The spatial contribution of translation speed to tropical cyclone wind structure

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Basic issue: the methodologies of how storm speed asymmetries are included in parametric hurricane models may need to be re-examined

- Review the two main methodologies: the SLOSH method, and the Schwerdt method

- A third obscure equation from Jakobsen and Madsen will also be analyzed

- Rudimentary analysis conducted of storm speed asymmetries using HWINDS data

- Conclusions and discussion

References used in talk

Jakobsen, F., and H. Madsen, 2004: Comparison and further development of parametric tropical cyclone models for storm surge modeling. Journal of Wind Engineering, 92, 375-391.

Jelesnianski, C. P., 1966: Numerical computations of storm surges without bottom stress. Monthly Weather Review, 94, 379-394.

Jelesnianski, C. P., J. Chen, and W. A. Shaffer, 1992: SLOSH: Sea, lake, and overland surges from hurricanes. NOAA Technical Report NWS 48, 71 pp.

Schwerdt, R. W., F. P. Ho, and R. R. Watkins, 1979: Meteorological criteria for Standard Project Hurricane and probable maximum hurricane wind fields, Gulf and East Coast of the United States. NOAA Technical Report NWS 23, 317 pp.

Parametric equation philosophy

- $V_{sym}(\tilde{V}_{max}, r_{max}, r, x_1, x_2, x_3 \ldots \ldots)$ → symmetric wind field; often a shape factor is used
- $V_{total} = V_{sym} + A$ → asymmetry (A) added for total wind field
  note $\tilde{V}_{max}$ requires increasing 10-m V_{max} above PBL, and decreasing for asymmetry
- Compute pressure field from V_{sym} assuming gradient wind balance
- Reduce total wind field to 10-meter height
- Adjust for inflow angles

Used in most storm surge model applications. Also used in hurricane risk assessments and in many other purposes

SLOSH asymmetry equation

$$A(V_{spd}, r_{max}, r) = V_{spd}\frac{2rr_{max}}{r^2 + r_{max}^2}$$

Which looks suspiciously similar to the SLOSH symmetric wind field equation

$$V_{sym}(V_{max}, r_{max}, r) = V_{max}\frac{2rr_{max}}{r^2 + r_{max}^2}$$

Justification (pg 14, NOAA Technical Report NWS 48 on SLOSH, published 1992)

- “Empirical tests with SPLASH…show surges not overly sensitive” to asymmetry term

- No documentation or graphics supporting equation

- Does state “could be faulty for a weak storm moving rapidly”

- Originally documented in Jelesnianski (1966), who states this is a “gross correction” (pg 293)

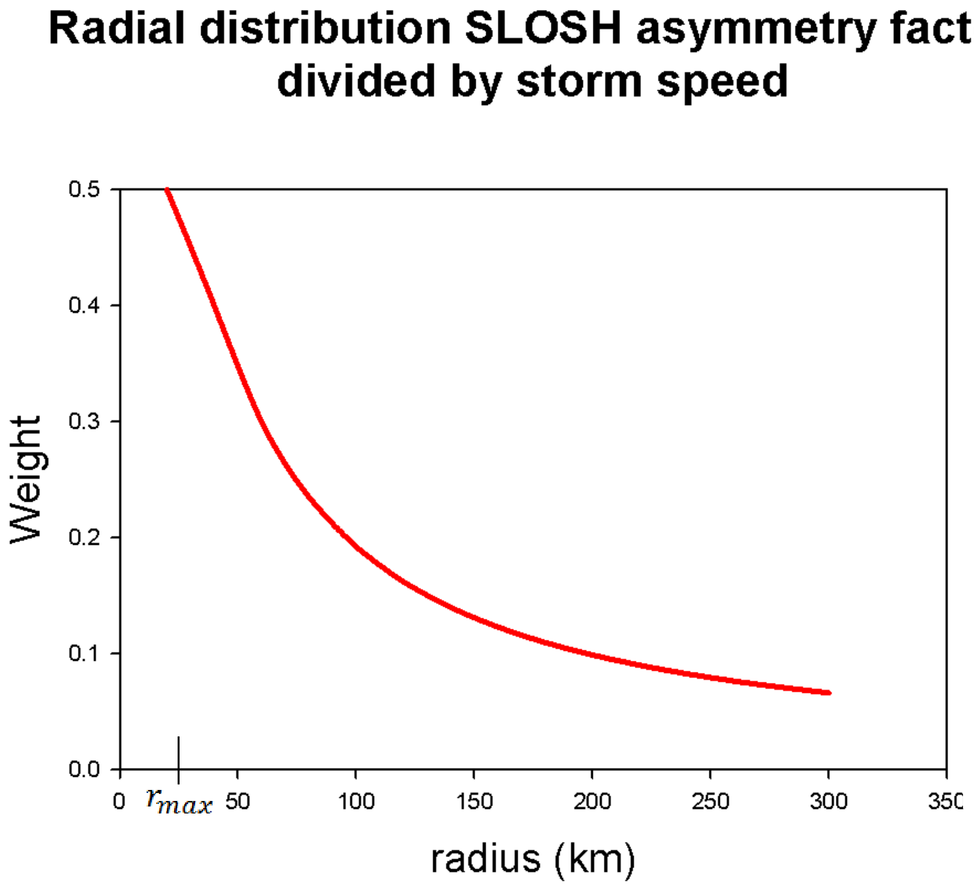
- Seems to have been chosen for consistency with symmetric wind profile equations, and because it produces “reasonable” results

