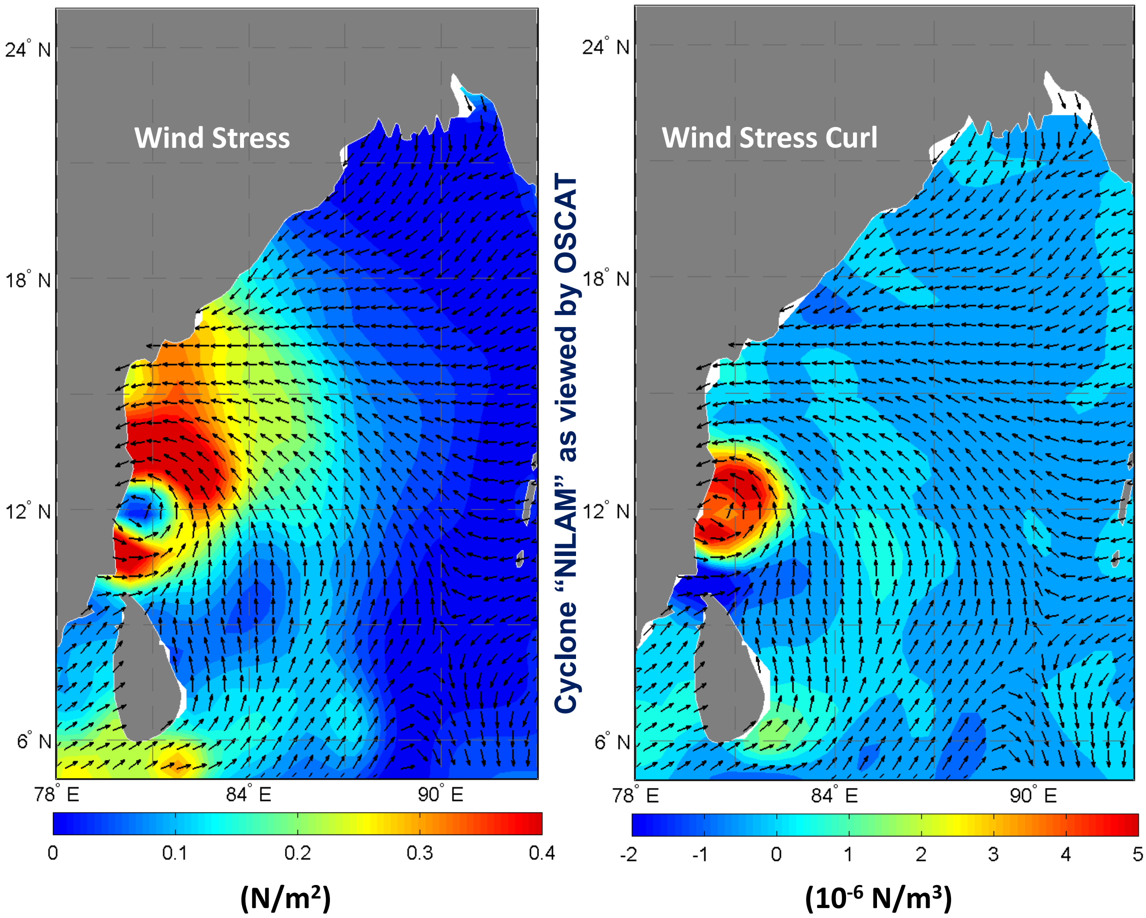
INDIAN SPACE RESEARCH ORGANISATION

OSCAT Wind Stress & Wind Stress Curl Products

Version 2.0



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Earth and Climate Science Area
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Hyderabad, INDIA

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nrsc

Contents

Abstract

Daily composites of ocean surface wind fields have been computed by interpolating Oceansat-2 scatterometer L2B wind data products using Variational Inverse Method (VIM) inbuilt in DIVA software. Using these wind fields composites, the derived products of Wind Stress and Wind Stress Curl are computed. In the process of wind stress computation, Large and Pond (1981) drag coefficients are used. While wind stress curl has been estimated using cross directional differential of wind stress. In the process, MATLAB tools are used to compute and map in standard formats with 50 km resolution. In this report, we summarize the computation of Wind Stress and Wind Stress Curl and generation of 'png' images, and Netcdf data of the derived parameters on a regular basis using the Oceansat-2 scatterometer wind data.

MATLAB codes have been generated for the computation of wind stress and curl. In the present version, daily composite products have been produced only for the Indian Ocean i.e. within the latitude-longitude range of 30^{o}S-30^{o}N and 30^{o}E-120^{o}E. These daily derived products are made available the next day by 0330 hrs UTC on NRSC website.

This document explains the procedures and tools used to obtain the wind stress and wind stress curl products using OSCAT daily composites of wind data. The products are still in the process of validation.

Acknowledgement

We take it as a deemed privelege to express our sincere thanks to all concerned who have contributed either directly or indirectly for the successful completion of Wind Stress and Wind Stress Curl computation and product generation using Oceansat-2 Scatterometer wind data.

We are highly grateful to Dr. V.K. Dadhwal, Director NRSC and Dr. C.B.S. Dutt, Deputy Director of ECSA for providing necessary support and motivation in completing the task.

Sincere thanks are due to Shri K.H. Rao, Head, Ocean Sciences Group (OSG) for his enthusiastic encouragement and providing all necessary facilities. We would like to gratefully acknowledge the enthusiastic supervision of Dr. S.K. Sasmal during this work. We are highly thankful to Shri M.V. Rao for his regular guidance and suggestions. We would also like to acknowledge all the colleagues and research scholars of OSG, NRSC for their continuous support.

