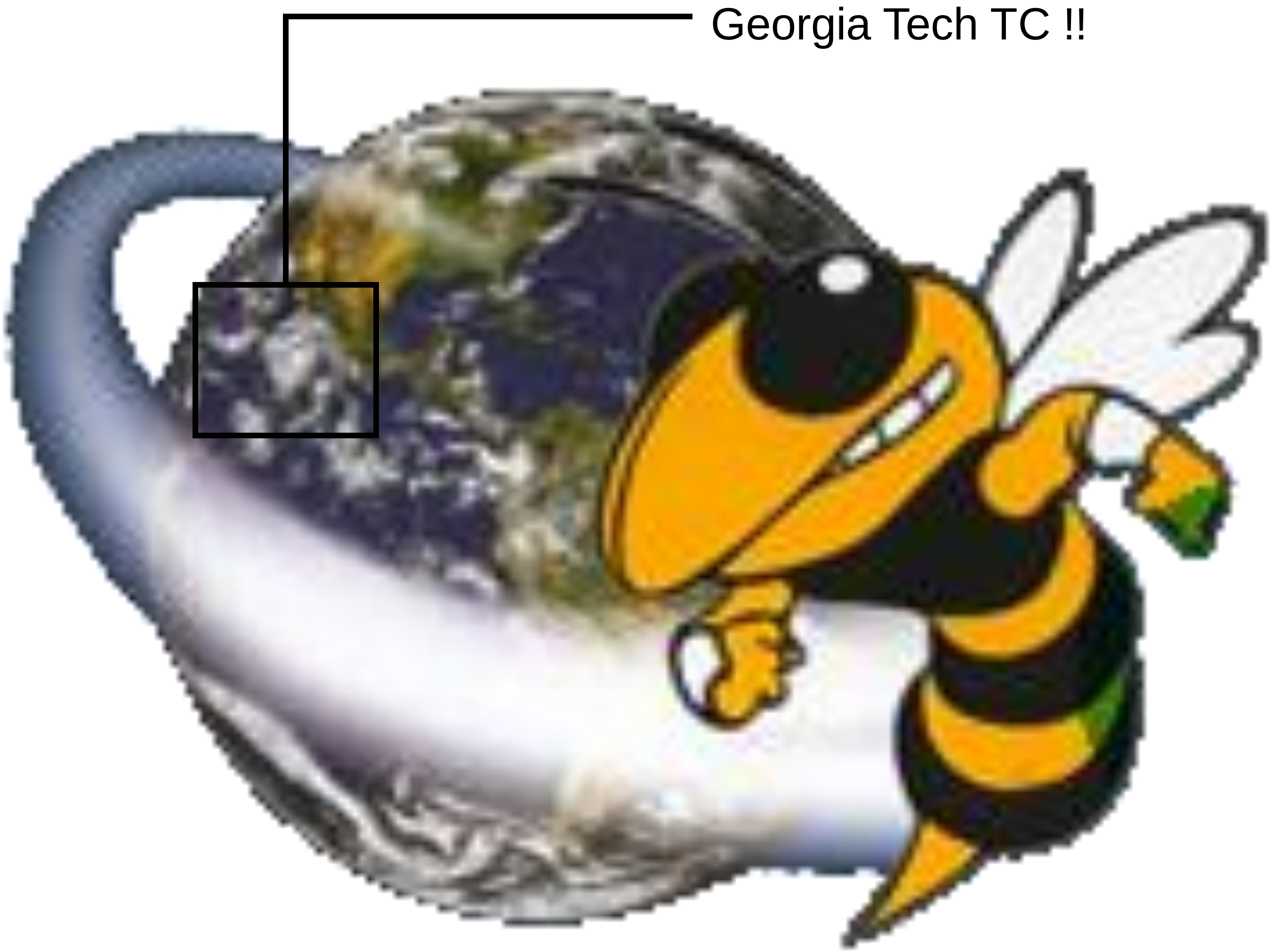
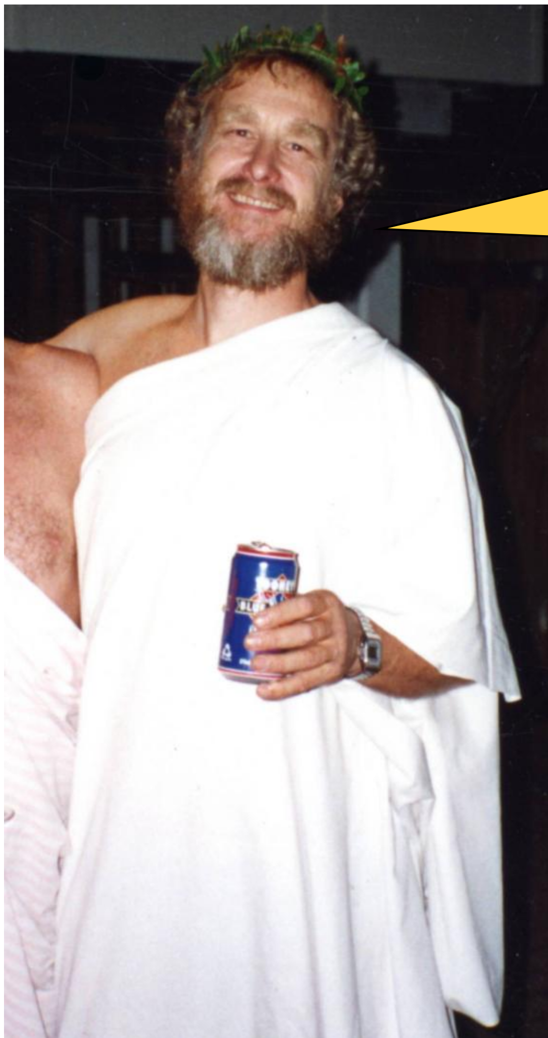
Intraseasonal Predictions of Tropical Cyclone Activity in the North Atlantic

Peter Webster, James I. Belanger, Hyemi KIm
Judith A. Curry, Carlos D. Hoyos, & Paula A. Agudelo

School of Earth & Atmospheric Sciences
Georgia Institute of Technology


Georgia Tech TC !!



Webster, have you thought about tropical cyclones as something to do in your golden years …… ?

My mother's advice:

" Beware of Greeks bearing beer!"

TROPICAL CYCLONE RESEARCH AT GEORGIA TECH

The Webster-Curry tropical cyclone group at Georgia Tech has concentrated on basic physics of hurricane genesis and extended prediction. Some recent publications related **to climate and tropical cyclones**:

Webster, P. J., G. J. Holland, J. A. Curry and H-R. Chang, 2005***: ŅChanges in tropical cyclone number, duration and intensity in a warming environment.Ó*** *Science*, 309 (5742), 1844-1846 (September 16).

and etc………….

Toma, V., P. J. Webster, 2009: ***Oscillations of the intertropical convergence zone and the gensis of easterly waves. I Theory and diagnostics.*** *Clim. Dyn.* doi: 10.1007/s00382-009-0584-

Toma, V., P. J. Webster, 2009: ***Oscillations of the intertropical convergence zone and the genesis of eeasterly waves. II Numerical experiments.*** *Clim. Dyn.* doi: 10.1007/s00382-009-0585-9

Kim, H-M., P. J. Webster and J. A. Curry, 2009: ***Impact of shifting patterns of Pacific Ocean warming on the frequency and tracks of North Atlantic tropical cyclones.*** *Science,* 325, 77-80

at htpp://webster.eas.gatech.edu/papers

and etc. …….

Done, J., G, J, Holland, and P. J. Webster, 2009: ***The Role of Wave Accumulation in Tropical Cyclone Genesis over the Tropical North Atlantic***. Under review, *Clim. Dyn.*

Belanger J.I., Curry J.A., Hoyos C.D. , 2009: ***Variability in tornado frequency associated with U. S. landfalling tropical cyclones.*** *Geophys. Res. Lettr*. 36, L17805

Holland, GJ, Fritz, A. Belanger, JI, 2010: ***A Revised Model for Radial Profiles of Hurricane Winds.*** Submitted to *Mon. Wea. Rev.*

Kim, H-M, Webster PJ, 2010: ***Changes in Pacific Ocean warming and Pacific tropical cyclones.*** To be submitted to *Geophys. Res. Lettr.*

at htpp://webster.eas.gatech.edu/papers

TROPICAL CYCLONE RESEARCH AT GEORGIA TECH (cont)

On prediction…………

Webster, P. J., 2008: ***Myanmar's deadly daffodil.*** *Nature Geoscience* doi: 10.1038/ngeo257

Belanger J.I., Webster P.J., 2010: ***Extended prediction of North Indian Ocean tropical cyclones.*** To be submitted to *Q. J. Roy. Met. Soc*..

Kim, H-M, Webster PJ, 2010: ***Numerical-statistical hybrid seasonal tropical cyclone forecasting in the North Atlantic Ocean.*** To be submitted to Geophys. Res. Lettr..

Agudelo, PA, Hoyos CD, Curry JA, Webster PJ, 2010: ***Probabilistic discrimination between large-scale environments of intensifying and decaying African Easterly Waves in the North Atlantic Ocean.*** In press *Clim. Dyn.*

Belanger, JI, Webster PJ, Curry JA, 2010: ***Probabilistic prediction of tropical cyclones on intraseasonal time scales.*** To be submitted to Geophys. Res. Lettr.

at htpp://webster.eas.gatech.edu/papers

TROPICAL CYCLONE RESEARCH AT GEORGIA TECH (cont)

On prediction…………

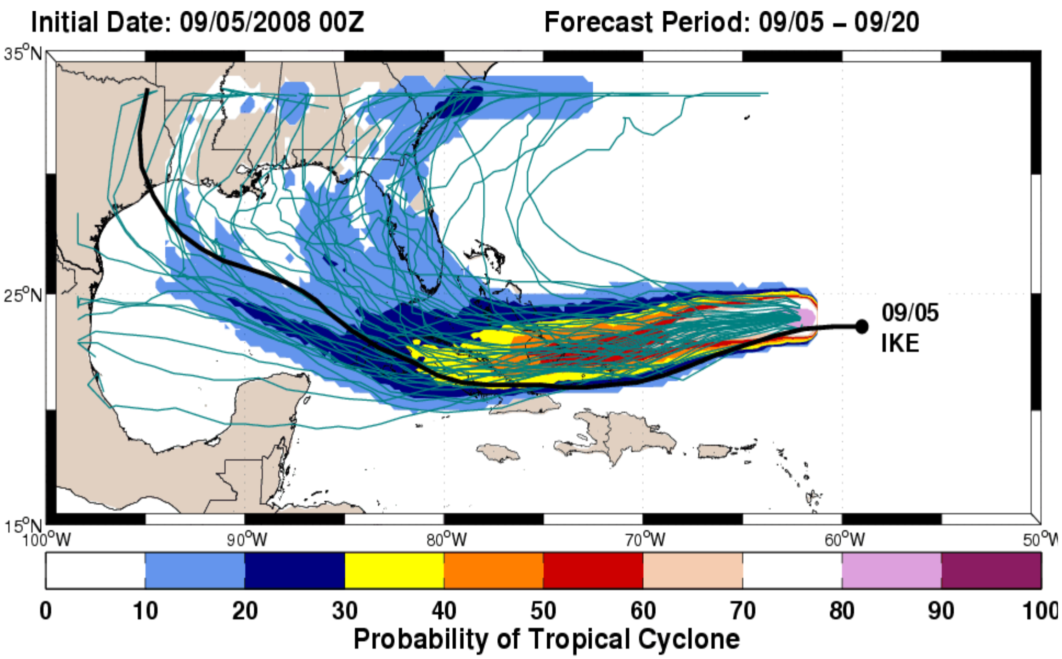
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

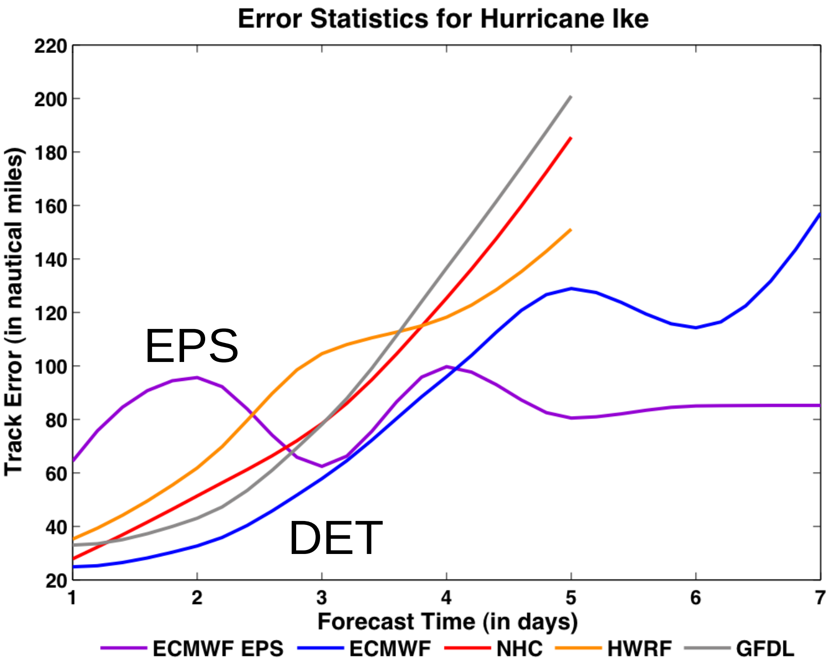
Belanger, JI, Webster PJ, Curry JA, 2010: ***Probabilistic prediction of tropical cyclones on intraseasonal time scales.*** To be submitted to Geophys. Res. Lettr.

“Shorter term”: 1-15 day North Atlantic Ocean Tropical Cyclones

- Using the ECMWF EPS:
- Forecasts daily 51 ensemble members
- Two examples: Ike and Gustav
- Question: is there skill at these extended horizons?
- Belanger et al. (2010)

Track Verification: HR Ike 2008 (7+ days)

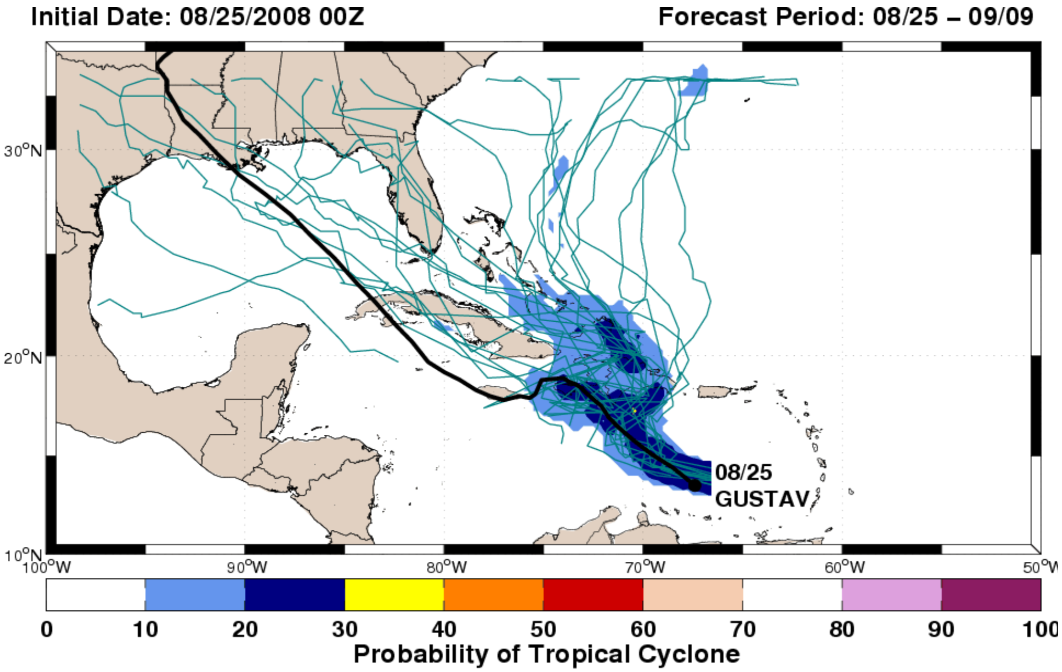


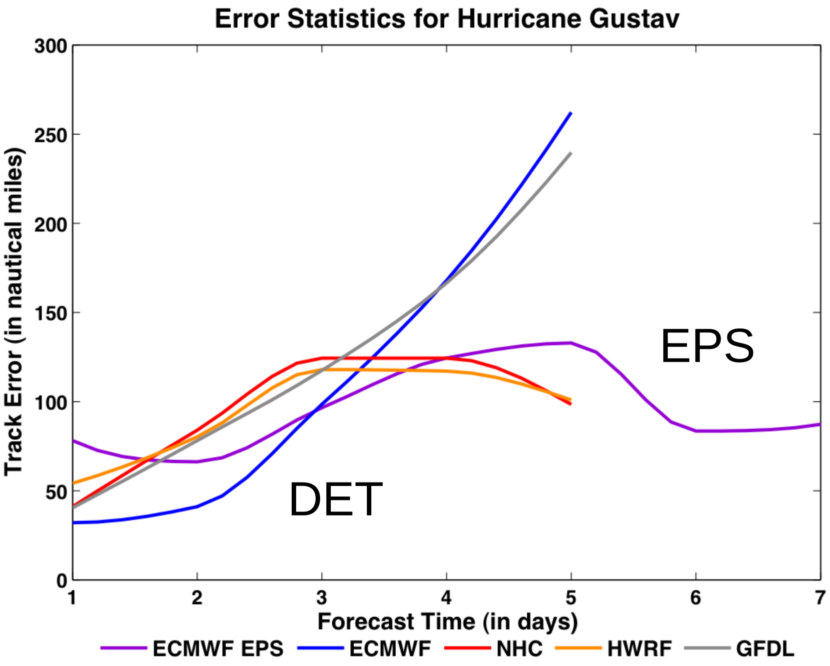


ECMWF provided superior track forecasts when compared to the HWRF/GFDL models and the National Hurricane Center

