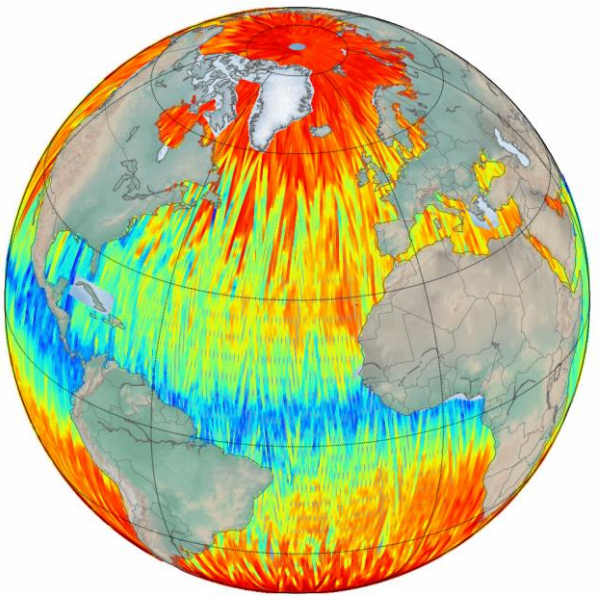
CTOH GNSS (Global Navigation Satellite Systems) derived Path Delay Plus (GPD+) Wet tropospheric Corrections Product Handbook



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Chronology Issues:			
Issue:	Date:	Validated by	Reason for change:
1.0	2020/03/06		Creation of the document from the CTOH existing handbook
1.1	2020/04/28		Addition of a temporal extension for C2, J2, J3
1.2	2020/05/12		Addition of a temporal extension for AL

List of Acronyms:

Aviso+	Archiving, Validation and Interpretation of Satellite Oceanographic data
C2	Cryosat-2
CLS	Collecte, Localisation, Satellites
CNES	Centre National d'Etudes Spatiales
CTOH	Centre de Topographie des Océans et de l'Hydrosphère
ECMWF	European Center for Medium-Range Weather Forecasts
ERA-Interim	ECMWF Re-Analysis Interim
ESA	European Space Agency
GFO	Geosat Follow On
GNSS	Global Navigation Satellite Systems
GPD+	GNSS derived Path Delay Plus
MWR	MicroWave Radiometer
NRT	Near Real Time
SLA	Sea Level Anomaly
SSMI	Special Sensor Microwave Imager
SSMI/S	Special Sensor Microwave Imager Sounder
WTC	Wet Tropospheric Correction

Contents

1. Introduction

Due to its large space-time variability, the wet tropospheric correction (WTC) is still considered a significant error source in satellite altimetry. The GPD+ (GNSS (Global Navigation Satellite Systems) derived Path Delay Plus) dataset (doi: 10.23831/FCUP_UPORTO_GPDPlus_v1.0) is the result of the most recent algorithm developed at the University of Porto to retrieve improved WTC for radar altimeter missions.

1.1. Data Policy and conditions of use

The GPD+ along-track products are available free of charge for any purpose (scientific, operational, commercial, etc) as stated in the licence agreement available at:

https://www.aviso.altimetry.fr/fileadmin/documents/data/License_Aviso.pdf

Please select the product “Along-track GDP+ Wet tropospheric correction” on

- the registration form on if you are not registered on Aviso+
https://www.aviso.altimetry.fr/en/data/data-access/registration-form.html
- your personal My Aviso+ products page if you already have an Aviso+ account
https://www.aviso.altimetry.fr/no_cache/en/my-aviso-plus.html

2. Processing

The GPD+ are WTC estimated at each along-track point with an invalid microwave radiometer (MWR) derived WTC by space-time objective analysis, by combining all available observations in the vicinity of the point: valid measurements from the on-board MWR, from GNSS coastal and island stations and from scanning imaging MWR on board various remote sensing missions. For satellites that do not possess any on-board MWR (CryoSat-2) the correction is estimated for all along-track points using only third party data.

- The computations include all sea points and first land point in a land/sea transition zone. This avoids the loss of points in the coastal regions when time interpolation is required for example for interpolation into 20 Hz points. For points for which no observations exist or from remaining surface types (enclosed sea or lake, continental ice or land) the correction equals the adopted model (ECMWF Op. for the most recent missions, with data only after 2004, and ERA Interim for all other missions).
- All missions have been inter-calibrated using the SSMI and SSMI/S sensors as reference, adjusting 3 parameters: scale factor, offset and linear trend. Details are provided in *Fernandes and Lázaro, 2016*.
- The corrections are continuous, providing valid and consistent WTC for all surface types. With respect to the on-board MWR and other existing algorithms, major improvements are found in the coastal and polar regions.

