



**CAUSES
OF
SEA LEVEL CHANGE
?**

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LEGOS-CNES

SWT JASON, Arles, November 2003

- **STERIC** sea level change : change in **Water Density**



Temperature

Salinity

- **EUSTATIC** sea level change: change in **Ocean Mass**



**Water mass exchange with
continental reservoirs, mountain glaciers
and ice sheets**

**STERIC
SEA LEVEL RISE
(Thermal Expansion)**

World Ocean Temperature Data Bases

**‘ Global ’ time series of ocean temperature data
at different depths:**

1. Levitus et al. (2000)

0-500 m : global yearly grids for 1945-1998

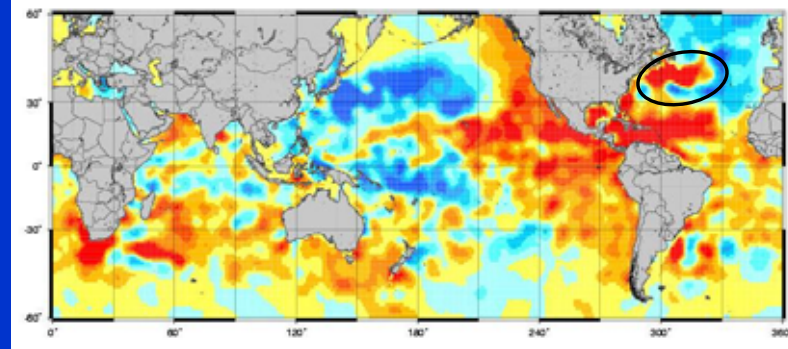
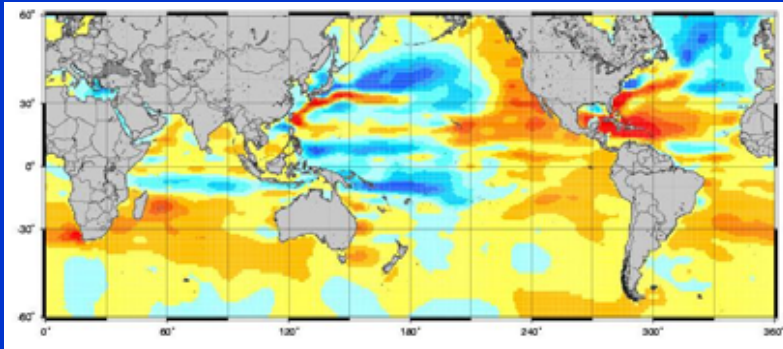
0-3000 m : global 5-year grids for 1945-1995

2. Ishii et al. (2003)

0-500 m : global monthly grids for 1945-1998

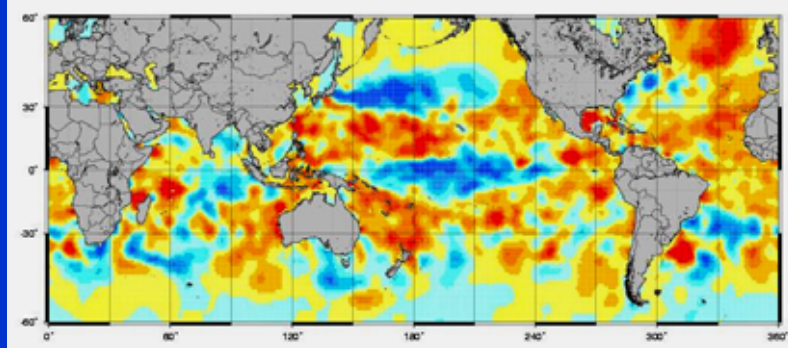
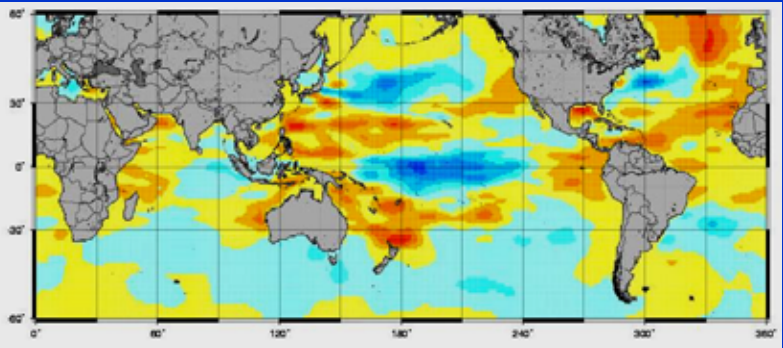
**3. In situ hydrographic profiles from various sources
(WOCE, ARGO, etc.) since 1993**

