Another Look At Maximum Potential Intensity Estimates for Tropical Cyclones

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Maximum Potential Intensity

- Two main thermodynamic theories
  - Carnot heat engine (Emanuel 1986; 1991; 1995)
    - Acquire enthalpy from the ocean
    - Convert to wind energy
    - Function of sea surface and storm outflow temperature
    - Calculates MPI in as a maximum surface wind speed
  - Eye subsidence (Miller 1958 and Holland 1996)
    - Requires SST, atmospheric sounding and surface pressure
    - Calculates MPI at a minimum central pressure

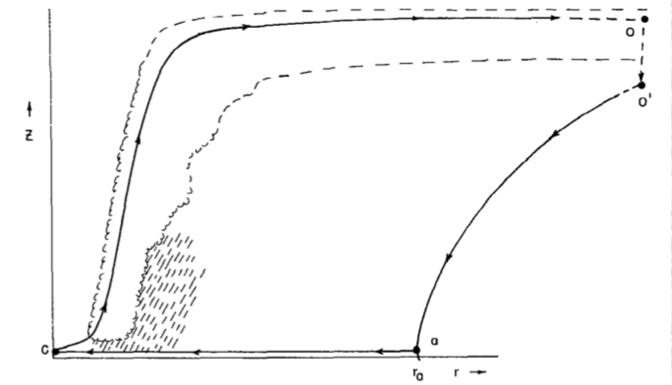


Figure 1 The hurricane Carnot cycle. Air begins spiraling in toward the storm center at point *a*, acquiring entropy from the ocean surface at fixed temperature T_s. It then ascends adiabatically from point *c*, flowing out near the storm top to some large radius, denoted symbolically by point *o*. The excess entropy is lost by export or by electromagnetic radiation to space between *o* and *o′* at a much lower temperature T_o. The cycle is closed by integrating along an absolute vortex line between *o′* and *a*. The curves *c–o* and *o′–a* also represent surfaces of constant absolute angular momentum about the storm's axis.

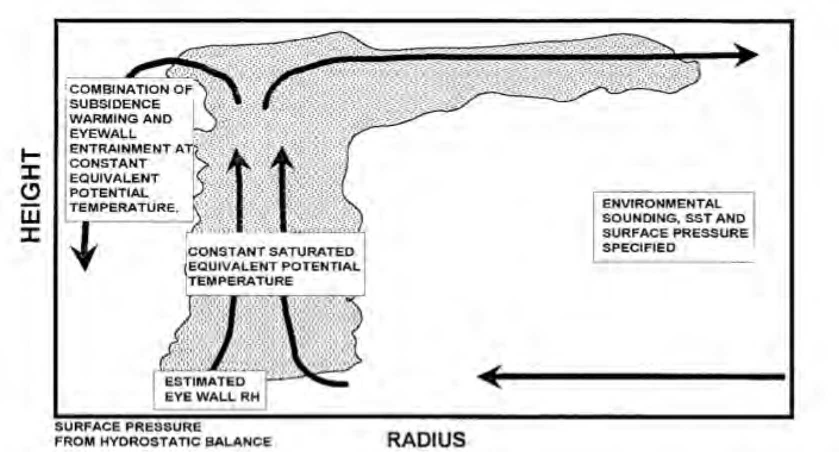


FIG. 2. Schematic of the basic components of the thermodynamic approach to estimating MPI.

Empirical MPI

- Atlantic (DeMaria and Kaplan 1994)
  - Sample from 1962-1992
  - Fit upper bound of climatological SST (least squares, exponential)
  - A = 28.2, B = 55.8, C = 0.1813, T_0 = 30.0 °C
  - T in °C
  - V given in ms-1
- E. Pacific (Whitney and Hobgood 1997)
  - Sample from 1963-1993
  - Fit upper bound of climatological SST (least squares, linear)
  - C_0 = -79.17 ms^{-1}, C_1 = 5.36 ms^{-1}
  - SST in °C
  - EPMPI given in ms^{-1}

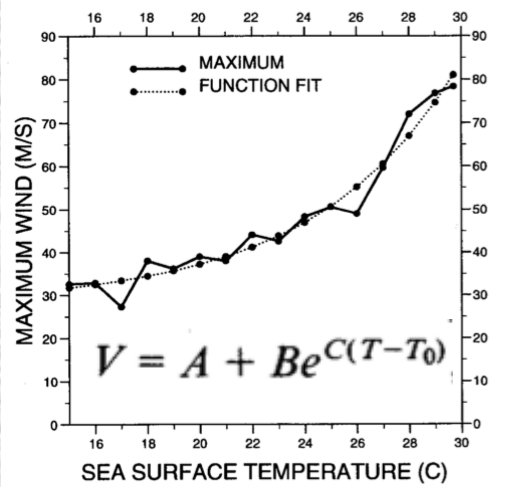


FIG. 2. The observed maximum storm intensity for each 1°C SST group and the least-squares function fit.

