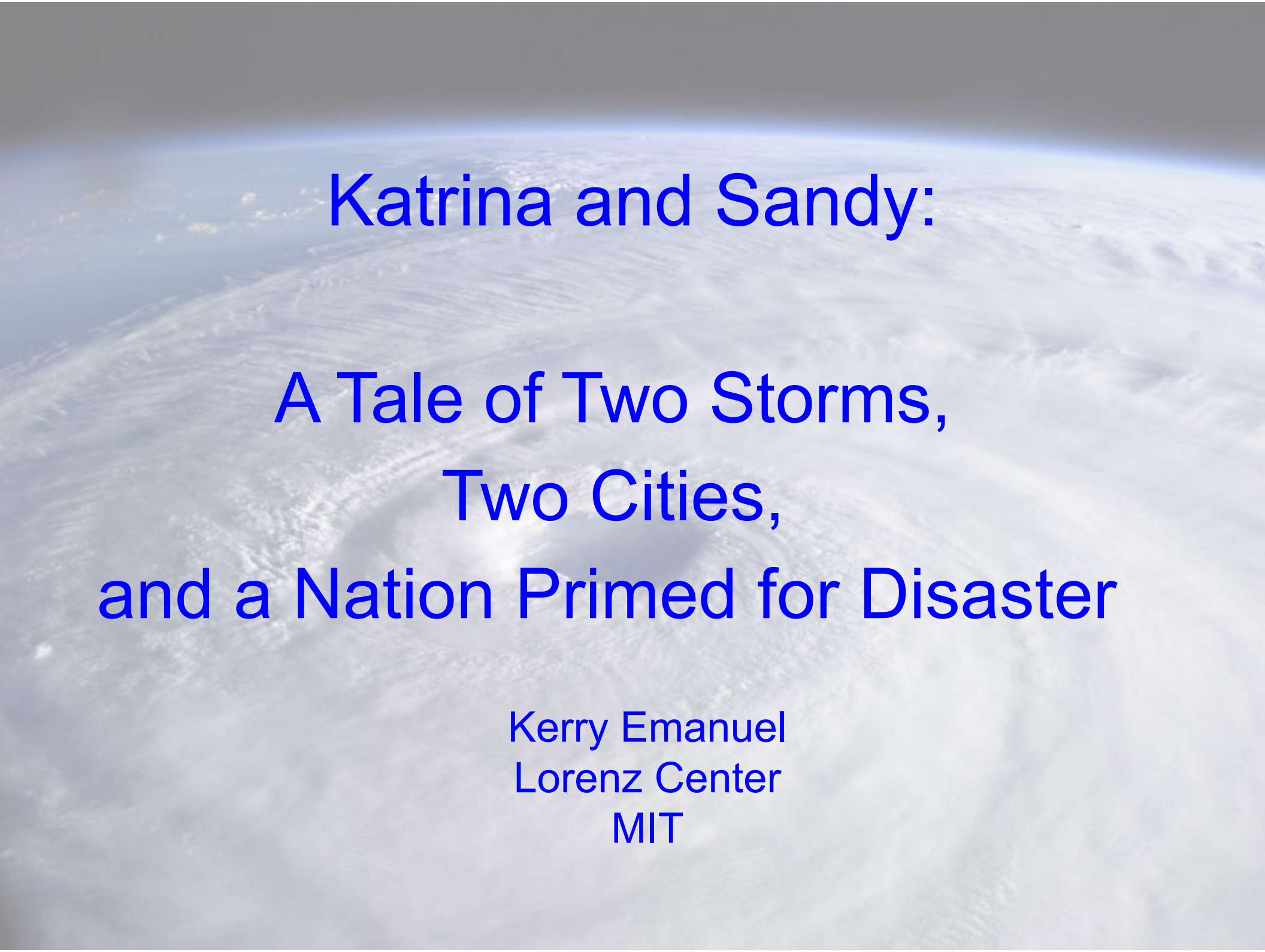
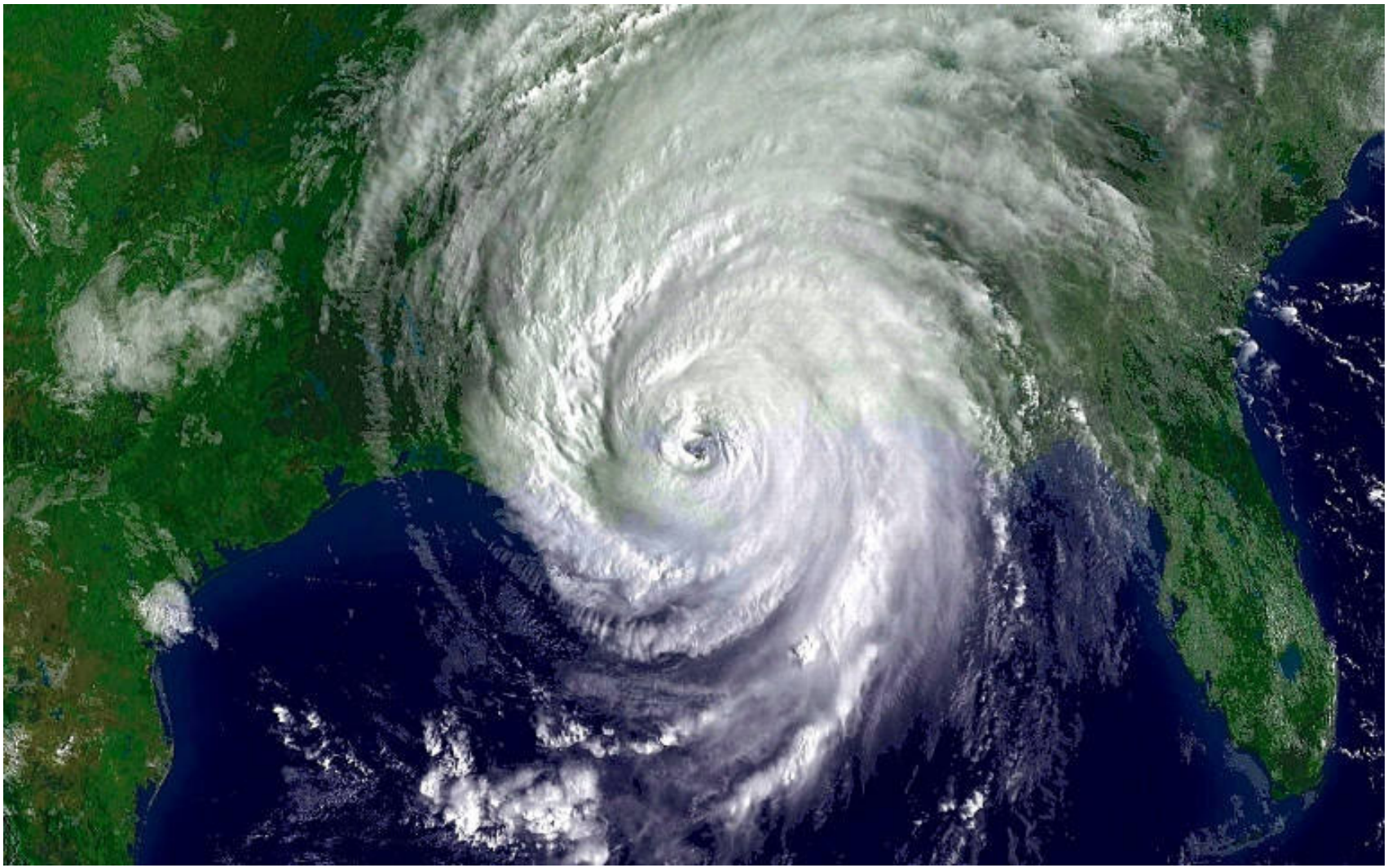


