ABSTRACT

Since 1991, several altimetry satellites have been launched, each satellite coming with its own, specific, data format. Moreover, high-level data were developed, using yet other formats. For users wishing to benefit from the whole wealth of altimetry data, things can become a bit complicated, since no general tool was ever made for all altimetry data, nor any altimetry tutorial to help understand the techniques and its possibilities.

ESA and CNES decided to support the realisation of an “all-altimeter” radar altimetry tutorial and toolbox:
- A general Radar Altimetry Tutorial (RAT) taking into account 16 years of efforts in outreach on satellite altimetry, as well as new users’ need for information
- An “Open Source” Basic Radar Altimetry Toolbox (BRAT). The Basic Radar Altimetry Toolbox is a collection of tools able to read most distributed radar altimetry data, from ERS-1 & 2, Topex/Poseidon, Geosat Follow-on, Jason-1, Envisat, and the future Cryosat missions, capable of doing some processing, data editing and statistics, and displaying the results.

The toolbox & tutorial overall objective is to facilitate the use of satellite altimetry products for altimetry users and answer to particular needs of specific applications (cryospheric science, oceanography, marine meteorology, land process studies including hydrology and geodesy).

1. NEED FOR AN ALTIMETRY TOOLBOX

Altimetry was at first used by a few scientific teams around the world, often with an actual knowledge of most aspects of the technique. However, altimetry users evolved over the years[1]: new users are now mostly neophytes, with little or no working knowledge of altimetry. The change was also from programmers, i.e. people able to write programmes in, e.g. Fortran or C, to “software users”, in a large part (i.e. people wanting ready-made, easy-to-use software to be delivered, for them to directly use the data). Another change is that geoscientists are not specialized in a specific observation technique anymore, as they might have been in the past, but use the whole range of observations and even models available. Thus they do not wish to delve too deeply in each technique and dataset characteristics, and expect to benefit from “standardized” dataset format, practical tools, highly processed data, and clear, to-the-point, information.

Moreover altimetry is now reaching a wide audience, including biologists, chemical oceanographers, climatologists, meteorologists, end-users, students (and even school kids!) [2], all of whom may not be used to handling data. The origin of users is more diverse, with more and more developing countries joining the altimetry users. With the broader audience comes the need for more and more “basic” information & tools since those new laboratories getting involved do not always have the background in altimetry data processing that previous users had, nor the support of programmers.

Even for more experienced users, simplification is in order. With data from more than six altimetry satellites available, and even more datasets, data reading and visualisation can be somewhat of a headache. Being able to find the information needed in the same place (the tutorial), and to use any dataset with the same set of tools (the toolbox), meet a real demand also from experienced users. In those respects, the development of a general altimetry tutorial and of a multi-altimeter toolbox is meeting a genuine user need, for newcomers and PIs both.

2. TARGET PUBLIC

Expected users can be sorted in three rather different groups:
- “Expert” altimetry data users.
  They already have tools to use most existing altimetry data. They know about altimetry, what it

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is, what are the processing and applications. They will be chiefly interested in level 1b and 2 data handling tools, and by some comparison and validation functions. They will also be interested by data quick-view capabilities.

- “Regular” altimetry users.
  They only have a few tools to use the data, and/or are able to write them with little problems. A general altimetry toolbox will allow them to broaden their sources of data, and especially use the missions they didn’t use yet. They will be mostly interested by the “integrated”, multi-mission approach, and by data quick-view capabilities.

- “Novice” altimetry users.
  They are the people trying to use altimetry data with little or no background in data handling, programming, altimetry and/or remote sensing principle in general. They will be interested by a Graphical User Interface (GUI) with interactive functions, and no programming.

The radar altimetry toolbox and tutorial are aimed at those three groups, even if their requirements are quite different. Moreover, such a tool can help giving students a feel of “real” data without having to programme.

3. DATA AND MISSIONS

For the first public version of the toolbox, the following missions are included

- ERS-1 and 2 missions,
- Topex/Poseidon,
- Geosat Follow-on,
- Jason-1,
- Envisat,
- And the future Cryosat.

The data selected are mainly data from the official data processing and archiving centres, i.e. ESA/F-PAC and Cersat for ERS, Envisat and Cryosat, CNES/Aviso and NASA/Podaac for Topex/Poseidon and Jason-1, NOAA for GFO. See Table 1 for a complete list of products read by the toolbox

In the tutorial, are also mentioned past (Skylab, Geosat-3, Seasat, Geosat), and fore planned missions (Jason-2, Saral/AltiKa, Sentinel 3). The tutorial is built to give general (non mission-specific) information about altimetry and also an overview of the missions.

