Making Earth System data records for Use in Research Environments (MEaSUREs)

# Integrated Multi-Mission Altimeter Data for Climate Research

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Remko Scharroo – Altimetrics LLC
Sylvie Labroue – CNES
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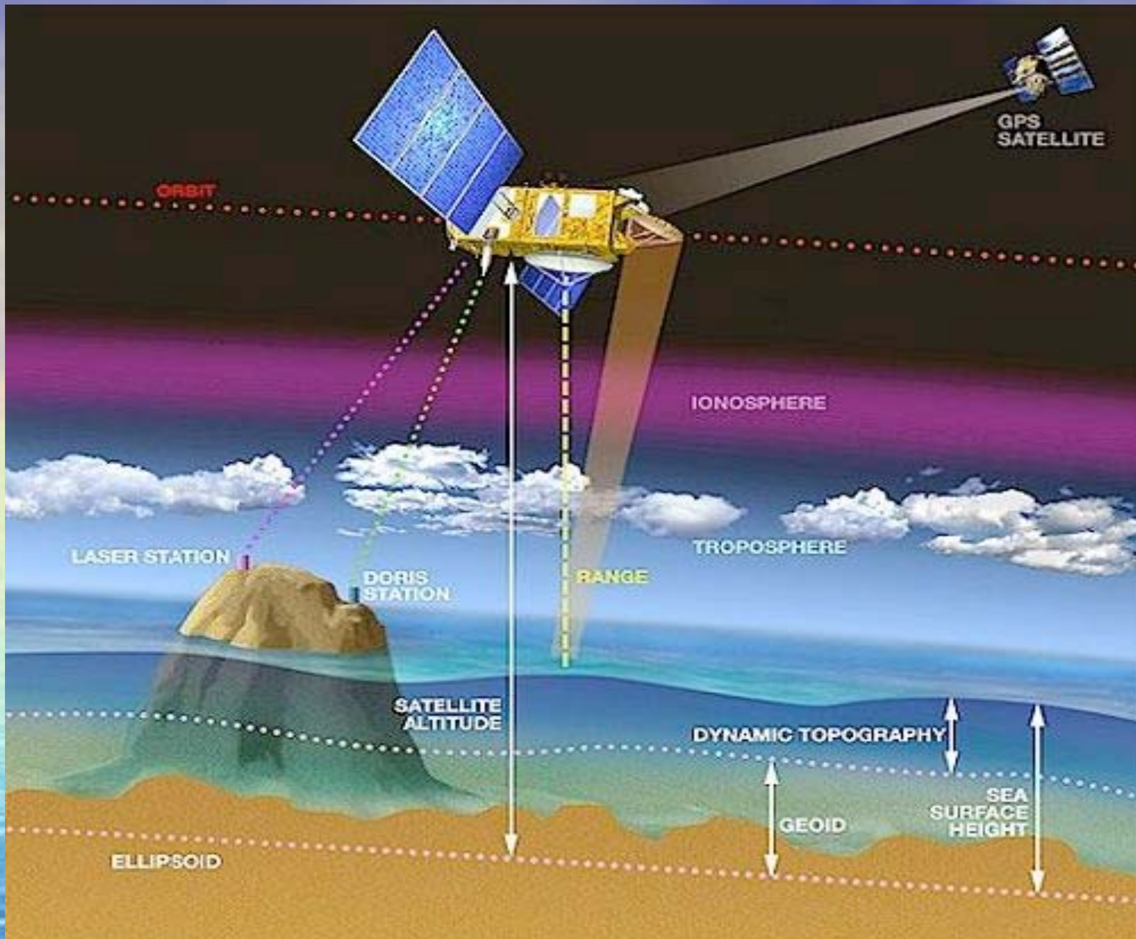
# OUTLINE

- Science - Research Ready Dataset
  - Reprocessed GDRs
    - Orbits, Gravity Models etc.
- Legacy Data Formats and Distribution
  - File Formats
  - Access Protocols and Software
- Future
  - NetCDF

## Motivation – Pathfinder Legacy




➢Satellite altimetry measures sea surface topography, a proxy for ocean heat content and ocean circulation.

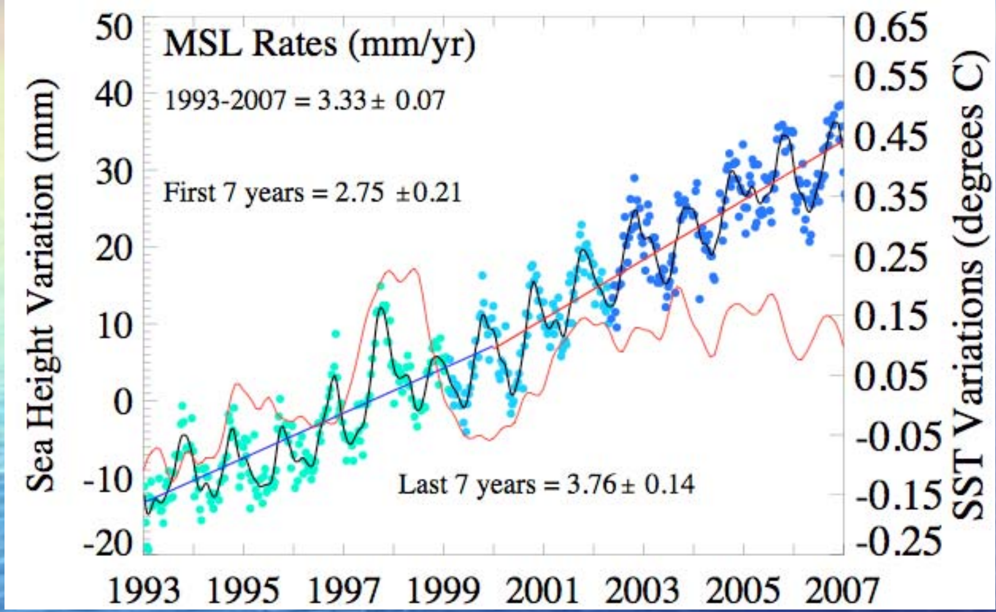
➢ The oceans are the memory of the climate system.

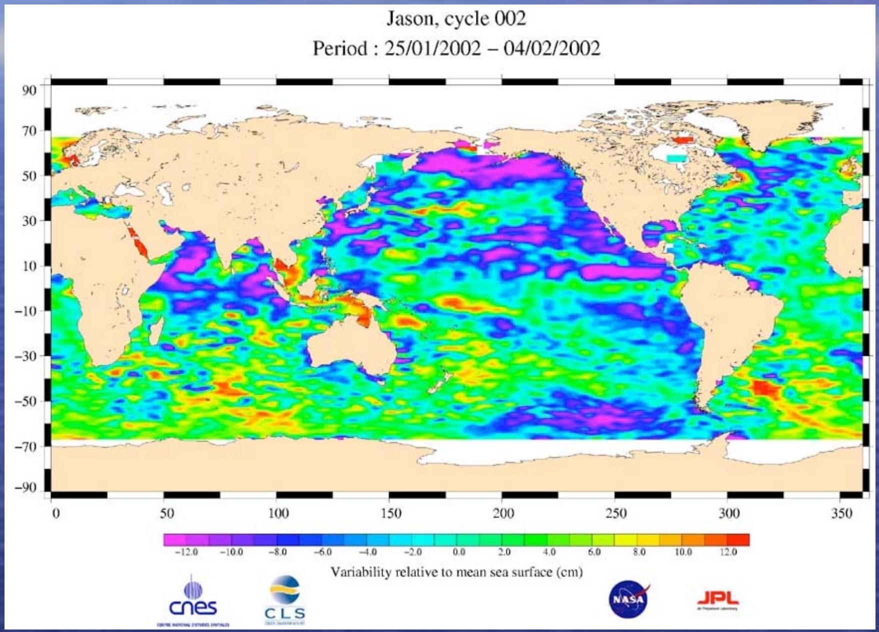
➢ Monitoring changes in global mean sea level requires inter-mission consistency.

➢Seasat (1978), Geosat (1985-89), ERS-1 (1991-96), TOPEX/POSEIDON (1992-2005), ERS-2 (1995-08), GFO (1998-pres), JASON-1 (2002-pres), ENVISAT (2002-pres), and OSTM (2008 - pres); these altimeter systems have very different accuracies, orbit peculiarities, measure or not auxiliary variables such as water vapor or ionospheric electron content.

➢The goal of this work is to apply the best possible physically-based corrections to each dataset within a consistent well defined geodetic reference frame, and produce **inter-decadal sea level time series**, so a change in time can be interpreted as a change in the ocean, not in the measurement system.

***From the launch of the first spaceborne altimeters, Precision Orbit Determination (POD) has been driven by the science goals of the geodetic altimeter missions…***

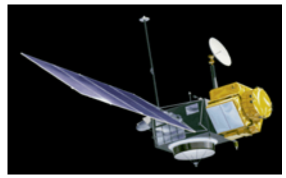



***The accurate knowledge of the spacecraft ephemeris in an accurate common reference frame is essential to the successful science derived from radar altimetry, particularly for global circulation and MSL studies…***

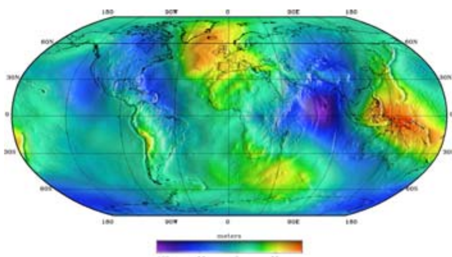
***Recent advances in POD have been made in accurately modeling the forces acting on the satellite… Force Modeling, accuracy and consistency of the reference frame as realized through the ground and space based tracking network … Reference Frame, and observing the satellite motion with high temporal sampling and accuracy … Tracking Technology and Measurement Modeling.***

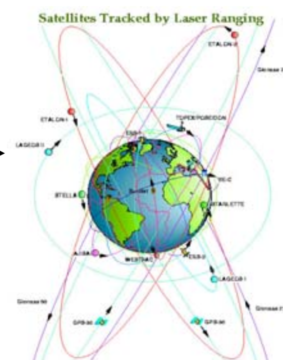
Onboard Tracking Systems
LRR
DORIS
GPS



Atmospheric Modeling
Ionospheric Propagation Delay
Tropospheric Refraction
Atmospheric Density

