PRODUCT USER MANUAL

For Global Ocean Hourly Sea Surface Wind and Stress from Scatterometer and Model Products

WIND_GLO_PHY_L4_NRT_012_004

WIND_GLO_PHY_L4_MY_012_006

Issue: 1.3

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RECORD TABLE

Issue	Date	§	Description of Change	Author	Validated By
1.0	2022/02/23	All	Creation of the document	Rianne Giesen, Ad Stoffelen, Anton Verhoef	
	2022/05/16	II, IV, V	Update regarding variables included in the product and calculation of additional variables	Rianne Giesen	
1.1	2022/06/16	All	Add multi-year product information	Rianne Giesen	
	2022/09/05	All	Update information about QuikSCAT dataset	Rianne Giesen	Copernicus Marine Product Management
1.2	2023/06/16	I, II	Update regarding backward extension with ERS SCAT instruments ; inclusion of winds closer to the coast in 0.125° dataset	Rianne Giesen	Copernicus Marine Product Management
1.3	2024/02/01	I, II	Backward extension MY product to 1991	Rianne Giesen	Copernicus Marine Product Management
	2024/03/11	I, II	Update starting date MY dataset to 1994	Rianne Giesen	

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GLOSSARY AND ABBREVIATIONS

CF	Climate Forecast (convention for netCDF)
CMEMS	Copernicus Marine Service
CMOD	C-band Geophysical Model Function
ECMWF	European Centre for Medium-range Weather Forecasts
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FTP	File Transfer Protocol
KNMI	Royal Netherlands Meteorological Institute
L2, L3, L4	Level-2, Level-3, Level-4
MARS	Meteorological Archival and Retrieval System
MB	Megabyte
MFC	Monitoring and Forecasting Centre
MIS	Marine Information Store
netCDF	Network Common Data Form
NRT	Near Real-Time
NWP	Numerical Weather Prediction
OSI SAF	Ocean and Sea Ice Satellite Application Facility
SC	Scatterometer Correction
SDD	Standard Deviation of Differences
SST	Sea Surface Temperature
U10N	10-m height neutral-equivalent wind
U10S	10-m height stress-equivalent wind

WMO	World Meteorological Organization

I INTRODUCTION

I.1 Summary

This document describes the hourly Level-4 (L4) ocean surface wind products, what data services are available to access the products, and how to use the files and services.

The products WIND_GLO_PHY_L4_NRT_012_004 and WIND_GLO_PHY_L4_MY_012_006 contain global gridded near real-time (NRT) and multi-year (MY) L4 sea surface wind and stress variables, respectively. The products are produced by the Royal Netherlands Meteorological Institute (KNMI) based on the Level-3 (L3) NRT and MY wind observations from scatterometer and on numerical weather prediction (NWP) model fields. The L3 global daily gridded scatterometer observations rely on the upstream Level-2 (L2) scatterometer products from the EUMETSAT Ocean and Sea Ice Satellite Application Facility (OSI SAF) Wind Centre at KNMI. L2 winds are extensively validated, e.g., Vogelzang and Stoffelen (2021), Polverari et al., (2021) or Xu and Stoffelen (2022).

Belmonte Rivas and Stoffelen (2019) compared scatterometer observations with collocated European Centre for Medium-range Weather Forecasts (ECMWF) model winds. They documented substantial systematic errors in global ECMWF fields on both small and large scales. Trindade et al. (2020) used temporally-averaged differences between geolocated scatterometer wind data and ECMWF fields to correct for persistent local NWP wind vector biases.

The basic method used to produce the L4 products is similar to the approach by Trindade et al. (2020), enhanced to include wind stress and spatial derivatives. Furthermore, differences in variances between scatterometer and model fields are computed. Scatterometer observations from the L3 products and their collocated ECMWF operational model fields are used to calculate mean differences over a multiple-day time window. These bias corrections are added to hourly ECMWF model fields to produce global bias-corrected 10-m stress-equivalent wind (U10S) and surface wind stress fields at 0.125° (NRT and MY) and 0.25° (MY) horizontal spatial resolution. In addition to the biases, the variance differences denote local deficiencies in model processes involving wind and stress.

Bias corrections in the L4 NRT product are based on Metop-B and Metop-C ASCAT scatterometer observations, collocated with ECMWF operational model winds (L3 product WIND_GLO_WIND_L3_NRT_OBSERVATIONS_012_002). Records from other scatterometers require further evaluation and may be included at a later stage. The bias corrections in the L4 MY product depend on scatterometer availability. They are currently based on observations from Metop-A, Metop-B and Metop-C ASCAT, QuikSCAT SeaWinds, ERS-1 and ERS-2 SCAT, collocated with ECMWF ERA5 reanalysis winds. The datasets are taken from the L3 MY product (WIND_GLO_WIND_L3_REP_OBSERVATIONS_012_005) where available. A reprocessed dataset is not yet available for Metop-C ASCAT, for which the L3 NRT product is used with the collocated ECMWF operational winds replaced by ECMWF ERA5 reanalysis winds.

Following updates in the Level-1 products, the minimum distance to the coast in the L2 OSI SAF Metop ASCAT coastal wind products was reduced from approximately 20 km to 5-10 km. As a consequence, the L3 datasets for Metop-B and Metop-C ASCAT at 0.125° also contain information for winds and derived variables closer to the coast.

