Next Generation HWRF

HYCOM coupling

Hyun-Sook Kim,
HWRF & HYCOM modeling team

Environmental Modeling Center
National Centers for Environmental Prediction
US National Weather Service

Overview

1. Introduction to HYCOM coupling & Background
2. HYCOM Hurricane Domains
3. Initial and Boundary Conditions
4. Forecast Comparisons between Non-coupled and Coupled runs: Western North Pacific Typhoons 2012-2013
5. TC Forecasting: Sensitivity of SST
6. Importance of Initial Conditions: Seasonal and Spatial Variability
7. Importance of Realistic Ocean Simulations
8. Lessons Learned - Recommendations
9. Future Plans for Improvement of TC forecasting

1. HYCOM coupling

An experimental model proposed for next generation HWRF

- One of ocean models chosen for ocean model impact study as a Hurricane Forecast Improvement Project (HFIP) initiative.
- Forecast skills have been demonstrated
  - for the North Atlantic and Eastern North Pacific hurricanes (Kim et al., 2014), since 2009; and
  - for the Western North Pacific Typhoons (Kim et al. 2015), since 2012.
- Realistic and idealized configurations, along with diagnostic and graphic codes, exist in DTC SVN, but currently HYCOM coupling framework is not supported by DTC yet.

1. HYCOM coupling

Ocean model components of HWRF

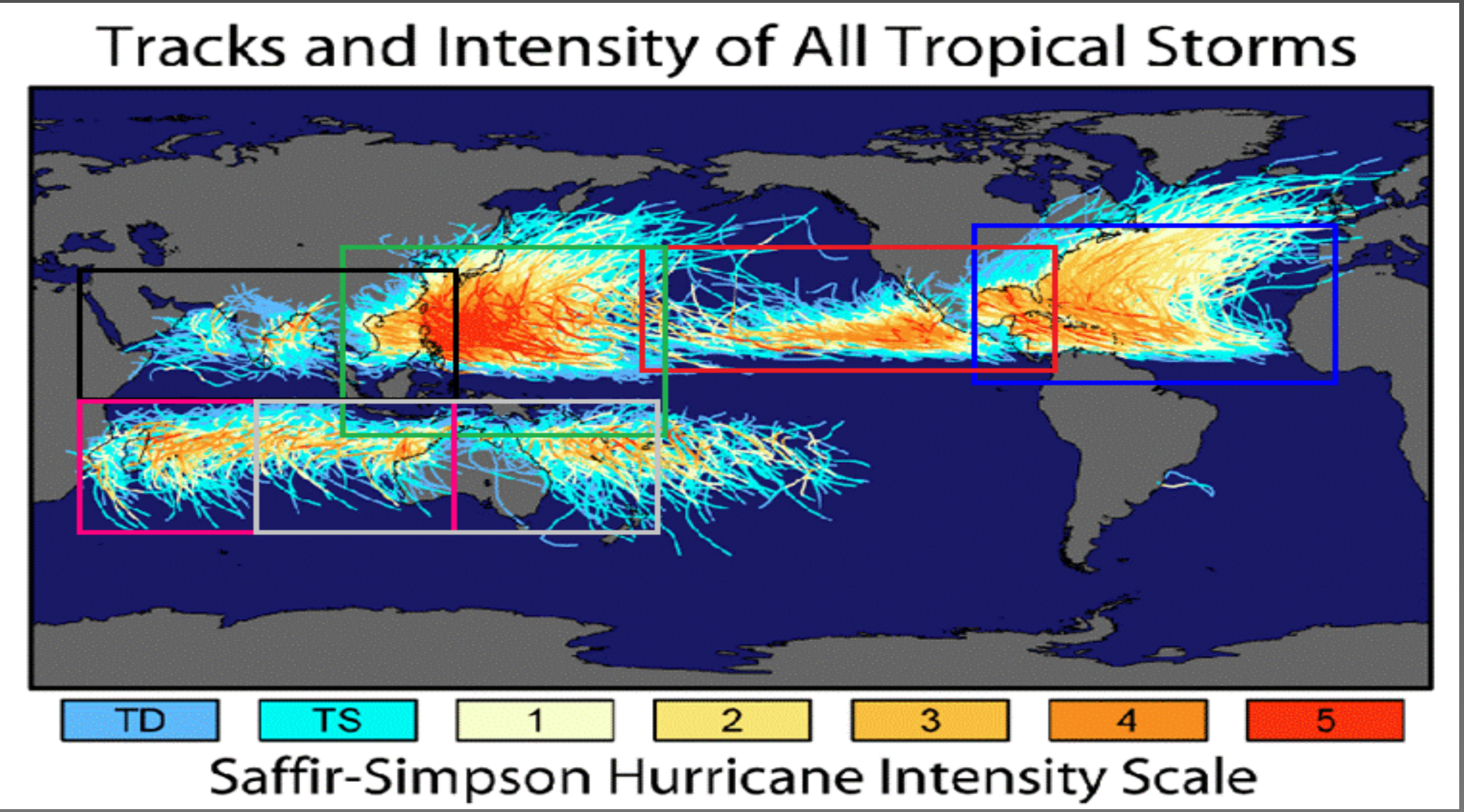
	POM	HYCOM
Dynamics & Numerics	Hydrostatic, free-surface, primitive equations on C grid	
	1/12-degree	
	23 hybrid sigma & Z	32 hybrid isopycnal & Z
Mixing Physics	Mellor-Yamada 2.5 closure	KPP
Initialization	Monthly GDEM3 Climatology + daily GDAS SST assimilation + Feature Model	6 hourly NCODA-HYCOM analysis
Lateral Boundary Values	Adjusted T/S fields	3 hourly 2D and 6 hourly 3D global RTOFS* forecasts

*: RTOFS = Real-Time Ocean Forecast System producing 2-day nowcasts and 8-day forecasts each day

HYCOM is the community model (but not HYCOM coupling), having NRL as the primary developer. *Reference at https://hycom.org*