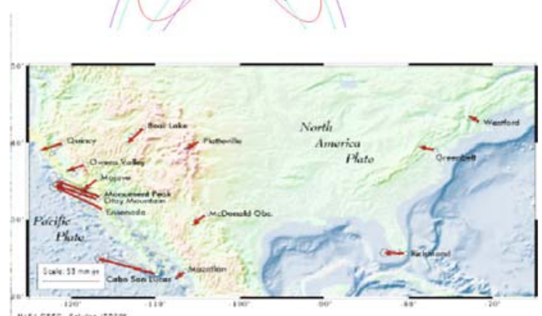
Surface Forces
Modeling
S/C Attitude





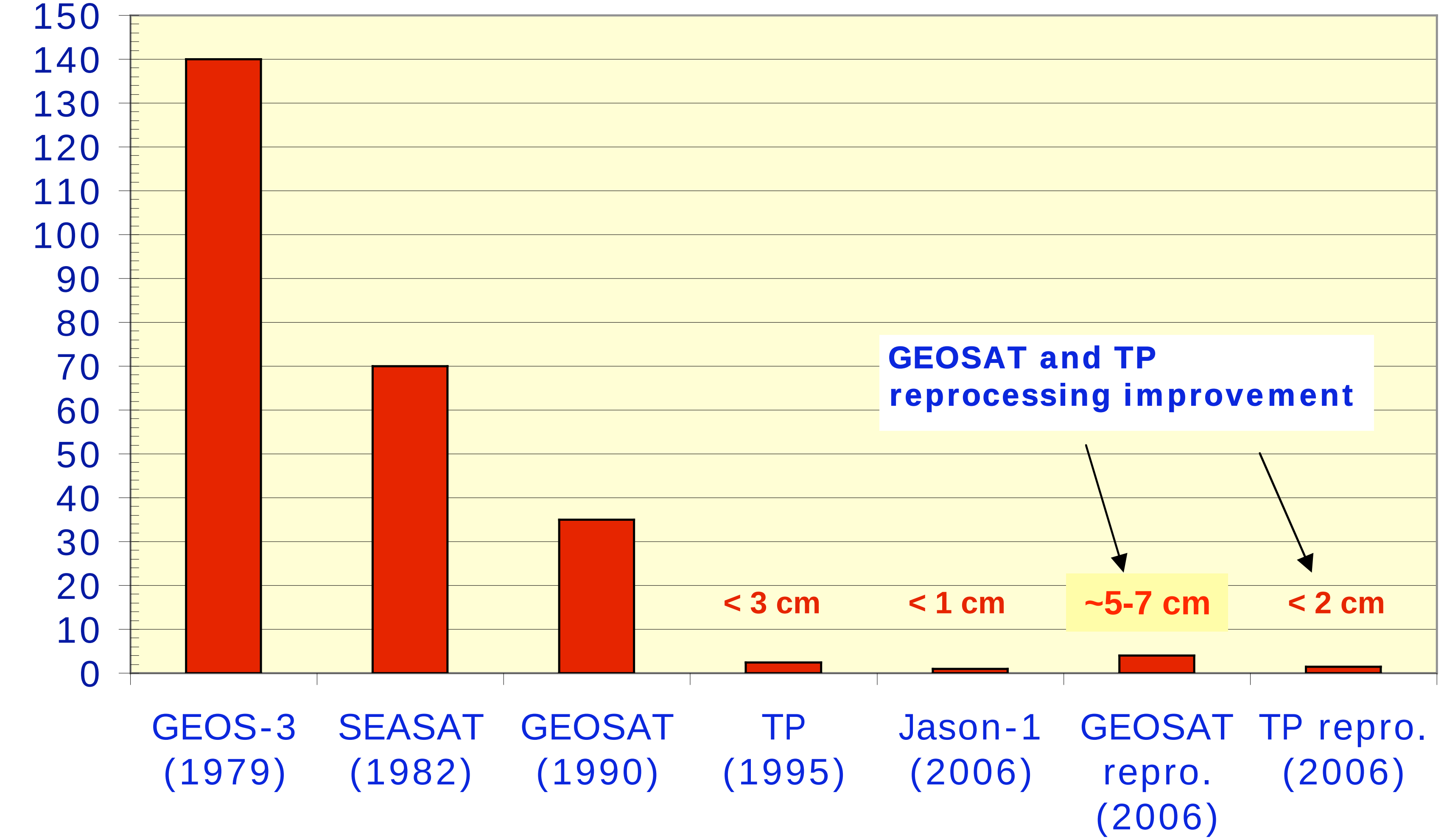

Orbit Determination
Force Modeling
Reference Frame
Tracking Technology

Geophysical Models
Gravity Models
Tide Models
Time Variable Gravity




Reference Frame
International Terrestrial Reference Frame
Horizontal plate and vertical site motion
Geocenter motion
Polar Motion and Earth Orientation

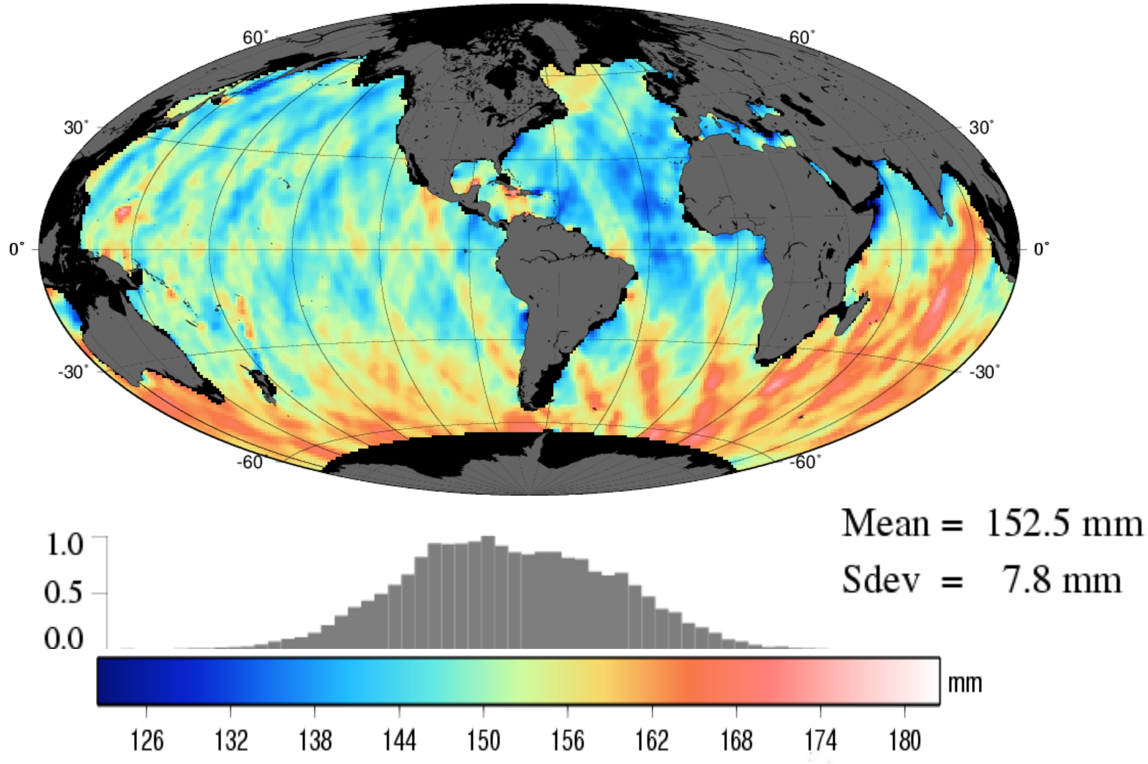
# Radial Orbit Accuracy Achievement



**Jason – T/P Mean SSH**

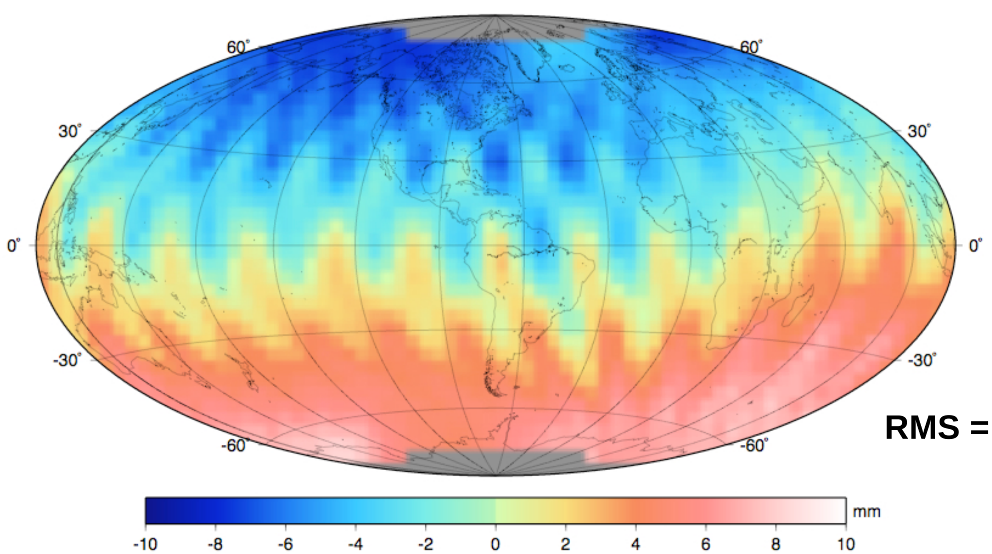
**Validation Phase**

**GDR based orbits**

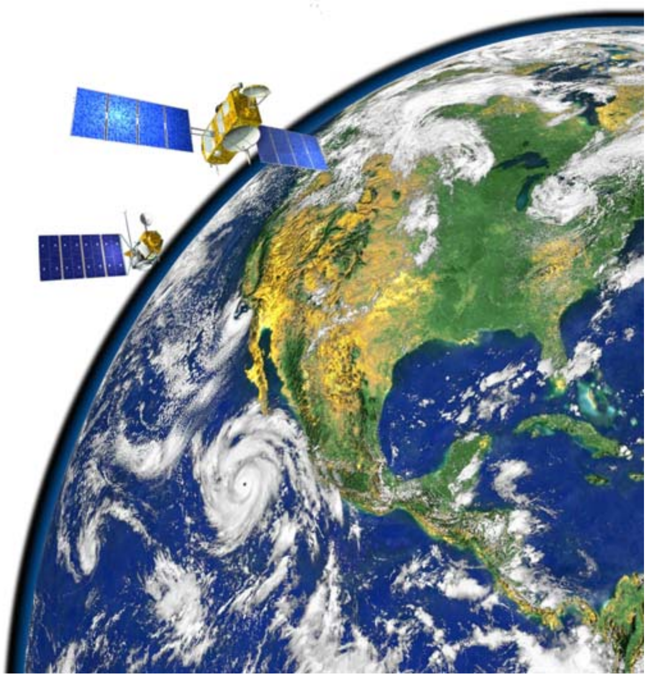



# Terrestrial Reference Frame Inconsistency

TOPEX Radial Orbit Difference
GSFC (ITRF2000) - GDR (CSR95)