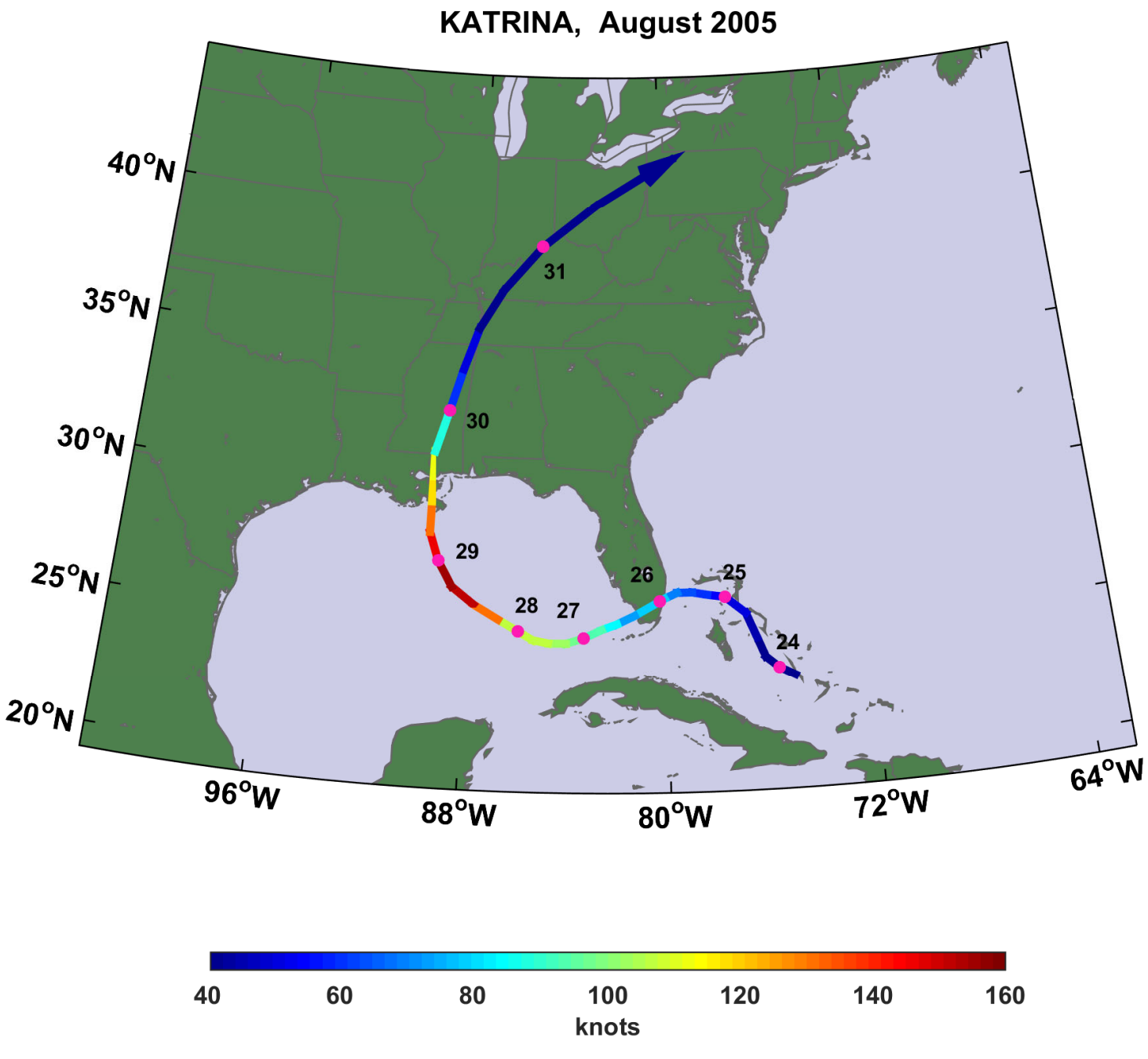
Katrina and Sandy:

A Tale of Two Storms, Two Cities, and a Nation Primed for Disaster

Kerry Emanuel
Lorenz Center
MIT

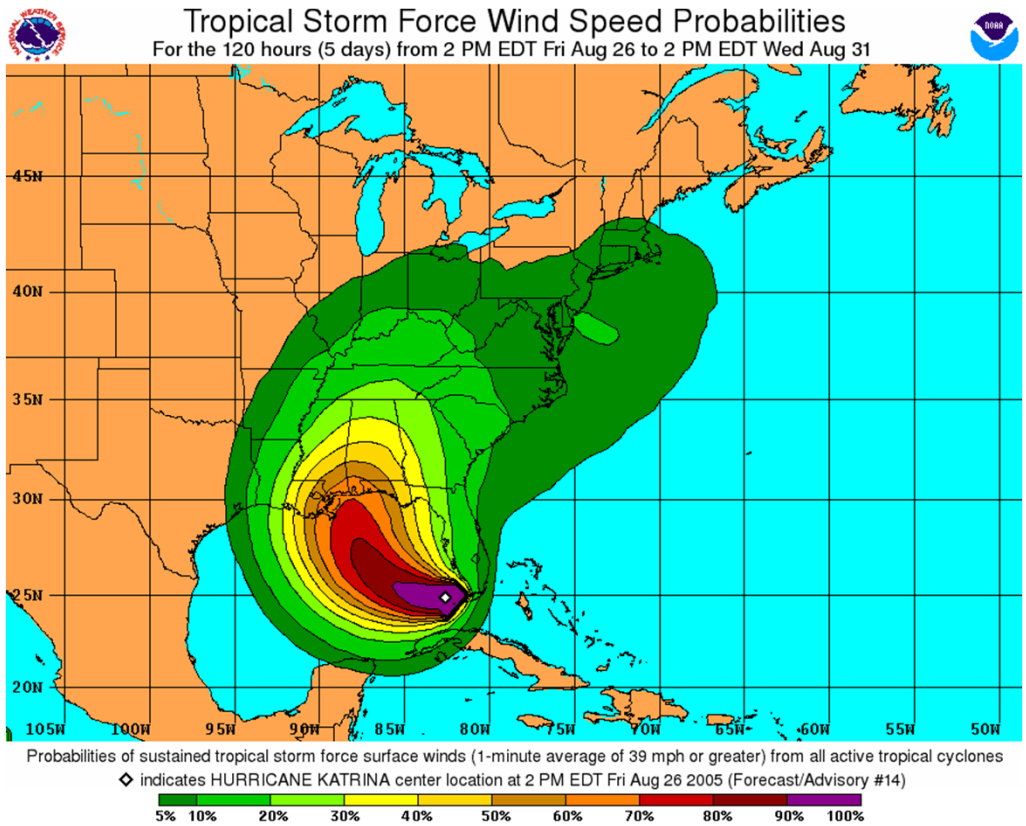
Part I: Hurricane Katrina
August, 2005



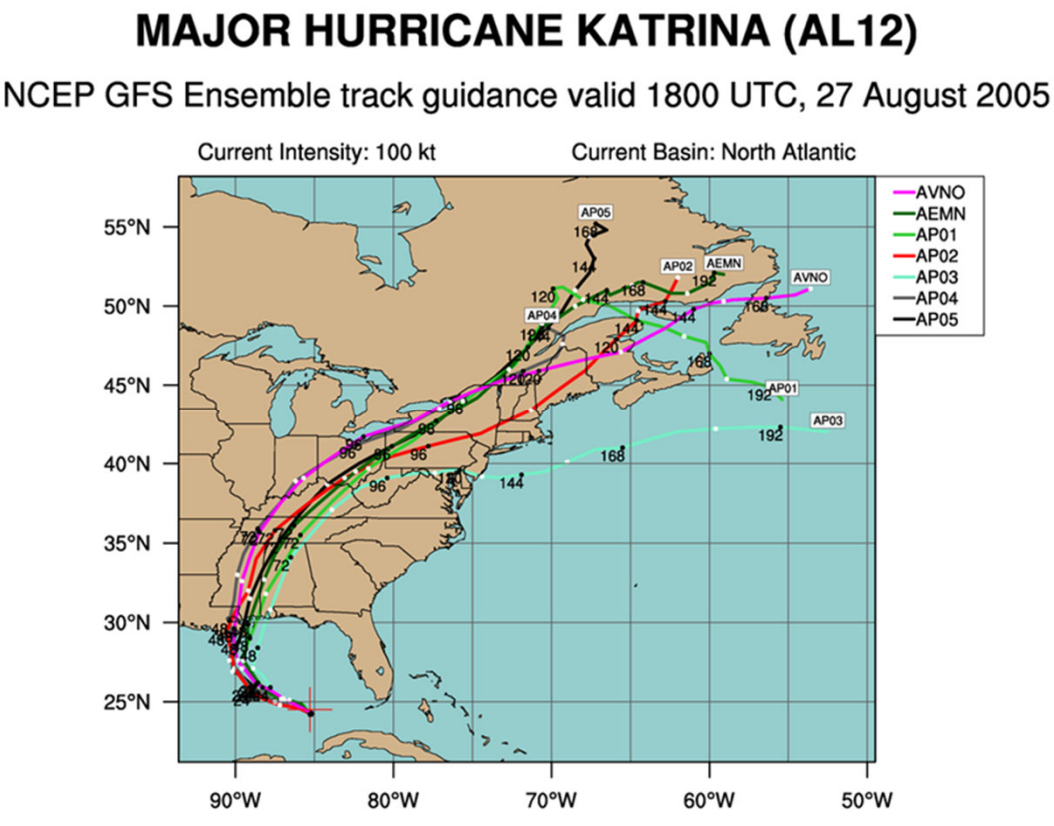

KATRINA, August 2005
40°N
35°N
30°N
25°N
20°N
96°W
88°W
80°W
72°W
64°W
24
25
26
27
28
29
30
31
40
60
80
100
120
140
160
knots

