Hurricane Dynamic and Thermodynamic Balances as Revealed by the Azimuth Asymmetry of Wind-stress

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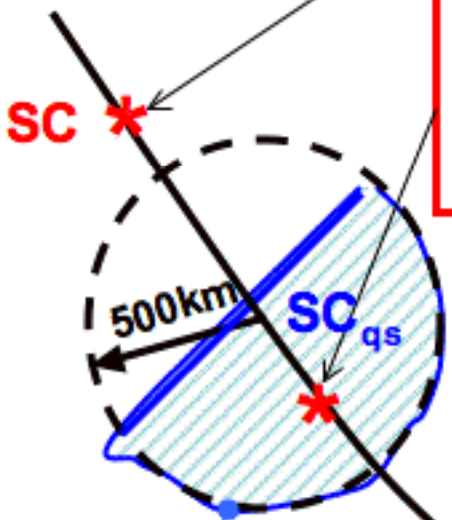
Introduction

❖Traditional measurements rarely give a complete map of hurricane structure; mapping usually depends of the extrapolation of measurements along aircraft flight paths or from point measurements of opportunity.

❖A wide-swath scatterometer is the best mean for synoptic mapping of a hurricane, but the map generated in one pass may still not be complete.

❖Characteristics of symmetry with respect to translation direction that are independent of the size of the hurricane are examined through composites of over 8000 scans of QuikSCAT, collocated to operational best track information, over global oceans in a decade.

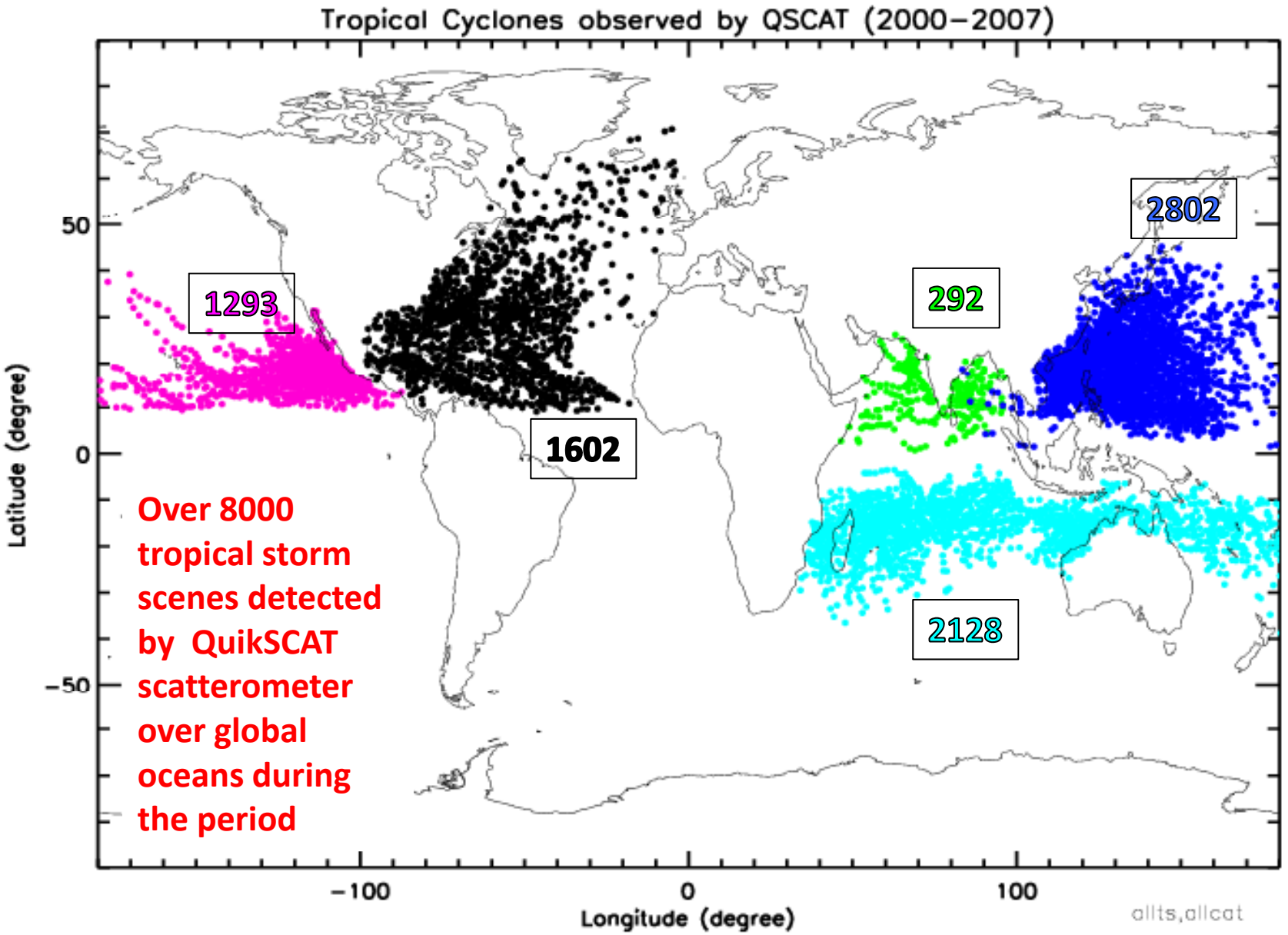


Best track reports every 6 hours:

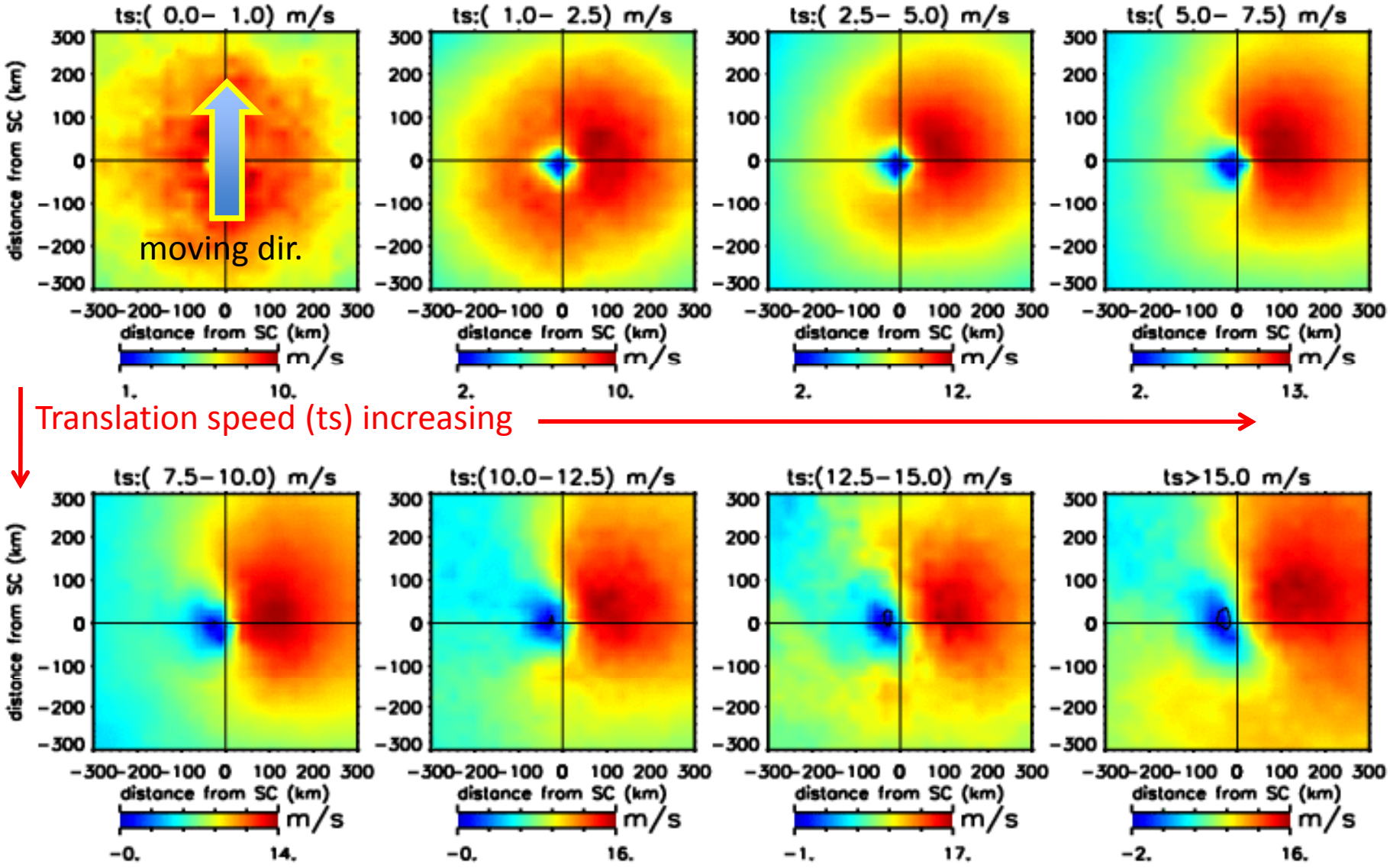
- Storm center location SC
- Hurricane moving direction
- Translation speed
- Maximum wind intensity
- .....

