Evaluating Medium-Range Tropical Cyclone Forecasts

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Objectives

- Develop appropriate verification framework
- Evaluate medium-range tropical cyclone (TC) forecasts
- Relate results (biases) to physical parameterizations

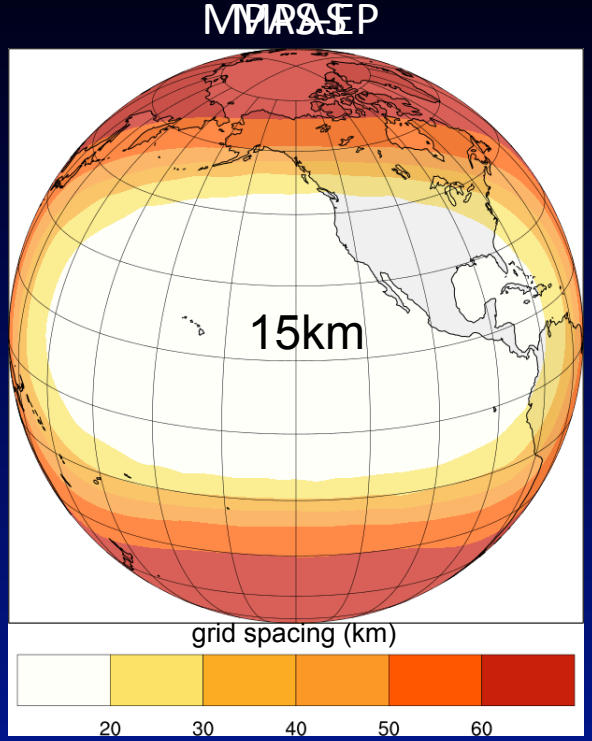
Models and Configurations

MPAS

- Uniform MPAS 15-km
- Variable MPAS-EP 60-15 km
- 00 UTC initializations
- Aug 1 – Nov 3, 2014 (95 cases)

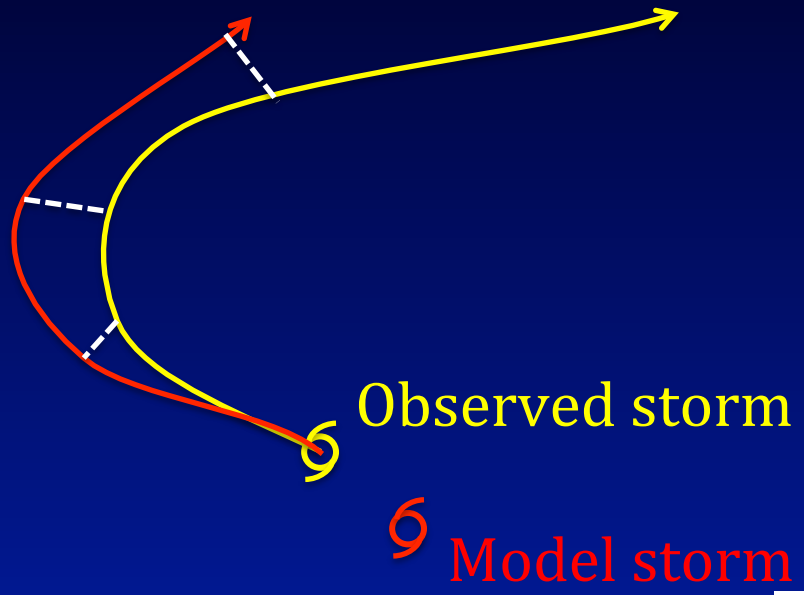
NCEP Global Forecast System (GFS)

- 27 km
- 00, 06, 12, 18 UTC



TC Verification: Identifying matching tracks

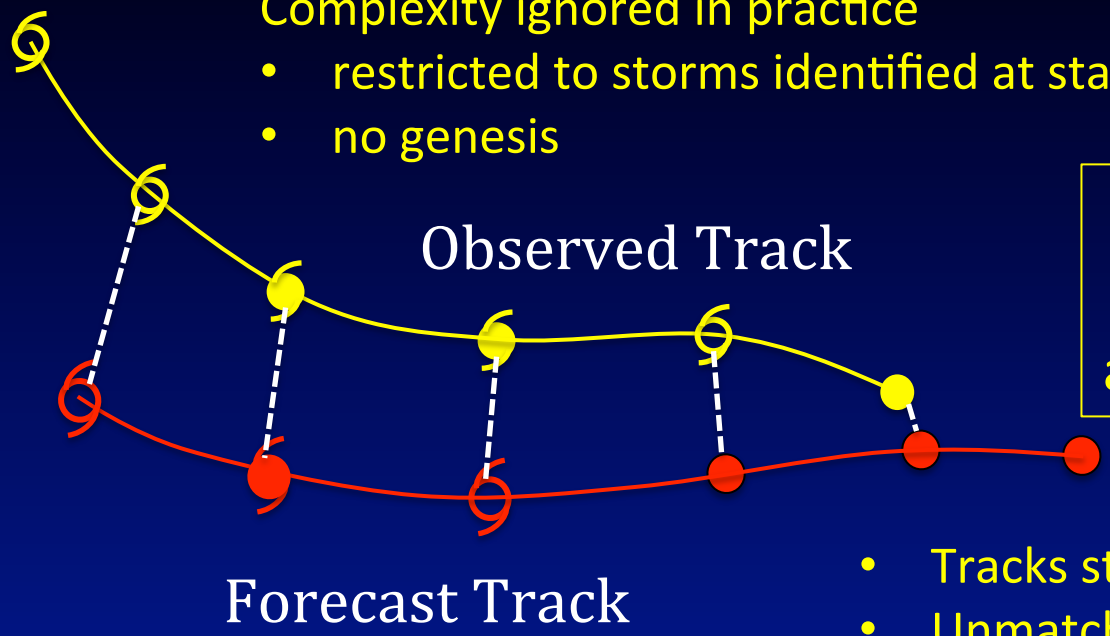
- Observed storm given in TC Vitals
  - Location Imposed in Model
- Track & Intensity errors



TC Verification: Identifying matching tracks

Complexity ignored in practice

- restricted to storms identified at start of forecast
- no genesis



How does one handle all possibilities to assess forecast quality?

- Tracks start and end at different times
- Unmatched times ignored
- Differing intensities
- Storm tracks generally diverge

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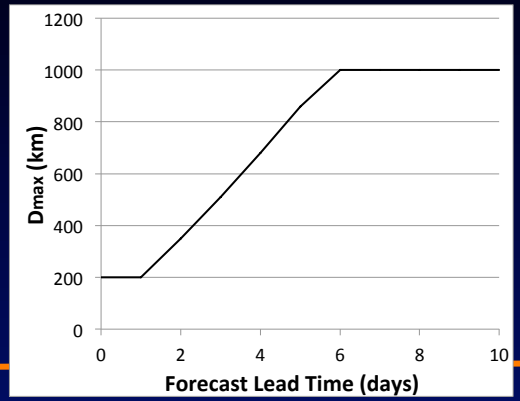
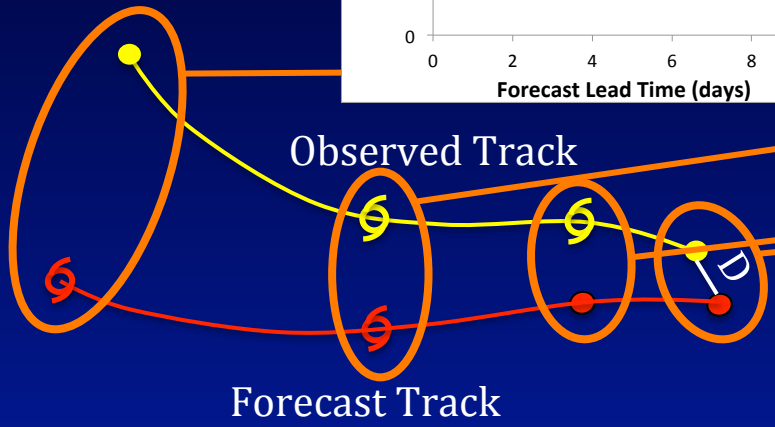
TC Verification: 2x2 Contingency Table