I.2 History of changes

Date	Description of changes and impacted product
30-11-2023	Spatial extension of scatterometer-based bias correction in the coastal zone (WIND_GLO_PHY_L4_NRT_012_004)
10-06-2024	Backward extension to 1994 using observations from ERS-1 and ERS-2 (WIND_GLO_PHY_L4_MY_012_006)

II DESCRIPTION OF THE PRODUCT SPECIFICATION

II.1 General Information

Product Lines	WIND_GLO_PHY_L4_NRT_012_004 WIND_GLO_PHY_L4_MY_012_006
Geographical coverage	180°W → 180°E ; 90°S → 90°N
Variables	• Zonal (eastward) (10-m stress-equivalent) wind velocity • Meridional (northward) (10-m stress-equivalent) wind velocity • Wind divergence • Wind curl • Zonal (eastward) wind stress • Meridional (northward) wind stress • Wind stress divergence • Wind stress curl
Product Type (No forecast)	Near real-time Multi-year
Available NRT time series	years-2 – day-1 (Metop-B and Metop-C ASCAT)
Available MY time series	1June1994 to 30 April 1996 (ERS-1 SCAT) 1 May 1996 to 31 July 1999 (ERS-2 SCAT) 1 August 1999 to 31 October 2009 (QuikSCAT SeaWinds) 11 January 2007 to 31 October 2012 (Metop-A ASCAT) 1 November 2012 to 31 October 2021 (Metop-A and Metop-B ASCAT) 1 November 2021 to month-3 (Metop-B and Metop-C ASCAT)
Temporal resolution	Hourly files with instantaneous values
Target delivery time	Daily (NRT) Monthly (MY)

Delivery mechanism	Copernicus Marine Information System: SUBSETTER, FTP
Horizontal resolution	0.125 degrees (NRT and MY based on ASCAT) 0.25 degrees (MY based on QuikSCAT, ERS-1 and ERS-2)
Number of vertical levels	1 (10 meter above the surface for wind, at the surface for stress)
Format	netCDF-4 classic model CF-1.6

Table 1: Wind TAC L4 NRT product

II.2 Details of datasets

WIND_GLO_PHY_L4_NRT_012_004 and WIND_GLO_PHY_L4_MY_012_006
Datasets: **cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H** **cmems_obs-wind_glo_phy_my_l4_0.125deg_PT1H** **cmems_obs-wind_glo_phy_my_l4_0.25deg_PT1H** contain: hourly instantaneous values Variable names in the netCDF file and unit: long_name & standard_name
eastward_wind [m s-1] stress-equivalent wind eastward component at 10 m eastward_wind
eastward_wind_bias [m s-1] scatterometer-model bias of stress-equivalent wind eastward component at 10 m eastward_wind_bias
eastward_wind_sdd [m s-1] standard deviation of differences of stress-equivalent wind eastward component at 10 m eastward_wind_standard_deviation_of_differences
northward_wind [m s-1] stress-equivalent wind northward component at 10 m northward_wind
northward_wind_bias [m s-1] scatterometer-model bias of stress-equivalent wind northward component at 10 m northward_wind_bias
northward_wind_sdd [m s-1] standard deviation of differences of stress-equivalent wind northward component at 10 m northward_wind_standard_deviation_of_differences
wind_divergence [s-1]

divergence of stress-equivalent wind at 10 m divergence_of_wind
wind_divergence_bias [s-1] scatterometer-model bias of divergence of stress-equivalent wind at 10 m divergence_of_wind_bias
wind_divergence_dv [s-2] difference of scatterometer and model variances of divergence of stress-equivalent wind at 10 m divergence_of_wind_difference_of_variances
wind_curl [s-1] curl of stress-equivalent wind at 10 m atmosphere_relative_vorticity
wind_curl_bias [s-1] scatterometer-model bias of curl of stress-equivalent wind at 10 m atmosphere_relative_vorticity_bias
wind_curl_dv [s-2] difference of scatterometer and model variances of curl of stress-equivalent wind at 10 m atmosphere_relative_vorticity_difference_of_variances
eastward_stress [N m-2] surface wind stress eastward component surface_downward_eastward_stress
eastward_stress_bias [N m-2] scatterometer-model bias of surface wind stress eastward component surface_downward_eastward_stress_bias
eastward_stress_sdd [N m-2] standard deviation of differences of surface wind stress eastward component surface_downward_eastward_stress_standard_deviation_of_differences
northward_stress [N m-2] surface wind stress northward component surface_downward_northward_stress
northward_stress_bias [N m-2] scatterometer-model bias of surface wind stress northward component surface_downward_northward_stress_bias
northward_stress_sdd [N m-2] standard deviation of differences of surface wind stress northward component surface_downward_northward_stress_standard_deviation_of_differences
stress_divergence [N m-3] divergence of surface wind stress divergence_of_surface_downward_stress
stress_divergence_bias [N m-3] scatterometer-model bias of divergence of surface wind stress divergence_of_surface_downward_stress_bias
stress_divergence_dv [N2 m-6] difference of scatterometer and model variances of divergence of surface wind stress divergence_of_surface_downward_stress_difference_of_variances
stress_curl [N m-3] rotation of surface wind stress vertical_component_of_surface_downward_stress_curl (proposed new name)

stress_curl_bias [N m-3] scatterometer-model bias of curl of surface wind stress vertical_component_of_surface_downward_stress_curl_bias
stress_curl_dv [N2 m-6] difference of scatterometer and model variances of curl of surface wind stress vertical_component_of_surface_downward_stress_curl_difference_of_variances
air_density [kg m-3] air density at 10 m air_density
number_of_observations [] number of observations used for scatterometer-model bias number_of_observations
number_of_observations_divcurl [] number of observations used for scatterometer-model divergence and curl bias number_of_observations

Table 2: List of the dataset variable names and units (first line), long_name (second line) and standard_name (third line, CF convention) for the WIND_GLO_PHY_L4_NRT_012_004 and WIND_GLO_PHY_L4_MY_012_006 products

II.3 Additional Information on parameters

Following Trindade et al. (2020) the wind and stress fields are computed using scatterometer corrections (SC) in vector components. Hence, the mean difference between scatterometer and ECMWF model vector components are aggregated over several days and subsequently the mean bias and Standard Deviation of Difference (SDD) is computed.

