Creating an extended and consistent ESDR of the ocean surface winds, stress and their dynamically-significant derivatives for the period 1999-2022. A MEaSUREs project

Step 1: L2 Product Formulation

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[4] - *Oregon State University*
[5] - *University of New Hampshire, Durham*

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

Table 2. Summary of Instrument/Mission characteristics

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)
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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
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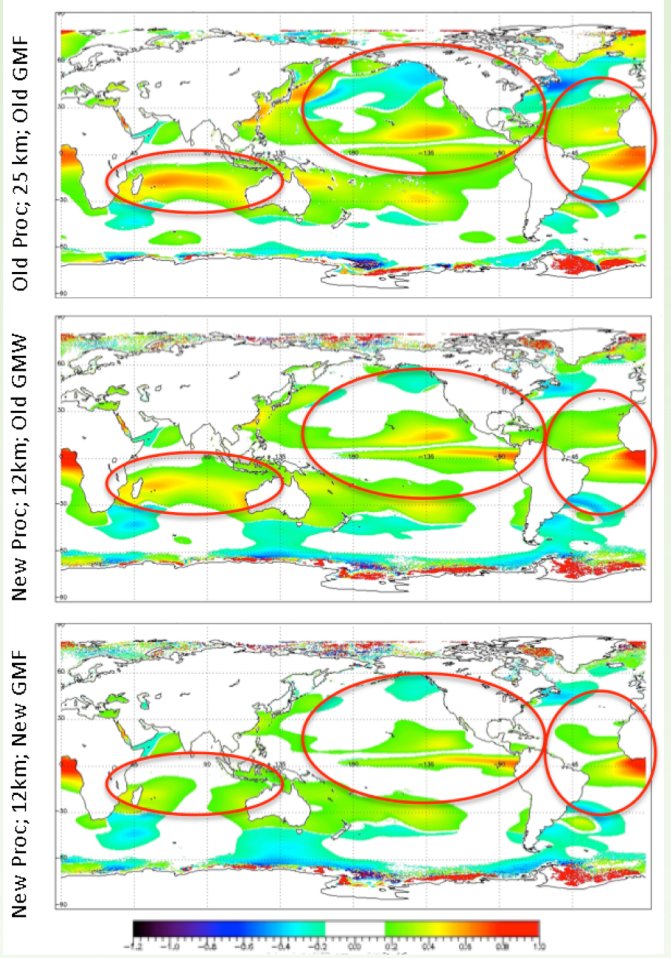
- **the retrieval (inversion) algorithm and all its assumptions,**
- **the frequency-dependent atmospheric corrections.**



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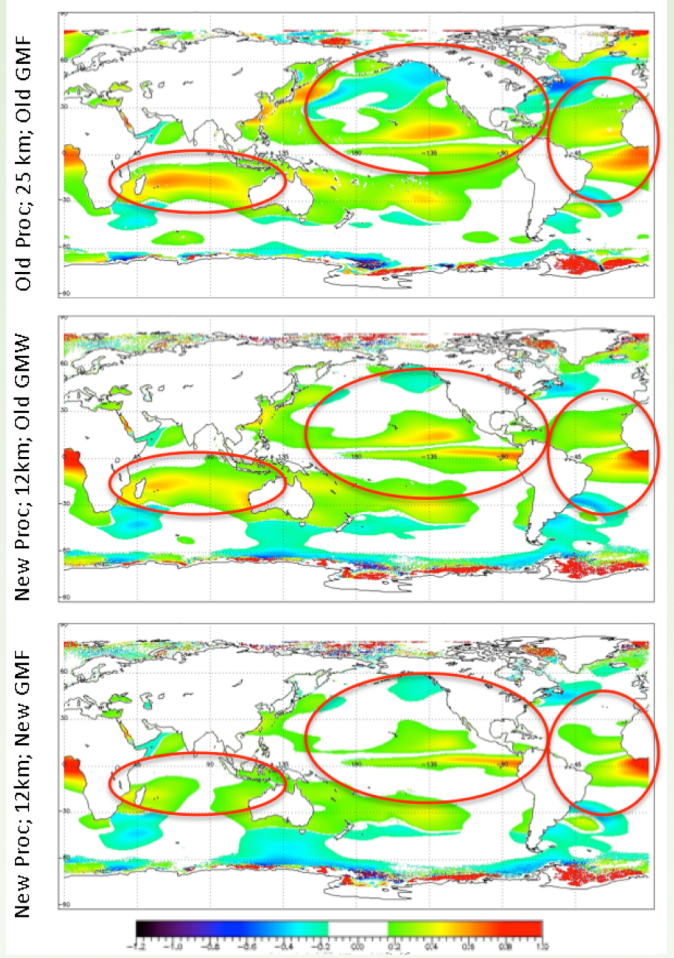

