Creating an extended and consistent ESDR of the ocean surface winds, stress and their dynamically-significant derivatives for the period 1999-2022 - a MEaSUREs-funded proposal: Developing and evaluating the harmonized retrievals of wind and stress

Svetla Hristova-Veleva[1], Mark Bourassa[2], Scott Dunbar[1], Alexander Fore[1], Thomas Kilpatrick[2], David Moroni[1], Larry O'Neill[4], Ernesto Rodriguez[1], Bryan Stiles[1], F. Joseph Turk[1], Douglas Vandemark[5], Alexander Wineteer[1], P. Peggy Li, Brian Knosp, Quoc Vu, Philip Callahan[1], Roy S. Dunbar[1], Marc Emond[5], Robert Jacobs[4], Ethan Wright[2] Robin Vane[1], Joseph Jacob[1]

[1] - Jet Propulsion Laboratory, California Institute of Technology
[2] - Florida State University
[3] – University of California at San Diego
[4] - Oregon State University
[5] - University of New Hampshire, Durham

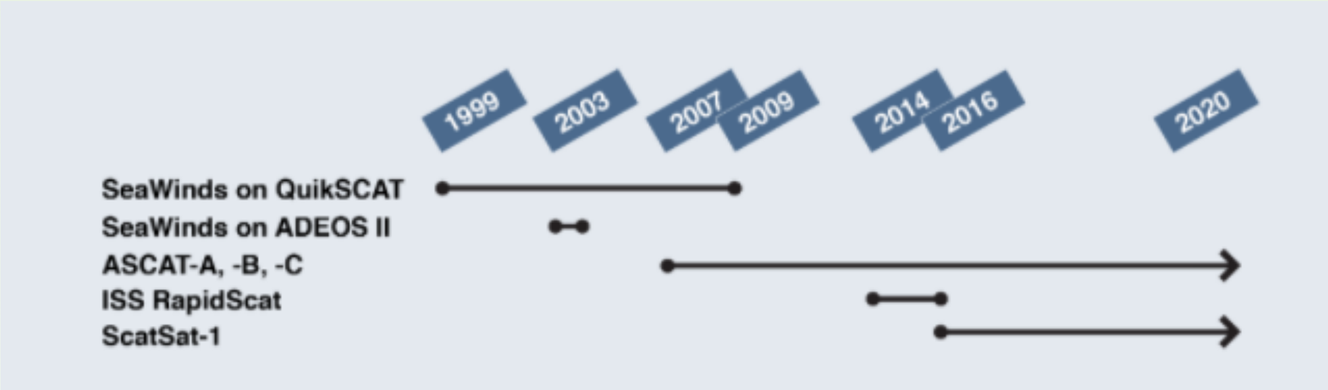
2021 IOVWST Meeting

- **Ocean surface winds are one of the key components of the Earth system**. Indeed, the ocean surface winds and stress are **Essential Climate Variables (ECV)** identified by the Global Climate Observing System (GCOS) [GCOS-200, 2016].
- They represent an unique measurement at the interface of two fluids – the ocean and the atmosphere. As such, they reflect the interactions at this interface and modify the boundary layers in each one of them.
- They are a major driver of
  - the ocean circulation through the surface stress
  - affect the air-sea interactions
    - provide fuel to the weather systems by modulating the sensible and latent heat fluxes.
    - modify the turbulent mixing in the upper levels of the ocean
  - Drive the atmospheric convection by providing dynamical forcing through the convergence of the near-surface winds
- Understanding these interactions is critical for improving ocean modeling and weather forecasting on a variety of spatial and temporal scales.

How we observe the wind vectors today

Space-borne scatterometer observations have been used extensively for over two decades to estimate the ocean surface winds.

- Satellite scatterometer observations have been made by a number of missions over a period of more than 20 years.
- Here we focus on the continuous scatterometer data record that started with the launch of NASA's QuikSCAT in 1999.



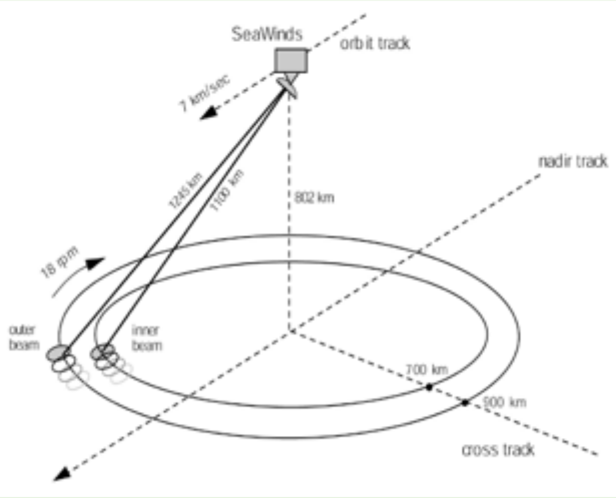
Launched between 1999 and 2016, these NASA, NOAA, ISRO and ESA scatterometers create a full, continuous picture of ocean surface winds that help improve weather forecasting.

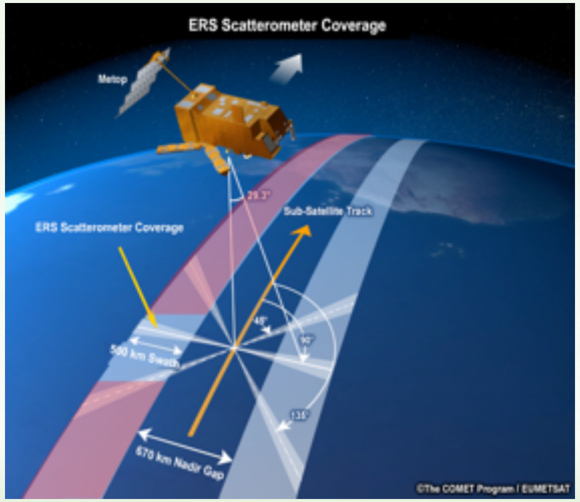
How we observe the wind vectors today

Missions	Diurnal Sampling Ascending-Descending
QuikSCAT	6:00am – 6:00pm
SeaWinds	10:30pm – 10:30am
ASCAT	9:30pm - 9:30am
OSCAT	12:00am – 12:00pm
RapidScat	*Diurnal Sampling*
ScatSat-1	~9:00pm – ~9:00am

- There is a significant diversity in the instrument geometry (incidence angle), spatial resolution and the mission-specific Local-Time-of-Day (LTD) of the observations.
- The scatterometer missions can be broadly classified in only two categories, defined by the:
  - channel-of-choice (the electromagnetic frequency)
  - the scanning strategy
- These are:
  - **the Ku-band, conically-scanning pencil** beam instruments (NASA and the Indian Space Research Organization - ISRO);
  - **the C-band, push-broom instruments -** EUMETSAT.
  - The pencil-beam approach provides a much wider swath than the push-broom one. However, the Ku-band that is used traditionally with this geometry has stronger sensitivity to rain (a negative impact)
- The two different measurement frequencies produce measurements that have different sensitivity to
  - atmospheric parameters (most importantly rain)
  - ocean surface parameters such as wind speed, sea surface temperature (SST) and sea state (e.g. significant wave height)

Instrument	Instrument Resolution	Retrieval Resolution	Incidence angles [°]	Scan Characteristics	Frequency [GHz]
QuikSCAT	25 x 7 km	25 & 12.5 km	46 & 54	Conical scan – One wide swath	Ku band (13.4)
SeaWinds	25 x 7 km	25 & 12.5 km	46 & 54	Conical scan - One wide swath	Ku band (13.4)
ASCAT	20 x 10 km	25 & 12.5 km	25 to 65	Push broom - Two narrower swaths	C band (5.25)
OSCAT	30 x 7 km	50 & 25 km	49 & 58	Conical scan - One wide swath	Ku band (13.5)
RapidScat	25 x 12km	12.5km	Variable	Conical scan – One swath (narrower)	Ku band (13.4)
ScatSat	30 x 7 km	50 & 25 km	49 & 58	Conical scan - One wide swath	Ku band (13.4)





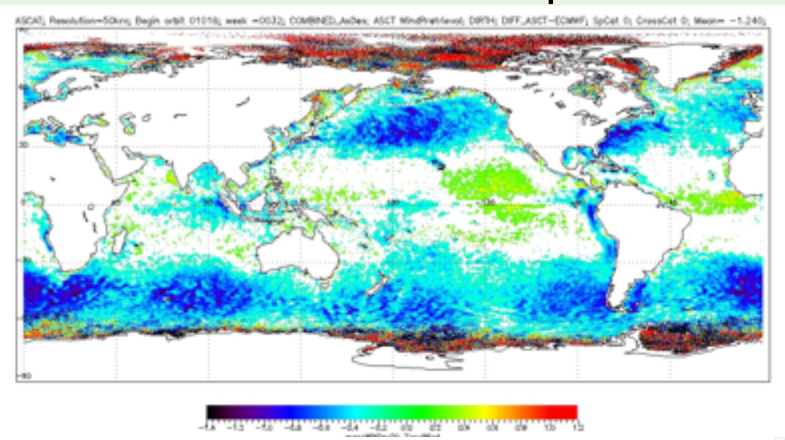
Schematic of the observation geometry for the two different observing systems: the rotating pencil beam of the Ku-band scatterometers (left) and the push-broom fan beam sampling by the C-band scatterometers (right)

Are the existing products consistent?

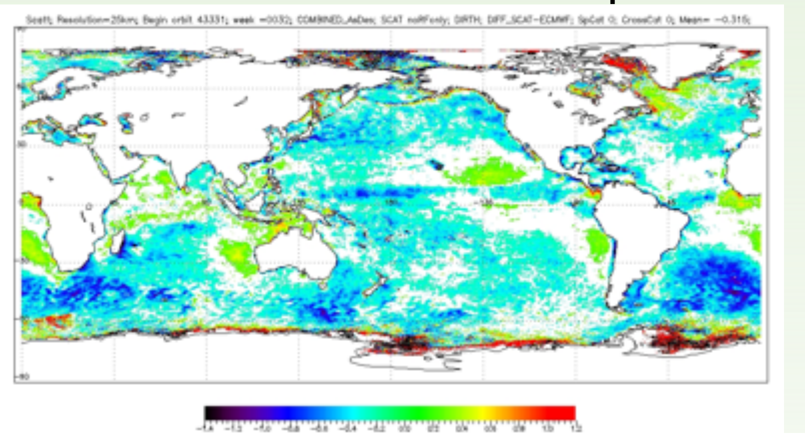
- Achieving consistency between the wind estimates from the different scatterometers has been a long-standing goal of the **International Ocean Vector Wind Science Team (IOVWST)**.

