# Changes in Future Hurricane Activity

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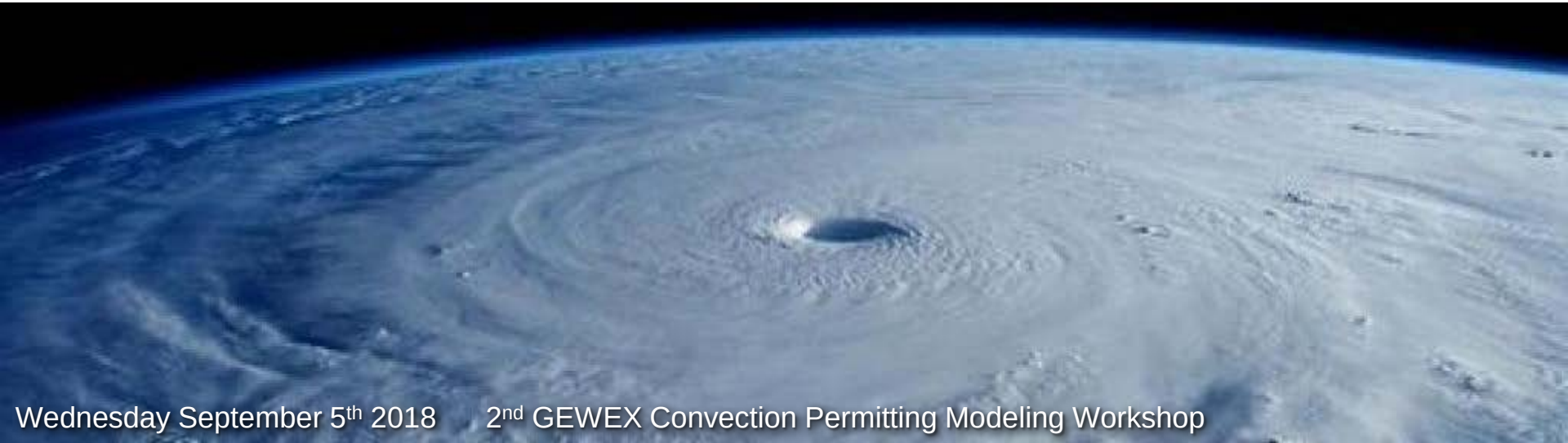


# Hurricane Damages

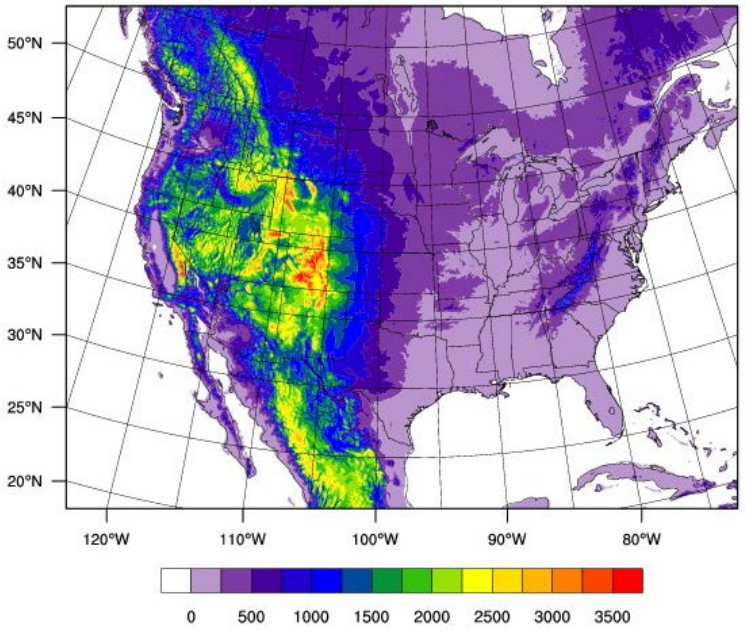
NCAR

- Winds
- Storm Surge
- Flooding
- Offshore Waves

| Name | Damage (Billions USD) | Season | Storm classification at peak intensity |
|---|---|---|---|
| Katrina | $125.0 | 2005 | Category 5 hurricane |
| Harvey | $125.0 | 2017 | Category 4 hurricane |
| Maria | $91.6 | 2017 | Category 5 hurricane |
| Sandy | $68.7 | 2012 | Category 3 hurricane |
| Irma | $64.8 | 2017 | Category 5 hurricane |
| Ike | $38.0 | 2008 | Category 4 hurricane |
| Wilma | $27.4 | 2005 | Category 5 hurricane |
| Andrew | $27.3 | 1992 | Category 5 hurricane |
| Ivan | $26.1 | 2004 | Category 5 hurricane |
| Rita | $18.5 | 2005 | Category 5 hurricane |
| Charley | $16.9 | 2004 | Category 4 hurricane |
| Matthew | $15.1 | 2016 | Category 5 hurricane |
| Irene | $14.2 | 2011 | Category 3 hurricane |
| Frances | $10.1 | 2004 | Category 4 hurricane |
| Hugo | $9.47 | 1989 | Category 5 hurricane |
| Georges | $9.37 | 1998 | Category 4 hurricane |
| Allison | $8.5 | 2001 | Tropical storm |
| Gustav | $8.31 | 2008 | Category 4 hurricane |
| Jeanne | $7.94 | 2004 | Category 3 hurricane |