- *The primary asymmetry equation used today in most storm surge model forcing*

SLOSH asymmetry equation radial distribution

$$w = \frac{A}{V_{spd}}$$

Note the radial weight is independent of storm speed



Weight is half storm speed at r_{max}, then decreases quickly radially

Relationship is

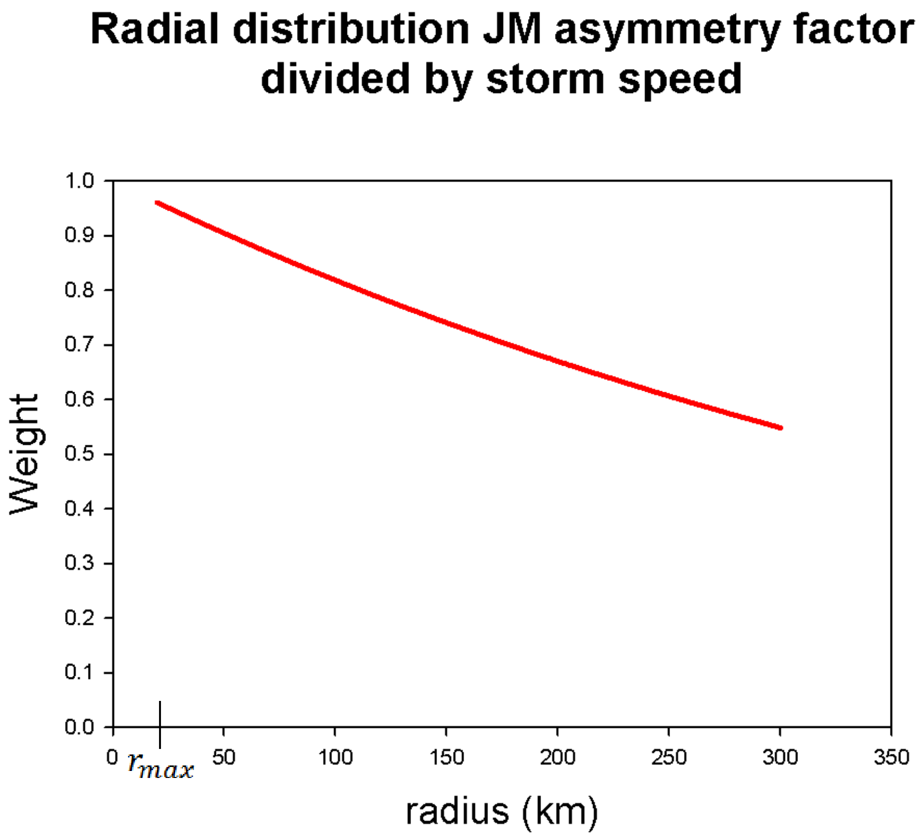
$$w = [a + br^{c}]^{-1/d}$$

Jakobsen and Madsen (JM) asymmetry equation

$$A(V_{spd}, r_{env}, r) = V_{spd}\, exp\left(-\frac{r}{r_{env}}\right)$$

where r_{env} is 500 km; published 2004

Note the radial weight is also independent of storm speed



Weight at r_{max} is nearly unity, then decreases slowly to 0.5 in the environment.

Schwerdt asymmetry equation at r_{max}

$$A(V_{spd}) = \alpha V_{spd}^{\kappa}$$

Justification (pg 234, NOAA Technical Report NWS 23, published in 1979)

- Graham and Nunn (1959) suggest $\alpha=0.5$, $\kappa=1$. Also in SLOSH references

- Schwerdt states "Appears to be…unreasonable. When V_{spd} is large, a lesser adjustment (is suggested). When V_{spd} is small, there is not enough asymmetry across the hurricane"

- Schwerdt altered to $\alpha=1.5$, $\kappa=0.63$ (for units of knots).

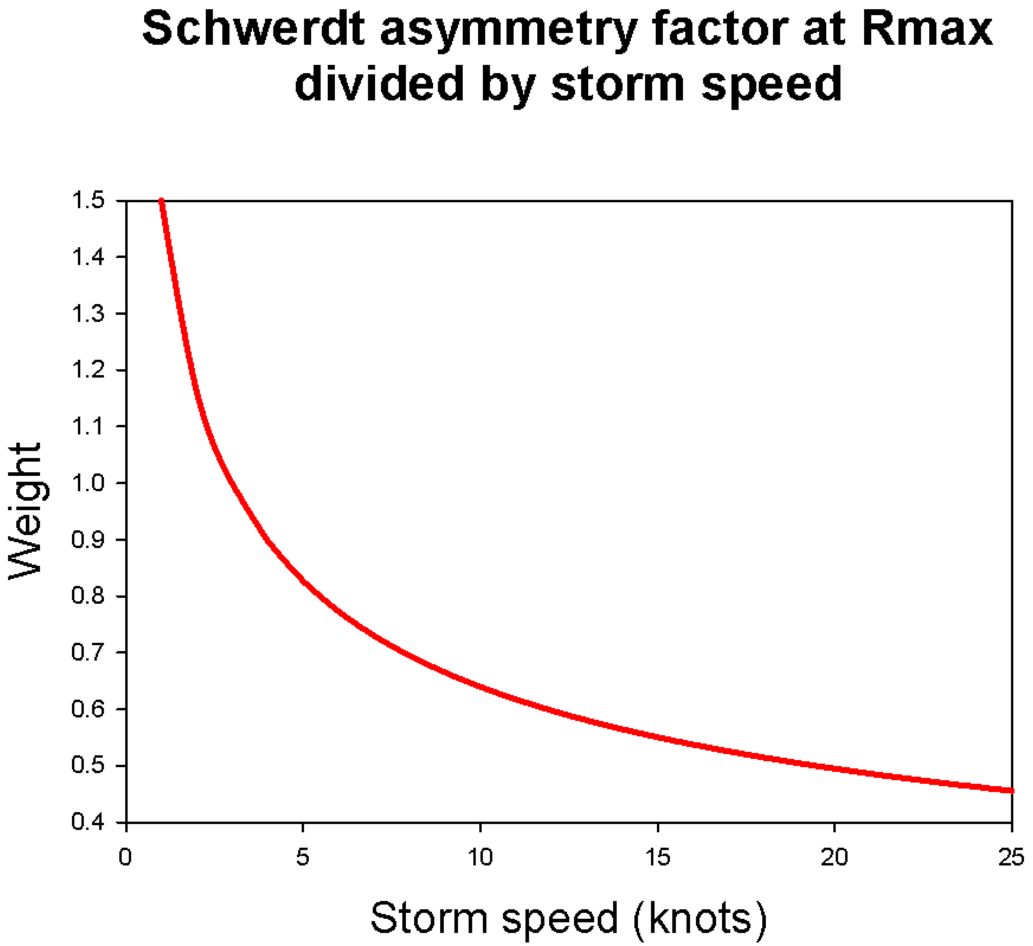
- No documentation or graphics supporting equation for A by itself.

- Used in some CIRA applications

Schwerdt asymmetry equation storm speed distribution

$$w = \frac{A}{V_{spd}}$$

Only valid at r_{max}. No radial distribution function.



Weight > 0.5 until 20 knots.

