



Match-up database Analyses Report

SMAP-L2-JPL-V4.2

Sea mammals

Southern Ocean

prepared by the Pi-MEP Consortium

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Acronym

Aquarius	NASA/CONAE Salinity mission
ASCAT	Advanced Scatterometer
ATBD	Algorithm Theoretical Baseline Document
BLT	Barrier Layer Thickness
CMORPH	CPC MORPHing technique
CTD	Instrument used to measure the conductivity, temperature, and pressure of seawater
DM	Delayed Mode
EO	Earth Observation
ESA	European Space Agency
FTP	File Transfer Protocol
GOSUD	Global Ocean Surface Underway Data
GTMBA	The Global Tropical Moored Buoy Array
Ifremer	Institut français de recherche pour l'exploitation de la mer
IPEV	Institut polaire français Paul-Émile Victor
IQR	Interquartile range
ISAS	In Situ Analysis System
Kurt	Kurtosis (fourth central moment divided by fourth power of the standard deviation)
L2	Level 2
LEGOS	Laboratoire d'Etudes en Géophysique et Océanographie Spatiales
LOCEAN	Laboratoire d'Océanographie et du Climat : Expérimentations et Approches Numériques
LOPS	Laboratoire d'Océanographie Physique et Spatiale
MDB	Match-up Data Base
MEOP	Marine Mammals Exploring the Oceans Pole to Pole
MLD	Mixed Layer Depth
NCEI	National Centers for Environmental Information
NRT	Near Real Time
NTAS	Northwest Tropical Atlantic Station
OI	Optimal interpolation
Pi-MEP	Pilot Mission Exploitation Platform
PIRATA	Prediction and Researched Moored Array in the Atlantic
QC	Quality control
R_{sat}	Spatial resolution of the satellite SSS product
RAMA	Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction
r^2	Square of the Pearson correlation coefficient
RMS	Root mean square
RR	Rain rate
SAMOS	Shipboard Automated Meteorological and Oceanographic System
Skew	Skewness (third central moment divided by the cube of the standard deviation)
SMAP	Soil Moisture Active Passive (NASA mission)
SMOS	Soil Moisture and Ocean Salinity (ESA mission)
SPURS	Salinity Processes in the Upper Ocean Regional Study
SSS	Sea Surface Salinity
$SSS_{in situ}$	In situ SSS data considered for the match-up

SSS _{SAT}	Satellite SSS product considered for the match-up
ΔSSS	Difference between satellite and in situ SSS at colocalized point ($\Delta\text{SSS} = \text{SSS}_{\text{SAT}} - \text{SSS}_{\text{insitu}}$)
SST	Sea Surface Temperature
Std	Standard deviation
Std*	Robust Standard deviation = $\text{median}(\text{abs}(x - \text{median}(x))) / 0.67$ (less affected by outliers than Std)
Stratus	Surface buoy located in the eastern tropical Pacific
Survostral	SURVeillance de l'Océan AuSTRAL (Monitoring the Southern Ocean)
TAO	Tropical Atmosphere Ocean
TSG	ThermoSalinoGraph
WHOI	Woods Hole Oceanographic Institution
WHOTS	WHOI Hawaii Ocean Time-series Station
WOA	World Ocean Atlas

1 Overview

In this report, we present systematic analyses of the Match-up DataBase (MDB) files generated by the Pi-MEP platform within the following Pi-MEP region and for the below pair of Satellite/In situ SSS data:

- Pi-MEP region: Southern Ocean (download the corresponding mask [here](#))
- SSS satellite product (SSS_{SAT}): SMAP-L2-JPL-V4.2
- In situ dataset ($SSS_{In situ}$): Sea mammals (download the corresponding report [here](#))

In the following, $\Delta SSS = SSS_{SAT} - SSS_{In situ}$ denotes the difference between the satellite and in situ SSS at the colocalized points that form the MDB.

This report presents successively:

The MDB file DataSets (Section 2)

- A short description of the satellite SSS product considered in the match-up (2.1)
- A short description of the In situ SSS dataset considered in the match-up (2.2)
- A short description of the auxiliary geophysical datasets co-localized with SSS pairs (2.3)
- An overview of how the Match-ups were evaluated (2.4)
- An overview of the MDB characteristics for the particular in situ/satellite pairs (2.5)

The major results of the MDB file Analyses (Section 3)

- Spatial Maps of the Time-mean and temporal Std of in situ and satellite SSS and of the ΔSSS (3.1)
- Time series of the monthly median and Std of in situ and satellite SSS and of the ΔSSS (3.2)
- Zonal mean and Std of in situ and satellite SSS and of the ΔSSS (3.3)
- Scatterplots of satellite vs in situ SSS by latitudinal bands (3.4)
- Time series of the monthly median and Std of the ΔSSS sorted by latitudinal bands (3.5)
- ΔSSS sorted as function of geophysical parameters (3.6)
- ΔSSS maps and statistics for different geophysical conditions (3.7)

All analyses are conducted over the Pi-MEP Region specified above and over the full satellite SSS product period. Original figures appearing in this report can be downloaded [here](#) as PNG files.

2 The MDB file datasets

2.1 Satellite SSS product

2.1.1 SMAP-L2-JPL-V4.2

This is the PI-produced JPL SMAP-SSS V4.2, level 2B CAP, validated sea surface salinity (SSS) and extreme winds orbital/swath product from the NASA Soil Moisture Active Passive (SMAP) observatory. It is based on the Combined Active-Passive (CAP) retrieval algorithm developed at JPL originally in the context of Aquarius/SAC-D and now extended to SMAP. SMAP-SSS V4.2 is a complete reprocessing of the entire mission series following on from the reprocessing of the source L1B-TB data by the SMAP mission on 6/4/2018. Updates in v4.2 include: improvement in the brightness temperature (TB) calibration using an adjusted reflector emissivity, inclusion of a Sea Surface Temperature (SST) dependent flat surface emissivity model, use of updated land correction tables, and inclusion of averaged ice concentration ancillary data in the v4.2 product. The JPL SMAP-SSS L2B CAP product includes data for a range of parameters: derived SMAP sea surface salinity, SSS uncertainty and wind speed/direction data for extreme winds, brightness temperatures for each radiometer polarization, ancillary reference surface salinity, ice concentration, wind and wave height data, quality flags, and navigation data. Each data file covers one 98-minute orbit (15 files per day). Data begins on April 1, 2015 and is ongoing, with a 3 day latency in processing and availability. Observations are global in extent and provided at 25km swath grid with an approximate spatial resolution of 60 km. The SMAP satellite is in a near-polar orbit at an inclination of 98 degrees and an altitude of 685 km. It has an ascending node time of 6 pm and is sun-synchronous. With its 1000km swath, SMAP achieves global coverage in approximately 3 days, but has an exact orbit repeat cycle of 8 days. On board Instruments include a highly sensitive L-band radiometer operating at 1.41GHz and an L-band 1.26GHz radar sensor providing complementary active and passive sensing capabilities. Malfunction of the SMAP scatterometer on 7 July, 2015, has necessitated the use of collocated wind speed for the surface roughness correction required for the surface salinity retrieval.

We only select data in the MDB files such as the following conditions or flags are met:

- Bits 5, 7, and 8 of quality_flag variable
- Bit 5 set to 0 - Ancillary wind speed < 20 m/s
- Bit 7 set to 0 - No land detected in SWC
- Bit 8 set to 0 - No ice detected in SWC

Table 1: Satellite SSS product characteristics

SMAP-L2-JPL-V4.2	
Spatial resolution	60 km (Along) x 60 km (Across)
Temporal repeat	8 days
Temporal coverage	From 2015-04-01 to now
Spatial coverage	Global [-180 180 -90 90]
Data Provider	JPL Climate Oceans and Solid Earth group
Release Date	2019-01-24
Version	4.2
User Guide	SMAP-SSS_JPL_V4.2_Documentation.pdf
Documentation	ftp://podaac-ftp.jpl.nasa.gov/allData/smap/docs/JPL-CAP_V42/
DOI	http://doi.org/10.5067/SMP42-2TOCS

2.2 In situ SSS dataset

Instrumentation of southern elephant seals with satellite-linked CTD tags proposes unique temporal and spatial coverage. This includes extensive data from the Antarctic continental slope and shelf regions during the winter months, which is outside the conventional areas of Argo autonomous floats and ship-based studies. The use of elephant seals has been particularly effective to sample the Southern Ocean and the North Pacific. Other seal species have been successfully used in the North Atlantic, such as hooded seals. The marine mammal dataset ([MEOP-CTD database](#)) is quality controlled and calibrated using delayed-mode techniques involving comparisons with other existing profiles as well as cross-comparisons similar to established protocols within the Argo community, with a resulting accuracy of ± 0.03 °C in temperature and ± 0.05 in salinity or better ([Treasure et al. \(2017\)](#)). The marine mammal data were collected and made freely available by the International MEOP Consortium and the national programs that contribute to it (<http://www.meop.net>). This dataset is updated once a year and can be downloaded [here](#) ([Roquet et al. \(2018\)](#)). A preprocessing stage is applied to the database before being used by the Pi-MEP which consist to keep only profile with salinity, temperature and pressure quality flags set to 1 or 2 and if at least one measurement is in the top 10 m depth. Marine mammal SSS correspond to the top (shallowest) profile salinity data provided that profile depth is 10 m or less.

2.3 Auxiliary geophysical datasets

Additional EO datasets are used to characterize the geophysical conditions at the in situ/satellite SSS pair measurement locations and time, and 10 days prior the measurements to get an estimate of the geophysical condition and history. As discussed in [Boutin et al. \(2016\)](#), the presence of vertical gradients in, and horizontal variability of, sea surface salinity indeed complicates comparison of satellite and in situ measurements. The additional EO data are used here to get a first estimates of conditions for which L-band satellite SSS measured in the first centimeters of the upper ocean within a 50-150 km diameter footprint might differ from pointwise in situ measurements performed in general between 10 and 5 m depth below the surface. The spatio-temporal variability of SSS within a satellite footprint (50–150 km) is a major issue for satellite SSS validation in the vicinity of river plumes, frontal zones, and significant precipitation. Rainfall can in some cases produce vertical salinity gradients exceeding 1 pss m^{-1} ; consequently, it is recommended that satellite and in situ SSS measurements less than 3–6 h after rain events should

be considered with care when used in satellite calibration/validation analyses. To identify such situation, the Pi-MEP test platform is first using CMORPH products to characterize the local value and history of rain rate and ASCAT gridded data are used to characterize the local surface wind speed and history. For validation purpose, the ISAS monthly SSS in situ analysed fields at 5 m depth are collocated and compared with the satellite SSS products. The use of ISAS is motivated by the fact that it is used in the SMOS L2 official validation protocol in which systematic comparisons of SMOS L2 retrieved SSS with ISAS are done. In complement to ISAS, monthly std climatological fields from the World Ocean Atlas (WOA13) at the match-up pairs location and date are also used to have an a priori information of the local SSS variability.

2.3.1 CMORPH

Precipitation are estimated using the CMORPH 3-hourly products at $1/4^\circ$ resolution (Joyce et al. (2004)). CMORPH (CPC MORPHing technique) produces global precipitation analyses at very high spatial and temporal resolution. This technique uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. At present NOAA incorporate precipitation estimates derived from the passive microwaves aboard the DMSP 13, 14 and 15 (SSM/I), the NOAA-15, 16, 17 and 18 (AMSU-B), and AMSR-E and TMI aboard NASA's Aqua, TRMM and GPM spacecraft, respectively. These estimates are generated by algorithms of Ferraro (1997) for SSM/I, Ferraro et al. (2000) for AMSU-B and Kummerow et al. (2001) for TMI. Note that this technique is not a precipitation estimation algorithm but a means by which estimates from existing microwave rainfall algorithms can be combined. Therefore, this method is extremely flexible such that any precipitation estimates from any microwave satellite source can be incorporated.

With regard to spatial resolution, although the precipitation estimates are available on a grid with a spacing of 8 km (at the equator), the resolution of the individual satellite-derived estimates is coarser than that - more on the order of 12 x 15 km or so. The finer "resolution" is obtained via interpolation.

In effect, IR data are used as a means to transport the microwave-derived precipitation features during periods when microwave data are not available at a location. Propagation vector matrices are produced by computing spatial lag correlations on successive images of geostationary satellite IR which are then used to propagate the microwave derived precipitation estimates. This process governs the movement of the precipitation features only. At a given location, the shape and intensity of the precipitation features in the intervening half hour periods between microwave scans are determined by performing a time-weighting interpolation between microwave-derived features that have been propagated forward in time from the previous microwave observation and those that have been propagated backward in time from the following microwave scan. NOAA refer to this latter step as "morphing" of the features.

