Sea Ice CCI+

Norwegian Meteorological Institute

ESA CCI+ CLIMATE CHANGE INITIATIVE

PHASE 1: NEW R&D ON CCI ECVS

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CCI+ Sea Ice ECV
SEA ICE CONCENTRATION
PRODUCT USER GUIDE for ESMR
(PUG-ESMR)

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FMI

DTU

Danmarks Meteorologiske Institut

Max-Planck-Institut für Meteorologie

UNIS The University Centre in Svalbard

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1 INTRODUCTION

The Electrically Scanning Microwave Radiometer (ESMR) on board the NIMBUS 5 satellite was a one channel 19.35 GHz horizontally polarized microwave radiometer operating from 11. Dec. 1972 to 16. May. 1977 (1617 days) with some interruptions. After a major data gap from 3. Jun. 1975 until 25. Aug. 1975 the instrument was only operated approximately every other day. The data have recently been made available online by NASA in the format which was used for the tape archive (TAP-files).

The experimental NIMBUS satellite programme was very successful and there is heritage from it in modern satellite programs and even though ESMR was a predecessor of modern multi-frequency radiometers there are still parts of modern processing methodologies which can be applied to the data to derive the sea ice extent globally. In fact both the dynamical tie-points and the atmospheric noise reduction of the brightness temperatures (Tb's) can reduce the noise over both ice and open water consistently. These are also the reasons for reprocessing the data. The ESMR sea ice dataset extends the sea ice climate data record with an important period in the 1970s.

The ESMR instrument was a cross-track scanner measuring at 78 scan positions from nadir to an incidence angle of about 63 degrees perpendicular to both sides (39 scan positions to the right and left of the flight track) of the flight track. The near circular orbit height was about 1112 km with an inclination of 81 degrees. The phased array antenna size was 85.5 x 83.3 cm and the spatial resolution about 25 km at nadir increasing to about 160 x 45 km at the edges of the swath. The full swath was about 3100 km with varying incidence angle and spatial resolution giving a very good (unprecedented) daily coverage in polar regions.

1.1 Purpose

This document is the ESMR PUG for sea ice concentration for the Sea Ice ECV within CCI+ PHASE 1 - NEW R&D ON CCI ECVs, which is being undertaken by a METNO-led consortium. It presents NIMBUS 5 ESMR sea ice concentration data-set covering the period between December 1972 and May 1977 with some interruptions.

1.2 Scope

This document presents the processed data, the variable names and meaning in the NetCDF files and the file structure. It also presents the land-masks and the climatological masks used in the processing and the flags which are signifying the processing status. The algorithms are not part of this document, but the ATBD (Ref. 1), and the validation of the product is part of a separate report, the PVIR-ESMR (Ref. 2).

1.3 Document Status

This product user's guide for ESMR is describing the NIMBUS 5 ESMR sea ice concentration dataset at the end of the ESA CCI+ Phase 1 project.

1.4 Applicable Documents

Table 1 below lists the Applicable Documents referred to in this document.

Table 1: Applicable Documents

Document ID	Document referred to
Ref 1	The ATBD for sea ice concentration for the Sea Ice ECV within CCI+ PHASE 1 - NEW R&D ON CCI ECVs
Ref 2	The ESMR PVIR for sea ice concentration for the Sea Ice ECV within CCI+ PHASE 1 - NEW R&D ON CCI ECVs

1.5 Acronyms and Abbreviations

The table below lists the acronyms and abbreviations used in this volume.

Table 2: Acronyms and Abbreviations. Acronyms for the deliverable items (URD, etc…) and partner institutions (AWI,..) are not repeated.

