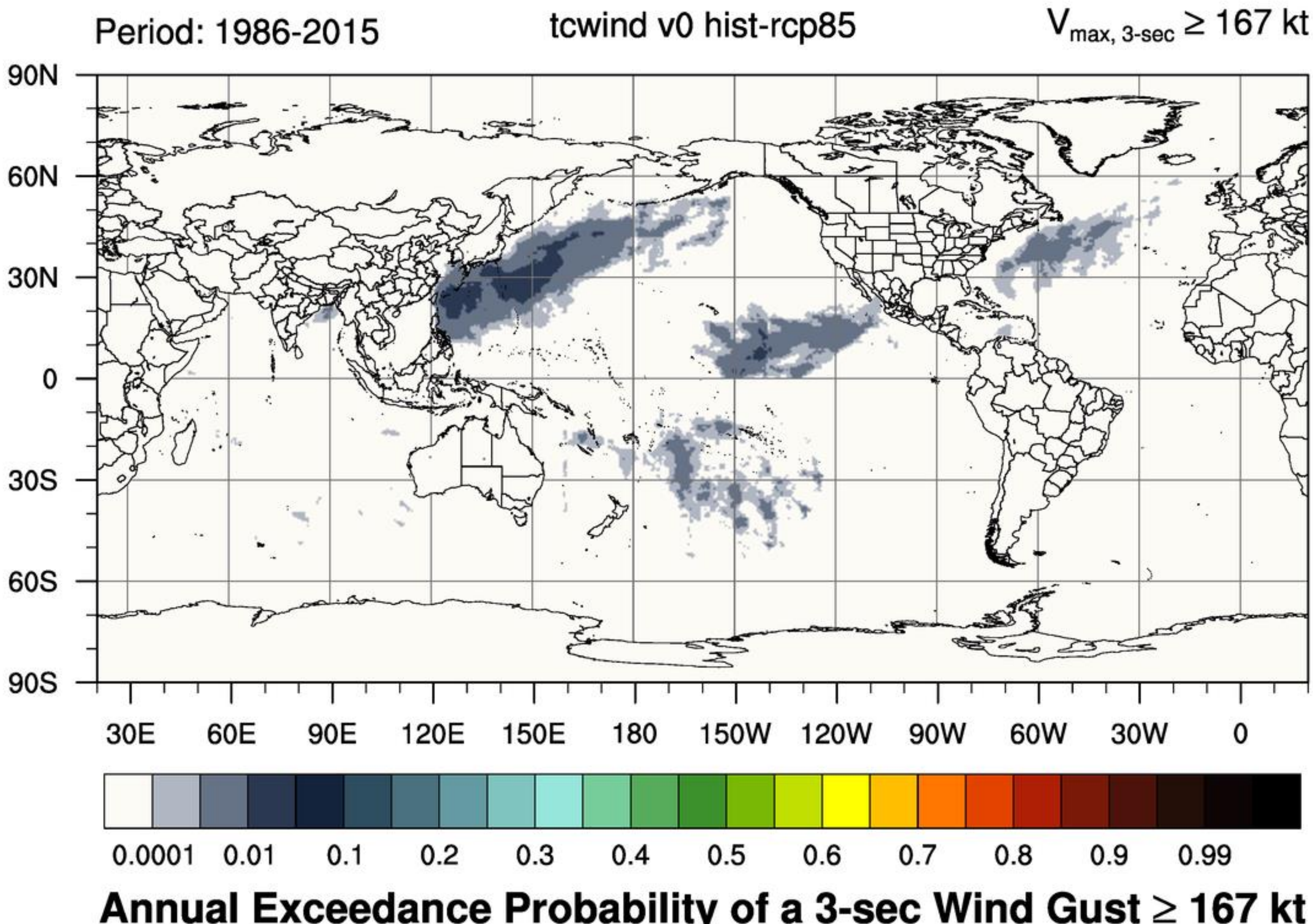

Category 2 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max,\ 3\text{-}sec} \geq 102$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 102 kt
NCAR


Category 3 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max,\ 3\text{-}sec} \geq 118$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 118 kt

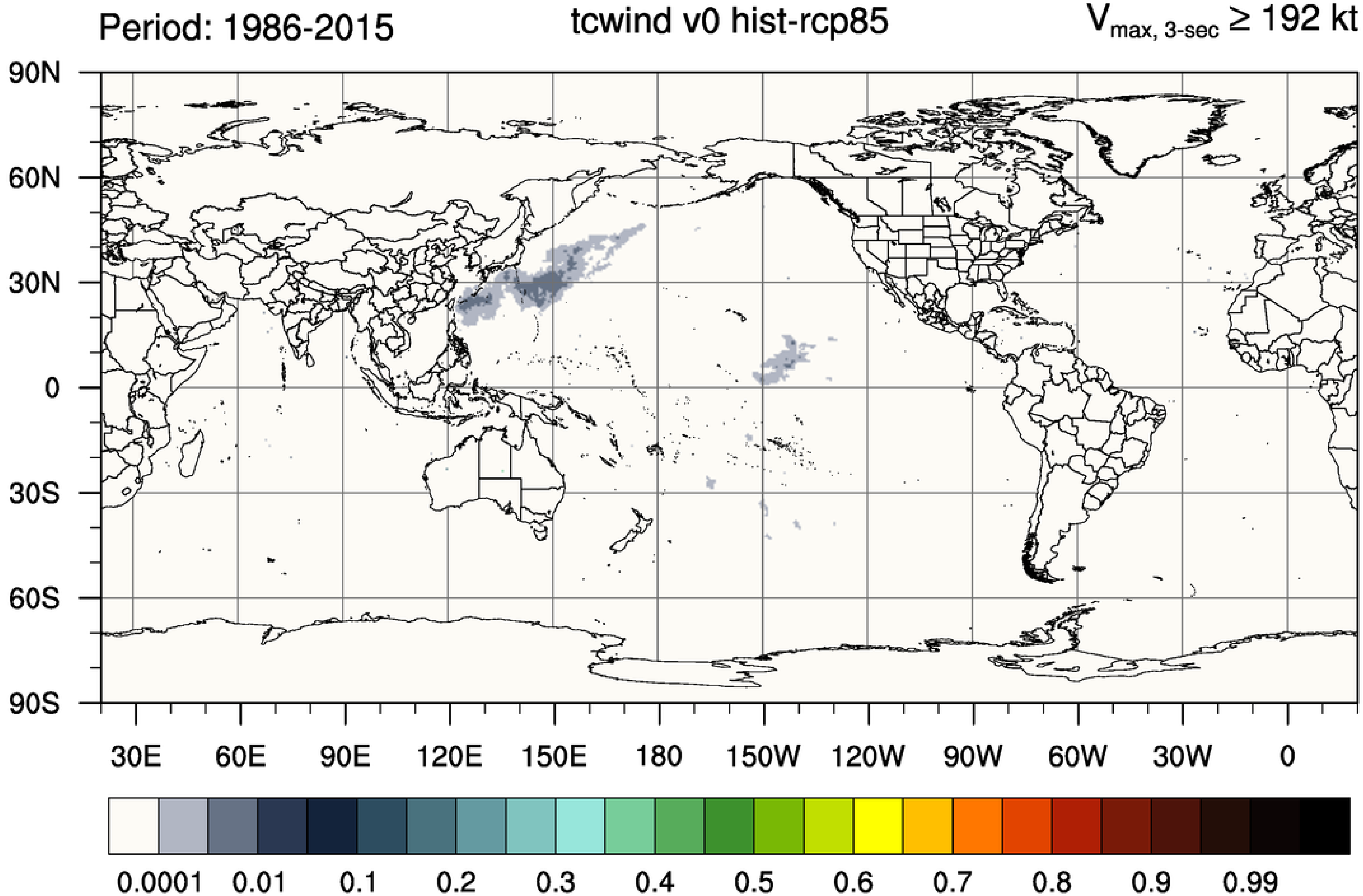

Category 4 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max, 3\text{-}sec} \geq 139$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 139 kt

