Estimating Maximum Surface Winds from Hurricane Reconnaissance Measurements

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Motivation

- Track forecasting is improving, but intensity forecasting lagging. Intensity and verification / BT system are problematic

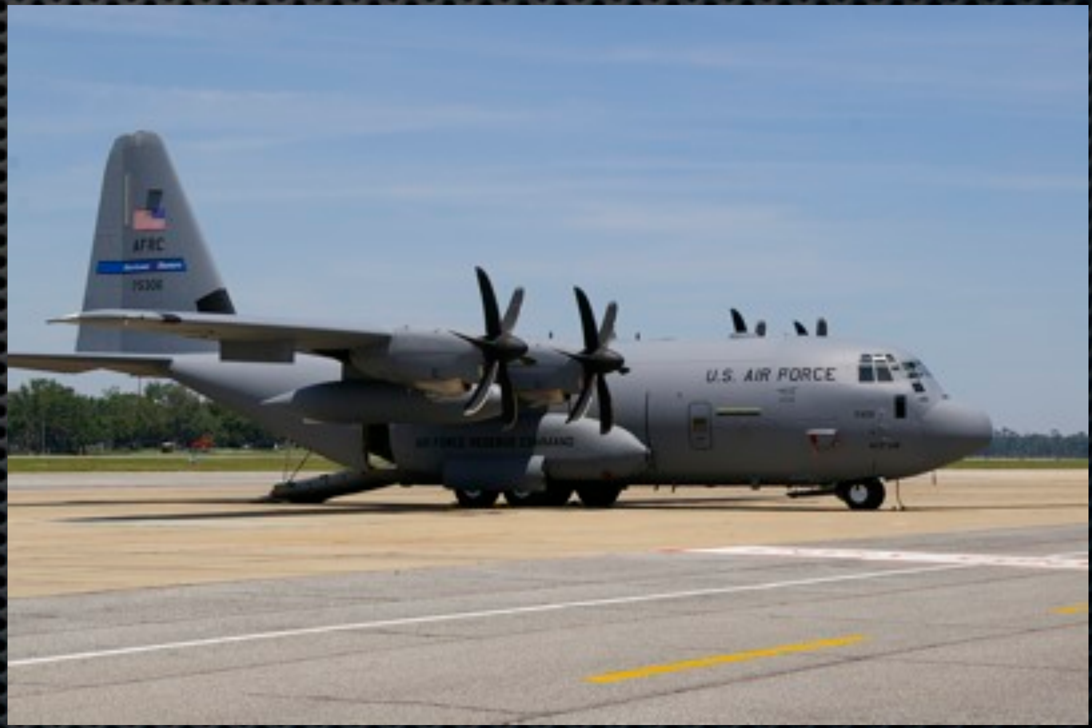
- To assess forecast performance we first need to be able to measure intensity and its uncertainty

- Since 2000 the GPS sonde has influenced intensity estimation

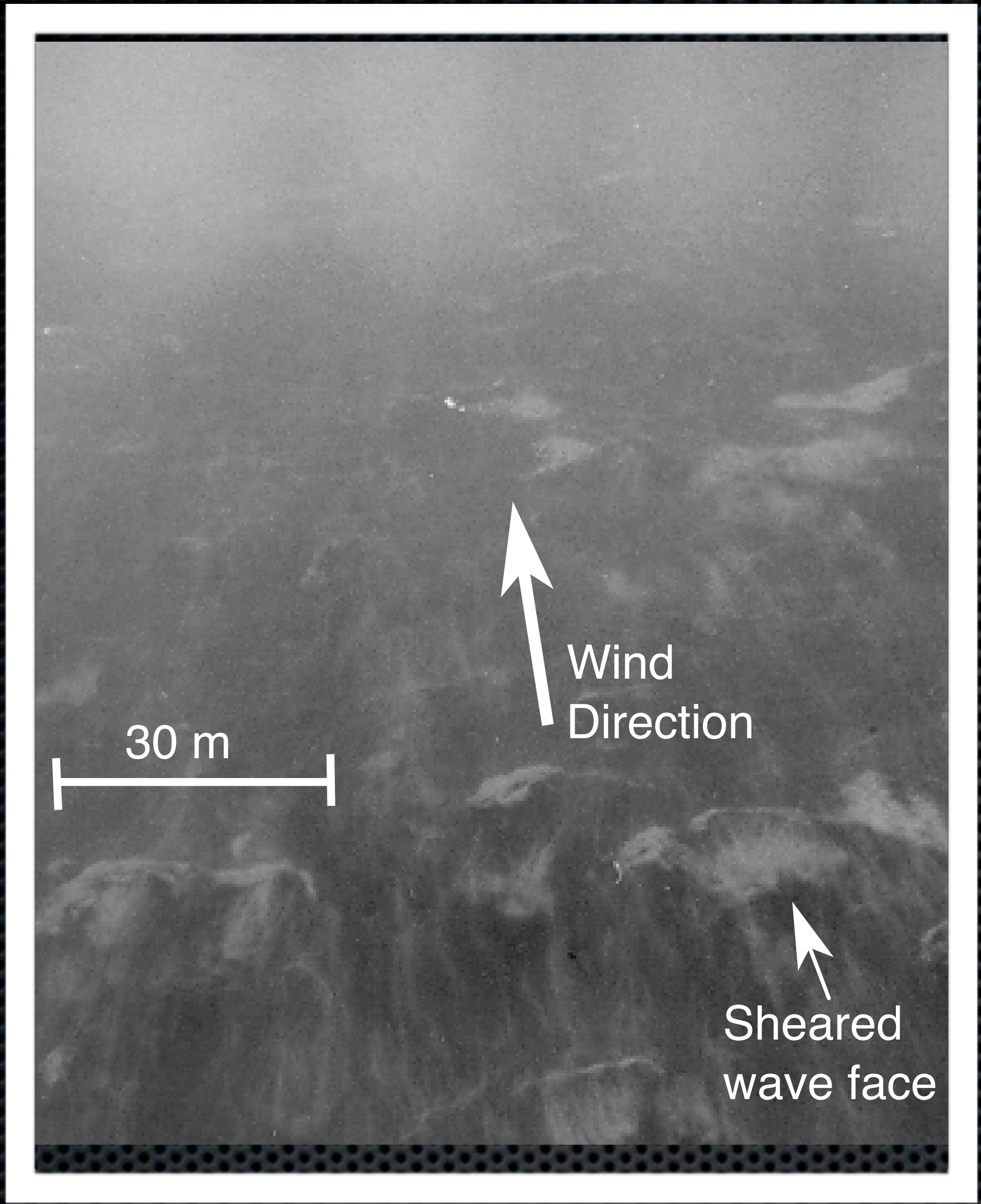
- Airborne microwave measurements (SFMR) provide greater radial resolution and reduced uncertainty

- Here we use SFMR and flight level data to develop new methods to estimate intensity

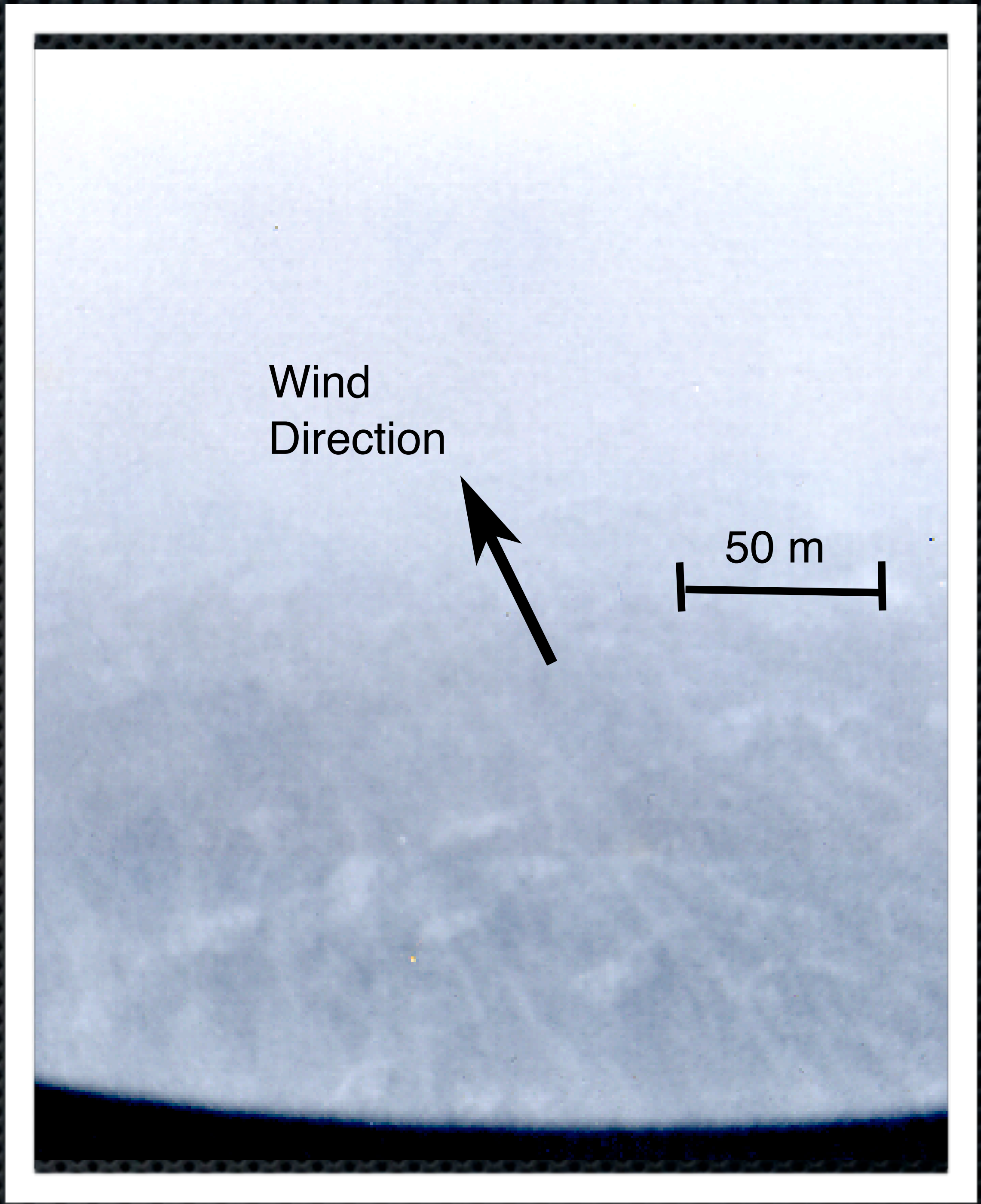
- **SFMR**
  - Measures emission from sea foam
  - Measures sfc brightness temperatures at 6 different frequencies 4-7 GHz
  - Each reacts differently to precip so rain can be removed*
  - signal does not saturate as winds increase
  - occasional spikes due to radar, RF interference, heavy rain in low winds
  - GMF tuned to GPS sonde measurements during 2005 season (Uhlhorn et al 2009)
  - Bias from non-wind sources/sinks of foam e.g. currents vs wind