For the present Pi-MEP products, we only considered the 3-hourly products at $1/4$ degree resolution. The entire CMORPH record (December 2002-present) for 3-hourly, $1/4$ degree lat/lon resolution can be found at: ftp://ftp.cpc.ncep.noaa.gov/precip/CMORPH_V1.0/CRT/. CMORPH estimates cover a global belt (-180° W to 180° E) extending from 60° S to 60° N latitude and are available for the complete period of the Pi-MEP core datasets (Jan 2010-now).

2.3.2 ASCAT

Advanced SCATterometer (ASCAT) daily data produced and made available at Ifremer/CERSAT on a $0.25^\circ \times 0.25^\circ$ resolution grid (Bentamy and Fillon (2012)) since March 2007 are used to characterize the mean daily wind at the match-up pair location as well as the wind history during the

10-days period preceding the in situ measurement date. These wind fields are calculated based on a geostatistical method with external drift. Remotely sensed data from ASCAT are considered as observations while those from numerical model analysis (ECMWF) are associated with the external drift. The spatial and temporal structure functions for wind speed, zonal and meridional wind components are estimated from ASCAT retrievals. Furthermore, the new procedure includes a temporal interpolation of the retrievals based on the complex empirical orthogonal function (CEOF) approach, in order to enhance the sampling length of the scatterometer observations. The resulting daily wind fields involves the main known surface wind patterns as well as some variation modes associated with temporal and spatial moving features. The accuracy of the gridded winds was investigated through comparisons with moored buoy data in [Bentamy et al. \(2012\)](#) and resulted in rms differences for wind speed and direction are about 1.50 m.s^{-1} and 20° .

2.3.3 ISAS

The In Situ Analysis System (ISAS), as described in [Gaillard et al. \(2016\)](#) is a data based re-analysis of temperature and salinity fields over the global ocean. It was initially designed to synthesize the temperature and salinity profiles collected by the Argo program. It has been later extended to accommodate all type of vertical profile as well as time series. ISAS gridded fields are entirely based on in-situ measurements. The methodology and configuration have been conceived to preserve as much as possible the data information content and resolution. ISAS is developed and run in a research laboratory (LOPS) in close collaboration with Coriolis, one of Argo Global Data Assembly Center and unique data provider for the Mercator operational oceanography system. At the moment the period covered starts in 2002 and only the upper 2000 m are considered. The gridded fields were produced over the global ocean 70°N – 70°S on a $1/2^\circ$ grid by the ISAS project with datasets downloaded from the Coriolis data center (for more details on ISAS see [Gaillard et al. \(2009\)](#)). In the Pi-MEP, the product in used is the `INSITU_GLO_TS_OA_NRT_OBSERVATIONS_013_002_a` v6.2 NRT derived at the Coriolis data center and provided by the Copernicus Marine Environment Monitoring Service (CMEMS). The major contribution to the data set is from Argo array of profiling floats, reaching an approximate resolution of one profile every 10-days and every 3-degrees over the satellite SSS period (<http://www.umr-lops.fr/SNO-Argo/Products/ISAS-T-S-fields/>); in this version SSS from ship of opportunity thermosalinographs are not used, so that we can consider SMOS SSS validation using these measurements independent of ISAS. The ISAS optimal interpolation involves a structure function modeled as the sum of two Gaussian functions, each associated with specific time and space scales, resulting in a smoothing over typically 3 degrees. The smallest scale which can be retrieved with ISAS analysis is not smaller than 300–500 km ([Kolodziejczyk et al. \(2015\)](#)). For validation purpose, the ISAS monthly SSS fields at 5 m depth are collocated and compared with the satellite SSS products and included in the Pi-MEP Match-up files. In addition, the "percentage of variance" fields (PCTVAR) contained in the ISAS analyses provide information on the local variability of in situ SSS measurements within $1/2^\circ \times 1/2^\circ$ boxes.

2.3.4 World Ocean Atlas Climatology

The World Ocean Atlas 2013 version 2 (WOA13 V2) is a set of objectively analyzed (1° grid) climatological fields of in situ temperature, salinity and other variables provided at standard depth levels for annual, seasonal, and monthly compositing periods for the World Ocean. It also includes associated statistical fields of observed oceanographic profile data interpolated to standard depth levels on 5° , 1° , and 0.25° grids. We use these fields in complement to ISAS to

characterize the climatological fields (annual mean and std) at the match-up pairs location and date.

2.4 Overview of the Match-ups generation method

The match-up production is basically a three steps process:

1. preparation of the input in situ and satellite data, and,
2. co-localization of satellite products with in situ SSS measurements.
3. co-localization of the in situ/satellite pair with auxiliary information.

In the following, we successively detail the approaches taken for these different steps.

2.4.1 In Situ/Satellite data filtering

The first step consists in filtering Sea mammals in situ dataset using the quality flags as described in 2.2 so that only valid salinity data remains in the produced match-ups.

For high-spatial resolution in situ SSS measurements such as the Thermo-SalinoGraph (TSG) SSS data from research vessels, Voluntary Observing Ships (VOS) or sailing ships, as well as SSS data from surface drifters, an additional spatial-filtering step is performed on the in situ data that will be in fine compared to the satellite SSS products. If R_{sat} is the spatial resolution of the satellite SSS product (L2 to L3-L4), we keep the in situ data at the original spatial resolution but we also estimate for all spatio-temporal samples a running median filtered SSS applied to all neighbouring in situ SSS data acquired within a distance of $R_{sat}/2$ from a given in situ acquisition. Both the original and the filtered data are finally stored in the MDB files.

Only for satellite L2 SSS data, a third step consist in filtering spurious data using the flags and associated recommendation as provided by the official data centers and described in 2.1.

2.4.2 In Situ/Satellite Co-localization

In this step, each SSS satellite acquisition is co-localized with the filtered in situ measurements. The method used for co-localization differ if the satellite SSS is a swath product (so-called Level 2-types) or a time-space composite product (so-called Level 3/level 4-types).

- For L2 SSS swath data :

If R_{sat} is the spatial resolution of the satellite swath SSS product, for each in situ data sample collected in the Pi-MEP database, the platform searches for all satellite SSS data found at grid nodes located within a radius of $R_{sat}/2$ from the in situ data location and acquired with a time-lag from the in situ measurement date that is less or equal than ± 12 hours. If several satellite SSS samples are found to meet these criteria, the final satellite SSS match-up point is selected to be the closest in time from the in situ data measurement date. The final spatial and temporal lags between the in situ and satellite data are stored in the MDB files.

- For L3 and L4 composite SSS products :

If R_{sat} is the spatial resolution of the composite satellite SSS product and D the period over which the composite product was built (e.g., periods of 1, 7, 8, 9, 10, 18 days, 1 month, etc..) with central time t_0 , for each in situ data sample collected in the Pi-MEP database during period D, the platform searches for all satellite SSS data of the composite product

found at grid nodes located within a radius of $R_{sat}/2$ from the in situ data location. If several satellite SSS product samples are found to meet these criteria, the final satellite SSS match-up point is chosen to be the composite SSS with central time to which is the closest in time from the in situ data measurement date. The final spatial and temporal lags between the in situ and satellite data are stored in the MDB files.

2.4.3 MDB pair Co-localization with auxiliary data and complementary information

MDB data consist of satellite and in-situ SSS pair datasets but also of auxiliary geophysical parameters such as local and history of wind speed and rain rates, as well as various information (climatology, distance to coast, mixed layer depth, barrier layer thickness, etc) that can be derived from in situ data and which are included in the final match-up files. The collocation of auxiliary parameters and additional information is done for each filtered in-situ SSS measurement contained in the match-up files as follows :

If t_{insitu} is the time/date at which the in situ measurement is performed, we collect:

- The [ASCAT](#) wind speed product of the same day than t_{insitu} found at the ASCAT $1/4^\circ$ grid node with closest distance from the in situ data location and the time series of the ASCAT wind speed at the same node for the 10 days prior the in situ measurement day.
- If the in situ data is located within the 60°N - 60°S band, we select the [CMORPH](#) 3-hourly product the closest in time from tin situ and found at the CMORPH $1/4^\circ$ grid node with closest distance from the in situ data location. We then store the time series of the CMORPH rain rate at the same node for the 10 days prior the in situ measurement time.

For the given month/year of the in situ data, we select the [ISAS](#) and [WOA](#) fields for the same month (and same year for ISAS fields) and take the SSS analysis (monthly mean, std) found at the closest grid node from the in situ measurement.

The distance from the in situ SSS data location to the nearest coast is evaluated and provided in km. We use a distance-to-coast map at $1/4^\circ$ resolution where small islands have been removed.

When vertical profiles of salinity (S) and temperature (T) are made available from the in situ measurements used to build the match-up (Argo or sea mammals), the following variables are included into each satellite/in situ match-up file:

1. The vertical distribution of pressure at which the profile were measured,
2. The vertical $S(z)$ and $T(z)$ profiles,
3. The vertical potential density anomaly profile $\sigma_0(z)$,
4. The Mixed Layer Depth (MLD). The MLD is defined here as the depth where the potential density has increased from the reference depth (10 meter) by a threshold equivalent to 0.2°C decrease in temperature at constant salinity: $\sigma_0 = \sigma_{010m} + \Delta\sigma_0$ with $\Delta\sigma_0 = \sigma_0(\theta_{10m} - 0.2, S_{10m}) - \sigma_0(\theta_{10m}, S_{10m})$ where θ_{10m} and S_{10m} are the temperature and salinity at the reference depth (i.e. 10 m) ([de Boyer Montégut et al. \(2004\)](#), [de Boyer Montégut et al. \(2007\)](#)).
5. The Top of the Thermocline Depth (TTD) is defined as the depth at which temperature decreases from its 10 m value by 0.2°C .
6. The Barrier Layer if present, is defined as the intermediate layer between the top of the thermocline and the bottom of the density mixed-layer and its thickness (BLT) is defined as the difference between the MLD and the TTD.

7. The vertical profile of the buoyancy frequency $N^2(z)$

The resulting match-ups files are serialized as NetCDF-4 files whose structure depends on the origin of the in-situ data they contain.