		Observation	
		Y	*N*
Forecast	*Y*	*YY*	*YN*
	N	*NY*	*NN*

Y $v_{max} \geq V$

N $0 < v_{max} < V$

Heidke Skill Score

		Observation	
		Y	*N*
Forecast	*Y*	*YY*	*YN*
	N	*NY*	*NN*

Heidke Score:
(Doswell et al. 1990, WaF)

$$S = \frac{C - E}{T - E}$$

Correct Forecasts:

$$C = YY + NN$$

E = Correct forecasts due to chance

T = Total number of pairs

In the limit of rare events (*NN* large):

$$\underset{NN \to \infty}{S} = \frac{YY}{YY + \frac{NY + YN}{2}}$$

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Heidke Skill Score

		Observation	
		Y	*N*
Forecast	*Y*	***YY***	*YN*
	N	*NY*	***NN***

Heidke Score:
(Doswell et al. 1990, WaF)

$$S = \frac{C - E}{T - E}$$

Correct Forecasts:

$$C = YY + NN$$

E = Correct forecasts due to chance

T = Total number of pairs

In the limit of rare events (*NN* large):

$$\underset{NN \to \infty}{S} = \frac{YY}{YY + \frac{NY + YN}{2}}$$

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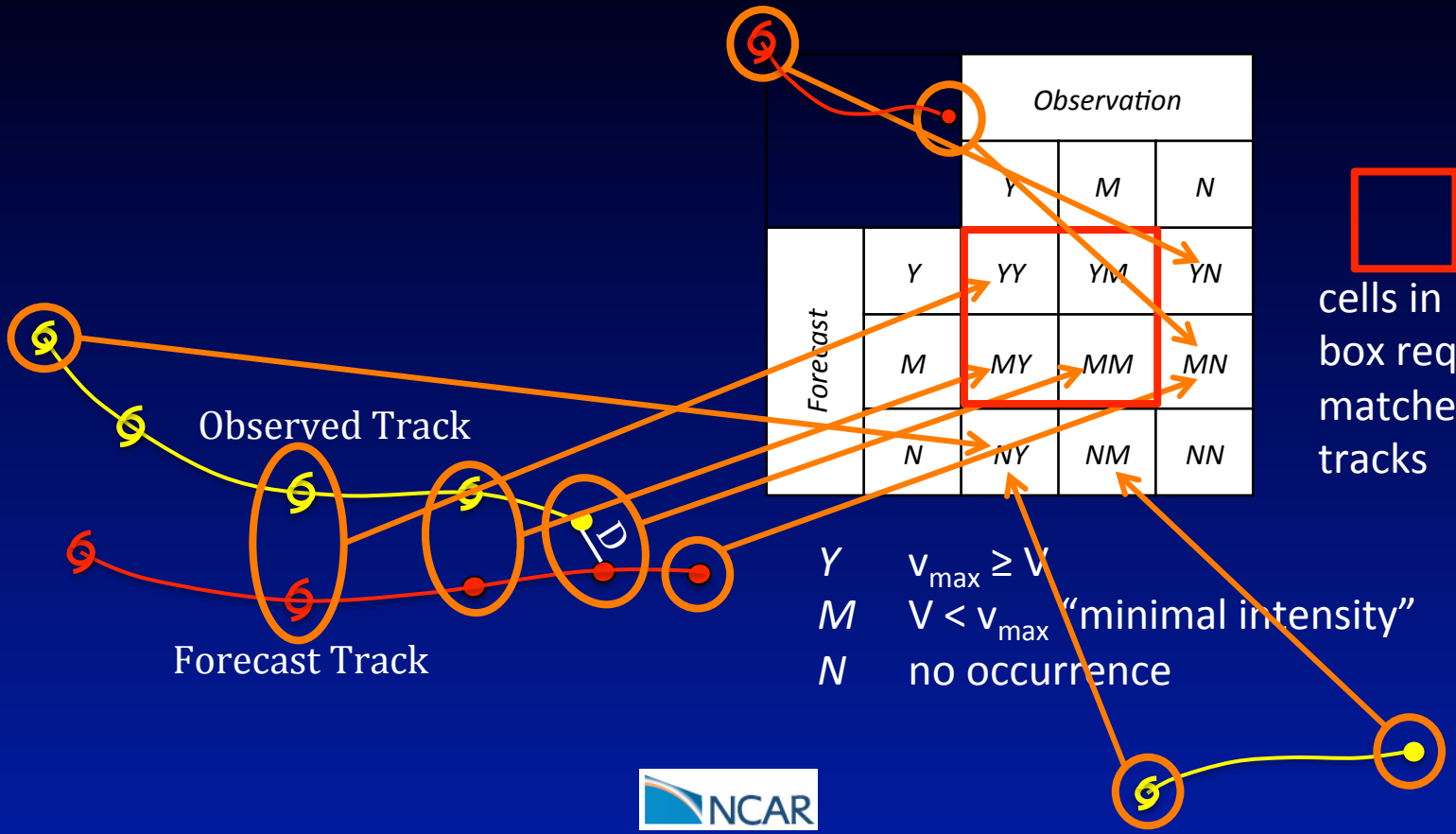
TC Verification: Multiple Categories



Heidke Skill Score: 3x3 Contingency Table

		Observation		
		Y	M	N
Forecast	Y	YY	YM	YN
	M	MY	MM	MN
	N	NY	NM	NN

Heidke Score: *(Doswell et al. 1990, WaF)*

$$S = \frac{C - E}{T - E}$$

Correct Forecasts: $C = YY + MM + NN$

E = Correct forecasts due to chance

T = Total number of pairs

In the limit of rare events (NN large):

$$\underset{NN \to \infty}{S} \to \frac{YY + MM + \frac{YM + MY}{2}}{YY + YM + MY + MM + \frac{NY + NM + YN + MN}{2}}$$

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Heidke Skill Score: 3x3 Contingency Table