2. HYCOM Hurricane Domains

Domains *vs.* All TC storms 1851-2006

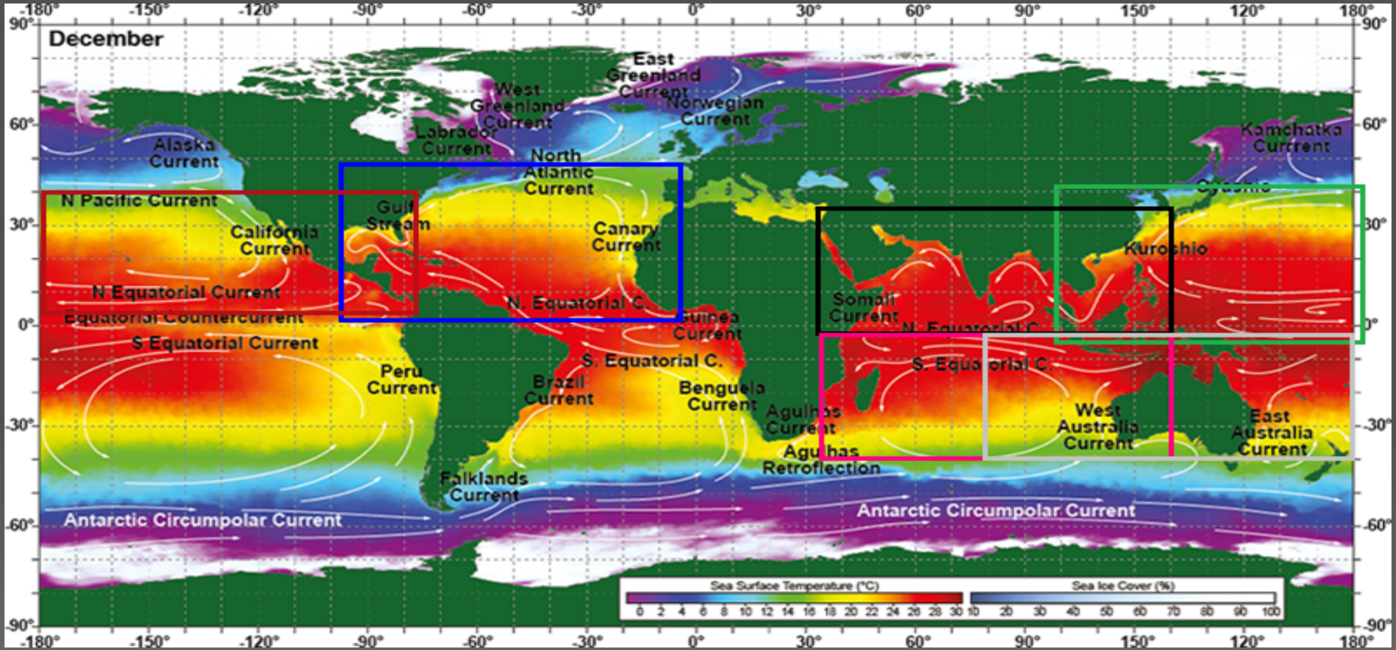


www.meted.ucar.edu, edited by Hyun-Sook Kim

- **NHC**: North Atlantic (blue), Eastern North Pacific (red), Central North Pacific (not shown).
- **JTWC**: Western North Pacific (green), Eastern South Indian/Western South Pacific (grey), North Indian (black), and South Indian (pink).

2. HYCOM Hurricane Domains

Domains vs. Boundary Currents



www.rapid.ac.uk/background.php, edited by Hyun-Sook Kim

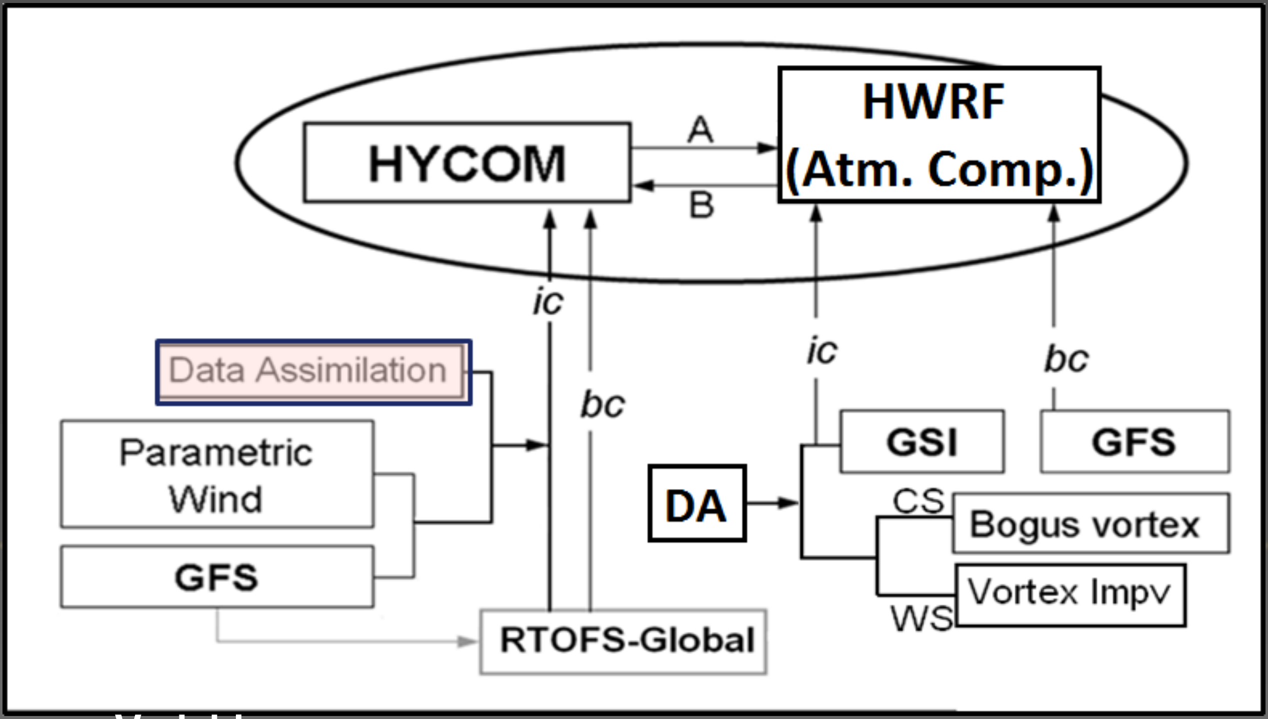
Major thermal fronts in each basin:

meandering and shedding eddies in meso scales by baroclinic instabilities

1. **North Atlantic (blue):** North Equatorial Current, Loop Current, Gulf Stream, Canary Current
2. **Eastern North Pacific (red):** Equatorial Countercurrent, California Current
3. **Western North Pacific (green):** Kuroshio Current, the North & Equatorial Current
4. **North Indian Ocean (black):** North Equatorial Current, Somali Current, coastal upwelling
5. **South Indian Ocean (pink):** South Equatorial Current, Agulhas Current
6. **Western South Indian/Eastern South Pacific (grey):** East Australian Current & West Australian Current

3. Initial and Boundary Conditions

Components and Data Flow



Pink Shade – future plan

Exchange Variables

A: sea surface temperature (SST)

B:

1. Precipitation
2. Atmospheric pressure
3. Heat fluxes – Sensible, latent, total radiation, and net shortwave radiation
4. Wind stress

ic = initial Conditions
bc = boundary conditions
CS/WS = cold/warm start
DA = data assimilation
GFS = Global Forecast System
GSI = Gridpoint Statistical Interpolation

