Observational Evidence for Trends and Variability in the Hadley Cell Based on 15 Years of Scatterometer Ocean Surface Wind Estimates

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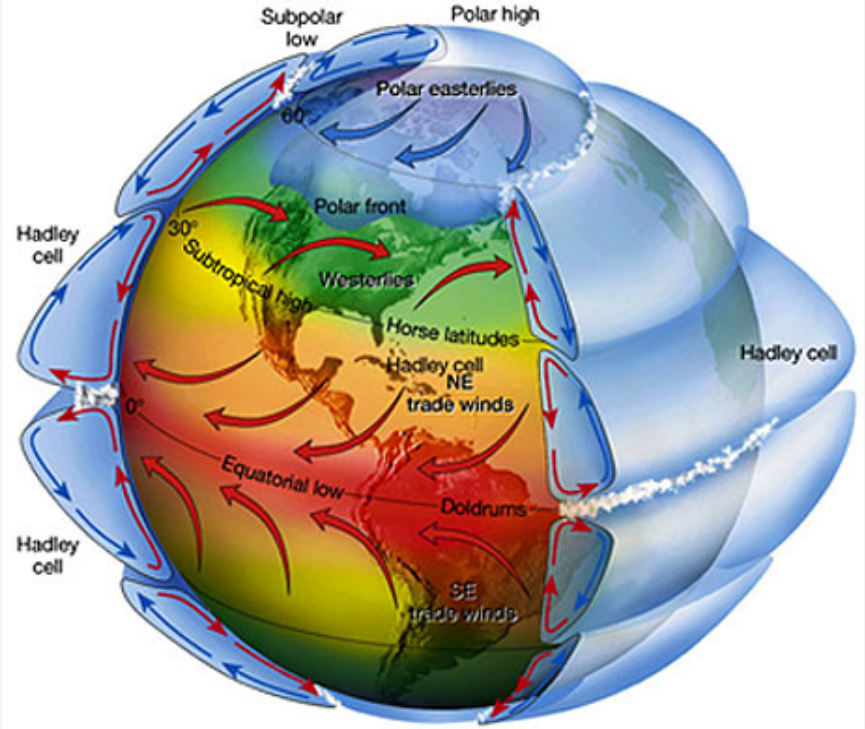
The Global Circulation and the Hadley Cell

Originally uploaded in EarthLabs:Hurricanes.

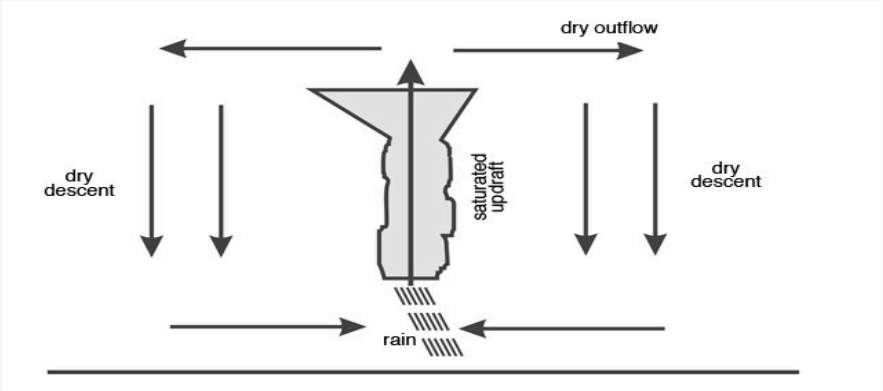


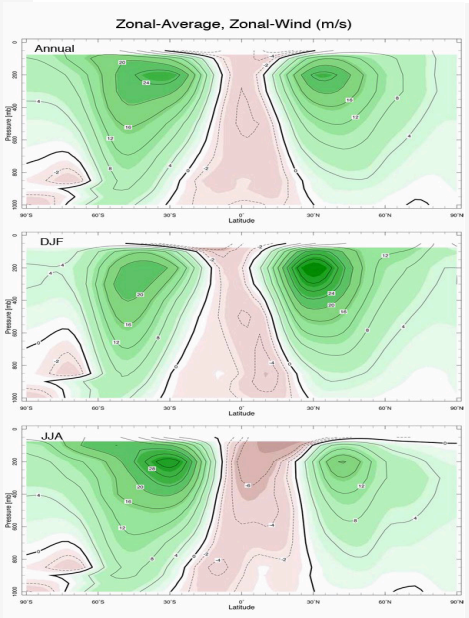
3D view of the global wind circulation due to unequal heating at the equator and the poles.

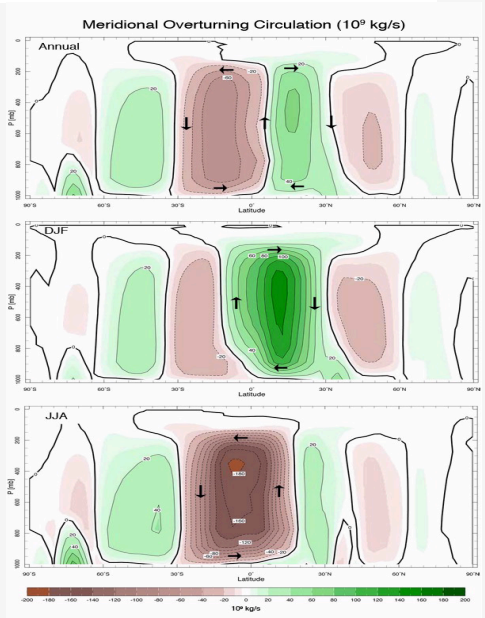
The Hadley cell depicts the equator-to-pole heat exchange in the tropical atmosphere.

Relatively simple overturning circulation, with

- rising motion near the equator
- poleward motion near the tropopause
- sinking motion in the subtropics, and
- an equatorward return flow near the surface







Motivation

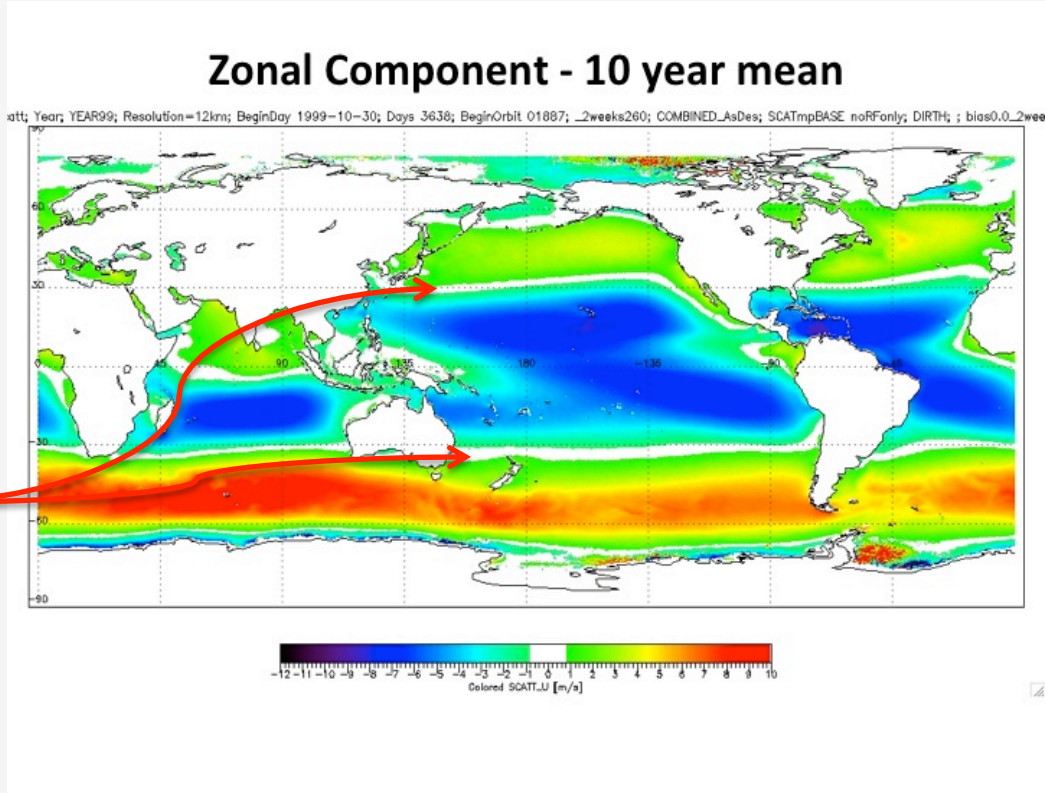
- Recent evidence suggests that **the tropics have expanded over the last few decades by a very rough 1 degree per decade.**
- This is considered to be **an atmospheric response to the observed tropical ocean warming trend** (e.g. Quan et al., 2004).
- If continued, the expansion of the tropics (the Hadley cell) could have a substantial impact on water resources and the ecology of the sub-tropics.
- **Until now, the understanding of the mechanisms that govern the changing width of the tropics has been confined to models and proxies (e.g. Johanson and Fu, 2009; Hu and Fu 2007 (OLR); Lu et al. 2007 (precipitation /evaporation estimates) because of the unavailability of systematic observations of the large-scale circulation.**
- Ocean surface vector winds, derived from scatterometer observations, provide for the first time an accurate **depiction of the large-scale circulation and allow the study of the Hadley cell evolution through analysis of its surface branch.**

Questions we ask …

- How to define the extent and intensity of the Hadley cell from scatterometer observations?
- How are the signatures of the Hadley cell changing during the 10-year QuikSCAT record?
- Looking beyond the QuikSCAT era:
  - The launches of ASCAT on METOP in 2006 (and follow-ups), the ISRO's OceanSAT-2 in 2010 and ScatSat in 2016 will assure the continuation of the climate data record of near-surface winds over the oceans.
  - Before we combine the signals from the different instruments we should:
    - Analyse them and understand whether they are consistent with each other
    - Determine the sources for disagreements if such are found
  - Failure to do so would lead to creating artificial cycles and trends in the Hadley cell structure
- How will RapidScat help!

Approach

- Use the observations from QuikSCAT and ASCAT. **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).



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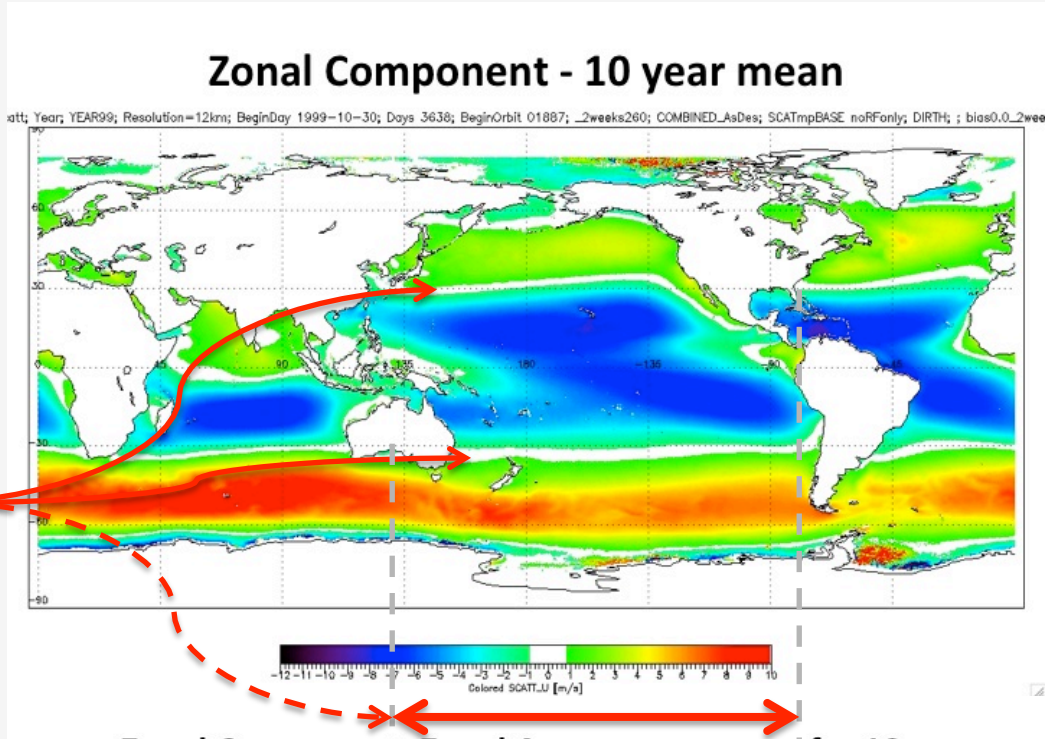

