SMOS OS Level 3
Algorithm Theoretical Basis Document (v300)

Version : 3.0

Date : 05/05/2017

Signatures

	Name	Company	Signature
Prepared by	Jean-Luc Vergely Jacqueline Boutin	ACRI-ST LOCEAN	

Changes Log

Version	Date	Changes
1.0	30/06/2014	Initial Version
2.0	27/09/2016	Update
3.0	05/05/2017	Update

Table Of Content

1 INTRODUCTION ---------- 5
1.1 SCOPE OF THE DOCUMENT ---------- 5
1.2 REFERENCE DOCUMENTS ---------- 5
1.3 DEFINITIONS, ACRONYMS AND ABBREVIATIONS ---------- 5
1.3.1 Definition ---------- 5
1.3.2 Acronyms and abbreviations ---------- 6
1.3.3 Product name convention ---------- 7
1.3.4 Global attributes ---------- 8

2 PROCESSING OVERVIEW ---------- 10
2.1 INTRODUCTION ---------- 10
2.2 L1 PROCESSING ---------- 10
2.3 L2OS PROCESSING ---------- 11
2.4 L3OS PROCESSING ---------- 12
2.5 INTRODUCTION ---------- 13
2.6 SMOS SSS CLASSIFICATION (L2P PRODUCTS) ---------- 14
2.6.1 Class definition ---------- 14
2.6.2 L2P product names. ---------- 17
2.6.3 L2P product content ---------- 18
2.7 SMOS SSS CORRECTION (BIAS CORRECTION : L2Q AND L3Q PRODUCTS) ---------- 19
2.7.1 Algorithm description ---------- 19
2.7.2 L2Q product name ---------- 20
2.7.3 L2Q product content ---------- 20
2.8 SALINITY AVERAGES (PRODUCT L3 'SIMPLE AVERAGE') ---------- 21
2.8.1 Algorithms ---------- 21
2.8.2 L3 product names. ---------- 23
2.8.3 L3 product content ---------- 24

List Of Figures

Figure 1: Scheme of the processing from L2OS products to L3OS products....................................... 13

List Of Tables

Table 1: Reference Document.. 5
Table 2: File name convention 7
Table 3: Global attribute of CATDS files 8
Table 4: List of products built by the prequalification L3-OS processor 17
Table 5: MIR_CSD2P and MIR_CSF2P content 18
Table 6: List of products built by the bias correction L3-OS processor 20
Table 7: MIR_CSD2Q and MIR_CSF2Q content 20
Table 8: List of products built by the L3-OS CARTO processor (averaging salinities)........................... 23
Table 9: MIR_CSD3 and MIR_CSF3 content 24

1 Introduction

1.1 Scope of the document

The purpose of this Algorithm Theoretical Basis Document is to describe the procedure that is used in the SMOS CATDS C-PDC center to generate the L3OS salinity product from L2OS salinities.

It describes the algorithms implemented in the v272 L3OS processing chain.

Moreover this document gives an overview of the different steps of the global processing, from L1b to L3OS products knowing that only L3OS products are provided to users by the CATDS.

1.2 Reference Documents

The following table presents the Reference Document (RD).

Table 1: Reference Document

ID	Title	Ref
[RD-1]	SMOS L1 Full Polarisation Data Processing	SO-TN-DME-L1PP-0024, 16/07/07
[RD-2]	SMOS L2 OS Algorithm Theoretical Baseline Document	SO-TN-ARG-GS-0007, 11/10/13

1.3 Definitions, Acronyms and Abbreviations

1.3.1 Definition

- **Brightness temperature measurement:** brightness temperature (BT) measured in one MIRAS polarisation mode, along with relevant information (radiometric noise, observation conditions, contributions as computed by the model, flags, polarisation direction). A measurement is associated with one Grid point and one Snapshot at a spatial resolution of about 40 km.
- **Grid Point:** point on Earth surface where Measurements are available in SMOS L1c, L2 and L3 product. Note that only L3 products are delivered by CATDS.
- **Dwell line:** ensemble of Measurements at the same Grid Point available in SMOS L1c product.
- **SSS:** Sea Surface Salinity. Salinity of the upper ocean that contributes to L-band emission (approx. 1 cm depth)
- **SST:** Sea Surface Temperature. What matters for SMOS it is the temperature of the upper fraction of the ocean that contributes to L-band emission (approx. 1 cm)

- **EASE grid**: **set of Grid Points** on Earth Surface where the BTs are reconstructed and the salinities are retrieved. This grid used by the CATDS is different from ISEA grid used by ESA DPGS (Data Processing Ground Segment). Pixels have a constant area, longitudes are equally spaced but not latitudes.
- **Snapshot:** Ensemble of measurements acquired at the same time. Distinction of snapshots per polarization is done.
- **Polarization direction**: axes of the polarization frames: **X** and **Y** for the MIRAS antenna polarization frame.
- **MIRAS operating mode**: MIRAS has two operating modes (see RD1):
  - **Dual polarization mode:** measurement sequence is - XX – YY – XX – YY –XX – YY -…
  - **Full polarization mode:** Measurement cycle is - XX – XY – YY – YX – XX – XY – YY – YX – XX - …
- **Retrieval Polarization mode**: to derive SSS, one can use
  - Stokes 1 parameter, i.e. the sum of brightness temperatures in X and Y polarization directions (Stokes 1 retrieval mode).
  - Brightness temperatures in X and Y polarization directions (dual pol retrieval mode).
  - Brightness temperatures in X and Y directions and real and imaginary part in XY (full pol retrieval mode).

