Diurnal Variability in Tropical Surface Winds, Convergence and the Associated Precipitation

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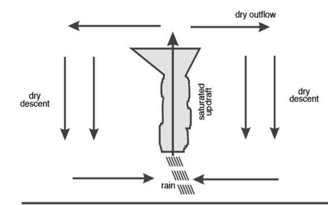
Global Circulation and the Hadley Cell

The sun heats the air over the equator more than at the poles. This differential heating causes the warmer air near the equator to rise, and cells of convection develop (Hadley cells). The Hadley cell is an overturning circulation with four branches:

1) Rising motion near the equator,
2) Poleward motion near the tropopause,
3) Sinking motion in the subtropics near ±30-deg latitude,
4) Equatorward return flow near the surface.



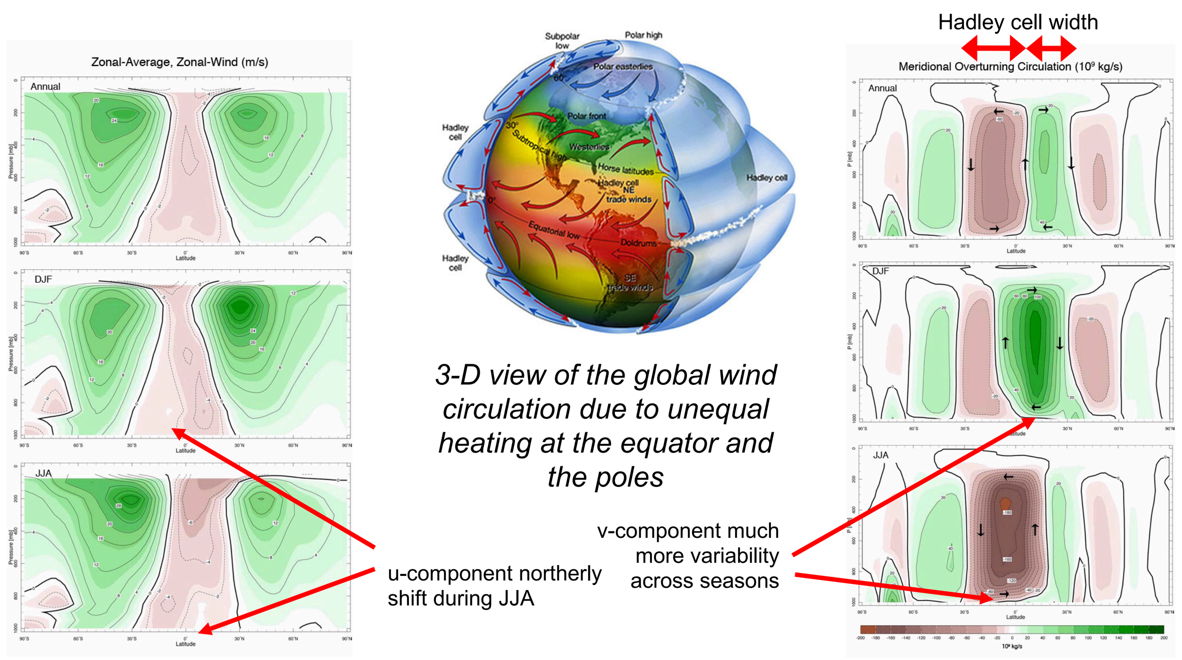


Figure courtesy of EarthLabs https://serc.carleton.edu/eslabs/hurricanes/1b.html

Motivation

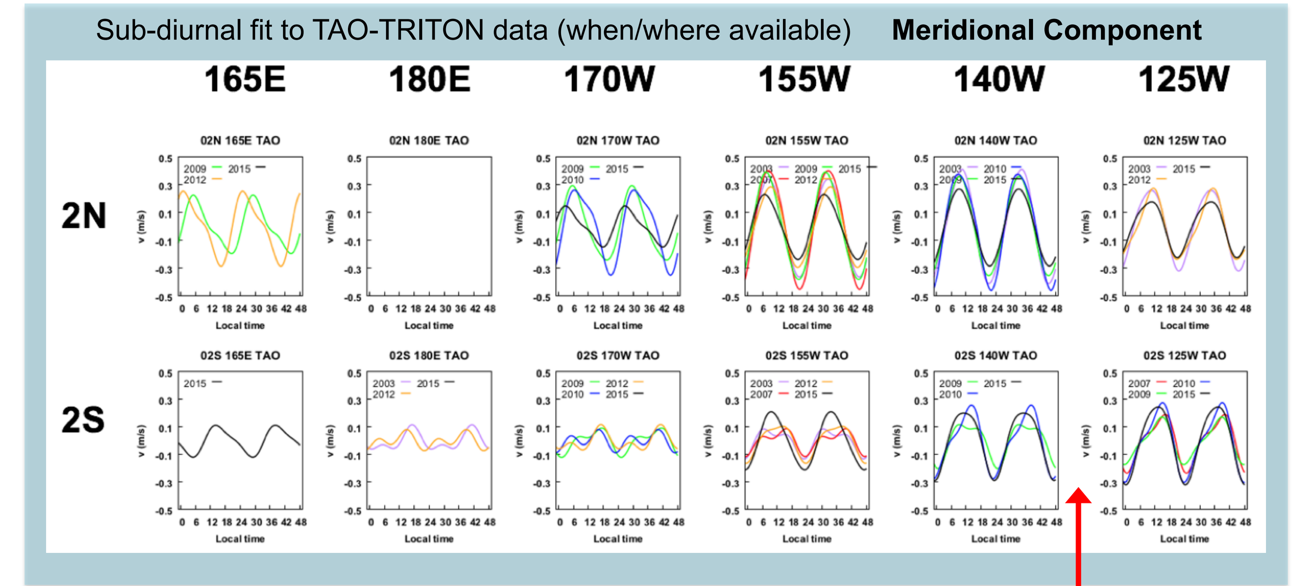
Recent evidence suggests that the tropics, as estimated by the edges of the Hadley cells, have expanded over the last few decades by ≈ 1-degree/decade. This is considered to be an atmospheric response to the observed tropical ocean warming trend (*Quan et al.*, 2004). If continued, the expansion of the tropics (the Hadley cell) could have a substantial impact on water resources in the subtropics.

Until now, the understanding of the mechanisms that govern the changing width of the tropics has been confined to models and proxies (e.g., P-E estimates) because of the unavailability of systematic observations of the large-scale circulation. Ocean surface vector winds derived from scatterometer observations provide an global depiction of the large-scale circulation, and allow the study of the Hadley cell evolution through analysis of its surface branch (ocean winds) (item 4 on left). The 20-yr set of coincident scatterometer and TRMM/GPM data since 1999 prompts several investigations to study the role of surface wind convergence:

1) Can features of the Hadley call be extracted from the long and overlapping periods of scatterometer observations (QuikSCAT, ASCAT, RapidScat, etc.) and corresponding precipitation structure observations (asynchronous TRMM, GPM profiling radars)?

2) Can these joint (surface wind and its derivative fields, and precipitation) observations provide better physical rationale for Hadley cell changes?

3) Do the diurnal cycles of wind and precipitation vertical structure strengthen independently, or shift under different forcing (SST, convergence)?