The mean SC is added to the hourly ECMWF model fields in order to obtain the vector components in this product (eastward wind, northward wind, eastward stress, northward stress). The bias correction field is provided in the product for reference. It also allows for backward calculation of the uncorrected stress-equivalent ECMWF model winds. For example, the uncorrected eastward wind (u) is computed as:

$$u = u^* - SC,$$

with u^* the corrected eastward wind and SC the mean bias as provided in the product.

Bias-corrected wind speed (U^*), wind direction (θ^*) and wind stress magnitude (τ^*) are not provided in the product but can be calculated from the wind and stress vector components. The equations below for the wind variables can also be applied for wind stress, by replacing the wind vector components by the stress vector components.

$$U^* = \sqrt{u^{*2} + v^{*2}}$$

$$\theta^* = \theta_{\mathrm{ref}} - f_c \arctan\left(\frac{v^*}{u^*}\right),$$

where u^* and v^* are the corrected vector components as provided in the product. θ_{ref} depends on the desired wind direction convention. It is either 90º ($\frac{1}{2}\pi$ radians) for oceanographic convention (direction the wind blows towards) or 270º ($\frac{3}{2}\pi$ radians) for meteorological convention (direction the wind blows from). f_c is a conversion factor and is 1 for angles in radians and $\frac{180}{\pi}$ for angles in degrees. Note that the implementation of the arctan function varies for different types of software, for instance the order of the input parameters. Most computer languages provide an arctan2 (or atan2) function that directly computes the four-quadrant arctan. For a correct implementation, the four (u^*, v^*) pairs (-1, -1), (1, -1), (1, 1) and (-1, 1) should give wind directions 45º, 315º, 225º and 135º (meteorological convention), respectively.

The corresponding bias corrections for wind speed and stress magnitude can be computed as the difference between the corrected and uncorrected ECMWF fields. Calculating bias corrections for wind direction is not advised as it is a complex variable and highly sensitive to small changes at low wind speeds.

Spatial derivatives are computed from the vector winds on the L2 scatterometer swath grid for the scatterometer corrections (following King et al., 2022) and on the model grid for the basic model fields. Spatial derivatives are treated in the same way as the vector components to compute the bias. The L3 scatterometer and collocated ECMWF model spatial derivative fields differ considerably in terms of magnitude and small-scale variability. Therefore, a measure of the local difference in scatterometer and model variability is most relevant for the spatial derivatives. As such, the product provides the difference of scatterometer and model variances (DV) computed over the local sample.

Height is referred to as height above sea level following standard WMO conventions, though the scatterometer measurements depict solely the sea surface condition. Hence, all atmospheric effects on the 10-m wind are eliminated by referring to stress-equivalent winds (de Kloe et al., 2017).

II.4 Production System Description

The production of the bias-corrected global ocean surface wind and stress fields consists of two parts:

1) the calculation of variables from the hourly ECMWF model winds on the reduced Gaussian grid and subsequent interpolation to an equirectangular grid.

2) the calculation of temporally averaged differences between scatterometer observations and collocated ECMWF model winds and application of these bias corrections to the hourly ECMWF fields.

The basis for the hourly ECMWF model fields are 10-m neutral wind components (U10N) retrieved from the ECMWF Meteorological Archival and Retrieval System (MARS) on the original reduced Gaussian grid. Hourly forecasts with forecast steps between 3 and 14 hours after analysis time are used to ensure independence of the model fields and scatterometer observations. Analyses are available daily at 0:00 and 12:00 UTC for the ECMWF operational model and daily at 6:00 and 18:00 for the ECMWF ERA5 reanalysis. The U10N wind components are converted to 10-m stress-equivalent winds (U10S, de Kloe et al., 2017) using air density calculated from model fields of 2-m temperature, specific humidity and mean sea level pressure. Identical to the L3 wind products, wind stress is calculated using a drag coefficient that is linear with U10S and has been derived by fitting a line to a drag versus U10S comparison for a full year of ERA-Interim model data (de Kloe et al., 2017). The resulting drag relation is very close to the well-known COARE3 relation (Edson et al., 2013).

The vector wind and stress component fields are interpolated to an equirectangular grid with 0.125^o or 0.25^o horizontal spatial resolution using bi-linear interpolation based on the nearest four neighbouring grid points on the reduced Gaussian grid. The divergence and curl of the wind and stress at the target grid are similarly calculated from four grid points on the original grid.

Bias corrections for the ECMWF model fields and derived variables are based on scatterometer observations and their collocated stress-equivalent ECMWF model values from the L3 wind product. The scatterometer wind is already a stress equivalent wind by definition, because the CMOD function used for wind retrieval reflects ocean surface roughness and not any atmospheric effects.

For the NRT product, time-averaged differences between scatterometer and model values are calculated over a period of 20 days preceding the time of interest. For example, the bias corrections for the ECMWF operational model fields of 21 January at 6:00 UTC (taken from the forecast initialized at 0:00 with step +6) are based on all observation-model pairs in the period 1 January 6:00 UTC to 21 January 6:00 UTC. The bias corrections are based on the L3 datasets for Metop-B and Metop-C ASCAT which are applied with equal weights for both scatterometers and all observation times.