SEA STATE PHOTOS BY THE AUTHOR HURRICANE ELLA 1978*



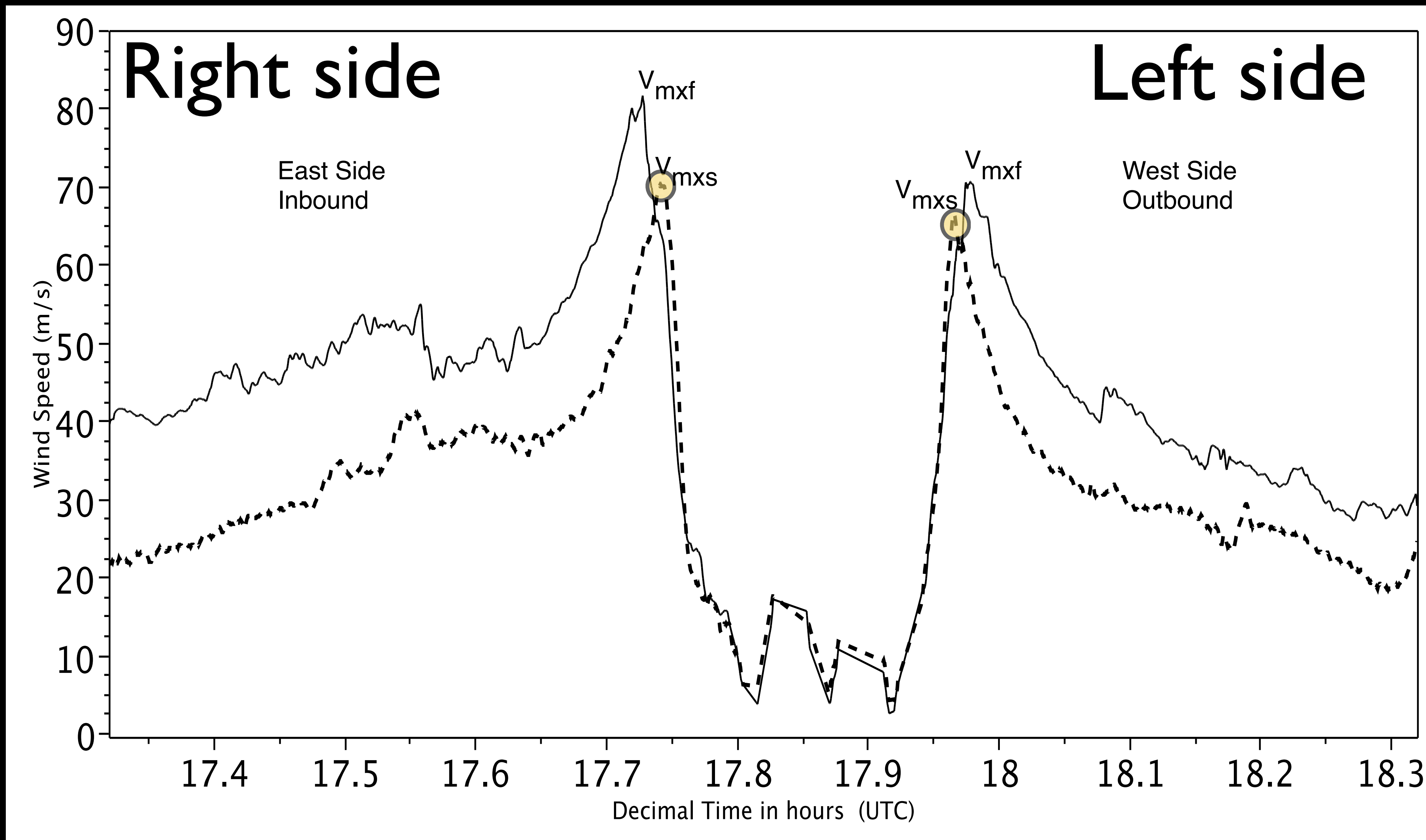
1521 UTC
240 M 90 KTS



2 MIN LATER
460 M 110 KTS

*WEIGHTING FACTOR OF 10 IS APPLIED TO ALL AUTHOR'S EYEWALL PENETRATION STATS FOR ALTITUDES < 500 M

Most sondes launched radially inside Rmax at flight level
Vfl is decreasing so Vsfc/Vfl is large... Better to use Vmax



Hurricane Katrina 28 Aug 2005

NHC Operational Practice since 2000

"90% Rule"
Std dev 0.19

Guidance for Reduction of Flight-level Observations and Interpretation of GPS Dropwindsonde Data

James L. Franklin
February 2001

This is an update of last year's guidance on the assessment of TC intensity based on GPS dropsonde data, both for when the dropsonde data are available, and more generally, for determining surface wind reduction factors (RF10m) for adjusting flight-level data. Although the sample size is large enough that the statistics have become rather stable, some new analyses of right-left wind asymmetries have changed some of the recommendations. Please note that these are mean reductions; there is significant storm to storm variability.

This note is divided into four sections; the first three concern flight-level wind reductions. The dropsonde data collected to date show that wind reductions vary with flight altitude, and are different in the inner and outer portions of the vortex, and so I have broken down the reductions accordingly. Section A gives guidelines for reducing flight-level winds in the *eyewall or maximum wind band* of the tropical cyclone. Section B gives reduction factors to be used for determining *quadrant wind radii*. The reduction factors imply particular flight-level wind thresholds that correspond to the 64, 50 , and 34 knot surface values, and for convenience I have included these thresholds in the tables. In the outer vortex, reduction factors vary significantly with convection, and so I have included an additional set of radii tables that can be used for weakly-convective storms (Section C). Section D provides some guidance on the interpretation of individual dropsonde profiles.

