The World Wide Lightning Location Network: Network overview, evaluation and its application to tropical cyclone research

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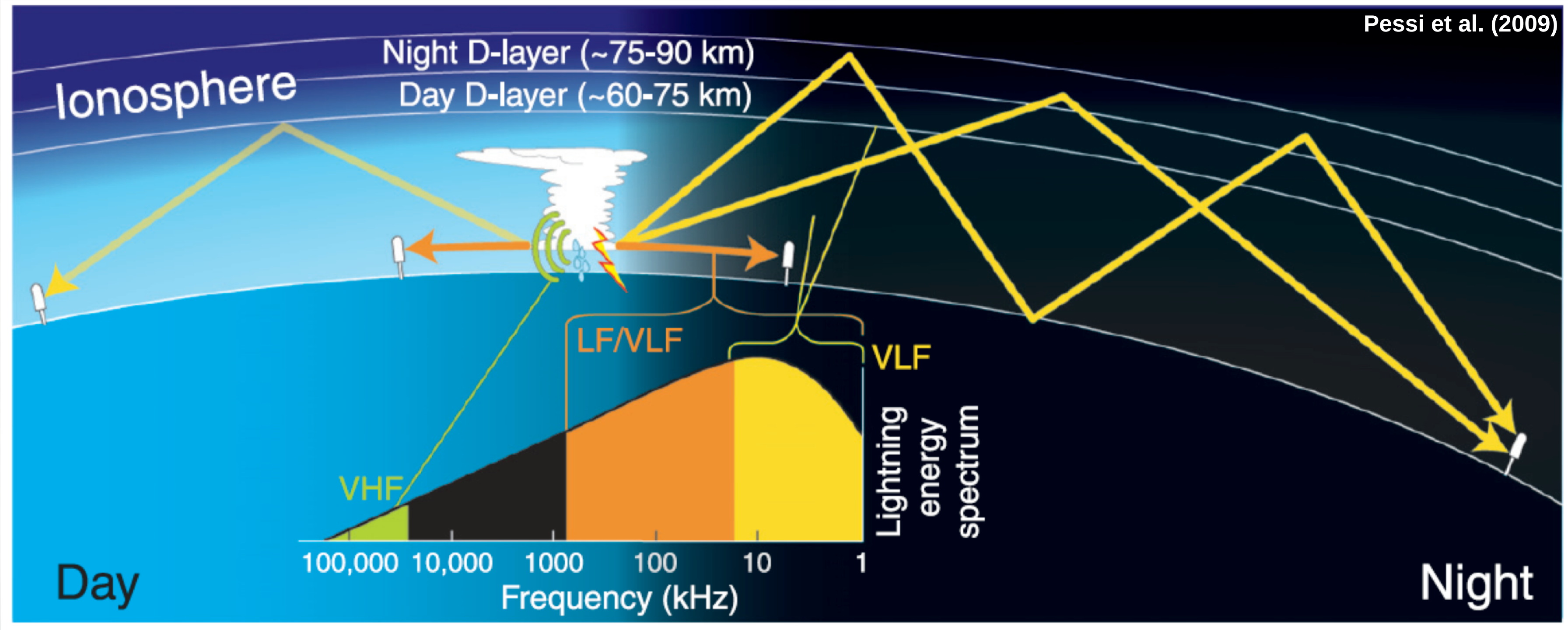
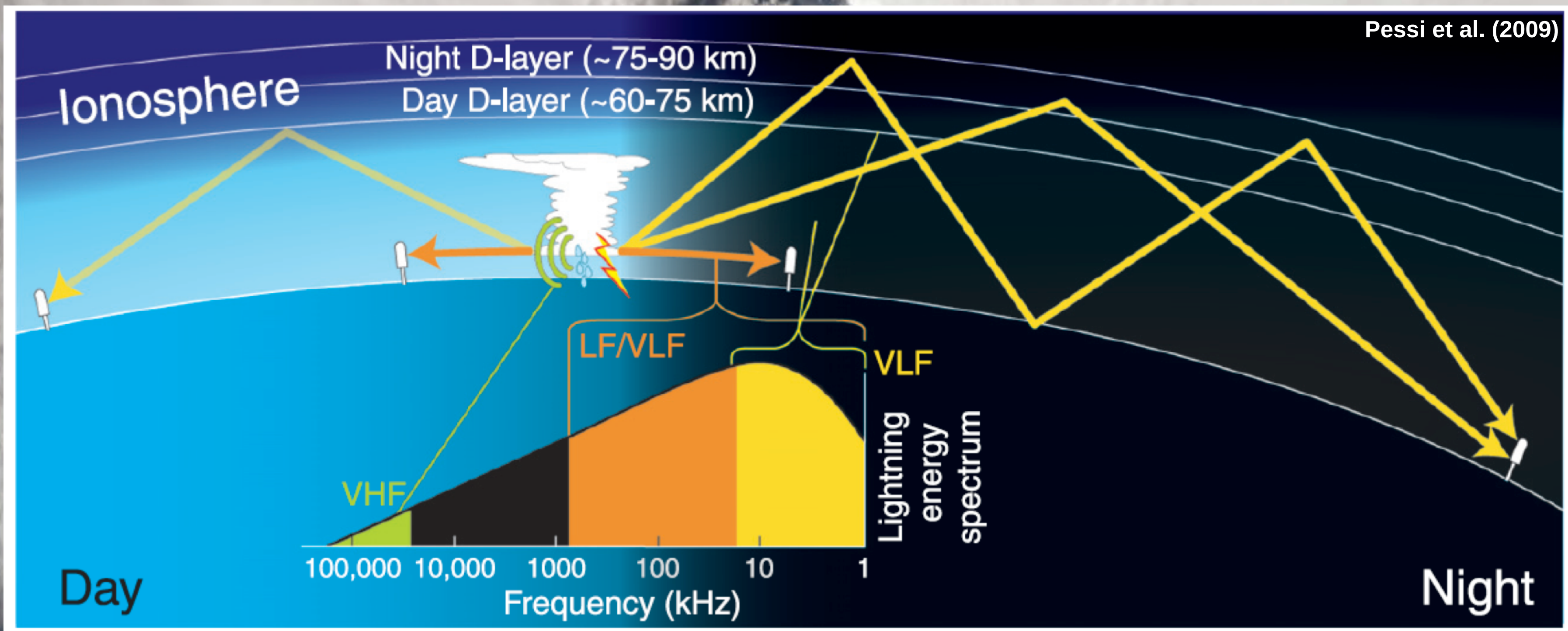
World Wide Lightning Location Network (WWLLN)

- The WWLLN ("woolen") is a global lightning network that detects the very low frequency (VLF; 3-30 kHz) emissions from lightning, known as sferics, that propagate long distances through the Earth-ionosphere waveguide.



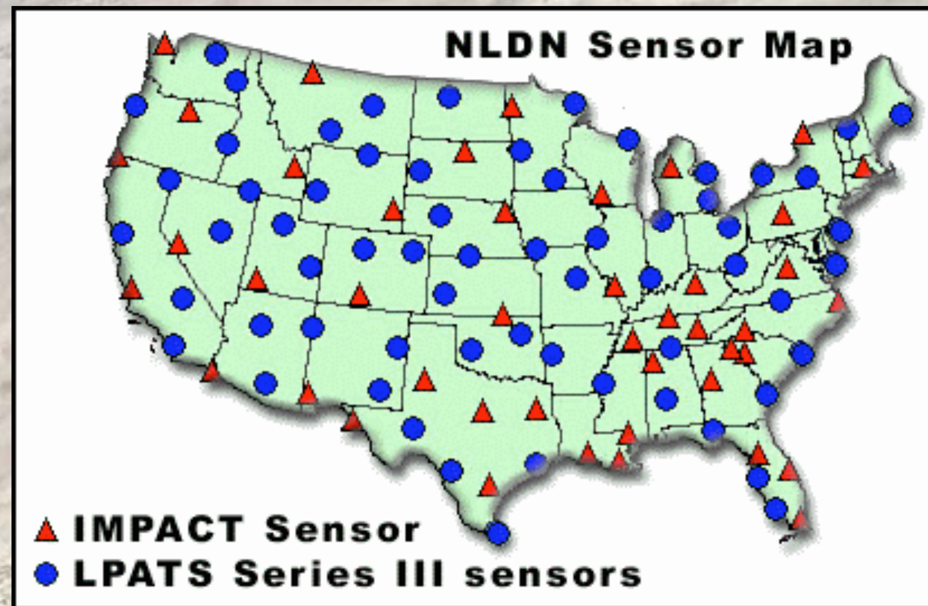
World Wide Lightning Location Network (WWLLN)

- Detection is best on the nighttime side of the Earth and over the open ocean where attenuation is minimal.
- The WWLLN differs significantly from networks like the National Lightning Detection Network (NLDN) that operate in the low to medium frequency band (.3-3 MHz) and detect only the ground wave.

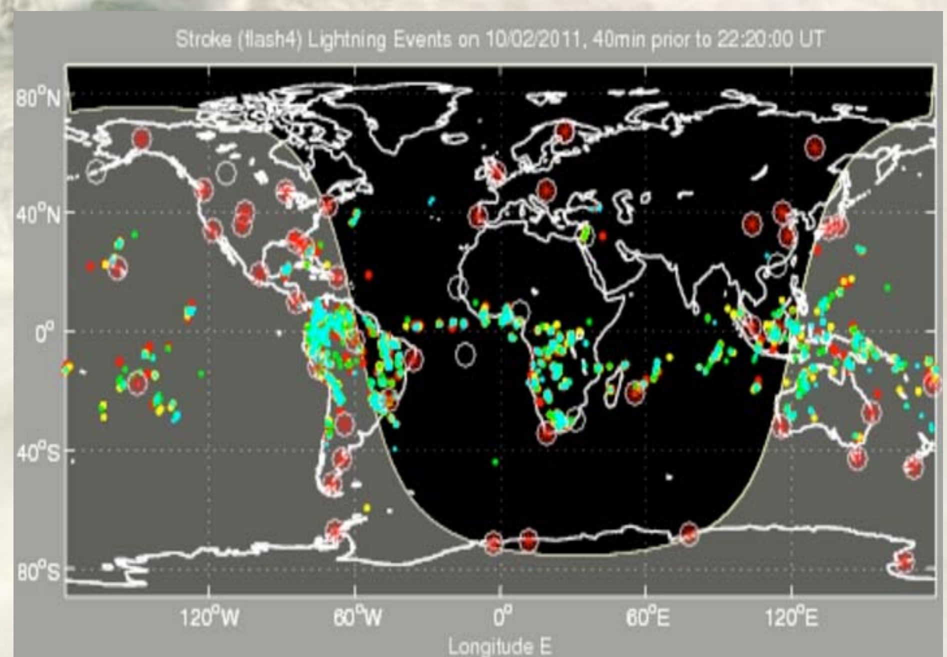


WWLLN vs. NLDN

- The NLDN, operated by Vaisala, is comprised of >100 sensors covering the U.S. and adjacent waters with excellent detection efficiency (DE) and location accuracy (LA).



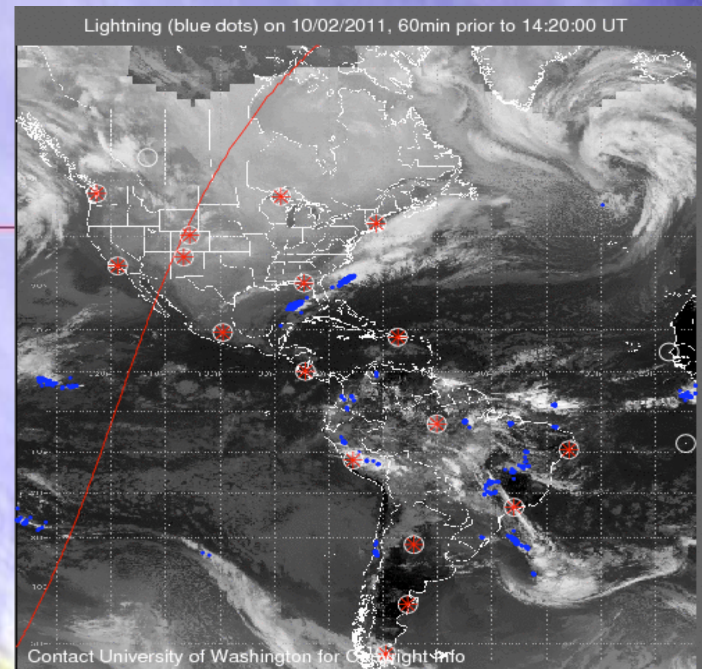
- The WWLLN, a research collaboration operated out of the University of Washington, is an expanding, global network currently composed of ~50 sensors with ever increasing DE and LA.

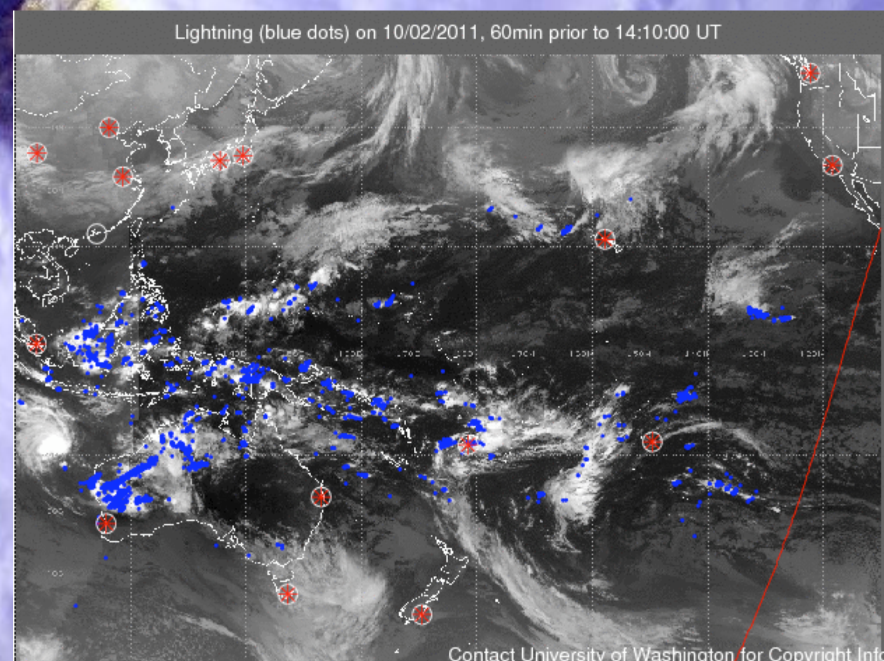


WWLLN at UCLA

- **Shortly after arriving at UCLA in late 2007, a PhD student approached me about bringing a WWLLN sensor to UCLA.**

- **Working with the WWLLN developers, we helped establish a sensor at the Center for Geophysical Research at the University of Costa Rica, and received our own sensor in March 2008 that has became the 4th largest detector of flashes in the network.**





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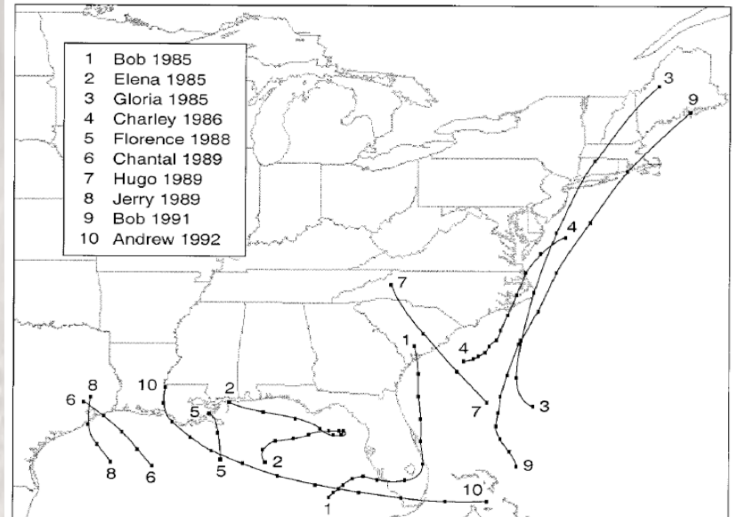
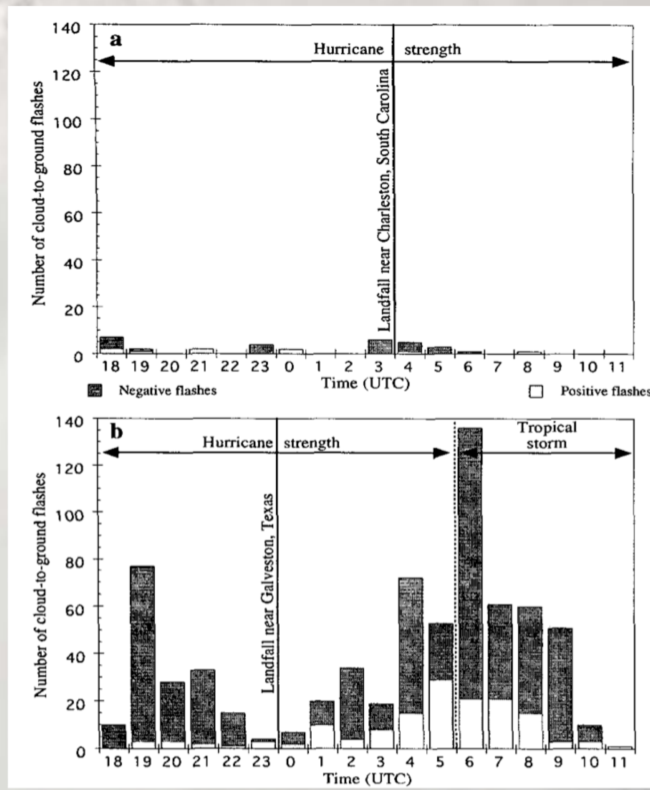
Lightning in Hurricanes

- In the 1990's, a number of research groups started to document the lightning characteristics of tropical cyclones (TCs) approaching the U.S. using the NLDN.