NCAR

Category 5 Risk



Category "6" Risk

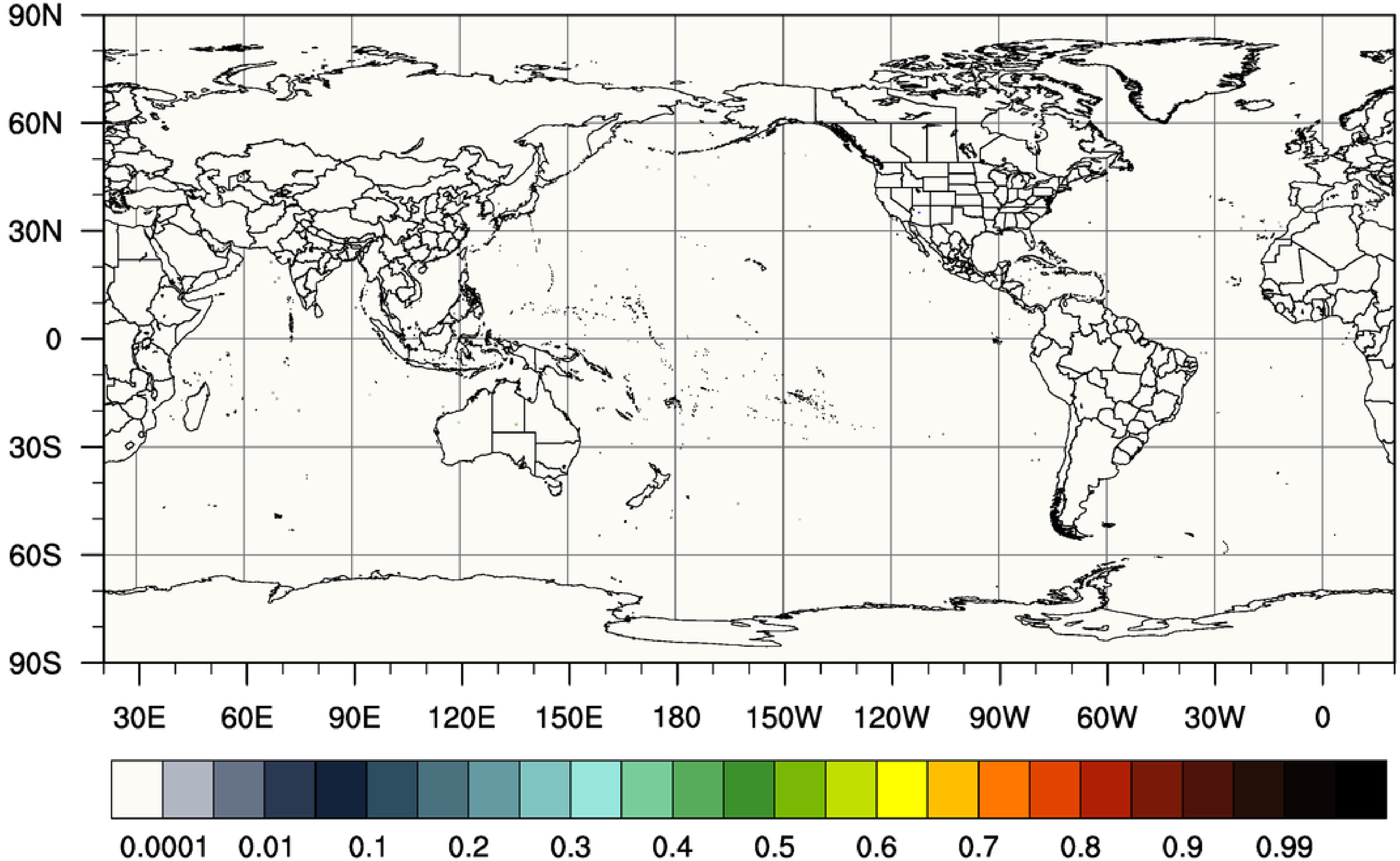


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 192 kt

NCAR

Category "7" Risk

Period: 1986-2015 | tcwind v0 hist-rcp85 | $V_{max,\ 3\text{-sec}} \geq 216$ kt

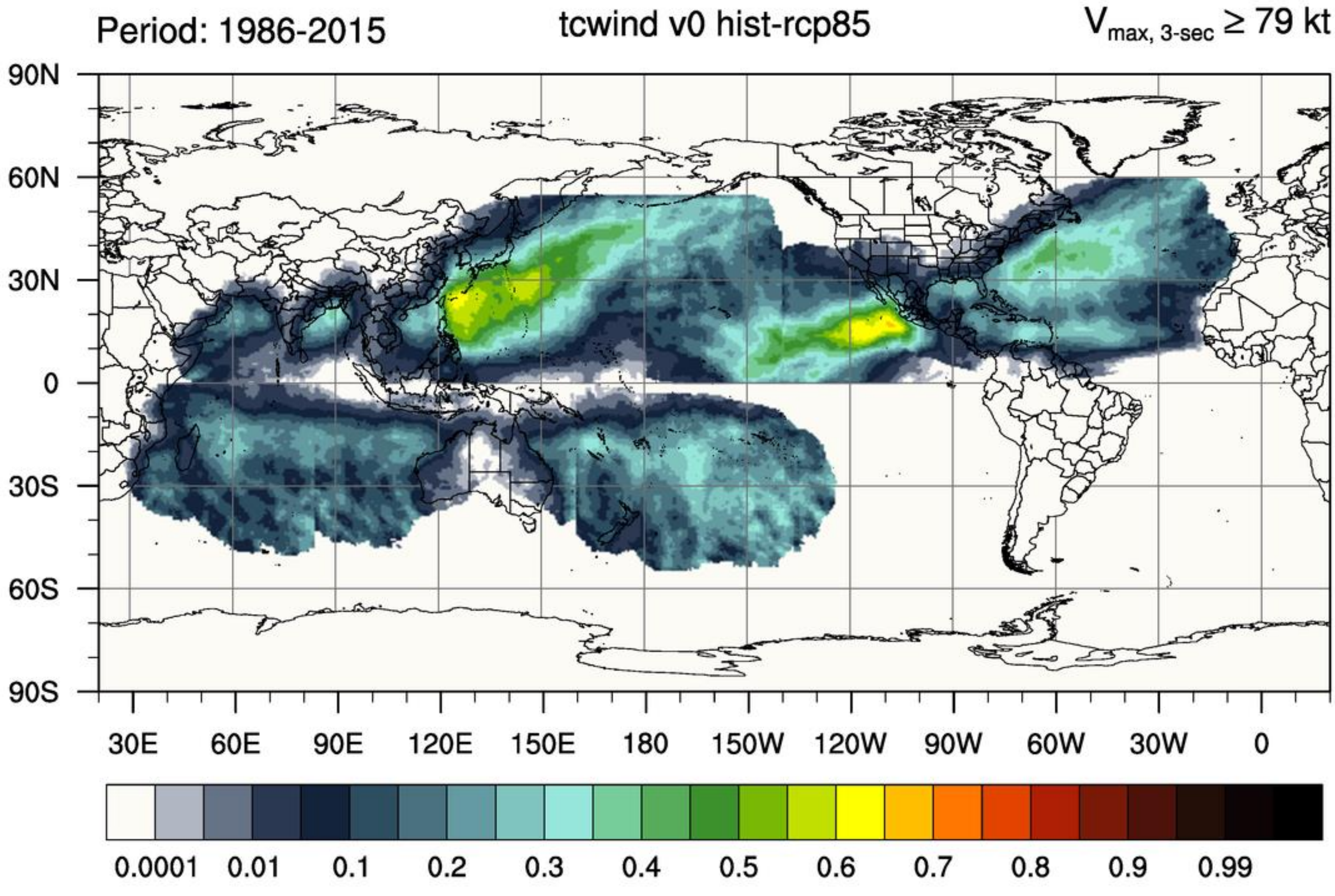


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 216 kt

NCAR

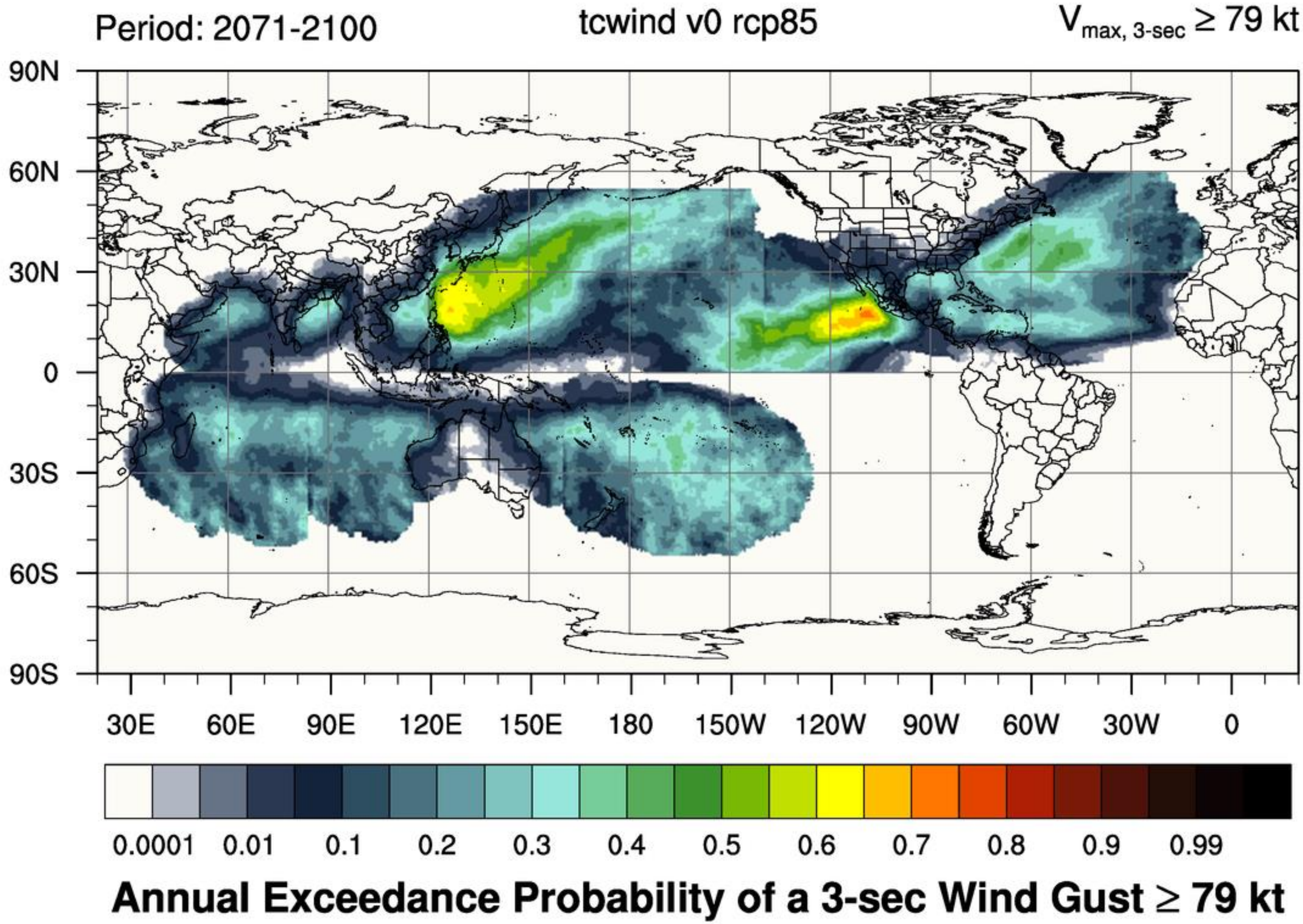
Current vs. Future: Category 1

Category 1 Risk



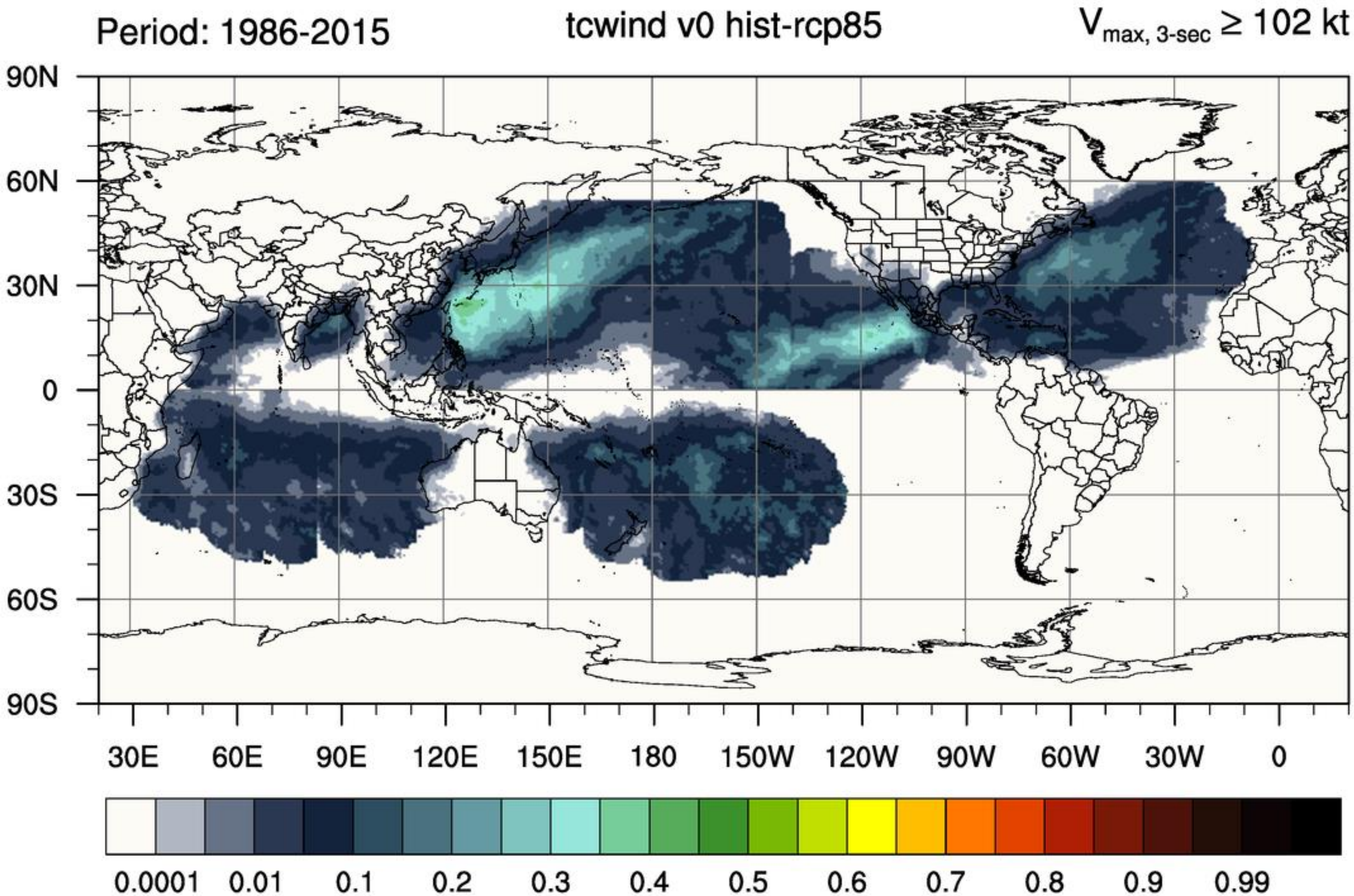
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 79 kt