# Convection Permitting (4 km) WRF simulations

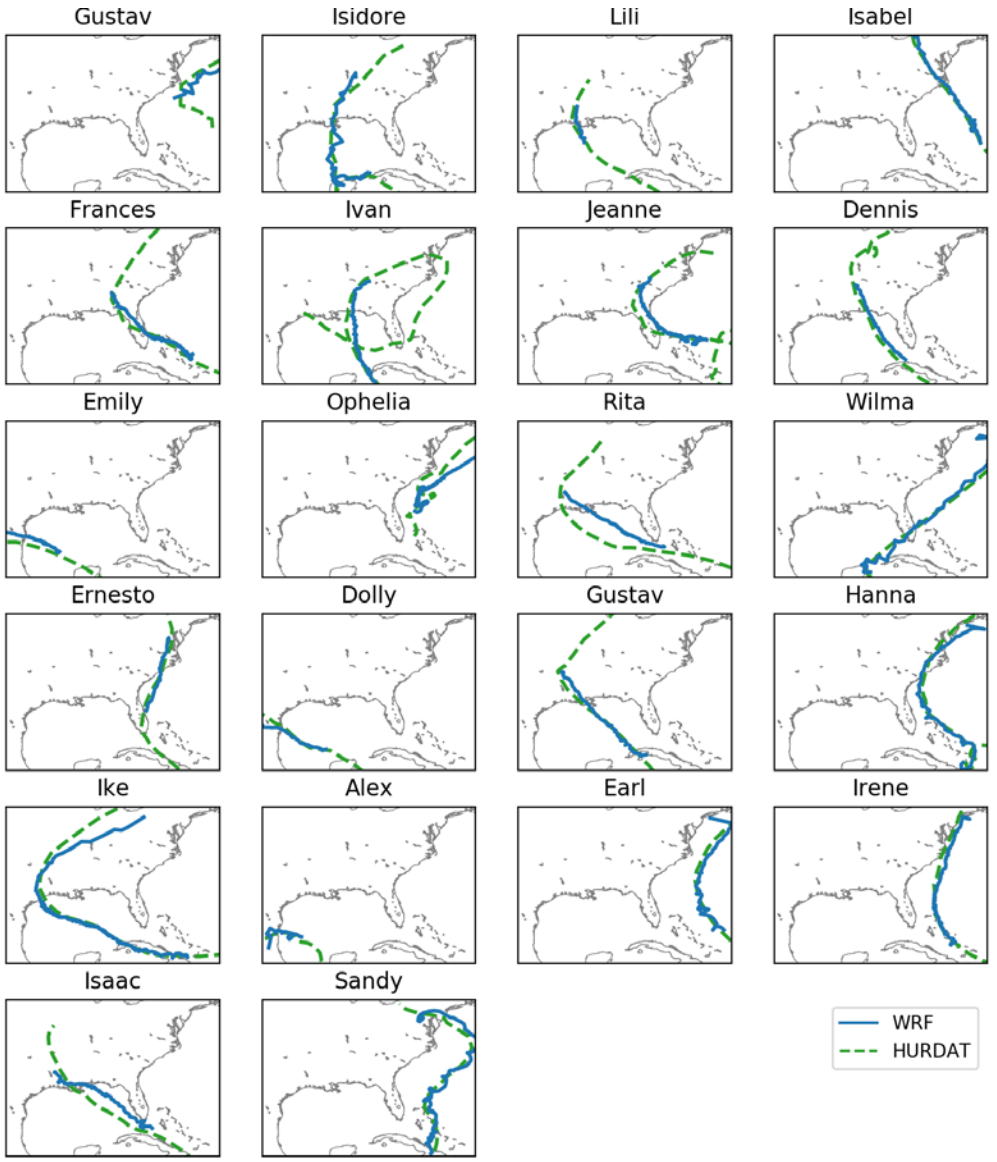
- **WRF V3.4.1**
  - Microphysics: Thompson w/aerosol
  - Convection scheme: **None**
  - PBL schemes: YSU
  - Radiation: RRTMG
  - Land surface model: NoahMP
- **Reanalysis: ERA-Interim**
- **PGW: from CMIP5**
  - multi-model average change signal




**1360 x 1016 grid points**

# Simulating Hurricanes

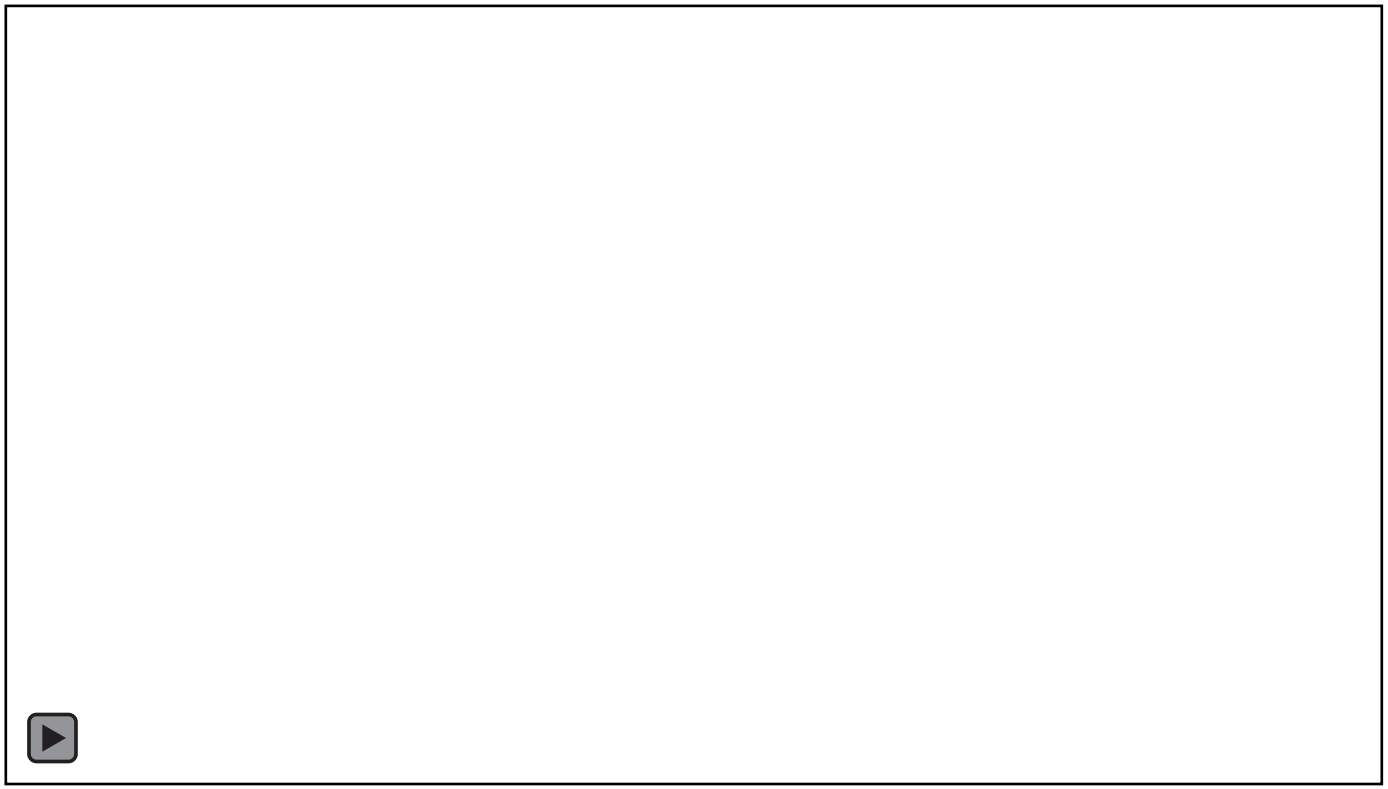
- Simulation of 22(+) Hurricanes
- Tracks all compare well to observations
- Intensities are realistic if too weak
- Storms need time to spinup inside domain