- These studies found:
  - ~ Flash rates generally much smaller than midlatitude convection
  - ~ Inconclusive relationship between flash frequency and intensity change
  - ~ Common radial distribution of lightning



Molinari et al. (1999)



Samsury and Orville (1994)

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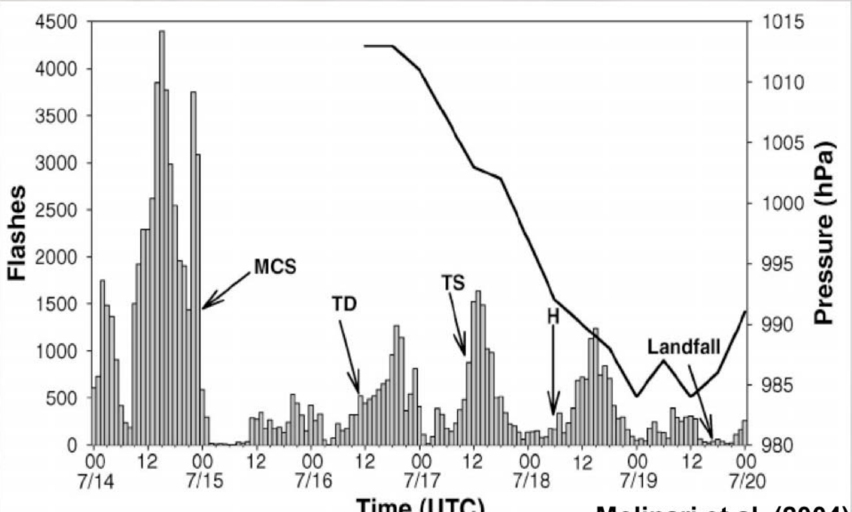

Molinari et al. (2004)

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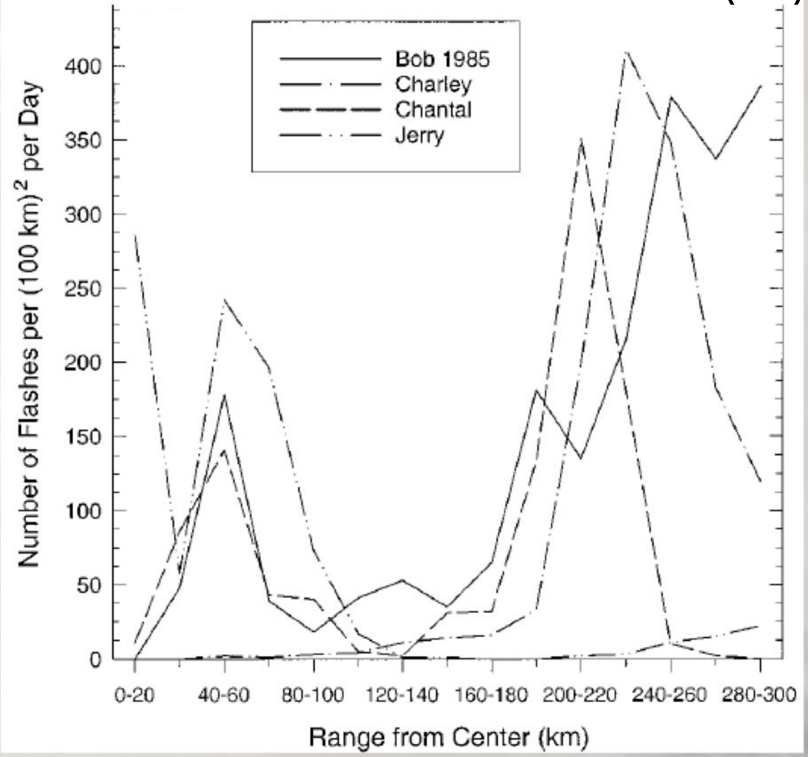
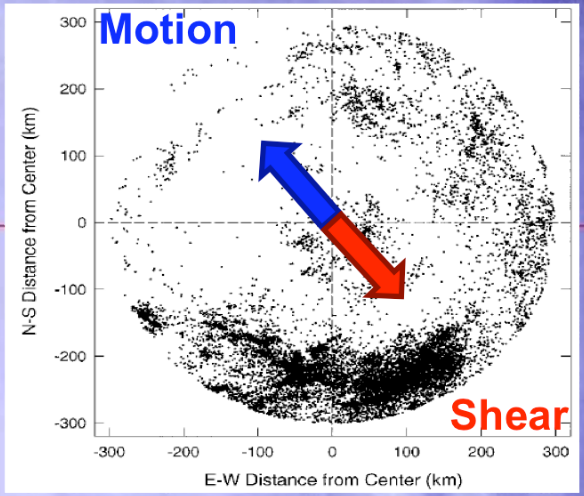
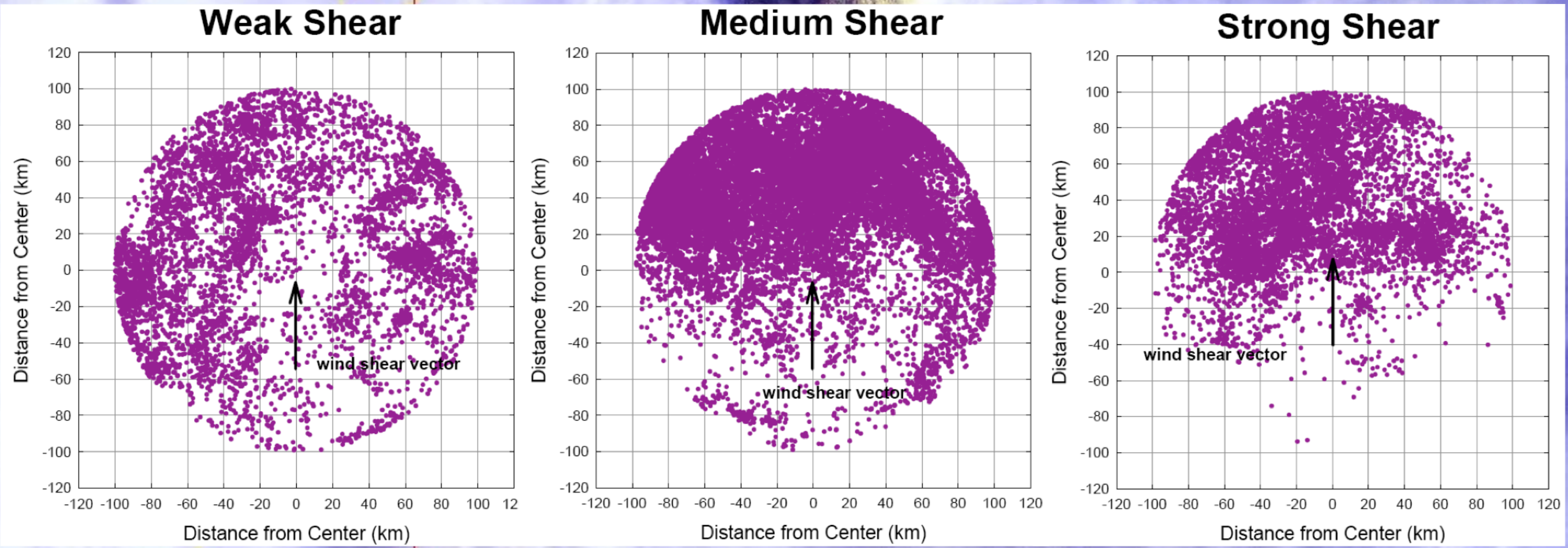
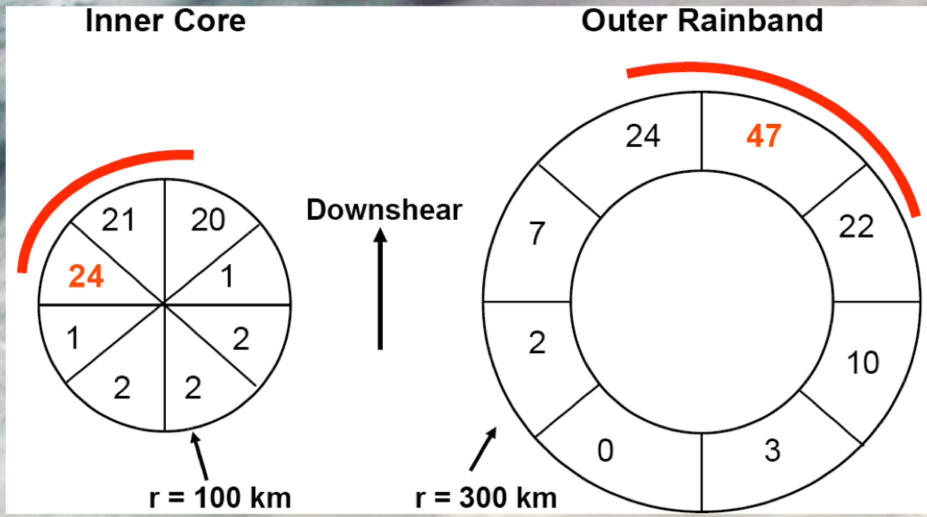


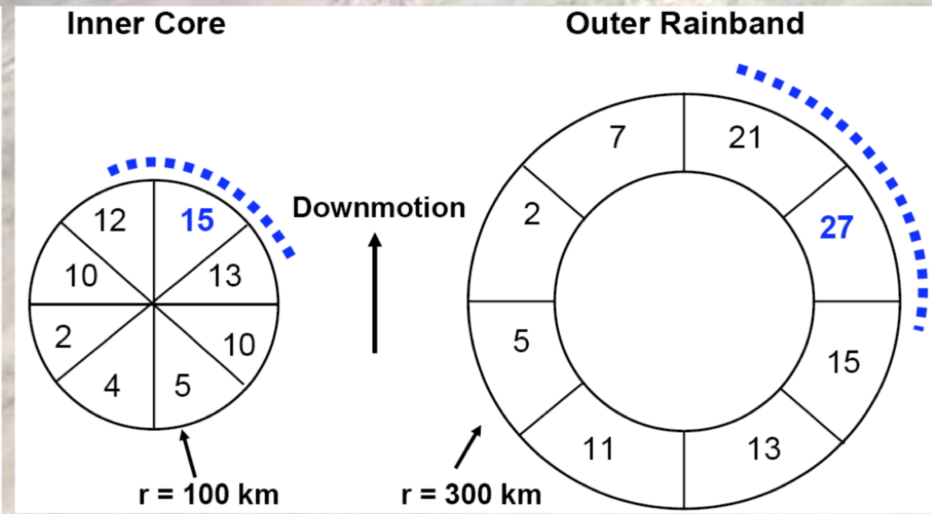
Lightning in Hurricanes



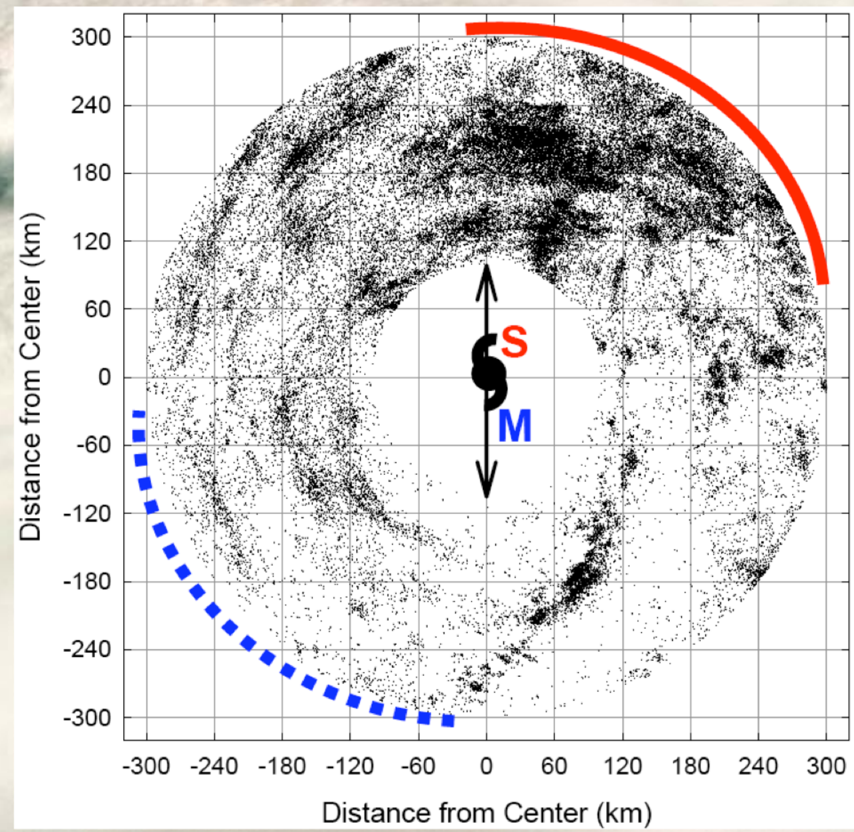
- Molinari et al. (1999) also noted that the northwest quadrant, the one nearest to the NLDN, was the least electrically active.
- Corbosiero and Molinari (2002, 2003) studied the azimuthal distribution of flashes with respect to the directions of vertical wind shear and storm motion.

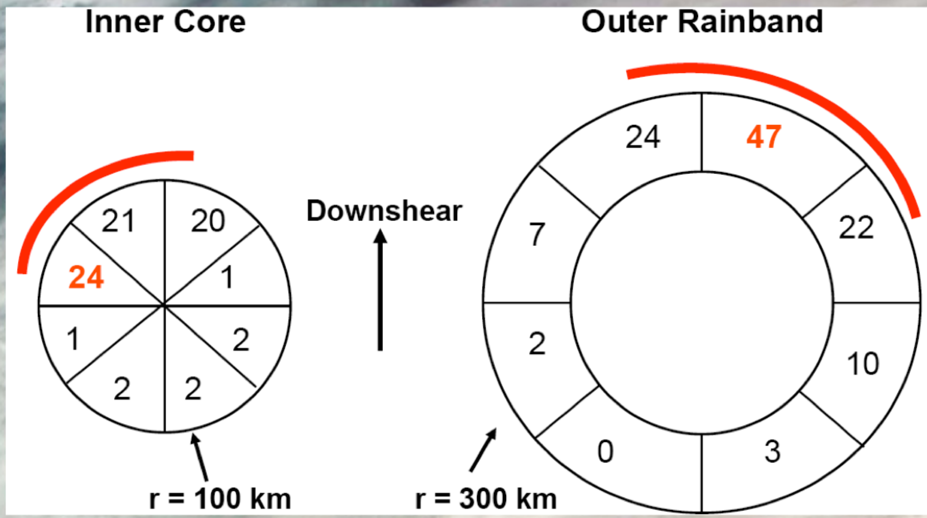


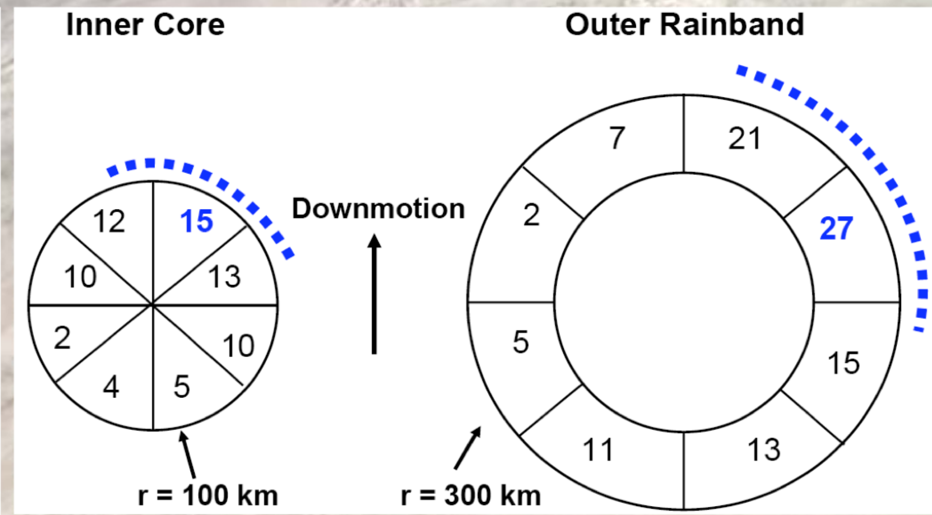


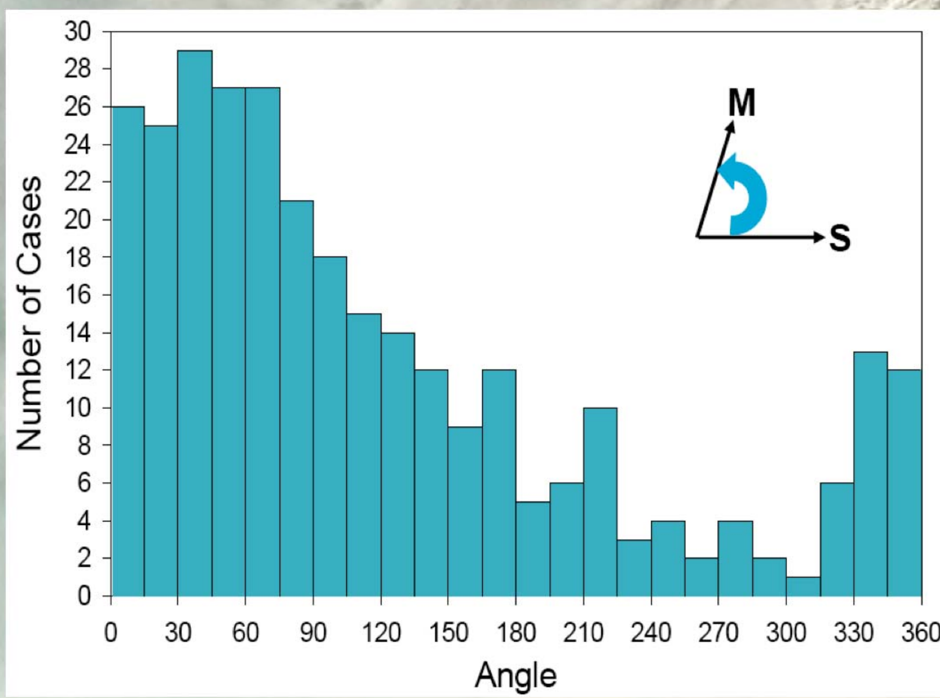


- **Corbosiero and Molinari (2002, 2003) showed that NLDN flashes had distinct azimuthal locations with respect to both the directions of vertical wind shear and storm motion, but the strong shear signature dominated the distribution.**