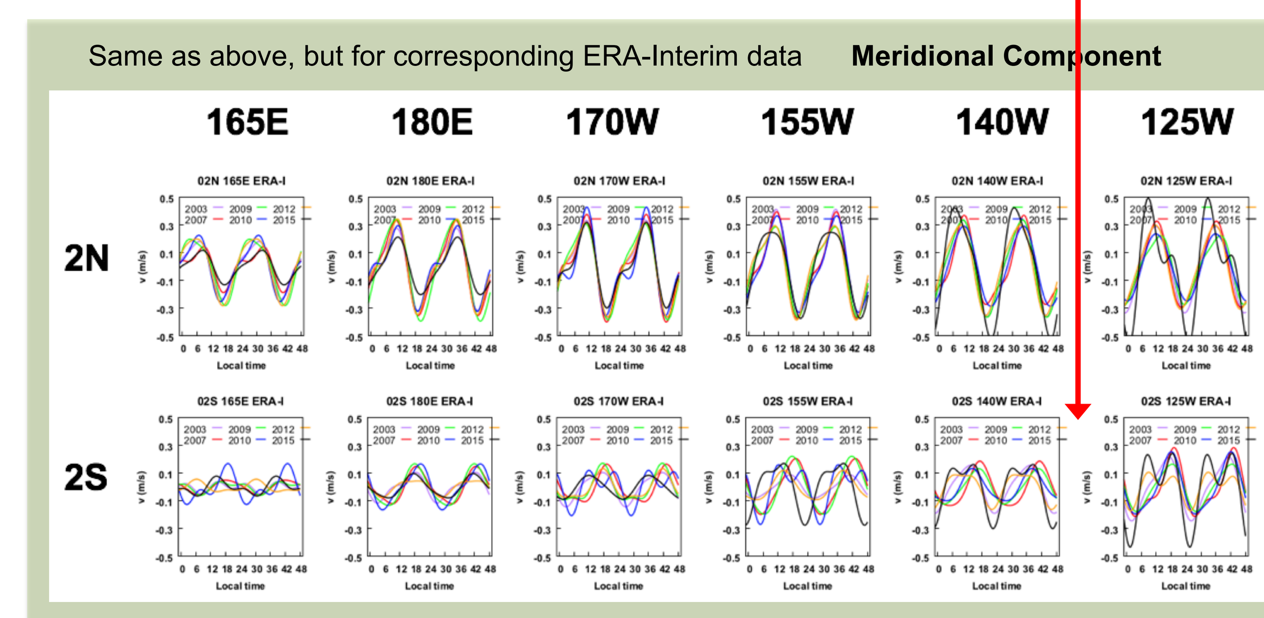


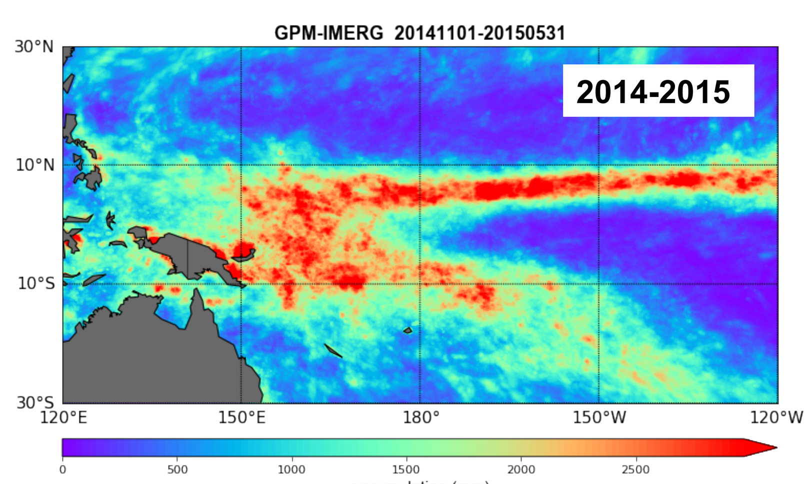
ERA-I generally captures observed eastward increase in meridional amplitude

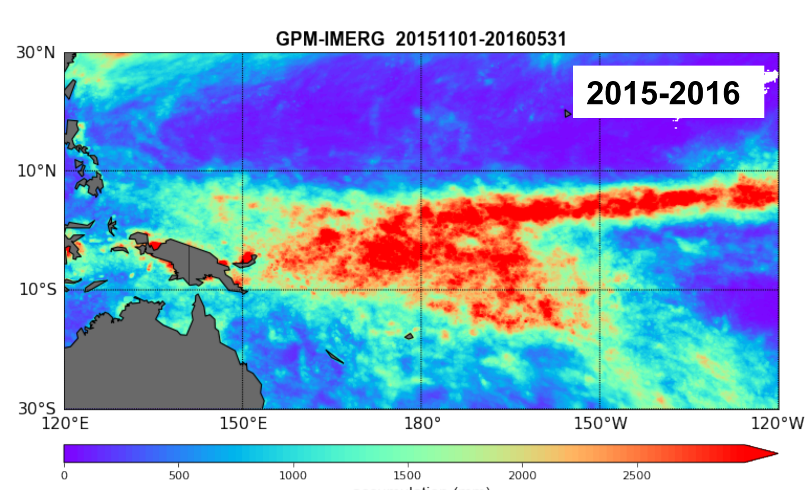
ERA-I year-to-year variability, phase offset

