Poster #12

Seasonal Global Mean Sea Level Change From Altimetry, GRACE, and Geophysical Models

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Objectives

- **Global Mean Sea Level Change from Satellite Altimeter(s)**
  - Steric Contribution
  - Mass conservation of ocean pole tide correction
- **Global Mean Sea Level Change from Water Mass Balance**
  - Terrestrial water storage change
  - Atmospheric water vapor
- **Global Mean Sea Level Change from GRACE** (Gravity Recovery And Climate Experiment)
  - Time-variable gravity change
  - Geocenter variation from satellite laser ranging (SLR)
  - Degree-2 harmonics from Earth rotation (EOP) and SLR

About Sea Level Change

- **Observed sea level change can be introduced by many geophysical processes, including**
  - **Steric effects – temperature and salinity changes;**
  - **Water mass redistributions (glaciers, ice sheets, land, atmosphere, …) ;**
  - **Deformation of the Earth crust (post glacial rebound, …);**
  - **Other minor effects (sediment deposition, permafrost, …);**

- **Additional contributions to satellite altimeter observed sea level change**
  - **Reference frame (geocenter motion, …);**
  - **Geophysical corrections, e.g., inverted barometer (IB), mass conservation in ocean pole tide (OPT) correction, and etc.;**
  - **Instrument errors;**

About Sea Level Change (Cont.)

- **Long–Term Sea level Change**
  - Thermal expansion;
  - Glacial, ice sheet melting, land, atmosphere;
  - Post glacial rebound (PGR);
- **Seasonal Sea Level Change**
  - Thermal expansion;
  - Terrestrial water storage;
  - Atmospheric water vapor;
  - Others

Data and Processing

- **Satellite Radar Altimeter Sea Level Measurements**
  - AVISO merged mean sea level anomaly
  - TOPEX/Poseidon, Jason-1, ERS-1/2, Envisat
  - October 1992 to August 2004, 7-day intervals
  - 1/3° x 1/3° Mercator grids, only data from 65° S to 65° N are included.
- **World Ocean Atlas 2001 (WOA01)**
  - Climatologies of temperature and salinity fields
  - 1° x 1° grids, 24 layers (0 – 1500 m depth)
  - Data from 65° S to 65° N are included

Data and Processing (cont.)

- **Terrestrial Water Storage**
  - NASA Global Land Data Assimilation System (GLDAS)
  - Soil moisture and snow, 3–hourly, Jan. 2001 – Dec. 2004, 1° x 1° grids
- **Atmospheric Water Vapor**
  - NCEP Reanalysis Surface Pressure data
  - Daily, Jan. 1993 – Aug. 2004 (same as altimeter data)
  - Gaussian grids (~ 1.904° x 1.875°)

Data and Processing (cont.)

- **GRACE Time-Variable Gravity Observations**
  - **22 monthly solutions (April/May 2002 through to July 2004).**
  - **Spherical harmonics up to degree and order 120x120.**
  - **Ocean tide, solid Earth tide, solid earth pole tide (rotational deformation), and long-term ΔC_{20} (or ΔJ_2) are modeled and removed.**
  - **Ocean pole tide (OPT) is not applied.**
  - **Atmospheric and oceanic dealiasing (AOD) is applied.**

Data and Processing (cont.)

- **Special notes on GRACE data over the oceans**
  - **Ocean pole tide (OPT) does not change the total volume/mass of the oceans. Therefore, not applying OPT correction does not affect GRACE estimated total oceanic mass change.**
  - **The barotropic ocean general circulation model used in AOD conserves mass. Therefore, applying AOD does not affect GRACE estimated total oceanic mass change either.**
  - **Geocenter motions, i.e., degree-1 harmonics are not not measured by GRACE, but do have non-negligible effects on GRACE estimated mass change.**
  - **GRACE measured degree-2 terms (e.g. C20 and C21) are not accurate at the moment.**
  - **GRACE high degree harmonics are dominated by noise.**

Data and Processing (cont.)