# Hurricane Ivan

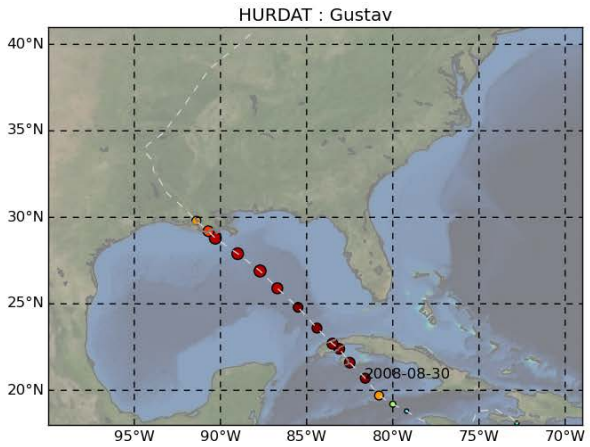
**Hurricane Ivan** (2005)
Current climate

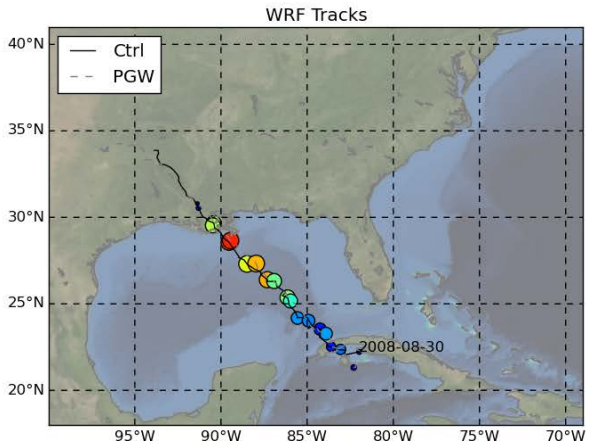
**Hurricane Ivan** (Future)
warmer atmosphere

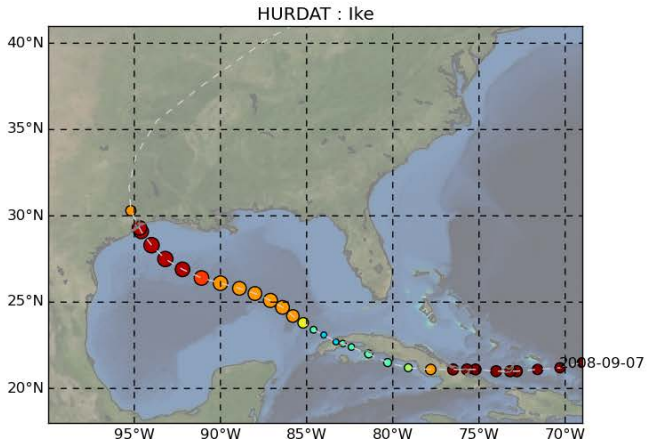


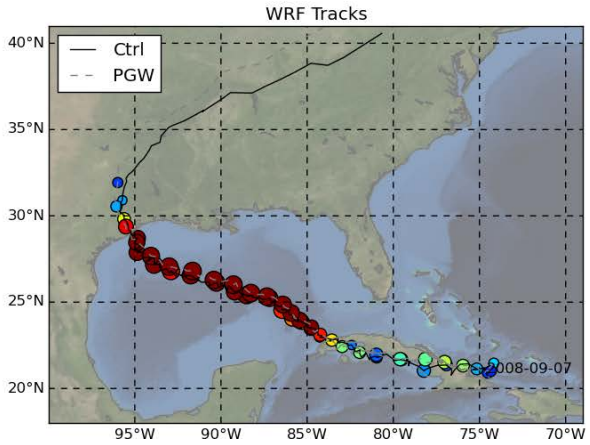
# Simulating Hurricanes

- Model Simulates Hurricane track well
- Sometimes too strong, sometimes too weak