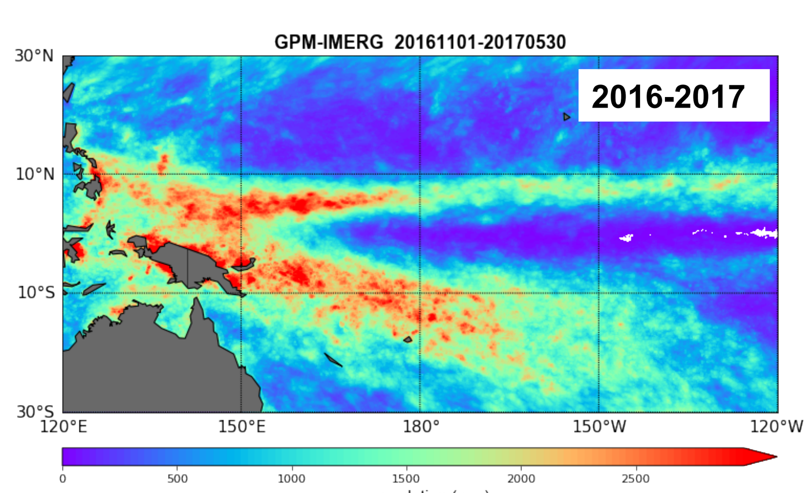
Diurnal Winds

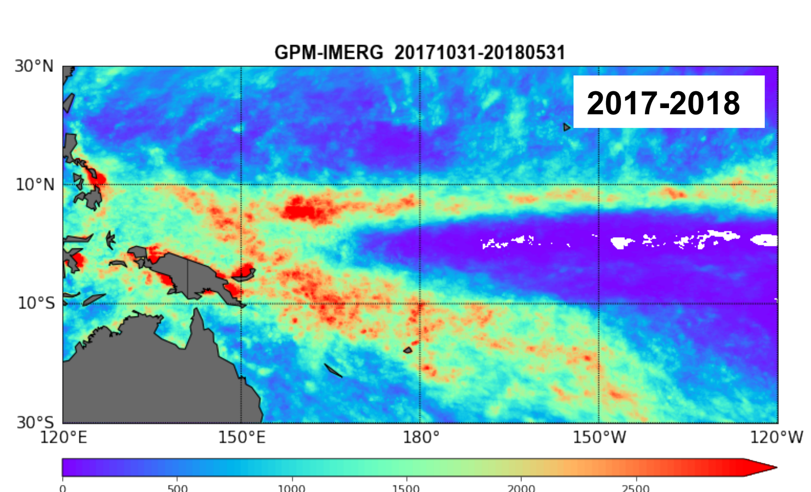
While current models can replicate the (mostly sub-diurnal) variability in the zonal (*u*) wind component (not shown), there is more discrepancy amongst the (mostly diurnal) weaker meridional (*v*) wind component, especially in the Intertropical Convergence Zone (ITCZ).