- **Oceanic mass change from GRACE**
  - **Truncation ad degree and order 60**
  - **Gaussian smoothing of 400 km**
  - **Case 1: GRACE ΔC20 is excluded.**
  - **Case 2: GRACE ΔC20 is included.**
  - **Case 3: GRACE ΔC20 is included, plus geocenter motion from SLR.**
  - **Case 4: EOP/SLR estimated ΔC20, ΔC21, ΔS21 are adopted, plus geocenter motion from SLR (seasonal fit only).**

Equivalent global mean sea level (GMSL) changes are computed in these 4 cases.

Results

- **Seasonal Sea Level Change (Apr 2002 – Jul 2004)**
  - AVISO merged altimeter MSLA
  - WOA01 steric effect
  - OPT mass conservation (OPT MC)
- **Water Mass Balance**
  - GLDAS terrestrial water storage
  - NCEP water vapor
- **GRACE Observations**
  - Cases 1, 2, 3, 4

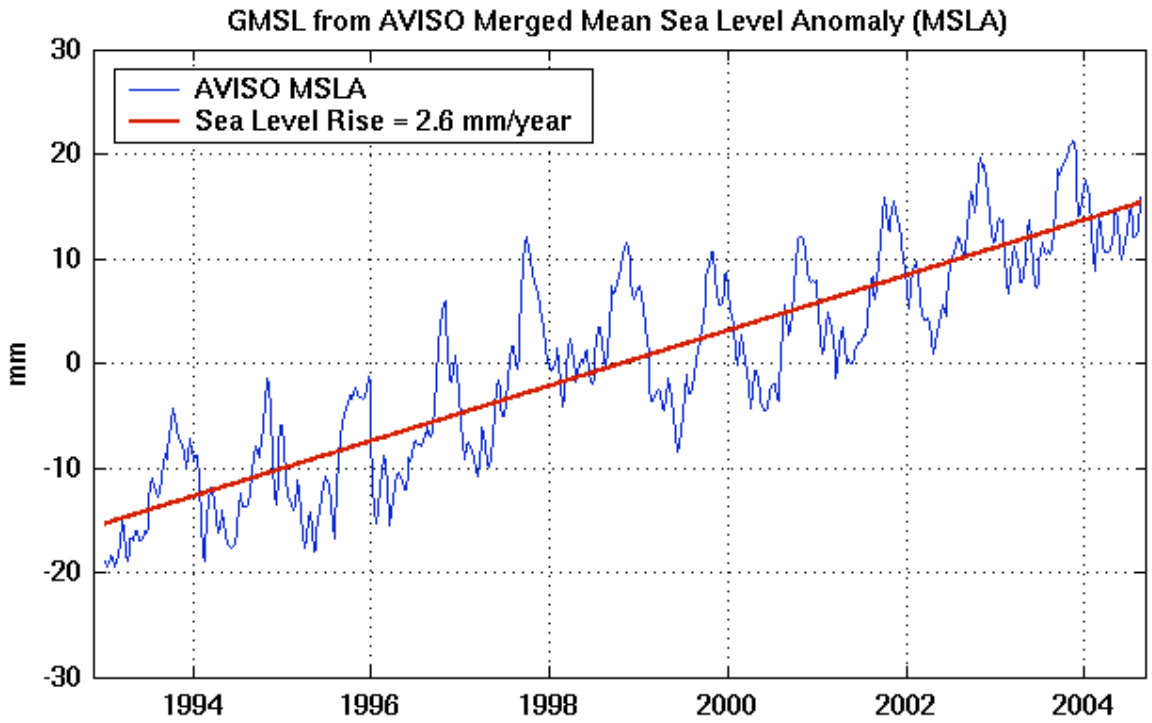

Figure 1. Global mean sea level change (GMSL) estimated from AVISO merged satellite altimeter sea level anomaly data during 1993 to 2004. The 'long-term' sea level rise (red line) of 2.6 mm/year is estimated from least squares fit.