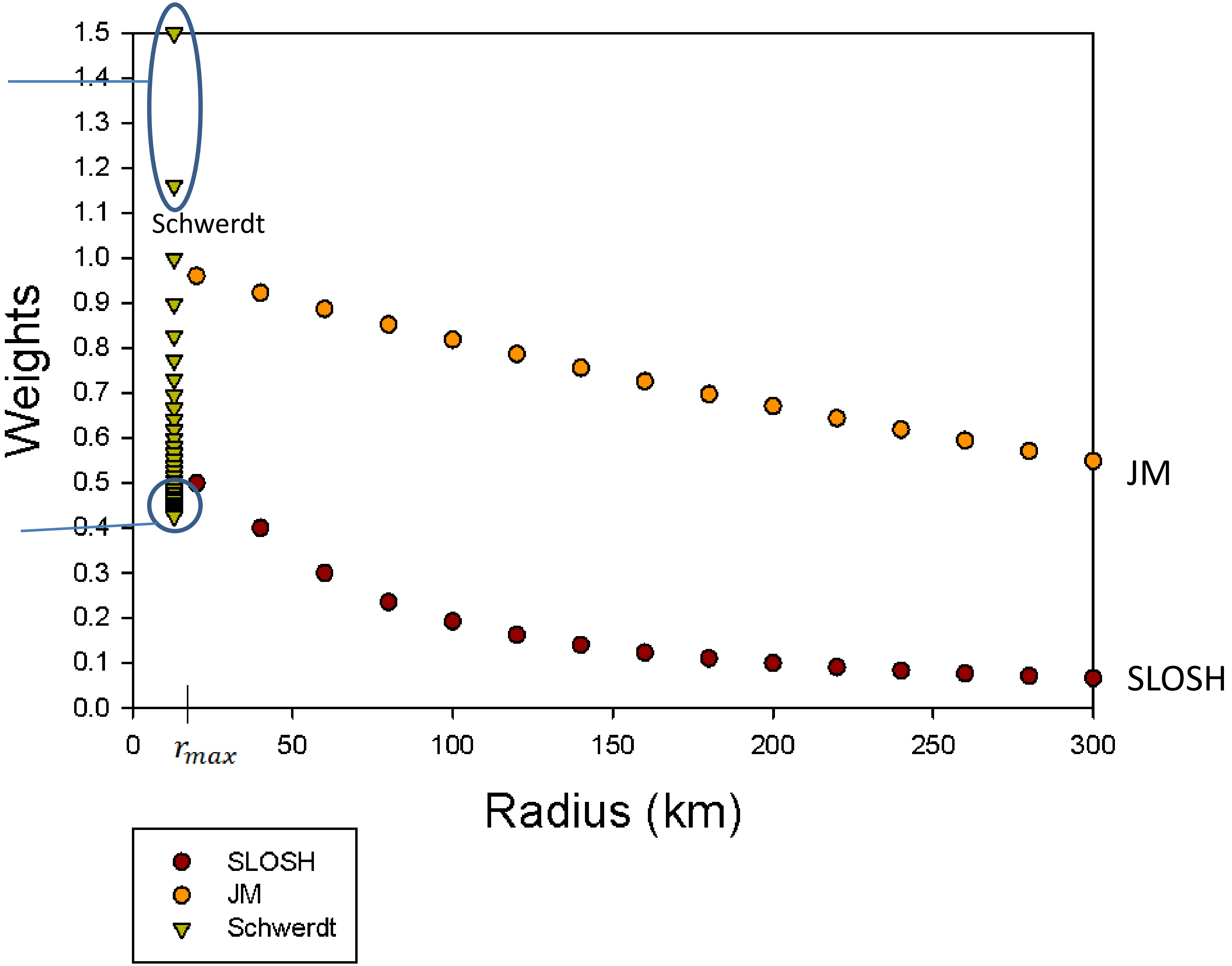
Less than 1.0 except for very slow movers

Examination of asymmetry equations using HWINDS

Methodology (rudimentary)

- Archive 2D tropical cyclone surface wind analyses product HWINDS (2005-2012)
- Akima spline fit to storm centers; storm speed computed from spline
- V_{max} and R_{max} computed in each dataset. V_{opp} computed at R_{max} in opposite quadrant
- Compute $(V_{max}-V_{opp})/2$. Perform scatterplots versus V_{spd} and least squares
- Hypothesis – Acknowledging that asymmetries are formed from several mechanisms, a relationship can still be identified capturing a glimpse of the radial storm speed asymmetry contribution