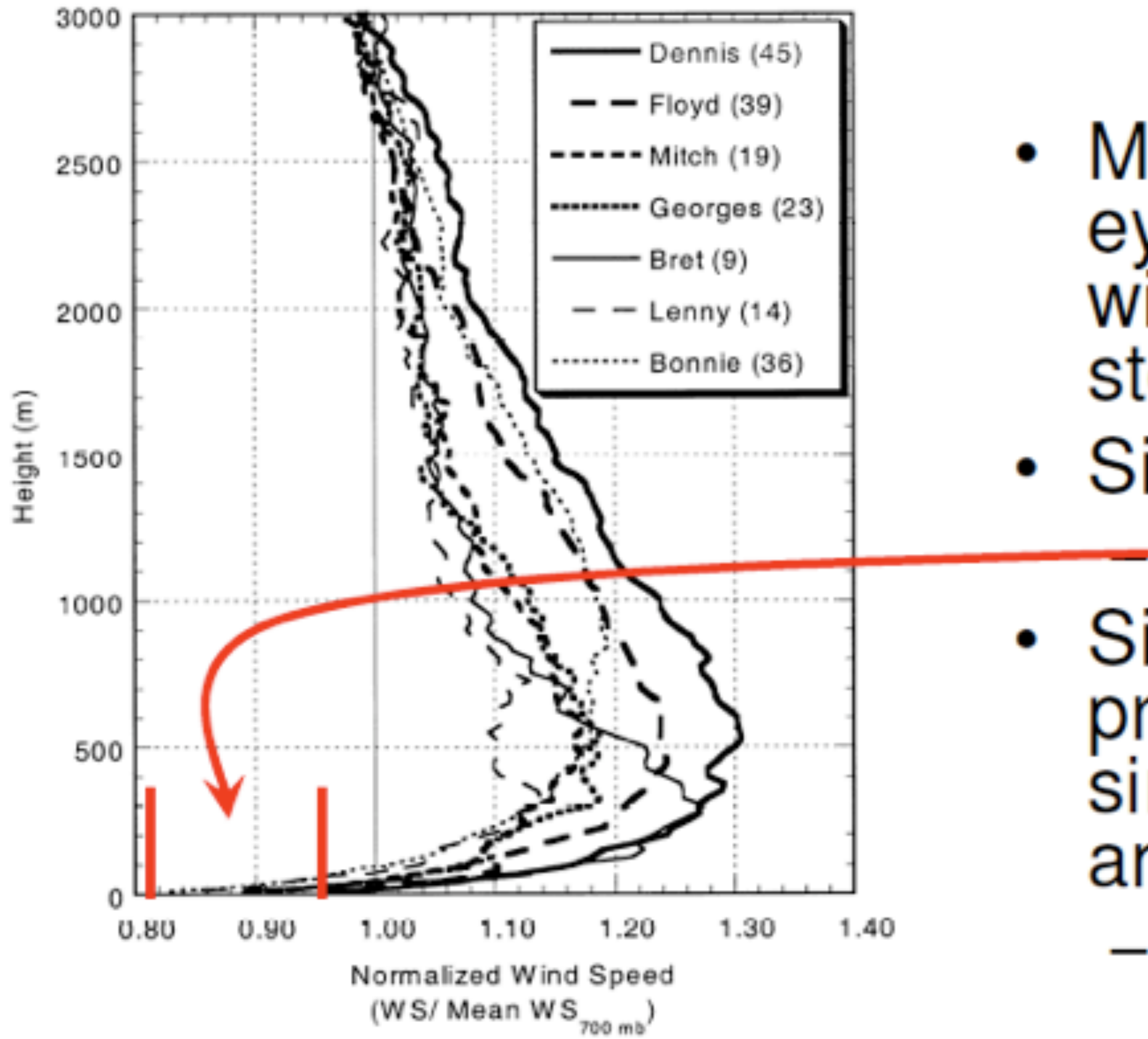
A. Determining maximum sustained winds from flight-level data.

Table 1. Reduction factors for determining a cyclone's maximum sustained wind from flight-level data.

Reference Level	RF10m
700 mb	0.90
850 mb	0.80
925 mb	0.75
1000 ft	0.80

GPS sonde profiles

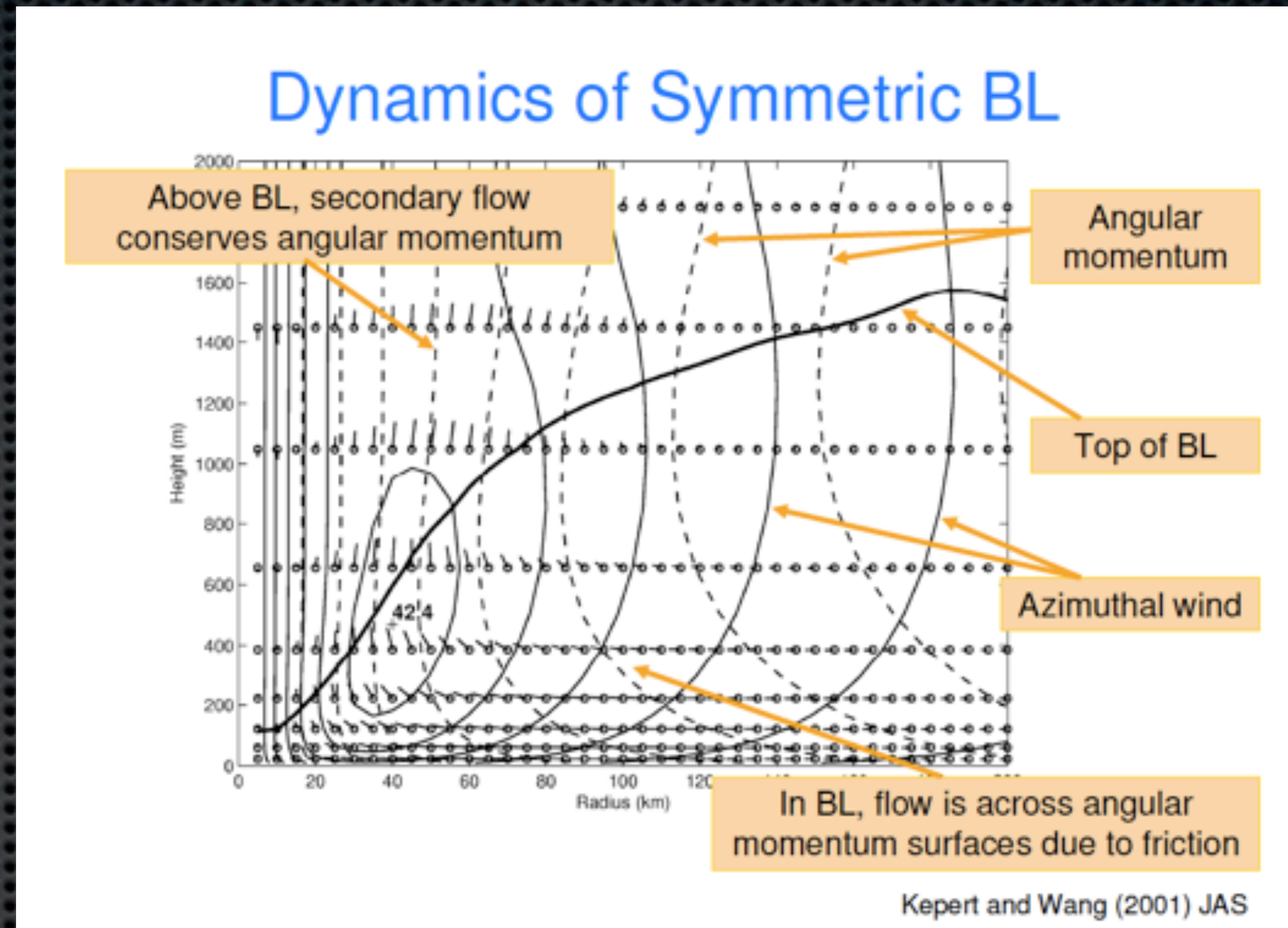
BL Variability Between Storms



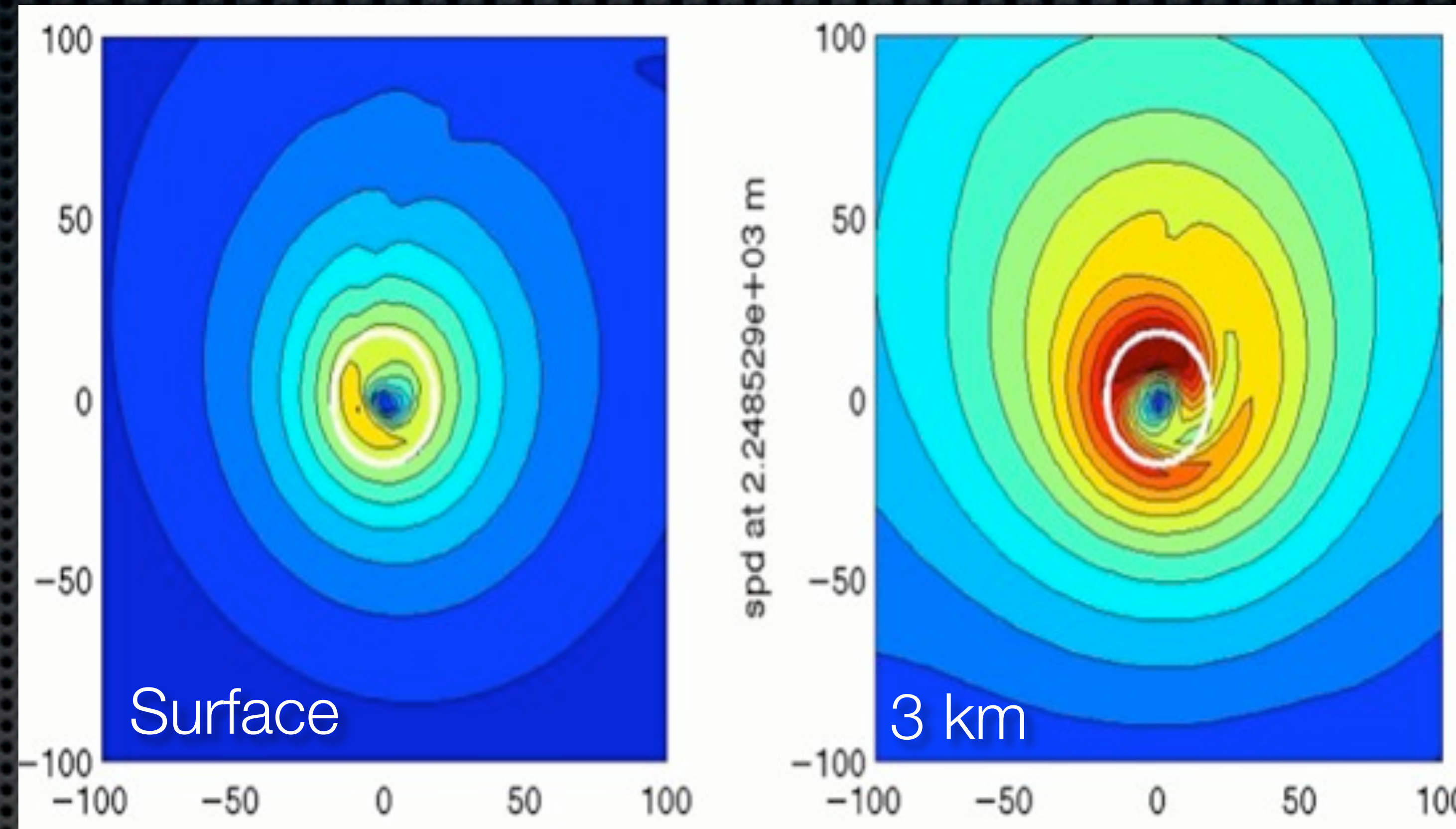
- Mean observed eyewall normalised wind speed profile in 7 storms.
- Significant variation
  - Incl in surface wind.
- Similar variation present in idealised simulations (Kepert and Wang 2001).
  - Due to differences in storm structure.