Steric Sea Level Trends (1950-1990) (0-500 m)



Ishii et al., 2003

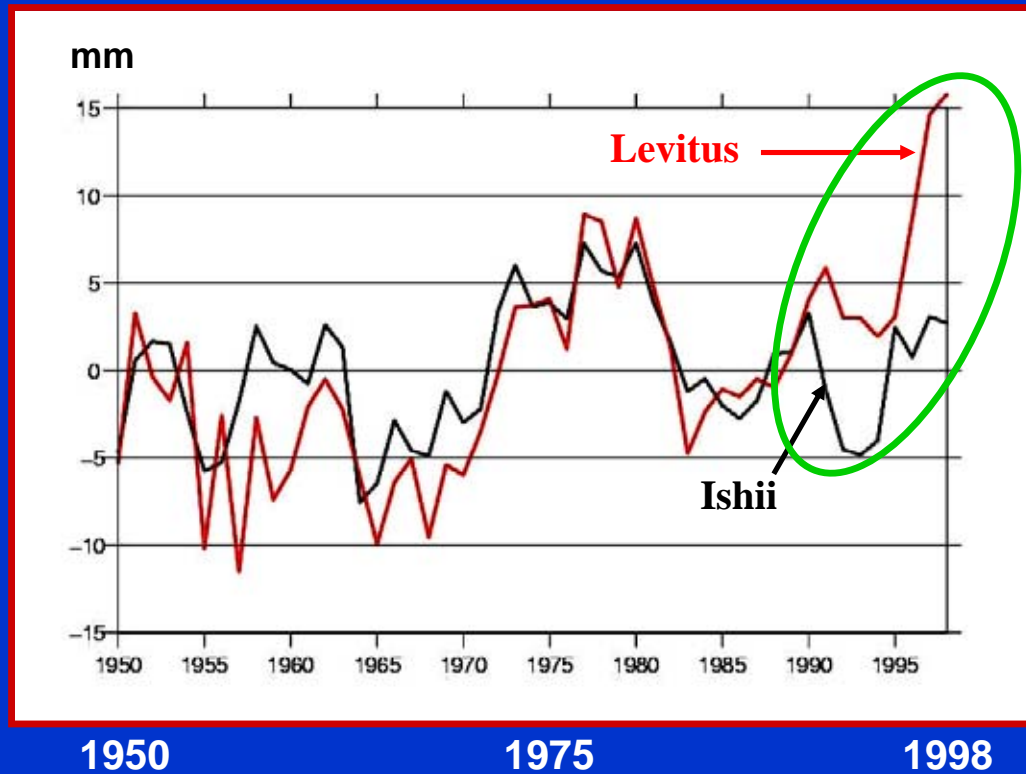
Levitus et al., 2000

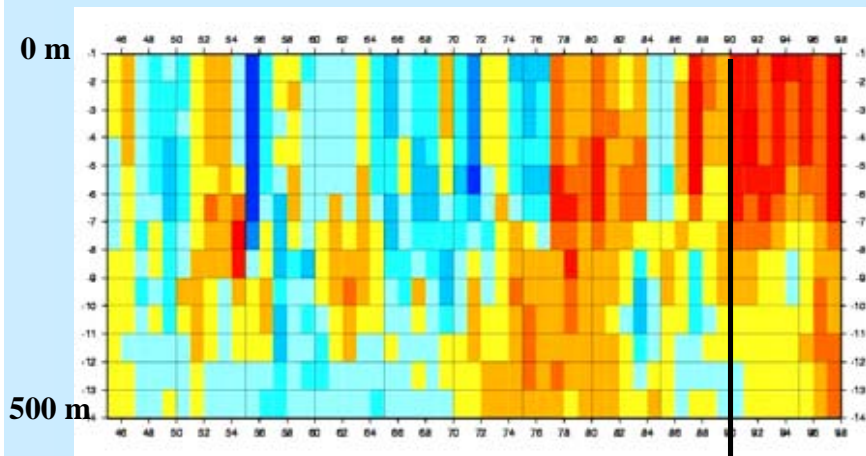


(1990-1998) (0-500 m)

