EXPERIMENTAL S-I
HURRICANE FORECASTS FROM WINTER

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SEASONAL HURRICANE FORECASTS INITIALIZED
IN BOREAL MID-SPRING TO EARLY-SUMMER ARE:
FEASIBLE, POTENTIALLY SKILLFUL AND MADE

• Statistical prediction schemes
  (e.g., Gray, Klotzbach and Gray, Elsner et al)

• Dynamical prediction schemes
  (e.g., Vitart, Vitart et al)

• Hybrid schemes (e.g., Wang et al, LaRow et al, Zhao et al)
GOAL:

Use understanding and tools developed for exploring the link of climate change and hurricanes to push window of North Atlantic seasonal hurricane forecasts to winter, with skill and quantified uncertainty.
GFDL C-X HIRAM GCMS

Family of global atmospheric models designed for better-representing tropical cyclone frequency. **C90 - 1°, C180=1/2°, C360=1/4°, C720=1/8°, C2000=5km**


**Adapted from AM2 with:**

- Deep convection scheme adapted from Bretherton, McCaa and Grenier (MWR, 2004)
- Cubed sphere dynamical core
- Changes to parameterizations of cloud microphysics
- C90 Atm. resolution of 1°x1°

**North Atlantic Tropical Storms***

*lasting 2 days or more*

![Graph showing North Atlantic Tropical Storms](image-url)

*r=0.77*
Figure 1. (a) North Atlantic July to December hurricane counts for each year for the period of 1982-2008. Red: IBTrACS observations, blue: 5-member ensemble mean from the FCST experiments; shaded area shows the maximum and minimum number for each year from the 5-member integrations. (b) For the AMIP experiment with 4-member ensemble.

Model time series are normalized as described in text.

Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)
With Persisted June SST Anomalies (retrospective July fcst.), HiRAM C180 AGCM Recovers NA Hurricane Counts

Can we extend lead by forecasting SST?
Zhao et al. (2010, MWR, Sub.)
Cost of Running Thousands of Retrospective Forecasts with HiRAM-C180 is Prohibitive.

Need to Build a Statistical Emulator of the AGCM.

So: What is a good predictor of Hurricane Frequency? Catch: It should be predictable itself.

HiRAM-C180 (and other Hi-Res GCMs), Sensitivity of Large-Scale conditions, Analyses of Long-term Observations suggest two predictors:

Atlantic SST and Global-Tropical SST
Figure 1. 
(a) North Atlantic July to December hurricane counts for each year for the period of 1982-2008. Red: IBTrACS observations, blue: 5-member ensemble mean from the FCST experiments; shaded area shows the maximum and minimum number for each year from the 5-member integration. 
(b) As for (a) but for the AMIP experiment with 4-member ensemble.

Model time series are normalized as described in text.

Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.)
HiRAM C180 (and observations + controls to large-scale) suggest **Relative SSTA** as a Predictor

Relative SSTA = Atlantic SSTA minus Tropical SSTA

Zhao et al. (2009, J. Climate), Zhao et al. (2010, MWR, Sub.) &
SEASONAL HURRICANE FREQUENCY FORECAST SCHEME

• Build a statistical emulator of HiRAM-C180, two predictors:
  • $\text{SST}_{\text{MDR}}$ (SST anomaly $80^\circ W$-$20^\circ W$, $10^\circ N$-$25^\circ N$)
  • $\text{SST}_{\text{TROP}}$ (SST anomaly $30^\circ S$-$30^\circ N$)

• Use S-I forecast models to predict two indices

• Convolve PDF of SST forecasts with PDF from statistical model.
**Build a Statistical Emulator of C180-HiRAM Using ASO Atlantic MDR and Tropical-Mean SSTA (Poisson)**

### Training of Hurricane Frequency Statistical Model Fit on HiRAM C180 Experiment Years

- **Formula:**
  \[
  p(C=k | \lambda) = \frac{\lambda^k \cdot e^{-\lambda}}{k!}
  \]
  \[
  \lambda = e^{(a + b \cdot \text{SSTmdr} + c \cdot \text{SSTtrop})}
  \]

- **Coefficients:**
  \[
  a = 1.707 \quad b = 1.388 \quad c = -1.521
  \]

Vecchi et al. (2010, MWR submitted)

see Villarini et al. (2010, MWR in press) for methodology

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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)
SST INDEX RELEVANT TO HURRICANES COMPLEX, MORE THAN ENSO AND ATLANTIC SST

$SST_{MDR}$ and $SST_{TROP}$ share a recent trend, but amplitude differs. $SST_{TROP}$ more than ENSO, trend, warm mid-2000’s, etc.
EXPLORE TWO SYSTEMS TO FORECAST THE SST INDICES

- GFDL-CM2.1 Experimental Forecast System:
  - 12-month retrospective and forward forecasts
  - Basis of GFDL’s efforts to understand decadal predictability

- NCEP-CFS Operational S-I Forecast System:
  - GFS atmosphere and MOM3 ocean, initialized to NCEP (atm/land) and GODAS (ocn) - Saha et al (2006)
  - Nine-month retrospective and actual forecasts
  - Used operationally at NCEP
Apply Statistical Hurricane Frequency Model to CM2.1
Retrospective Forecasts of January SST

\[ p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid \text{relSSTA}=x) \cdot p(\text{relSSTA} = x) \, dx \]

\[ p(\text{relSSTA}=x) \text{ from CM2.1 ensemble} \]

Vecchi et al. (2010, MWR submitted)
HYBRID (STATISTICAL-DYNAMICAL) FORECAST SYSTEM EXHIBITS POTENTIAL FOR MULTI-SEASON LEAD FORECASTS

Vecchi et al. (2010, MWR submitted)
HURRICANE FORECASTS INITIALIZED MARCH 2010

SYSTEM ANTICIPATES ACTIVE 2010

Experimental forecasts suggests 2010 season likely to be above average in hurricane frequency.

