Hurricane Attribution, Predictions & Projections

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Image: NASA.
Outline

- Historical Atlantic TS & Hurricane Record
- Downscaling Techniques
- Extended Range S-I Hurricane Predictions
- Attribution of Recent TS Frequency Increase
- Response of Hurricanes to Radiative Forcing
- Internal Climate Variability and NA Hurricane Frequency
- Note of caution
- Summary

Data Archeology and Paleo-proxy Indicators Complement Instrumental Records (e.g., Chennoweth and Divine 2008, Mann et al 2009)
Sources For (& Limits To) Predictability

Current Climate State → Forcing → Future Climate State

Current Climate State → Dynamics → Future Climate State
Sources For (& Limits To) Predictability

Current Climate State

Forcing

Dynamics

Future Climate State

“Downscale”

Extreme or Local “Impact”
Sources For (& Limits To) Predictability

**Forcing**

- Current Climate State
- Dynamics
- Future Climate State
- “Downscale”
- Extreme or Local “Impact”

*Downscaling techniques:*

- **Statistical models built on observed record**

- **Counting AGCM/CGCM “modelcanes”**
  (e.g., Broccoli and Manabe 1990, Camargo et al 2006, Vitart et al 2006, 2007...)

- **High-res regional and global AGCMs**

- **Statistical models built on sensitivity of high-res models**
  (e.g., Vecchi et al 2010)
GFDL HiRAM Model recovers many aspects of observed hurricane tracks

Zhao et al (2009, J. Climate)
Dynamical Models Exhibit Skill in Seasonal Basin-wide Hurricane Frequency

Statistical-dynamical hybrid model

Emanuel et al (2008, BAMS)
- Model ensemble
- Observed

Knutson et al (2007, BAMS)
- Model ensemble
- Observed

100km SST-forced AGCM

LaRow et al (2009, J.Climate)
- Model ensemble
- Observed

18-km regional model

50km SST-forced AGCM

Zhao et al (2009, J.Climate)
- Model ensemble
- Observed
- Ensemble spread

Figure adapted from Knutson et al (2010, Nat. Geosci.)
Skill in Century-Scale SST-Forced AGCM Hindcasts
Using 100km version of Zhao et al (2009, J. Clim.) AGCM

North Atlantic TC

East Pacific TC

Vecchi, Zhao and Held (2010, in prep.)
HiRAM C180 (and observations + controls to large-scale) Suggest Relative SSTA as a Predictor

Relative SSTA = Atlantic SSTA minus Tropical SSTA

Seasonal Hurricane Frequency Forecast Scheme

• Build a statistical emulator of HiRAM-C180, training on AGCM response to broad range of climates (projections, past climate, idealized forcing)

• Two predictors:
  • $\text{SST}_{\text{MDR}}$ (SST anomaly 80°W-20°W, 10°N-25°N)
  • $\text{SST}_{\text{TROP}}$ (SST anomaly 30°S-30°N)

• Use S-I forecast models (GFDL-CM2.1 and NCEP-CFS) to predict two indices

• Convolve PDF of SST forecasts with PDF from statistical model.
HiRAM-C180 with full SST gives $r=0.78$, RMSE=1.91
Cannot justify additional predictors at this time

Vecchi et al. (2010, MWR submitted)
Statistical-Dynamical Hurricane Frequency Retrospective Forecasts Initialized January Exhibit Skill

Vecchi et al. (2010, MWR submitted)
Hybrid (Statistical-Dynamical) Forecast System Exhibits Potential for Multi-season Lead Forecasts

(a) Retrospective Correlation Monthly Ensemble Atlantic Hurricane Forecasts

- Persistence of monthly SSTA
- Persistence of 3-month SSTA
- Persistence of previous year’s count
- NOAA-GFDL-CM2.1 dynamical forecast
- NOAA-NCEP-CFS dynamical forecast
- Two-model average forecast

(b) Retrospective Correlation Lagged Ensemble Atlantic Hurricane Forecasts

- Zhao et al (2009) full SST
- AGCM hindcast
- Zhao et al (2010) persisted SST
- AGCM forecast
- Perfect ASO SSTA

Vecchi et al. (2010, MWR submitted)
Attribution of Recent TS Frequency Increase in North Atlantic

100km GFDL-HiRAM AGCM recovers recent NA TS Trend when forced with HadISST.v1 SST

What aspect of SST drove increase?

Vecchi, Zhao and Held (2010, in prep.)
Is AGCM Increase in NATS Driven By Uniform Warming?

100km AGCM 1982-2007
North Atlantic tropical storm count not sensitive to removing tropical-mean SSTA forcing.