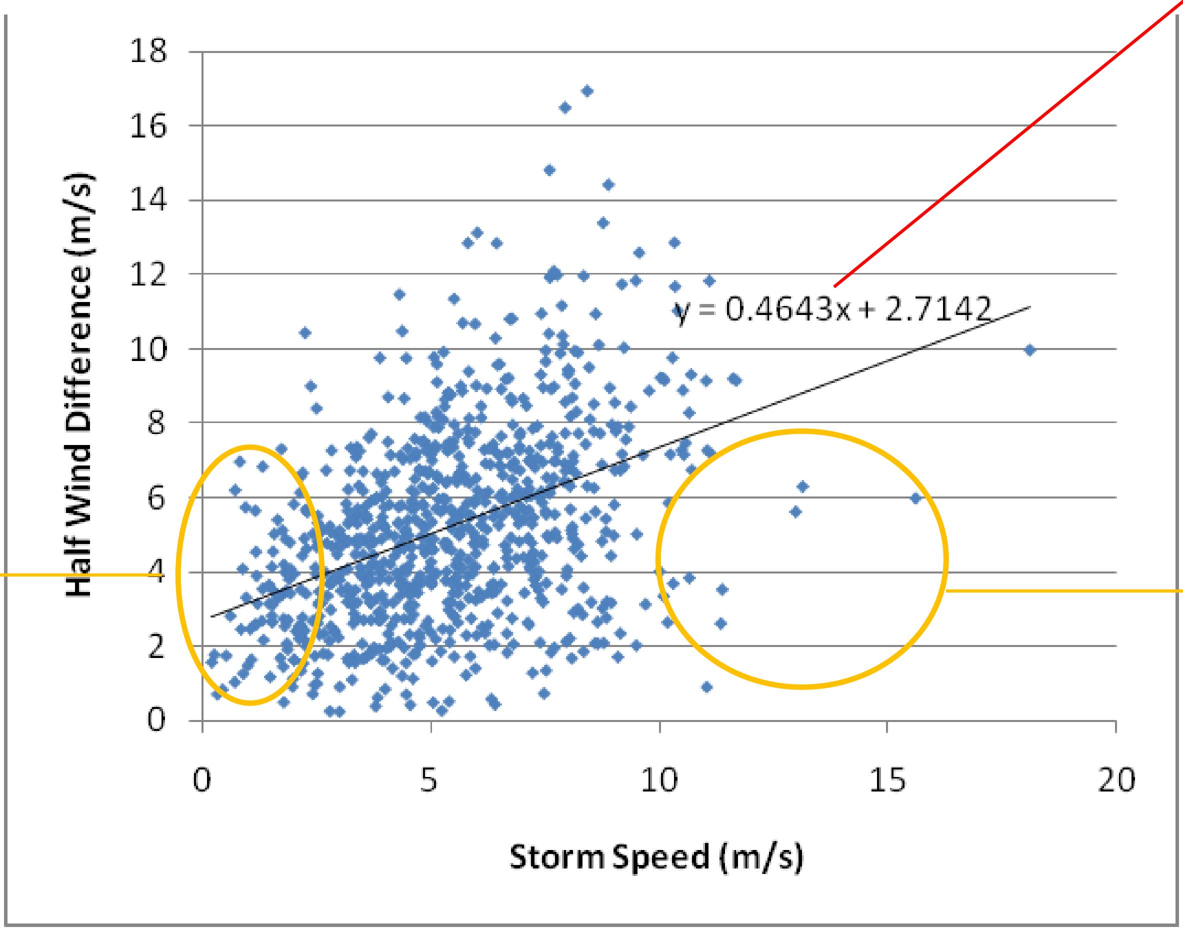
Summary, Asymmetry Weights



Storms moving 1 and 2 knots

Storms moving 20-30 knots

Scatterplot, asymmetry versus V_{SPD} at r_{max}
Explained variance = 19%

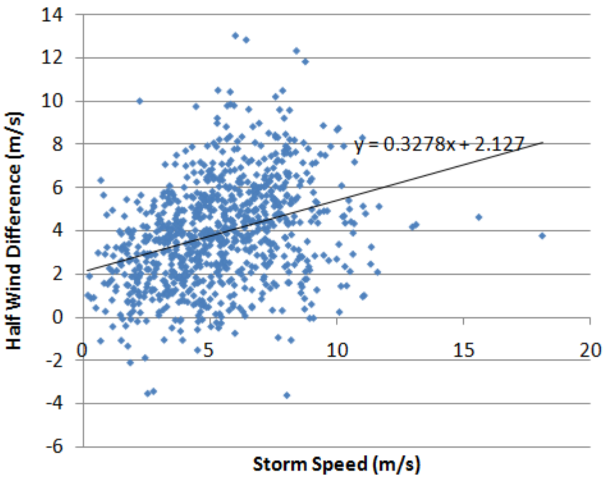


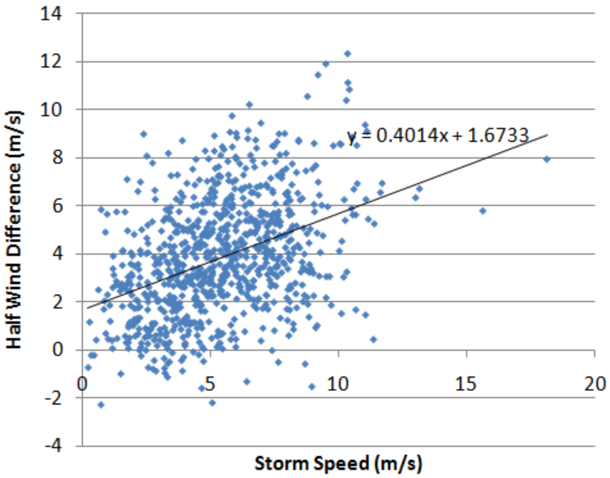
Large asymmetry relative to slow motion, consistent with Schwerdt

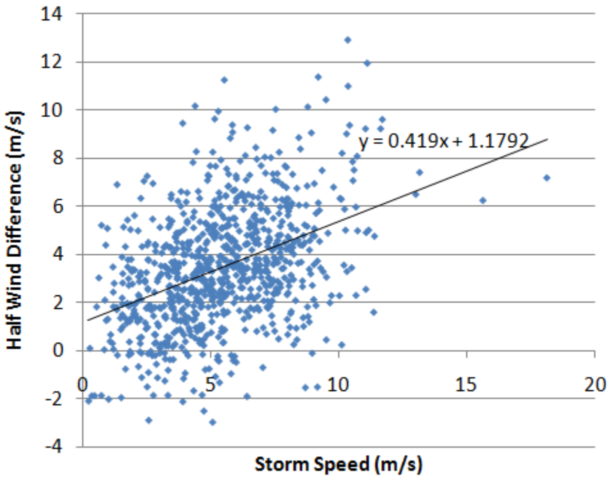
Slope of 0.46 at r_{max} plus y intercept indicates > 0.5, more than SLOSH formulation

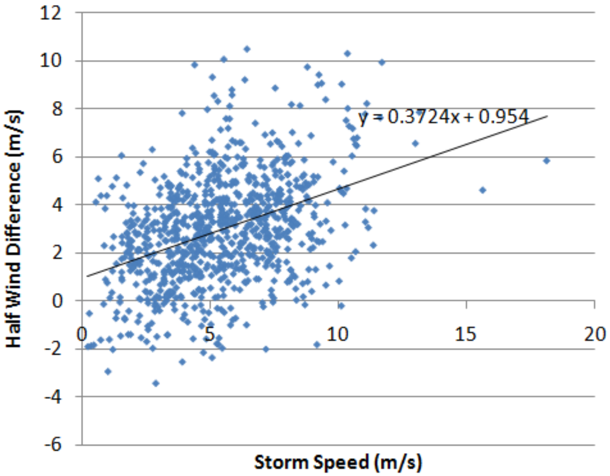
Consistent with Schwerdt for fast storms. Cluster indicates more reduced inner-core asymmetry factor for fast storms may be needed

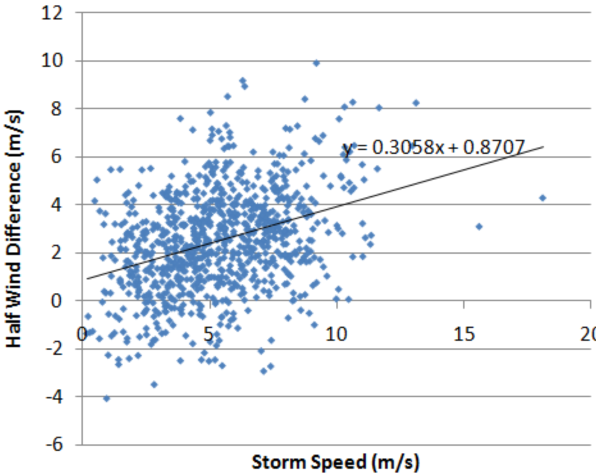
Scatterplots at different radii, asymmetry versus V_{SPD}
Explained variance ranges from 9% to 18%