2.4.4 Content of the Match-Up NetCDF files

```
netcdf pimep-mdb_smap-l2-jpl-v4.2_mammal_20100116_v01 {
dimensions:
    N_prof = 1 ;
    N_LEVELS = 27 ;
    N_DAYS_WIND = 10 ;
    N_3H_RAIN = 80 ;
    STRING = 8 ;
    TIME_Sat = UNLIMITED ; // (1 currently)
variables:
float DATE_MAMMAL(N_prof) ;
    DATE_MAMMAL:long_name = "Date of marine mammal profile" ;
    DATE_MAMMAL:units = "days since 1990-01-01 00:00:00" ;
    DATE_MAMMAL:standard_name = "time" ;
    DATE_MAMMAL:_FillValue = -999.f ;
float LATITUDE_MAMMAL(N_prof) ;
    LATITUDE_MAMMAL:long_name = "Latitude of marine mammal profile" ;
    LATITUDE_MAMMAL:units = "degrees_north" ;
    LATITUDE_MAMMAL:valid_min = -90. ;
    LATITUDE_MAMMAL:valid_max = 90. ;
    LATITUDE_MAMMAL:standard_name = "latitude" ;
    LATITUDE_MAMMAL:_FillValue = -999.f ;
float LONGITUDE_MAMMAL(N_prof) ;
    LONGITUDE_MAMMAL:long_name = "Longitude of mammal profile" ;
    LONGITUDE_MAMMAL:units = "degrees_east" ;
    LONGITUDE_MAMMAL:valid_min = -180. ;
    LONGITUDE_MAMMAL:valid_max = 180. ;
    LONGITUDE_MAMMAL:standard_name = "longitude" ;
    LONGITUDE_MAMMAL:_FillValue = -999.f ;
float SSS_DEPTH_MAMMAL(N_prof) ;
    SSS_DEPTH_MAMMAL:long_name = "Sea water pressure at marine mammal location
(equals 0 at sea level)" ;
    SSS_DEPTH_MAMMAL:units = "decibar" ;
    SSS_DEPTH_MAMMAL:standard_name = "sea_water_pressure" ;
    SSS_DEPTH_MAMMAL:_FillValue = -999.f ;
float SSS_MAMMAL(N_prof) ;
    SSS_MAMMAL:long_name = "Mammals SSS" ;
    SSS_MAMMAL:units = "1" ;
    SSS_MAMMAL:salinity_scale = "Practical Salinity Scale(PSS-78)" ;
    SSS_MAMMAL:standard_name = "sea_water_salinity" ;
    SSS_MAMMAL:_FillValue = -999.f ;
float SST_MAMMAL(N_prof) ;
    SST_MAMMAL:long_name = "Mammals SST" ;
    SST_MAMMAL:units = "degree Celsius" ;
```

```

        SST_MAMMAL:standard_name = "sea_water_temperature" ;
        SST_MAMMAL:_FillValue = -999.f ;
float DISTANCE_TO_COAST_MAMMAL(N_prof) ;
        DISTANCE_TO_COAST_MAMMAL:long_name = "Distance to coasts at marine mammal
location" ;
        DISTANCE_TO_COAST_MAMMAL:units = "km" ;
        DISTANCE_TO_COAST_MAMMAL:_FillValue = -999.f ;
float PLATFORM_NUMBER_MAMMAL(N_prof) ;
        PLATFORM_NUMBER_MAMMAL:long_name = "Mammals unique identifier" ;
        PLATFORM_NUMBER_MAMMAL:conventions = "WMO float identifier : A9IIII" ;
        PLATFORM_NUMBER_MAMMAL:units = "1" ;
        PLATFORM_NUMBER_MAMMAL:_FillValue = -999.f ;
float PSAL_MAMMAL(N_prof, N_LEVELS) ;
        PSAL_MAMMAL:long_name = "Mammals salinity profile" ;
        PSAL_MAMMAL:units = "1" ;
        PSAL_MAMMAL:salinity_scale = "Practical Salinity Scale (PSS-78)" ;
        PSAL_MAMMAL:standard_name = "sea_water_salinity" ;
        PSAL_MAMMAL:_FillValue = -999.f ;
float TEMP_MAMMAL(N_prof, N_LEVELS) ;
        TEMP_MAMMAL:long_name = "Mammals temperature profile" ;
        TEMP_MAMMAL:units = "degree Celsius" ;
        TEMP_MAMMAL:standard_name = "sea_water_temperature" ;
        TEMP_MAMMAL:_FillValue = -999.f ;
float PRES_MAMMAL(N_prof, N_LEVELS) ;
        PRES_MAMMAL:long_name = "Mammals pressure profile" ;
        PRES_MAMMAL:units = "decibar" ;
        PRES_MAMMAL:standard_name = "sea_water_pressure" ;
        PRES_MAMMAL:_FillValue = -999.f ;
float RHO_MAMMAL(N_prof, N_LEVELS) ;
        RHO_MAMMAL:long_name = "Mammals in-situ density profile" ;
        RHO_MAMMAL:units = "kg/m" ;
        RHO_MAMMAL:_FillValue = -999.f ;
float SIGMA0_MAMMAL(N_prof, N_LEVELS) ;
        SIGMA0_MAMMAL:long_name = "Mammals potential density anomaly profile" ;
        SIGMA0_MAMMAL:units = "kg/m3" ;
        SIGMA0_MAMMAL:_FillValue = -999.f ;
float N2_MAMMAL(N_prof, N_LEVELS) ;
        N2_MAMMAL:long_name = "Mammals buoyancy frequency profile" ;
        N2_MAMMAL:units = "1/s2" ;
        N2_MAMMAL:_FillValue = -999.f ;
float MLD_MAMMAL(N_prof) ;
        MLD_MAMMAL:long_name = "Mixed Layer Depth (MLD) calculated from marine mam-
mал profile (depth where  $\sigma_0 = \sigma_{010m} + \Delta\sigma_0$  with  $\Delta\sigma_0 = \sigma_0(\theta_{10m} - 0.2, S_{10m}) - \sigma_0(\theta_{10m}, S_{10m})$ 
)" ;
        MLD_MAMMAL:units = "m" ;
        MLD_MAMMAL:_FillValue = -999.f ;
float TTD_MAMMAL(N_prof) ;
        TTD_MAMMAL:long_name = "Top of Thermocline Depth (TTD) calculated from marine
mammал profile (depth where  $\theta = \theta_{10m} - 0.2$ )" ;
    
```

```

        TTD_MAMMAL:units = "m" ;
        TTD_MAMMAL:FillValue = -999.f ;
float BLT_MAMMAL(N_prof) ;
        BLT_MAMMAL:long_name = "Barrier Layer Thickness (TTD-MLD)" ;
        BLT_MAMMAL:units = "m" ;
        BLT_MAMMAL:FillValue = -999.f ;
float DATE_Satellite_product(TIME_Sat) ;
        DATE_Satellite_product:long_name = "Central time of satellite SSS file" ;
        DATE_Satellite_product:units = "days since 1990-01-01 00:00:00" ;
        DATE_Satellite_product:standard_name = "time" ;
float LATITUDE_Satellite_product(N_prof) ;
        LATITUDE_Satellite_product:long_name = "Satellite product latitude at marine mammal
location" ;
        LATITUDE_Satellite_product:units = "degrees_north" ;
        LATITUDE_Satellite_product:valid_min = -90. ;
        LATITUDE_Satellite_product:valid_max = 90. ;
        LATITUDE_Satellite_product:standard_name = "latitude" ;
        LATITUDE_Satellite_product:FillValue = -999.f ;
float LONGITUDE_Satellite_product(N_prof) ;
        LONGITUDE_Satellite_product:long_name = "Satellite product longitude at marine mam-
mal location" ;
        LONGITUDE_Satellite_product:units = "degrees_east" ;
        LONGITUDE_Satellite_product:valid_min = -180. ;
        LONGITUDE_Satellite_product:valid_max = 180. ;
        LONGITUDE_Satellite_product:standard_name = "longitude" ;
        LONGITUDE_Satellite_product:FillValue = -999.f ;
float SSS_Satellite_product(N_prof) ;
        SSS_Satellite_product:long_name = "Satellite product SSS at marine mammal location" ;
        SSS_Satellite_product:units = "1" ;
        SSS_Satellite_product:salinity_scale = "Practical Salinity Scale(PSS-78)" ;
        SSS_Satellite_product:standard_name = "sea_surface_salinity" ;
        SSS_Satellite_product:FillValue = -999.f ;
float SST_Satellite_product(N_prof) ;
        SST_Satellite_product:long_name = "Satellite product SST at marine mammal location" ;
        SST_Satellite_product:units = "degree Celsius" ;
        SST_Satellite_product:standard_name = "sea_surface_temperature" ;
        SST_Satellite_product:FillValue = -999.f ;
float Spatial_lags(N_prof) ;
        Spatial_lags:long_name = "Spatial lag between marine mammal location and satellite SSS
product pixel center" ;
        Spatial_lags:units = "km" ;
        Spatial_lags:FillValue = -999.f ;
float Time_lags(N_prof) ;
        Time_lags:long_name = "Temporal lag between marine mammal time and satellite SSS
product central time" ;
        Time_lags:units = "days" ;
        Time_lags:FillValue = -999.f ;
float ROSSBY_RADIUS_at_MAMMAL(N_prof) ;
        ROSSBY_RADIUS_at_MAMMAL:long_name = "Baroclinic Rossby radius of deformation
    
```



```

(Chelton et al., 1998) at marine mammal location" ;
    ROSSBY_RADIUS_at_MAMMAL:units = "km" ;
    ROSSBY_RADIUS_at_MAMMAL:FillValue = -999.f ;
float Ascet_daily_wind_at_MAMMAL(N_prof) ;
    Ascet_daily_wind_at_MAMMAL:long_name = "Daily Ascet wind speed module at marine
mammal location" ;
    Ascet_daily_wind_at_MAMMAL:units = "m/s" ;
    Ascet_daily_wind_at_MAMMAL:FillValue = -999.f ;
float CMORPH_3h_Rain_Rate_at_MAMMAL(N_prof) ;
    CMORPH_3h_Rain_Rate_at_MAMMAL:long_name = "3-hourly CMORPH rain rate at ma-
rine mammal location" ;
    CMORPH_3h_Rain_Rate_at_MAMMAL:units = "mm/3h" ;
    CMORPH_3h_Rain_Rate_at_MAMMAL:FillValue = -999.f ;
float Ascet_10_prior_days_wind_at_MAMMAL(N_prof, N_DAYS_WIND) ;
    Ascet_10_prior_days_wind_at_MAMMAL:long_name = "Prior 10 days time series of Ascet
wind speed module at marine mammal location" ;
    Ascet_10_prior_days_wind_at_MAMMAL:units = "m/s" ;
    Ascet_10_prior_days_wind_at_MAMMAL:FillValue = -999.f ;
float CMORPH_10_prior_days_Rain_Rate_at_MAMMAL(N_prof, N_3H_RAIN) ;
    CMORPH_10_prior_days_Rain_Rate_at_MAMMAL:long_name = "Prior 10 days times series
of 3-hourly CMORPH Rain Rate at marine mammal location" ;
    CMORPH_10_prior_days_Rain_Rate_at_MAMMAL:units = "mm/3h" ;
    CMORPH_10_prior_days_Rain_Rate_at_MAMMAL:FillValue = -999.f ;
float SSS_ISAS_at_MAMMAL(N_prof) ;
    SSS_ISAS_at_MAMMAL:long_name = "ISAS SSS (5m depth) at marine mammal location"
;
    SSS_ISAS_at_MAMMAL:units = "1" ;
    SSS_ISAS_at_MAMMAL:salinity_scale = "Practical Salinity Scale(PSS-78)" ;
    SSS_ISAS_at_MAMMAL:standard_name = "sea_water_salinity" ;
    SSS_ISAS_at_MAMMAL:FillValue = -999.f ;
float SSS_PCTVAR_ISAS_at_MAMMAL(N_prof) ;
    SSS_PCTVAR_ISAS_at_MAMMAL:long_name = "Error on ISAS SSS (5m depth) at marine
mammal location (% variance)" ;
    SSS_PCTVAR_ISAS_at_MAMMAL:units = "%" ;
    SSS_PCTVAR_ISAS_at_MAMMAL:FillValue = -999.f ;
float SSS_WOA13_at_MAMMAL(N_prof) ;
    SSS_WOA13_at_MAMMAL:long_name = "Annual WOA 2013 (DECAV-1deg) SSS (0m
depth) at marine mammal location" ;
    SSS_WOA13_at_MAMMAL:units = "1" ;
    SSS_WOA13_at_MAMMAL:salinity_scale = "Practical Salinity Scale(PSS-78)" ;
    SSS_WOA13_at_MAMMAL:standard_name = "sea_surface_salinity" ;
    SSS_WOA13_at_MAMMAL:FillValue = -999.f ;
float SSS_STD_WOA13_at_MAMMAL(N_prof) ;
    SSS_STD_WOA13_at_MAMMAL:long_name = "Annual WOA 2013 (DECAV-1deg) SSS
STD (0m depth) at marine mammal location " ;
    SSS_STD_WOA13_at_MAMMAL:units = "1" ;
    SSS_STD_WOA13_at_MAMMAL:FillValue = -999.f ;
float SSS_ISAS15_at_MAMMAL(N_prof) ;
    SSS_ISAS15_at_MAMMAL:long_name = "Monthly ISAS-15 SSS (5m depth) at marine
    
```

```

mammal location" ;
    SSS_ISAS15_at_MAMMAL:units = "1" ;
    SSS_ISAS15_at_MAMMAL:salinity_scale = "Practical Salinity Scale (PSS-78)" ;
    SSS_ISAS15_at_MAMMAL:standard_name = "sea_water_salinity" ;
    SSS_ISAS15_at_MAMMAL:FillValue = -999.f ;
float SSS_PCTVAR_ISAS15_at_MAMMAL(N_prof) ;
    SSS_PCTVAR_ISAS15_at_MAMMAL:long_name = "Error on monthly ISAS-15 SSS (5m
depth) at marine mammal location (% variance)" ;
    SSS_PCTVAR_ISAS15_at_MAMMAL:units = "%" ;
    SSS_PCTVAR_ISAS15_at_MAMMAL:FillValue = -999.f ;
float SSS_WOA18_at_MAMMAL(N_prof) ;
    SSS_WOA18_at_MAMMAL:long_name = "Monthly WOA 2018 (DECAV-1deg) SSS (0m
depth) at marine mammal location" ;
    SSS_WOA18_at_MAMMAL:units = "1" ;
    SSS_WOA18_at_MAMMAL:salinity_scale = "Practical Salinity Scale (PSS-78)" ;
    SSS_WOA18_at_MAMMAL:standard_name = "sea_surface_salinity" ;
    SSS_WOA18_at_MAMMAL:FillValue = -999.f ;
float SSS_STD_WOA18_at_MAMMAL(N_prof) ;
    SSS_STD_WOA18_at_MAMMAL:long_name = "Monthly WOA 2018 (DECAV-1deg) SSS
STD (0m depth) at marine mammal location" ;
    SSS_STD_WOA18_at_MAMMAL:units = "1" ;
    SSS_STD_WOA18_at_MAMMAL:FillValue = -999.f ;
float SEA_ICE_CONCENTRATION_at_MAMMAL(N_prof) ;
    SEA_ICE_CONCENTRATION_at_MAMMAL:long_name = "Daily sea ice area fraction
(EUMETSAT OSI-SAF OSI-450) at marine mammal location (%)" ;
    SEA_ICE_CONCENTRATION_at_MAMMAL:units = "1" ;
    SEA_ICE_CONCENTRATION_at_MAMMAL:standard_name = "sea_ice_area_fraction" ;
    SEA_ICE_CONCENTRATION_at_MAMMAL:FillValue = -999.f ;
float CCMP_6h_Wind_Speed_at_MAMMAL(N_prof) ;
    CCMP_6h_Wind_Speed_at_MAMMAL:long_name = "6-hourly CCMP wind speed at ma-
rine mammal location" ;
    CCMP_6h_Wind_Speed_at_MAMMAL:units = "m s-1" ;
    CCMP_6h_Wind_Speed_at_MAMMAL:standard_name = "wind_speed" ;
    CCMP_6h_Wind_Speed_at_MAMMAL:FillValue = -999.f ;
float CCMP_10_prior_days_Wind_Speed_at_MAMMAL(N_prof, N_DAYS_WIND_CCMP) ;
    CCMP_10_prior_days_Wind_Speed_at_MAMMAL:long_name = "Prior 10 days time series
of CCMP wind speed at marine mammal location" ;
    CCMP_10_prior_days_Wind_Speed_at_MAMMAL:units = "m s-1" ;
    CCMP_10_prior_days_Wind_Speed_at_MAMMAL:standard_name = "wind_speed" ;
    CCMP_10_prior_days_Wind_Speed_at_MAMMAL:FillValue = -999.f ;
float CDM_GLOBCOLOUR_at_MAMMAL(N_prof) ;
    CDM_GLOBCOLOUR_at_MAMMAL:long_name = "8-day Coloured dissolved and detrital
organic materials - mean of the binned pixels at marine mammal location" ;
    CDM_GLOBCOLOUR_at_MAMMAL:units = "m-1" ;
    CDM_GLOBCOLOUR_at_MAMMAL:standard_name = "volume_absorption_coefficient_of_radiative_flux_in_sea_
;
    CDM_GLOBCOLOUR_at_MAMMAL:FillValue = -999.f ;
float CHL1_GLOBCOLOUR_at_MAMMAL(N_prof) ;
    CHL1_GLOBCOLOUR_at_MAMMAL:long_name = "8-day Chlorophyll concentration - mean
    
```

```

of the binned pixels at marine mammal location" ;
    CHL1_GLOBCOLOUR_at_MAMMAL:units = "mg m-3" ;
    CHL1_GLOBCOLOUR_at_MAMMAL:standard_name = "mass_concentration_of_chlorophyll_a_in_sea_water"
;
    CHL1_GLOBCOLOUR_at_MAMMAL:_FillValue = -999.f ;
float EVAPORATION_OAFLUX_at_MAMMAL(N_prof) ;
    EVAPORATION_OAFLUX_at_MAMMAL:long_name = "Daily mean evaporation rate (OAFlux)
at marine mammal location" ;
    EVAPORATION_OAFLUX_at_MAMMAL:units = "cm year-1" ;
    EVAPORATION_OAFLUX_at_MAMMAL:_FillValue = -999.f ;
float SSS_SCRIPPS_at_MAMMAL(N_prof) ;
    SSS_SCRIPPS_at_MAMMAL:long_name = "Argo gridded monthly mean SSS (0m depth)
from SCRIPPS (Roemmich-Gilson) at marine mammal location" ;
    SSS_SCRIPPS_at_MAMMAL:units = "1" ;
    SSS_SCRIPPS_at_MAMMAL:salinity_scale = "Practical Salinity Scale (PSS-78)" ;
    SSS_SCRIPPS_at_MAMMAL:standard_name = "sea_water_salinity" ;
    SSS_SCRIPPS_at_MAMMAL:_FillValue = -999.f ;
float SSS_IPRC_at_MAMMAL(N_prof) ;
    SSS_IPRC_at_MAMMAL:long_name = "Argo gridded monthly mean SSS (0m depth) from
IPRC at marine mammal location" ;
    SSS_IPRC_at_MAMMAL:units = "1" ;
    SSS_IPRC_at_MAMMAL:salinity_scale = "Practical Salinity Scale (PSS-78)" ;
    SSS_IPRC_at_MAMMAL:standard_name = "sea_water_salinity" ;
    SSS_IPRC_at_MAMMAL:_FillValue = -999.f ;
float SST_AVHRR_at_MAMMAL(N_prof) ;
    SST_AVHRR_at_MAMMAL:long_name = "Daily OI AVHRR-only v2 SST (Reynolds et al.,
2007) at marine mammal location" ;
    SST_AVHRR_at_MAMMAL:units = "degree Celsius" ;
    SST_AVHRR_at_MAMMAL:standard_name = "sea_water_temperature" ;
    SST_AVHRR_at_MAMMAL:_FillValue = -999.f ;
float U_EKMAN_GLOBCURRENT_at_MAMMAL(N_prof) ;
    U_EKMAN_GLOBCURRENT_at_MAMMAL:long_name = "15m depth Ekman current ve-
locity: zonal component at marine mammal location" ;
    U_EKMAN_GLOBCURRENT_at_MAMMAL:units = "m s-1" ;
    U_EKMAN_GLOBCURRENT_at_MAMMAL:_FillValue = -999.f ;
float V_EKMAN_GLOBCURRENT_at_MAMMAL(N_prof) ;
    V_EKMAN_GLOBCURRENT_at_MAMMAL:long_name = "15m depth Ekman current ve-
locity: meridian component at marine mammal location" ;
    V_EKMAN_GLOBCURRENT_at_MAMMAL:units = "m s-1" ;
    V_EKMAN_GLOBCURRENT_at_MAMMAL:_FillValue = -999.f ;
float U_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL(N_prof) ;
    U_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL:long_name = "Absolute geostrophic
velocity: zonal component at marine mammal location" ;
    U_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL:units = "m s-1" ;
    U_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL:_FillValue = -999.f ;
float V_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL(N_prof) ;
    V_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL:long_name = "Absolute geostrophic
velocity: meridian component at marine mammal location" ;
    V_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL:units = "m s-1" ;
    
```

```

V_GEOSTROPHIC_GLOBCURRENT_at_MAMMAL: FillValue = -999.f ;

// global attributes:
:Conventions = "CF-1.6" ;
:title = "Marine Mammals Match-Up Database" ;      :Satellite_product_name = "SMAP-
L2-JPL-V4.2" ;
:Satellite_product_spatial_resolution = "60 km" ;
:Satellite_product_temporal_resolution = "98 min" ;
:Satellite_product_filename = "v4.2/2015/091/SMAP_L2B_SSS_00870_20150401T004402_R16010_V4.2.h5" ;
:Match-Up_spatial_window_radius_in_km = 30;
:Match-Up_temporal_window_radius_in_days = 0.5;
:start_time = "20100114T000005Z" ;
:stop_time = "20100118T235026Z" ;
:northernmost_latitude = 77.676f ;
:southernmost_latitude = -66.423f ;
:westernmost_longitude = -179.219f ;
:easternmost_longitude = 179.199f ;
:geospatial_lat_units = "degrees north" ;
:geospatial_lat_resolution = "60 km" ;
:geospatial_lon_units = "degrees east" ;
:geospatial_lon_resolution = "60 km" ;
:institution = "ESA-IFREMER-ODL-OCEANSCOPE" ;
:project_name = "SMOS Pilot-Mission Exploitation Platform (Pi-MEP) for salinity" ;
:project_url = "https://www.salinity-pimep.org" ;
:license = "Pi-MEP data use is free and open" ;
:product_version = "1.0" ;
:keywords = "Oceans > Ocean Salinity > Sea Surface Salinity" ;
:acknowledgment = "Please acknowledge the use of these data with the following state-
ment: These data were provided by the SMOS Pilot-Mission Exploitation Platform (Pi-MEP)
for salinity" ;
:source = "v4.2/2015/091/SMAP_L2B_SSS_00870_20150401T004402_R16010_V4.2.h5" ;
:references = "https://www.salinity-pimep.org" ;
:history = "Processed on 2018-04-18 using MDB-generator" ;
:date_created = "2018-04-18 17:09:30" ;
}
    
```