One QuikSCAT cases created if:

- A swath covers SC within 3 hours;
- Data collocated within 500km from interpolated SC_{qs} at QSCAT time;
- WVCs dropped if rain prob. > 10%;
- More than 20% coverage of the circular area

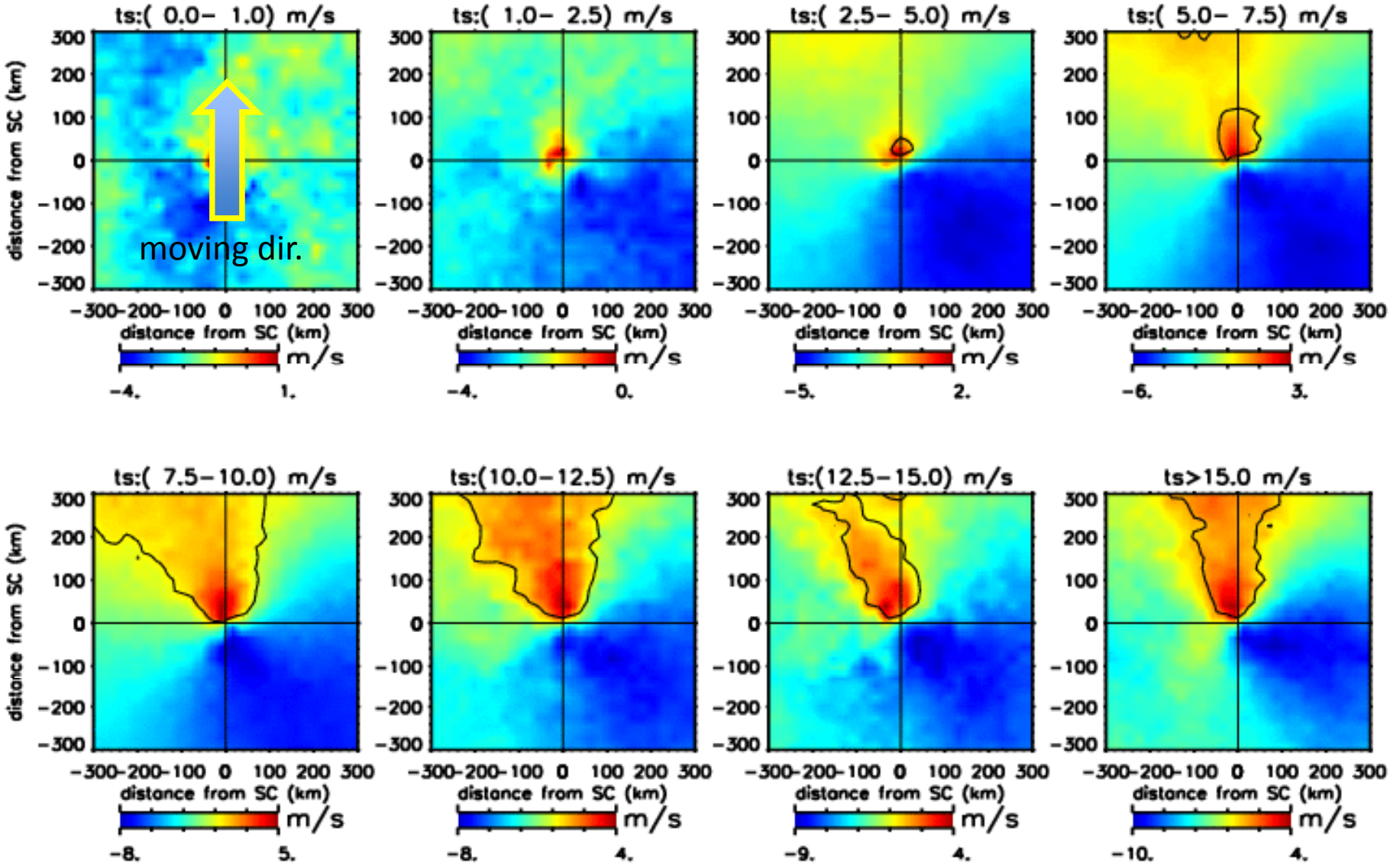

Tropical Cyclones observed by QSCAT (2000–2007)
Latitude (degree)
50
0
−50
−100
0
100
Longitude (degree)
allts,allcat
1293
1602
292
2802
2128
Over 8000 tropical storm scenes detected by QuikSCAT scatterometer over global oceans during the period