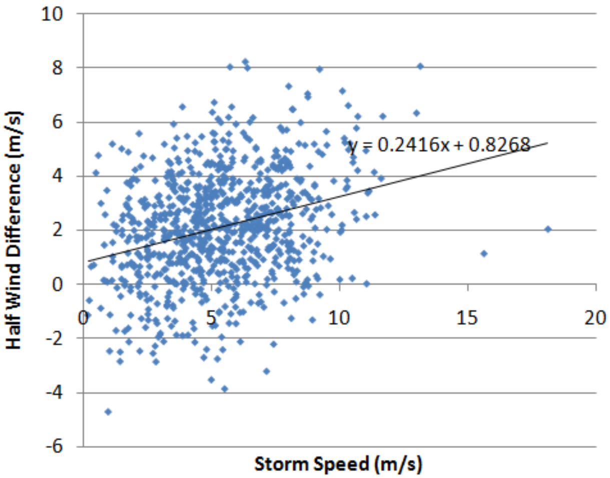

at 50 km Away from Center


at 100 km Away from Center


at 150 km Away from Center

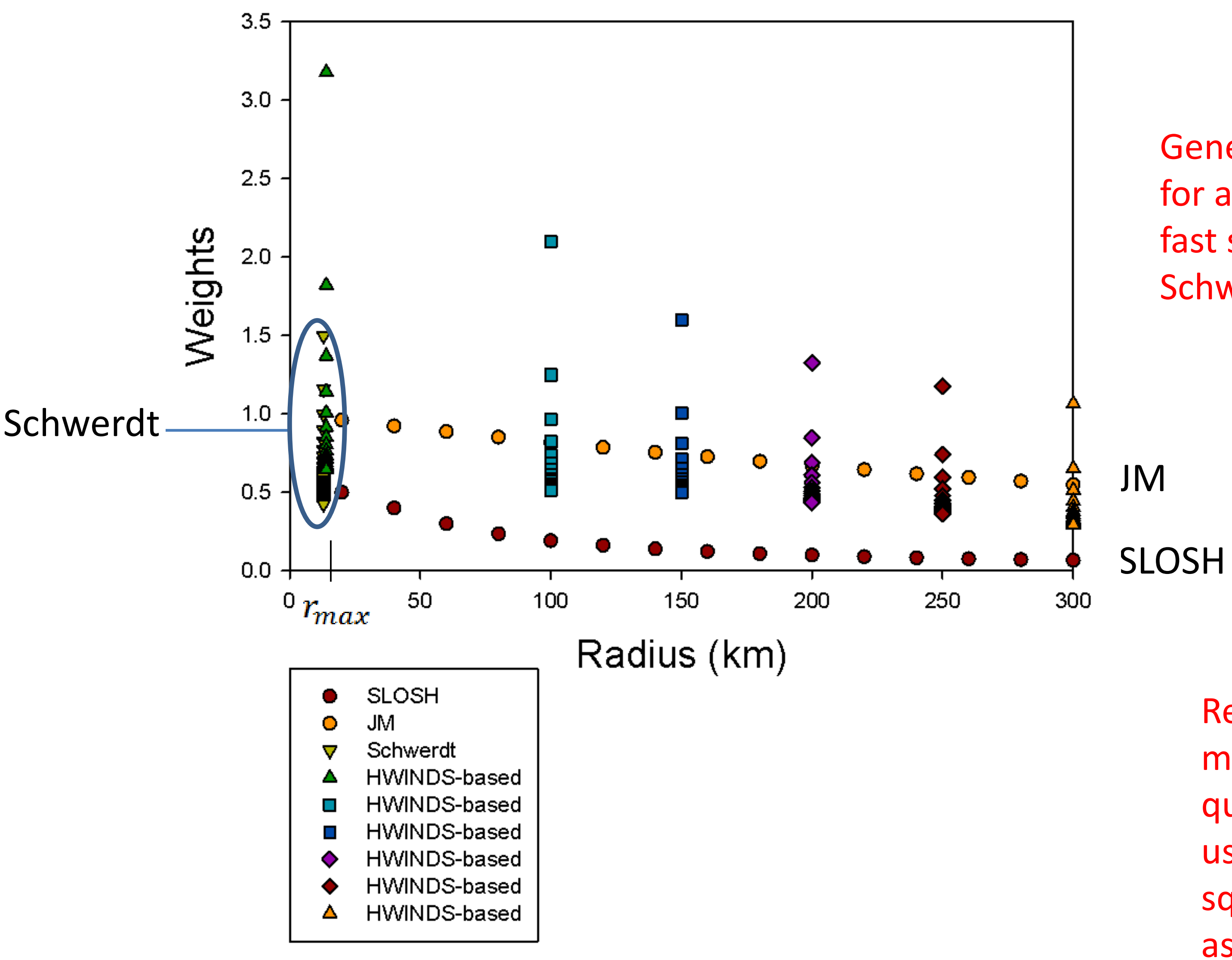

at 200 km Away from Center


at 250 km Away from Center


at 300 km Away from Center

- Storm speed dependence still seen. Outliers for fast storms decrease outside of 100 km.
- Slope and y intercept decreases out to 300 km, indicating asymmetry decreases radially

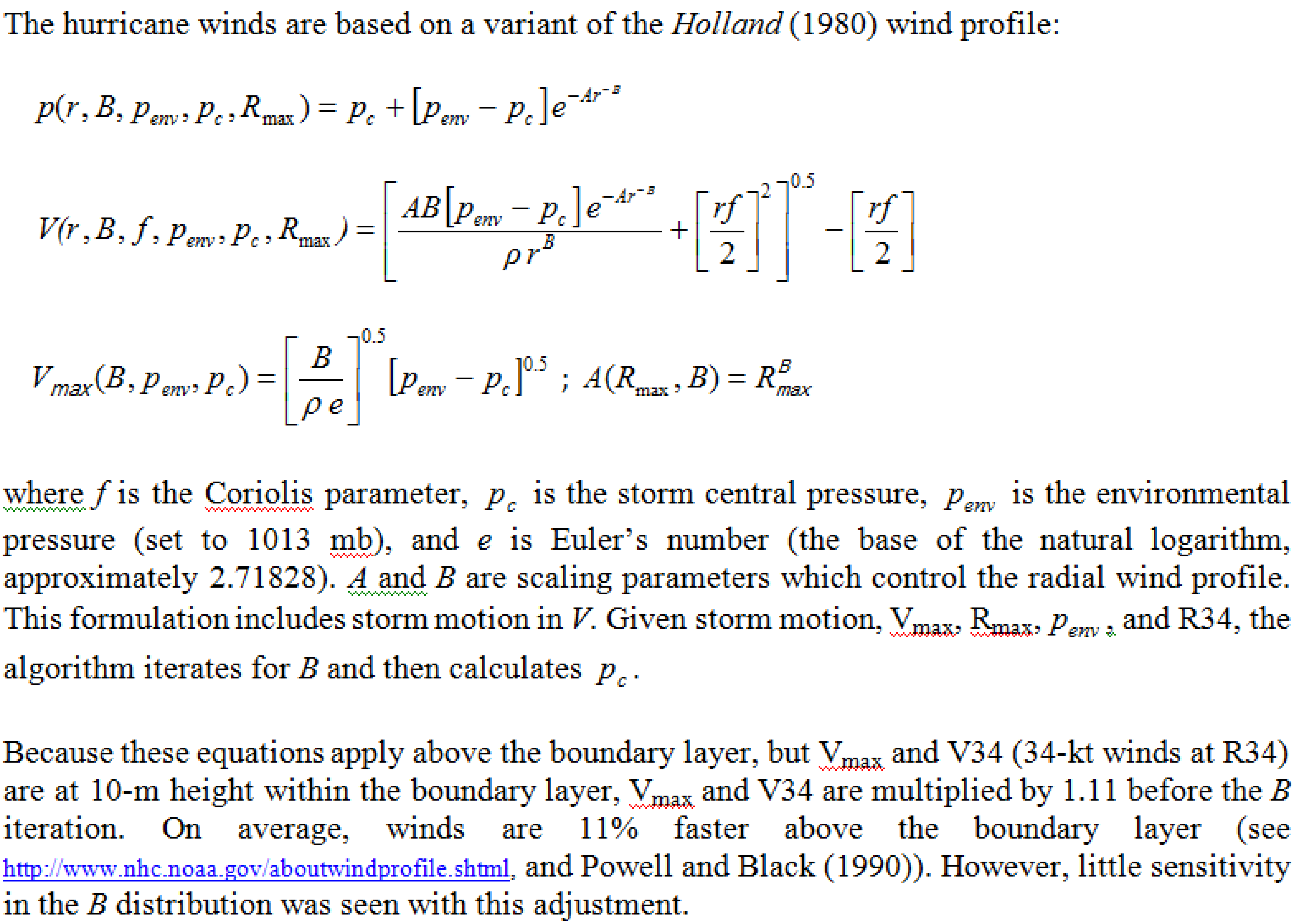
Summary, Assymmetry Weights
Including HWINDS dataset



Generally matches JM for avg speeds. Slow and fast speeds follow Schwerdt correction

Results don’t change much using other cross-quadrant techniques, or using robust least squares. Least square assumptions met.