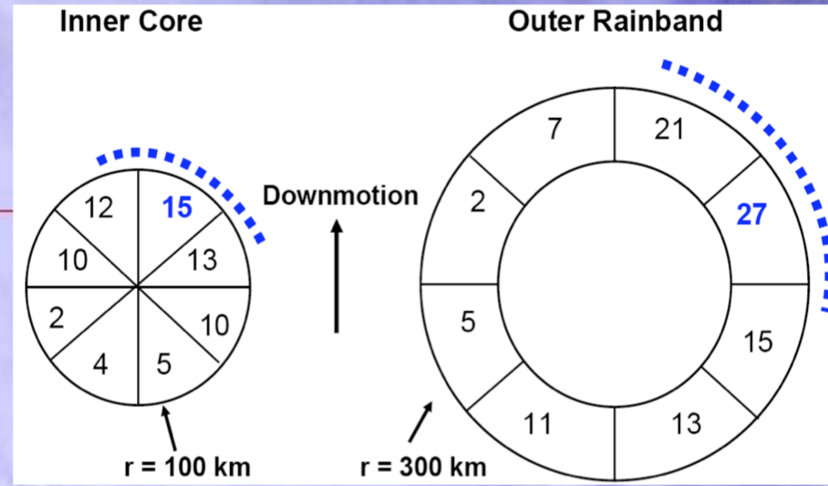


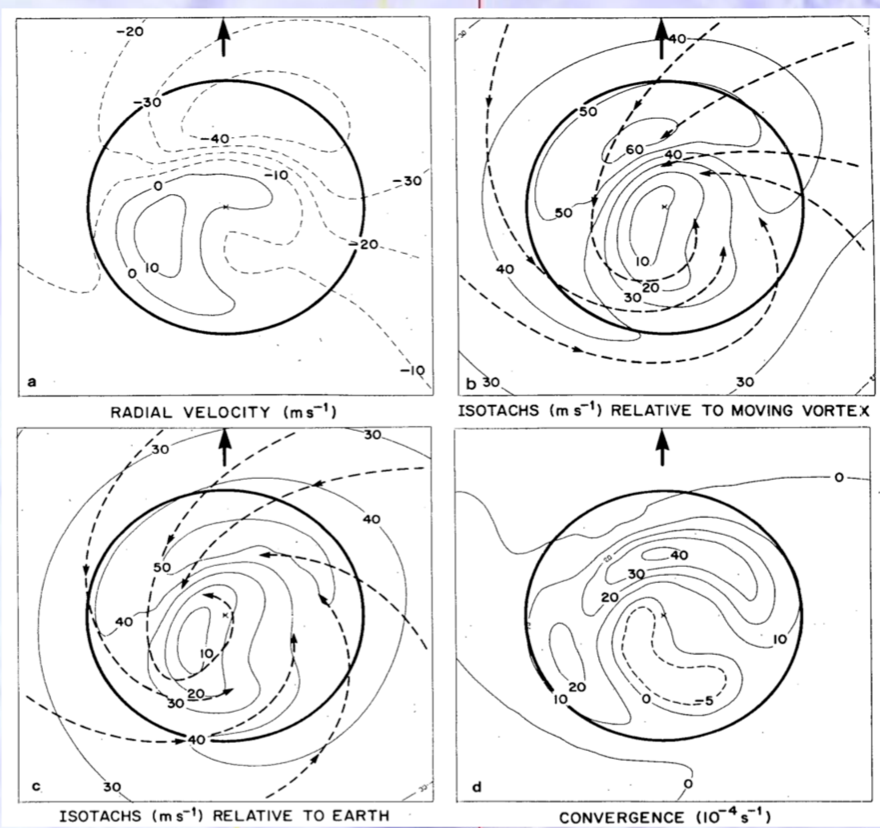


- Moreover, we argued that the storm motion asymmetry was largely an artifact of the much stronger (and deeper) vertical wind shear signal, as the predominant directions of the vectors close to the U.S. cause the asymmetries to overlap.

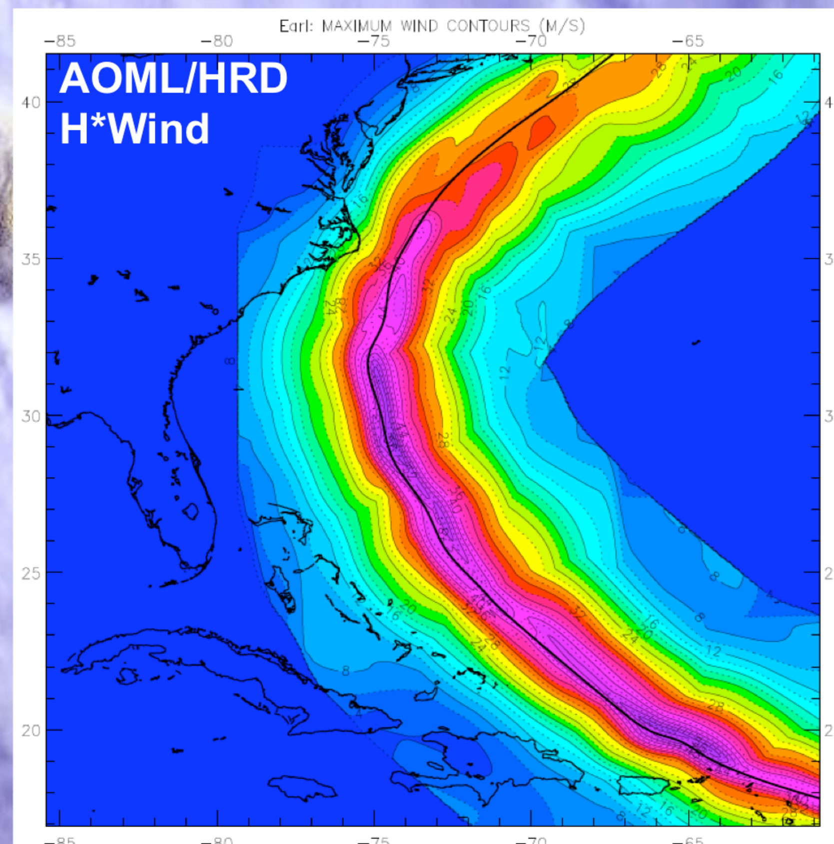
Storm motion asymmetry

- **Asymmetric friction in the hurricane boundary layer, proportional to square of the wind speed, is responsible for the front right maximum.**



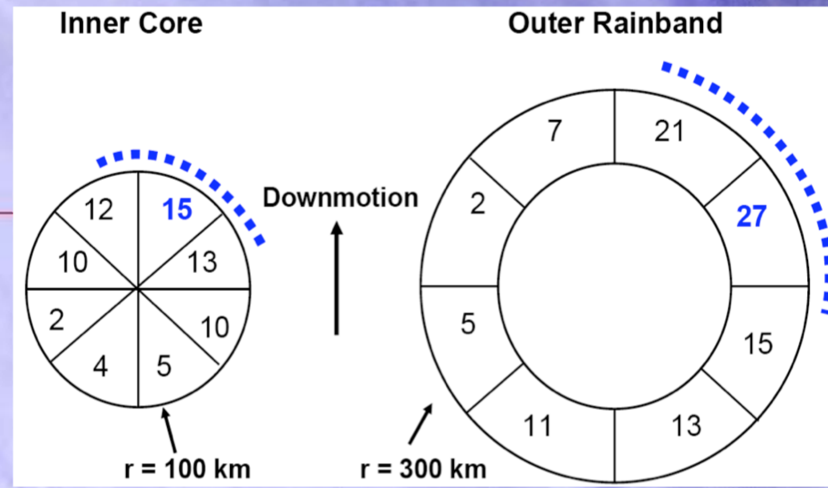


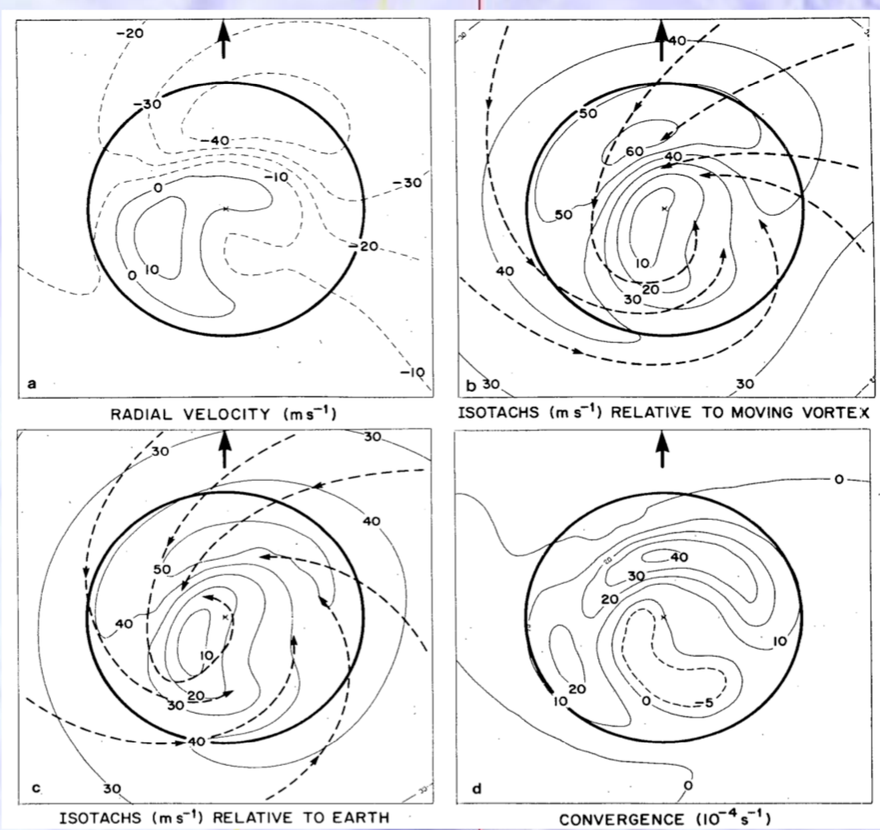
Shapiro (1983)

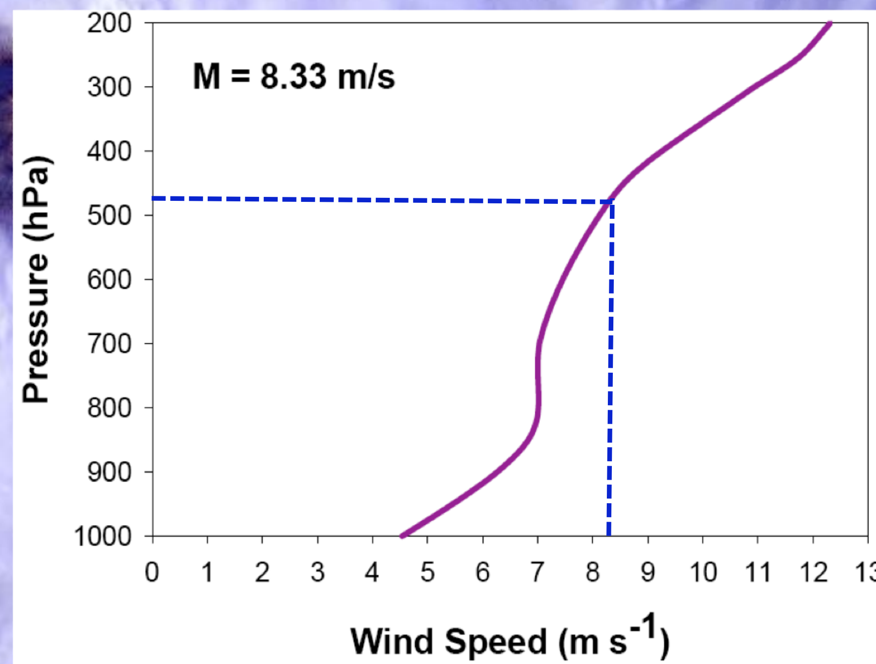


Storm motion asymmetry

- The mean current in the boundary layer is ~3 m s^{-1} smaller than the mean storm motion of 8.3 m s^{-1}.



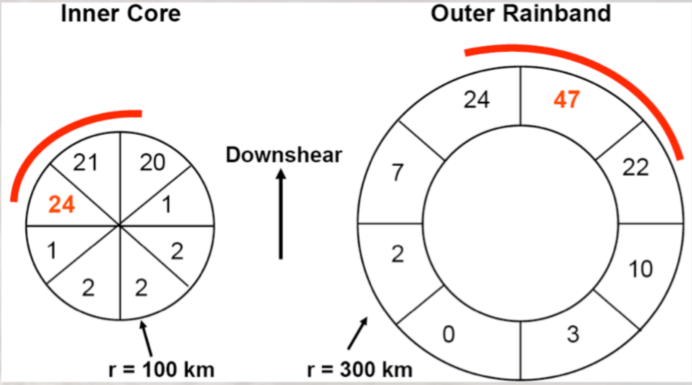


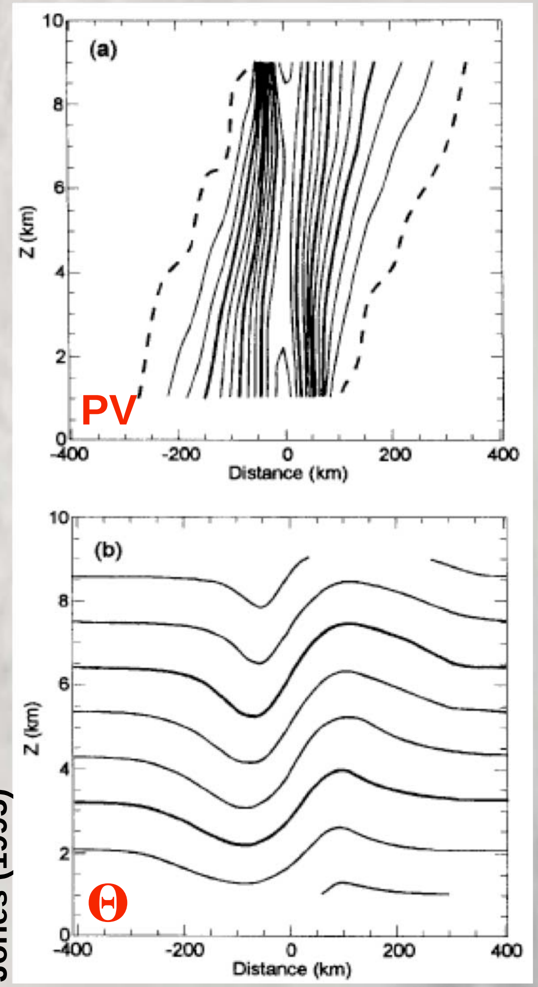


Shapiro (1983)

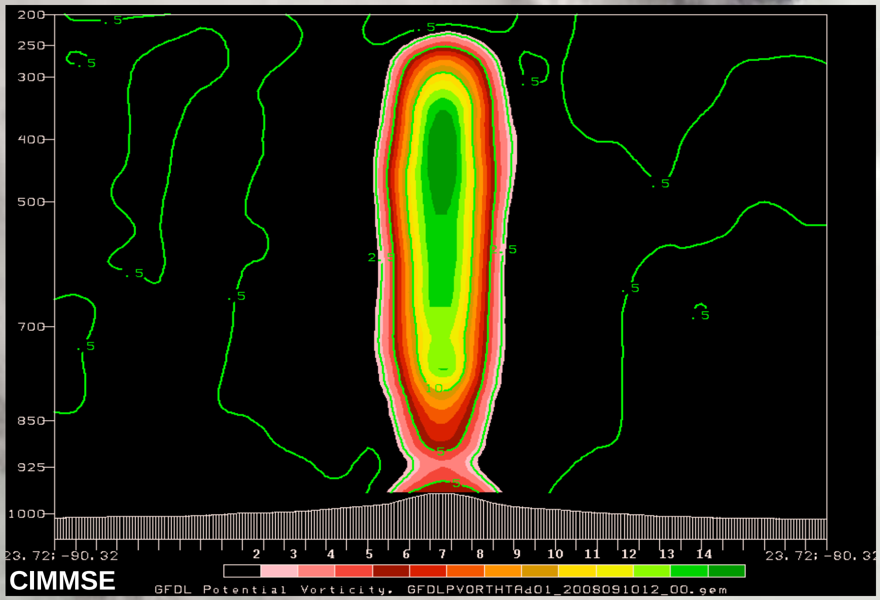
Vertical wind shear asymmetry

- The initial action of vertical wind shear on a TC is to tilt the vortex downshear.
- To maintain balanced mass fields in a shear titled vortex, the isentropes must bow up (down) downshear (upshear) creating a cold (warm) anomaly.



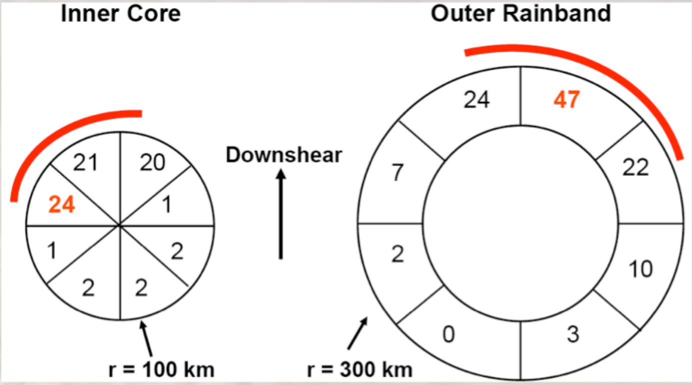


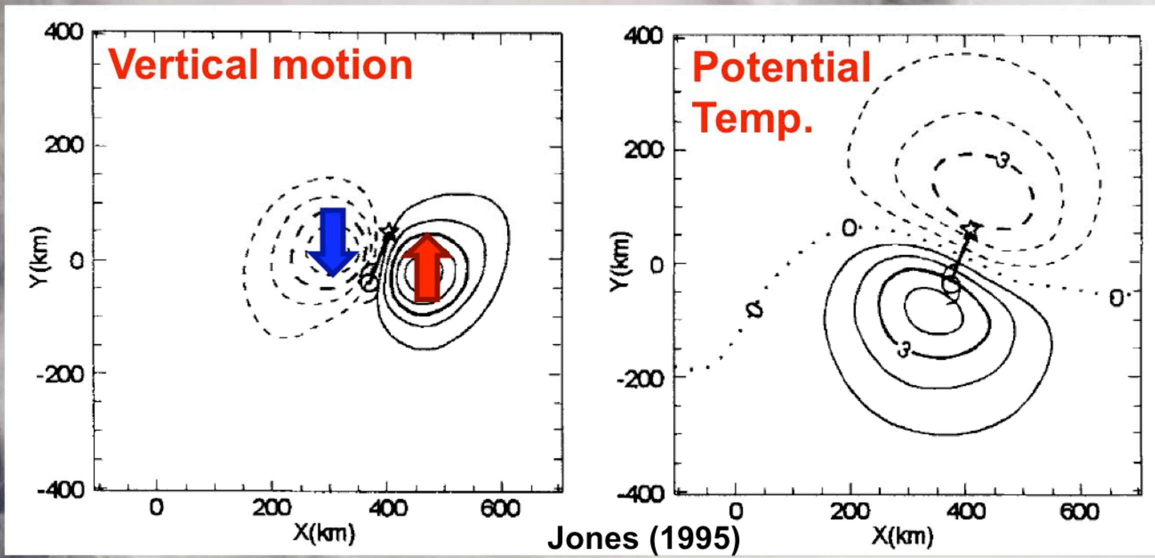
Jones (1995)

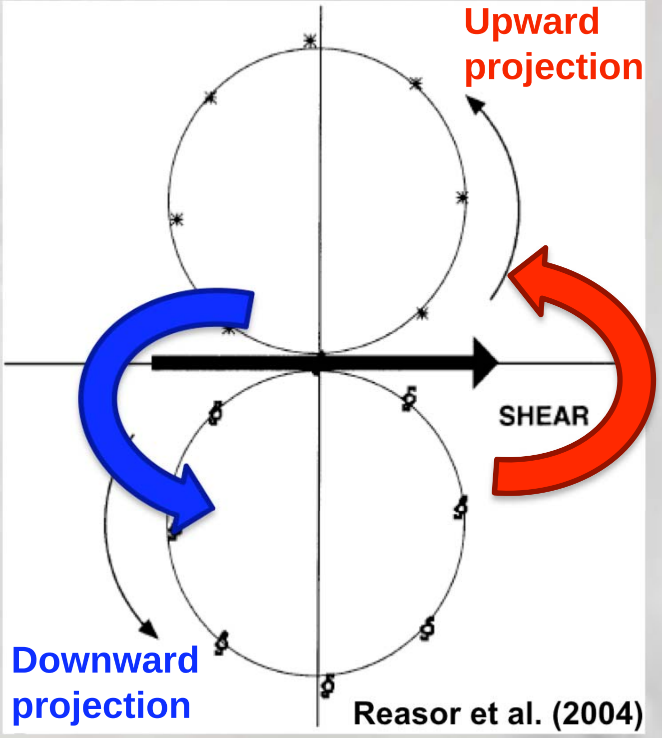


Vertical wind shear asymmetry

- Cyclonic vortex flow on distorted vortex isentropes creates asymmetric vertical motion.
- Upward motion occurs to the right of the tilt vector, the direction of which rotates from directly downshear to left of shear, the optimal direction to oppose the shear and reduce tilt.