- Significant effort has gone into instrument calibration, algorithm validation and cross-evaluation. **Under most rain-free conditions the differences between retrievals from different instruments are small**.
- **Yet, these small differences have a systematic impact on power density spectra for vorticity and hence they are important in the context of derivative products.**
- **These discrepancies have geographical patterns that suggest differences in the estimated large-scale atmospheric circulation and in the estimated forcing of the ocean.**

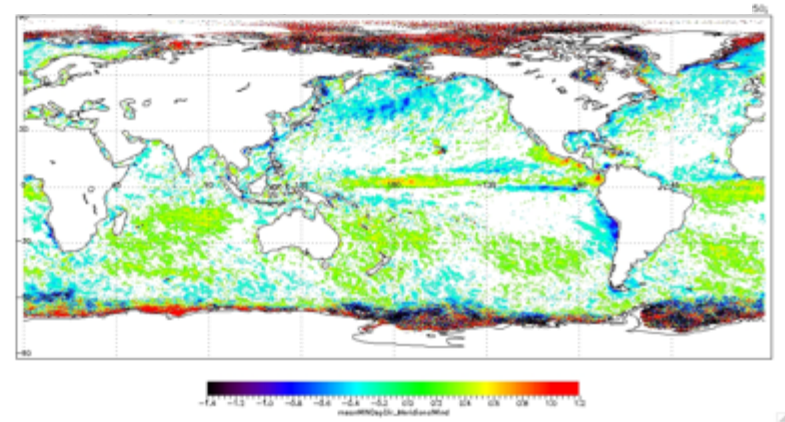
ASCAT-ECMWF – Zonal Wind Component



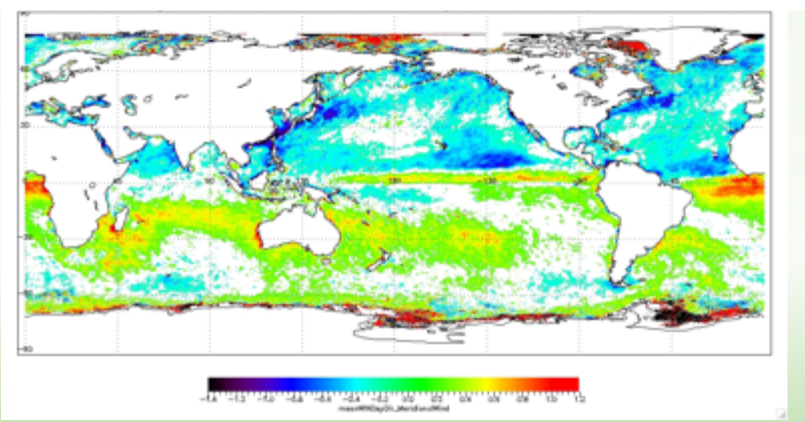
QuikSCAT-ECMWF – Zonal Wind Component



ASCAT-ECMWF – Meridional Wind Component



QuikSCAT-ECMWF – Meridional Wind Component



The goals of our MEaSUREs project

- After nearly 20 years of continuous scatterometer observations of the ocean surface vector winds by a variety of scatterometer instruments we are now positioned to address three issues of significant importance that still face the ocean surface vector wind user community:

1. **Creation of a consistent long-term Earth Science Data Record (ESDR)** that includes observations from all different missions while eliminating inconsistencies between them.
2. **Development of the dynamically-significant derived products** including the surface wind stress and the curl and divergence of the surface wind and stress. These products need to be generated at the highest possible resolution of the observations (i.e. at the swath - Level 2);
3. **Development of scatterometer-only user-friendly gridded products (Level 3 products)** of the wind, stress, curl and divergence of the wind and the stress. These new ocean wind L3 products will fill an unmet user need and complement existing L4 products, which have their own roles.

Products

Variable or other description	Spatial Extent & Resolution	Temporal Extent & Resolution	Remarks
Wind vector (EN and 10m): - Speed and direction - Zonal and meridional components (U and V) Stress vector: - Magnitude and direction - Zonal and meridional components Derivatives: - Curl and Divergence of the wind - Curl and Divergence of the stress	Resolution: - 12.5 km Spatial extent: - Swath	Temporal resolution: - Twice daily: ascending / descending Temporal Extent: - QuikSCAT – 1999-2009 - SeaWinds – 2003 - ASCAT-A – 2009 – present - ASCAT-B – 2014 - present - ASCAT-C – 2018 - present - RapidScat – 2014-2016 - ScatSat – 2017 – present	Level 2; Orbital data; Global coverage
Wind vector (EN and 10m): - Speed and direction - Zonal and meridional components (U and V) Stress vector: - Magnitude and direction - Zonal and meridional components Derivatives: - Curl and Divergence of the wind - Curl and Divergence of the stress	Resolution: 0.125^{0} Spatial extent: - Swath mapped on a grid		Level 3; Gridded; Global Coverage

Four different types of L2 products

- Generate four different **L2 products, each having both the ascending and the descending passes. These products are all targeted toward the specialists in the field. L3 products will be simplified and targeted toward the needs of the user community.**
- **The L2 products :**
  - **A file** that contains comprehensive information on the wind/stress estimates:
    - a comprehensive set of flags
    - the most necessary information on the uncertainty
    - EN wind speed and direction, wind zonal and meridional components
    - wind stress magnitude, wind stress zonal and meridional components
    - 10m real wind magnitude and direction, zonal and meridional components
    - File naming convention: qs_l2_wind_stress_RRRRR_vN.N_sYYYYMMDD-HHMMSS-eYYYYMMDD-HHMMSS.nc
  - **B file** an overlay (on the same grid as the main file) and contains fields to be **used by experts and by modelers**:
    - a comprehensive set of flags
    - a comprehensive set of fields regarding the observations that were used to produce the winds
    - **A comprehensive depiction of the uncertainty/ambiguity**
    - File naming convention: qs_l2_expert_RRRRR_vN.N_sYYYYMMDD-HHMMSS-eYYYYMMDD-HHMMSS.nc
  - **C file** that is an overlay (on the same grid as the main file) and contains model fields and other products for evaluation:
    - The model fields (ECMWF – ERA5) that were used to create the real 10m winds
    - The model equivalents to the scatterometer wind products, to be used for validation:
      - EN wind speed and directions, zonal and meridional components
      - Wind stress magnitude and components
      - Real 10m wind magnitude, direction and components
    - IMERG
    - Currents
    - File naming convention: qs_l2_ancillary_RRRRR_vN.N_sYYYYMMDD-HHMMSS-eYYYYMMDD-HHMMSS.nc
  - **D file** that is an overlay (on the same grid as the main file) and contains the derivative fields:
    - Curl and divergence of the EN wind
    - Curl and divergence of the stress
    - Curl and divergence of the 10m real wind
    - Same from ECMWF
    - File naming convention: qs_l2_derivatives_RRRRR_vN.N_sYYYYMMDD-HHMMSS-eYYYYMMDD-HHMMSS.nc

Does it matter if the scatterometer retrievals are consistent?

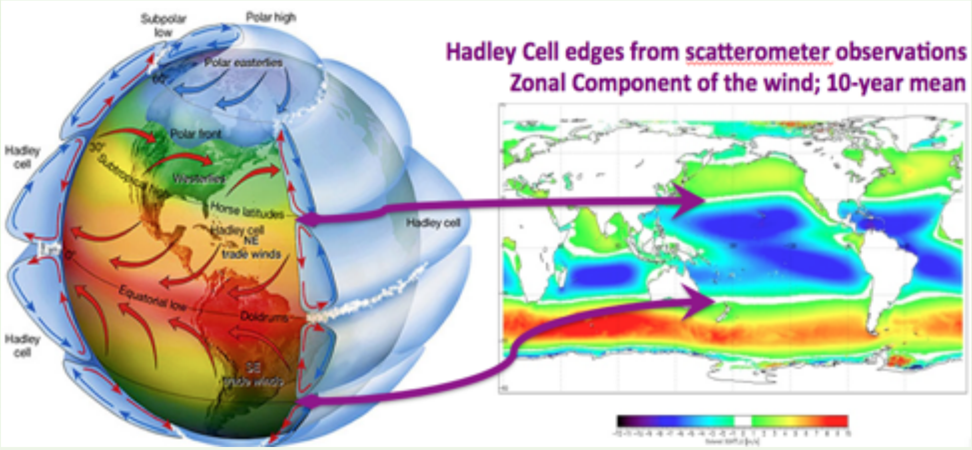


Fig. 1. Schematic of the large-scale circulation (left panel) and the zonal component of the surface wind as determined from QuikSCAT (right panel).

Fig. 2. Time evolution of the width of the combined Hadley cell as determined from the zero crossing of the mean zonal wind (from 1-year running averages)

- Recent evidence suggests that the tropics have expanded over the last few decades by a very rough 1^{o} latitude per decade, considered to be an atmospheric response to the observed tropical ocean warming trend. If continued, the expansion of the tropics (the widening of 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 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.
- In a 2015 study we determine the extent of the Hadley cell as defined by the subtropical zero-crossing of the zonally-averaged zonal wind component, determined from QuikSCAT observations (Fig. 1) - (Hristova-Veleva et al., 2015). We found:
  - The first half of the 10-year record shows two distinct cycles in the width of the Hadley cell while the latter part of the record shows a steady increase in the width, as has been shown by others (~1^{o}/decade, both south and north, for a total of about 2^{o} / decade);
  - The two cycles in the 1999-2004 time period are likely a reflection of the modulation of the Hadley cell by the La Nina (1999) /El Nino (2002) events that dominated this period;
- To investigate the consistency in the trends and variability when determined by different scatterometers, we performed similar analysis of the Hadley cell using the wind estimates from ASCAT. **We found an apparent discontinuity in the signal when the data source changes from one observing system to another (Fig. 2). What is the reason? Diurnal signal or retrieval inconsistencies?**

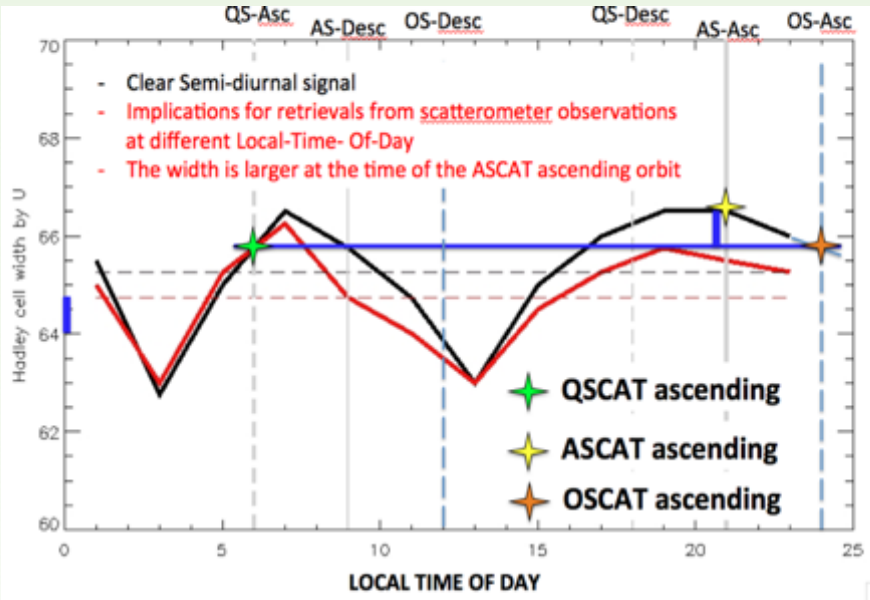
Creation of a consistent long-term Earth Science Data Record (ESDR) of the winds.