2.5 MDB characteristics for the particular in situ/satellite pairs

2.5.1 Number of paired SSS data as a function of time and distance to coast

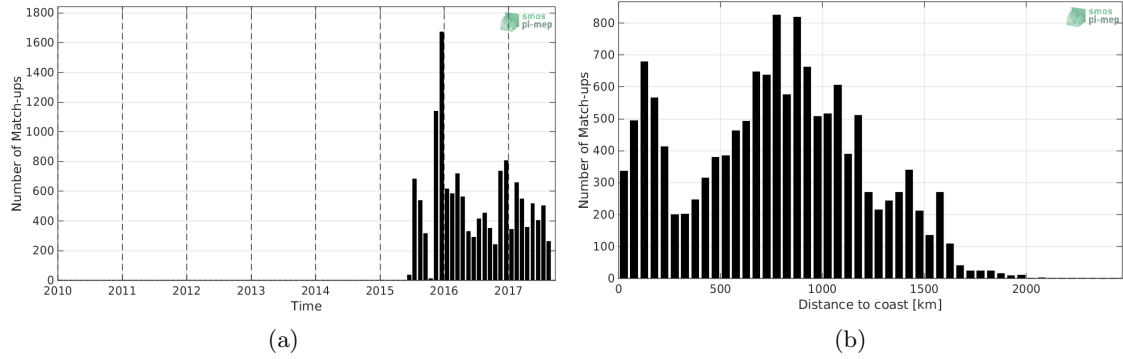


Figure 1: Number of match-ups between Sea mammals and SMAP-L2-JPL-V4.2 SSS as a function of time (a) and as function of the distance to coast (b) over the Southern Ocean Pi-MEP region and for the full satellite product period.

2.5.2 Histograms of the SSS match-ups

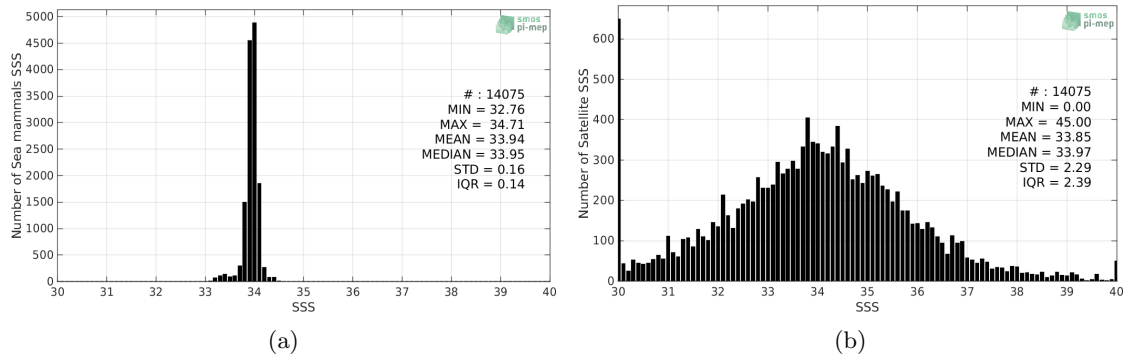


Figure 2: Histograms of SSS from Sea mammals (a) and SMAP-L2-JPL-V4.2 (b) considering all match-up pairs per bins of 0.1 over the Southern Ocean Pi-MEP region and for the full satellite product period.

2.5.3 Distribution of in situ SSS depth measurements

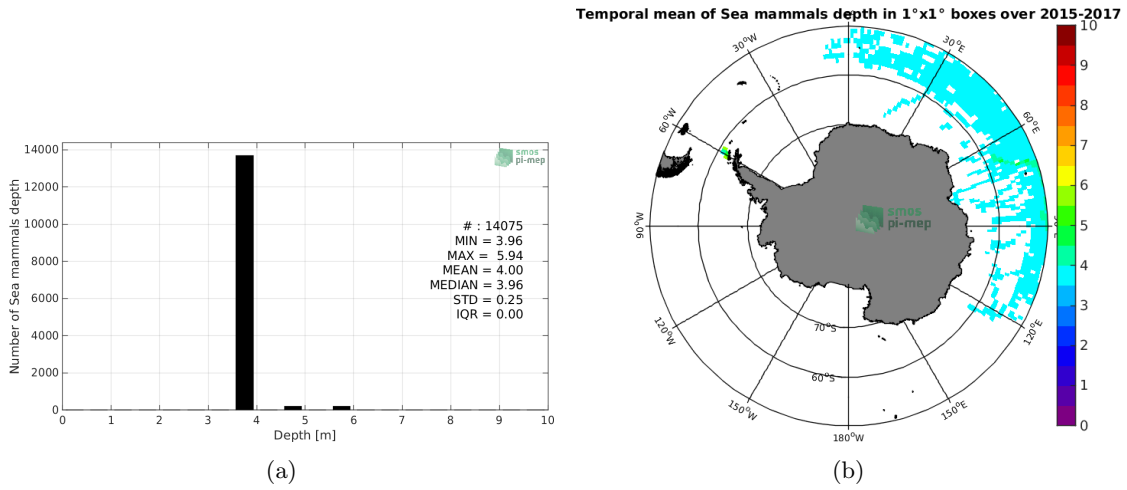


Figure 3: Histograms of the depth of the upper level SSS measurements from Sea mammals in the Match-up DataBase for the Southern Ocean Pi-MEP region (a) and temporal mean spatial distribution of pressure of the in situ SSS data over 1°x1° boxes and for the full satellite product period (b).