Since the MY production system is not constrained by short delivery times, time-averaged differences are calculated for a window centered around (instead of preceding) the time of interest. For example, the bias corrections for the ECMWF ERA5 model fields of 21 January at 6:00 UTC (taken from the forecast initialized at 18:00 on the previous day with step +12) are based on all observation-model pairs in the period 11 January 6:00 UTC to 31 January 6:00 UTC. All available scatterometer observations available in the averaging time window are applied with equal weights. For the QuikSCAT and ASCAT periods (1 August 1999 onwards) a 20-day averaging window is used, consistent with the NRT product. Observations from ERS-1 and ERS-2 SCAT (available for the period 1994 to 2001) have lower spatial coverage and need to be averaged over a longer time window to provide bias correction statistics similar to QuikSCAT and ASCAT. An averaging window of 90 days is used for the ERS period (until 31 July 1999).

Bias corrections are calculated for the wind and stress vector components and the divergence and curl of the wind and stress fields and added to the uncorrected ECMWF model fields.

To avoid large variability in the bias-corrected fields near coastlines and sea ice due to poor sampling, the SC is not applied in coastal zones and close to the sea-ice margin. Uncorrected stress-equivalent ECMWF model wind fields are provided over land and sea ice, stress variables are only available over water. Large spatial gradients may be present at the transition from corrected to uncorrected wind fields near coastlines and sea ice. While validation of the bias-corrected fields in coastal regions is ongoing, users requiring a smooth transition may apply reduced bias corrections near the coastline.

Details on the production system and product validation can be found in the Quality Information Document (QUID, CMEMS-WIND-QUID-012-004-006). Further information on stress-equivalent versus neutral-equivalent winds and the computation of surface wind stress can be found in the QUID for the L3 wind products (CMEMS-WIND-QUID-012-002-005).

II.5 Grid

The L4 wind product is available on a global grid with a regular horizontal latitude and longitude spacing of 0.125° (2007-present) and 0.25° (1994-2009).

II.6 Domain

The domain geographical coverage is 90°S-90°N and 180°W-180°E, with grid center points ranging from 89.9375°S to 89.9375°N and from 179.9375°W to 179.9375°E (0.125° grid) and from 89.875°S to 89.875°N and from 179.875°W to 179.875°E (0.25° grid).

The first and last latitude rows of the domain are outside the outer latitude rows of the ECMWF model grid used. Because the interpolation scheme does not allow for interpolation of the ECMWF model values beyond the maximum latitudes, these rows do not contain valid data.

II.7 Update Time

The WIND_GLO_PHY_L4_NRT_012_004 product is updated daily at around 15 UTC, providing the surface wind and stress fields for the previous day.

The WIND_GLO_PHY_L4_MY_012_006 product is updated monthly around day 15, providing the surface wind and stress fields up to three months before present.

III DOWNLOAD A PRODUCT

After registration, you will be able to download our data. To assist you, our HelpCenter is available, and more specifically its section about download.

Information on operational issues on products and services can be found on our User Notification Service. If you have any questions, please contact us.

IV FILES NOMENCLATURE

IV.1 Nomenclature of files when downloaded through the Web Portal Subsetter Service

File nomenclature when downloaded through the Copernicus Marine Web Portal Subsetter is based on the product dataset name and a numerical reference related to the request date on the MIS.

The scheme is: **[datasetname]_[nnnnnn].nc**

where :

- **datasetname** is a character string corresponding to:
  - cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H for the NRT product
  - cmems_obs-wind_glo_phy_my_l4_0.125deg_PT1H for the 0.125° MY product
  - cmems_obs-wind_glo_phy_my_l4_0.25deg_PT1H for the 0.25° MY product

- **nnnnnn** is 6 digit integer corresponding to the current time (download time) in milliseconds since January 1, 1970 midnight UTC.
- **.nc** is the standard netCDF filename extension

Example:

cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H_435283.nc

IV.2 Nomenclature of files when downloaded through the FTP Service

File nomenclature when downloaded through the Copernicus Marine FTP Service is based on the product dataset name, the validity date and time and the ECMWF forecast used.

The scheme is: **[datasetname]_[valdate][valtime]_R[refdate]T[reftime]_[fcststep].nc**

where:

- **datasetname** is a character string corresponding to:
  - cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H for the NRT product
  - cmems_obs-wind_glo_phy_my_l4_0.125deg_PT1H for the 0.125° MY product
  - cmems_obs-wind_glo_phy_my_l4_0.25deg_PT1H for the 0.25° MY product

- **valdate** and **valtime** represents the date (yyyymmdd) and hour (hh) for which the fields are valid
- **refdate** and **reftime** are the date and time of the reference for the ECMWF forecast used
- **fcststep** is the forecast step since the reference time
- **.nc** is the standard netCDF filename extension

For example:

cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H_2020062303_R20200622T12_13.nc

provides the wind and stress fields for 23 June 2020 at 1:00 UTC based on forecast step +13 from the ECMWF operational model analysis started at 12:00 UTC on 22 June 2020,

and cmems_obs-wind_glo_phy_my_l4_0.125deg_PT1H_2020062303_R20200622T18_09.nc

provides the wind and stress fields for 23 June 2020 at 1:00 UTC based on forecast step +9 from the ECMWF ERA5 reanalysis started at 18:00 UTC on 22 June 2020.

IV.3 Other information: mean centre of Products, land mask value, missing value

The variables in the netCDF files are stored with (short) integer coding for best compression, using an offset and scale factor:

real_value = (display_value x scale_factor) + add_offset.