Future work
Incorporation of new asymmetry scheme into MSU parametric scheme



The hurricane winds are based on a variant of the *Holland* (1980) wind profile:

$$p(r, B, p_{env}, p_c, R_{\max}) = p_c + [p_{env} - p_c]e^{-Ar^{-B}}$$

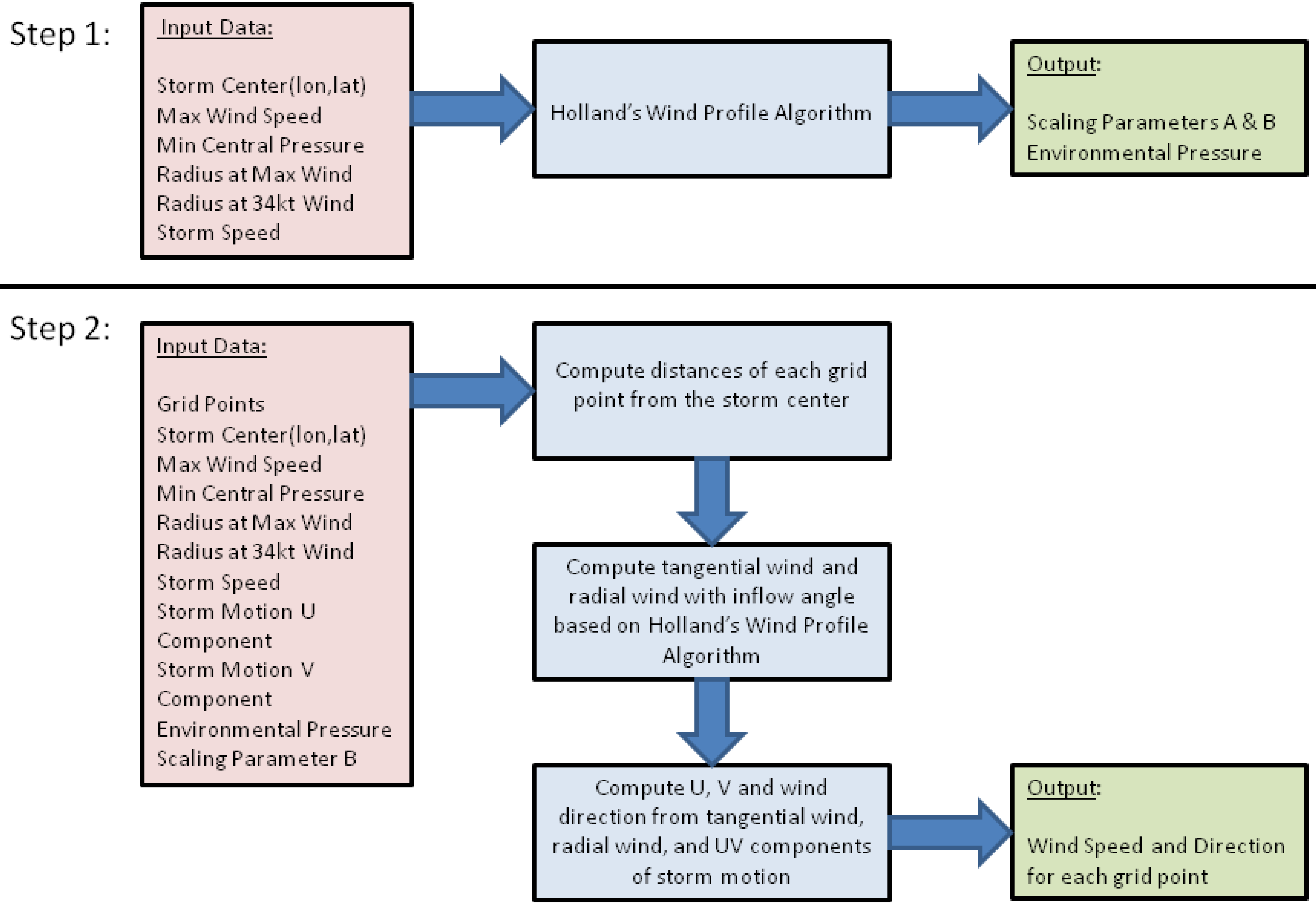
$$V(r, B, f, p_{env}, p_c, R_{\max}) = \left[\frac{AB\left[p_{env} - p_c\right]e^{-Ar^{-B}}}{\rho r^{B}} + \left[\frac{rf}{2}\right]^{2}\right]^{0.5} - \left[\frac{rf}{2}\right]$$

$$V_{max}(B, p_{env}, p_c) = \left[\frac{B}{\rho e}\right]^{0.5}\left[p_{env} - p_c\right]^{0.5} \;;\; A(R_{\max}, B) = R_{max}^{B}$$

where f is the Coriolis parameter, p_c is the storm central pressure, p_{env} is the environmental pressure (set to 1013 mb), and e is Euler's number (the base of the natural logarithm, approximately 2.71828). A and B are scaling parameters which control the radial wind profile. This formulation includes storm motion in V. Given storm motion, V_{max}, R_{max}, p_{env}, and R34, the algorithm iterates for B and then calculates p_c.

Because these equations apply above the boundary layer, but V_{max} and V34 (34-kt winds at R34) are at 10-m height within the boundary layer, V_{max} and V34 are multiplied by 1.11 before the B iteration. On average, winds are 11% faster above the boundary layer (see http://www.nhc.noaa.gov/aboutwindprofile.shtml, and Powell and Black (1990)). However, little sensitivity in the B distribution was seen with this adjustment.

Parametric hurricane wind model flow chart



Step 1:

Input Data:

Storm Center(lon,lat)
Max Wind Speed
Min Central Pressure
Radius at Max Wind
Radius at 34kt Wind
Storm Speed

Holland's Wind Profile Algorithm

Output:

Scaling Parameters A & B
Environmental Pressure

Step 2:

Input Data:

Grid Points
Storm Center(lon,lat)
Max Wind Speed
Min Central Pressure
Radius at Max Wind
Radius at 34kt Wind
Storm Speed
Storm Motion U Component
Storm Motion V Component
Environmental Pressure
Scaling Parameter B

Compute distances of each grid point from the storm center

Compute tangential wind and radial wind with inflow angle based on Holland's Wind Profile Algorithm

Compute U, V and wind direction from tangential wind, radial wind, and UV components of storm motion

Output:

Wind Speed and Direction for each grid point

Conclusions

The subjectively-based Schwerdt and PM asymmetry equations capture some components of this study, but some magnitudes do not match HWINDS data. More study is warranted.

- In the context of the mean of all storms and average speeds, PM generally agrees with this study. The concept of decreasing asymmetry with radii is also supported.

- HWINDS overall shows smaller weights than PM for most storm speeds

- SLOSH weights do not align with this study in any context except at r_{max} for fast-moving storms

- The Schwerdt concept of larger (smaller) weight contribution to asymmetry for slow (fast) moving storms is supported. For slow-moving storms, HWINDS shows higher asymmetries than Schwerdt. The relationship is seen for all radii. (Recall Scwerdt only examined r_{max}.)