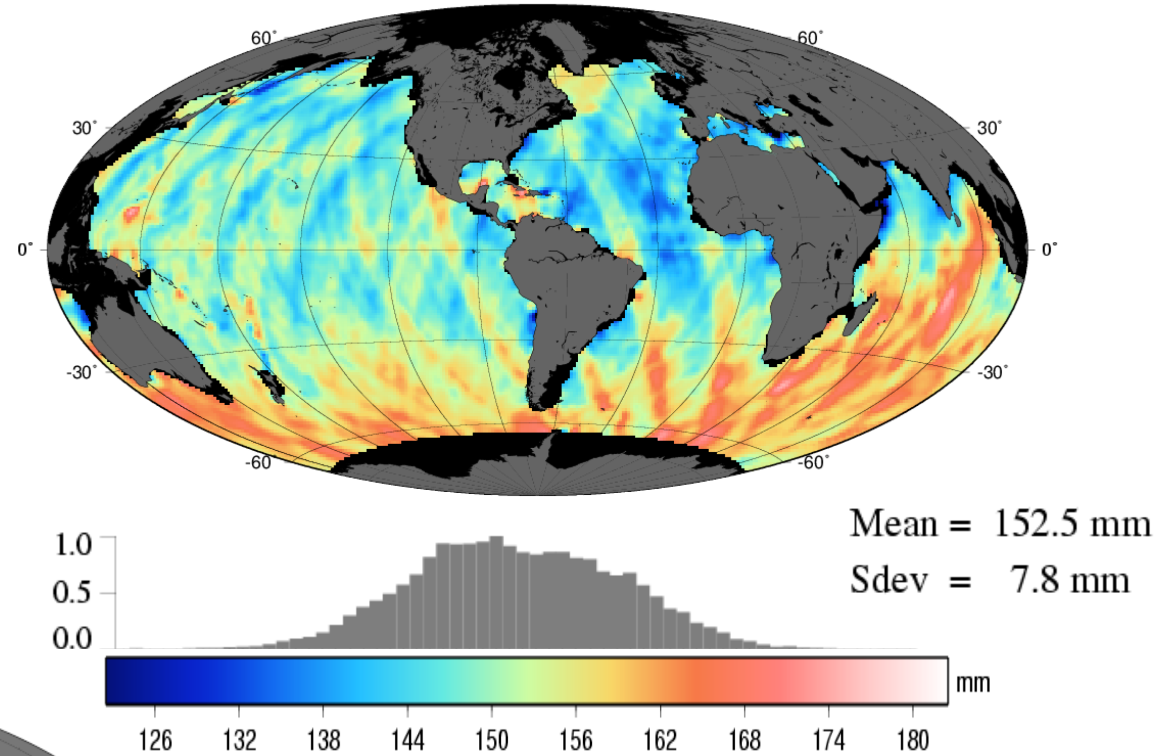

**RMS = 4.7 mm**



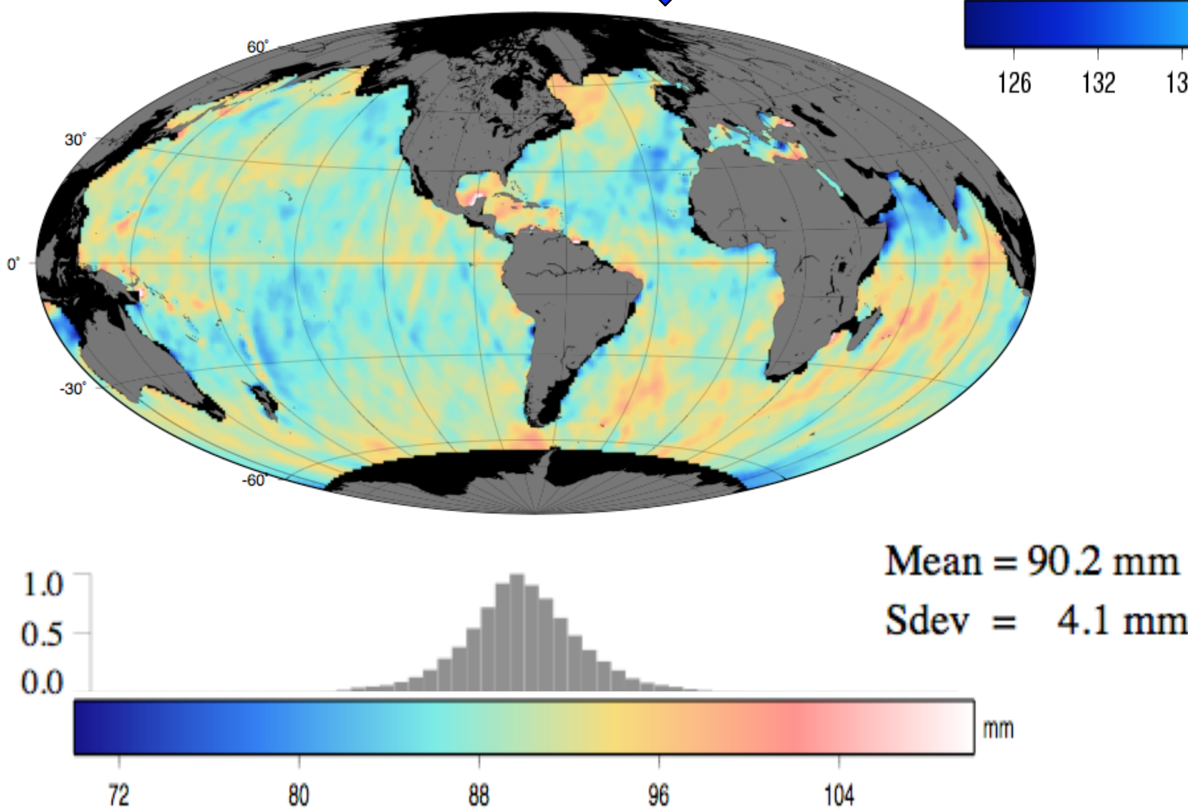
# Jason – T/P Mean SSH

Effect of precision orbits in mean sea level determination

**GDR based orbits**



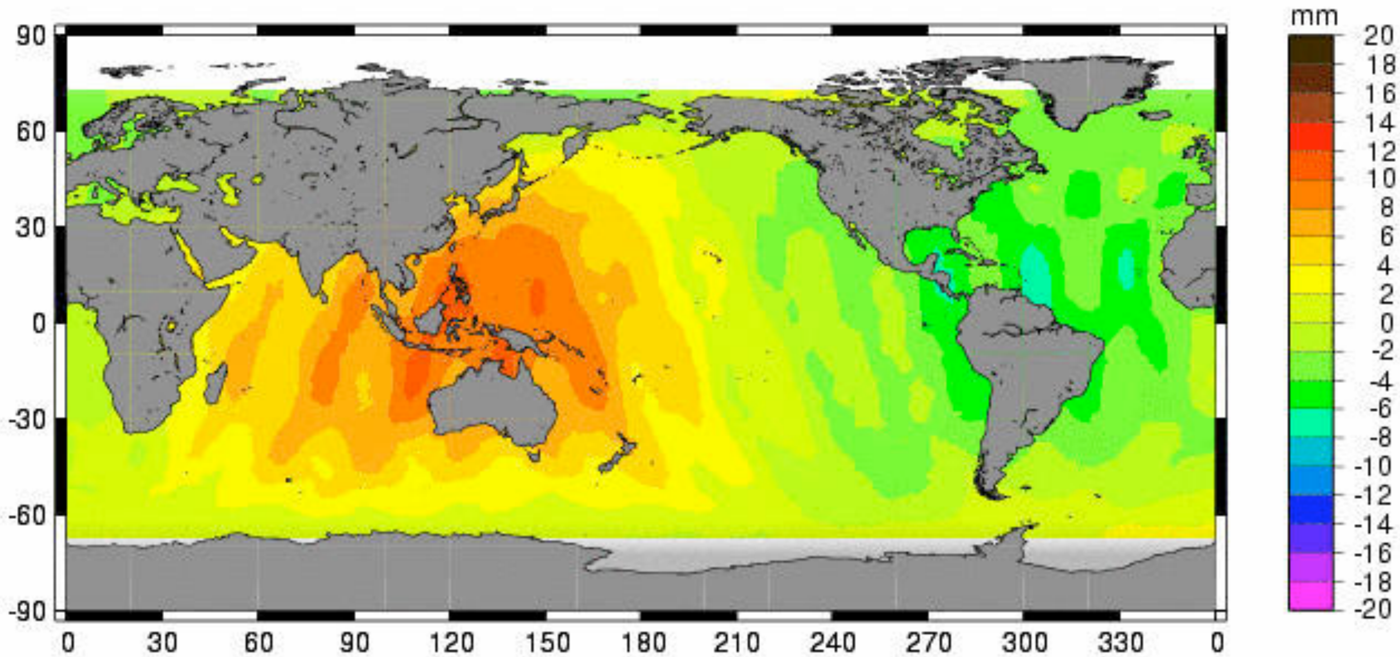

**GSFC replacement orbits**




Improved agreement seen in image at left results from improved TOPEX and Jason-1 orbits. Improvement was realized by using the more current **ITRF2005** reference frame and associated station complement in the orbit computations, the **GGM02C** gravity field, and other improved force and measurement models.

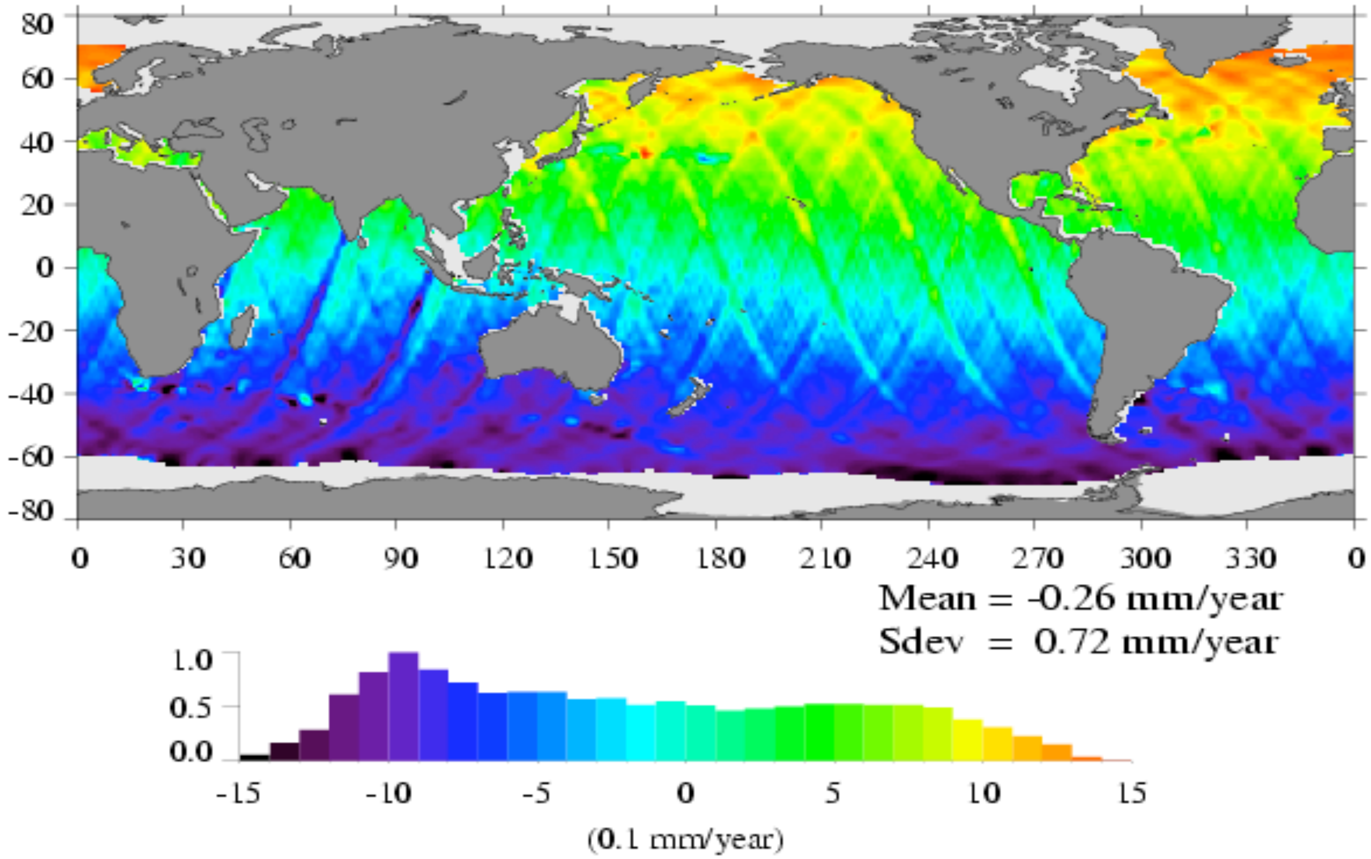
## Precision Modeling Issues: Gravity Model Consistency?