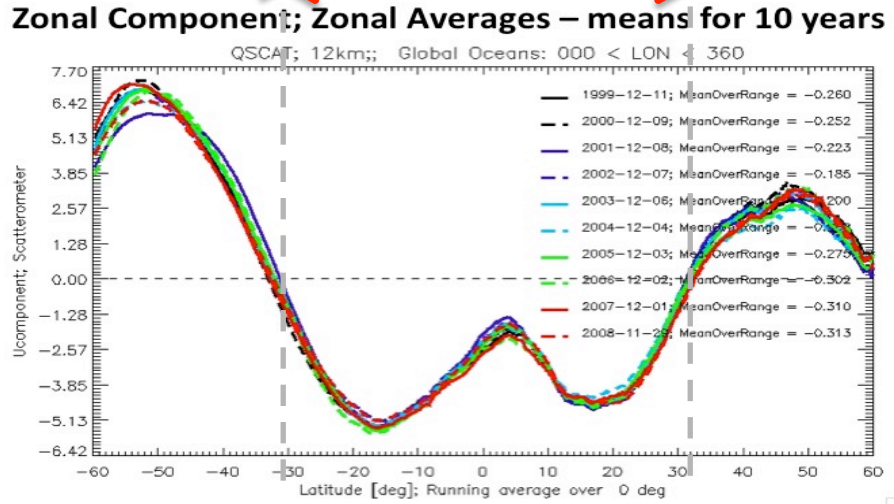

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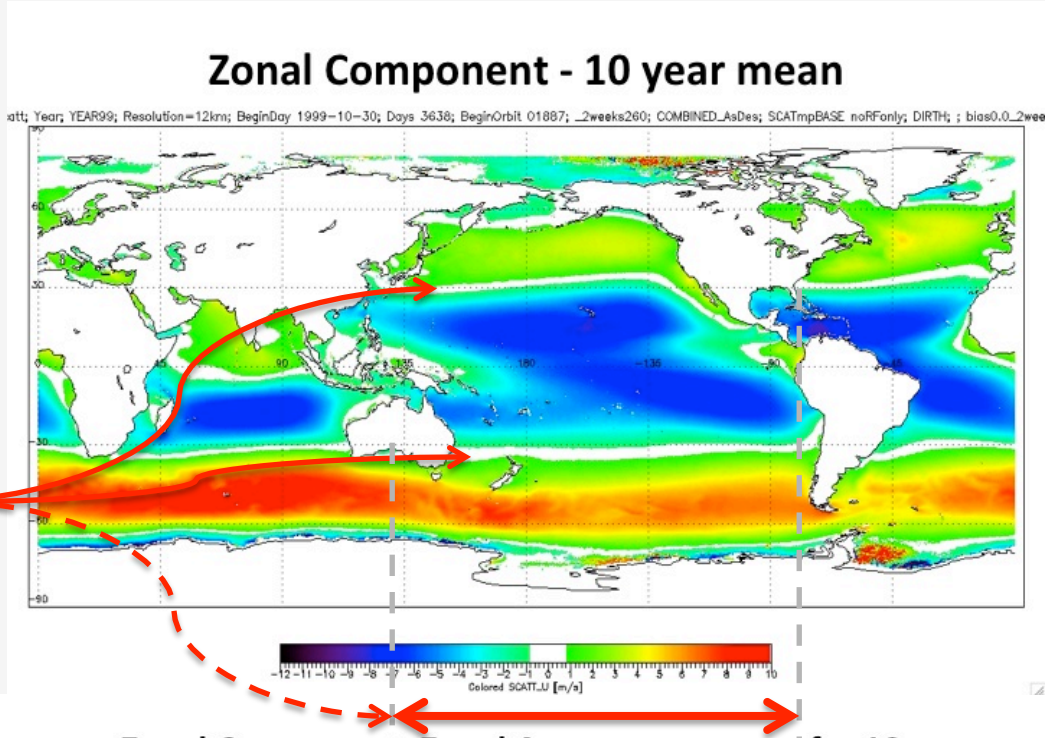

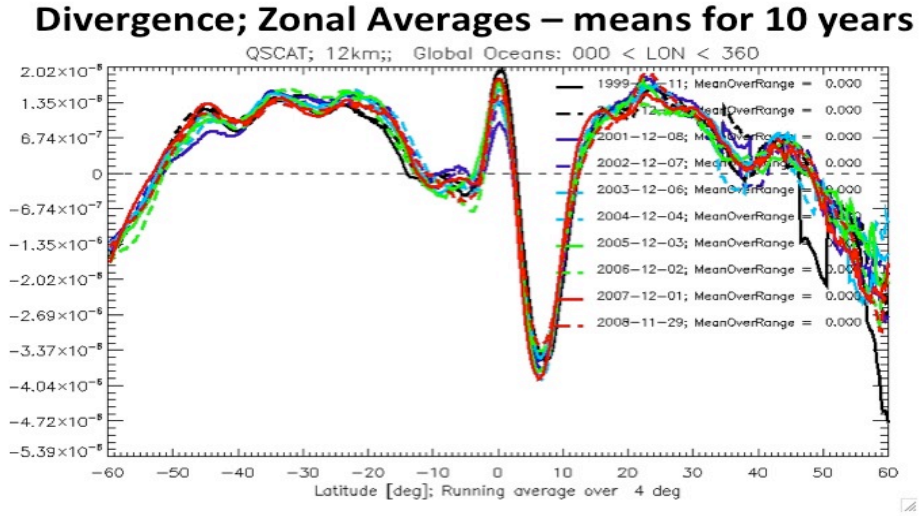

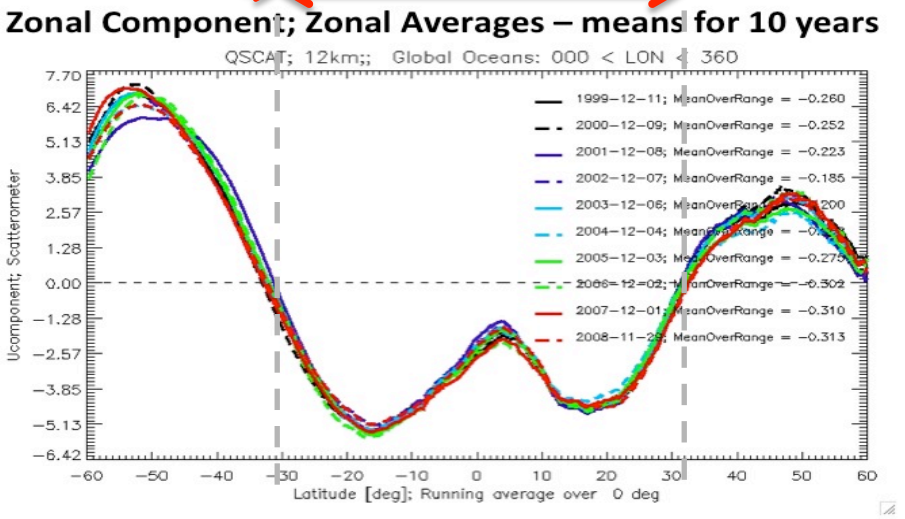

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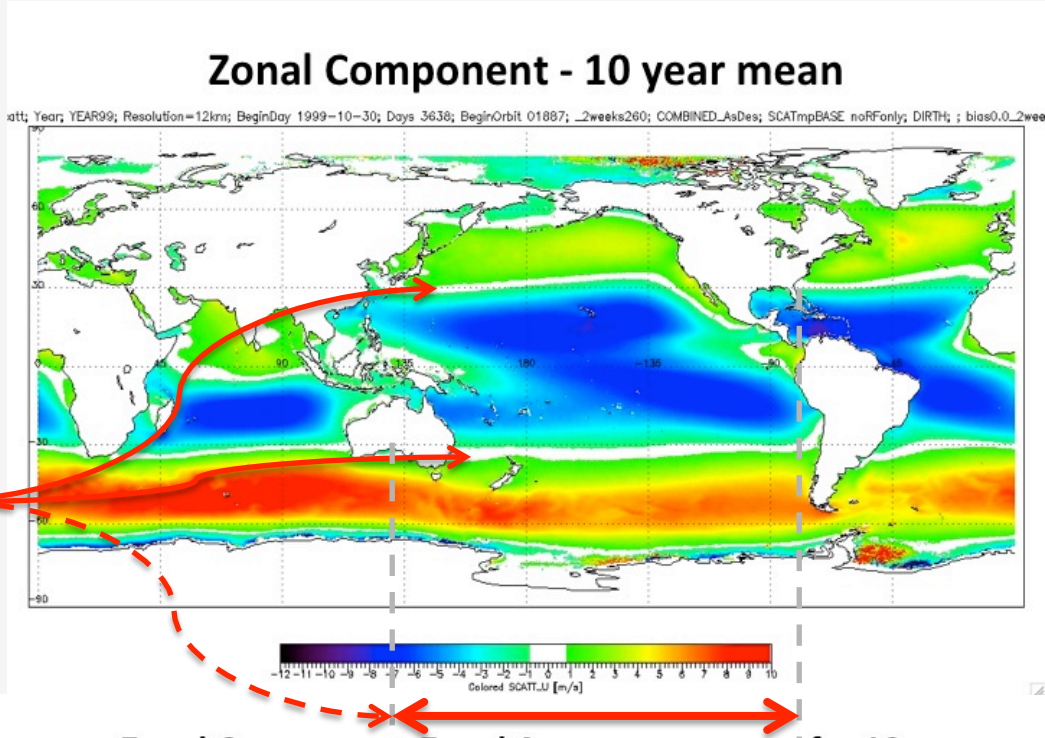