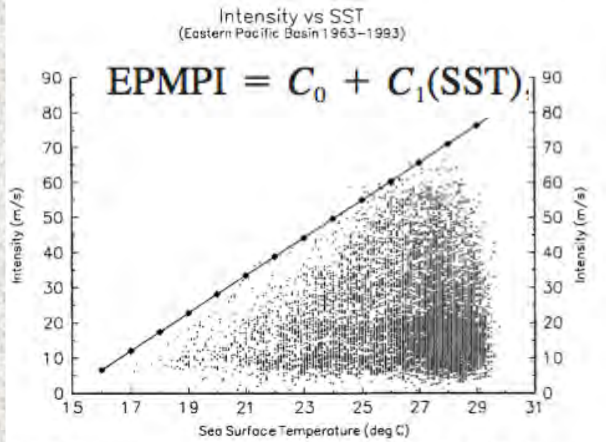
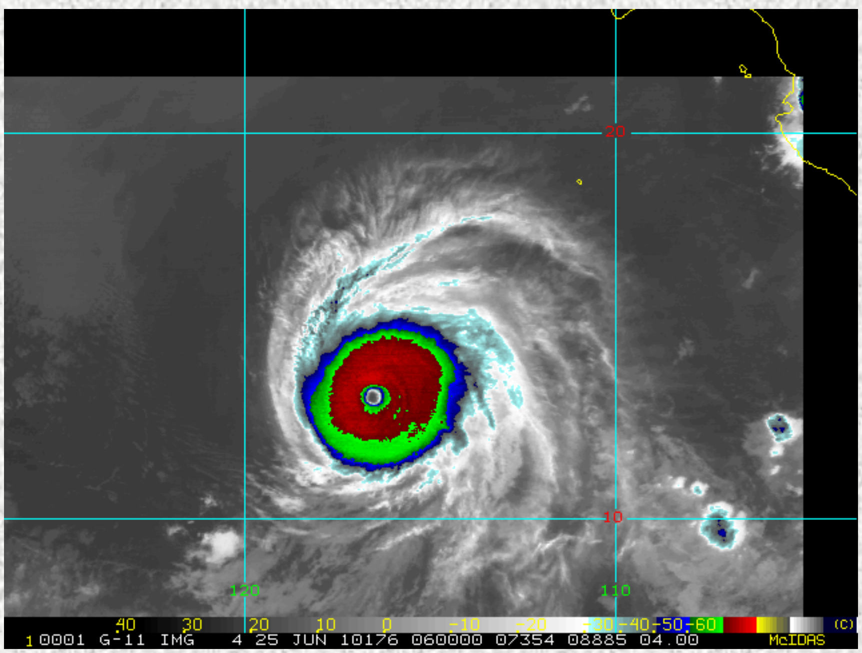
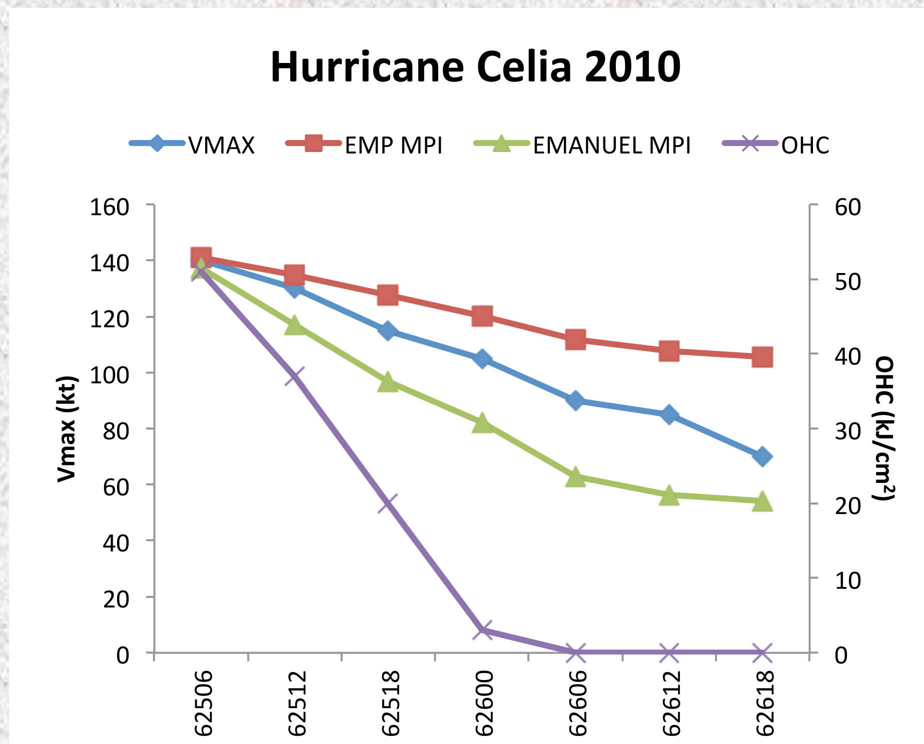


FIG. 4. Comparison of the EPMPI function and all 11 062 observations in the 31-yr sample (1963–93).

Motivation

- MPI provides upper bound to TC intensity – important when estimating and predicting intensity
- Sudden changes in MPI can have drastic impact in TC intensity
- Example: Hurricane Celia 2010 as it passes over low SST/OHC water