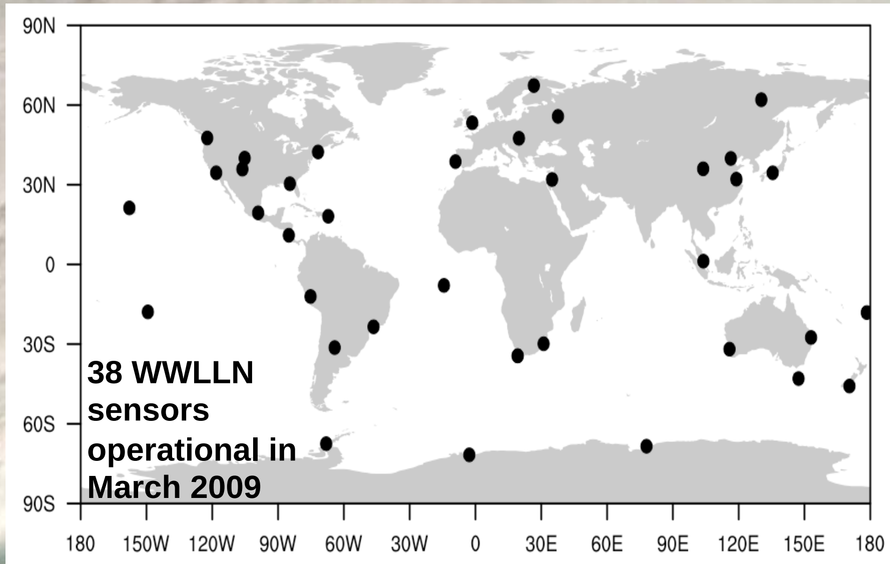






WWLLN Evaluation Using the NLDN

- When we began investigating the distribution of lightning in TCs (and the WWLLN in general), we noticed that no formal evaluation of the network's capabilities had been done in many years and never with the NLDN.



Abarca et al. (2010)

Table 1. Summary of WWLLN Comparisons With Other Networks

	Period	Region Lat × Lon	Active Sensors	DE (%)	Mean LA (km)
[*Lay et al.* 2004]	6, 7, 14, 20, and 21 March 2003	Brazil 15° × 15°	11	0.3	20.25 ± 13.5
[*Rodger et al.* 2004]	23, 24 Jan 2003	Australia 8° × 10°	6	1.0	30.0
[*Rodger et al.* 2005]	Feb–Apr 2004	Australia 8° × 10°	18	13.0	3.4
[*Rodger et al.* 2006]	1 Oct 2003 to 31 Dec 2004	New Zealand 15° × 15°	20	5.4	—
[*Jacobson et al.* 2006]	27 Apr to 30 Sept 2004	Florida Circle with radius of 400 km	19	<1.0	15–20

3 years and 15+ new sensors since last evaluation

1 year 3 months was the longest period of evaluation

Area equivalent to the western U.S. was the largest study area

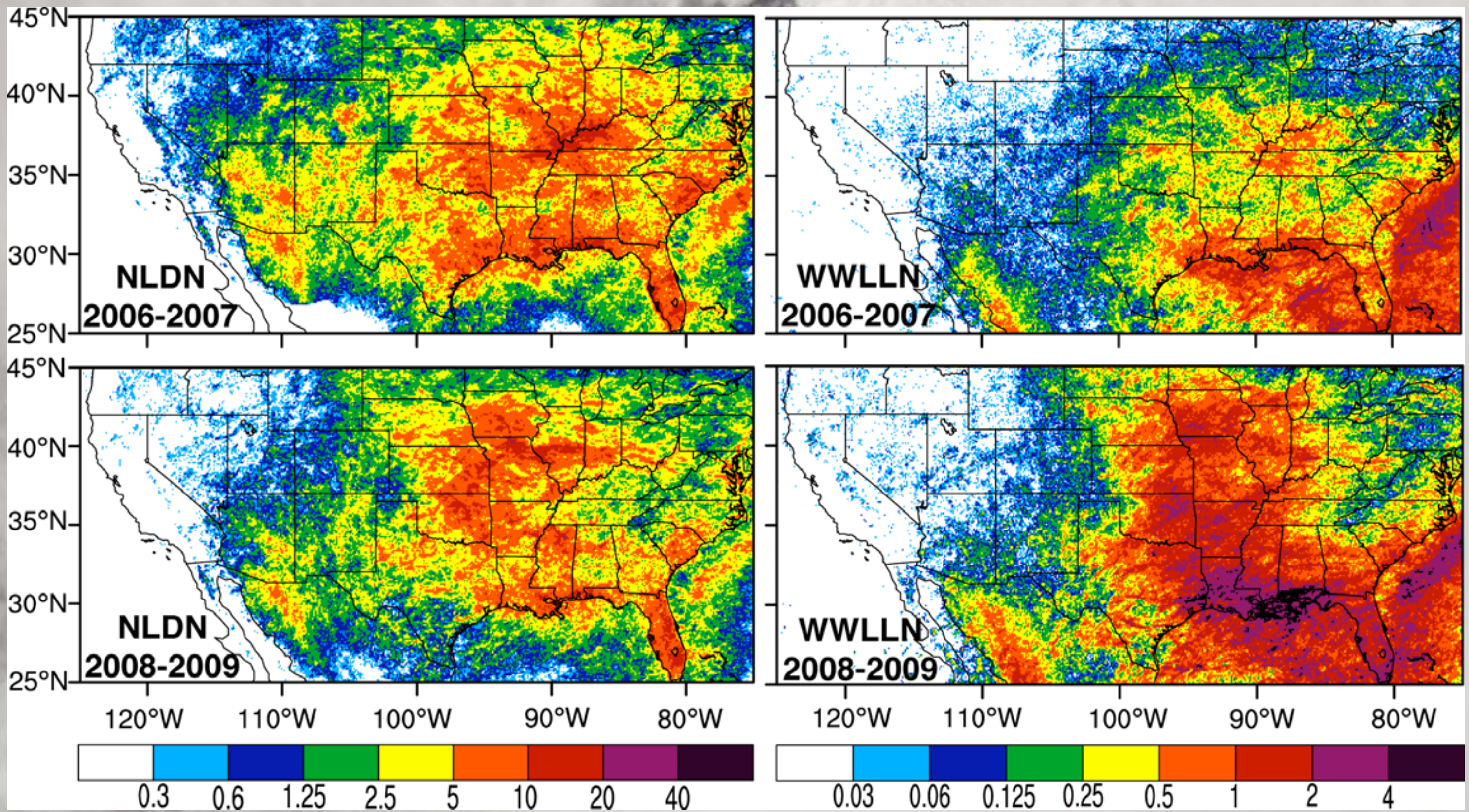
WWLLN Evaluation Using the NLDN

- We performed an evaluation of the WWLLN using the NLDN as ground truth on unprecedented time (3 years) and spatial scales (20° x 50°).

Table 2. Number of Flashes Reported by the WWLLN and the NLDN, by Year, Between 25°N–45°N and 125°W–75°[a]

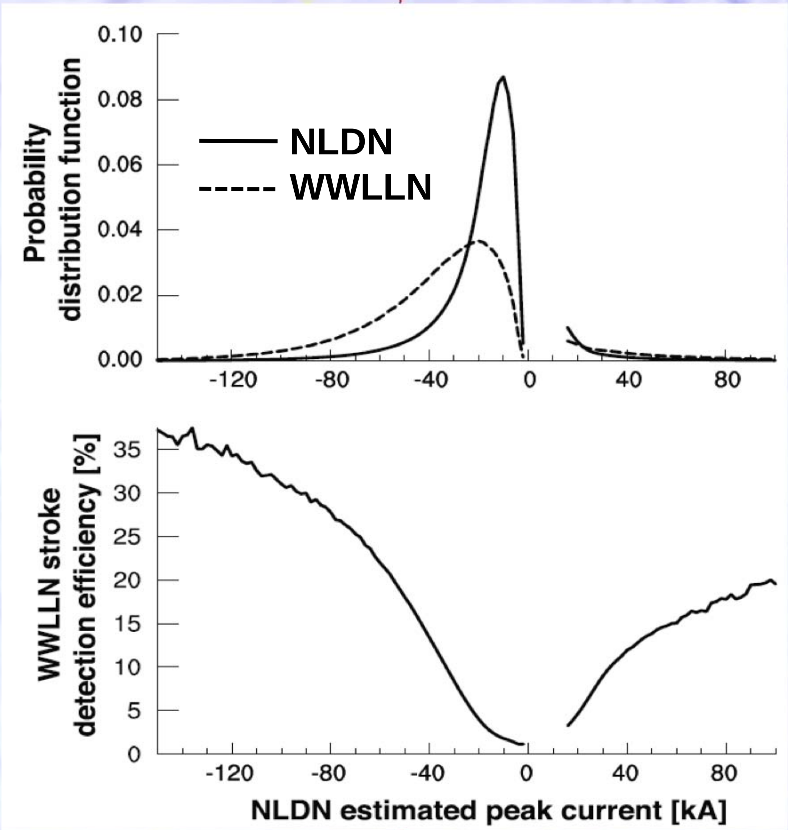
Year	2006–2007	2007–2008	2008–2009
All WWLLN flashes	2,732,366	3,228,444	6,154,394
All (CG) NLDN flashes	29,614,920	27,567,606	24,839,997
Coincidences	1,147,815	1,346,692	2,558,809
CG DE (%)	3.88	4.89	10.30
IC DE (%)	1.78	2.28	4.82
CG + IC DE (%)	2.31	2.93	6.19

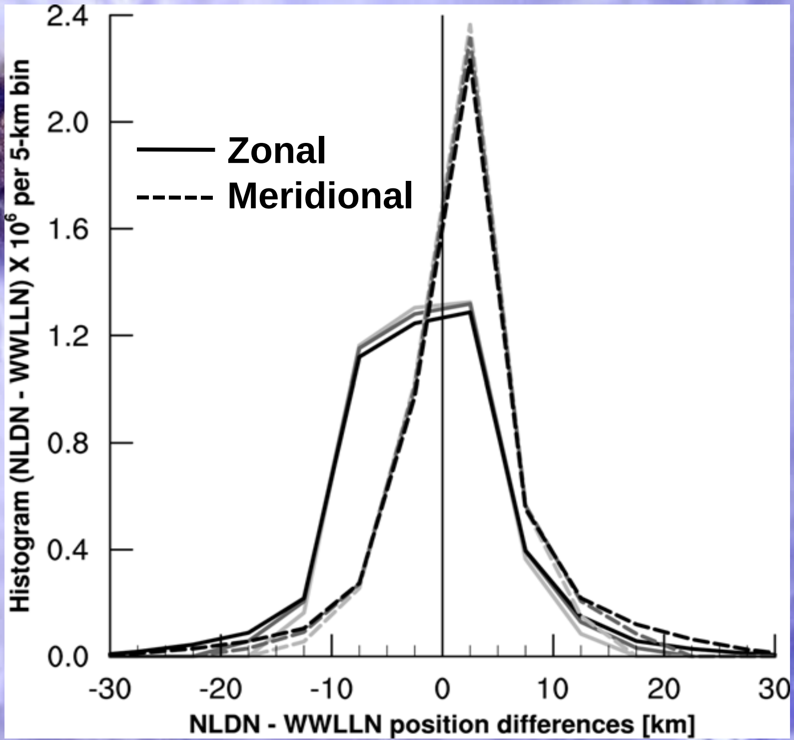
Abarca et al. (2010)



WWLLN Evaluation Using the NLDN

- **Detection efficiency is strongly dependent on peak current, attaining values > 10% for currents stronger than ±35 kA and values < 2% for flashes between 0 and −10 kA.**
- **The location accuracy is found to have northward and westward biases, with average location errors of 4-5 km.**





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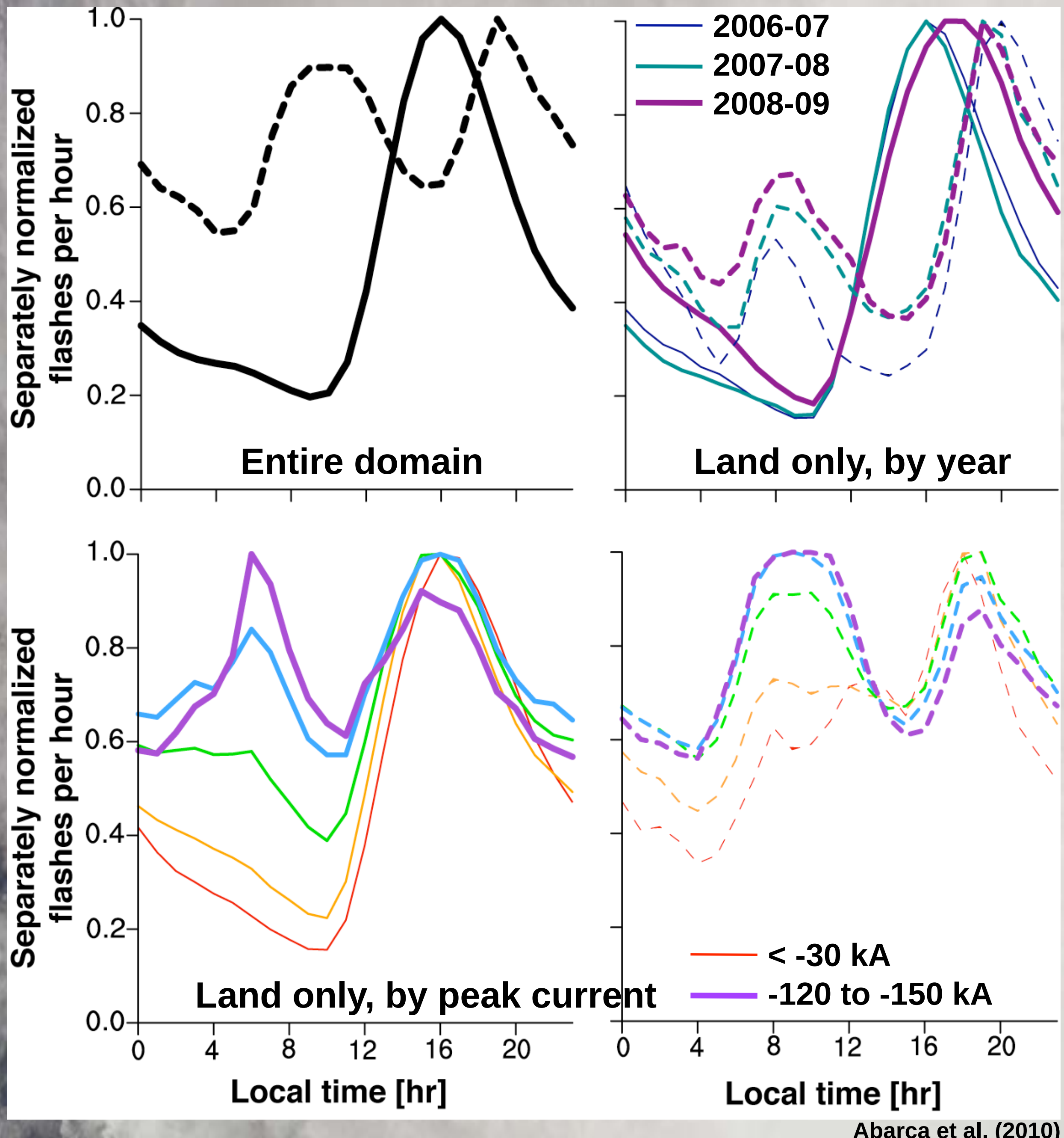
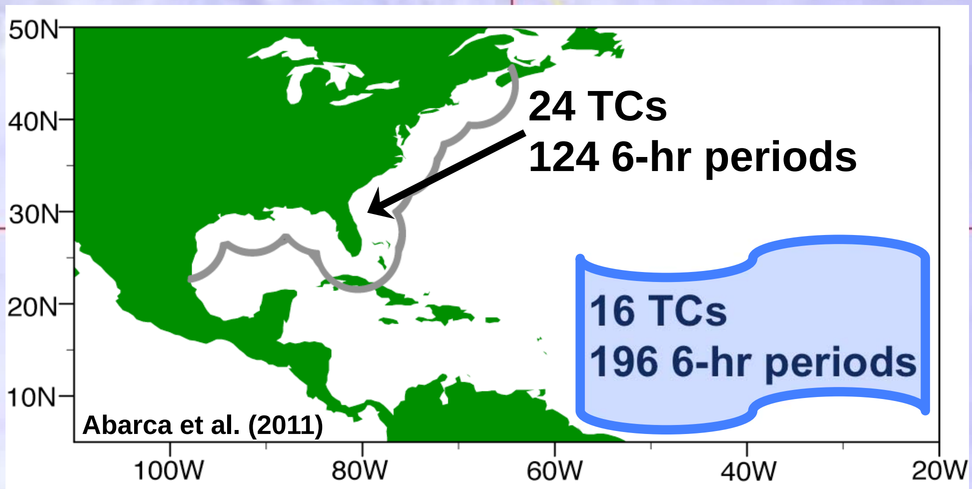