4. RADAR ALTIMETRY TUTORIAL

The Radar Altimetry Tutorial gives general information about altimetry applications, access to data, software and documentation as well as the overview of the missions and techniques. It also presents a series of data use cases, showing the basic methods for some of the most frequent ways of using altimetry data

4.1. General tutorial

The new generation of altimetry users has few or no knowledge of what is an altimetry data, what processing are applied – and thus what the possible problems are – of such datasets. Moreover, there are completely new uses arising, and those are not always documented in a single place, at least not for beginners. The tutorial is aimed mostly to users or would-be users, with a scientific background, but no specific knowledge of altimetry.
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Table 1. Altimetry products read by BRAT. Some data are available with different delays (near-real time or delayed mode). Products including Cryosat are fore coming.
Tutorial contents are the following:

- Altimetry technologies and processing
  - how it works
  - data flow
  - Future technology improvements
- Altimetry applications
  - geodesy & solid Earth
  - ocean
  - ice
  - climate
  - weather
  - hydrology & land
  - coastal
- Altimetry missions
  - past
  - current
  - future
- Products
  - Data, Software, Documentation
  - Toolbox
- FAQs

4.2. Data use cases

The data use cases explain meaningful examples of applications of altimetry. They present the particular examples in-depth, with information, documentation, references and figures. The presentation consists in describing and documenting the data using process, from identifying useful products, processing and algorithms needed, to how to produce the expected results. Subjects like the use of altimetry data in hydrology (Fig. 3), mesoscale studies or for mean sea level monitoring are developed.

4.3. Product fact sheets

By “products” we are not only referring to data, but also to software and documentation. We made templates so as to fill in the appropriate information concerning altimetry products in a standardized way. The first Product fact sheets are of course the data read by the toolbox (with a link towards the data producer web site), existing reading software and accompanying documentation. However, the list is not closed, and the template will be available for further additions of other data, software and documentation.

Two kinds of software are described: data-using software (reading routines, etc.) but also some modelling and correction software. We thus hope to collect the most complete list of available software of interest for altimetry users, and propose it to them. A model sheet can be disseminated among the community for those interested to complete and have their software thus publicized.

5. BASIC RADAR ALTIMETRY TOOLBOX

The Basic Radar Altimetry Toolbox package contains a set of libraries, command line tools and application programming interfaces (APIs), along with a Graphical User Interface (GUI). It is available either on DVD or on the web (http://www.altimetry.info or http://earth.esa.int/brat), as Windows or Linux auto-installers (you only have to download the desired file, execute it, and the BRAT software package will install), or as source file, to be compiled.

Its main functions are:

- Data Import and Quick Look: basic tools for extracting data from standard formats and generating quick-look images.
- Data Export: output of data to NetCDF (ASCII dump provided). Raster images (png, jpeg, bmp, tiff, pnm) can be saved.
- Statistics: calculation of statistical parameters from data.
- Combinations: computation of combinations of data fields (and saving of those formulas)
- Resampling: over and under sampling of data; data binning.
- Data editing: data selection using simple criteria, or a combination of criteria (that can also be saved)
- Exchanges: data editing and combinations can be exchanged between users
- Data visualisation: Display of results, with user-defined preferences. The viewer enables the user to display data stored in the internal format (NetCDF).
The Toolbox is designed with a Graphical user interface that enables the operator to easily specify the processing parameters required by each function. Those parameters can also be defined directly in parameter files. APIs are also available with data reading, date and cycle/pas conversion and statistical computation functions for C, Fortran, IDL and Matlab. For beginners, we recommend using the GUI.

BRAT is provided as open source software, enabling the user community to participate in further development and quality improvement. The tools are pre-compiled for Windows™ 2000/ XP, GNU/Linux RedHat EL 4.

5.1. Data reading

The reading (or “ingestion”) tools are a data dictionary, based on Handbooks and data structures. They free the users of looking at each and every data format, byte by byte, in order to be able to read their products. The data read are the ones listed above (see Table 1).

Some previously existing reading software are also listed in the tutorial’s Product fact sheets (see 4.3).

5.2. Processing functions

Reading a data product is a good thing, but some processing is in order, especially for complex data like altimetry level 1B and 2. Thus we propose some processing routines, to enable the user to go further than ‘simple’ reading. The functions of those routines are:

- gridding tools
  these are routines allowing users to transform an along-track dataset into a grid (mostly to plot smoothed maps), or to spatially subsample already gridded data, by using binning functions.
- extraction (of a geographical area, of one parameter, of a period),
- combination of basic altimeter parameters (corrected SSH, SLA,…) from data fields,
- basic statistical functions (mean, standard deviation, minimum, maximum…).
- selection (data editing, etc.)