As scatterometer winds are only available over the sea surface, bias corrections can only be calculated and applied over the ocean. In addition, computed surface wind stress is only valid over water. Stress values above land and sea ice are therefore set to missing values, for wind variables the uncorrected fields are provided. Land is defined where the ECMWF land and sea mask has a value of 0.025 or higher. For sea ice, bias corrections are not applied where the ECMWF sea surface temperature (SST) is below 2°C and the number of available scatterometer observations is lower than 10.

IV.4 File size

The individual hourly files are around 76 MB (0.125° grid) and 20 MB (0.25° grid) in size.

V FILE FORMAT

V.1 Format and reading software

The products are stored using the netCDF format.

To know more about the NetCDF format, please follow this link:

What is the format of Copernicus Marine products ? NetCDF

V.2 Structure and semantic of netCDF maps files

The structure and semantics of the netCDF files is provided below for an arbitrary NRT product file. The structure and semantics of the MY product files is identical.

```
netcdf cmems_obs-wind_glo_phy_nrt_l4_0.125deg_PT1H_2022030112_R20220301T00_12 {
dimensions:
    time = UNLIMITED ; // (1 currently)
    lat = 1440 ;
    lon = 2880 ;
variables:
    int time(time) ;
        time:units = "seconds since 1990-01-01 00:00:00" ;
        time:axis = "T" ;
        time:long_name = "validity time" ;
        time:standard_name = "time" ;
        time:calendar = "gregorian" ;
    float lat(lat) ;
        lat:units = "degrees_north" ;
        lat:axis = "Y" ;
        lat:long_name = "latitude" ;
        lat:standard_name = "latitude" ;
        lat:valid_min = -90.f ;
        lat:valid_max = 90.f ;
    float lon(lon) ;
        lon:units = "degrees_east" ;
```

```
		lon:axis = "X" ;
		lon:long_name = "longitude" ;
		lon:standard_name = "longitude" ;
		lon:valid_min = -180.f ;
		lon:valid_max = 180.f ;
	short eastward_wind(time, lat, lon) ;
		eastward_wind:_FillValue = -32767s ;
		eastward_wind:missing_value = -32767s ;
		eastward_wind:units = "m s-1" ;
		eastward_wind:long_name = "stress-equivalent wind eastward component at 10 m" ;
		eastward_wind:standard_name = "eastward_wind" ;
		eastward_wind:scale_factor = 0.01 ;
		eastward_wind:add_offset = 0. ;
		eastward_wind:valid_min = -5000s ;
		eastward_wind:valid_max = 5000s ;
	short eastward_wind_bias(time, lat, lon) ;
		eastward_wind_bias:_FillValue = -32767s ;
		eastward_wind_bias:missing_value = -32767s ;
		eastward_wind_bias:units = "m s-1" ;
		eastward_wind_bias:long_name = "scatterometer-model bias of stress-equivalent wind eastward component at 10 m" ;
		eastward_wind_bias:standard_name = "eastward_wind_bias" ;
		eastward_wind_bias:scale_factor = 0.01 ;
		eastward_wind_bias:add_offset = 0. ;
		eastward_wind_bias:valid_min = -5000s ;
		eastward_wind_bias:valid_max = 5000s ;
	short eastward_wind_sdd(time, lat, lon) ;
		eastward_wind_sdd:_FillValue = -32767s ;
		eastward_wind_sdd:missing_value = -32767s ;
		eastward_wind_sdd:units = "m s-1" ;
		eastward_wind_sdd:long_name = "standard deviation of differences of stress-equivalent wind eastward component at 10 m" ;
		eastward_wind_sdd:standard_name = "eastward_wind_standard_deviation_of_differences" ;
		eastward_wind_sdd:scale_factor = 0.01 ;
		eastward_wind_sdd:add_offset = 0. ;
		eastward_wind_sdd:valid_min = 0s ;
```

eastward_wind_sdd:valid_max = 5000s ;

short northward_wind(time, lat, lon) ;

northward_wind:_FillValue = -32767s ;

northward_wind:missing_value = -32767s ;

northward_wind:units = "m s-1" ;

northward_wind:long_name = "stress-equivalent wind northward component at 10 m" ;

northward_wind:standard_name = "northward_wind" ;

northward_wind:scale_factor = 0.01 ;

northward_wind:add_offset = 0. ;

northward_wind:valid_min = -5000s ;

northward_wind:valid_max = 5000s ;

short northward_wind_bias(time, lat, lon) ;

northward_wind_bias:_FillValue = -32767s ;

northward_wind_bias:missing_value = -32767s ;

northward_wind_bias:units = "m s-1" ;

northward_wind_bias:long_name = "scatterometer-model bias of stress-equivalent wind northward component at 10 m" ;

northward_wind_bias:standard_name = "northward_wind_bias" ;

northward_wind_bias:scale_factor = 0.01 ;

northward_wind_bias:add_offset = 0. ;

northward_wind_bias:valid_min = -5000s ;

northward_wind_bias:valid_max = 5000s ;

short northward_wind_sdd(time, lat, lon) ;

northward_wind_sdd:_FillValue = -32767s ;

northward_wind_sdd:missing_value = -32767s ;

northward_wind_sdd:units = "m s-1" ;

northward_wind_sdd:long_name = "standard deviation of differences of stress-equivalent wind northward component at 10 m" ;

northward_wind_sdd:standard_name = "northward_wind_standard_deviation_of_differences" ;

northward_wind_sdd:scale_factor = 0.01 ;

northward_wind_sdd:add_offset = 0. ;