		Observation		
		Y	M	N
Forecast	Y	**YY**	YM	YN
	M	MY	**MM**	MN
	N	NY	NM	**NN**

Heidke Score: *(Doswell et al. 1990, WaF)*

$$S = \frac{C - E}{T - E}$$

Correct Forecasts: $C = YY + MM + NN$

E = Correct forecasts due to chance

T = Total number of pairs

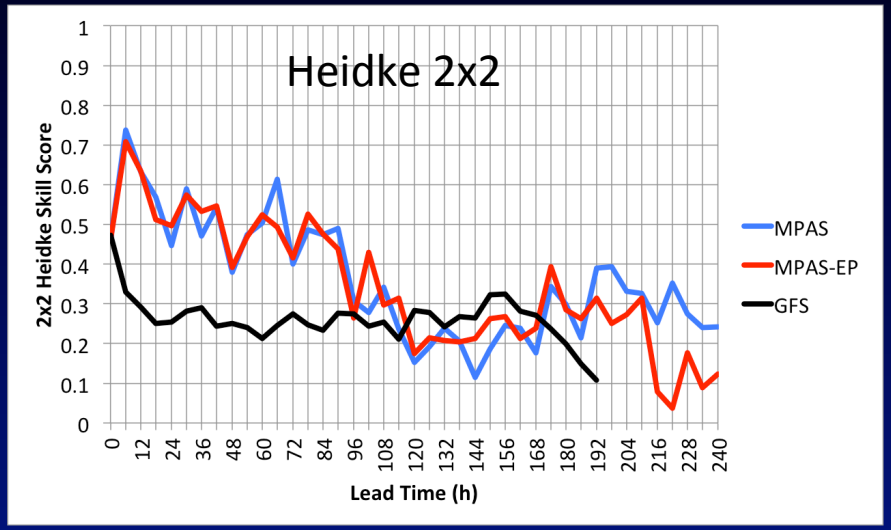
In the limit of rare events (NN large):

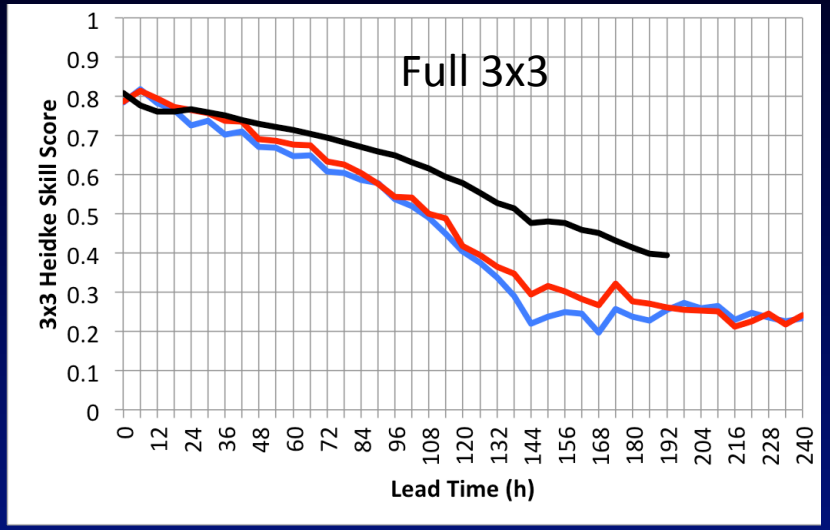
$$\underset{NN \to \infty}{S} \to \frac{YY + MM + \frac{YM + MY}{2}}{YY + YM + MY + MM + \frac{NY + NM + YN + MN}{2}}$$

partial credit!

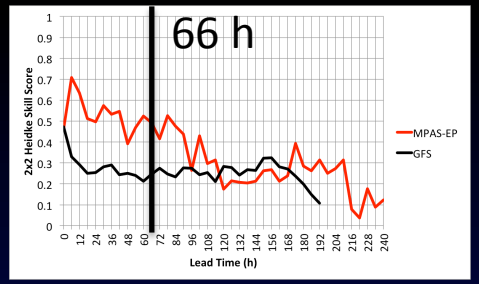
Heidke Skill Scores (for hurricane threshold)

E Pac 2014





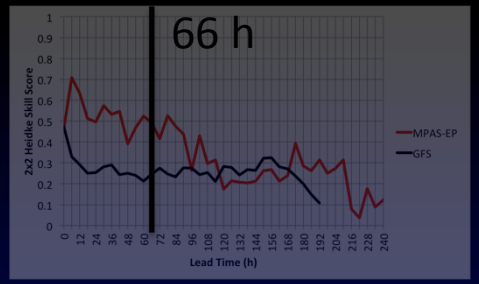
- MPAS better discriminates hurricanes through 90 h
- GFS skill greater overall

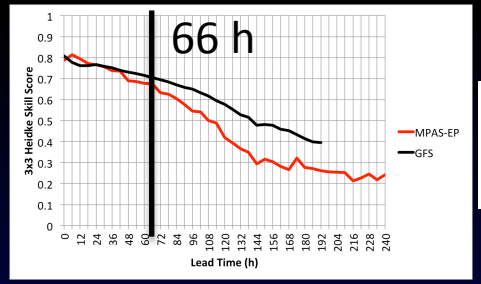


$$S = \frac{YY + NN - E}{YY + YN + NY + NN - E}$$

MPAS-EP		Observation	
		Y	N
Forecast	Y	17	3
	N	19	76

GFS		Observation	
		Y	N
Forecast	Y	7	1
	N	27	72





$$\underset{NN\to\infty}{S} \to \frac{YY + MM + \frac{YM + MY}{2}}{YY + YM + MY + MM + \frac{NY + NM + YN + MN}{2}}$$

MPAS-EP		Observation		
		Y	M	N
Forecast	Y	17	3	1
	M	19	76	62
	N	0	17	900

GFS		Observation		
		Y	M	N
Forecast	Y	7	1	0
	M	27	72	31
	N	1	21	936

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Summary

- Developed verification methodology appropriate for medium range TC forecasts
  - accounts for genesis and dissipation
  - partial credit for matching but wrong intensity
  - penalizes unmatched false alarms and misses
- Results of comparisons
  - Variable- and uniform-resolution MPAS performed similarly
  - GFS and MPAS similar through day 3-4: suggests “physics” exerts importance after this time
  - Excessive cross-equatorial flow in 2014: relation to E. Pac. genesis

$$HSS = \frac{C - E}{T - E}$$

$$\begin{matrix} a & b & c \\ d & e & f \\ g & h & i \end{matrix}$$

$$C = a + e + i$$

$$T = a + b + c + d + e + f + g + h + i$$

$$HSS = \frac{a + e + i - E}{a + b + c + d + e + f + g + h + i - E}$$

$$E = \frac{\sum F_Y \sum O_Y + \sum F_M \sum O_M + \sum F_N \sum O_N}{T}$$

$$E = \frac{(a+b+c)(a+d+g) + (d+e+f)(b+e+h) + (g+h+i)(c+f+i)}{T}$$

$$E = \frac{a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2}{T}$$

$$HSS = \frac{a + e + i - \frac{a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2}{T}}{T - \frac{a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2}{T}}$$

$$HSS = \frac{T(a+e+i) - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}{T^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}$$

$$HSS = \frac{a^2 + ab + ac + ad + 2ae + af + ag + ah + 2ai + be + ce + de + e^2 + ef + eg + eh + 2ei + bi + ci + di + fi + gi + hi + i^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}{T^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}$$