OSCAT L2B, L3 data are made freely available on www.nrsc.gov.in since 2010. NDC team and network support group of NRSC and last but not the least OSCAT project team are sincerely acknowledged for successfully making OSCAT data available to the users within a short interval after the satellite pass.

We would also like to acknowledge GeoHydrodynamic and Environmental Research (GHER) group at the University of Liège, for the development of DIVA software.

MATLAB tools have been used for developing the necessary algorithm to obtain the derived data products.

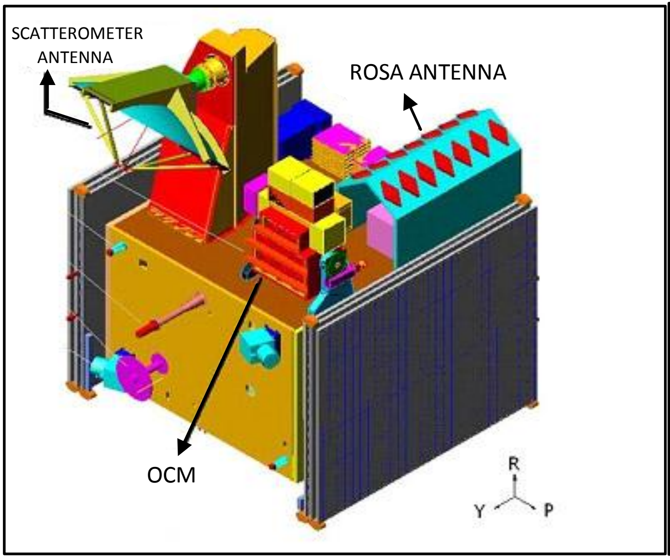
List of Figures

1. Introduction

The Earth and Climate Science Area (ECSA) of National Remote Sensing centre (NRSC), at the Indian Space Research Organisation (ISRO) is engaged in the process of generating scientific quality data from the space based sensors. The ECSA has the interest in building up of long term database on wind field and related parameters. In this regard, it is planned to create a database of wind stress and wind stress curl from scatterometer wind fields to support in the climatic studies. This leads to the scatterometer on the indigenous Oceansat-2 mission, which consists of two other remote sensing sensors. With the payloads of Oceansat Scatterometer (OSCAT), Ocean Colour Monitor (OCM) and Radio Occultation Sounder for Atmospheric studies (ROSA), the Oceansat-2 mission has the objective to improve ocean winds towards improved weather forecasts and understanding of the global atmosphere, along with sediment and chlorophyll mapping with improved accuracy. The databases thus generated are expected to support climatic studies in various ways. The objective of the present document is to provide details of wind stress and wind stress curl products to the user community for their further utilization in the ocean and atmospheric studies, besides climatic database.

1.1 OCEANSAT -2

Oceansat-2 was launched by PSLV-C14 from Satish Dhawan Space Centre, Sriharikota on Sept. 23, 2009. It carries three payloads:



Operator	Indian Space Research Organisation
Bus	IRS
Mission type	Oceanography
Launch date	23 September 2009
Carrier rocket	PSLV-C14
Launch site	Satish Dhawan Space Centre
COSPAR ID	OCEANS2
Mass	960 kilograms (2,100 lb)
Orbital elements	
Regime	Sun-Synchronous Circular orbit
Inclination	98.280^{o}
Apoapsis	720 kilometres (450 mi)
Periapsis	720 kilometres (450 mi)
Orbital period	99.31 minutes

Figure 1: OceanSat-2 satellite and launch characteristics.

- **Oceansat Scatterometer (O2-SCAT or simply OSCAT) –** OSCAT, ku-band (13.515 GHz) scatterometer, is a conically scanning pencil beam scatterometer which is designed and developed at ISRO/SAC, Ahmedabad. OSCAT covers a continuous swath of 1400 km for inner beam and 1840 km outer beam respectively, and provides a ground resolution of 50 × 50 km. The system works with a 1-m parabolic dish antenna and a dual feed assembly to generate two pencil beams and is scanned at a rate of 20.5 rpm to cover the entire swath. The aim is to provide global ocean coverage and wind vector retrieval with a revisit time of 2 days.