northward_wind_sdd:valid_min = 0s ;

northward_wind_sdd:valid_max = 5000s ;

int wind_divergence(time, lat, lon) ;

wind_divergence:_FillValue = -2147483647 ;

wind_divergence:missing_value = -2147483647 ;

wind_divergence:units = "s-1" ;

wind_divergence:long_name = "divergence of stress-equivalent wind at 10 m" ;

wind_divergence:standard_name = "divergence_of_wind" ;

wind_divergence:scale_factor = 1.e-07 ;

wind_divergence:add_offset = 0. ;

wind_divergence:valid_min = -5000000 ;

wind_divergence:valid_max = 5000000 ;

int wind_divergence_bias(time, lat, lon) ;

wind_divergence_bias:_FillValue = -2147483647 ;

wind_divergence_bias:missing_value = -2147483647 ;

wind_divergence_bias:units = "s-1" ;

wind_divergence_bias:long_name = "scatterometer-model bias of divergence of stress-equivalent wind at 10 m" ;

wind_divergence_bias:standard_name = "divergence_of_wind_bias" ;

wind_divergence_bias:scale_factor = 1.e-07 ;

wind_divergence_bias:add_offset = 0. ;

wind_divergence_bias:valid_min = -5000000 ;

wind_divergence_bias:valid_max = 5000000 ;

int wind_divergence_dv(time, lat, lon) ;

wind_divergence_dv:_FillValue = -2147483647 ;

wind_divergence_dv:missing_value = -2147483647 ;

wind_divergence_dv:units = "s-2" ;

wind_divergence_dv:long_name = "difference of scatterometer and model variances of divergence of stress-equivalent wind at 10 m" ;

wind_divergence_dv:standard_name = "divergence_of_wind_difference_of_variances" ;

wind_divergence_dv:scale_factor = 1.e-11 ;

wind_divergence_dv:add_offset = 0. ;

wind_divergence_dv:valid_min = -5000000 ;

wind_divergence_dv:valid_max = 5000000 ;

int wind_curl(time, lat, lon) ;

wind_curl:_FillValue = -2147483647 ;

wind_curl:missing_value = -2147483647 ;

wind_curl:units = "s-1" ;

wind_curl:long_name = "curl of stress-equivalent wind at 10 m" ;

wind_curl:standard_name = "atmosphere_relative_vorticity" ;

wind_curl:scale_factor = 1.e-07 ;

```
            wind_curl:add_offset = 0. ;
            wind_curl:valid_min = -5000000 ;
            wind_curl:valid_max = 5000000 ;
      int wind_curl_bias(time, lat, lon) ;
            wind_curl_bias:_FillValue = -2147483647 ;
            wind_curl_bias:missing_value = -2147483647 ;
            wind_curl_bias:units = "s-1" ;
            wind_curl_bias:long_name = "scatterometer-model bias of curl of stress-equivalent wind at 10 m" ;
            wind_curl_bias:standard_name = "atmosphere_relative_vorticity_bias" ;
            wind_curl_bias:scale_factor = 1.e-07 ;
            wind_curl_bias:add_offset = 0. ;
            wind_curl_bias:valid_min = -5000000 ;
            wind_curl_bias:valid_max = 5000000 ;
      int wind_curl_dv(time, lat, lon) ;
            wind_curl_dv:_FillValue = -2147483647 ;
            wind_curl_dv:missing_value = -2147483647 ;
            wind_curl_dv:units = "s-2" ;
            wind_curl_dv:long_name = "difference of scatterometer and model variances of curl of stress-
equivalent wind at 10 m" ;
            wind_curl_dv:standard_name = "atmosphere_relative_vorticity_difference_of_variances" ;
            wind_curl_dv:scale_factor = 1.e-11 ;
            wind_curl_dv:add_offset = 0. ;
            wind_curl_dv:valid_min = -5000000 ;
            wind_curl_dv:valid_max = 5000000 ;
      int eastward_stress(time, lat, lon) ;
            eastward_stress:_FillValue = -2147483647 ;
            eastward_stress:missing_value = -2147483647 ;
            eastward_stress:units = "N m-2" ;
            eastward_stress:long_name = "surface wind stress eastward component" ;
            eastward_stress:standard_name = "surface_downward_eastward_stress" ;
            eastward_stress:scale_factor = 0.01 ;
            eastward_stress:add_offset = 0. ;
            eastward_stress:valid_min = -5000 ;
            eastward_stress:valid_max = 5000 ;
      int eastward_stress_bias(time, lat, lon) ;
            eastward_stress_bias:_FillValue = -2147483647 ;
```

eastward_stress_bias:missing_value = -2147483647 ;

eastward_stress_bias:units = "N m-2" ;

eastward_stress_bias:long_name = "scatterometer-model bias of surface wind stress eastward component" ;

eastward_stress_bias:standard_name = "surface_downward_eastward_stress_bias" ;

eastward_stress_bias:scale_factor = 0.01 ;

eastward_stress_bias:add_offset = 0. ;

eastward_stress_bias:valid_min = -5000 ;

eastward_stress_bias:valid_max = 5000 ;

int eastward_stress_sdd(time, lat, lon) ;

eastward_stress_sdd:_FillValue = -2147483647 ;

eastward_stress_sdd:missing_value = -2147483647 ;

eastward_stress_sdd:units = "N m-2" ;

eastward_stress_sdd:long_name = "standard deviation of differences of surface wind stress eastward component" ;

eastward_stress_sdd:standard_name = "surface_downward_eastward_stress_standard_deviation_of_differences" ;

eastward_stress_sdd:scale_factor = 0.01 ;