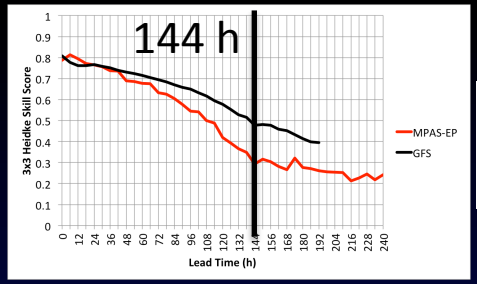
$$HSS = \frac{2ae + af + ah + 2ai + ce + eg + 2ei + bi + di - (bd + bg + cd + cg + bd + dh + bf + fh + cg + fg + ch + fh)}{T^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}$$

$$HSS = \frac{2ae + af + ah + 2ai + ce + eg + 2ei + bi + di - 2bd - bg - cd - 2cg - dh - bf - 2fh - fg - ch}{T^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}$$

$$HSS(\lim i \to \infty) = \frac{2a + 2e + b + d}{\frac{T^2 - (a^2 + ad + ag + ab + bd + bg + ac + cd + cg + bd + de + dh + be + e^2 + eh + bf + ef + fh + cg + fg + gi + ch + fh + hi + ci + fi + i^2)}{i}}$$

$$HSS(\lim i \to \infty) = \frac{2a + 2e + b + d}{\frac{ab + ac + ad + 2ae + 2af + ag + 2ah + 2ai + b^2 + be + bf + bg + 2bh + 2bi + c^2 + cd + 2ce + 2cf + ch + ci + d^2 + de + 2df + 2dg + dh + 2di + ef + 2eg + eh + 2ei + f^2 + fg + fi + g^2 + 2gh + gi + h^2 + hi}{i}}$$

$$HSS(\lim i \to \infty) = \frac{2a + 2e + b + d}{2a + 2b + c + 2d + 2e + f + g + h} = \frac{a + e + \frac{b+d}{2}}{a + b + d + e + \frac{c+f+g+h}{2}}$$



$$\underset{NN\to\infty}{S} \to \frac{YY + MM + \frac{YM + MY}{2}}{YY + YM + MY + MM + \frac{NY + NM + YN + MN}{2}}$$

MPAS-EP		*Observation*		
		Y	*M*	*N*
Forecast	*Y*			
	M			
	N			

GFS		*Observation*		
		Y	*M*	*N*
Forecast	*Y*			
	M			
	N			

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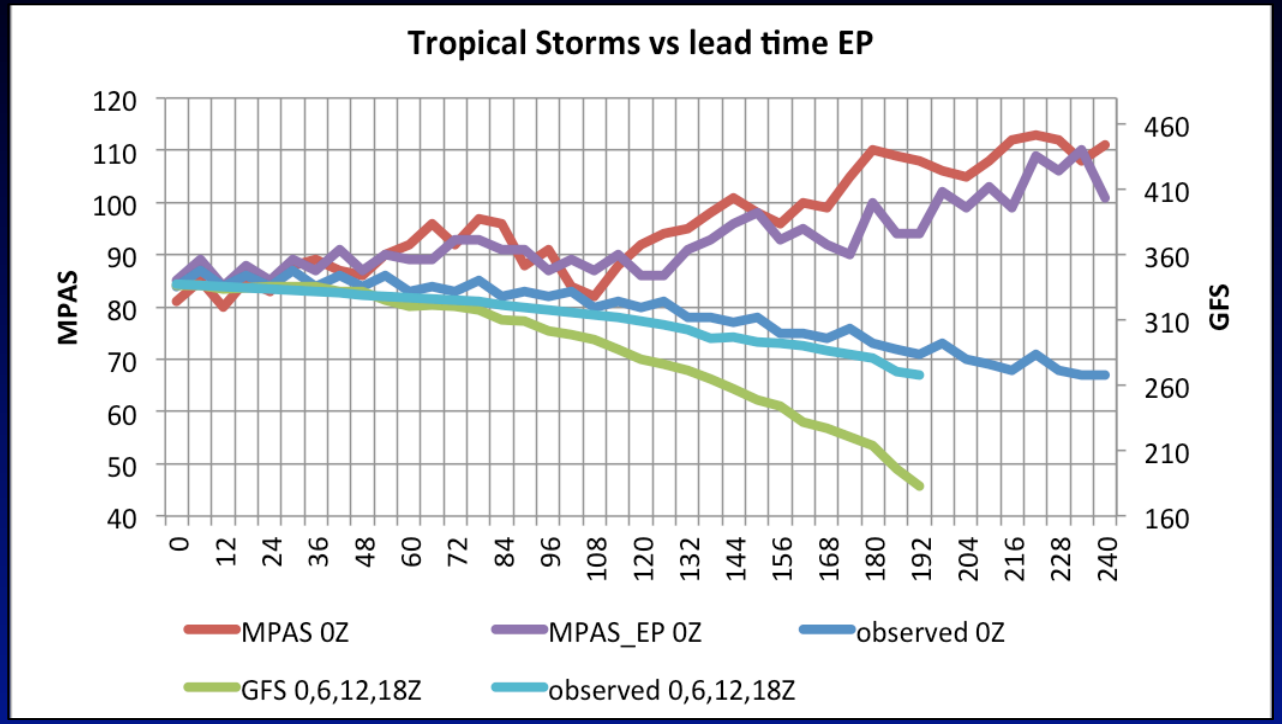
TC Counts

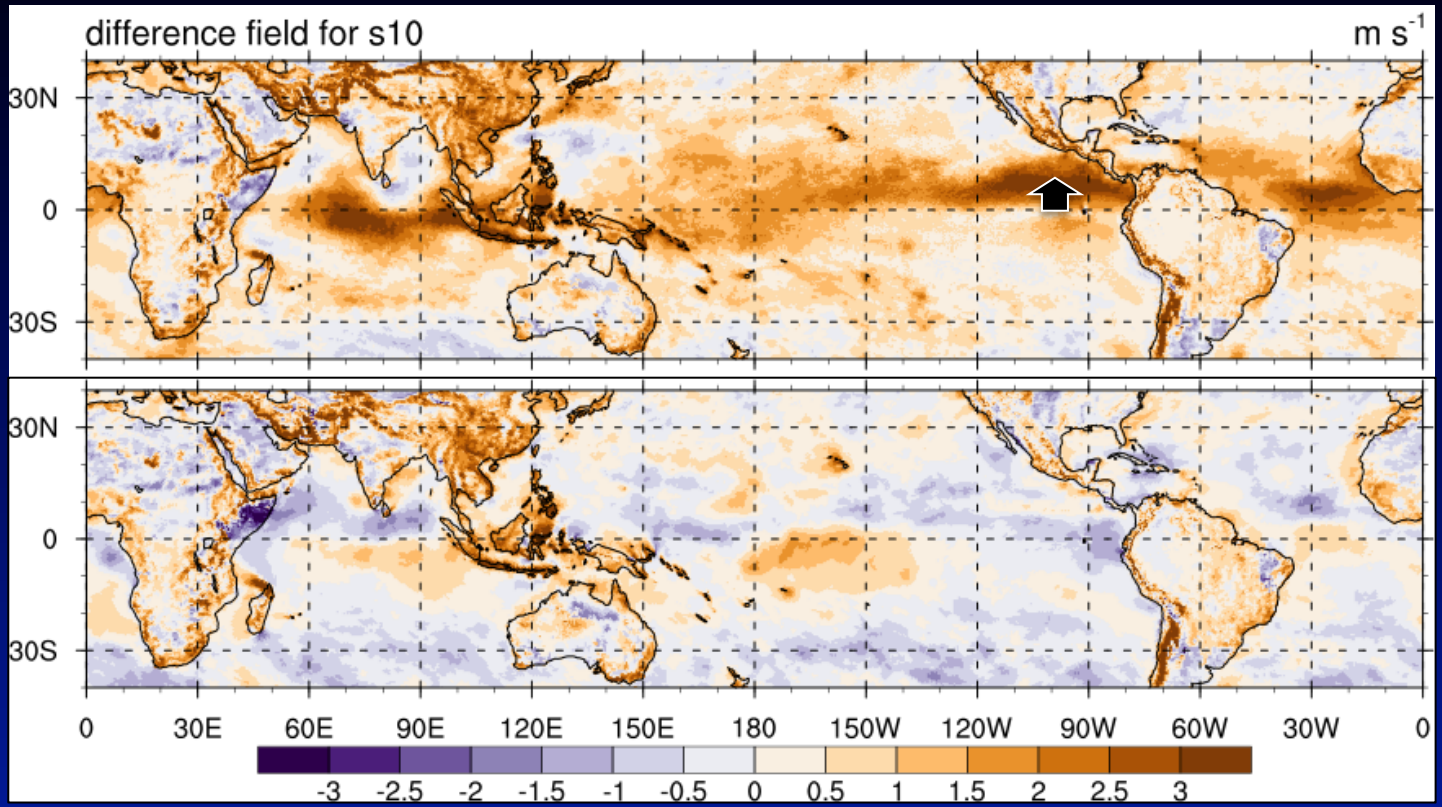
- Too many TCs in MPAS
- Too Few in GFS
- (00 Z GFS similar to all cycles)