Acronym	Meaning
AMSR-E / AMSR2	Advanced Microwave Scanning Radiometer (for EOS / #2)
AOGCM	Arctic Ocean General Climate Model
AR5, AR6	WMO IPCC Assessment Report series
ASAR	Advanced Synthetic Aperture Radar
C3S	EU Copernicus Climate Change Service
CCI	Climate Change Initiative
CDR	Climate Data Record
CMEMS	EU Copernicus Marine Environment Monitoring Service
CMIP5, CMIP6	Coupled Model Intercomparison Project series
CMUG	Climate Modelling User Group
CRG	Climate Research Group
CS-2	ESA's CryoSat-2
DEWG	CCI Data Engineering Working Group
EASE grid	Equal-Area Scalable Earth Grid
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
ENVISAT	ESA's Environmental Satellite
EO	Earth Observation
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ESMR	Electrically Scanning Microwave Radiometer
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FoV (*alt* FOV)	Field-of-View
FY3	Feng Yun 3
FYI	First Year Ice
GCOS	WMO's Global Climate Observing System
GCW	WMO's Global Cryosphere Watch
ICDR	Interim Climate Data Record
IMB	Ice Mass Balance buoy
IPCC	WMO's Intergovernmental Panel on Climate Change
L1b, L2, L3C, ...	Satellite data processing Level (Level-1b, …)
MERIS	MEdium Resolution Imaging Spectrometer
EPS, EPS-SG	EUMETSAT's Polar System, EPS Second Generation

MIZ	Marginal Ice Zone
MODIS	Moderate Resolution Imaging Spectroradiometer
MWI	MicroWave Imager (EPS-SG)
MWRI	Micro-Wave Radiation Imager (Feng Yun 3)
MYI	Multi-Year Ice
NASA	National Aeronautics and Space Administration
NOAA	US National Oceanic and Atmospheric Administration
NSIDC	US National Snow and Ice Data Centre
OE	Optimal Estimation
OIB	Operation Ice Bridge
OSI SAF	EUMETSAT Ocean and Sea Ice Satellite Application Facility
OWF	Open Water Filter
PMR	Passive Microwave Radiometer
PMW	Passive Microwave
RA	Radar Altimeter
RRDP	Round Robin Data Package
SIC	Sea Ice Concentration
SIT	Sea Ice Thickness
SAR	Synthetic Aperture Radar
SIRAL	Synthetic Aperture Radar (SAR) Interferometer Radar Altimeter
SOA	Service Oriented Architecture
SMMR	Scanning Multichannel Microwave Radiometer
SMOS	Soil Moisture and Ocean Salinity
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager/Sounder
ULS	Upward Looking Sonar
WMO	World Meteorological Organization
WSM	Wide Swath Mode

1.6 Executive Summary

This product user's guide is describing the NIMBUS 5 ESMR input data: which variables in the original tape files are used in the processing and which ERA5 meteorological variables are added to the dataset to produce the NetCDF files in swath projection which are input to the sea ice concentration processing chain. The processing chain is presented at flow-chart level: the flow of data through the processes and what data is added (land and climatological masks). Next the central equations for deriving the sea ice concentration, and its uncertainties

are presented briefly and then the postprocessing of the swath files is presented describing the processing status flags and giving examples of the final NetCDF file structure. The data are stored at ESA's open data portal where it can be retrieved together with the documentation.

2 The input data

2.1 The NIMBUS 5 ESMR TAB data and atmospheric reanalysis colocation

The ESMR data were retrieved from the NASA Goddard Earth Sciences Data and information services center (GES DISC) online data archive (https://disc.gsfc.nasa.gov/datasets/ESMRN5L1_001/summary). The quote from the homepage is describing the data:

"ESMRN5L1 is the Nimbus-5 Electrically Scanning Microwave Radiometer (ESMR) Level 1 Calibrated Brightness Temperature product and contains calibrated radiances expressed in units of brightness temperature measured at 19.35 GHz. The data, originally written on IBM 360 machines, were recovered from magnetic tapes, also referred to as the Calibrated Brightness Temperature Tapes (CBTT). The data are archived in their original IBM binary proprietary format, also referred to as a binary TAP file."