3. Initial and Boundary Conditions

HYCOM for 2-way coupling to HWRF

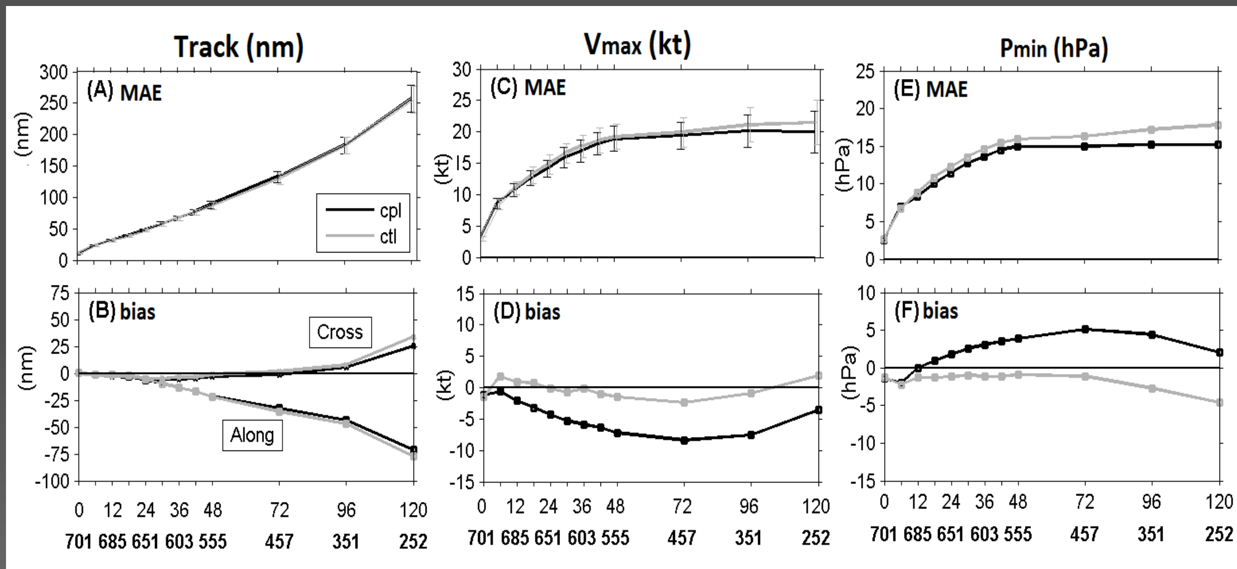
1) IC/BC from real-time global RTOFS (Real-Time Ocean Forecast System) . RTOFS uses the same eddy-resolving HYCOM dynamics and physics solutions on 1/12-degree horizontal and 36 vertical layers.
2) IC uses NCODA*-HYCOM analysis and available for 321any cycle.
3) BC uses 5.25 day forecasts from daily RTOFS products.
4) **E**arth **S**ystem **M**odeling **F**ramework (**ESMF**) compliance: ready for coupling in **N**OAA **E**nvironmental **M**odeling **S**ystem (**NEMS**) framework.

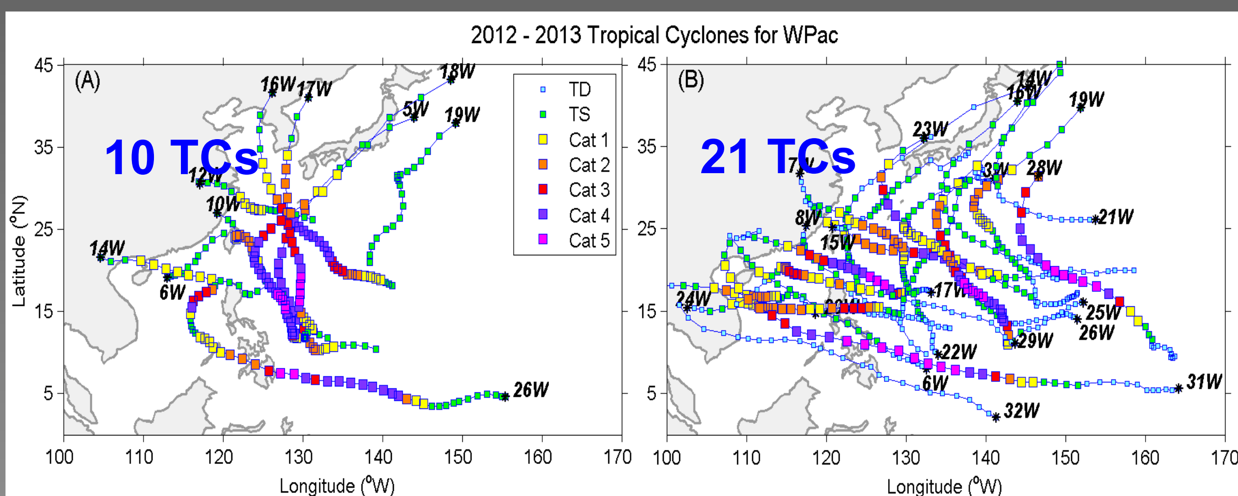
* NCODA: Navy Coupled Ocean Data Assimilation

4. Non-coupled vs. coupled (HYCOM) Typhoon Forecasts for 2012-2013

Two Seasons Combined

Verification





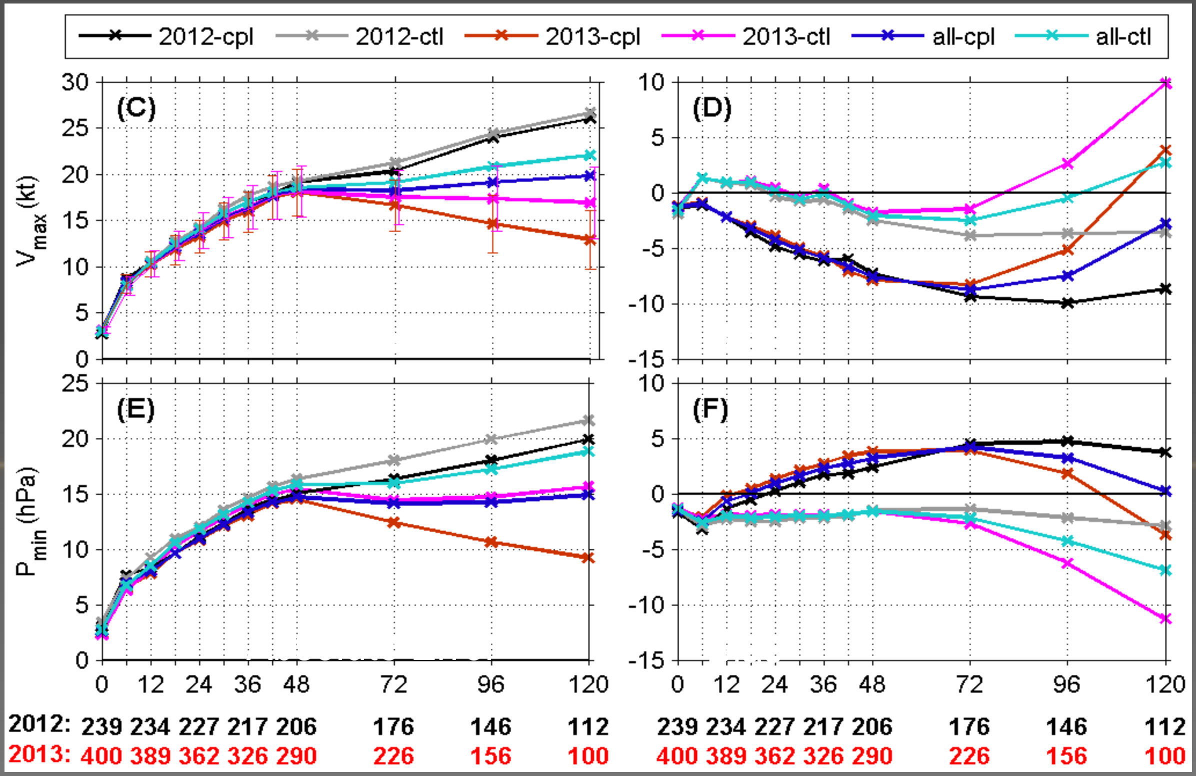
- Track: Little difference
- Intensity: 2 kt/3 hPa
- Bias in V_{max} and P_{min} is worse by coupling than control.
- Similar negative bias observed in other studies, e.g., Wada (2010).