Composite of Tangential (v) Wind in N. Hemis. 2000-2007

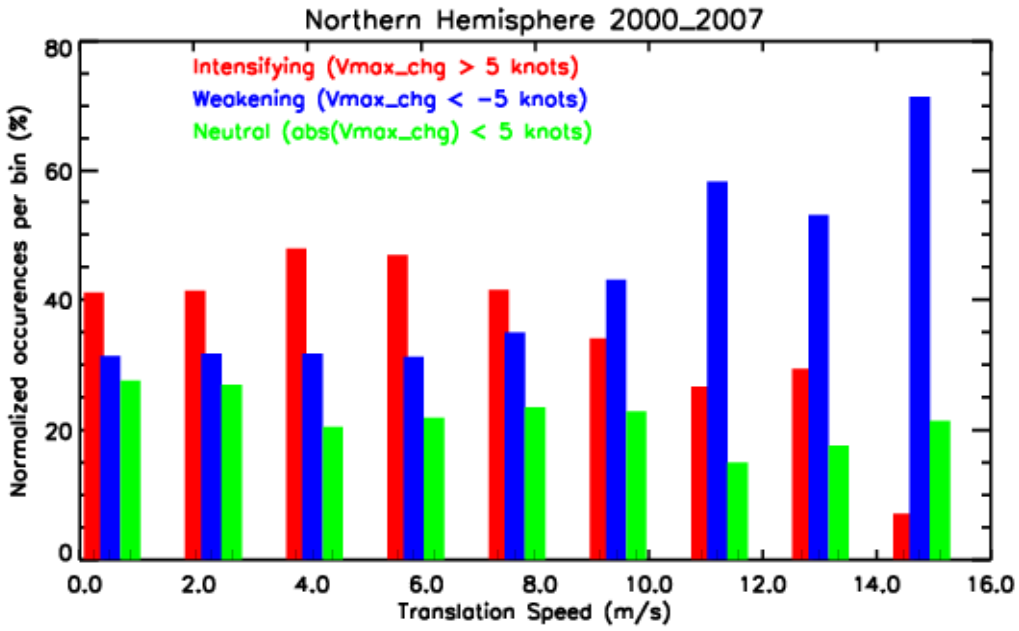


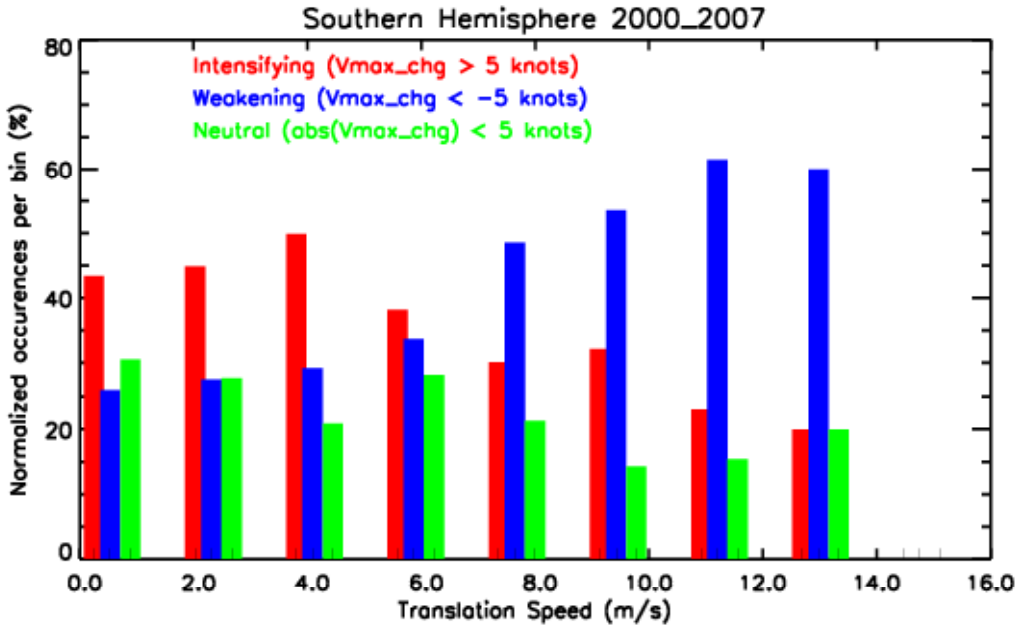
The tangential component is near symmetric for slow-moving storms. The left-right asymmetry induced by and becomes stronger for fast-moving storms.

Composite of Radial (u) Wind in N. Hemisphere 2000-2007



Radial wind component indicates inflow around storm center with maximum from right-rear; also detects area of outflow in front when translation speed picks up





To study the influence of wind asymmetry induced by storm translation speed on hurricane intensification

We define index of storm intensity change (ΔV_{max}) as the change of sustained maximum wind speed during 12-hour period centered at the moment of satellite wind measurement, and segregated into groups of:

INTENSIFYING if $\Delta V_{max} > 5$ knots
WEAKENING if $\Delta V_{max} < -5$ knots
NEUTRAL if $abs(\Delta v_{max}) < 5$ knots

Statistics on storms data between 2000-2007 indicates when translation speed larger than 7m/s, the probability for storms to intensify is greatly suppressed.

We examine possible underlying mechanism through the angular momentum balance.

The budget equation for Absolute Angular Momentum (AAM)

$$\frac{\partial}{\partial t}\int_m M_a\,dm = [F_H]_{r_1}^{r_2} + [F_v]_{p_2}^{p_1} + \left[F_{friction}\right]_{r_1}^{r_2}$$

The horizontal angular momentum flux into cyclone per unit circumference across a circle at radius r from cyclone center

$$[F_H]_{r_1}^{r_2} = \frac{1}{g}\int_{p_1}^{p_2} dp \int_0^{2\pi} rd\theta\left[-rvu - \frac{1}{2}fr^2u\right]$$

Relative Angular Momentum caused by cyclonic circulation

$$F_{RAM} = -rvu$$

Caused by Coriolis force

$$F_{COR} = -\frac{1}{2}fr^2u$$

The surface frictional dissipation:

$$\left[F_{friction}\right]_{r_1}^{r_2} = \int_0^{2\pi} d\theta \int_{r_1}^{r_2} rdr\left[-\rho C_D|V_S|v_s r\right]$$

$$F_\theta = -\rho C_D|V_S|v_s r$$

$$C_D = (0.75 + 0.067|V_S|)\times 10^{-3}$$

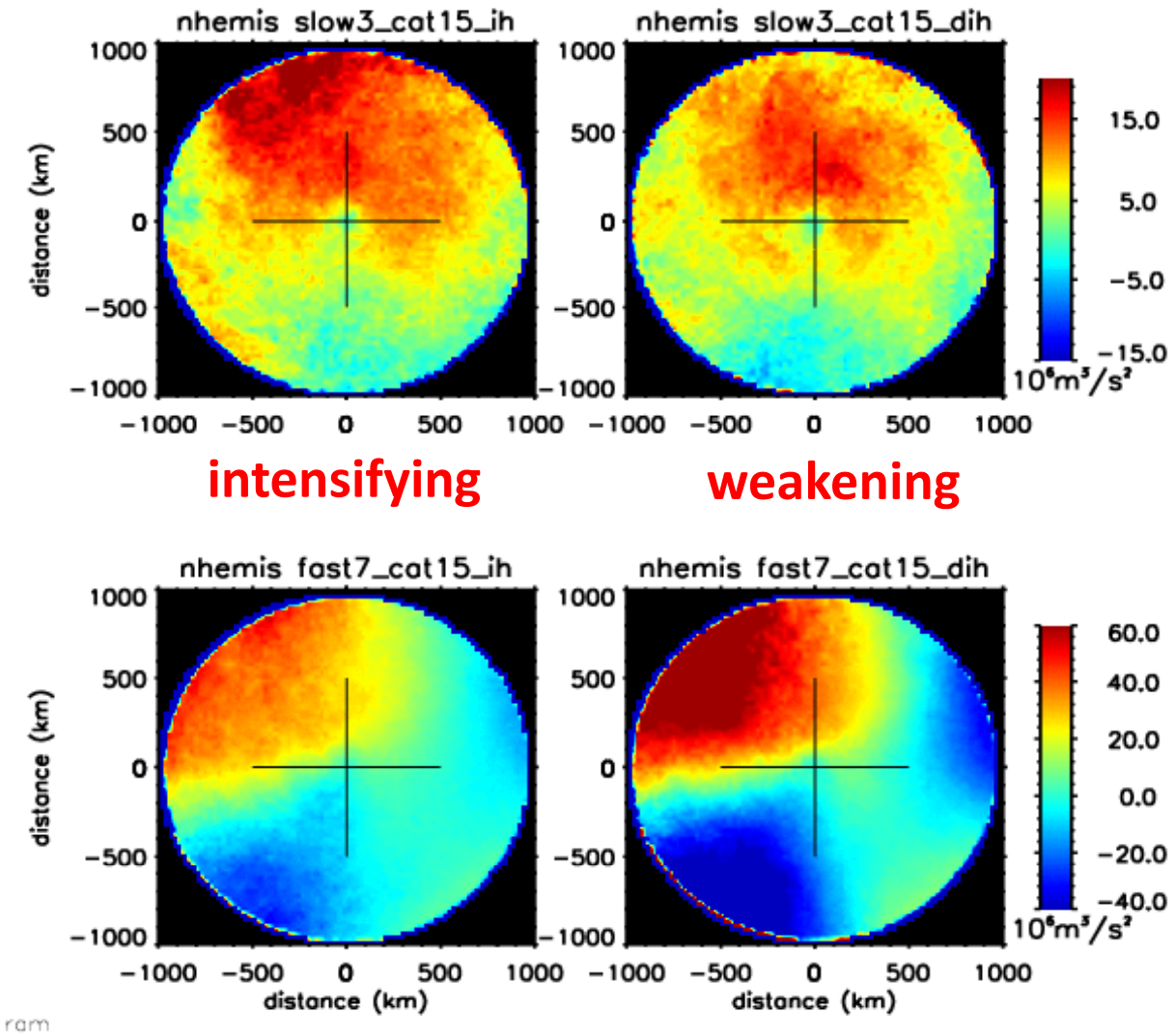
The vertical boundary fluxes:

$$[F_v]_{p_2}^{p_1} = \frac{1}{g}\int_0^{2\pi} d\theta \int_{r_1}^{r_2} rdr\left[rv\omega + \frac{1}{2}fr^2\omega\right]$$

Vertical velocity

$$\omega = \frac{dp}{dt}$$

Composite of F_{RAM} (angular momentum flux by circulation)



$$F_{RAM} = -rv$$

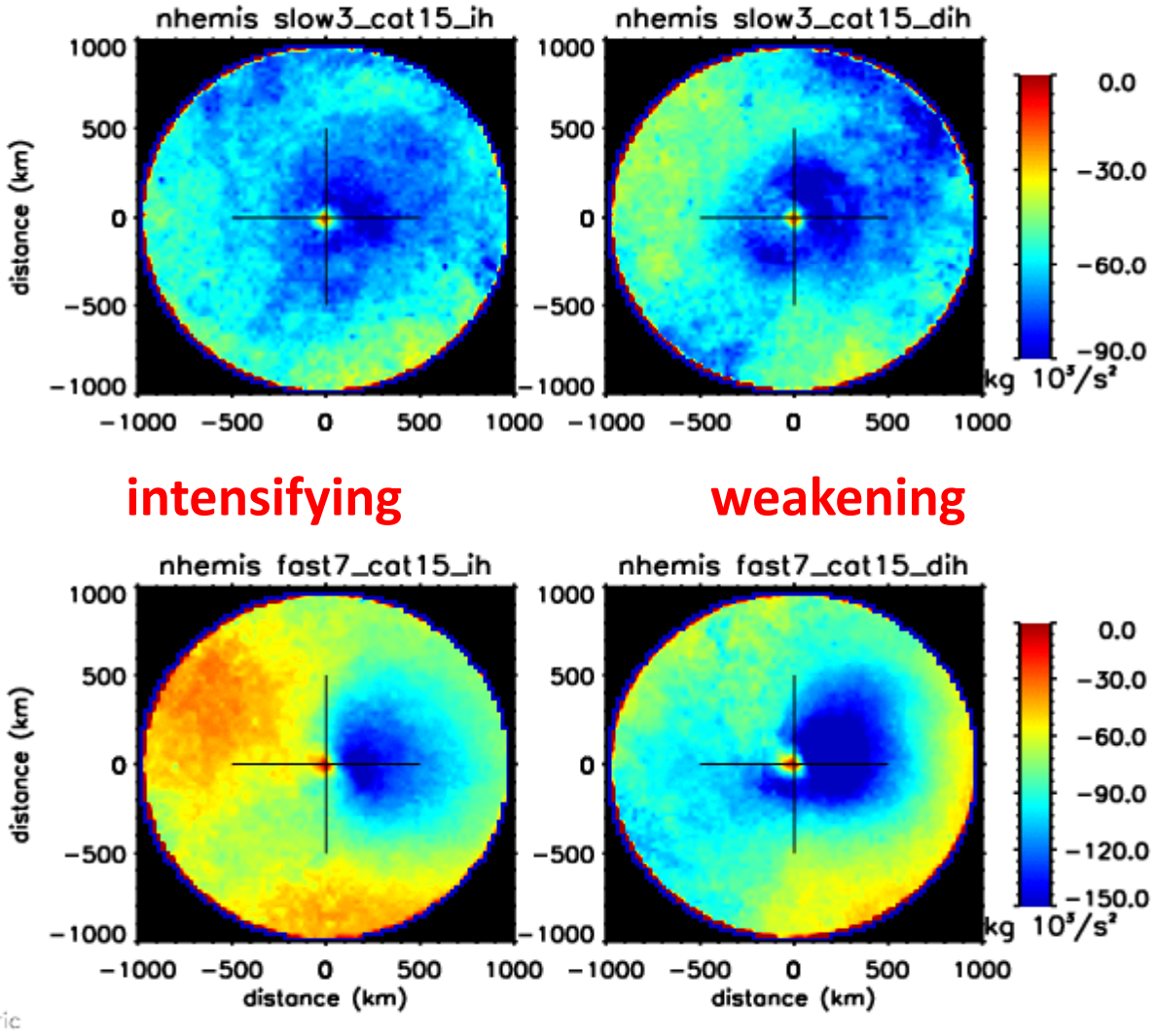
Slow moving (TS < 3m/s)

All cases in hurricane category (V_{max} > 64 knots)

Fast moving (TS > 7 m/s)

Left-right wind asymmetry induced by storm motion translates to front-back asymmetry in relative angular momentum , which has clear impact on weakening storms

Composite of $F_{friction}$ (surface frictional dissipation)



intensifying

weakening

$$F_\theta = -\rho C_D |V_S| v_s r$$

Slow moving (TS < 3m/s)

All cases in hurricane category (V_{max} > 64 knots)

Fast moving (TS > 7 m/s)