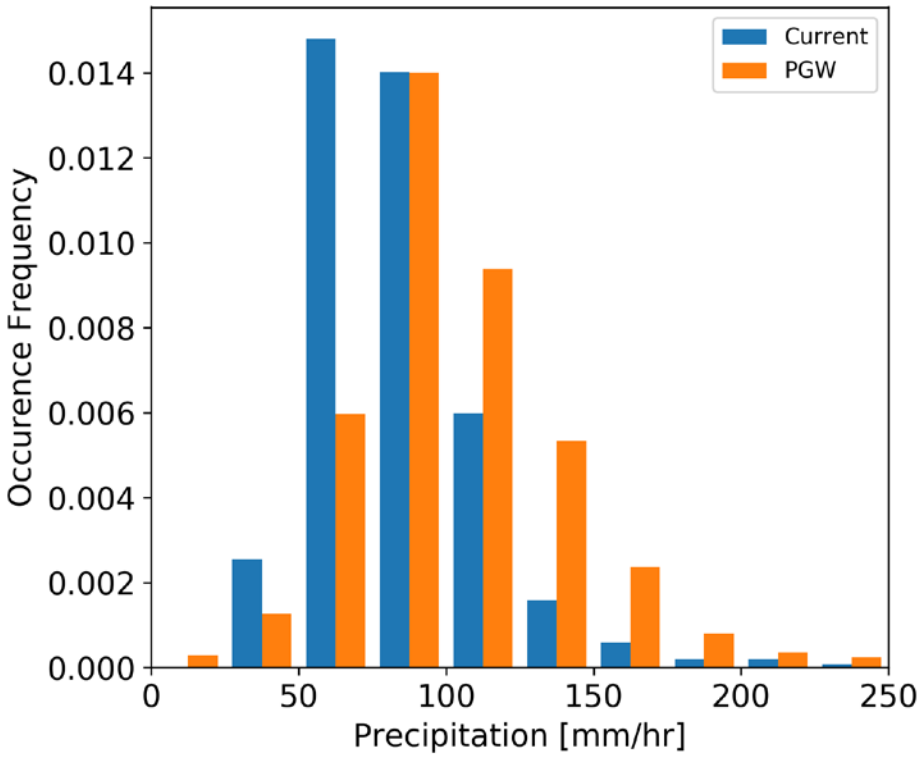



# Future Changes

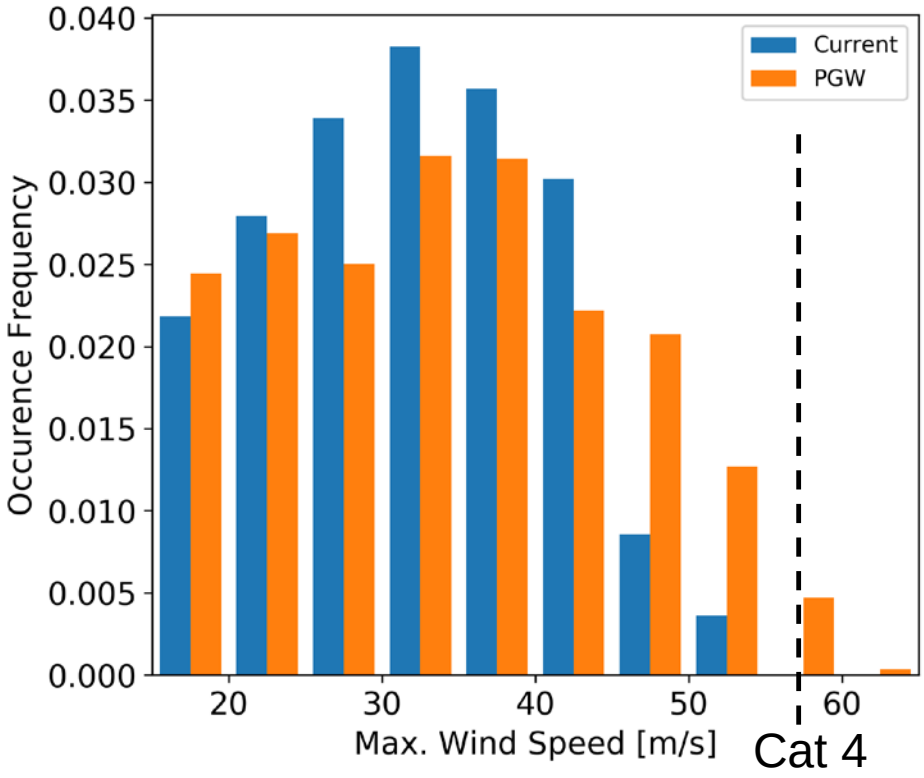
- Some storms get large, some get smaller
- Some storms have faster winds, some slightly slower
- Maximum Rainfall rates increase 20%
- All storms get wetter