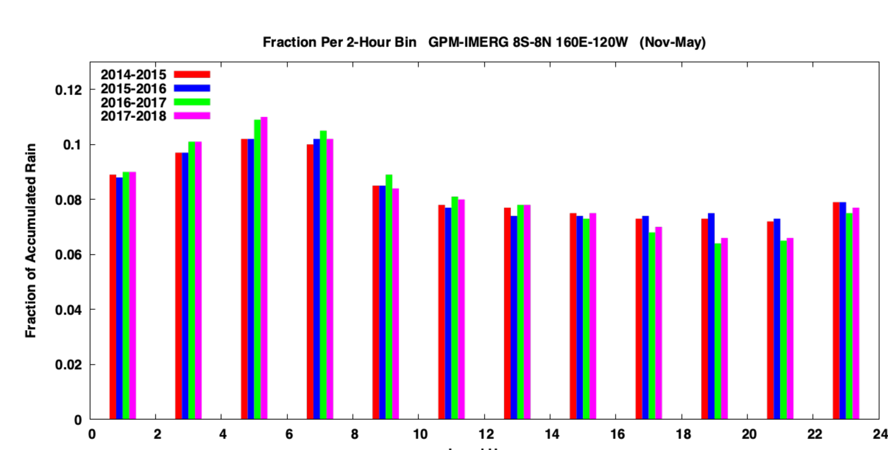




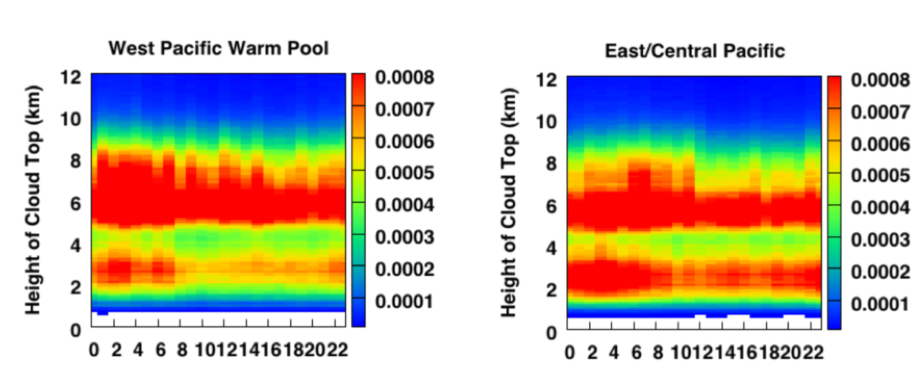
The 20-yr set of coincident scatterometer and TRMM/GPM data since 1999 provides a unique dataset to examine the role of the surface convergence and its impact upon the convective precipitation vertical structure, and how changes to the ascending branch of the Hadley cells (convergence) is manifested in any noted diurnal (and/or semi-diurnal) variability.

Precipitation Variability within the ITCZ

The Intertropical Convergence Zone (ITCZ) extending roughly between. The ITCZ essentially tracks the ascending branch of the Hadley cell, producing convection by solar heating opposite occurs on the descending branch. The descending branch is dominated by a subtropical high pressure area, which suppresses convection. The Southern Pacific Converge Zone extends southeast from the tropical west Pacific warm pool toward French Polynesia, although and its size and orientation varies (Kidwell et.al., 2016), especially during strong El Niño years (e.g., 2015-2016 to left).



Within the ITCZ latitudes, the satellite-observed precipitation generally follows a diurnal pattern with a maximum near 5 UTC, as shown in the analysis of GPM-IMERG precipitation data above. However its associated diurnal amplitude was stronger during 2016-2017 seasons than during 2014-2015 (above).



2-D histogram of GPM Dual Frequency Precipitation Radar (DPR)-detected 20-dB cloud top height vs. local time, for all data within the west Pacific warm pool area the east/central Pacific. All overpasses from 2014-2018 are included.

Moreover, the cloud systems producing the precipitation in this area exhibit a double peak in vertical structure, for shallow warm rain (little ice phase) and convective rain. Compared to the East/Central Pacific, the West Pacific warm pool area exhibits more (less) convective (shallow) precipitation, but its diurnal signal for the shallow precipitation is more apparent.