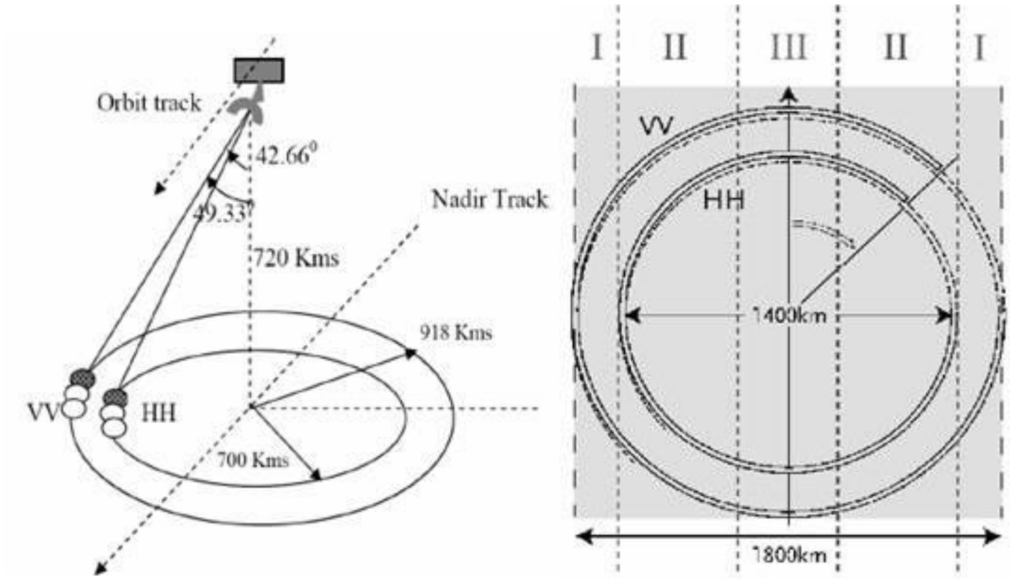


Figure 2: OSCAT – A rotating pencil beam scatterometer with details of swath.

The details of Oceansat-2 wind scatterometer data and their format can be acquired from ISRO with respective web sites of Space Application Centre (SAC) at Ahmedabad and National Remote Sensing Centre at Hyderabad and also the product handbook [Ref. 1].

- **Ocean Colour Monitor (OCM)** - OCM is a solid-state radiometer providing observations in eight spectral bands in the VNIR region. The instrument employs push-broom scanning technology with linear CCD detector arrays. A swath width of 1420 km is provided. The ground resolution is 360 m in the along-track and 236 m in the cross-track direction.
- **Radio Occultation Sounder for Atmospheric Studies (ROSA)** – It is a GPS receiver for atmospheric sounding by radio occultation, provided by ASI (Italian Space Agency). It determines position, velocity and time using GPS signals.

The document provides details on wind stress and wind stress curl estimations from the wind fields as obtained using Data-Interpolating Variational Analysis (DIVA) techniques on OSCAT L2B data sets [see Sec. 2.2]. An overview of Oceansat-2 wind derivation algorithm and its principles is also given. OSCAT data products can be acquired from the web sites of the SAC-MOSDAC (Ahmadabad) and NRSC (Hyderabad). Wind Stress and Wind Stress Curl data are often used for ocean and atmospheric studies in air sea interaction and energy flux studies. The dynamics of ocean surface also use these products to estimate surface current and energy fields to understand the state of the sea surface. Some of the results along with the method of data processing are discussed in details with examples. The products description and file details with naming convention, contents overview and format are provided. Accuracy analysis and validation of the products will be soon carried out with contemporary products.

1.2 Scatterometer Wind

A radar scatterometer is designed to determine the normalized radar cross-section (sigma-0) of the surface, by transmitting microwave pulses and measuring the backscattered power. Since the atmospheric effect is least on radiation emitted and received by the radar signal, scatterometer helps in measuring wind velocity over the ocean. Wind stress over the ocean generates ripples and small waves, which roughens the surface. This irregular sea surface modifies the radar cross-section (sigma-0) of the ocean surface and hence, the magnitude of backscattered power.

Geophysical Model Function (GMF) is used to retrieve near-surface wind vector from the sigma-0 measurements in HH and VV polarization, along with azimuth angles [Ref. 2]. For the derivation of wind fields, angular diversity of scatterometer measurements at the same point is required, which is provided by different azimuth angles of observation of the scatterometer. This backscattered power is a function of the wind speed and direction. This estimation process is also termed as ‘wind retrieval' or 'model function inversion'. Though the backscatter or sigma-0 is related to the ocean surface, the wind products are provided at 10 m height. The products at this height can be easily validated with the widely available 10m height wind data.

The GMF has two unknowns, namely wind speed and wind direction. So if more than two backscatter measurements are available then these two unknowns are estimated using the maximum-likelihood estimator (MLE) as the objective function to determine wind vector solutions [Ref. 3]. The MLE is defined as [Ref. 4]

$$J = (z_{oi} - z_{mo}(u, \chi_i))^2$$

Where $z = (\sigma_0)^{0.625}$ are the transformed backscatter data, z_{oi} are the observed backscatter values, $z_m(u,\chi_i)$ are the model backscatter values corresponding to the measurements. The local minima of J corresponds to wind vector solutions. The three independent measurements (fore, mid and aft beam) well sample the azimuth variation of the GMF in order to resolve the wind direction, albeit ambiguously.

2. Products Background

Surface winds over oceans are required for several operational, oceanographic, atmospheric and climatological studies. These winds are the most important forcing parameter in the upper ocean circulation. Wind stress and wind stress curl information is required in the major ocean circulation models, and these are computed from the surface (or near) wind observations.

The force of the wind, parallel to the surface, exerted on the sea surface is called the wind stress. It is the vertical transfer of horizontal momentum. Thus momentum is transferred from the atmosphere to the ocean by the wind stress. Wind stress is computed using bulk formulae based on the standard meteorological data. Wind vector data from scatterometer provide essential high-resolution surface forcing information for analyses of global ocean-atmosphere processes.

The Wind Stress Curl (WSC) fluctuations have a big influence on the sea surface temperature (SST), cooling of the sea surface during positive wind stress curl and warming during negative wind stress curl and relaxation periods [Ref. 5]. This relationship between wind stress Curl and SST is strongly correlated to the upwelling and down-welling [Ref. 6]. In the present study we have utilized wind vector fields from Scatterometer on-board Oceansat-II Satellite. Our goal is to provide global wind stress and wind stress curl composites on daily basis.