The TAP files were read using NASA software and converted to NetCDF format. Each data point in the TAP file was matched up with ERA5 data (Hersbach et al., 2020) in time and space (nearest) and written to the NetCDF file. The data are structured line by line (across-track) retaining the original data structure and all variables. The variables are listed in section 2.1.1 and 2.1.2,

2.1.1 Satellite variables

Data variables used in the processing:

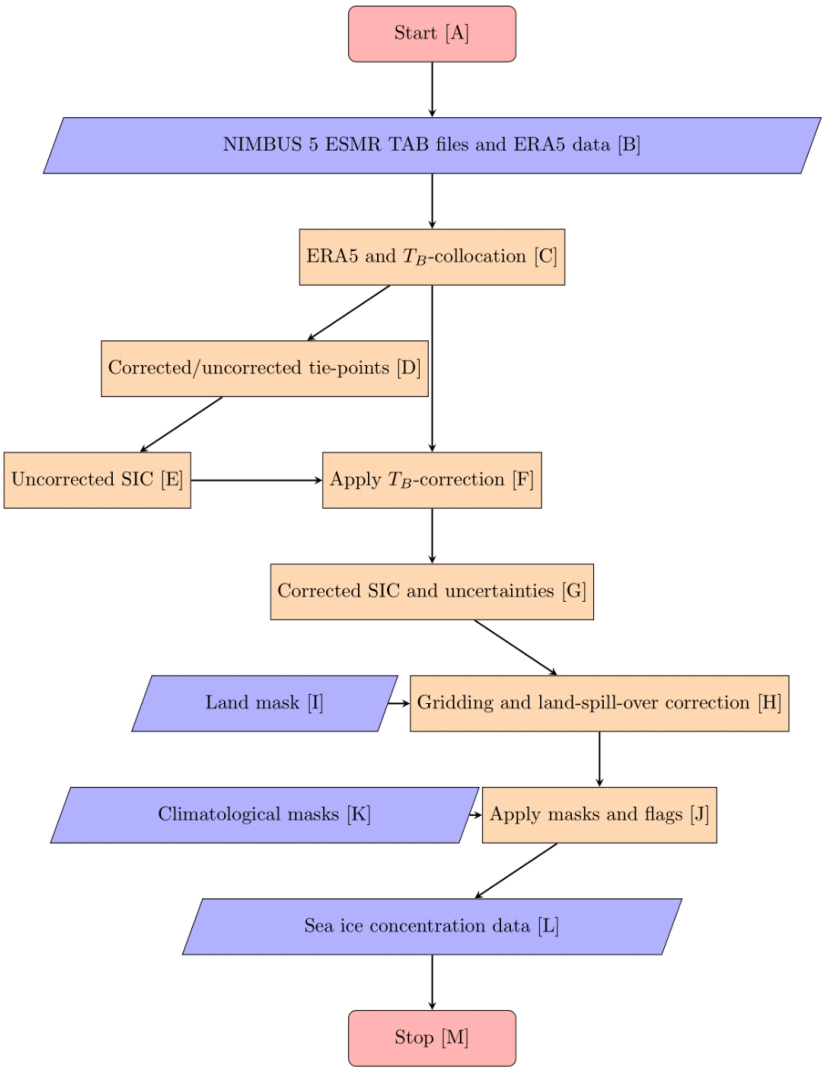
Time	time of data
Brightness_temperature	Brightness temperature of the 78 scan spots
Latitude	latitude of the 78 scan spots [degrees]
Longitude	longitude of the 78 scan spots [degrees

2.1.2 ERA5 variables

u10	u component of the wind speed at 10 m (parallel to longitude)
v10	v component of the wind speed at 10 m (parallel to longitude)
t2m	2 m air temperature
siconc	sea ice concentration [0,1]
sst	sea surface temperature [K]
tcw	total column water [kgm-2]
tcwv	total column water vapor [kgm-2]
era_time	valid time for analysis

3. The processing chain flow-chart

The processing chain flow chart is shown in Figure 1. Each of the processes are explained briefly in the figure caption and details are provided in the next section, section 4.



