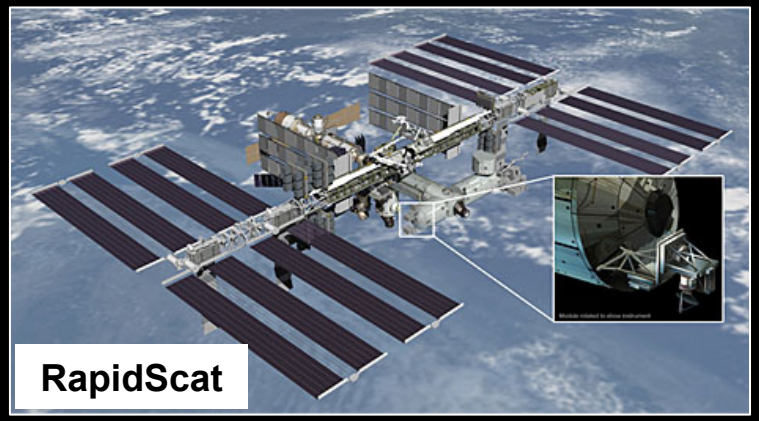
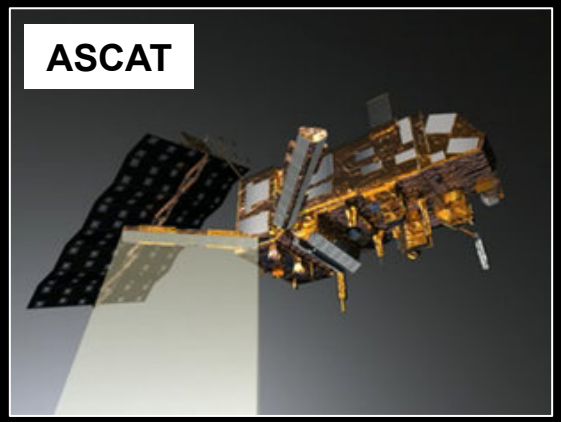
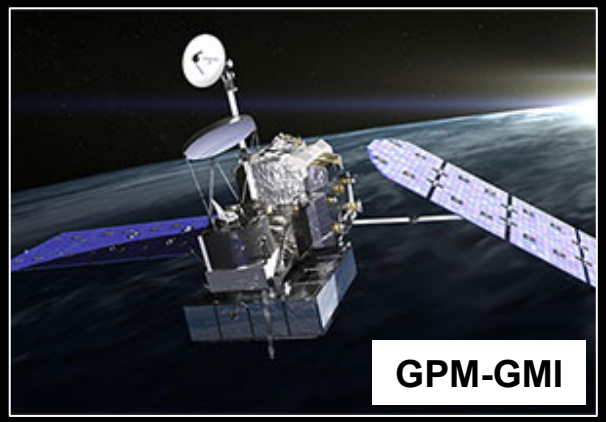


Examining the Constellation of Scatterometers and Radiometers for Diurnal and Sub-Diurnal Wind Vector Variability

F. Joseph (Joe) Turk, S. Hristova-Veleva

Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA





21st AMS Satellite Meteorology and Oceanography Conference 15-19 August 2016, Madison

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

Examining the Constellation of Scatterometers and Radiometers for Diurnal and Sub-Diurnal Wind Vector Variability

The constellation of satellite-based ocean surface wind and precipitation observations since 1999 consists of a diverse collection of both sun-synchronous and asynchronous orbiting satellite platforms, both wind vector-capable (e.g., RapidScat, QuikSCAT, ASCAT) and speed-only radiometers (e.g., TRMM and GPM imagers, AMSR-E)

The surface wind varies widely throughout the day, owing to various meteorological forcings, such as land/sea temperature differences, coastal forcings, or possible variations associated with tropical convection

Where are regions of strongest time-of-day variability?

Acknowledgements
Remote Sensing Systems, Inc., (RSS)
Physical Oceanography Distributed Active Archive (PO.DAAC)
Support from NASA Ocean Vector Winds Science Team (E. Lindstrom, NASA HQ) and the RapidScat Cal-Val effort (B. Stiles, E. Rodriguez, JPL)