Category 1 Risk



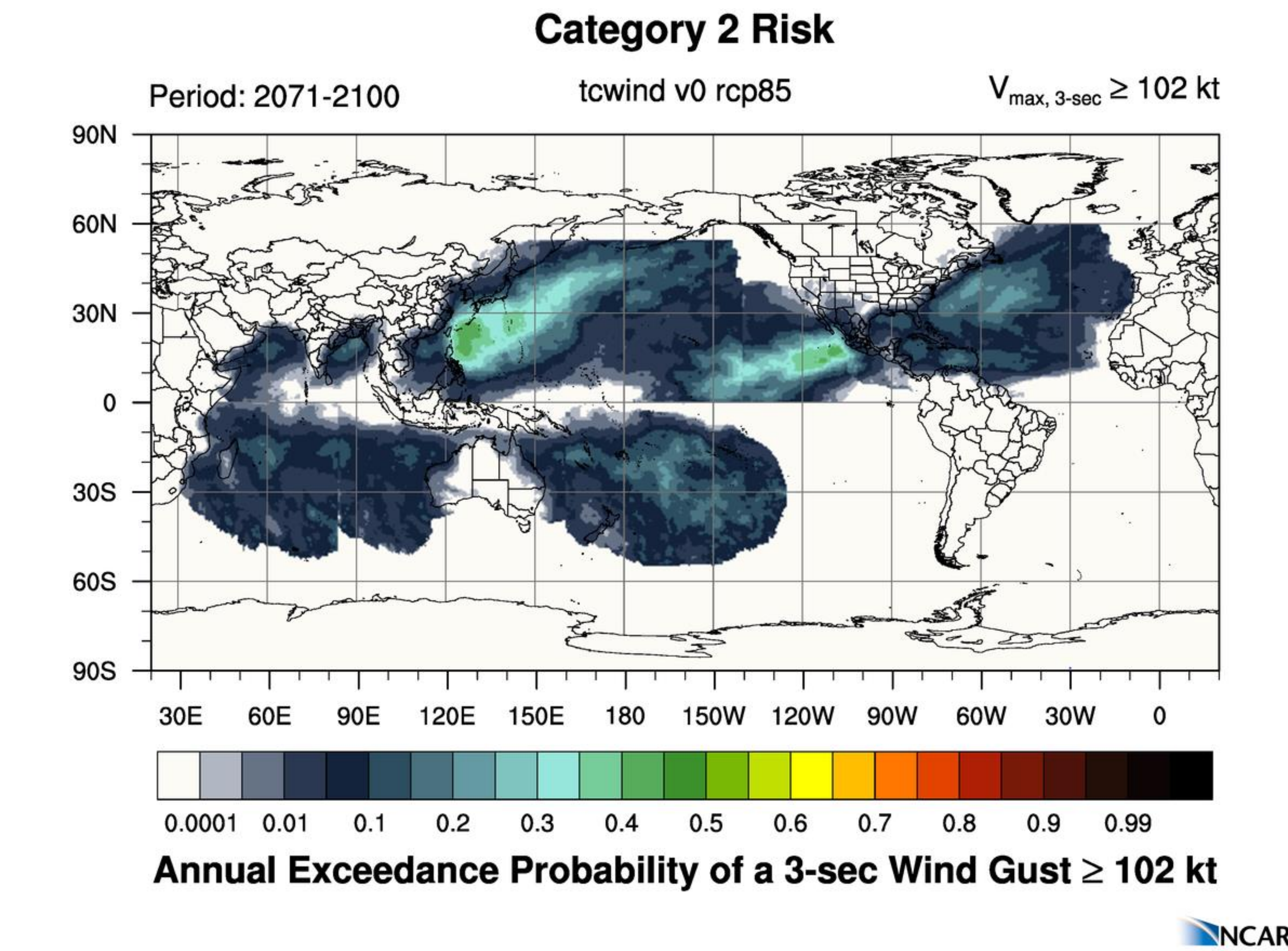
Current vs. Future: Category 2

Category 2 Risk

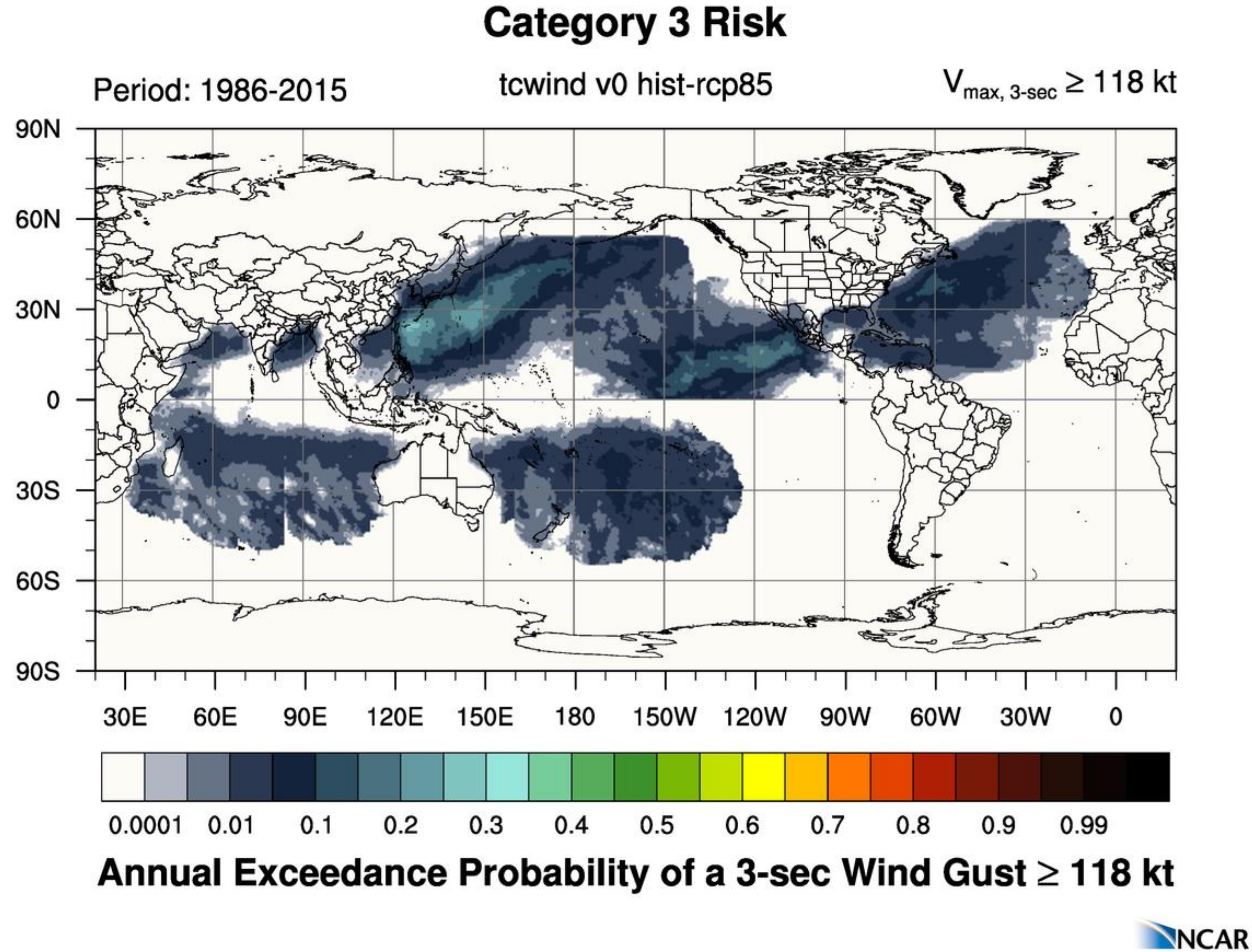


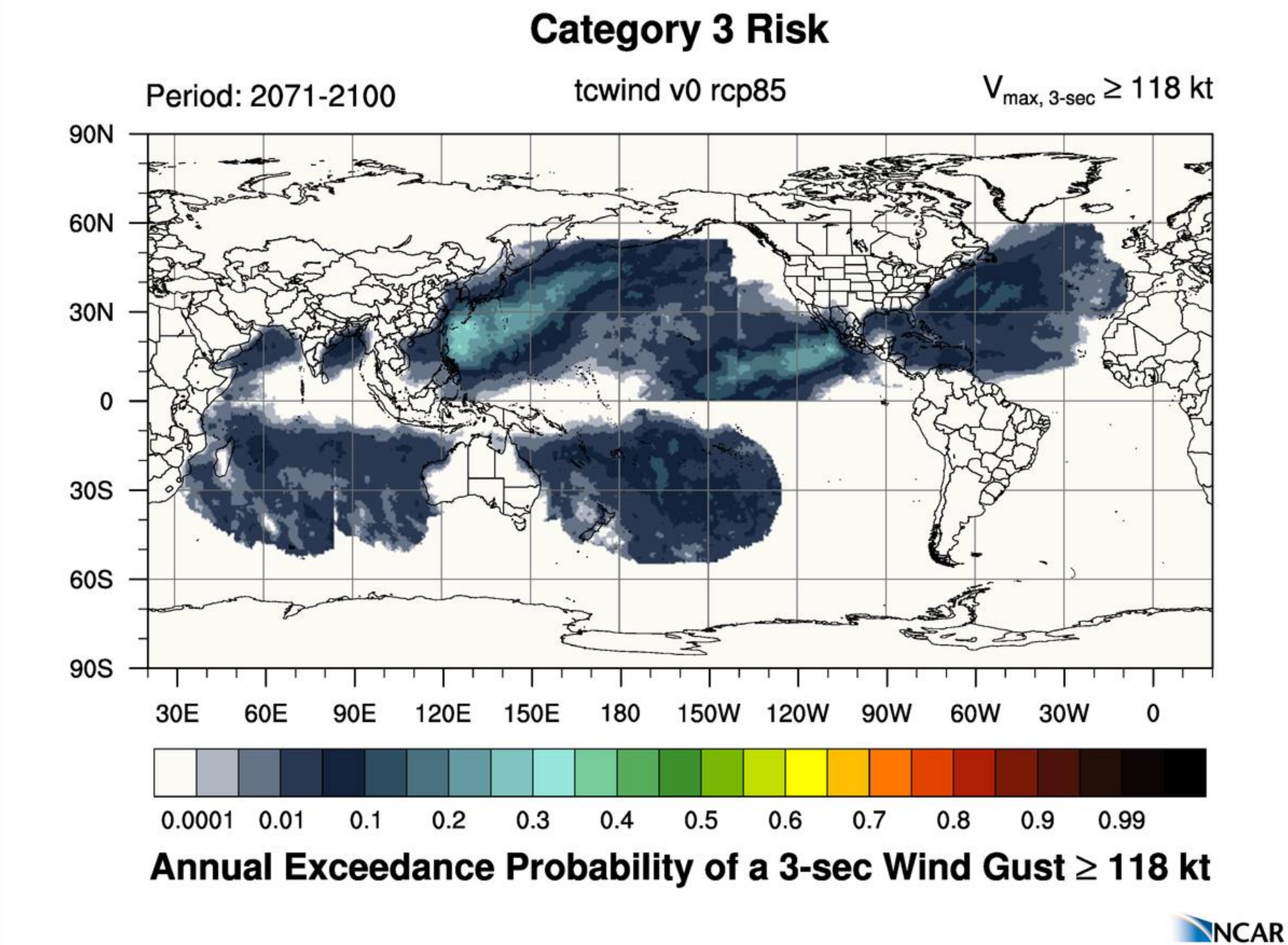
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 102 kt

NCAR

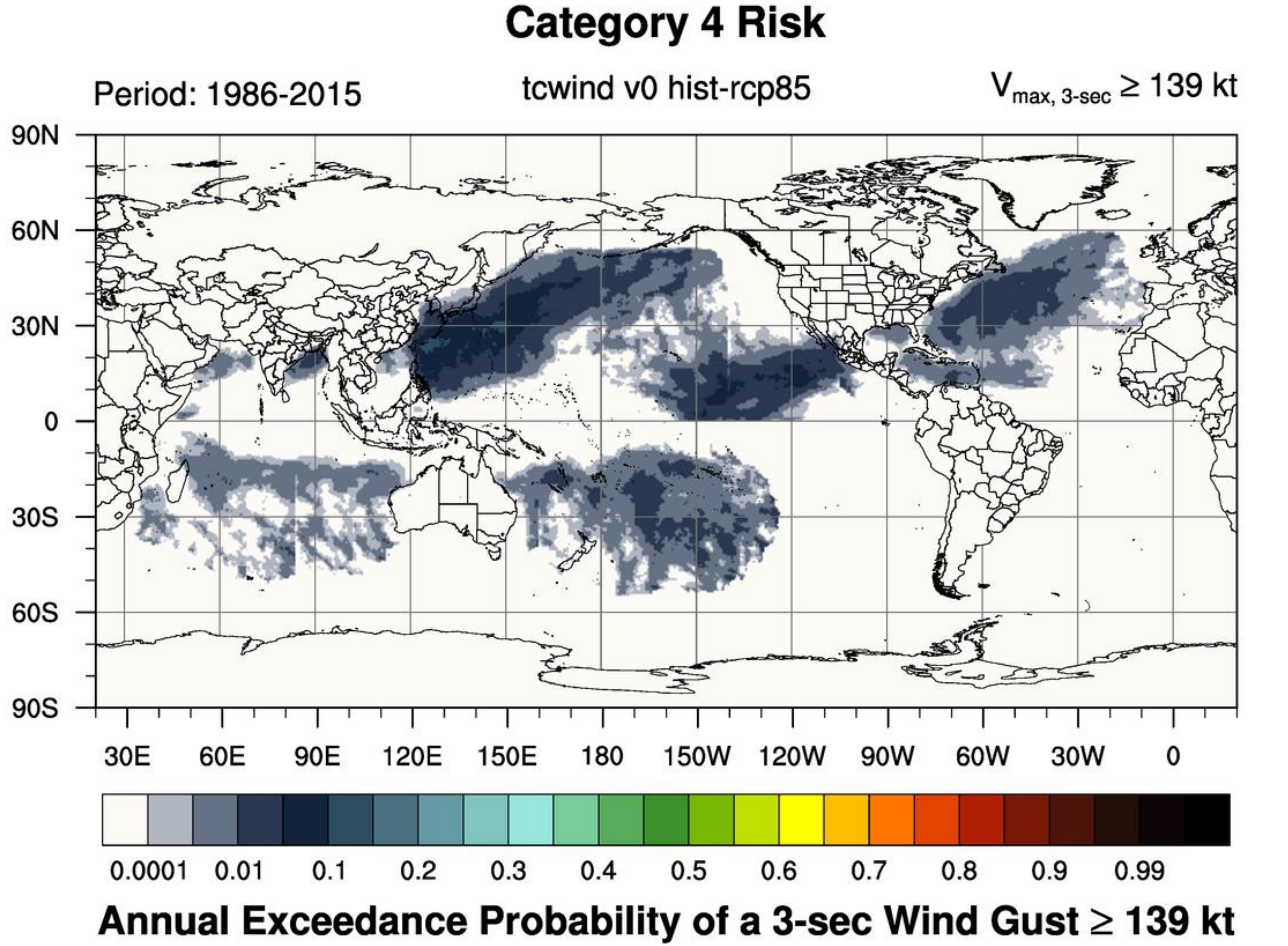

Category 2 Risk
Period: 2071-2100
tcwind v0 rcp85
$V_{max,\ 3\text{-}sec} \geq 102$ kt
90N
60N
30N
0
30S
60S
90S
30E 60E 90E 120E 150E 180 150W 120W 90W 60W 30W 0
0.0001 0.01 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 102 kt
NCAR

Current vs. Future: Category 3


Category 3 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max,\ 3\text{-}sec} \geq$ 118 kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 118 kt
NCAR