1

Figure 1. The ESMR sea ice concentration processing chain flow chart: A: starting the process, B: the ESMR TAB files and the ERA5 files are read and formatted, C: The ESMR and ERA5 files are collocated to the nearest point in time and space, D: the corrected and uncorrected tie-points are derived using the ERA5 data and the radiative transfer model, E:

the uncorrected SIC is derived using the tie-points, F: the Tb's are corrected using the ERA5 data, the radiative transfer model and the sea ice concentration from E, G: the sea ice concentration and its uncertainties are computed based on the corrected Tb's (from F) and the corrected tie-points (from D), H: the sea ice concentrations are corrected for åland-spill-over and gridded into daily 25km EASE-2 grids using the land-mask as input (from I), J: the climatological masks are applied (from K) and flags are applied to each of the daily grid-points, L: is the final sea ice concentration dataset.

4. The sea ice concentration and its uncertainty

The sea ice concentration (c_{ice}) in eq. 1 is estimated using the measured brightness temperature ($T_{B,measured}$) and the open water ($T_{p,water}$) and ice ($T_{p,ice}$) tie points, i.e.

$$c_{ice} = \frac{T_{B,measured} - T_{p,water}}{T_{p,ice} - T_{p,water}} \quad (1)$$

However because of the geophysical noise reduction using the radiative transfer calculation, needs c_{ice} as input, the sea ice concentration is processed iteratively in two steps: 1) the c_{ice} is estimated using uncorrected TB's and tie-points derived from uncorrected data. The c_{ice} estimate is truncated to the interval between 0 and 1 and an open water filter is applied forcing all c_{ice} values less than 0.15 to 0. 2) The c_{ice} estimate from step (1) is used in the radiative transfer calculation together with ERA5 data for for the geophysical noise reduction of the brightness temperatures and c_{ice} is then estimated again in a second iteration this time using corrected brightness temperatures and corrected tie-points. The mean values of $\overline{V}, \overline{W}, \overline{L}$... used in the reference simulation is a weighted average with c_{ice} of the mean water and ice tie-point values.

These iterations updating c_{ice} could in principle continue. However, tests show that updates are small after two iterations (e.g. Lavergne et al., 2019).

The total sea ice concentration uncertainty is the combination of two components: 1) the algorithm uncertainty which includes instrument noise and tie-point variability (geophysical noise) and 2) the resampling uncertainty which is uncertainty due to data resampling.

The algorithm uncertainty is the squared sum of the independent components following Parkinson et al. (1987), without the instrument noise term which is included in the two tie-point uncertainties in eq. 2

$$\delta c_{ice,algorithm} = \left(\left(\frac{-(1-c_{ice})\delta T_{p,water}}{T_{p,ice}-T_{p,water}}\right)^2 + \left(\frac{-c_{ice}\delta T_{p,ice}}{T_{p,ice}-T_{p,water}}\right)^2\right)^{1/2} \quad (2)$$

where δT_B is the brightness temperature error of 3 K (Parkinson et al., 1987), $\delta T_{p,water}$, is the water tie-point error, here the (one) standard deviation of the daily tie-point, $\delta T_{p,ice}$, is the ice

tie-point error here the (one) standard deviation of the daily tie-point. The water and ice tie-point errors are weighted with the sea ice concentration and all three errors are normalized with the ice - water brightness temperature contrast here the 2-weekly tie-points. The algorithm uncertainty is computed on swath data.

The resampling uncertainty, $\delta c_{ice,\,resampling}$ is the maximum c_{ice} - minimum c_{ice} difference of a 3 x 3 pixel window. The resampling uncertainty is computed on resampled data.

The total uncertainty is the squared sum of the algorithm and the resampling uncertainty in eq. 3, i.e.

$$\delta c_{ice,\,total} = \sqrt{\delta c_{ice,\,algorithm}{}^{2} + \delta c_{ice,\,resampling}{}^{2}} \qquad (3)$$

The two uncertainty components and the total uncertainty are provided separately in the data file.

5. The output sea ice concentration dataset

5.1 The land, coast and climatological masks

The land-mask is based on the ESA CCI land cover project coastline here called the ESA CCI sea ice version 3 landmask.

5.2 The processing flags and land-spill over correction

Land-spill_over correction is following the procedure described in Markus and Cavalieri (2009). The flag number and its meaning is summarized in Table 1.