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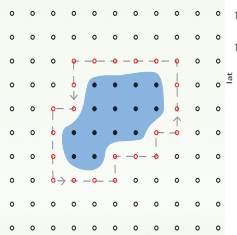
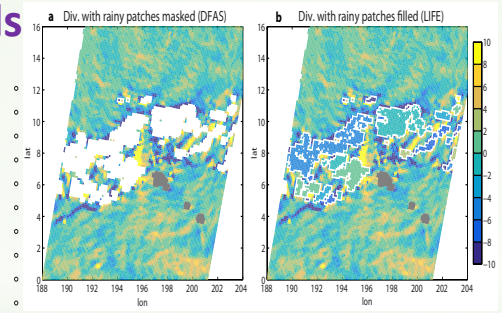
We plan to implement and test a number of strategies that have been proposed for mitigating the effects of rain-flagged data in the derivative wind fields.

LIFE: The "Line Integral Fill holEs"





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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.

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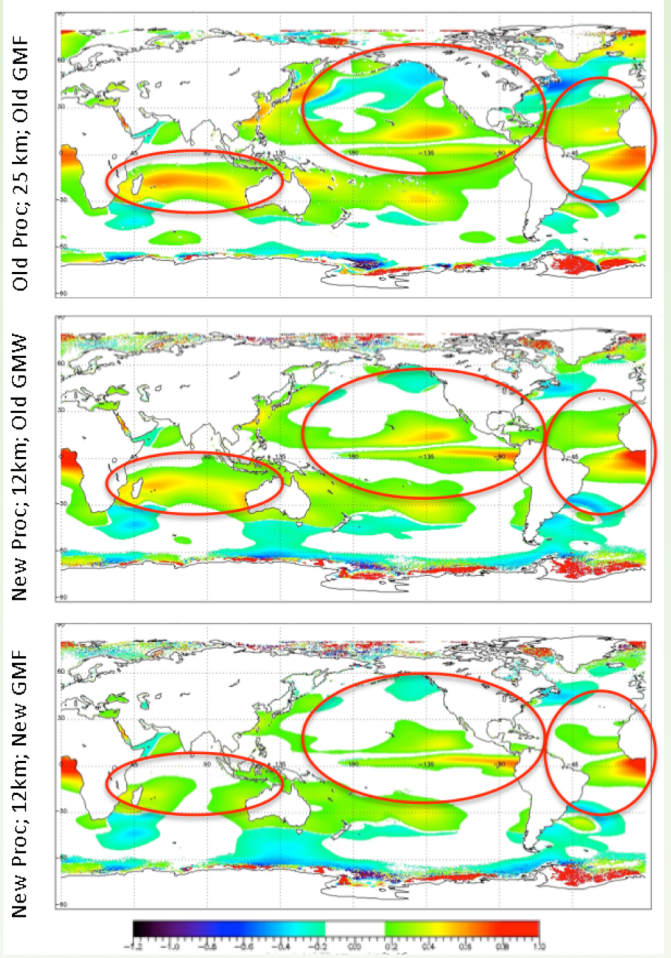