eastward_stress_sdd:add_offset = 0. ;

eastward_stress_sdd:valid_min = -5000 ;

eastward_stress_sdd:valid_max = 5000 ;

int northward_stress(time, lat, lon) ;

northward_stress:_FillValue = -2147483647 ;

northward_stress:missing_value = -2147483647 ;

northward_stress:units = "N m-2" ;

northward_stress:long_name = "surface wind stress northward component" ;

northward_stress:standard_name = "surface_downward_northward_stress" ;

northward_stress:scale_factor = 0.01 ;

northward_stress:add_offset = 0. ;

northward_stress:valid_min = -5000 ;

northward_stress:valid_max = 5000 ;

int northward_stress_bias(time, lat, lon) ;

northward_stress_bias:_FillValue = -2147483647 ;

northward_stress_bias:missing_value = -2147483647 ;

northward_stress_bias:units = "N m-2" ;

northward_stress_bias:long_name = "scatterometer-model bias of surface wind stress northward component" ;

northward_stress_bias:standard_name = "surface_downward_northward_stress_bias" ;

northward_stress_bias:scale_factor = 0.01 ;

northward_stress_bias:add_offset = 0. ;

northward_stress_bias:valid_min = -5000 ;

northward_stress_bias:valid_max = 5000 ;

int northward_stress_sdd(time, lat, lon) ;

northward_stress_sdd:_FillValue = -2147483647 ;

northward_stress_sdd:missing_value = -2147483647 ;

northward_stress_sdd:units = "N m-2" ;

northward_stress_sdd:long_name = "standard deviation of differences of surface wind stress northward component" ;

northward_stress_sdd:standard_name = "surface_downward_northward_stress_standard_deviation_of_differences" ;

northward_stress_sdd:scale_factor = 0.01 ;

northward_stress_sdd:add_offset = 0. ;

northward_stress_sdd:valid_min = -5000 ;

northward_stress_sdd:valid_max = 5000 ;

int stress_divergence(time, lat, lon) ;

stress_divergence:_FillValue = -2147483647 ;

stress_divergence:missing_value = -2147483647 ;

stress_divergence:units = "N m-3" ;

stress_divergence:long_name = "divergence of surface wind stress" ;

stress_divergence:standard_name = "divergence_of_surface_downward_stress" ;

stress_divergence:scale_factor = 1.e-10 ;

stress_divergence:add_offset = 0. ;

stress_divergence:valid_min = -500000000 ;

stress_divergence:valid_max = 500000000 ;

int stress_divergence_bias(time, lat, lon) ;

stress_divergence_bias:_FillValue = -2147483647 ;

stress_divergence_bias:missing_value = -2147483647 ;

stress_divergence_bias:units = "N m-3" ;

stress_divergence_bias:long_name = "scatterometer-model bias of divergence of surface wind stress" ;

stress_divergence_bias:standard_name = "divergence_of_surface_downward_stress_bias" ;

stress_divergence_bias:scale_factor = 1.e-10 ;

stress_divergence_bias:add_offset = 0. ;

stress_divergence_bias:valid_min = -500000000 ;

```
        stress_divergence_bias:valid_max = 500000000 ;
    int stress_divergence_dv(time, lat, lon) ;
        stress_divergence_dv:_FillValue = -2147483647 ;
        stress_divergence_dv:missing_value = -2147483647 ;
        stress_divergence_dv:units = "N2 m-6" ;
        stress_divergence_dv:long_name = "difference of scatterometer and model variances of divergence of surface wind stress" ;
        stress_divergence_dv:standard_name = "divergence_of_surface_downward_stress_difference_of_variances" ;
        stress_divergence_dv:scale_factor = 1.e-15 ;
        stress_divergence_dv:add_offset = 0. ;
        stress_divergence_dv:valid_min = -500000000 ;
        stress_divergence_dv:valid_max = 500000000 ;
    int stress_curl(time, lat, lon) ;
        stress_curl:_FillValue = -2147483647 ;
        stress_curl:missing_value = -2147483647 ;
        stress_curl:units = "N m-3" ;
        stress_curl:long_name = "curl of surface wind stress" ;
        stress_curl:standard_name = "vertical_component_of_surface_downward_stress_curl" ;
        stress_curl:scale_factor = 1.e-10 ;
        stress_curl:add_offset = 0. ;
        stress_curl:valid_min = -500000000 ;
        stress_curl:valid_max = 500000000 ;
    int stress_curl_bias(time, lat, lon) ;
        stress_curl_bias:_FillValue = -2147483647 ;
        stress_curl_bias:missing_value = -2147483647 ;
        stress_curl_bias:units = "N m-3" ;
        stress_curl_bias:long_name = "scatterometer-model bias of curl of surface wind stress" ;
        stress_curl_bias:standard_name = "vertical_component_of_surface_downward_stress_curl_bias" ;
        stress_curl_bias:scale_factor = 1.e-10 ;
        stress_curl_bias:add_offset = 0. ;
        stress_curl_bias:valid_min = -500000000 ;
        stress_curl_bias:valid_max = 500000000 ;
    int stress_curl_dv(time, lat, lon) ;
        stress_curl_dv:_FillValue = -2147483647 ;
        stress_curl_dv:missing_value = -2147483647 ;
```

stress_curl_dv:units = "N2 m-6" ;

stress_curl_dv:long_name = "difference of scatterometer and model variances of curl of surface wind stress" ;

stress_curl_dv:standard_name = "vertical_component_of_surface_downward_stress_curl_difference_of_variances" ;

stress_curl_dv:scale_factor = 1.e-15 ;

