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Improving Tropical Cyclone Guidance Tools by Accounting for Variations in Size

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Introduction to the problem we will investigate:

- Tropical Cyclones come in many sizes and structures (Figure 1)
- Many tropical cyclone diagnostic and forecast applications do not account for TC size variability (i.e., based on a one-size assumption). This leads to the poor separation of structural features like rainbands and core regions.
- This shortcoming has likely lead to biases in TC guidance
  - ✓ e.g. Dvorak Technique
  - ✓ e.g., Inland decay
  - ✓ e.g., Surface to flight-level wind reductions
- Scaling storms by size (from the outside inward) is an alternative to scaling TC by the radius of maximum wind (RMW), does not require estimating the often elusive RMW, and is likely more valid outside the core/eyewall region.

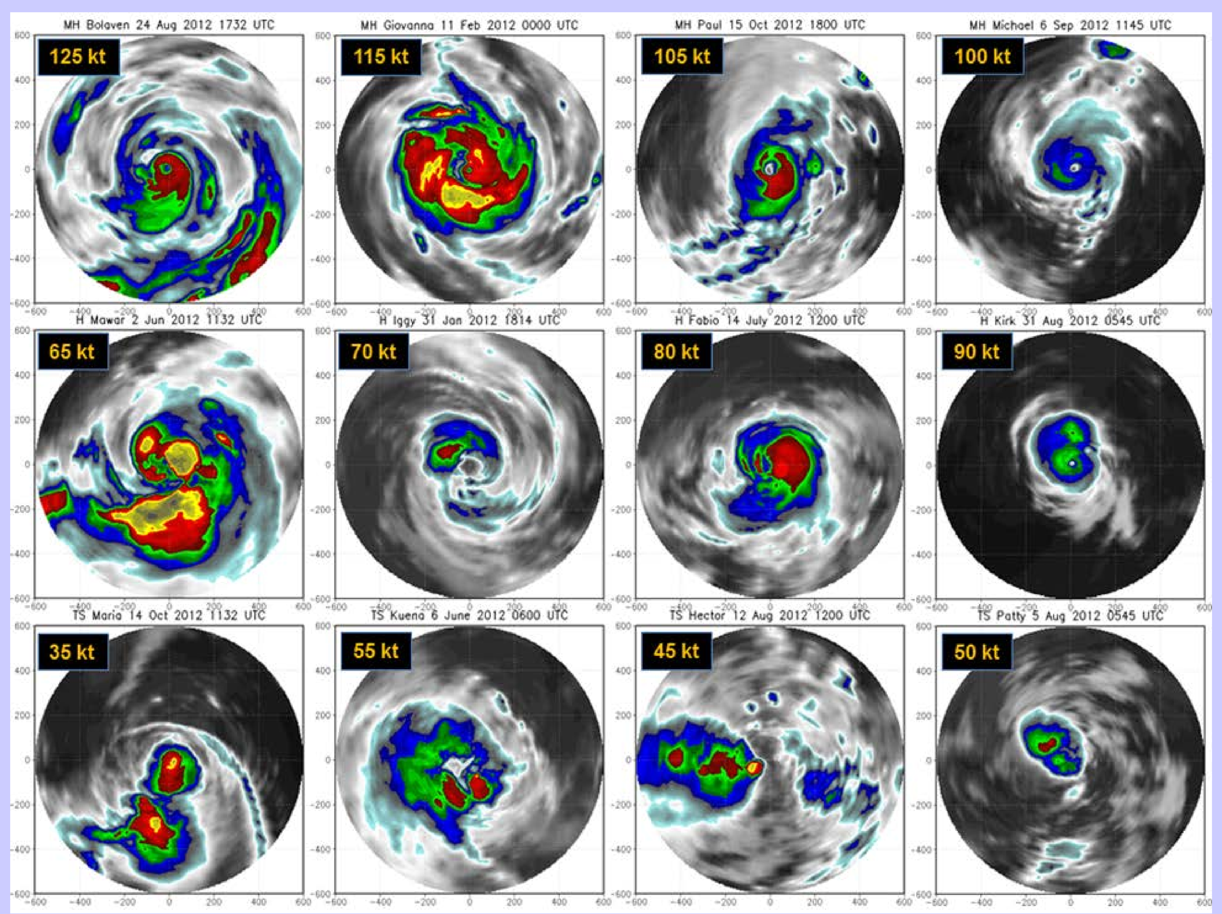


Figure 1. IR images of several TCs that occurred during 2012 that illustrates the variety of shapes and sizes that are observed. Rows show major hurricane, non-major hurricane, and tropical storm intensities, respectively. Columns show storms occurring in the western North Pacific, Southern Hemisphere, East Pacific, and Atlantic basins, respectively. The domains are 600 km.