2.1 OSCAT Winds

Oceansat-2 scatterometer (O2 SCAT or simply, OSCAT) is a conically scanning pencil beam scatterometer that measures the backscattered coefficient (sigma-0). The sigma-0 values are later used to derive wind velocity vectors using Geophysical Model Functions (GMF). There are three levels of data products available from OSCAT: Level-1B (Raw data), Level-2 (Along-track data) and Level-3 (Global gridded data). Figure 3 shows all the products obtained from OSCAT.

The OSCAT data from NRSC website is available in HDF (.h5) file format. For our computation, we have used daily composites of wind vector fields as generated using DIVA techniques on OSCAT L2B products.

2.2 Data-Interpolating Variational Analysis (DIVA)

DIVA is a data analysis tool developed by GeoHydrodynamic and Environmental Research (GHER) under the SeaDataNet project of the European Union [Ref. 7]. DIVA has the unique provision in-built into it to identify the coastline and topography and has a numerical coast independent of the number of observations. Automatic outlier detection based on the comparison of the data residual and the standard deviation is some of the additional features of this analysis tool. It is therefore considered suitable for the present work. Daily passes of OSCAT are merged and a daily OSCAT wind product is generated using DIVA. DIVA utilizes Variational Inverse Method (VIM) for data interpolation. Different techniques for error estimation are also in-built in DIVA software. The wind products generated using OSCAT L3 wind products are validated with an existing operational scatterometer ASCAT and also with *in situ* measured winds from RAMA and NDBP buoys in the Indian Ocean. The results are found to be encouraging [Ref. 8] and therefore, the same technique has been implemented with OSCAT L2B wind products.

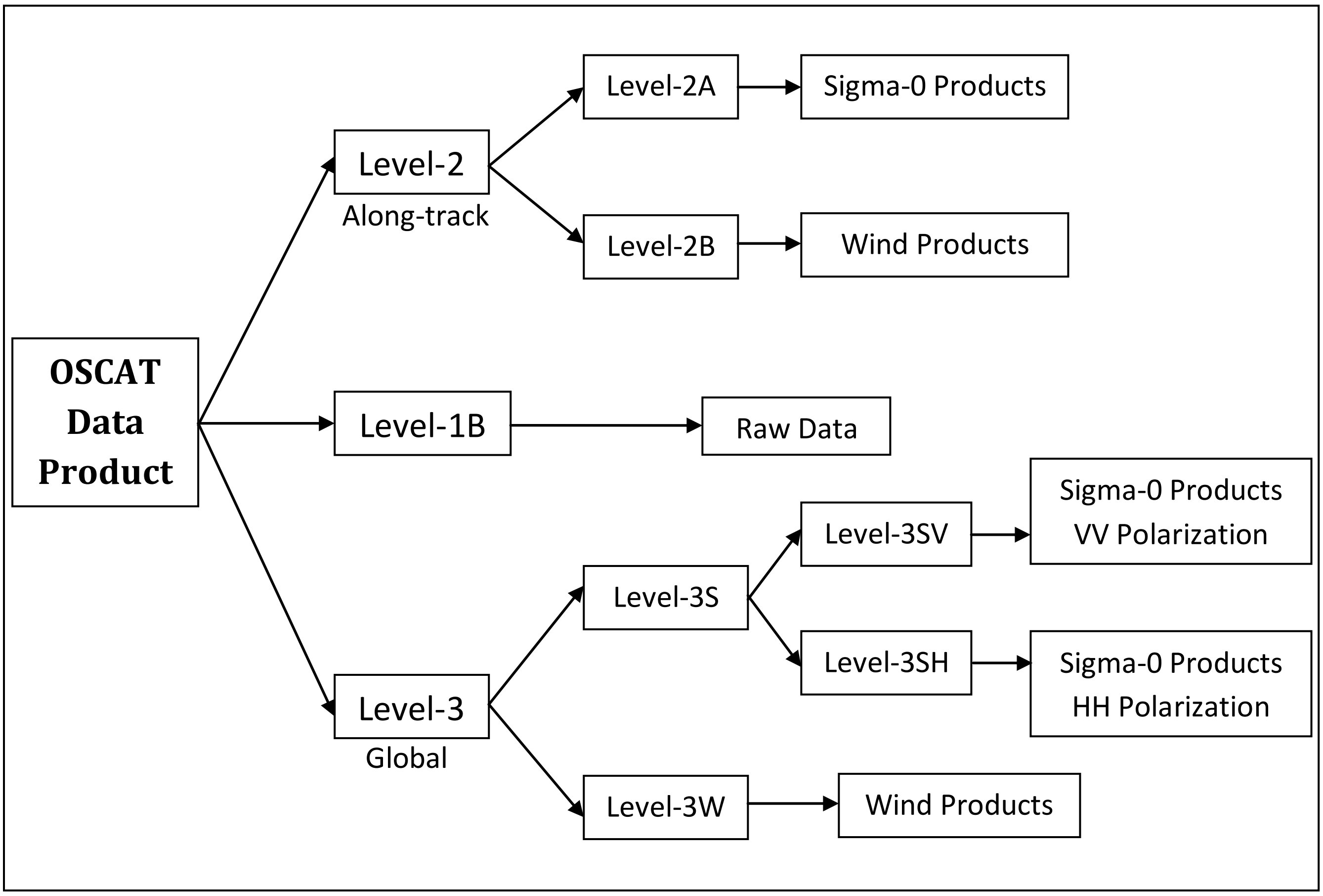


Figure 3: Details of OSCAT Data Product.