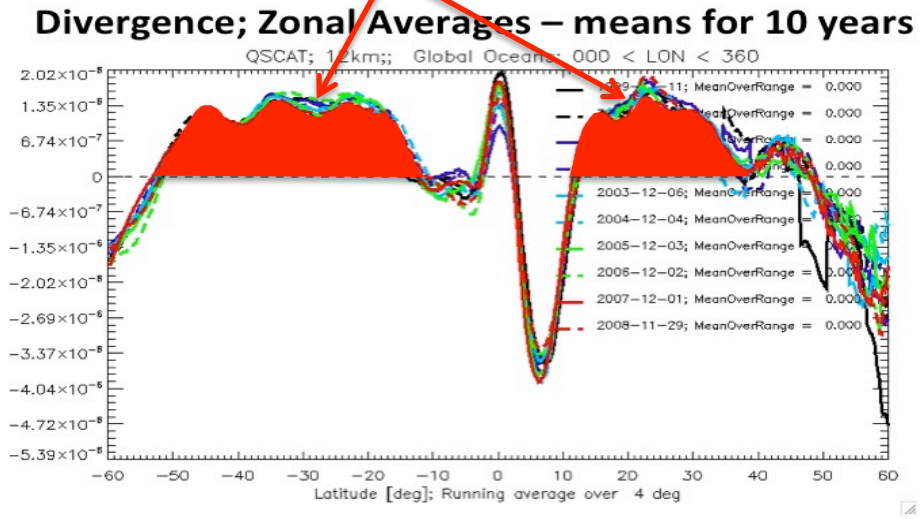

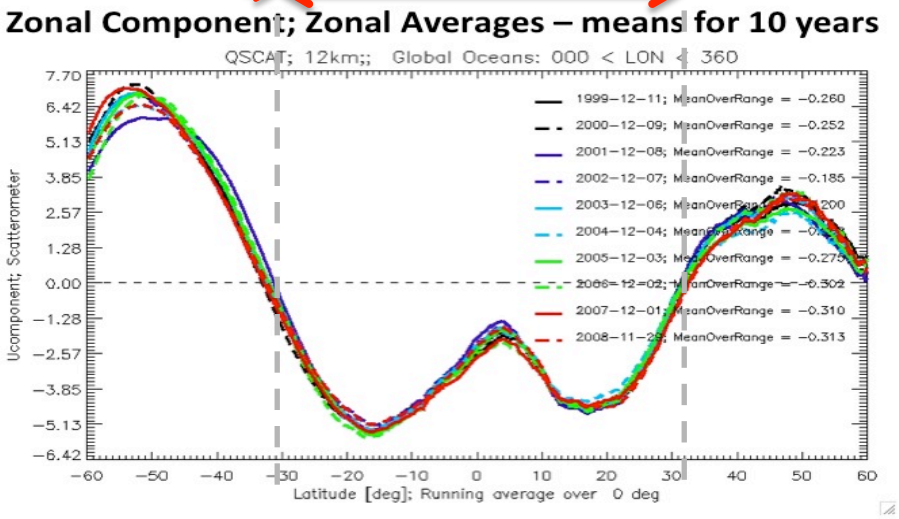

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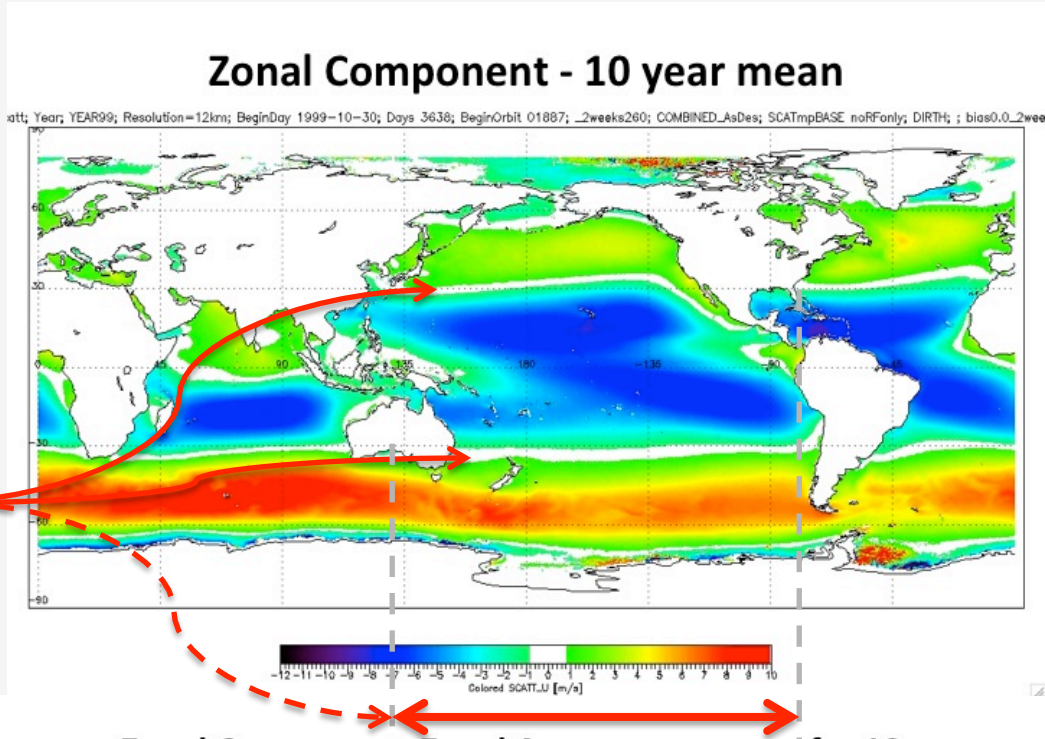
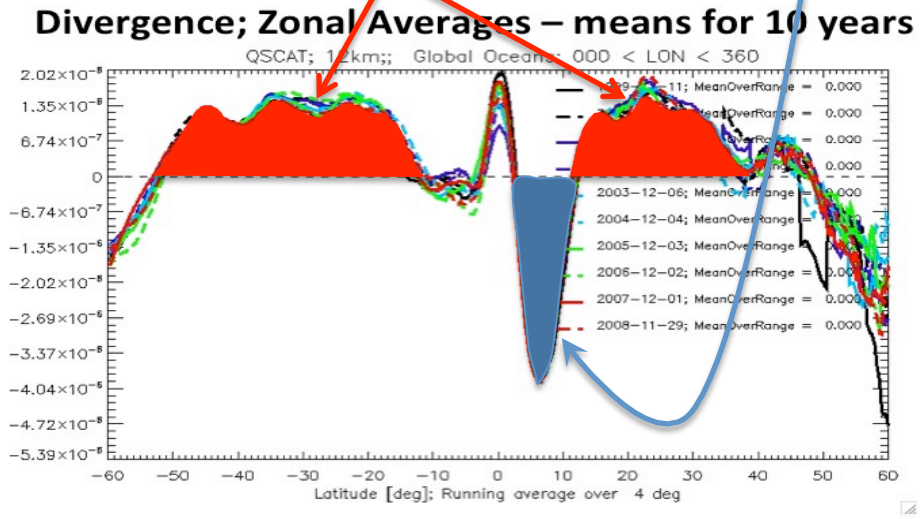
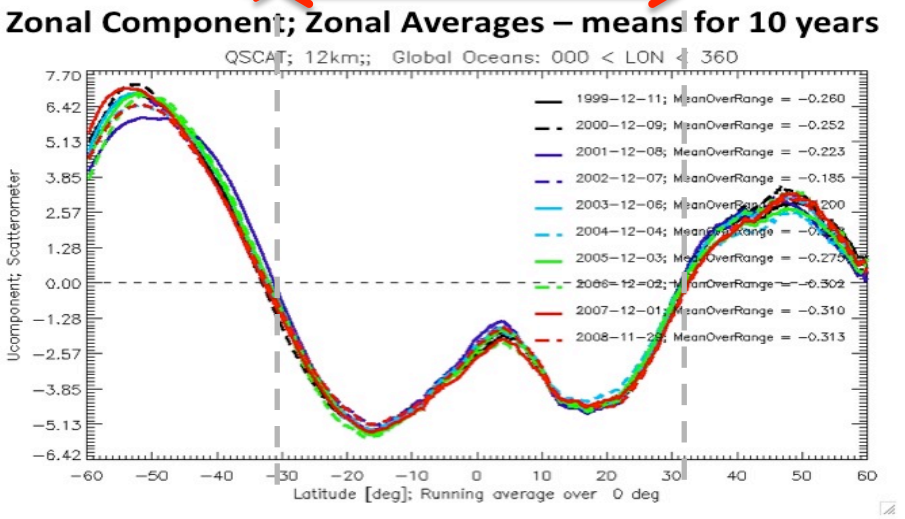
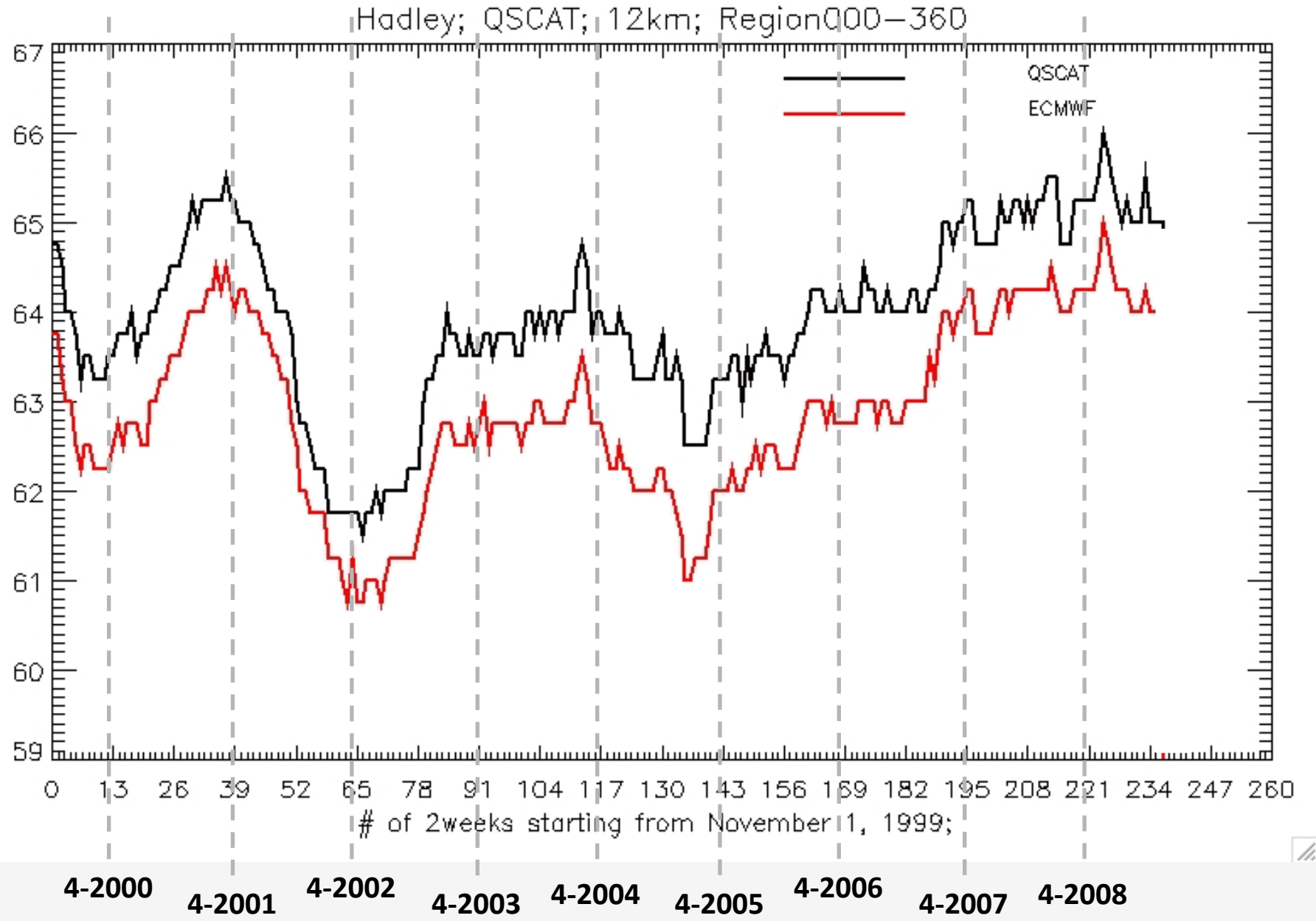






