Sea level rise as viewed in the SODA ocean reanalysis and the warming of the oceans

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Recent altimeter observations have indicated an increase in the rate of sea level rise during the past decade to 3.1 mm/yr, well above centennial estimates of 1.5-2 mm/yr. This apparent increase raises possibilities of enhanced recent melting of continental ice. The alternative explanation invokes decadal changes in thermo- and halo-steric effects as suggested by *Cabanes et al.* [2001] and *Cazenave and Nerem* [2004]. *Miller and Douglas* [2003] argue that inhomogeneities in observations may affect the conclusions. The new SODA1.2 ocean reanalysis for the period 1958-2001 is used to distinguish the steric and eustatic components of sea level rise. The applicability of this reanalysis is evaluated by comparison of subseasonal variability with a collection of 20 tide gauge station sea level records, comprising a total of 736 years of data. A positive relationship is found at all gauge stations, with an average correlation of 0.67 after correction for the inverted barometer effect.

During the 9-year period of 1993-2001 the 0/1000m dynamic height increases at a global rate of 2.3±1 mm/yr, a substantial acceleration beyond the multi-decadal steric rate of 0.5 mm/yr. The increase in the thermosteric contribution to sea level rise as well as the striking correspondence of the spatial structure to that derived from the altimeter data does explain the recent increase in the rate of sea level rise by the thermosteric effect.

SODA 1.2 Ocean Reanalysis

- Parallel Ocean Program POP1.3 numerics on global displaced-pole grid (1/4°x40L)
- ECMWF ERA-40 reanalysis winds
- Global Precipitation Climatology Project monthly rainfall
- UNESCO river discharge

Data:

- 7x10^6 profiles, including World Ocean Database 2001 {**no altimetry**}
- AVHRR, buoy, and intake SST

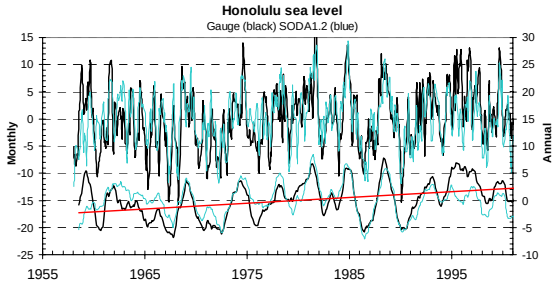


Fig.1 Monthly and annually averaged sea level at Honolulu (19.8°N, 205.0°E). Gauge data after correction for inverted barometer effects is shown in black, SODA1.2 in blue. Linear trend for the gauge record (red) has a slope of 0.96mm/yr.

Table: Comparison of annually averaged tide gauge and SODA1.2 sea level. Honolulu is shown in Fig. 1.

Station Name	Location		Time	yrs	DH Corr	s.l. corr	$\frac{\sigma_{SODA}}{\sigma_{Gauge}}$
Auckland	36.9S	174.8E	1959-98	40		0.49	1.2
Lyttleton[3]	44.4S	171.3E	1958-87	30	0.21	0.44	1.0
Pago Pago	14.4S	189.4E	1958-99	39	0.74	0.83	0.7
Rabaul	4.3S	152.3E	1975-97	34	0.97	0.96	1.1
Christmas[1]	2.1N	203.0E	1974-99	23	0.95	0.95	0.8
Kwajalein	8.8N	167.8E	1958-99	43	0.79	0.77	1.4
Balboa[1]	9.1N	280.5E	1958-86	29	0.79	0.76	1.2
Quepos	9.5N	275.9E	1958-94	36	0.68	0.70	0.7
Johnston	16.8N	191.0E	1958-98	40	0.65	0.63	1.3
Hilo	19.8N	205.0E	1958-98	43	0.56	0.61	1.0
Honolulu	21.4N	202.2E	1958-98	43	0.71	0.77	0.9
Naha	26.2N	127.7E	1967-99	33	0.87	0.87	1.4
San Francisco	37.8N	122.5W	1958-01	44	0.66	0.81	0.6
Sitka	57.1N	135.3W	1958-99	42	0.55	0.75	1.3
Fremantle	32.1S	115.7E	1958-00	41	0.62	0.84	0.8
Tenerife[2]	28.5N	16.3W	1958-89	33	0.25	0.27	1.1
St. Georges	32.4N	64.7W	1958-98	37	0.48	0.66	0.9
Brest	48.4N	4.5W	1958-99	42	0.26	0.70	0.6
Reykjavik[2]	64.2N	21.9W	1958-83	24	0.24	0.50	0.8
Argentine Islands	65.3S	64.3W	1960-99	40	-0.26	0.22	0.5
				37		0.68	1.0