1.3.2 Acronyms and abbreviations

Acronym	Description
ADF	Auxiliary Data File
ATBD	Algorithm Theoretical Baseline Document
BT	Brightness Temperature
CATDS	Centre Aval de Traitement des Données SMOS
CNES	Centre National d'Etudes Spatiales
DDI	Dossier des Interfaces
DPGS	Data Processing Ground Segment
DPM	Data Processing Model
ECMWF	European Centre for Medium-Range Weather Forecasts
EASE-Grid	Equal-Area Scalable Earth Grid (used in the CATDS)
ESA	European Space Agency
ESRIN	ESA Centre for Earth Observation
ESTEC	European Space Research and Technology Center
IFREMER	Institut français de recherche pour l'exploitation de la mer

ISEA-grid	Icosahedral Snyder Equal Area grid (used in the DPGS)
L1OP	SMOS Level 1 Operational Processor
L1PP	SMOS Level 1 Prototype Processor
L2OS, L3OS	Level 2 or 3 Ocean Salinity
LOCEAN	Laboratoire d'Océanographie et du Climat Expérimentation et Approches Numériques
LUT	Look Up Table
MIRAS	Microwave Imaging Radiometer using Aperture Synthesis
OS	Ocean Salinity
OTT	Ocean Target Transformation
SMOS	Soil Moisture and Ocean Salinity
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
SUM	Software User Manual
UDP	User Data Product

1.3.3 Product name convention

The logical file name is to be of the following structure:

MM_CCCC_FFF_DDDDDD_<instance ID>

The meaning of the different subset of character string is given in the following table.

Table 2: File name convention

Naming element	Value	Description	Format
MM	SM	SMOS mission ID	2 characters
CCCC	OPER (operationnal product), REnn (reprocessing nn product)	File Class, i.e. the type of activity for which the file is used.	4 characters
FFF	MIR	MIRAS	3 characters
DDDDDD=abcdef	*a* = C	From CATDS	1 character
	b = S	Sea product	1 character
	c = D or F for L3 simple average products; other letters for more evoluted products : Q=Qualified products	Dual or Full pol acquisition mode Q=bias corrected product	1 character
	d=2 (not open delivery) or 3	Level product	1 character

	e=A, B, C, D, P	Product resolution if *d*=2, P corresponds to prequalification if *d*=3, A, B, C, D, P correspond to 25 km, 50 km, 100 km,200 km, 200 km respectively	1 character
	f = A, D or _	for ascending, descending or both	1 character
<instance ID>	*yyyymmddThhmmss_*	Validity start time	16 characters
	*YYYYMMDDTHHMMSS_*	Validity stop time	16 characters
	*vvv_*	Processor version number	4 characters
	*ccc_*	file counter	4 characters
	s	Code of the data center ('7' for CPDC)	1 character

Note: only e=P is available for current operational products (still June 2014).

1.3.4 Global attributes

CATDS product files are always in netcdf format. Attributes for these files are common to all products and are as follows:

Table 3: Global attribute of CATDS files

Attribute name	Description	Value
title	File title	
netcdf_version_id	NetCDF library version	
creation_date	Creation date	
product_version	Product version	
institution	From what institution the file is built	
source	Name of the processor which built the file	
references	Document reference name	
conventions	Product norm: « CF-1.4 »	« CF-1.4 »
history	Not used	« none »
ease_projection	Type of projection used to generate the CATDS DGG	
ease_resolution	Resolution used to generate the CATDS DGG (km)	
ease_global	Indicate if the CATDS DGG used for the product is global or not	

ease_origin_lat	Latitude of the origin point	
ease_origin_lon	Longitude of the origin point	

2 Processing overview

2.1 Introduction

This section gives an overview of the whole processing, including DPGS processing which is done upstream of the CATDS processing.

The DPGS processing (under the ESA responsibility) begins from L0 and ends to L2OS.

The CATDS processing is dedicated to L3 and L4 products, i.e. L2OS salinity averaging and derived products. Because the CATDS does not use the same grid and not exactly the same L2OS processor than the ones used by the DPGS, the processing begins from L1b products.

The mission ground segment is organized around a Level 1 processor, which has for main task the reconstruction of SMOS brightness temperatures, and a Level 2 processor aimed at retrieving Sea Surface Salinity from SMOS data.

2.2 L1 processing

SMOS Level 1 processing (RD1) ingests raw SMOS data and produces inputs (Level 1c products) to the level 2 processors. Three out of the numerous aspects of level 1 processing are detailed in the section because either they contribute to the detailed definition of SMOS brightness temperature provided in the Level 1c products or they shape the Level 1c products.

The reconstruction

The L1b reconstruction process consists to obtain brightness temperature Fourier components from visibilities in the antenna plan. At this level, apodization window and interpolation procedure is applied in order to obtain brightness temperatures in a regular grid.

Because the geophysical parameters have to be estimated in the earth frame, Fourier interpolation and apodization is applied in order to give Brightness temperatures at the EASE grid point location. The data are sorted in order to obtain for each grid point the set of brightness temperatures corresponding to different snapshots, i.e. different incidence angles (L1c data).