30 Years of Satellite-Based Winds

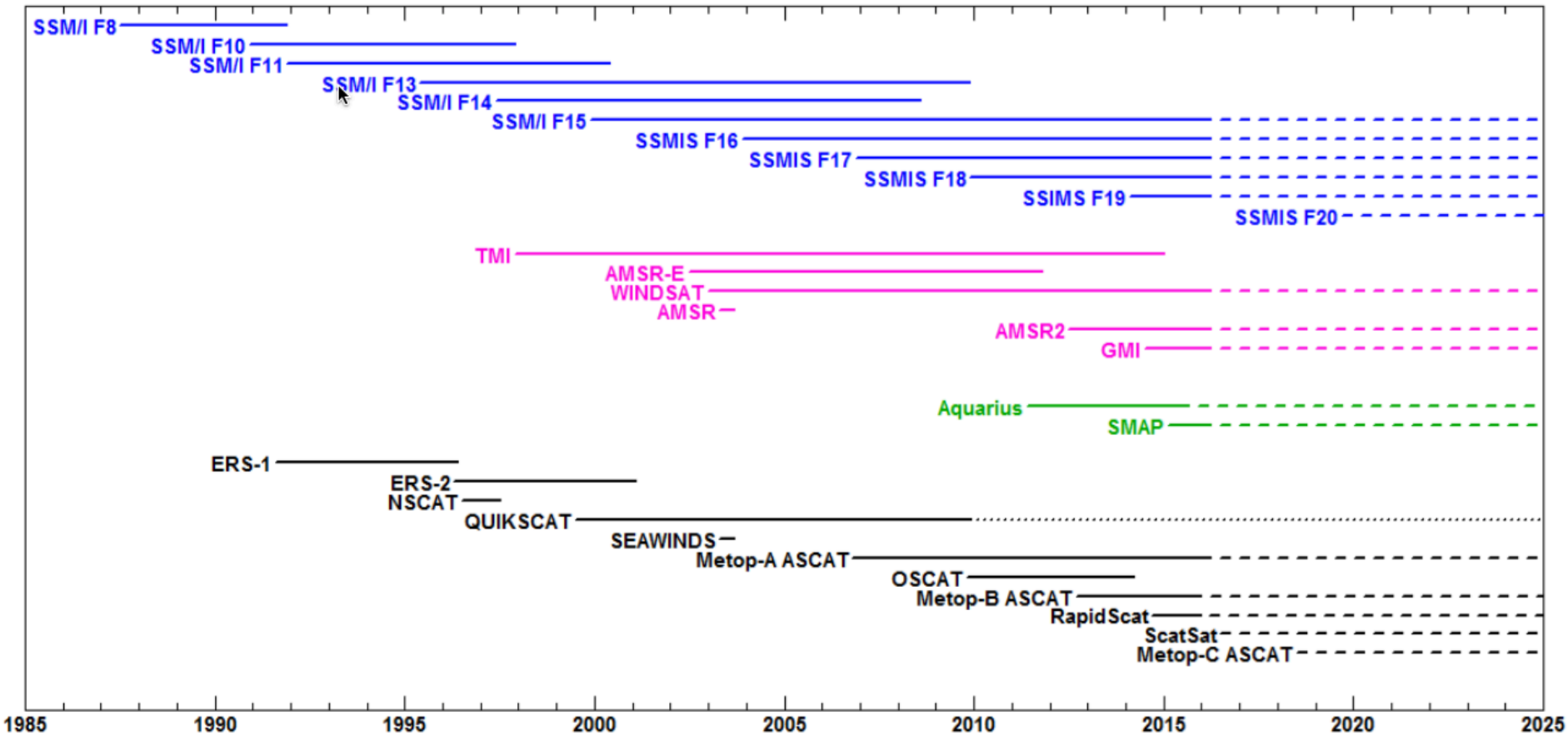


Figure Courtesy Remote Sensing Systems, Santa Rosa, CA

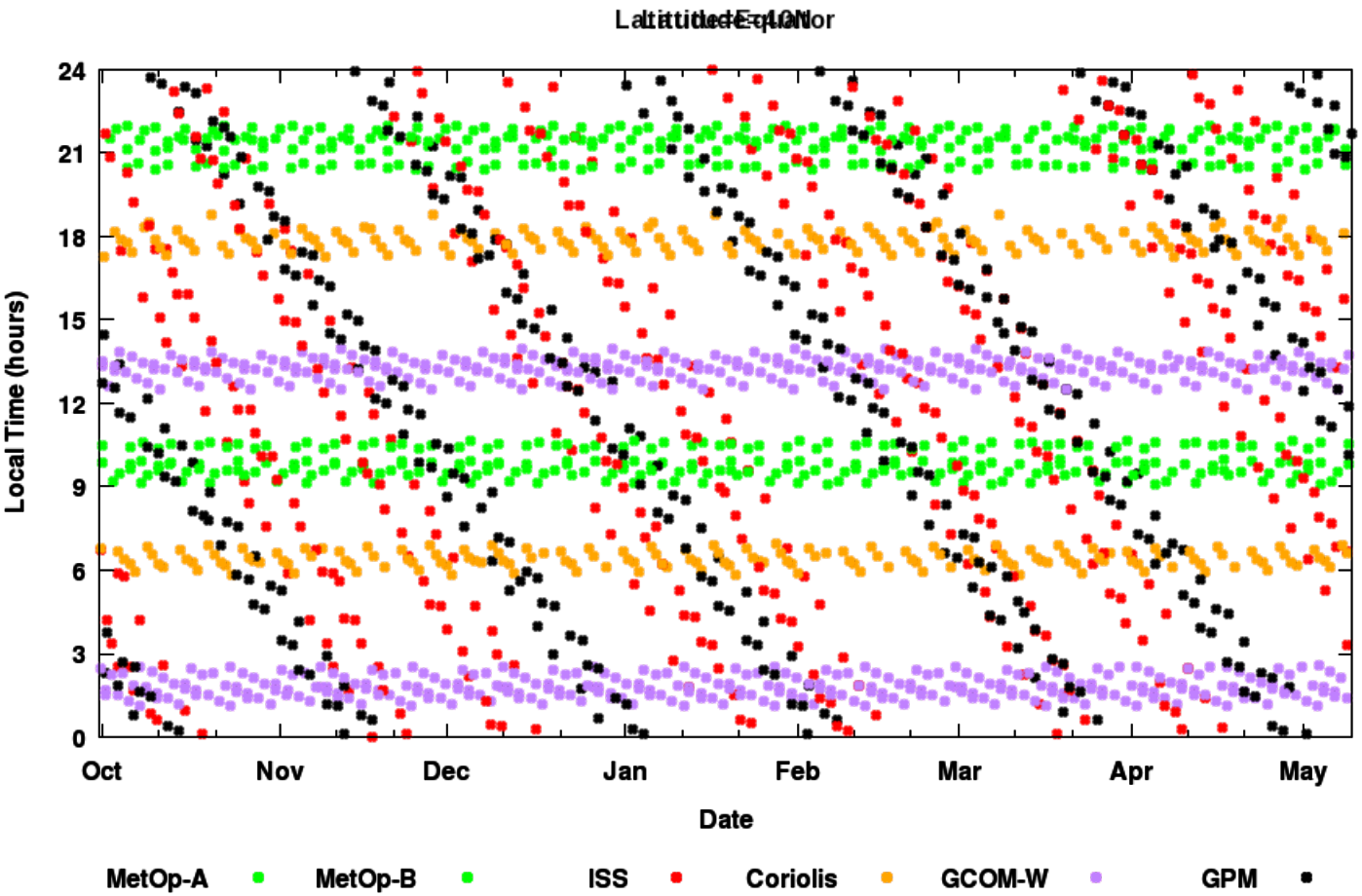
Excerpted from **Evaluating and Extending the Ocean Wind Climate Data Record**, *JSTARS Special Issue on New Challenges and Opportunities in Scatterometry*, 2016, in review.

28 Satellite Wind Sensors:

- 18 passive microwave radiometers
- 10 active microwave scatterometers

(Altimeters not included)

Local Time Repeat (Oct 2014-May 2015)



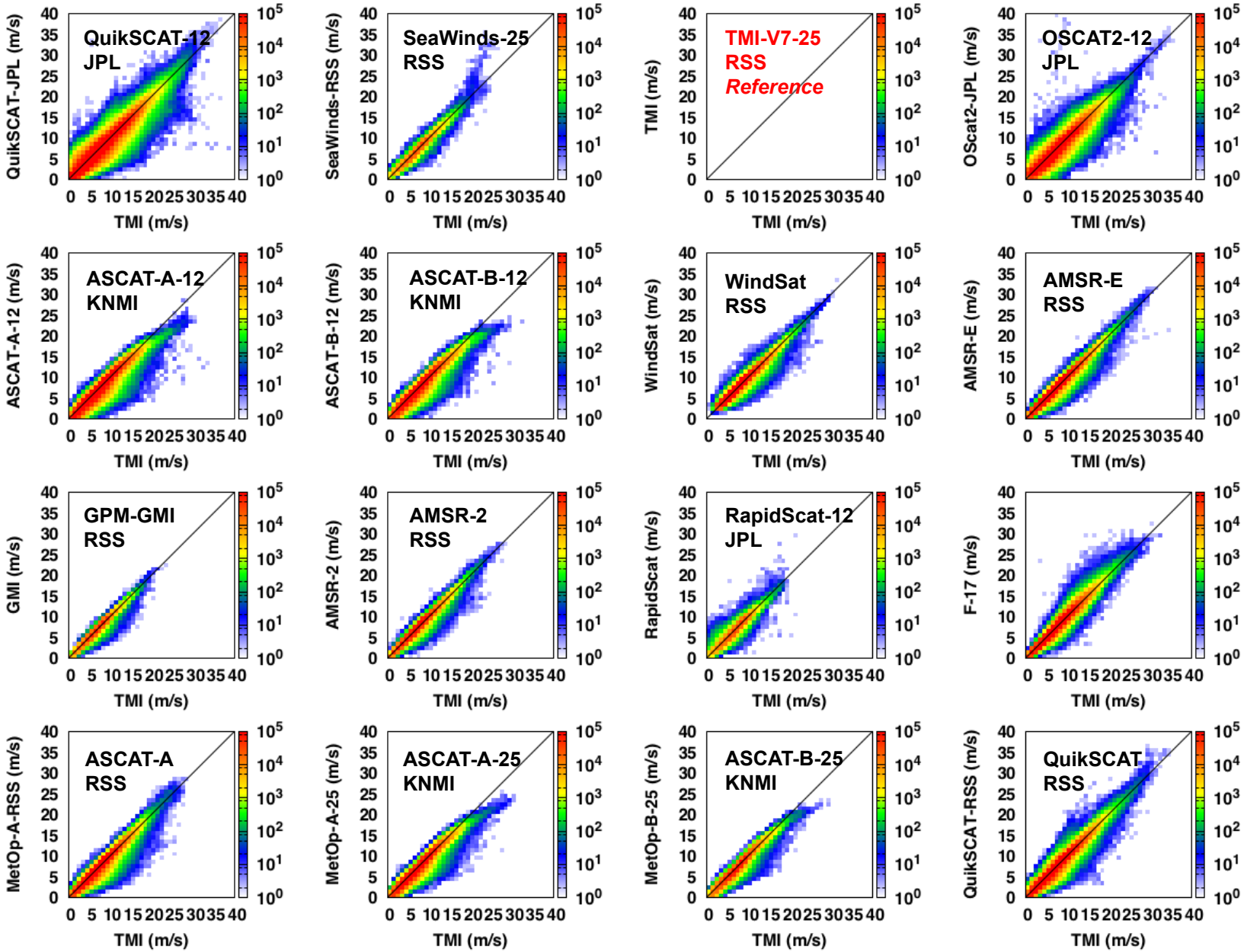
Examining the Constellation of Scatterometers and Radiometers for Diurnal and Sub-Diurnal Wind Vector Variability

Since there is no worldwide “truth”, adopt a sensor-referencing approach. TRMM winds (TMI) used as the “intercalibrator” until mid/late-2014, GPM GMI after that

Currently examining 16 different datasets, covering different sensor lifetime periods

Includes RapidScat up to Feb 2016 (exclude periods from various low SNR state conditions)