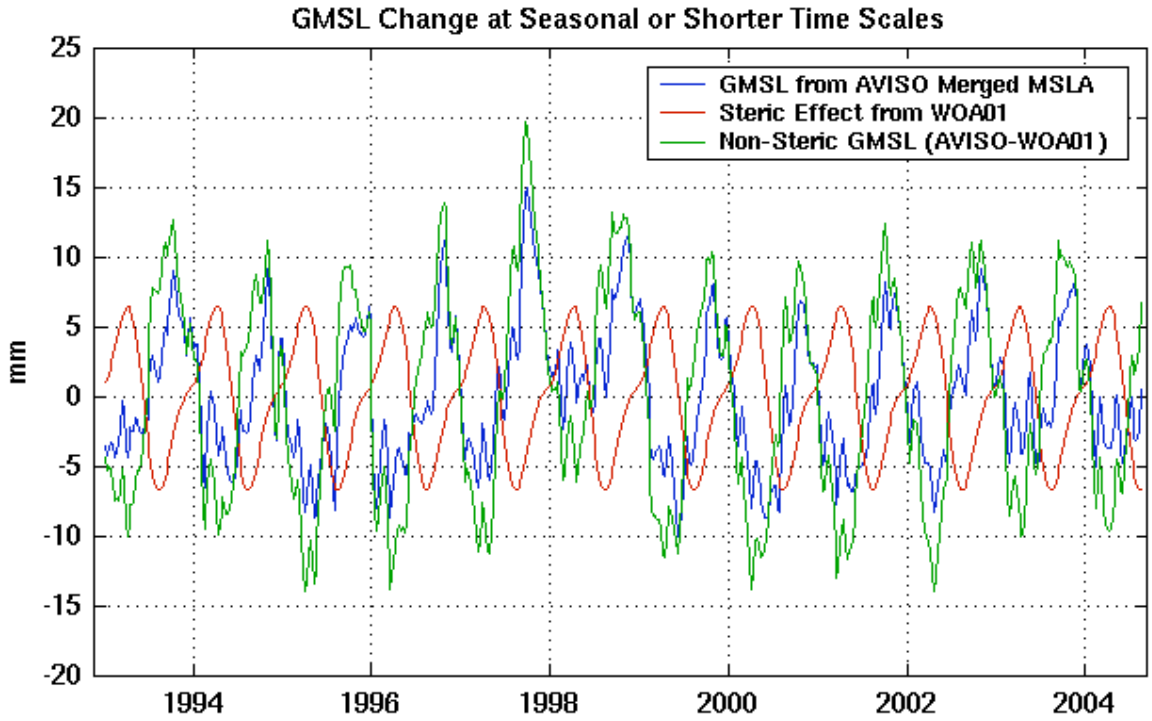

Figure 2. Comparison of global mean sea level changes (GMSL) at seasonal or shorter periods from altimetry (AVISO merged), steric effects (WOA01), and non-steric GMSL change (AVISO - WOA01).