Sources of uncertainty

- **There are three main sources that contribute to the uncertainty of the global wind estimates.**
  - **Diurnal variability of the winds**
    - Previous research clearly indicated that **there is diurnal variability of the winds, the diurnal signal having significant geographical variability** (e.g. Gille et al., 2005; Turk et al, 2021).
    - largely facilitated by the 7-month tandem QuikSCAT/SeaWinds missions in 2003. **The short record did not allow for in-depth understanding of the diurnal signal**.
    - The launch of the RapidScat mission in 2014 provided, for the first time a much closer look into the diurnal signal as its non-sun-synchronous orbit allowed sampling the diurnal variability, using observations from a single instrument. **This mission also did not operate long enough to allow de-convolving of the diurnal from the seasonal variability.**
    - Thus, even today, **we do not know well enough the diurnal variability of the winds, and the geographical variability of this diurnal signal, to allow us to properly isolate its contribution to the differences in the wind estimates from missions that observe at different Local Times of Day (LTD);**
  - **Differences in the observing systems**
    - frequency of the observations (Ku vs C band), with **possible differences in the physics of the relationship between the observations (σ^0) and the underlying winds**;
    - **instrument design and geometry** (push-broom vs pencil beam, variable incidence angles of the observations);
  - **Retrieval algorithms and assumptions - inconsistencies remain in the different components of the different retrieval schemes.**

NASA's ISS-RapidScat was launched on September 21st 2014. The ISS (International Space Station) orbit provided unique opportunity to help understand and untangle the diurnal signal.

Hadley Cell Width from RapidScat



Our analyses of the RapidScat observations showed the presence of a clear semidiurnal signal in the width of the Hadley cell.

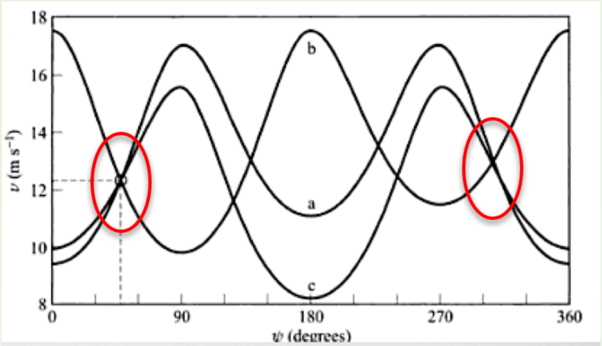
This helps better explain previously found discrepancies.

Creation of a consistent long-term Earth Science Data Record (ESDR) of the winds

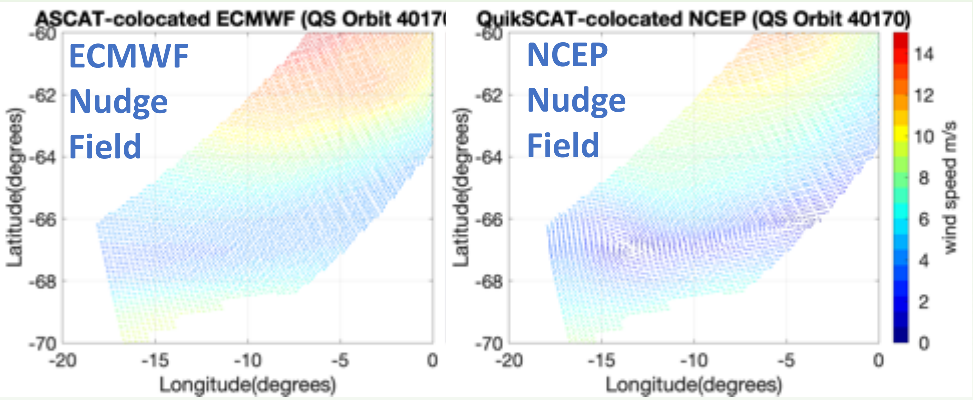
GOAL: addressing the uncertainty in Retrieval algorithms and assumptions – Our approach

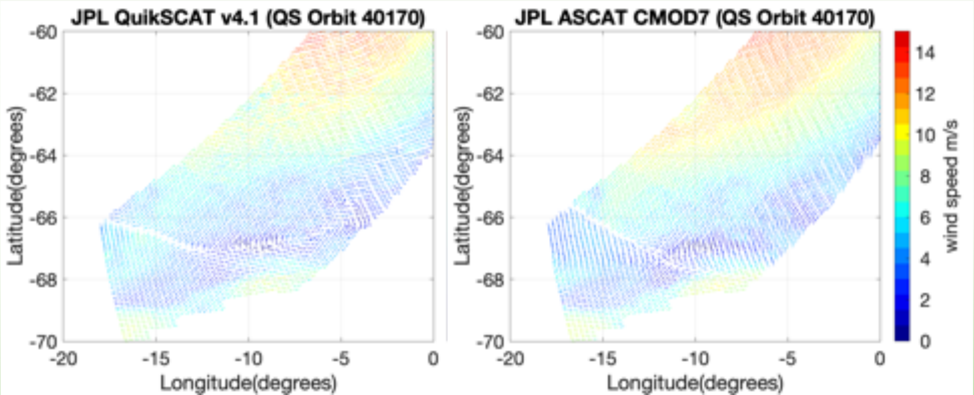
- **Retrieval algorithms and assumptions** – two main factors for inconsistencies
  1. **differences in the frequency-dependent and incidence angle dependent Geophysical Model Function (GMF)**.
  2. **differences in the retrieval algorithms, their assumptions and the use of ancillary data;**
     - The wind vector is estimated by retrieval algorithms that invert the GMF, given several σ0 measurements at different azimuth angles, typically obtaining a few possible solutions at each observation point (ambiguities).
     - Different producers make use of different techniques for selecting solutions from the ambiguities. A background wind and its spatial error estimate (from a global NWP model) is generally used to produce a unique and self-consistent wind vector field. In this process, the associated spatial filtering can be performed in a number of different ways (e.g., median-filter versus 2DVAR).
- **Addressing the second source of difference by using the JPL retrieval system**, with the same assumptions and ancillary data. Our analysis of collocated QuikSCAT/ASCAT observation revealed that the differences still persist, even when the same algorithm was used. This points to the first source of the disagreement as being a very important one –the differences in the GMF.
- **A critically important objective of our work is the need to revisit the GMFs.**

Ambiguities



Determination of wind velocity over an ocean surface using three scatterometer measurements: a) looking north; b) looking east; c) looking south. In this case, the two likely solutions are where the GMFs retrievals from all three observations agree - ~48^O and ~312^O .





Creation of a consistent long-term Earth Science Data Record (ESDR) of the winds. **(Stiles & Fore)**

Our approach to addressing the GMF – use ScatSat/ASCAT collocated observations

- One could assume that either the Ku-band GMF or the C-band GMF are the correct ones.
- Here we begin by postulating the that 10-year record of QuikSCAT retrievals provides the “truth”, outside rain.
- Hence, to achieve our main goal we need to modify the C-band GMF.
- We would then assume that the JPL ASCAT retrievals provide the “truth” in rain and use collocations to develop rain correction for the Ku-band scatterometers.

- **To develop the C-band GMF one needs collocate Ku and C-band observations.**
- The launch of ISRO’S ScatSat in an orbit very similar to that of ASCAT provided a great opportunity to obtain many collocations, in a variety of conditions.
- Decided to develop the modified C-band GMF, in a two-step process:
  - **use Neural Network (NN) approach to develop a “harmonization of the wind speed**” estimates from the two instruments, considering ScatSat to be the truth;
  - **translate the newly established relationships in the form of a GMF**.
- Figure 1 illustrates the results from the first step – the “harmonization of the winds speed”, each panel representing different steps in the process.
  - 1. initially, the 2D joint distribution of winds deviated from the ideal 1:1 line.
  - 2. illustrates the results after using NN in clear air and adjusting the ASCAT speeds to look like the ScatSat - removing the meandering in the maximum occurrence ridge (getting closer to the 1:1 line).
  - 3. used another NN to correct the ScatSat winds in rain, using ASCAT as truth.
  - This resulted in improved rain correction (3) when compared to the old rain correction (4) which did not use ASCAT winds!

Harmonization of the winds using collocated ScatSat/ASCAT
IOWVST 2021 -Stiles et al.; Fore et al.;

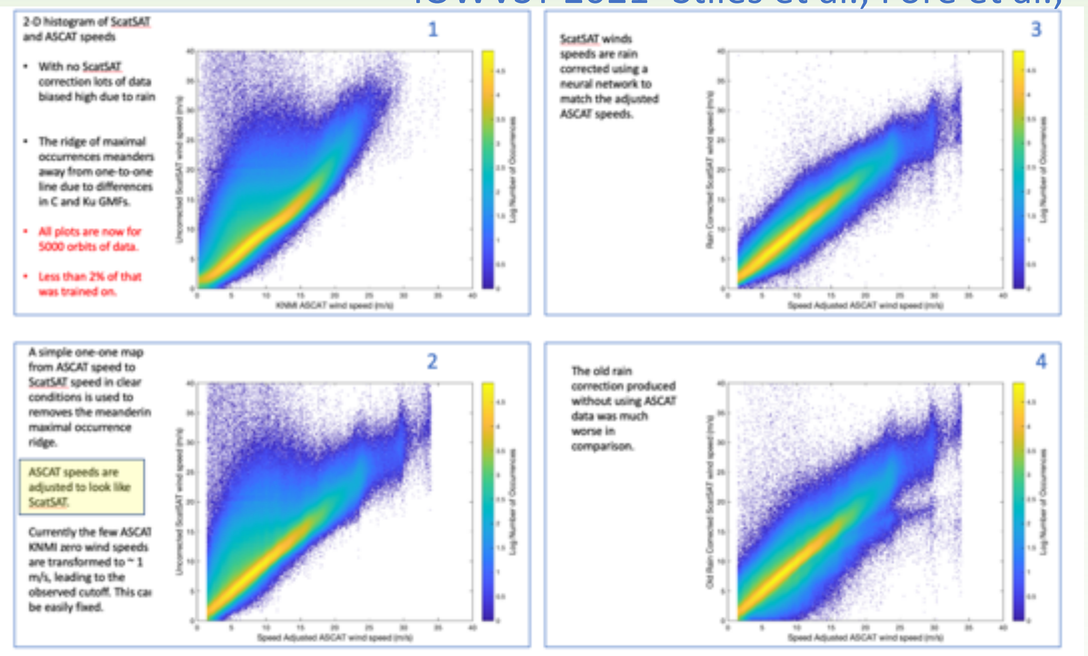


Figure 1: 2D histograms of collocated ASCAT and ScatSat wind speeds. The four panels show the statistics change from the original (top-left) with the implementation of NN harmonization in clear air (bottom-left), and then with the development of Rain correction for ScatSat based on ASCAT (top right). The top-right shows the best performance, an improvement over an older Rain correction (bottom-right).

Creation of a consistent long-term Earth Science Data Record (ESDR) of the winds. **(Stiles & Fore)**

Our approach to addressing the GMF – use ScatSat/ASCAT collocated observations (cont.)

Need to have consistency among retrievals from 3 different instruments:
Would the ASCAT winds with the new C-band GMF compare similarly to QuikSCAT as they do to ScatSat?