Katrina was exceptionally well forecast

Forecast from 18 GMT 26 August



Forecast from 18 GMT 27 August



Relevant Facts

- Excellent forecasts from > 3 days prior to landfall
- Costliest natural disaster in U.S. history
- Among the 5 deadliest hurricanes in U.S. history
  - > 1800 deaths
  - Highest death toll since 1928 Okeechobee Hurricane
- > 50 breaches of New Orleans surge protection system
- > 80% of city flooded
- Total economic impact in Louisiana and Mississippi may have exceeded $150 billion

Time Line of a Disaster

- 23 August 1800 UTC; Tropical Depression 12 forms over southeastern Bahamas
- 24 August 1200 UTC: Depression 12 becomes Tropical Storm Katrina over central Bahamas
- 25 August 2100 UTC: Katrina becomes a hurricane just two hours before landfall in southeastern Florida
- 26 August 0500 UTC: After passing over the Everglades, Katrina emerges from Florida's west coast as a tropical storm
- 26 August 0600 UTC: Katrina regains hurricane status and begins the first of two periods of rapid intensification

- 26 August 17 UTC: National Hurricane Center (NHC) Director Max Mayfield warns Walter Maestri, Director of the Emergency Management Center in Jefferson Parish, that Katrina is intensifying rapidly and several models have it affecting New Orleans. He tells Maesri “you need to be ready”. Mayfield also alerts Department of Homeland Security

- 27 August 12 UTC: Katrina upgraded to Category 3

- 27 August 14 UTC: Mayfield warns FEMA that Katrina could make landfall near New Orleans as a Category 4 storm and overwhelm the city’s levees

- 27 August, afternoon EDT: Mayfield tells Times-Picayune that “this is really scary”

- 27 August, evening EDT: Mayfield appears on CNN and recommends evacuation of southeastern Louisiana

- 27 August, evening EDT: Mayfield personally calls Louisiana Governor Blanco and Mississippi Governor Barbour, telling them that Katrina will be a “big, big deal”.

- 27 August 8 PM EDT: Mayfield has been trying to reach Ray Nagin, mayor of New Orleans, and finally contacts him by routing call through White House. Mayfield asks Nagin to order a mandatory evacuation. Nagin later recalled that Mayfield “scared the crap out of me”. But Nagin orders only a voluntary evacuation and asks his attorneys to look into his legal liability to lawsuits from local businesses.

- 28 August 0500 UTC: NOAA data buoy 42003, 200 nm west of Naples, FL, capsizes after reporting 11 meter significant wave heights. First capsizing of a 10-meter buoy in the Gulf of Mexico in NDBC's 30-year history of operation.

- 28 August 1200 UTC: Katrina upgraded to Category 5. Hurricane warning is issued for north central Gulf Coast including New Orleans

- 28 August 9:30 AM CDT: Mayor Nagin finally issues mandatory evacuation order

- 28 August 10:10 AM CDT: NWS New Orleans issues nearly apocalyptic statement:

Most of the area will be uninhabitable for weeks ... perhaps longer. At least one half of well constructed homes will have roof and wall failure. … The majority of industrial buildings will become non functional. … Airborne debris will be widespread and may include heavy items such as household appliances and even light vehicles. … Persons, pets, and livestock exposed to the winds will face certain death if struck. Power outages will last for weeks … water shortages will make human suffering incredible by modern standards.

- 29 August 1110 UTC: Katrina makes landfall near Buras, Louisiana, as a high Category 3 hurricane
- 29 August, morning CDT: Mayor Nagin abandons post at Emergency Operations Center in favor of the Hyatt hotel, which then loses power, cutting off communications
- 29 August 1300 CDT: Two major flood-control levees are breached and the National Weather Service reports "total structural failure" in parts of New Orleans. Many are feared dead in flooded neighborhoods under as much as 20 feet of water
- 29 August, morning: Many New Orleans Police officers abandon duty in favor of saving their families. More than 200 are later put on trial
- 29 August: By evening, 80% of New Orleans is underwater

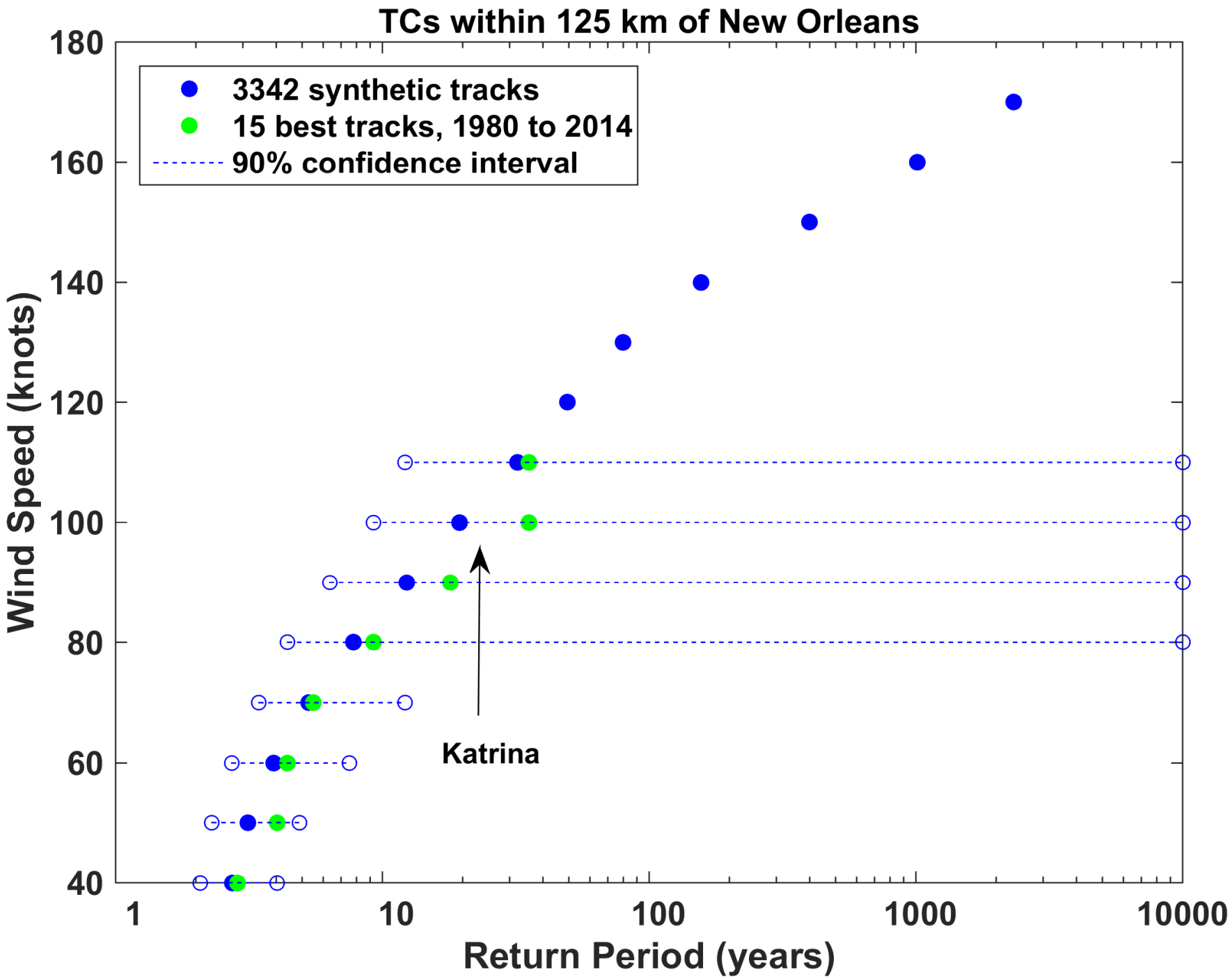
The Aftermath

- 30 August: New Orleans is left with no power, no drinking water, dwindling food supplies, widespread looting, fires and steadily rising waters from major levee breaches. Efforts to limit the flooding are unsuccessful and force authorities to try evacuating the thousands of people at city shelters
- Individual acts of heroism and the action of the U.S. Coast Guard and Louisiana Wildlife and Fisheries Department save many
- FEMA director Michael Brown is virtually missing for several days
- Politicians begin finger-pointing
- Cuba and Venezuela offer aid
- September 1, 2 PM CDT: On national television New Orleans Mayor Ray Nagin issues a "desperate SOS" for help from the federal government