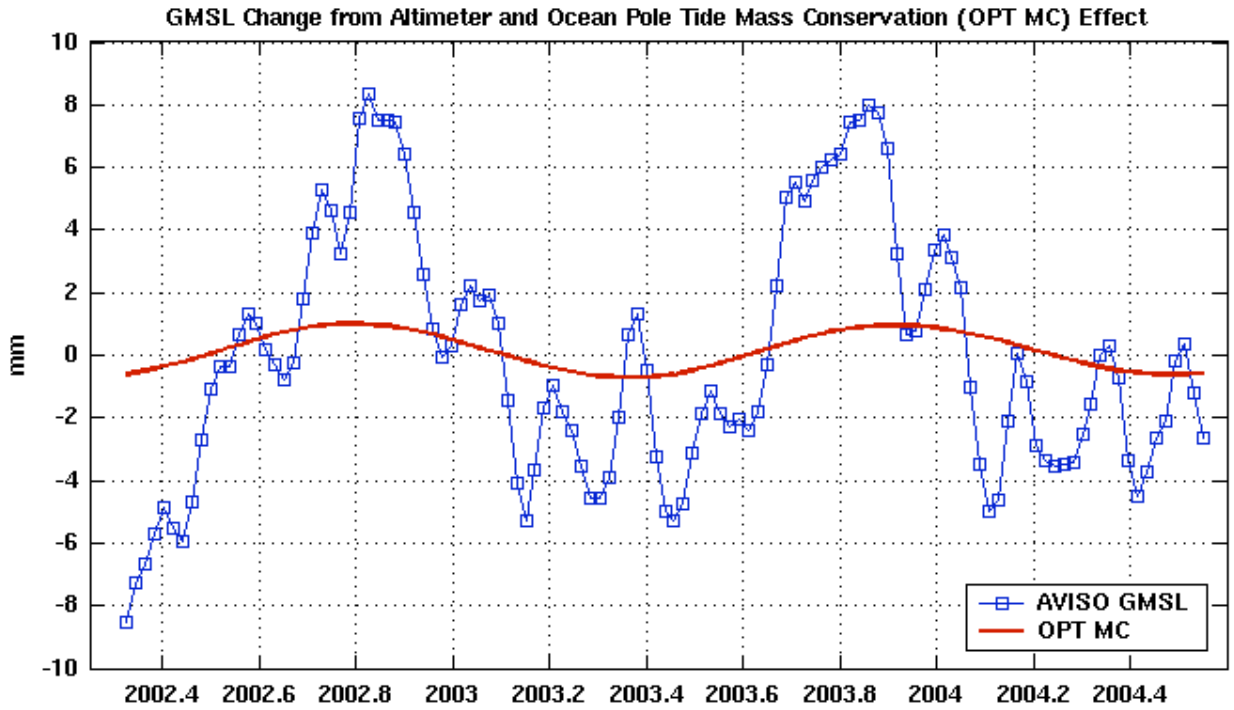

Figure 3. Non-negligible effects on global mean sea level changes (GMSL) from non-conservation of mass in the ocean pole tide (OPT) model used in altimeter data. This artificial change (red curve) should be removed from altimeter results.

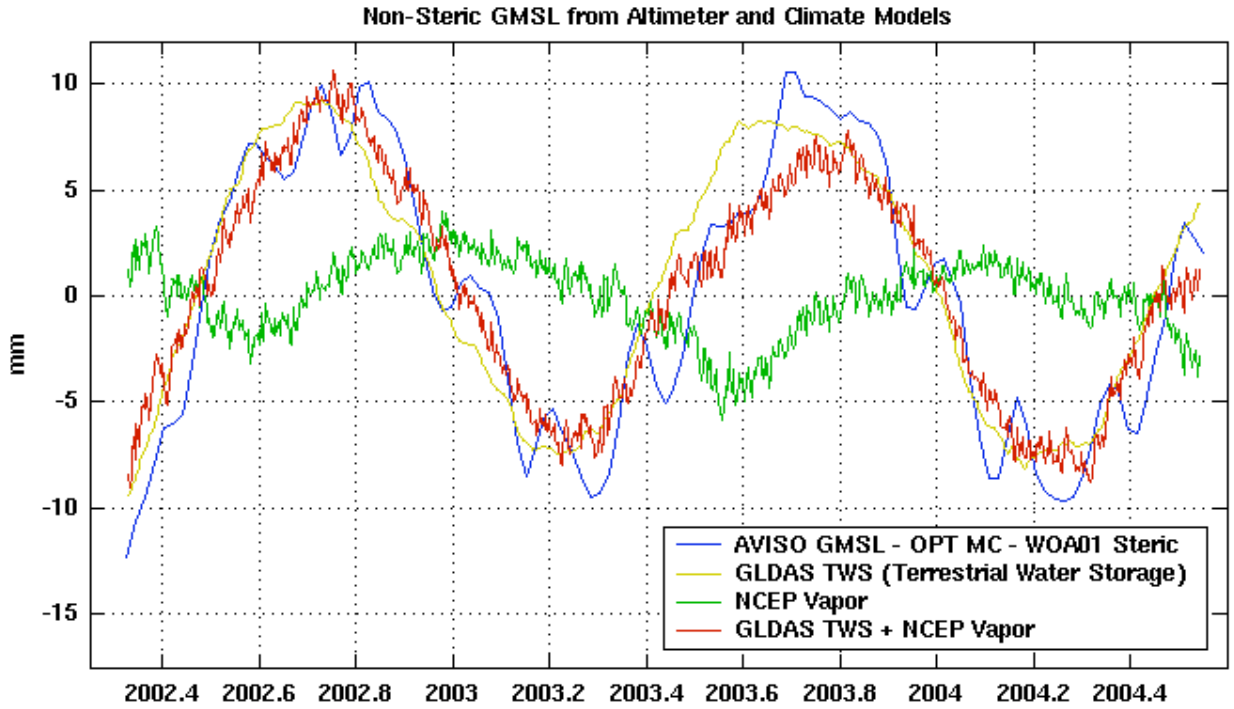

Figure 4. Comparison of non-steric GMSL changes from altimetry (AVISO - OPT - WOA01), model estimated terrestrial water effects on GMSL (GLDAS), and model estimated atmospheric water vapor effects on GMSL (NCEP).