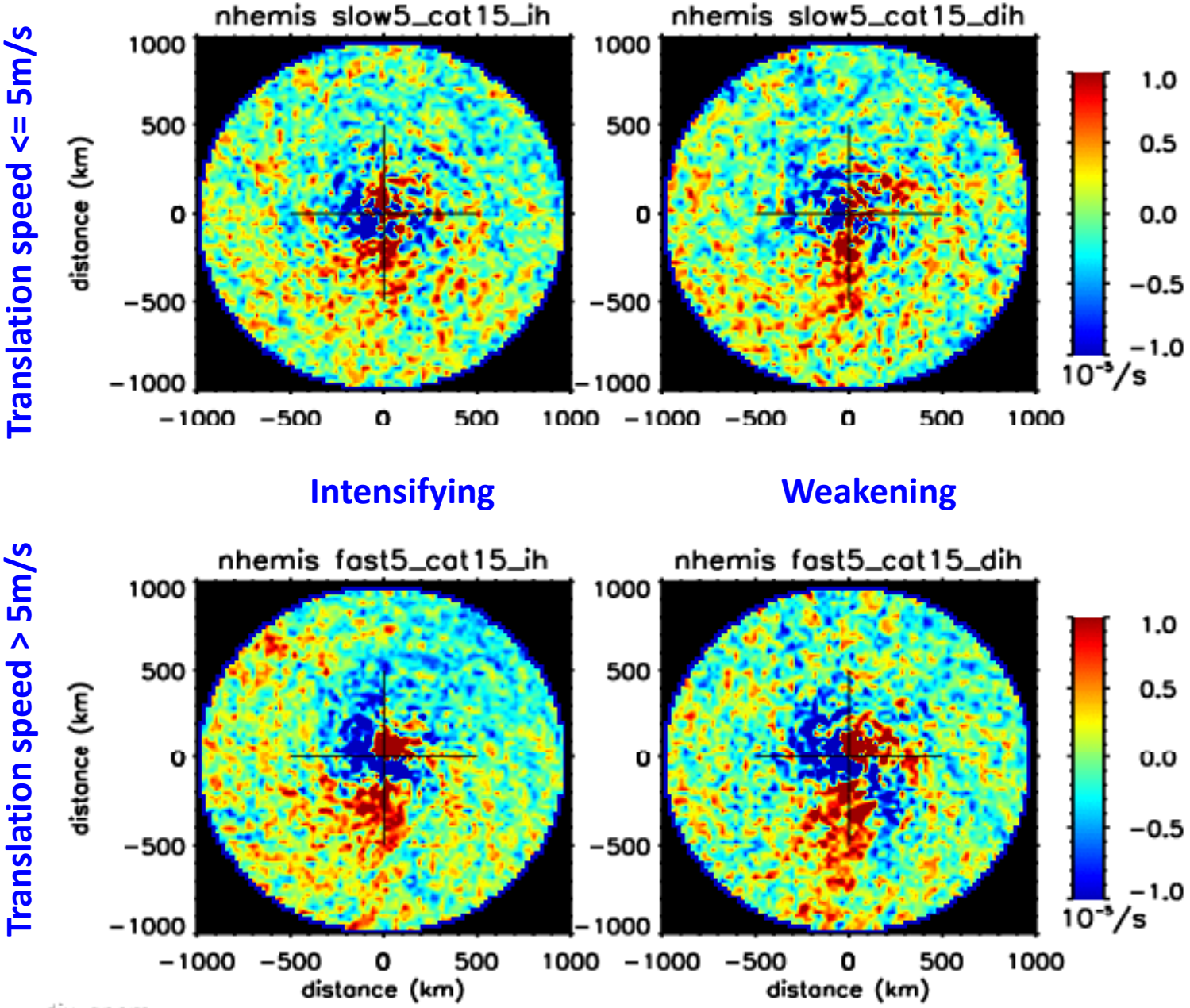
Frictional drag is near symmetric for slow moving cyclones, and increase on the right side of the track when moving fast

❖**The results infer that the strong asymmetry induced by fast-moving storms may act like a built-in break, hindering cyclone intensification.**

❖**We are trying to relate wind convergence to other satellite measurements:**

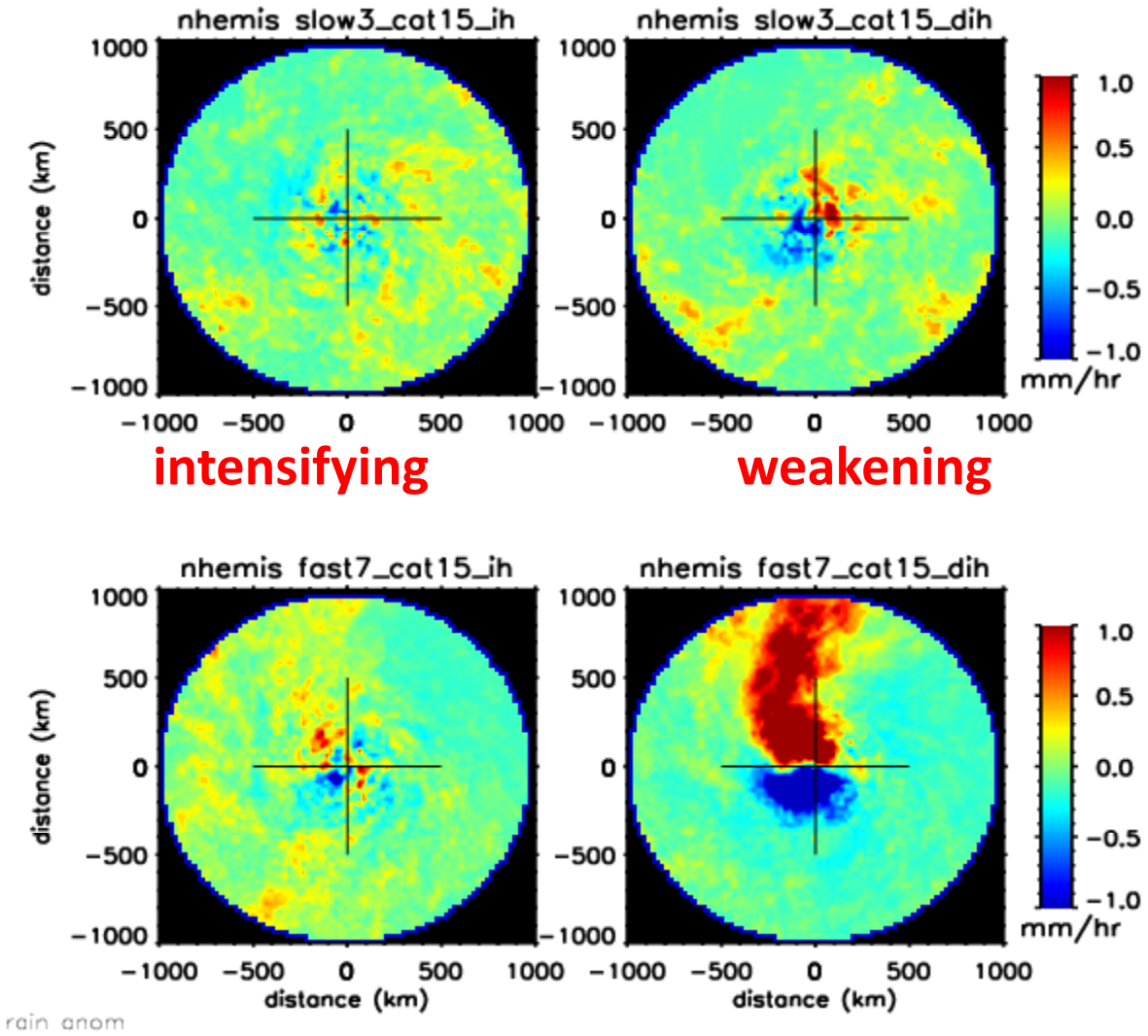
- **precipitation (TRMM/TMI)**
- **SST (AMSR)**
- **Rain profile (TRMM/PR)**

Northern Hemisphere, 2000-2007, all tropical storms, Convergence (anomaly)



Anomaly : composite with annular mean removed

Composite of Surafce Rainrate (Annular Anomaly) in N. Hemis. 2000-2007



intensifying

weakening

Slow moving (TS < 3m/s)

All cases in hurricane category (V_{max} > 64 knots)