Surface Wind Bias (5-day forecast)

2014
Bias in cross-equatorial flow

2015
Modified Tiedtke Scheme



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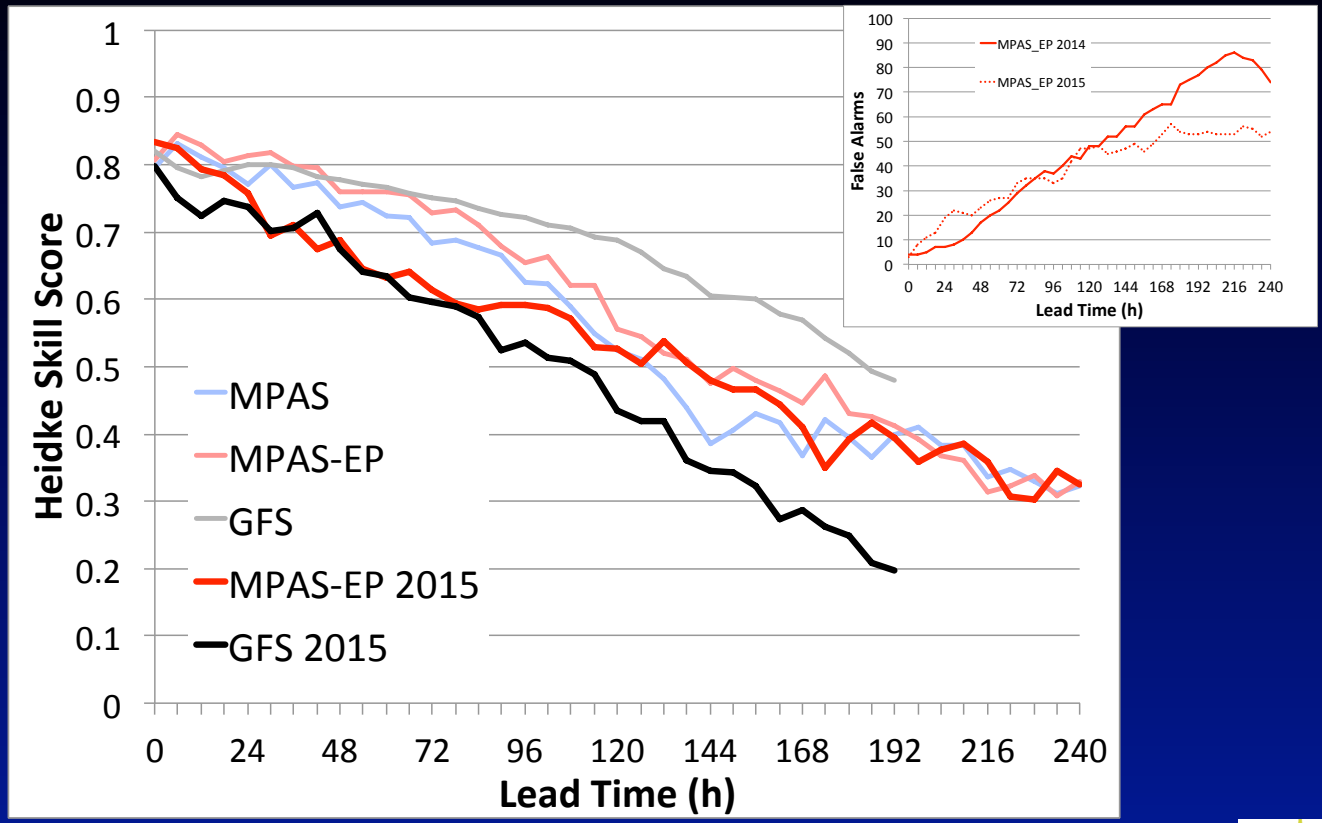
Comparison of 2014 and 2015: Skill Scores

- Notable decrease in skill for GFS in 2015
- Decrease at shorter time ranges in both models



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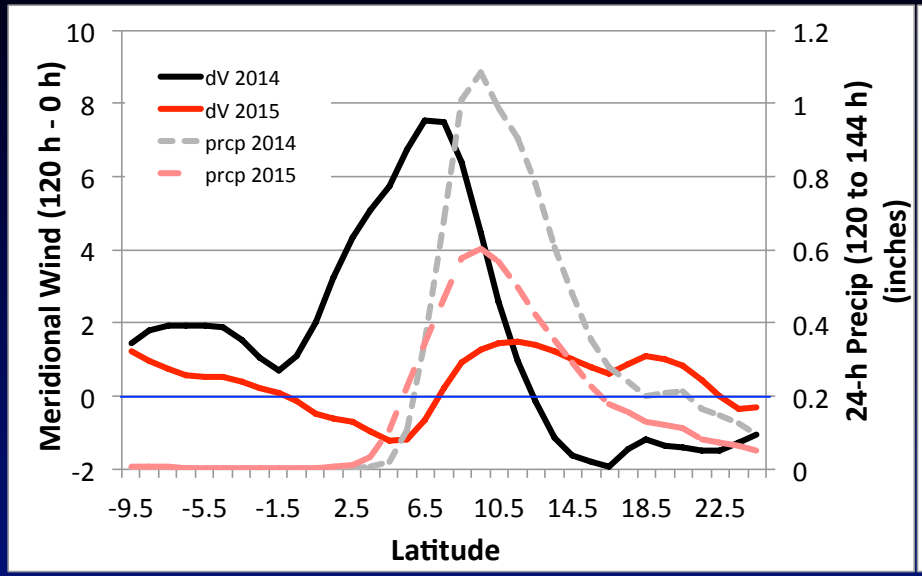
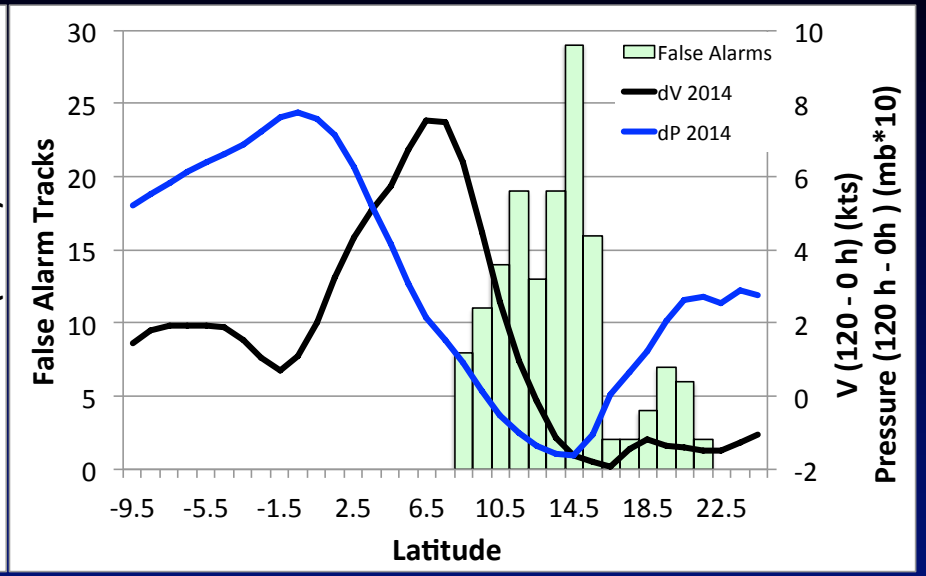
Further Analysis of Bias in 2014