For Days 3+, maximizing the ECMWF ensemble spatial PDF produced the best long-range track forecast

Track Verification: HR Gustav 2008 (7+ days)





ECMWF deterministic provided best 1-3 day track forecasts

For Days 3+, ECMWF ensembles provided comparable performance to NHC and HWRF

Track errors through ensemble method grew less rapidly than using ECMWF deterministic alone

“Longer term”: 1-30 day North Atlantic Ocean Tropical Cyclones

- Using the ECMWF EPS:
- Forecasts daily 51 ensemble members once/week extended for 30 days in coupled O/A mode
- Two examples: Ike and Gustav
- Question: is there skill at these extended horizons?
- Belanger et al. (2010)

Introduction

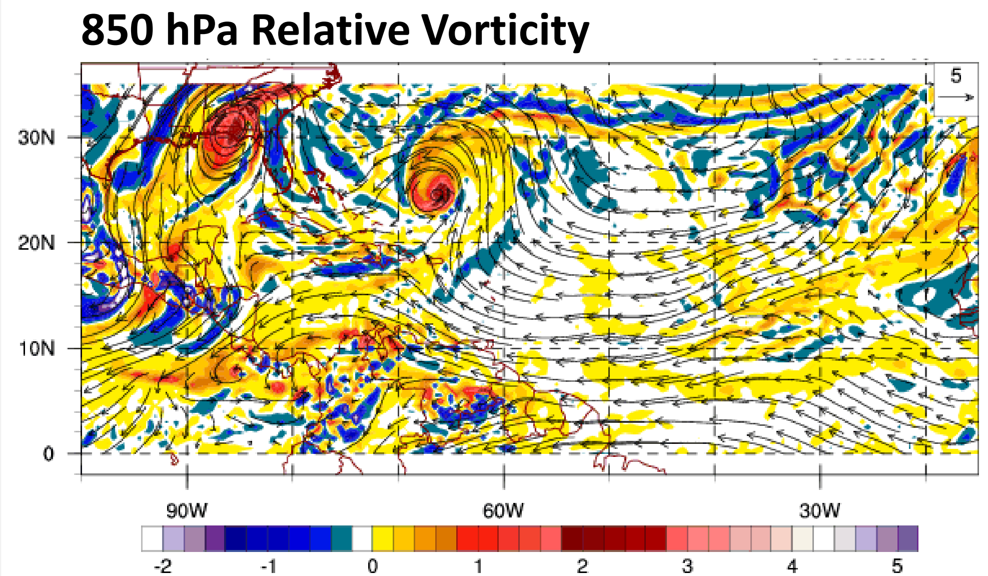
- Why Attempt Intraseasonal Forecasts?
  - Some atmospheric memory from initial conditions
  - Ocean circulation begins forcing atmospheric variability
  - Additional predictability source: Madden-Julian Oscillation

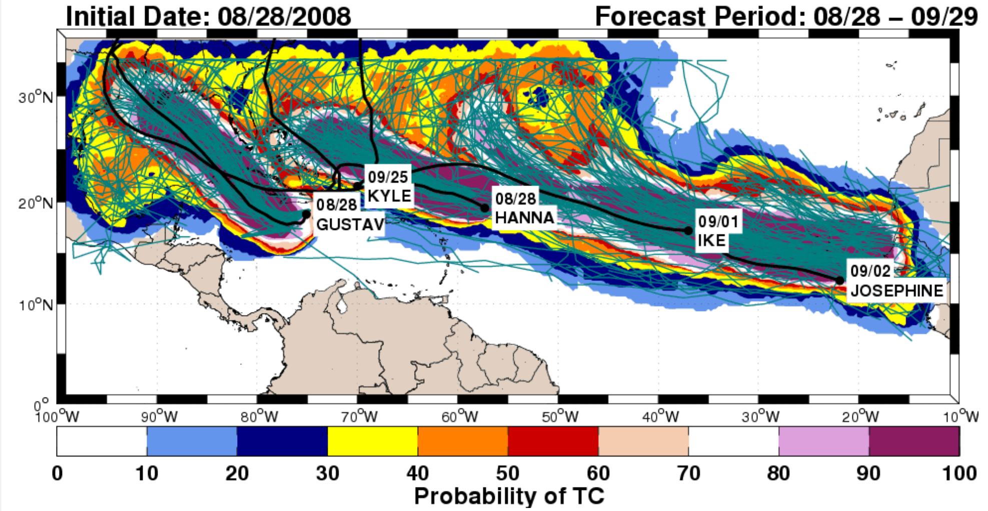
- Benefits of a Monthly Forecast System
  - Provide additional lead-time for disaster mitigation
  - Support adaptive policies for managing energy resources
  - Develop hedging strategies based on probabilistic forecasts

Methodology

- **ECMWF Monthly Forecast**
  - 51-member ensemble
  - Days 1-10: T399 (50 km)
  - Days 11-32: T255 (80 km)
  - Day 10+ HOPE Ocean Model

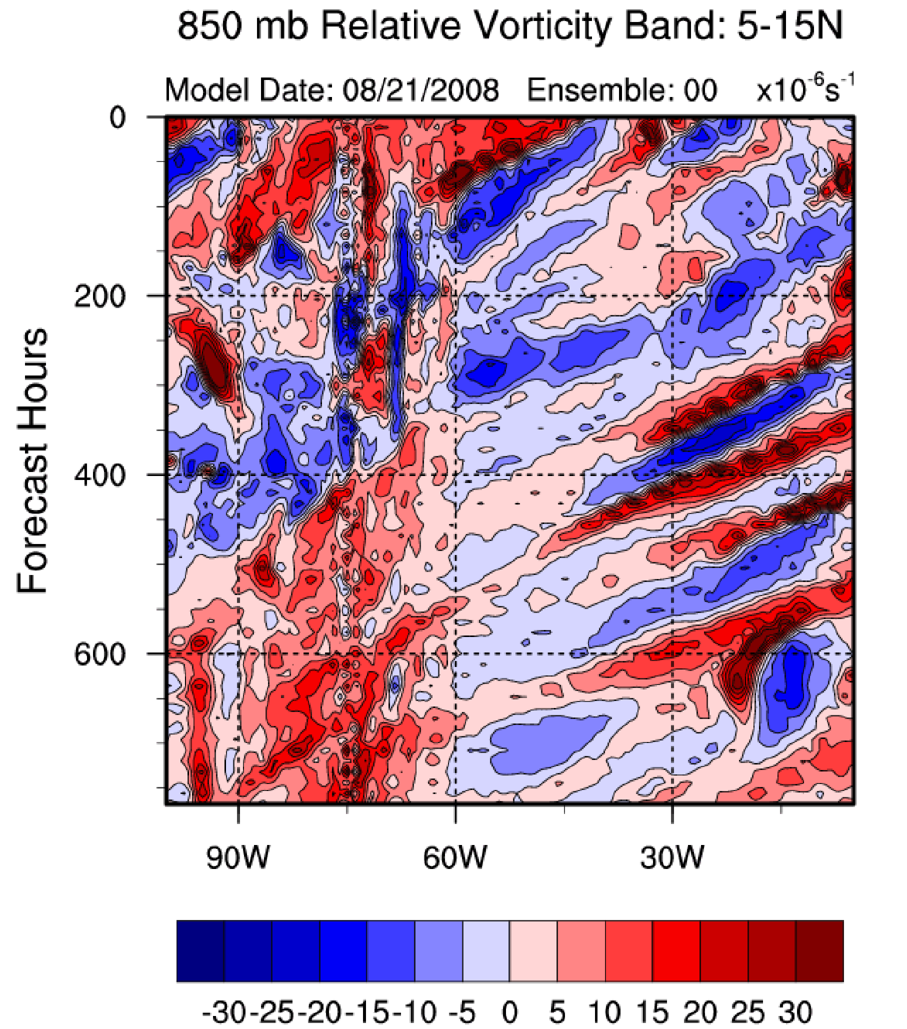
- **TC Tracking Scheme**
  - Modified from Vitart (1997)
  - Variables include:
    - 850 hPa Relative Vorticity
    - Mean Sea Level Pressure
    - 500 – 200 hPa Temperatures
    - 1000 – 200 hPa Thickness





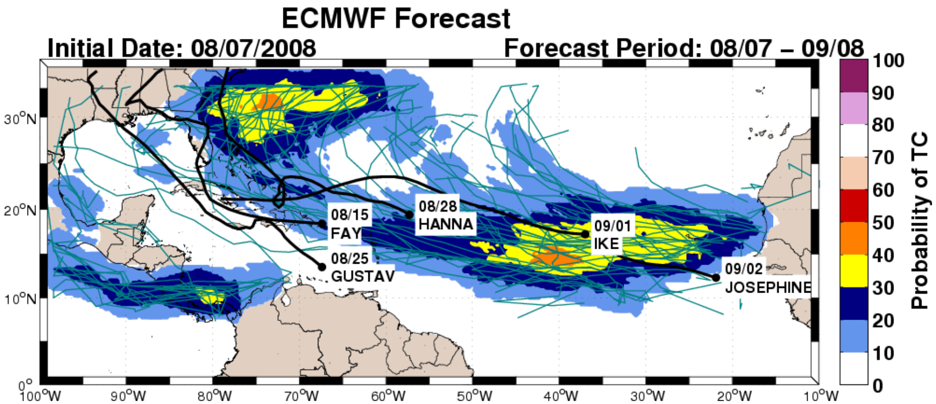
Methodology Cont'd

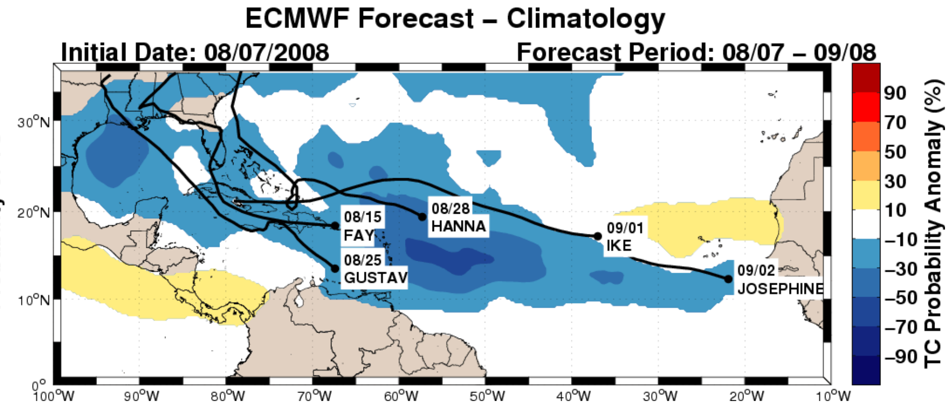
- **Easterly Wave Algorithm**
  - Based on Hovmöller method from Agudelo et al. (2010)
  - Fourier filtered 2-6 day positive westward vorticity anomalies
  - Recursive algorithm to identify grid points neighboring maximum anomalies
  - Linear fit of maximum vorticity anomalies using least absolute deviation



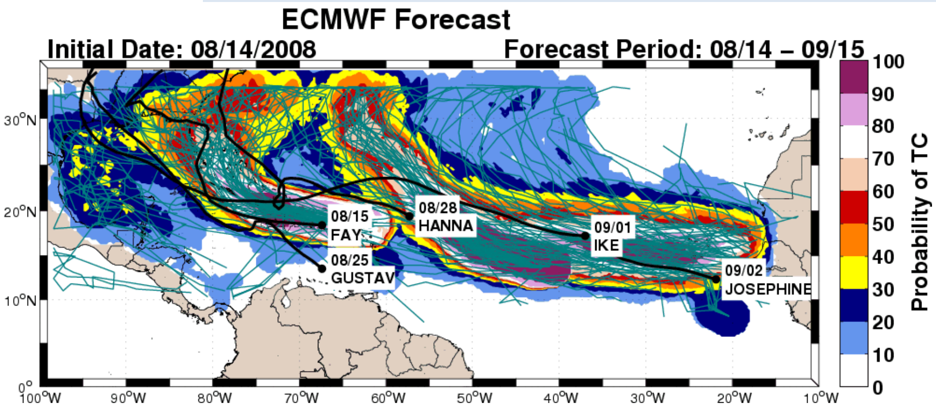
Example: ECMWF Monthly TC Forecasts

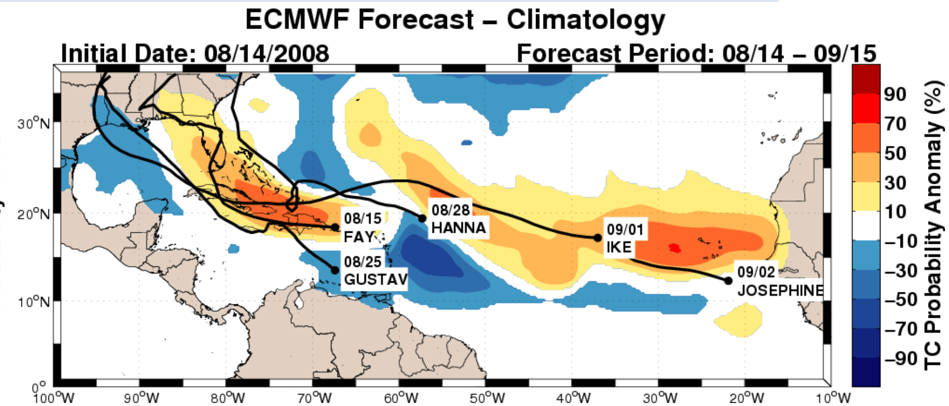
Weak Amplitude MJO @ Model Initialization