Diurnal Cycle of Lightning

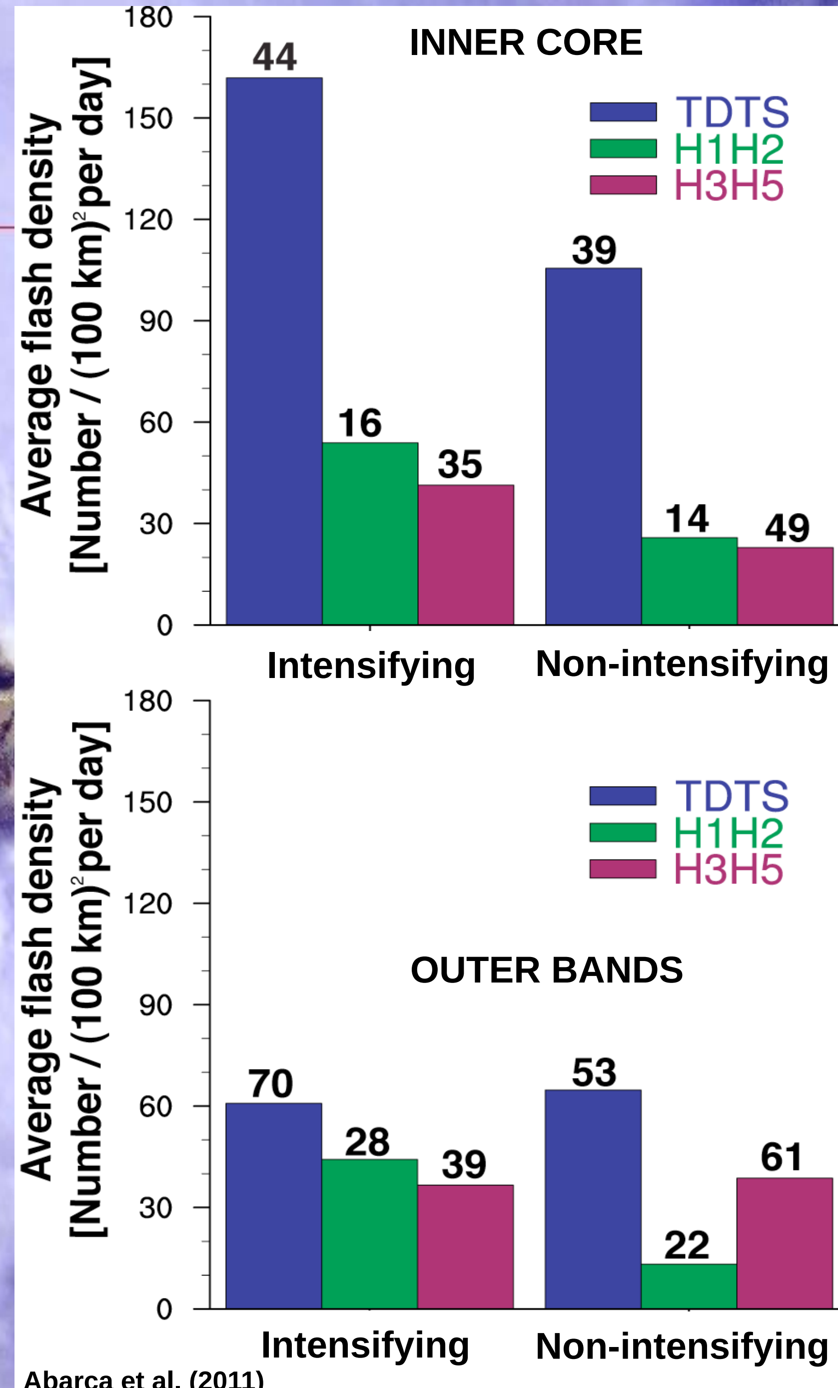
WWLLN (dashed)
NLDN (solid)

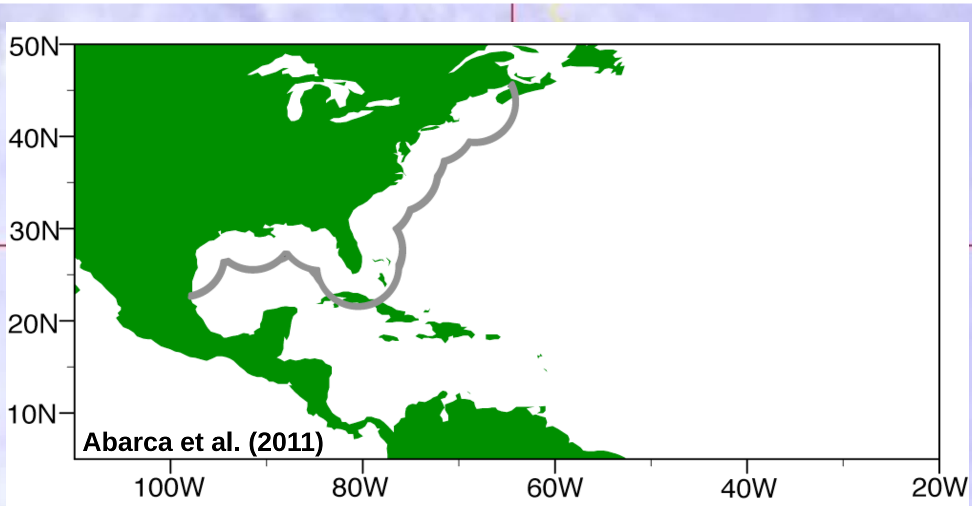
The double peak in the WWLLN is reduced when only land and the weakest flashes are considered, but the issue appears to be growing with time.



Atlantic Basin TCs 2004 – 2007

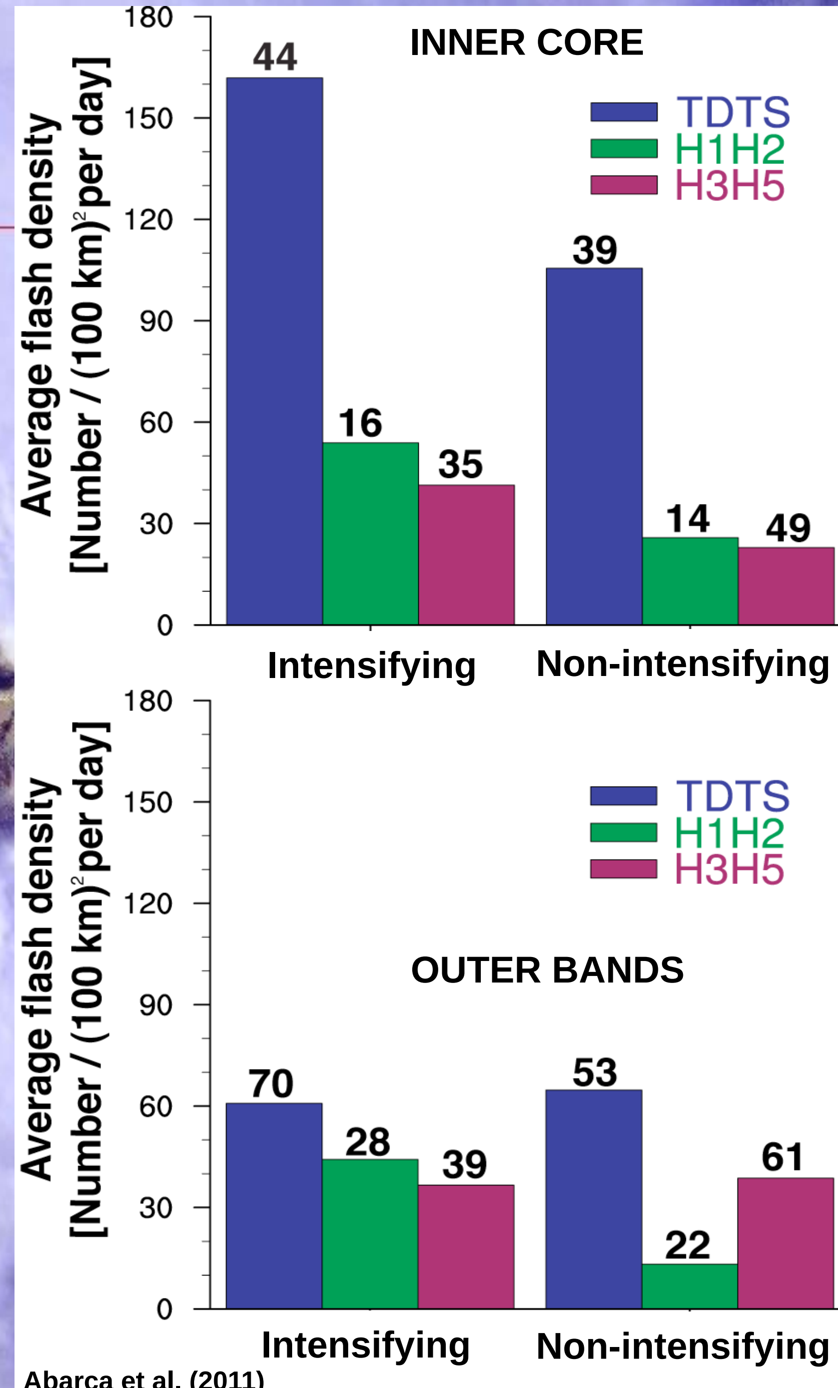
- WWLLN-NLDN evaluation (scalloped) and WWLLN open ocean (box) domains
- Intensifying vs. non-intensifying flash densities for the inner 100 km (core; top) and 100-300 km ring (outer bands; bottom) over the open ocean





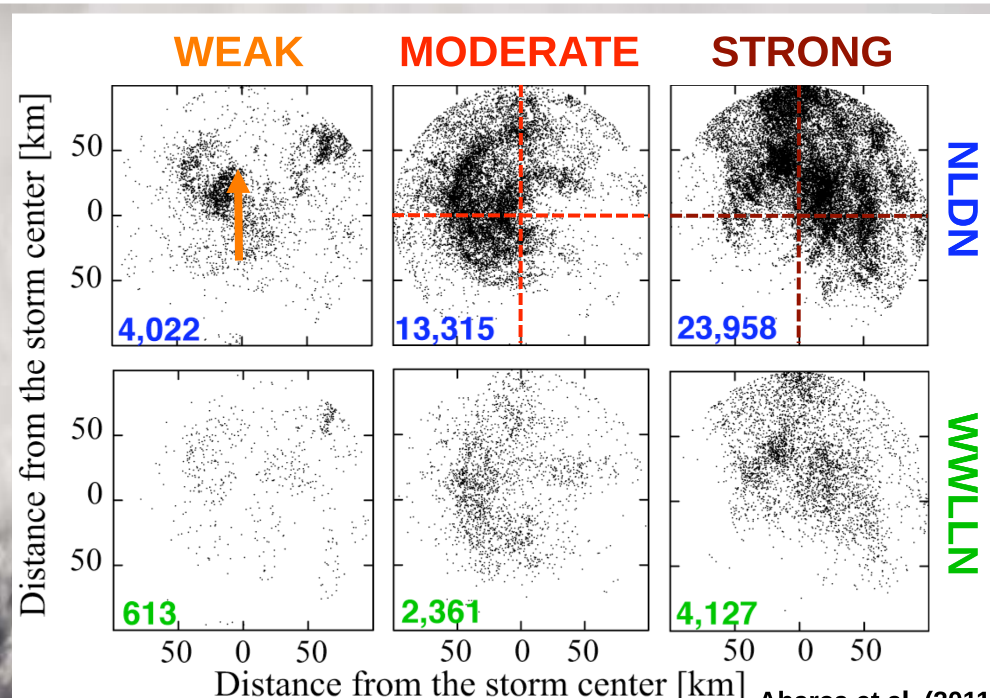
Atlantic Basin TCs
2004 – 2007

- ~ The inner core is more electrically active than the outer bands, especially in weaker TCs.
- ~ The average number of flashes in the inner core is larger in intensifying periods for all strengths of TCs.



Azimuthal Distribution of Flashes: Inner Core Region (< 100 km)

WWLLN (green)
NLDN (blue)



Abarca et al. (2011)

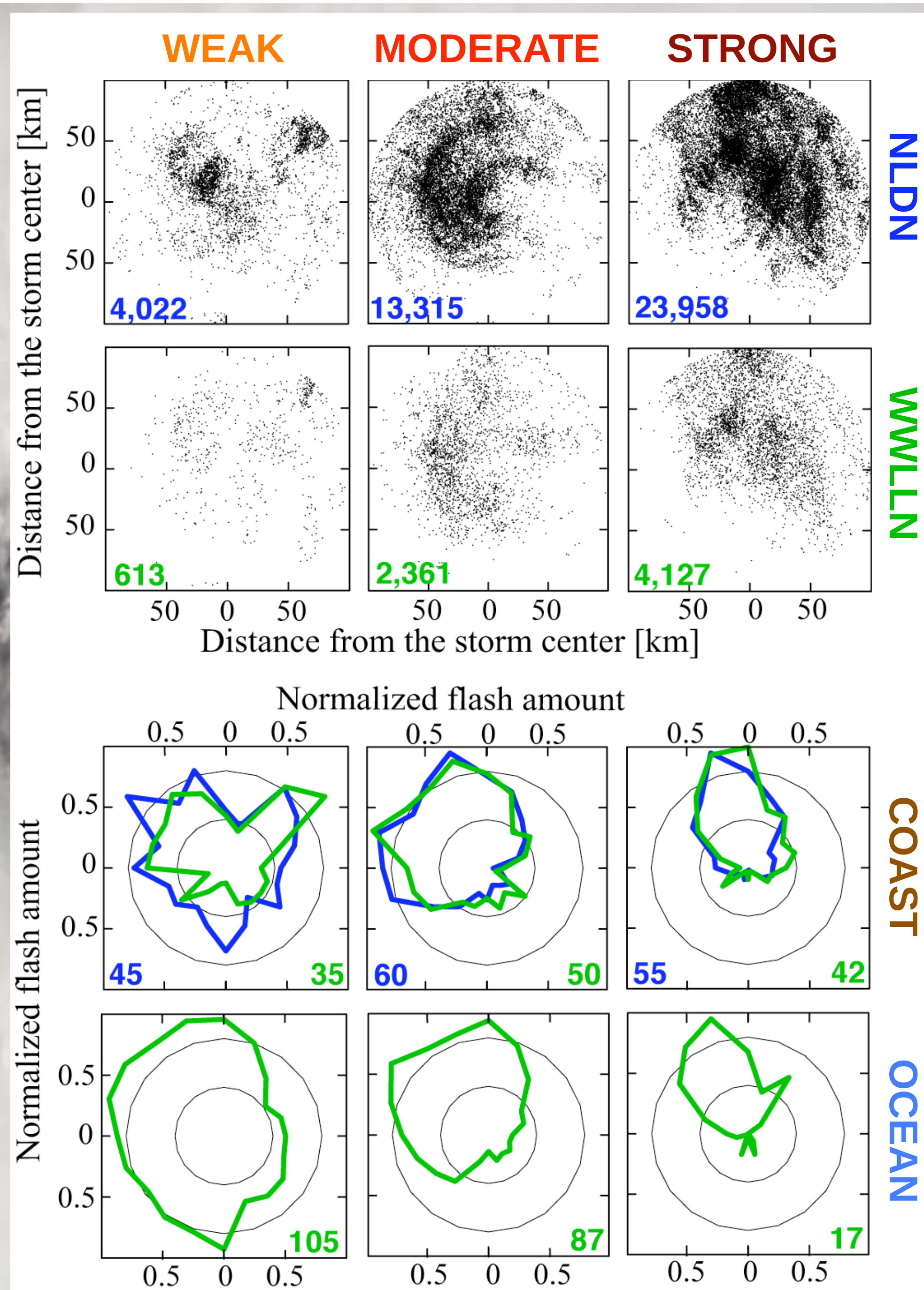
Flashes in each 6-hr period have been rotated around the center so that the shear vector is pointing due north and then composited.

Weak shear: < 5 m s^{-1}
Moderate shear: 5-10 m s^{-1}
Strong shear: > 10 m s^{-1}

Azimuthal Distribution of Flashes: Inner Core Region (< 100 km)

The flashes in 18° sectors around each 6-hr period are summed and normalized by the largest value.

The normalized sums are plotted as the vertices of 20-sided polygons and plotted at a radius proportional to the normalized sum in the direction of the sector.



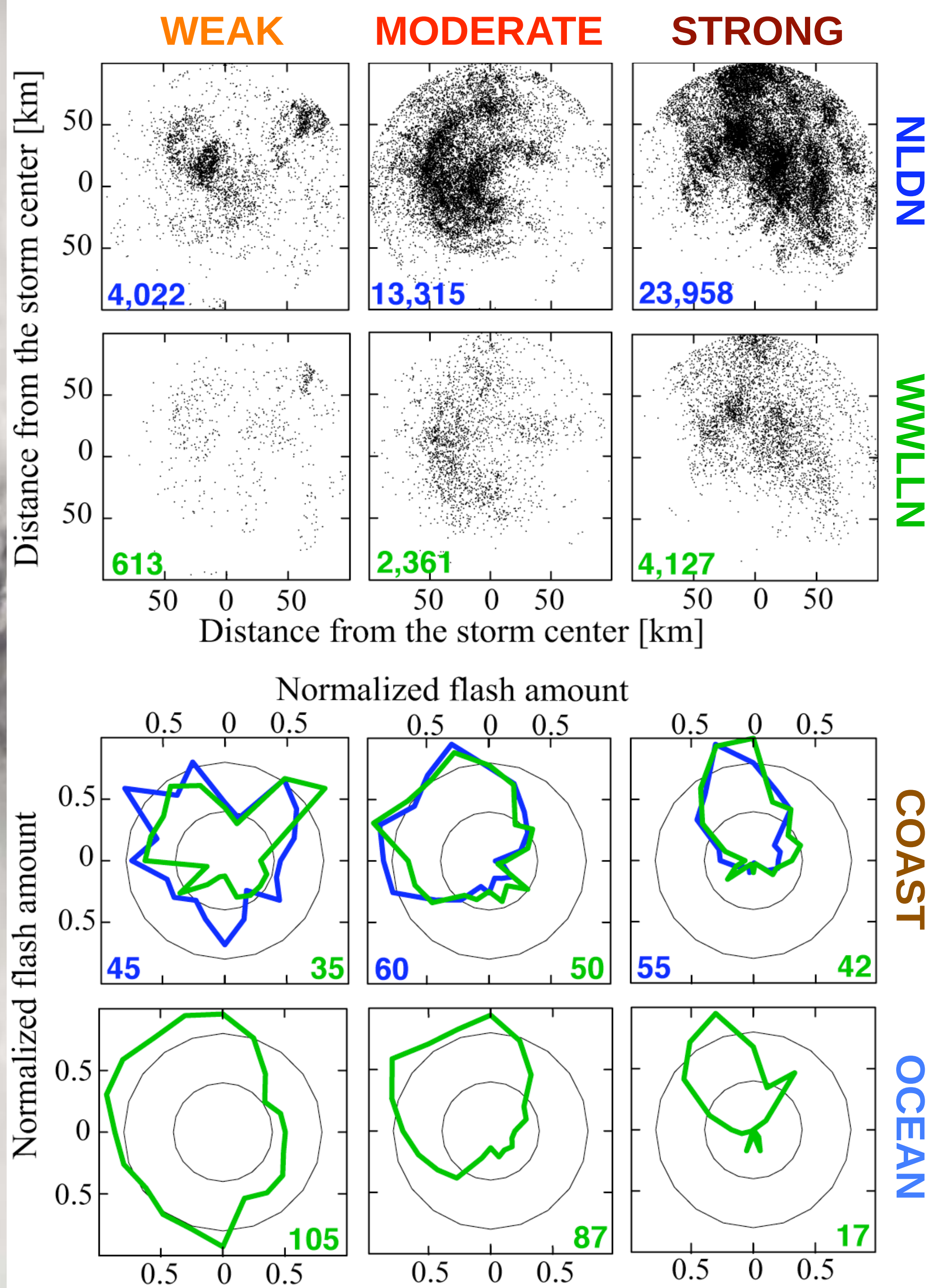
Abarca et al. (2011)

Azimuthal Distribution of Flashes: Inner Core Region (≤ 100 km)

WWLLN (green)
NLDN (blue)

Shear

Lightning in the inner core shows a downshear left preference for shear > 5 m s^{-1}, with the azimuthal span of the convection sharpening with larger shear values.