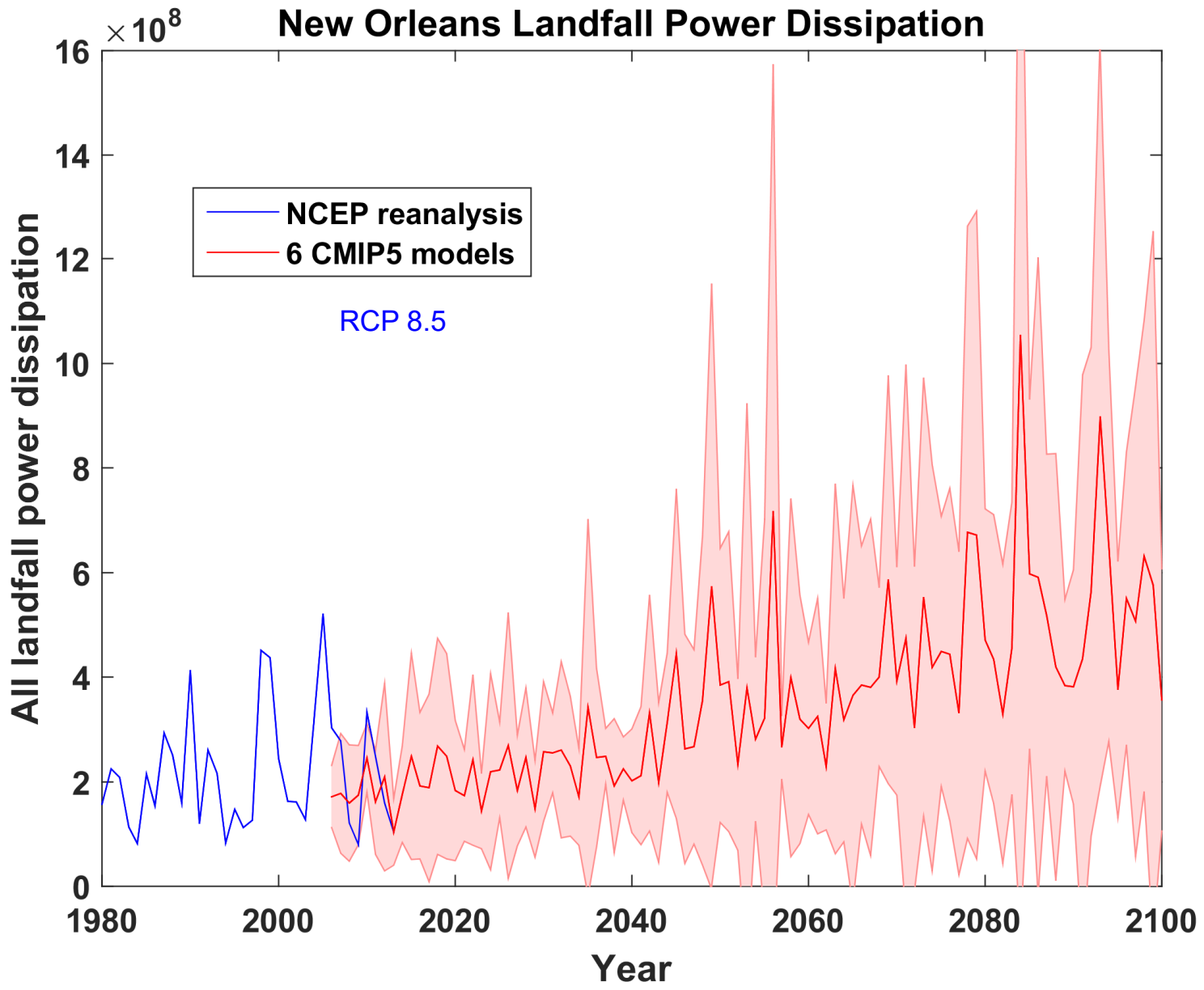
Lessons from Katrina

- Years of planning and excellent forecasts cannot succeed when leadership fails owing to corruption, cowardice, and incompetence
- Breakdown of technical and human communication is a major element in many disasters
- Business interests can trump safety considerations in the lead-up to disasters
- Short-term rescue and recovery often depends on ad-hoc and creative acts of bravery and spontaneous organization among individuals and organizations with much local knowledge
- Local culture is a critical element in preparing for and reacting to natural disasters

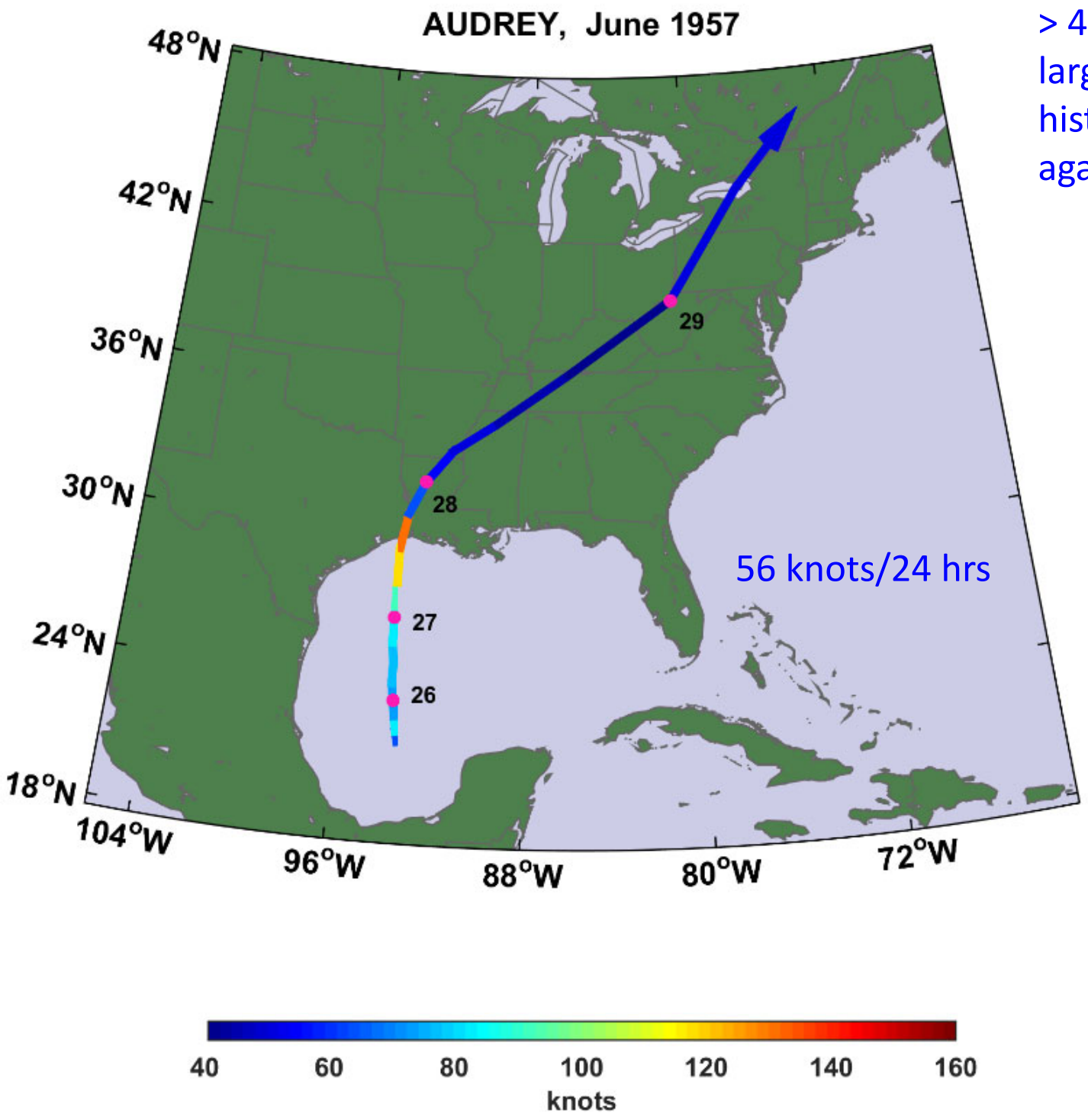
Is New Orleans Sustainable?