**Jason GSFC (GGM02C) – CNES GDR-B ( EIGEN3) radial orbit differences (cycles 1-21)**



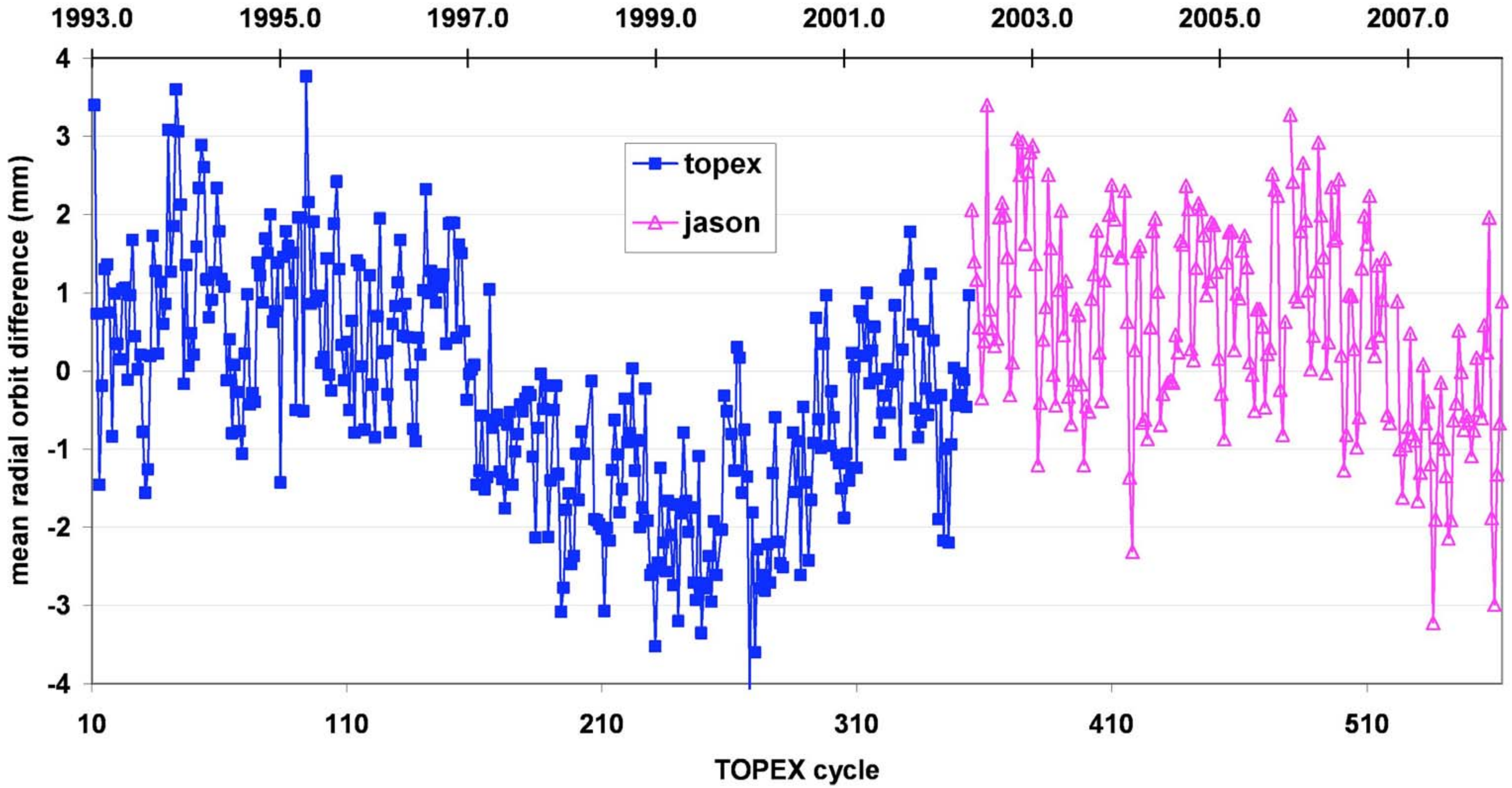

**The differences might be derived from how the two GRACE models handle C21/S21. In comparing or combining two altimeter time series, this could introduce a bias and/or rate in MSL determination.**

# Impact of Terrestrial Reference Frame on MSL Trends



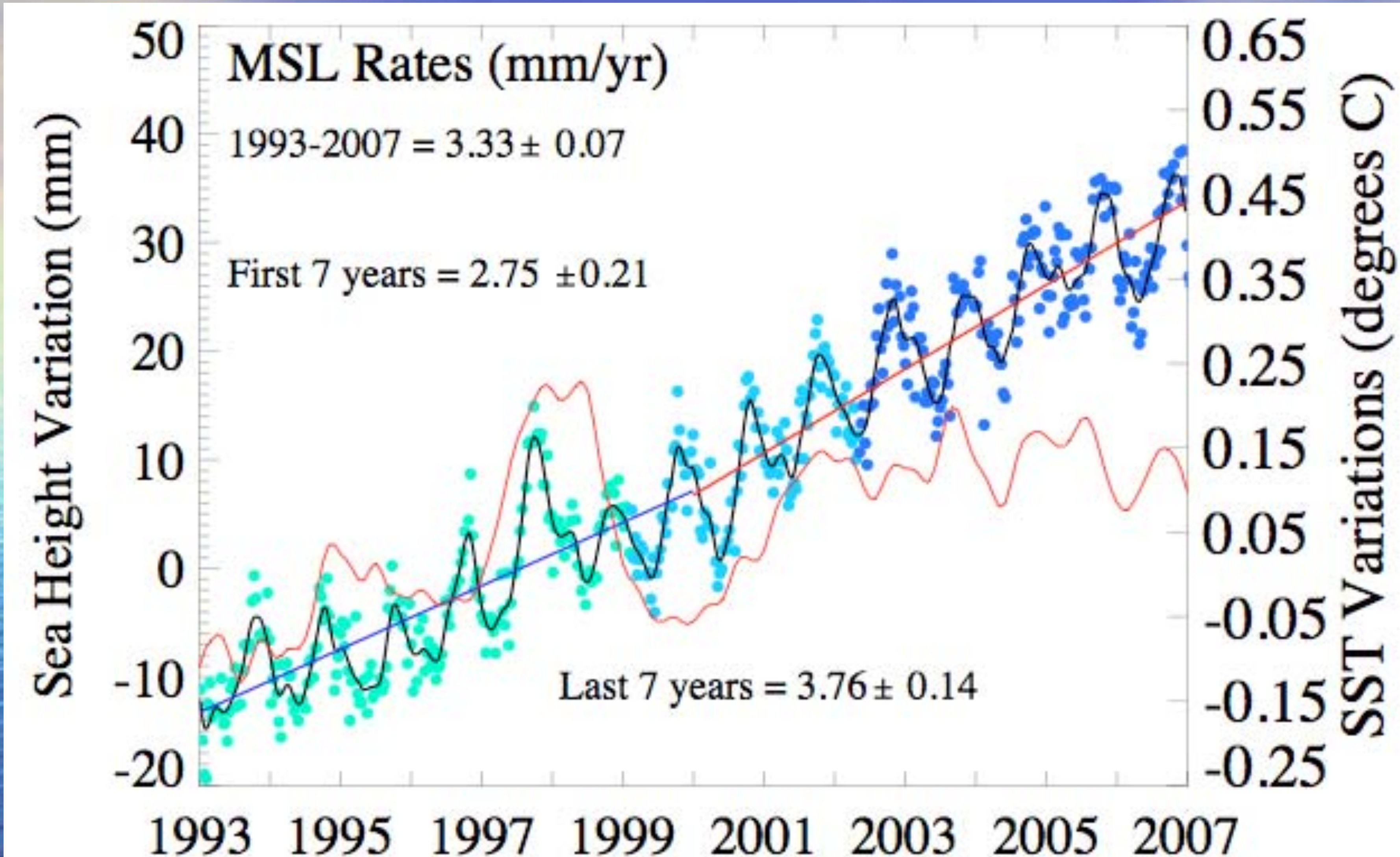

Regional **TOPEX** (**1993-2002**) Sea Surface Height Trend differences from direct impact of the **ITRF2005** (GGM02C) minus **CSR95** (JGM3) orbit differences. The positive values in the northern hemisphere indicate a previous underestimation of MSL of up to 1.5 mm/yr in the North Atlantic. The striping in the orbit differences indicates the removal of orbit error through gravity model and other modeling improvements.

## Mean radial orbit differences for TOPEX & Jason-1
## (ITRF2005 minus CSR95 & ITRF2000; Sampled over the oceans)



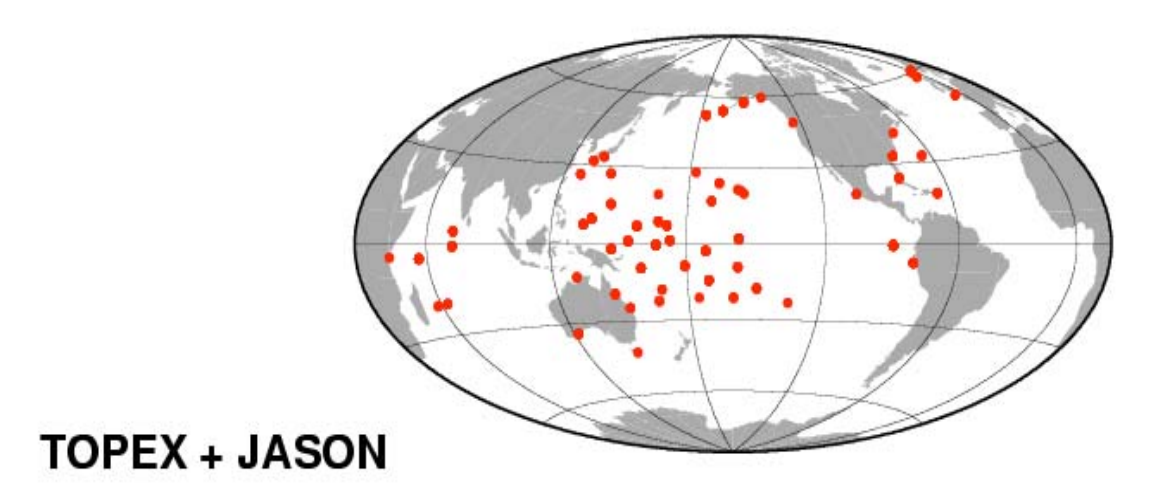

Mean radial orbit differences by cycle, computed between orbits based on the **ITRF2005 reference frame** and the GGM02 (Grace-derived) gravity model and those on the TOPEX/Poseidon MGDR-B (**CSR95**) and Jason-1 GDR-B (**ITRF2000**) GDR's. Differences are sampled only over the oceans.