2.5.4 Spatial Distribution of Match-ups

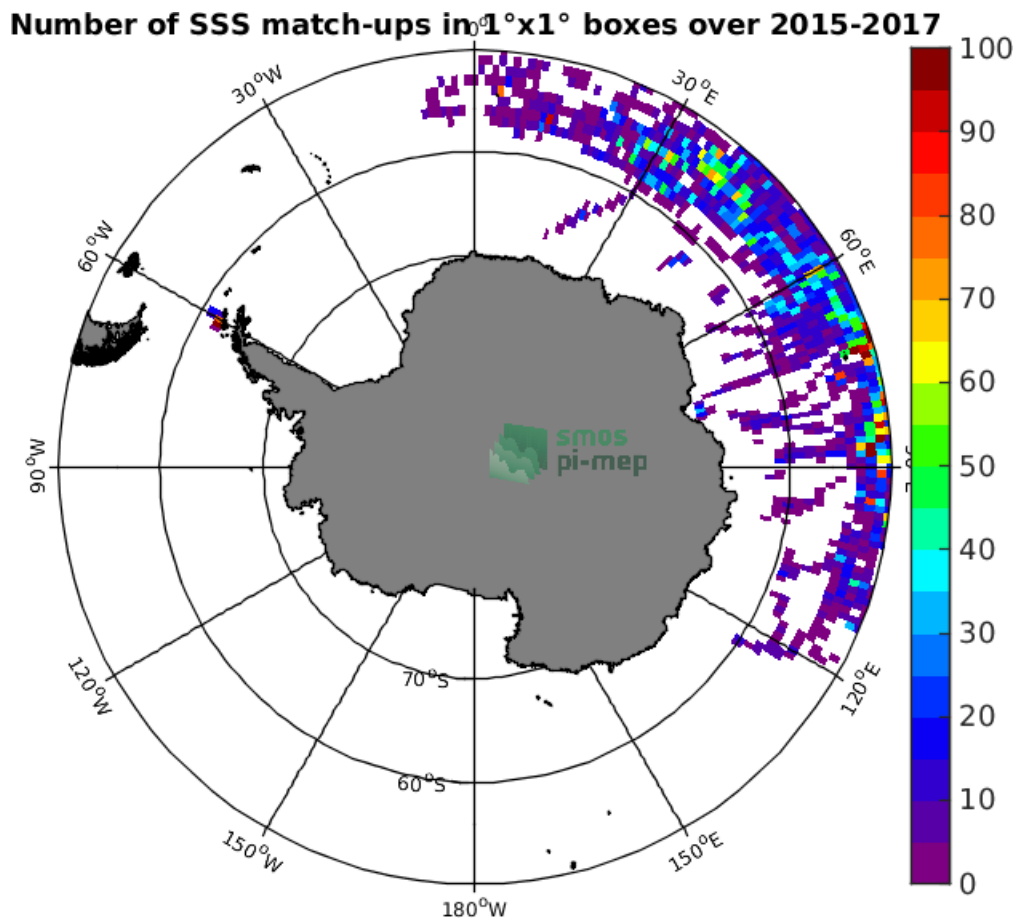


Figure 4: Number of SSS match-ups between Sea mammals SSS and the SMAP-L2-JPL-V4.2 SSS product for the Southern Ocean Pi-MEP region over $1^\circ \times 1^\circ$ boxes and for the full satellite product period.

2.5.5 Histograms of the spatial and temporal lags of the match-ups pairs

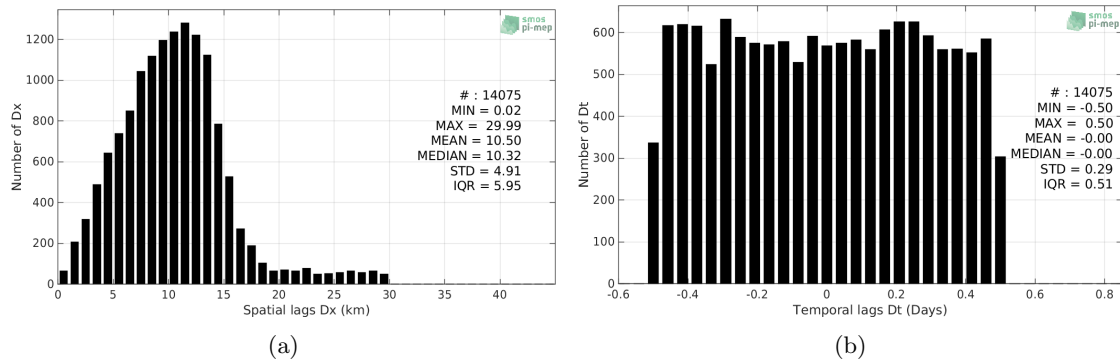


Figure 5: Histograms of the spatial (a) and temporal (b) lags between the time of the Sea mammals measurements and the date of the corresponding SMAP-L2-JPL-V4.2 SSS product.

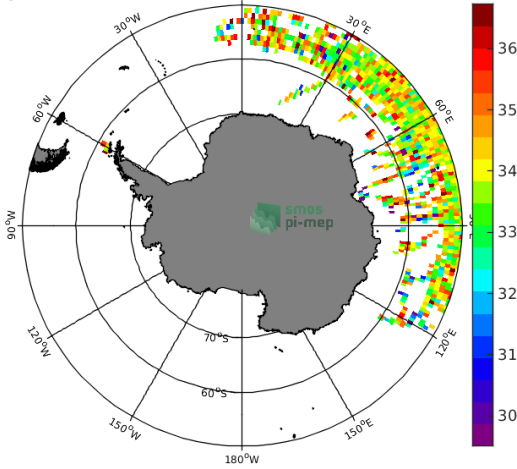
3 MDB file Analyses

3.1 Spatial Maps of the Temporal mean and Std of in situ and satellite SSS and of the difference (Δ SSS)

In Figure 6, we show maps of temporal mean (left) and standard deviation (right) of the SMAP-L2-JPL-V4.2 satellite SSS product (top) and of the Sea mammals in situ dataset at the collected Pi-MEP match-up pairs. The temporal mean and std are gridded over the full satellite product period and over spatial boxes of size $1^\circ \times 1^\circ$.

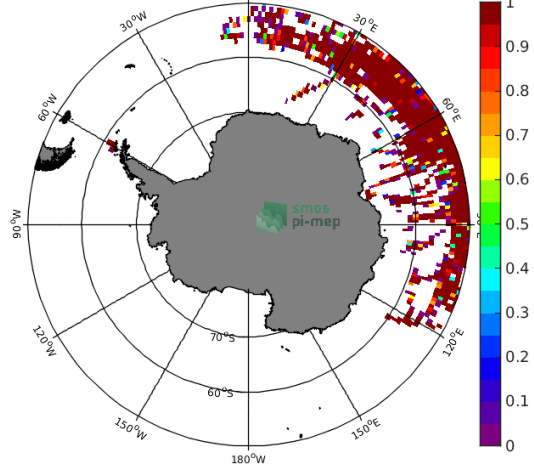
At the bottom of Figure 6, the temporal mean (left) and standard deviation (right) of the differences between the satellite SSS product and in situ data found at match-up pairs, namely Δ SSS (Satellite - Sea mammals), is also gridded over the full satellite product period and over spatial boxes of size $1^\circ \times 1^\circ$.

Temporal mean of Satellite SSS in 1°x1° boxes over 2015-2017



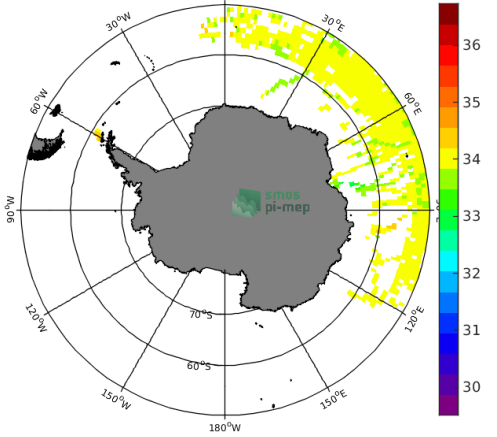
(a) MEAN(Satellite SSS)

Temporal STD of Satellite SSS in 1°x1° boxes over 2015-2017



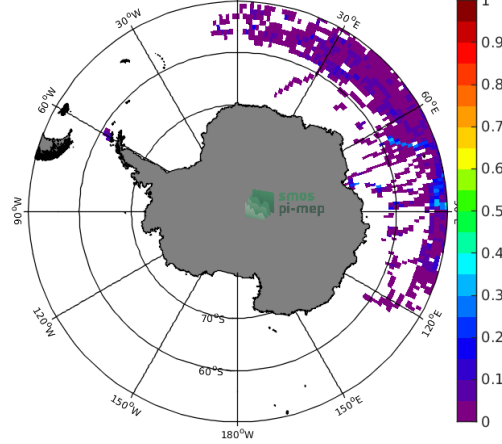
(b) Std(Satellite SSS)

Temporal mean of Sea mammals SSS in 1°x1° boxes over 2015-2017



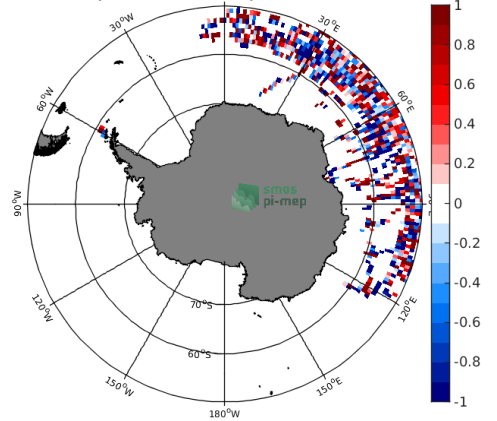
(c) MEAN(Sea mammals SSS)

Temporal STD of Sea mammals SSS in 1°x1° boxes over 2015-2017



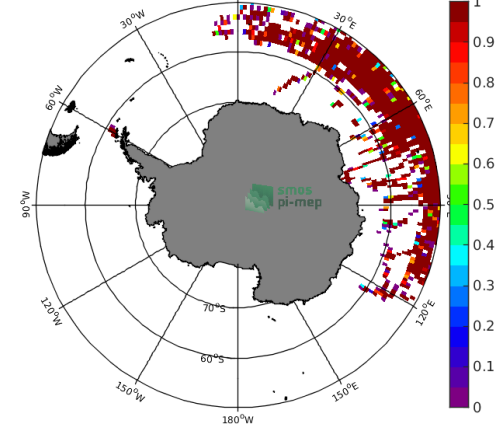
(d) Std(Sea mammals SSS)

Temporal mean of (Sat - Sea mammals) in 1°x1° boxes over 2015-2017



(e) MEAN(Δ SSS) (Satellite - Sea mammals)

Temporal STD of (Sat - Sea mammals) in 1°x1° boxes over 2015-2017



(f) Std(Δ SSS) (Satellite - Sea mammals)

Figure 6: Temporal mean (left) and Std (right) of SSS from SMAP-L2-JPL-V4.2 (top), Sea mammals (middle), and of Δ SSS (Satellite - Sea mammals). Only match-up pairs are used to generate these maps.

3.2 Time series of the monthly median and Std of in situ and satellite SSS and of the (Δ SSS)

In the top panel of Figure 7, we show the time series of the monthly median SSS estimated over the full Southern Ocean Pi-MEP region for both SMAP-L2-JPL-V4.2 satellite SSS product (in black) and the Sea mammals in situ dataset (in blue) at the collected Pi-MEP match-up pairs.

In the middle panel of Figure 7, we show the time series of the monthly median of Δ SSS (Satellite - Sea mammals) for the collected Pi-MEP match-up pairs and estimated over the full Southern Ocean Pi-MEP region.

In the bottom panel of Figure 7, we show the time series of the monthly standard deviation of the Δ SSS (Satellite - Sea mammals) for the collected Pi-MEP match-up pairs and estimated over the full Southern Ocean Pi-MEP region.