Table 1: The processing flags applied to each of the data points

Flag number	**Flag meaning**
0	Nominal retrieval by the SIC algorithm
1	Position is over land
2	Position is lake
3	SIC is set to zero by the open water filter
8	SIC value is changed for correcting land spill-over effects
16	Handle with caution, the 2m air temperature is high at this position, and this might be false ice
32	Coast

64	SIC is set to zero since position is outside maximum sea ice climatology
128	Point not accepted but no other flags raised

5.3 Sea ice concentration data-set structure

A dump of the NetCDF data structure for the first file in the dataset is provided below. There is a daily file unless no data is available for that day. The dataset begins on launch day Dec. 11, 1972 and continues until May 16. 1977, however, there are gaps especially after the summer 1975.

NCDUMP output:

netcdf Nimbus5-ESMR_1972m1211ease2_25_n {

dimensions:

time = 1 ;

nv = 2 ;

yc = 432 ;

xc = 432 ;

variables:

int Lambert_Azimuthal_Grid ;

Lambert_Azimuthal_Grid:grid_mapping_name = "lambert_azimuthal_equal_area" ;

Lambert_Azimuthal_Grid:longitude_of_projection_origin = 0 ;

Lambert_Azimuthal_Grid:latitude_of_projection_origin = 90 ;

Lambert_Azimuthal_Grid:semi_major_axis = 6378137 ;

Lambert_Azimuthal_Grid:semi_minor_axis = 6356752.314245 ;

Lambert_Azimuthal_Grid:inverse_flattening = 298.257223563 ;

Lambert_Azimuthal_Grid:proj4_string = "+proj=laea +lat_0=90 +lon_0=0 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs +type=crs" ;

double time_bnds(time, nv) ;

double ice_conc(time, yc, xc) ;

ice_conc:_FillValue = NaN ;

ice_conc:long_name = "fully filtered concentration of sea ice using atmospheric correction of brightness temperatures and open water filters" ;

ice_conc:standard_name = "sea_ice_area_fraction" ;

ice_conc:units = "%" ;

ice_conc:valid_min = 0 ;

ice_conc:valid_max = 100 ;

ice_conc:grid_mapping = "Lambert_Azimuthal_Grid" ;

ice_conc:ancillary_variables = "total_standard_error status_flag" ;

ice_conc:comment = "this field is the primary sea ice concentration estimate for this climate data record" ;

ice_conc:coordinates = "lon lat" ;

double raw_ice_conc_values(time, yc, xc) ;

raw_ice_conc_values:_FillValue = NaN ;

raw_ice_conc_values:long_name = "sea ice concentration estimates as retrieved by the algorithm, and that were edited away by the various filters" ;

raw_ice_conc_values:units = "%" ;

raw_ice_conc_values:grid_mapping = "Lambert_Azimuthal_Grid" ;

raw_ice_conc_values:comment = "this field can be used in combination with \"ice_conc\" to access un-bounded normal distribution of sea ice concentration estimates corresponding to the uncertainty estimate in \"total_standard_error\". It does also feature some amount of un-physical data (below 0 and above 1)." ;

raw_ice_conc_values:coordinates = "lon lat" ;

double total_standard_error(time, yc, xc) ;

total_standard_error:_FillValue = NaN ;

total_standard_error:long_name = "total uncertainty (one standard deviation) of concentration of sea ice" ;

total_standard_error:standard_name = "sea_ice_area_fraction standard_error" ;

total_standard_error:units = "%" ;

total_standard_error:grid_mapping = "Lambert_Azimuthal_Grid" ;

total_standard_error:coordinates = "lon lat" ;

double smearing_standard_error(time, yc, xc) ;

smearing_standard_error:_FillValue = NaN ;

smearing_standard_error:long_name = "smearing uncertainty (one standard deviation) of concentration of sea ice" ;

smearing_standard_error:units = "%" ;

smearing_standard_error:grid_mapping = "Lambert_Azimuthal_Grid" ;