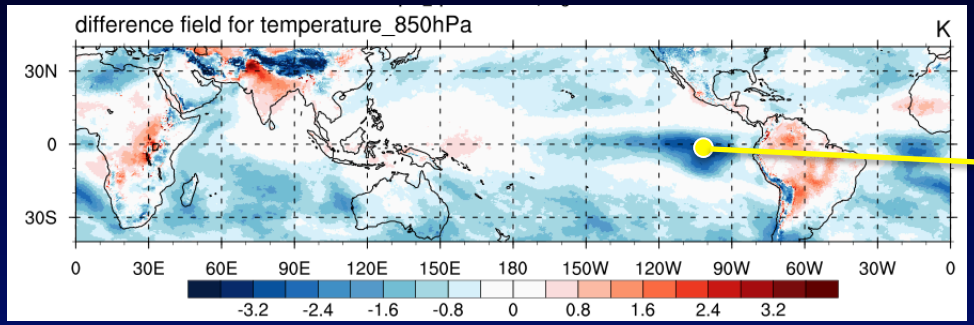


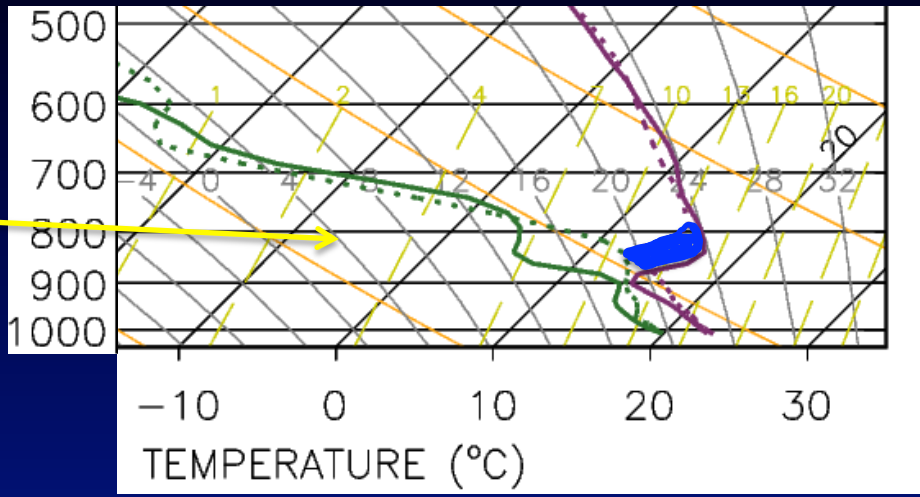


- Excessive cross-equatorial flow (2014)
- Bias in surface fluxes (not shown)
- High bias in convergence and rainfall

- High bias in SH pressure
- False alarms in phase with convergence, increase of Coriolis force

Shallow convection: Cross-Hemisphere Influence





- Cold anomaly at 850 hPa is associated with erroneous lifting/weakening of inversion
- Hydrostatic pressure increase (negative PV anomaly)

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Summary

- Developed verification methodology appropriate for medium range TC forecasts
- Results of comparisons
  - GFS and MPAS similar through day 3-4: suggests “physics” exerts importance after this time
  - MPAS with modified Tiedtke shows improvement over GFS (new in 2015)
  - Excessive cross-equatorial flow in 2014: relation to E. Pac. genesis
  - Variable- and uniform-resolution MPAS performed similarly

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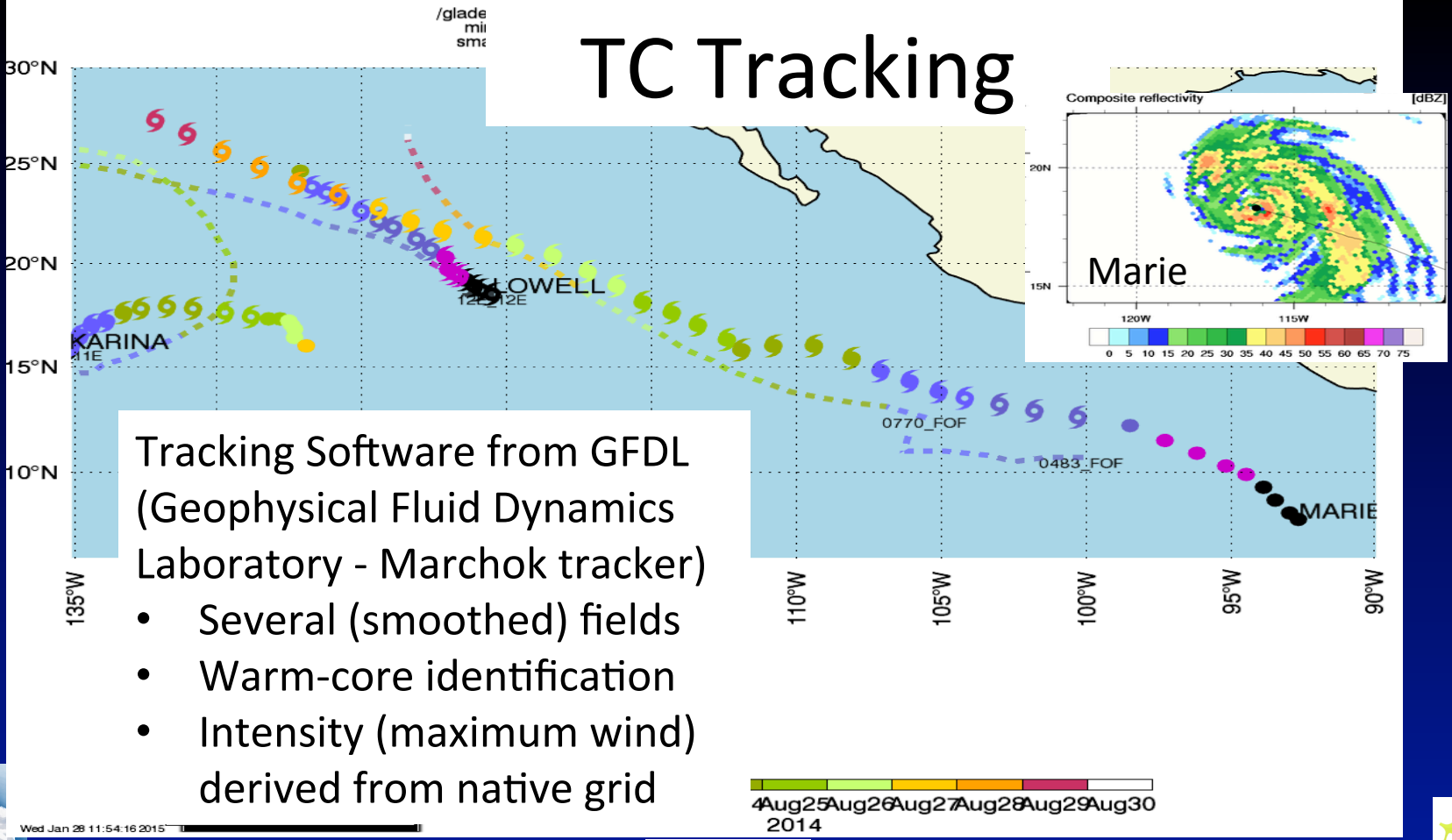
TC Tracking