Fig. 4. A ‘dataset’ within the Graphical User Interface. Left, the list of chosen files making up the dataset; right (top) the list of available field within the selected file format, (bottom), the description of the selected field extracted from the data dictionary.

Fig. 5. The computation of Sea Surface Height from Envisat GDR files within the Graphical User Interface.

Data editing is necessary to remove altimeter measurement having lower accuracy from GDR data. The Basic radar altimetry toolbox provides the mean to do such editing, by using flags, threshold conditions. Such editing can be saved for future use.

Fig. 5. The data editing for ocean for Envisat GDR files within the Graphical User Interface. A number of requirements can be defined and combined.
5.3. Visualisation

Visualisation of selected and computed data is of course an important part of the Basic Radar Altimetry Toolbox.

Any parameter available in the data or combination, or statistics, of parameters can be plotted vs another (e.g. SWH vs Wind speed modulus, SSH vs latitude, ...). Several parameters can be plotted against another (e.g. SSH for the same track for different cycles), provided they are of the same dimension. The type of parameters in abscissa and ordinate are user-defined (depending on the data): along the track, along the time, along a longitude or a latitude, etc. for abscissa.

For all modes, title and comments can be written by the user, with the parameter name as default. The user is able to choose a colour scale among a pre-defined set, with user-defined minima and maxima (default are absolute minimum and maximum value of the data). A “do-your-own colour scale” tool is also provided.

5.4. Graphical User Interface (GUI)

An interactive interface has been developed, to provide the user with an easy-to-use tool. The BRAT Graphical User Interface (GUI) is a windowed interface to the BRAT Tools. It enables user to read, select, process, and visualise altimetry data without programming.

The Graphical User Interface works with 'workspaces'. A workspace contains:
- Datasets, which are collections of data files of the same kind,
- Operations, for reading and/or processing and/or selecting data within a dataset, with the end-product of operations, intermediate data files (NetCDF), and a parameter file for each operations,
- formulas, to enable you to use pre-defined combinations of data fields or to define them yourself, save them, and re-use them later.
- Views, that plot results of one or more operations
A ‘view’ produces a parameter file and opens the visualisation tool

The main point of a workspace is that it can be saved for later use. Some or all elements of a workspace can be imported into another workspace (however, file paths, in particular data files ones, may have to be changed in order to have the workspace working correctly).

In order to use the toolbox through the Graphical User Interface the user must:
- create or open a ‘Workspace’;
- define a ‘Dataset(s)’;
- define an ‘Operation(s)’:
  - define a ‘Data Expression’ (the data field(s) & what to do with them)
  - optionally, define a ‘Data Selection’ (edit the data and/or select them with respect to criteria – geographical, time, thresholds,...);
- Execute the operation to obtain an output NetCDF file
- define a ‘View(s)’;
- Execute it to obtain an output image (to be saved in png, jpeg, bmp, tiff, pnm)
Fig. 8. Resulting output figure for Lake Level Height along-track computation from Topex/Poseidon for the Aral Sea in December 1992 (red, T/P cycle 10) and June 2002 (green, T/P cycle 360).

6. POSSIBLE DEVELOPMENTS

The tutorial as well as the toolbox offers a whole new set of possibilities for altimetry users. However, they are not “finished”: several updates and enhancements can be considered. User feedback is important, of course, and will be taken into account for improvements of both tutorial and toolbox.

Updates of the tutorial will be needed, to follow the new missions’ decisions, integrations and launches. New products, new information can also be included.

As for the toolbox, several developments can be envisioned:

- include other datasets and other missions; e.g. Geosat data could be added. Of course, the future Jason-2 and AltiKa data are considered for inclusion, and later on Jason-3 and Sentinel 3 should be.

- enhance some of the tools’ possibilities, especially to give it maximum value for the PIs. Some ideas are already expressed, but users’ feedback will play an important role there.

- And, finally, give maximum ease of use for this tool, so as to level (most) problems encountered by novice users, e.g., some homogenisation of the data field names (which are different from one dataset to another) could be implemented as aliases (the names as they appear in the handbooks being the “true” names, and an alias enabling not to have to delve into the long list of fields in order to find the right one).

The Basic Radar Altimetry Toolbox should be strongly linked to the GOCE Toolbox (GUT), with the ability of reading GUT outputs.

The Basic Radar Altimetry Toolbox aims to become ‘the’ tool for altimetry users, enabling easy, multi-satellite, multi-centre, data reading, computations and visualisation, thus enhancing the visibility and use of all available altimetry products.

REFERENCES


[2] Rosmorduc, V., Aviso, at the crossroad between user service, outreach and education, Advances in Geosciences, 4, 1-4, 2005


http://www.altimetry.info