Lombard et al., 2003

Thermosteric Sea Level Curve





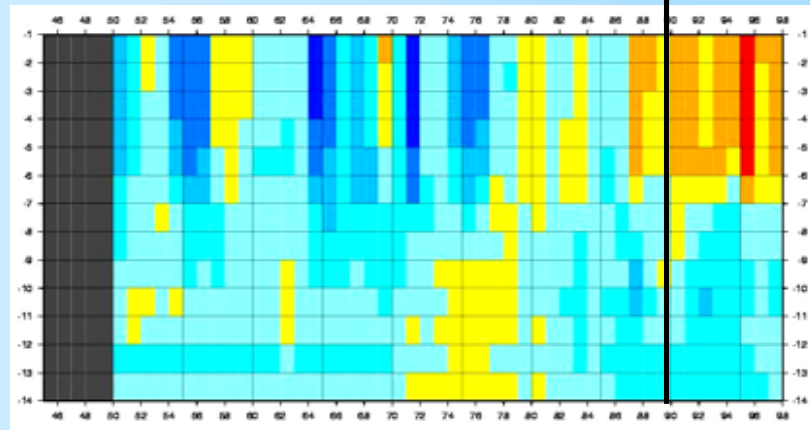
1950

1998

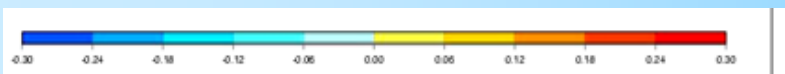
Levitus



**DEPTH-TIME
diagram
of
TEMPERATURE**

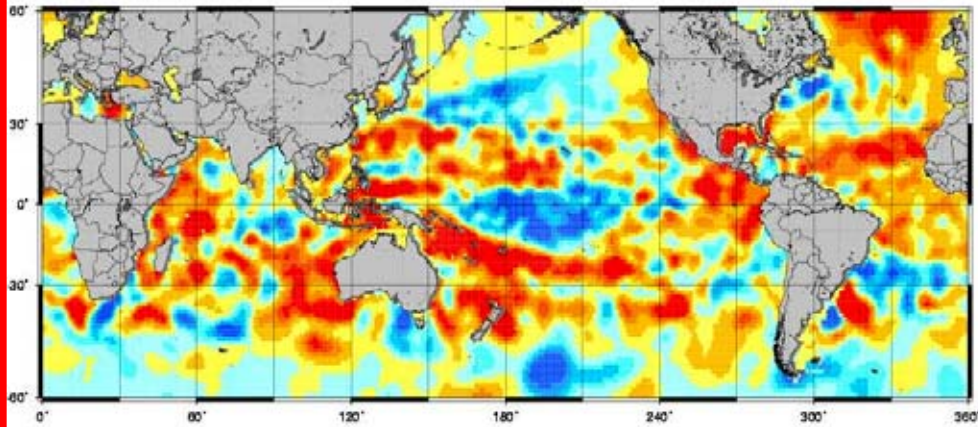


