Q. What are the advantages of the satellite data products?

The primary science objectives of satellite-based radar altimeters require the monitoring of global and regional sea level change, and the mapping of ice sheets and sea ice distribution. The instruments are also successful at monitoring the water level variations in river reaches, wetland regions, and lakes/reservoirs. The advantages of radar altimetry include day/night and all-weather operation, and the measurements are generally unhindered by canopy or vegetation cover. Elevations are provided with respect to a common reference frame, and continuous systematic monitoring of water levels along carefully controlled 'reference' ground tracks, can be achieved over the lifetime of the mission. Data are also available across a ~25yr archive period (1992 to present day), and in real time (within 24hrs) and near real time (1-3 days). Data processing techniques are mature and well validated, and mission continuity is assured to at least 2030.

Q. Are there any limitations?

Yes. Satellite radar altimeters are profiling (not swath) instruments, they only 'see' what is directly below them. The mission orbits are also set into place at the start of the mission and the instruments cannot be rolled sideways to view a 'target' off-nadir. Hence a lake/reservoir may or may not have a satellite overpass, and the intersection of satellite ground track with river reach or wetland surface (in either case this defines the location of a virtual station) will be static over the mission lifetime.

A number of factors will also affect how small or narrow a lake or river reach can be to acquire water level information, and a number of factors affect the quantity and quality of the measurements. Heavy rain events and strong winds may affect elevation accuracy, and in particular the presence of ice/snow may produce erroneous water levels due to radar penetration effects (affecting the radar altimeter Range estimate, and the atmospheric Range correction deduced by the onboard microwave radiometer).

Note must be made that while a ground-based gauge records water level variations at a single location ('spot' height), altimetric elevations are an average across the instrument footprint, and are further averaged from bank to bank to reduce noise on the altimetric range measurement – the distance between the antenna and the surface.

Q. What products are available?

This web site delivers surface elevation products in the form of water level fluctuations in lakes, reservoirs, river reaches and wetlands.

The continental water level products are not interpolated to equal time steps and may contain time gaps due to data drop-outs, instrument failure, or end of mission. The elevation products are derived from multi-mission data, often with an overlap period between a follow-on mission and its predecessor. Elevations from both instruments are provided during these overlap or 'tandem mission' periods. Repeat track techniques help create time series of relative water level variations with an arbitrary datum associated with that particular water body. The products are then updated either weekly or monthly.

Q. What are the temporal resolutions?

The continental water level variations fall into 2 groups, those with an approximate 10-day temporal resolution, and those with an approximate monthly temporal resolution. The 10-day resolution products are derived from the NASA/CNES TOPEX/Jason instrument series. The monthly products are derived from the ESA/ISRO/CNES instrument series which can have either 27-day or 35-day resolution.

Q. What are the spatial resolutions?

This can vary depending on the mission orbit and the latitude, but generally the spacing of the ground tracks formed by the nadir-pointing altimetric instruments is of the order of a hundred kilometers at the equator. The TOPEX/Jason missions have geographic coverage to ±66˚latitude, and the ERS/ENVISAT/SARAL/Sentinel-3 missions to 81.5˚latitude. Instrument measurements are processed by ground-control centers into various data set types. In these data sets elevations are posted at various along-track resolutions (~300m for example). To improve accuracy the employed technique uses all available altimetric elevation data, forming an average from bank to bank, or coastline to coastline.

Q. Which product should I select?

For time series analysis (e.g., climate or dynamics variability) preference is given to the 10-day products with improved temporal resolution, though monthly products are potentially available for (a factor of three) more lakes/reservoirs and river reach/wetland virtual stations.

The 10d, 27d, and 35d products (with *.2 nomenclature) are based on a single-date datum i.e., one that has been formed from height measurements on a single satellite overpass on one particular day. This select date (and thus the datum) is specific to each water body and is an overpass date within the Jason-2 mission (for the 10-day products) or the ENVISAT mission (for the monthly products). These products are of general use for all types of time series analysis.