4. Non-coupled vs. coupled (HYCOM) Typhoon Forecasts for 2012-2013

Seasonal Variations

Vmax

Pmin



- MAE: HYCOM coupling (**cpl**) has smaller MAE (<16 kt), compared to non-coupled (**ctl**).
- Bias: HYCOM coupling shows a consistent bias.
- Seasonal variability in forecast is probably related to the large scale variations.

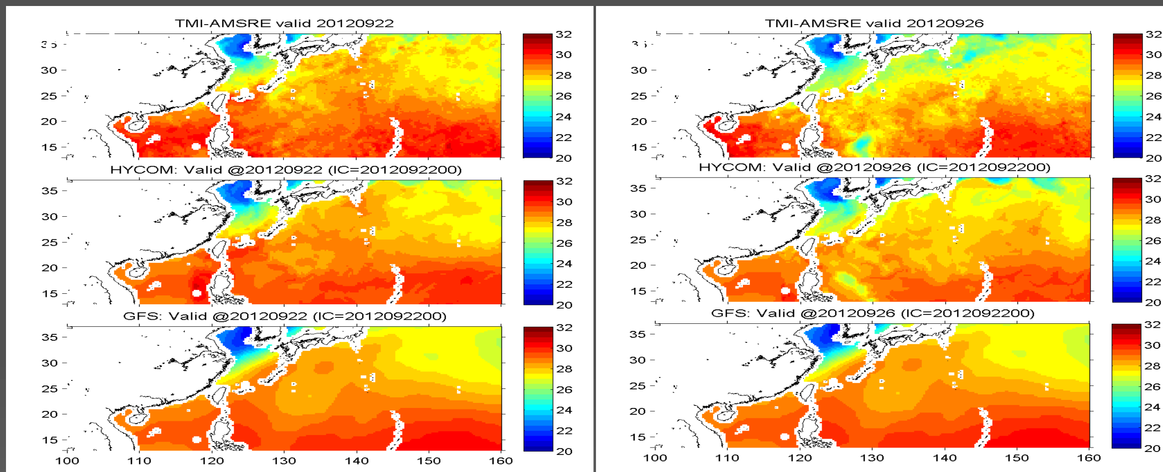
4. SST cooling comparison

Comparison against daily TMI & AMSRE OI SST

Obs.

HYCOM

GFS



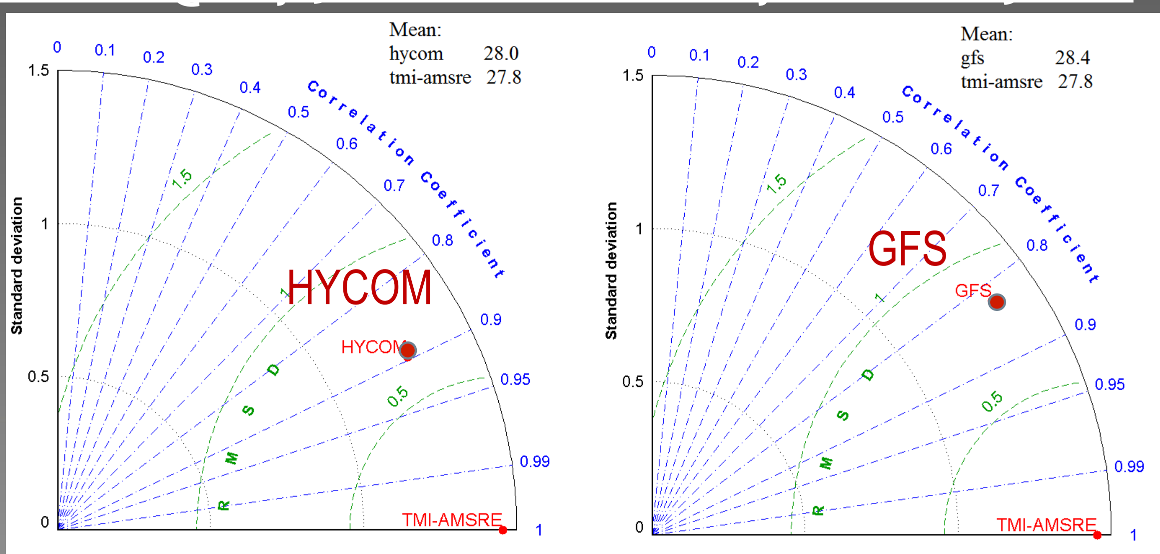
HYCOM SST

- Similar cold wake (~26°C) at a similar degree of cooling (~3°C)
- Mesoscale variability

GFS SST

- No change in GFS SST
- No cold wake and no cooling
- No Mesoscale variability

statistics @day 5 for Jelawat 18W: cycle=2012092200



HYCOM SST

- Similar magnitude of mean
- Higher correlation coefficient (0.899)
- Lower RMSD (0.6) and STD (0.5).

4. Non-coupled vs. Coupled

- SST feedback: Ocean Coupling changes the TC thermodynam dynamics loop.
- SST cooling is real, and important to TC intensity

Maximum Potential Intensity and SST

Maximum Potential Intensity (Emanuel 2003)

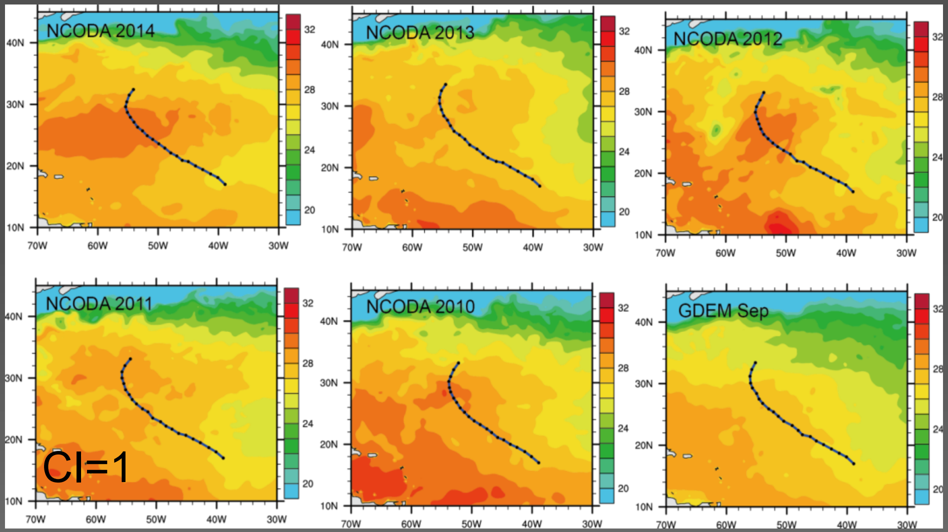
$$V_{\max}^2 \propto \frac{(T_1 - T_2)}{C_d T_2} F_h$$

T_1 = *SST*;
T_2 = outflow temperature;
C_d = drag coefficient;
and
F_h = (*LHT*+*SHT*) the surface flux of enthalpy.

T1, LHT, SHT, Cd and (Ch) are either explicitly or implicitly related with SST.