Ishii

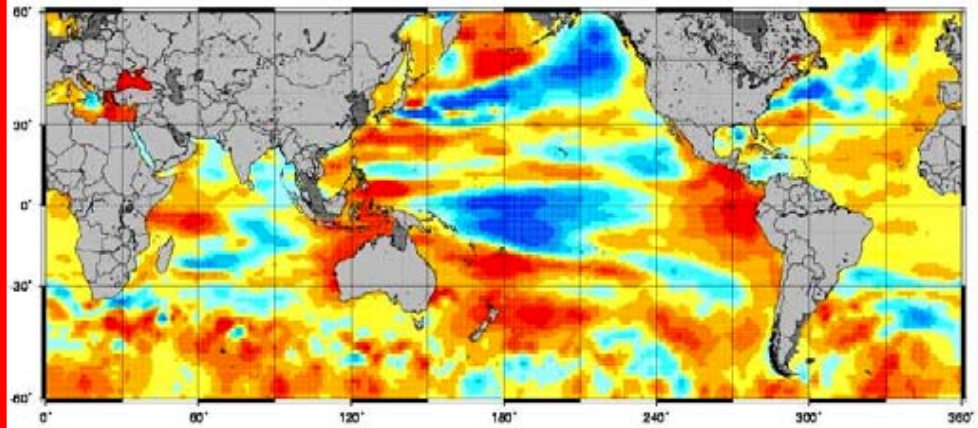


-0.3°C

+0.3°C



← Thermosteric
sea level trends
(1993-1998)
based on Levitus
data



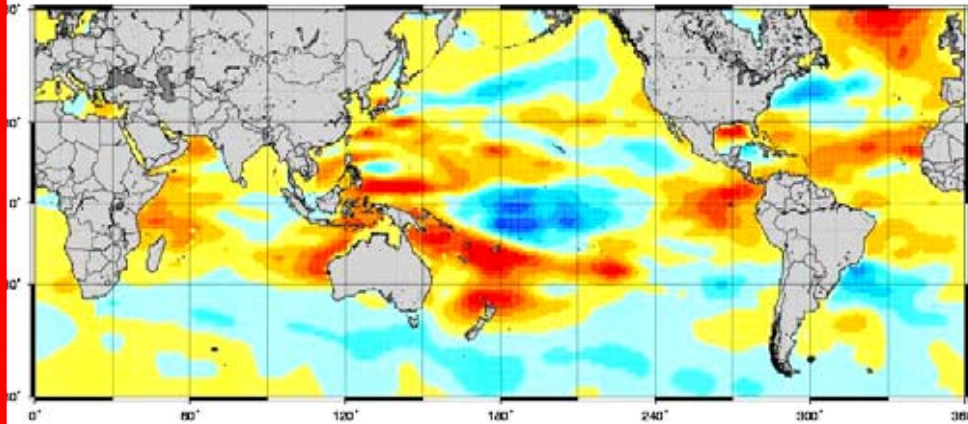
← Sea level trends
(1993-1998)
from
Topex/Poseidon