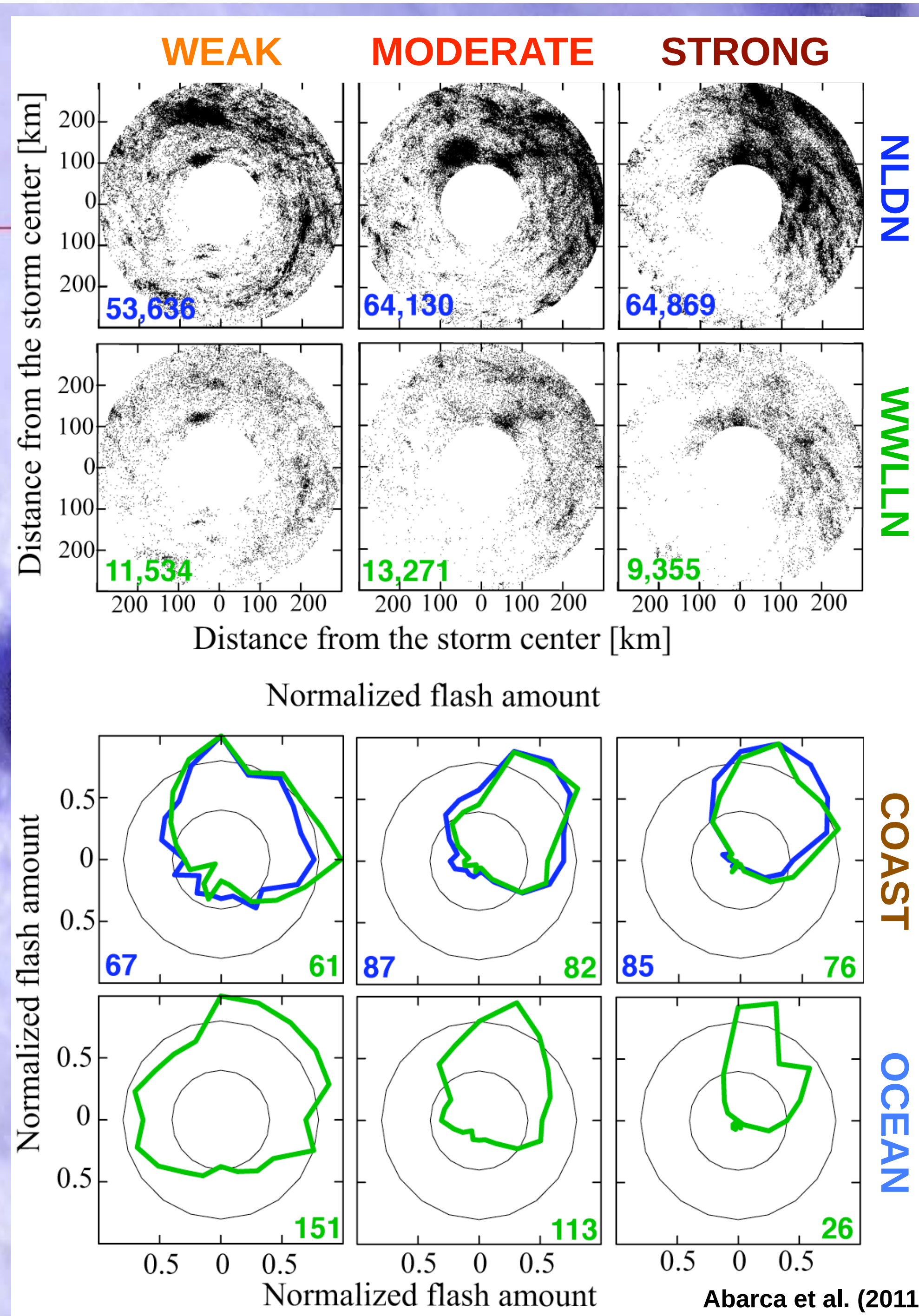
Abarca et al. (2011)

Azimuthal Distribution of Flashes: Outer Band Region (100-300 km)

WWLLN (green)
NLDN (blue)

Shear

Lightning in the **rainband** region shows a distinct preference for the **downshear right** quadrant with a narrowing of the region with increasing shear.

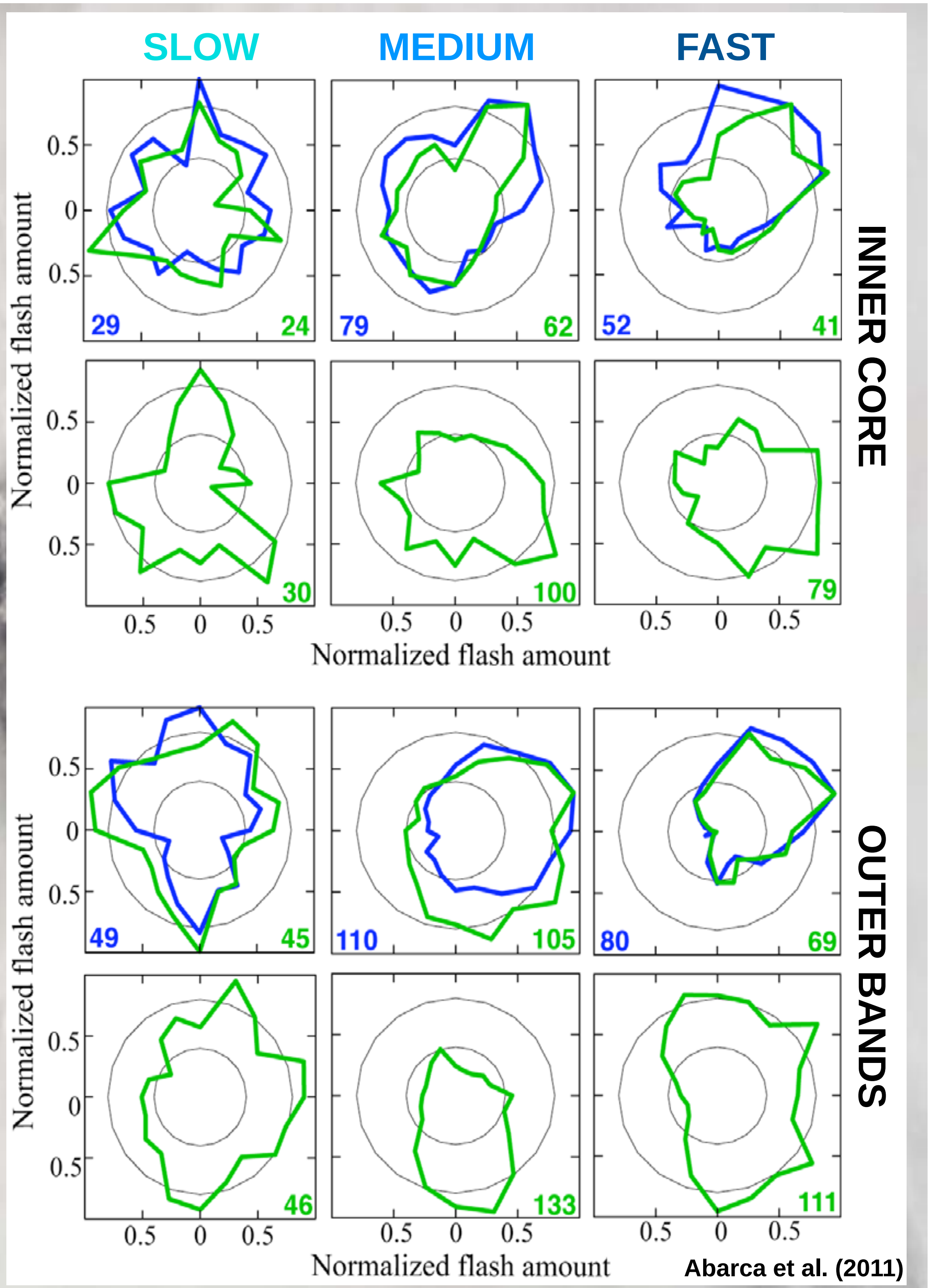


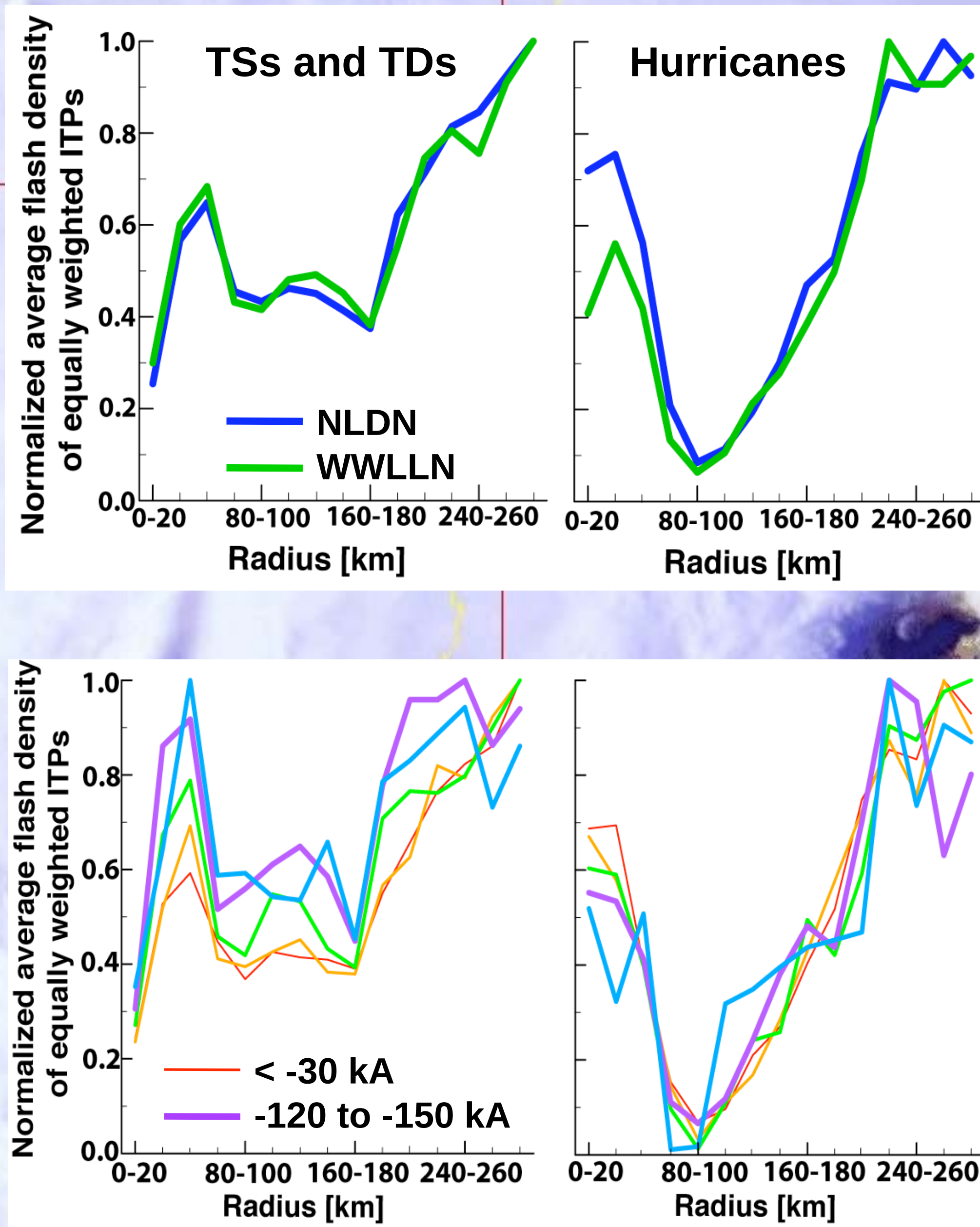
Azimuthal Distribution of Flashes: Storm Motion

WWLLN (green)
NLDN (blue)

Motion

The asymmetries associated with motion are less clearly defined than those associated with shear, with a right of motion preference only seen in the faster moving TCs.

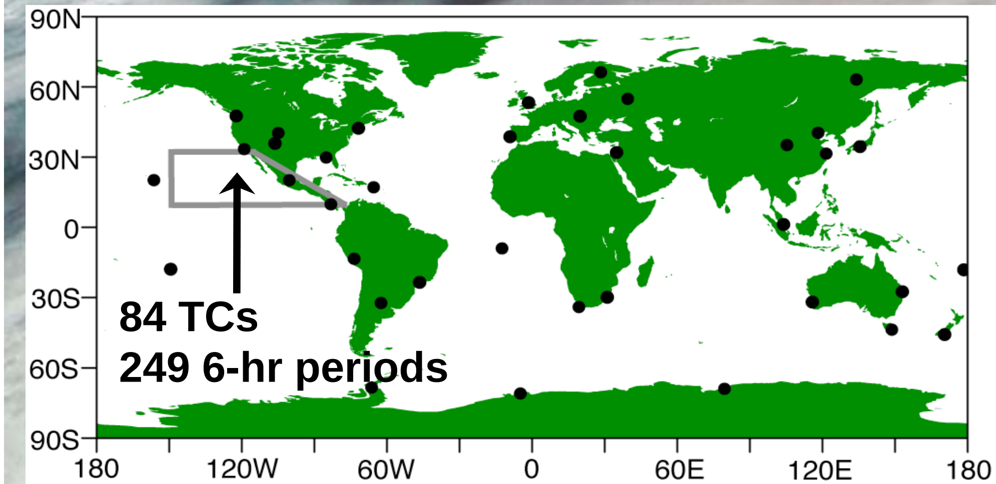




Abarca et al. (2011)

Radial Distribution of Flashes:

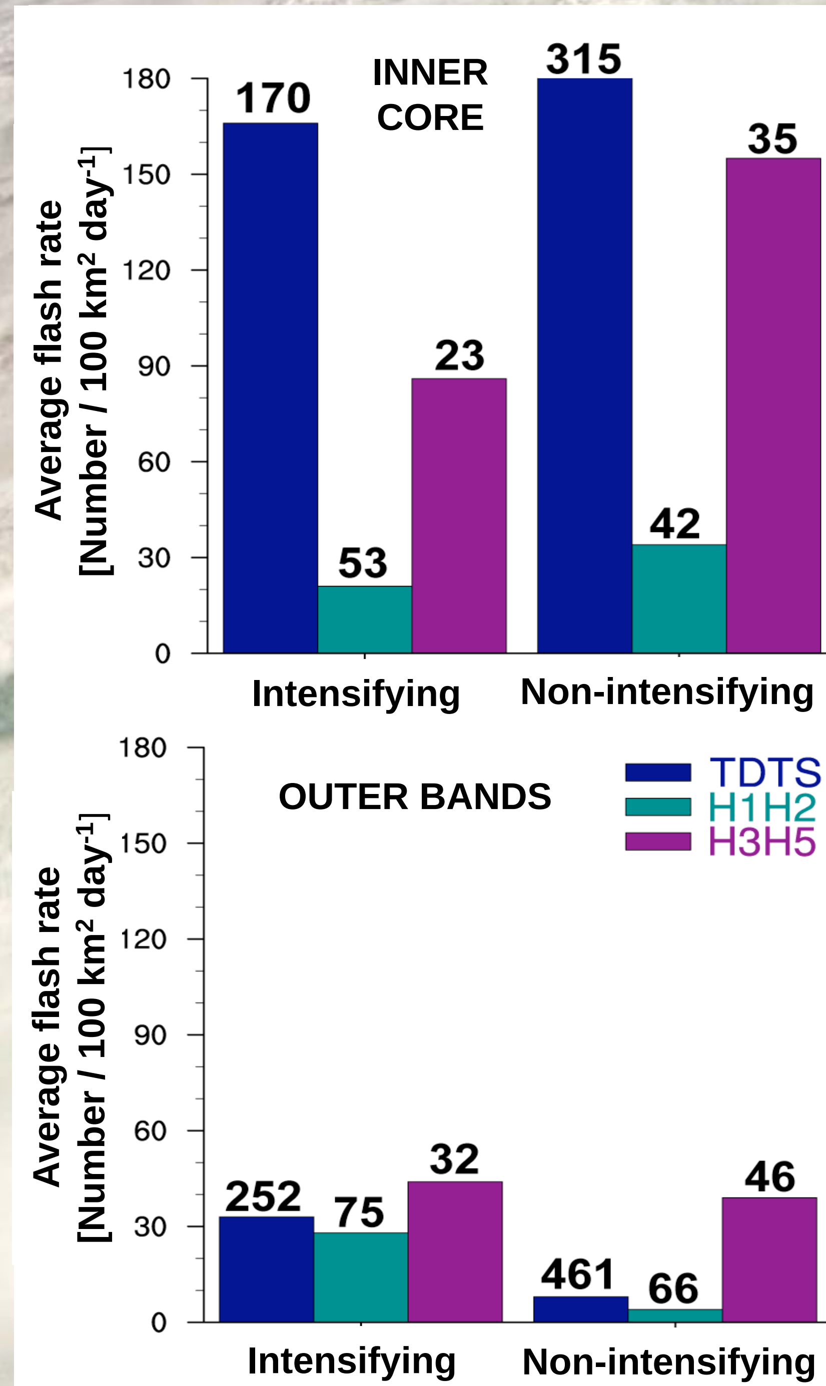
The radial distribution of flashes exhibits a narrow region of little activity (between 60 and 120 km), with increased activity in regions both closer to, and more distant from, the center that is more pronounced in hurricanes.