2.3 Wind Stress

The horizontal force of the wind on the sea surface is called the **wind stress**, denoted by **τ.** It can also be defined as the tangential (drag) force per unit area exerted on the surface of the ocean (earth) by the adjacent layer of moving air.

To estimate surface wind stress (τ) for each scatterometer wind value, the following relation based on [Ref. 9] has been used:

$$\tau = \rho C_D W^2$$

Zonal and Meridional wind stress components are computed as:

$$\tau_x = \rho_{air} C_D W^2 \sin\theta \qquad \tau_y = \rho_{air} C_D W^2 \cos\theta$$

Where,

ρ is the density of air (1.2 kg/m^3).
C_D is a dimensionless coefficient called **drag coefficient.**
W is the wind speed.
θ is the angle of the wind vector from true north.

Drag coefficient depends on the roughness of the surface and the lapse rate. The drag coefficient C_D for the ocean surface has a non-linear relation with the wind speed, which generally increases with wind speed.

2.4 Wind stress Curl

The **curl** is a measure of the **rotation** of a vector field. **Wind Stress Curl (WSC)** is the measure of the rotation of the wind stress (or ocean surface circulation).

Wind stress Curl is computed using the following basic relation [Ref. 9]:

$$\text{Curl}(\tau) = \partial\tau_y/\partial x - \partial\tau_x/\partial y$$

Where,

τ_x is the Zonal wind stress (West - East direction).

τ_y is the meridional wind stress (North - South direction).

WSC is a vector quantity with its direction pointing parallel to the z-axis. Following right-hand rule, positive value of curl implies anti-clockwise circulation, and negative curl is for clockwise circulation. Cyclones in the northern hemisphere have positive curl, whereas cyclones in the southern hemisphere have negative curl.

3. Products Evolution

For the computation of wind stress and wind stress curl, daily composites (using DIVA) of OSCAT wind products have been used. The data is available for the Indian Ocean (30^{o}S to 30^{o}N and 30^{o}E to 120^{o}E) at the spatial resolution $0.5^{o} \times 0.5^{o}$. In this section, an elaborate description of wind stress curl data products and methodology is provided (Figure 4).

3.1 OSCAT DIVA Wind Stress & its Curl Data Product

The output data files are available in NETCDF (.nc) format. The images are provided in PNG image format. Figure 4 presents the flow diagram of the procedure followed for generation of daily composites of OSCAT wind fields, wind stress and wind stress curl.

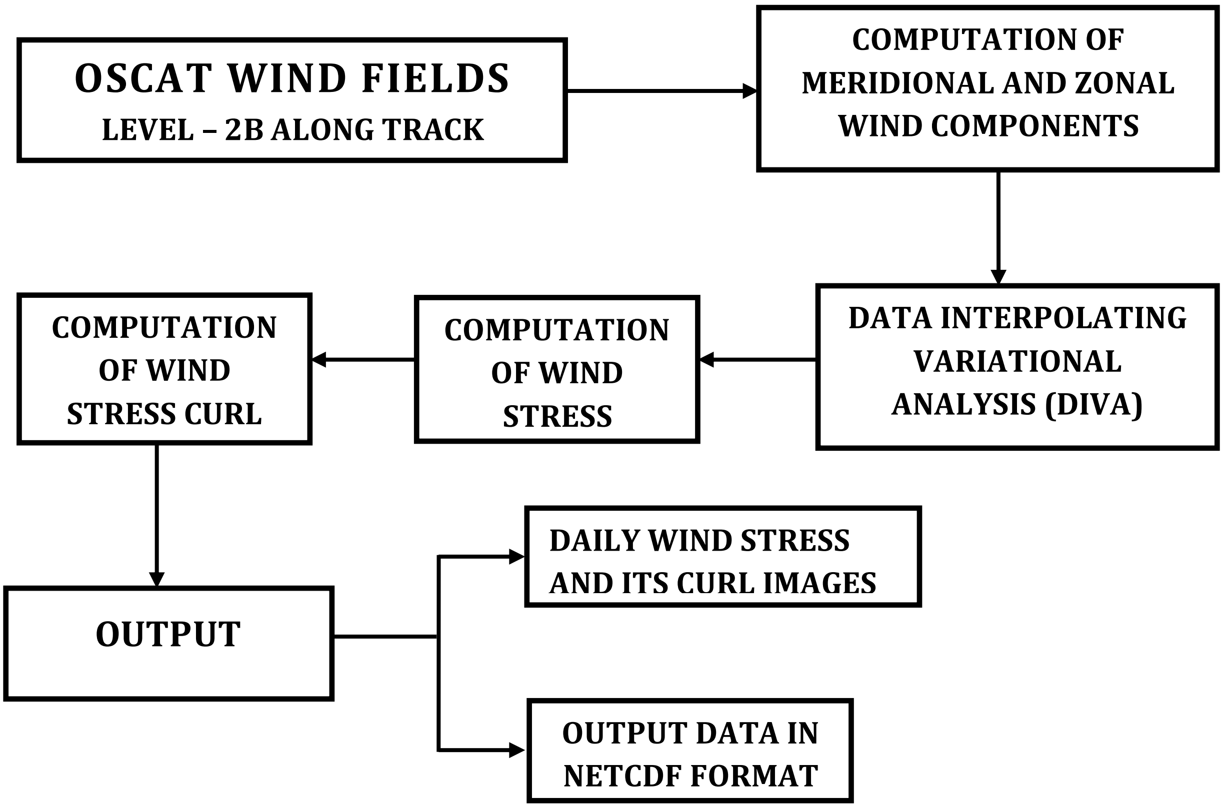


Figure 4: Flow diagram of the Wind Stress and Wind Stress Curl computation using OSCAT data.