Width of Hadley as determined from:
Global data; 1-year averages; The zero-crossing of U



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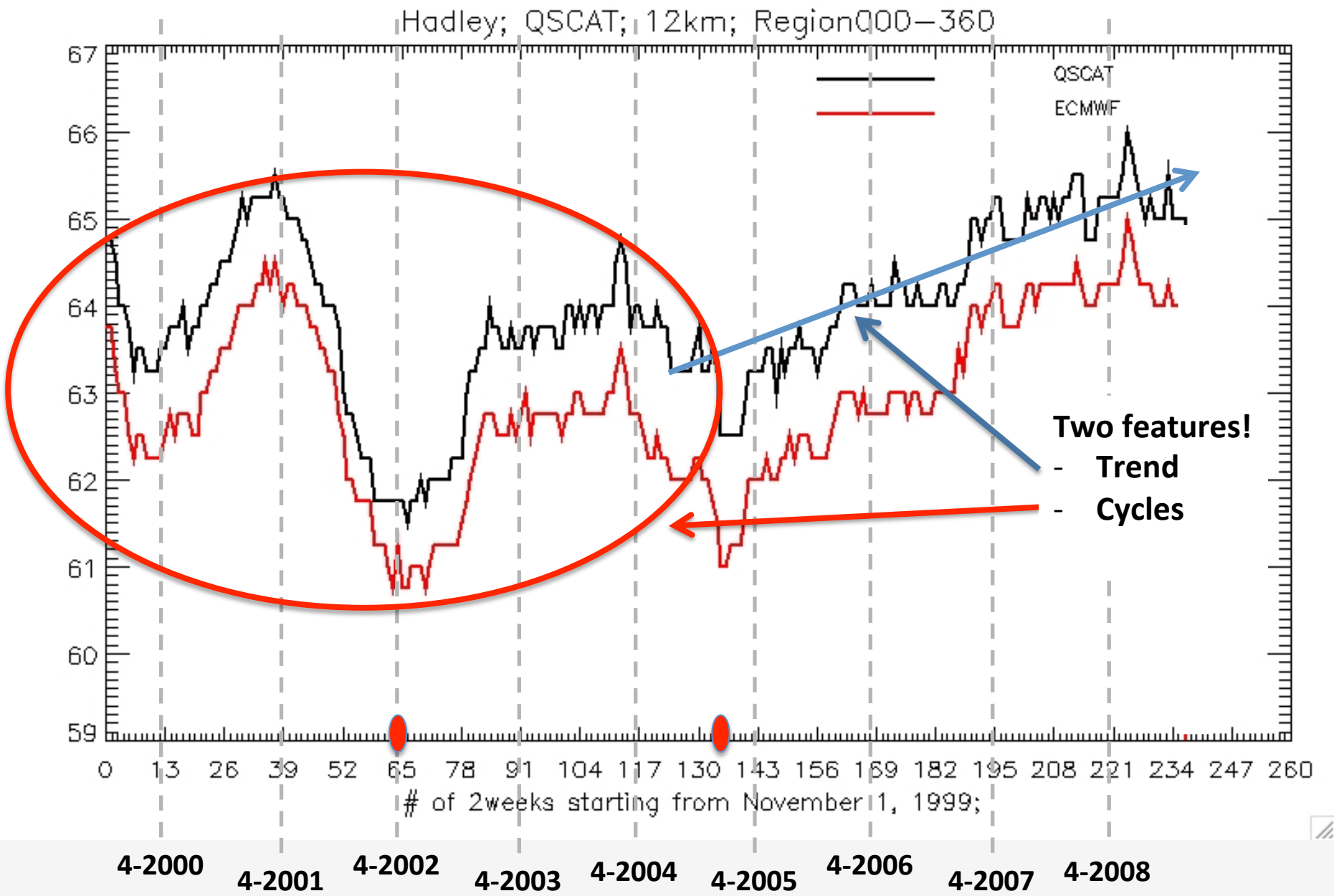
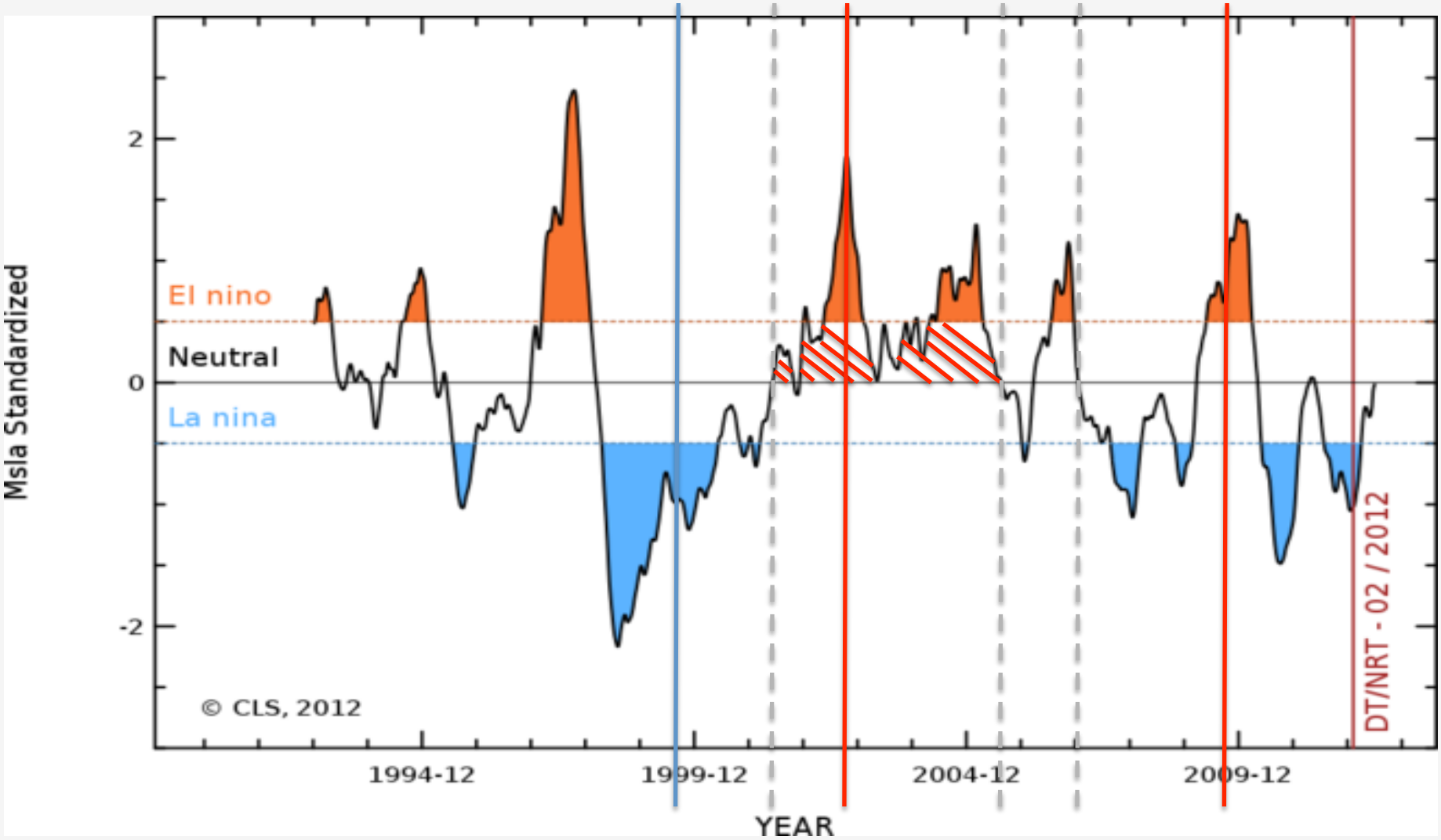
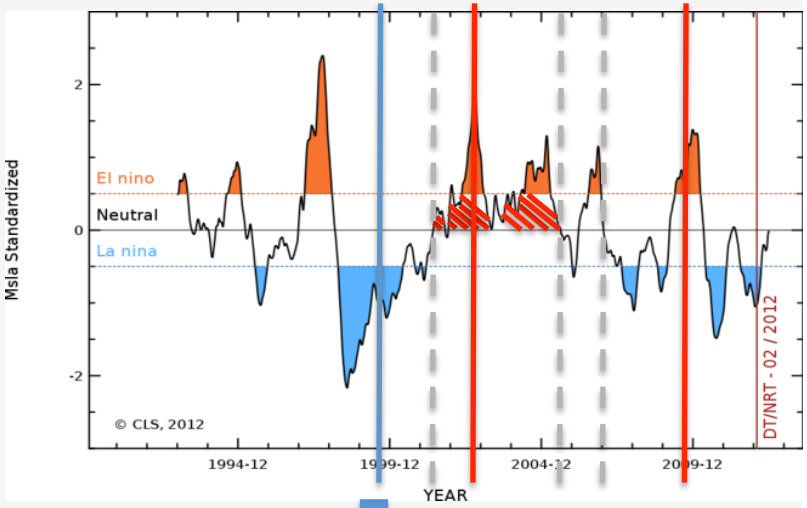
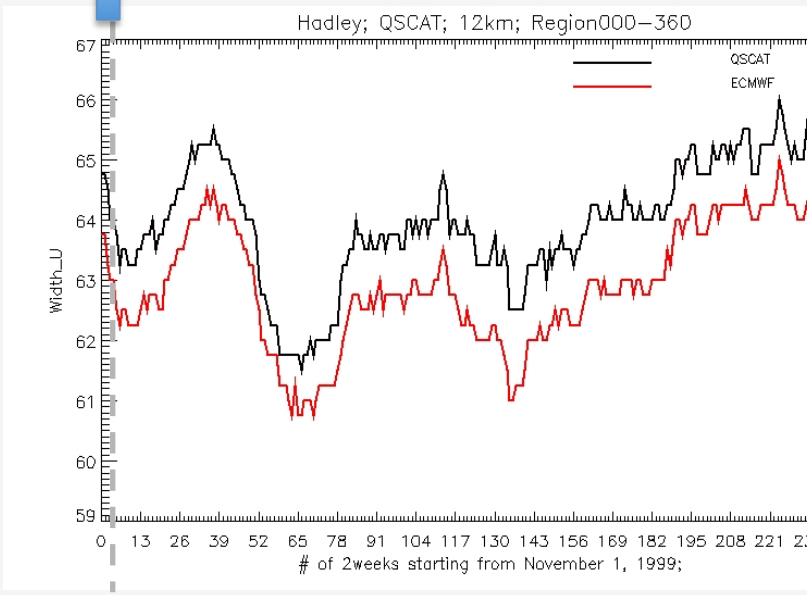