Franklin et al. (2003) W&F

- **Low level jet**
- Frictional inflow forces radial/azimuthal advection of momentum in PBL
- Inertial stability forces eyewall updraft near sfc Rmax
- Vertical variation of horizontal temp. gradient (warm core) causes outward tilt of eyewall above PBL. Rmax tilts outward with height as do lines of const angular momentum above the PBL
- Vertical advection of momentum helps generate supergradient winds above sfc layer in eyewall
- The proximity of jet to sfc leads to larger sfc wind factors (Vsfc/Vfl) near the eyewall than at outer radii.
- Unrelated to momentum transports associated with moist convection*



- Kepert's low-level Jet modeling and observations (2001-2006)
  - Motion-induced asymmetry and azimuthal advection of momentum cause jet to be lower, more supergradient, on left side of storm
  - Angular momentum advection depends on the radial variation in wind speed:
    - Flat profiles are inertially stable (radial gradient of momentum throughout) and ~gradient jet from Rmax to large R e.g. Georges 1998 (Kepert 2006a)
    - Peaked profiles near inertially neutral (weak radial gradient of momentum outside Rmax, very strong at Rmax) -> stronger jet confined to near Rmax e.g. Mitch 2001 Kepert 2006b



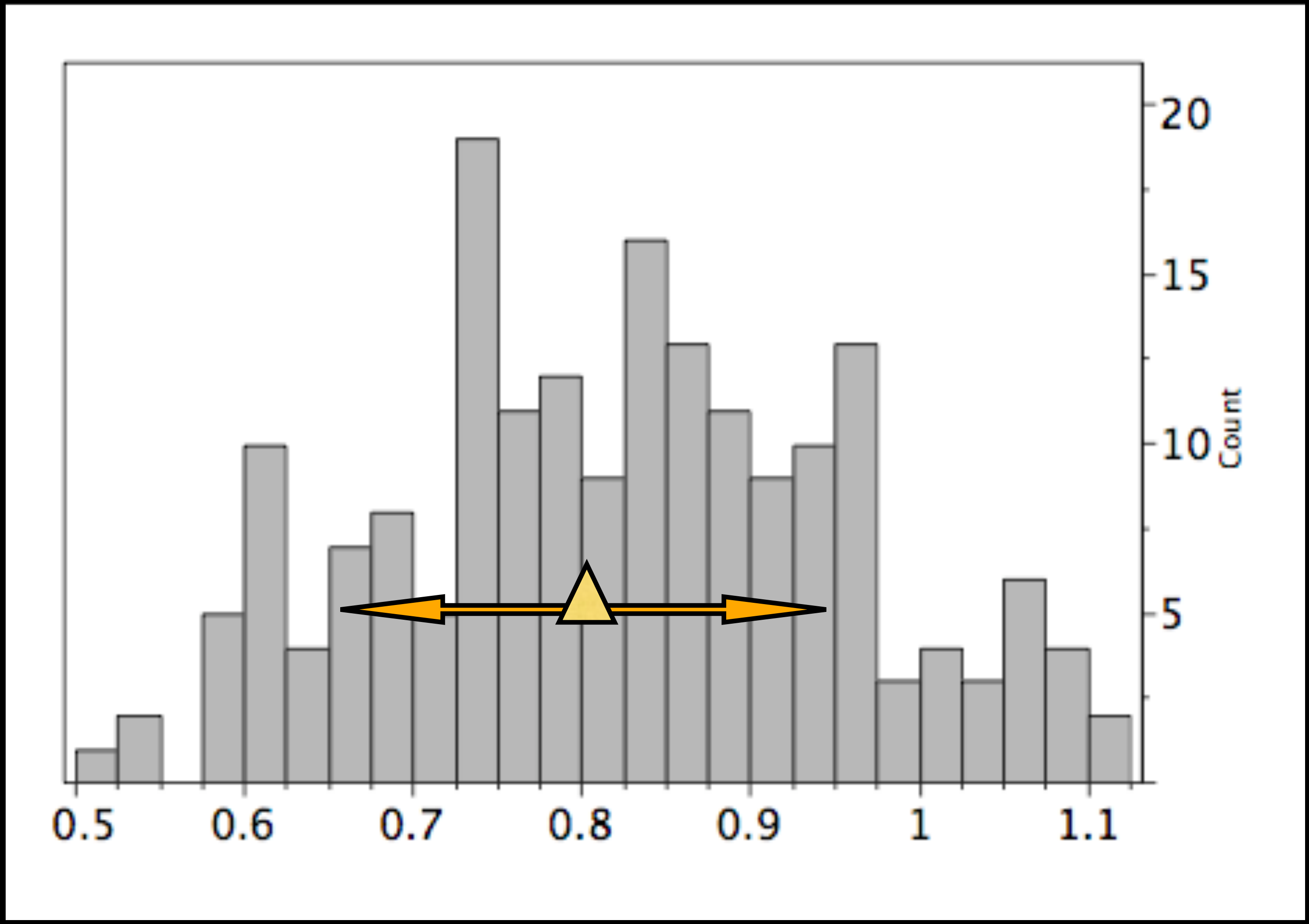
Kepert's modeling of Hurricane Andrew's wind field during the Florida landfall

Re-examination of GPS sonde results

742 sonde profiles
Filter
Vmax fl > 33 m/s
Vsfc > 30 m/s

Slant sfc wind factor:
For 147 eyewall drop sondes at 2-4 km with sfc wind computations
1997-2003
Vsfc/Vmax 0.81 (.14)

Vertical sfc wind factor:
For 62 sondes near 700 mb without regard to Rmax
Vsfc/V700= 0.89 (.18)