- Understanding these comparisons is very important before deciding to proceed with the C-band GMF we have already developed based on the ScatSat/ASCAT collocations, in clear air.
- Figures 1 and 2 illustrates the results from the ScatSat/ASCAT and QuikSCAT/ASCAT comparisons. Results revealed that there is some similarity in the QuikSCAT/ASCAT comparisons to that of ScatSat/ASCAT, a good news
- **However, we found that there are also important differences:**
    - In the “wiggles” – i.e. the variability in the comparison for different wind speed ranges;
    - In the impact of the harmonized winds:
        - **ScatSat/ASCAT comparison improved significantly with the use of the NN-derived modifications;**
        - **QuikSCAT/ASCAT comparisons did not improve as much and showed different variability with wind-speed ranges.**
- **These results are indications for non-linearity in the ScatSat observations, suggesting that there is a strong need to modify our approach.**

IOWVST 2021 -Stiles et al.; Fore et al.;

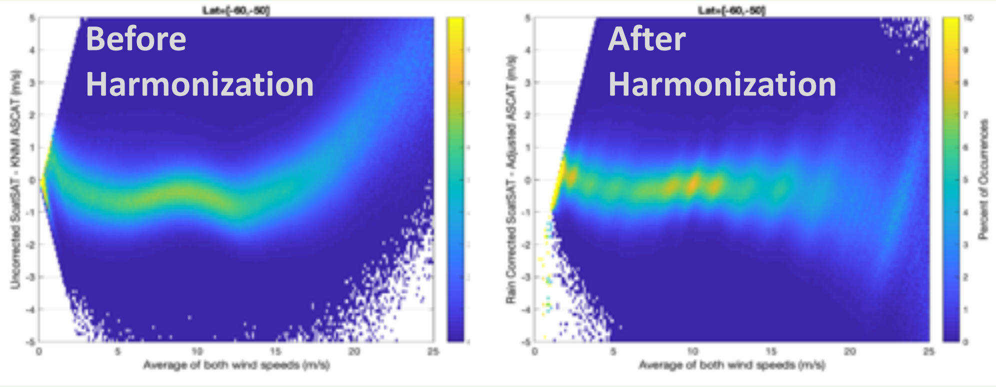


Fig. 1 ***ScatSat-ASCAT*** *biases in Southern Ocean (50 to 60 S). The average of both wind speeds is shown on the x-axis and the difference of these same two wind speeds is plotted on the y-axis.*

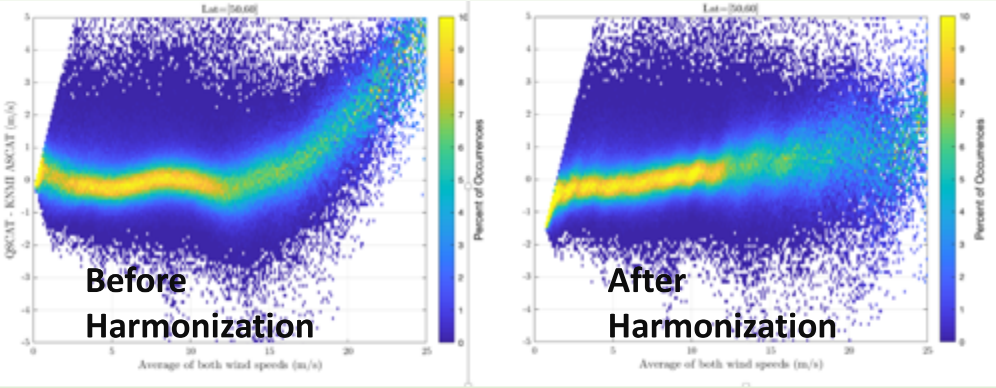


Fig. 2 Same as above except for the comparison is between collocated ***QuikSCAT and ASCAT*** *comparisons.*

Creation of a consistent long-term Earth Science Data Record (ESDR) of the winds. **(Stiles & Fore)**

Changing Our approach to addressing the GMF – use QuikSCAT/ASCAT collocated observations

- We follow the steps developed before:
  1. use NN to develop a function that harmonizes the independently-retrieved Ku- band (JPL algorithm, Ku_sst GMF) and C-band (JPL algorithm, CMOD7 GMF) wind speeds;
  2. based on that functional relationships, develop a modified C-band GMF, calling it now with CMOD7jpl.
- **The difference from before is in** :
  - **Using 3 years of QuikSCAT and ASCAT-A collocated data**, instead of using 1 year of ScatSat/ASCAT collocations
  - **Using ASCAT-A retrievals produced with the JPL retrieval**. Will call this product **ASCAT-A$_{\text{JPL-CMOD7}}$**
  - **Analyze the QuikSCAT/ASCAT biases as a function of SST** (for a given wind speed range, are biases a function of SST)
- Figure 1 illustrates the impact of the "harmonization" on the PDF distributions of the retrieved speed.

Achievement: a new C-band GMF was developed.

- We call that CMOD7jpl as it was developed starting with CMOD7 (KNMI) and modifying it to achieve winds that are "homogeneous" with QuikSCAT retrievals.
- Preliminary investigations confirm that the new GMF achieves the goal in retrieving winds from ASCAT observations with the same PDF as those, retrieved from collocated QuikSCAT retrievals

- **The ScatSat calibration (removal of non-linearity) will be achieved during this year. The new Rain correction will be developed at the same time. Both will use collocated ScatSat/ASCAT observations.**

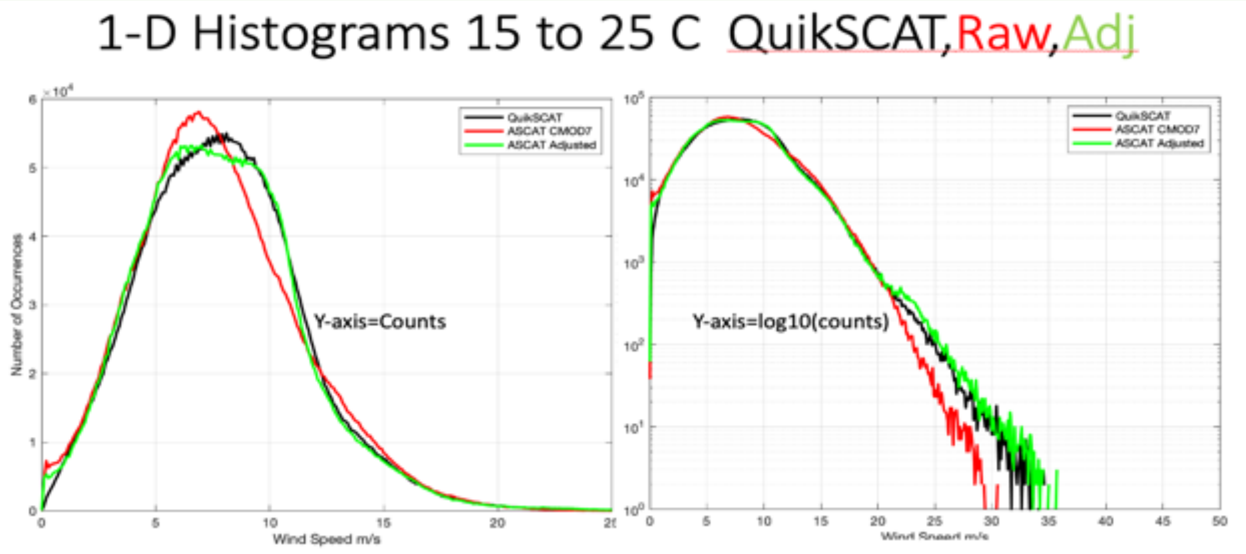


Figure 1. Univariate (single parameter) Probability Density function (PDF) of the retrieved speeds. Left panel show the PDF on a linear scale while the right panel shows the same on the log scale.

Other considerations:
Need to understand the impact of the sea state
(Bourassa and Wright)

Assess the validity of using buoys as a high wind speed source.

1. Does the sea state significantly affect the accuracy of high wind speed buoy observations?
   - Yes, both ASCAT and QuikSCAT wind speed residuals increase with SWH, for similar values of scatterometer wind speed, pointing that the problem is with the buoys and not the scatterometer.

2. What physical buoy characteristics affect the high wind speed readings?
   - Anemometer height plays a key role on the distribution of wind speed residuals.
   - QuikSCAT residuals show a clear pattern of increasing residuals with decreasing anemometer height.

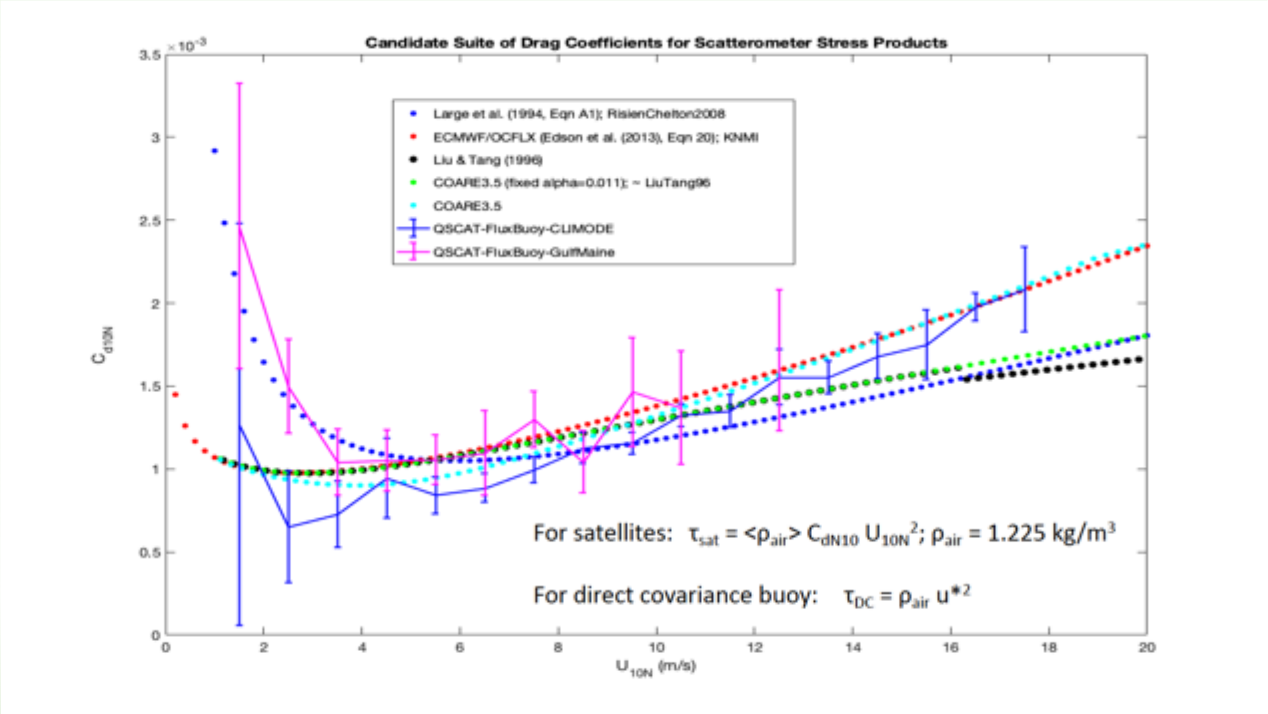
3. Under what sea-state and wind speed conditions are buoys a valid source of ground comparison data?
   - For combined SWH under 3 m and wind speeds below 12 m/s as long as swell is accounted for.
   - The location of the buoys matter, even if off-shore and in deep water, presumably because sea state and SST change.
   - There appears to be room for correction of low wind speed biases by knowing the swell characteristics.