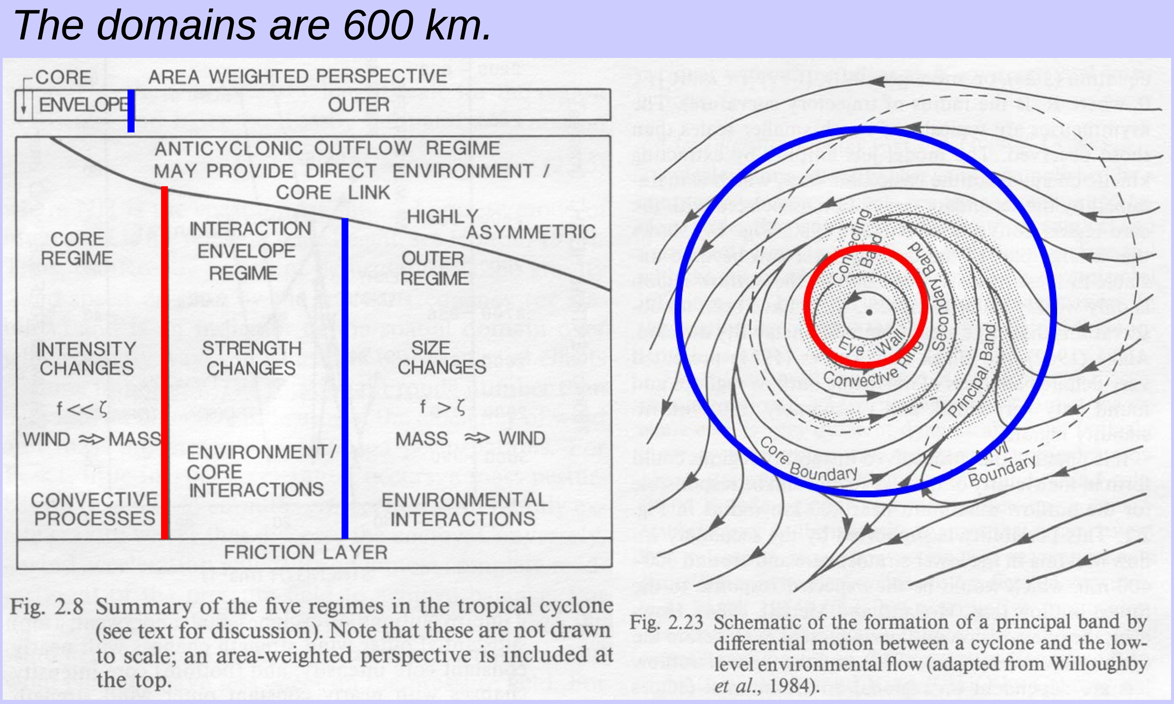


Figure 2. Examples of tropical cyclone structural features. These include the eyewall, the core region, the moat, the rainband region, and the environmental interaction envelope. Each of these varies with TC size (figures from Holland 1997).

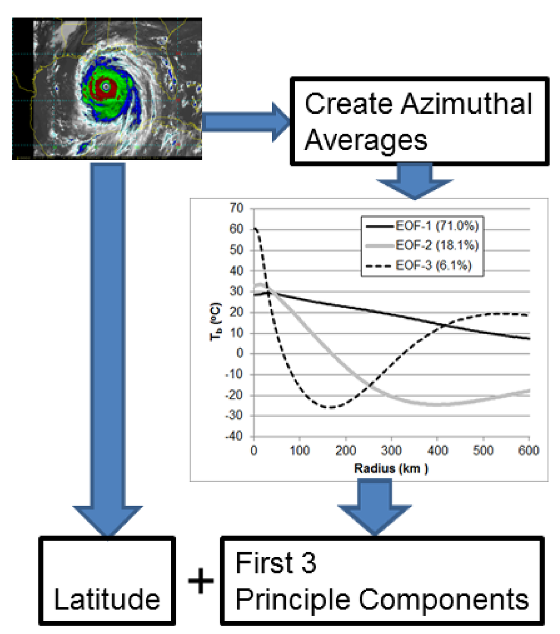
Hypothesis:

- That by scaling tropical cyclone information we can better separate structural features like those illustrated in Figure 2
  - ✓ Inner core/Eyewall & inner Rainband region
  - ✓ Outer Rainband /Environmental Interface Region
- Improved separation of tropical cyclone features will lead to better statistical relationships
  - ✓ Intensity forecasting
  - ✓ Intensity diagnostics
  - ✓ Data assimilation (possibly)

Proposed Solution:

- Objectively scale the radial extent of each tropical cyclone by an infrared (IR) measures of TC size (i.e., from the outside inward) We use the R5 Metric discussed in Knaff et al. (2014) to accomplish the "Scaling" as shown in Figure 3.

Review IR-Based TC Metric (R5)



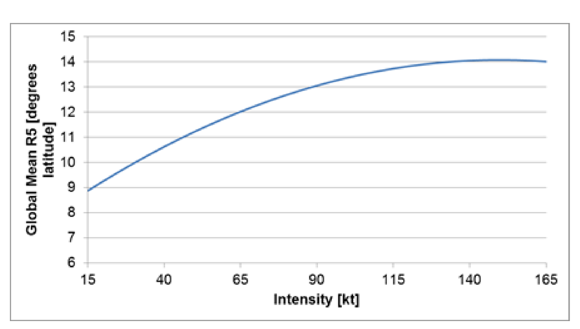
$$V500 = 2.488 + 11.478 * \sin|\varphi| - 1.350 * PC1 + 0.912 * PC2 + 0.319 * PC3$$

V500 ≡ 850-hPa mean tangential wind at r= 500 km induced by the TC

$$R5 = (\overline{R5} + (V500 - V500c) * \frac{500}{V500c - V1000c}),$$

R5 ≡ the radius of where the TC wind field is indistinguishable from the background flow in a climatological environment.

R5 as a function of intensity ($R5_c$)



R5 Scaling Factor:

$$F_{R5} = \frac{R5}{R5_c(v_m)}$$

$F_{R5} \equiv$ scaling factor
$R5_c \equiv$ climatological R5
$v_m \equiv$ maximum intensity

Scaled radius:

$$r_{scaled} = r / F_{R5}$$

Examples of using the scaled radius or "scaling":

To better visualize the affects of scaling, Figure 3 shows the images used in Figure 1, but the individual panels have been re-scaled using R5, F_{R5}, and r_{scaled}. The most dramatic changes are shown between Typhoon Mawar and Hurricane Kirk. Similarly, Figure 4 shows differences between lightning density composited by intensity and physical radius compares with composites based on intensity and scaled radius. Notice the improved comparison between Atlantic (larger storms) composites and East Pacific (smaller storms) composites. Similarities are more evident, particularly for Major Hurricanes (MH), Tropical Storms (TC) and Tropical Depressions (TD). The scaling also results in a shift of the radial bands associated with rapid intensification (RI), average intensity change (AIC) and rapid weakening (RW) (Figure 5).