One feature of the reconstruction process is the reconstruction grid, which is the ensemble of geographic locations where SMOS brightness temperatures will be derived. It is worth noting that in SMOS processing, centre of picture elements (grid points) are not driven by the instrument but are in the hands of the SMOS project team.

The apodization window

The apodization function is applied in the reconstruction and participates to the definition of the synthetic antenna beam. This way, it shapes the measurement footprints. In the Level 2 SSS processor, the footprint information is provided by the level 1c, i.e. the semi-minor and semi-major axis of the equivalent 3dB ellipse (footprint can approximated by pseudo ellipsoidal function), to which definition of the apodization function shall be added.

Sorting SMOS data

In the Level 1c product, SMOS data are sorted out in such a way that all brightness temperatures reconstructed at the same grid point and auxiliary information are packed together. The ability of SMOS to capture signal variations as a function of viewing conditions is a constraint contributing to better retrieval of sea surface salinity.

A single Level 1c product includes SMOS acquisitions during one day (from pole to pole), with a separation between ascending and descending orbits.

The CATDS C-PDC generates its own L1c products, starting from L1b, on the EASE grid which is different from the ISEA grid used in ESA processing made at DPGS. These L1 products are internal to the CATDS and are not distributed to the users.

2.3 L2OS processing

The L2OS processor takes in input the L1c brightness temperatures provided by the L1 processor at antenna level. The main output of the L2OS processor is the retrieved salinity which is computed at grid point level, using multi incidence angle observations (see RD2).

The CATDS L2OS products are provided on the EASE specific grid with a 24 km resolution (at the latitude 30°). These L2OS products are internal to the CATDS and are not distributed to the users.

Forward models

In this processor, three different forward models are implemented in order to retrieve the salinity and other geophysical parameters. This is done using a series of physical models which are applied to auxiliary parameters (SST, wind, etc.) and a first guess SSS, in order to compute the brightness temperature that should be measured at a specific polarization and geometric configuration. These values are transported to SMOS antenna level and then compared to actually measured BT.

OTT correction

Because L1 reconstruction generates biases, an empirical correction, called OTT, is applied on the BT before SSS retrieval. The correction is applied according to the position of the BT on the FOV and differs from one polarization to the other.

BT filtering

Because of RFI contamination and reconstruction biases, a specific module allows to detect BT outliers which are removed before SSS retrieval. This option has been removed in v272 (in agreement with ESA v622) in order to improve filtering at SSS level using Chi2 flagging.

Iterative scheme

An iterative process (considering all measurements/views of a single grid point obtained in consecutive snapshots) allows minimization of the difference between modelled and measured values, until identifying a retrieved SSS for this grid point. This minimization is done using a Levenberg-Marquardt algorithm which allows the estimation of the salinity and its error.

Three different models are proposed for the effect of ocean surface roughness in L-band emissivity and then three retrieval processes will be run in parallel, and three SSS values provided in the L2 Output Product.

So far, the CATDS L3OS processor uses in input only one of these three SSS, obtained from a semi-empirical ocean surface model developed at LOCEAN.

Post processing

A post processing step allows building quality indicators of the retrieved SSS. These indicators are used in input of the prequalification L3OS processor, in order to qualify the SSS as "valid" or "not valid".

2.4 L3OS processing

The L3OS processing begins with the run of the L3OS prequalification processor which allows classifying salinities in about 30 different classes.

This step uses L2OS outputs:

- Salinity retrieved from the LOCEAN model (semi-empirical 2 scale roughness and foam model).
- Flags and descriptors associated to the salinities and external data files: (SSS climatology, land-sea mask).

The prequalification products are, as L2OS products, daily products given on a 24 km EASE grid. This product is called L2P. Because SMOS SSS is affected by seasonal latitudinal bias and coastal bias, a corrected L2 product has been performed. This latter product is called L2Q and contain, as L2P, daily corrected SSS.

From these data, L3OS prequalification processing allows classifying SSS in some classes described in more details in section 0. The SSS and associated classes are stored in L2P and L2Q products (daily product for ascending, descending and ascending plus descending orbits respectively).

After salinity classification, the L3OS CARTO processor averages the salinity at different time and spatial scales. This average is obtained by using L2P (uncorrected SSS) or L2Q (corrected SSS) products. L3OS processing