Creation of a consistent long-term Earth Science Data Record (ESDR) of the **STRESS**.

(Vandemark & Emond)

- Bourassa et al. (2010 TOS)
  - *Recent studies find that* ***scatterometers, and presumably other wind-sensing instruments, respond to stress rather than wind****, accounting for variability due to wind, buoyancy, surface currents, waves, and air density.*
  - *This is a* ***tremendous advantage for improved accuracy in other turbulent fluxes because wind stress is more closely related to fluxes than wind:***
    - *stress observations are believed to account for all sea-state-related variability in surface fluxes of momentum, heat, and moisture.*
    - *Because sea state is not well observed from space, this approach should remove one source of error in studies of climate change.*

- Specifically, they highlight the consensus that
  - the satellite scatterometer provides a more direct measure of stress than of wind
  - **proper formulation of the sea state-dependent drag coefficient is critical, and perhaps most importantly for this proposal**
  - **the current mix of available wind stress data products needs to be improved**.
- **Related to this last point, a survey of satellite ocean wind stress measurement products that make some use of NASA or ESA satellite scatterometer data has been performed.**



Creation of a consistent long-term Earth Science Data Record (ESDR) of the **STRESS**

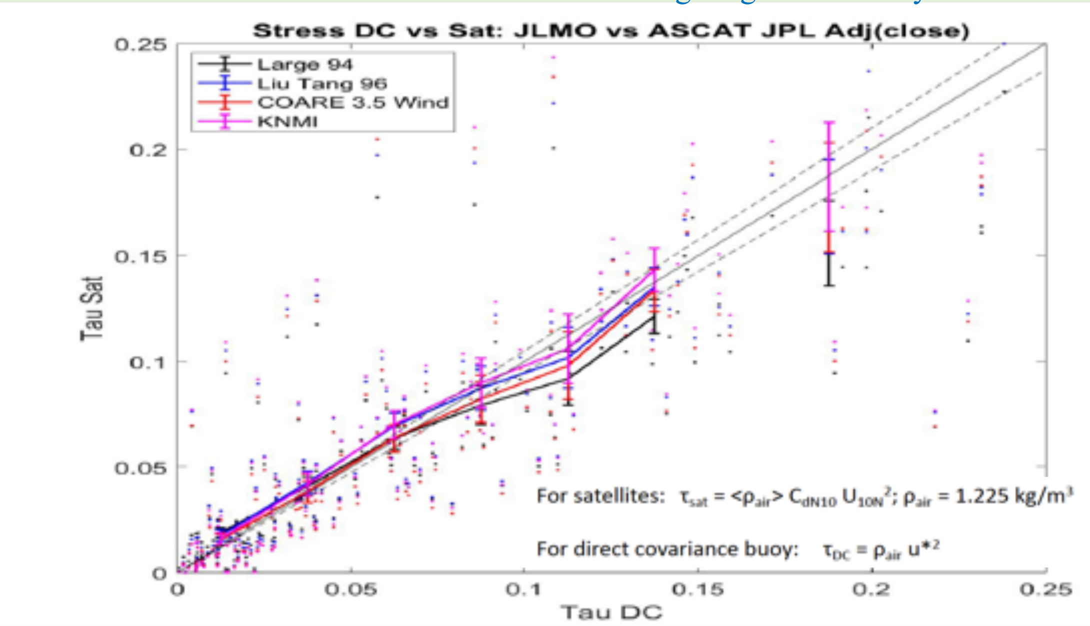
Validation of Wind and Stress with in-situ observations

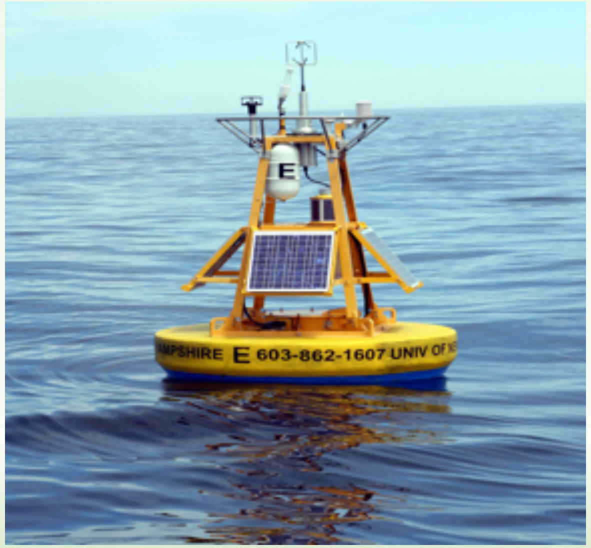
(D. Vandemark and M. Emond)

- Under this project, we are **employing and testing several candidate drag coefficient** models in developing the wind stress data products
- then **assessing their validity and impact on product uncertainty using satellite data matchups with in situ data**. (e.g. three differing drag coefficients. representing consensus (COARE4) and extremes (Large94, YTaylor2002) will be applied against in situ data.)

- Specifically
  - 2007-2009 scatterometer products and buoy matchups
  - Looking at
    - QSCAT v4.1 (JPL retrieval using KuSST)
    - ASCAT-$A_{JPL\text{-}CMOD7}$ (ASCAT JPL product using CMOD7)
    - ASCAT-$A_{JPL\text{-}CMOD7jpl}$ (ASCAT JPL product using CMOD7jpl – the JPL_adjusted CMOD7
    - ASCAT-A_{KNMI} (comping-up)
  - Rather limited amount of buoy data available in 2007-2009 window (just UNH Gulf of Maine data)
  - More data available in 2005-2006 (WHOI CLIMODE) and 2011-2020 (UNH, SPURS, NSF OOI)
  - Matchup criterion: search radius is 50 km and time window is 30 min or less; Archive the closest satellite sample as well as average of data within the search radius

Satellite stress with differing drag models buoy vs. satellite

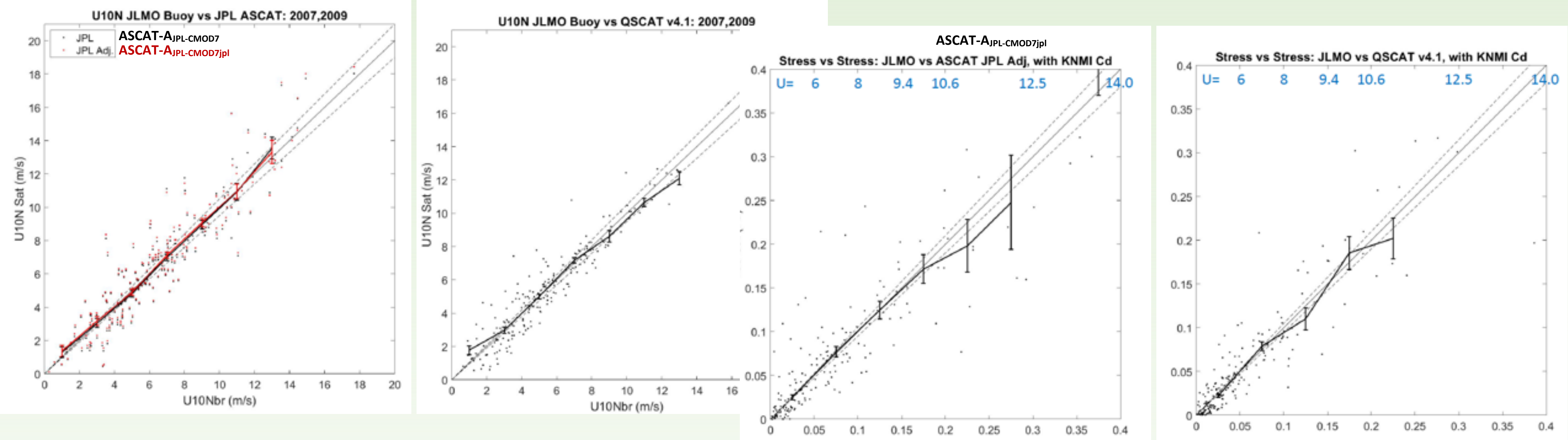




Limited buoy and scatt data in 2007-2009; Limited higher wind data
ASCAT-A = 243 matchups; QSCAT = 238

Creation of a consistent long-term Earth Science Data Record (ESDR).

Validation of Wind and Stress with in-situ observations (D. Vandemark and M. Emond)



- Wind and stress matchups at flux buoy deployments show no obvious systematic biases but the available data are limited. We have a) limited samples (~ 170) and b) only UNH buoy Gulf of Maine UNH data in the 2007-2009 window

Next:

- Will bring in Climode with QSCAT v4.1 to look at Cd model differences in U=3-15 m/s range more closely. Do the data allow us to find any statistically-significant difference between satellite stress vs. buoy data?
- Will also include and evaluate KNMI ASCAT vs ASCAT-JPL data in this framework.
- Will develop a Cd that expands to the higher wind speeds

Products ready for analyses by the team

Terminology

- **Products**
  - ASCAT retrievals produced by KNMI - **ASCAT$_{KNMI}$**
  - ASCAT retrievals produced by JPL - **ASCAT$_{JPL}$**
  - QuikSCAT and ScatSat retrievals will similarly be named **QuikSCAT$_{JPL}$** and **ScatSat$_{JPL}$**
- **GMFs**
  - QuikSCAT JPL/RSS Ku-band GMF – **KuSST**
  - ASCAT KNMI C-band – **CMOD7**
  - ASCAT JPL C-band – **CMOD7jplX where X stands for the version number; e.g. A, B, etc.**
- **Product/GMF combinations**
  - ASCAT KNMI product with CMOD7 – **ASCAT$_{KNMI\text{-}CMOD7}$**
  - ASCAT JPL product with CMOD7 – **ASCAT$_{JPL\text{-}CMOD7}$**
  - ASCAT JPL product with CMOD7$_{JPL}$ – **ASCAT$_{JPL\text{-}CMOD7jplX}$**
  - QuikSCAT JPL product with KuSST - **QuikSCAT$_{JPL\text{-}KuSST}$**
  - ScatSat JPL product with KuSST - **ScatSat$_{JPL\text{-}KuSST}$**

DATA LOCATIONS

Will be used to disseminate to the IOVWST for early evaluation and feedback

- **PO.DAAC**
  - ASCAT KNMI product with CMOD7 – **ASCAT$_{KNMI-CMOD7}$ - 12.5km KNMI coastal product available from PO.DAAC - https://podaac.jpl.nasa.gov/dataset/ASCATA_L2_COASTAL_CDR**
  - QuikSCAT JPL products with KuSST – **QuikSCAT$_{JPL-KuSST}$ – 12.5km v4.1 coastal – from PO.DAAC - https://podaac-tools.jpl.nasa.gov/drive/files/allData/quikscat/L2B12/v4.1**