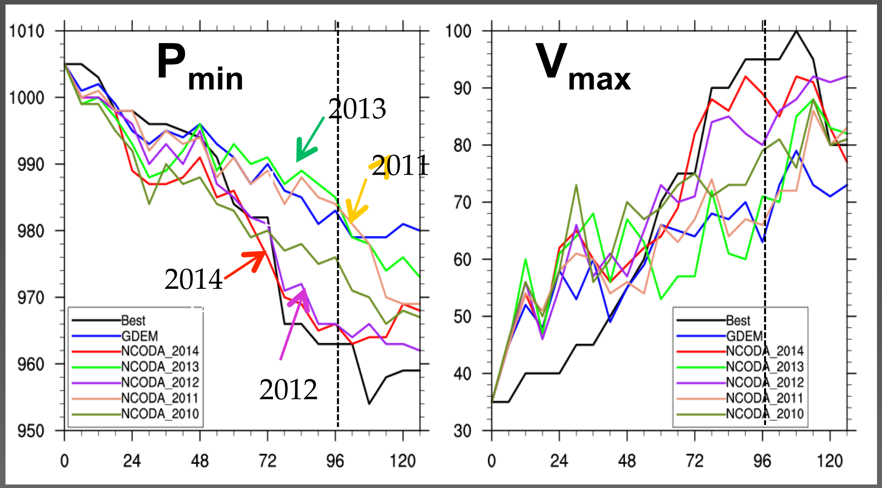
5. Sensitivity of SST – Edouard (2014)

using ***non-coupled*** HWRF
for Initial SST and location, size and strength of a **warm pool**



Sources:

- NCODA SST from 2010-2014
- GDEM September climatology



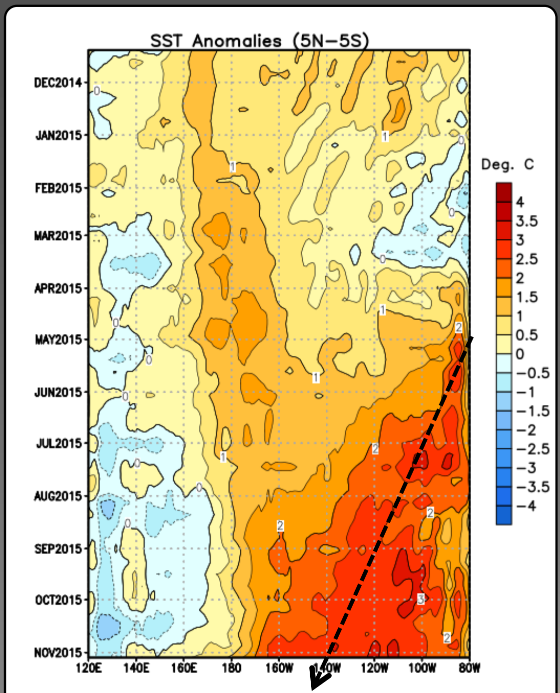
For example, at 96 h, wrt BT
ΔPmin = 4 hPa (2014/2012) *vs*. 28 hPa
ΔVmin = -15 kt (2014/2012) *vs*. -30 kt

- Best Forecast was achieved with NCODA 2014 dataset.
- Better Intensity Forecast with
  a. Larger and warmer beneath the storm
  b. Stronger temperature gradient along the track

6. Importance of oceanic initial conditions: Seasonal and Spatial variations

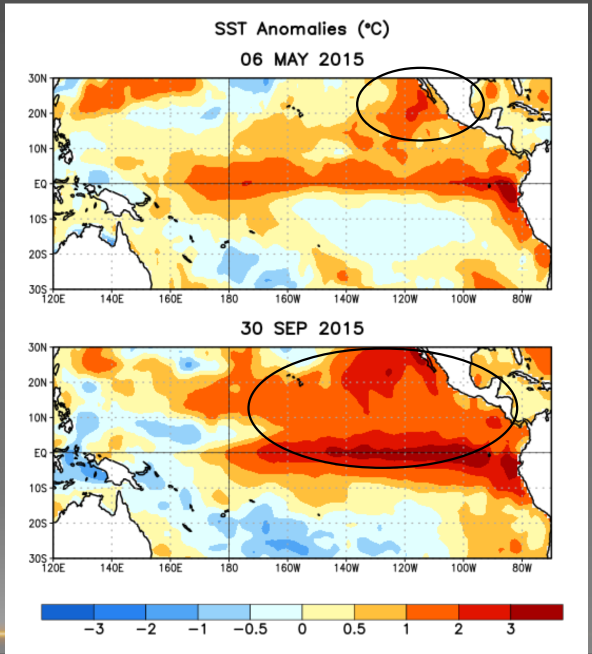
East North Pacific 2015 Season

El Nino
Early season – NiNo index 1-2
Mid and Late season – NiNo index 3-4



ENSO: Recent Evolution, Current Status and Predictions
By CPC/NCEP, November 9, 2015

Also, body of warm water residing at 20N, expanding southwestward over time ➔ set up unseasonally warm SST in the tropics.

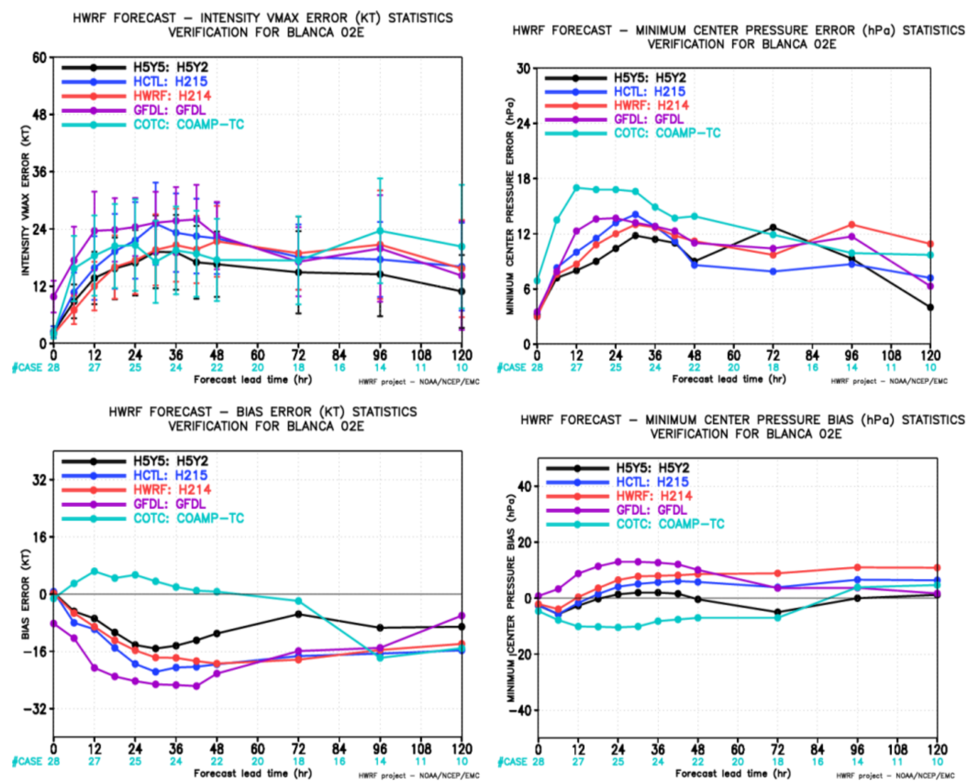


Further extends favorable conditions for TCs in later season.