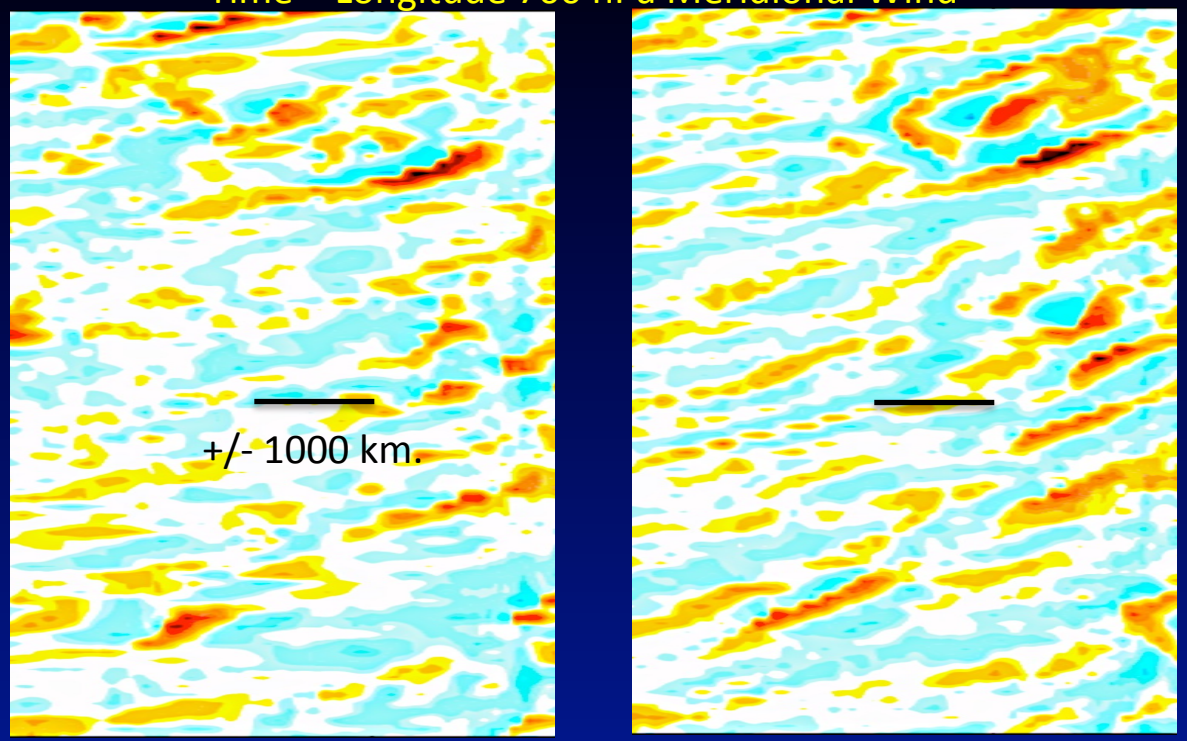


Tracking Software from GFDL (Geophysical Fluid Dynamics Laboratory - Marchok tracker)

- Several (smoothed) fields
- Warm-core identification
- Intensity (maximum wind) derived from native grid

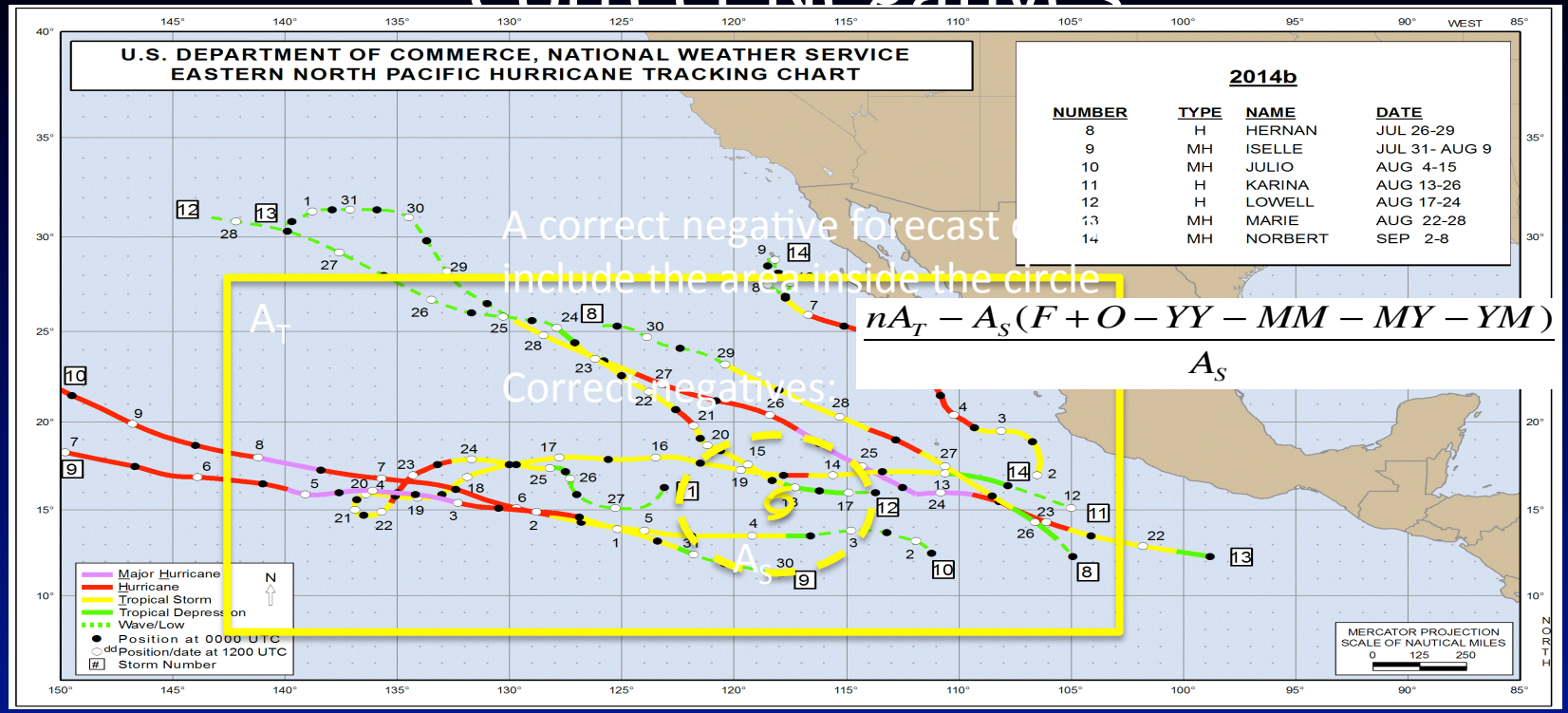
Rationale for $D_{max}(t)$

- TCs slaved to tropical waves
- Wave trough errors grow in fcst.
- Largest NHC fcst. errors provide quantitative bound
- half-wavelength > 1000 km