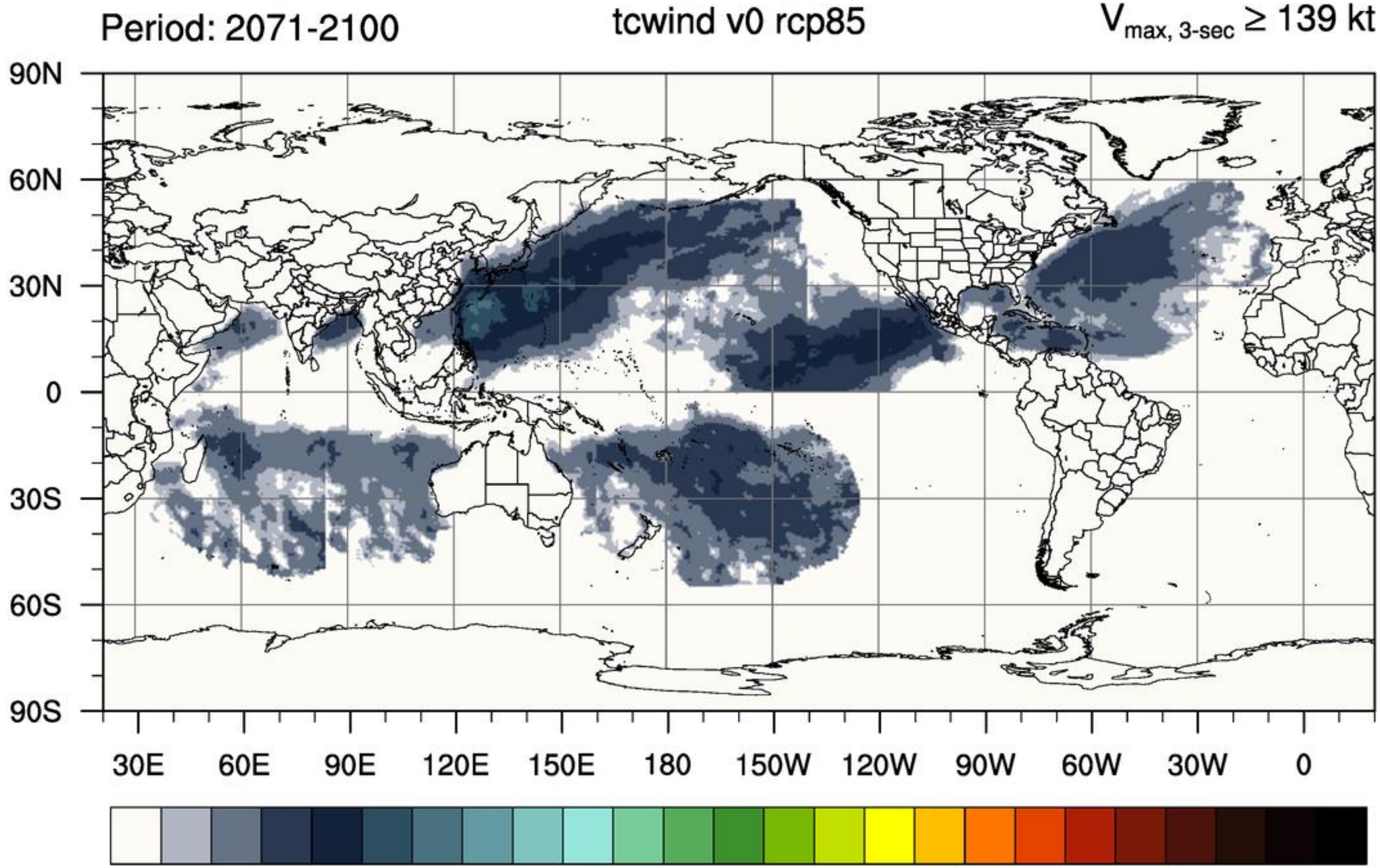

Category 3 Risk
Period: 2071-2100
tcwind v0 rcp85
$V_{max, 3\text{-}sec} \geq 118$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 118 kt
NCAR

Current vs. Future: Category 4


Category 4 Risk
Period: 1986-2015
tcwind v0 hist-rcp85
$V_{max,\ 3\text{-}sec} \geq 139$ kt
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
0.0001
0.01
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.99
Annual Exceedance Probability of a 3-sec Wind Gust ≥ 139 kt