2.5 Introduction

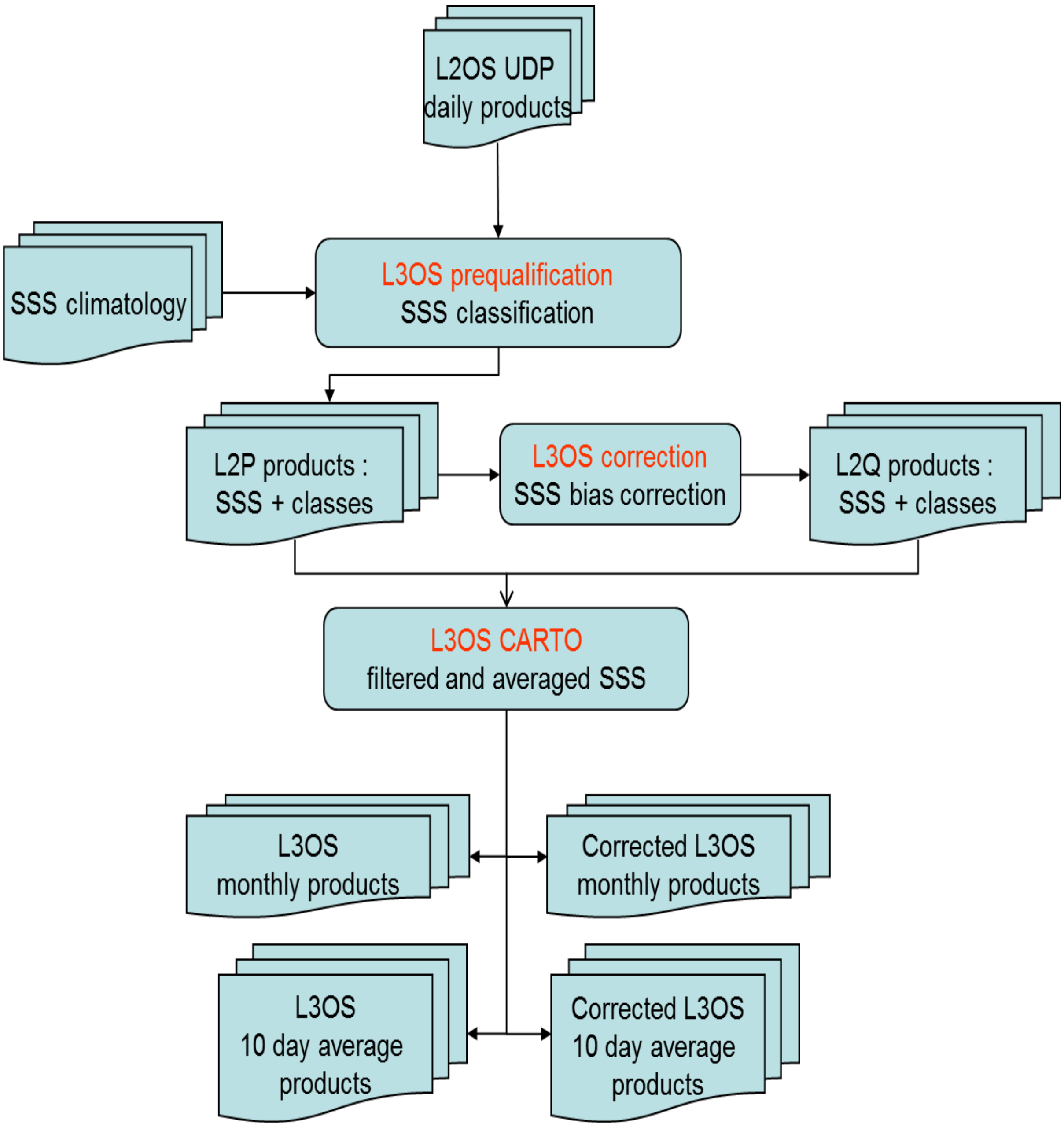

Figure 1: Scheme of the processing from L2OS products to L3OS products.

The Figure 1 presents the two main different steps of the L3OS processing and the associated products:

- SSS classification stored in L2P products
- SSS averages stored in L3OS monthly products or 10 day products (uncorrected or corrected from biases).

The classification step allows identifying the salinities to be kept or discarded before the averaging step.

The salinity average is done at different resolutions. The spatial resolutions of averaged salinities are 25, 50, 100 and 200 km and the time scales are one month or ten days. The ten day maps are given for the first, second and third month decades.

The grid points where the average salinity is computed depend on the considered distance scale. The spatial sampling is given in the product.

All the products are in NetCDF format.

2.6 SMOS SSS classification (L2P products)

2.6.1 Class definition

As mentioned in introduction, salinities are classified before averaging. At this stage, the SSS is not modified and directly copied in the prequalification product.

The prequalification step allows classifying the salinities into 29 different classes using L2OS flags, external information and self-consistency tests.

Each SSS, associated to a ground grid point, is qualified by L2OS flags which are:

- Fg_ctrl_many_outliers : raised if a lot of BTs used for SSS retrieval have been identified as outliers
- Fg_ctrl_sunglint : raised if the grid point is affected by sun glint.
- Fg_ctrl_moonglint : raised if the grid point is affected by moon glint.
- Fg_ctrl_gal_noise : raised if the grid point is affected by large galactic noise reflection.
- Fg_sc_TEC_gradient : raised if BTs are affected by large TEC variations along the dwell line.
- Fg_sc_in_clim_ice : raised if grid point is contaminated by ice (from climatology)
- Fg_sc_ice : raised if grid point is contaminated by ice (from SST and BT values)
- Fg_sc_suspect_ice : raised if grid point is contaminated by ice
- Fg_sc_rain : raised if grid point is contaminated by rain
- Fg_sc_Land_Sea_coast1/2 : raised if grid point is contaminated by coast
- Fg_ctrl_num_meas_low : raised if number of BT available for retrieval are too low

- Fg_ctrl sigma : raised if SSS a posteriori theoretical error is larger to 5 psu
- Fg_ctrl_chi2 : raised if chi2 after convergence is larger than 1.35
- Fg_ctrl_chi2_P : raised if poor fit quality (chi2_P > 0.95 or chi2_P < 0.05
- Fg_ctrl_reach_maxiter : raised if iterative algorithm has reached the max number of iteration
- Fg_ctrl_marq : raised if Marquardt amplifier reaches a threshold
- Fg_ctrl_range : raised if SSS > 50 or < 10 psu
- Fg_oor_LUT_XXX_YYY : raised if forward model used for SSS retrieval is out of range of one LUT.