1999-2014 ±5-min Coincidences With TRMM-TMI (GPM-GMI post-TRMM)
16 Different Wind or Wind Vector Datasets



Analytical Formulation

(*u*,*v*) from N observations

$$\begin{pmatrix} u_1 \\ v_1 \\ \vdots \\ u_n \\ v_n \end{pmatrix} = \begin{pmatrix} \overbrace{a_0 + a_1\cos(2\pi t_1/24) + a_2\sin(2\pi t_1/24)}^{\textbf{daily}} + \overbrace{a_3\cos(4\pi t_1/24) + a_4\sin(4\pi t_1/24)}^{\textbf{sub-daily}} \\ b_0 + b_1\cos(2\pi t_1/24) + b_2\sin(2\pi t_1/24) + b_3\cos(4\pi t_1/24) + b_4\sin(4\pi t_1/24) \\ \vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots \\ a_0 + a_1\cos(2\pi t_n/24) + a_2\sin(2\pi t_n/24) + a_3\cos(4\pi t_n/24) + a_4\sin(4\pi t_n/24) \\ b_0 + b_1\cos(2\pi t_n/24) + b_2\sin(2\pi t_n/24) + b_3\cos(4\pi t_n/24) + b_4\sin(4\pi t_n/24) \end{pmatrix}$$

$$[A] = \begin{pmatrix} 1 & \cos(2\pi t_1/24) & \sin(2\pi t_1/24) & \cos(4\pi t_1/24) & \cos(4\pi t_1/24) \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & \cos(2\pi t_n/24) & \sin(2\pi t_n/24) & \cos(4\pi t_n/24) & \cos(4\pi t_n/24) \end{pmatrix}$$

$$\vec{x} = \left(a_0\ a_1\ a_2\ a_3\ a_4\right)^T$$

$$\vec{y} = \left(b_0\ b_1\ b_2\ b_3\ b_4\right)^T$$

$$\vec{x} = \left(A^T D_u^{-1} A\right)^{-1} A^T D_u^{-1} U$$

$$\vec{y} = \left(A^T D_v^{-1} A\right)^{-1} A^T D_v^{-1} V$$

In either case, these expressions can be expressed in matrix form, where D_u and D_v are diagonal matrices with the variance of the *u* and *v* observations.

Analytical Formulation

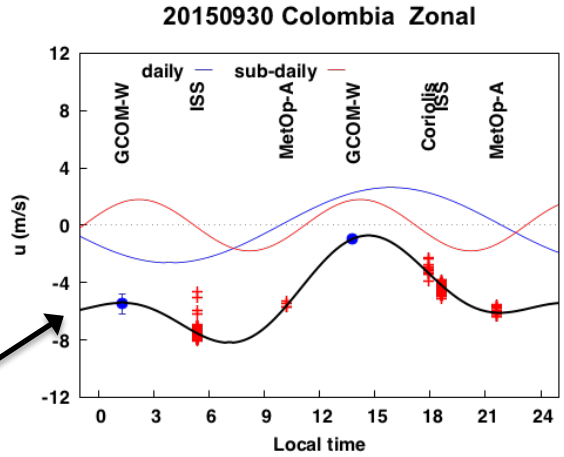
For the speed-only (*w*) radiometers, since the relation between *w* and the *u* and *v* components is non-linear, hypothetical vectors are created by varying the directions one degree at a time

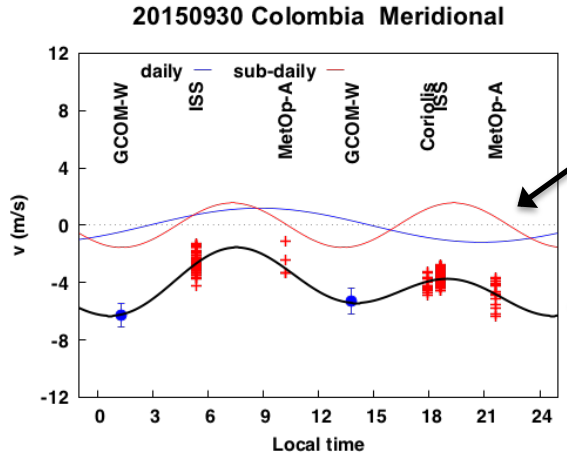
For example, for one radiometer:

$$u_{n+1} = w\cos(\theta) = a_0 + a_1\cos(2\pi t_1/24) + a_2\sin(2\pi t_1/24) + a_3\cos(4\pi t_1/24) + a_4\cos(4\pi t_1/24)$$
$$v_{n+1} = w\sin(\theta) = b_0 + b_1\cos(2\pi t_1/24) + b_2\sin(2\pi t_1/24) + b_3\cos(4\pi t_1/24) + b_4\cos(4\pi t_1/24)$$

$$E(\theta) = \min\left(\sum_{i=1}^{n}\left(u_{n+1} - u_i\right)^2 + \left(v_{n+1} - v_i\right)^2\right)$$

And locating the directions θ that best agree with the observed vectors.