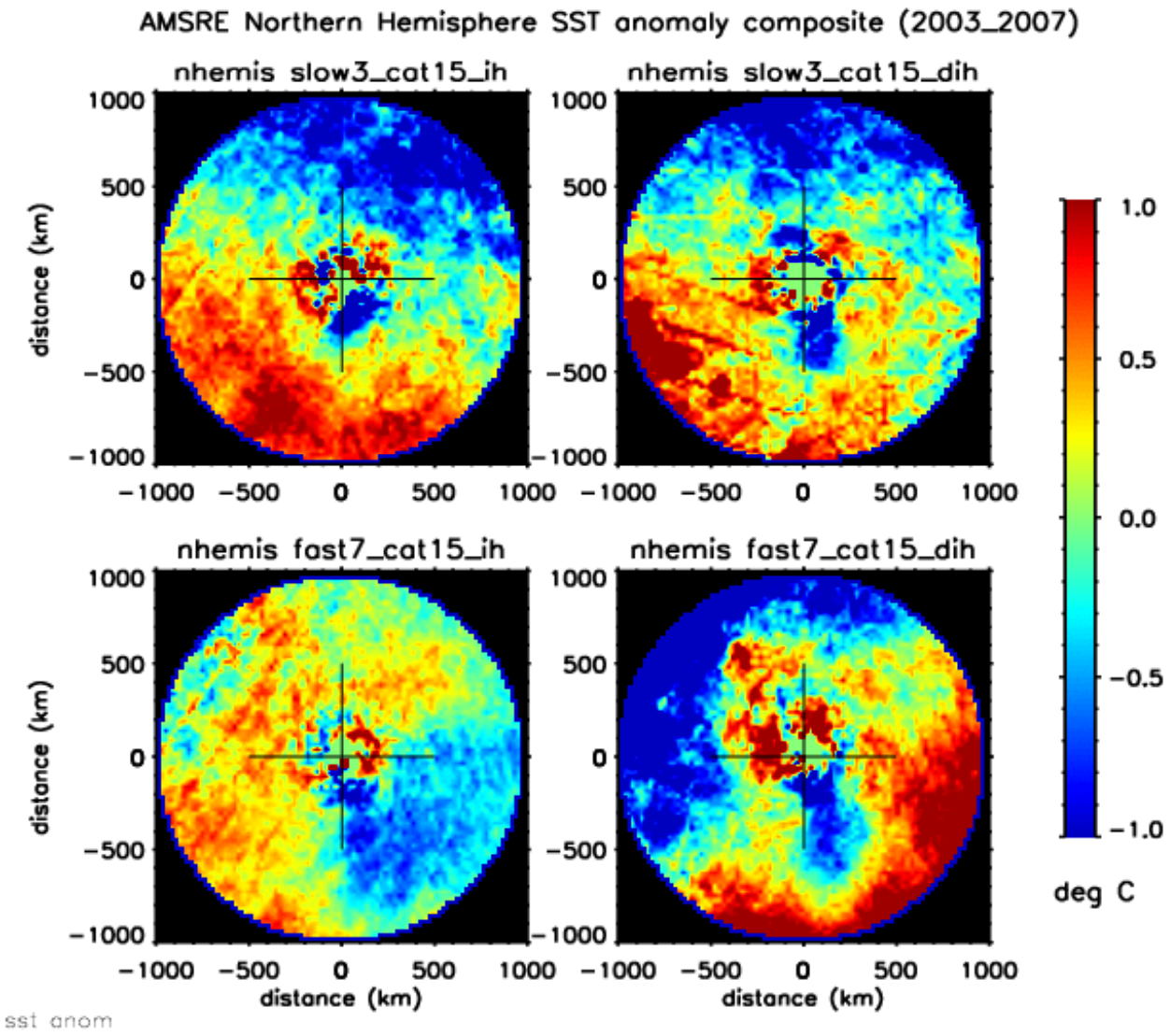
Fast moving (TS > 7 m/s)

The strongest rain rate anomaly is observed in the front-left quadrant, associated with weakening fast-moving storms.

Anomaly patterns of precipitation and surface wind convergence have a phase shift.

Moisture convergence at surface may be followed by strong upward motion in the eye wall, and may return as precipitation in the later phase of the cyclonic circulation.

Composite of AMSR SST (Annular Anomaly) in N. Hemis. 2003-2007



Slow moving (TS < 3m/s)

All cases in hurricane category (V_{max} > 64 knots)

Fast moving (TS > 7 m/s)

The strongest SST asymmetry is off track, cold in the front-left / warm rear right, associated with weakening fast-moving storms.

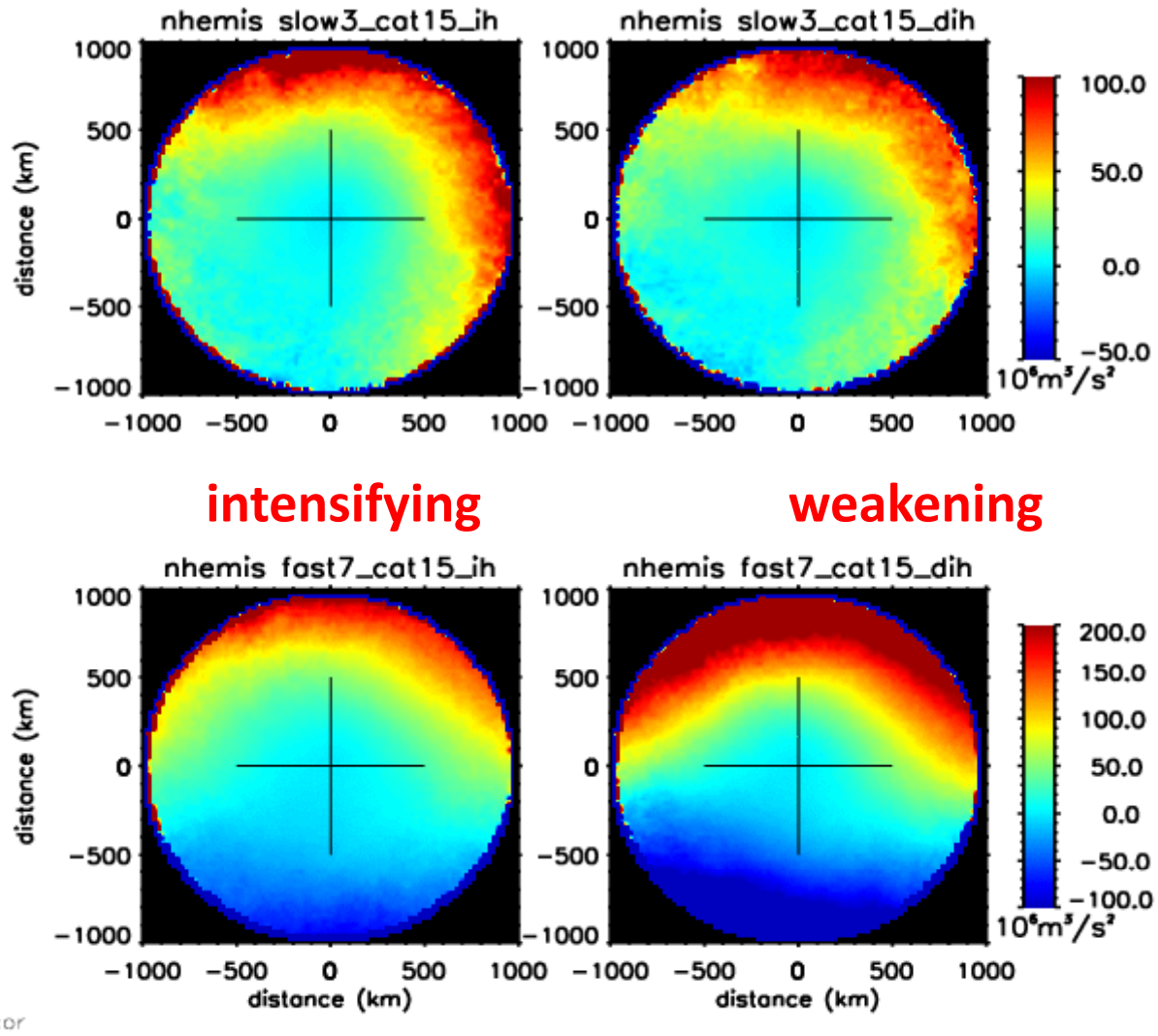
Hypothesis

A *hurricane* is a nearly symmetric, warm-core cyclone powered by wind-induced enthalpy fluxes from the sea surface.