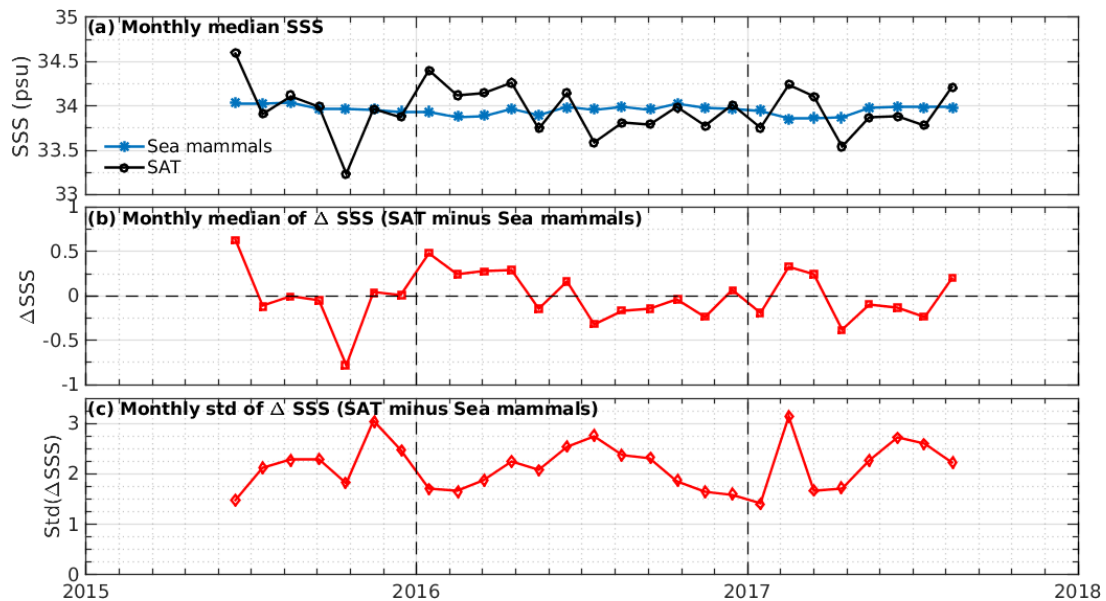


Figure 7: Time series of the monthly median SSS (top), median of Δ SSS (Satellite - Sea mammals) and Std of Δ SSS (Satellite - Sea mammals) over the Southern Ocean Pi-MEP region considering all match-ups collected by the Pi-MEP platform.

3.3 Zonal mean and Std of in situ and satellite SSS and of the Δ SSS

In Figure 8 left panel, we show the zonal mean SSS considering all Pi-MEP match-up pairs for both SMAP-L2-JPL-V4.2 satellite SSS product (in black) and the Sea mammals in situ dataset (in blue). The full satellite SSS product period is used to derive the mean.

In the right panel of Figure 8, we show the zonal mean of Δ SSS (Satellite - Sea mammals) for all the collected Pi-MEP match-up pairs estimated over the full satellite product period.

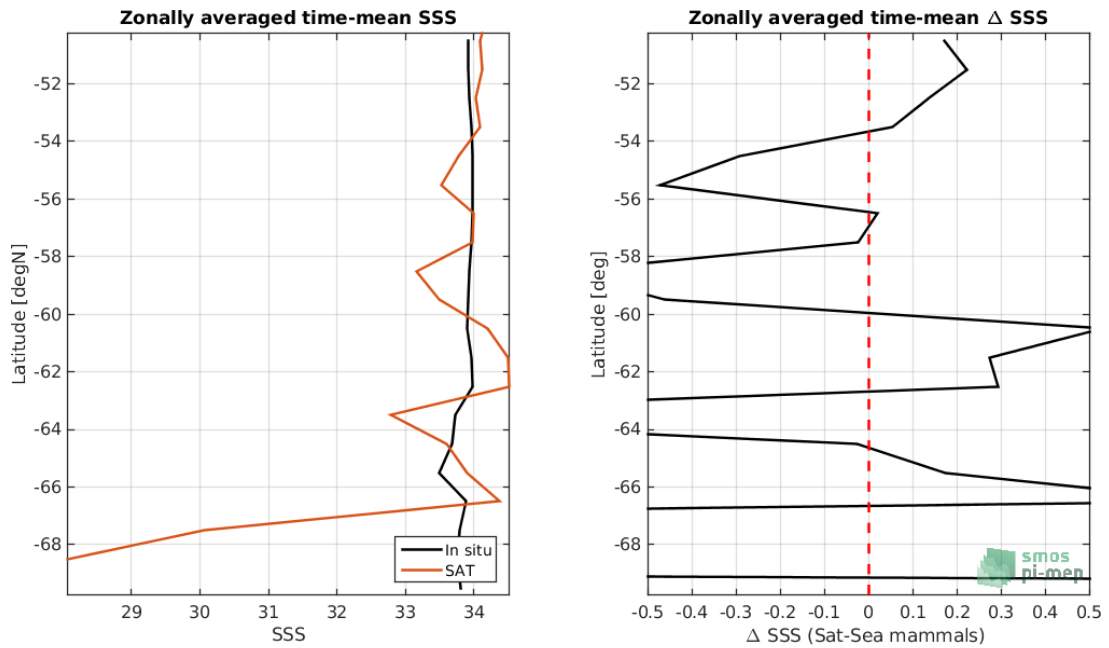


Figure 8: Left panel: Zonal mean SSS from SMAP-L2-JPL-V4.2 (black) and from Sea mammals (blue). Right panel: Zonal mean of Δ SSS (Satellite - Sea mammals) for all the collected Pi-MEP match-up pairs estimated over the full satellite product period.

3.4 Scatterplots of satellite vs in situ SSS by latitudinal bands

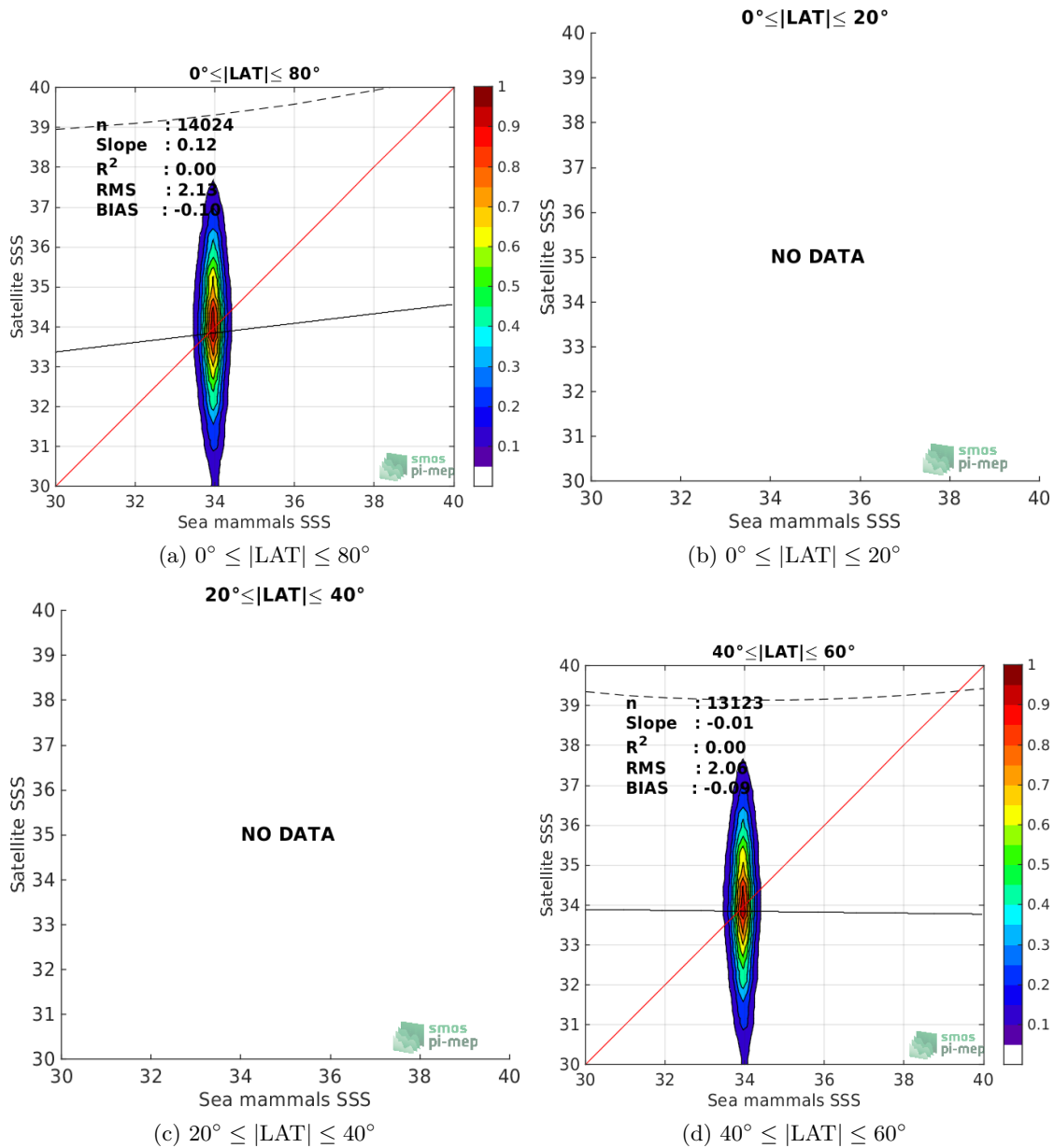


Figure 9: Contour maps of the concentration of SMAP-L2-JPL-V4.2 SSS (y-axis) versus Sea mammals SSS (x-axis) at match-up pairs for different latitude bands. For each plot, the red line shows $x=y$. The black thin and dashed lines indicate a linear fit through the data cloud and the $\pm 95\%$ confidence levels, respectively. The number match-up pairs n , the slope and R^2 coefficient of the linear fit, the root mean square (RMS) and the mean bias between satellite and in situ data are indicated for each latitude band in each plots.

3.5 Time series of the monthly median and Std of the Δ SSS sorted by latitudinal bands

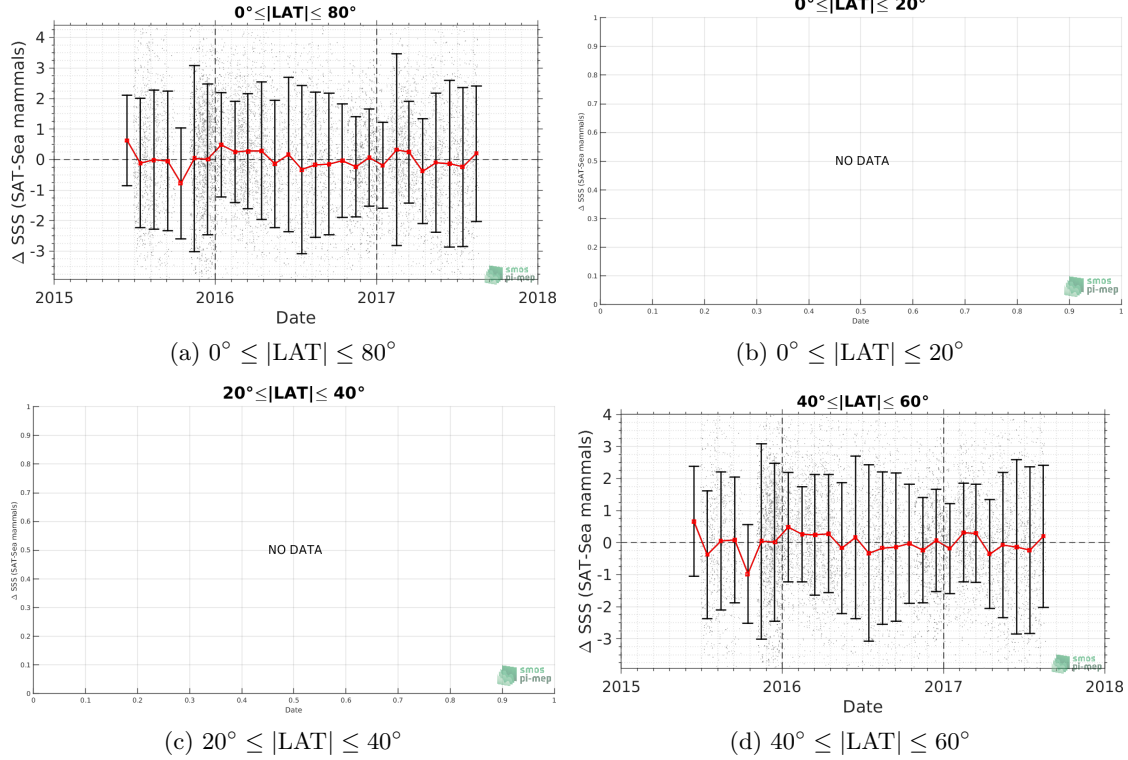


Figure 10: Monthly median (red curves) of Δ SSS (Satellite - Sea mammals) and ± 1 Std (black vertical thick bars) as function of time for all the collected Pi-MEP match-up pairs estimated over the Southern Ocean Pi-MEP region and for the full satellite product period are shown for different latitude bands: (a) Latitude band 80°S-80°N, (b) latitude band 20°S-20°N, (c) Mid Latitude bands 40°S-20°S and 20°N-40°N and (d) Latitude bands 60°S-40°S and 40°N-60°N.

3.6 Δ SSS sorted as function of geophysical parameters

In Figure 11, we classify the match-up differences Δ SSS (Satellite - in situ) between SMAP-L2-JPL-V4.2 and Sea mammals SSS as function of the geophysical conditions at match-up points. The mean and std of Δ SSS (Satellite - Sea mammals) is thus evaluated as function of the

- in situ SSS values per bins of width 0.2,
- in situ SST values per bins of width 1°C,
- ASCAT daily wind values per bins of width 1 m/s,
- CMORPH 3-hourly rain rates per bins of width 1 mm/h, and,
- distance to coasts per bins of width 50 km.