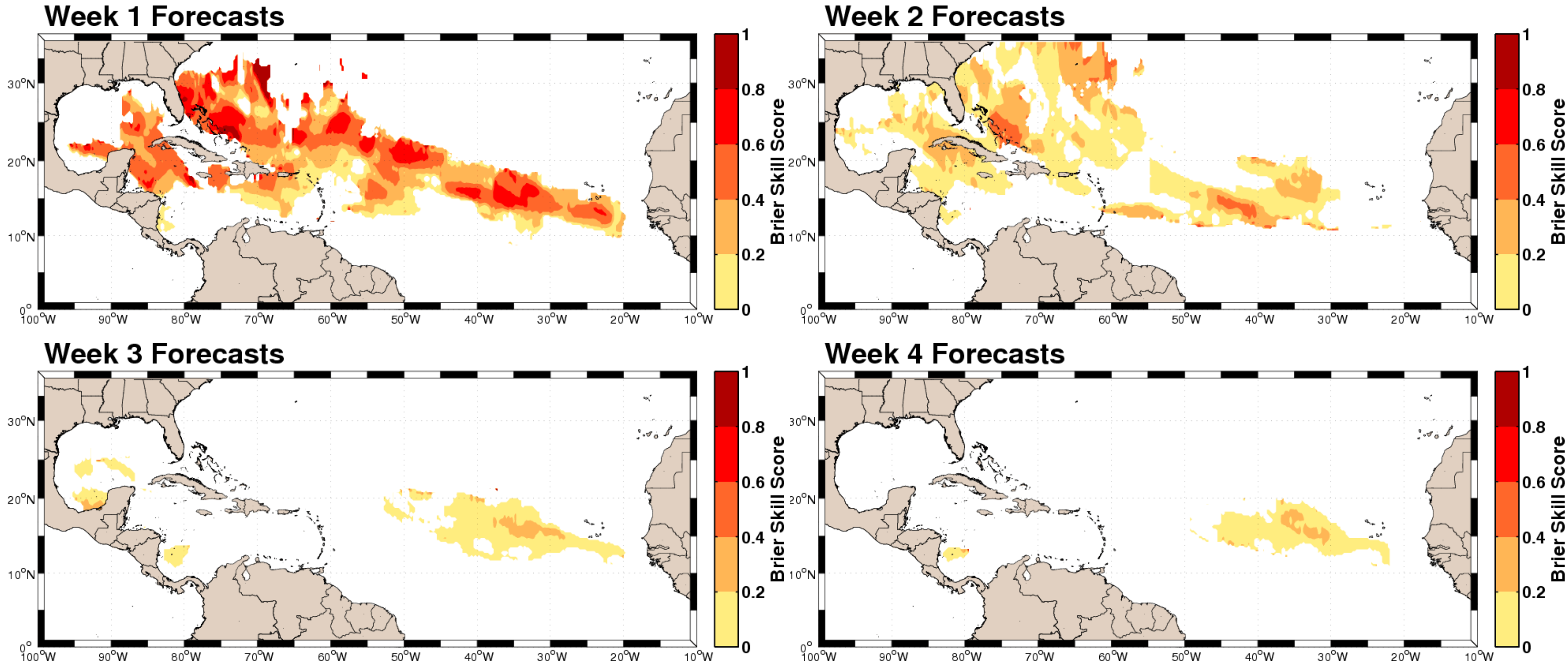


Strong Amplitude MJO @ Model Initialization





ECMWF Monthly TC Forecast Skill



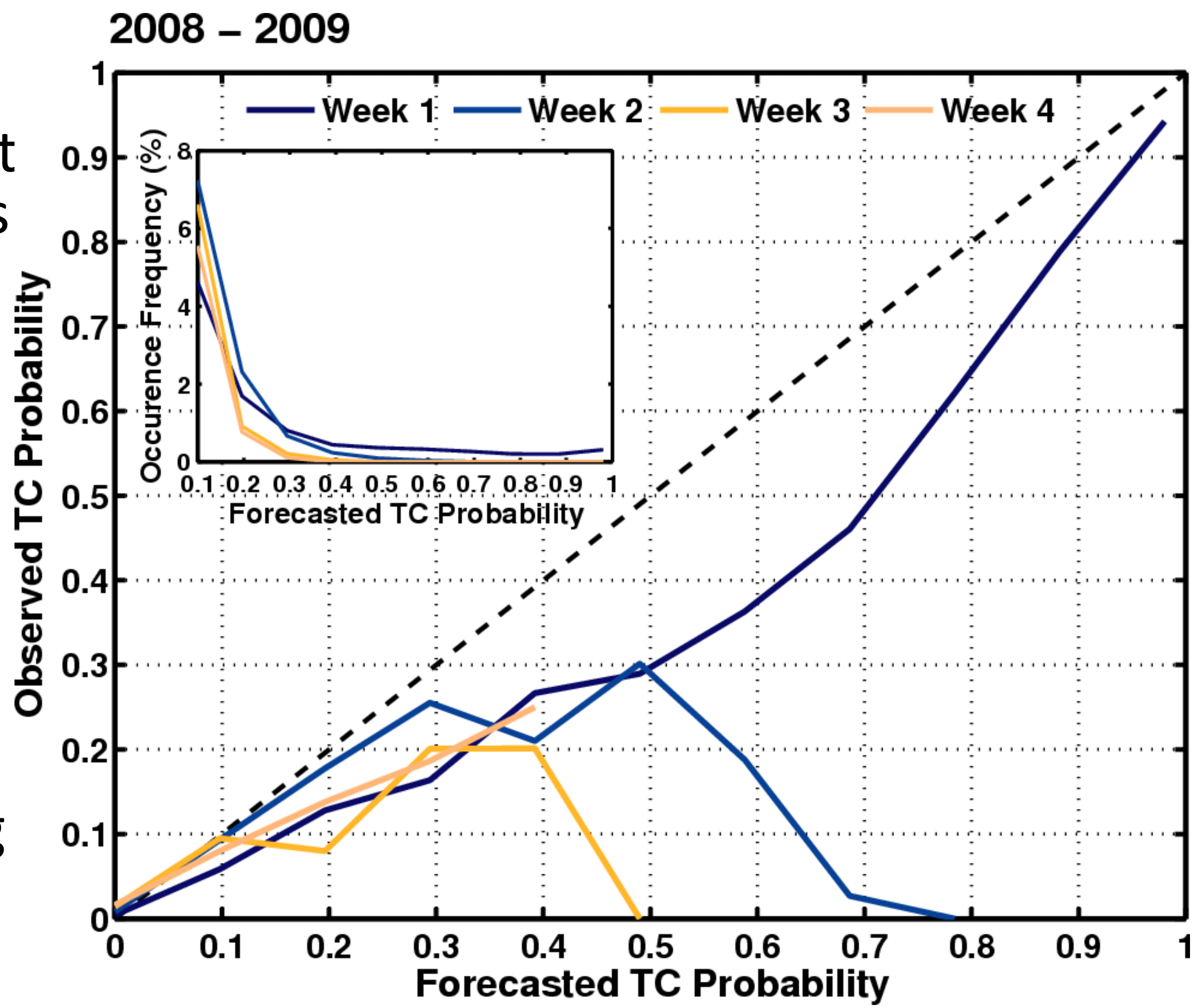
- Reference Forecast: Climatology (1970-2000)
- Regions with forecast skill include:
  - **Northern Caribbean** (Weeks 1-2)
  - **Western Subtropical Atlantic** (Weeks 1-2)
  - **Main Development Region** (Weeks 1-4)

$$Brier\ Score\ (BS) = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2$$

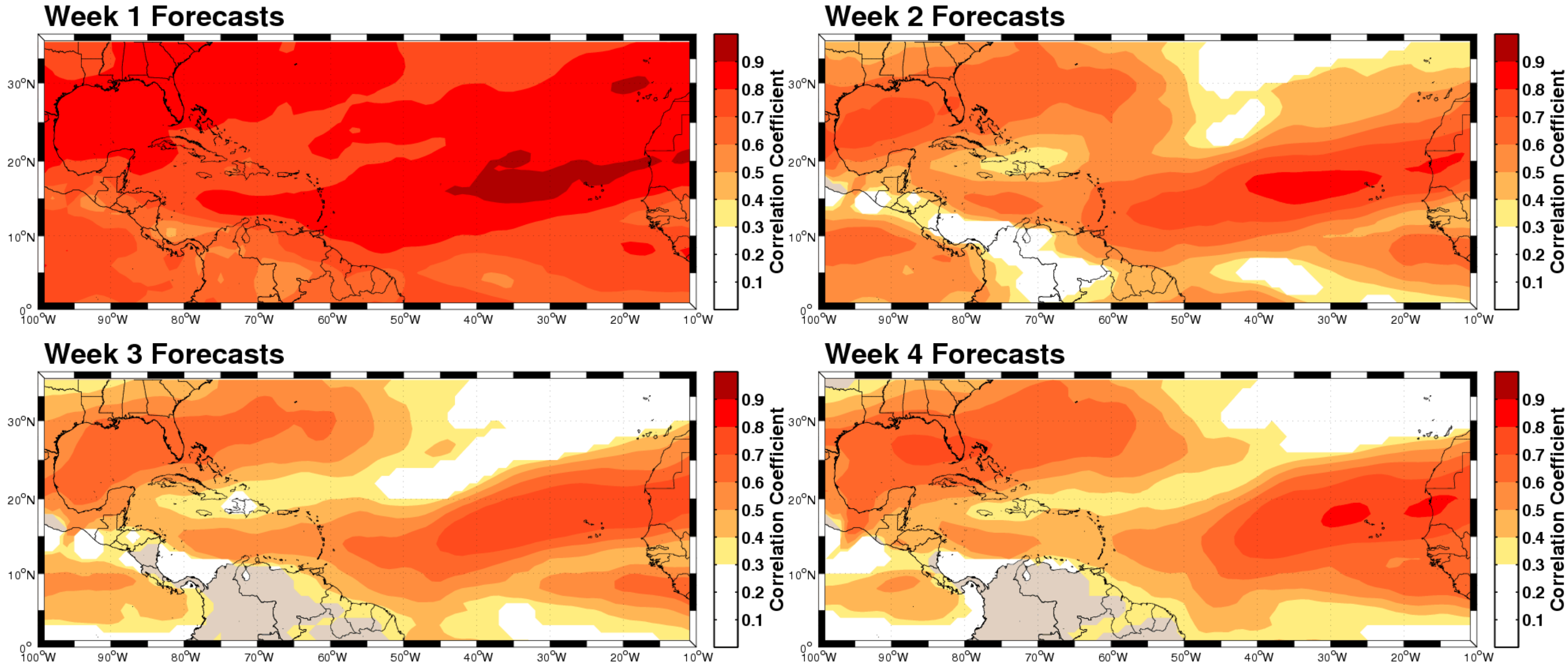
$$Brier\ Skill\ Score = 1 - \frac{BS}{BS_{ref}}$$

Reliability of Monthly Forecasts

- ECMWF forecasts are underdispersive for most TC probability categories
- Beyond Weeks 1 – 2, ECMWF peak TC probabilities verify 30% of the time
- For Weeks 3 – 4, insufficient number of forecast cases exceeding 30% probability level



Large-Scale Environment: Deep-Layer Vertical Wind Shear



- ECMWF Monthly is skillful at forecasting deep-layer vertical shear in the Gulf of Mexico and Main Development Region
- Weak correlation in Caribbean tied to variability in TUTT strength

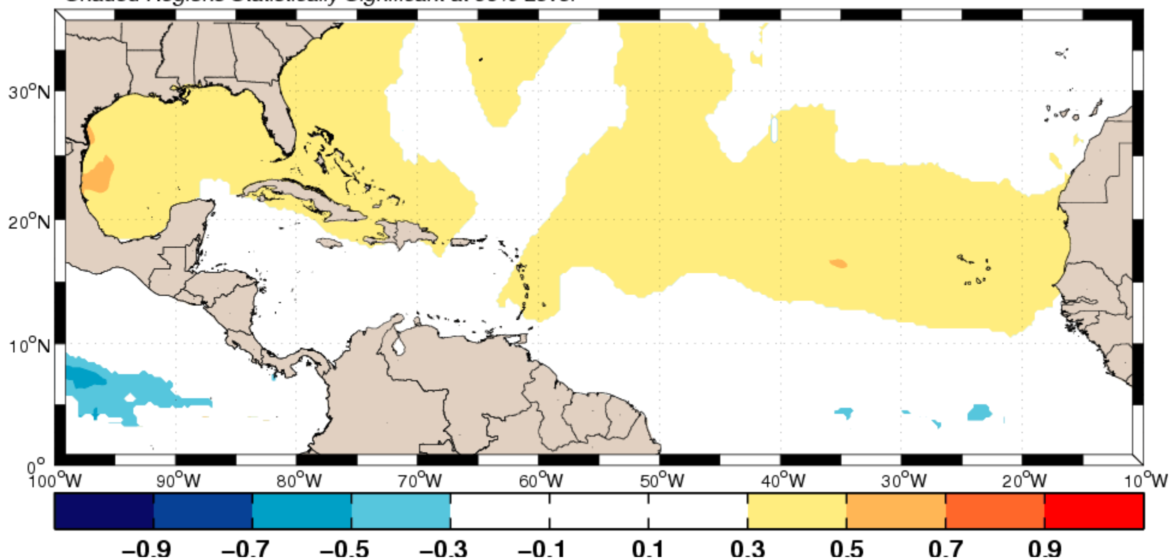
Large-Scale Environment: Variability in African Easterly Waves

- Frequency of easterly waves explains about 10-20% of the variance in ECMWF TC forecasts

- Spatial pattern of covariability coincides with regions of positive Brier skill scores

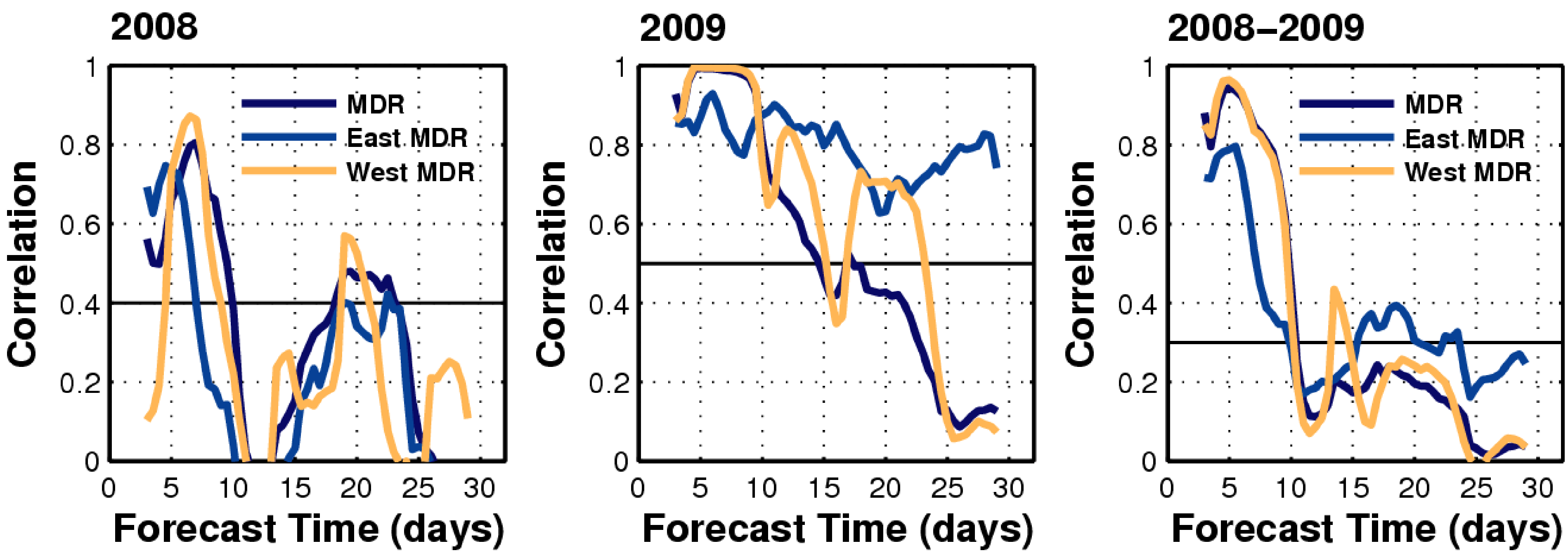
ECMWF TC Probability and AEW Frequency

Shaded Regions Statistically Significant at 95% Level



Production Region	Gulf of Mexico	Caribbean	Main Development Region
0.46	**0.57**	0.28	**0.40**

Large-Scale Environment: Variance in 850 hPa Relative Vorticity



- In general, predictability extends through 10 to 15 days with longer skillful forecasts in 2009 compared to 2008
- Greater variance captured in West MDR compared to East MDR within the first 10 days