Vecchi, Zhao and Held (2010, in prep.)
1982-94 and 1995-2007 PDFs of NA TS Count*

* lasting two days or more

2005 Observed

Vecchi, Delworth, Held and Zhao (2010, in prep.)
Recent Increase Not Robustly “Forced” in CMIP3 Models

Recent trend in statistical hurricane model applied to CMIP3 20c3m runs

1960-2000 Trend in Hurricane Freq. Index from 20C3M CMIP3 Models

Response of NATS Frequency to Radiative Forcing
Divergence of 21st Century projections of TS Frequency

• Even sign of NATS frequency response to GHG unclear: Not big help in decadal predictability (yet?)

• Various studies downscale different coupled models, and over different periods

Anthropogenic-Influence: Projected 21s Century Changes in NA TS Frequency

Is there any consistency in the various projections?
Dynamical models exhibit consistent relationship to MDR and tropical SSTs - all consistent with observations


Poisson model of 2-day duration TS (vertical) vs. dynamical downscaling results (horizontal)
NA Hurrs Projections: Internal Variability Dominant Source of Uncertainty Even in 100-year Trends

Apply statistical model for NA hurricane frequency built from sensitivity of 50km AGCM to 4,000 years of GFDL-CM2.1 output.

Statistical model uses two predictors:
- Tropical Atlantic SST
- Global Tropical SST
Power Spectrum of Atlantic Basinwide Storm Counts
Projected by Villarini Model from GFDL-CM2.1 Preindustrial Control (1st 1000 years)

-1.3
-1.5
-1.7
-1.9
-2.1
-2.3
-2.5

log(Spectral Power, (Storms/Year)^2)

100 Yr  50 Yr  40 Yr  30 Yr  20 Yr  10 Yr  7 Yr  5 Yr  3 Yr

Multi-decadal variations in Atlantic heat Xport convergence?

ENSO
Statistical counts and meridional ocean heat transport

Key region for relSSTA variations

Multi-decadal (0 lag)

2000-Year Linear Least-squares Regression of Villarini Model Atlantic Basinwide TS Counts onto Vertically-integrated Meridional Ocean Heat Transport - CM2.1 Preindustrial Control
Hurricane Index Correlated with max(MOC) at lowest frequencies (centennial).

At decadal timescales perhaps related to shifts in MOC max & shallow changes.
In GFDL-CM2.1 Perfect Model/Perfect Obs. Experiments: MOC Predictability Appears to Vary (see Poster #5)

In GFDL-CM2.1 Perfect Model/Perfect Obs. Experiments: MOC Predictability Appears to Vary (see Poster #5)

Comparing Two Cases in CM2.1:
Hurricane Index Has Some Predictability When MOC Does

Idealized Predictions of MOC
Msadek, Dixon, Delworth and Hurlin (2010)

"Unpredictable MOC" Case

"Predictable MOC" Case
Sensitivity to SST Uncertainty

If AGCM sensitivity (and relative-SST statistical models) correct:

We may need to predict decadal SST changes better than we know past changes (even over the satellite-SST era; 1982-2010).
Ability of AGCM to Recover Multi-decadal TS Variability Depends on SST Forcing

- Observed
- HadISST-Forced AGCM
- ERSST-Forced AGCM

Vecchi, Zhao and Held (2010, in prep.)
Model Response Exhibits Sensitivity To Forcing Used

Tropical Storm Frequency Response to Same AGCM but different estimates of observed SST

HadISST forced

NOAA-OI.v2 forced

AGCM is 100km version of Zhao et al (2009, J. Clim.)

Vecchi, Zhao and Held (2010, in prep.)

How do we evaluate model skill in this context?
Summary

• 1982-2007 TC increase in NA due to pattern of SST change
  (what drove pattern? Not robustly associate with forcing in CMIP3 models; consistent with internal
  variability in CMIP3 models)

• Hybrid hurricane forecast system exhibits skill from November of previous
  year

• Projected radiative forcing not big source of predictability in freq.

• Internal variability dominant source of uncertainty even in 100-year trends.

• In CM2.1 decadal hurricane frequency variability associated with tropical
  Atlantic oceanic changes.

• If sensitivity in high-res GCM correct, may need to predict decadal SST
  better than we have known it.

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Hurricane-Relevant Large-Scale Conditions Co-vary Constructively With Relative-SST
Build statistical model of basin-wide tropical storms using Atlantic and Tropical-mean SST as covariates

Atlantic SST increases frequency.

Tropical-mean SST reduces frequency.

Factors in fit (w/standard error)

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<th>Uncorrected</th>
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<td>1.05 (0.15)</td>
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<td>( \text{SST}_{\text{Trop}} )</td>
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<td>-0.91 (0.20)</td>
<td>-1.05 (0.19)</td>
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Villarini et al. (2010, MWR)