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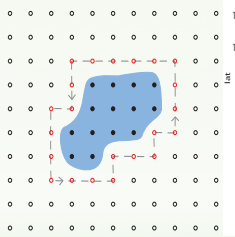

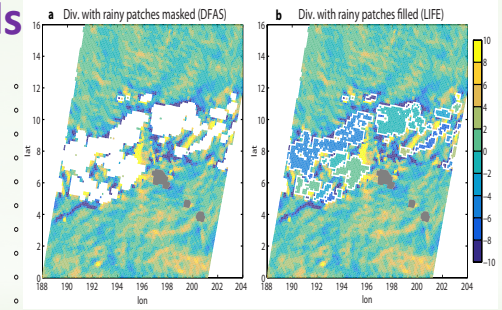

Note: **RSS's daily** (ascending/descending) **wind products** have very significant level of use.

Variable or other description	Spatial Extent & Resolution	Temporal Extent & Resolution	Remarks
Wind vector: - 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 - RapidScat – 2014-2016 - ScatSat – 2017 – present	Level 2; Orbital data; Global coverage
Wind vector: - 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

Project Schedule

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

QuikSCAT — RSCAT, SeaWinds
ScatSat
ASCAT — ALL

	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										

First year work:

L2:

- Winds:
  - C-band GMF development
  - **Rain effects in KU**
- Stress
  - **Algorithm development (QS)**
- Derivatives
  - We should start the work

Product formulation

- **L2 For Winds – finish by May**
- **L2 For Stress – finish by May**
- **L2 for derivatives - -II-**
- L3 – work on the formulation

Analyses: begin work on:

- Developing metrics

Establishing the MEaSUREs website:

- Design of the front page
- Initial modifications of WOW

QuikSCAT, ScatSat, ASCAT — RSCAT, SeaWinds — ALL

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Goal 1: Level 2 product formulation (metadata, parameters, formats) for all geophysical variables (wind, stress, derivatives of wind and stress) and for all instruments.

The objective was for the formulation to be done by May 2019 so that the design can be presented at the IOWVST meeting and the community can comment and contribute.

What should the product formulation do?

- **Define the products (the scatterometer-based estimates and related derived fields) to be included**
- **Determine the Flags**
- **Design the file structure**
- **Establish the Resolution**
- **Define the file formats**
- **Define a validation dataset?**

Wind and Stress

- ***Format - NetCDF4 Compressed***
- ***Resolution - 12km***
- ***What products to have:***
  - *Traditionally scatterometers have been providing the Equivalent neutral winds (ENW).*
  - **New: develop stress; produce 10m real winds; in addition to having ENW**
- ***How to describe the wind and stress fields****?*
  - *Traditionally by magnitude and direction.*
  - **New, including also the zonal and meridional components of the wind and the stress**
- ***How to represent ambiguities?***
  - Traditionally Ku-band scatterometer retrievals have included 4 ambiguities.
  - **Still open for discussions!!!** Discussed here are several other options.
    - keep full objective function ridge and speed as a function of direction?
    - maybe a coarse 2D PDF?
    - probability, speed and some measure of PDF width as a function of direction
    - **a polynomial fit – maybe the preferred option?**
    - a separate product with a full description of the PDF
- ***What types of flags to include?***
  - traditionally the products include many flags. While useful for experts, these flags are a source of confusion for ordinary users
  - **recommending the inclusion of overall quality level: value = 1(great), 2 (good), 3 (bad), 9 (missing). Follow ESIPs convention.**

Wind and Stress *(cont.)*

- ***How to present the uncertainties?***
  - in magnitude only? in u and v? –
  - **Decision: in all three of them - uncertainty in magnitude, in zonal and in meridional components (NOT in direction).**
  - **Decision: present the uncertainty in each wind vector cell, as a function of:**
    - **cross-track position, speed, retrieved wind direction relative to cross-track**