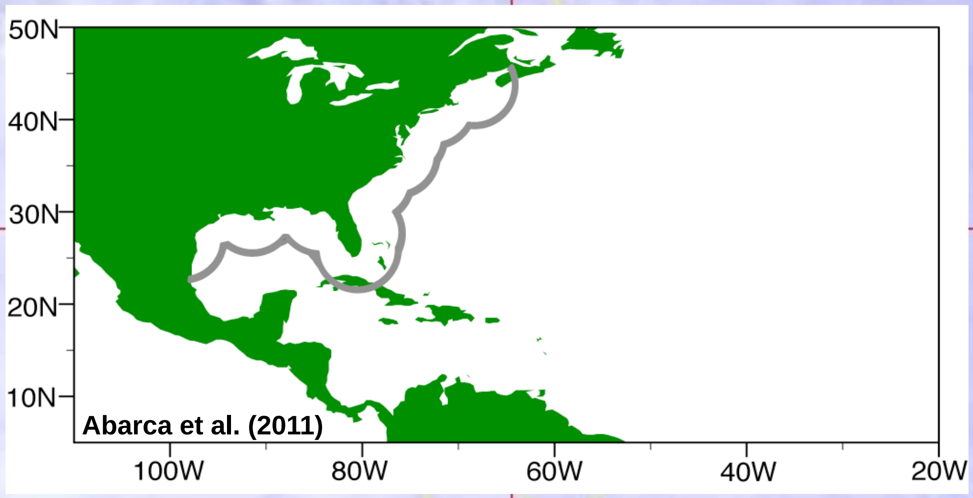


Eastern Pacific TCs
2004 – 2009

~ Like the Atlantic, the inner core is more electrically active than the outer bands.

~ However, the average flash rate in the inner core is larger in non-intensifying periods, especially for the strongest TCs.





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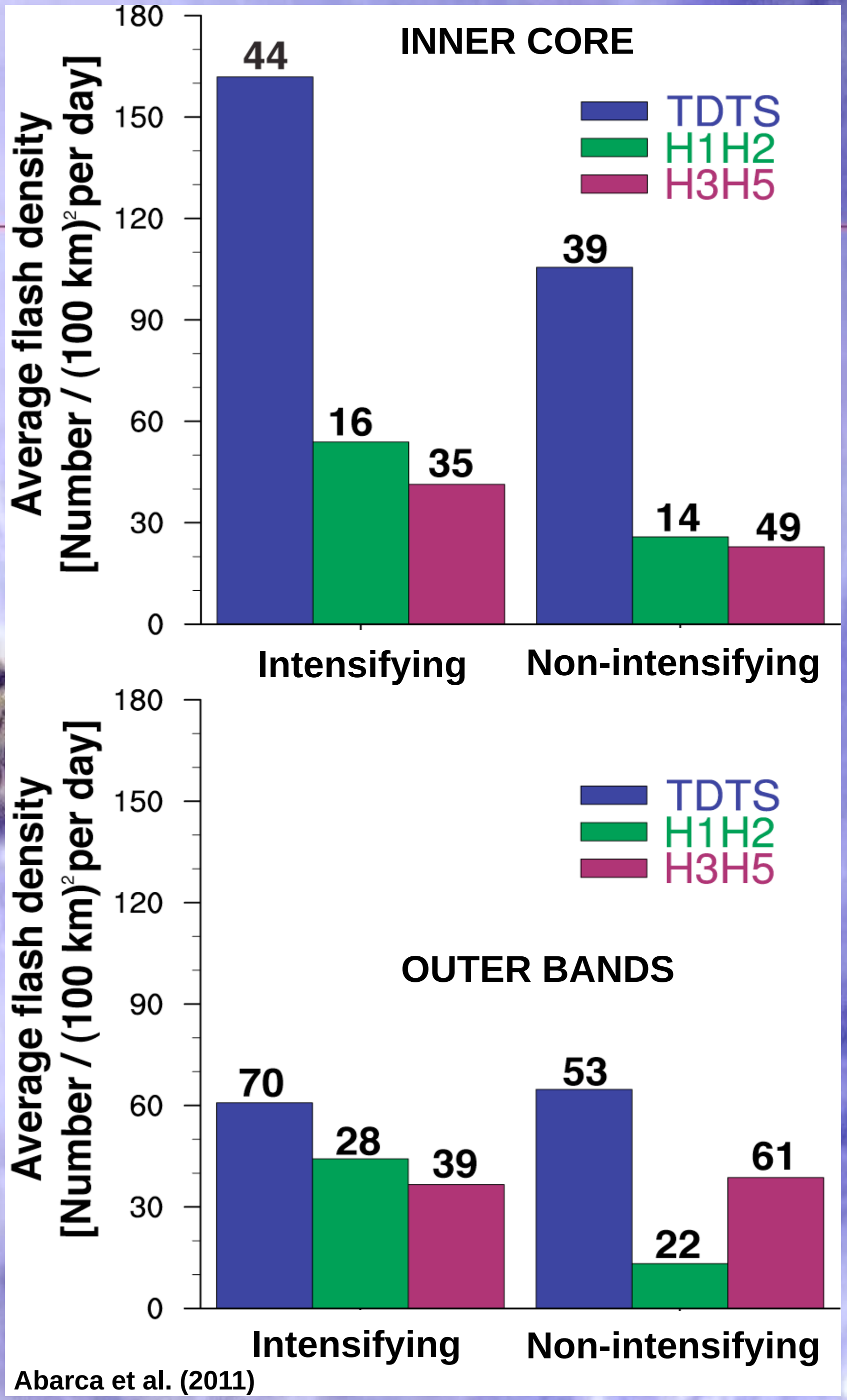
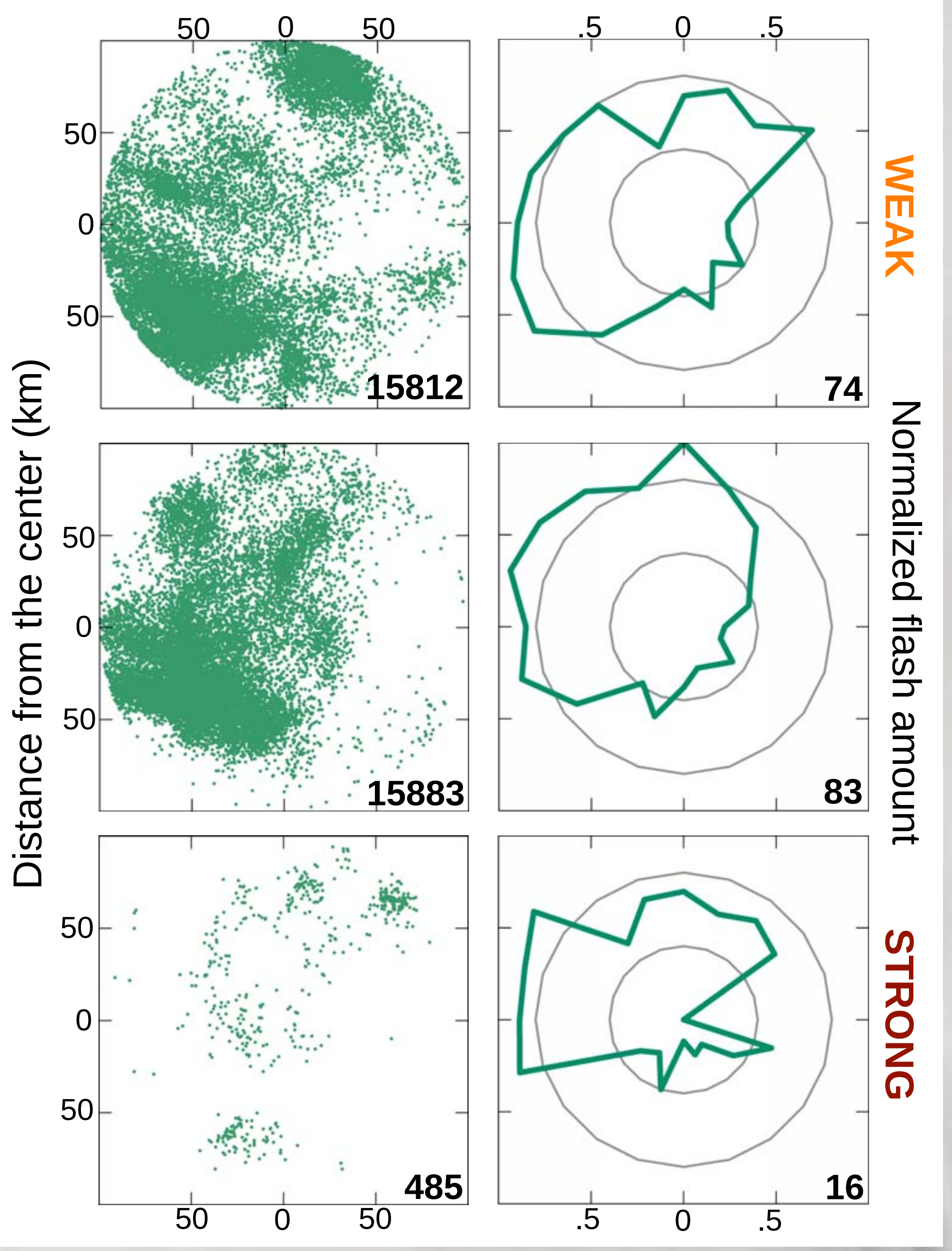


Azimuthal Distribution of Flashes: Inner Core Region (< 100 km)

Only WWLLN flashes

Shear

Similar to the Atlantic, the inner core flashes in the eastern Pacific show a strong downshear left preference, but without the narrowing of the main region of convective activity.

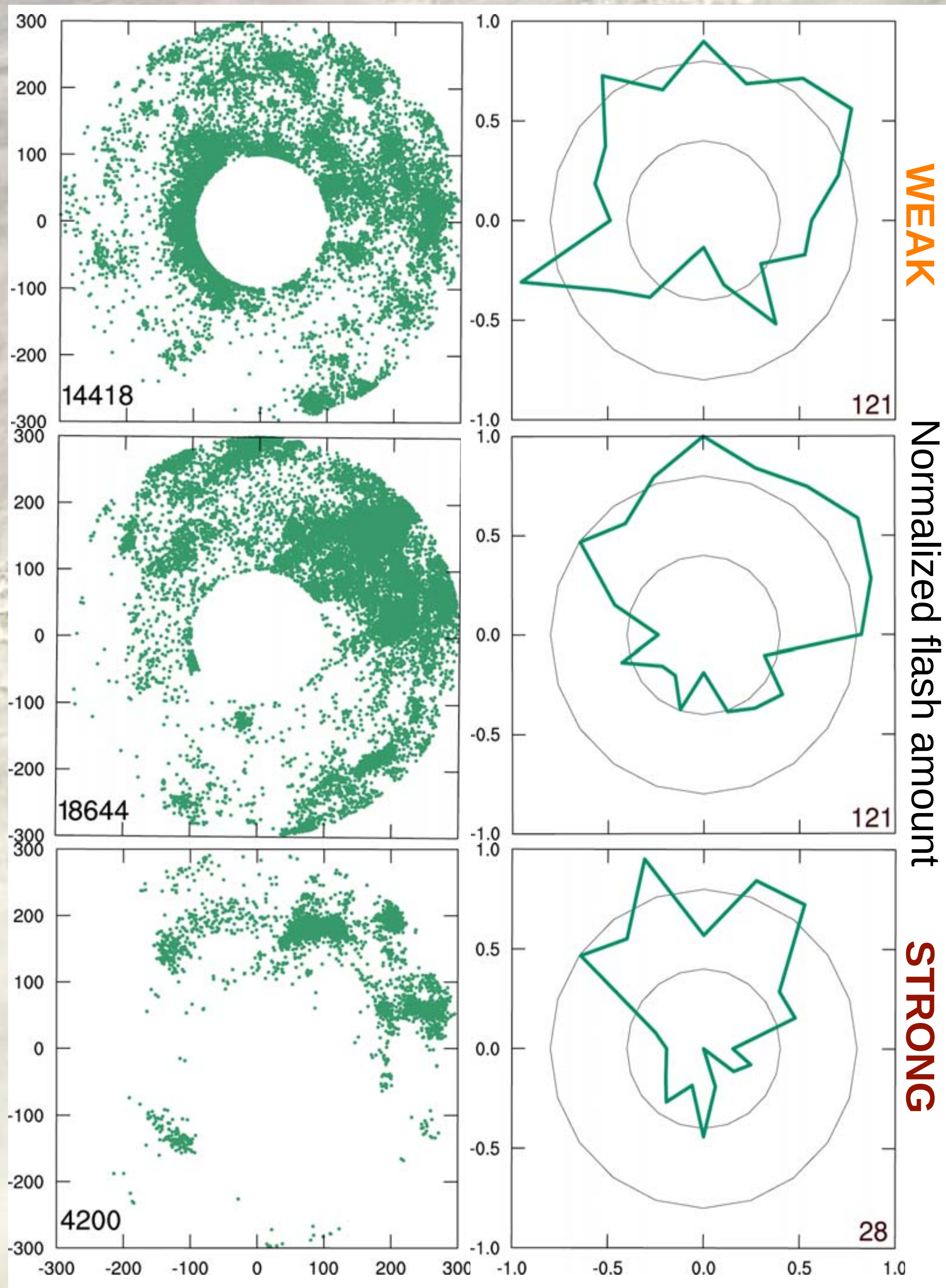


Azimuthal Distribution of Flashes: Outer Band Region (100-300 km)

Only WWLLN flashes

Shear

Outer rainband flashes in the eastern Pacific show a distinct downshear asymmetry, with only a slight preference for downshear right .

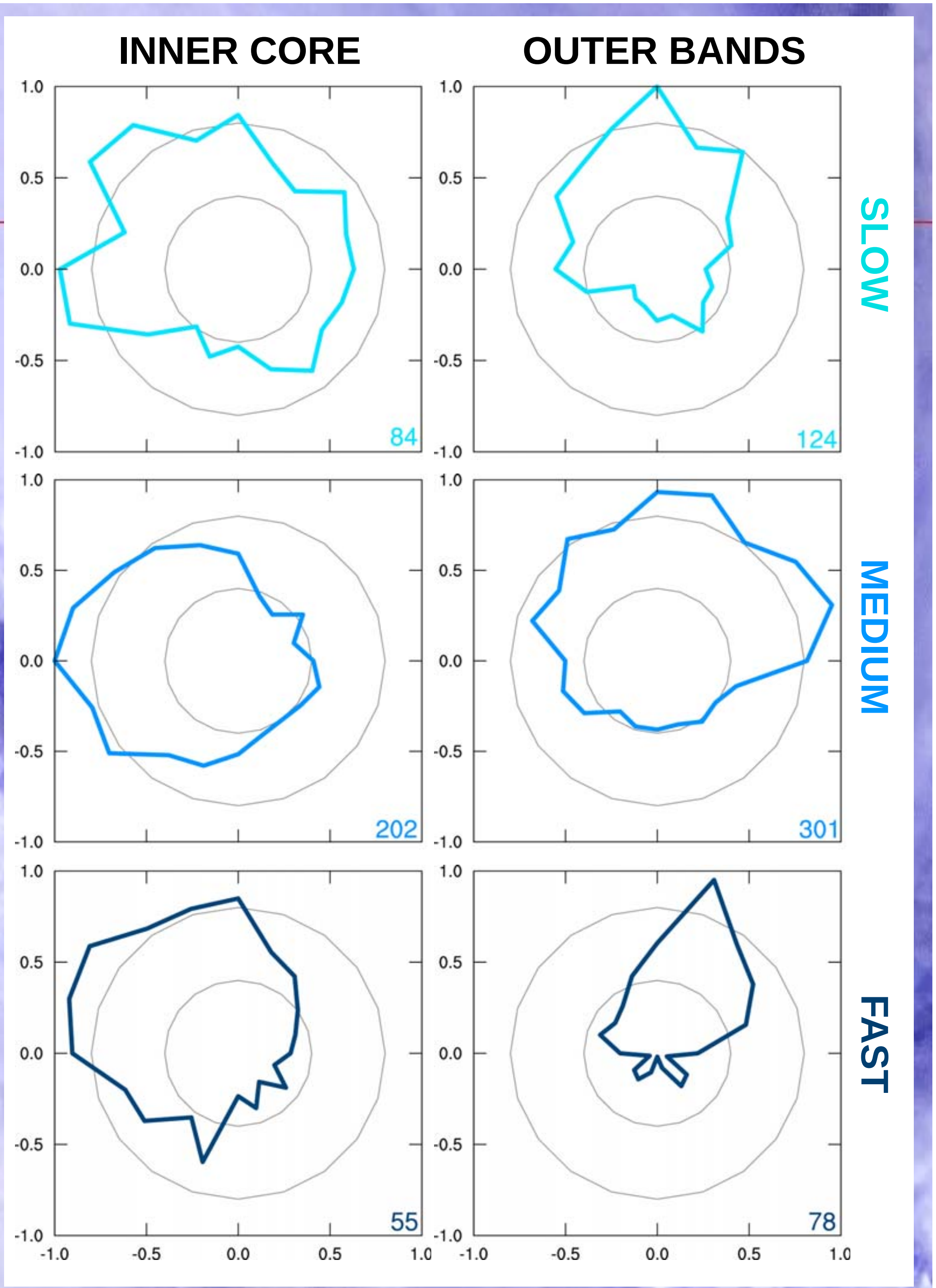


Azimuthal Distribution of Flashes: Storm Motion

Only WWLLN

Motion

Distinctly different from the Atlantic, the motion asymmetry in the core is to left of motion, and in the front and slightly right of motion in the outer rainbands.