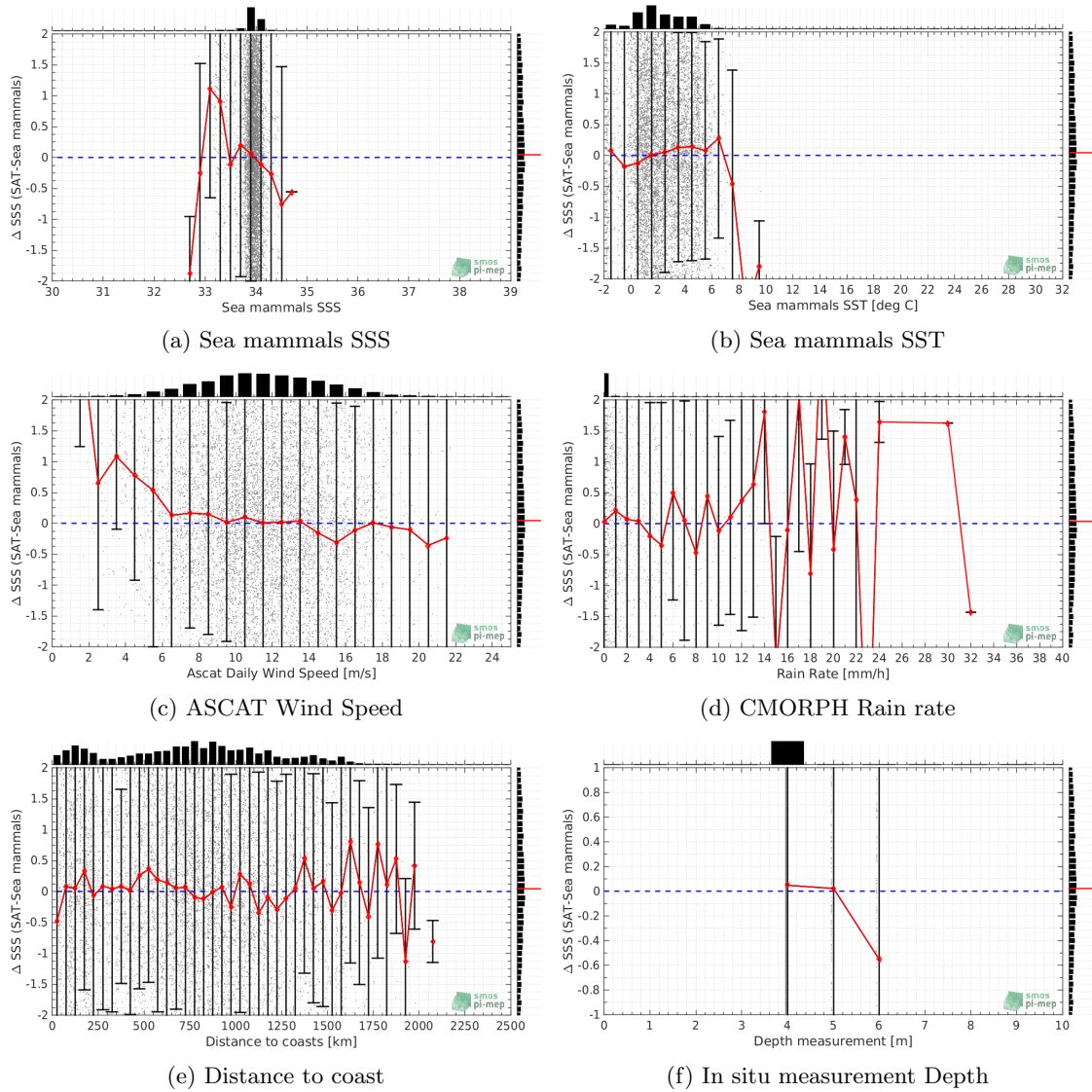


Figure 11: Δ SSS (Satellite - Sea mammals) sorted as function of Sea mammals SSS a), Sea mammals SST b), ASCAT Wind speed c), CMORPH rain rate d), distance to coast (e) and in situ measurement depth (f). In all plots the median and Std of Δ SSS for each bin is indicated by the red curves and black vertical thick bars (± 1 Std)

3.7 Δ SSS maps and statistics for different geophysical conditions

In Figures 12 and 13, we focus on sub-datasets of the match-up differences Δ SSS (Satellite - in situ) between SMAP-L2-JPL-V4.2 and Sea mammals for the following specific geophysical conditions:

- **C1**: if the local value at in situ location of estimated rain rate is zero, mean daily wind is in the range [3, 12] m/s, the SST is $> 5^{\circ}\text{C}$ and distance to coast is > 800 km.
- **C2**: if the local value at in situ location of estimated rain rate is zero, mean daily wind is

in the range [3, 12] m/s.

- **C3**:if the local value at in situ location of estimated rain rate is high (ie. > 1 mm/h) and mean daily wind is low (ie. < 4 m/s).
- **C4**:if the mixed layer is shallow with depth < 20 m.
- **C5**:if the in situ data is located where the climatological SSS standard deviation is low (ie. above < 0.2).
- **C6**:if the in situ data is located where the climatological SSS standard deviation is high (ie. above > 0.2).

For each of these conditions, the temporal mean (gridded over spatial boxes of size $1^\circ \times 1^\circ$) and the histogram of the difference Δ SSS (Satellite - in situ) are presented.

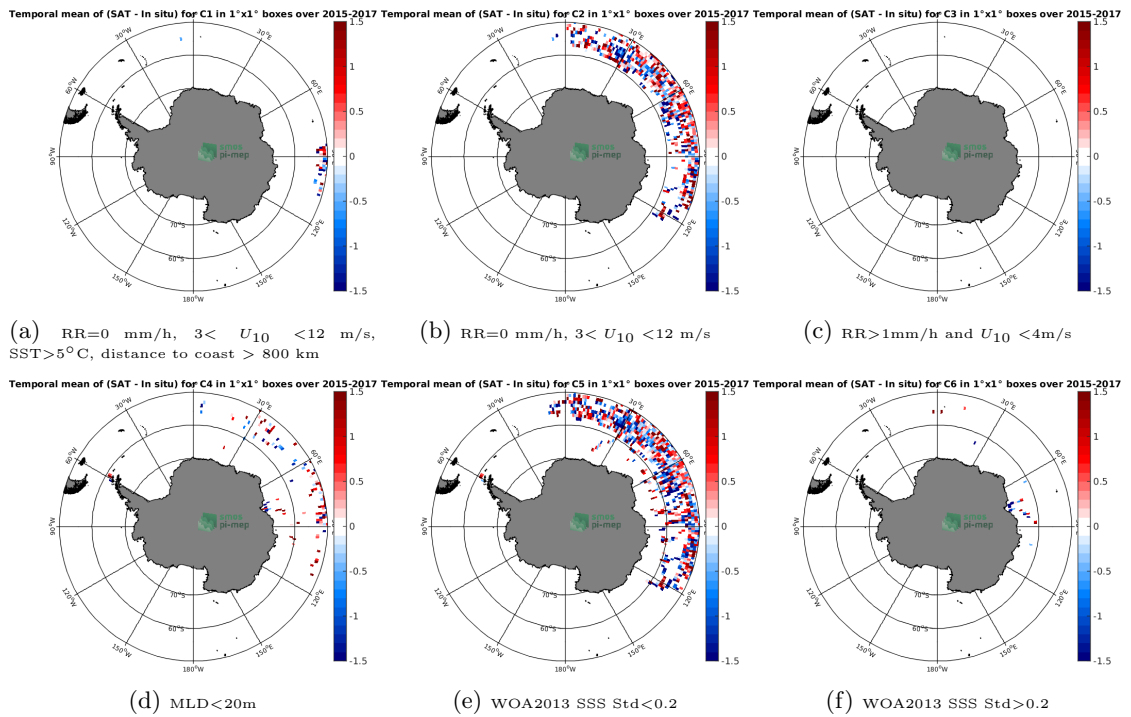


Figure 12: Temporal mean gridded over spatial boxes of size $1^\circ \times 1^\circ$ of Δ SSS (SMAP-L2-JPL-V4.2 - Sea mammals) for 6 different subdatasets corresponding to:RR=0 mm/h, $3 < U_{10} < 12$ m/s, SST $>5^\circ$ C, distance to coast > 800 km (a), RR=0 mm/h, $3 < U_{10} < 12$ m/s (b), RR >1 mm/h and $U_{10} < 4$ m/s (c),MLD <20 m (d),WOA2013 SSS Std <0.2 (e),WOA2013 SSS Std >0.2 (f).

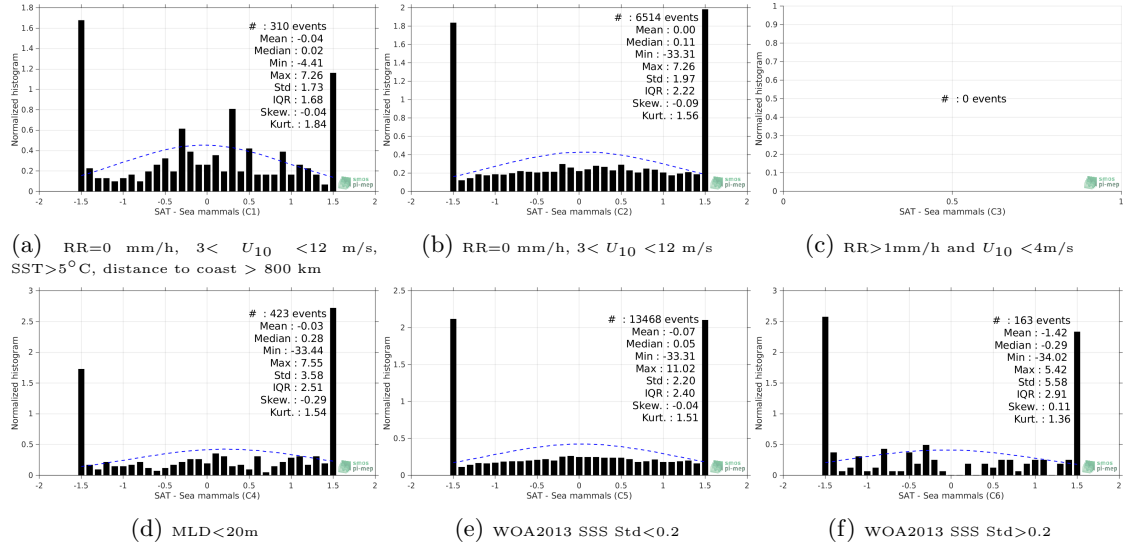


Figure 13: Normalized histogram of ΔSSS (SMAP-L2-JPL-V4.2 - Sea mammals) for 6 different subdatasets corresponding to: RR=0 mm/h, $3 < U_{10} < 12$ m/s, SST>5°C, distance to coast > 800 km (a), RR=0 mm/h, $3 < U_{10} < 12$ m/s (b), RR>1mm/h and $U_{10} < 4$ m/s (c), MLD<20m (d), WOA2013 SSS Std<0.2 (e), WOA2013 SSS Std>0.2 (f).

4 Summary

Table 1 shows the mean, median, standard deviation (Std), root mean square (RMS), interquartile range (IQR), correlation coefficient (r^2) and robust standard deviation (Std*) of the match-up differences ΔSSS (Satellite - in situ) between SMAP-L2-JPL-V4.2 and Sea mammals derived over the Southern Ocean Pi-MEP region and for the full satellite product period and for the following conditions:

- all: All the match-up pairs satellite/in situ SSS are used to derive the statistics
- C1: only pairs where RR=0 mm/h, $3 < U_{10} < 12$ m/s, SST>5°C, distance to coast > 800 km
- C2: only pairs where RR=0 mm/h, $3 < U_{10} < 12$ m/s
- C3: only pairs where RR>1mm/h and $U_{10} < 4$ m/s
- C4: only pairs where MLD<20m
- C5: only pairs where WOA2013 SSS Std<0.2
- C6: only pairs at WOA2013 SSS Std>0.2
- C7a: only pairs where distance to coast is < 150 km.
- C7b: only pairs where distance to coast is in the range [150, 800] km.
- C7c: only pairs where distance to coast is > 800 km.
- C8a: only pairs where in situ SST is < 5°C.

- C8b: only pairs where in situ SST is in the range $[5, 15]^{\circ}\text{C}$.
- C8c: only pairs where in situ SST is $> 15^{\circ}\text{C}$.
- C9a: only pairs where in situ SSS is < 33 .
- C9b: only pairs where in situ SSS is in the range $[33, 37]$.
- C9c: only pairs where in situ SSS is > 37 .