- **The JPL server**
  - **How to access it**
    - Server: sftp://oceansftp.jpl.nasa.gov
    - user: will be provided to IOVWST members
    - pass: will be provided to IOVWST members
  - **What is on the JPL server**
    - **ASCAT-A data - /data/measures/ascat/**
      - **Revlists** - relating the orbit number with the date/time info
      - ASCAT JPL product with CMOD7 – **ASCAT$_{JPL-CMOD7}$** - jpl-cmod7-ascat-a-20070101-20101002
      - ASCAT JPL product with CMOD7$_{JPL}$ (CMOD7 adjusted to QuikSCAT) - **ASCAT$_{JPL-CMOD7jpl}$** - jpl-cmod7adj-ascat-a-20070101-20101002
      - **Merged/collocated data** - ascat-matchups-to-qscat-merged
        - single NetCDF files for the collocated QuikSCAT/ASCAT-A data. Data are on the QuikSCAT grid (available lat/lon) and have collocated ECMWF fields plus 3 types of collocated ASCAT data:
          - ASCAT-A $_{JPL\_CMOD7}$
          - ASCAT-A $_{JPL\_CMOD7jpl}$
          - ASCAT-A $_{KNMI\_CMOD7}$ (at 12.5km resolution)
    - **ScatSat - /data/measures/v1-beta**

Currently converting to the developed NetCDF file structures for dissemination to the IOVWST in the next two months:

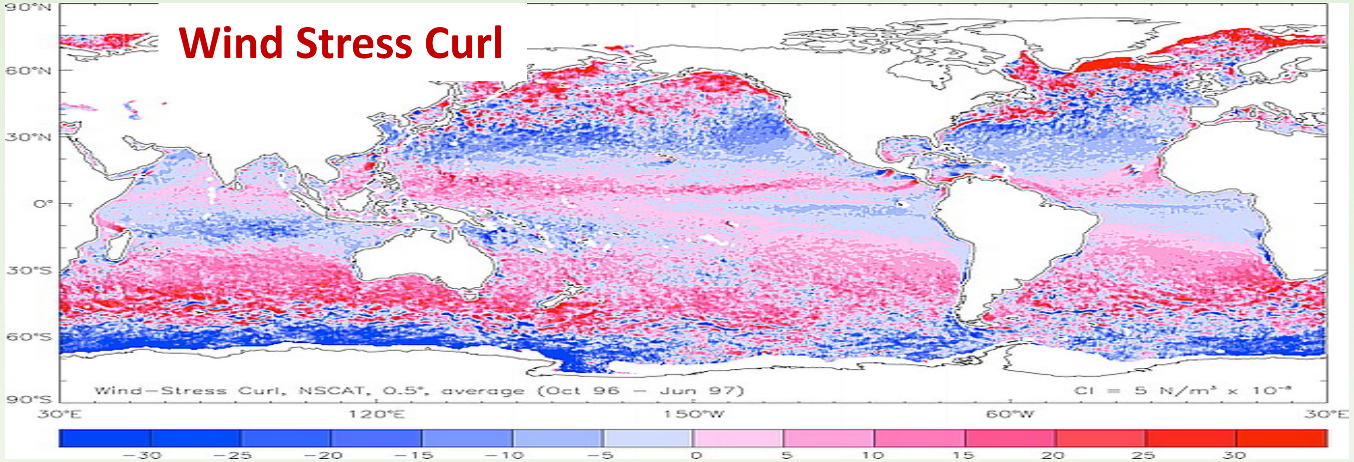
- File types and structure for each type was developed in collaboration with the entire MEaSUREs team

- Format/metadata/variable definitions were coordinated with PO.DAAC (David Moroni who is a team member)

Derivatives of winds and stress

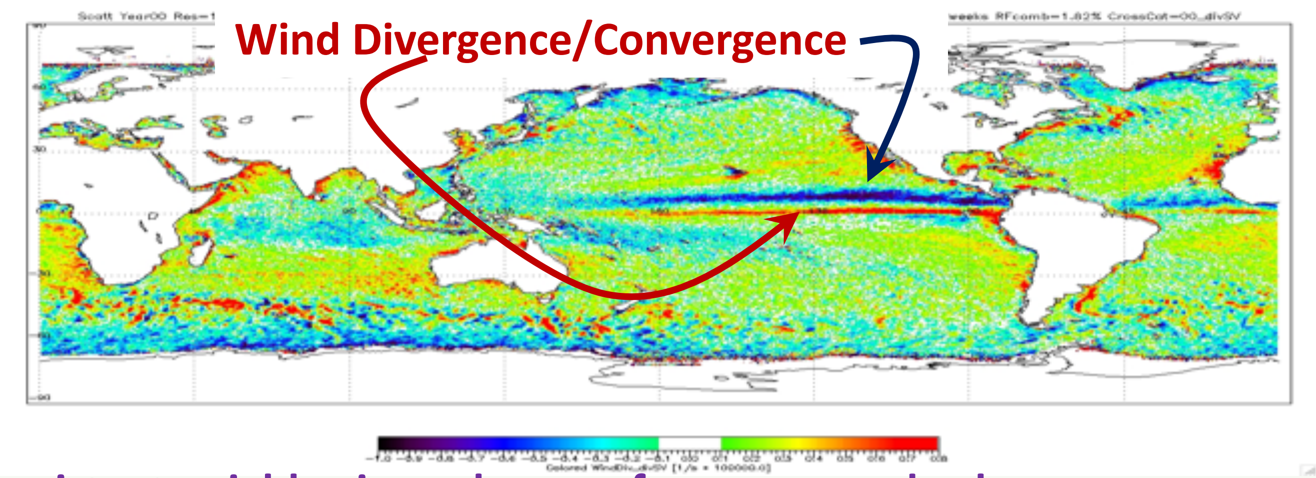
(O'Neill & Jacob; Bourassa & Wright; Hristova-Veleva; Kilpatrick; Rodriguez)

- ***Spatial derivatives*** **of surface winds and the wind stress are of paramount importance for many dynamical processes in the ocean and atmosphere.**
  - the mid-latitude basin-scale ocean circulation is driven by the **wind stress curl (**Sverdrup circulation),
  - rainfall anomalies are often coupled with low-level **wind convergence**
  - scatterometers provide practically the only means to estimate the surface derivative wind fields over most of the global oceans on a regular basis and **with higher resolution and accuracy.**
  - ***A data record consisting of carefully constructed estimates of these dynamically important fields is thus an opportunity to further our understanding of the general atmospheric and oceanic circulation.***



Milliff & Morzel, 2001

DOI: https://doi.org/10.1175/1520-0469(2001)058<0109:TGDOTT>2.0.CO;2



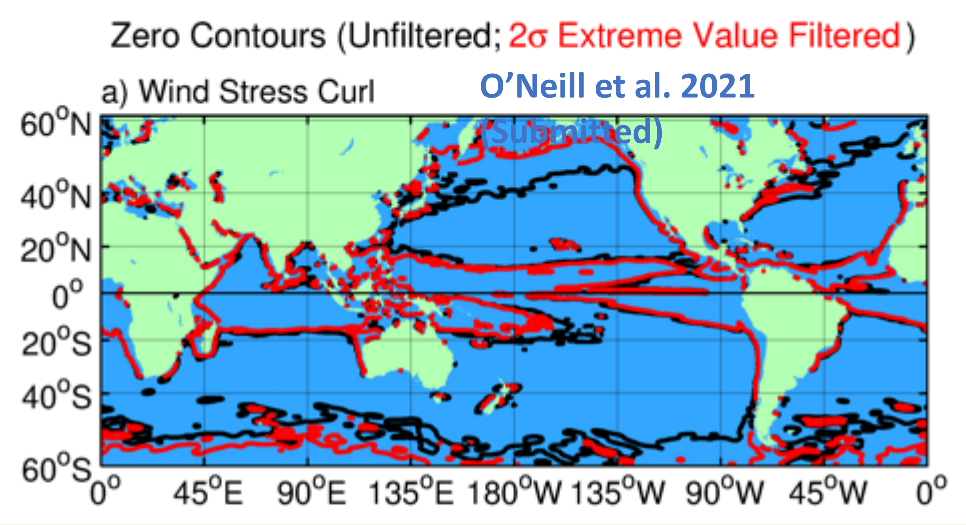
- **To avoid shortfalls of producing derivatives from time-inconsistent neighboring values, or from averaged values, we propose to compute the spatial derivatives from the L2 swath-based data for which all neighboring points come from the nearly-coincident observations in time (within several minutes).**
- **The big advantage of this approach is the ability to preserve and properly reflect the intensity of the small-scale and transient features (e.g. the frontal convergence).**

Derivatives of winds and stress: Sources of uncertainty

(O'Neill & Jacob; Bourassa and Wright; Hristova-Velleva; Kilpatrick; Rodriguez)

The different ways of computing the derivatives reflect different approaches to addressing two important issues:

- **Trade-offs between high resolution and noise**
- **The treatment of the rainy points**
  - Rain is the leading source of error in scatterometer wind retrievals
  - whether rain-flagged wind observations are used in computing derivatives has an enormously strong impact on resultant time-mean derivative wind fields
  - This is because precipitation tends to occur in regions of surface wind convergence and cyclonic vorticity so omitting rain-flagged wind observations results in a spatially-variable sampling bias of the wind field toward divergent and anti-cyclonic winds when averaged in time.
  - This effect is particularly acute in the mid-latitude storm tracks and tropical convergence zones, which are often regions of interest to researchers.
  - **How winds in rain are treated has a crucial impact on the time-mean derivative wind fields that has not been appreciated until recently.**
  - Vitally important to carefully consider how rain-flagged grid cells are treated
  - Because of the number of consequential issues which novice users must face when producing their own derivative wind fields, **we will develop a dataset of spatial derivative fields of surface winds and stress, employing our experience and understanding of the issues.**
  - This dataset will be distributed to the community, with documentation of the methodology. This represents an important departure from past releases of scatterometer wind data, for which wind vectors and rain flags are distributed to the community with little guidance on how to compute spatial derivatives.



The wind stress curl is instrumental in driving upper ocean circulation

The time-mean zero wind stress curl line to first order separates the mid-latitude ocean into distinct gyres

Removing just a few of the strongest weather events (~4% of all observations) from the wind stress curl drastically changes the position of these contours

One implication is that the ocean circulation is driven much more by intense storms than previously thought, and that satellite wind observations in these extreme events are critical to understanding large-scale ocean gyre circulation

Derivatives: Curl and Divergence - Approach

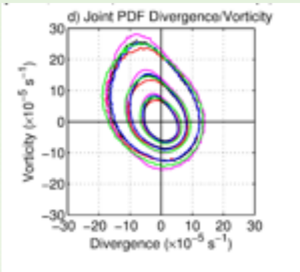
- Algorithms - we now have five candidates with different:
  - Treatment of the rain-flagged winds
  - Smoothing assumptions
  - Posting (at the actual locations of the observations versus at a regular latitude/longitude grid, but still orbital)!
- Approach:
  - Design a common netcdf file structure, containing
    - Curl and divergence,
    - of the ENW wind, stress, and 10m real wind,
    - from observations, and from collocated model (ECMWF) fields
    - with significant metadata
  - Produce estimates using all five algorithms, taking as input QuikScat and ASCAT observations over ~2 year period
  - Develop several metrics (including spectral analysis) and perform extensive inter-comparison
- At the end of the year, select 1 or 2 algorithms, depending on characteristics and proposed use.