Convergence: QuikSCAT and ASCAT Data

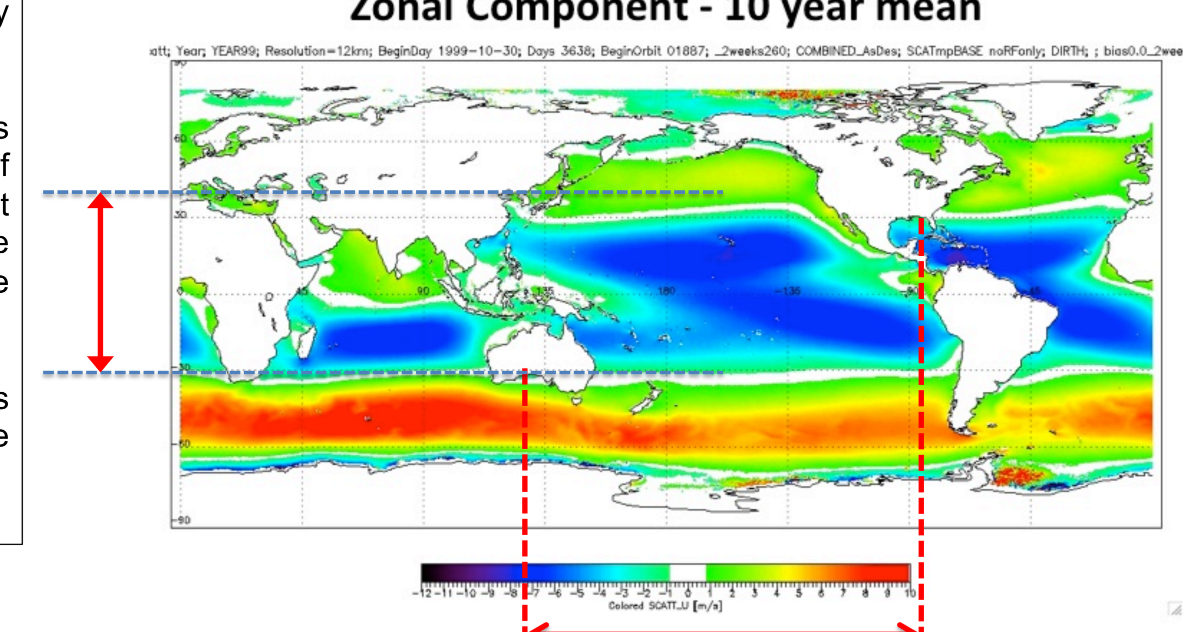
Method

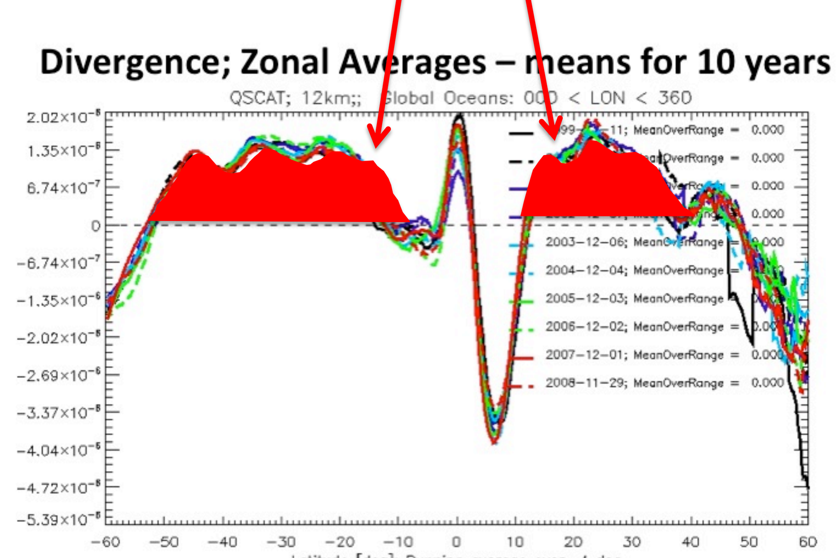
Compute statistics from time composites (1-year and 3-month running averages, offset by 2 weeks.)

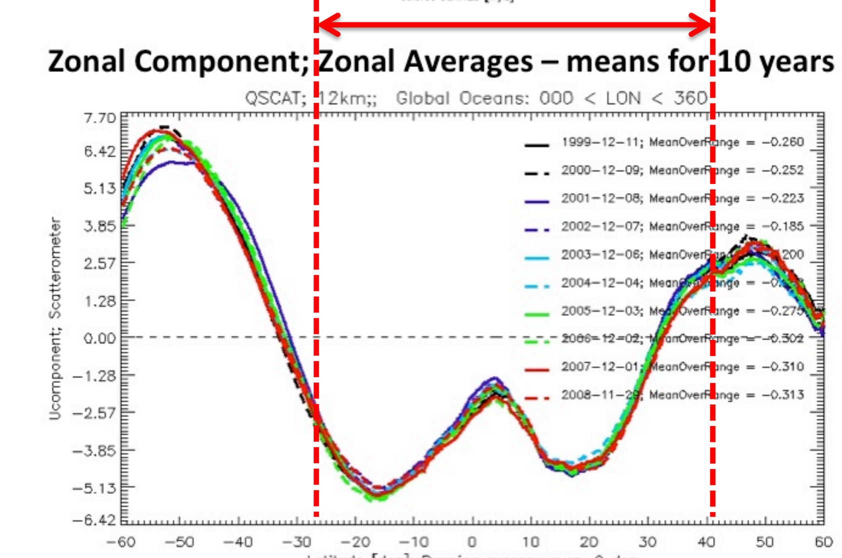
Determine the **extent of the Hadley cell** as defined by the subtropical zero-crossing of the zonally-averaged zonal wind component (the separation between the midlatitude westerlies and the easterly winds in the tropics).