Sensitivity to the Madden-Julian Oscillation

200 hPa Velocity Potential Anomalies

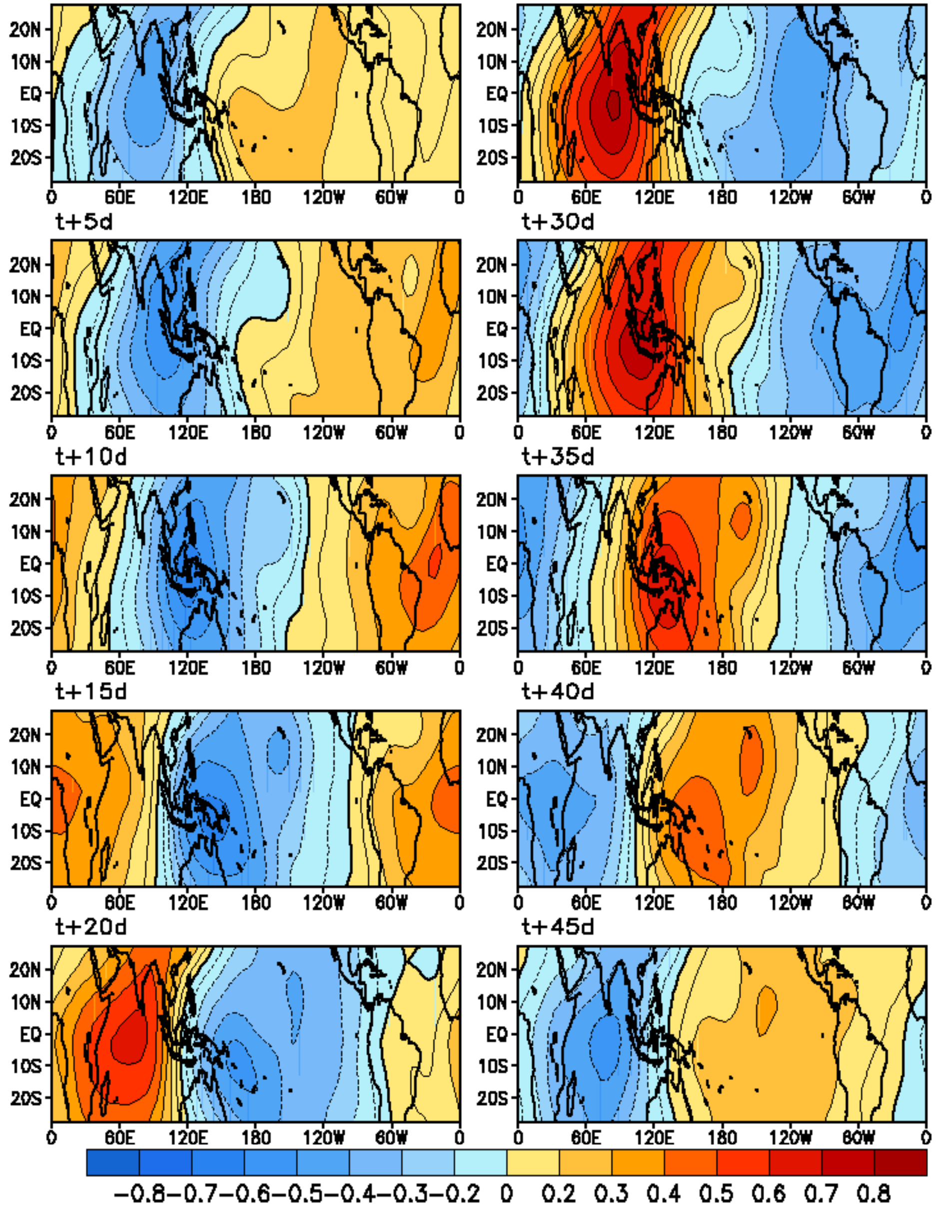
Index 1 (80°E)

Index 2 (100°E)

Index 3 (120°E)

Index 4 (140°E)

Index 5 (160°E)



Index 6 (120°W)

Index 7 (40°W)

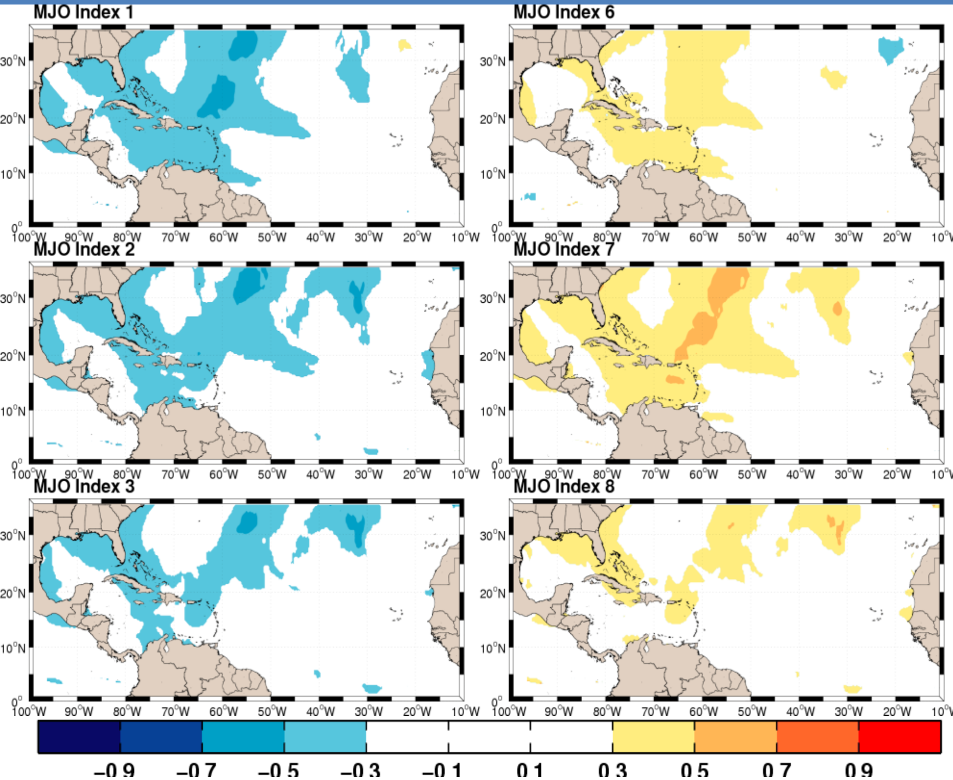
Index 8 (10°W)

Index 9 (20°E)

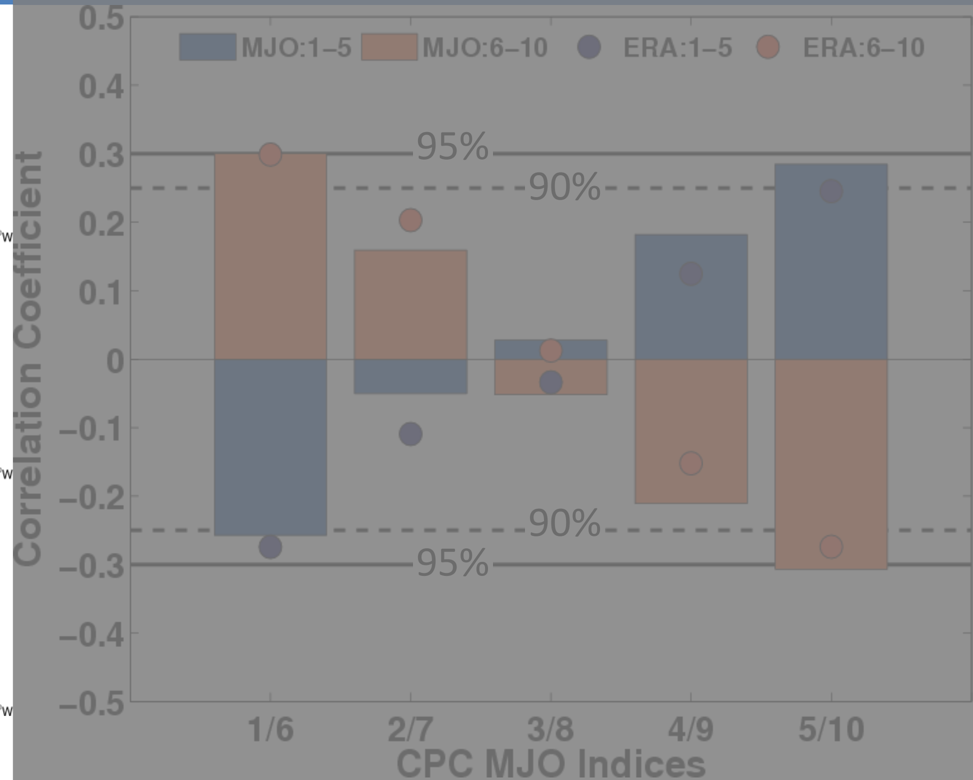
Index 10 (70°E)

Image from NCEP's CPC

TC Probabilities: Full 32 Days



Easterly Waves: Full 32 Days



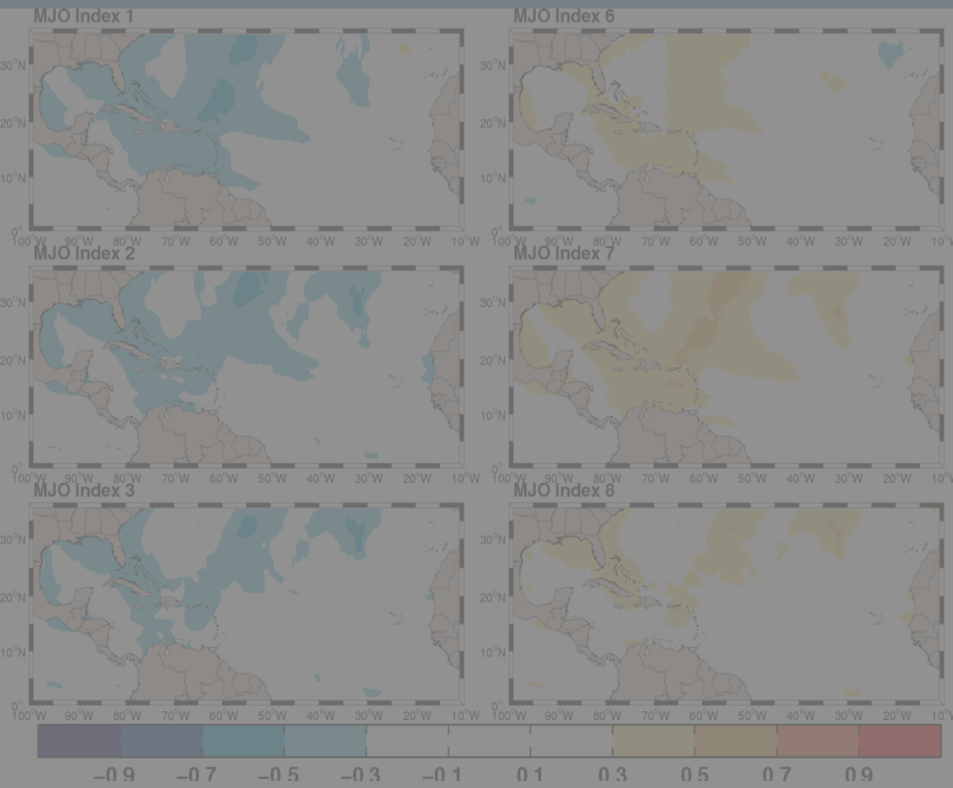
When active MJO *initially* centered in **Indian Ocean** (**Western Hemisphere**), TC activity **enhanced** (**suppresed**)

MJO phasing/intensity modulates 10-20% of TC probability forecasts for the Caribbean & Gulf of Mexico

Initial phase of the MJO projects weakly on forecasted frequency of easterly waves

Modeled relationship for MJO phasing agrees with observations from the ERA-Interim Reanalysis

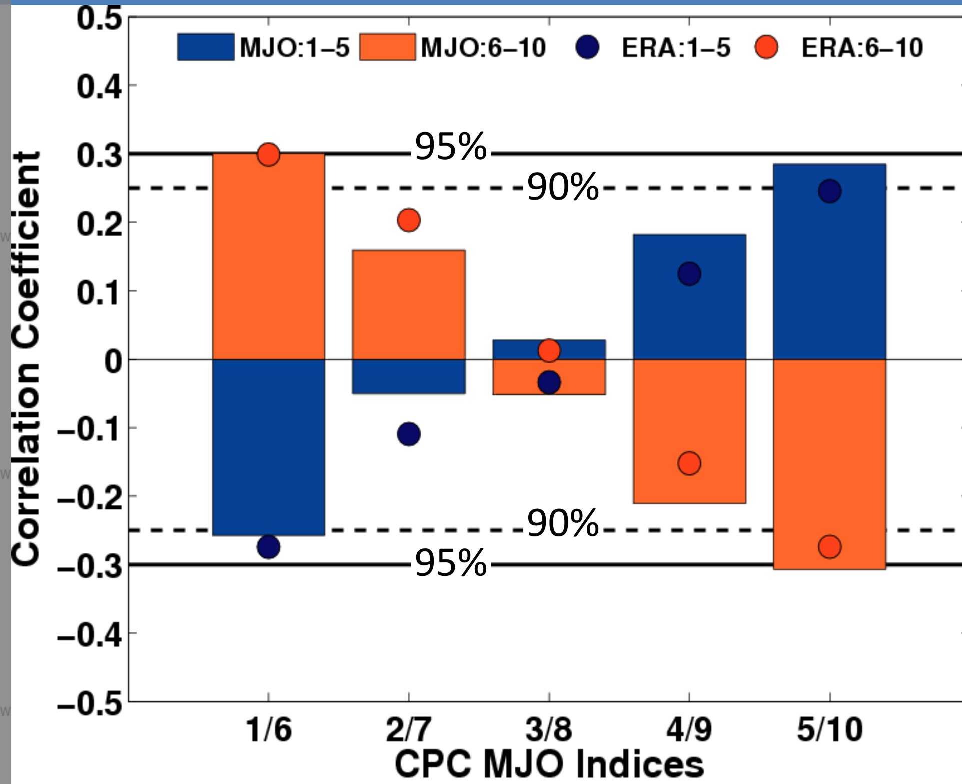
TC Probabilities: Full 32 Days



When active MJO *initially* centered in **Indian Ocean** (**Western Hemisphere**), TC activity **enhanced** (**suppresed**)

MJO phasing/intensity modulates 10-20% of TC probability forecasts for the Caribbean & Gulf of Mexico

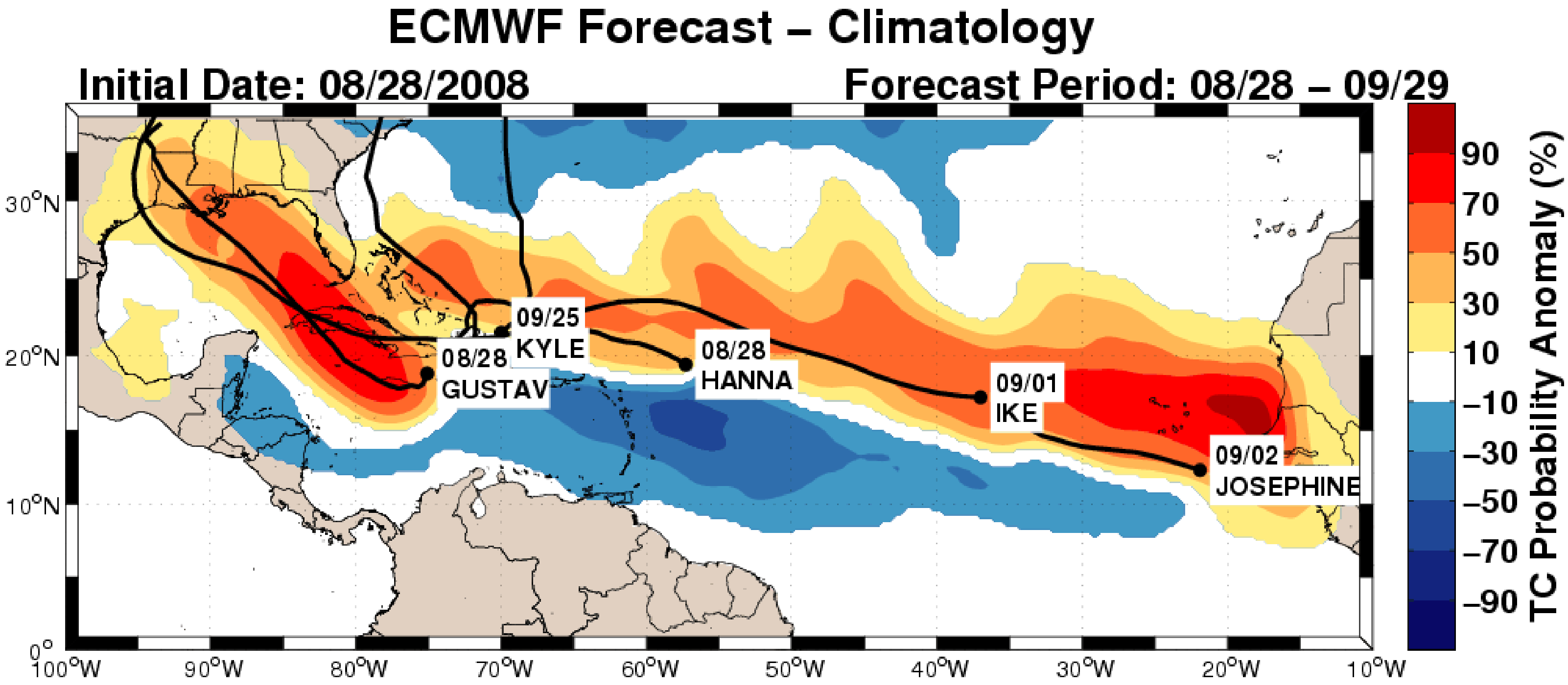
Easterly Waves: Full 32 Days



Initial phase of the MJO projects weakly on forecasted frequency of easterly waves