- Having the five different algorithms, some run with different resolutions, will provide a measure of uncertainty! This is very important as there is no ”truth” for these products

Example of how we are evaluating different products: Strong correlation between surface wind divergence and vorticity

(O’Neill and Jacobs)

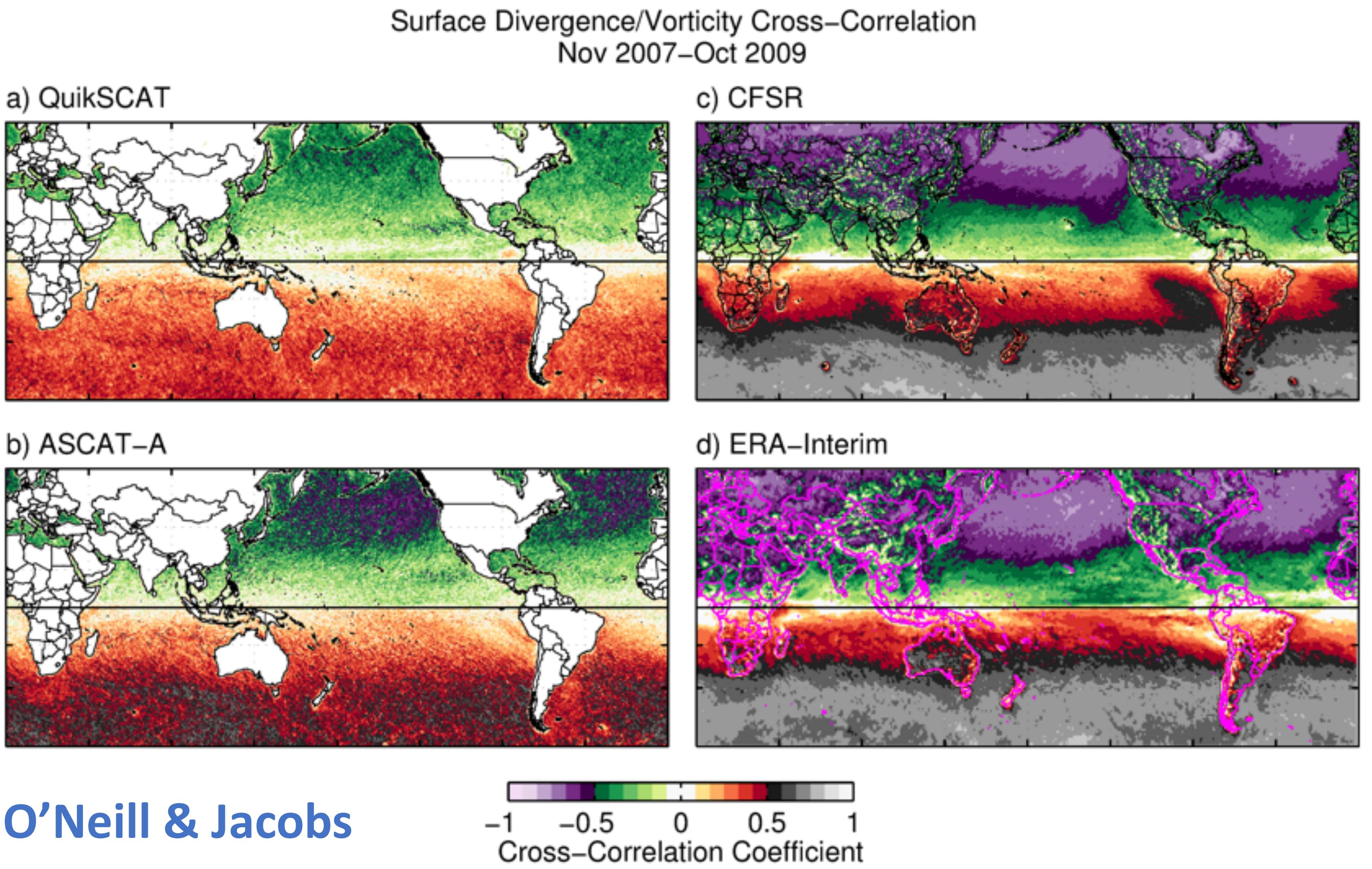
- Convergence and cyclonic vorticity extremes are fairly well correlated
- Fair correlations for weaker div/curl cases, which comprise the majority of observations
- *Main point: surface divergence and vorticity are correlated*



Scatterometers (left) and reanalyses (right) show a **strong and robust correlation between surface wind divergence and vorticity** away from the tropics that has not been reported previously.

The degree of correlation differs strongly between observations and models.

Investigation into the nature of the correlation and the source of these differences are currently underway as part of the MEaSUREs project (**O’Neill and Jacobs).**



O’Neill & Jacobs

10 m winds ("Real" winds) – A. Wineteer

- Scatterometers are sensitive to the roughness of the ocean's surface.
- Through geophysical model functions, we convert scatterometer measurements of roughness into "winds."
- But this surface roughness is not generated by the wind per-se, but instead by the wind stress, that is relative to surface currents.
- The wind stress is related to the wind speed by T = rho*Cd*(U10-Us)|U10-Us|. Note the difference between U10 and Us; this is referred to as the moving reference frame, or the "relative winds".
- By training scatterometer geophysical model functions to go between winds and surface roughness, we are really training to go between stress equivalent winds given a neutral boundary layer and surface roughness.
- Can we make an adjustment to our results to give something that more closely resembles "real winds?" **A two step process:**

1. Accounting for the Boundary Layer Stability

- COARE 3.5 was written to iteratively solve the equations of momentum, temperature, and humidity stratification in the boundary layer. It is a modern version of the LKB algorithm.
- Typically, this algorithm is used to solve for a wind speeds under neutral conditions, given wind speeds under non-neutral conditions. We aim to do the opposite.

- COARE requires inputs of:
  - Relative wind speed
  - Air temperature
  - Relative humidity
  - Surface air pressure
  - Sea surface temperature
  - Latitude
  - Rain rate
  - Wave height
  - Dominant wave phase speed
  - Boundary layer height
  - Short and longwave downward radiation

$$U(z) = U_s + \frac{U_*}{\kappa}\left(\ln\left(\frac{z}{z_o}\right) - \varphi\left(\frac{z}{L}\right)\right)$$

$$T(z) = T_s + \frac{T_*}{\kappa}\left(\ln\left(\frac{z}{z_{oT}}\right) - \phi\left(\frac{z}{L}\right)\right)$$

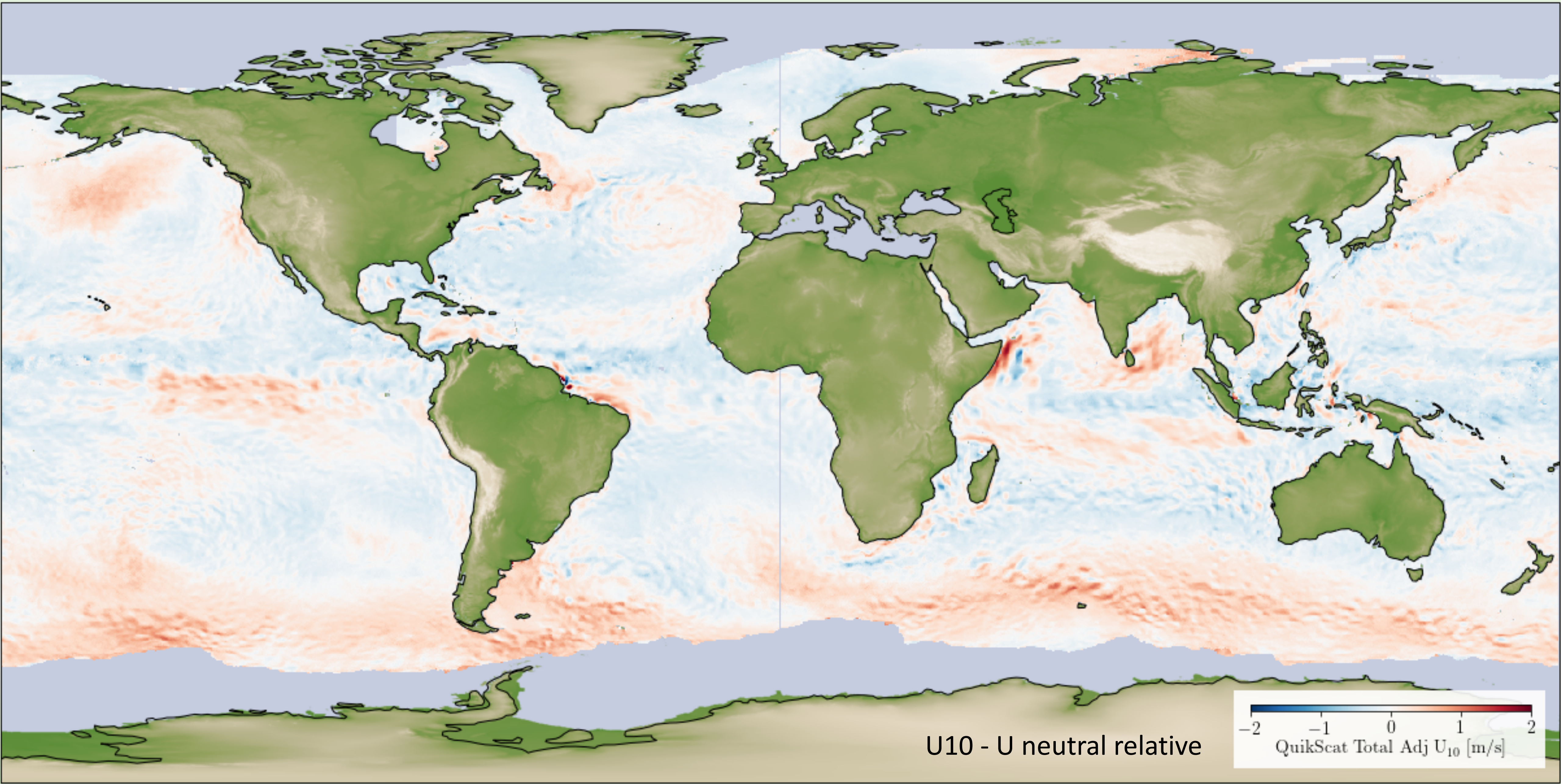
$$q(z) = q_s + \frac{q_*}{\kappa}\left(\ln\left(\frac{z}{z_{oq}}\right) - \phi\left(\frac{z}{L}\right)\right)$$

2. Accounting for Currents

- A simple vector addition of surface currents onto surface relative winds.
- There are a few potential sources of surface currents, perhaps the most well known here is Oscar.
- Oscar is the summation of geostrophic currents and Ekman currents.
  - Geostrophic currents computed from Altimetry.
  - Ekman computed from NCEP winds assuming a varied Ekman depth.
- GlobCurrent is the summation of geostrophic currents, Ekman currents, and Stokes drift.
  - Similar geostrophic
  - Ekman is computed using an empirically derived function (Rio 2004), with parameters fit across latitude and time (monthly).
  - Stokes is computed using wave spectra from WaveWatch III
  - Better fit to drifters than Oscar (although probably by design)

10m winds - Total adjustment: Preliminary results

A. Wineteer



QuikSCAT
RSCAT, SeaWinds
ScatSat
ASCAT
ALL

Project Schedule

[milestone list, or schedule chart for development and product delivery]