6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Blanca: Intensity Forecast Verification

1. 2015 HYCOM coupling (H5Y2) performed the best, showing small MAE (< 18 kt) and small bias, followed by H214 (2014 operational HWRF was run before the 2015 season).
2. GFDL performed the worst.
3. 2015 HWRF (HCTL=H215) performed worse, especially for early lead hours (< 48 h), than 2014 HWRF.
4. COAMPS-TC (COTC) performance was between HWRF and GFDL for Vmax. But, Vmax bias, and Pmin MAE and bias were quite different.

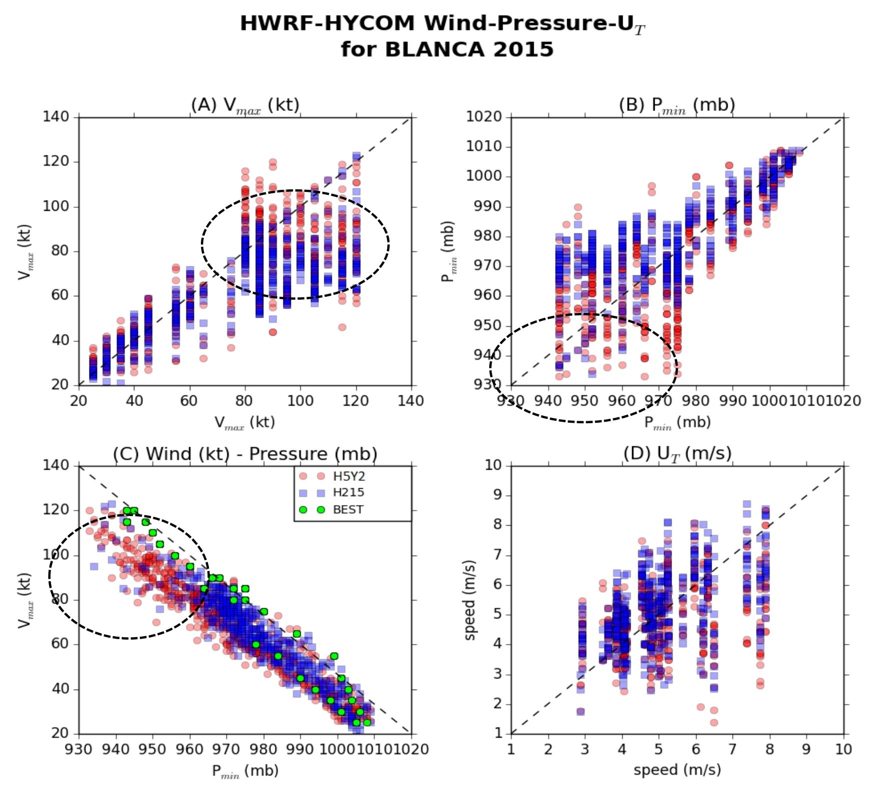


V_{max} (kt) P_{min} (hPa)

6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Blanca: 2015 HYCOM coupling vs. POM coupling

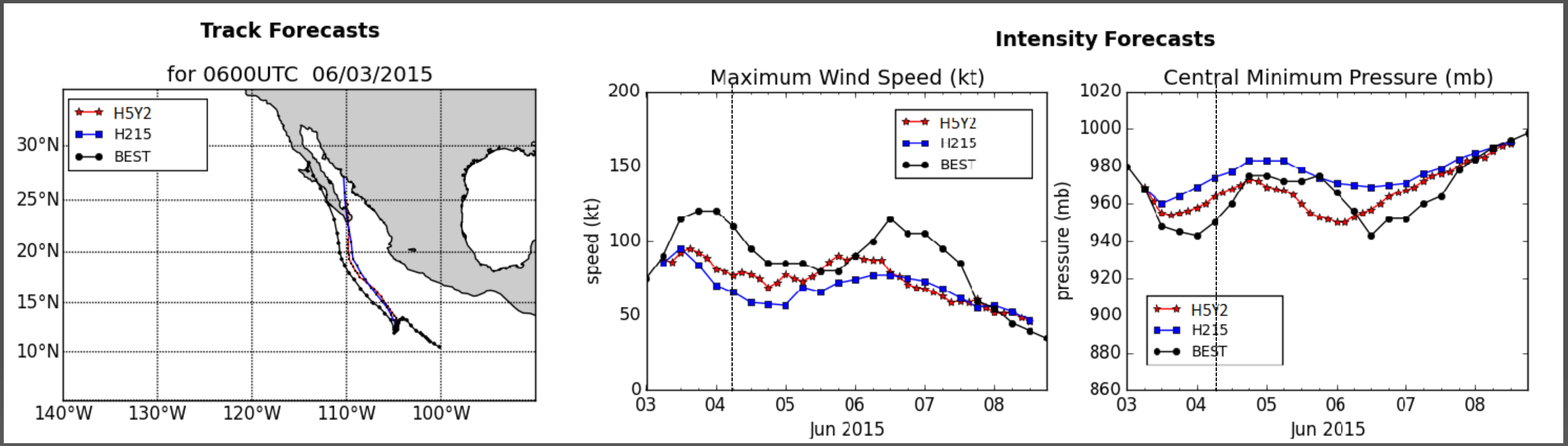
- **Intensity**: Between HYCOM (red) and POM coupling (blue), the former performs better at higher winds or lower pressure (dashed ovals).
- U_T (storm translation speed): Over-estimate for slow and under-estimate for fast moving storm (more so for HYCOM).



Scatter plots for V_{max}, P_{min}, and U_T

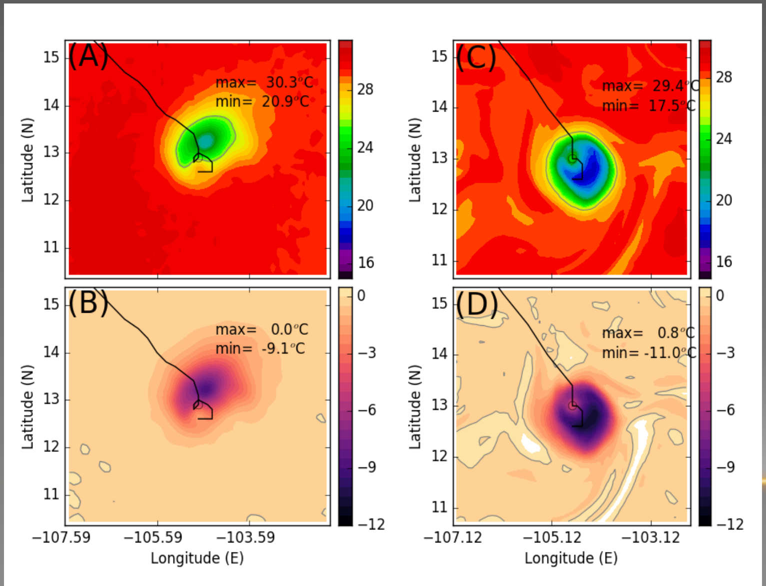
6. Importance of oceanic initial conditions: Seasonal and Spatial variations