- ***Uncertainty - how to estimate it?***
  - The uncertainty is a gross representation of the probability space (ignores ambiguity):
  - ASCAT has gaussian errors (on speed (and vector components)).
    - We can use this to do **difference metrics of ScatSat wrt ASCAT and remove ascat errors.** Empirical?
    - **variogram**: compute variance versus collocation distance or times (between ASCAT and ScatSat); extrapolate down to zero in time and collocation offset (distance probably not issue).
    - **Build empirical uncertainty table as a function of these parameters: cross-track distance, speed, retrieved direction relative to cross-track**.
  - Empirical table to give u and v uncertainty errors
    - Train table with scatsat / ascat; use some other reference to map it onto other scatterometers.
    - possible other references: rapidscat; buoys

Wind and Stress *(cont.)*

- ***How to include the ancillary data*** **(model fields and other observations) to use for validation and research**
  - **As a separate overlay**, interpolated in space and time to the observations
  - Include
    - NWP model fields
    - OSCAR currents
    - IMERG (v6.0) - the GPM product that uses a variety of observations (including PMW and IR) to produce global estimates of surface rain rate every 30 min.
- ***What models and which fields?***
  - Recommended to use model fields that have been propagated by the model for at least 6 hours. Do not use analysis fields as Data Assimilation tends to make the fields unphysical at analysis times and this relaxes out as the model propagates.
  - **ECMWF for validation**, research and ancillary data (**as a separate overlay**).
    - The model variables to be included are:
      - sst, air temperature, pressure, water vapor,
      - real 10m wind, stress, ENW.
    - Find a source of ECMWF that is:
      - consistent over the entire period;
      - high-resolution;
      - has not assimilated the scatterometer winds (again, use a short-term model forecast, not analysis)
  - **GFS for nudging** (**as part of the scatterometer product**): surface wind, sst

QuikSCAT – V4.0

- dimensions:: along_track = 3248 ; cross_track = 152 ; ambiguities = 4 ;
- variables:
  - double time(along_track) ;
  - float lat(along_track, cross_track) ;
  - float lon(along_track, cross_track) ;
  - float retrieved_wind_speed(along_track, cross_track) ;
  - float retrieved_wind_direction(along_track, cross_track) ;
  - float rain_impact(along_track, cross_track) ;
  - short flags(along_track, cross_track) ;
  - short eflags(along_track, cross_track) ;
  - float nudge_wind_speed(along_track, cross_track) ;
  - float nudge_wind_direction(along_track, cross_track) ;
  - float retrieved_wind_speed_uncorrected(along_track, cross_track) ;
  - float cross_track_wind_speed_bias(along_track, cross_track) ;
  - float atmospheric_speed_bias(along_track, cross_track) ;
  - float wind_obj(along_track, cross_track) ;
  - float ambiguity_speed(along_track, cross_track, ambiguities) ;
  - float ambiguity_direction(along_track, cross_track, ambiguities) ;
  - float ambiguity_obj(along_track, cross_track, ambiguities) ;
  - byte number_in_fore(along_track, cross_track) ;
  - byte number_in_aft(along_track, cross_track) ;
  - byte number_out_fore(along_track, cross_track) ;
  - byte number_out_aft(along_track, cross_track) ;
  - float gmf_sst(along_track, cross_track) ;
  - float distance_from_coast(along_track, cross_track) ;

Specific wind products

Common products ?