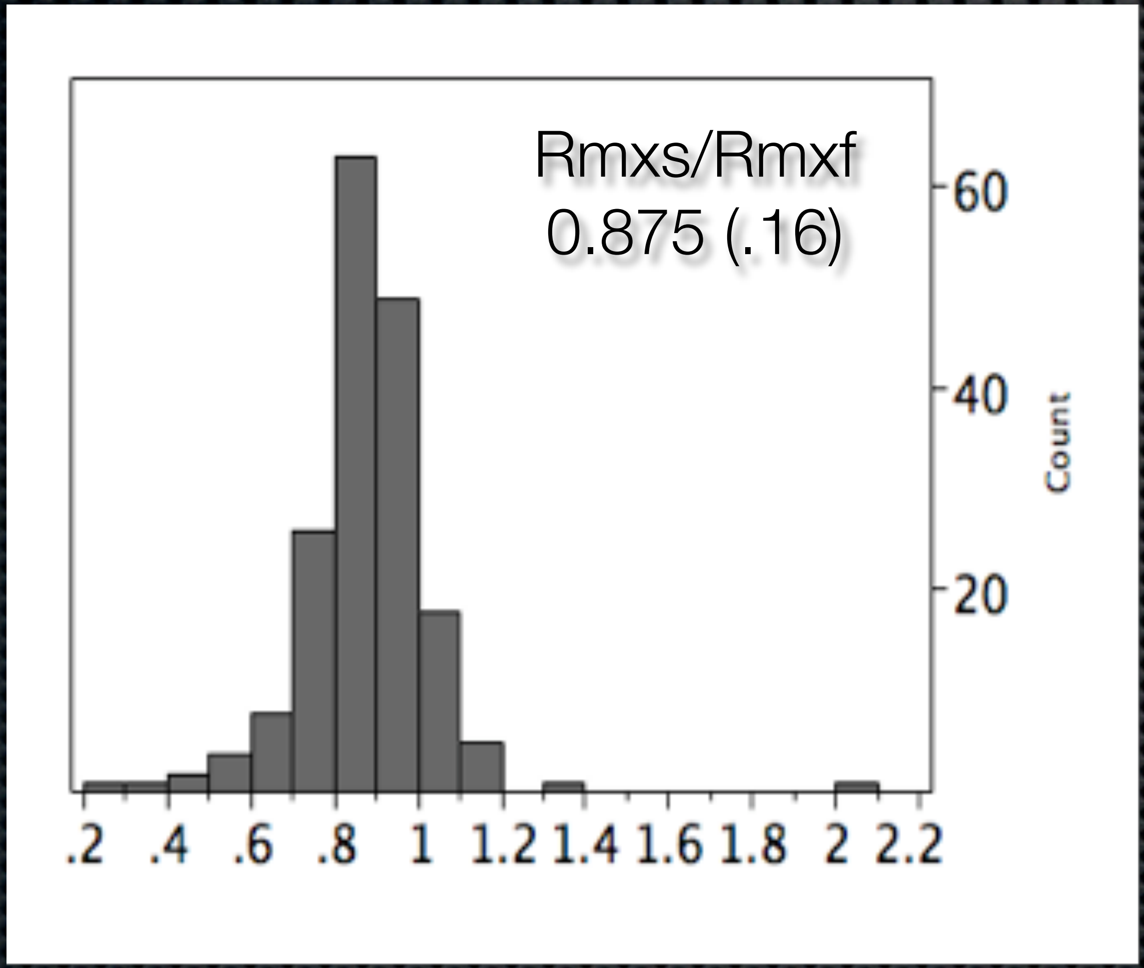


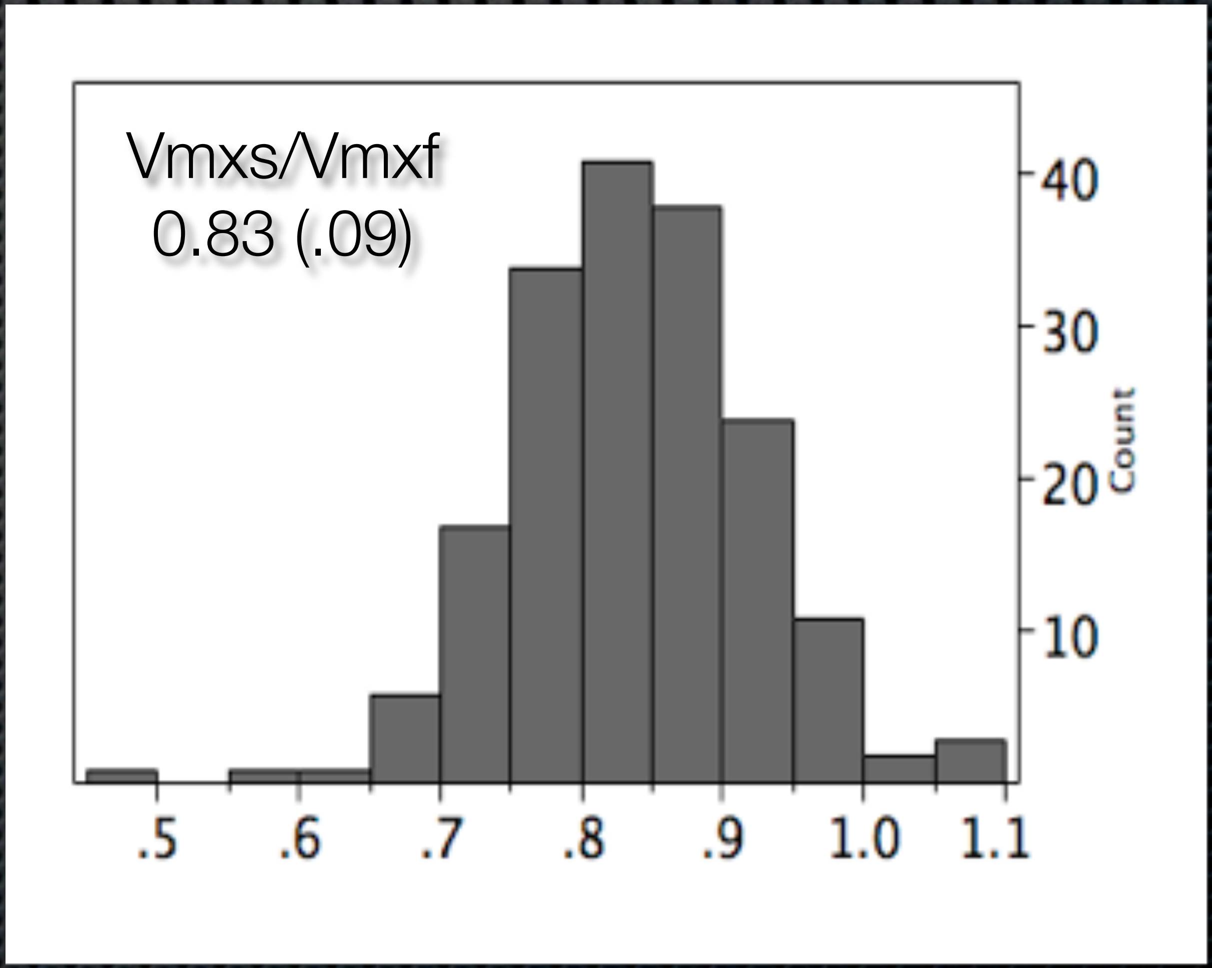
Vsfc / VmaxFL

SFMR and 2-4 km Flight level data

35 NOAA P3 research missions,15 Hurricanes (1998-2005)
179 VmxFl, Vsfc max (10 s cent running mean) pairs along radial legs
SFMR processed according to Uhlhorn et al 2007