SST Cooling & Intensity using HWRF and HWRF-HYCOM



SST

SST cooling

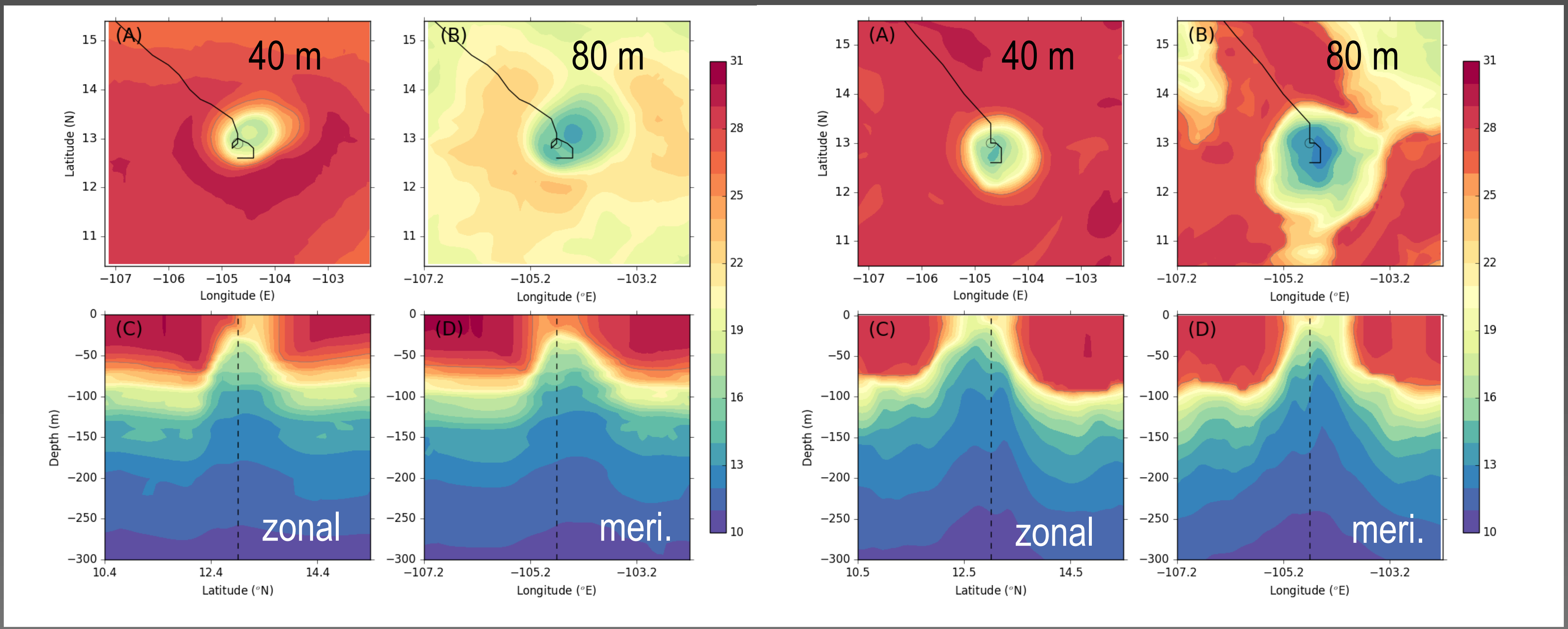


- **SST cooling over 24 h (entire cycle) in the storm field:**
  - POM - 9.1 (3.6-17.6)^{o}C for 62 kt/975 hPa
  - HYCOM - 11.0 (3.6-13.1)^{o}C for 77 kt/964 hPa
- **SST cooling in environment:**
  - POM – uniform cooling (-0.5^{o}C)
  - HYCOM – large variation of cooling and warming responsible for primarily advection

6. Importance of oceanic initial conditions: Seasonal and Spatial variations

Subsurface Temperature Structure

POM coupling | HYCOM coupling

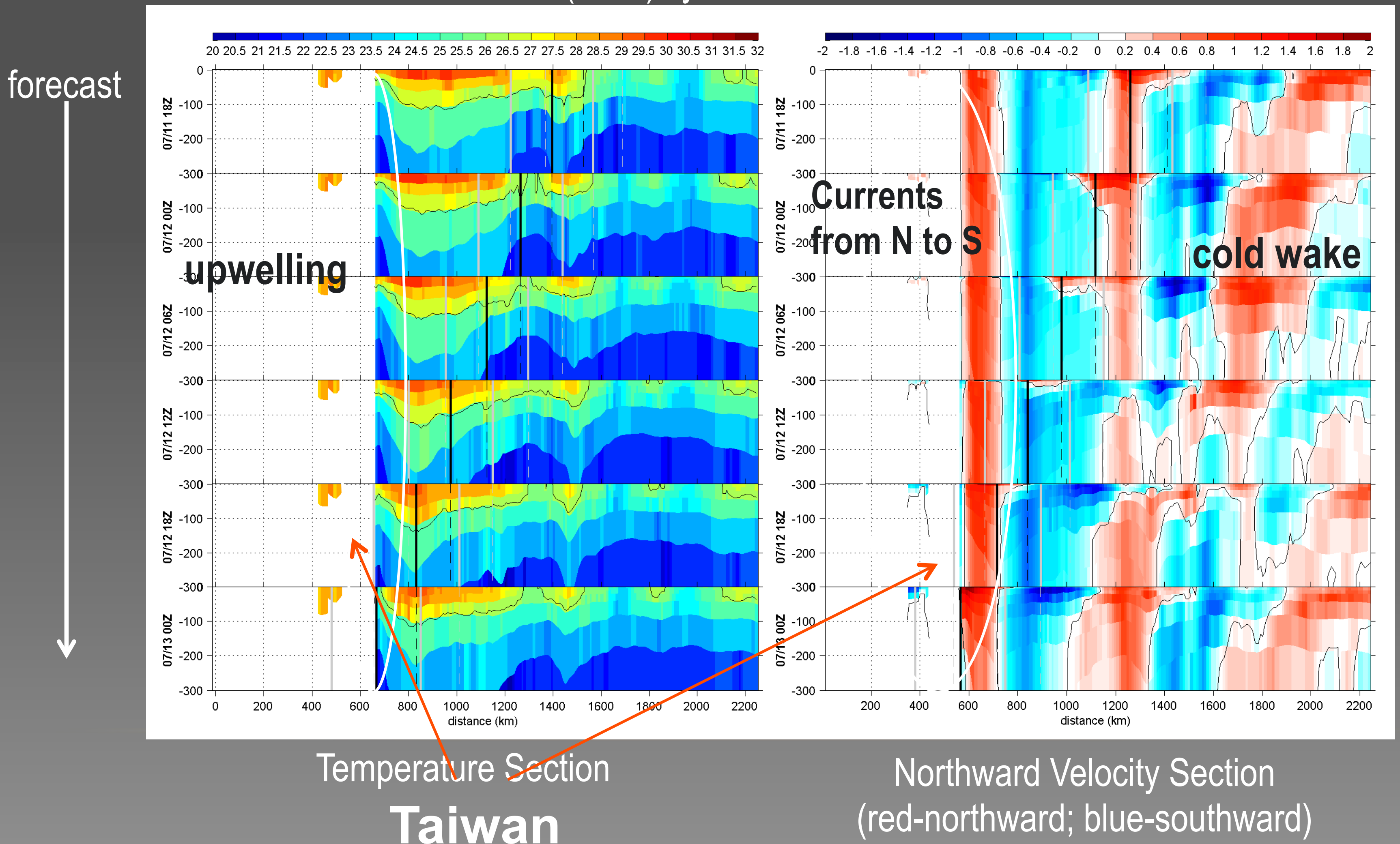


- POM: Shallower and colder upper layer, with 23.3°C of maximum temperature at 80 m.
- HYCOM: Deeper and warmer upper layer, with 28.8°C of maximum temperature at 80 m.
  - Higher Ekman pumping.
  - Features of warm core are more intensive and expansive in horizontal.
  - Depth of 26°C (Z26) is 20-25 m deeper → higher Ocean Heat Content.