NCAR

Category 4 Risk

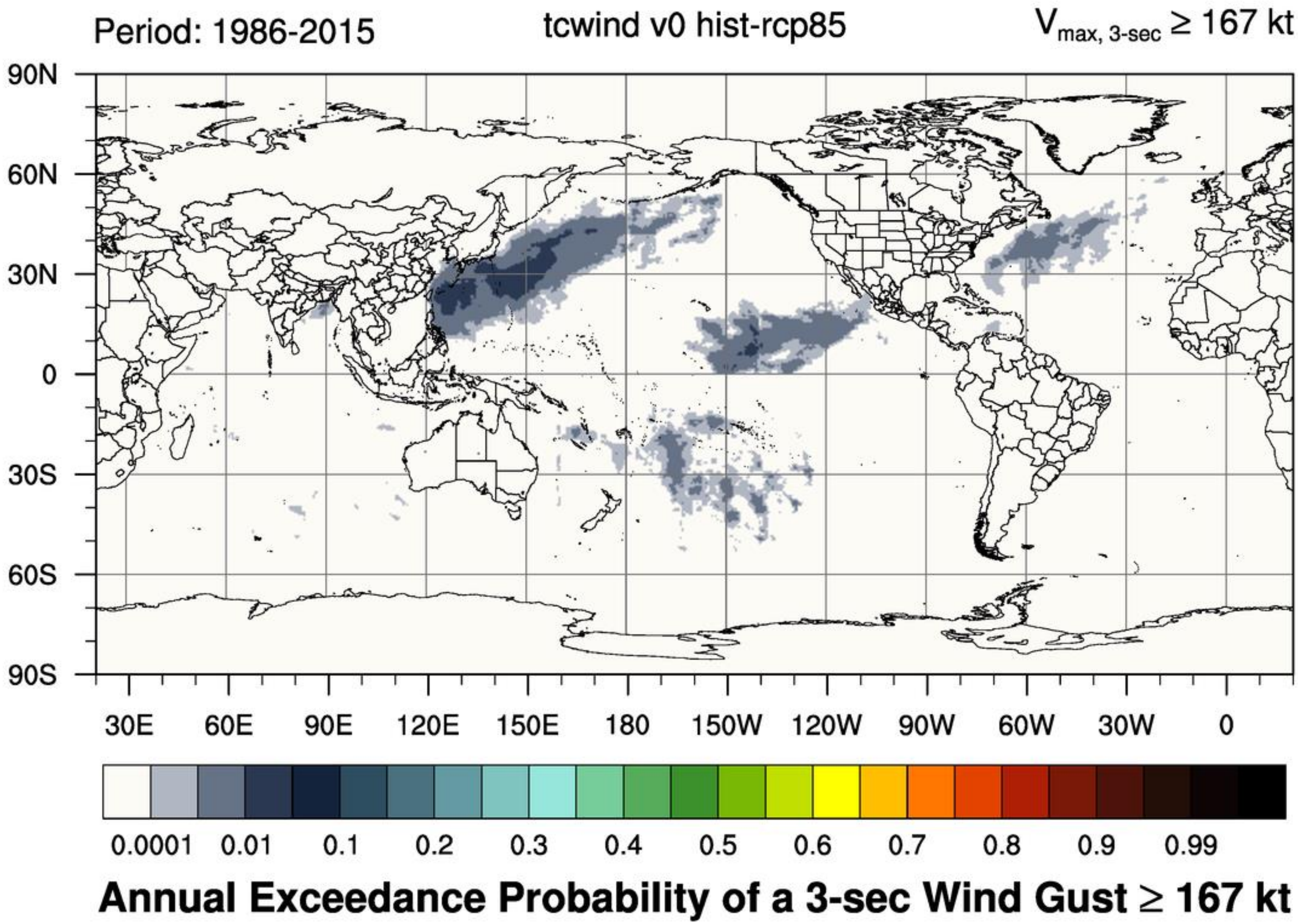


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 139 kt

NCAR

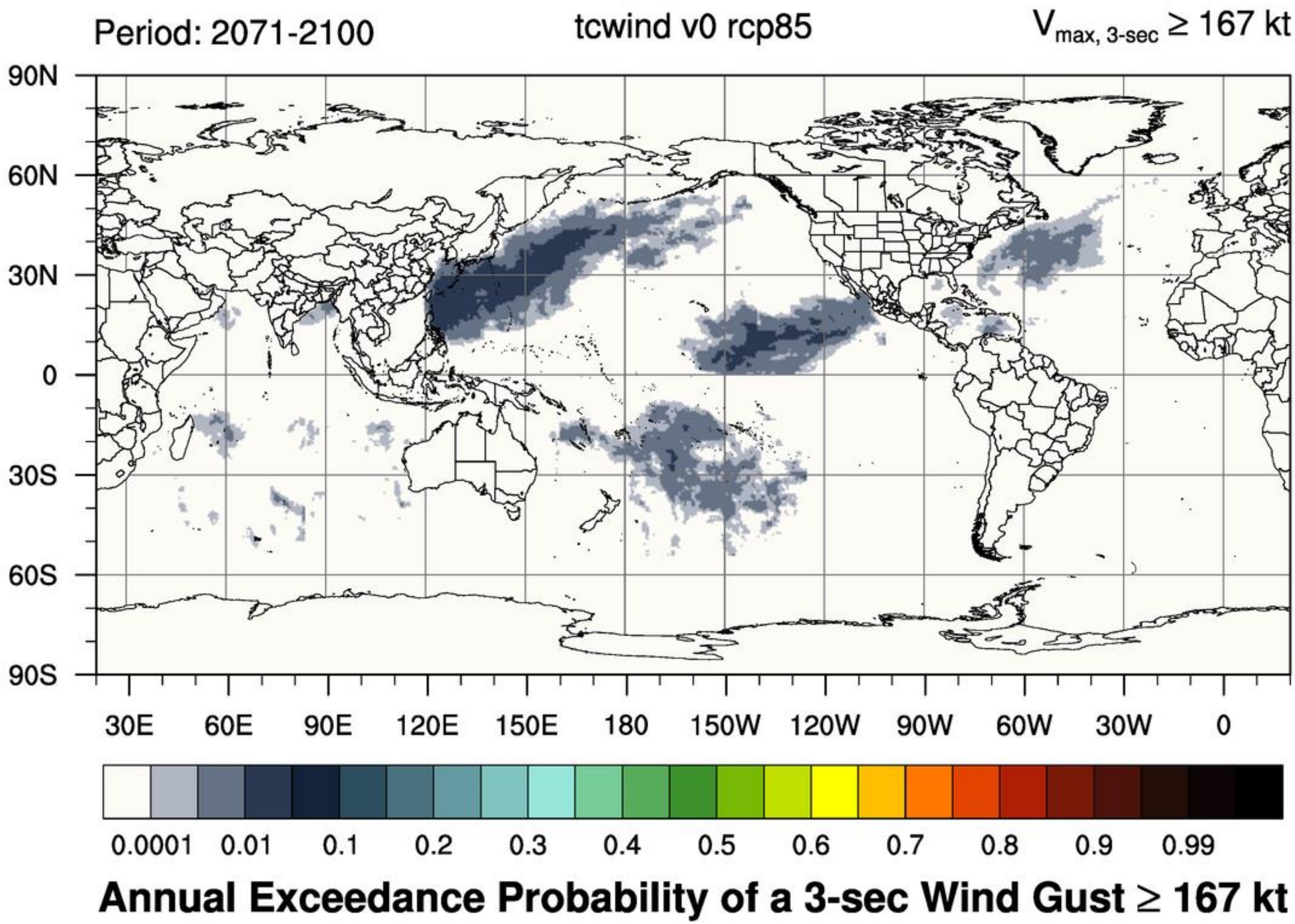
Current vs. Future: Category 5

Category 5 Risk



NCAR

Category 5 Risk



NCAR

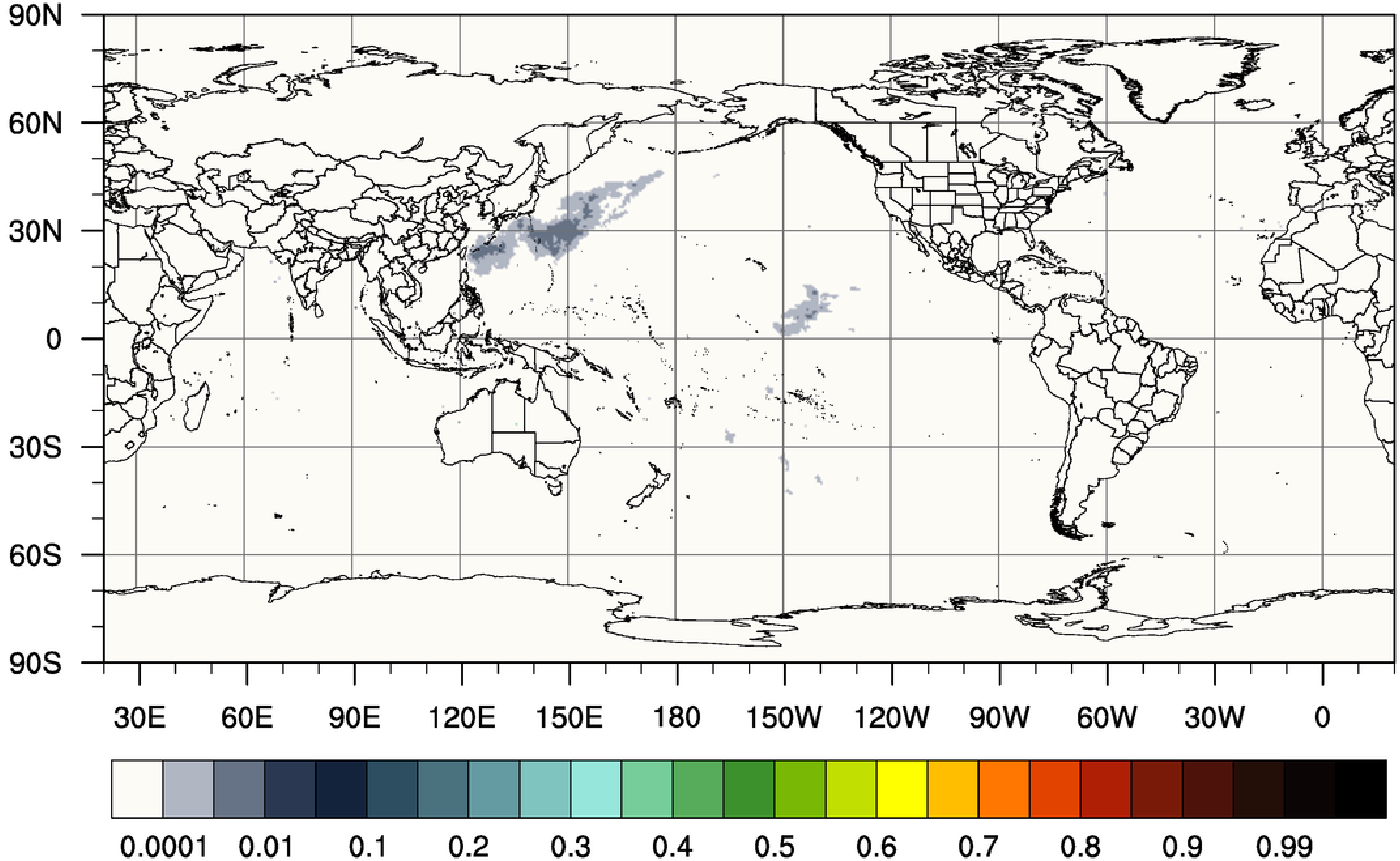
Current vs. Future: Category 6

Category "6" Risk

Period: 1986-2015

tcwind v0 hist-rcp85

$V_{max,\ 3\text{-}sec} \geq 192$ kt

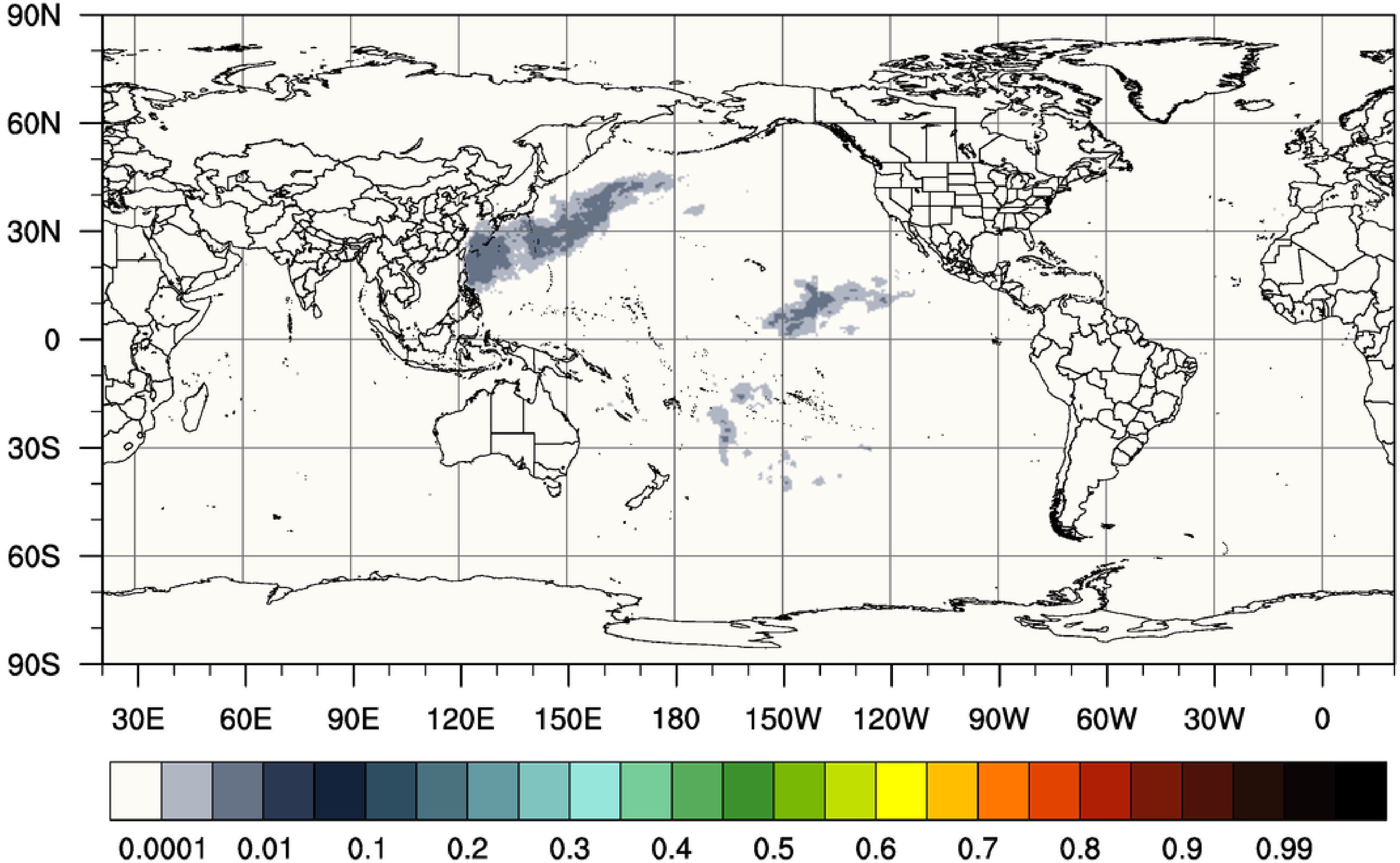