TCs within 125 km of New Orleans
3342 synthetic tracks
15 best tracks, 1980 to 2014
90% confidence interval
Katrina
Wind Speed (knots)
Return Period (years)
180
160
140
120
100
80
60
40
1
10
100
1000
10000

Projections of TC Power at Landfall near New Orleans

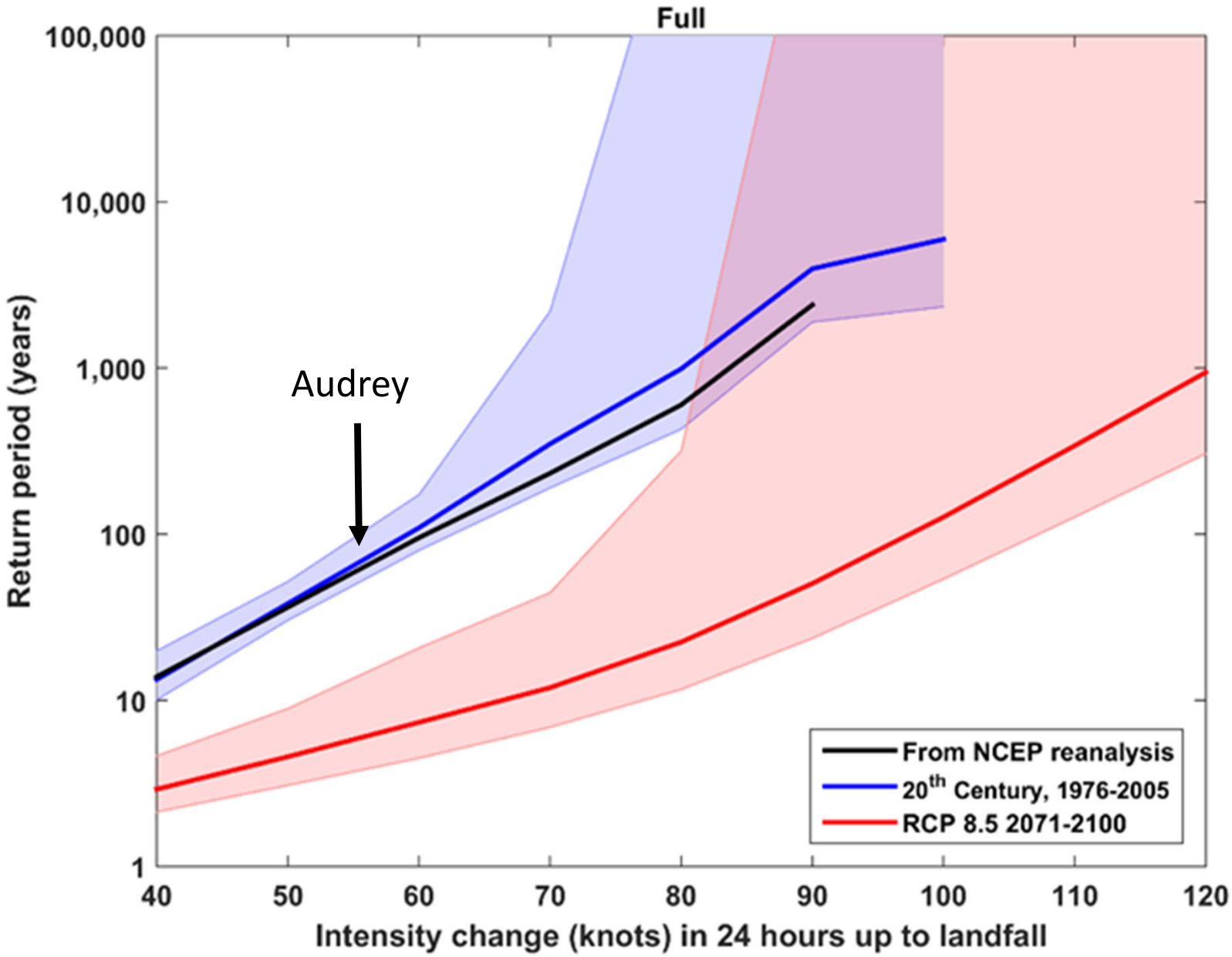


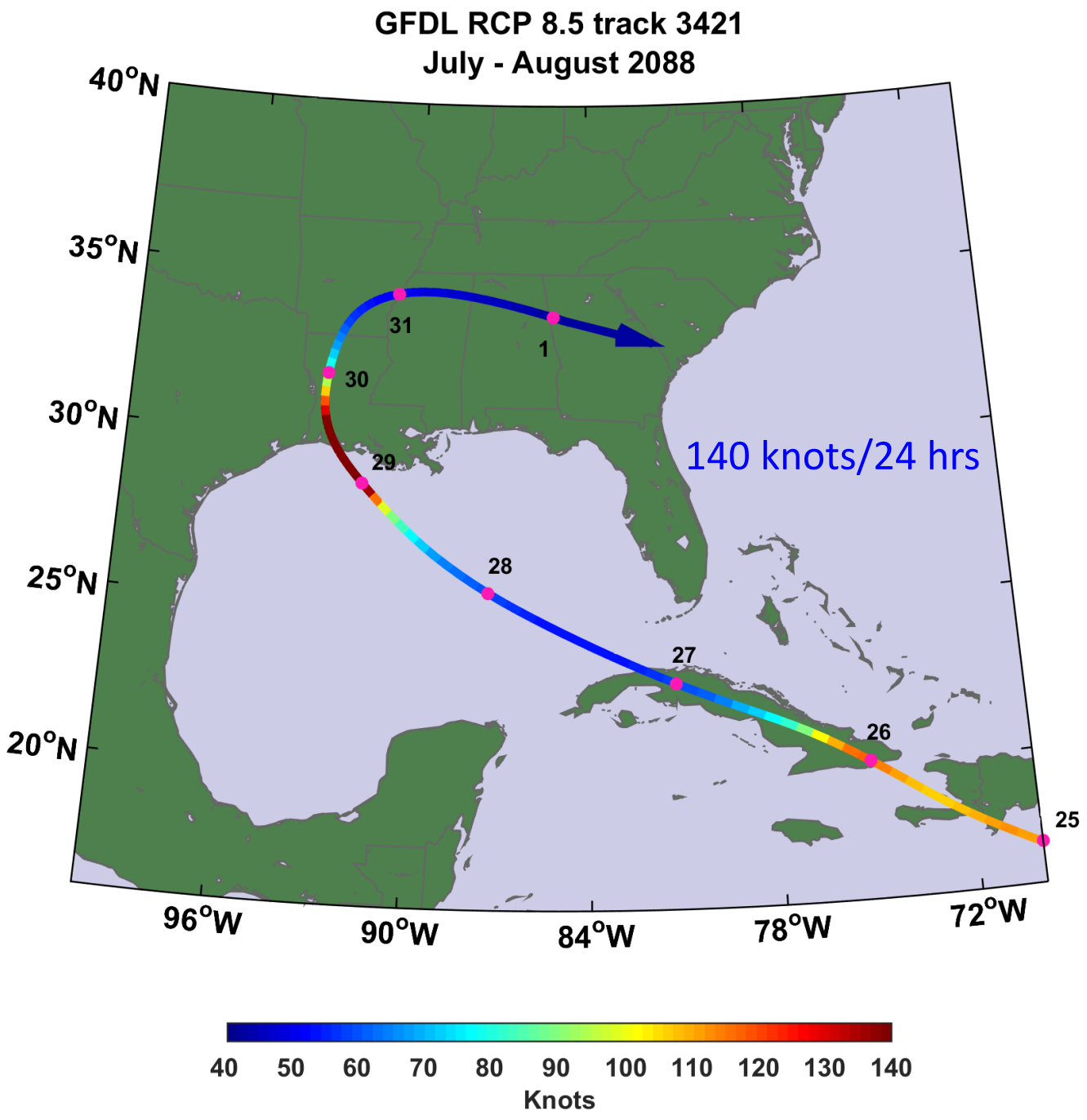
TC Forecasting Nightmares



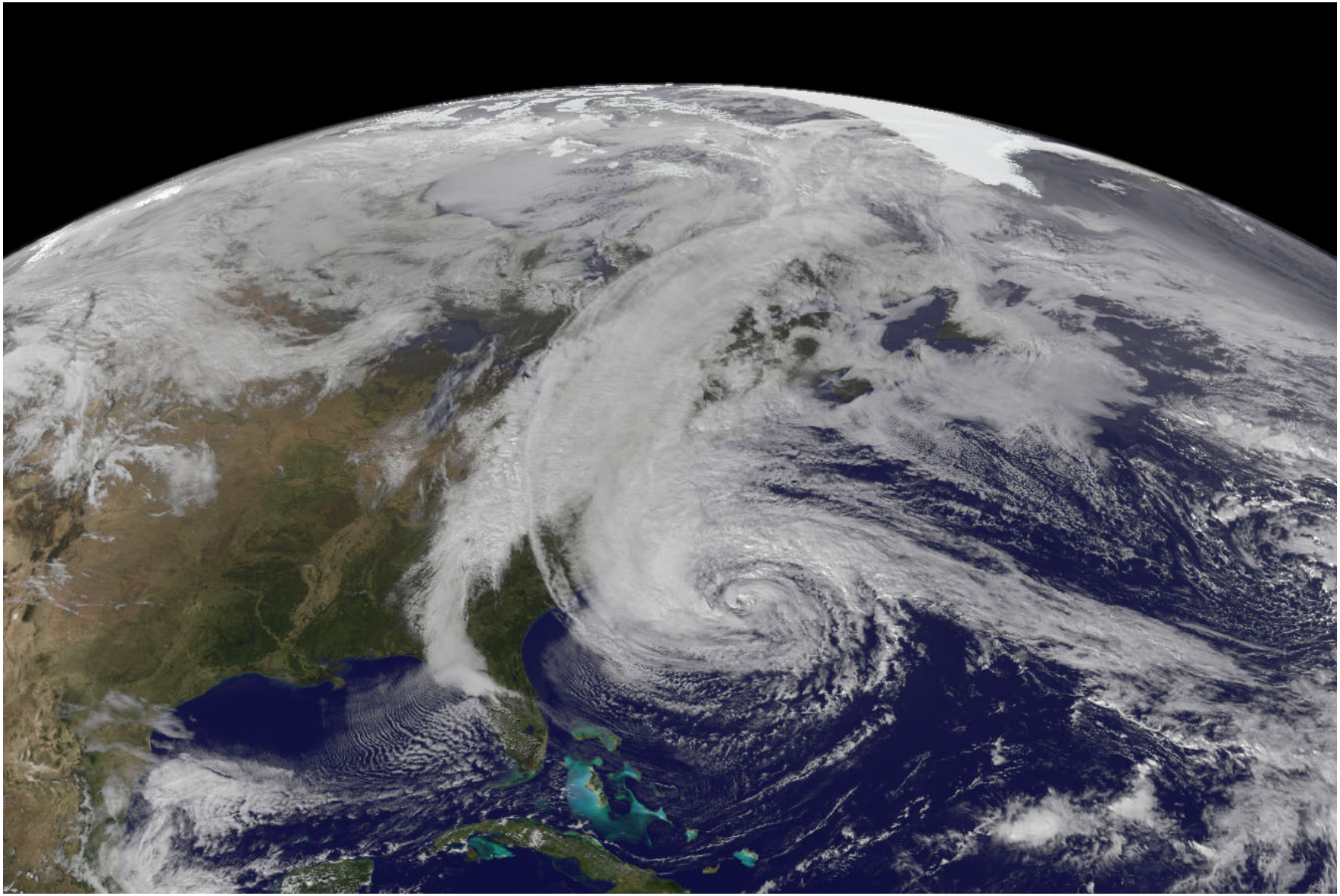