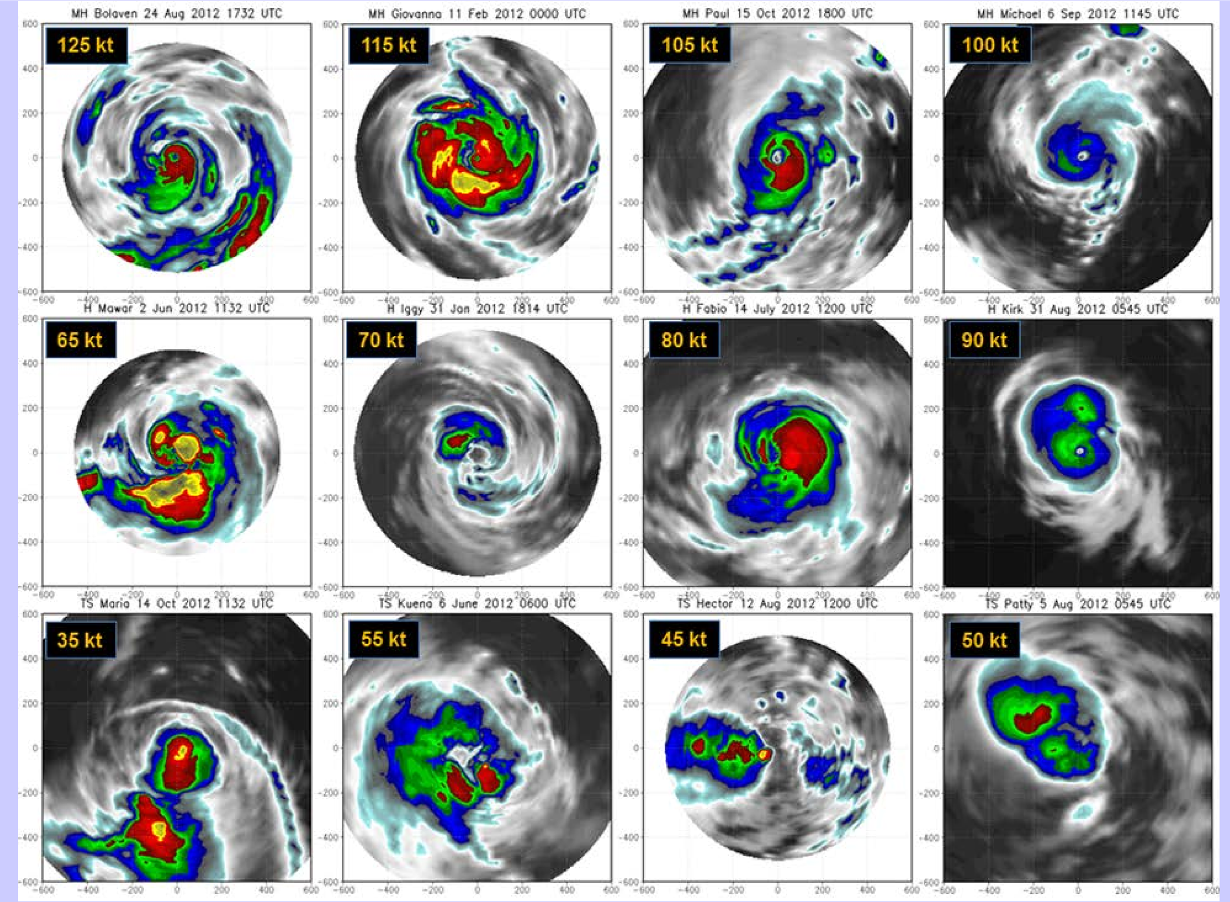


Figure 3. The same as Figure 1 save the individual panels have be scaled using R5 information . The domains are 600 scaled km.