Table 1: Statistics of ΔSSS (Satellite - Sea mammals)

Condition	#	Median	Mean	Std	RMS	IQR	r^2	Std*
all	14075	0.04	-0.09	2.29	2.29	2.42	0.00	1.80
C1	310	0.02	-0.04	1.73	1.73	1.68	0.00	1.23
C2	6514	0.11	0.00	1.97	1.97	2.22	0.00	1.65
C3	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN
C4	423	0.28	-0.03	3.58	3.58	2.51	0.01	1.88
C5	13468	0.05	-0.07	2.20	2.20	2.40	0.00	1.79
C6	163	-0.29	-1.42	5.58	5.75	2.91	0.00	2.21
C7a	1510	0.01	-0.26	2.90	2.91	2.80	0.01	2.08
C7b	5770	0.09	0.03	2.23	2.23	2.31	0.01	1.73
C7c	6795	0.00	-0.15	2.18	2.18	2.45	0.00	1.82
C8a	13228	0.04	-0.09	2.32	2.32	2.46	0.00	1.83
C8b	847	0.08	-0.02	1.75	1.75	1.89	0.00	1.39
C8c	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN
C9a	7	-0.97	-0.28	1.86	1.74	2.00	0.26	1.08
C9b	14068	0.05	-0.09	2.29	2.29	2.42	0.00	1.80
C9c	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN

For the same conditions, Table 2 presents statistics of ΔSSS (Satellite - ISAS). Only ISAS SSS values with $\text{PCTVAR} < 80\%$ are used to derive the statistics.

Table 2: Statistics of ΔSSS (Satellite - ISAS)

Condition	#	Median	Mean	Std	RMS	IQR	r^2	Std*
all	13705	0.05	-0.09	2.28	2.28	2.42	0.00	1.82
C1	309	0.00	-0.05	1.72	1.72	1.43	0.00	1.05
C2	6357	0.10	0.00	1.98	1.98	2.21	0.00	1.65
C3	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN
C4	413	0.29	0.03	3.22	3.22	2.40	0.01	1.83
C5	13122	0.05	-0.07	2.21	2.21	2.41	0.00	1.80
C6	162	-0.27	-1.20	4.98	5.10	2.90	0.01	2.19
C7a	1502	0.05	-0.18	2.74	2.74	2.72	0.01	2.03
C7b	5573	0.10	0.02	2.24	2.24	2.31	0.00	1.72
C7c	6630	0.00	-0.16	2.19	2.19	2.48	0.00	1.83
C8a	12871	0.04	-0.09	2.31	2.31	2.46	0.00	1.84
C8b	834	0.12	-0.03	1.73	1.73	1.79	0.00	1.31
C8c	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN
C9a	7	-1.07	-0.45	1.90	1.81	2.00	0.21	0.96
C9b	13698	0.05	-0.09	2.28	2.28	2.42	0.00	1.82
C9c	0	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Numerical values can be downloaded as csv files for [Table 1](#) and [Table 2](#).

5 More Comparison/Validation Materials

5.1 Comparisons with other satellite products

Table 1 shows the mean, median, standard deviation (Std), root mean square (RMS), interquartile range (IQR), correlation coefficient (r^2) and robust standard deviation (Std*) of the match-up differences Δ SSS (Satellite - in situ) between different satellite products and **Sea mammals** derived over the Southern Ocean Pi-MEP region considering all match-up pairs satellite/in situ SSS values to derive the statistics:

Table 1: Statistics of Δ SSS (Satellite - In situ)

Satellite products	#	Median	Mean	Std	RMS	IQR	r^2	Std*
smos-l2-v662	2983	-0.22	-0.29	1.77	1.79	2.15	0.00	1.61
smos-l3-catds-ifr-v2-1d-05deg	38213	0.01	-0.08	1.61	1.62	1.21	0.03	0.90
smos-l3-catds-ifr-v2-1m-025deg	50565	0.04	-0.10	1.55	1.55	0.75	0.00	0.56
smos-l3-catds-cpdc-v321-l2q	7382	0.28	0.24	1.87	1.88	2.34	0.00	1.74
smos-l3-catds-cpdc-v317-10d-25km	36451	0.15	0.11	0.92	0.92	0.98	0.02	0.73
smos-l3-catds-cpdc-v317-1m-25km	40231	0.14	0.11	0.82	0.83	0.73	0.02	0.55
smos-l3-catds-locean-v4-9d	63463	-0.04	-0.03	0.42	0.42	0.51	0.09	0.38
smos-l3-catds-locean-v4-18d	63463	-0.03	-0.03	0.23	0.24	0.28	0.22	0.21
smos-l3-bec-oa-v1-9d	22077	-0.22	-0.22	0.28	0.35	0.34	0.24	0.26
smos-l3-icdc-v3-1m	26470	0.06	0.09	1.09	1.09	1.14	0.02	0.85
smos-l4-catds-ifr-v2-1w	48500	-0.05	-0.17	1.28	1.29	0.65	0.06	0.49
aquarius-l2-or-v5	11405	0.12	0.06	0.90	0.90	0.93	0.02	0.69
aquarius-l3-or-v5-7dr	26140	0.11	0.01	0.82	0.82	0.51	0.01	0.38
aquarius-l3-or-v5-1m	28646	0.11	-0.08	1.03	1.04	0.40	0.02	0.29
aquarius-l3-or-v5-7dr-rain-mask	26138	0.12	0.01	0.82	0.82	0.51	0.01	0.38
aquarius-l3-or-v5-1m-rain-mask	28646	0.11	-0.08	1.03	1.04	0.40	0.02	0.29
aquarius-l2-jpl-v5	10201	0.27	0.27	1.44	1.47	1.37	0.01	1.03
aquarius-l3-jpl-v5-7dr	22684	0.33	0.30	0.50	0.58	0.58	0.05	0.43
aquarius-l3-jpl-v5-1m	23811	0.31	0.29	0.36	0.46	0.44	0.09	0.33
aquarius-l4-iprc-v5-1w	17989	-0.02	-0.02	0.15	0.15	0.18	0.58	0.13
aquarius-l4-iprc-v5-1m	18522	-0.02	-0.02	0.11	0.11	0.12	0.73	0.09
smap-l2-rss-v4	846	0.14	0.05	1.02	1.02	1.25	0.01	0.95
smap-l3-rss-v4-8dr	14091	-0.02	-0.11	0.95	0.95	0.73	0.00	0.54
smap-l3-rss-v4-1m	15016	-0.01	-0.15	0.91	0.92	0.49	0.00	0.36
smap-l2-jpl-v4.2	14075	0.04	-0.09	2.29	2.29	2.42	0.00	1.80
smap-l3-jpl-v4.2-8dr	13111	0.01	-0.10	1.39	1.39	0.96	0.00	0.71
smap-l3-jpl-v4.2-1m	14306	0.01	-0.19	1.82	1.83	0.63	0.00	0.47
cci-l4-esa-merged-oi-v1.8-7dr	39459	0.00	0.00	0.21	0.21	0.23	0.24	0.17
cci-l4-esa-merged-oi-v1.8-30dr	42524	-0.01	-0.01	0.21	0.21	0.23	0.23	0.17

Table 2 is similar to Table 1 but considering only match-up pairs where $RR=0$ mm/h, $3 < U_{10} < 12$ m/s, $SST > 5^\circ\text{C}$, distance to coast > 800 km.

Table 2: Statistics of Δ SSS (Satellite - In situ)

Satellite products	#	Median	Mean	Std	RMS	IQR	r^2	Std*
smos-l2-v662	113	-0.09	-0.31	1.46	1.49	1.93	0.00	1.38
smos-l3-catds-ifr-v2-1d-05deg	404	-0.15	-0.12	0.68	0.69	0.97	0.03	0.73
smos-l3-catds-ifr-v2-1m-025deg	536	-0.08	-0.09	0.43	0.44	0.50	0.04	0.38
smos-l3-catds-cpdc-v321-l2q	124	0.50	0.23	1.39	1.40	1.99	0.02	1.62
smos-l3-catds-cpdc-v317-10d-25km	415	0.12	0.07	0.60	0.60	0.79	0.02	0.60
smos-l3-catds-cpdc-v317-1m-25km	437	0.08	0.08	0.40	0.41	0.52	0.06	0.39
smos-l3-catds-locean-v4-9d	647	-0.04	0.00	0.39	0.39	0.55	0.02	0.42
smos-l3-catds-locean-v4-18d	647	-0.03	0.01	0.27	0.27	0.33	0.06	0.23
smos-l3-bec-oa-v1-9d	486	-0.16	-0.13	0.27	0.30	0.36	0.14	0.26
smos-l3-icdc-v3-1m	505	-0.11	-0.13	0.64	0.65	0.83	0.02	0.63
smos-l4-catds-ifr-v2-1w	535	-0.18	-0.19	0.45	0.48	0.58	0.06	0.43
aquarius-l2-or-v5	60	0.20	0.08	0.66	0.66	0.90	0.00	0.65
aquarius-l3-or-v5-7dr	139	0.10	0.08	0.31	0.32	0.50	0.14	0.38
aquarius-l3-or-v5-1m	144	0.09	0.08	0.24	0.25	0.32	0.19	0.24
aquarius-l3-or-v5-7dr-rain-mask	139	0.11	0.09	0.31	0.32	0.50	0.14	0.39
aquarius-l3-or-v5-1m-rain-mask	144	0.09	0.08	0.25	0.26	0.30	0.16	0.24
aquarius-l2-jpl-v5	61	0.28	0.13	0.92	0.92	1.19	0.01	0.81
aquarius-l3-jpl-v5-7dr	139	0.23	0.22	0.40	0.45	0.56	0.02	0.43
aquarius-l3-jpl-v5-1m	139	0.26	0.21	0.26	0.34	0.37	0.17	0.25
aquarius-l4-ipc-v5-1w	138	-0.03	-0.03	0.18	0.18	0.17	0.49	0.13
aquarius-l4-ipc-v5-1m	133	-0.03	-0.04	0.12	0.12	0.14	0.76	0.11
smap-l2-rss-v4	187	0.19	0.10	0.83	0.84	1.13	0.01	0.84
smap-l3-rss-v4-8dr	240	0.09	0.06	0.49	0.50	0.61	0.05	0.48
smap-l3-rss-v4-1m	240	0.09	0.17	0.37	0.40	0.54	0.01	0.38
smap-l2-jpl-v4.2	310	0.02	-0.04	1.73	1.73	1.68	0.00	1.23
smap-l3-jpl-v4.2-8dr	240	-0.14	-0.09	0.65	0.66	0.80	0.00	0.61
smap-l3-jpl-v4.2-1m	240	-0.12	-0.05	0.45	0.45	0.56	0.00	0.39
cci-l4-esa-merged-oi-v1.8-7dr	437	0.00	0.03	0.24	0.24	0.27	0.16	0.19
cci-l4-esa-merged-oi-v1.8-30dr	435	-0.01	0.02	0.24	0.24	0.24	0.14	0.18

Numerical values can be downloaded as csv files for [Table 1](#) and [Table 2](#).

5.2 Statistics derived for the different in situ databases

Table 1 shows the mean, median, standard deviation (Std), root mean square (RMS), interquartile range (IQR), correlation coefficient (r^2) and robust standard deviation (Std*) of the match-up differences Δ SSS (Satellite - in situ) between **SMAP-L2-JPL-V4.2** and all the available in situ datasets derived over the Southern Ocean Pi-MEP region and for the full satellite product period and considering all match-up pairs satellite/in situ SSS values to derive the statistics:

Table 1: Statistics of Δ SSS (Satellite - In situ)

In situ database	#	Median	Mean	Std	RMS	IQR	r^2	Std*
argo	56829	0.22	0.15	2.01	2.01	2.16	0.00	1.61
tsg-gosud-sailing-ship	7415	0.28	0.23	1.34	1.36	1.53	0.02	1.13
mammal	14075	0.04	-0.09	2.29	2.29	2.42	0.00	1.80
drifter	31281	0.43	0.41	2.06	2.10	2.51	0.00	1.88
tsg-polarstern	15222	0.65	0.52	3.01	3.05	2.30	0.01	1.72

Table 2 is similar to Table 1 but considering only match-up pairs where $RR=0$ mm/h, $3 < U_{10} < 12$ m/s, $SST > 5^\circ\text{C}$, distance to coast > 800 km.

Table 2: Statistics of ΔSSS (Satellite - In situ)

In situ database	#	Median	Mean	Std	RMS	IQR	r^2	Std*
argo	6996	0.16	0.14	1.34	1.35	1.59	0.01	1.19
tsg-gosud-sailing-ship	340	-2.56	-2.34	0.80	2.47	1.11	0.33	0.79
mammal	310	0.02	-0.04	1.73	1.73	1.68	0.00	1.23
drifter	90	1.67	1.35	0.88	1.61	1.03	0.27	0.77
tsg-polarstern	104	1.25	1.46	1.05	1.79	1.48	0.00	0.90

Numerical values can be downloaded as csv files for [Table 1](#) and [Table 2](#).

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