Increase in translational speed increases asymmetry in surface wind-stress, disturbs the coherence, and weakens the hurricane engine.

Backup slides

Composite of F_{COR} (angular momentum flux by Coriolis)



intensifying

weakening

$$F_{COR} = -\frac{1}{2} fr^2 u$$

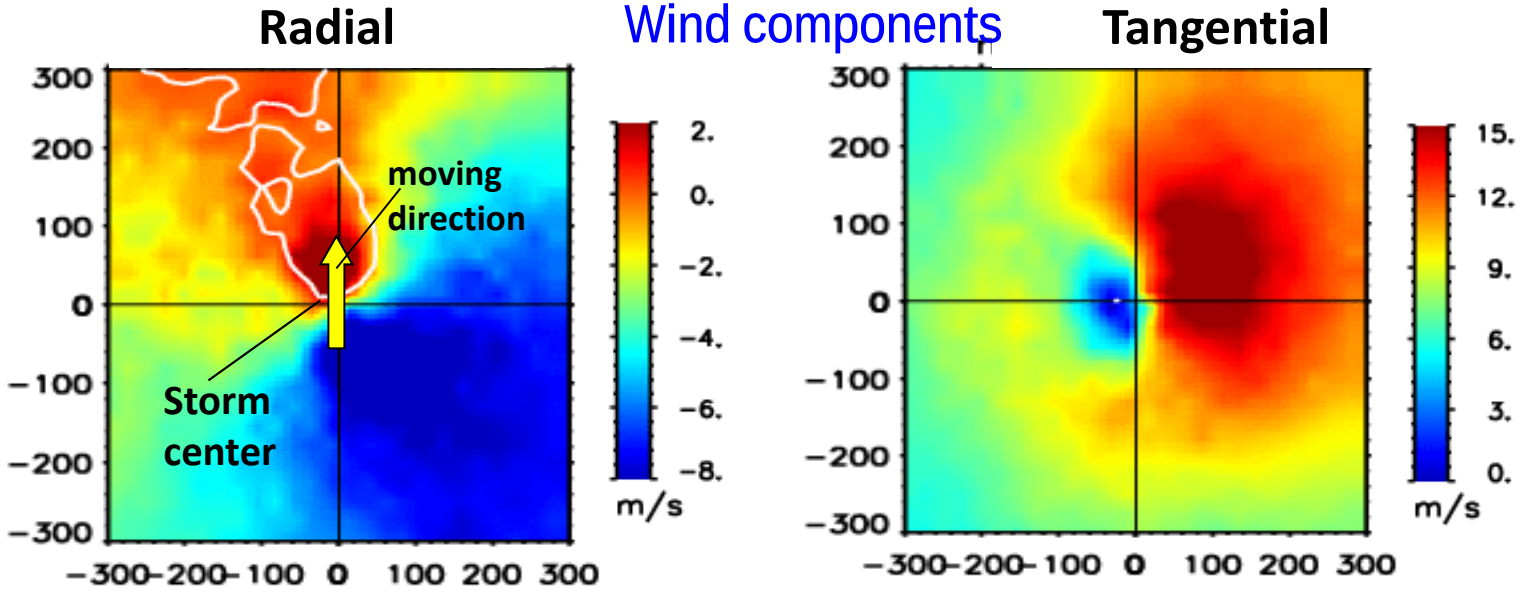
Slow moving (TS < 3m/s)

All cases in hurricane category (V_{max} > 64 knots)

Fast moving (TS > 7 m/s)

Coriolis torque transport angular momentum from front, as expected considering the general pole-ward motion of storms