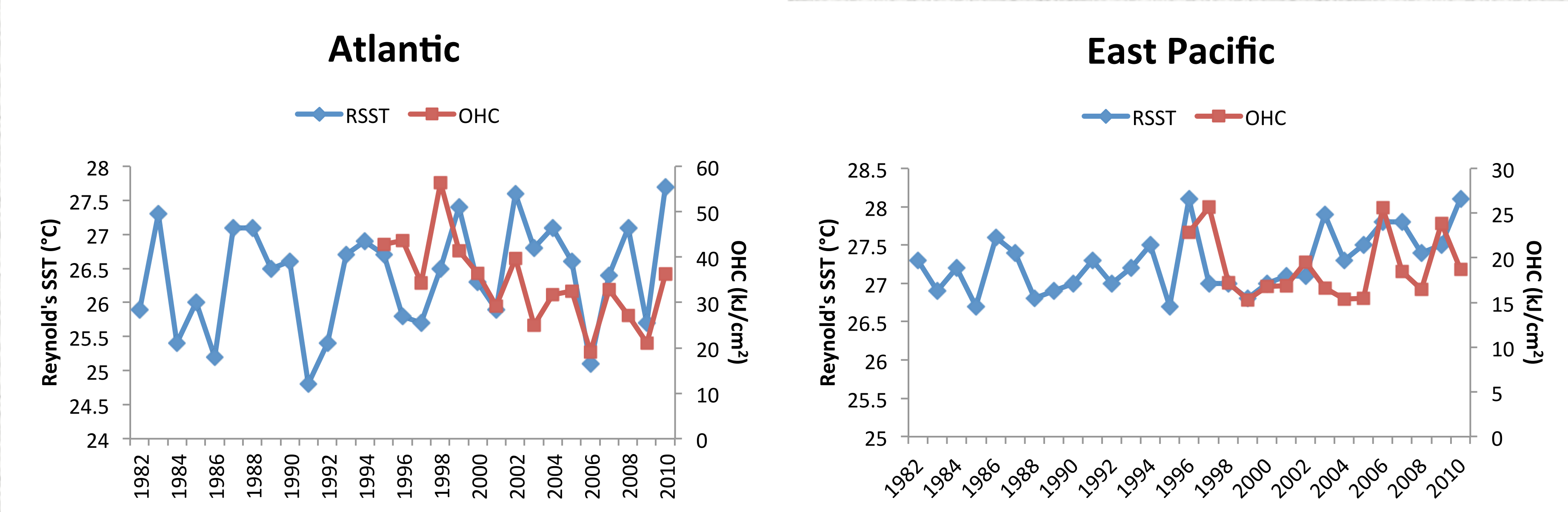




Motivation (cont…)

- Current version of SHIPS uses empirical formulas for MPI in the Atlantic and E. Pacific
  - Pros: Better fit to recent intensity data than theoretical formula, availability (function of SST only)
  - Cons: Fit to relatively small (31-year) sample sets, does not take into account atmospheric changes that likely impact MPI, doesn't consider changes in ocean thermodynamic structure, does not use satellite data (soundings, imagery, altimetry)

Motivation (cont…)

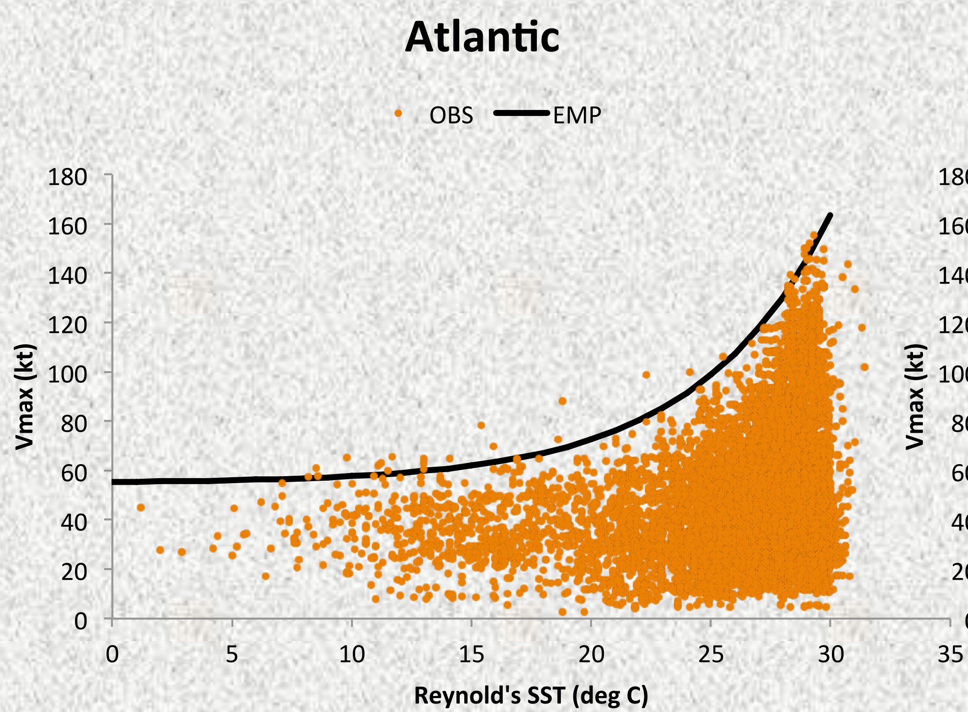


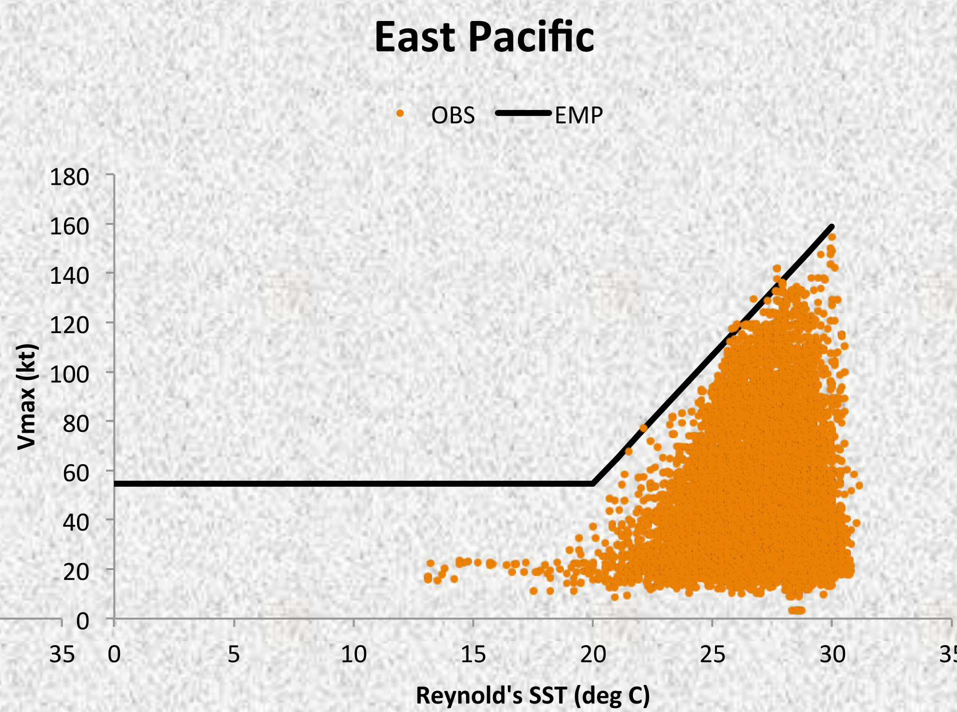
- For example, ocean heat content (OHC, satellite altimetry)
  - Found to influence TC intensity / intensity change
  - Especially important at high OHC values / strong TCs
  - Likely important factor in MPI
  - Not necessarily correlated with SST on longer time scales (above)