Summary of the QuikSCAT Level2 product – V4.0

Modified QuikSCAT-like as a result of the discussions

- dimensions:: along_track = 3248 ; cross_track = 152 ; ambiguities = 4??? ;
- **variables: (The exclusive ones – wind and stress; from observations and models)**
- float retrieved_wind_speed(along_track, cross_track) ;
- float retrieved_wind_direction(along_track, cross_track) ;
- **float retrieved_Uwind(along_track, cross_track) ;**
- **float retrieved_Vwind(along_track, cross_track) ;**
- float retrieved_wind_speed_uncorrected(along_track, cross_track) ;
- float ambiguity_speed(along_track, cross_track, ambiguities) ; ….????
- float ambiguity_direction(along_track, cross_track, ambiguities) ; ….????
- **float uncertainty_speed(along_track, cross_track); function of cross-track, speed, retrieved wind direction relative to cross-track) ;**
- ~~float uncertainty_direction();~~
- **float uncertainty_Uwind(along_track, cross_track): function of cross-track, speed, retrieved wind direction relative to cross-track) ;**
- **float uncertainty_Vwind(along_track, cross_track); function of cross-track, speed, retrieved wind direction relative to cross-track) ;**
- float ecmwf_wind_speed(along_track, cross_track) ;
- float ecmwf_wind_direction(along_track, cross_track) ;
- **float ecmwf_Uwind(along_track, cross_track) ;**
- **float ecmwf_Vwind(along_track, cross_track) ;**
- float retrieved_wind_stress_magnitude(along_track, cross_track) ;
- float retrieved_wind_stress_direction(along_track, cross_track) ;
- **float retrieved_tauX(along_track, cross_track) ;**
- **float retrieved_tauY(along_track, cross_track) ;**
- ~~float retrieved_wind_stress_uncorrected(along_track, cross_track) ; …… ????~~
- ~~float ambiguity_stress_magnitude(along_track, cross_track, ambiguities) ;…… ????~~
- ~~float ambiguity_stress_direction(along_track, cross_track, ambiguities) ;…… ????~~
- **float uncertainty_stress_magnitude(along_track, cross_track); function of cross_track, speed, retrieved wind direction relative to cross-track) ;**
- ~~float uncertainty_stress_direction() ;~~
- **float uncertainty_tauX(along_track, cross_track); function of cross_track, speed, retrieved wind direction relative to cross-track) ;**
- **float uncertainty_tauY(along_track, cross_track); function of cross_track, speed, retrieved wind direction relative to cross-track) ;**
- float ecmwf_wind_stress_magnitude(along_track, cross_track) ;
- float ecmwf_wind_stress_direction(along_track, cross_track) ;
- **float ecmwf_tauX(along_track, cross_track) ;**
- **float ecmwf_tauY(along_track, cross_track) ;**

First iteration:

- Includes the new products
  - Zonal and meridional components of the wind & the stress
  - Uncertainty in wind/stress magnitude and in components
  - All ECMWF counterparts

- All agreed: remove uncorrected wind stress, and ambiguities wind stress

Current L2 product for wind and stress

- dimensions:: along_track = 3248 ; cross_track = 152 ; ambiguities = 4??? ;
- **variables: (The exclusive ones – EN wind, 10m real wind, stress)**
- float retrieved_wind_speed(along_track, cross_track) ;
- float retrieved_wind_direction(along_track, cross_track) ;
- **float retrieved_Uwind(along_track, cross_track) ;**
- **float retrieved_Vwind(along_track, cross_track) ;**
- float retrieved_wind_speed_uncorrected(along_track, cross_track) ;
- float ambiguity_speed(along_track, cross_track, ambiguities);
- float ambiguity_direction(along_track, cross_track, ambiguities) ;
- **float uncertainty_speed(along_track, cross_track);**
- **float uncertainty_Uwind(along_track, cross_track):**
- **float uncertainty_Vwind(along_track, cross_track);**
- **float retrieved_wind_stress_magnitude(along_track, cross_track) ;**
- **float retrieved_wind_stress_direction(along_track, cross_track) ;**
- **float retrieved_tauX(along_track, cross_track) ;**
- **float retrieved_tauY(along_track, cross_track) ;**
- **float uncertainty_stress_magnitude(along_track, cross_track);**
- **float uncertainty_tauX(along_track, cross_track);**
- **float uncertainty_tauY(along_track, cross_track);**
- **float retrieved_wind10mReal_magnitude(along_track, cross_track) ;**
- **float retrieved_wind10mReal_direction(along_track, cross_track) ;**
- **float retrieved_Uwind10mReal(along_track, cross_track) ;**
- **float retrieved_Vwind10mReal(along_track, cross_track) ;**
- **float uncertainty_wind10mReal_magnitude(along_track, cross_track) ; ???**
- **float uncertainty_Uwind10mReal(along_track, cross_track) ; ???**
- **float uncertainty_Vwind10mReal(along_track, cross_track) ; ???**