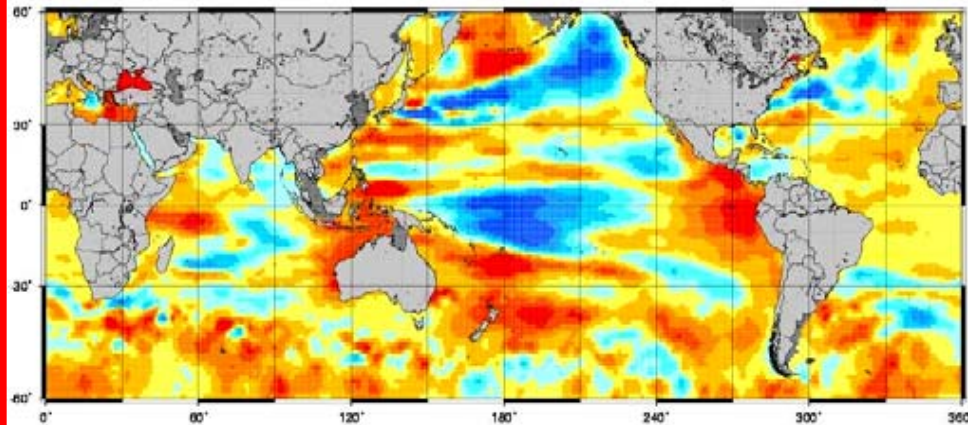
-20 mm/yr

+20 mm/yr

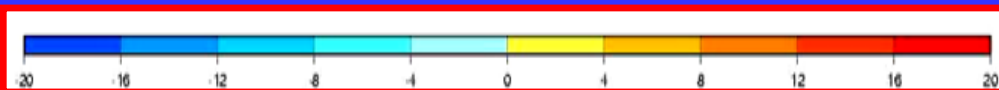
Lombard et al., 2003



← Thermosteric
sea level trends
(1993-1998)
based on Ishii data

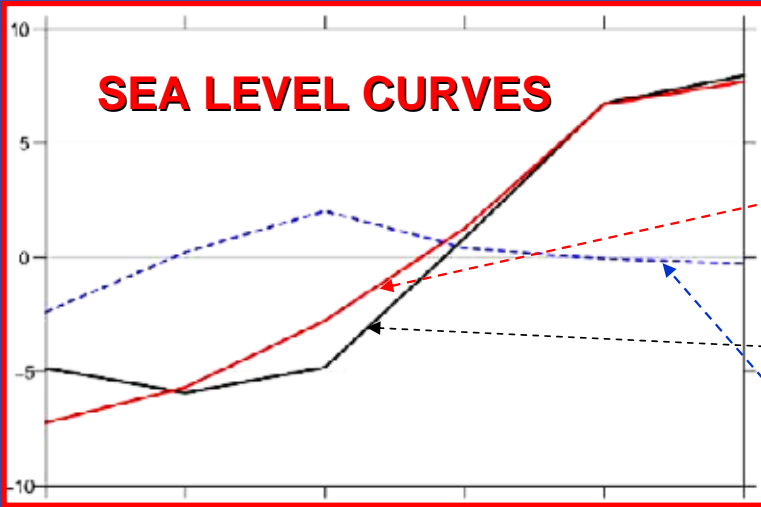


← Sea level trends
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-20 mm/yr

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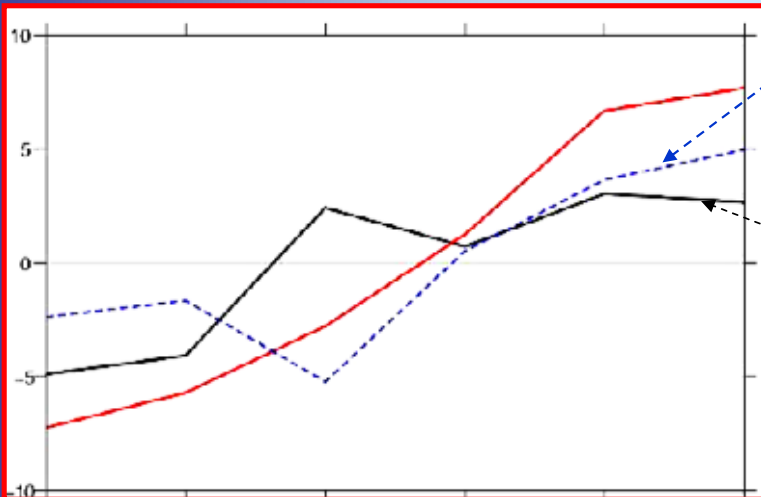
1993