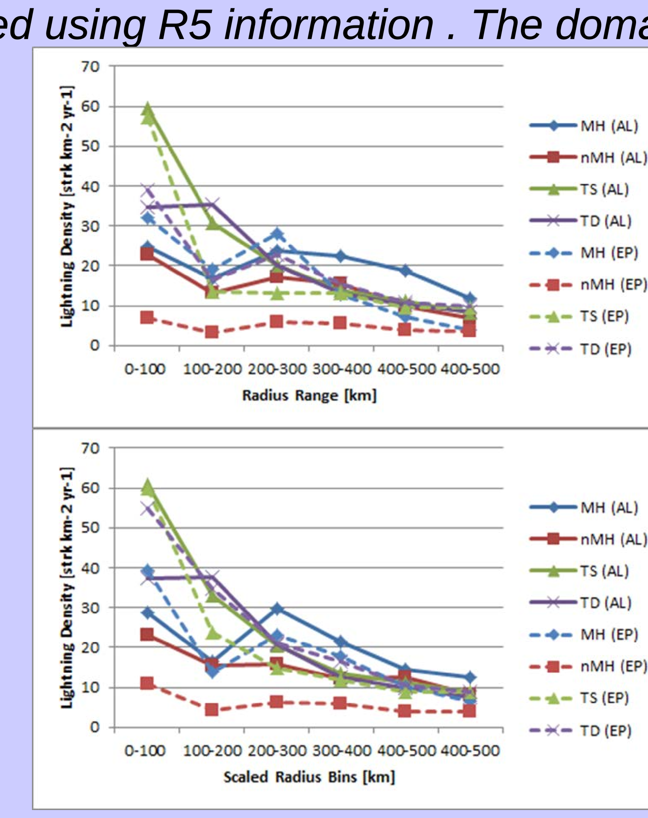


Figure 4. Plot of the storm-relative lightning density climatologies [strikes km-2 year-1] shown as a function of intensity and radius (top), and intensity and scaled radius (bottom). The plot is based on 2005-2012 WWLLN data.

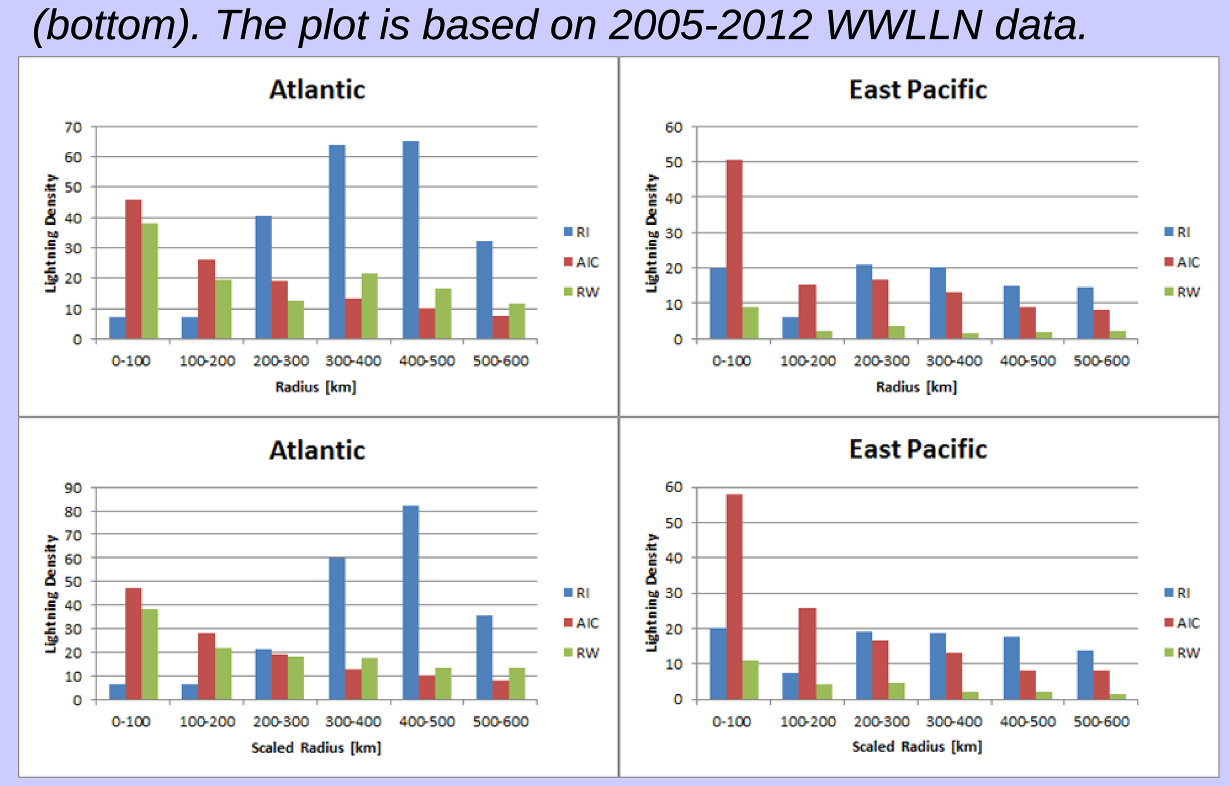


Figure 5. Radial shifts of lightning density are shown for intensity changes, physical radius (top), scaled radius (bottom).

Testing the Hypothesis:

To test our hypothesis that by accounting for TC size improvements can be made to tropical cyclone guidance and forecast products we test un-scaled and scaled predictors in the relatively simple Statistical Hurricane Intensity Prediction Scheme (SHIPS), the Logistic Growth Model (LGEM) and experimental version of the Rapid Intensification Index (RII). The later makes use of lightning information explicitly. SHIPS, LGEM, RII have 22, 19, and 9 (11) predictors, (with lightning) respectively.

