RADS version 4: an efficient way to analyse the multi-mission altimeter database

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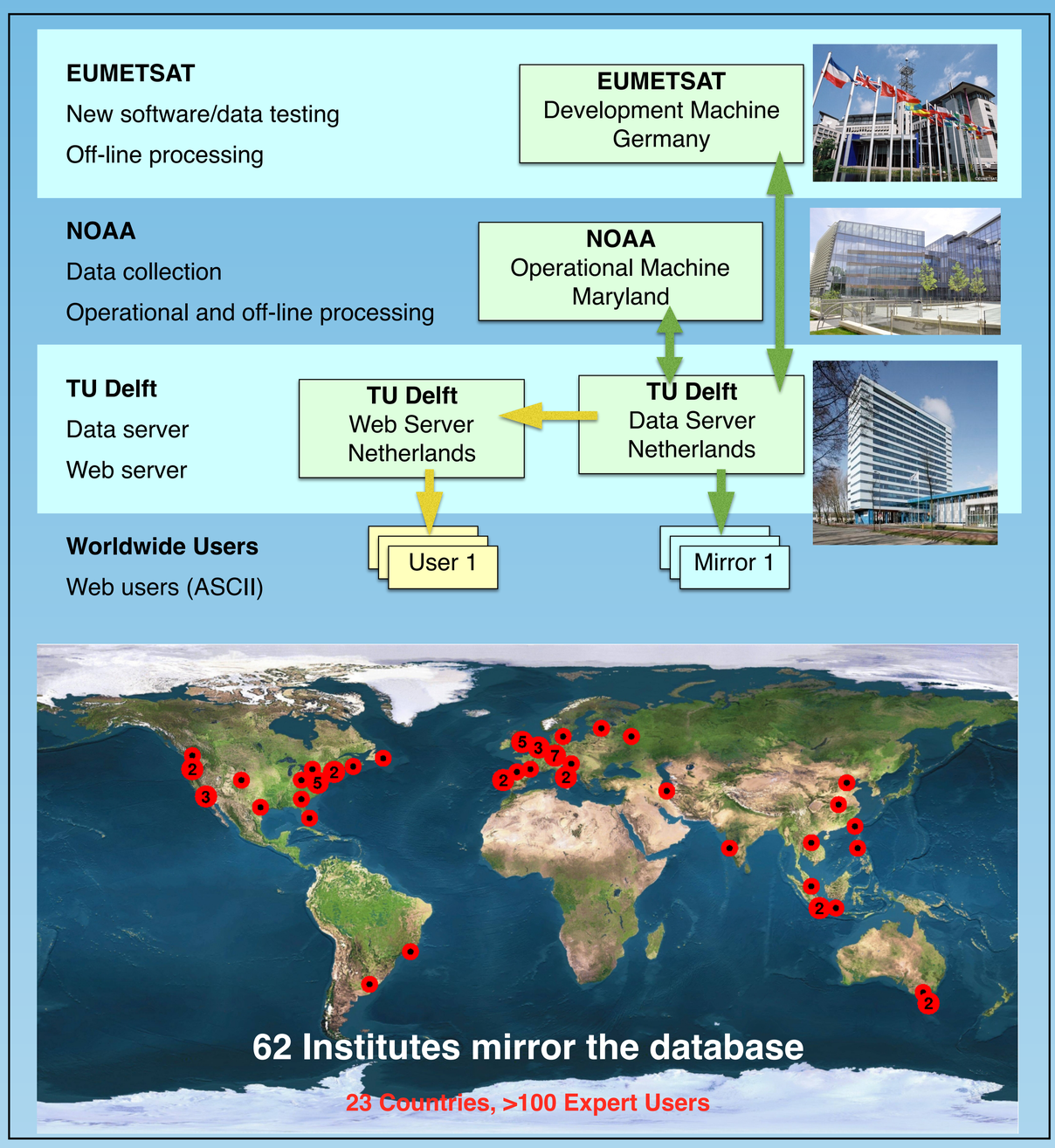
Summary

For satellite altimeter data to become a fundamental Climate Data Record (CDR) for sea level, mm-level signals need to be extracted from measurements taken from an altitude of 700-1400 km.