smearing_standard_error:comment = "this is one of the two components contributing to \'total_standard_error\'" ;

smearing_standard_error:coordinates = "lon lat" ;

double algorithm_standard_error(time, yc, xc) ;

algorithm_standard_error:_FillValue = NaN ;

algorithm_standard_error:long_name = "algorithm uncertainty (one standard deviation) of concentration of sea ice" ;

algorithm_standard_error:units = "%" ;

algorithm_standard_error:grid_mapping = "Lambert_Azimuthal_Grid" ;

algorithm_standard_error:comment = "this is one of the two components contributing to \'total_standard_error\'" ;

algorithm_standard_error:coordinates = "lon lat" ;

int status_flag(time, yc, xc) ;

status_flag:long_name = "status flag bit array for sea ice concentration retrievals" ;

status_flag:standard_name = "sea_ice_area_fraction status_flag" ;

status_flag:valid_min = 0 ;

status_flag:valid_max = 32767 ;

status_flag:grid_mapping = "Lambert_Azimuthal_Grid" ;

status_flag:flag_masks = 0.f, 1.f, 2.f, 4.f, 8.f, 16.f, 32.f, 64.f, 128.f ;

status_flag:flag_meanings = "land lake open_water_filtered land_spill_over high_t2m coast max_ice_climo" ;

status_flag:flag_descriptions = "\n",

"all bits to 0 (flag 0): Nominal retrieval by the SIC algorithm\n",

"bit 1 (flag 1): Position is over land\n",

"bit 2 (flag 2): Position is lake\n",

"bit 3 (flag 4): SIC is set to zero by the open water filter\n",

"bit 4 (flag 8): SIC value is changed for correcting land spill-over effects\n",

"bit 5 (flag 16): Handle with caution, the 2m air temperature is high at this position, and this might be false ice\n",

"bit 6 (flag 32): Coast\n",

"bit 7 (flag 64): SIC is set to zero since position is outside maximum sea ice climatology \n",

"bit 8 (flag 128): Point not accepted but no other flags raised." ;

status_flag:comment = "Flag values found in the map might be combinations of those listed above. For example flag value 80 (= 2^4 + 2^6 = 16 + 64) indicates high_t2m AND temporal_interp" ;

status_flag:coordinates = "lon lat" ;

double Tb_corr(time, yc, xc) ;

Tb_corr:_FillValue = NaN ;

Tb_corr:long_name = "corrected brightness temperatures" ;

Tb_corr:standard_name = "brightness_temperature_corrected" ;

Tb_corr:units = "K" ;

Tb_corr:valid_min = 90 ;

Tb_corr:valid_max = 273.15 ;

Tb_corr:grid_mapping = "Lambert_Azimuthal_Grid" ;

Tb_corr:comment = "these are the corrected brightness temperatures" ;

Tb_corr:coordinates = "lon lat" ;

double Tb(time, yc, xc) ;

Tb:_FillValue = NaN ;

Tb:long_name = "(uncorrected) brightness temperatures" ;

Tb:standard_name = "brightness_temperature" ;

Tb:units = "K" ;

Tb:valid_min = 90 ;

Tb:valid_max = 273.15 ;

Tb:grid_mapping = "Lambert_Azimuthal_Grid" ;

Tb:comment = "these are the uncorrected brightness temperatures" ;

Tb:coordinates = "lon lat" ;

int time(time) ;

time:long_name = "reference time of product" ;

time:standard_name = "time" ;

time:axis = "T" ;

time:bounds = "time_bnds" ;

time:units = "days since 1900-01-01T12:00:00" ;

time:calendar = "proleptic_gregorian" ;

double xc(xc) ;

xc:_FillValue = NaN ;

xc:units = "km" ;

xc:long_name = "x coordinate of projection (eastings)" ;

xc:standard_name = "projection_x_coordinate" ;

double yc(yc) ;

yc:_FillValue = NaN ;

yc:units = "km" ;

yc:long_name = "y coordinate of projection (northings)" ;

yc:standard_name = "projection_y_coordinate" ;

float lat(yc, xc) ;

lat:_FillValue = NaNf ;

lat:units = "degrees_north" ;

lat:long_name = "latitude coordinate" ;

lat:standard_name = "latitude" ;

float lon(yc, xc) ;

lon:_FillValue = NaNf ;

lon:units = "degrees_east" ;

lon:long_name = "longitude coordinate" ;

lon:standard_name = "longitude" ;