Project Goals

- Re-examine SHIPS empirical formulas using 1982-2010 sample set – valid?
- Re-examine use of Emanuel's theoretical MPI in SHIPS
  - Identify strengths / weaknesses
- Create a combined theoretical / empirical formula for MPI in SHIPS
  - Improve MPI by utilizing satellite data (AMSU/ATMS, CrIS, etc)

SHIPS Empirical MPI Validation 1982-2010

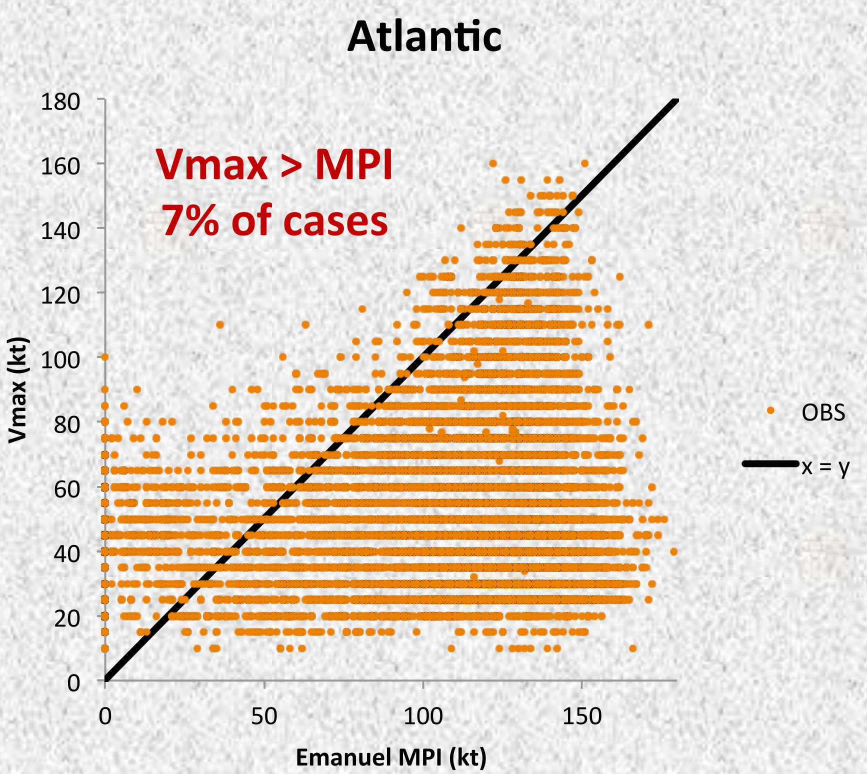


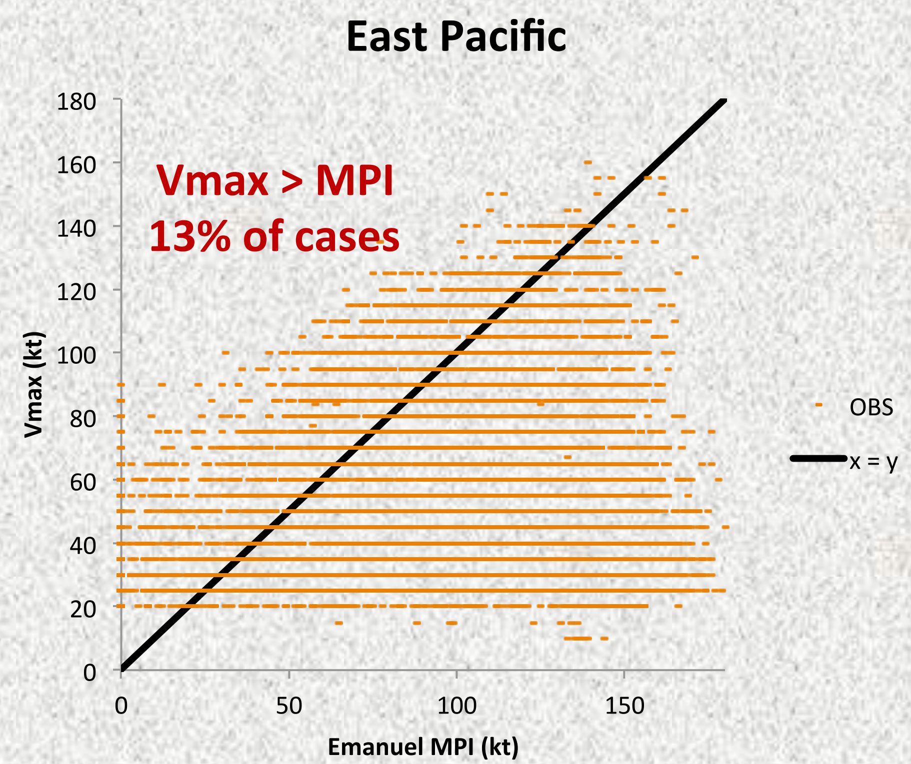


10653 cases total
Vmax > MPI for 30 cases (0.3%)
→ Good upper bound for sample

13003 cases total
Vmax > MPI for 8 cases (0.1%)
→ Good upper bound for sample

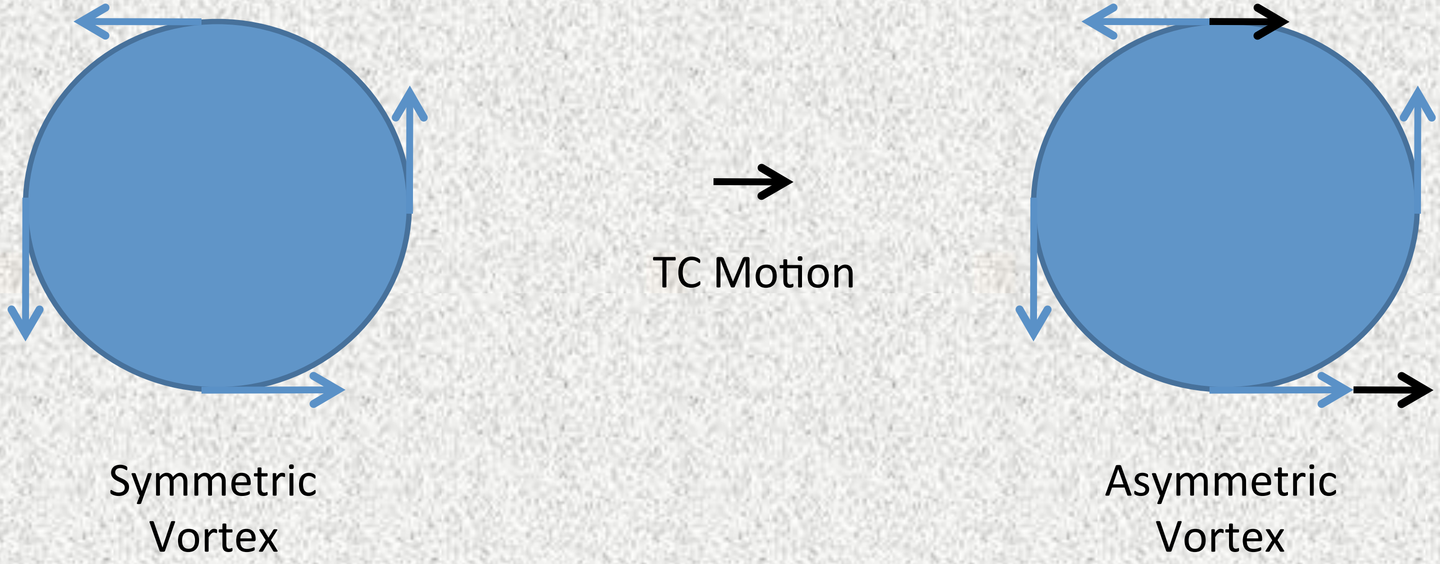
Emanuel MPI in SHIPS 1982-2010





First, try a few simple improvements...