Modeled relationship for MJO phasing agrees with observations from the ERA-Interim Reanalysis

Summary



From a regional track perspective, ECMWF monthly forecasts shows remarkable ability to indicate the expected trajectory of TC tracks over a 30 days period

Await better model simulations of MJO

Example: Monthly forecast made on August 28, 2008

Summary

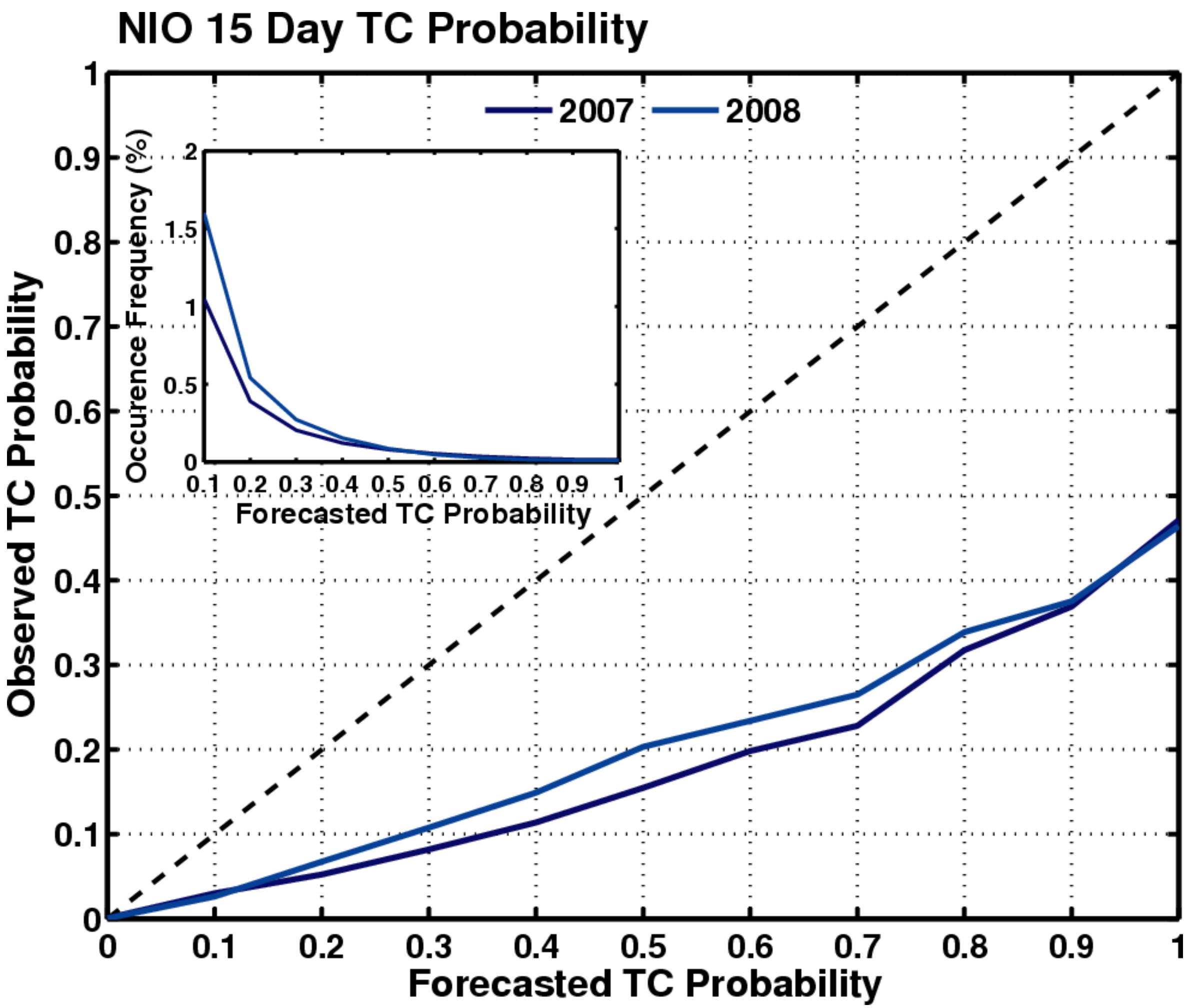
- Regions with Skillful TC Forecasts include:
  - Main Development Region: Full 32 Day Period
  - Northern Caribbean: Weeks 1 – 2
- Regional TC predictability tied to deep-layer wind shear forecasts and frequency of easterly waves
- Initial phase of MJO explains 10 – 20% variance in TC forecasts across western Subtropical Atlantic
  - Weaker impact on forecasted easterly wave frequency

North Indian Ocean Tropical Cyclones

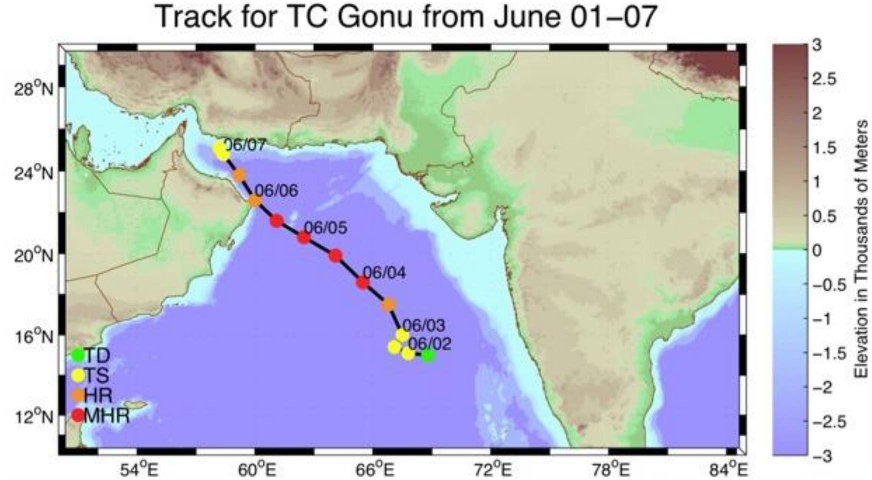
- We routinely run North Indian Ocean extended (1-15 day) as part of the Climate Forecast Applications in Bangladesh (CFAB) project.
- Extended prediction necessary in developing countries as evacuation is on foot (generally) often without roads. Local WMO authority (India) provides a deterministic 3 day forecast with no storm surge.
- Predicted genesis of Gonu, Sidr and Nargis at > 7 days (Nargis even longer).
- A number of false positives of weak TCs. Tuneable?
- Belanger and Webster (2010)

Reliability Diagram 15 Day Forecasts

- ECMWF 15 day probability forecasts are underdispersive at all forecast levels
- Limited reliability due to two problems:
  - Overly sensitive TC tracking scheme
    - Too many weak TCs
  - Probabilities crafted using total # of TC tracks instead of unique ensemble tracks



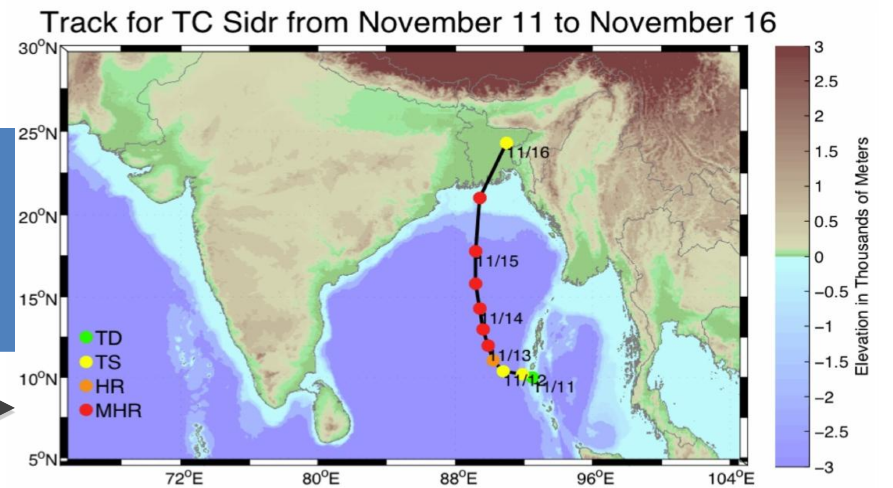
Observed Track and Intensity



First Tropical Storm Advisory: 6/2/07 00 UTC

Landfall: Eastern tip of Oman 6/6 00 UTC

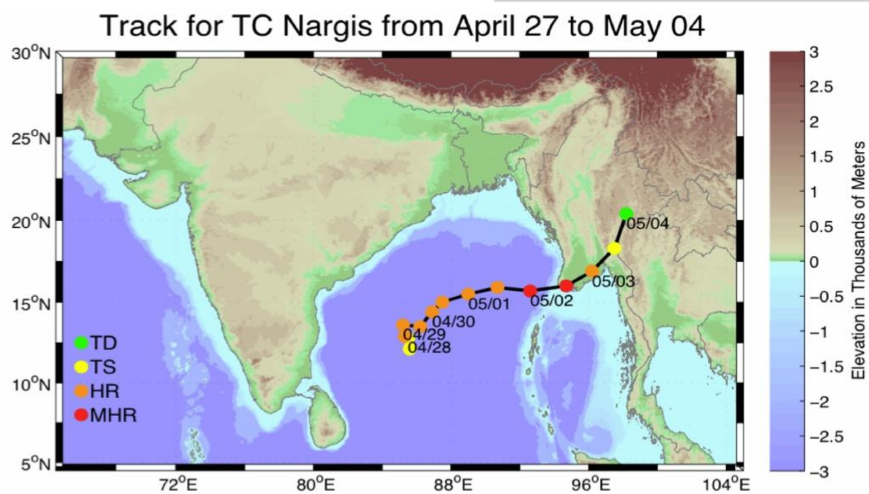
Maximum Intensity: 145 kts



First Tropical Storm Advisory: 11/11/07 06 UTC

Landfall: Patuakhali, Bangladesh 11/15 18 UTC

Maximum Intensity: 140 kts

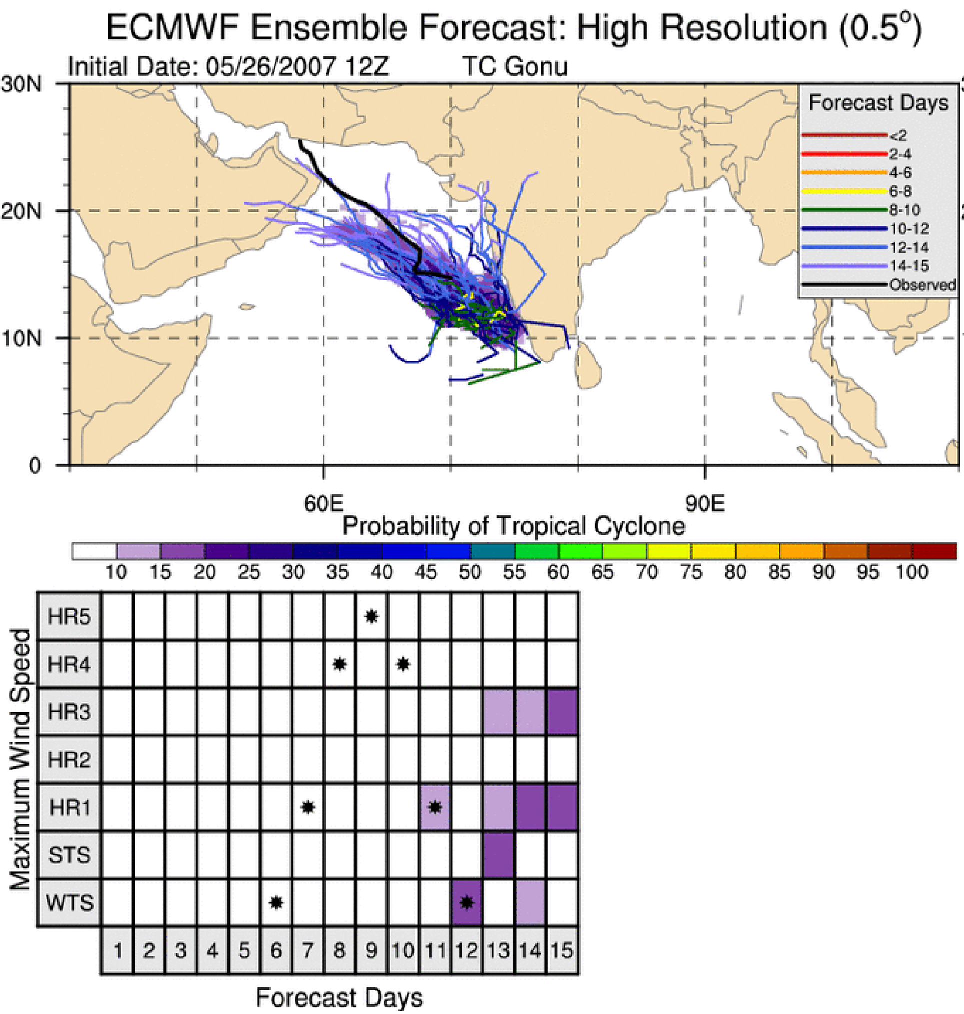


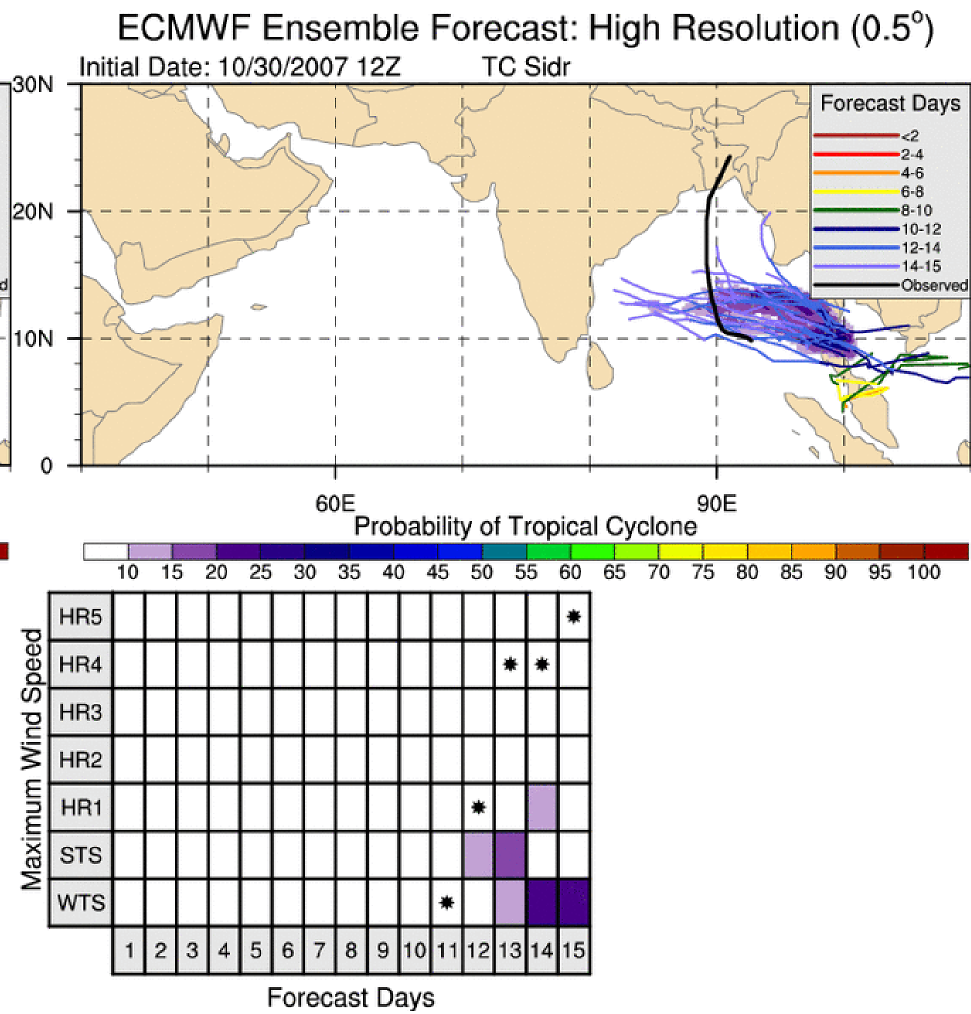
First Tropical Storm Advisory: 4/27/08 12 UTC