// global attributes:

:description = "Weather related data." ;

:title = "Sea Ice Concentration Climate Data Record from ESA Climate Change Initiative" ;

:summary = "This climate data record of sea ice concentration is obtained from passive microwave satellite data over the polar regions (ESMR). The processing chain features: 1) dynamic tuning of tie-points and algorithms, 2) correction of atmospheric noise using a Radiative Transfer Model, 3) computation of per-pixel uncertainties, and 4) one channel sea ice concentration algorithm. This dataset was generated by the ESA Climate Change Initiative." ;

:opiccategory = "Oceans ClimatologyMeteorologyAtmosphere" ;

:keywords = "Earth Science > Cryosphere > Sea Ice > Sea Ice Concentration\n",

"Earth Science > Oceans > Sea Ice > Sea Ice Concentration\n",

"Earth Science > Climate Indicators > Cryospheric Indicators > Sea Ice Concentration,Geographic Region > Northern Hemisphere,Vertical Location > Sea Surface,NO/MET > Norwegian Meteorological Institute" ;

:keywords_vocabulary = "GCMD Science Keywords" ;

:geospatial_lat_min = 16.6239266930037 ;

:geospatial_lat_max = 89.8417311687249 ;

:geospatial_lon_min = -179.867063395126 ;

:geospatial_lon_max = 179.867063395126 ;

:geospatial_vertical_min = 0. ;

:geospatial_vertical_max = 0. ;

:sensor = "ESMR" ;

:platform = "Nimbus-5" ;

:source = "ESMR from Nimbus 5,ERA-5 fields from ECMWF" ;

:time_coverage_duration = "P1D" ;

:time_coverage_resolution = "P1D" ;

:project = "ESA Climate Change Initiative" ;

:institution = "ESA Climate Change Initiative" ;

:creator_name = "DTU Space" ;

:creator_type = "instituti" ;

:creator_url = "https://climate.esa.int/en/projects/sea-ice/" ;

:creator_email = "" ;

:license = "All intellectual property rights of the ESA Climate Change Initiative products belong to ESA. The use of these products is granted to every user, free of charge. If users wish to use these products, ESA\'s copyright credit must be shown by displaying the words \'Copyright EUMETSAT\' under each of the products shown. EUMETSAT offers no warranty and accepts no liability in respect of the Ocean and Sea Ice SAF products. EUMETSAT neither commits to nor guarantees the continuity, availability, or quality or suitability for any purpose of, the Ocean and Sea Ice SAF products." ;

:references = "Paper title - in preparation" ;

:history = "2021-11-10T14:00:00Z creation" ;

:date_created = "2021-10-11" ;

:cdm_data_type = "Grid" ;

:spatial_resolution = "25.0 km grid spacing" ;

:algorithm = "ESMR" ;

:geospatial_bounds_crs = "EPSG:6931" ;

:contributor_name = "Rasmus Tonboe, Leif Toudal Pedersen, Thomas Lavergne, Atle Soerensen, Roberto Saldo, Wiebke Margitta Kolbe" ;

:contributor_role = "PrincipalInvestigator,author,author,author,author,author,author,author,author" ;

:product_version = "3.0" ;

:tracking_id = "1b406bc7-3879-43cf-ba8b-d6d35f5e254d" ;

:naming_authority = "int.eumetsat" ;

:Conventions = "CF-1.6 ACDD-1.3" ;

:standard_name_vocabulary = "Using Standard Name Table Version 78 (2021-09-21T11:55:06Z)" ;

}

5.4 Where to get the data?

The data are freely available from the ESA CCI open data portal: https://climate.esa.int/en/odp/#/project/sea-ice

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