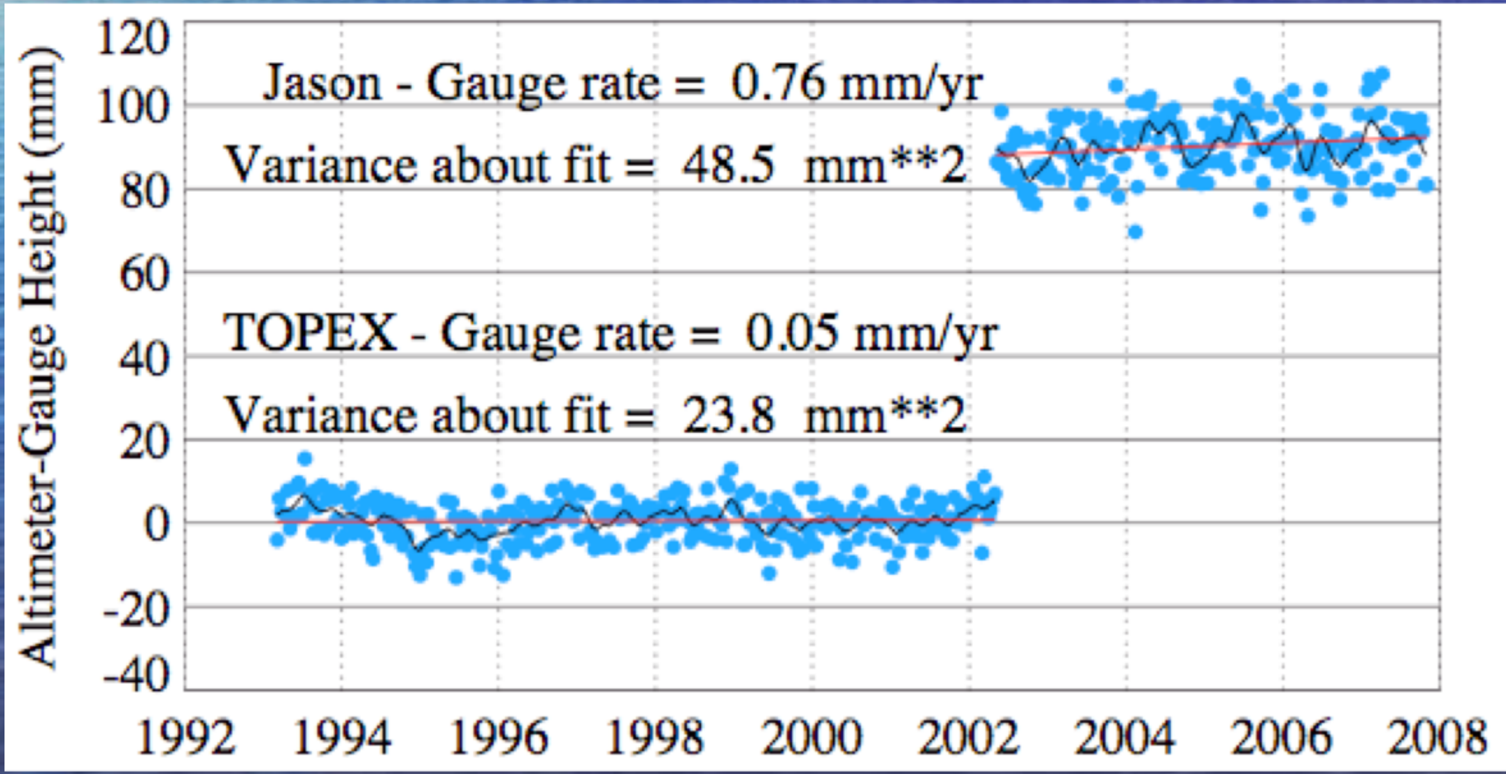
# Global Mean Sea Level Trends from TOPEX and Jason-1



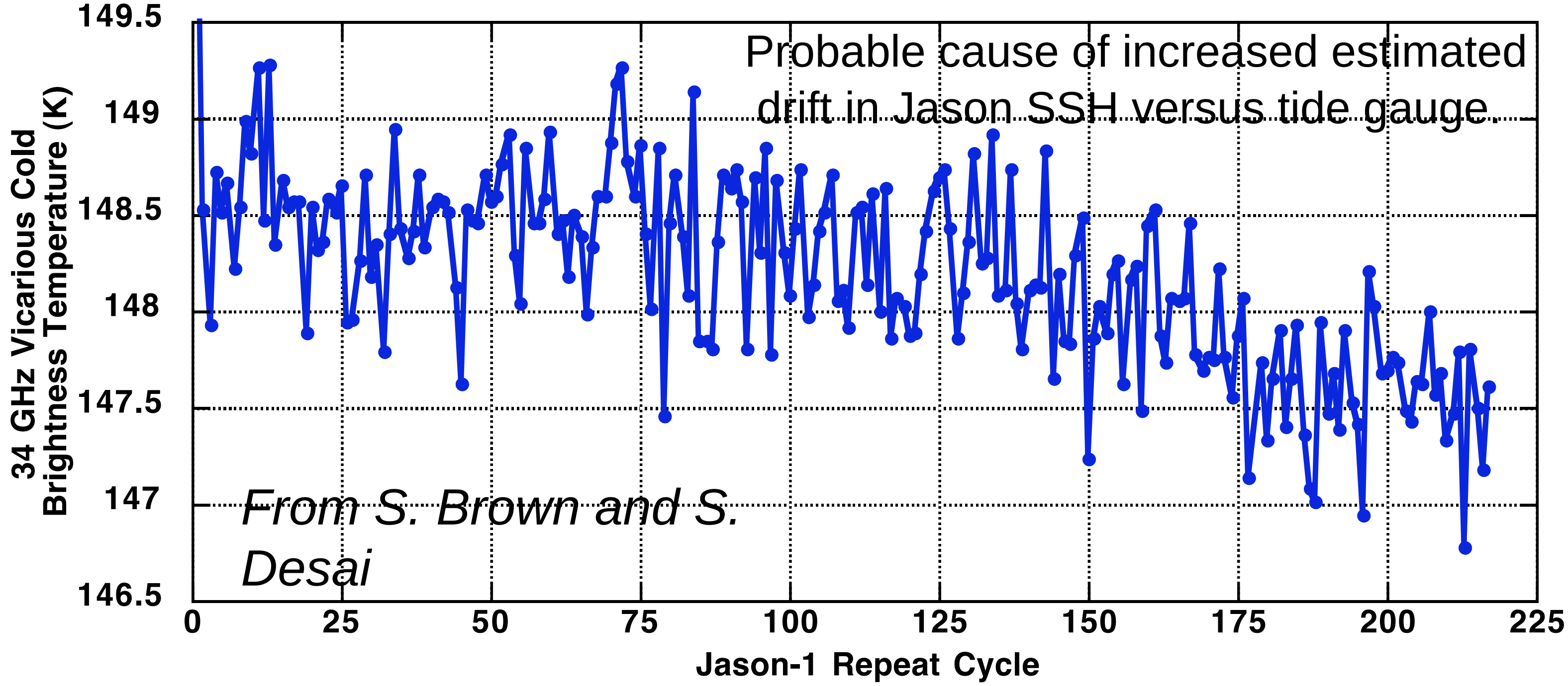

B. D. Beckley, F. G. Lemoine, S. B. Luthcke, R. D. Ray, and N. P. Zelensky , A reassessment of global and regional mean sea level trends from TOPEX and Jason-1 altimetry based on revised reference frame and orbits, *Geophys. Res. Lett*., 34, 2007.

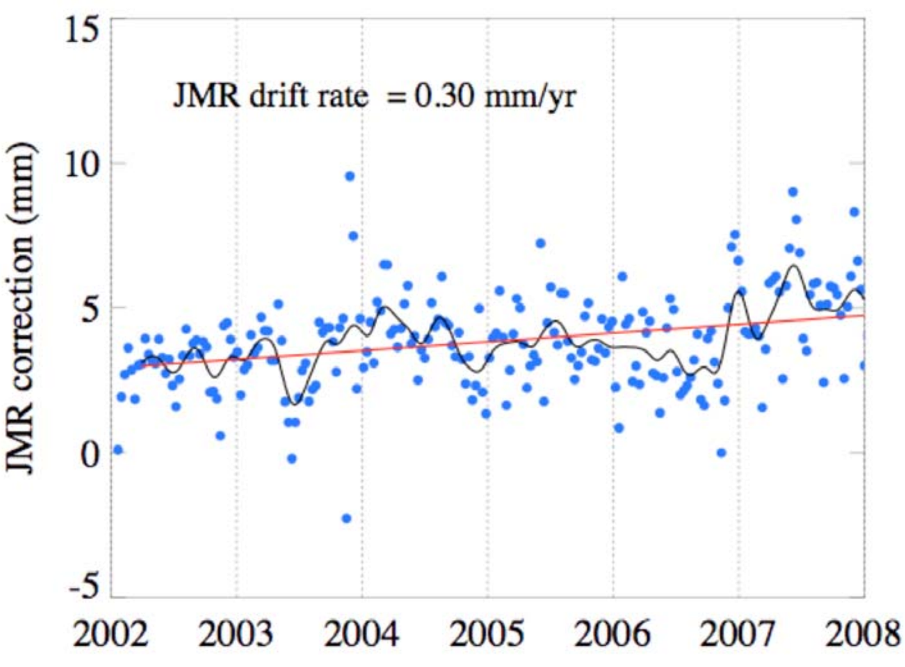
# Tide Gauge Verification - Gary Mitchum, University of S. Florida



# Monitoring the stability of the Jason Microwave Radiometer




JMR 34 GHz brightness temperatures have drifted ~ 1K from last calibration (from cycle 127-212). Impact is **~ +0.9 mm/yr drift** in JMR wet path delay measurements since cycle 127.

Mean 1Hz JMR differences averaged per cycle between GDR_B and preliminary proposed JMR recalibration for GDR_C ( *S. Brown and S. Desai, 2008.)*

# Ocean Tide Modeling

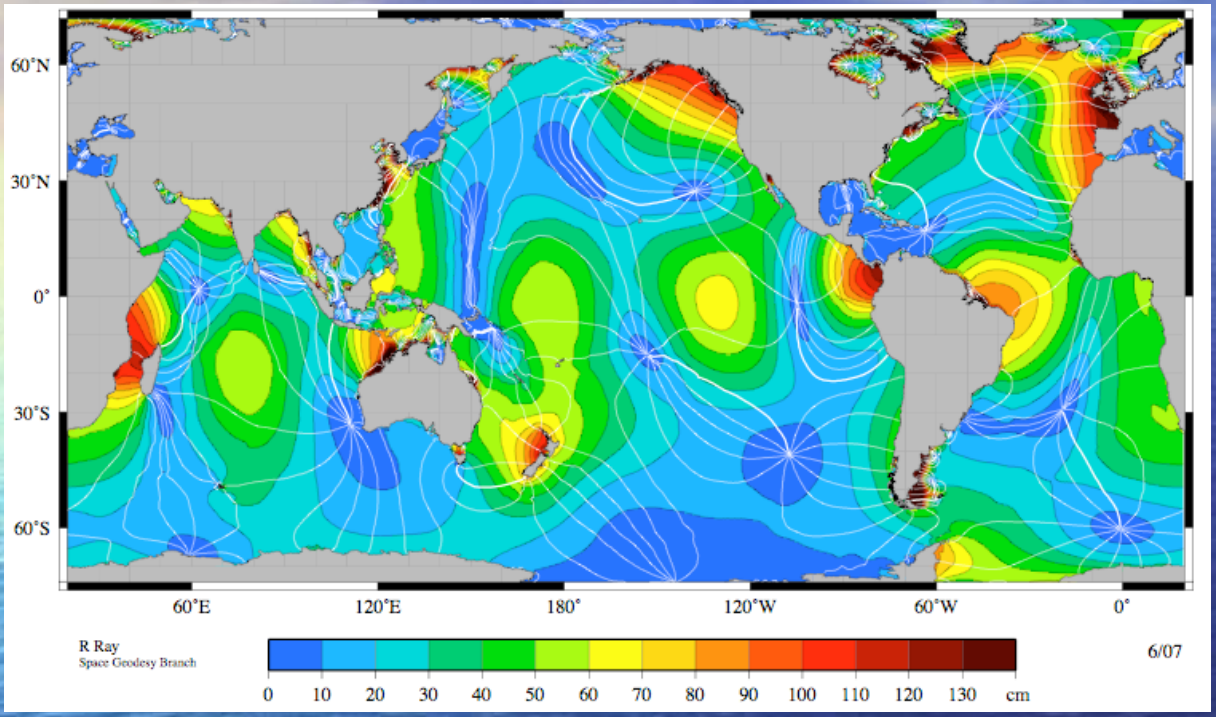



FIGURE: AMPLITUDE AND PHASE OF M2 TIDAL COMPONENT

## Major Tidal Constituents

### Semi-diurnal

$M_2$ principal lunar

$S_2$ principal solar

$N_2$ larger lunar elliptic

$K_2$ luni-solar

### Diurnal

$K_1$ luni-solar

$O_1$ principal lunar

$P_1$ principal solar

$Q_1$ larger lunar elliptic

And recent addition of:

$S_1$ solar diurnal and $M_4$ barotropic

PI Richard Ray (GSFC) developed the recently revised GOT4.7 Ocean Tide Model derived from T/P, Jason-1, ERS and GFO altimetry; a significant improvement over all previous versions (1-2 cm accuracy in the open ocean), especially for the larger coastal tides.