Second iteration:

- Includes the new products
  - Zonal and meridional components of the wind & the stress
  - Uncertainty in wind/stress magnitude and in components
  - ~~**All ECMWF counterparts**~~
  - **All counterparts of the 10m real winds**

Legend:

- EN WIND
- STRESS
- Real 10m WIND

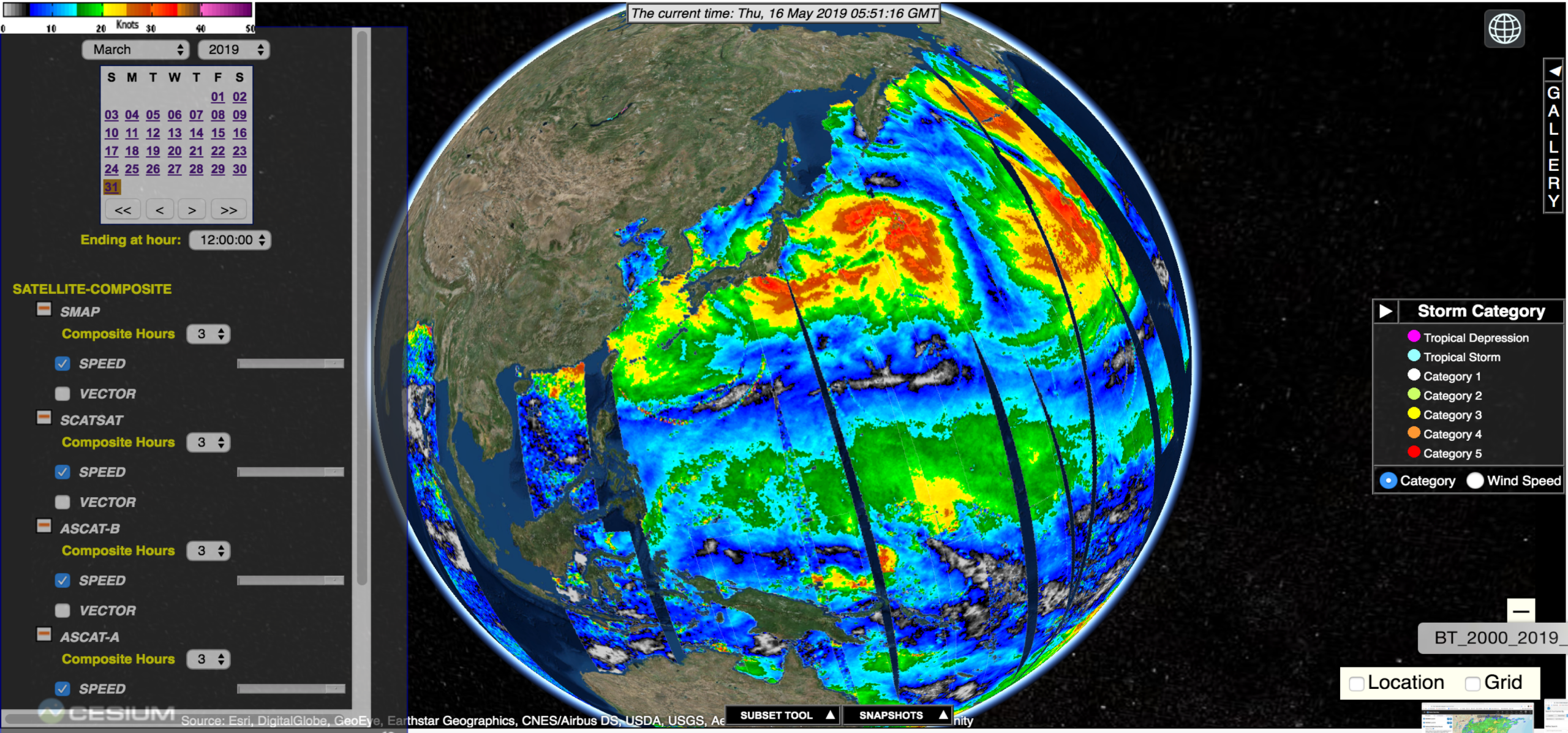
Derivatives: Curl and Divergence

- 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)!

- **Plan:**
  - **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.**

WORLDWIDE OCEAN WINDS

WOW.jpl.nasa.gov



Questions, discussions, suggestions

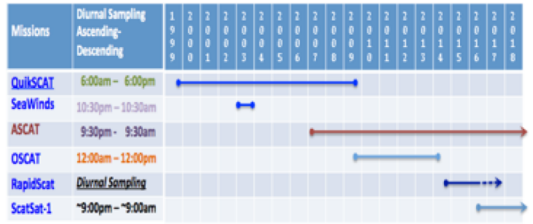
- We are looking for your input and guidance
- Please, come and visit our poster summarizing what was presented here
- We can continue the discussions there.

Background

Science Focus/Objectives

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 users:

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 **their curl and divergence**.
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.



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)
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ASCAT	20 x 10 km	25 & 12.5 km	25 to 65	Push broom - Two narrower swaths	C band (5.25)