Results (based on dependent results):

- Both SHIPS and LGEM forecasts were slightly degraded by using scaled infrared predictors. Predictors included the 0-200 km standard deviation of brightness temperature (GSTd) and the percentage of pixels colder than -20 ºC in the annulus 50-200 km (PC20). Other pixel count temperature thresholds showed the same result.
- RII, that makes use of IR information through GSTD and pixel counts (1995-2012) showed improvement in the Atlantic and mixed results in the East Pacific (Figure 6).
- RII (2005-2012) that made use of both IR and lightning –based predictors showed improvement in the Atlantic and some improvements in the East Pacific (Figure 7).
- Scaling the lightning density data shifted the RII signal associated with rainband lightning from 200-400 km to 300-500 scaled km, but resulted in an improved relationship.
- RII probably should make use of the -50ºC temperature threshold for pixel count-based predictors.

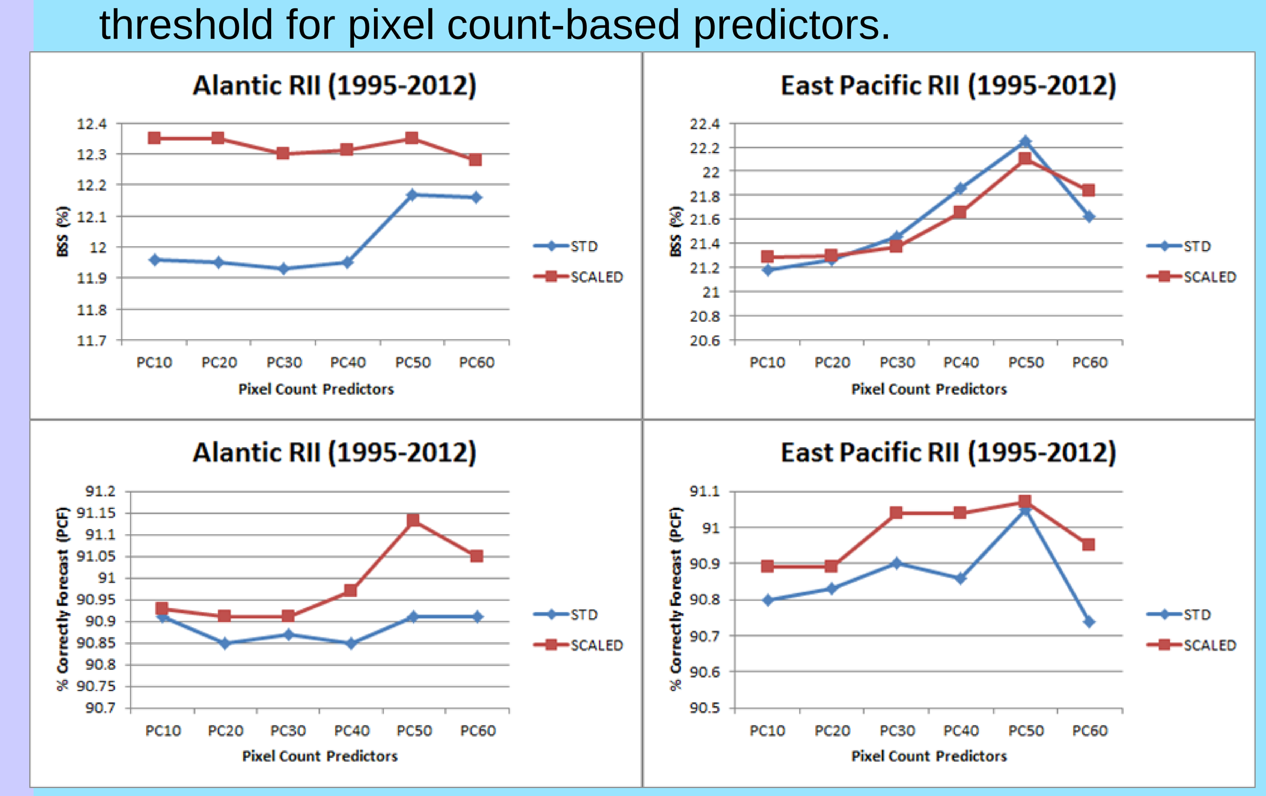


Figure 6. Dependent results based on the experimental version of the RII (1995-2012) run in the Atlantic (left) and East Pacific (right) as a function of pixel count predictors in this model. Results show the impact of scaling the IR predictors as a function of TC size on resulting BSS (top) and PFC (bottom). Blue lines show the control and red lines show the results when IR predictors are scaled.