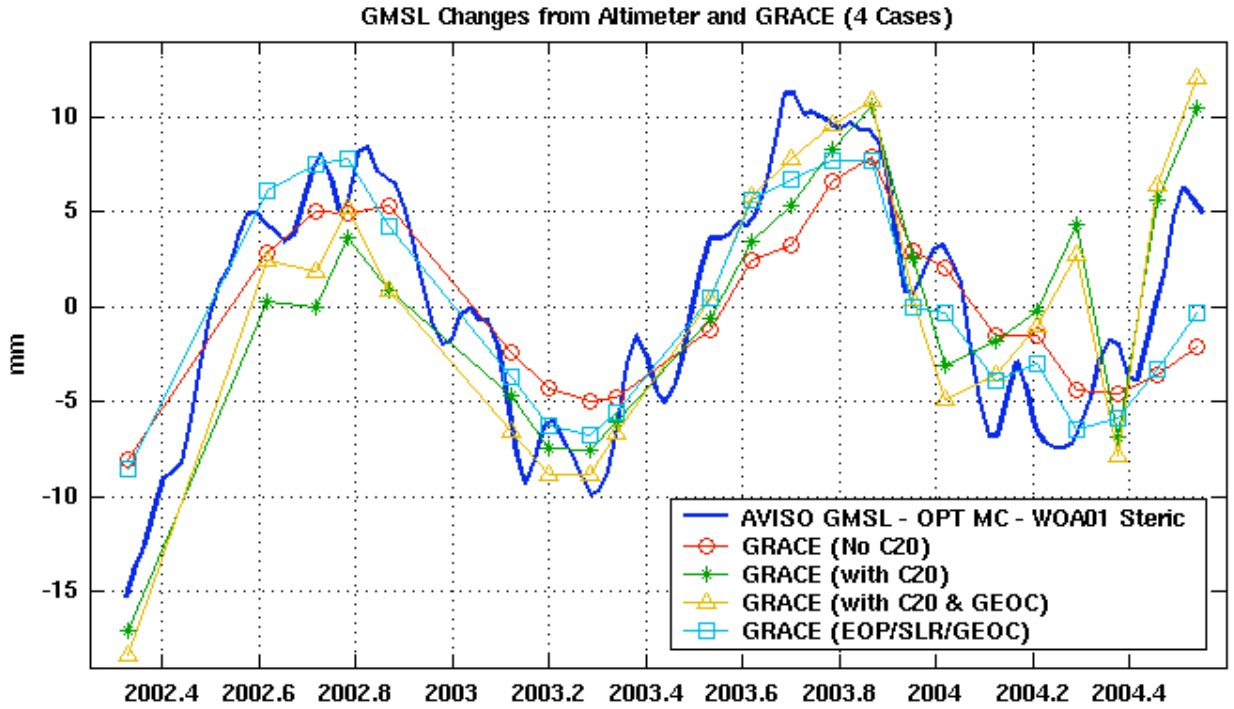

Figure 5. Comparison of non-steric GMSL changes from altimetry (AVISO - OPT - WOA01), and GRACE estimates with different treatments of low-degree spherical harmonic change.