25 missions with 3 or more radial legs to determine peak intensity by mission

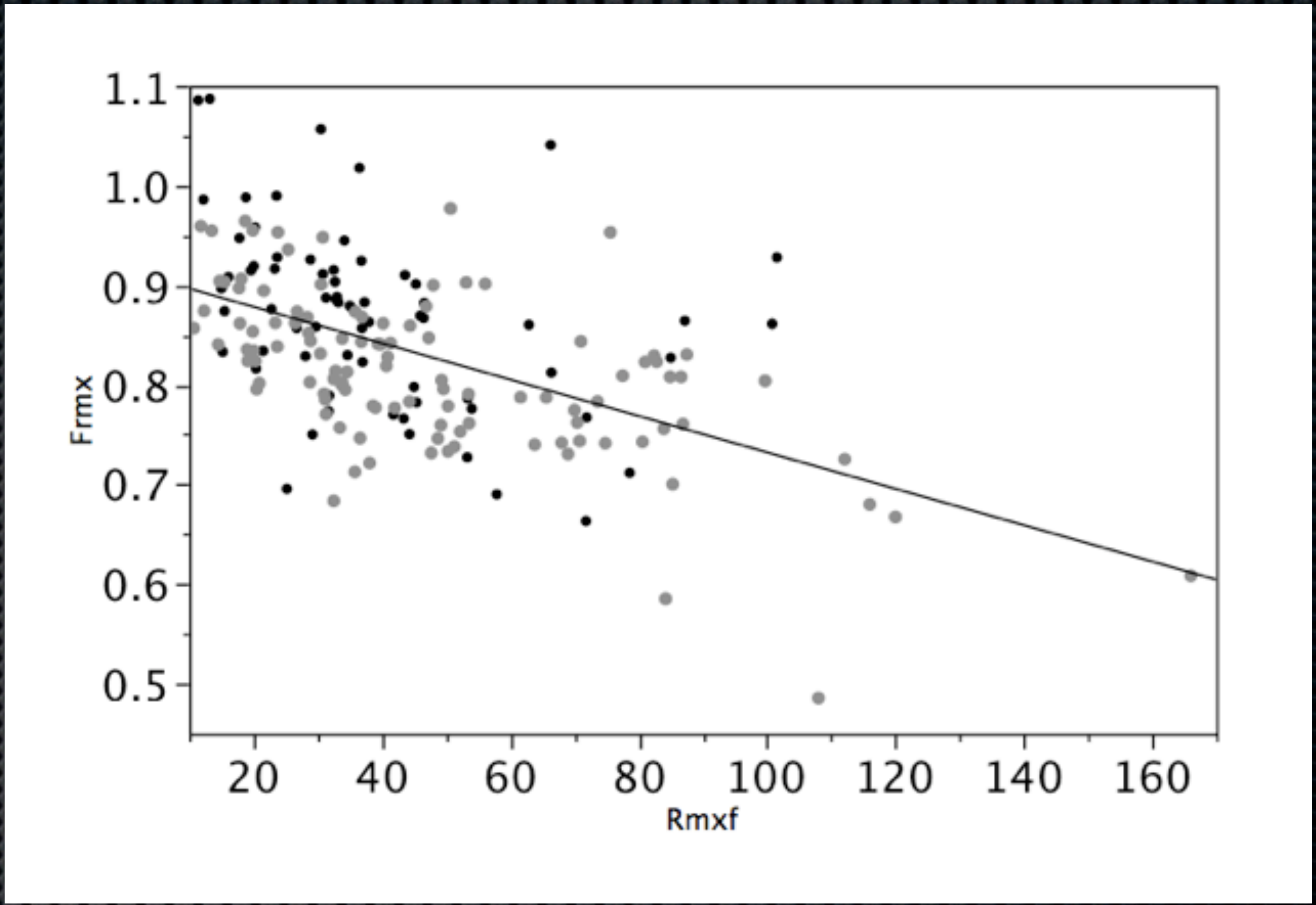




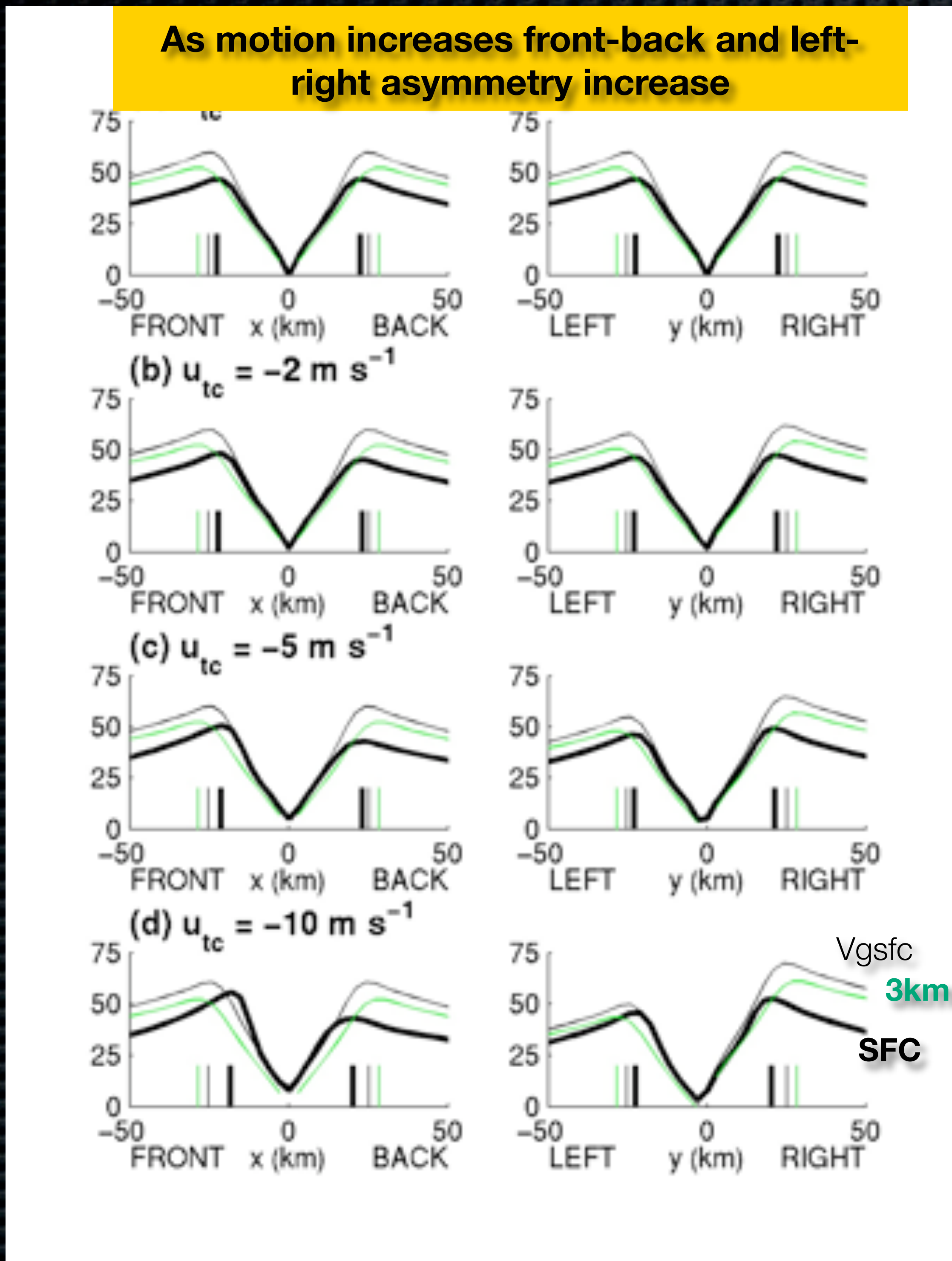
- Investigate dependence of Slant wind factor on flight level or storm motion quantities
  - Inertial stability
  - relative angular momentum
  - storm motion
  - storm relative azimuth and radius
- Construct regression model for slant wind factor
- Compare to Keperts 2001 modeling results

Slant factor vs. Rmaxfl

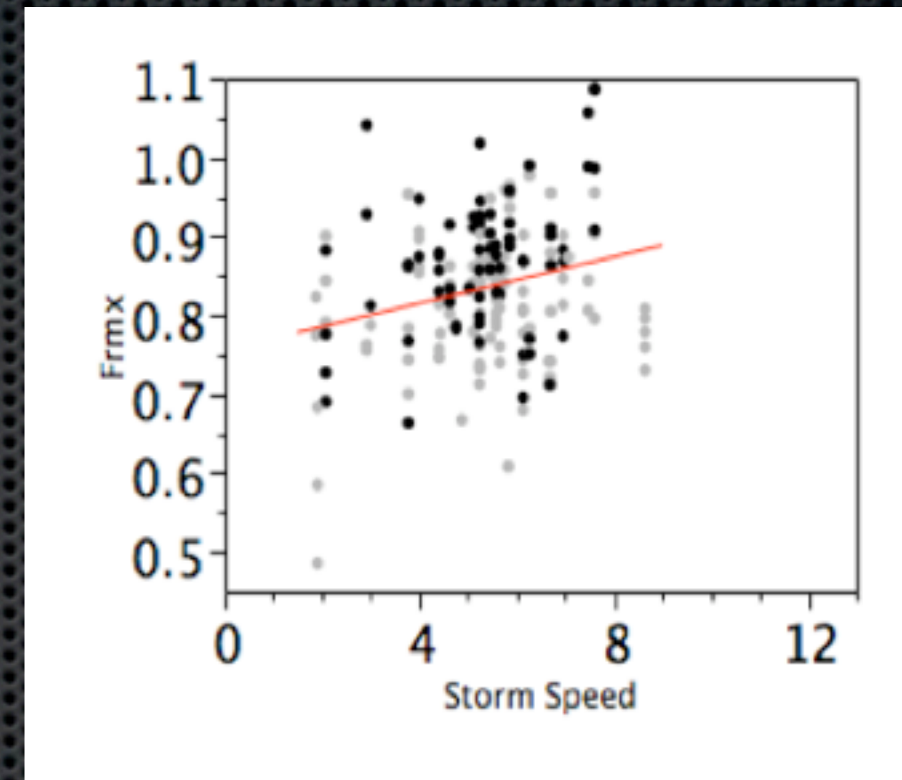
- negative correlation
- Left side (black) > right
- fit explains ~ 30% of variance
- Similar to Kepert 2001 (no convection)
- Related to shape of wind profile
- L-R asymmetry seen in Kepert 2001 and Franklin 2003