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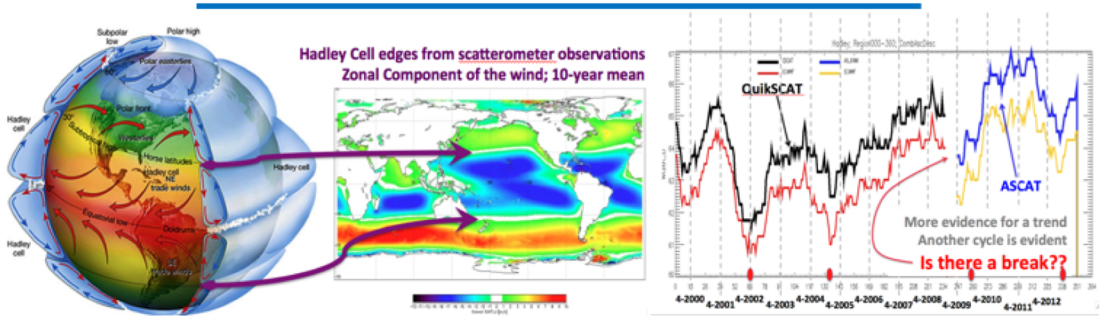


A diverse and long-term set of scatterometer observations. Need to create a consistent ESDR to study climate trends

Approach to ESDR Development

Goal 1: *adopt the IOVWST Ku-band Geophysical Model Function (GMF),* developed to perform equally well across the multitude of Ku-band scatterometers (NASA & ISRO); use collocated ScatSat Ku-band and ASCAT C-band observations to *modify the existing C-band GMF* to eliminate the still remaining small differences between the wind estimates; *produce winds from the entire set of QuikSCAT, ASCAT, and ScatSat observations, using the JPL wind retrieval system*.

Goal 2: *adopt published approaches in estimating wind stress and in computing the spatial derivatives; evaluate and compare the different approaches and develop criteria to select the most appropriate one*. Using multiple algorithms will also provide a measure of the uncertainty in the derived products.

Goal 3: *design gridded products; create daily gridded data, separately for ascending/descending orbits,* to facilitate use in model validation, data assimilation and in the understanding of the surface winds.