# RMS Differences (cm) with Validation Gauge Data

**Shallow Water**

**Units: cm.**

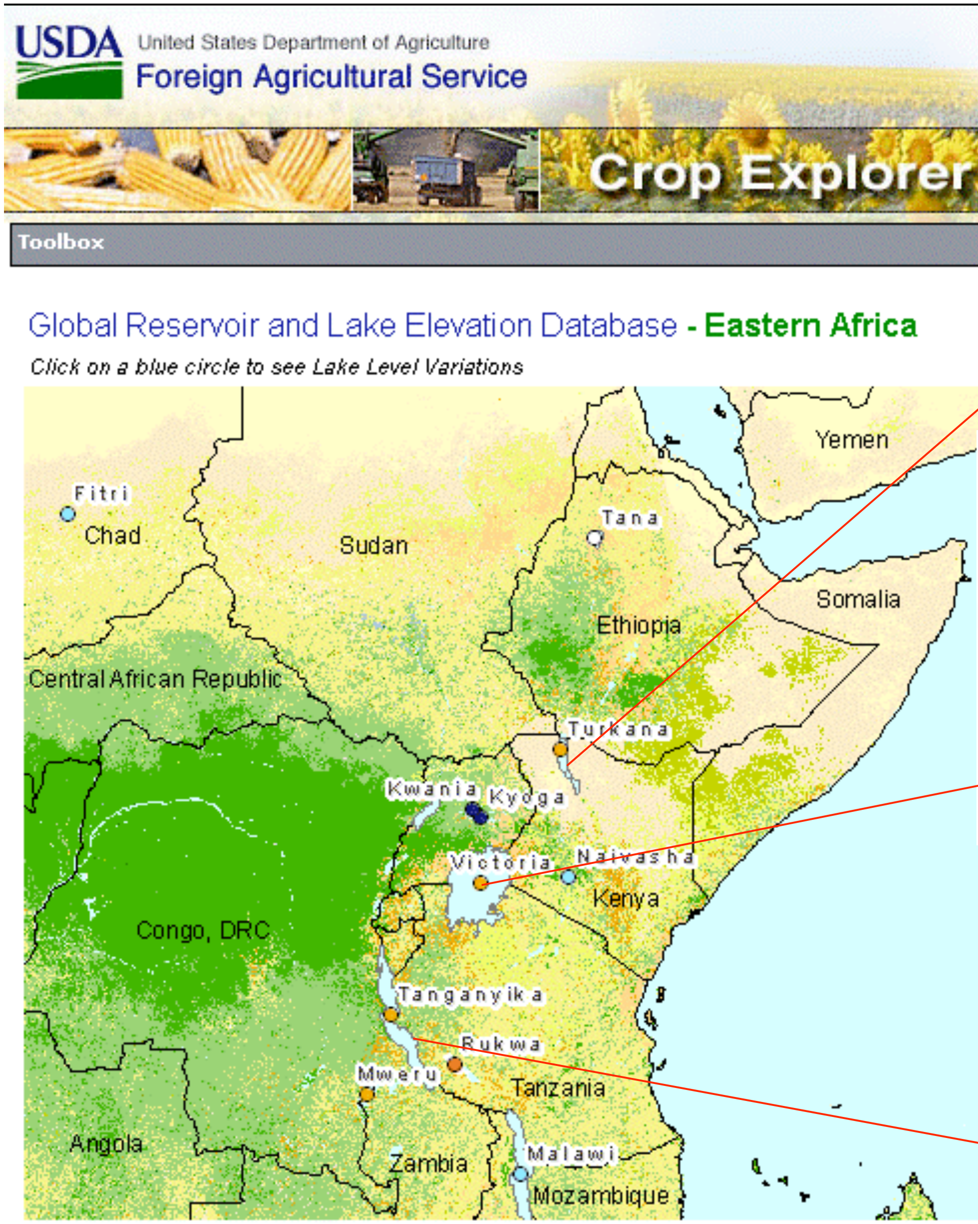
| | Q1 | O1 | P1 | K1 | N2 | M2 | S2 | K2 | M4 | Total RSS |
|---|---|---|---|---|---|---|---|---|---|---|
| GOT00.2 | 0.89 | 1.50 | 0.99 | 2.02 | 2.48 | 7.89 | 5.80 | 2.48 | 3.70 | 11.40 |
| GOT4.1 | 1.03 | 1.48 | 0.99 | 1.86 | 2.17 | 7.25 | 4.14 | 1.78 | 3.70 | 9.95 |
| GOT4.7 | 0.84 | 1.30 | 0.94 | 1.64 | 2.05 | 6.02 | 3.37 | 1.64 | 2.32 | 8.11 |
| FES2002 | 1.06 | 1.44 | 1.04 | 1.96 | 2.80 | 7.70 | 4.89 | 2.19 | 3.70 | 10.85 |
| FES2004 | 0.93 | 1.30 | 1.08 | 1.87 | 2.67 | 7.53 | 4.82 | 2.94 | 4.21 | 10.98 |

***Conclusion:***
**Even in shallow water, simple empirical mapping is competitive with hydrodynamic assimilation. But.....**