3.2 Naming Convention

Input and output file naming conventions are mentioned below:

Input file:

- Level 2B : S1L2BYYYYDDD_NNNNN_MMMMM.h5

Output data file:

- Daily Composite : S1L2WSCYYYYMMDD.nc

Output images:

- Daily Composite : S1L2TTTYYYYMMDD.png

Where,

- YYYY : The calendar year when data was acquired.
- MM : The month when data was acquired.
- DD : The day of the month when data was acquired.
- DDD : The day of the year when data was acquired.
- NNNNN : Satellite orbit number at start of revolution.
- MMMMM : Satellite orbit number at end of revolution.
- TTT : Product Type (WSW → Surface winds, WST → Wind Stress, WSC → Wind Stress Curl).

The date 1st January 2013 corresponds to day number 1, and 31st December 2013 corresponds to day number 365. For more information on OSCAT-2 products, visit http://www.nrsc.gov.in/.

3.3 Netcdf file structure

```
Global attributes:
  Title = "OSCAT daily wind composites for Indian region";
  Version = "1.0";
  Organization_Name = "ISRO-DOS";
  Processing_Centre = "NRSC";
  Satellite_Name = "Oceansat-2";
  Sensor_Name = "Scatterometer";
  Software = "DIVA 4.6";
  Resolution = "0.5 x 0.5 degress";
  Product_Date = "DD-MMM-YYYY";
  Day_Number = "DDD";
        #Day_Number corresponds to day of the year, as per given in OSCAT data products.
  Year = "YYYY";
  Conventions = "CF-1.6";
  Creation_Date = "YYYY/MM/DD hh:mm:ss";
  Created_By = "OSG/ECSA";
  Comment = "Check the technical documents for more information.";

Dimensions:
  latitude = 120;
  longitude = 180;
  day = 1;

Variables:
  double zonal_wind(latitude=120, longitude=180);
    standard_name = "zonal wind speed";
```

```
    long_name = "east-west component of wind velocity.";
    units = "m/s";
    comment = "For error values check "zonal_wind_error"";
    FillValue = -9999.0;

  double zonal_wind_error(latitude=120, longitude=180);
    standard_name = "zonal wind speed error";
    long_name = "error in east-west component of wind velocity.";
    units = "Normalized";
    comment = "Acceptable if less than or equal to 0.3.";
    FillValue = -9999.0;

  double meridional_wind(latitude=120, longitude=180);
    standard_name = "meridional wind speed";
    long_name = "north-south component of wind velocity.";
    units = "m/s";
    comment = "For error values check "meridional_wind_error"";
    FillValue = -9999.0;

  double meridional_wind_error(latitude=120, longitude=180);
    standard_name = "meridional wind speed error";
    long_name = "error in north-south component of wind velocity.";
    units = "Normalized";
    comment = "Acceptable if less than or equal to 0.3.";
    FillValue = -9999.0;

  double zonal_wind_stress(latitude=120, longitude=180);
    standard_name = "zonal wind stress";
    long_name = "east-west component of wind stress.";
    units = "N/m^2";
    comment = "Computed using "zonal_wind"";
    FillValue = -9999.0;

  double meridional_wind_stress(latitude=120, longitude=180);
    standard_name = "meridional wind stress";
    long_name = "north-south component of wind stress.";
    units = "N/m^2";
    comment = "Computed using "meridional_wind"";
    FillValue = -9999.0;

  double wind_stress_curl(latitude=120, longitude=180);
    standard_name = "wind stress curl";
    long_name = "wind stress curl";
    units = "N/m^3";
    comment = "Computed using "zonal_wind_stress" and
"meridional_wind_stress"";
    FillValue = -9999.0;

  double latitude(latitude=120);
    standard_name = "latitude";
    long_name = "latitude";
    units = "degrees_north";
    limits = "30S to 30N in degrees";
    comment = "Positive latitude is North latitude, negative latitude is
South latitude.";
    FillValue = -9999.0;

  double longitude(longitude=180);
    standard_name = "longitude";
    long_name = "longitude";
    units = "degrees_east";
```

```
    limits = "30E to 120E in degrees";
    comment = "East longitude relative to Greenwich meridian.";
    FillValue = -9999.0;

  double day(day=1);
    standard_name = "day";
    long_name = "day number";
    units = "days since 2000-1-0";
    comment = "Day number since 1-Jan-2000. 1-Jan-2000 is Day number 1.";
    FillValue = -9999.0;
```

3.4 Methodology

All the Wind Stress and its curl products are provided for the Indian Ocean (30^{o}S to 30^{o}N and 30^{o}E to 120^{o}E) with the spatial resolution of $0.5^{o}\times0.5^{o}$. MATLAB tools have been used for the computation and generation of output products [Ref. 10]. The following steps have been adopted for the derivation of products:

STEP 1- Using DIVA for estimating daily wind composites: Daily wind composites have been generated by interpolating OSCAT L2B wind data using Variational Inverse Method (VIM, in-built in DIVA). Zonal and meridional wind components with their respective error fields have been estimated and provided in the output netcdf data files. For error estimation, Clever poor man error estimation method has been used [Ref. 7]. It is recommended to use wind fields with error values less than 0.3.