> 416 fatalities, 6th largest death toll in U.S. history, not exceeded again until Katrina

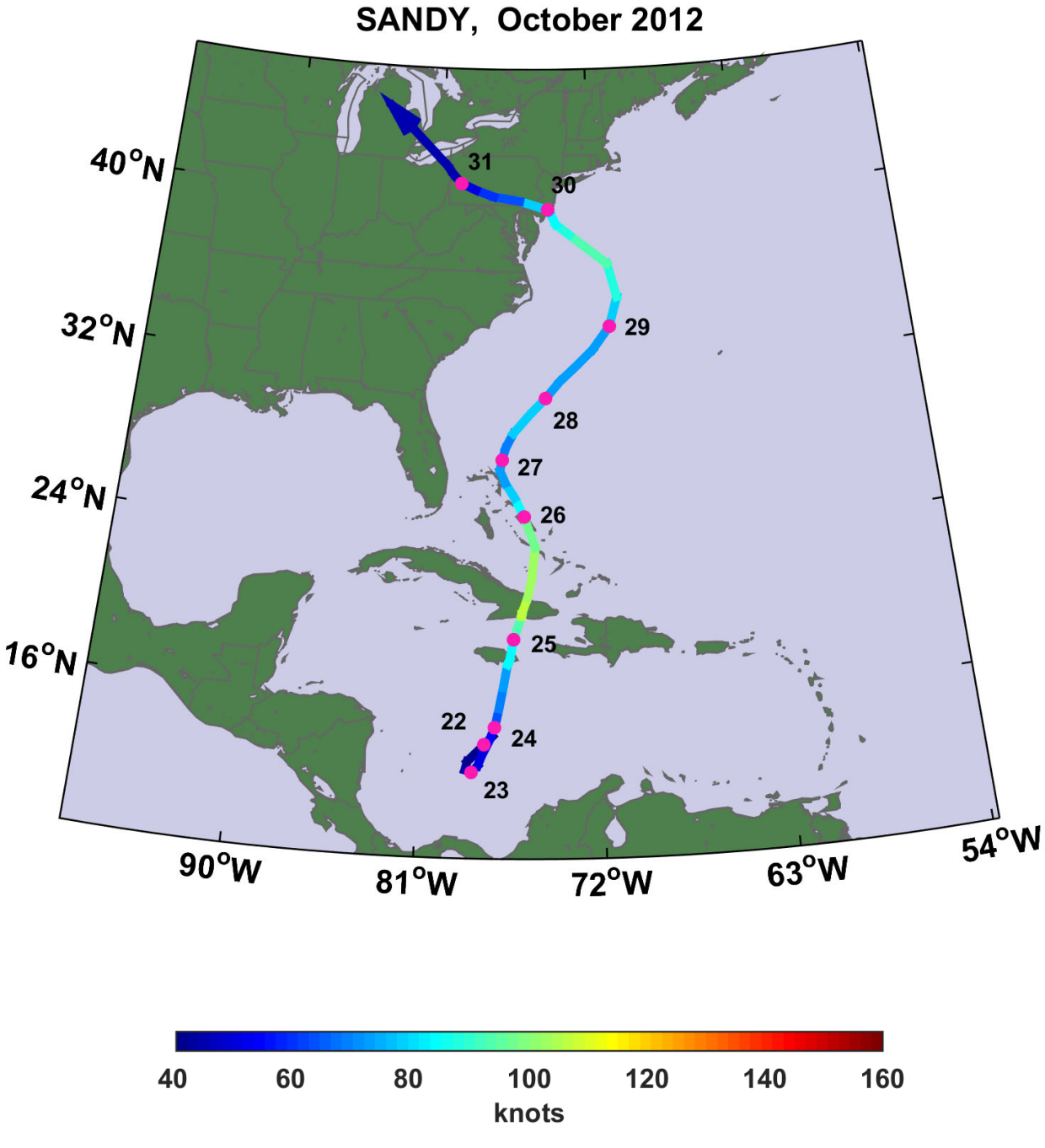
Return Periods by Intensification in 24 hrs Prior to Landfall from 6 CMIP5 RCP 8.5 models




GFDL RCP 8.5 track 3421
July - August 2088
40°N
35°N
30°N
25°N
20°N
96°W
90°W
84°W
78°W
72°W
31
1
30
29
28
27
26
25
140 knots/24 hrs
40
50
60
70
80
90
100
110
120
130
140
Knots