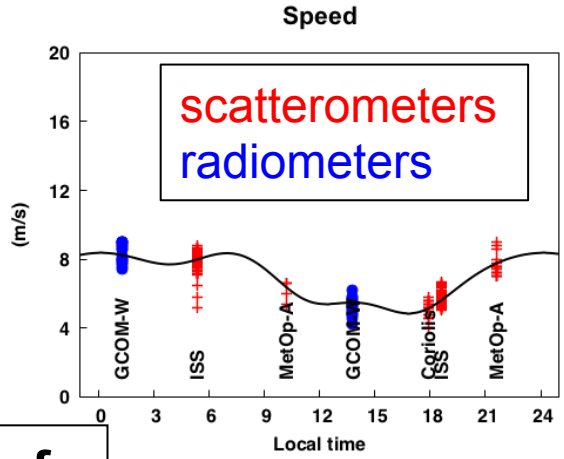




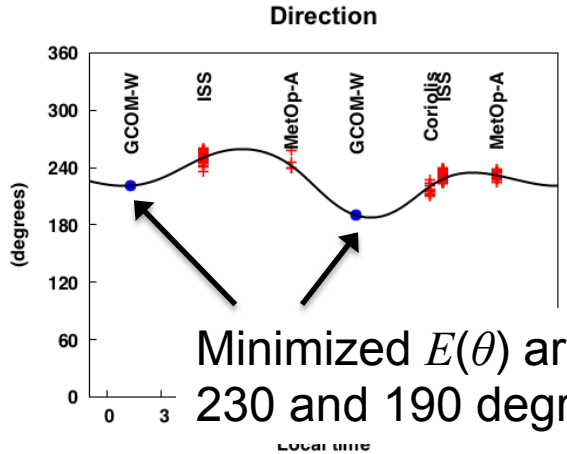
Diurnal and sub-diurnal components

fitted *v* component

fitted *u* component



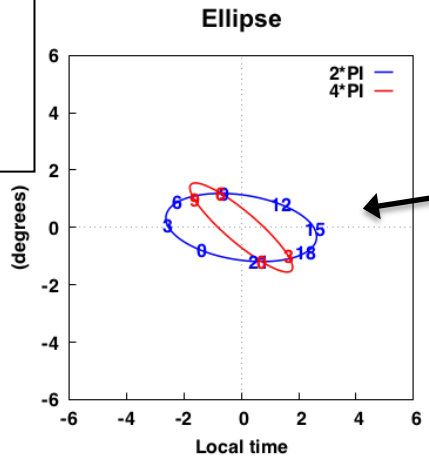
Speed



Direction

Minimized $E(\theta)$ are near 230 and 190 degrees

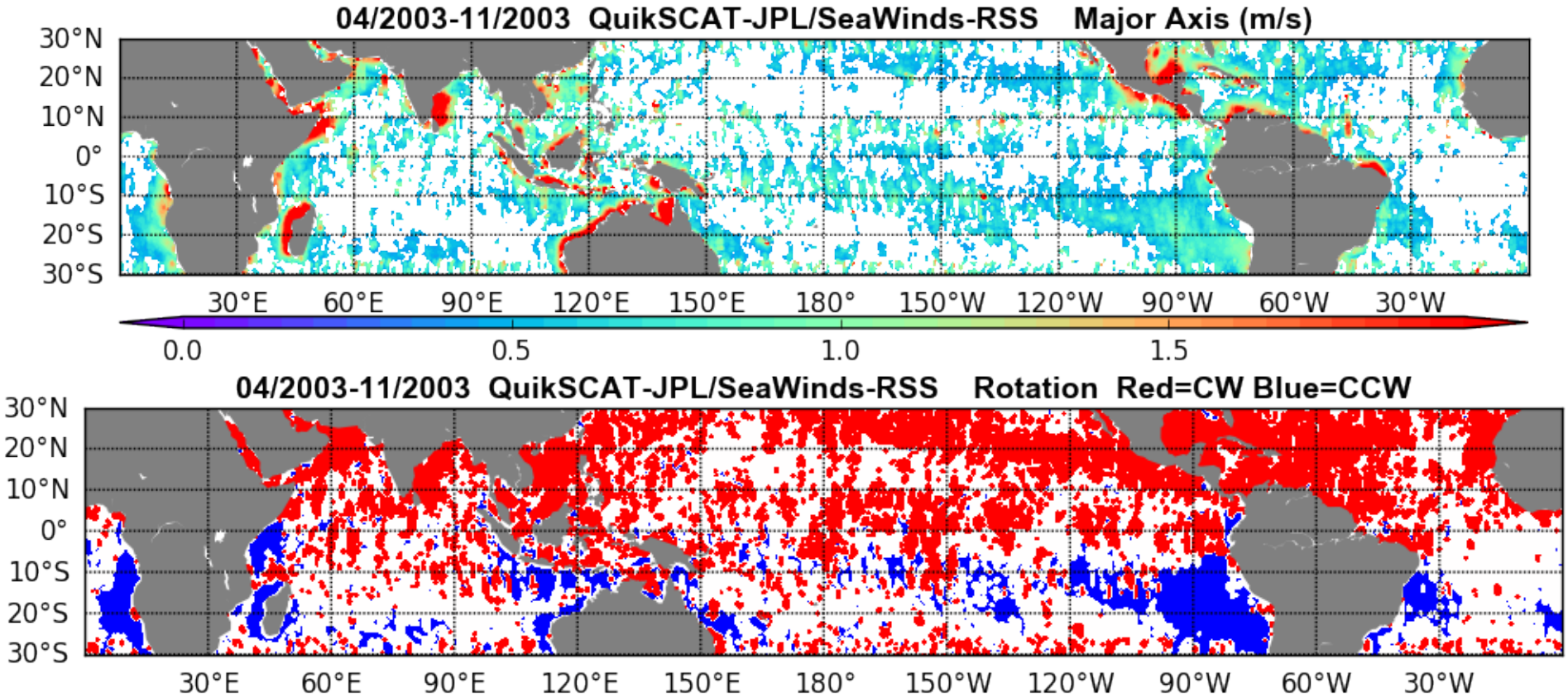
Offshore of Colombia 12N 74.75W



One analysis day from 30 Sep 2015 with 2 RapidScat, 2 ASCAT, WindSat, 2 AMSR-2 (n=7). Both the diurnal (blue) and sub-diurnal (red) wind ellipse spin CW with similar magnitudes under 2 m s^{-1}.

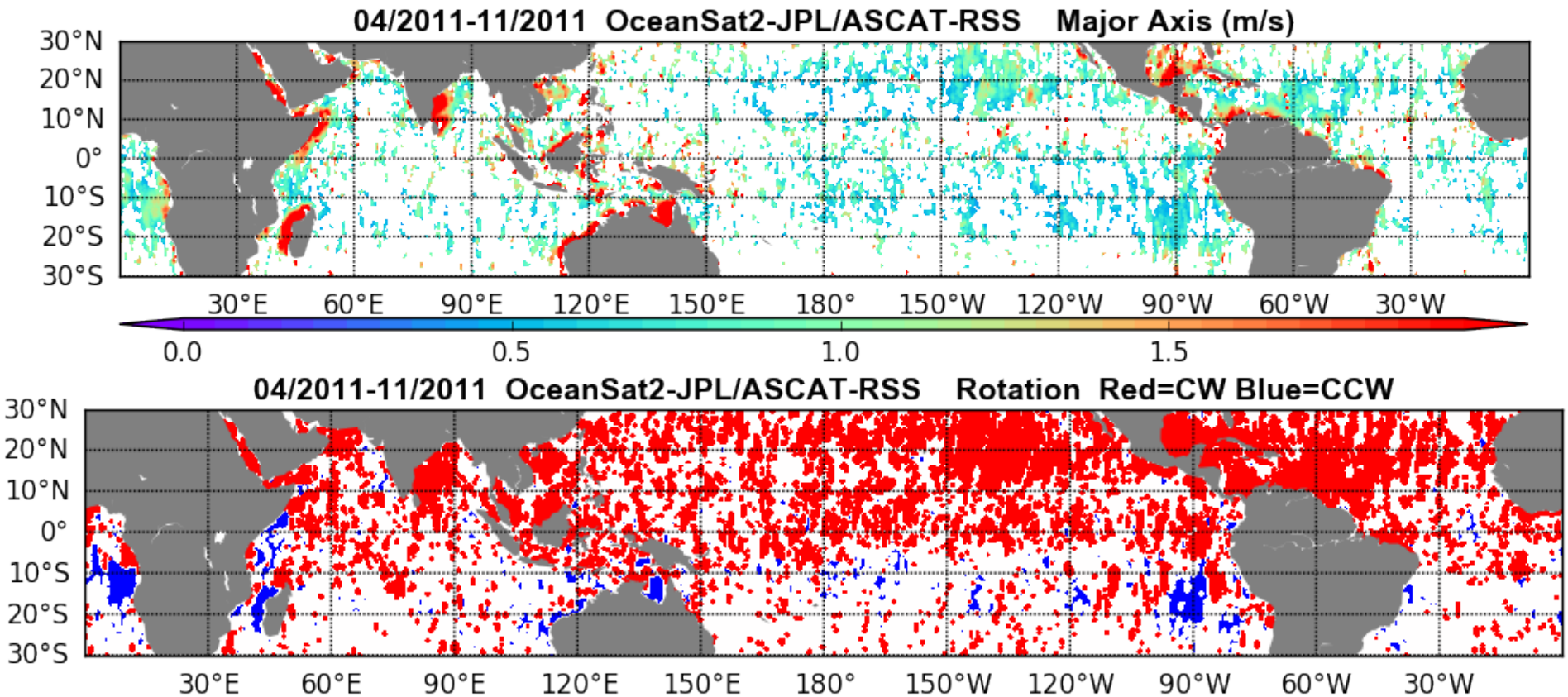
Diurnal ellipse major axis (m s^{-1}) and the direction of the ellipse rotation (red=CW, blue=CCW), derived from the April-November 2003 QuikSCAT-SeaWinds tandem mission (n=4 day^{-1}), which agrees closely with Figure 1 of *Gille et. al. (2005)*.

2003



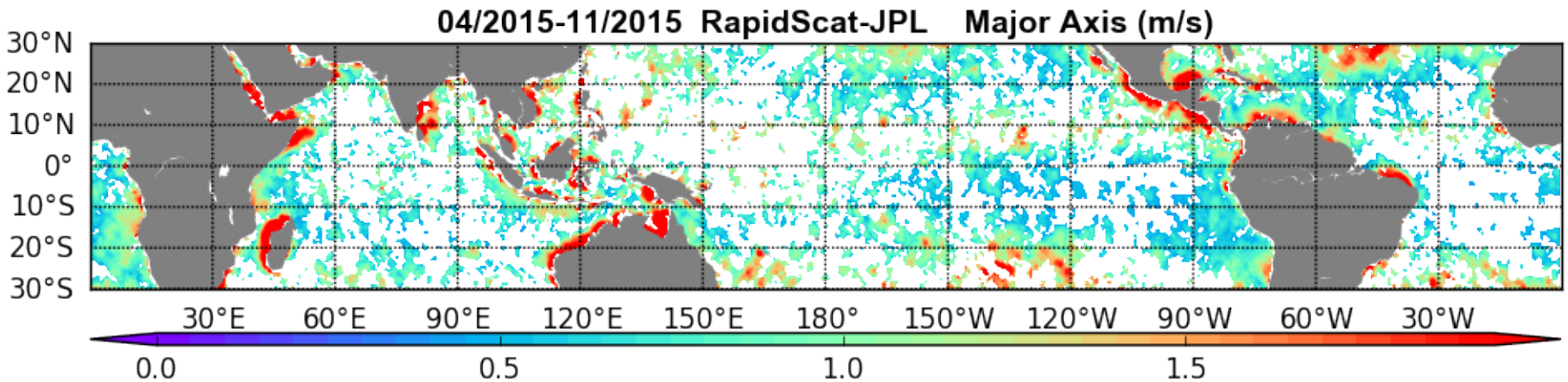
Diurnal ellipse major axis (m s^{-1}) and the direction of the ellipse rotation (red=CW, blue=CCW), derived from the April-November months of 2011 with OceanSat-2-JPL and MetOp-A ASCAT-RSS (Version 2.1) (n=4 day^{-1})