Determine the **circulation strength** as defined by the area of divergence (positive values).

Zonal Component - 10 year mean

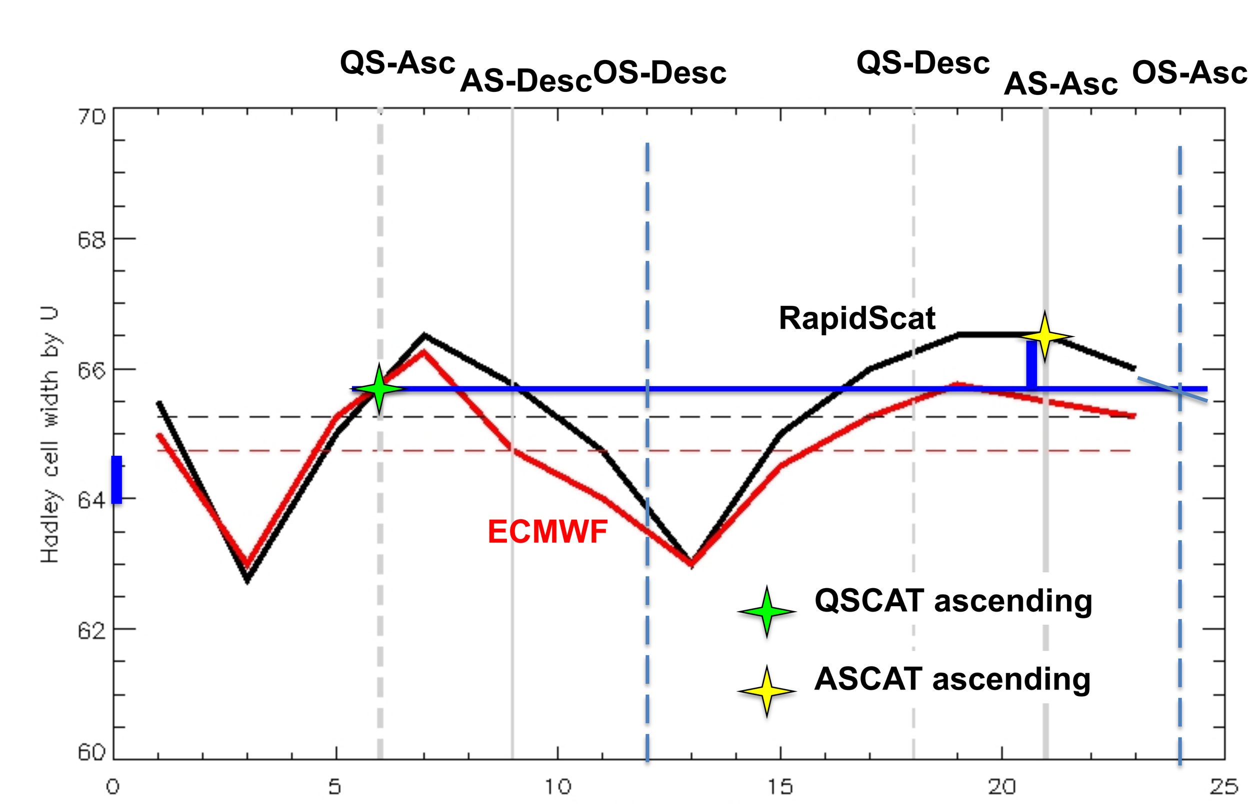






Hadley Width by Zonal (u) Component

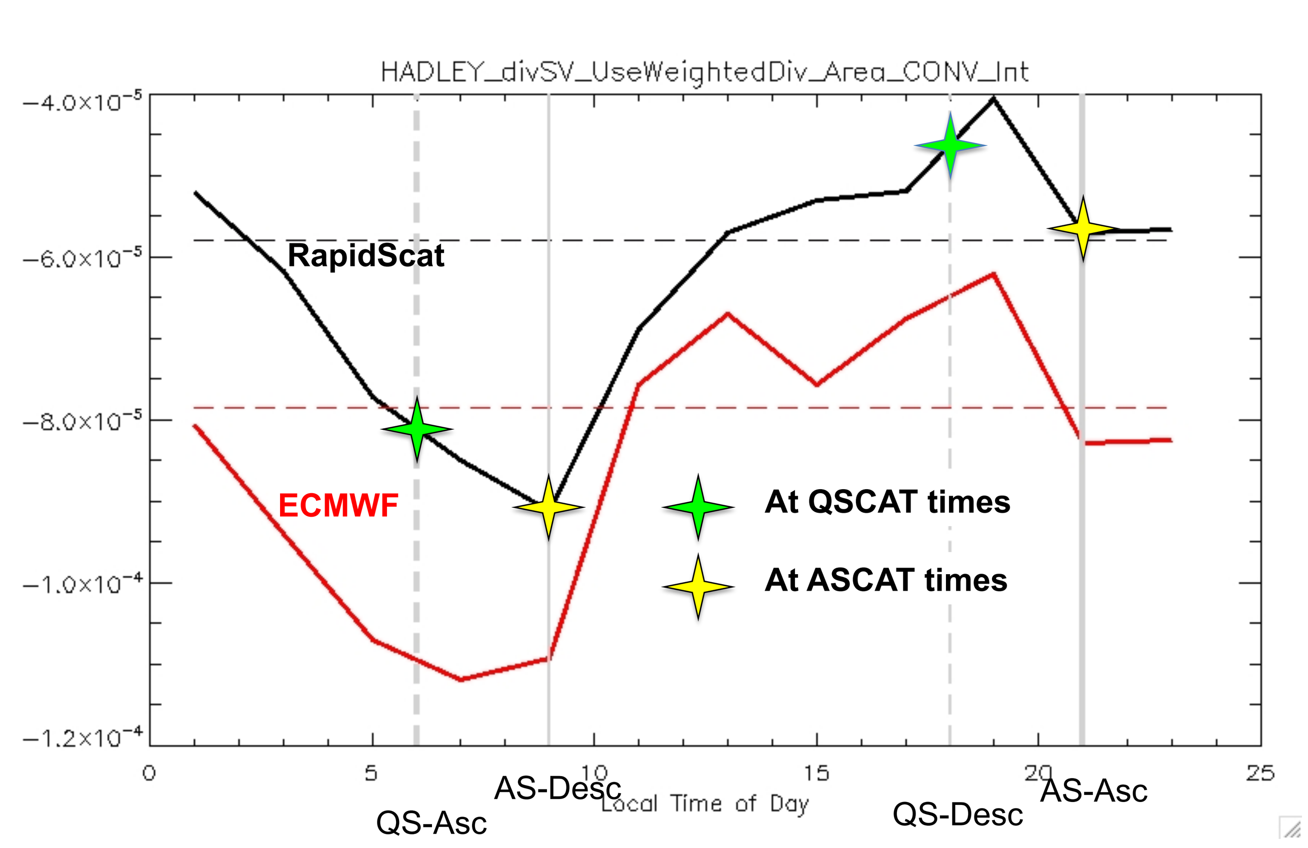
There is a clear semi-diurnal signal in the u component, which has implications for retrievals from scatterometer observations at different local times of day. Note that the width is larger at the time of the ASCAT ascending orbit.



Hadley Convergence (Integral)

The diurnal signal in collocated ECMWF analysis is different than that in the RapidScat observations.

Note that there is a stronger ITCZ convergence in the ASCAT observations (i.e., the integral over the area of convergence is more negative).



Summary

Scatterometer surface winds were used to determine the extent of the Hadley cell. While not shown here, breaks in the Hadley width (as determined from the zonal wind U) were found when using different satellites. We suspected the cause might be an unaccounted for diurnal variability. To investigate this diurnal signal we looked now at tandem scatterometer missions and RapidScat observations.

Tandem mission analyses appear to support the significance of the diurnal signal. RapidScat analyses revealed that there is a significant variability in the Hadley cell width, with a clear semidiurnal signal, providing observational evidence that the Hadley cell is wider during the ASCAT observing times than it is during the QuikScat observing times.

This supports a theory that diurnal variability might be (one) cause for previously found discrepancies between QSCAT and ASCAT observations. The diurnal signal in the ECMWF collocated analysis is different than that in RapidScat.

Acknowledgements

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