stress_curl_dv:add_offset = 0. ;

stress_curl_dv:valid_min = -500000000 ;

stress_curl_dv:valid_max = 500000000 ;

short air_density(time, lat, lon) ;

air_density:_FillValue = -32767s ;

air_density:missing_value = -32767s ;

air_density:units = "kg m-3" ;

air_density:long_name = "air density at 10 m" ;

air_density:standard_name = "air_density" ;

air_density:scale_factor = 0.001 ;

air_density:add_offset = 0. ;

air_density:valid_min = 0s ;

air_density:valid_max = 2000s ;

air_density:source = "ECMWF Operational model" ;

short number_of_observations(time, lat, lon) ;

number_of_observations:_FillValue = -32767s ;

number_of_observations:missing_value = -32767s ;

number_of_observations:units = "1" ;

number_of_observations:long_name = "number of observations used for scatterometer-model bias" ;

number_of_observations:standard_name = "number_of_observations" ;

number_of_observations:valid_min = 0s ;

number_of_observations:valid_max = 2000s ;

short number_of_observations_divcurl(time, lat, lon) ;

number_of_observations_divcurl:_FillValue = -32767s ;

number_of_observations_divcurl:missing_value = -32767s ;

number_of_observations_divcurl:units = "1" ;

number_of_observations_divcurl:long_name = "number of observations used for scatterometer-model divergence and curl bias" ;

number_of_observations_divcurl:standard_name = "number_of_observations" ;

number_of_observations_divcurl:valid_min = 0s ;

number_of_observations_divcurl:valid_max = 2000s ;

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// global attributes:
        :title = " Global Ocean - Wind and Stress - Hourly - From Scatterometer and Model" ;
        :summary = "Global ocean 10-m stress-equivalent wind and surface wind stress fields based on the ECMWF operational model winds, bias-corrected using scatterometer observations" ;
        :keywords = "ocean winds, wind speed, wind direction, wind stress, divergence, vorticity" ;
        :Conventions = "CF-1.6, ACDD-1.3" ;
        :project = "Copernicus Marine Service Wind Thematic Assembly Centre" ;
        :institution = "Royal Netherlands Meteorological Institute (KNMI)" ;
        :geospatial_lat_min = -89.9375f ;
        :geospatial_lat_max = 89.9375f ;
        :geospatial_lat_resolution = "0.125" ;
        :geospatial_lat_units = "degrees_north" ;
        :geospatial_lon_min = -179.9375f ;
        :geospatial_lon_max = 179.9375f ;
        :geospatial_lon_resolution = "0.125" ;
        :geospatial_lon_units = "degrees_east" ;
        :processing_level = "L4" ;
        :platform = "Metop-B, Metop-C" ;
        :platform_vocabulary = "CEOS" ;
        :instrument = "ASCAT, ASCAT" ;
        :instrument_vocabulary = "CEOS" ;
        :model = "ECMWF Operational model" ;
        :time_coverage_start = "2022-03-01T12:00:00" ;
        :time_coverage_end = "2022-03-01T12:00:00" ;
        :references = "Copernicus Marine Service Product User Manual CMEMS-TAC-WIND-PUM-012-004, Trindade et al. (2020) doi:10.1109/TGRS.2019.2946019" ;
        :history = "N/A" ;
        :date_created = "2022-05-18T10:42:07" ;
        :date_modified = "2022-05-18T10:42:07" ;
}
```

VI REFERENCES

Belmonte Rivas, M. and A. Stoffelen (2019). *Characterizing ERA-Interim and ERA5 surface wind biases using ASCAT*, Ocean Sci., 15, 831–852, doi: 10.5194/os-15-831-2019.

Edson, J. B., V. Jampana, R. A. Weller, S. P. Bigorre, A. J. Plueddemann, C. W. Fairall, S. D. Miller, L. Mahrt, D. Vickers and H. Hersbach (2013). *On the Exchange of Momentum over the Open Ocean, Journal of Physical Oceanography*, 43(8), 1589-1610. doi: 10.1175/JPO-D-12-0173.1.

King, G. P., M. Portabella, W. Lin and A. Stoffelen (2022). *Correlating extremes in wind divergence with extremes in rain over the tropical Atlantic*, Remote Sensing, manuscript 1581451, accepted.

Kloe, J. de, A. Stoffelen and A. Verhoef (2017). *Improved use of scatterometer measurements by using stress-equivalent reference winds*, IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 10 (5), doi: 10.1109/JSTARS.2017.2685242.

Polverari, F., M. Portabella, W. Lin, J. W. Sapp, A. Stoffelen, Z. Jelenak and P. S. Chang (2022). *On high and extreme wind calibration using ASCAT*, IEEE Transactions on Geoscience and Remote Sensing, 60, 1-10, doi: 10.1109/TGRS.2021.3079898.

Trindade, A., M. Portabella, A. Stoffelen, W. Lin and A. Verhoef (2020). *ERAstar: A high-resolution ocean forcing product*, IEEE Trans. Geosci. Remote Sens., 1-11, doi: 10.1109/TGRS.2019.2946019.

Vogelzang, J. and A. Stoffelen (2021). *Quadruple collocation analysis of in-situ, scatterometer, and NWP winds*. Journal of Geophysical Research: Oceans, 126, e2021JC017189, doi: 10.1029/2021JC017189.

Xu, X. and A. Stoffelen (2021). *Support vector machine tropical wind speed retrieval in the presence of rain for Ku-band wind scatterometry*, Atmos. Meas. Tech. 14, 7435-7451, doi: 10.5194/amt-14-7435-2021.