Landfall: Ayeyarwady Div. of Burma 5/2 12 UTC

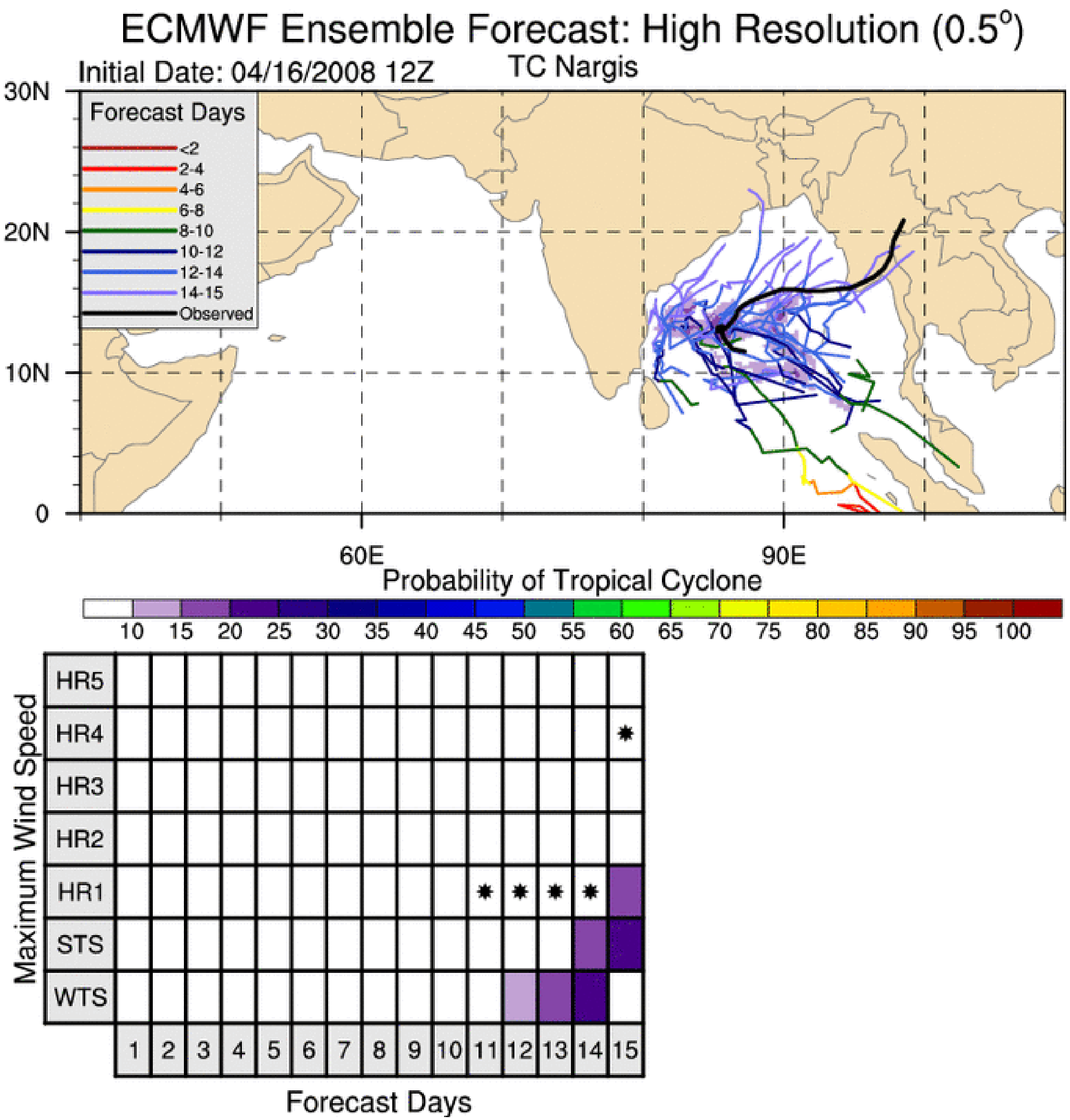
Maximum Intensity: 115 kts

Forecast Evaluation: Gonu & Sidr '07





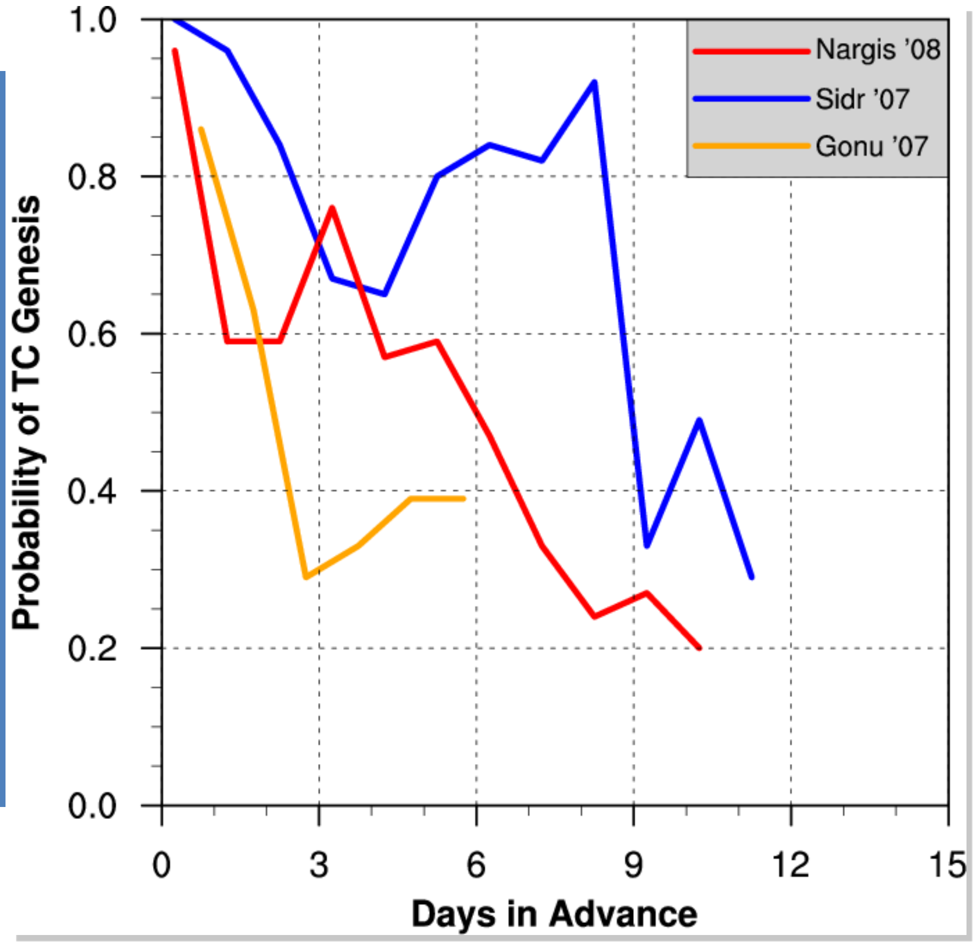
Forecast Evaluation: Nargis '08



Genesis Verification

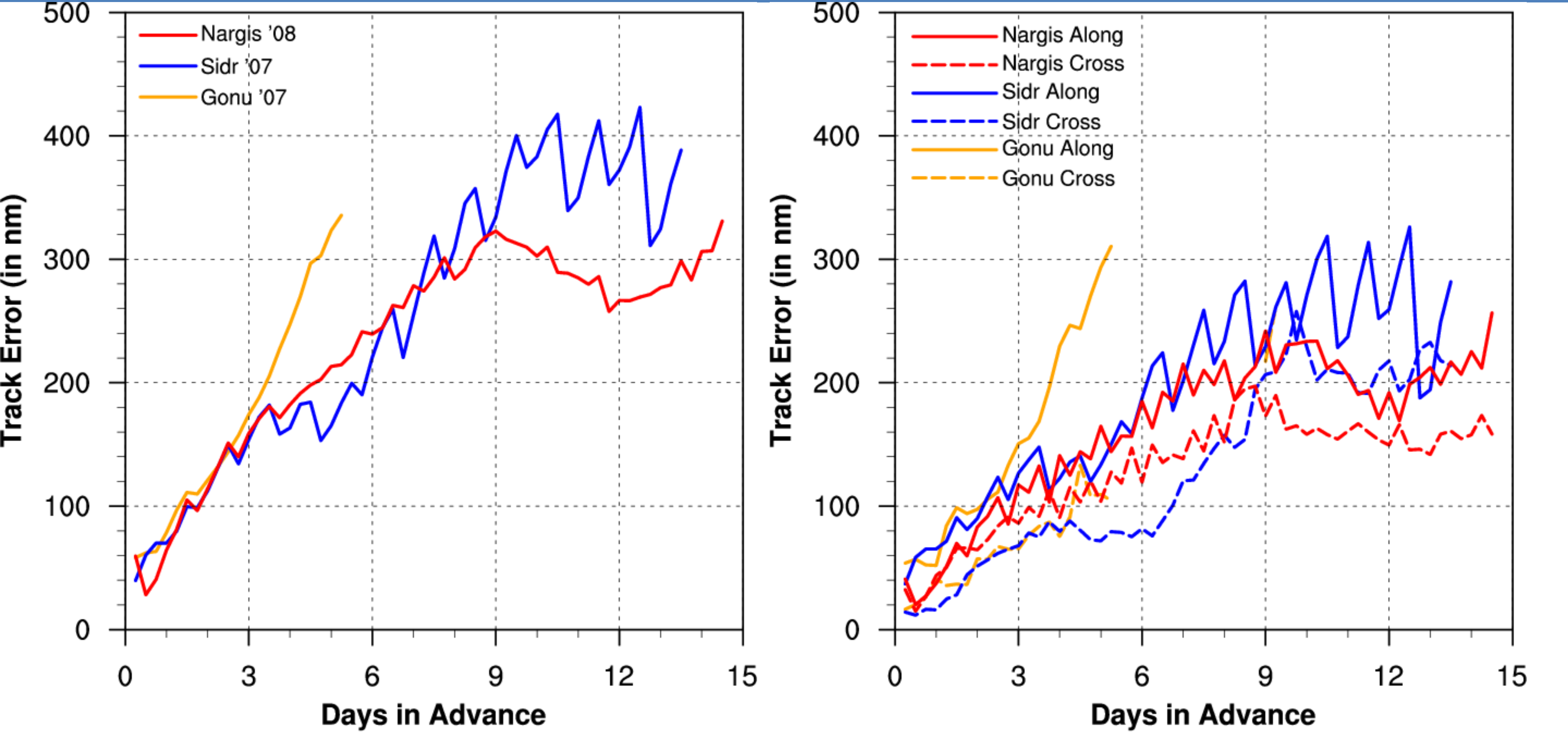
- ECMWF provided skillful TC genesis forecasts:
  - *5.75 days in advance for Gonu*
  - *7 days in advance for Nargis*
  - *11 days in advance for Sidr*

- Similar to NATL TC forecasts, predictability plateaus for discrete lead time intervals



Note: Probability of TC genesis is the maximum ECMWF TC probability at the *time* of the first tropical storm advisory issued by the JTWC

Track Verification



- Track error for low/high ECMWF cases not significantly different
- Along track errors for both TCs are larger than cross track errors
  - For lead times > 3 days, along track errors for Gonu exceeded Sidr errors

- *Note: IMD errors on average exceed 270 nm for Day 3 track forecasts*

"Long term": 1-4 month prediction of NATL Hurricanes (1-5)

- Use the ECMWF System 3:
- 41 ensembles/month 1-7 months
- Choose predictors from observation
- Use ECMWF System 3 to predict predictors
- Kim and Webster (2010)

Seasonal Tropical Cyclone Forecast

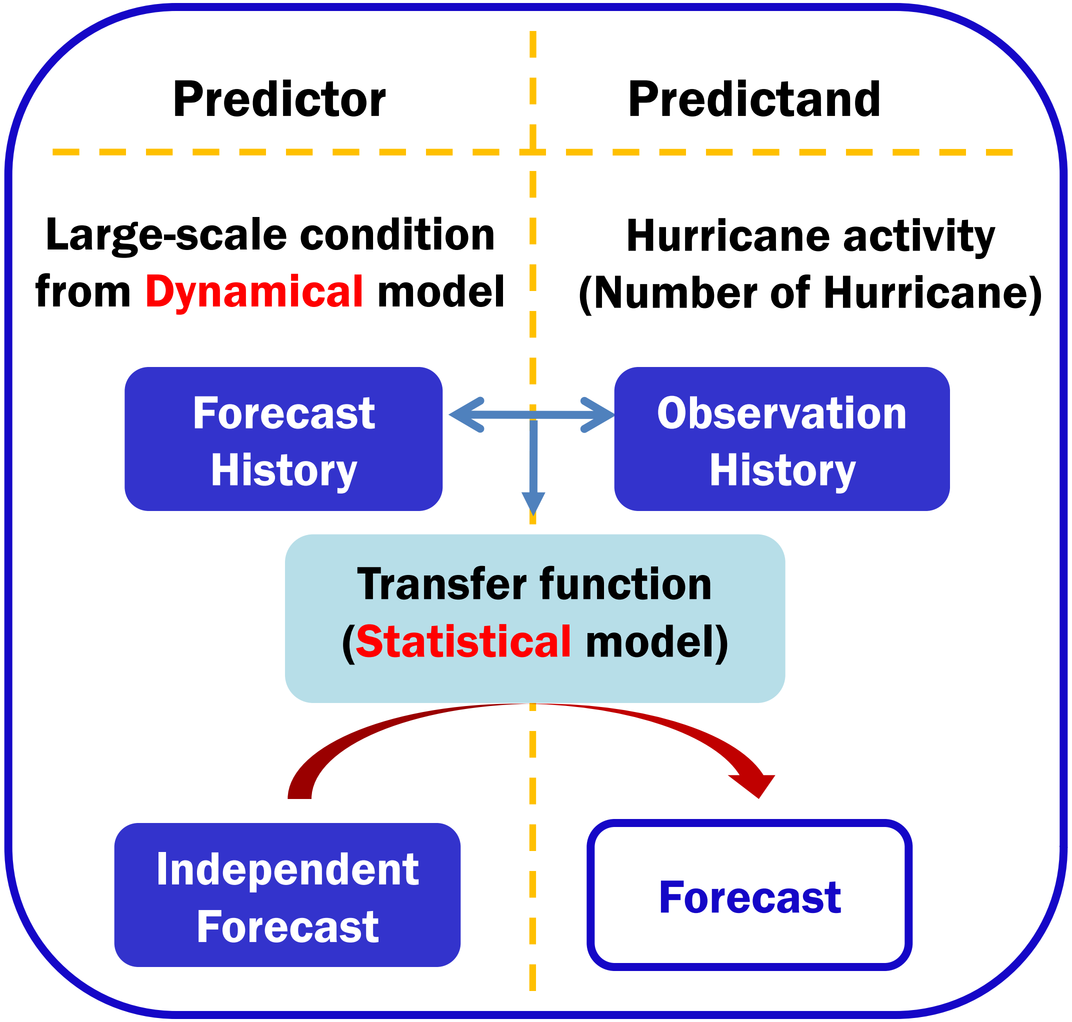
Groups that issue the seasonal TCs forecasts over the Atlantic basin

Group	Type
CSU	Statistical
NOAA CPC	Statistical
Tropical Storm Risk (TSR)	Statistical
ECMWF	Dynamical
IRI	Dynamical