- For 10-knot moving storm, HWINDS shows an average weight of 1.0 at rmax, 0.75 50-100 km, then decreasing from 0.65 to 0.4 at 150-300 km.

- There is some evidence of outer-core asymmetry is a function of intensity (not shown). This is still being studied.

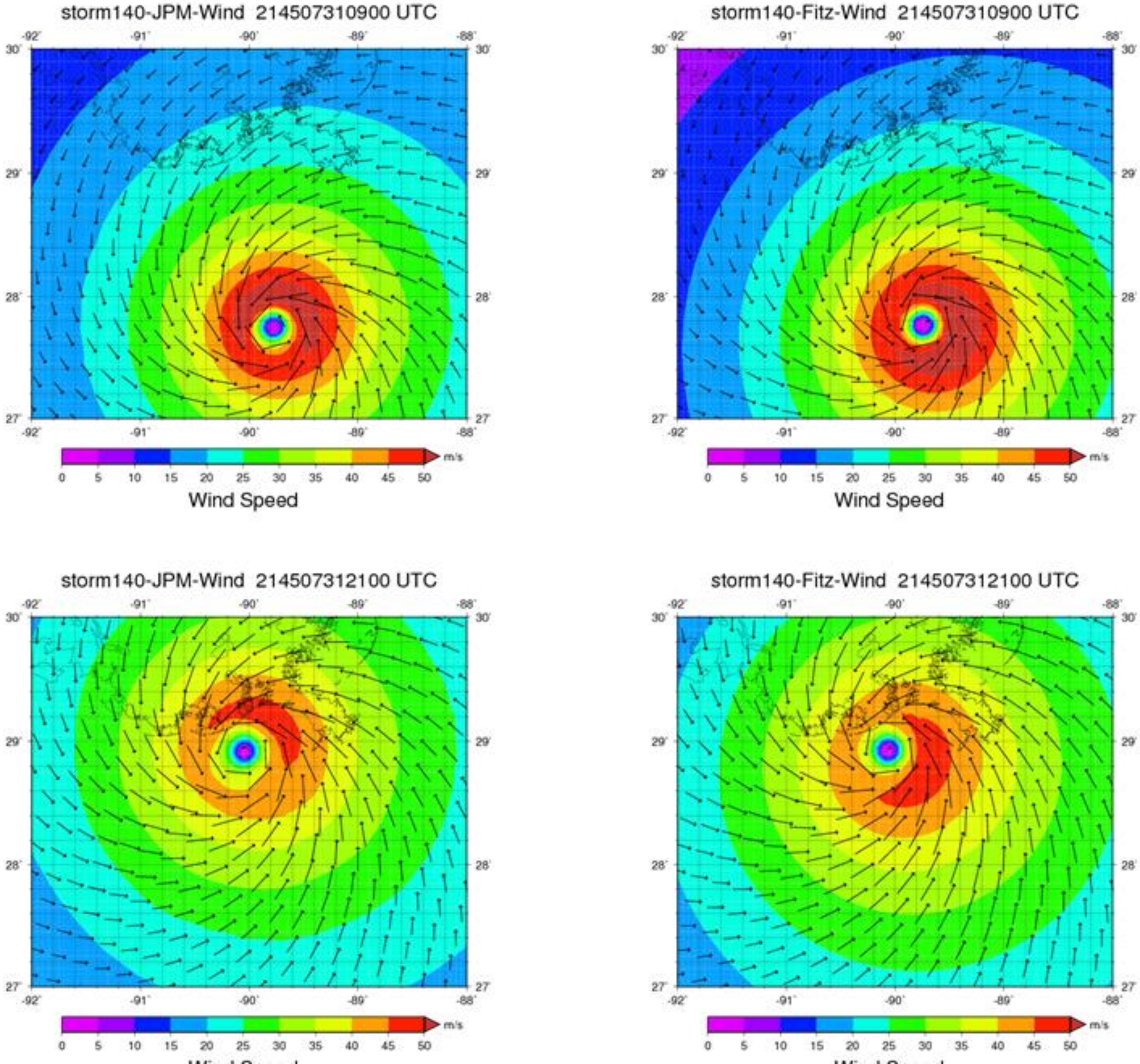
- *Comment – In addition to parametric equation applications, this type of analyses could provide clues on data initialization and track forecast issues*

Supplementary material

Advantage of this method

- 10-meter surface winds **match** the observed peak **eyewall wind**
- 10-meter surface winds **match** the observed **radius of 34-knots winds**
- **Holland B an iterated solution**, not predetermined
- **Specification of wind direction** that can vary radially
- **Storm motion is included in the iteration, not added afterwards**
    - ➢ Vmax=storm speed plus hurricane vortex eyewall
    - ➢ V34=storm speed plus edge of hurricane vortex
- This allows a parametric model which:
    - ➢ **Matches the National Hurricane Center forecast**
    - ➢ Can **match hindcast hurricane data** for JPM studies, theoretical studies, risk modeling, etc.
    - **Correctly uses storm motion**. Many schemes superimpose storm speed translation. This is incorrect usage. Super-positioning changes the wind stress, often artificially increasing the winds. The winds are then faster than Vmax and V34. However, observed winds already include storm motion.

Comparison of Storm 140 Winds from JPM-OS (left) versus Fitz Wind Model (right)