# Change Analysis

Maximum Precipitation Rates




Maximum Wind Speeds




Damage ~ Wind$^3$

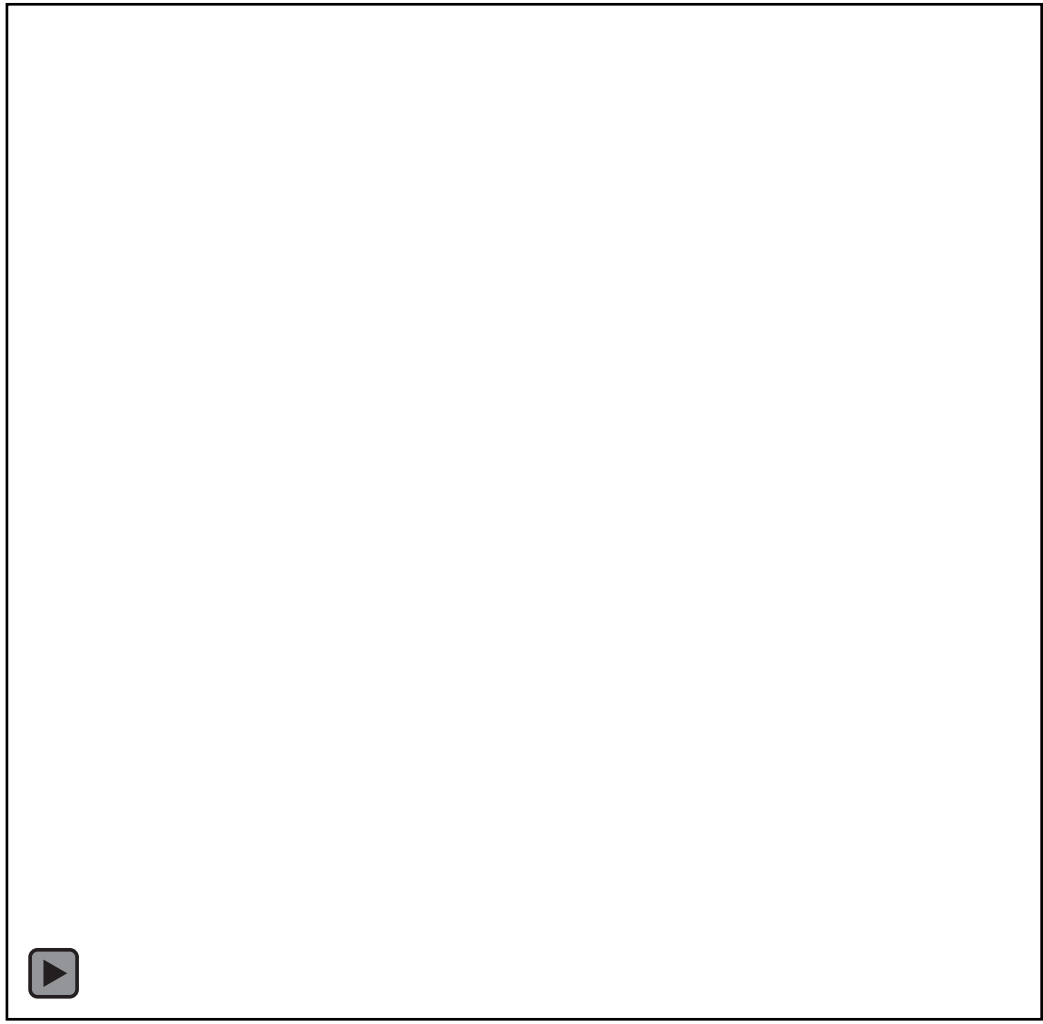
Fastest winds not fast enough

**Note**: instantaneous winds, ocean roughness not limited

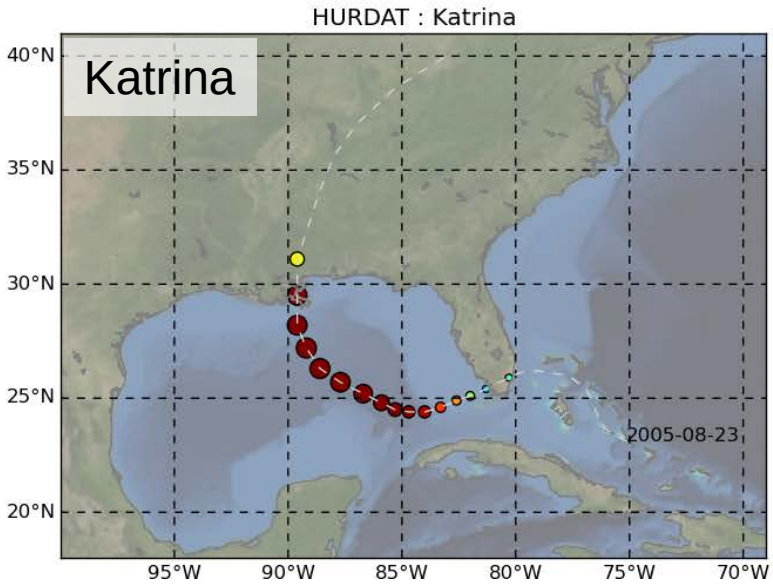
# Difficult Hurricanes to Simulate

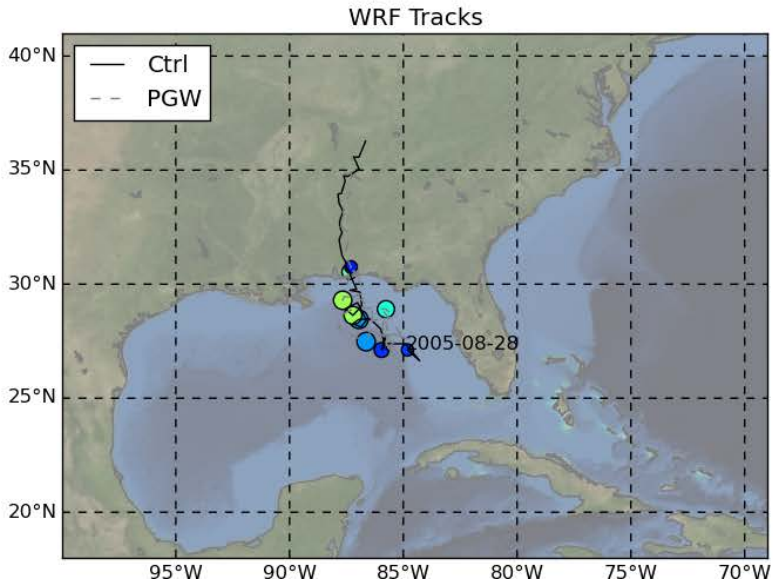
- Katrina : too weak, wrong track
  - Quasi-internal genesis, close to southern boundary
- Charley never formed in WRF
  - Moved across southern boundary too quickly and was very weak in reanalysis
- Hurricane genesis internal to domain
  - Chaotic variability caused some to form that didn't in reality and some that were present in reality not to form.

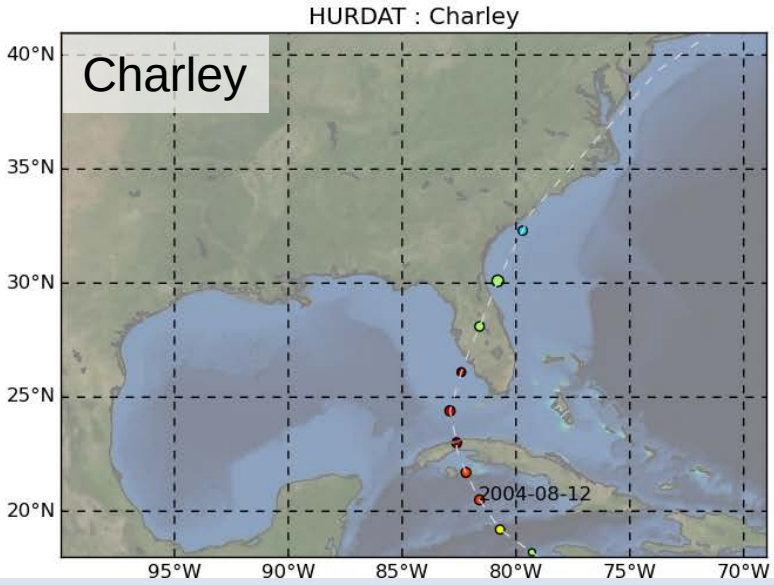
Hurricane Katrina

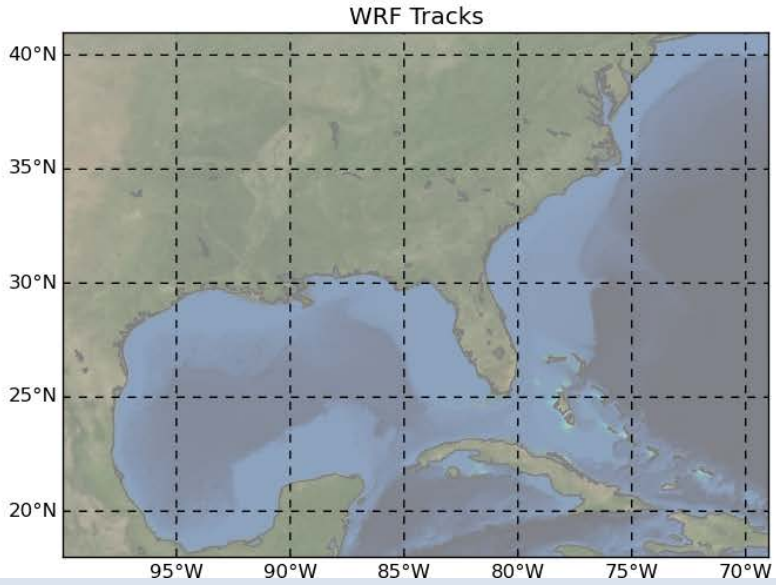


# Problem Simulations



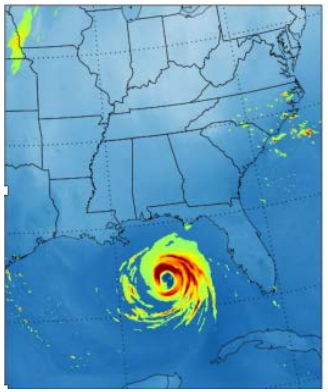



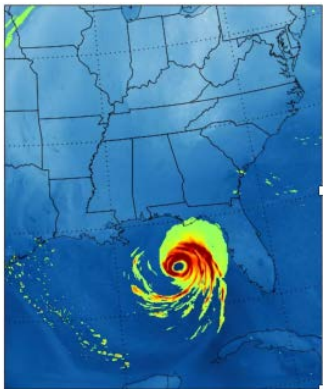



# Summary

- High-resolution atmospheric models can provide excellent simulations of hurricanes
- These simulations can be used to examine the effects of changes in background climate
- Maximum precipitation rates increase by ~20%
- Simulations suggest extreme winds will increase
- No two storms are alike