Part II: Hurricane Sandy
October, 2012



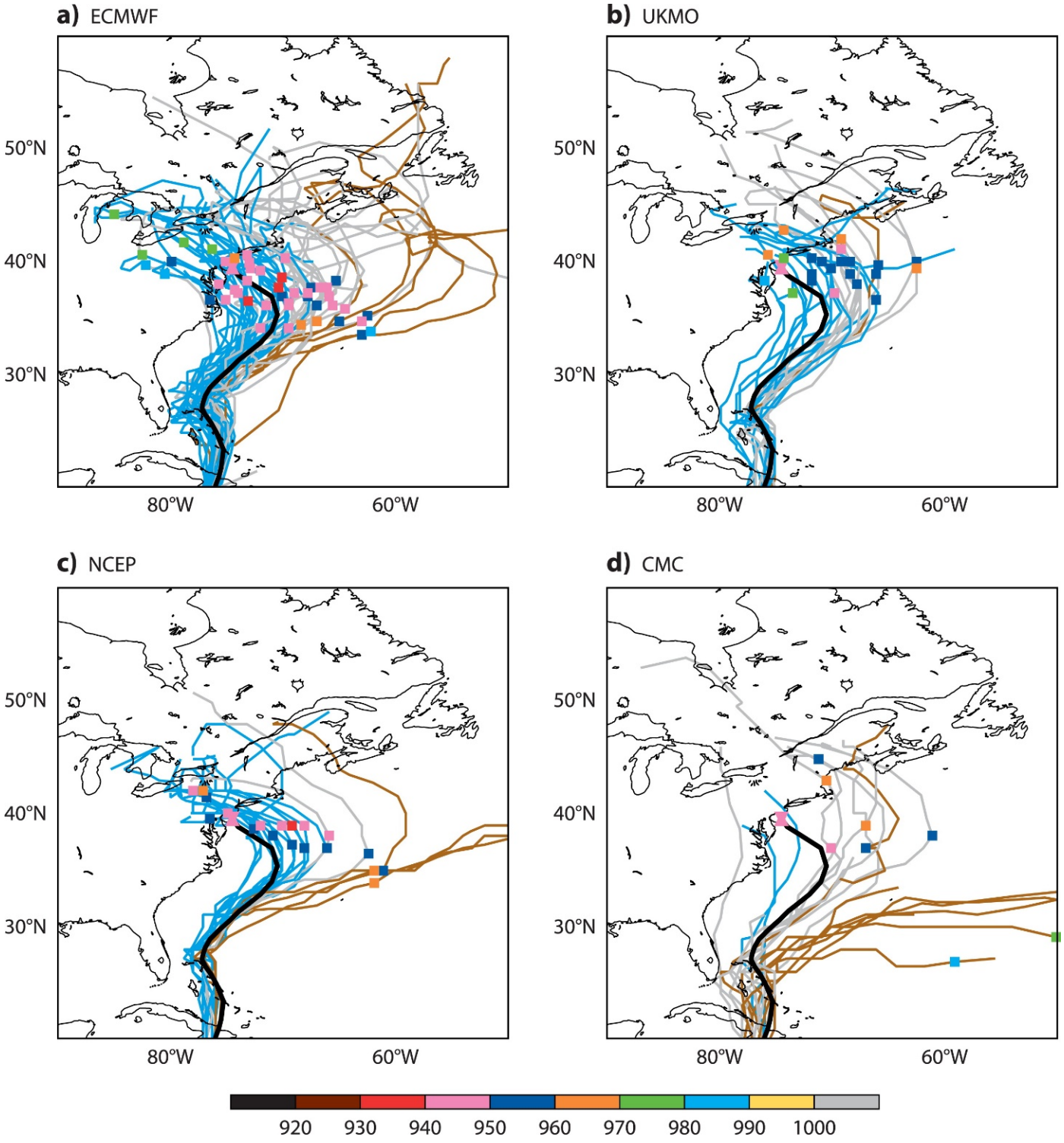

SANDY, October 2012
40°N
32°N
24°N
16°N
90°W
81°W
72°W
63°W
54°W
31
30
29
28
27
26
25
22
24
23
40
60
80
100
120
140
160
knots

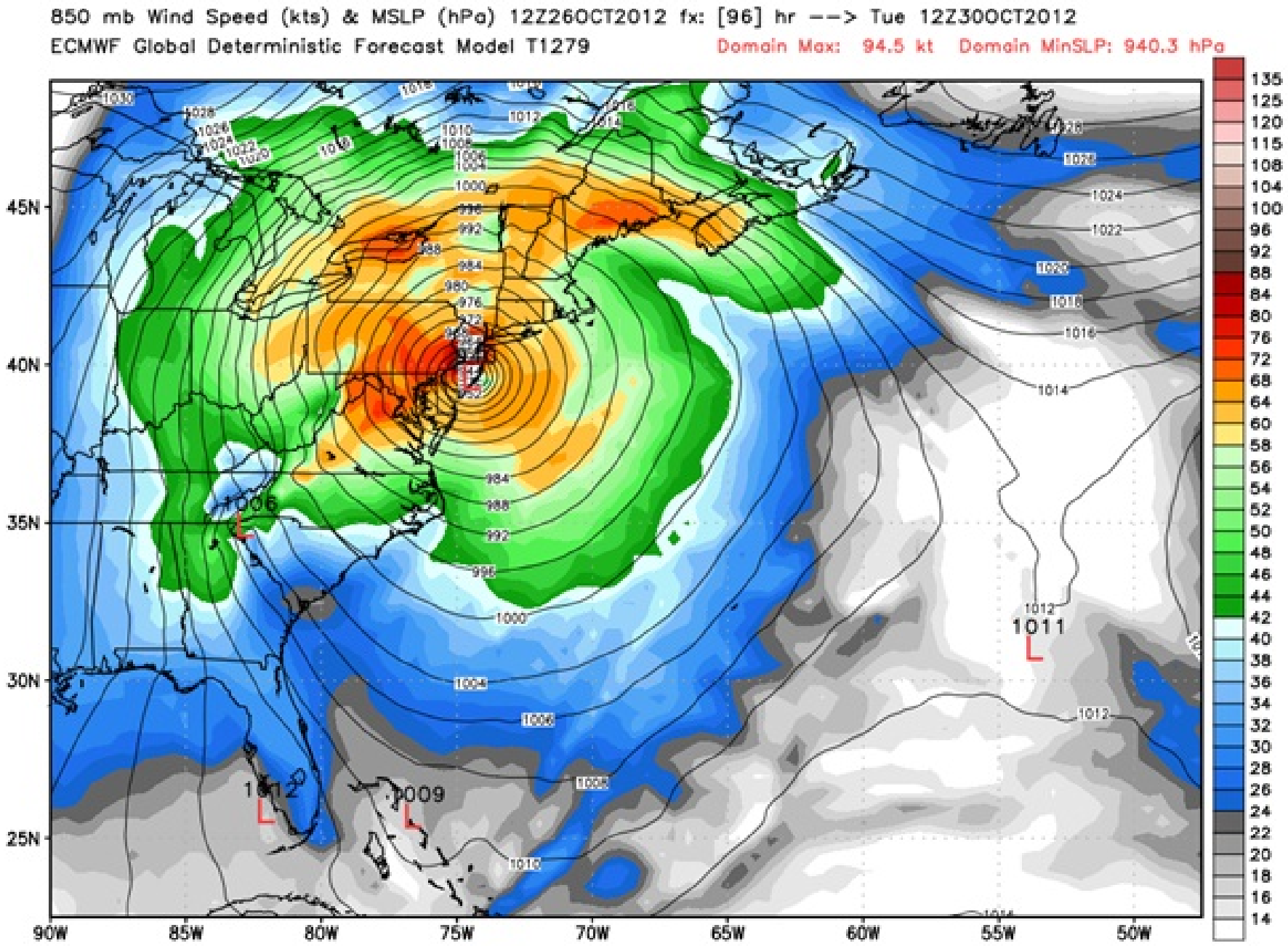
Hard to imagine better track forecasts

Sandy made landfall in New Jersey around 00 GMT October 30

Ensemble forecasts initialized at 1200 UTC 24 Oct (5 ½ days before U.S. landfall)

(Magnusson et al., *Mon. Wea. Rev.*, 2014)





96-hour forecast by the European Center for Medium-Range Forecasts

Relevant Facts

- 233 fatalities
- Strongly affected Haiti and Cuba as well as a large swath of the U.S. eastern seaboard
- $75 billion 2012 U.S. dollars in damage – second costliest hurricane in U.S. history (after Katrina)
- While a Category 2 hurricane off the U.S. northeastern coast, Sandy became the largest Atlantic hurricane in history, with a diameter of 1800 km - this contributed to the large magnitude of its storm surge in New York
- Governor Andrew Cuomo declared a statewide state of emergency and asked for a pre-disaster declaration on October 26

- Record 13.88 foot storm surge at the Battery, Manhattan
- Worst disaster in the 108-year history of the New York Subway System
- New York Stock Exchange closed for two days – for the first two-day weather closure since the Blizzard of 1888
- Over 10 billion gallons of raw and partially treated sewage released in New York and New Jersey
- 1-3 feet of snow in West Virginia

Hurricane Sandy Timeline

- 22 October 12 UTC: Tropical depression forms about 300 nm south-southwest of Kingston, Jamaica
- 22 October 18 UTC: Tropical depression becomes Tropical Storm Sandy
- 24 October 12 UTC: Sandy becomes a hurricanes while 80 nm south of Kingston
- 24 October 12 GMT Numerical simulations by major forecast centers begin to indicate major threat to U.S. northeast and mid-Atlantic states
- 24 October 19 UTC: Sandy makes landfall in Jamaica causing severe damage and knocking out power to 70% of residents. But Sandy does not weaken over the island.