Development and Delivery Schedule

- Product formulation (metadata, parameters, formats – 12 m
- Initiate communications with PO.DAAC - 12m
- Website describing the MEaSUREs proposal - 12m
- C-band GMF developed - 18m
- All Level 2 products from QuikSCAt over 1 year period - 24 m
- Design of L3 products - 30m
- All L2 and L3 products from QSCAT, ASCAT and ScatSat (1y)- 36 m
- All L2 and L3 products from QSCAT, ASCAT and ScatSat - 48m
- All L2 and L3 products from RapidScat and SeaWinds - 54 m
- All validation completed - 57 m
- All data migrated to PO.DAAC - 59 m
- All documents and code delivered to PO.DAAC - 60m
- Papers published - 60 m

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.

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

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.

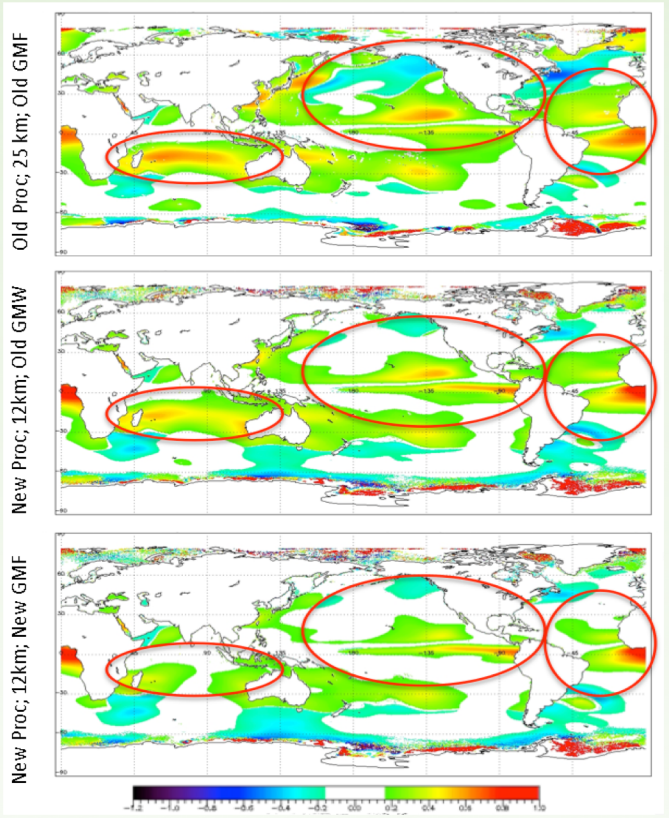
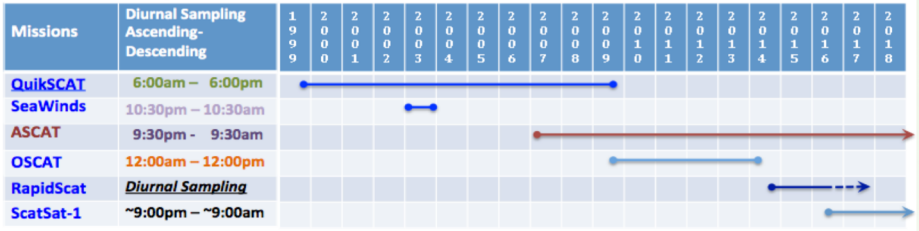


Table 2. Summary of Instrument/Mission characteristics



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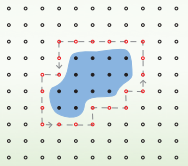
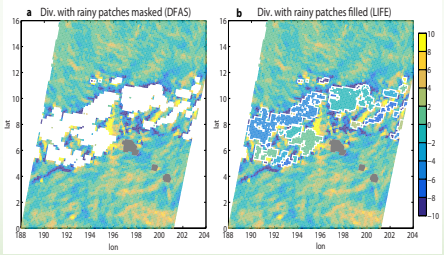
Rain is the leading source of error in scatterometer winds

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.