If one or more of the previous flags is raised, the associated salinity is considered as invalid (it does not belong to the class of valid salinities) and is not used for averaging.

The L3OS prequalification algorithms will be improved in the future in order to better classify the salinities and improve the selection before averaging. The following table presents the different classes in detail (for advanced users).

Classe	Flags used	Description	Thresholds	Bit
1	Fg_ctrl_X, Fg_sc_X, Fg_oor_X (UDP L2OS)	Valid salinities	No L3 thresholds (only flags from L2).	1
2a	Fg_grad_space_SST Fg_grad_space_SSS	SSS and SST not well mixed horizontally	(Tg_grad_space_SSS, Tg_grad_space_SST) Apply a threshold on the modulus of the spatial gradient of the SSS and SST.	2
2b	Fg_grad_space_SST Fg_grad_space_SSS	SSS not well mixed horizontally and SST well mixed horizontally	(Tg_grad_space_SSS, Tg_grad_space_SST) Apply a threshold on the modulus of the spatial gradient of the SSS and SST.	3
3	Fg_SSS_distrib_boiteX_seuilY	SSS far from climatology.	(Tg_SSS_distrib_boiteX_statY) Depends on the averaging box. Flag is raised if significant difference observevd at least in one box.	4
4a	Fg_SSS_nsig_scale1	SSS not self-consistent with its neighbours (in space and in time)	(Tg_SSS_nsig2) Self-consistency indexes from box n°1.	5

4b	Fg_SSS_nsig_scale2	SSS not self-consistent with its neighbours (in space and in time)	(Tg_SSS_nsig2) Self-consistency indexes from box n°2.	6
4c	Fg_SSS_nsig_scale3	SSS not self-consistent with its neighbours (in space and in time)	(Tg_SSS_nsig2) Self-consistency indexes from box n°3.	7
5a	Fg_sc_high_wind (UDP L2OS)	SSS associated with high wind speed (instantaneous WS)	No L3 threshold WS > 10 m/s	8
5b	Fg_low_wind (UDP L2OS)	SSS associated with high low speed (instantaneous WS)	No L3 threshold WS < 4 m/s.	9
5c	Fg_high_wind_48	SSS associated with high wind speed (average WS over 48h00)	(Tg_mean_WShigh_48)	10
5d	Fg_low_wind_48	SSS associated with high low speed (average WS over 48h00)	(Tg_mean_WSlow_48)	11
5e	Fg_sc_high_SST (UDP L2OS)	SSS measured with high SST	No L3 threshold SST > 28°C	12
5f	Fg_sc_low_SST (UDP L2OS)	SSS measured with low SST	No L3 threshold SST < 10°C	13
5g	Fg_high_SST_48	SSS measured with high SST (average over 48 H)	Tg_mean_SSThigh_48 Average SST over 48h > 28°C	14
5h	Fg_low_SST_48	SSS measured with low SST (average over 48 H)	Tg_mean_SSTlow_48 Average SST over 48h < 10°C	15
5i	Fg_SSS_distrib_boite1_seuil3	SSS climato with high variability	Tg_SSS_distrib_boite1_stat3 SSS variability > threshold for the box 1	16
5j	Fg_grad_time_WS_48[	SSS from extreme geophysical conditions	(Tg_grad_time_WS_48) High WS time gradient	17
5k	Fg_grad_time_SSTC_48	SSS from extreme geophysical conditions	(Tg_grad_time_SSTC) High SST time gradient	18
5l	Fg_grad_time_partot	SSS from extreme	(Tg_Param1_prior_M1_gradtime)	19

		geophysical conditions	High geophysical parameter time gradient (other than SSS and SST)	
5m	Fg_sc_low_wave_height1 (UDP L2OS)	« swell-dominated » SSS	No L3 threshold	20
5n	Fg_sc_low_wave_height2 (UDP L2OS)	« mixed sea » SSS	No L3 threshold	21
5o	Fg_sc_low_wave_height3 (UDP L2OS)	« young sea » SSS	No L3 threshold	22
5p	Fg_sc_moderate_wave_height4 (UDP L2OS)	« older seas/mix » SSS	No L3 threshold	23
5q	Fg_sc_moderate_wave_height5 (UDP L2OS)	« young sea (steep) » SSS	No L3 threshold	24
5r	Fg_sc_extreme_wave_height6 (UDP L2OS)	« high sea » SSS	No L3 threshold	25
6	Fg_param_retr	Problem with retrieved parameter other than the SSS (SST, WS, TEC…)	(Tg_ParamX_prior_MY_retr) Estimated parameter too far from the prior	26
7	Fg_low_wind_48 (L3) Fg_low_wind (UDP L2OS)	SSS not well mixed vertically	(Tg_mean_WSlow_48) instantenous WS < 4 m/s and WS average over 48h < 4 m/s	27
8	Fg_ctrl_X, Fg_sc_X, Fg_oor_X	outlier SSS	Complementary of Class 1	28
9	Fg_border_swath	SSS from the edge of the swath	(Tg_border_swath) Threshold to be applied on x_swath	29

2.6.2 L2P product names.

See section 1.3.3 for general information.