storm140-JPM-Wind 214507310900 UTC

storm140-Fitz-Wind 214507310900 UTC

storm140-JPM-Wind 214507312100 UTC

storm140-Fitz-Wind 214507312100 UTC

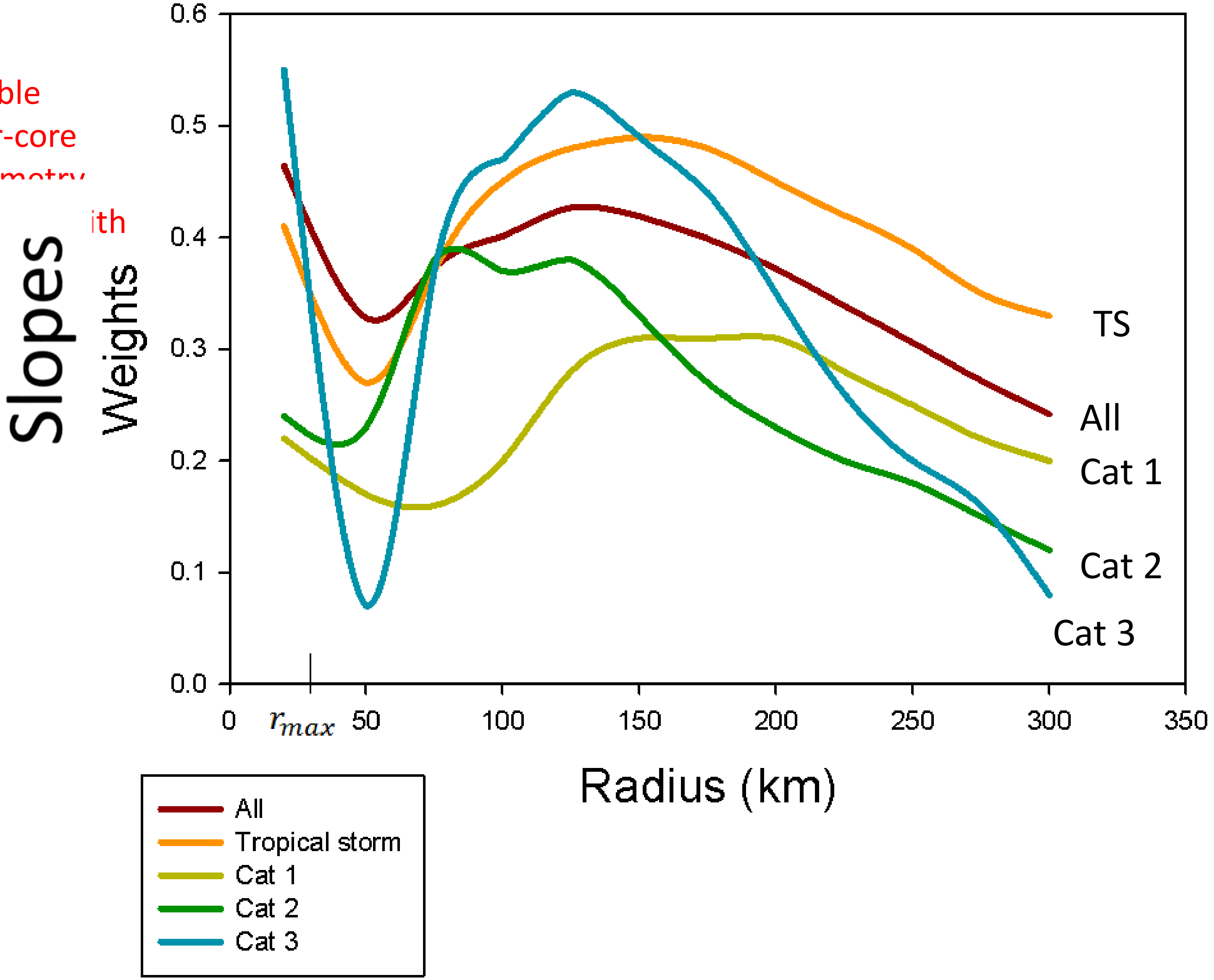
Odd placemen
of peak winds
in NNE eyewal
sector for
JPM-OS

Our placement
based on spee
and track
direction

Everything els
matches well

HWINDs-derived a Slopes by intensity classes

Possible
outer-core
asymmetry
dec ith
inte

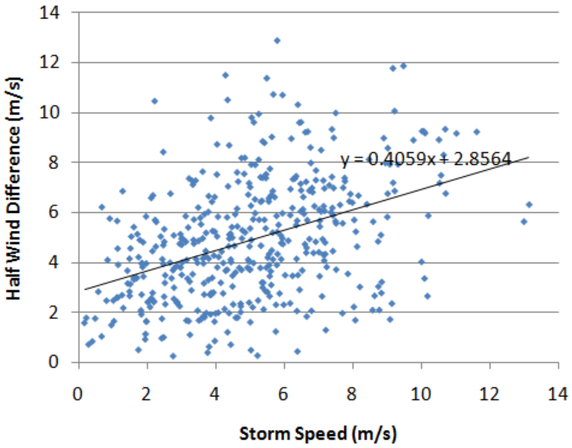


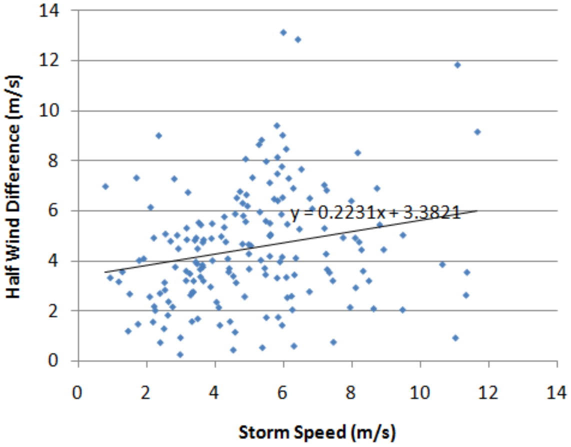
Sample size
All=849
TD=37 (not shown)
TS= 440
Cat 1= 172
Cat 2=93
Cat 3=64
Cat 4=38 (not shown)
Cat 5=5 (not shown)

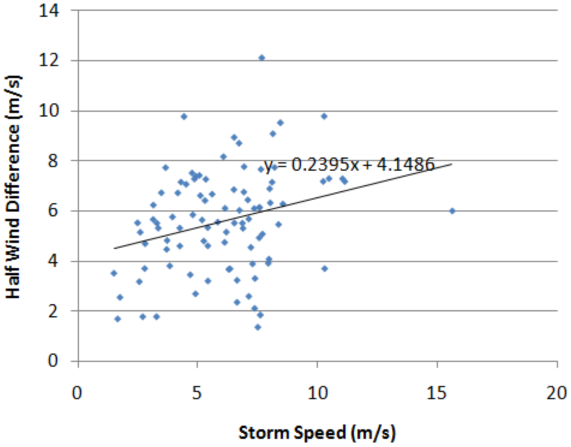
Cat 4 has much higher slopes; possibly not representative due to limited sample.

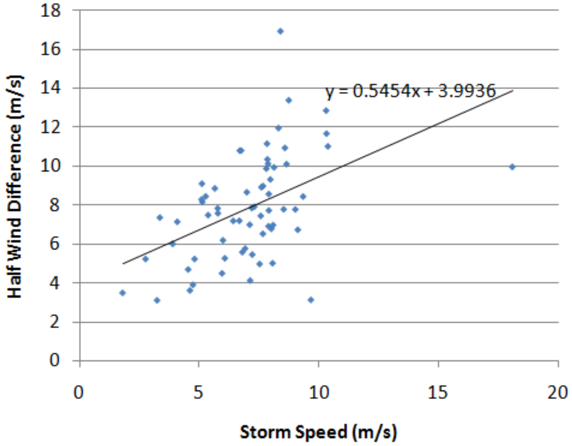
Need to examine inner-core region data more closely for contaminated signal or a unique signal.

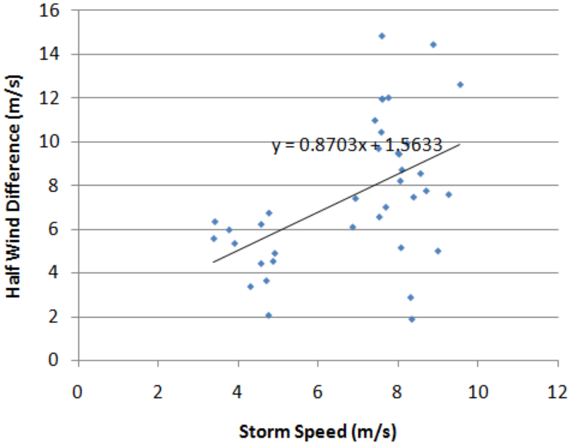
r_{max}, TS to Cat 4











300 km, TS to Cat 4