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 192 kt

NCAR

Category "6" Risk

Period: 2071-2100 tcwind v0 rcp85 $V_{max,\ 3\text{-}sec} \geq 192$ kt

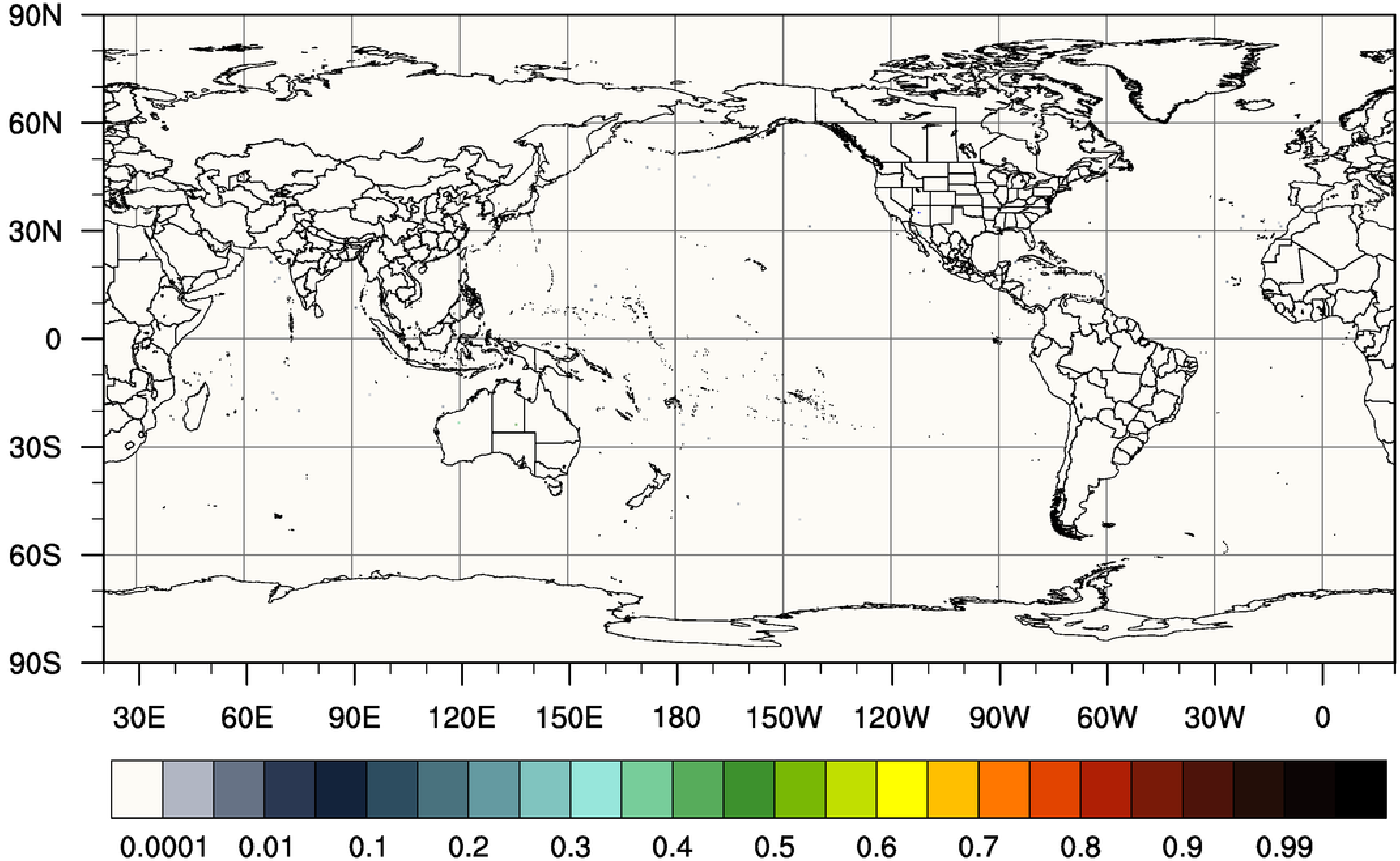


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 192 kt

Current vs. Future: Category 7

Category "7" Risk

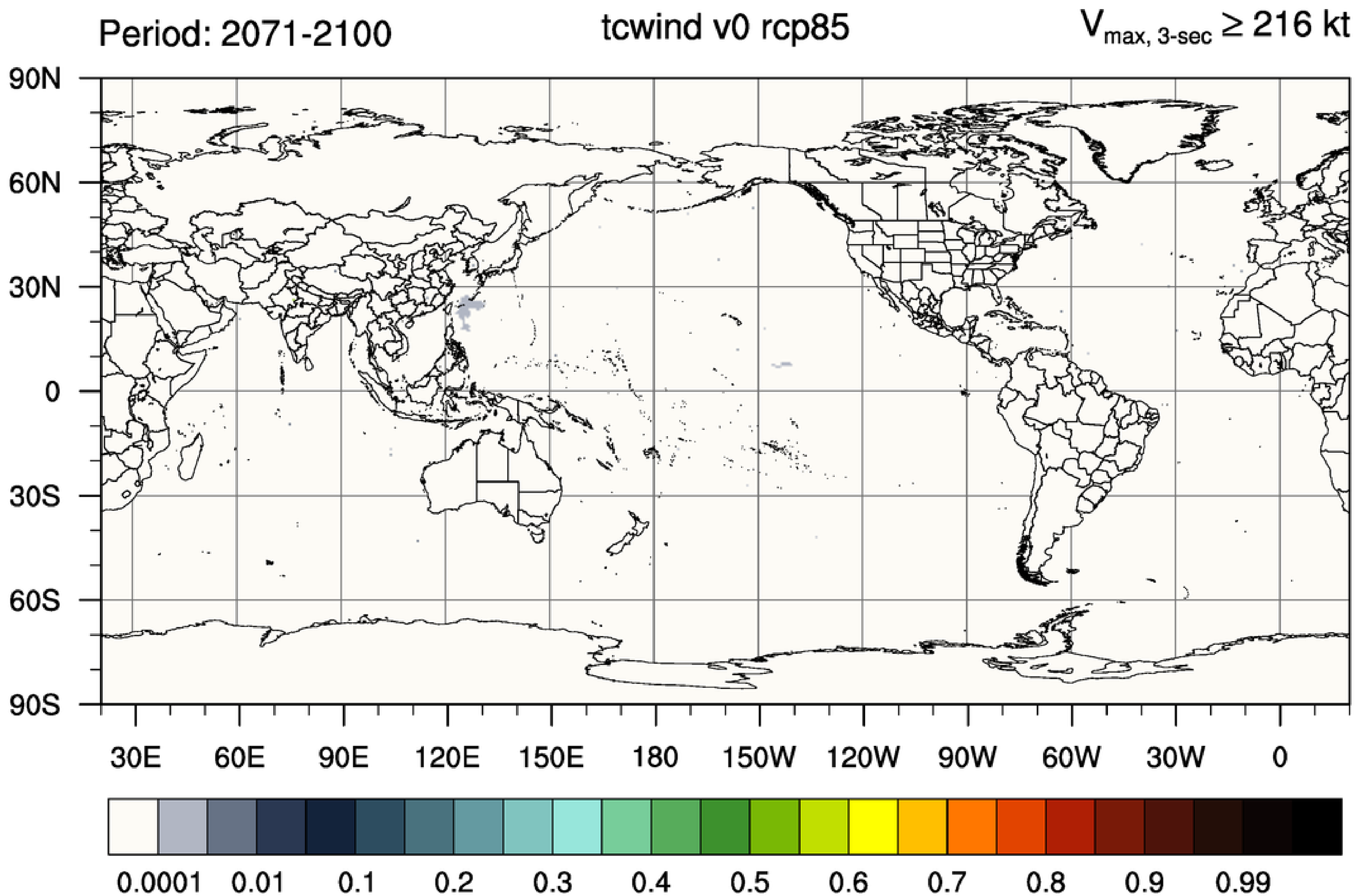
Period: 1986-2015 | tcwind v0 hist-rcp85 | $V_{max,\ 3\text{-}sec} \geq 216$ kt