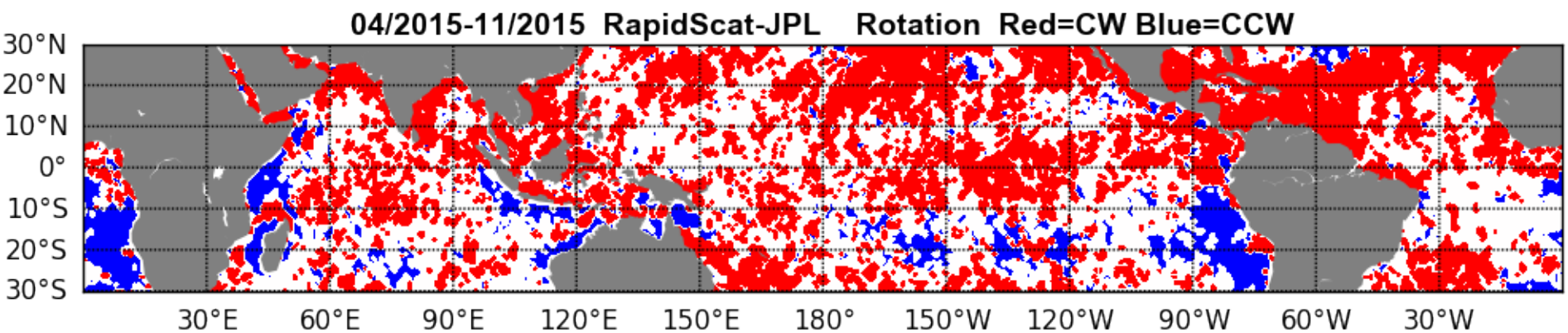
2011



Diurnal ellipse major axis (m s^{-1}) and the direction of the ellipse rotation (red=CW, blue=CCW), derived from the April-November months of 2015 with RapidScat only

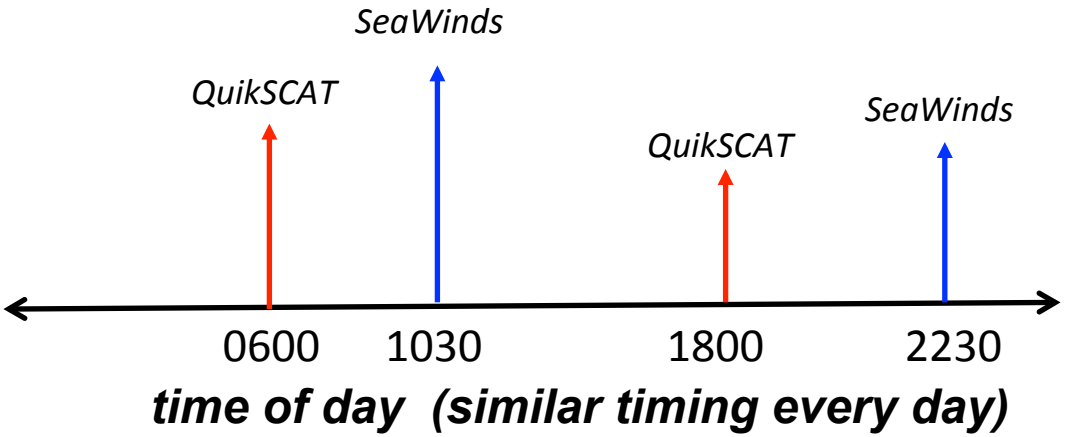
2015



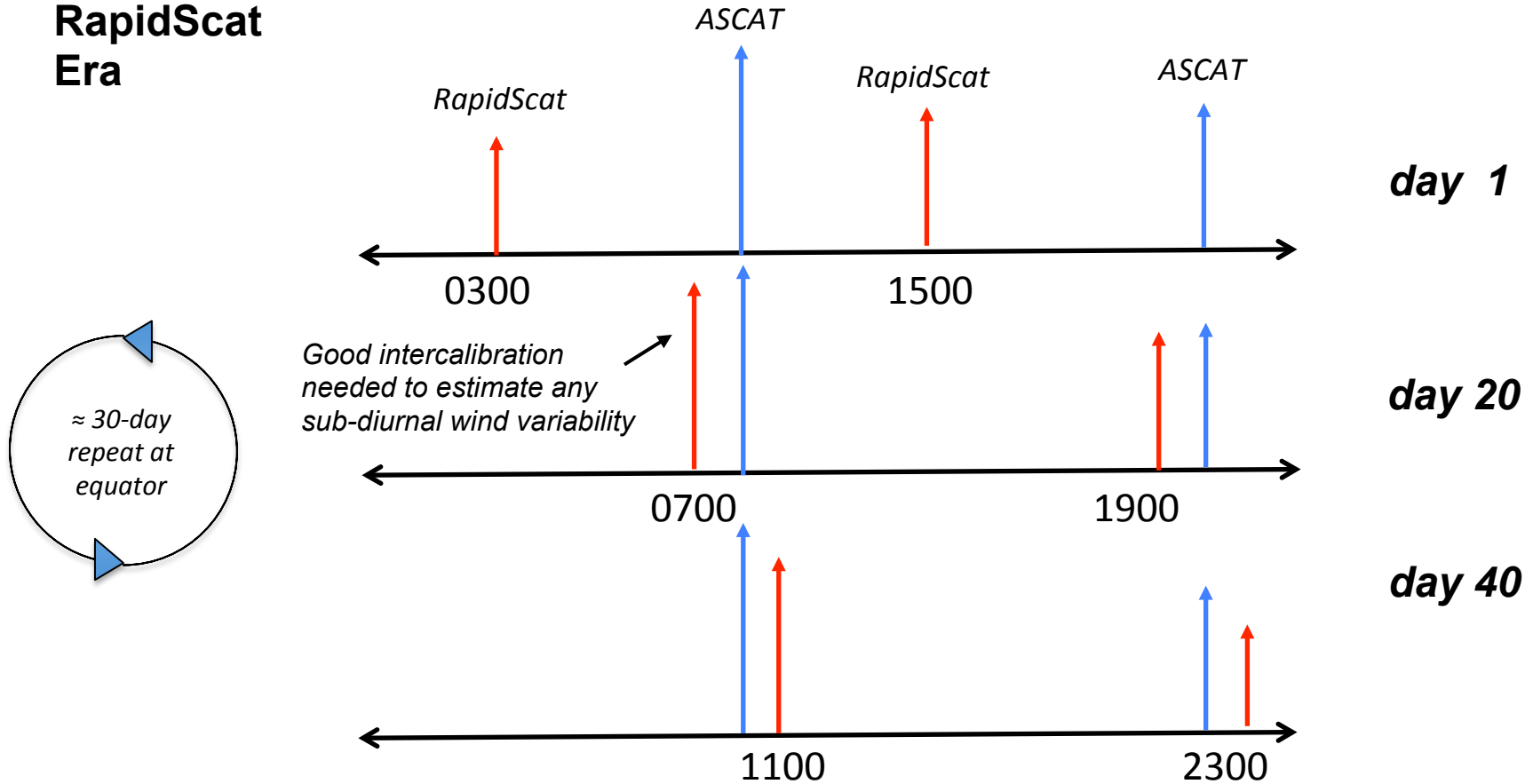


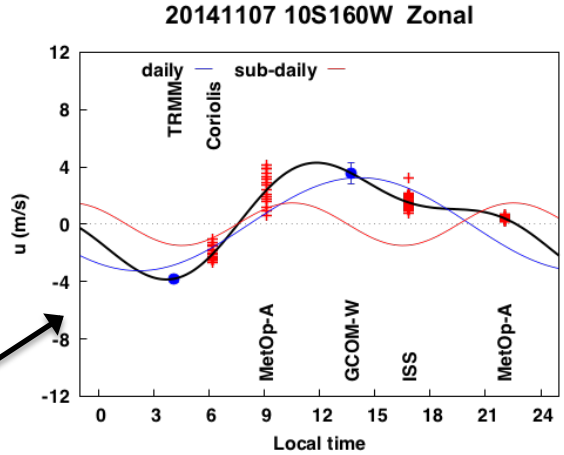
RapidScat can be used for examining daily wind variability in places where the phenomena underlying the daily wind variability is sustained and captured over several RapidScat local time repeat cycles