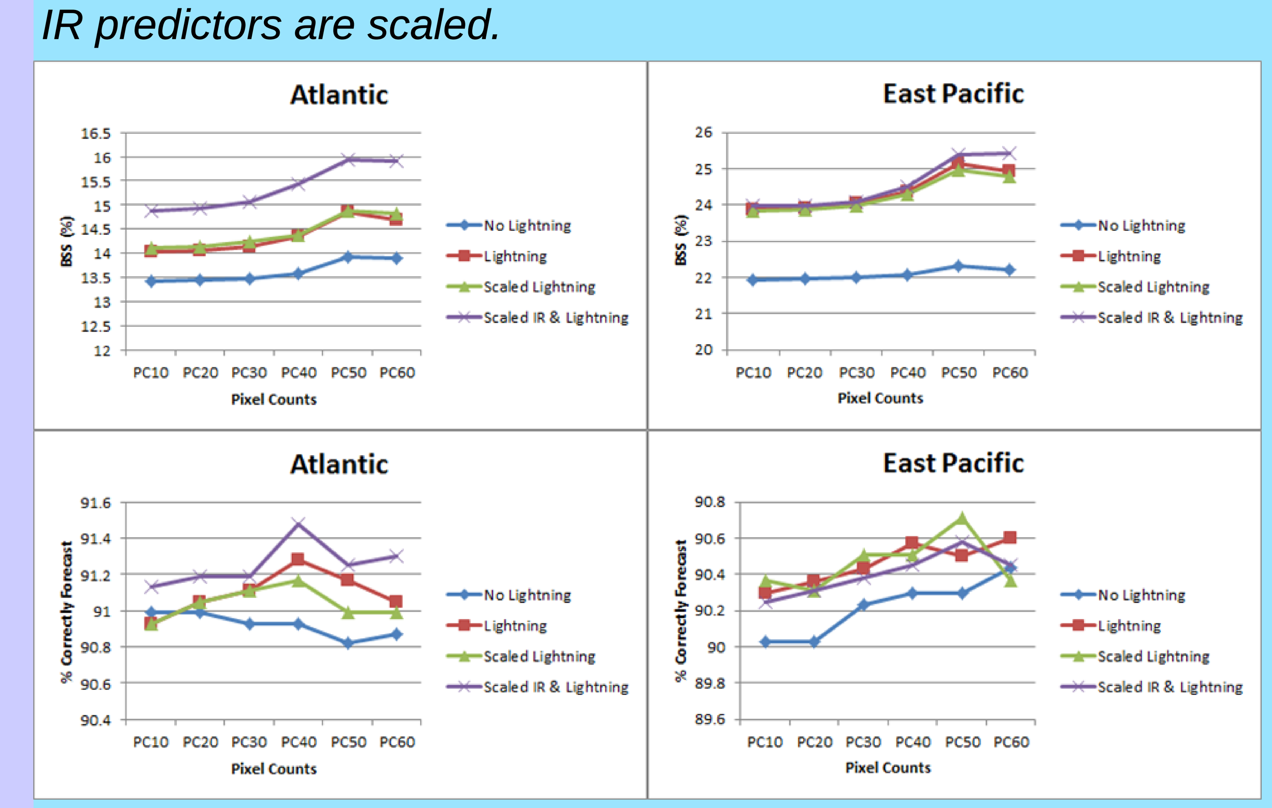


Figure 7. Dependent results from the RII that contains lightning and IR information, 2005-2012, in the Atlantic (left) and East Pacific (right) in terms of variable pixel count predictors. The model developed without lightning information (blue), with lightning information (red), using scaled lightning information (green) and scaled lightning and IR data (purple).

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More detailed information about this study and complete references can be found in the conference extended abstract.