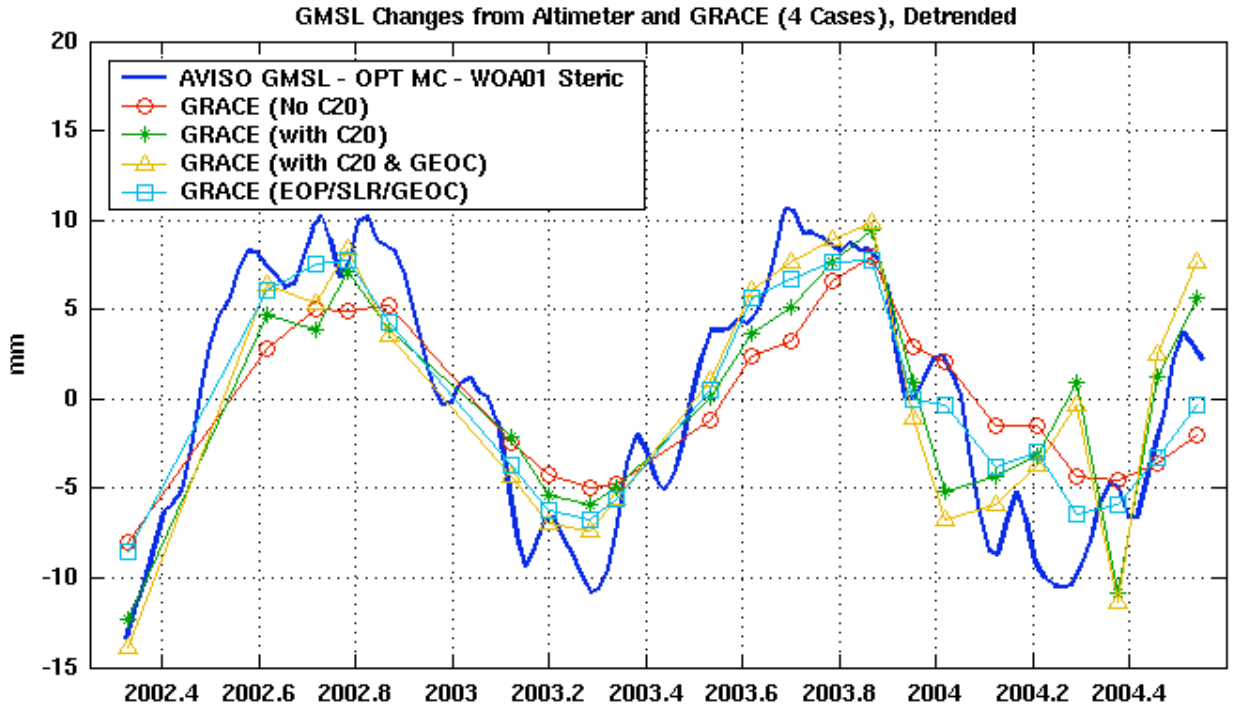

Figure 6. Comparison of non-steric GMSL changes from altimetry (AVISO - OPT - WOA01), and GRACE estimates with different treatments of low-degree spherical harmonic change. Time series are detrended.