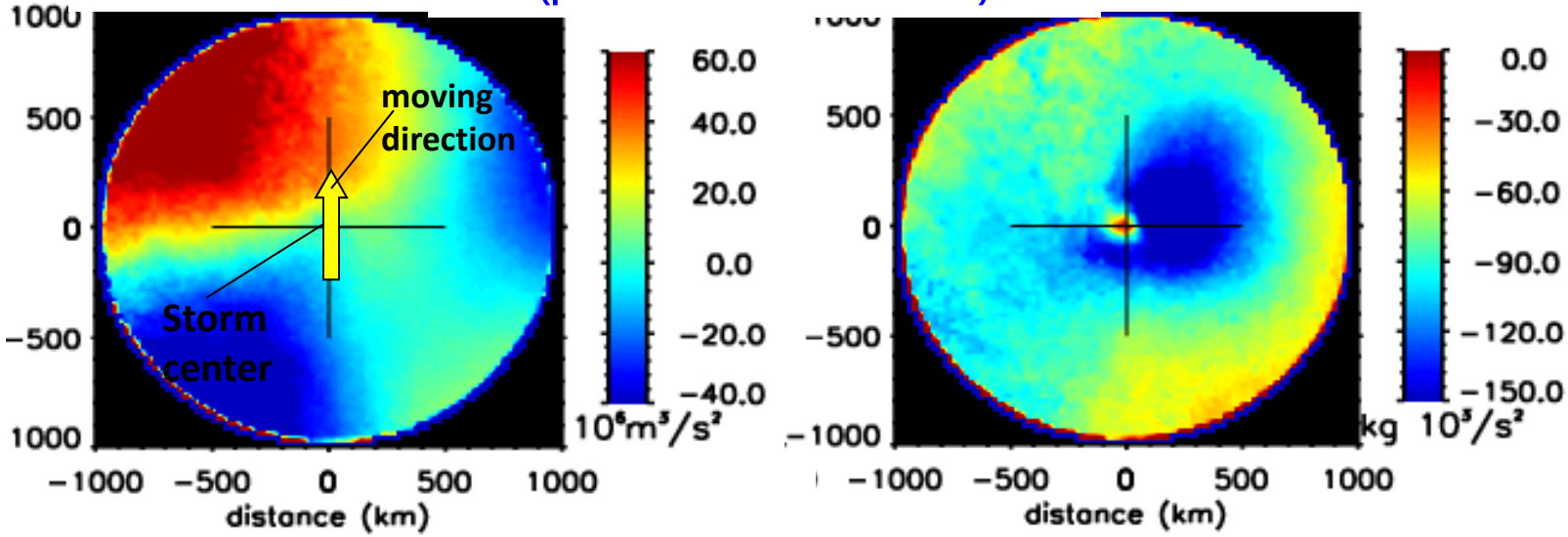
Wind components



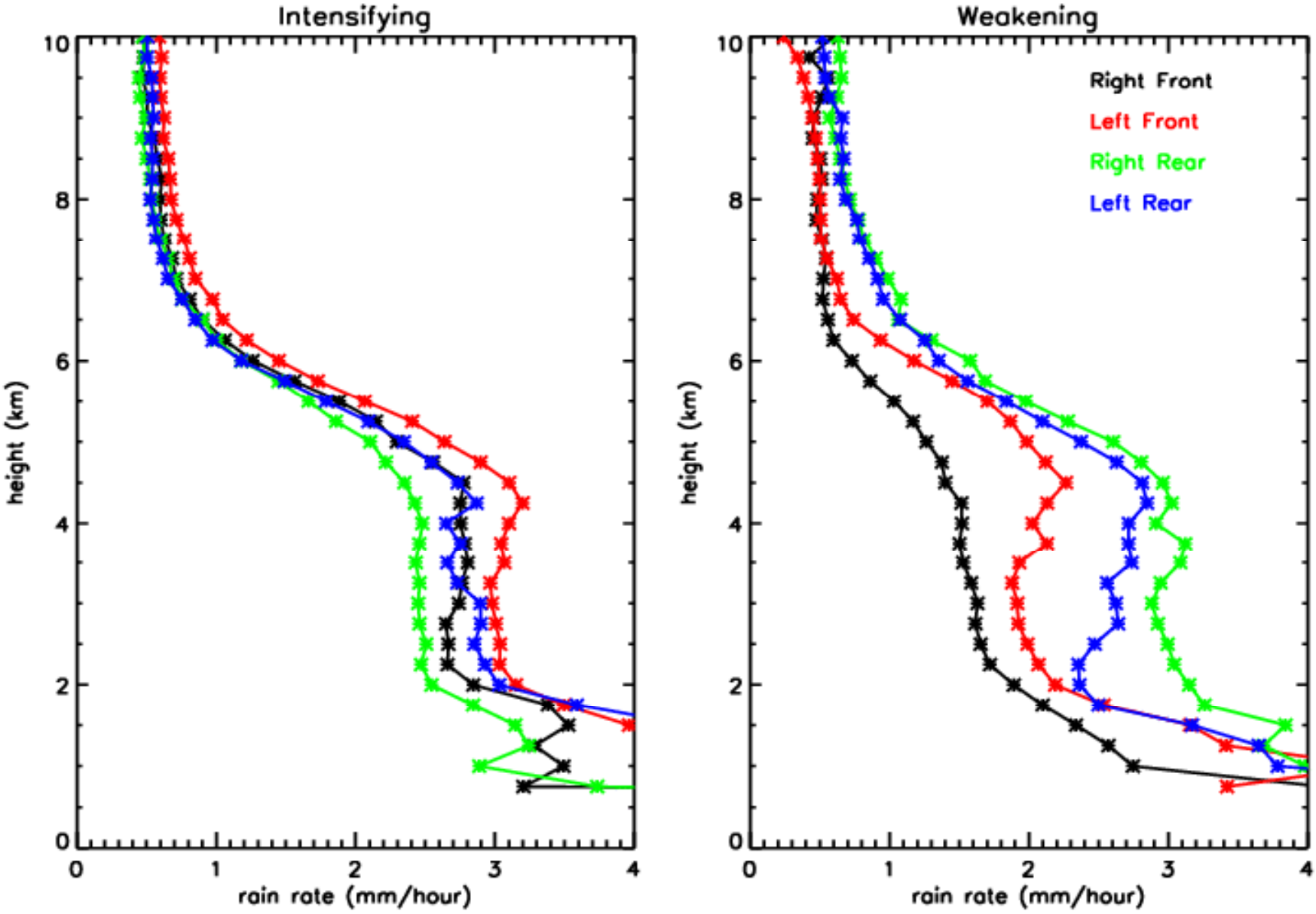
Asymmetry increases with translation speed and is associated with the weakening of tropical cyclones

Angular momentum transport

(positive into the core)



Composite ofTRMM/PR Rain profile in N. Hemis. 2003-2007



Weakening storms are associated with large asymmetry in rain profiles

Conclusion

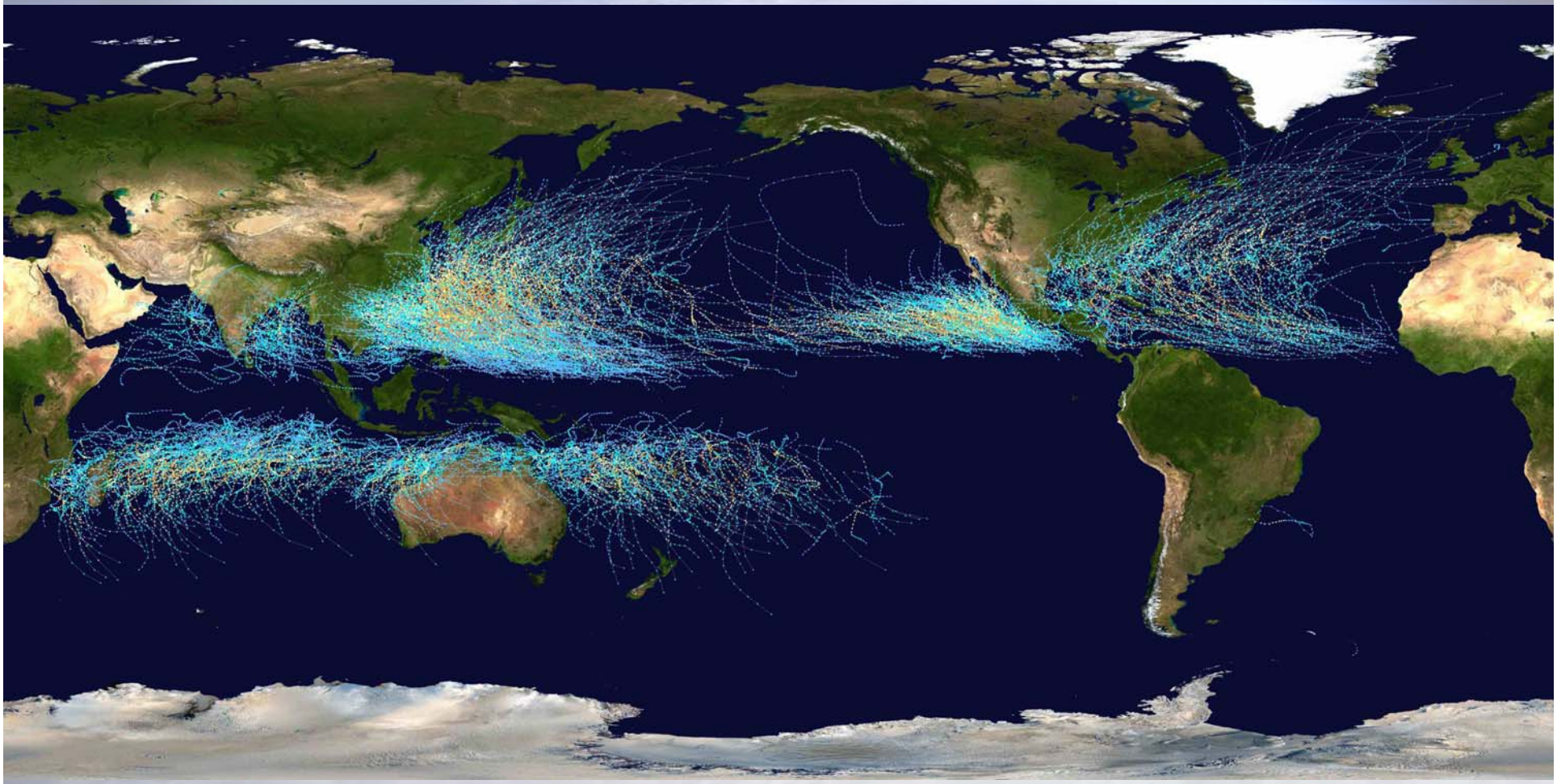
❖Fast translating speed induces strong asymmetry relative to storm track in the surface wind structure, as depicted by SeaWinds/QuikSCAT scatterometer wind/stress fields;

❖When storms moving at speed faster than ~ 7m/s, the probability for storm to intensify is greatly suppressed (based on statistics on tropical cyclones best track);

❖Asymmetry in the angular momentum fluxes, as calculated from surface wind, input into the storm system (instead of its absolute values) dominates the storm weakening;

❖For fast translating storms, upper atmospheric environment (vertical shear) determines the storms' intensity change: upper air circulation pattern rather total wind difference between 200 and 850 hPa differentiate the cases of intensifying or weakening.

Tracks of all tropical cyclones, 1985-2005



Source: Wikipedia

Northern Hemisphere, 2000-2007, all tropical storms, Convergence (composite)