Vecchi et al (2010, MWR submitted)
Experimental forecasts for 2010 season
large increase in probability of an extremely active year

Vecchi et al (2010, MWR submitted)
SUMMARY

• Used understanding built assessing AGW/hurricane connection to build S-I hurricane frequency forecast system

• SST contains a great deal of the information about seasonal Atlantic hurricane activity:
  • Two indices ($SST_{MDR}$ and $SST_{TROP}$) in ASO contain most

• Existing S-I forecast systems can predict these SST indices with skill from as early as November of the previous year, consistently predicting active 2010 since Nov. 2009.

• “Perfect” retrospective skill from CFS on short leads

• Room for improvement long-range (>6 month) hurricane outlooks from improved SST forecasts.

• How far back can we push it? Was 1982-2009 exceptionally predictable? Can we predict other quantities (efforts at Cat3-5, Cat4-5 and landfall)
BINKY SLIDES
Apply Statistical Hurricane Frequency Model to CM2.1 and CFS Retrospective Forecasts of March SST

In this diagram, we have:

- **Monthly forecasts**
  - March Forecast:
    - CM2.1: $r=0.49$, $rmse=2.63$
    - CFS: $r=0.49$, $rmse=2.69$
    - MME: $r=0.55$, $rmse=2.57$

- **30-member lagged ensemble forecasts**
  - March Forecast:
    - CM2.1: $r=0.58$, $rmse=2.44$
    - CFS: $r=0.50$, $rmse=2.63$
    - MME: $r=0.58$, $rmse=2.48$

The equations are:

$$p(C=k) = \int_{-\infty}^{\infty} p(C=k \mid relSSTA=x) \cdot p(relSSTA=x) \, dx$$

$$p(relSSTA=x) \text{ from CM2.1 and CFS ensemble}$$

Vecchi et al. (2010, MWR submitted)
<table>
<thead>
<tr>
<th></th>
<th>Mean Count (hurr)</th>
<th>Median (hurricanes)</th>
<th>p(count&gt;6)</th>
<th>p(count&gt;10)</th>
<th>p(count≤3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed 1982-2009</td>
<td>6.21</td>
<td>5</td>
<td>0.46</td>
<td>0.07</td>
<td>0.21</td>
</tr>
<tr>
<td>GFDL-CM2.1 Simple Ens.</td>
<td>9.88</td>
<td>9</td>
<td>0.80</td>
<td>0.39</td>
<td>0.03</td>
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<tr>
<td>GFDL-CM2.1 Lagged Ens.</td>
<td>8.27</td>
<td>8</td>
<td>0.64</td>
<td>0.24</td>
<td>0.09</td>
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<tr>
<td>NCEP-CFS Simple Ens.</td>
<td>7.64</td>
<td>7</td>
<td>0.61</td>
<td>0.19</td>
<td>0.04</td>
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<tr>
<td>NCEP-CFS Lagged Ens.</td>
<td>8.24</td>
<td>8</td>
<td>0.65</td>
<td>0.25</td>
<td>0.03</td>
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<tr>
<td>Two-model Simple Ens.</td>
<td>8.54</td>
<td>8</td>
<td>0.68</td>
<td>0.27</td>
<td>0.07</td>
</tr>
<tr>
<td>Two-model Lagged Ens.</td>
<td>8.23</td>
<td>8</td>
<td>0.75</td>
<td>0.25</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Vecchi et al (2010, MWR submitted)
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)

<table>
<thead>
<tr>
<th></th>
<th>Uncorrected</th>
<th>Corrected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.03 (0.03)</td>
<td>2.11 (0.03)</td>
</tr>
<tr>
<td></td>
<td>2.03 (0.03)</td>
<td>2.10 (0.03)</td>
</tr>
<tr>
<td>$SST_{\text{Atl}}$</td>
<td>1.13 (0.20)</td>
<td>1.05 (0.15)</td>
</tr>
<tr>
<td></td>
<td>1.05 (0.15)</td>
<td>1.02 (0.14)</td>
</tr>
<tr>
<td>$SST_{\text{Trop}}$</td>
<td>-0.98 (0.23)</td>
<td>-1.22 (0.22)</td>
</tr>
<tr>
<td></td>
<td>-0.91 (0.20)</td>
<td>-1.05 (0.19)</td>
</tr>
</tbody>
</table>

Villarini, Vecchi and Smith (2010, MWR, in press)
Observed Activity

Absolute MDR SST

If causal, can attribute to GHG.

see also Emanuel (2005)

Relative MDR SST

If causal, cannot attribute.

see also Swanson (2008)

Vecchi, Swanson and Soden (2008, Science)
Atlantic Tropical Cyclone Power Dissipation Index Anomalies: Observed and Based on Sea Surface Temperature

Observed Activity
Absolute SST
Model Abs. SST

High-resolution model activity change
Emanuel et al (08), Knutson et al (08), Oouchi et al (06), Bengtsson et al (07)

Relative SST
Model Rel. SST

Vecchi, Swanson and Soden (2008, Science)
Processes controlling Tropical Atlantic Variability are seasonally dependent

Doi et al. (2010, J. Climate)
HURRICANE-RELEVANT LARGE-SCALE CONDITIONS CO-VARY CONSTRUCTIVELY WITH RELATIVE-SST

Interannual Correlation of Large-Scale Conditions to Relative-SST (Aug-Oct - CM2.1 1860 Control)

- SLP
- Shear
- PI
- 700hPa RH
- 850hPa vort.
- Precip

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