Courtesy of Tom Galarneau, Univ. of Arizona

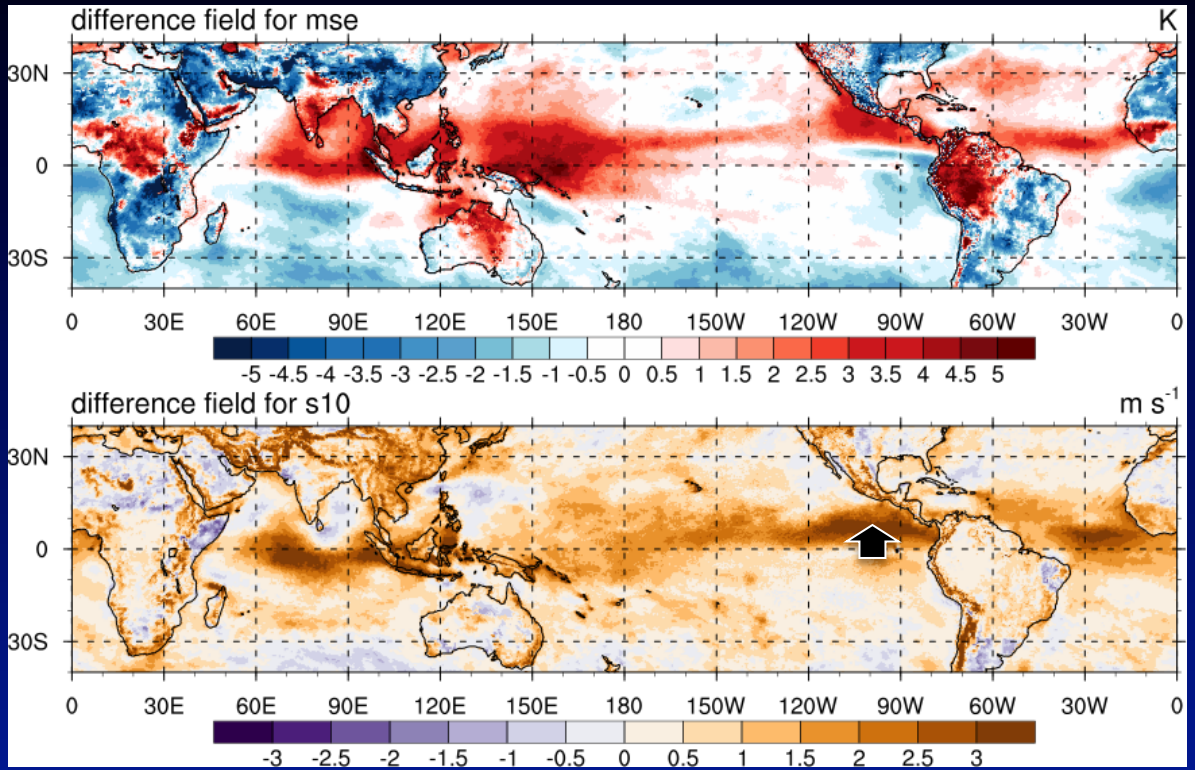
Correct Negatives



Biases at day 5 (MPAS-EP)

(Moist Static Energy)/Cp (K)

10-m wind speed (m/s)



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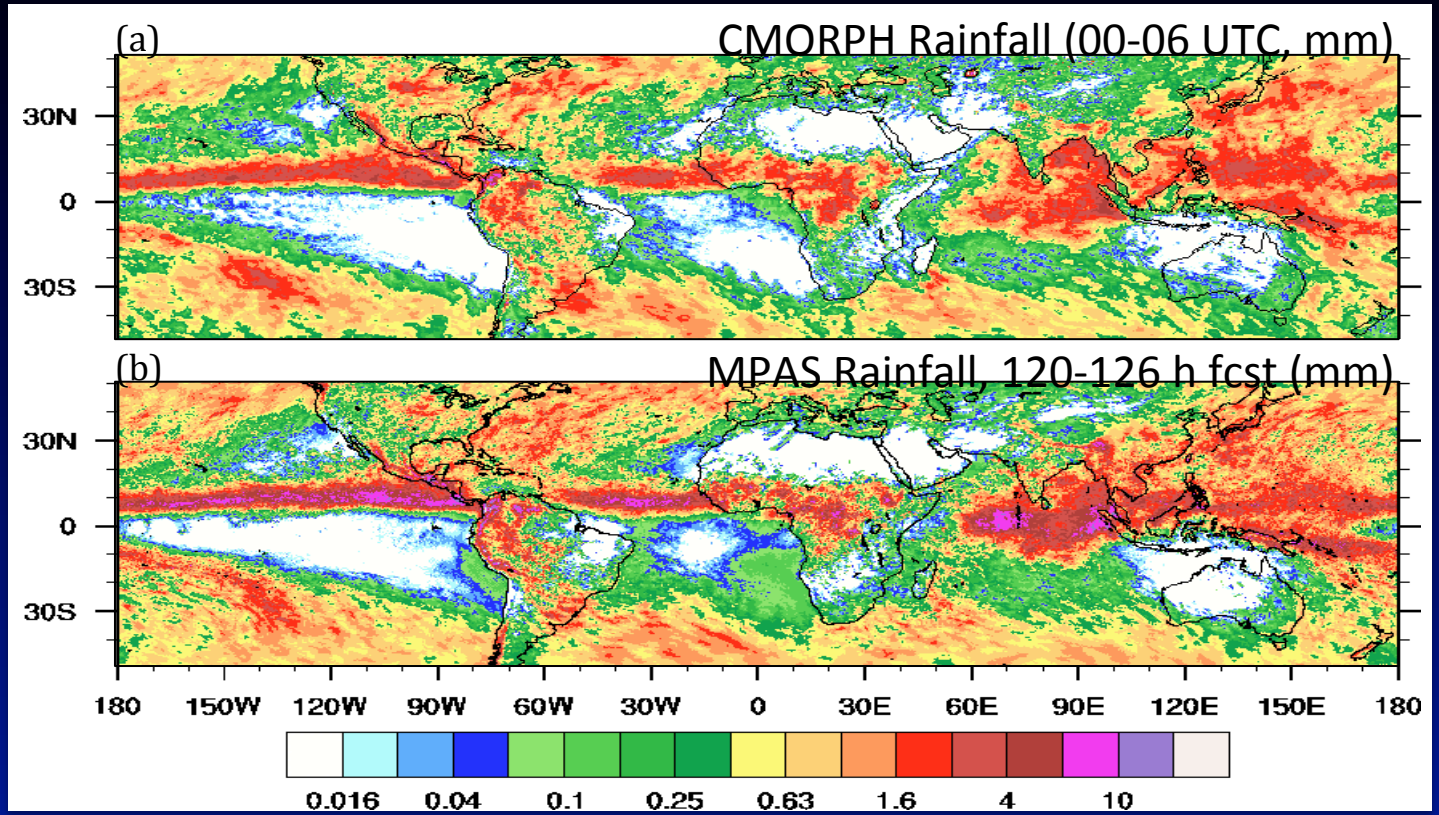
Rainfall



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