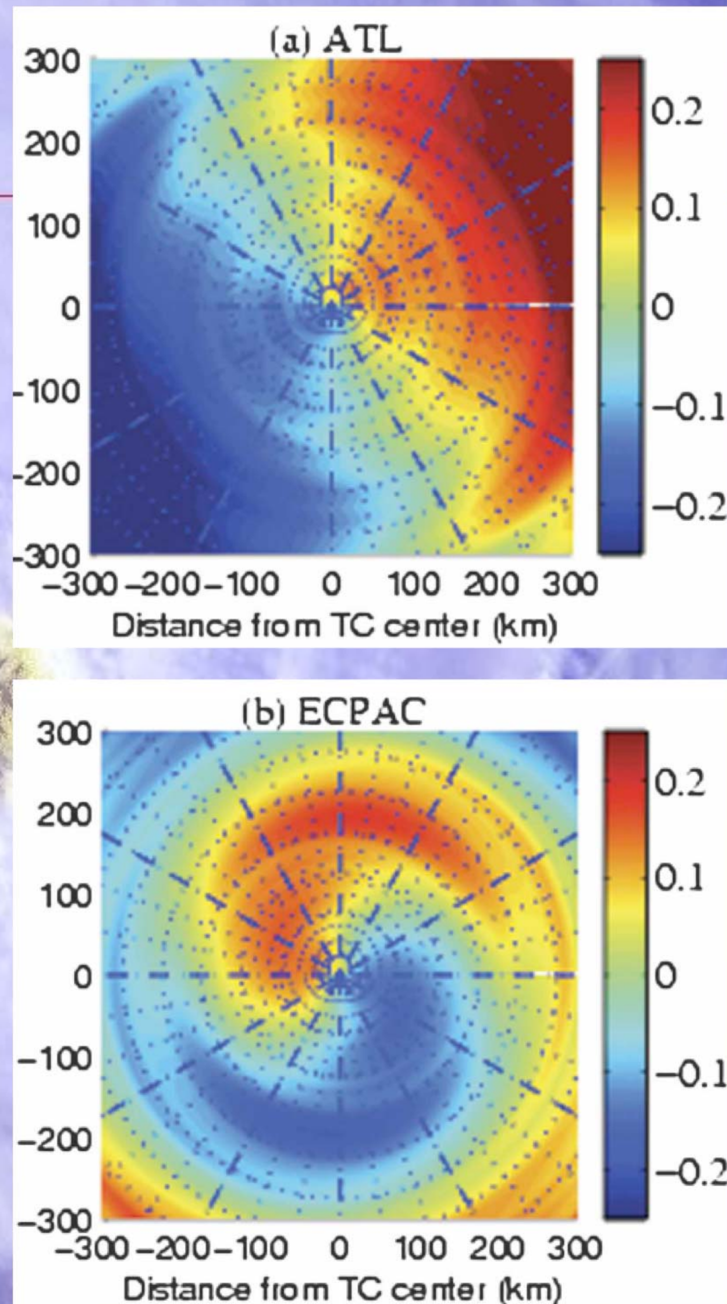


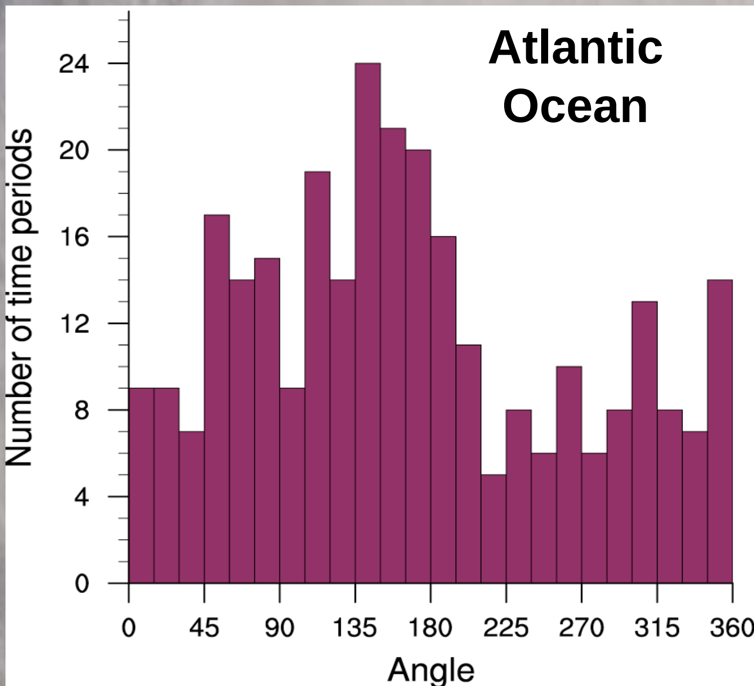
Azimuthal Distribution of Rainfall: Storm Motion

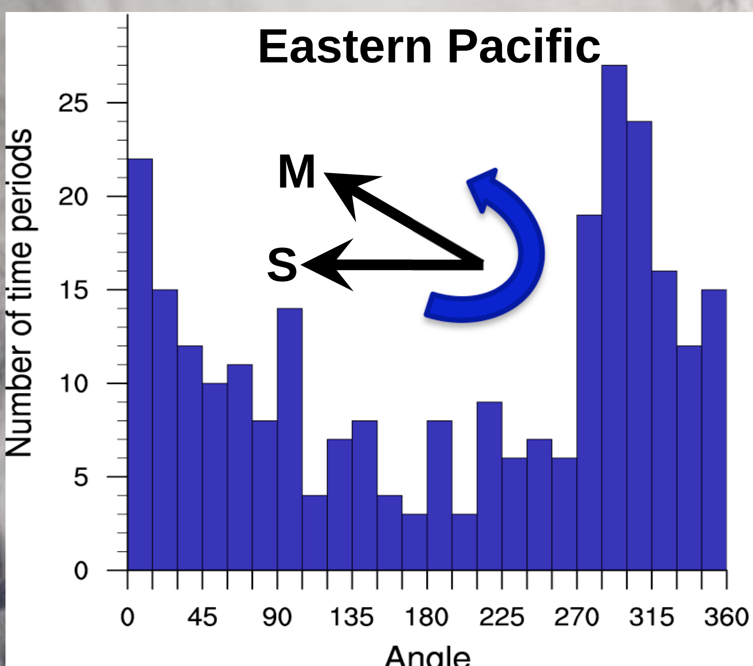
TRMM rainfall

Motion

The differences in the WWLLN flash asymmetries with respect to storm motion between the Atlantic and Eastern Pacific were also seen by Chen et al. (2006) using TRMM rainfall estimates.

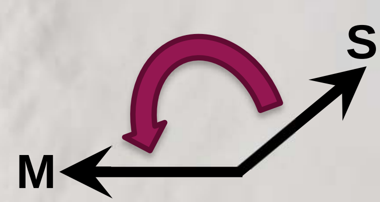




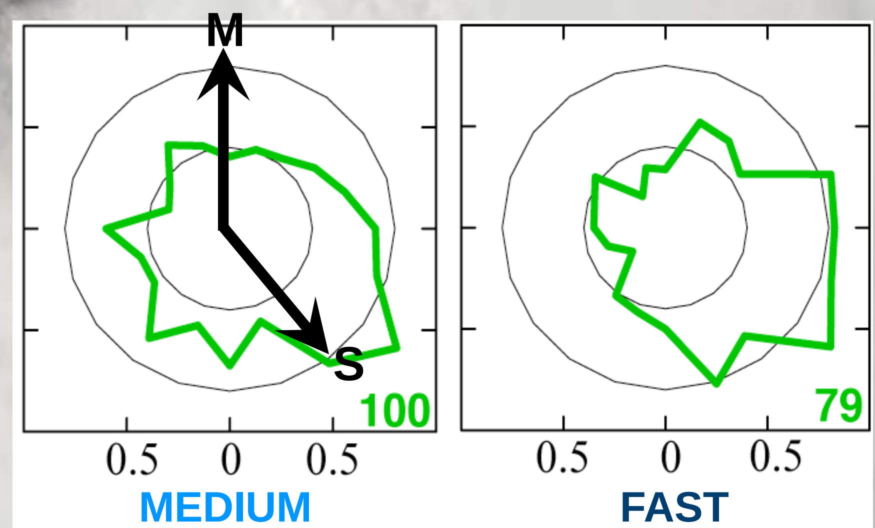


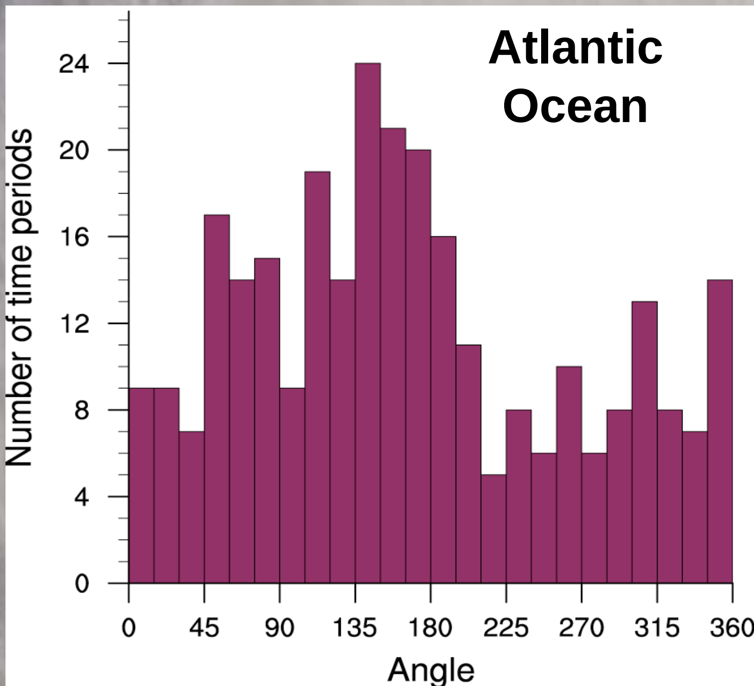
Directions of Shear and Motion Vectors:

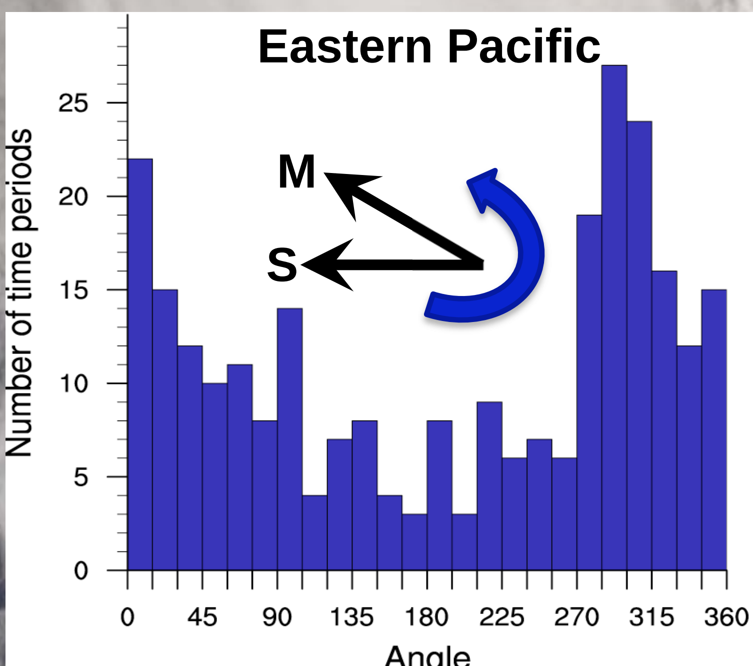
Angle between the shear and motion vectors, counterclockwise from S to M



Inner core Atlantic:
Right rear = Downshear left

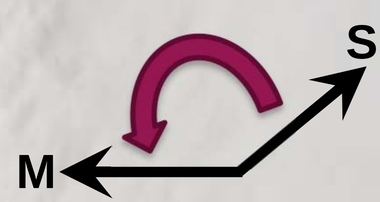




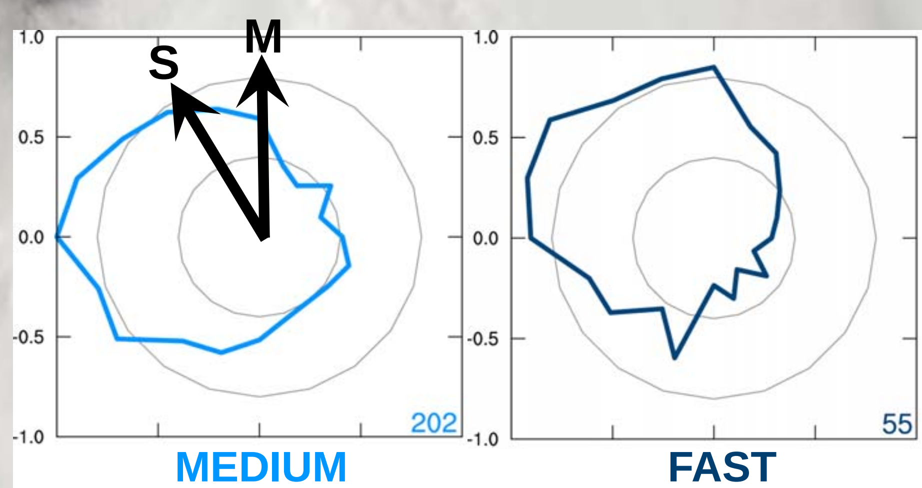


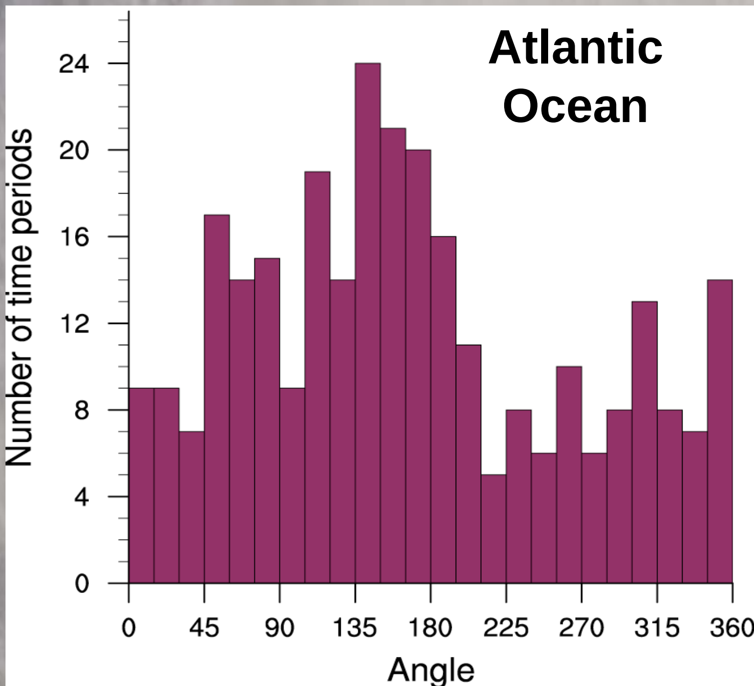
Directions of Shear and Motion Vectors:

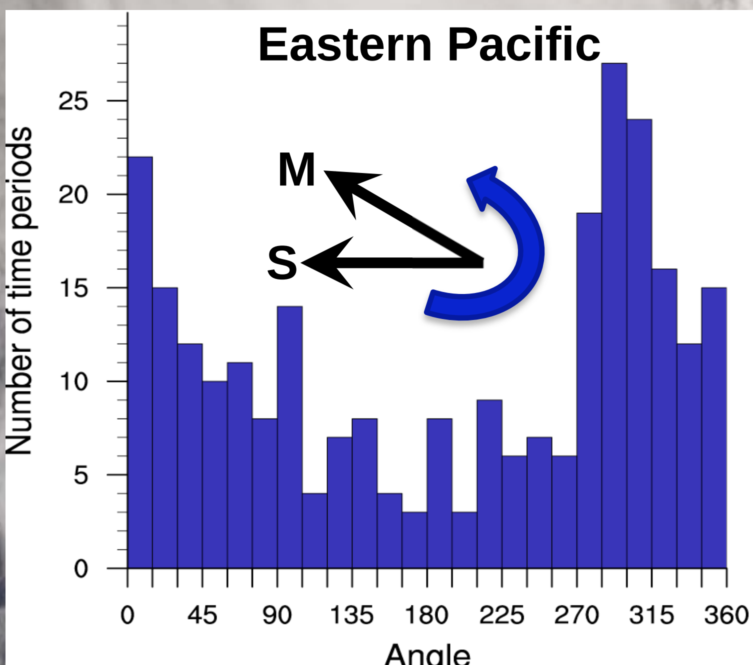
Angle between the shear and motion vectors, counterclockwise from S to M



Inner core Eastern Pacific:
Left front = Downshear left

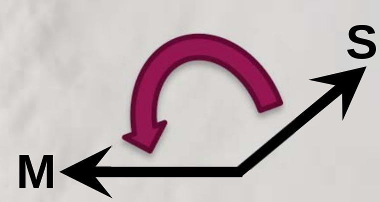




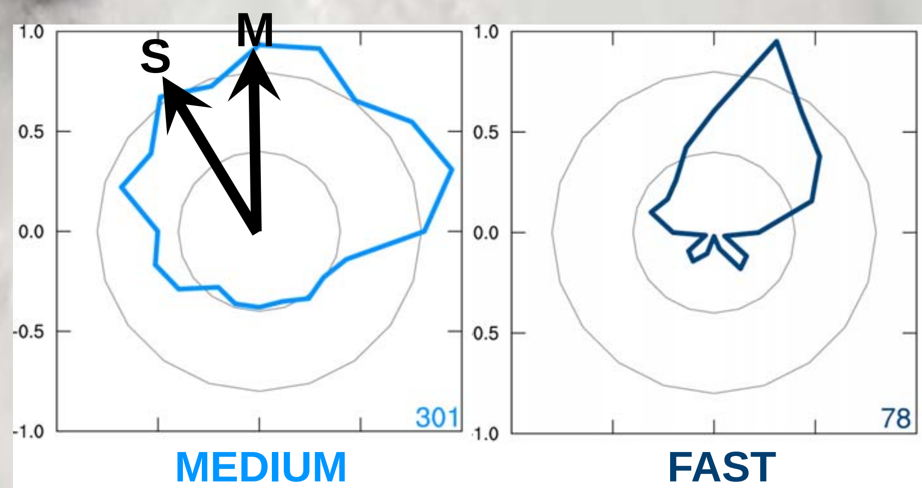


Directions of Shear and Motion Vectors:

Angle between the shear and motion vectors, counterclockwise from S to M



Outer bands Eastern Pacific:
Right front = Downshear right



Summary & Future Work

- The World Wide Lightning Location Network (WWLLN) is a developing, global, long range lightning detection network with potential for meteorological research applications

- Despite relatively low detection efficiency (DE) and issues with the diurnal cycle of convection, the network shows good spatial coherency and proportionality with a higher DE network (NLDN)

- In the Atlantic and eastern Pacific basins, convective activity is maximized in the downshear left quadrant in the core, and downshear right in the outer rainbands

Summary & Future Work

- The much weaker motion asymmetry is largely an artifact of the shear signature and depends on the relative directions of shear and motion

- Flash density in the inner core may have potential for distinguishing between intensifying and non-intensifying TCs in the Atlantic, while in the Pacific the strongest, non-intensifying TCs have the highest flash rates

- Continue to investigate the flash densities and distributions in the eastern Pacific and other basins where aircraft reconnaissance is not routine