***Implication:***
**We need more and denser altimetry in shallow regions.**

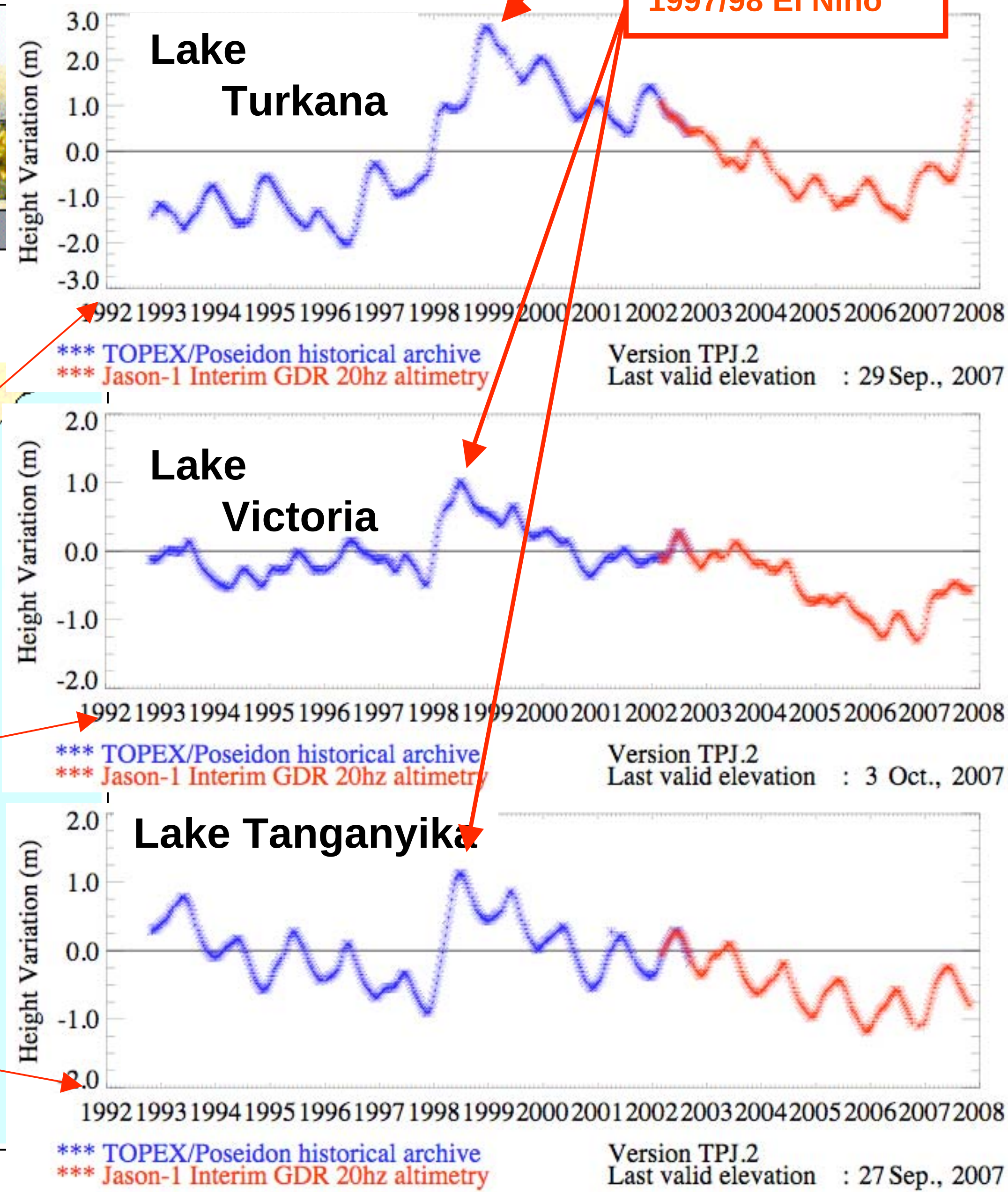
179 Shallow-water sites

# Regional Drought in East Africa




http://www.pecad.fas.usda.gov/
cropexplorer/global_reservoir/

Decrease in lake water levels since 1997/98 El Nino

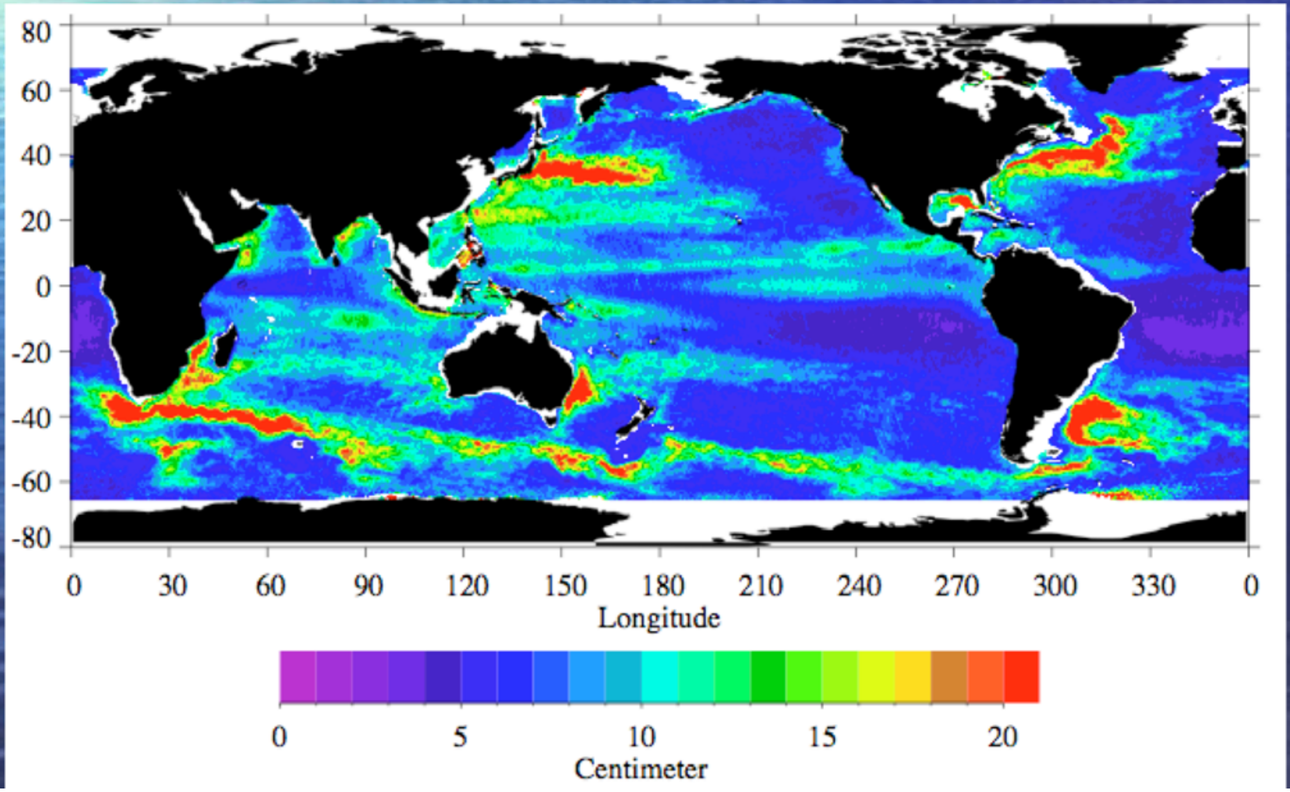


# Data Structure

- Along-track GDR repeat data aligned to nominal 1Hz geo-referenced locations by re-sampling 20Hz (10Hz) data essentially providing a network of nearly ½ million tide gauges.

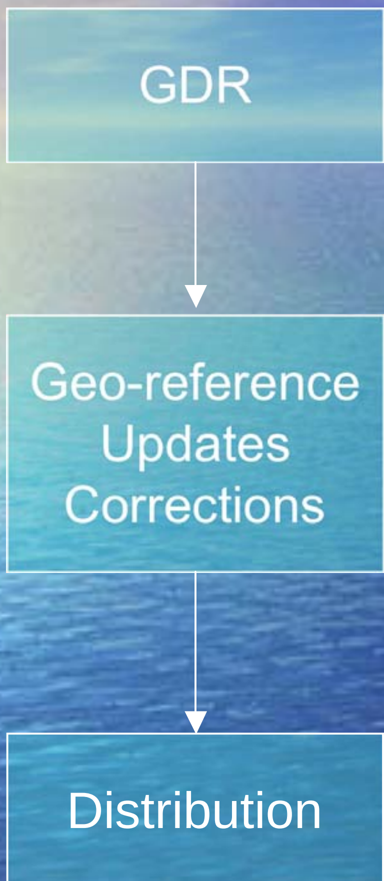
- SSH anomaly product output as direct access binary indexed in 3-dimensions based on orbit revolution, along-track index, and repeat cycle allowing spatial and temporal sampling and updates.

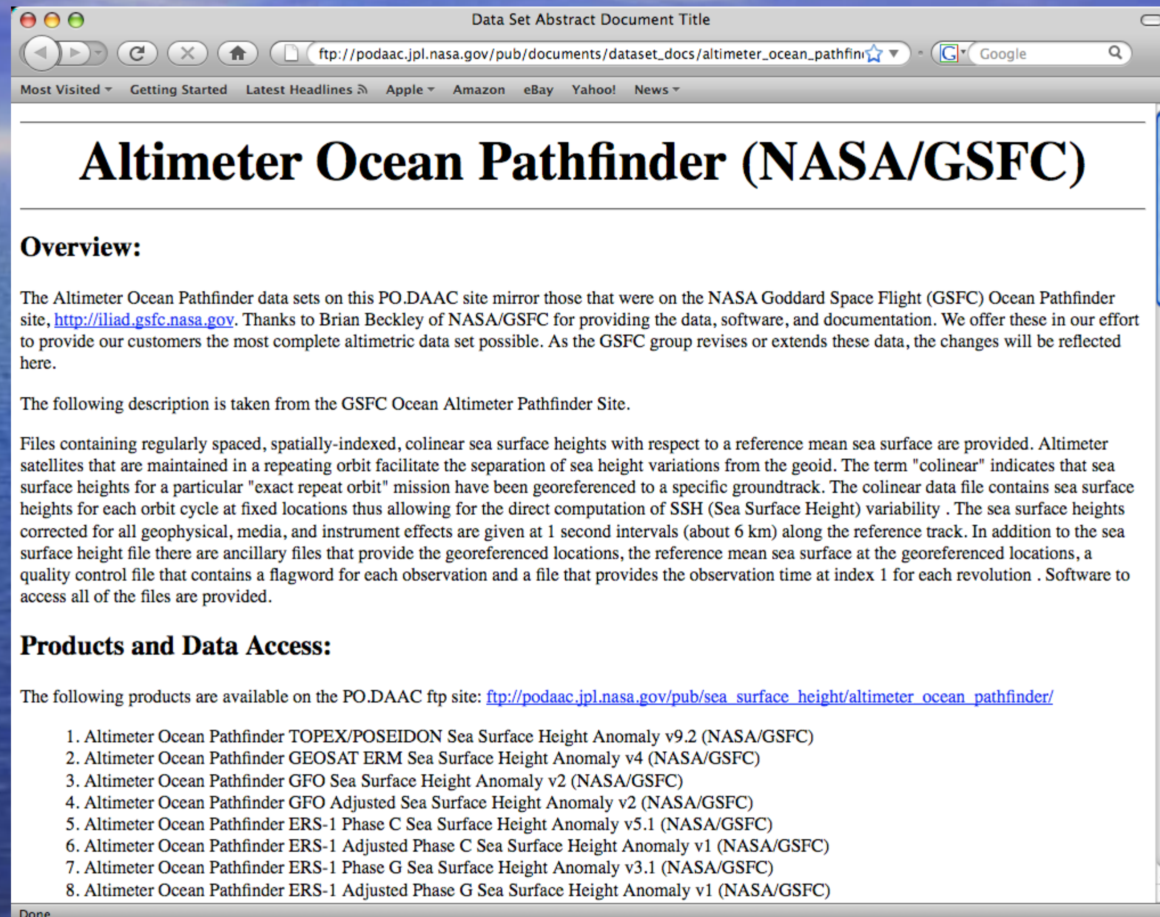
- 3-D structure provides capability for user to readily make revisions to SSH file based on similar structured auxiliary files for individual range or geophysical corrections (i.e. ocean tide model, sea state bias model, inverted barometer, etc.).




High resolution sea surface height variability generated from combined T/P and ERS at geo-referenced locations.

# ALTIMETER OCEAN PATHFINDER LEGACY




# Altimeter Ocean Pathfinder (NASA/GSFC)

## Overview:

The Altimeter Ocean Pathfinder data sets on this PO.DAAC site mirror those that were on the NASA Goddard Space Flight (GSFC) Ocean Pathfinder site, http://iliad.gsfc.nasa.gov. Thanks to Brian Beckley of NASA/GSFC for providing the data, software, and documentation. We offer these in our effort to provide our customers the most complete altimetric data set possible. As the GSFC group revises or extends these data, the changes will be reflected here.

The following description is taken from the GSFC Ocean Altimeter Pathfinder Site.

Files containing regularly spaced, spatially-indexed, colinear sea surface heights with respect to a reference mean sea surface are provided. Altimeter satellites that are maintained in a repeating orbit facilitate the separation of sea height variations from the geoid. The term "colinear" indicates that sea surface heights for a particular "exact repeat orbit" mission have been georeferenced to a specific groundtrack. The colinear data file contains sea surface heights for each orbit cycle at fixed locations thus allowing for the direct computation of SSH (Sea Surface Height) variability . The sea surface heights corrected for all geophysical, media, and instrument effects are given at 1 second intervals (about 6 km) along the reference track. In addition to the sea surface height file there are ancillary files that provide the georeferenced locations, the reference mean sea surface at the georeferenced locations, a quality control file that contains a flagword for each observation and a file that provides the observation time at index 1 for each revolution . Software to access all of the files are provided.

## Products and Data Access:

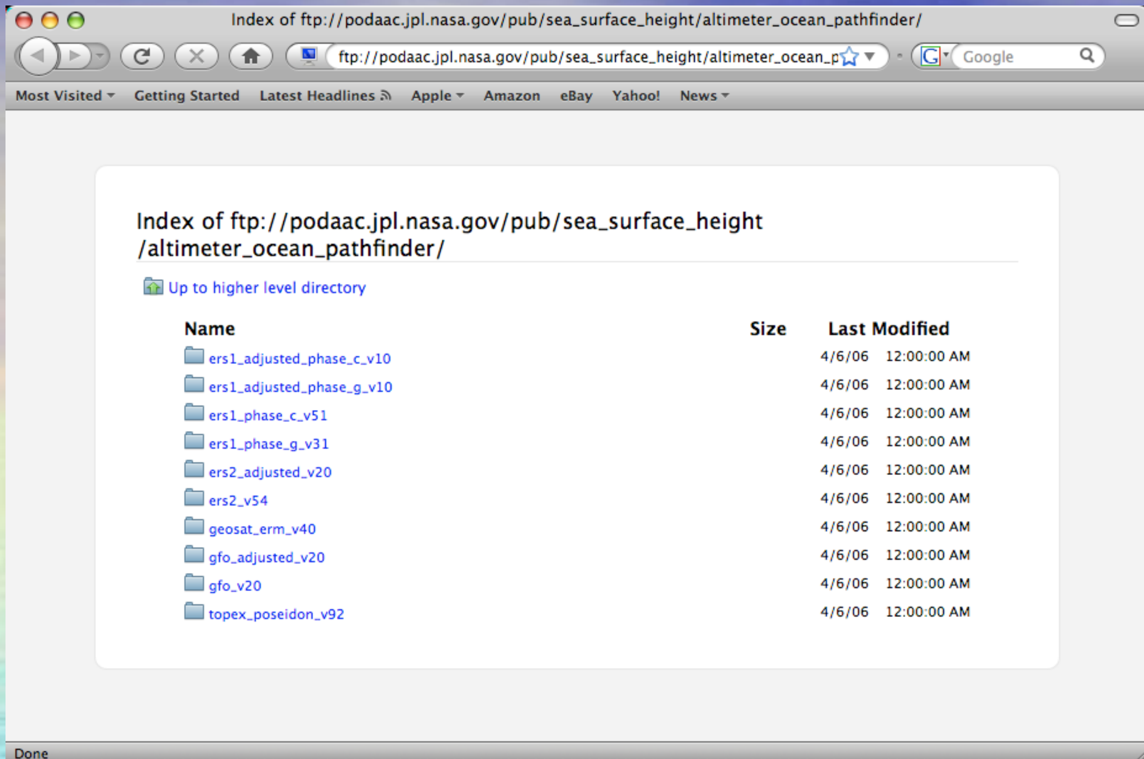
The following products are available on the PO.DAAC ftp site: ftp://podaac.jpl.nasa.gov/pub/sea_surface_height/altimeter_ocean_pathfinder/