Another paper is in preparation describing the corrections for all missions except C2 and GFO. For the time being, the corrections should be cited by reference to the following papers:

Fernandes, M. J., Lázaro, C. (2016). GPD+ Wet Tropospheric Corrections for CryoSat-2 and GFO Altimetry Missions. Remote Sensing, 8(10), 851. doi:10.3390/rs8100851

Fernandes, M. J., Lázaro, C., Ablain, M., Pires, N. (2015). Improved wet path delays for all ESA and reference altimetric missions. Remote Sensing of Environment, 169, 50-74. doi:10.1016/j.rse.2015.07.023

Fernandes, M. J., Lazaro, C., Nunes, A. L., Pires, N., Bastos, L., Mendes, V. B. (2010). GNSS-Derived Path Delay: An Approach to Compute the Wet Tropospheric Correction for Coastal Altimetry. IEEE Geoscience and Remote Sensing Letters, 7(3), 596-600. doi:10.1109/lgrs.2010.2042425.

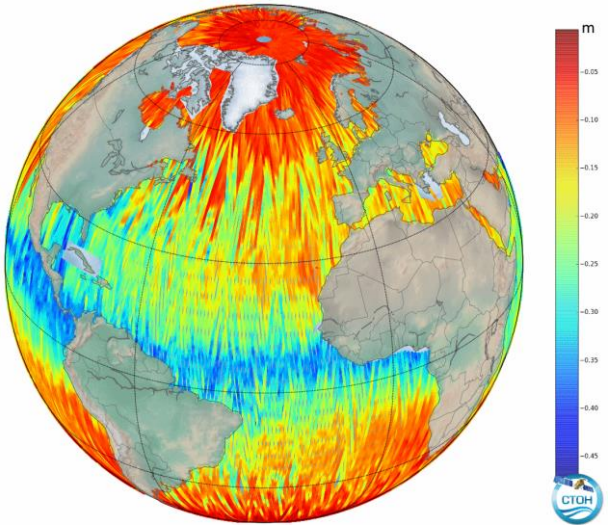

Figure 1: Along-track coverage of the Wet tropospheric correction (GPD+) for Cryosat-2, cycle 093. Credits CTOH/CNES.

2.1. Product content

The product available for different missions consists in 1-Hz along track time series. They are provided in NetCDF format and include:

- **GPD_wet_tropo_corr_01** is the wet tropospheric correction along a nominal ground-track,
- **GPD_wet_tropo_corr_qual_01** is the validity flag of the wet_GPD estimate:
    - 0 - point for which the radiometer correction (rad_wet_tropo_cor) is valid - for these points wet_GPD equals rad_wet_tropo_cor (after applying calibration factors)
    - 1 - wet_GPD is a valid estimate
    - 2 – there were no observations for this point. In this case wet_GPD equals the model value (ERA Interim for TOPEX/Poseïdon,ERS-1,ERS-2,Envisat, Jason-1 or ECMWF Op. for OSTM/Jason-2, Jason-3, Cryosat-2, Saral/AltiKa) with possible small bias applied.
    - 3 - wet_GPD was outside the interval [-0.5, 0.0]. In this case the values -0.5 and 0.0 were attributed to the correction.

3. GPD+ wet tropospheric corrections Products

3.1. Temporal availability

Table 1 indicates for each satellite mission the first and last dates available (and the corresponding cycle numbers).

Mission	Start	End
ERS-1	1991/08 (phase A, cycle 1)	1996/04 to phase g, cycles 156 (RADS convention) or 53 (AVISO convention)
ERS-2	1995/04 (cycle 1)	2011/05 (cycle 167)
Envisat	2002/04 (cycle 1)	2012/03 (cycle 113)
TOPEX/Poseidon	1922/07 (cycle 1)	2005/08 (cycle 481)
Jason-1	2002/01 (cycle 1)	2012/03 (cycle 374)
Jason-2	2008/05 (cycle 1)	2019/10/01 (cycle 383)
Jason-3	2016/02/17 (cycle 1)	2020/02/14 (cycle 147)
Cryosat-2	2010/07 (subcycle 4)	2020/01/10 (subcycle 126)
Saral/Altika	2013/03/14 (cycle 1)	2016/07/04 (cycle 35)

Table 1: temporal availability of each time series

3.2. Nomenclature of files

The nomenclature used for these products is:

< MISSION>_c_<CYCLE_NUMBER1>_<CYCLE_NUMBER2>_gpd.nc

(there are two files for missions J2/J3/C2/AL for the extension of April/May 2020)

MISSION	TP J1 J2 J3 E1 E2 EN C2 SA	TOPEX/Poseidon Jason-1 OSTM/Jason-2 Jason-3 ERS-1 ERS-2 Envisat Cryosat-2 Saral/AltiKa
CYCLE_NUMBER1	XXX	Number of begin cycle (depending on the satellite)
CYCLE_NUMBER2	XXX	Number of end cycle (depending on the satellite)

4. Data format

This chapter presents the data storage format used for the GPD+ correction products.

4.1. NetCdf

The products are stored using the NetCDF format.