Gutmann et al. 2018, **Changes in Hurricanes from a 13 Year Convection Permitting Pseudo-Global Warming Simulation**, *Journal of Climate,* 31, 3643–3657, doi:10.1175/JCLI-D-17-0391.1
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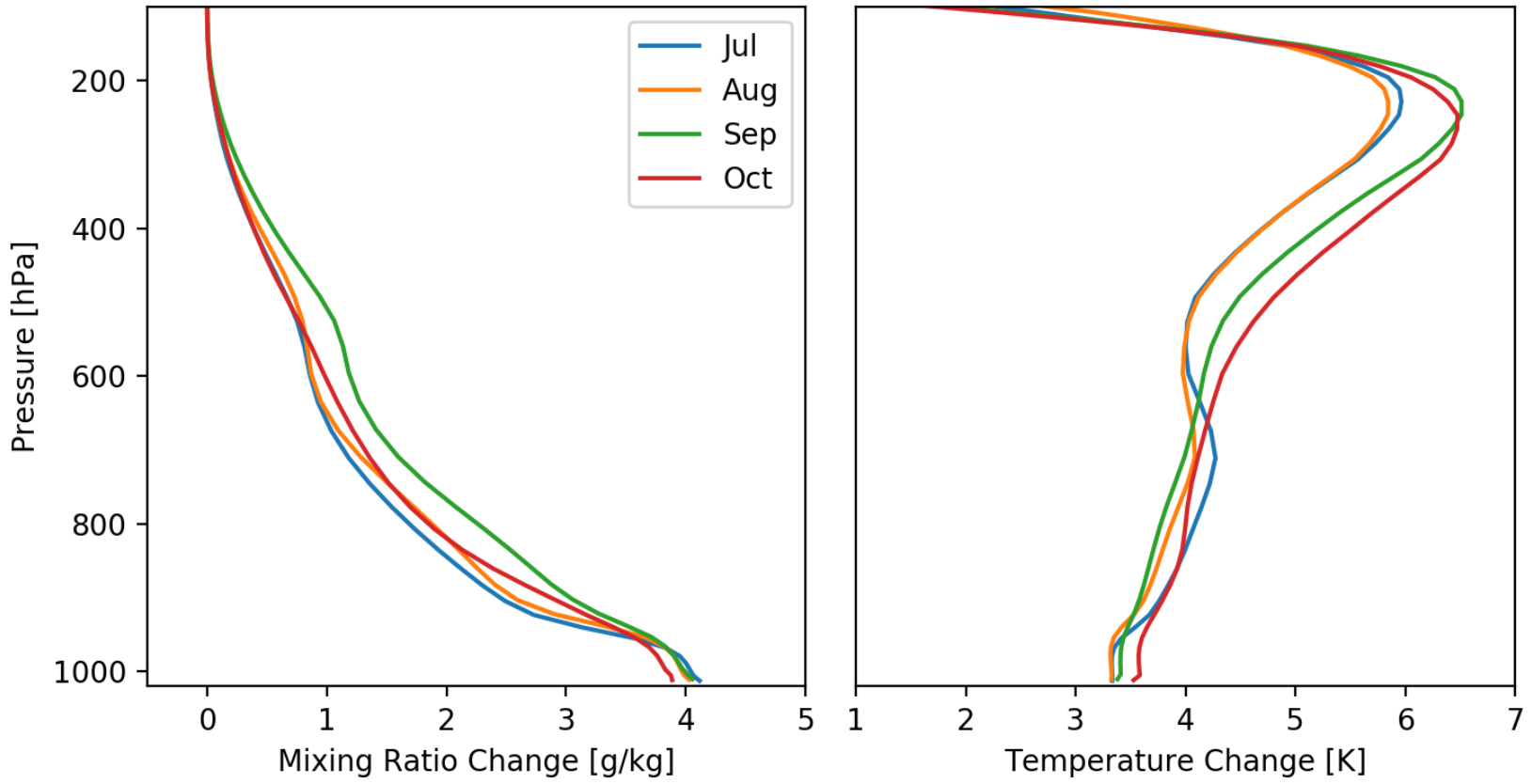
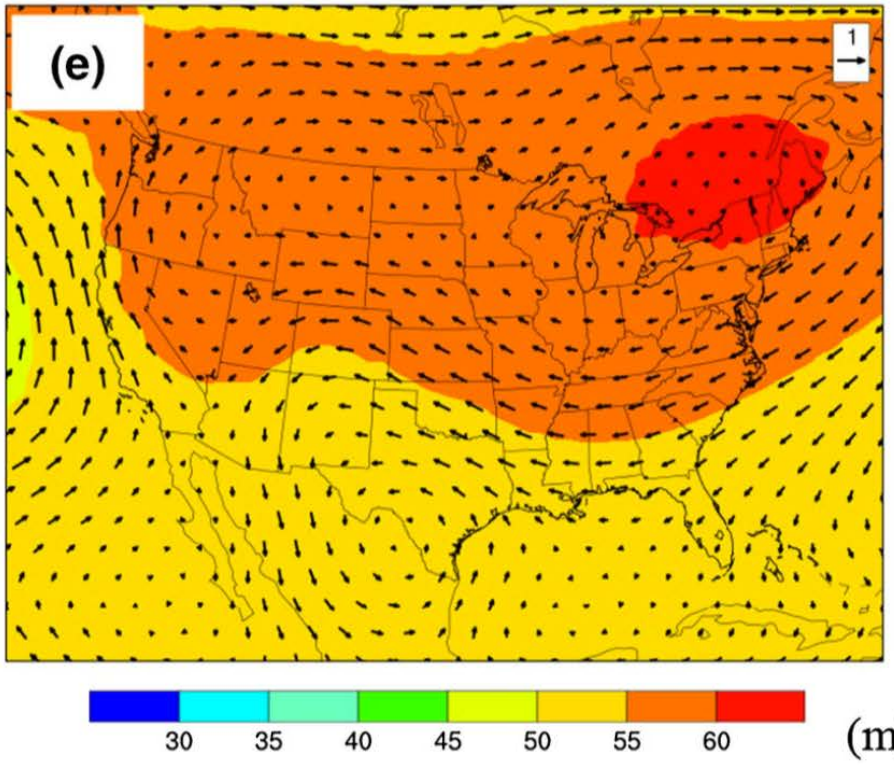
Analysis funded by Det Norske Veritas (DNV) and CONUS simulation by NSF under NCAR Water System Program