The Oscillation – maybe related to La Nina/ El Nino



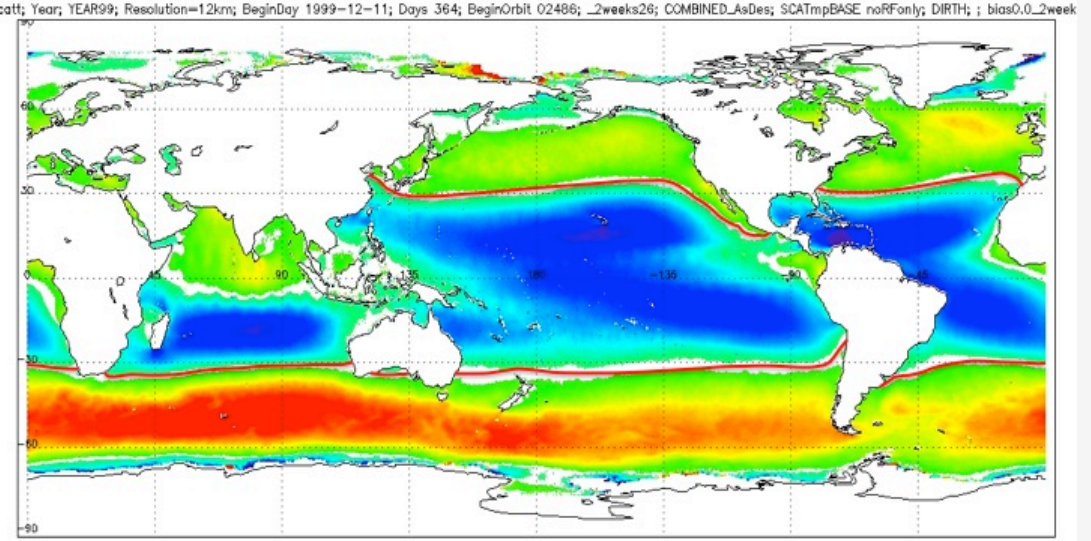
La Nina

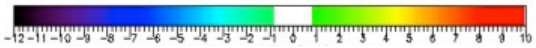


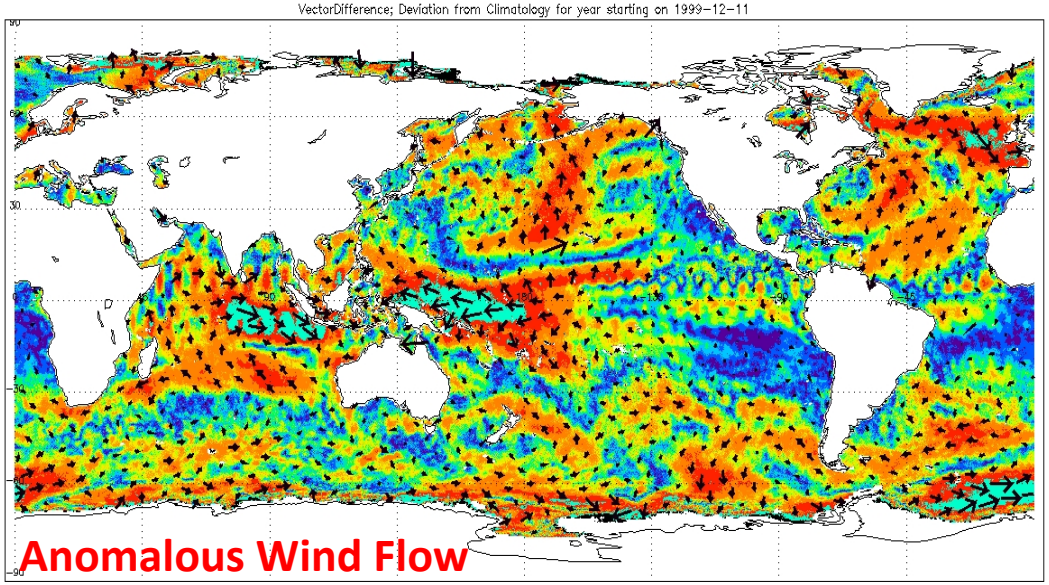


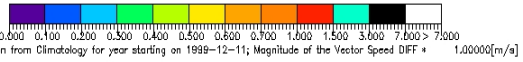
12-1999

Zonal Component – Year Beginning on 12-11-1999

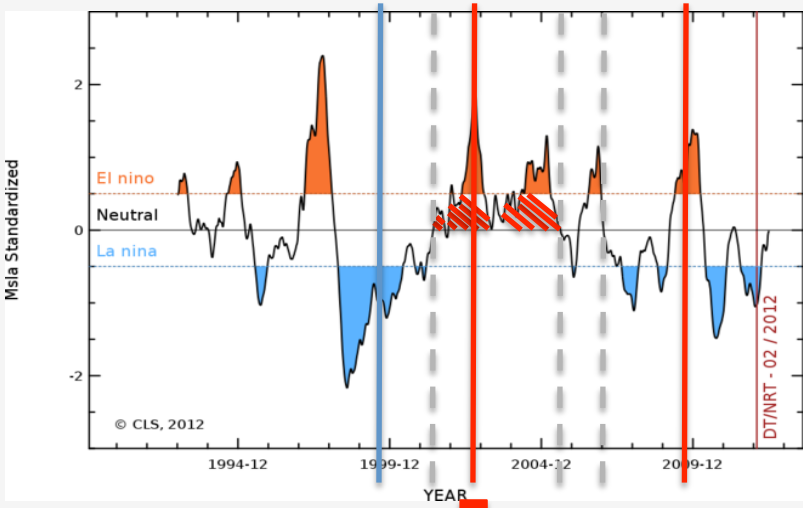




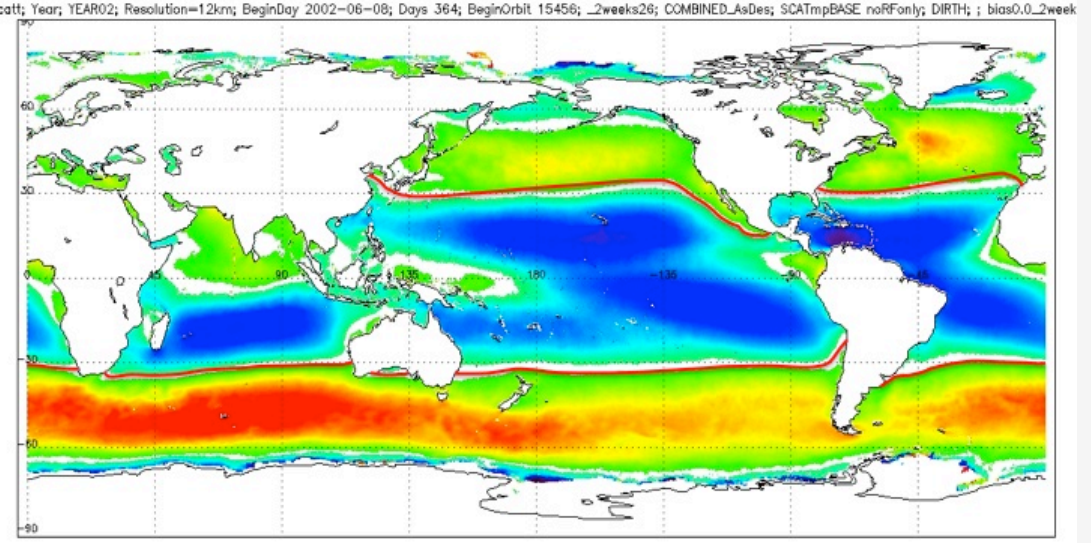


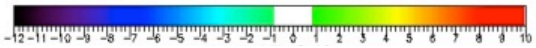


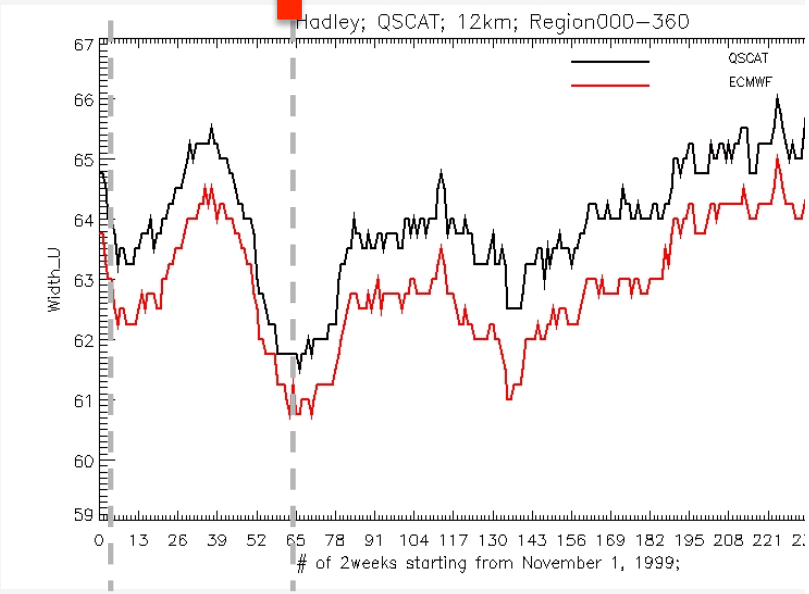
El Nino



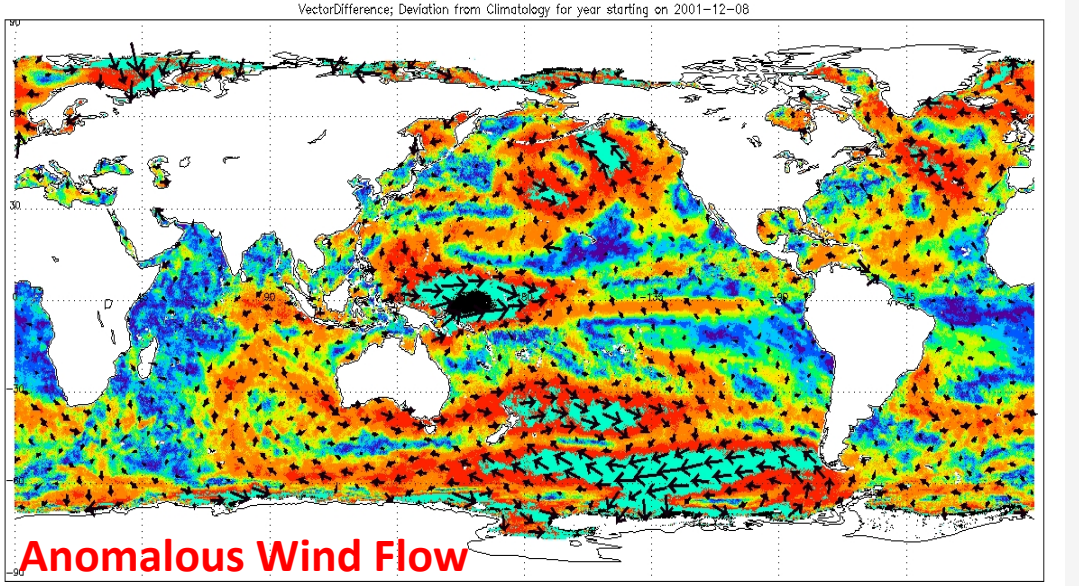
Zonal Component – Year Beginning on 06-08-2002



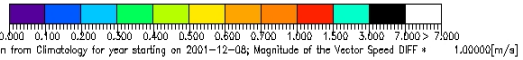




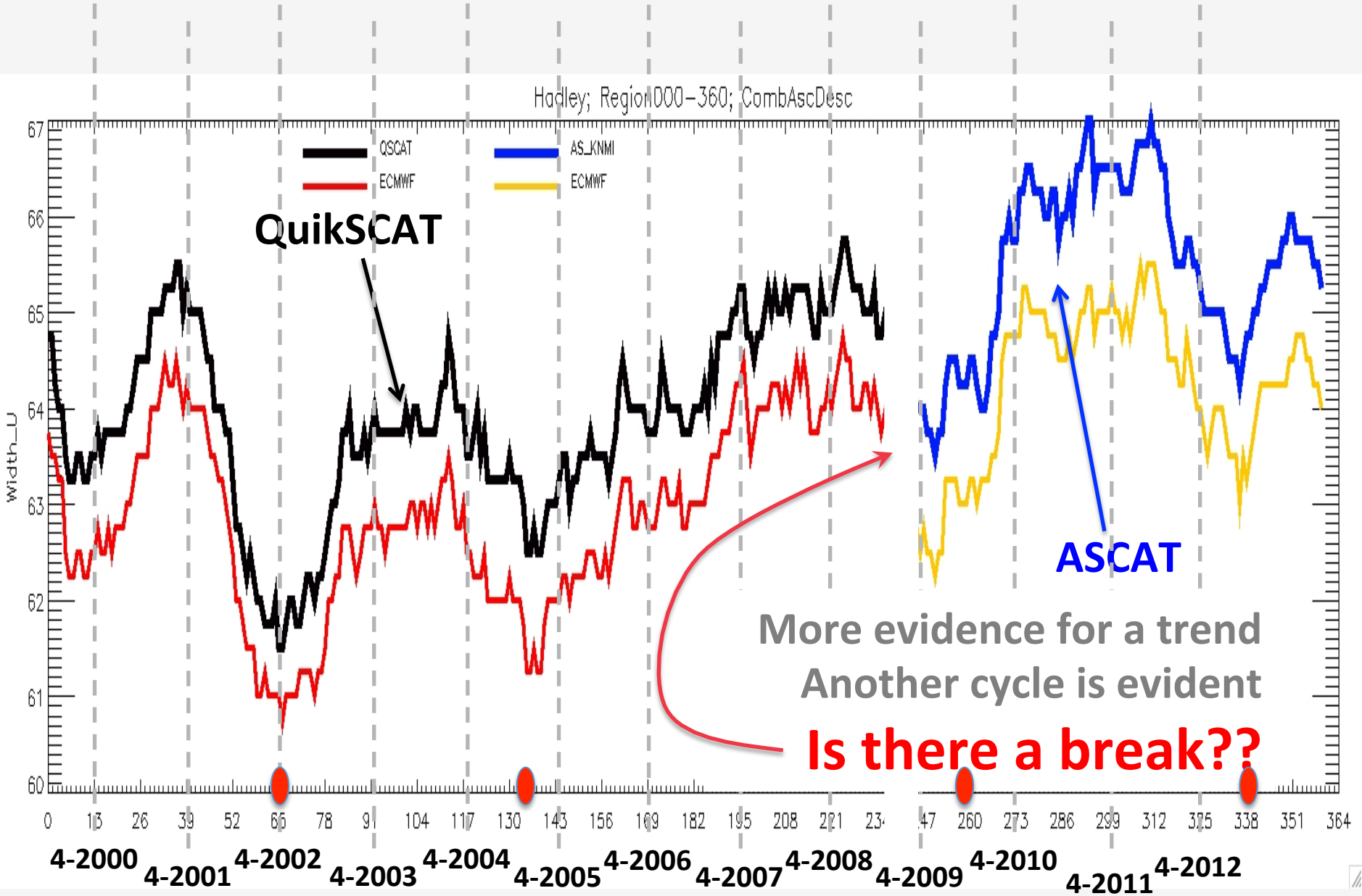
12-1999 **4-2002**



Anomalous Wind Flow



Looking beyond QuikSCAT



More evidence for a trend
Another cycle is evident

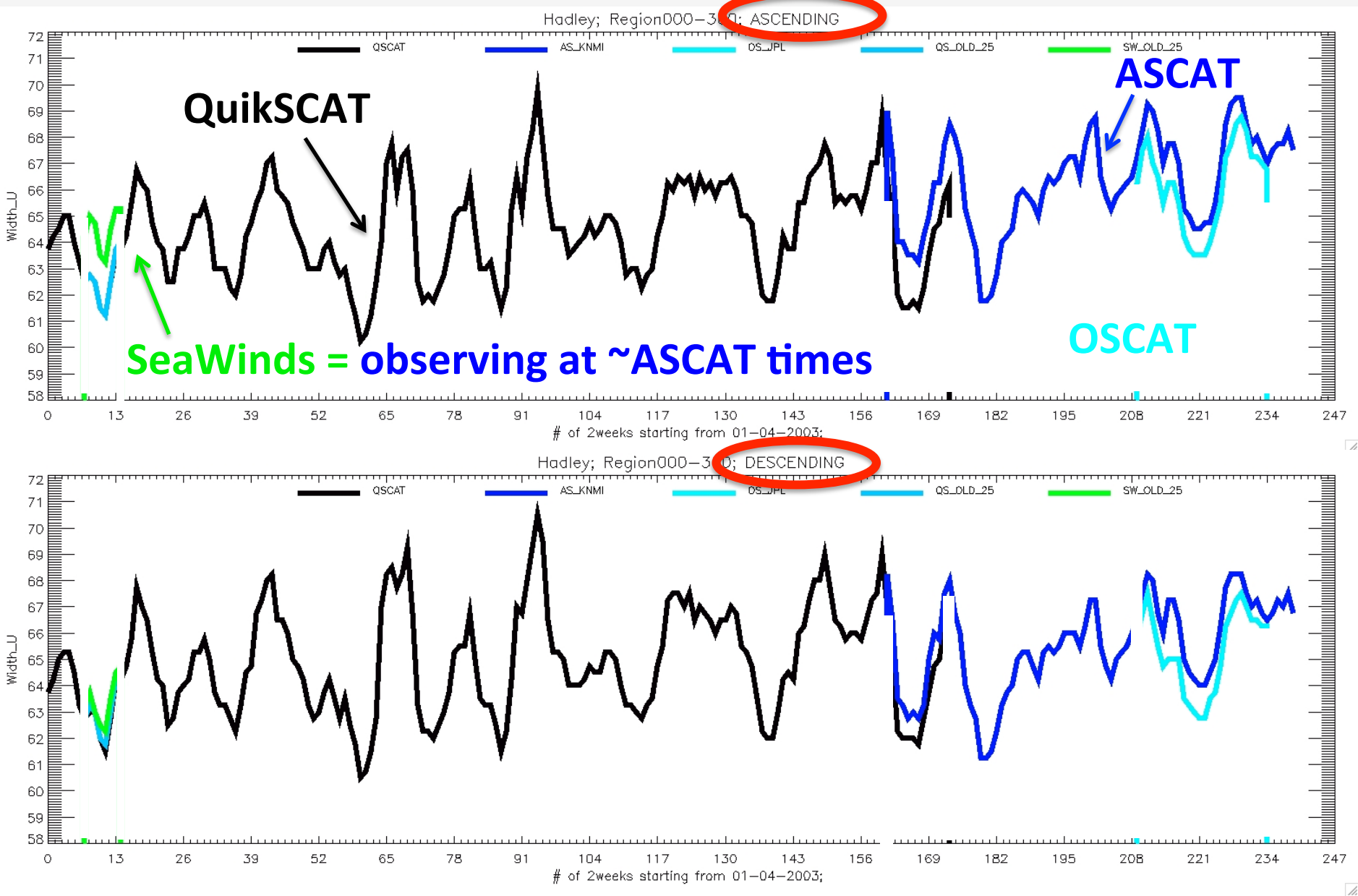
Is there a break??

In summary ….

- There is a discontinuity the Hadley cell width record when using different satellites !!
- Diurnal variability might be the reason.
  - Tandem Missions – what do they show
    - There were some time overlaps (tandem missions)
      - 2003 - QuikScat and SeaWinds (same instruments; different missions)
      - 2009 – QuikScat and ASCAT (different instruments; different missions)
      - 2009-2011 – OSACT and ASCAT (different instruments; different missions)
  - RapidSCAT will help attribute the differences

Tandem Missions (using running 3-month averages)

Breaks in the Hadley width (by U) when using different satellites !!