NetCDF (network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The netCDF library also defines a machine-independent format for representing scientific data. Together, the interface, library, and format support the creation, access, and sharing of scientific data. The netCDF software was developed at the Unidata Program Center in Boulder, Colorado. The netCDF libraries define a machine-independent format for representing scientific data. Please see Unidata NetCDF pages for more information, and to retreive NetCDF software package on:

https://www.unidata.ucar.edu/

NetCDF data is:

- Self-Describing. A netCDF file includes information about the data it contains.
- Architecture-independent. A netCDF file is represented in a form that can be accessed by computers with different ways of storing integers, characters, and floating-point numbers.
- Direct-access. A small subset of a large dataset may be accessed efficiently, without first reading through all the preceding data.
- Appendable. Data can be appended to a netCDF dataset along one dimension without copying the dataset or redefining its structure. The structure of a netCDF dataset can be changed, though this sometimes causes the dataset to be copied.
- Sharable. One writer and multiple readers may simultaneously access the same netCDF file.

The products are stored in **NetCDF** defined by the Cooperative Ocean/Atmosphere Research Data Service (COARDS) and Climate and Forecast (CF) metadata conventions.

The CF convention generalises and extends the COARDS convention but relaxes the COARDS constraints on dimension and order and specifies methods for reducing the size of datasets. A wide range of software is available to write or read NetCDF/CF files. API are made available by UNIDATA http://www.unidata.ucar.edu/ :

- C/C++/Fortran
- Java
- MATLAB, Objective-C, Perl, Python, R, Ruby, Tcl/Tk

In addition to these conventions, the files are using a common structure and semantic as shown in the example below:

```
netcdf SA_c006_gpd {
dimensions:
    time_01 = 1917656 ;
variables:
    double time_01(time_01) ;
        time_01:units = "seconds since 1990-01-01 00:00:00.0" ;
        time_01:long_name = "UTC: 1 Hz" ;
        time_01:standard_name = "time" ;
        time_01:calendar = "gregorian" ;
    int lat_01(time_01) ;
        lat_01:comment = "Positive latitude is North latitude, negative latitude is South latitude" ;
        lat_01:scale_factor = 1.e-06 ;
        lat_01:add_offset = 0. ;
        lat_01:long_name = "latitude: 1 Hz" ;
        lat_01:standard_name = "latitude" ;
        lat_01:units = "degrees_north" ;
    int lon_01(time_01) ;
        lon_01:comment = "East longitude relative to Greenwich meridian" ;
        lon_01:scale_factor = 1.e-06 ;
        lon_01:add_offset = 0. ;
        lon_01:long_name = "longitude: 1 Hz" ;
        lon_01:standard_name = "longitude" ;
        lon_01:units = "degrees_north" ;
    short gpd_wet_tropo_corr_01(time_01) ;
        gpd_wet_tropo_corr_01:_FillValue = -32768s ;
        gpd_wet_tropo_corr_01:comment = "Computed at the altimeter time-tag through space-time objective analysis
using the GPD+ algorithm, by combining all available observations. The correction has been calibrated with respect to the
SSM/I and SSM/IS imaging radiometers. The correction has been computed only over ocean points (surface_type=0). For
non-ocean surfaces and whenever observations are not available, the correction equals the WTC from the ECMWF
operational model. A wet tropospheric correction must be added (negative value) to the instrument range to correct this
range measurement for wet tropospheric range delays of the radar pulse." ;
        gpd_wet_tropo_corr_01:standard_name = "altimeter_range_correction_due_to_wet_troposphere" ;
        gpd_wet_tropo_corr_01:scale_factor = 0.0001 ;
        gpd_wet_tropo_corr_01:long_name = "GPD+ wet tropospheric correction: 1 Hz" ;
        gpd_wet_tropo_corr_01:units = "m" ;
        gpd_wet_tropo_corr_01:institution = "UPorto" ;
        gpd_wet_tropo_corr_01:coordinates = "lon_01 lat_01" ;
        gpd_wet_tropo_corr_01:add_offset = 0. ;
    byte gpd_wet_tropo_corr_qual_01(time_01) ;
        gpd_wet_tropo_corr_qual_01:_FillValue = -128b ;
        gpd_wet_tropo_corr_qual_01:flag_meanings = "0: point for which the radiometer correction
(rad_wet_tropo_corr) is valid - for these points wet_GPD=rad_wet_tropo_corr; 1: wet_GPD is a valid estimate; 2: there
were no observations for this point. In this case wet_GPD equals the model value (ERA Interim or ECMWF Op.); 3: wet_GPD
was outside the interval [-0.5, 0.0], in this case the values -0.5 and 0.0 were attributed to the correction." ;
        gpd_wet_tropo_corr_qual_01:flag_values = "0 1 2 3" ;
        gpd_wet_tropo_corr_qual_01:coordinates = "lon_01 lat_01" ;
        gpd_wet_tropo_corr_qual_01:long_name = "GPD+ wet tropospheric correction quality flag: 1Hz" ;
```

5. Contacts

For more information, please contact:

Aviso+ User Services
CLS
11 rue Hermès
Parc Technologique du canal
F-31520 Ramonville Cedex
France
E-mail: aviso@altimetry.fr
On Internet: https://www.aviso.altimetry.fr/

The user service is also interested in user feedbacks; questions, comments, proposals, requests are much welcome.

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