- 25 October 05 UTC: Hurricane Sandy makes landfall in Cuba with sustained winds of 100 knots, killing 117 and causing $2 billion in damage
- 25 October 12 UTC: Global models increasingly focus threat on mid-Atlantic states and northeast U.S.
- 25-26 October: Sandy passes over Bahamas killing 2 and causing $700 million in damages
- 27 October 00 UTC: NHC downgrades Sandy to tropical storm but notes great expansion in its diameter.
- 27 October 12 UTC: Sandy regains hurricane status but remains exceptionally large. Because storm is expected to undergo extratropical transition, no hurricane warnings are ever posted north of Cape Hatteras
- 27 October 12 UTC: Global models focus on New Jersey landfall

- 28 October 00 UTC: New York Mayor Michael Bloomberg holds press conference, explaining that he is not ordering any evacuations “based on the nature of the storm….it is not expected to be a tropical storm or hurricane-type surge”
- 28 October 00-12 UTC: NHC Director Richard Knabb has numerous phone conversations with NYC Office of Emergency Management
- 29 October, morning EDT: Mayor Bloomberg orders evacuation of Zone A…home to about 375,000 residents, and announces shut-down of entire NYC public transportation system at 7 PM EDT that evening
- 29 October 12 UTC: Hurricane Sandy reaches second peak intensity of 85 knots, 220 nm southeast of Atlantic City
- 29 October 21 UTC: NHC advisory continues to emphasize powerful surge threat extending far north of actual storm center

- 29 October 21 UTC: NHC declares that Sandy has become extratropical but continues to issue warnings on storm, including its first ever snowfall advisory (for the mountains of West Virginia)

- 29 October 2330 UTC: Post-tropical Storm Sandy makes landfall near Brigantine, NJ, with an estimated intensity of 70 kt and a minimum pressure of 945 mb

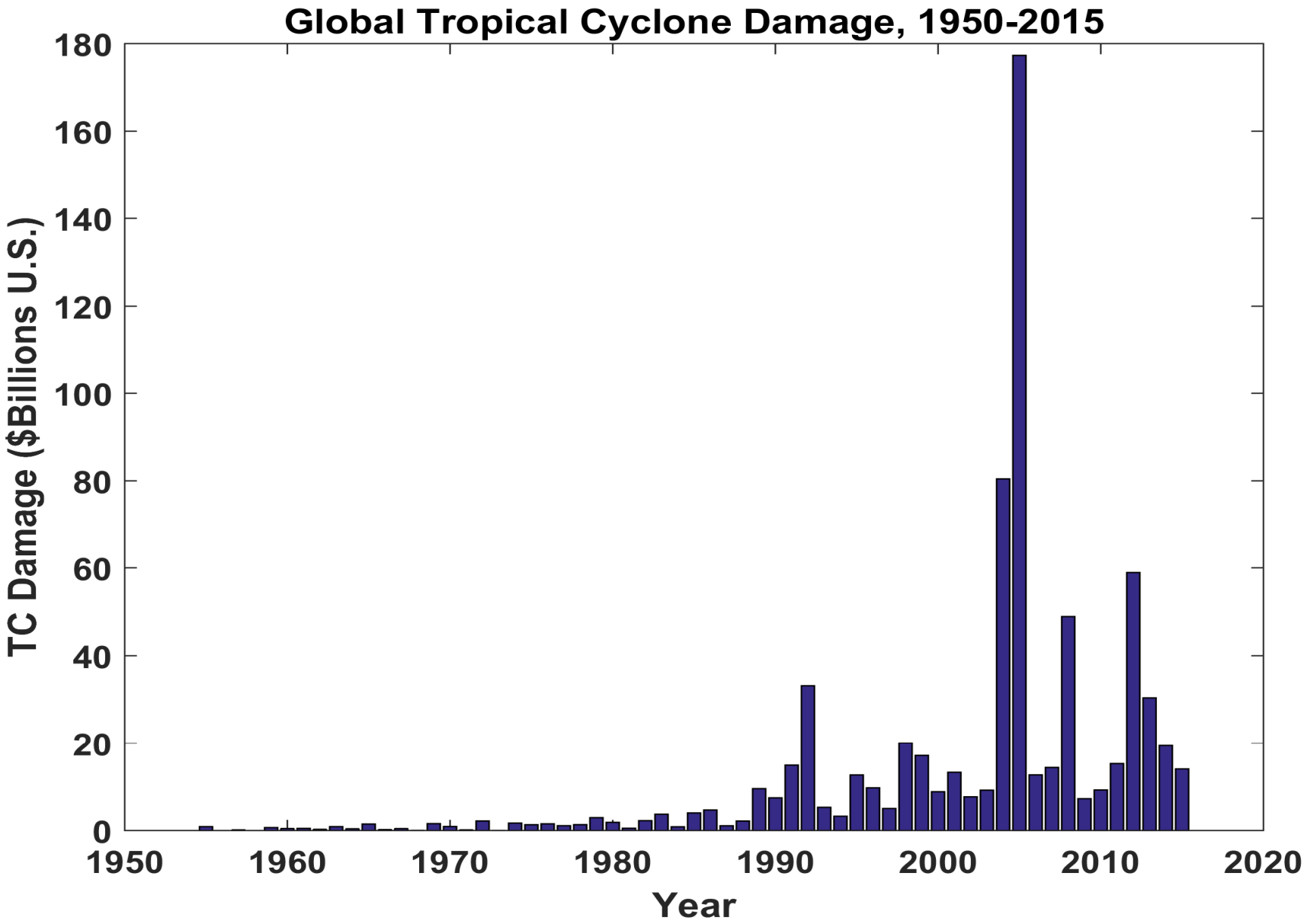
- 30 October 00-12 UTC: Record surge arrives in lower Manhattan overtopping seawall at The Battery and flooding parts of the NYC subway system as well as the Hugh Carey Tunnel, which links Lower Manhattan and Brooklyn. Much of lower Manhattan flooded

Lessons from Hurricane Sandy

- Remarkably good forecasts, excellent communications between forecasters, emergency managers, and political leaders still did not prevent loss of >150 lives
- Preparations for and reactions to Sandy were by and large greatly superior to those in Katrina
- Management of and resilience to natural disasters *strongly* depends on local culture
- Much confusion and delayed evacuation resulted from misunderstandings arising from use of multiple and culturally loaded terms such as “hurricane”. Some insurance policies tied to tropical status and/or “named storm” status. Strong impetus for re-visiting warning terminology, storm categorization, and related issues

Epilogue:
The Elephant in the Room

- Global population exposed to tropical cyclone hazards has *tripled* since 1970
- Sea level is rising and is projected to do so at an accelerating pace through this century
- Incidence of intense tropical cyclones is expected to increase
- In spite of improving forecasts, incidence of tropical cyclone disasters will almost certainly rise alarmingly


Global Tropical Cyclone Damage, 1950-2015
TC Damage ($Billions U.S.)
0
20
40
60
80
100
120
140
160
180
1950
1960
1970
1980
1990
2000
2010
2020
Year

Why the U.S. Will Have Many More Katrinas and Sandys

- Federal and State governments massively subsidize flood risk
- National Flood Insurance Program (NFIP) created by Congress in 1968 in response to reluctance of private firms to insure flood risk
- Most states heavily regulate property insurance and many restrict premium pricing under pressure from wealthy coastal property owners
- NFIP was amended in 2012 by the Biggart-Waters Act that changed NFIP premiums to match actuarial risk-based premiums. In some areas, premiums rose by a factor of 10
- Under pressure from coastal and floodplain property owners, Congress effectively repealed many provisions of Biggart-Waters with the Homeowner Flood Insurance Affordability Act of 2014

- Political left emphasizes “affordability”; means-tested subsidies (such as vouchers) helps those of modest means but inadvertently encourages them to live in risky places
- Political right favors effective subsides for wealthy coastal property owners over free-market principles
- Net result is massive publicly financed incentives to live and build in risky locations
- We can predict with confidence that U.S. coastal TC-related losses will increase over time, exacerbated by sea level rise and, possibly, by increases in TC risk itself