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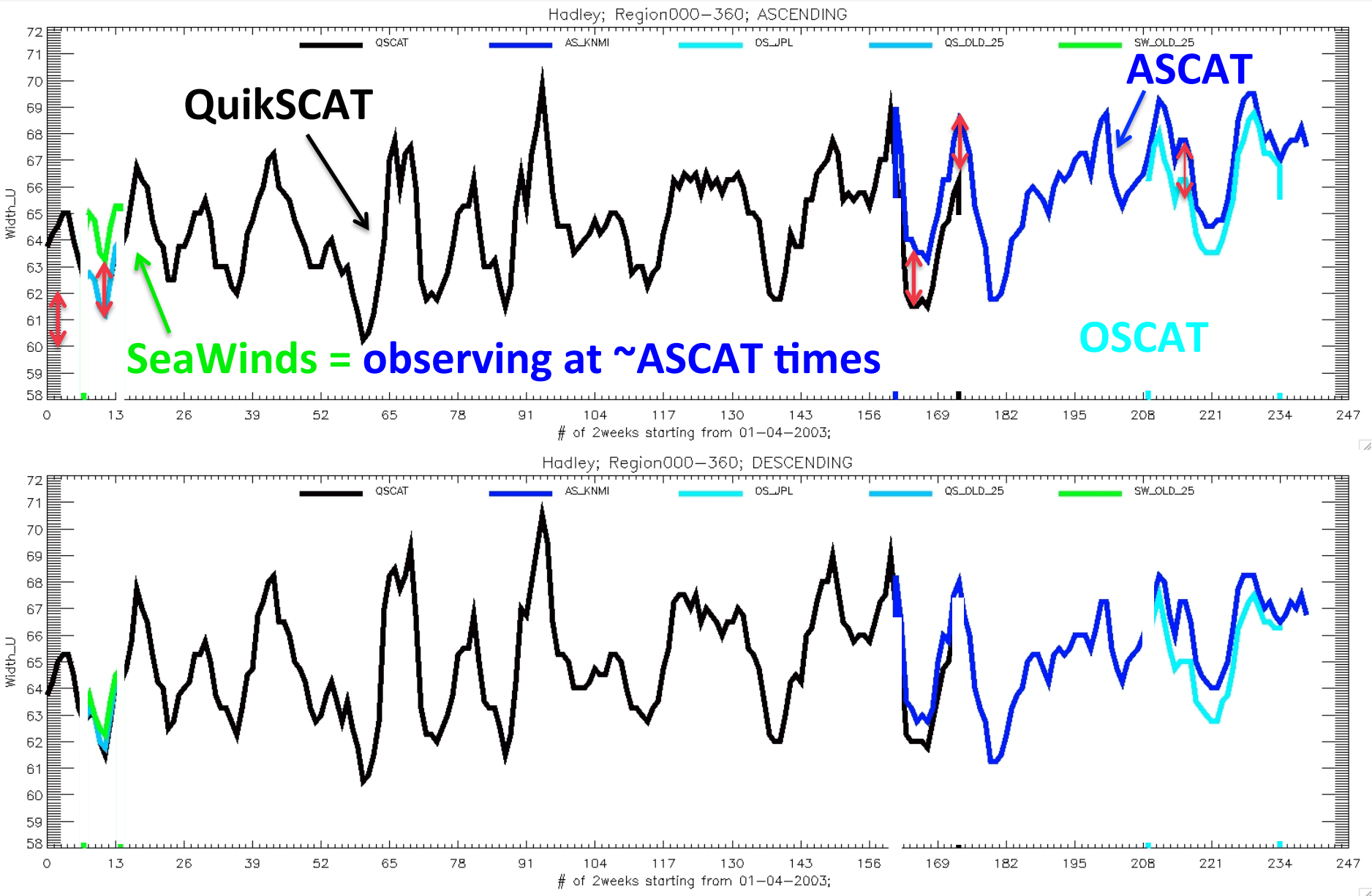
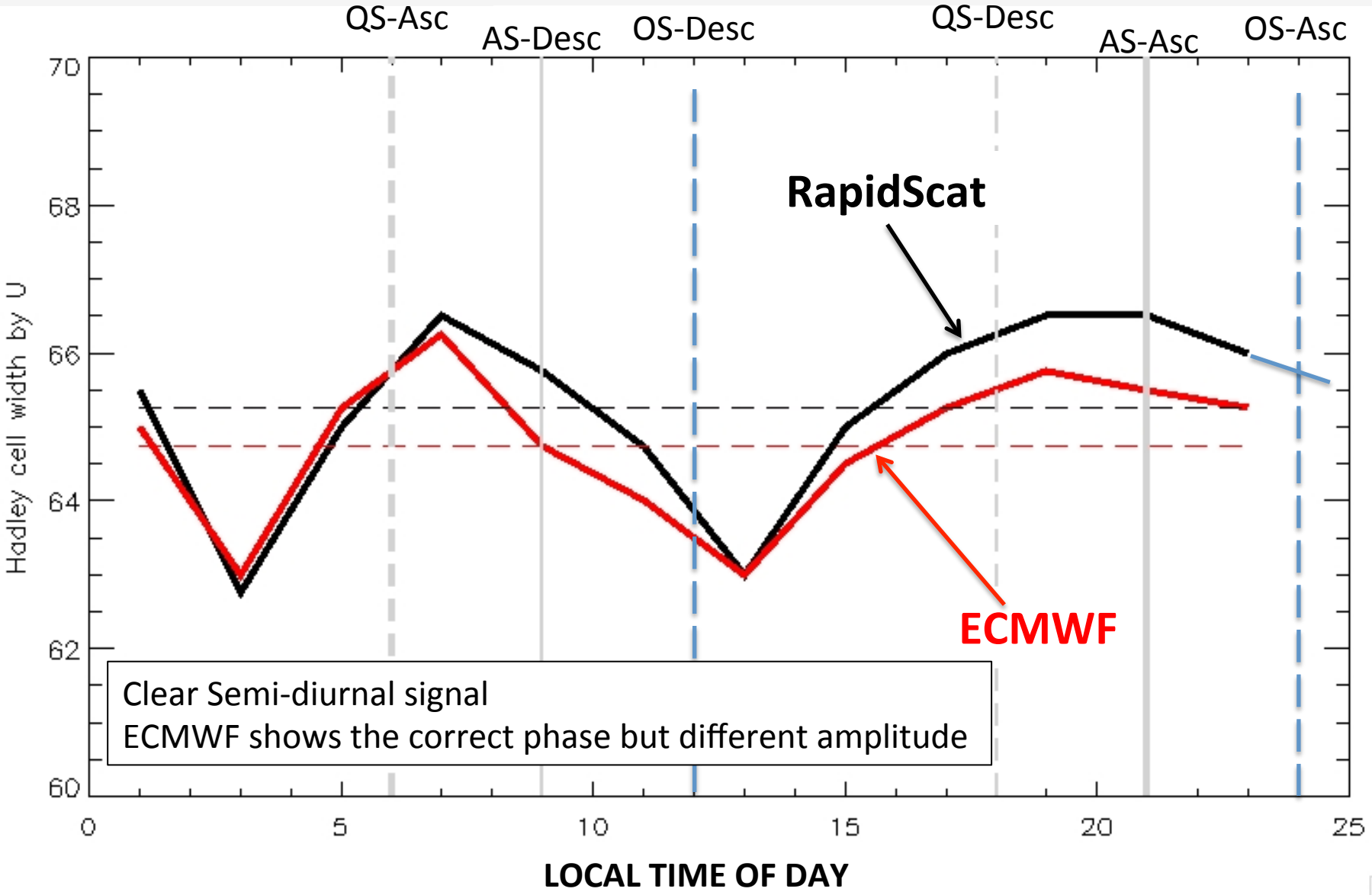


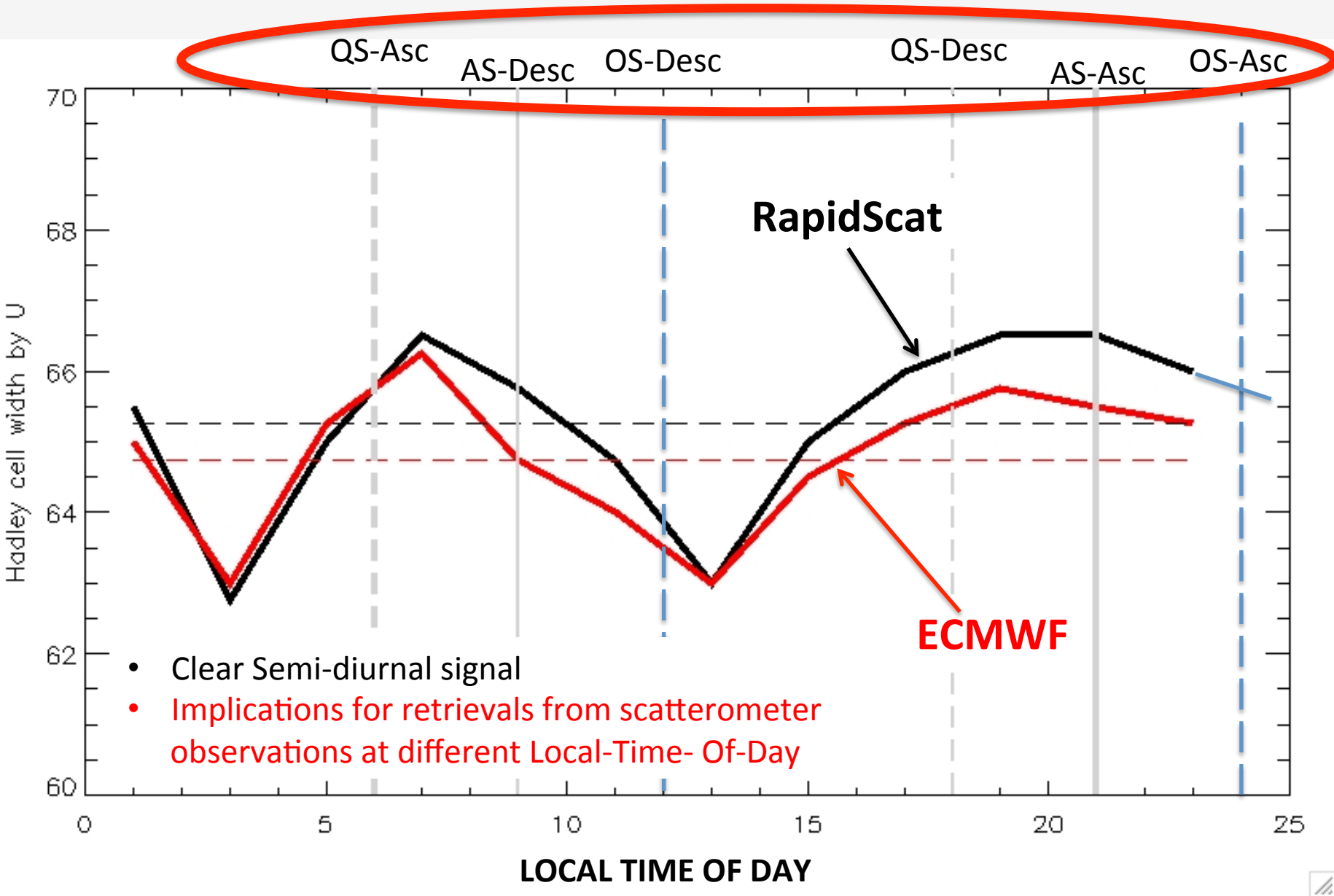
In summary ….

- There is a discontinuity the Hadley cell width record when using different satellites !!
- Diurnal variability might be the reason.
  - Tandem Missions – what do they show
  - RapidSCAT will help attribute the differences because of its non-sun-synchronous orbit as it flew on the ISS
    - It allowed us to compute the Hadley cell structure as a function of the Local-Time-of-Day
    - Note:
      - seasonal signal is folded in
      - Rather short record

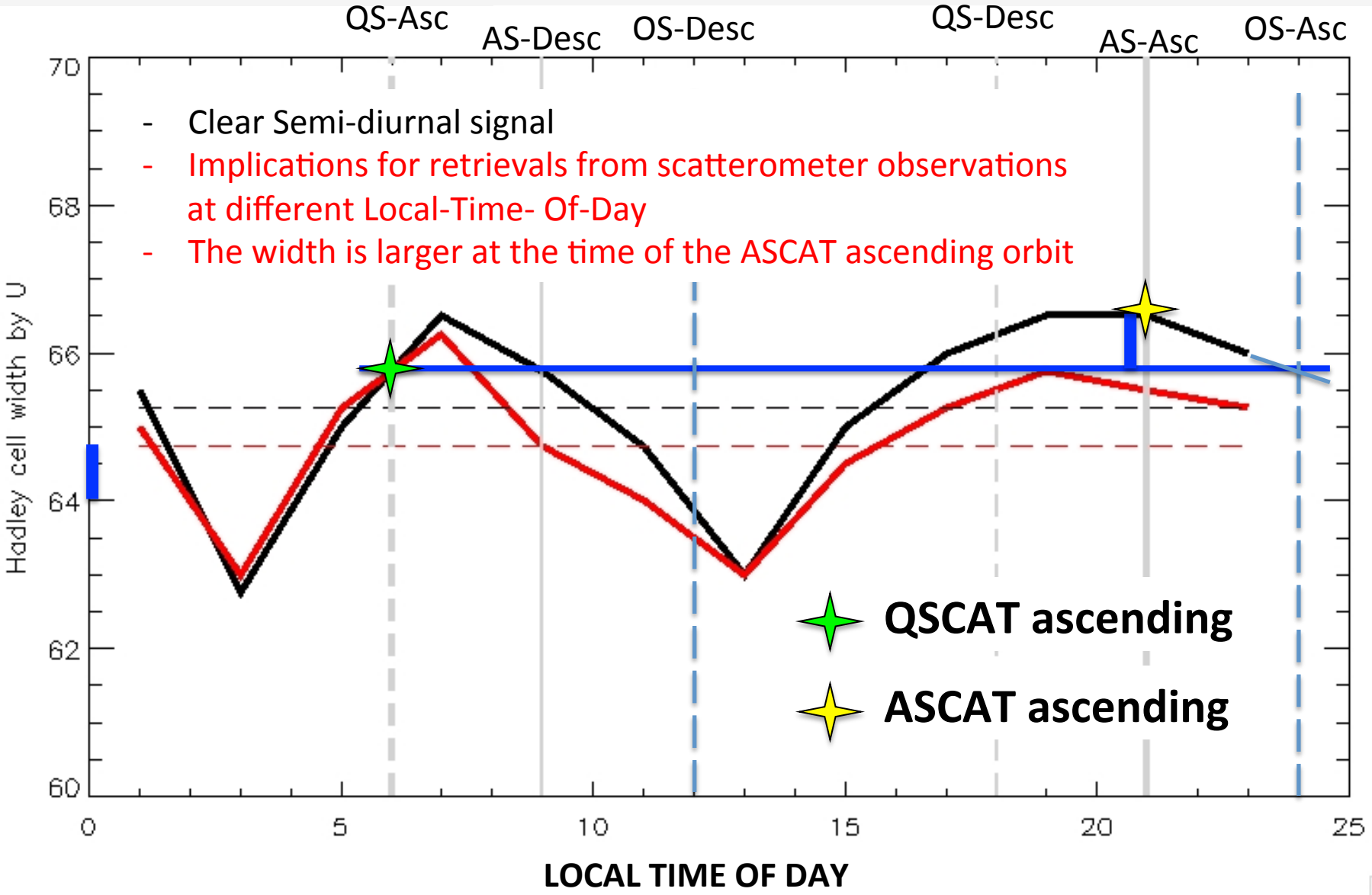
RapidScat
Hadley Width by the Zonal Wind U