Table 4: List of products built by the prequalification L3-OS processor

Name	Description	Type
MIR_CSD2PA	This product contains prequalified salinity (ascending orbits, dual pol)	NETCDF
MIR_CSD2PD	This product contains prequalified salinity (descending orbits, dual pol)	
MIR_CSF2PA	This product contains prequalified salinity (ascending orbits, full pol)	

MIR_CSF2PD	This product contains prequalified salinity (descending orbits, full pol)	

2.6.3 L2P product content

The MIR_CSD2PA, MIR_CSD2PD, MIR_CSF2PA MIR_CSF2PD products have the same data format. They contain information about the prequalification of the L2 salinity. The grid points on which are given the results of pre-qualification are the same of those of the L2OS UDP product. Part of the L2 product is copied in the prequalification product: salinities and salinity errors, X_Swath and Mean_Acq_Time.

The format of these products is the NetCDF format. Qualification (class allocation) depends on the salinity retrieval context and the forward model used for the inversion (3 forward models, see section 2.3).

The data are given on an EASE grid which is defined in the product ((nlat,nlon) dimensions).

Table 5: MIR_CSD2P and MIR_CSF2P content

	Parameter	Description	Type	Unit
1	Grid_point_ID(nlat,nlon)	Grid number ID	int	
2	lat(nlat)	Grid point latitude	float	degree
3	lon(nlon)	Grid point longitude	float	degree
4	Sea_Surface_Salinity_Model1_Value(nlat,nlon)	SSS estimator from model 1	short	psu
5	Sea_Surface_Salinity_Model2_Value(nlat,nlon)	SSS estimator from model 2 (not relevant)	short	psu
6	Sea_Surface_Salinity_Model3_Value(nlat,nlon)	SSS estimator from model 3 (not relevant)	short	psu
7	Sea_Surface_Salinity_Model1_Error(nlat,nlon)	SSS error from model 1	short	psu
8	Sea_Surface_Salinity_Model1_Bias(nlat,nlon)	SSS bias (external information) (not relevant)	short	psu
9	Sea_Surface_Salinity_Model2_Error(nlat,nlon)	SSS error from model 2 (not relevant)	short	psu
10	Sea_Surface_Salinity_Model2_Bias(nlat,nlon)	SSS bias (external information) (not relevant	short	psu
11	Sea_Surface_Salinity_Model3_Error(nlat,nlon)	SSS error from model 3 (not relevant)	short	psu
12	Sea_Surface_Salinity_Model3_Bias(nlat,nlon)	SSS bias (external information) (not relevant	short	psu
13	X_Swath(nlat,nlon)	Distance from grid node to the satellite ground track	short	km

14	Mean_Acq_Time(nlat,nlon)	Mean acquisition time	float	dd
15	Sea_Surface_Salinity_Model1_Classes(nlat,nlon)	Classification of SSS model 1. 29 classes (only 5 used for averaging)	Int (29 bits used)	
16	Sea_Surface_Salinity_Model2_Classes(nlat,nlon)	Classification of SSS model 2. 29 classes (only 5 used for averaging) (not relevant)	Int (29 bits used)	
17	Sea_Surface_Salinity_Model3_Classes(nlat,nlon)	Classification of SSS model 3. 29 classes (only 5 used for averaging) (not relevant)	Int (29 bits used)	

2.7 SMOS SSS correction (bias correction : L2Q and L3Q products)

2.7.1 Algorithm description

The SMOS sea surface salinities (SSS) are affected by biases coming from various unphysical contaminations such as the so-called land contamination and latitudinal biases likely due to the thermal drift of the instrument. These biases are relatively weak and have almost no impact on soil moisture retrieval. On the contrary, for salinity estimation, the impact is non negligible and can reach more than 1 salinity unit in some regions close to the coasts.

These biases are not easy to characterize because they exhibit very strong spatial gradients and they depend on the coast orientation in the Field Of View (FOV). Moreover, these biases are dependent on the position on the swath.

The zero order bias is the so-called Ocean Target Transformation (OTT) which is a correction applied at brightness temperature level. Here, we consider remaining biases on the SSS retrieved from brightness temperatures corrected with an OTT. SSS maps are obtained from a correction applied at salinity level. This correction is determined using simultaneously the July 2010-March 2016 period of SMOS observations. Indeed, it is possible to build salinity time series for each grid point depending on the observation conditions (for instance depending on the orbit direction) and check, from a statistical point of view, the consistency of the salinities.

The first step of this empirical approach is to characterize as accurately as possible these biases as a function of the dwell line position. We first characterize the seasonal variation of the latitudinal biases using SSS in the Pacific Ocean further than 800km from the coast. The second step is to correct for biases in the vicinity of land. We have found that these biases vary little in time, and can be characterized according to the grid point geographical location (latitude, longitude) and to its location across track. If we assume that the salinity at a given grid point varies very slowly during a given period, then, the different satellite passes crossing the same pixel during the given period should give consistent salinities. Additionally, assuming that the bias does not vary temporally for a given grid point implies that the relative salinity variation over the whole period should be the same whatever the distance to the center of the track. It is then possible to estimate the relative biases between the various distances across track and to obtain, with a least squares approach, a time series of relative salinity variations obtained from all the passes. Note that these steps estimation do not use any external climatology. It allows checking that all the dwell-lines and orbit types (ascending or descending) give consistent results.