Data from ten altimeter missions are presently available in the Radar Altimeter Database System (RADS), forming the basis for a prototype Level 2 sea level CDR. The 24 years of "reference missions" (TOPEX/Poseidon, Jason-1, Jason-2, and Jason-3) are complemented by "mesoscale missions" (Geosat, GFO, ERS-1, ERS-2, Envisat, SARAL, and Sentinel-3) and the "polar mission" CryoSat-2. The latter two groups increase the spatial coverage of sea level change and start yielding stability comparable to the reference missions through some recent developments in corrections, like orbits and ionospheric corrections.

Since 2013, development and off-line processing has continues at EUMETSAT, while NOAA provides the operational (near-realtime) processing. TU Delft provides a web interface, an rsync server, and a mailing list server. About 62 institutes in 23 countries are mirroring part or all of the data set, while many others access the web site to make data requests on demand. Currently, RADS provides a multitude of additional variables needed to convert the original satellite range measurement into a climate-quality sea level record. RADS includes alternative variables to allow the user to assess the possible influence of model errors on sea level.

More recent developments in RADS include: Fortran 95 code (for easier expansion and parallelisation); documented software library (for users builds and software sharing); GitHub repository; full data documentation.

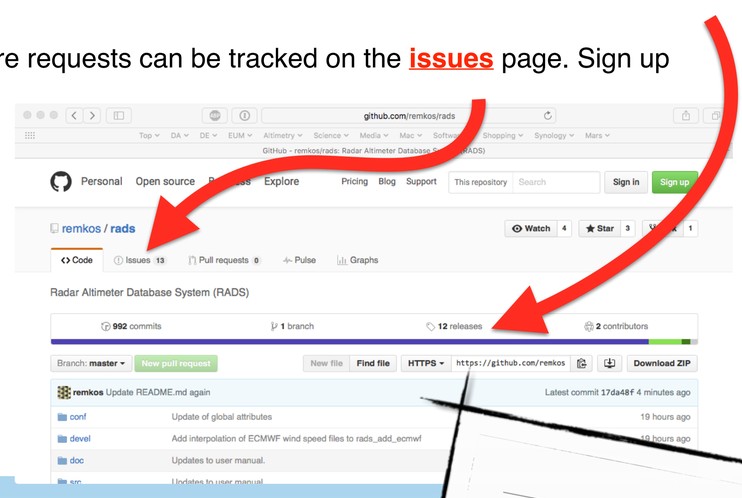


Processing and data access

- **Twice daily processing** of near-realtime and interim GDR products of **Jason-2, -3** and **SARAL.** Also, **CryoSat-2 LRM data with MOE orbits** retracked from Level 1B; global coverage filled in with PLRM data retracked from SAR Level 1A after approximately 1 month.
- **Continuous and consistent datasets** from start of mission to a maximum of 9 hours old data.
- **Downloadable in ASCII** form (for small projects) through web interface: **http://rads.tudelft.nl**
- **Rsync server** for netCDF data. Easy mirroring of all or parts of the data set. **rsync://rads.tudelft.nl** (password protected)
- **To be deployed later: OpenDAP server**
- **Software tools** for data extraction, statistics, collinear track analysis, crossover generation.

GitHub

- **OpenSource.** All the source code is visible on the GitHub website **https://github.com/remkos/rads**.
- **Distributions.** Download tarballs from the **releases** page. New releases are made every few months.
- **Issues.** Bug reports and feature requests can be tracked on the **issues** page. Sign up to GitHub to submit your own bug reports or feature requests.
- **Always up-to-date.** If you want to have the cutting-edge, you can use the **git** command to keep up with the latest commits to the repository.
- **Contributions.** Users who want to contribute their code are invited to do so.