RapidScat (128 days)
Hadley Width by the Zonal Wind U

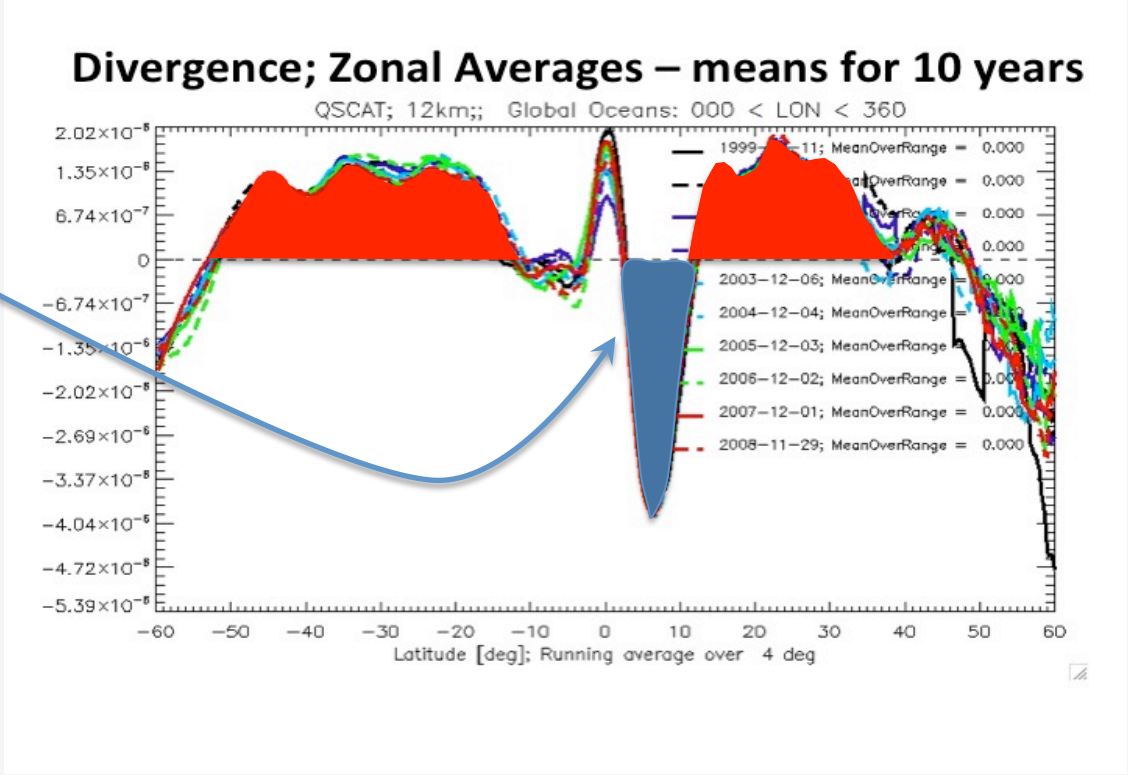


Hadley Width by U (128 days)



Diurnal Signals in Convergence

- How does the ITCZ convergence change when using observations from different scatterometers?

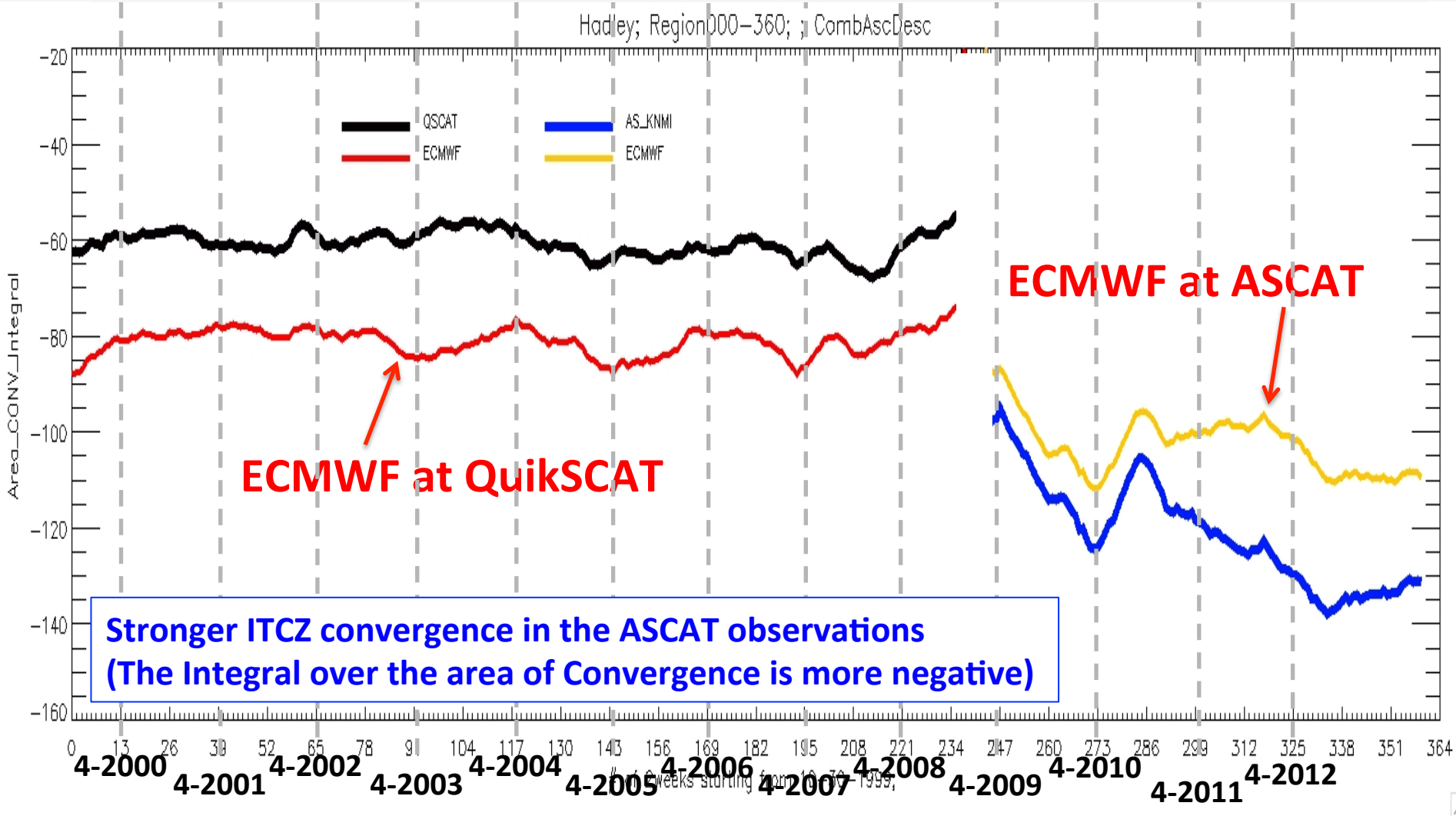


- Could we use the models to infer the Diurnal Signals in the Hadley cell?
- What is the diurnal signal in RapidScat observations

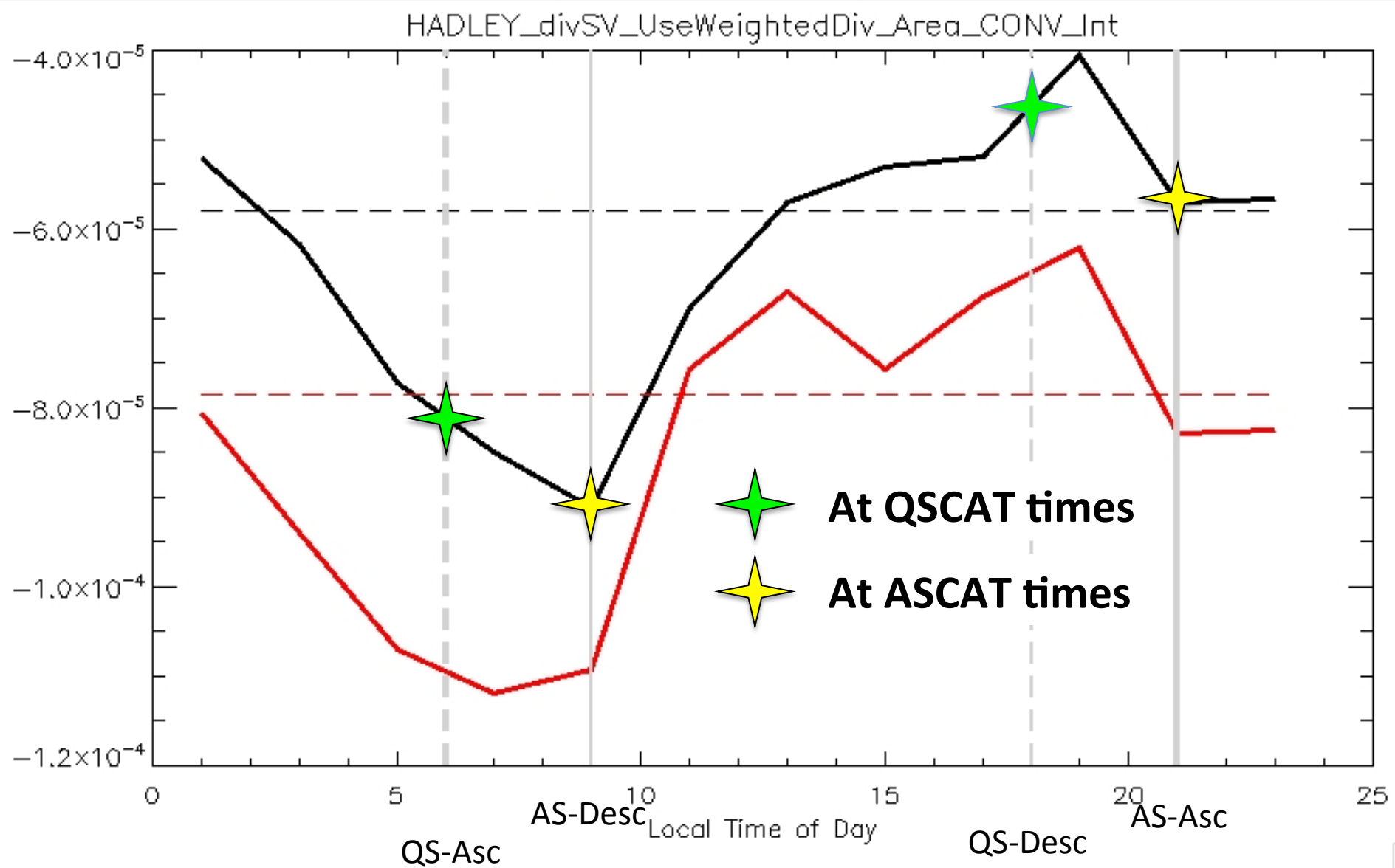
Convergence (area integral) – is there a break?

Is ECMWF capturing the signal correctly ?

- ECMWF shows no significant change between the QuikSCAT and the ASCAT periods
- **Scatteromter observations show a change – why the difference from ECMWF??**

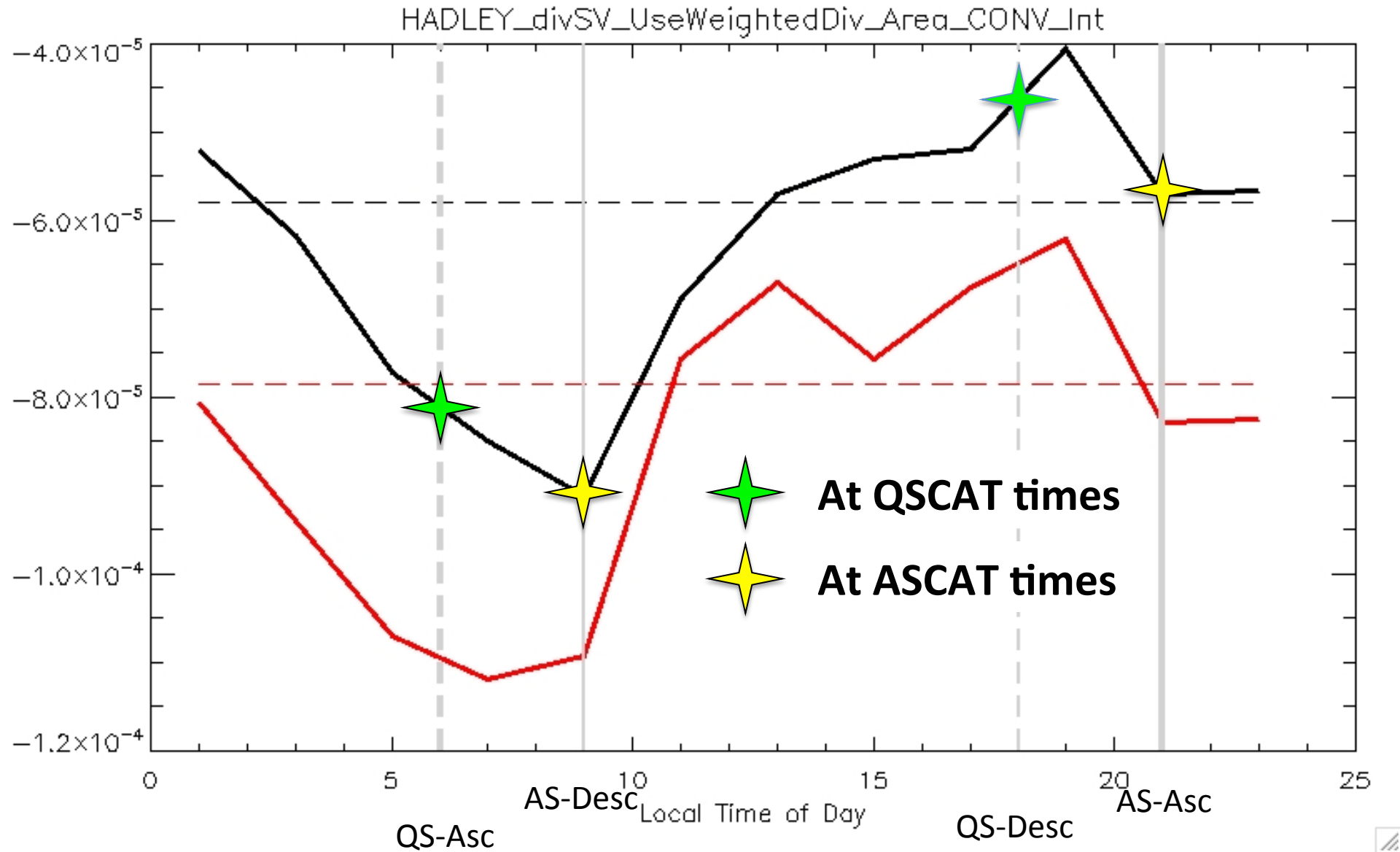


Hadley Convergence (Integral) from RapidScat observations



Hadley Convergence (Integral)