STEP 2- Computation of Wind Stress components: For the computation of wind stress, a non-linear drag coefficient (C_D) based on [Ref. 11], modified for low wind speeds [Ref. 12] is used. It is defined as:

C_D =	0.00218	W (wind speed) ≤ 1m/s
	$(0.62 + 1.56/W)\times0.001$	1 m/s < W < 3 m/s
	0.00114	3 m/s < W < 10 m/s
	$(0.49 + 0.065W)\times0.001$	W ≥ 10 m/s

And the wind stress components have been computed as:

$$\tau_x = \rho_{air} C_D W^*U; \qquad \tau_y = \rho_{air} C_D W^*V$$

Where

τ_x → Zonal Wind Stress
τ_y → Meridional Wind Stress
ρ_{air} → Density of air (~1.2 Kg/m^3)
W → Wind Speed
U → Zonal Wind component
V → Meridional Wind component

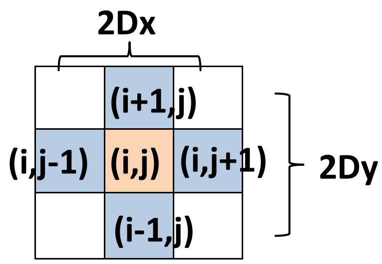
For the computation of wind stress, error fields are not taken into consideration (i.e. wind stress has also been computed for wind fields with error values more than 0.3). Zonal and meridional wind stress components have been provided in the output netcdf data file.

<u>STEP 3- Computation of Wind Stress Curl</u>: The stress curl, ***curl (τ)*** at each $0.5^o \times 0.5^o$ grid cell is then evaluated from the resultant wind stress fields as follows:

$$curl(\tau) = \frac{\tau y(i,j+1) - \tau y(i,j-1)}{2Dx} - \frac{\tau x(i+1,j) - \tau x(i-1,j)}{2Dy}$$

Where, **τx** and **τy** are the zonal and meridional components of the wind stress vector.

- **i** and **j are** the row and column index of the current grid cell. (as shown in figure)
- **Dx** and **Dy** are the width (parallel to longitude) and height (parallel to latitude) of the current grid cell. (Dy = 55,588 metres).



In the output images, the scale of the colorbar for wind stress and wind stress curl varies from 0 to 0.5 N/m^2 and -3 to $3*10^{-6}$ N/m^3, respectively. The latitude-longitude values defined in the output file are the centre of the grid cells. If the number of available passes within a day are less than 14, the output products indicate the unavailability of data.

Daily composite products are available by 0330 hours, GMT (0830 hrs IST) next day. For example, daily composite products for 1^{st} Sept, 2013 will be available by 0330 hrs, GMT (0830 hrs IST) on 2^{nd} Sept, 2013.

4. Sample Products

In this section, different output products have been discussed using sample images. In the following images, equidistant cylindrical projection of the world map has been used. The grid cell size is $0.5^o \times 0.5^o$. The title of the image consists of following parameters:

I. OSCAT – Oceansat-2 Scatterometer.
II. Wind parameter shown. (Wind stress / wind stress curl)
III. Units and scale. (N/m^2 or 10^{-6} N/m^3)
IV. Observation date.

As seen in the images (Figure 5 & 6), the latitude range is -30° to 30° and longitude ranges from 30° to 120°.

4.1 Daily Products

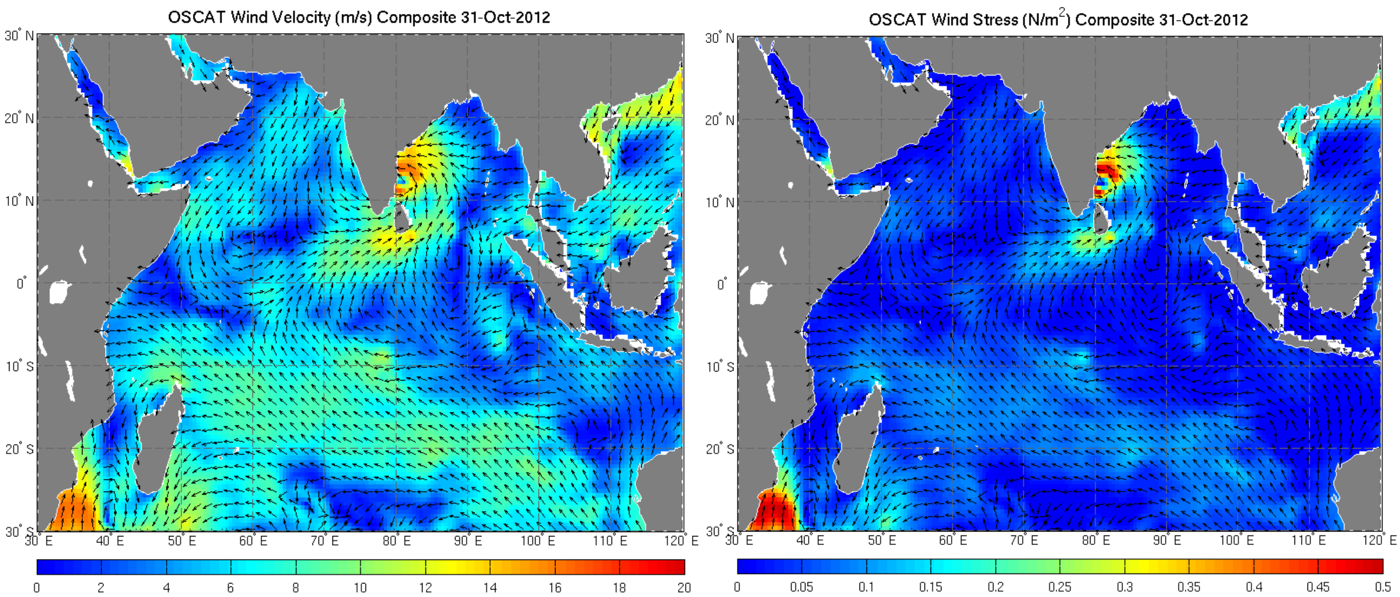


Figure 5: Image of wind velocity (left) and wind stress (right) composite for Cyclone Nilam.