1. Altimeter Ocean Pathfinder TOPEX/POSEIDON Sea Surface Height Anomaly v9.2 (NASA/GSFC)
2. Altimeter Ocean Pathfinder GEOSAT ERM Sea Surface Height Anomaly v4 (NASA/GSFC)
3. Altimeter Ocean Pathfinder GFO Sea Surface Height Anomaly v2 (NASA/GSFC)
4. Altimeter Ocean Pathfinder GFO Adjusted Sea Surface Height Anomaly v2 (NASA/GSFC)
5. Altimeter Ocean Pathfinder ERS-1 Phase C Sea Surface Height Anomaly v5.1 (NASA/GSFC)
6. Altimeter Ocean Pathfinder ERS-1 Adjusted Phase C Sea Surface Height Anomaly v1 (NASA/GSFC)
7. Altimeter Ocean Pathfinder ERS-1 Phase G Sea Surface Height Anomaly v3.1 (NASA/GSFC)
8. Altimeter Ocean Pathfinder ERS-1 Adjusted Phase G Sea Surface Height Anomaly v1 (NASA/GSFC)

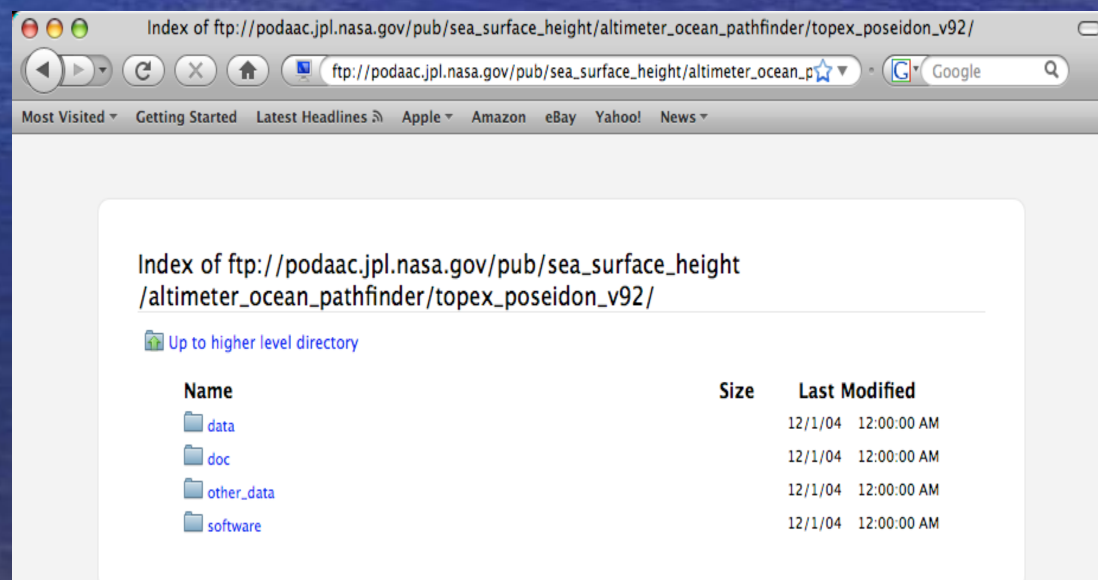
Distribution of Data: Through PO-DAAC JPL (instead of through dedicated server and CDs)

# Example: Topex-POSEIDON

Naming Conventions

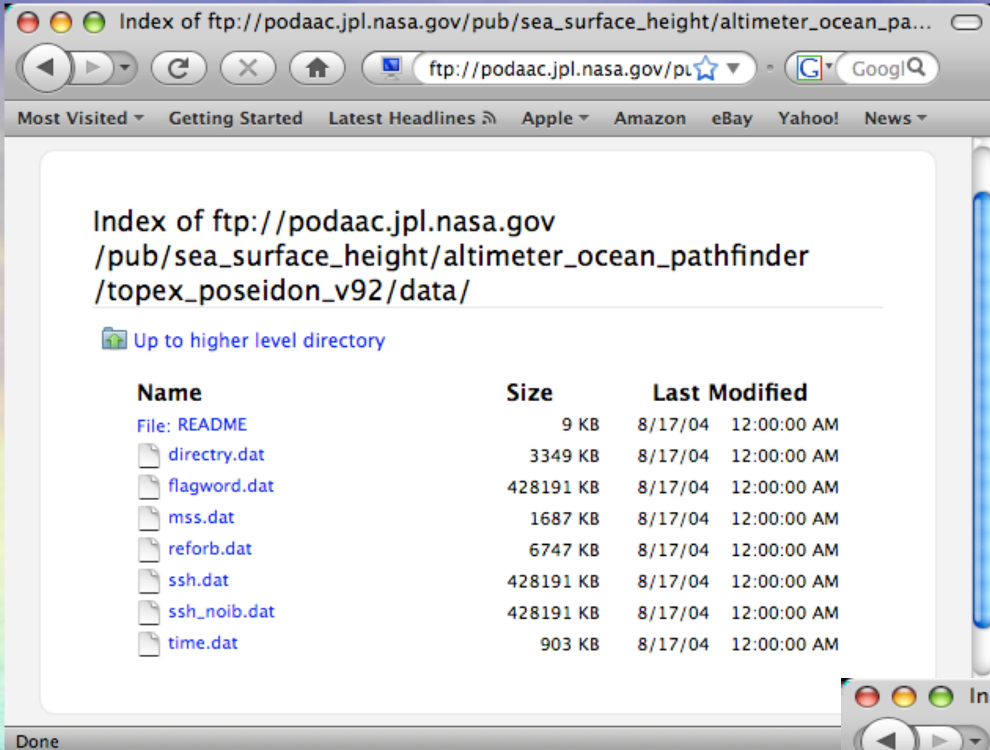



Structure



# Example: Topex-POSEIDON

Data



Index of ftp://podaac.jpl.nasa.gov/pub/sea_surface_height/altimeter_ocean_pathfinder/topex_poseidon_v92/data/

Up to higher level directory

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|---|---|---|---|
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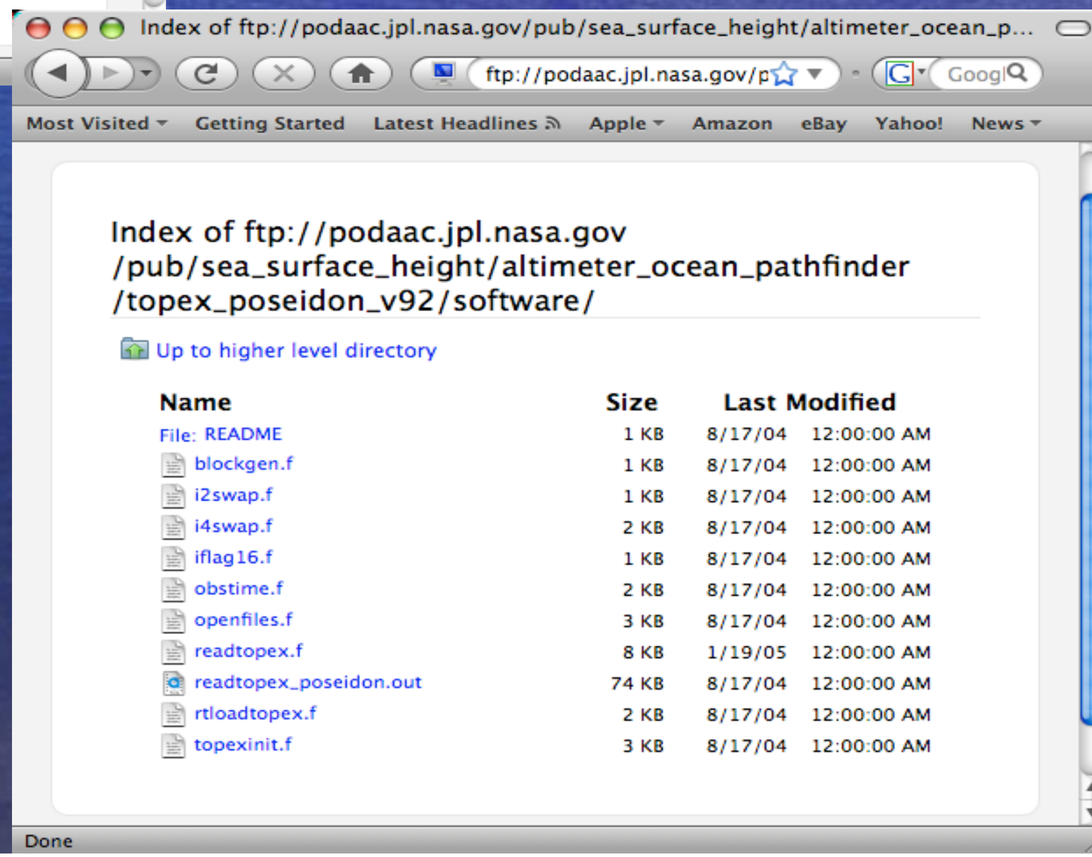
| directry.dat | 3349 KB | 8/17/04 | 12:00:00 AM |
| flagword.dat | 428191 KB | 8/17/04 | 12:00:00 AM |
| mss.dat | 1687 KB | 8/17/04 | 12:00:00 AM |
| reforb.dat | 6747 KB | 8/17/04 | 12:00:00 AM |
| ssh.dat | 428191 KB | 8/17/04 | 12:00:00 AM |
| ssh_noib.dat | 428191 KB | 8/17/04 | 12:00:00 AM |
| time.dat | 903 KB | 8/17/04 | 12:00:00 AM |

Read Software



Index of ftp://podaac.jpl.nasa.gov/pub/sea_surface_height/altimeter_ocean_pathfinder/topex_poseidon_v92/software/

Up to higher level directory

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| i4swap.f | 2 KB | 8/17/04 | 12:00:00 AM |
| iflag16.f | 1 KB | 8/17/04 | 12:00:00 AM |
| obstime.f | 2 KB | 8/17/04 | 12:00:00 AM |
| openfiles.f | 3 KB | 8/17/04 | 12:00:00 AM |
| readtopex.f | 8 KB | 1/19/05 | 12:00:00 AM |
| readtopex_poseidon.out | 74 KB | 8/17/04 | 12:00:00 AM |
| rtloadtopex.f | 2 KB | 8/17/04 | 12:00:00 AM |
| topexinit.f | 3 KB | 8/17/04 | 12:00:00 AM |

# FUTURE: Transition to NetCDF

Advantages:

- Self Describing Format
- Efficient Data Model - Datasets are not too big
- Variety of Tools available
- Appendable

Divided in to four sections:

- Variable Definitions and Dimensions
- Details: Source GDR, Reprocessing Procedures
- Data
- Process Updates

# Variable Dimensions and Definitions

- Processed Date and Time (YYYYMMDDHHMISS)
- Reference Date and Time
- Number of Cycles (N_CYCLE)
- Number of Orbits/ Cycle (N_TRACK)
- Number of Points/ Orbit (N_POS)
- Geo-referenced Positions (LAT, LON)
- Number of Data Fields and Array Definitions (Mean Sea Surface, IB etc.)
- Flags

# Details

- Satellite/ Source GDR/ Release Information
- Terrestrial Reference Frame (with references)
- Orbits (with references)
- Inverted Barometer Correction
- Sea State Bias
- Tides
- Radiometer Correction
- Flag Definitions
- Atmospheric Corrections

# Data

- Time
- Mean Sea Surface
- SSH
- Inverted Barometer Correction or SSH with no IB
- Sea State Bias
- Tidal Correction
- Radiometer Correction
- Flag Values
- Atmospheric Corrections

# Process Updates

Version Control

- History of Updates (Dates)
- History of individual updates
  - Sea State Bias
  - Tidal Correction
  - Radiometer Correction
  - Flag Values
  - Atmospheric Corrections
- Full/ Partial Mission Information