** Camargo et al. 2007, WMO Bulletin*

Hybrid Forecast : Dynamical – Statistical Forecast

Statistical prediction based on Dynamical model predictors



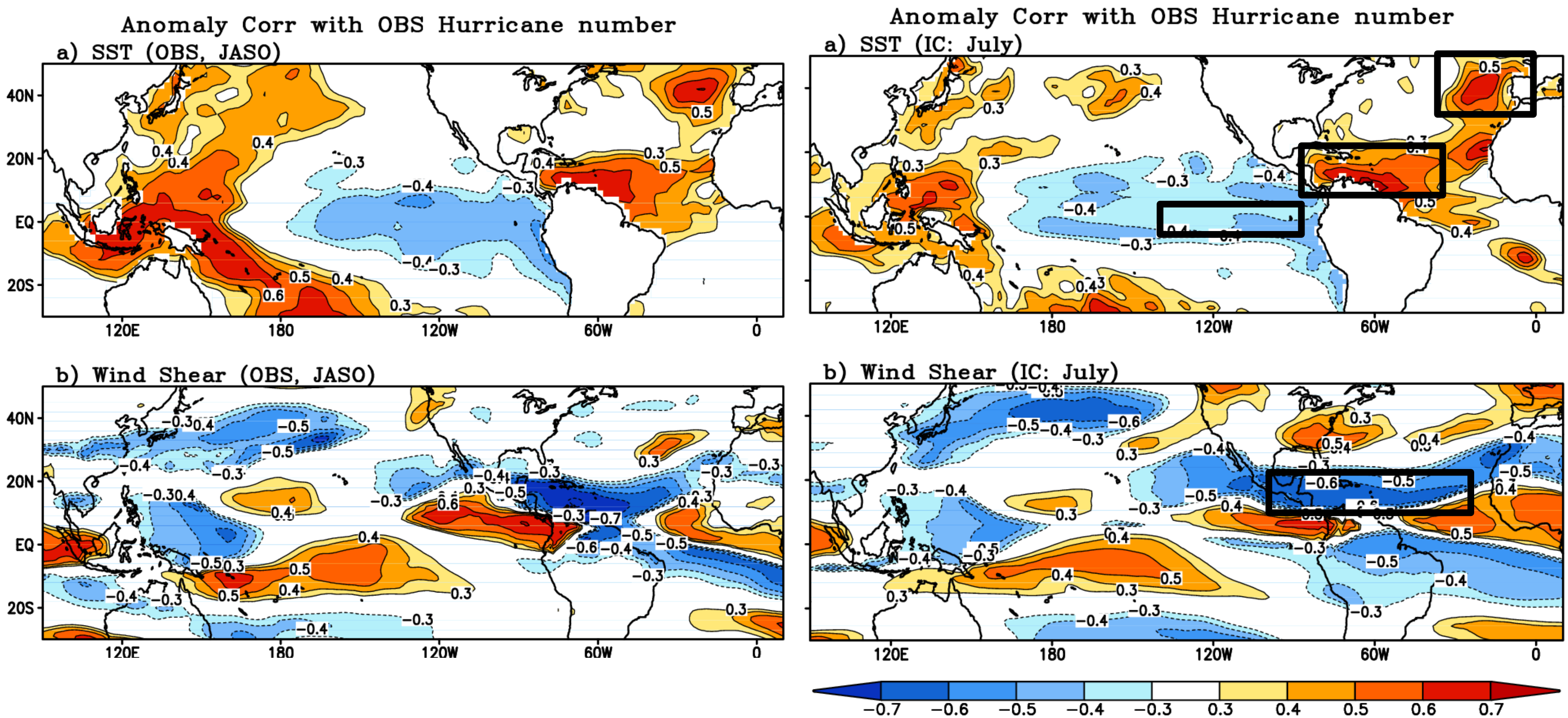
OBS	MODEL
- Wind (ERA interim), - ERSST - Hurricane (Cat 1-5)	ECMWF system 3 (IC: July 1^{st})

Period: 1981- 2009, July-October

Predictor selection

Correlation Coeff. with OBS Hurricane Number

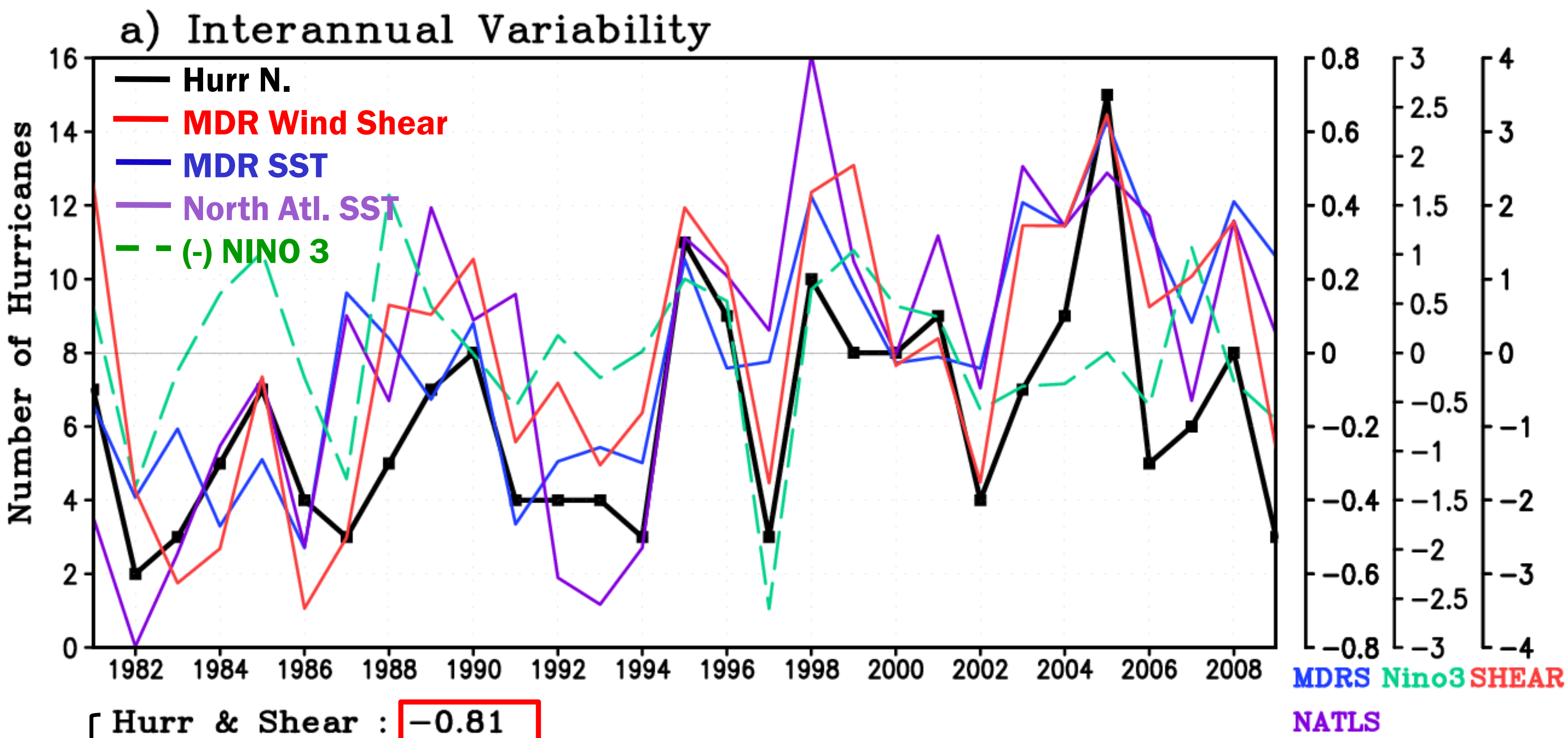
Observation | **ECMWF (IC: JUL)**



Hurricane Number is correlated with MDR wind shear, MDR SST, North Atlantic SST, and tropical Pacific both in the OBS and MODEL

Predictor selection

Observation

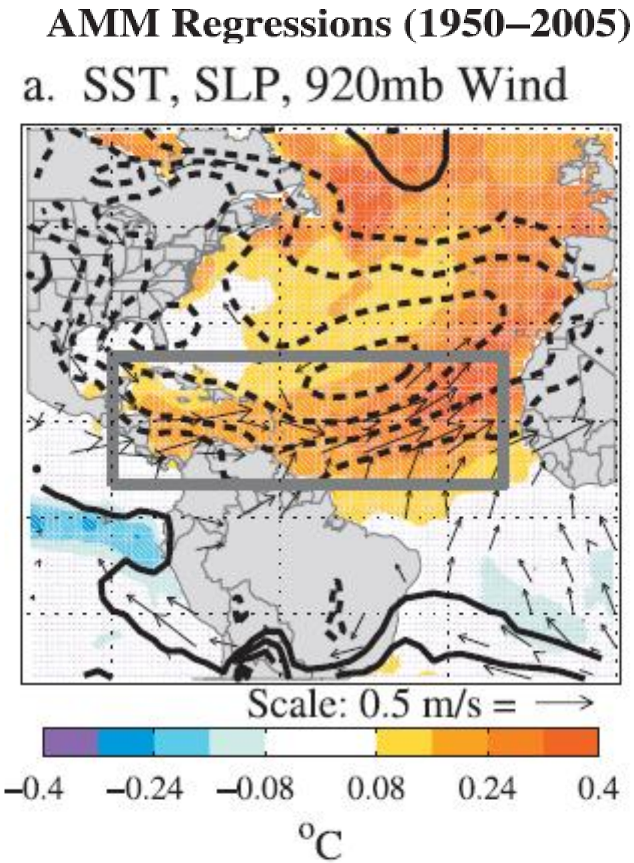


CORR
- Hurr & Shear : −0.81
- Hurr & MDR_SST : 0.61
- Hurr & NATL_SST : 0.66
- Hurr & NINO3 : −0.46

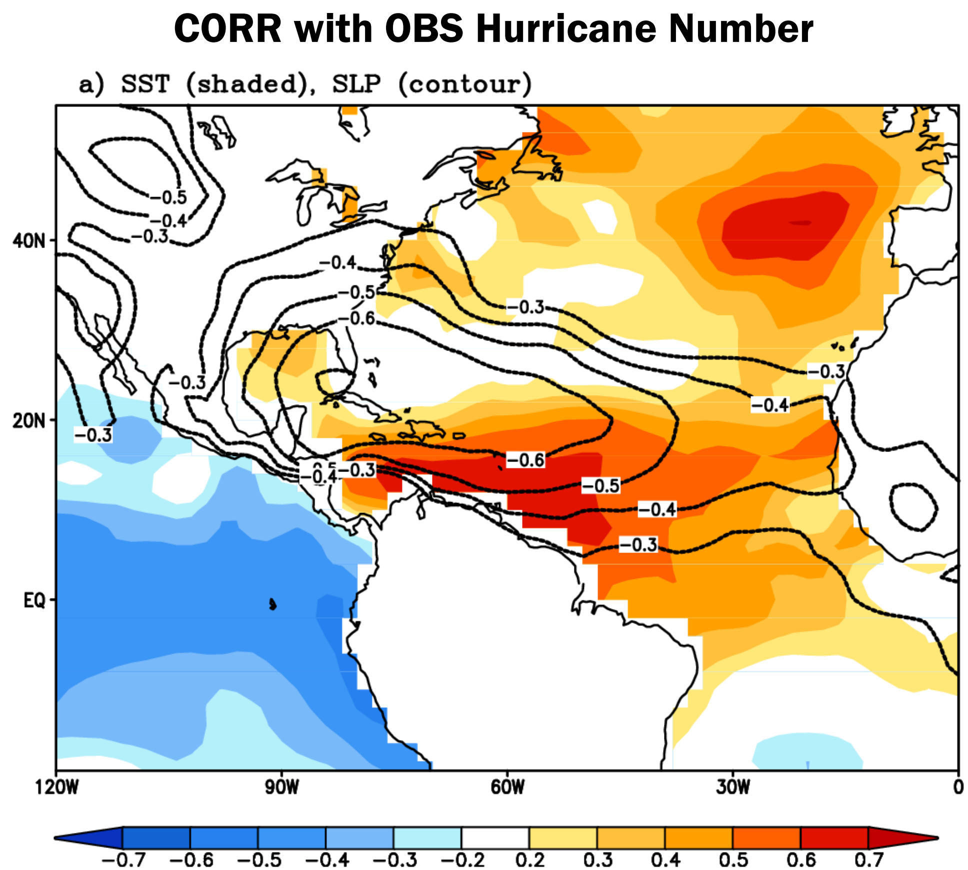
Hurricane Number is highly correlated with MDR wind shear and North Atlantic SST

Predictor selection

Atlantic Meridional Mode



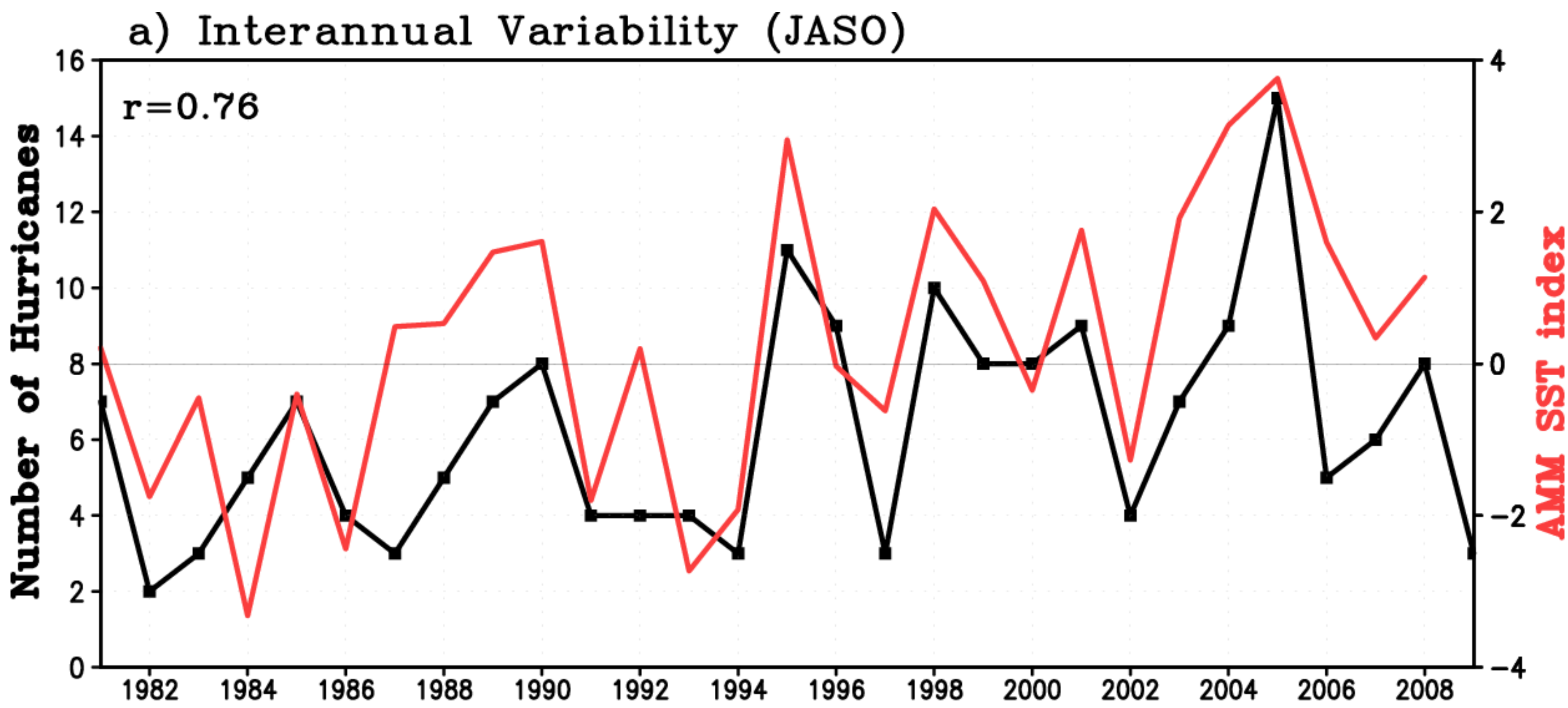
* Vimont and Kossin 2007



The spatial structure of large-scale atmospheric-ocean variables is similar to the AMM pattern

Predictor selection

Atlantic Meridional Mode



Hurricane Number is highly correlated AMM

Predictor selection

Predictor: ECMWF wind shear over MDR, and SST over MDR/NATL/NINO3
Predictand: Number of hurricanes

1st step

- Simple and Multi linear regression between ECMWF Forecast (IC: July 1st) history & Observed history for Hurricane N.
- The target year is removed from the regression analysis