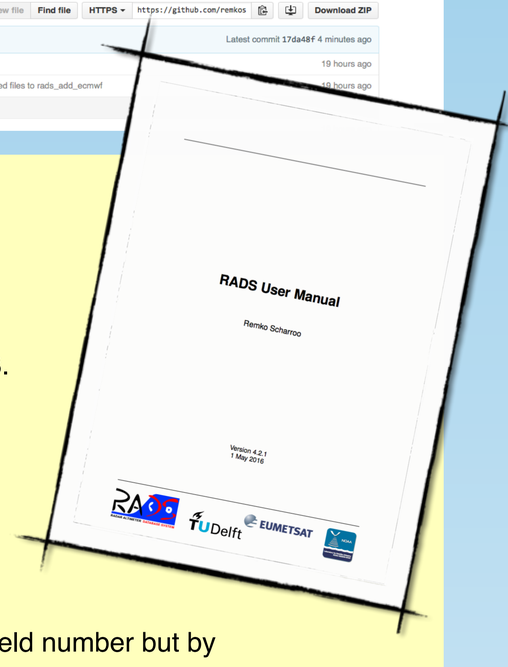


Database

- **Geosat.** Both Geodetic and ERM mission.
  All up-to-date models and Goddard orbits based on GDR-C' standards.
  Updated SSB models. Data of Geodetic mission retracked. **ERM data to follow.**
- **ERS-1 and ERS-2.** New orbits from REAPER project and up-to-date models.
  Corrected radiometer drift and gain loss and applied neural network algorithm.
  Fixed varying sigma0 bias. Updated SSB models. Removed scaling error in ECMWF wet tropo correction. **Official REAPER products to be added soon.**
- **TOPEX/Poseidon.** GFZ SLCCI and Goddard GDR-C' orbits. Corrected radiometer drift.
  Fixed C-band bias. Updated windspeed (Gourrion) and SSB models. Corrected SWH degradation. Removed scaling error in ECMWF wet tropo correction.
- **GFO.** Updated orbits, SSB and WVR wet tropo correction. **Regional retracking planned.**
- **Jason-1.** GDR-C with GFZ SLCCI, Goddard GDR-C', and CNES GDR-E orbits.
  Adjusted sigma0 for bias with TOPEX and use (Collard) windspeed model.
  Moved all JMR data by one second and apply Enhanced JMR Product (coastal).
  Reducing sigma0 noise using Quartly algorithm. **To be updated soon to GDR-E.**
- **Envisat.** Consistent orbits from ESOC and CNES.
  Corrected MWR side lobe effects. Hybrid SSB model. Fixed S-band sigma0 and range bias. Fixed USO drift. Improved rain flag algorithm. Applied drift on 23.8 GHz brightness temperatures and recompute wet tropospheric correction using neural network algorithm.
- **Jason-2.** Reduced sigma0 noise by adjusting for apparent off-nadir angle.
  GDR-D data. MLE4 (default) and MLE3 retracker results both available.
- **Cryosat-2.** Low bit-rate ocean data, retracked, from LRM/FDM Level 1 and Pseudo-LRM data from Level 1A SAR data. **All patched for numerous problems in Baseline B, consistent with Baseline C data. To be updated all to Baseline C soon.**
- **Jason-3.** GDR-E standards. Currently available for only to OSTST PIs. General release expected in June.
- **Sentinel-3A.** Will be made available first to S3VT members, then to wider community.