Annual Exceedance Probability of a 3-sec Wind Gust ≥ 216 kt

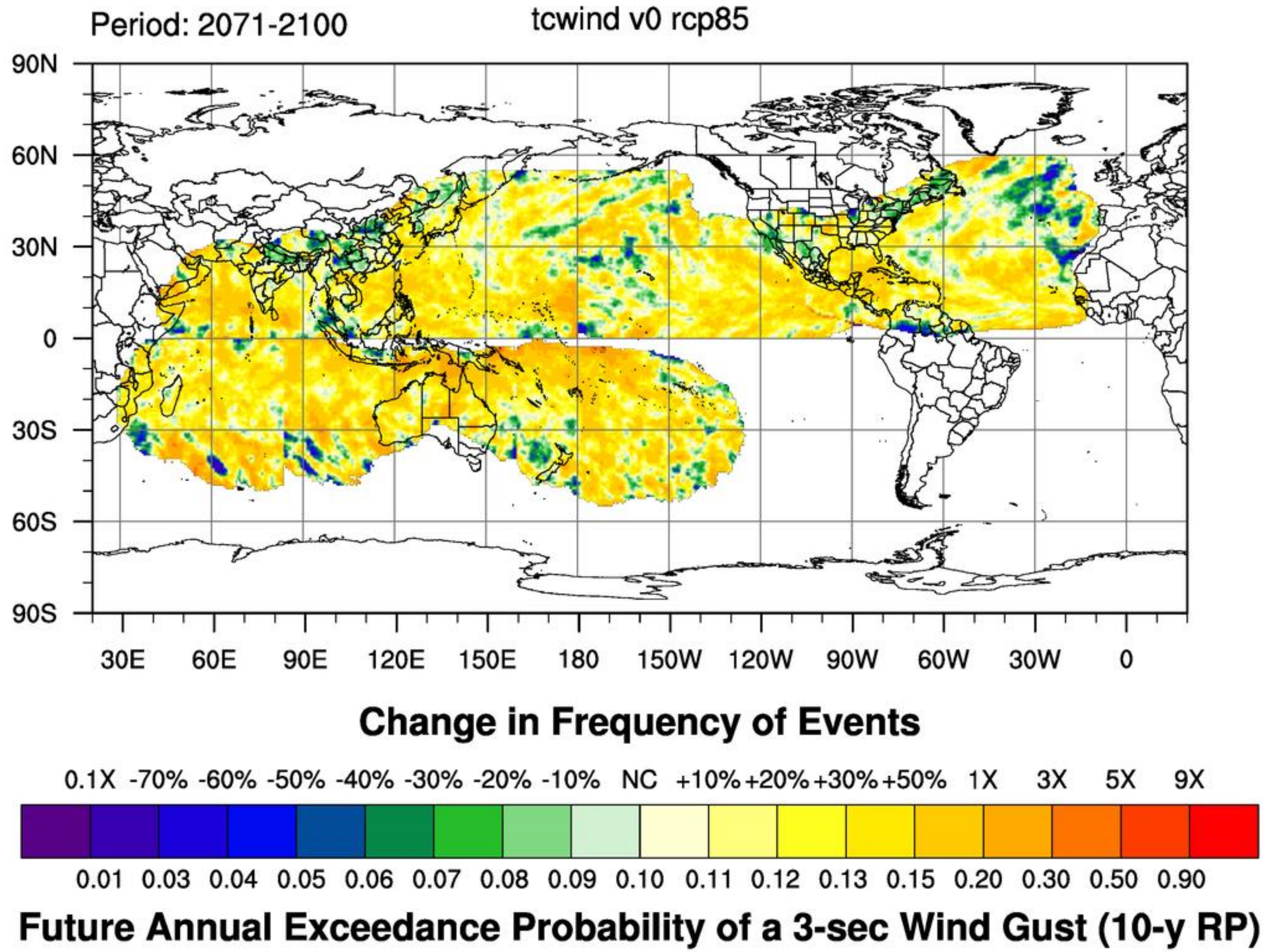
NCAR

Category "7" Risk

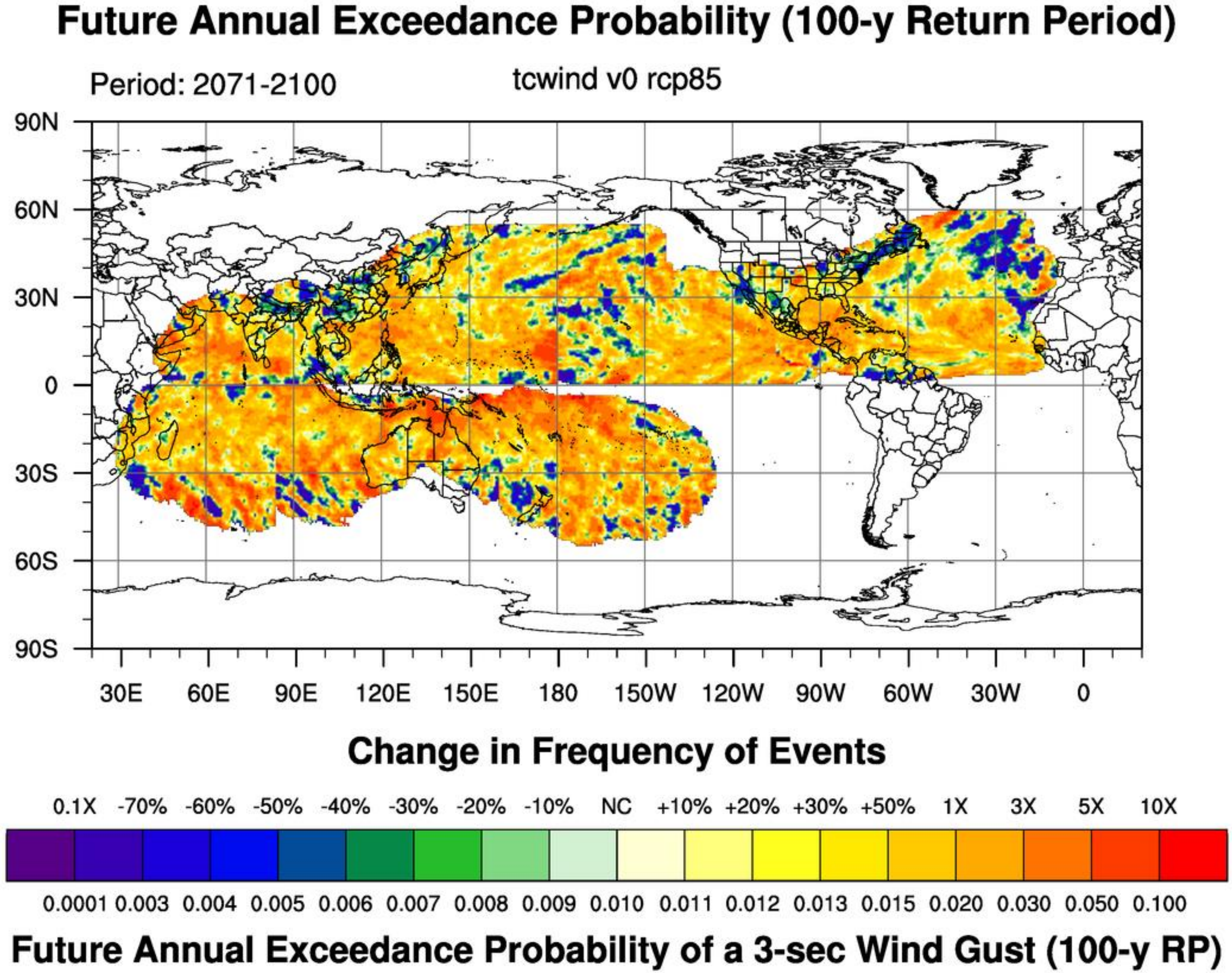


Annual Exceedance Probability of a 3-sec Wind Gust ≥ 216 kt

Future Annual Exceedance Probability (10-y Return Period)



NCAR


Future Annual Exceedance Probability (100-y Return Period)
Period: 2071-2100
tcwind v0 rcp85
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
Change in Frequency of Events
0.1X -70% -60% -50% -40% -30% -20% -10% NC +10% +20% +30% +50% 1X 3X 5X 10X
0.0001 0.003 0.004 0.005 0.006 0.007 0.008 0.009 0.010 0.011 0.012 0.013 0.015 0.020 0.030 0.050 0.100
Future Annual Exceedance Probability of a 3-sec Wind Gust (100-y RP)

Summary

- Many different approaches to assessing TC wind hazard
- Synthetic tracks / parametric models probably offer the most quantitative results although there will still be local biases
- For basin-wide statistics, a statistical approach may be best
- For questions of future climate change, there are many uncertainties

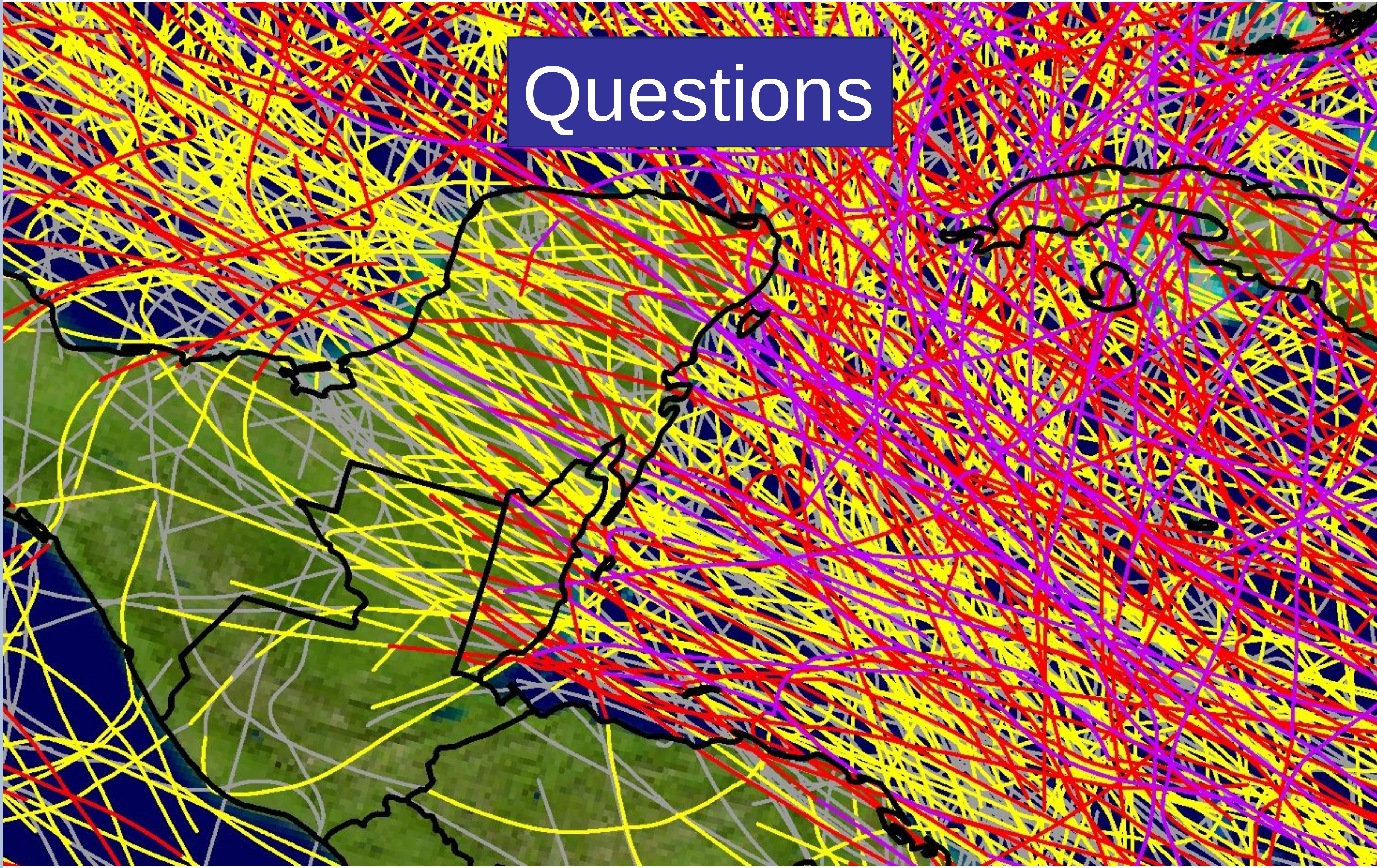
Summary, cont'd

- **Intensity**
  - Likely to increase in many of the global TC basins with significant interbasin variability
  - The most intense TCs are likely to become more intense
- **Frequency**
  - Likely to decrease somewhat or stay the same with significant interbasin variability
- **Rainfall**
  - Likely to increase substantially

Summary, cont'd

NCAR

- **Storm surge inundation**
  - May increase somewhat with increasing intensity, but sea level rise will likely result in substantially worse inundation
- **Track**
  - There is possibility that TC tracks will shift further poleward, however this is quite controversial
  - Such changes could result in drastic increases in TC hazard which currently have low risk



All North Atlantic and Eastern North Pacific tropical cyclones (from Ethan Gibney, NHC/WFO SGX)