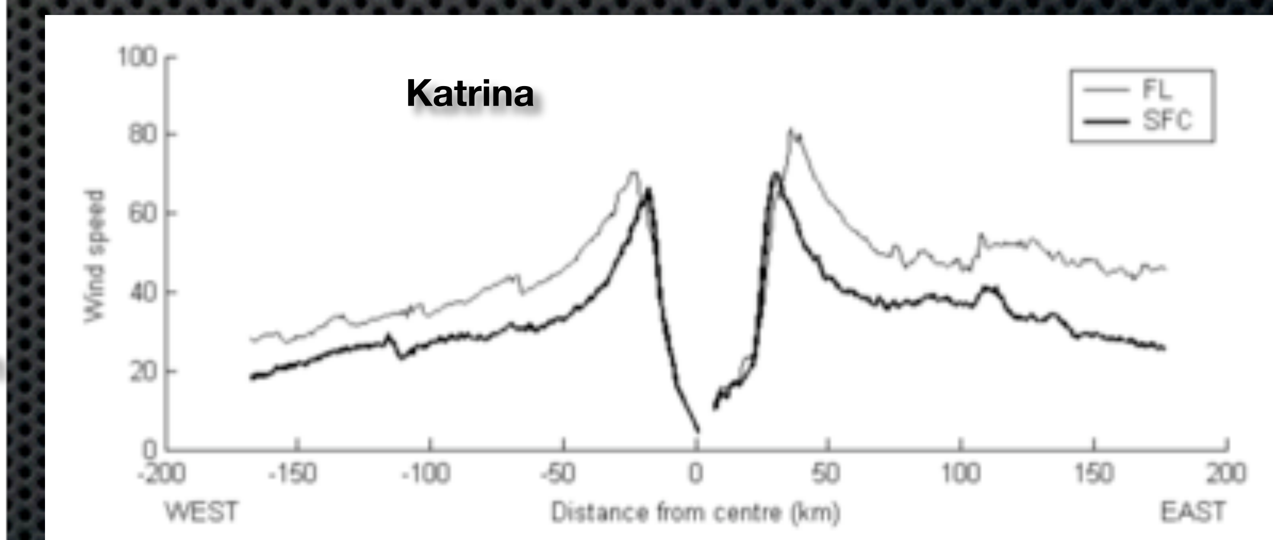


Kepert and Wang simulation showing effect of storm motion

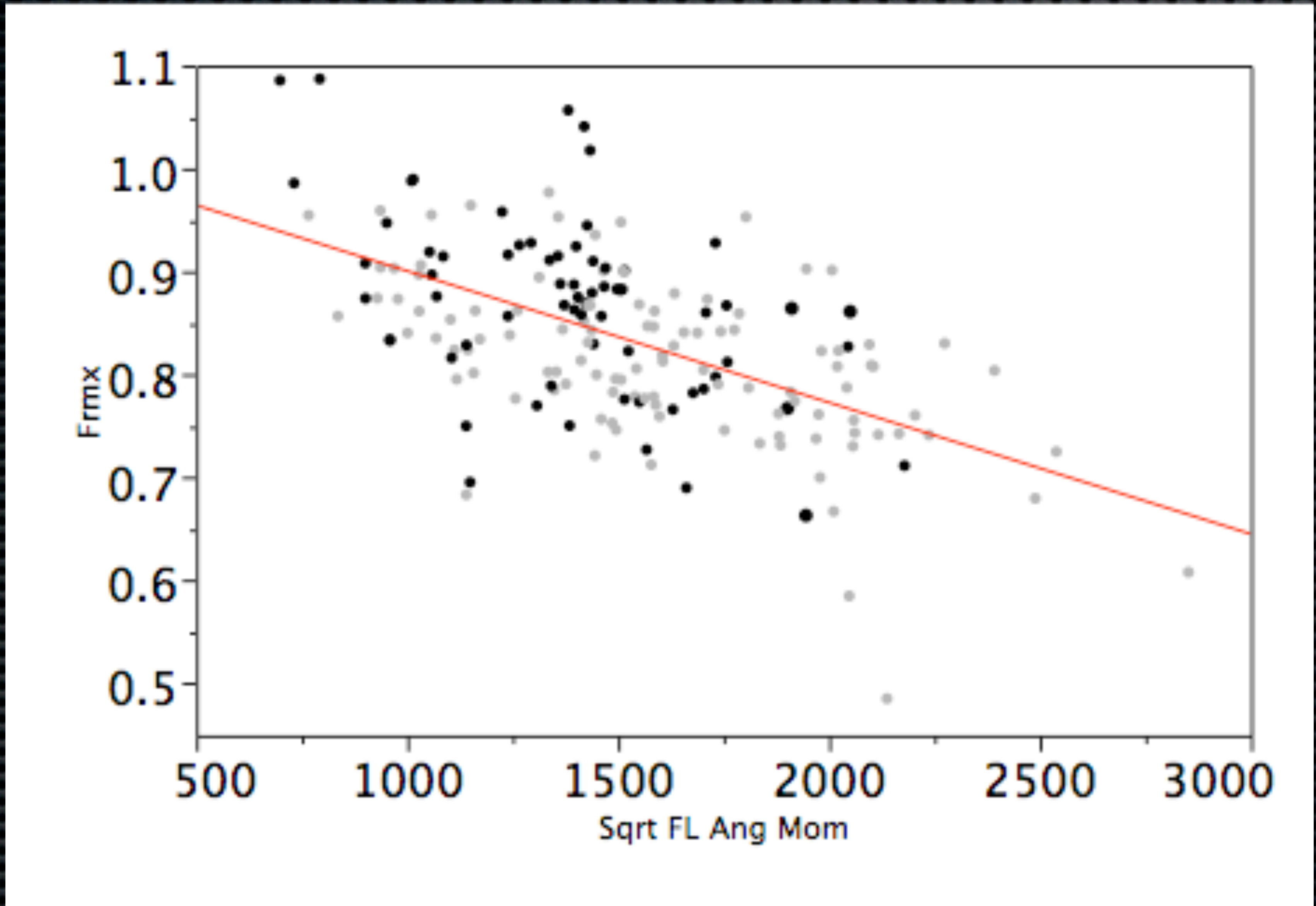


Slant factor higher for faster moving storms

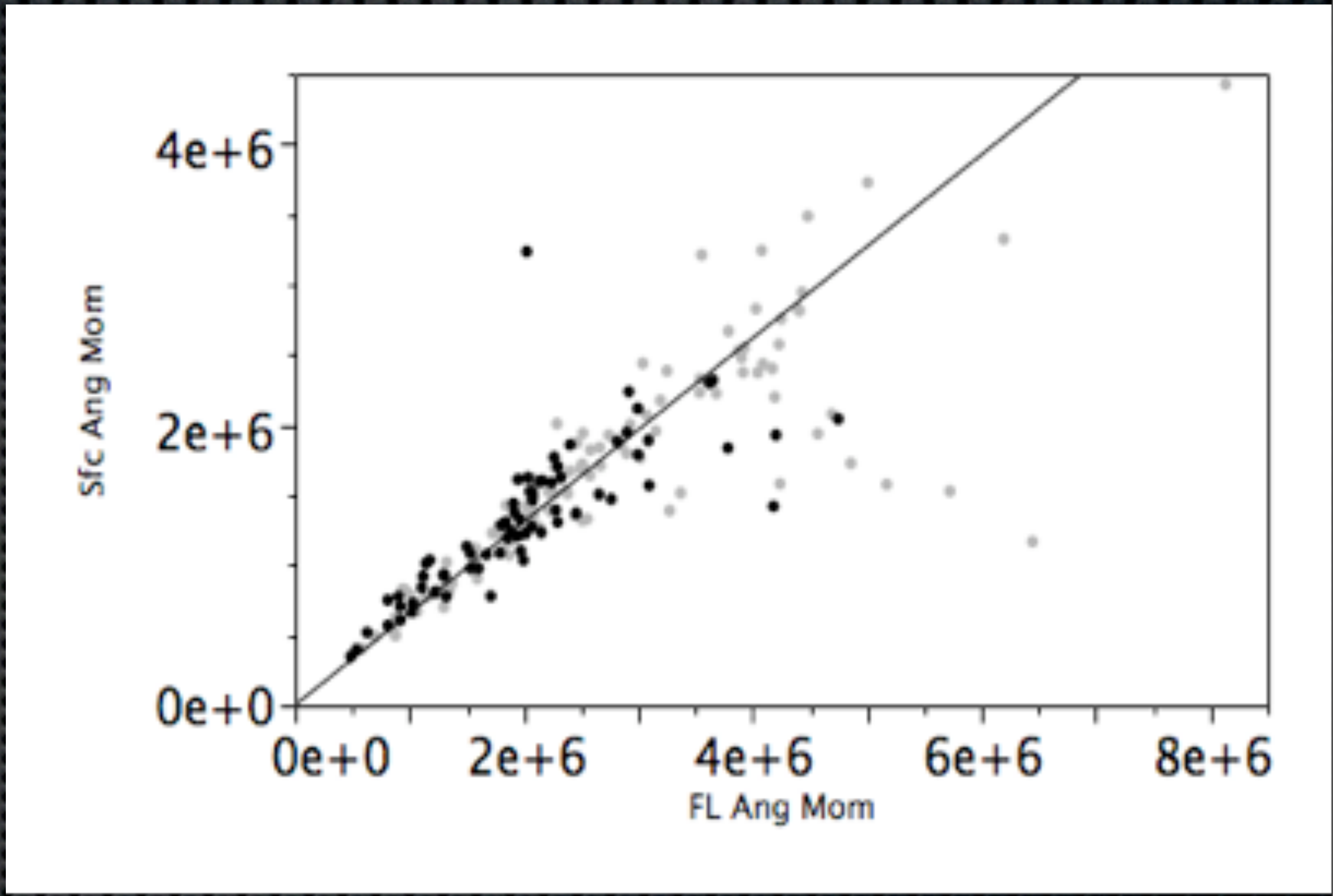




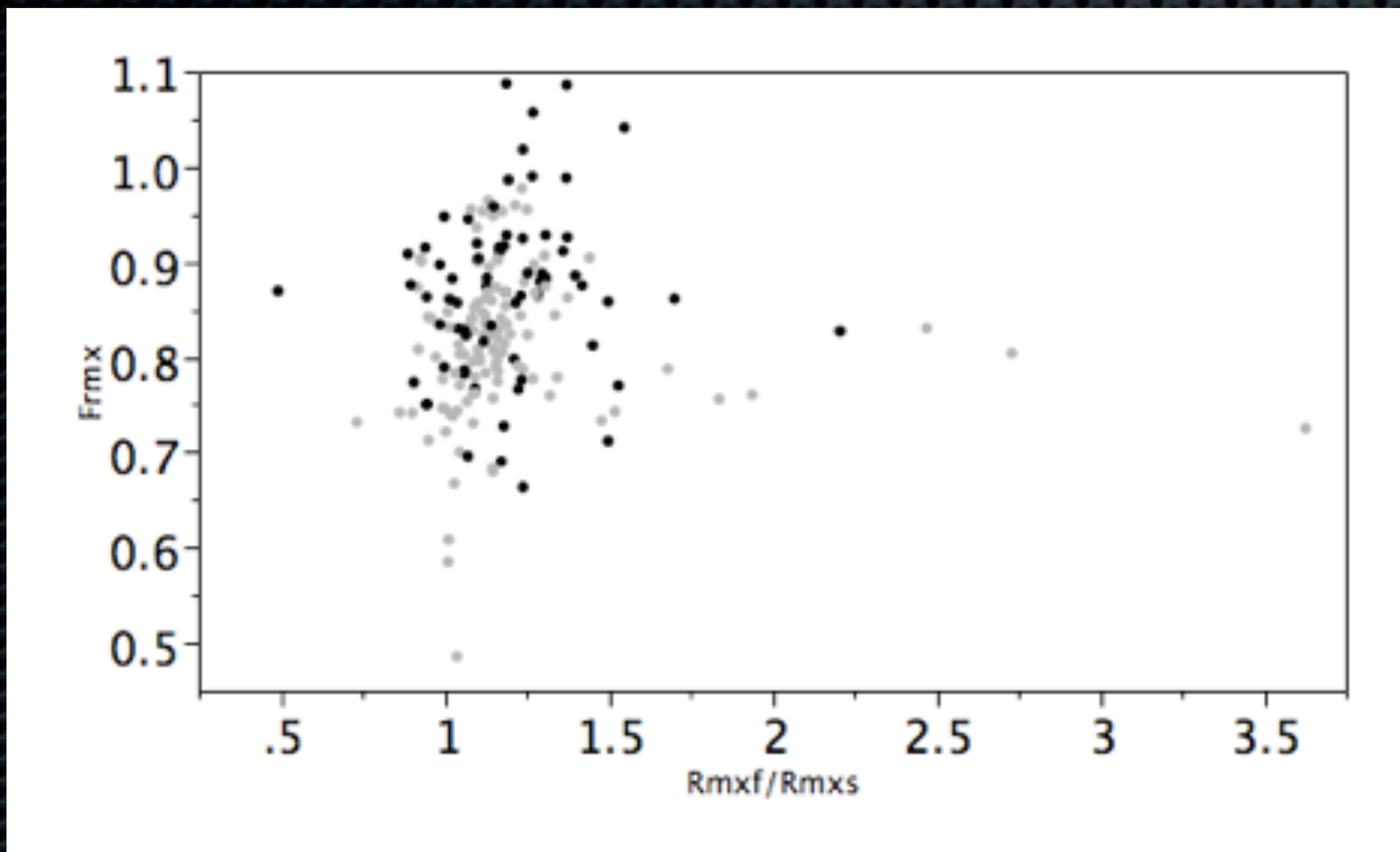
- Slant factor depends inversely on angular momentum (30% of variance) consistent with Kepert 2001. M is nearly conserved above the PBL along sloping Rmax.

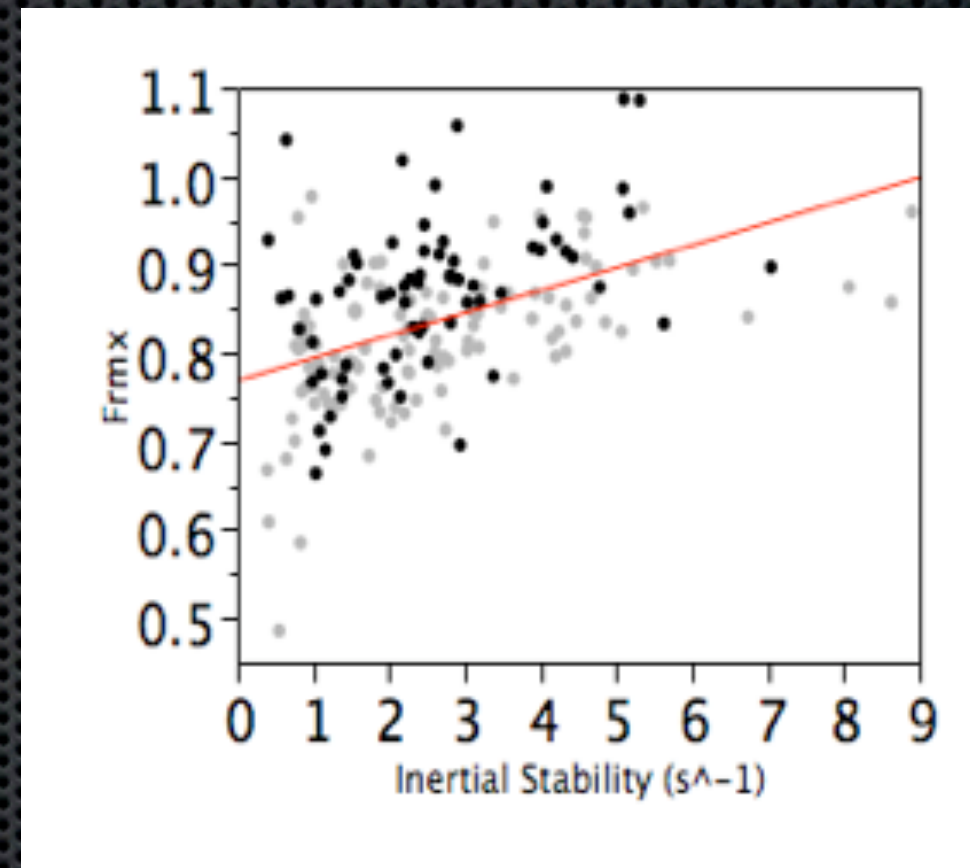


- Sfc momentum along Rmax is about 65% of that at flight level
- VmxsRmxs =.65 VmxfRmxf
- Frmx= .64 Rmxf/Rmxs
- Frmx should depend on relative Rmax slope



- Some dependence on eyewall slope (smallest values for near vertical slope, largest for slopes around 1.2





- Dependence on inertial stability (22%)

I= Sqrt(2) Vmxf/Rmxf

- **Regression model for Frmx**
  - Predictors: FL Ang. Momentum, Inertial stability, Storm speed, Storm relative azimuth
  - Explains 41% of variance
  - Independent evaluation in 2006 -0.7 m/s (~2%) bias and 3 m/s rms error (~ 8%)
  - 90% rule has 3.7 m/s high bias (~8%), 6 m/s rms error (~12%)
  - This (regression validated on SFMR data) method is used in H*Wind to estimate max sfc wind for each radial leg

- **Regression model for max sfc wind anywhere in storm over the course of a mission (~8 h)**
  - 21/25 missions had Vmxf on right side of storm
  - 13/25 missions had Vmxs at different azimuth than Vmxf (3 on opposite side of storm)
    - Predictors: Vmxf, Rmxf (Explains 66% of variance, rms 2.5 m/s or ~ 5%)
    - Useful for retrospective assessment of intensity and training satellite imagery