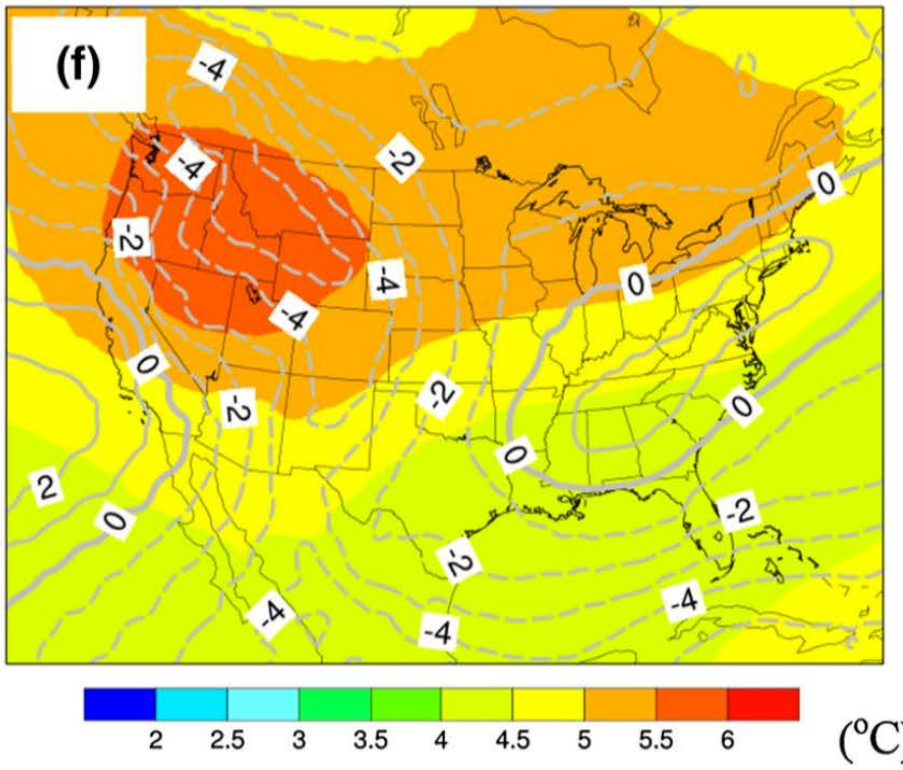
# PGW change over Gulf of Mexico



# PGW Regional Change

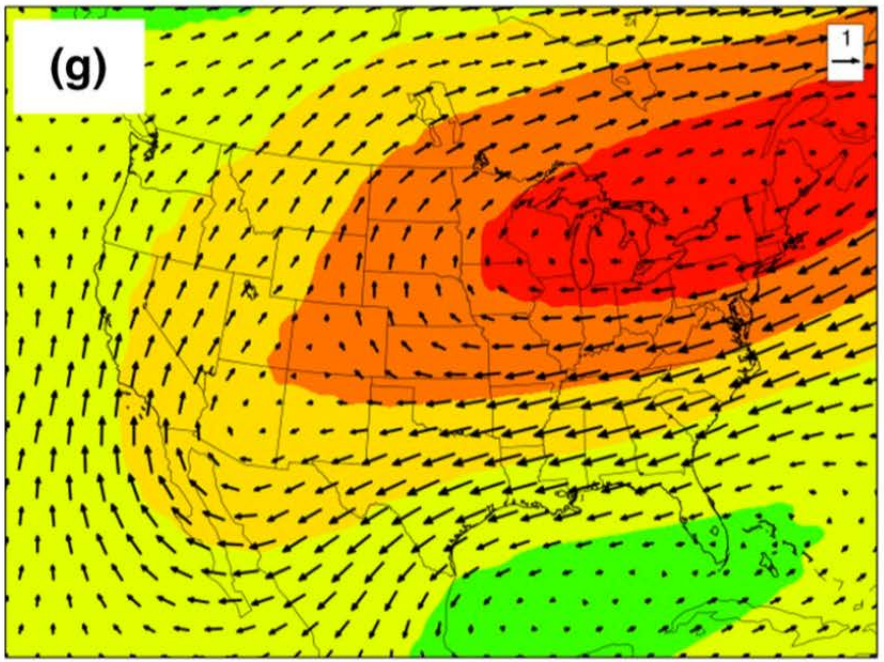
- JJA change in 700 hPa
  - left:GPH (colors) and winds (arrows)
  - Right: T (color), and RH (contours)