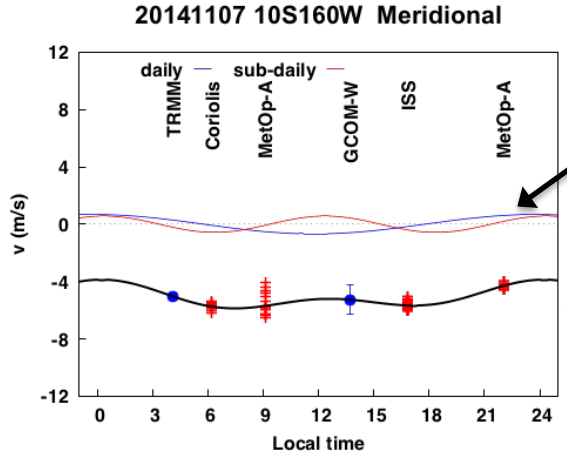
2003 Tandem Period



RapidScat Era



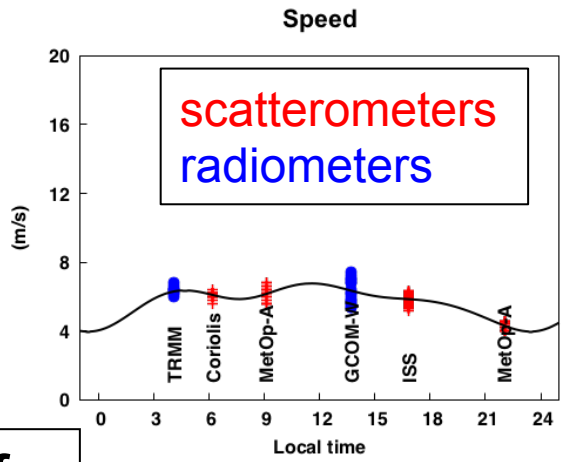




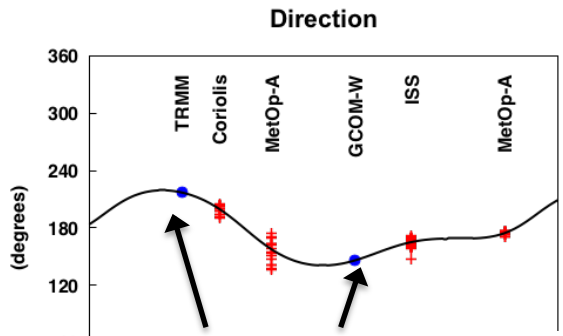
Diurnal and sub-diurnal components

fitted *v* component

fitted *u* component



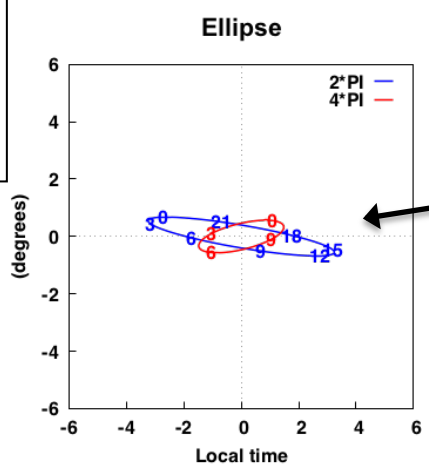
Speed



Direction

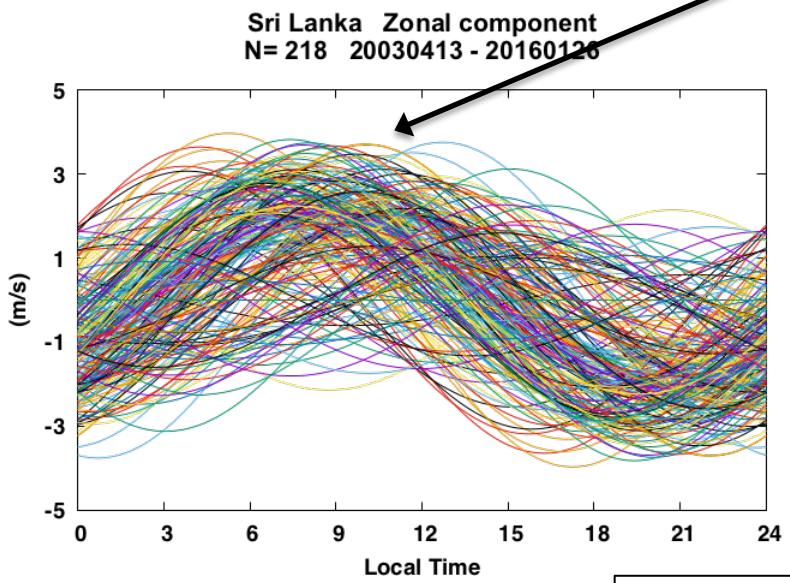
Minimized $E(\theta)$ are near 220 and 140 degrees

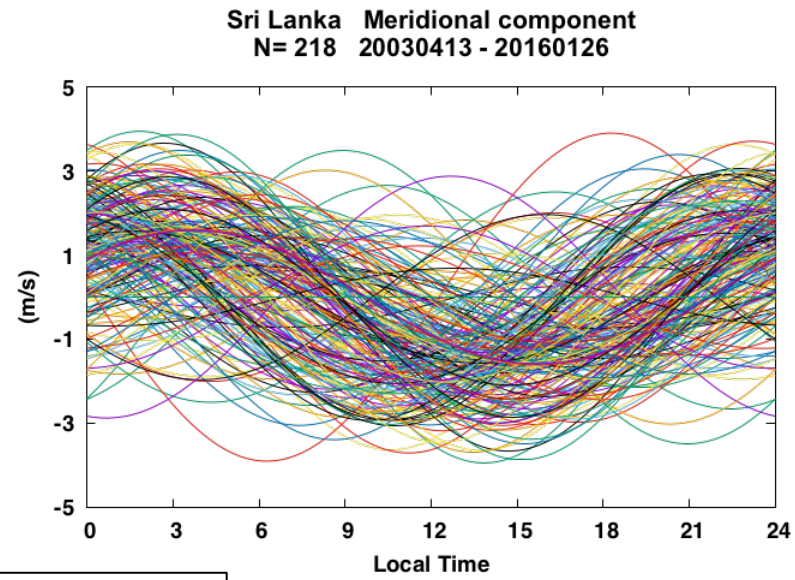
Middle of East Pacific 10S 160W



One analysis day from 7 Nov 2014 with RapidScat, 2 ASCAT, WindSat, TRMM, and AMSR-2 (n=7). Both the diurnal (blue) and sub-diurnal (red) wind ellipse spin CCW with magnitudes under 4 and 2 m s^{-1}.