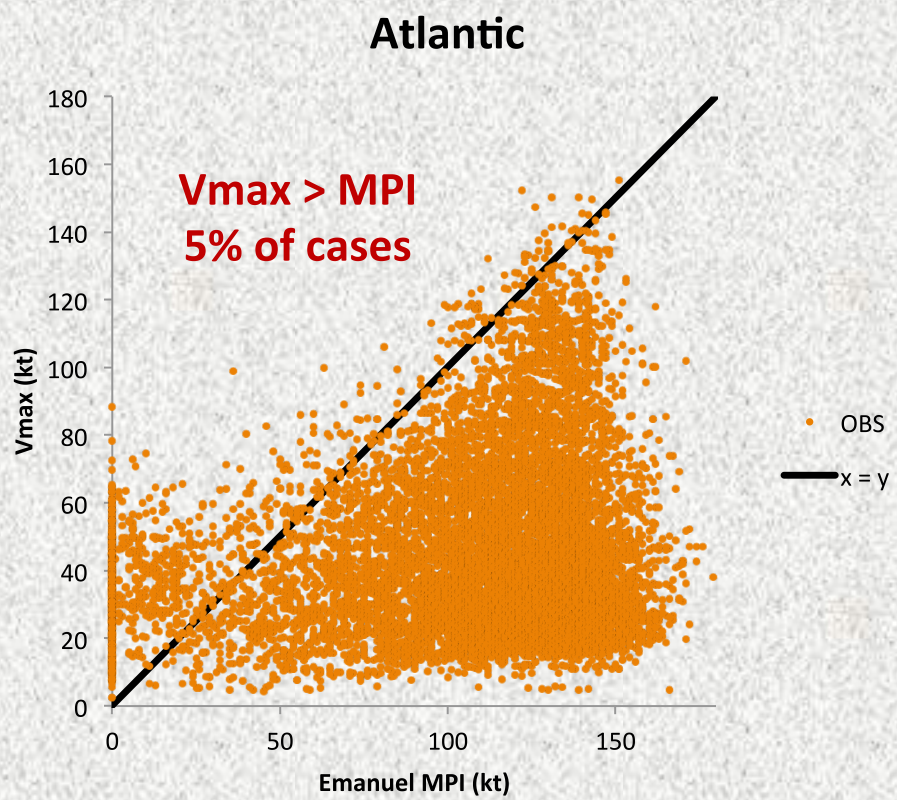
Asymmetry Adjustment

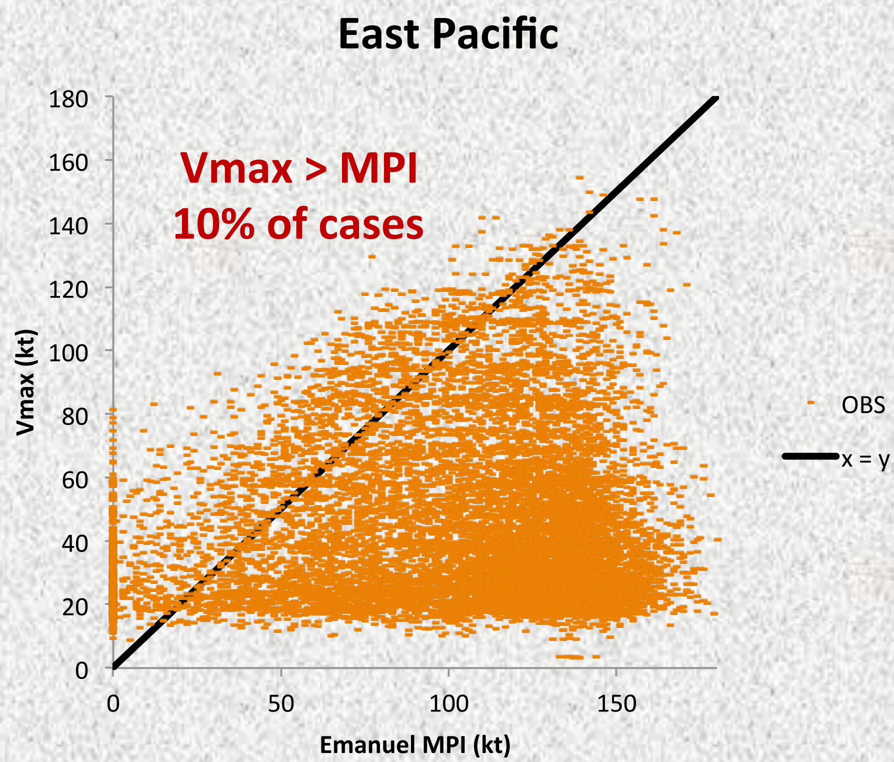


- Vmax includes asymmetric adjustment, MPI does not
- For proper comparison, remove asymmetric component from storm motion