Q. How accurate are the time series of surface elevation variations?

Accuracy of the altimetric elevations will be variable. The extent and roughness of the surface water are two strongly contributing factors, but atmospheric and tidal influences, as well as interference from dry land can all play a role. In practice a time series of altimetric measurements are compared to those obtained via a conventional ground-based gauge station and the root mean square (rms) of the differences in heights acts as a measure of the accuracy. This accuracy is then assumed to be globally applicable for a similar water body type (roughness/extent). Typical rms values (excluding winter ice-on periods) range from a few centimeters for the largest of lakes with open, rough (wind-driven) surfaces, to 15-30cm rms for smaller lakes or those with calm, sheltered surfaces. The latter accuracy range is also often observed for river reaches and across wetland regions. The presence of ice in lakes or rivers can cause erroneous height measurements due to radar penetration.

Overall, end users should note the error bar on the time series elevation value (column 7) and note whether i) the data source pertains to a more recent or historical mission (column 1), ii) the data is near real time or the more accurate archive (Column 16), iii) the elevation

<u>measurement has been obtained during an ice-on period, and iv) the elevation measurement has a defaulted radar backscatter value (column 8). Defaulted radar backscatter values and/or winter freezes are potentially indicative of erroneous height measurements.</u>

Q. What are "Time Series Advisories"?

These are a number of water body, satellite data or satellite overpass attributes that could affect the accuracy of the time series and its application.

"**Series mission-merger compromised**" highlights problems when merging results from multiple satellite missions. The altimetry community takes full advantage of the fact that before an existing mission is retired, both the old and new mission fly in tandem for several months to help cross-calibration. Lack of (almost) simultaneous data points during these Tandem mission periods or complete loss of a mission's results can hamper the merging process. In this product creation system, the Jason-2 mission results act as a baseline to which the Jason-3 and Jason-1 results are appended. The TOPEX/Poseidon results are then appended to Jason-1. This flag is set to denote that there is a lack of valid points in the tandem mission period and so instead an average inter-mission height adjustment is applied as a first order approximation.

"**Regulated water levels**" pertains to water level controls via a man-made structure directly on the lake outlet e.g., a dam, weir, barrage, enclosure etc.

"**Anthropogenic effects**" indicates that there are no structures on the lake, but there are man-made influences on water levels via modification of inflows/outflows.

"**Mid-series reservoir formation**" is flagged to denote that the reservoir formed, or that the lake became artificially controlled, during the satellite monitoring period. This monitoring period spans from the present day back to 1992 (10-day products), 1995 (35-day and monthly composite products), and 2016 (27-day products). Note that changes in reservoir operation maybe observed within the products but these are not specifically flagged or highlighted.

"**Winter ice**" denotes a water body that is known to freeze for a certain time-period and "**High Latitude**" warns of potential freezing. In both cases the presence of ice can cause erroneous water level measurements if derived from the radar altimeters. In addition, with a large instrument footprint, the build-up of snow and ice on the lake or river channel or even on the surrounding terrain, can also influence the microwave-based elevation results. For these water bodies use winter water level measurements with caution, particularly those showing deep water level drops or large rapid rises during the October to April period. Elevation measurements derived from the laser altimeters should not suffer such limitations.

"**Potential seiche/wind effects**" marks water bodies known to have strong wind set-up or seiche effects.

"**Potential tide effects**" marks water bodies that potentially suffer from centimeter to decimeter tidal influences. For example, The Great Lakes (USA/Canada) suffer centimeter spring tides, the Amazon River can experience spring bore tides, and coastal bay waters are tidal. Coastal lagoons are usually cut-off from the sea by a narrow sand bar or spit but may have an occasional inflow of sea water during storms. Due to lack of tidal information data, the satellite series is not corrected for these local effects.

"**Narrow water crossing**" indicates that the satellite overpass takes it across a narrow stretch of water (≤3km for lakes, ≤1km for river reaches (excluding main islands but the sum of all channels if braided). For some water bodies this may be an outer limb rather than the main extent location. In general, the wider the stretch of water the increased potential for a greater number of altimetric height measurements and the more accurate the mean elevation of the water.

"**Overpass skims coastline/riverbank**" is a warning that land may be interfering with the water signal.

"**Overpass far from dam**" informs the end user that the satellite is measuring height variations at a great distance from the reservoir dam location. Also set when the overpass is near the reservoir inflow entrance, a potential issue when there are large reservoir extent variations.

"**Shallow waters**" indicates a water body which may seasonally dry out or have exposed islands. At times of water level minima, the altimetric elevation could be biased towards emerging land, or be forming an average of multiple small pools all of which are undergoing different water level variability. For these water bodies, use water level minima with caution.