Peak in zonal wind in the early morning

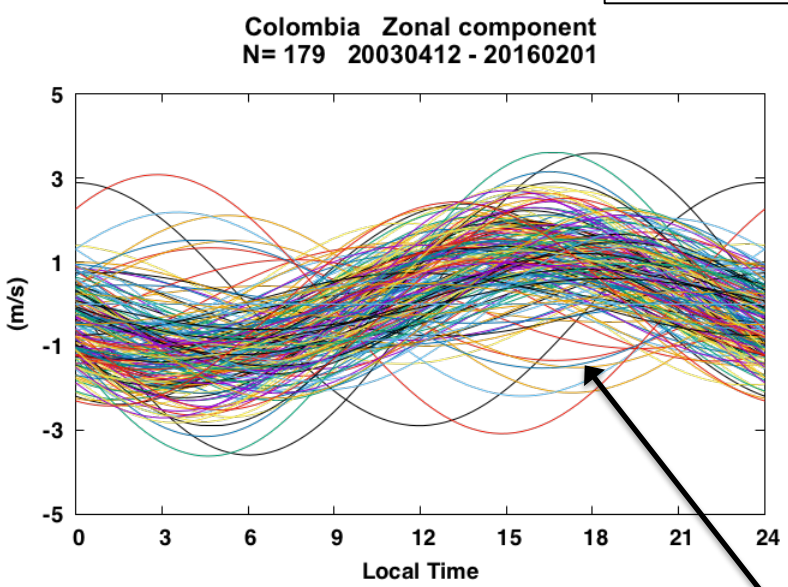


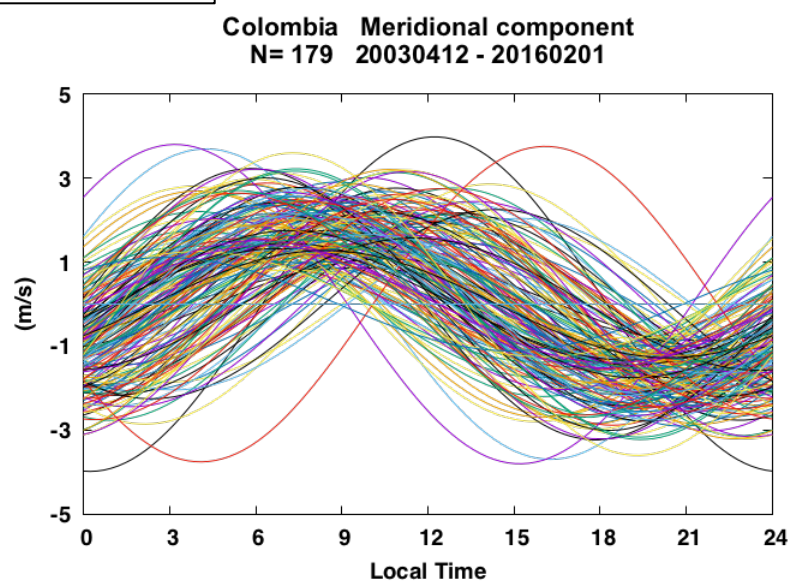


North of Sri Lanka 11N 81E

20030413-20160126

Daily (2π terms)

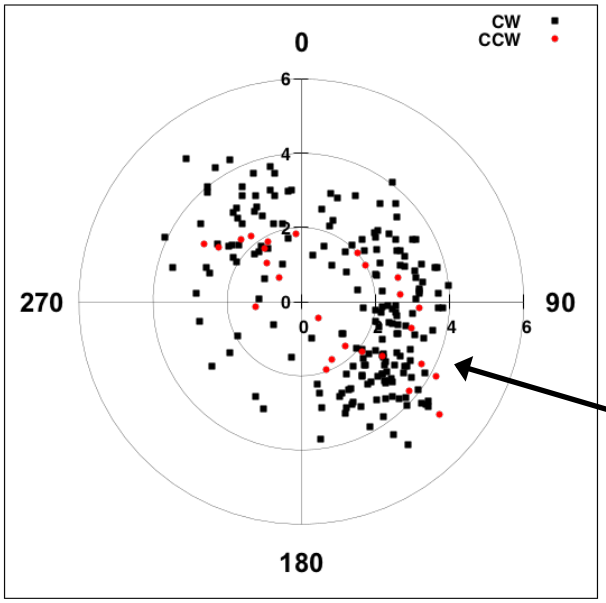




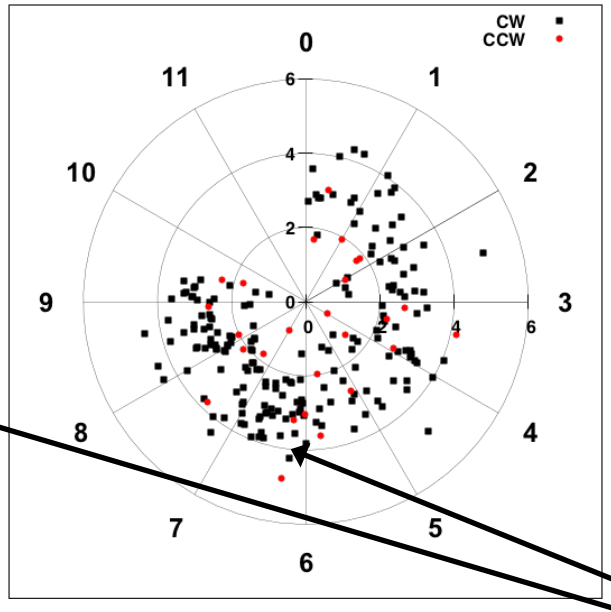
Offshore of Colombia 12N 74.75W

20030412-20160201

Peak in zonal wind in the late afternoon



Wind Direction When Aligned with Major Axis

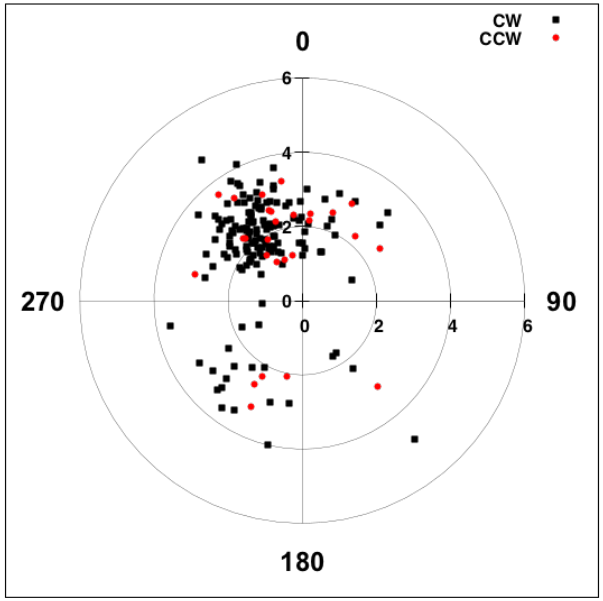


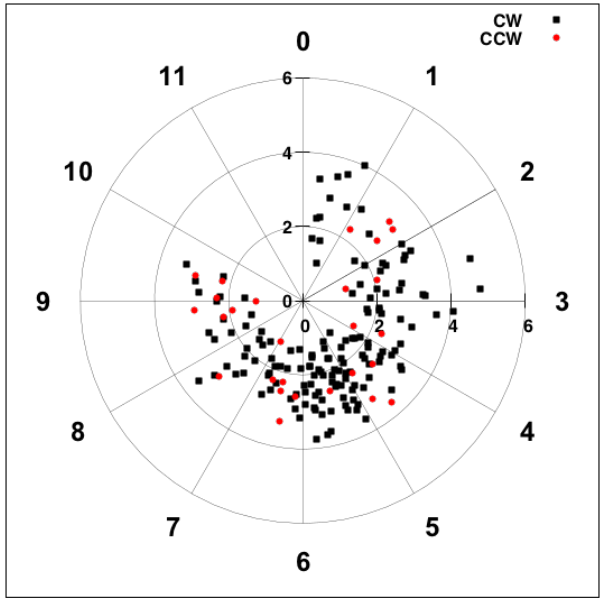
Hours After Noon/Midnight When Aligned with Major Axis

North of Sri Lanka 11N 81E

20030413-20160126

When the time is aligned with the major axis, winds are mostly SE or NW (180-deg ambiguity) and peak at about 6-9 hours after noon/midnite