$$\text{Vmax(adjusted)} = \text{Vmax} - 1.5*(\text{TC speed})^{0.63}$$

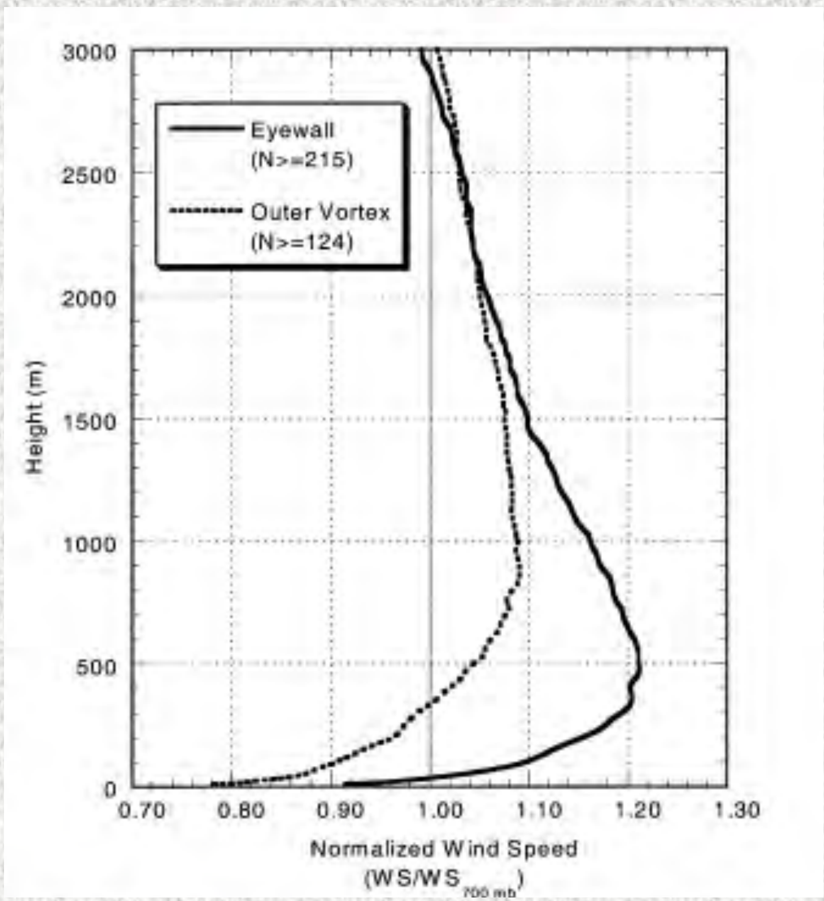
Emanuel MPI + Asymmetry Adjustment



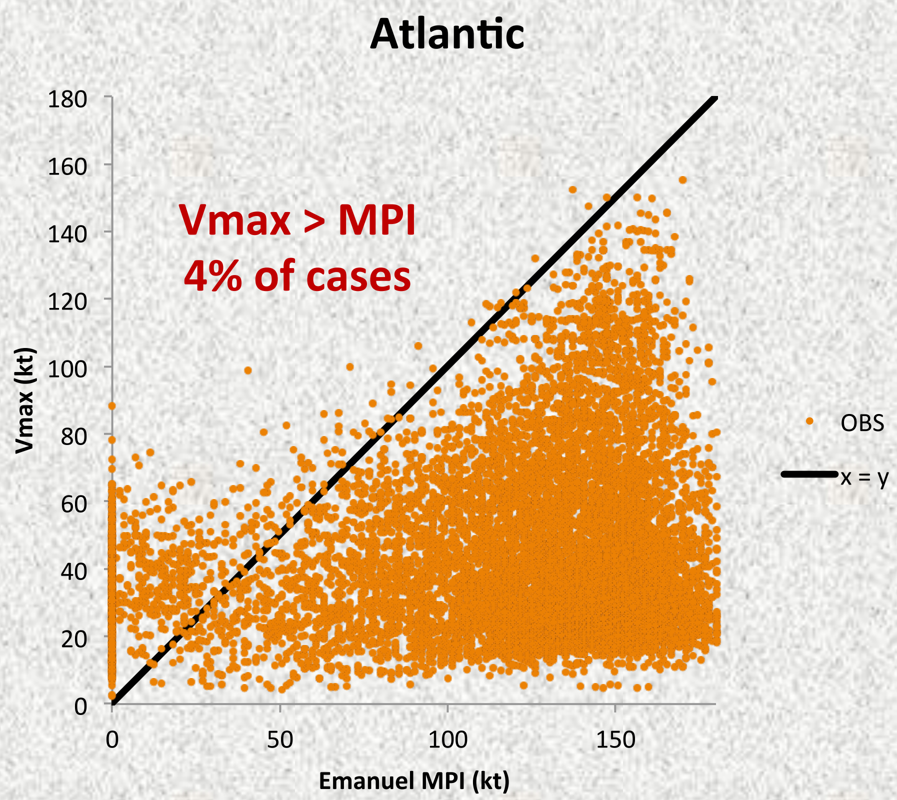


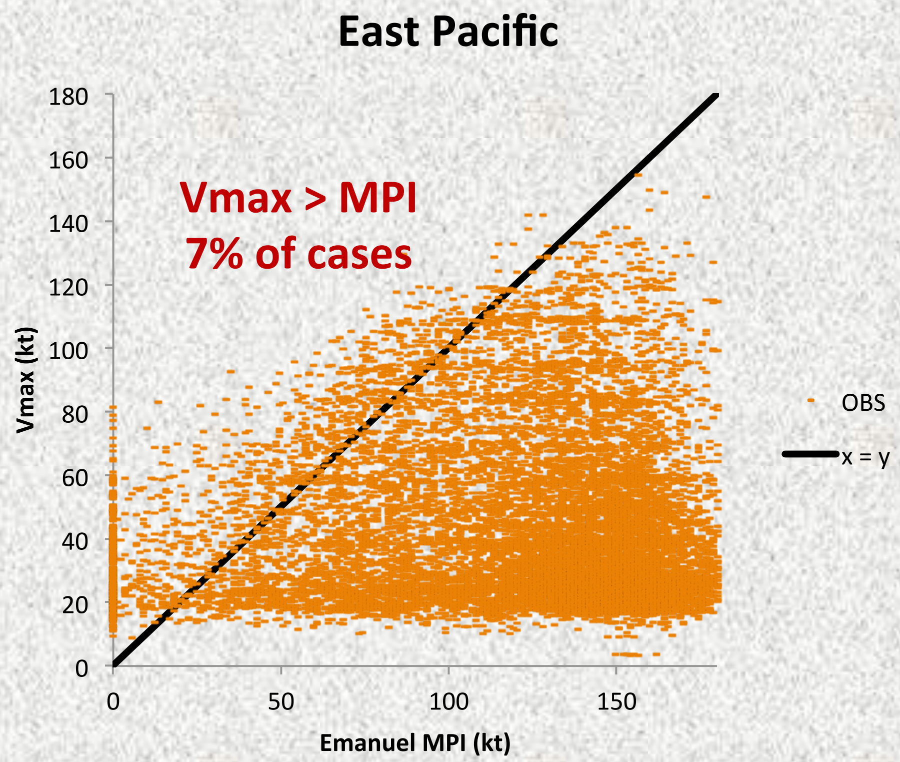
Improved Reduction Factor

- Emanuel MPI assumes 700-mb winds reduced by factor of 0.8 at surface (friction)
- Franklin et al. (2002) used dropwinsonde data to show reduction factor is closer to 0.9
- Multiplied Emanuel MPI by 0.9/0.8