7. Importance of Realistic Ocean Simulations

Example for upwelling and interactions with the Kuroshio Current

Soulik (2013) cycle=2013/7/10 00Z



Temperature Section

Northward Velocity Section (red-northward; blue-southward)

8. Lessons Learned - Recommendations

Better physics should result in better models

But, there are more subtle reasons too:

- Coupling forces you to take a closer look at details of the constituent models, in ways that are often complementary to the way the models are conventionally validated.

- This often leads to systematic improvement of the constituent models. That often has a positive impact on the component models, even if the impact on the actual coupling is found to be minimal.

8. Lessons Learned - Recommendations

1. Focus on best possible description of physical states for all models.
   - Better physics makes for a better model. However, better physics in a well tuned model will almost always detune the model in a coupled framework.

2. Deal with de-tuning of model due to “improved” physics in two ways, which makes most sense.
   - Deal with this as bias treatment in coupler (quick and dirty).
   - Retune as possible, particularly when individual processes are documented to describe nature better (long term systematic approach).

3. We need to have a set of metrics for HWRF that reflects these mentioned above: Track and intensity verification alone will never work.

4. Coupled model makes further development of modeling system a little more complicated.
   - This is an unavoidable side effect of doing things physically better.

8. Lessons Learned - Recommendations

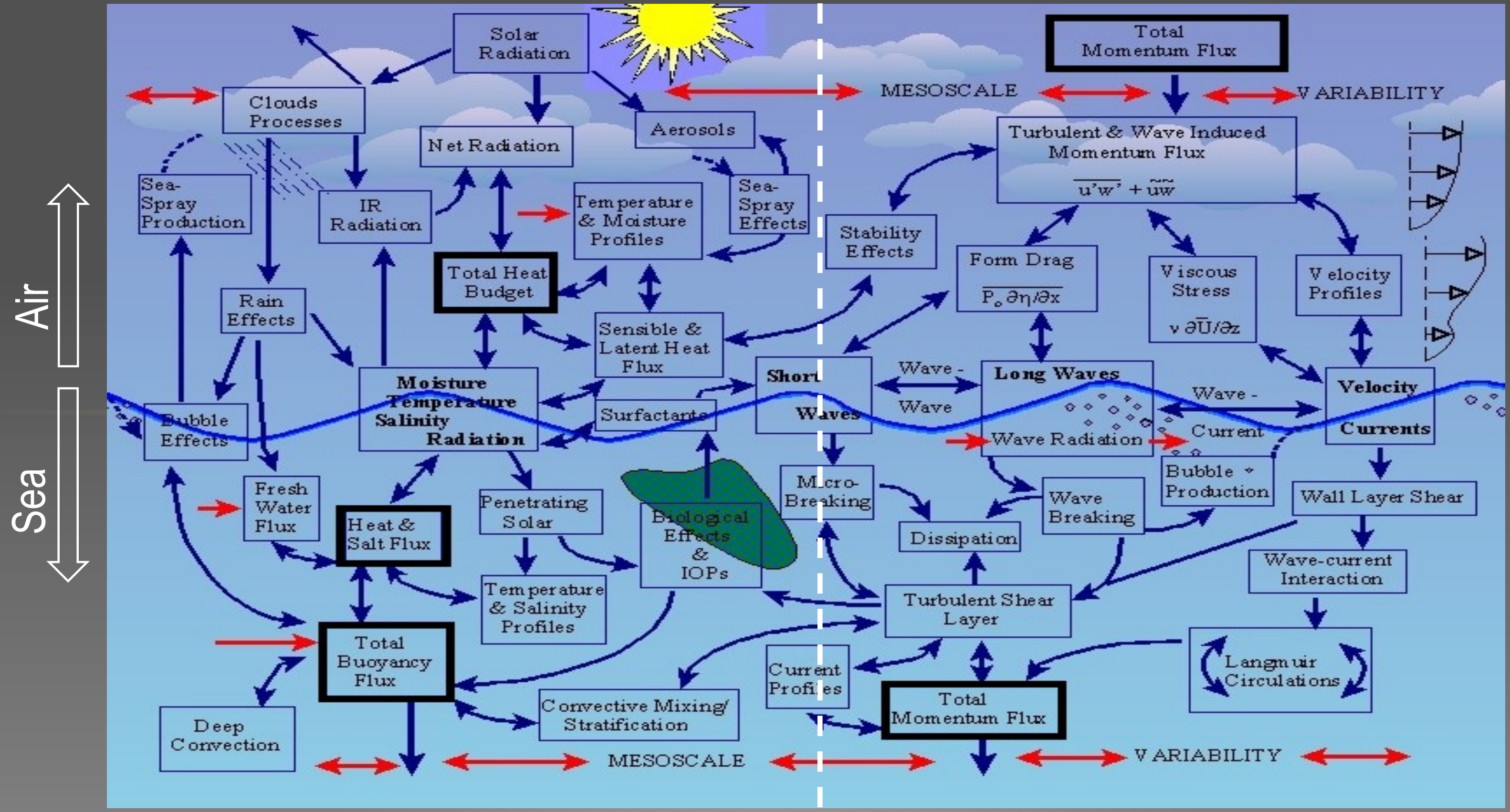
5. The key for coupled modeling is in the fluxes.

   A weather model with a fixed or climatological SST is constrained in terms of systematic seasonal and climate shifts. But, in a coupled model, there is no constraint to the ocean state and also to the weather model. Hence, spurious drifts of the SST and mixed layer in general in the ocean will result in spurious drifts in the weather model, with a strong possibility of (nonlinear) feedback.

6. Developing a coupled model is a cyclic process:
   - First emphasis on getting the ocean right.
   - In the process, many issues with HWRF were revealed.
     - Not necessarily major issues, but critical for realistic coupling with a realistic ocean model.
     - Climatology based ocean model component appears less sensitive to these errors as ocean responses are suppressed to gain a more robust system.
   - Fixes and updates require a revisit to make sure that all ocean responses are realistic.
   - … and this will never stop…

9. Future Plans for Improvement of TC forecastings

Processes in the Air-Sea Interface



http://www.whoi.edu/science/AOPE/dept/CBLASTmain.html

This is a simplified version of reality!

9. Future Plans for Improvement of TC forecastings

3-way coupling HWRF-HYCOM-WW3

1. HWRF:

a) Surface stress modified by effects of sea state, directionality of wind and wave, and surface currents

2. WAVEWATCH III (WW3):

a) Forced by sea-state dependent wind stress, including effects of ocean currents

3. HYCOM:

a) Forced by sea-state dependent wind stress, modified by growing/ decaying waves and Coriolis-Stokes forcing

b) Turbulent mixing modulated by the Stokes drift (Langmuir turbulence)

Data Assimilation in a coupled framework

Currently GSI for HWRF, and NCODA for HYCOM, in separate.