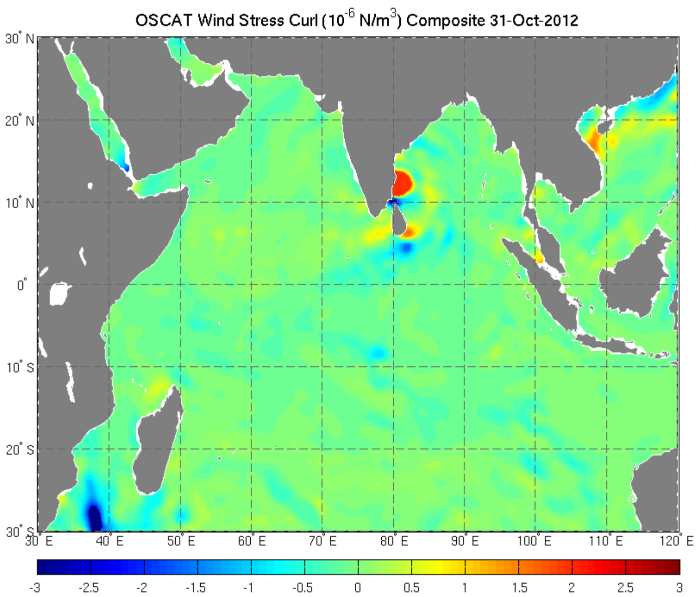


Figure 6: Image of wind stress curl composite for Cyclone Nilam as computed from the OSCAT DIVA daily wind composite for 31-Oct-2013.

Originating from an area of low pressure over the Bay of Bengal on October 28, 2013 Cyclone Nilam made landfall towards the eastern coast of South India on October 31 as a strong Cyclonic Storm with peak winds of 85 km/h. The images show the wind field, wind stress and wind stress curl for Cyclone Nilam as observed by OSCAT. The inner parts of the cyclone (see Fig. 5 and 6) indicate high stress and curl of about 0.45 N/m^2 and 2x10^{-6} N/m^3 respectively.

5. Conclusion

The curl of wind stress is helpful in identifying areas of cyclogenesis and their propagation, besides the mass movement and productive zones. The products of Wind Stress and Wind Stress Curl composite will be daily generated using OSCAT wind data and Data-Interpolating Variational Analysis (DIVA) method. These data products will be made available NRSC website. Other methods for the estimation of wind stress [Ref. 13] and data analysis [Ref. 14] are expected to be employed in upcoming versions.

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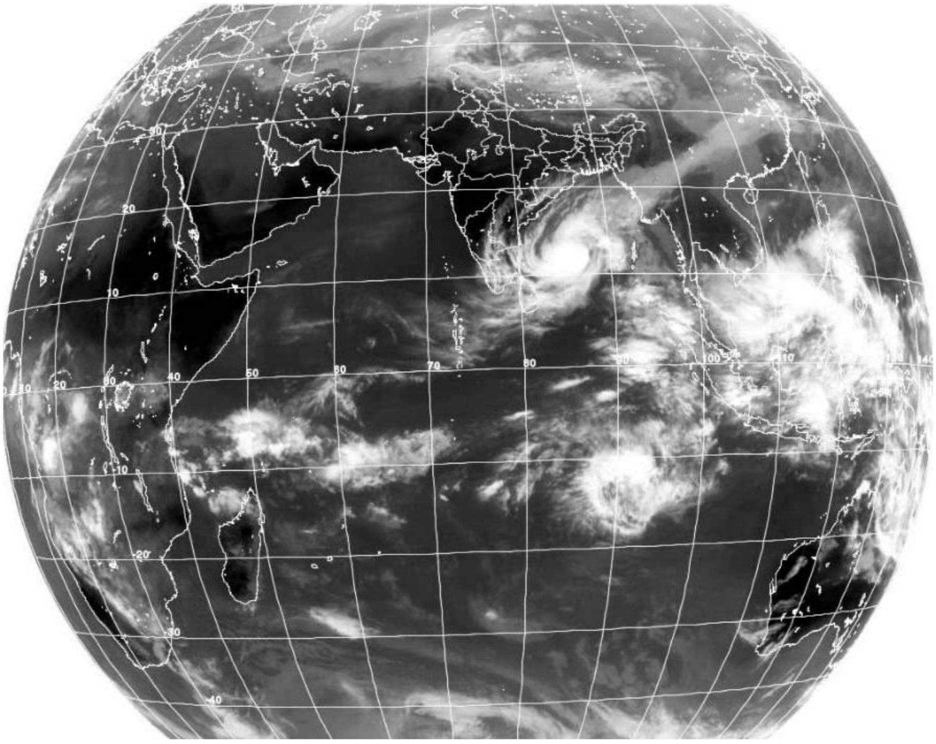

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