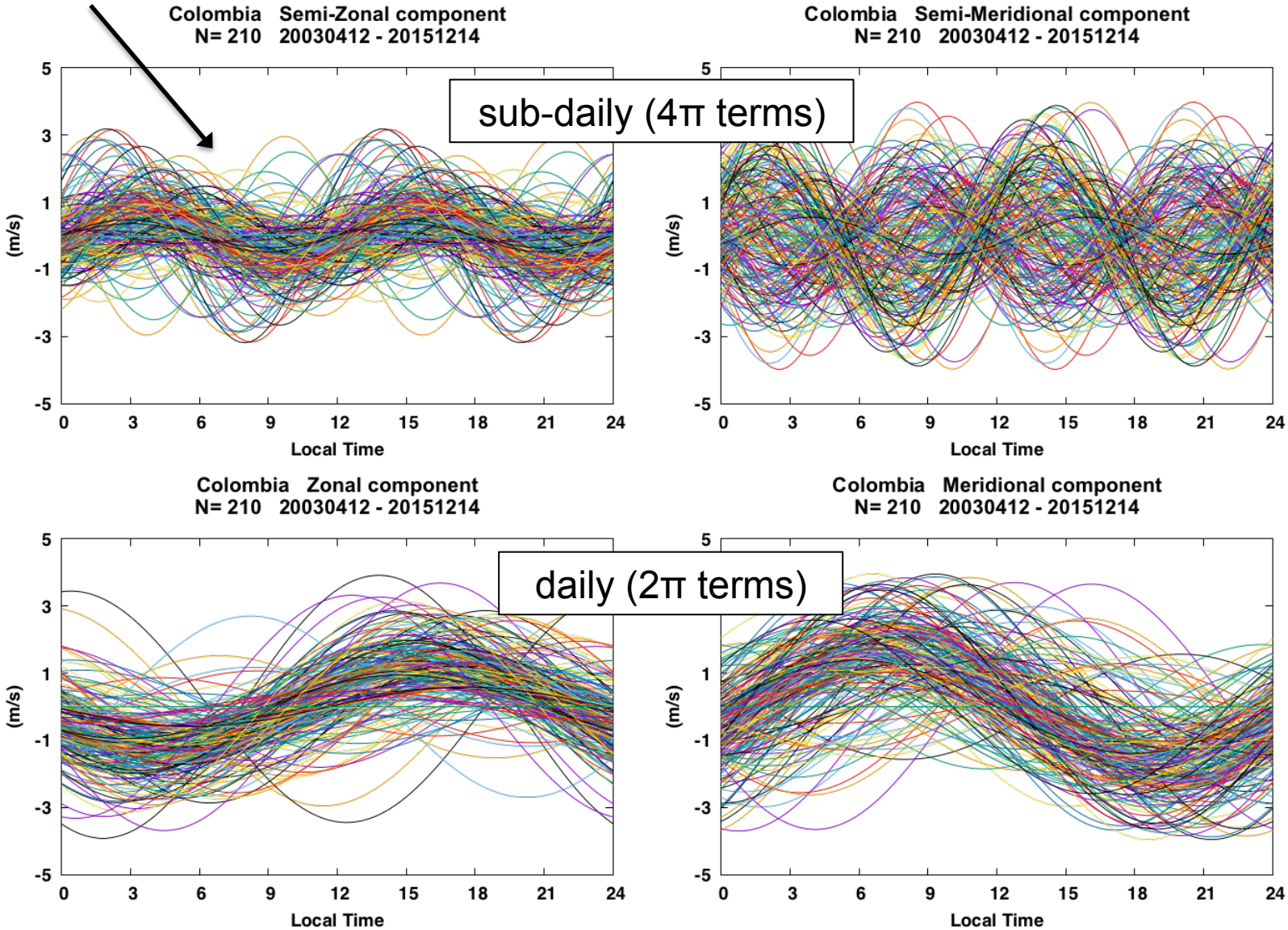


Offshore of Colombia 12N 74.75W

20030412-20160201

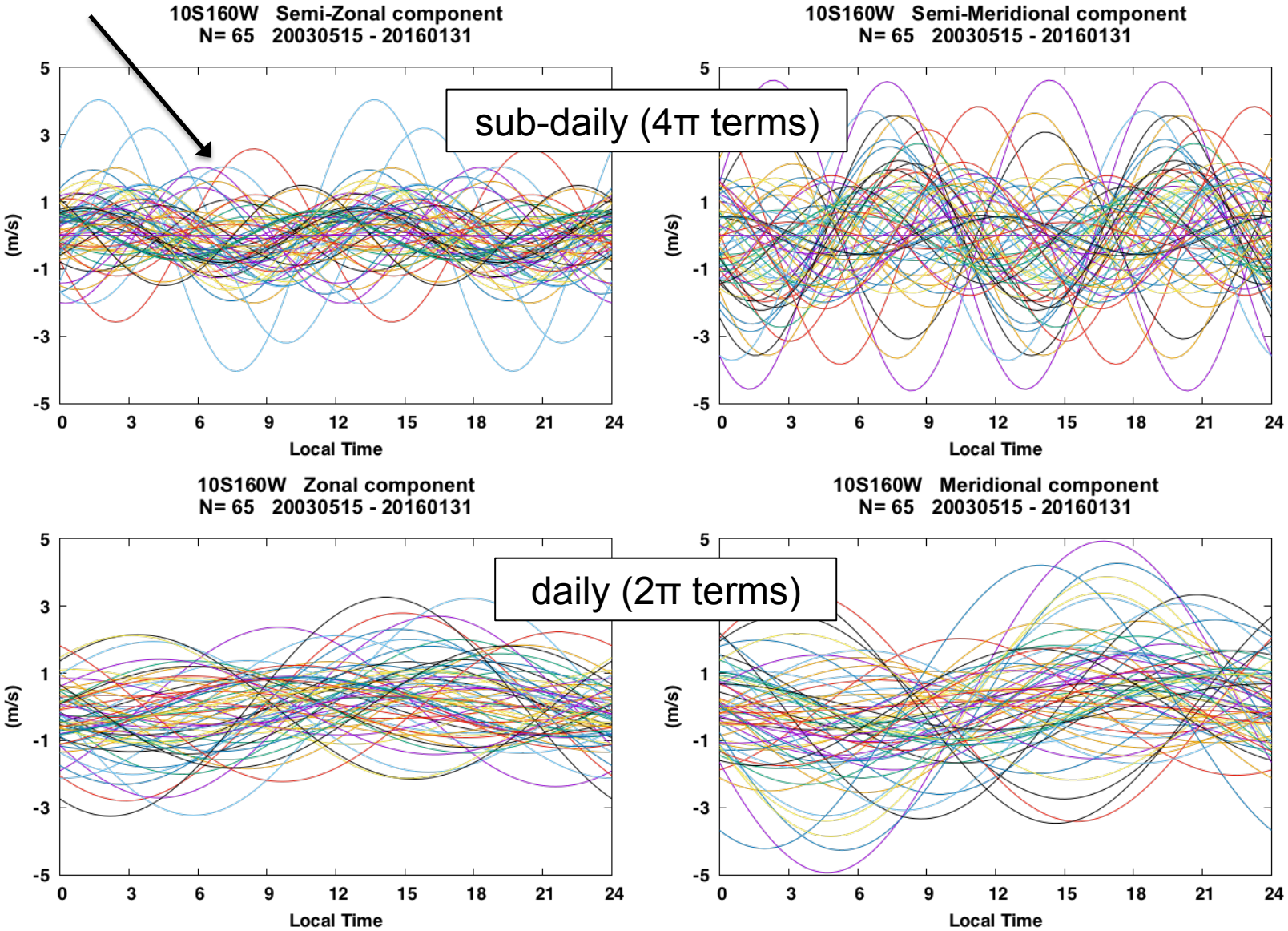
Similar diurnal variability in u and v, but with evidence of a weak sub-daily variability in *u*, but none in *v*

Offshore of Colombia
12N 74.75W 20030412-20160201



No diurnal variability stand out in *u* and *v*, but evidence of a weak sub-daily variability in *u* (perhaps?), but none in *v*

Middle of East Pacific
10S 160W 20030515 - 20160131



Examining the Constellation of Scatterometers and Radiometers for Diurnal and Sub-Diurnal Wind Vector Variability

Summary

The data record from multiple scatterometer (vector capable) and radiometer-derived (speed only) ocean surface wind data records was examined from 1999-early 2016, to locate and investigate regions of significant diurnal (and in cases, sub-diurnal) wind variability

TRMM winds (TMI) used as the intercalibrator until mid-2014, GPM GMI after that

More comprehensive regional analysis is ongoing

Future New/Existing Measurements:

ISS-RapidScat: Through October 2017
CYGNSS: Late 2016, wind only
ScatSat: ISRO follow-on to OceanSat2, late 2016. Similar orbit as MetOp, providing opportunities for simultaneous C/Ku-band winds