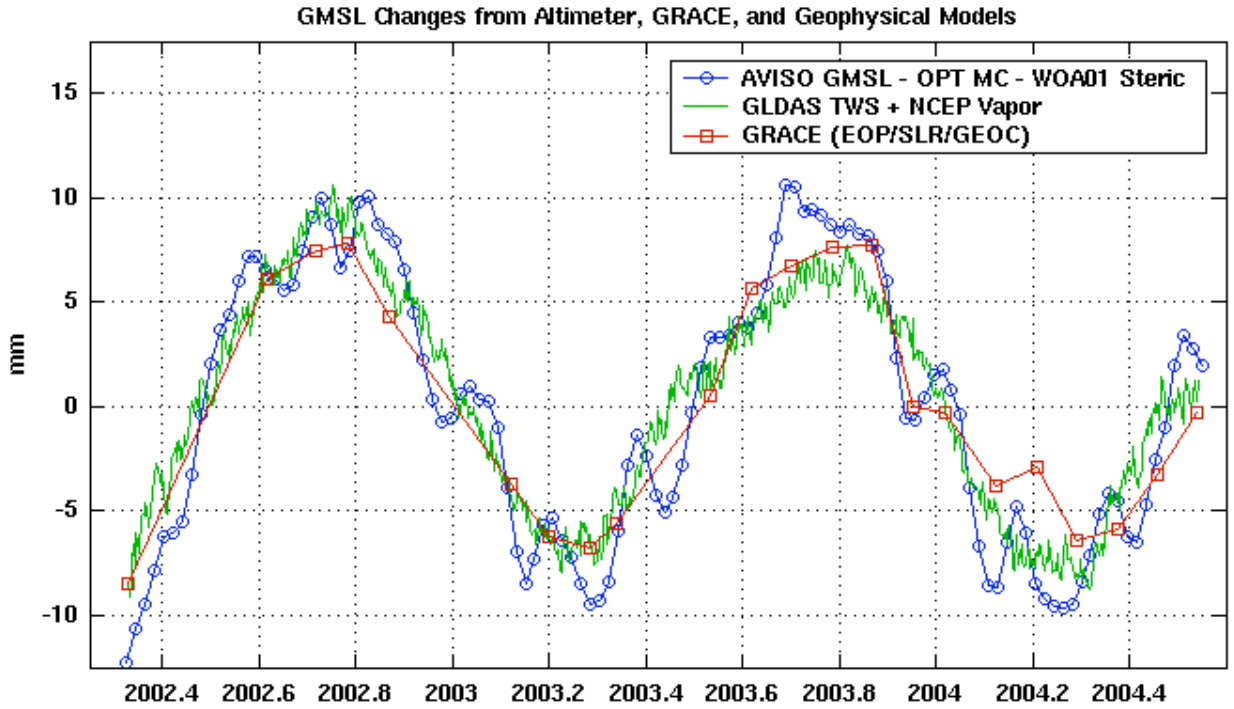

Figure 7. Three independent estimates of non-steric GMSL changes from satellite altimetry (AVISO - OPT - WOA01), GRACE time-variable gravity, and geophysical model prediction (GLDAS + NCEP).

Table 1. Amplitude and phase of annual and semiannual global mean sea level changes during April 2002 and July 2004 estimated from altimeter (AVISO merged), steric effects (WOA01), ocean pole tide (OPT) mass conservation effects, global water mass balance, and GRACE (GRC) time-variable gravity. The phase is defined as ϕ in $\sin(2\pi(t - t_0) + \phi)$, where t_0 refers to h^0 on January 1.

GMSL Change	Annual		Semiannual	
	Amplitude (mm)	Phase (deg)	Amplitude (mm)	Phase (deg)
GMSL (AVISO)	4.89	152	1.34	212
OPT Mass Conservation (OPT MC)	0.82	133	0.08	297
GMSL (AVISO/OPT MC)	4.18	154	1.36	210
Steric GMSL (WOA01)	5.30	18	1.70	206
Non-steric GMSL (AVISO-WOA01)	9.38	176	0.39	4
Non-steric GMSL (AVISO/OPT-WOA01)	8.81	179	0.36	12
Non-steric GMSL (Chambers)	8.50	188	N/A	N/A
GLDAS TWS	8.33	192	0.61	54
NCEP Vapor	2.09	63	0.66	185
TWS + Vapor	7.17	180	0.53	125
GRACE (no C20)	5.85	154	0.64	276
GRACE (with C20)	6.77	179	1.51	286
GRACE (with C20 & GEOC)	8.47	188	2.07	293
GRACE (EOP/SLR/GEOC)	7.22	174	1.44	303
GRACE (+GEOC, Chambers)	8.60	175	N/A	N/A
GRACE (+GEOC, Chambers) (OPT MC)	8.00	179	N/A	N/A

Main Conclusions

- Seasonal sea level changes estimated from satellite altimeter(s), geophysical models, and GRACE show remarkably good agreement during the period Apr 2002 to Jul 2004.
- The non-conservation of mass in ocean pole tide correction applied in current altimeter data has non-negligible effects on seasonal global mean sea level change.
- GLDAS shows significantly better agreement with altimeter observations than previous estimates based on other hydrological models.
- Geocenter and degree-2 gravitational changes have significant impacts on GRACE estimated total oceanic mass change.

Additional Notes

- **This research was supported by NASA's Solid Earth and Natural Hazards, GRACE, and NIP Programs (under grants NNG04GF10G, NNG04GF22G, NNG04G060G, NNG04GP70G) .**

- **Results presented here are being published in**

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Thanks !