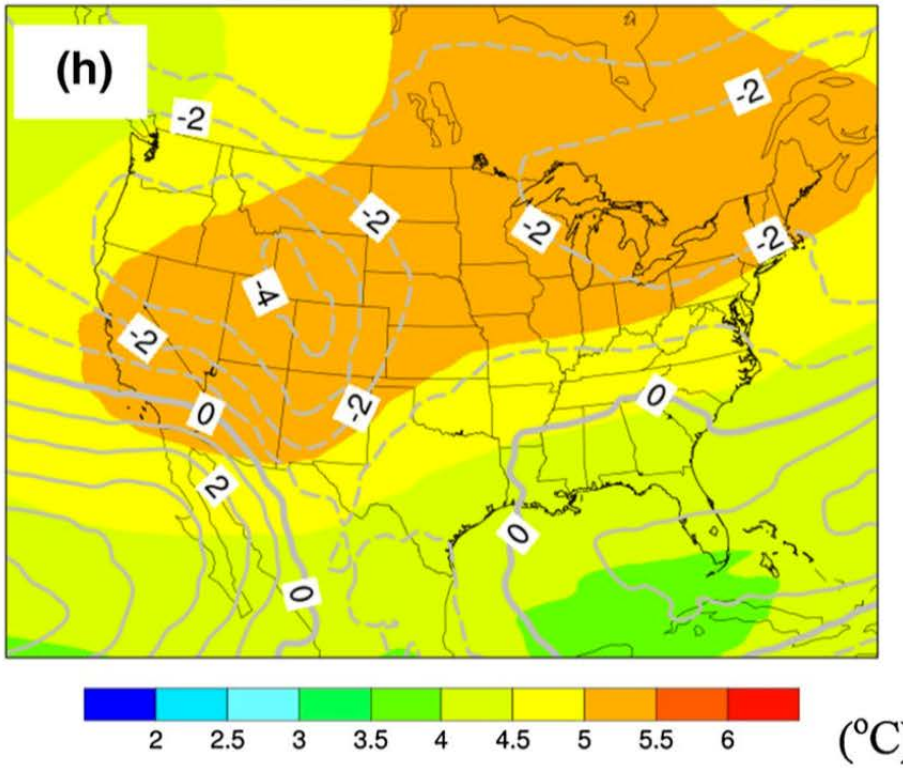


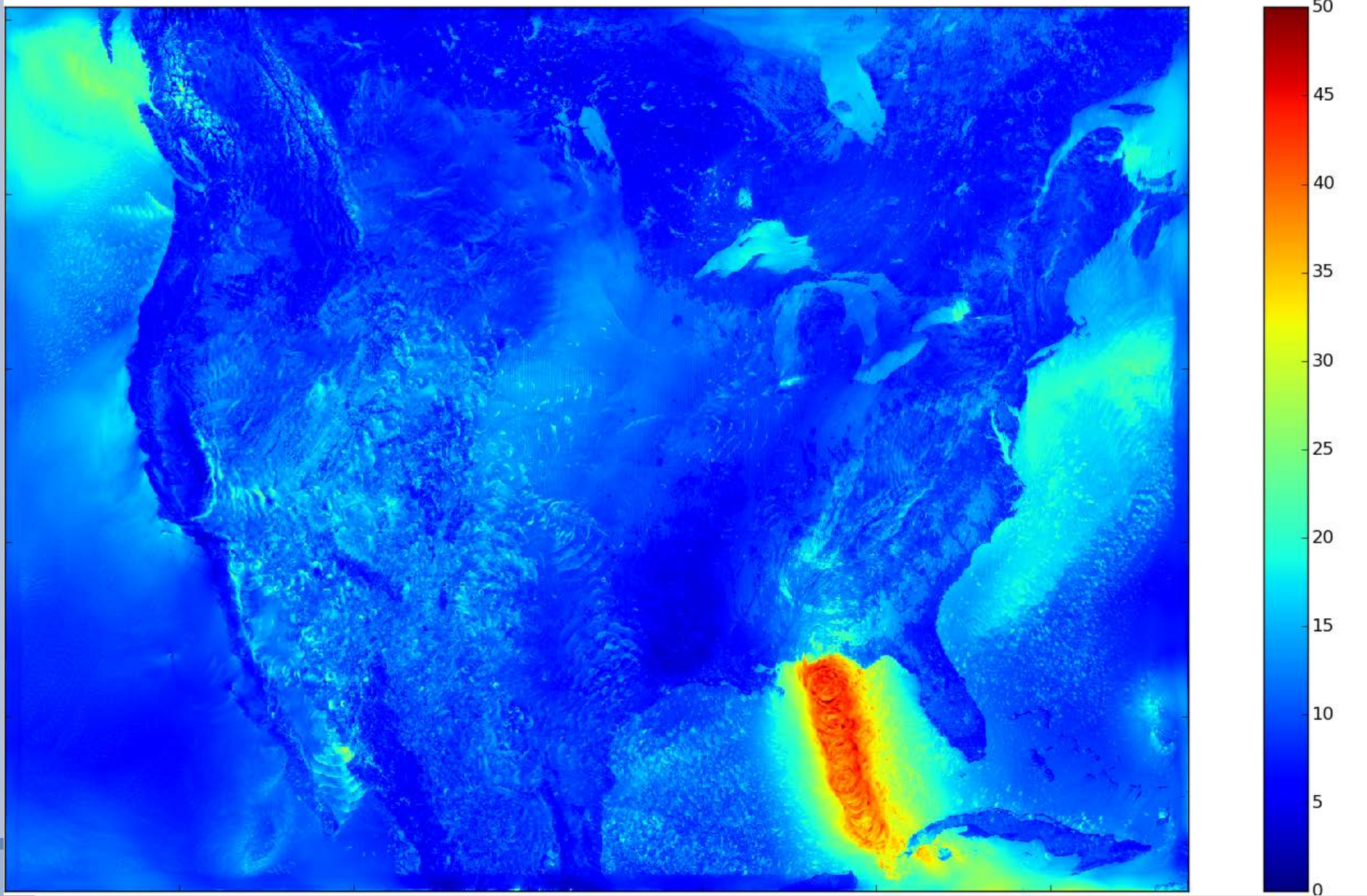
# PGW Regional Change

- SON change in 700 hPa
  - left:GPH (colors) and winds (arrows)
  - Right: T (color), and RH (contours)

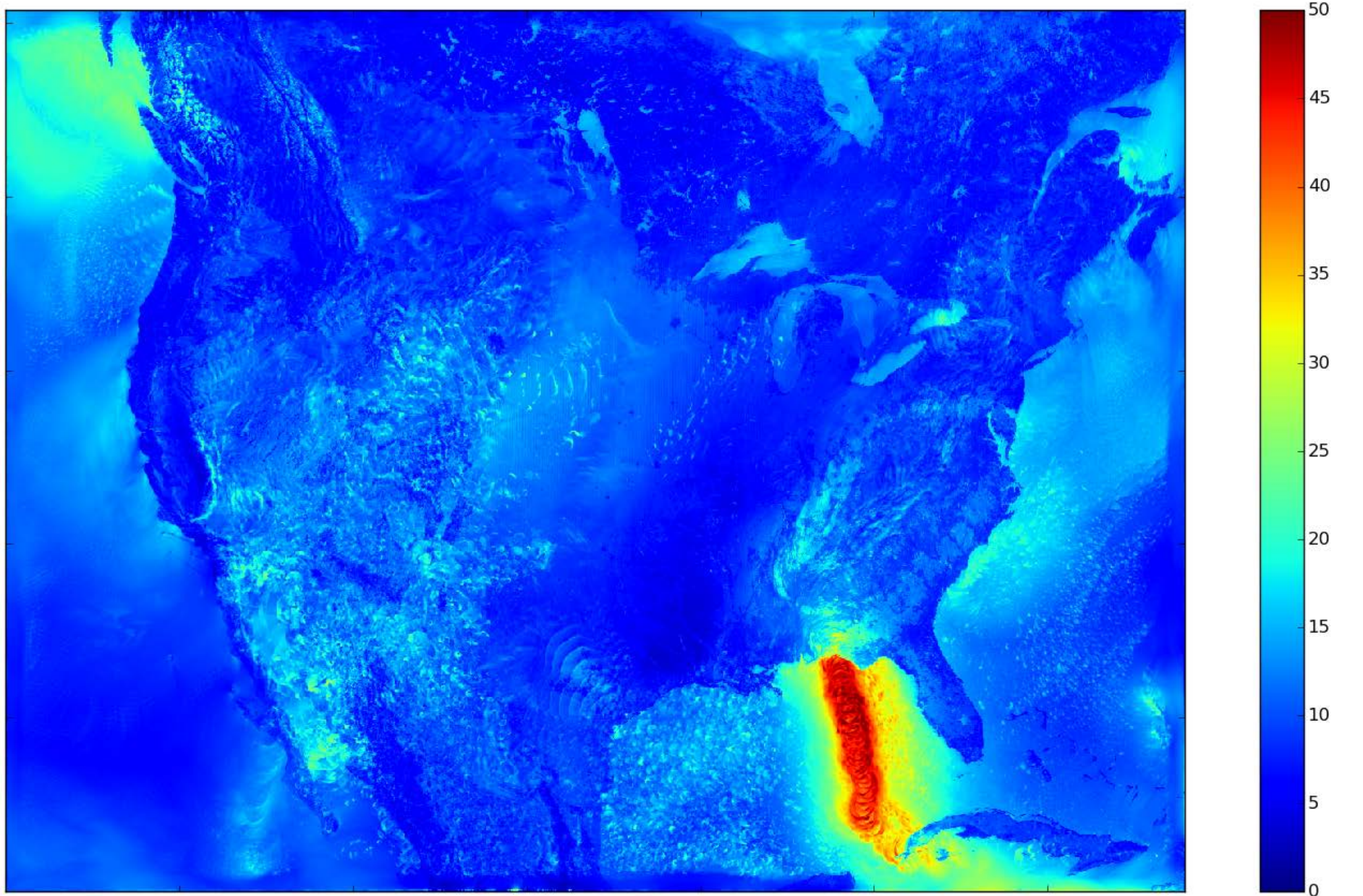


# Ivan Max Wind Speeds Current



# Ivan Max Wind Speeds PGW



# Ivan Max Wind Speeds Change