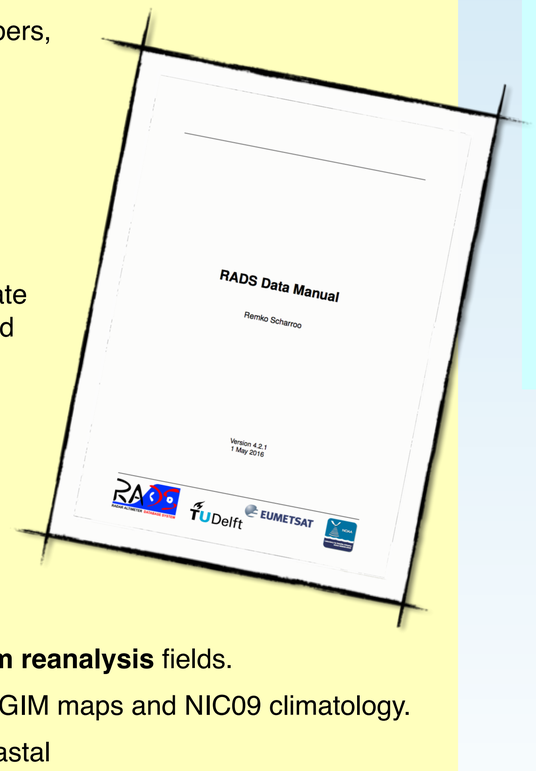
New in RADS 4

- **Fortran 95.** Almost complete recoding from scratch.
  Easily scalable with flexible memory allocation.
  Parallelization of vector *(pass data)* math.
- **New & updated utilities.** Mostly compatible with RADS3.
  rads2asc, rads2nc. RADS data selection and conversion to ASCII or netCDF.
  radscolin. Collinear track stacking program.
  radsstat. Averages of data fields per pass, day, cycle.
  radsxogen, radsxolist, radsxostat. RADS crossover generator, lister, and statistics.
  rads2grd. Grid one data field as a function of others.
- **Variables by name.** Addressing variables no longer by field number but by name, similar to the variables in the Jason netCDF GDRs.
- **Settings per variable.** Each data field will be allowed its own editing criteria, instead of a single edit criterion for all variables of the same type (i.e. all ionospheric corrections).
- **XML configuration files.** Global or for special purposes. Instead of namelist files. More flexible and readable. Conversion tool provided.
- **Fully documented.** 50+ page RADS User Manual describing tools and software **API**.



Up-to-date data fields

- **Fully documented.** 30+ page RADS Data Manual with description of all data fields and references.
- **Tides.** FES2012, GOT4.8 and GOT4.10c with appropriate long-period and load tides. WebTide (around Canada and US). Consistent pole and solid earth tides.
- **Geoid, MSS.** EIGEN4 and EGM2008 geoid. DTU13, DTU15 and CNES-CLS11 MSS.
- **Bathymetry.** DTU10 and SRTM30PLUS.
- **Wind/wave.** WaveWatch 3 model.
- **Inverse barometer (DAC).** Latest version of MOG2D.
- **Meteo.** NCEP and **full resolution ECMWF ERA-interim reanalysis** fields.
- **Ionosphere.** Smoothed dual-frequency correction. JPL GIM maps and NIC09 climatology.
- **Coastal.** High-res land mask, distance to coast, and coastal proximity parameter for editing.
- **Land types.** Six level ocean, land, lake, ice mask **to be added soon.**



Program sample

```
program rads_sample
use rads                    ! Use rads module
type(rads_sat) :: S         ! Structure that contains all mission information
type(rads_pass) :: P        ! Structure for pass information
real(eightbytereal), allocatable :: lon(:), lat(:), sla(:)
integer :: cycle, pass, i
call rads_init (S, 'e1')    ! Initialize RADS. Select ERS-1. No mission phase needed!
do cycle = 1, 30                                              ! Loop through 30 cycles
    do pass = 1, 10, 2                                        ! List ascending passes 1-9
        call rads_open_pass (S, P, cycle, pass)               ! Open pass file
        allocate (lon(P%ndata), lat(P%ndata), sla(P%ndata))   ! Allocate memory
        call rads_get_var (S, P, 'lon', lon)                  ! Get longitude
        call rads_get_var (S, P, 'lat', lat)                  ! Get latitude
        call rads_get_var (S, P, 'sla', sla)                  ! Get sea level anomaly
        do i = 1, P%ndata
            write (*,*) lon(i), lat(i), sla(i)                ! Print the data
        enddo
        deallocate (lon, lat, sla)                            ! Deallocate memor
        call rads_close_pass (S, P)                           ! Close pass
    enddo
enddo
call rads_end (S)               ! End RADS; free data structure.
end program rads_sample
```

Sea level change record

- **Nine altimeters.** All records combined. Annual signals removed. 4-month smoothing. Corrected for GIA, which means that this value represents volume change.
- **Regional trends.** Mid-1992 to early-2016. Trend variations associated with El Niño and currents.