Stronger ITCZ convergence in the ASCAT observations
(The Integral over the area of Convergence is more negative)



Summary

- **We use scatterometer surface wind observations to detect the extent of the Hadley cell and to study its characteristics over the last 15 years.**
- **QuikSCAT period:**
  - **Two distinct cycles in the Hadley cell width during the first half of the QuikSCAT record**
    - **They are likely a reflection of the modulation of the Hadley cell by the La Nina(1999)/El Nino (2002) events that dominated this period.**
  - **A steady increase in the width during the later part of the QuikSCAT record**
  - Analyzing the time series of 3-month running averages **reveals the seasonal variations of the Hadley cell.**
- **ASCAT period: Extending the record to include the ASCAT period shows**
  - **more evidence for a trend**
  - **and reveals another cycle**
- **There is a discontinuity between the two records. Need to understand why.**
  - **Diurnal variability might be the reason. RapidSCAT will help address this issue**
- **ECMWF analysis of the Hadley cell structure and evolution show differences from the scatterometer-based ones. These differences vary both in space and in time!**

Summary (cont.): RapidScat

- We found breaks in the record of the Hadley width (as determined from the zonal wind U) 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 Missions
  - RapidScat observations !!
- Our analysis show that:
  - Tandem mission analyses seem 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
    - provide strong evidence that the Hadley cell is wider during the ASCAT observing times than it is during the QuikScat observing times
    - This supports our theory that diurnal variability might be the cause for previously found discrepancies between QSCAT and ASCAT observations and supports our earlier findings

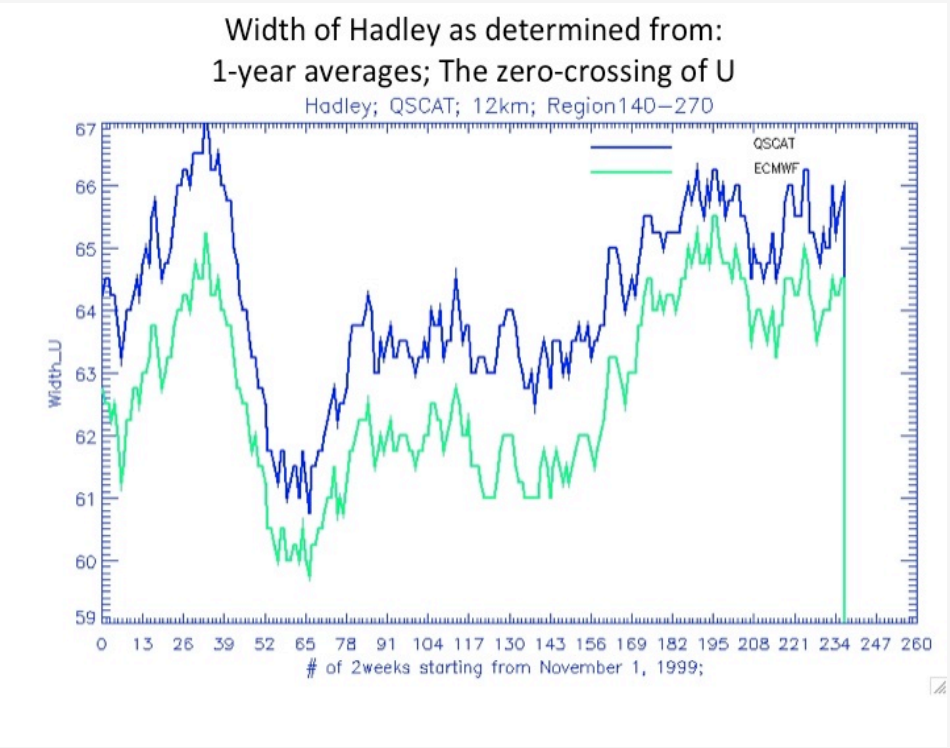
Our response to the AMS request to help identify the greatest observation needs of our community.

- 1. Observations needed to benefit your future research, application or product development
  - Coincident (or very near-coincident) observations of
    - the near-surface wind VECTORS
    - The atmospheric moisture (vertical structure)
    - The precipitation structure (in 2D and in 3D)
  - Why – to study the interplay between
    - near-surface convergence,
    - the associated development of precipitation and
    - The positive feedback in which precipitation-developed surface cold pools lead, through leading line convergence, to the organization and the up-scale growth of precipitating systems
  - Why do we care about that – see also the justification for the upcoming NASA CPEX
    - The atmospheric processes that lead to convective initiation, and that determine convective organization and its upscale growth, are still poorly understood.
    - Not only are these processes critical to the development of severe weather, they are also important in the resulting vertical transport of heat and moisture and to the cloud and radiation feedbacks that have a large impact on the climate system.
    - Need to improve our understanding of these relations and improve their representation in models.
- 2. Recommended instruments that are needed to make these observations
  - Scatterometer/radiometer all weather observations of the ocean surface vector wind (convergence/divergence)
  - Radiometer observations of precipitation; humidity/temperature profiles
- 3. Your view on the greatest observational needs for your discipline in general
  - High temporal resolution to understand the processes !!!

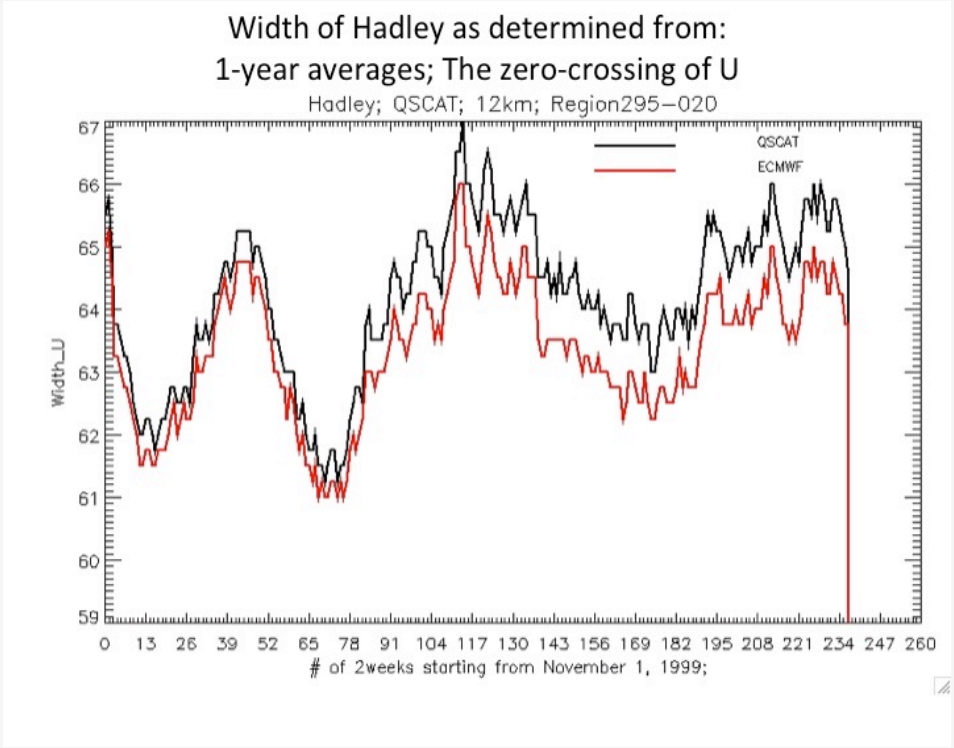
BACKUP

Geographical Variability

Pacific Basin



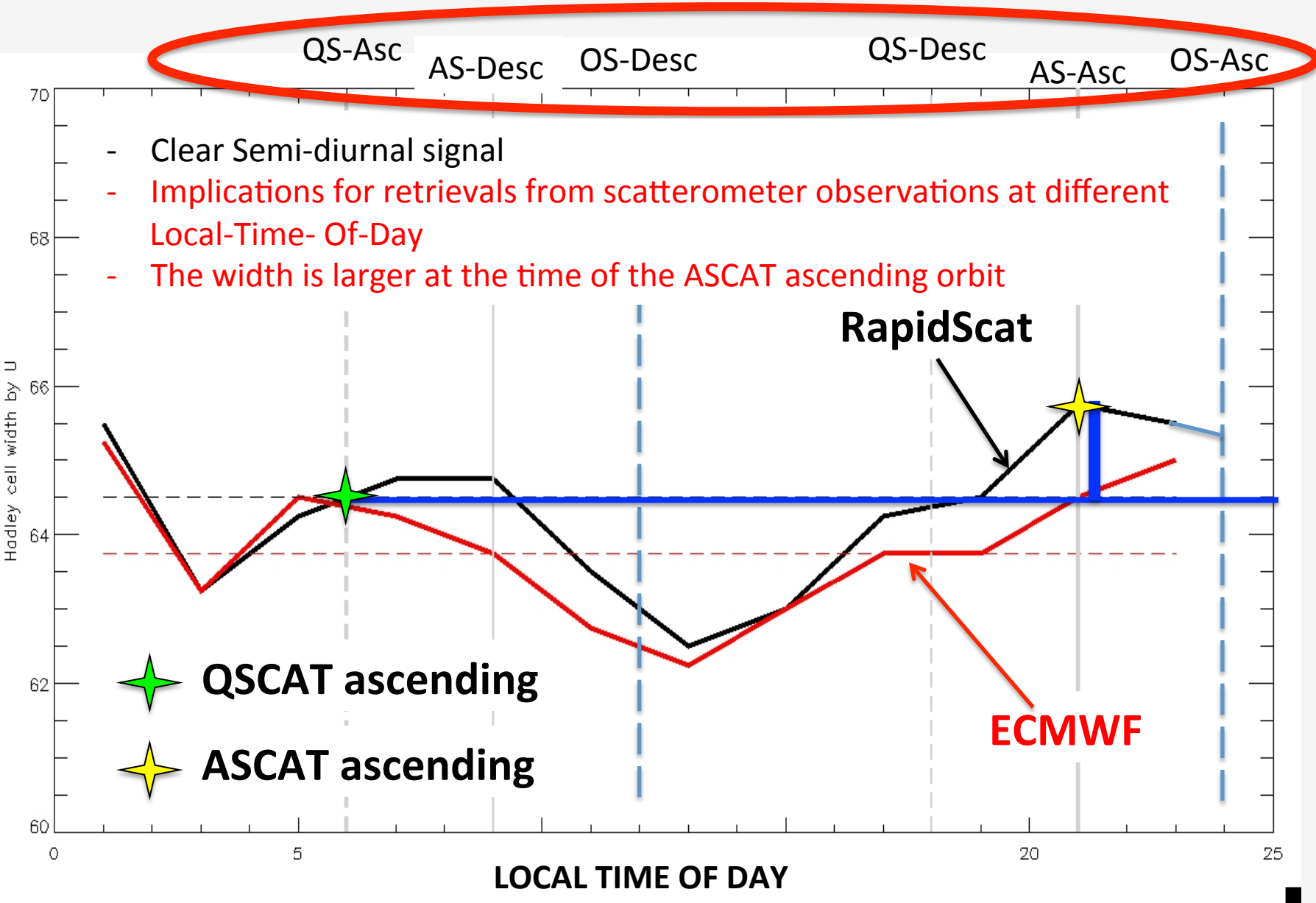
Atlantic Basin



It appears that the behavior has a geographical variability with:

- More pronounced trend in the Pacific
- More pronounced oscillations in the Atlantic

RapidScat (308 days)
Hadley Width by the Zonal Wind U



Tandem Missions (using running 3-month averages)

Breaks in the Hadley width (by U) when using different satellites !!