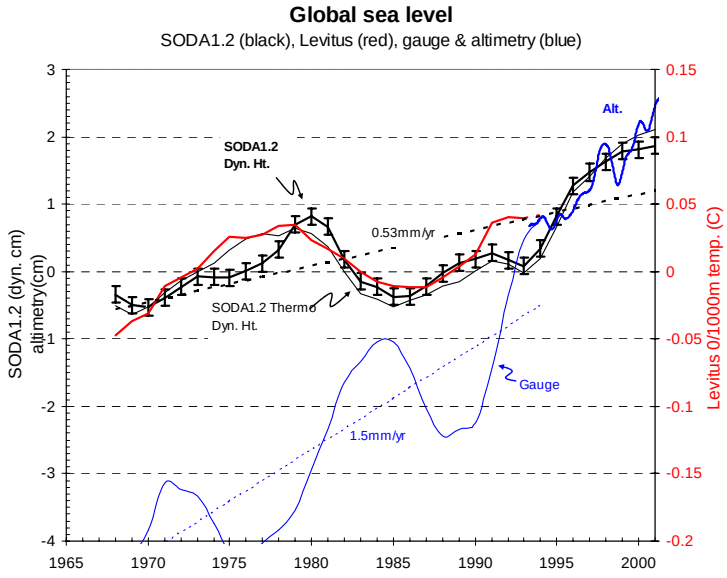


Fig. 2 Global sea level 1968-2001 showing the gauge (see *Cabanes et al.* 2001) and altimeter sea level as well as *Levitus [2000]* and SODA1.2 steric estimates.

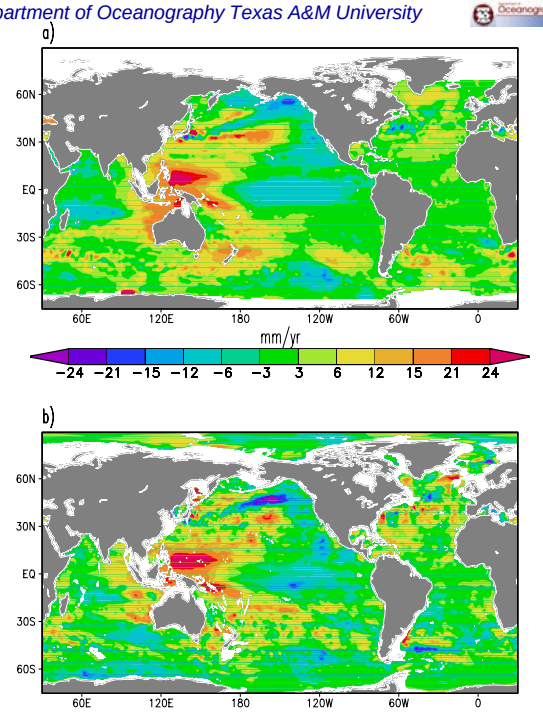
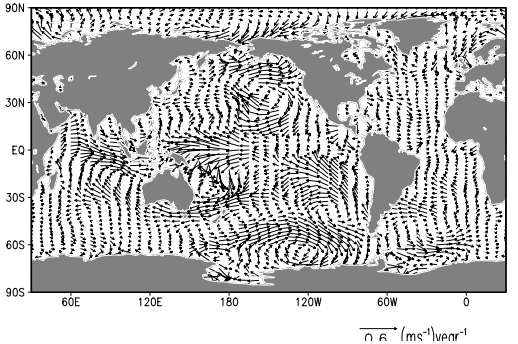


Fig. 3 Linear trends during 1993-2001. a) Topex/Poseidon sea level, b) SODA1.2 0/1000 m dynamic height in dyn-mm/yr.



GrADS: CO **Fig. 4** Linear trend in ERA40 surface wind velocity 1993-2001 showing changes in the trade winds consistent with the redistribution of heat in the tropics and midlatitudes.

~Conclusions~

1) SODA1.2 reanalysis:

>Relative to a previous generation of the SODA ocean reanalysis, SODA1.2 comparison with tide gauge sea level has improved average correlation from 0.44 to 0.70. The average correlation of annual average sea level at the complete 20-gauge set in **Table** above is 0.67.

2) Steric contribution to sea level rise:

>For the 34-year period 1968-2001 is 0.5 dyn-mm/yr, in line with previous estimates.

>Salinity effect on global sea level is small.

3) Recent changes in sea level rise:

>Steric component has increased 1.8 dyn-mm/yr from 0.5 to 2.3 dyn-mm/yr since 1993 likely explaining the increase in the rate of sea level rise.

>Spatial patterns of the altimeter sea level rise and the steric component are similar with the most notable increases in the western tropical Pacific.

>Requires an imbalance of net heat flux of 1.8 Wm^{-2} averaged over the ocean surface. The Earth's radiation budget at the top of the atmosphere has been examined during these years by *Wielicki et al (2002).* Their results suggest a decrease in tropical albedo due to a reduction in low level clouds in the 1990s which leads to a net increase in surface heating of a couple of Wm^{-2} {but the tiny size of the imbalance puts it on the edge of detection}.

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