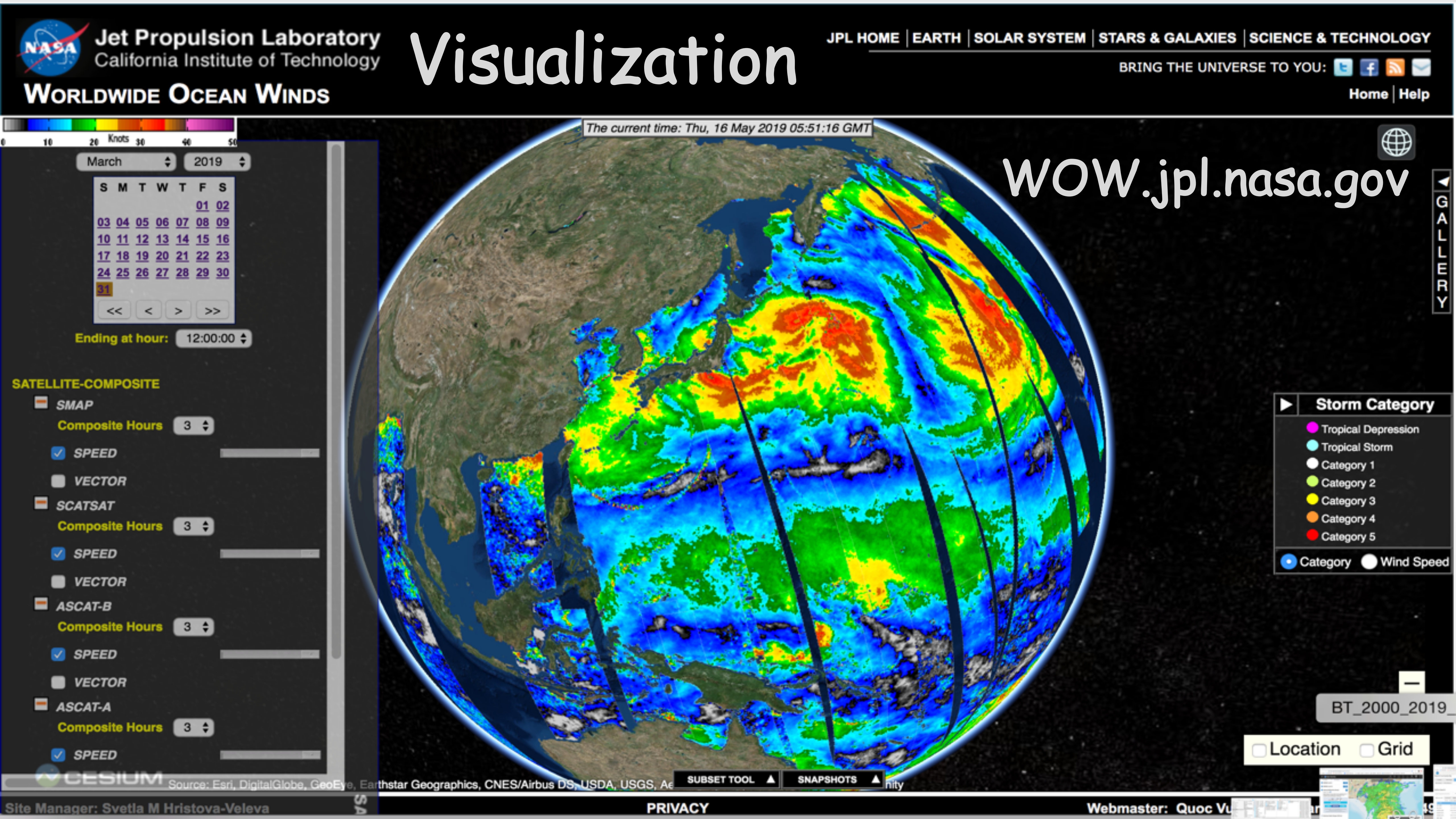
	Product	Tasks	Y1-Q12	Y1-Q34	Y2-Q12-	Y2-Q34	Y3-Q12	Y3-Q34	Y4-Q12	Y4-Q34	Y5-Q12	Y5-Q34
L 2	Winds	Product Formulation (all missions)										
		Calibration ScatSat Ku-band										
		Rain effects										
		- Ku-band										
		- C-band										
		GMF C-band										
		Producing 1 year of data										
		Producing entire record										
	Stress	Product Formulation										
		Algorithm development										
		Validation with the use of buoy										
		Producing 1 year of data										
		Producing entire record										
	Derivatives (Curl and Divergence)	Product Formulation										
		Development of multiple algorithms										
		Evaluation of features and alg. selection										
		Producing 1 year of data										
		Producing entire record										
L 3	Winds, Stress and Derivatives	Product Formulation										
		Product Design										
		Producing 1 year of data										
		Producing Entire record										
	Analyses	Consistency (e.g. PDF, spectra, etc.)										
		- developing metrics										
		- evaluation										
		Uncertainty; error propagation										
		Long-term trends - global and regional										
		Phenomena (Hadley Cell, El Nino, etc.)										
	Website	MEaSUREs project										
		WOW portal and features										
	Transfer to PO.DAAC	Products										
		Code and Documents										

What will our products do

- **The products we are developing are** needed to develop a “clean”, and consistent scatterometer-based long-term Earth Science Data Record (ESDR), unconstrained and unaliased by model data.
- These products are important to the user community as they will support a wide-range of the studies;
  - establishing the variability and trends of the ocean surface winds on a variety of spatial and temporal scales (diurnal, intraseasonal and decadal);
  - understanding the processes at the air-sea interface that drive the circulation in the ocean and the tropical atmosphere;
  - evaluating and improving models;

Visualization

WOW.jpl.nasa.gov



Outreach:
A Home page for our MEaSUREs project

- A desire is to develop a highly-engaging page that will introduce our project and will provide significant information in a concise and interactive way.
- The goals are two:
    - to develop content, and its graphical presentation to help a broader audience to better understand the climate science behind our MEaSUREs project;
    - to help scientists access data and help them quickly access the visualization tools.
- The current design provides:
    - an overview of scatterometry in general, and on the goals of our project
    - information about the different scatterometer missions that are part of our project. This includes comparative discussions on the similarity and the differences of the various technological designs employed by the different scatterometer instruments, including discussions on the advantages and the disadvantages for each one.
    - Overview of the products we are developing and why they are important

Background

Table 1. Summary of the proposed products

	Missions	Period	Resolution (spatial/temporal)	Variables
Level 2 and Level 3	QuikScat. SeaWinds. ASCAT-A, ASCAT-B, RapidScat; Scatsat-1	1999-2020 (when available)	L2 -12.5km; orbital L3 -0.125deg; twice daily maps	Wind vector (u, v speed); Stress vector(tau_x; tau_v; magnitude) Derivatives of wind and of stress

After nearly 20 years of continuous scatterometer observations by a variety of instruments we are now positioned to address three issues of great importance that still face the ocean surface vector wind user community:

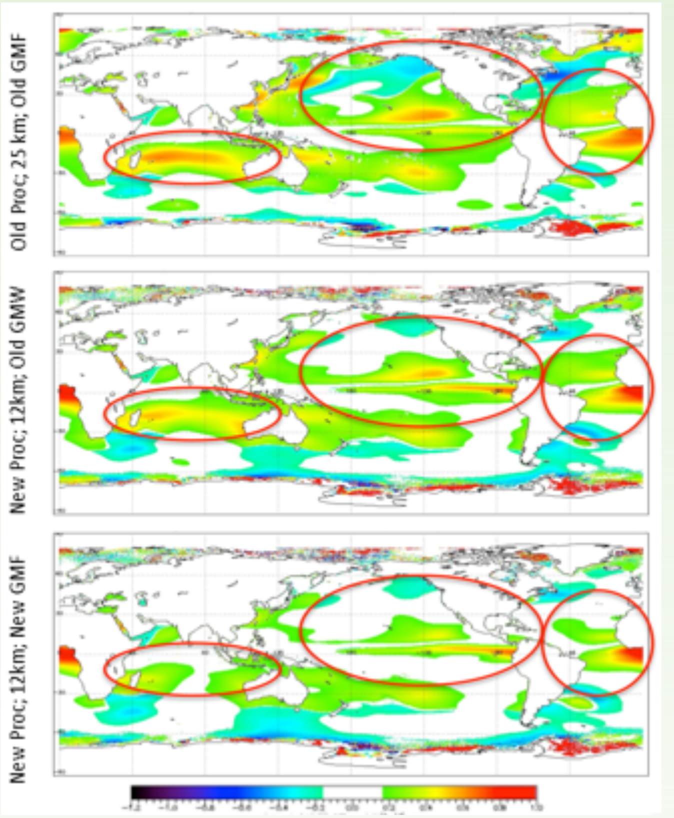
1. **Creation of a consistent long-term Earth Science Data Record (ESDR)** that includes observations from all different missions while eliminating inconsistencies between them.
2. **Development of the dynamically-significant derived products** including the surface wind stress and the curl and divergence of both.
3. **Development of scatterometer-only user-friendly gridded products (Level 3 products)** of the wind, stress, curl and divergence of the wind and the stress. These new ocean wind L3 products will fill an unmet user need and complement existing L4 products, which have their own roles.

Several factors introduce uncertainty in the wind estimates:
- the frequency and incidence-angle-dependent GMF,
- the retrieval (inversion) algorithm and all its assumptions,
- the frequency-dependent atmospheric corrections.

Table 2. Summary of Instrument/Mission characteristics

Missions	Diurnal Sampling Ascending-Descending	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
QuikSCAT	6:00am – 6:00pm																				
SeaWinds	10:30pm – 10:30am																				
ASCAT	9:30pm - 9:30am																				
OSCAT	12:00am – 12:00pm																				
RapidScat	Diurnal Sampling																				
ScatSat-1	~9:00pm – ~9:00am																				

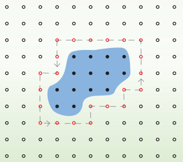
Instrument	Instrument Resolution	Retrieval Resolution	Incidence angles [°]	Scan Characteristics	Frequency [GHz]
QuikSCAT	25 x 7 km	25 & 12.5 km	46 & 54	Conical scan – One wide swath	Ku band (13.4)
SeaWinds	25 x 7 km	25 & 12.5 km	46 & 54	Conical scan - One wide swath	Ku band (13.4)
ASCAT	20 x 10 km	25 & 12.5 km	25 to 65	Push broom - Two narrower swaths	C band (5.25)
OSCAT	30 x 7 km	50 & 25 km	49 & 58	Conical scan - One wide swath	Ku band (13.5)
RapidScat	25 x 12km	12.5km	Variable	Conical scan – One swath (narrower)	Ku band (13.4)
ScatSat	30 x 7 km	50 & 25 km	49 & 58	Conical scan - One wide swath	Ku band (13.4)

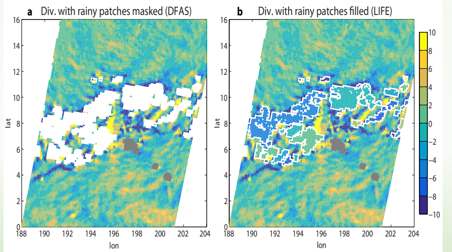


Rain is the leading source of error in scatterometer winds

We plan to implement and test a number of strategies that have been proposed for mitigating the effects of rain-flagged data in the derivative wind fields.

LIFE: The "Line Integral Fill holEs"





Note: **RSS's daily** (ascending/descending) **wind products** have very significant level of use.