2nd step

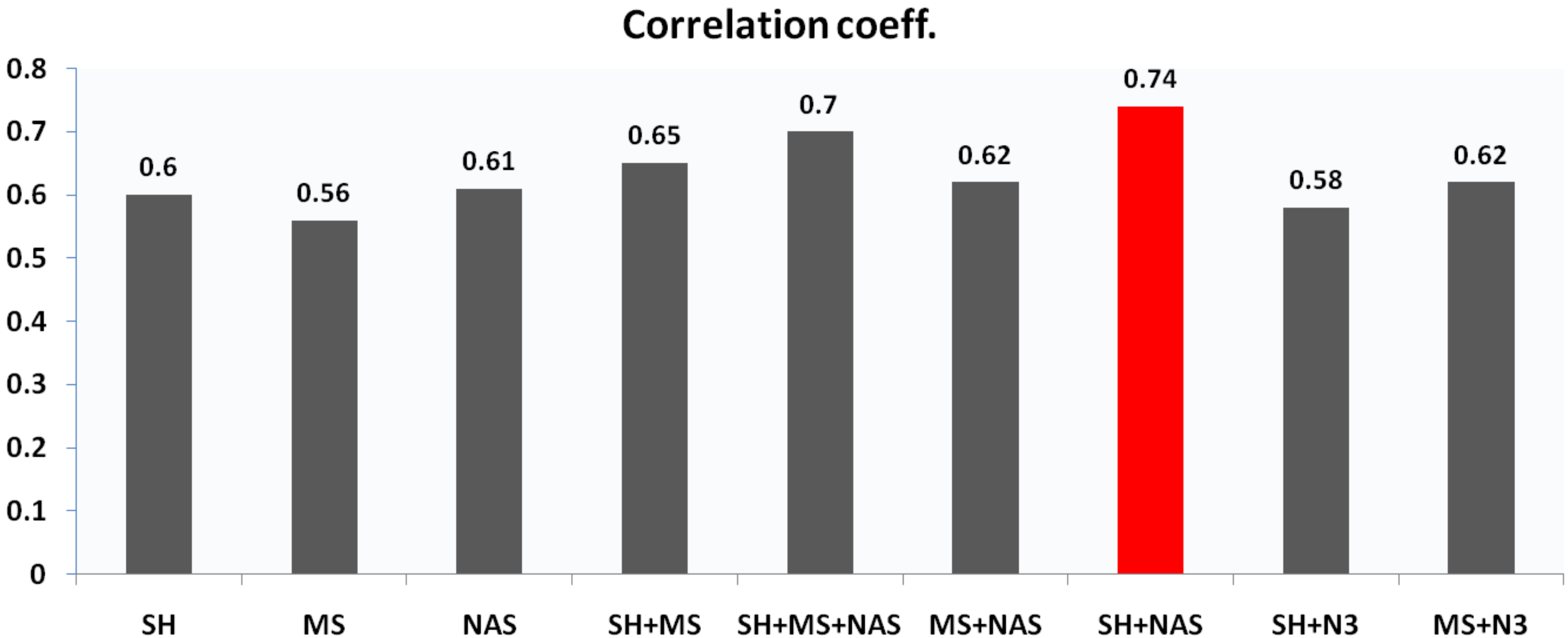
- Regression coefficients are projected to predictors from ECMWF forecast for the target year
- Regression coefficients are obtained from the ENS mean and applied to individual ensembles of the target year

3rd step

- Sensitivity tests for the optimal predictor selection

Predictor selection

Forecast skill (Correlation) using various predictor



SH : MDR Wind Shear (260-320E, 10-20N)
MS: MDR SST (280-310E, 5-15N)
NAS: North Atlantic SST (330-350E, 35-45N)
N3: Nino 3 index (210-270E, 5S-5N)

The highest forecast skill by using the MDR wind shear and North Atlantic SST as a predictor

Dynamical-Statistical Hybrid Forecast procedure

Predictor: ECMWF wind shear over MDR, and SST over NATL
Predictand: Number of hurricanes

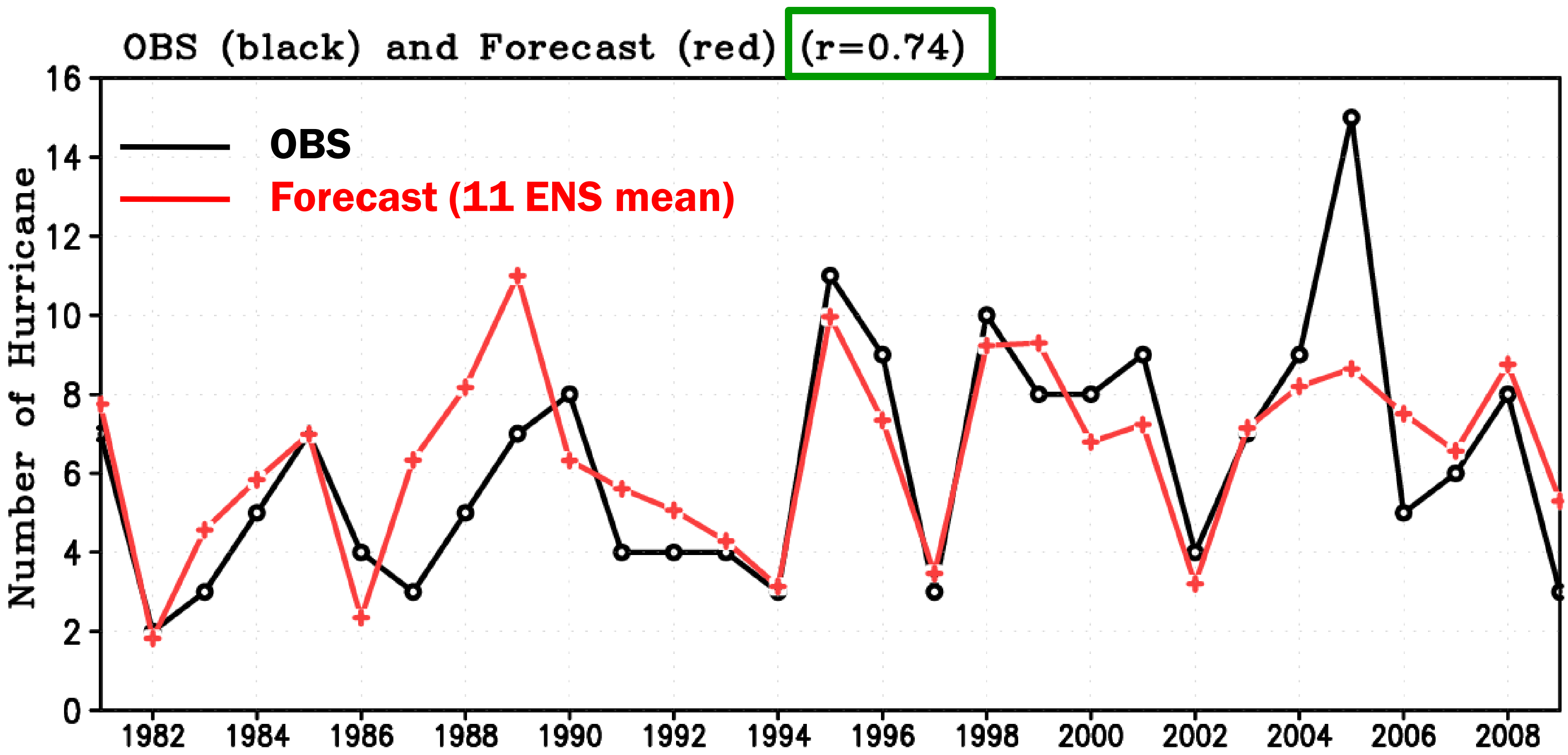
1st step

- **Multi linear regression between**
  ECMWF Forecast (IC: July 1st) history & Observed history for Hurricane N.
- **The target year is removed from the regression analysis (Cross-validation)**

2nd step

- **Regression coefficients are projected to predictors from ECMWF forecast for the target year**

Forecast Verification



CSU : r= 0.58 (1984-2008)

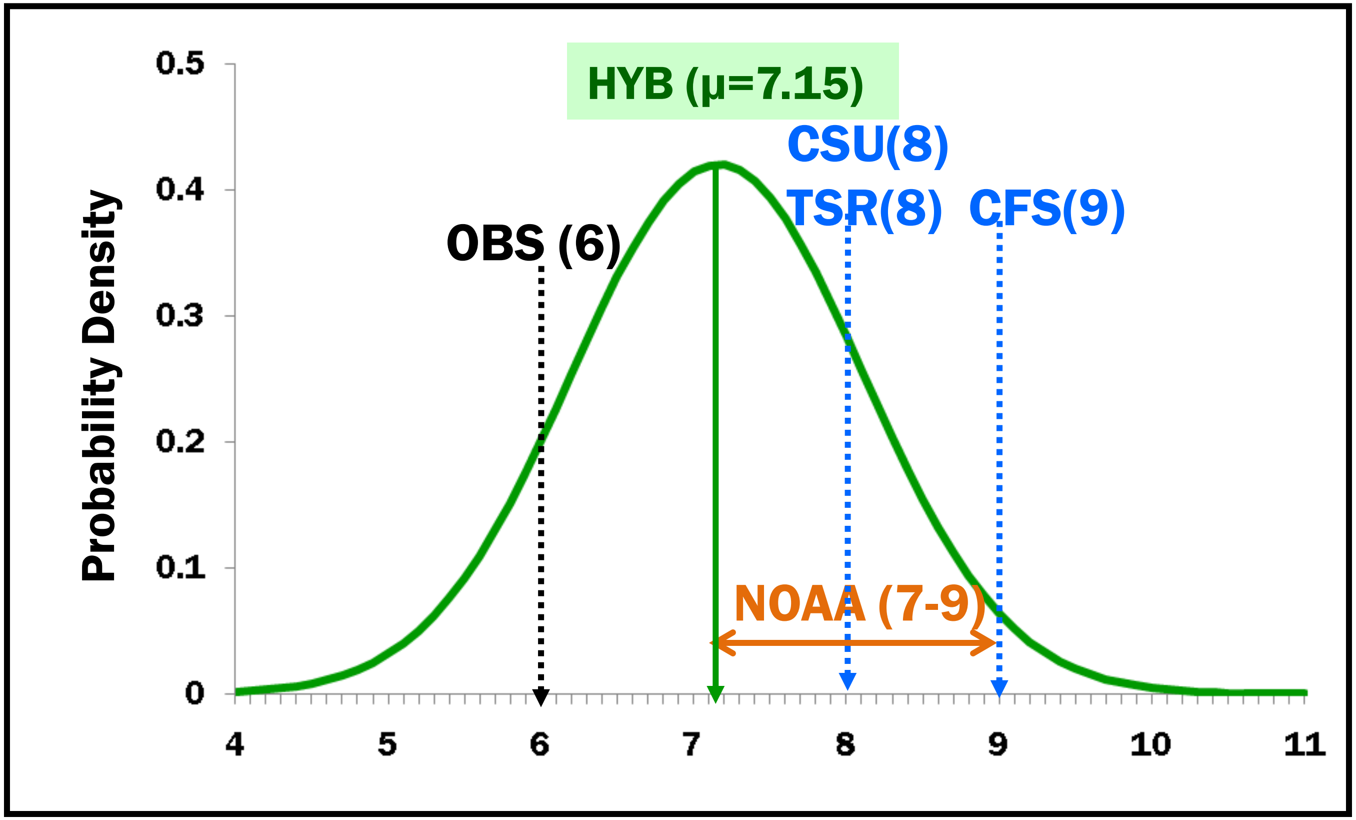
Hurricane Forecast issued at August (Storms forming after 1st August)

http://typhoon.atmos.colostate.edu

Probability Forecast with 41 ENSEMBLES

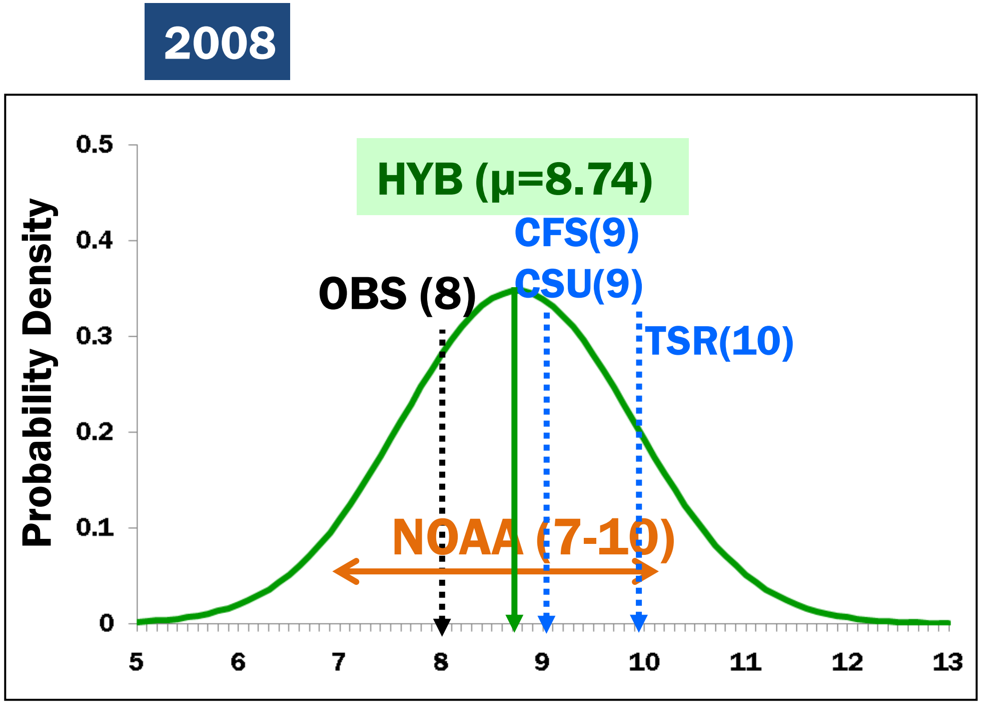
Forecast verification

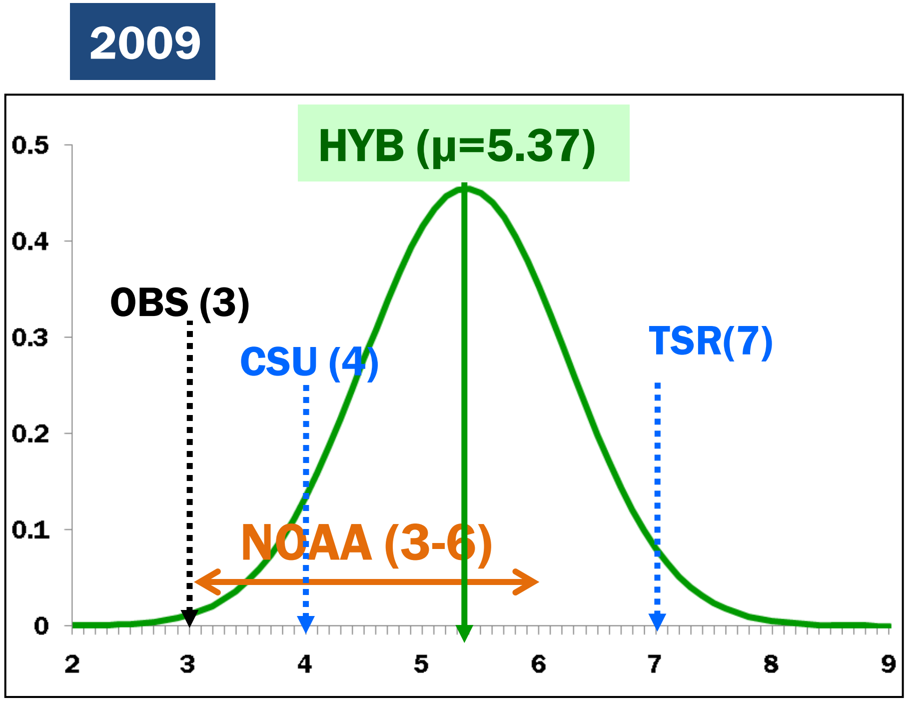
2007



Probability Forecast with 41 ENSEMBLES

Forecast verification





Dynamical-Statistical Hybrid Forecast

Summary

- The interannual variability of ATL Hurricanes (WNPAC Typhoons) correlates with North Atlantic SSTs and MDR vertical wind shear (wind shear over the equatorial central Pacific) both in the observation and ECMWF hindcast.

- Two (One) predictors from the dynamical model are considered as a predictor f or seasonal hurricane (Typhoon) activity: MDR wind shear and North Atlantic SS T (central Pacific wind shear)

- Even if we issue the forecast at 1st July with limited predictors from the dynamical model, the hybrid model is competitive with the current forecast models that issue the forecast at August (CU: late June).