"**Ephemeral lake**" indicates that the presence of water can be temporally and spatially variable across the basin.

"**Desiccated**" highlights current dry conditions.

"**Complex region**" flag can be set for several reasons, i) when a lake no longer has its historical coastline (and therefore variability), examples include those lakes where dykes have been created to divide the original lake into portions, or where the original lake is now sufficiently desiccated to split into multiple water bodies, ii) when a lake's coastline is extremely complex with unknown lake boundary limits, iii) for a wetland region where water level fluctuations can be location dependent, iv) for a very narrow river reach embedded within a wetland zone and where the time series is likely to be biased towards fluctuations in the wetland rather than the river channel.

"**Braided reach**" marks a section of river that is composed of multiple channels. Variability within each braid cannot be monitored, and the altimeter is likely recording some form of average elevation. In such situations the presence of islands may also be influencing the mean elevation.

"**Channel islands**" is a flag used for river reaches (not lakes/reservoirs/wetlands) when the satellite overpass takes it over one or more islands, rocky outcrops, or sand bars and where these are large in comparison to the width of the reach. Such mid-stream land emergence could influence river elevation accuracy.

"**Data Capture compromised**" highlights a time series where general surface acquisition has been compromised. Without the aid of an onboard Digital Elevation Model, the instruments can sometimes follow a nearby target (land or other bright water body), rather than the actual waters of the lake or river reach. The instrument may follow the erroneous target completely or ‘toggle’ between the surface of the erroneous target and the lake/river.

“**Data capture DEM compromised**” highlights loss of some mission data due to errors within the onboard Digital Elevation Model. This can also compromise the capture of full seasonal amplitudes.

Q. How can the elevation products be converted to a mean sea level or local datum?

The altimetric elevations are first provided by the ground control data centers (NOAA, AVISO etc.) with respect to a reference ellipsoid i.e. a geodetic datum. The TOPEX/Jason mission series utilize the TOPEX/Poseidon or ‘T/P’ ellipsoid, while the ESA missions often employ the WGS84 ellipsoid. In this project, all original satellite data is ingested and forced to conform to the T/P reference ellipsoid. This ellipsoid has equatorial radius = 6378136.3 meters and a flattening coefficient = 1/298.257. Repeat track techniques employed here to create the elevation products, take the data center elevations and shift the datum to an arbitrary one that is unique to the virtual station location of a given water body. End users requiring measurements in a WGS84 frame or orthometric (mean sea level) frame must apply translation factors to the elevation products (column 6 in the text products). These are provided in the text product headers.

a) To translate the relative elevations back to the TOPEX/Poseidon ellipsoid datum,

- ADD the “Mean geodetic height” to each height value (column 6) in the product text file.

b) To translate the relative elevations to the WGS84 ellipsoid datum (which shares the same axes as the TOPEX/Poseidon reference ellipsoid but its radius and flattening coefficients differ), i.e. remaining in a geodetic frame,

- Subtract the “WGS84 mean shift” value from the “Mean geodetic height” and then ADD the result to each height value (column 6) in the product text file.

c) To translate the relative elevations to a mean sea level (orthometric) frame, the geoid height along the satellite ground track section has to be considered. The EIGEN6C4 and the EGM (the historical EGM96 and revised EGM2008) geoid models are well known. However, all will have uncertainty at a given location and here, emphasis is on the technique using an elevation profile across the water body, and not a single geographical location. Nevertheless, to undertake the translation,

- Select one of the “Conversion Factors” given in the product header and ADD the result to each relative height value (column 6) in the product text file.
- Note that end users can go directly to column 15 which is the lake orthometric height with respect to the EGM2008 geoid. This value is also plotted on the lake product graph (right hand side y-axis).

d) Translation to a local datum is only possible if the local datum has been historically tied into an established global datum at some point, or if there is a partial overlap in time between satellite and gauge data set and so an estimated mean difference in elevation can be applied

Example, for lake 0012.Winnipeg and the 10-day TPJOJ.2 product,

- To convert to the WGS84 geodetic frame only (note b above) apply (185.73-0.71) =185.02m to the column 6 relative lake height values.
- To convert to the EIGEN6C4 orthometric (mean sea level) frame (note c above) apply 218.01m to the column 6 relative lake height values.