    - .9 rule has bias of 4.6 m/s (rms 7.6 m/s, ~12%)

Eqn 13 Applied to recon data from significant historical hurricanes

90% rule only used after 2000

ok in very strong storms with Vmxf > 75 m/s

too high with Vmxf < 75 m/s (Hugo)

The climate record for Allen, Gilbert, Mitch shows a low bias for selected times

TABLE 6. Estimates of V_{mxs} from Eq. (13) compared to the 90% rule and the BT for selected historical storms in which SFMR measurements were not available. With the exception of Andrew, which uses the peak 10-s flight-level wind speed, V_{mxf} values are from archived minob values.

Storm name and event time and date	V_{mxf} (m s^{-1})	V_{mxs} Eq. (13) (m s^{-1})	V_{mxs} 90% (m s^{-1})	BT (m s^{-1})	BT bias?
Allen, 1800 UTC 7 Aug 1980	86.8	79.5	78.1	74.0	low
Gilbert, 0000 UTC 14 Sep 1988	83.0	76.3	74.5	71.7	low
Hugo, 0400 UTC 22 Aug 1989	71.7	59.8	64.5	61.8	OK
Andrew, 0900 UTC 24 Aug 1992	83.6	76.7	75.2	74.0	OK
Mitch, 1900 UTC 26 Oct 1998	80.8	74.8	72.7	69.5	low

- **Conclusions**

  - Sfc wind factors based on peak SFMR and flight level winds show a dependence on azimuth, storm motion, inertial stability and relative angular momentum consistent with Kepert's hurricane boundary layer modeling

  - SFMR peak sfc wind data have been used to develop a regression model to estimate intensity from flight-level observations with a 5% rms error

  - The model is an improvement over the 90% rule which has a high bias of ~10% and rms error of ~ 12%

  - The intensity estimates in the climate record for the modern recon era should be adjusted for bias

the end

questions?