These relative salinity variations are then converted, in a last step, to salinities by adding a single constant determined, in each pixel, using an average SSS climatology over the whole period (ISAS v6.2 data). This last step, because it uses only one SSS climatology value per grid point as reference totally preserves the SMOS temporal dynamic. The corrected SSS are stored in the so-called L2Q products (Table 6).

The averaging of corrected SSS in order to obtain L3Q ten-days or monthly products is performed by using the same algorithm than for the uncorrected SSS (see section 2.8) but with a different pre-filtering. Indeed, an out-of-range filtering is applied by using min max SSS values obtained from CEC products. Moreover, a mask is applied for high latitudes. SSS coming from low quality adjustment (at brightness temperature level) are removed before average.

2.7.2 L2Q product name

See section 1.3.3 for general information.

Table 6: List of products built by the bias correction L3-OS processor

Name	Description	Type
MIR_CSD2QA	This product contains corrected salinity (ascending orbits, dual pol)	NETCDF
MIR_CSD2QD	This product contains corrected salinity (descending orbits, dual pol)	
MIR_CSF2QA	This product contains corrected salinity (ascending orbits, full pol)	
MIR_CSF2QD	This product contains corrected salinity (descending orbits, full pol)	

2.7.3 L2Q product content

The MIR_CSD2QA, MIR_CSD2QD, MIR_CSF2QA MIR_CSF2QD products have the same data format. They contain information about the L2 salinity corrected from coastal and latitudinal biases.
The grid points on which are given the results of corrected SSS are the same as those of the L2OS UDP product. Part of the L2 and L2P product is copied in the corrected SSS product: salinities and salinity errors, X_Swath, Mean_Acq_Time and L2P Classes. For the classes, we have added one bit (bit number 30) which gives an out-of-range SSS qualification after correction. Another class (bit number 31) contains the SSS mask to be applied at L3 level (allowing the removal of the high latitude regions).

The format of these products is the NetCDF format.

The data are given on an EASE grid which is defined in the product ((nlat,nlon) dimensions).

Table 7: MIR_CSD2Q and MIR_CSF2Q content

	Parameter	Description	Type	Unit
1	Grid_point_ID(nlat,nlon)	Grid number ID	int	

2	lat(nlat)	Grid point latitude	float	degree
3	lon(nlon)	Grid point longitude	float	degree
4	Sea_Surface_Salinity_Model1_Value(nlat,nlon)	SSS estimator from model 1 (corrected SSS)	short	psu
5	Sea_Surface_Salinity_Model2_Value(nlat,nlon)	SSS estimator from model 2 (not relevant)	short	psu
6	Sea_Surface_Salinity_Model3_Value(nlat,nlon)	SSS estimator from model 3 (not relevant)	short	psu
7	Sea_Surface_Salinity_Model1_Error(nlat,nlon)	SSS error from model 1	short	psu
8	Sea_Surface_Salinity_Model1_Bias(nlat,nlon)	SSS bias applied on L2OS SSS estimator from model 1	short	psu
9	Sea_Surface_Salinity_Model2_Error(nlat,nlon)	SSS error from model 2 (not relevant)	short	psu
10	Sea_Surface_Salinity_Model2_Bias(nlat,nlon)	SSS bias (external information) (not relevant)	short	psu
11	Sea_Surface_Salinity_Model3_Error(nlat,nlon)	SSS error from model 3 (not relevant)	short	psu
12	Sea_Surface_Salinity_Model3_Bias(nlat,nlon)	SSS bias (external information) (not relevant)	short	psu
13	X_Swath(nlat,nlon)	Distance from grid node to the satellite ground track	short	km
14	Mean_Acq_Time(nlat,nlon)	Mean acquisition time	float	dd
15	Sea_Surface_Salinity_Model1_Classes(nlat,nlon)	Classification of SSS model 1. 30 classes (only 5 used for averaging)	Int (31 bits used)	
16	Sea_Surface_Salinity_Model2_Classes(nlat,nlon)	Classification of SSS model 2. 30 classes (only 5 used for averaging) (not relevant)	Int (31 bits used)	
17	Sea_Surface_Salinity_Model3_Classes(nlat,nlon)	Classification of SSS model 3. 30 classes (only 5 used for averaging) (not relevant)	Int (31 bits used)	

2.8 Salinity averages (product L3 'simple average')

2.8.1 Algorithms

The averaging is done using only one of the three available salinities (see section 2.3).

This averaging is done by using uncorrected SSS (L2P) and corrected SSS (L2Q).