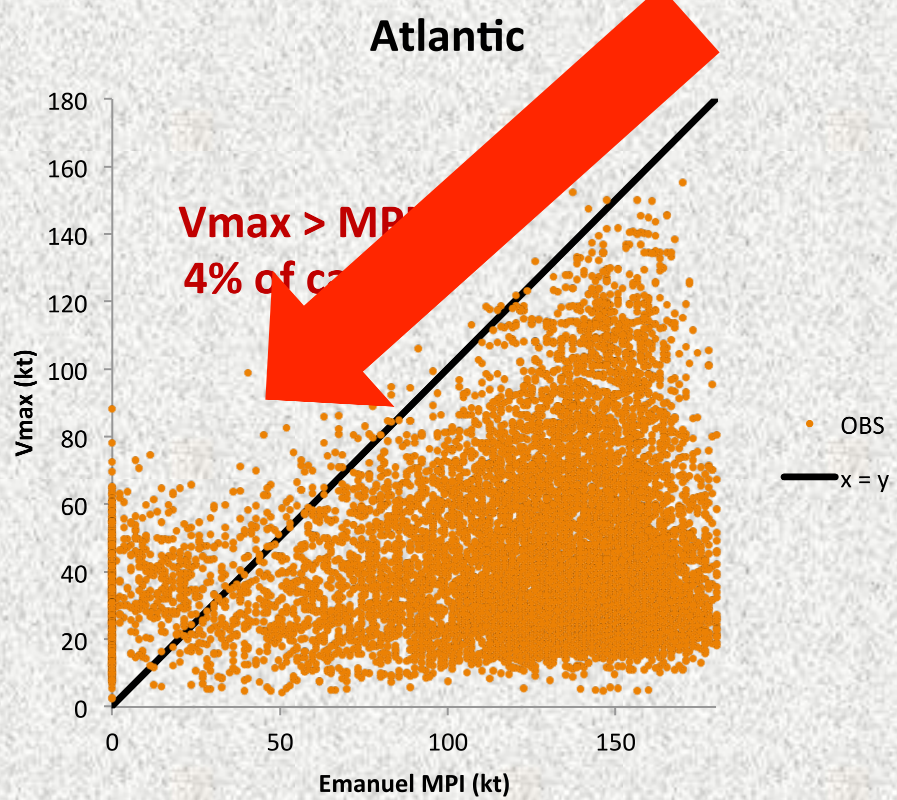


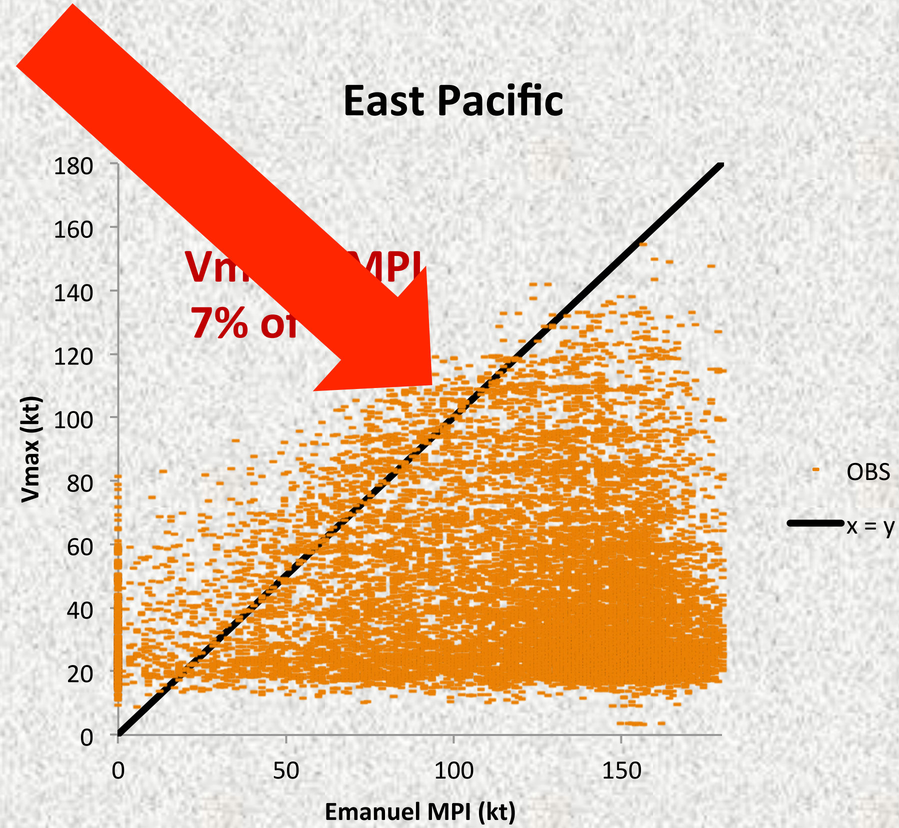
Emanuel MPI + Asymmetry Adjustment + Improved Reduction Factor





Observed Vmax Exceeds Theoretical MPI. Why? When?





Under what conditions is Emanuel MPI not valid in SHIPS?

Atlantic

	Average		Standard Dev.	
	Valid	Not Valid	Valid	Not Valid
RSST	27.4	17.1	2.0	4.6
OHC	36.1	0.5	32.4	5.5
T150	-65.4	-59.6	2.3	4.0
EPOS	10.4	2.4	3.8	3.8
TGRD	23.0	61.2	17.9	43.3
V500	4.7	7.3	4.0	6.5
V300	1.2	3.4	4.9	8.6
SHDC	17.8	33.3	11.4	17.8
V20C	5.4	22.5	13.0	19.3
CYT	4.8	13.4	5.7	10.1
CMAGT	10.9	23.5	6.3	11.0
TADV	1.5	-2.8	30.0	43.7

East Pacific

	Average		Standard Dev.	
	Valid	Not Valid	Valid	Not Valid
RSST	27.6	23.8	1.5	2.1
OHC	21.5	0.7	18.9	3.2
T150	-66.2	-65.3	1.3	1.7
EPOS	9.5	4.3	3.3	3.1
TGRD	18.9	21.9	11.3	13.1
V500	3.4	4.5	2.9	2.9
V300	0.6	1.5	3	3.3
SHDC	14	12.1	8.7	8.1
V20C	2.3	7.2	8.9	8.8
CYT	2.8	3.8	3.4	3.7
CMAGT	8.9	9.5	4.1	4
TADV	-0.5	-1.1	13.8	5.9

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- In Atlantic, fast TC motion (CMAGT) and lower SST/OHC
- In E. Pacific, lower SST/OHC
- Shear (SHDC), temp gradient (TGRD), speed (CMAGT) all associated with extratropical transition

Summary / Future Work

- Empirical MPI formulas providing good upper bound for intensity in SHIPS
- Emanuel theoretical MPI improved by
  - Adding asymmetry adjustment due to storm motion
  - Using more appropriate reduction factor when converting 700-mb winds to surface
- Future work
  - Identifying conditions where Emanuel MPI should be adjusted or replaced with empirical
    - Fast-moving TCs moving over cooler SST/OHC → lack of equilibrium
    - Extratropical cases (Atlantic)
    - Annular cases (E Pacific)
  - Creating combination empirical/theoretical MPI for testing in SHIPS

Future Satellite Work

- Replace model-derived thermodynamic fields with satellite data
- CAL/VAL
  - See if satellite-based TC products improved using MIRS-processed AMSU data
  - Prepare for ATMS
- With launch of NPP in Fall 2011
  - ATMS/CrIS satellite soundings
  - Higher spatial/temporal resolution satellite data → Improve MPI?