The salinity averaging is done as follows:

1. Selection of the salinities with the following criteria:

So far, only five classes are used by the L3OS processor:

- Class 1: valid salinities : only these salinities are kept for the averaging. The conditions of belonging to this class are described below.
- class 29: salinities which belong to the edge of the swath (further than 400 km from the ground track). These salinities are discarded before the averaging because they are very noisy.
- class 5a:salinities associated to large wind speed (WS > 12 m/s). These salinities are removed before the averaging because roughness model is inaccurate for high wind speed.
- class 5b:salinities associated to low wind speed (WS < 3 m/s). These salinities are removed before the averaging because errors on ECMWF WS are large at low WS, relationship between roughness and WS at low WS is badly known and the sensitivity of BT to wind speed increases at low WS (increasing the errors on retrieved SSS).
- class of salinities associated to high sea state. These salinities are removed before the averaging because roughness model is inaccurate for swell.

The L2OS SSS values which are used for averaging belongs to the interval [25 40 psu]. Salinities outside this interval are excluded (same SSS interval applied whatever the latitude is).

2. For each considered grid point, a selection of the spatiotemporal neighbours salinities is done: this selection is done using a distance criteria expressed in km (25, 50, 100 or 200 km) and an interval time (month or decade). The time interval is given in the product name (validity start time and validity stop time, see section 1.3.3). The spatial resolution is given in the product header and/or directly in the product name (see section 1.3.3).

3. From the neighbour salinities and for each pixel, the SSS mean, $\bar{S}$, is computed using weighted average algorithm:

$$\bar{S} = \frac{\dfrac{S_1}{sigSSS_1^2} + \ldots + \dfrac{S_n}{sigSSS_n^2}}{\dfrac{1}{sigSSS_1^2} + \ldots + \dfrac{1}{sigSSS_n^2}}$$

where S_1, S_2, … S_n are the selected salinities (see 1. and 2.) and $sigSSS_1$, $sigSSS_2$, … $sigSSS_n$, the associated errors. These errors are obtained from L2OS least square iterative processing. They come from the propagation of the brightness temperature errors and the auxiliary data errors (like errors on wind speed or sea surface temperature which are used in the L2OS inversion scheme).

Note that the previous equation gives the better estimator of the mean salinity in the least square sense.

4. For each grid point, the error on the mean salinity, Sss_Standard_Deviation, is computed as follows:

$$\mathrm{SSS\_error\_mean} = \sqrt{\frac{1}{\frac{1}{sigSSS_1^2} + \ldots + \frac{1}{sigSSS_n^2}}}$$

5. For each grid point the empirical standard deviation, Sss_Rms_Mean, is computed as follows:

$$\mathrm{SSS\_standard\_deviation} = \sqrt{\frac{\sum_{i=1}^{n}\left(\bar{S} - S_i\right)^2}{n-1}}$$

with $\bar{S}$ computed in 3/ and S_i the selected salinities.

Note: Before v272 products, the averaging is done using a simple mean (without error weighting) and the pre filtering does not exclude "high/low wind speed" salinities and "edge of swath" salinities.

In case of corrected SSS, the classes 30 and 31 are used in order to filter the out-of-range SSS before averaging. In this case, the class 1 (SSS validity class) is not used because we consider that the applied correction is able to make valid a data that was not valid before correction.

2.8.2 L3 product names.

See section 1.3.3 for general information.

Table 8: List of products built by the L3-OS CARTO processor (averaging salinities)

Name	Description	Type
MIR_CSD3(A,B,C,D,P)A	Average SSS map derived from L2P products, ascending orbits, dual polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	NetCDF
MIR_CSF3(A,B,C,D,P)A	Average SSS map derived from L2P products, ascending orbits, full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSD3(A,B,C,D,P)D	Average SSS map derived from L2P products, descending orbits, dual polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	

MIR_CSF3(A,B,C,D,P)D	Average SSS map derived from L2P products, descending orbits, full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSD3(A,B,C,D,P)_	Average SSS map derived from L2P products, ascending + descending orbits, dual polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSF3(A,B,C,D,P)_	Average SSS map derived from L2P products, ascending + descending orbits, full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSQ3(A,B,C,D,P)A	Average corrected SSS map derived from L2Q products, ascending orbits, dual or full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSQ3(A,B,C,D,P)D	Average corrected SSS map derived from L2Q products, descending orbits, dual or full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	
MIR_CSQ3(A,B,C,D,P)_	Average corrected SSS map derived from L2Q products, ascending + descending orbits, dual or full polarization for (A=25km or B=50km or C=100km or D=200km or P=200km) resolution	

Note that “full polarization” products are in majority. Dual polarization products are only available for few weeks at the beginning of the mission.

For corrected products (Q3), the distinction between dual and full pol is not used any more.

2.8.3 L3 product content

These products have a matrix structure with two dimensions (nlat, nlon) which depend on the spatial resolution. The definition of these products is as follows:

Table 9: MIR_CSD3 and MIR_CSF3 content

	Parameter	Description	Type	Unit
1	Mean_Sea_Surface_Salinity(nlat,nlon)	Mean sea surface salinity	short	psu
2	N_Used_Meas(nlat,nlon)	Number of measures used to compute the mean	short	
3	N_Rejected_Meas(nlat,nlon)	Number of rejected measures	short	
4	Class_Majority(nlat,nlon)	Majority class among used input salinity classes	short	
5	SSS_standard_deviation(nlat,nlon)	Sea surface salinity std	short	psu
6	SSS_error_mean(nlat,nlon)	Sea surface salinity mean error	ushort	
7	lat(nlat)	Grid point latitude	Float	degree
8	Lon(nlon)	Grid point longitude	Float	degree

End Of Document