1998

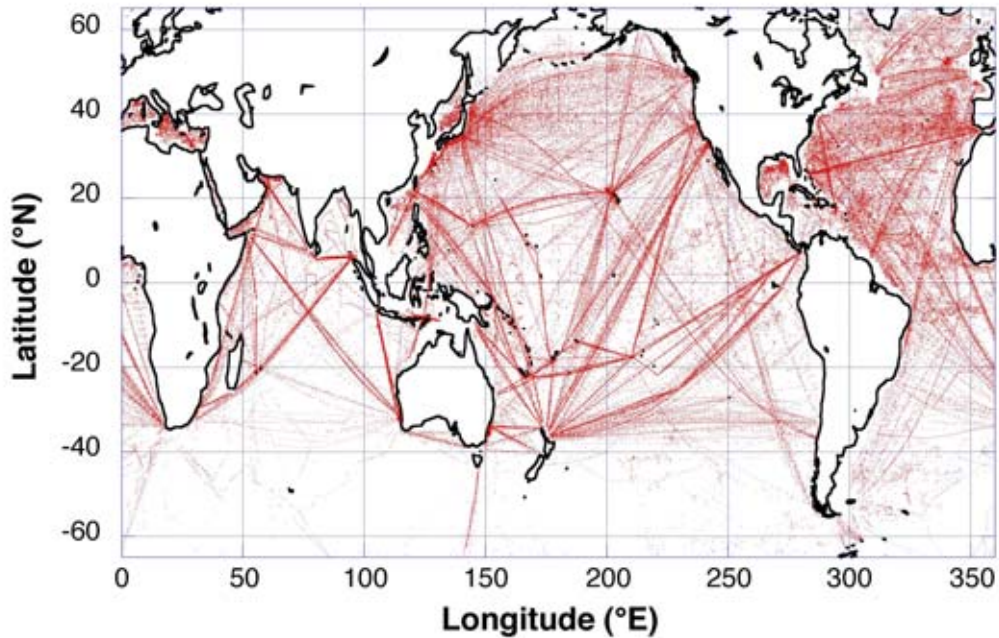
TOPEX (3.15 +/- 0.4 mm/yr)

LEVITUS (3.1 +/- 0.6 mm/yr)

RESIDUAL



ISHII (1.7 +/- 0.45 mm/yr)

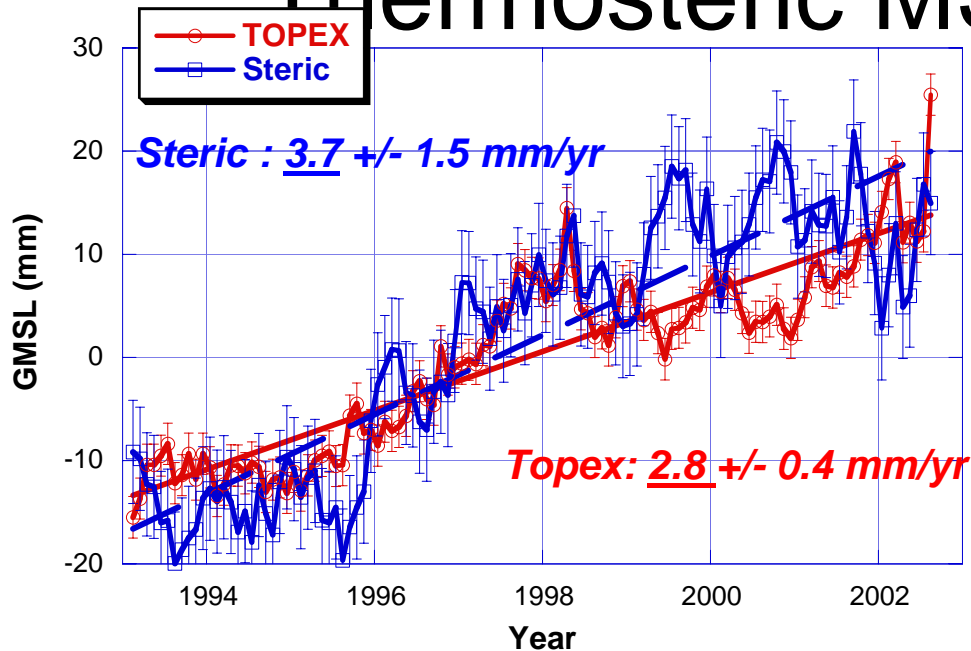


Coverage of in situ profiles (1993-2002)

From D. Chambers

From Don CHAMBERS (Univ. TEXAS)

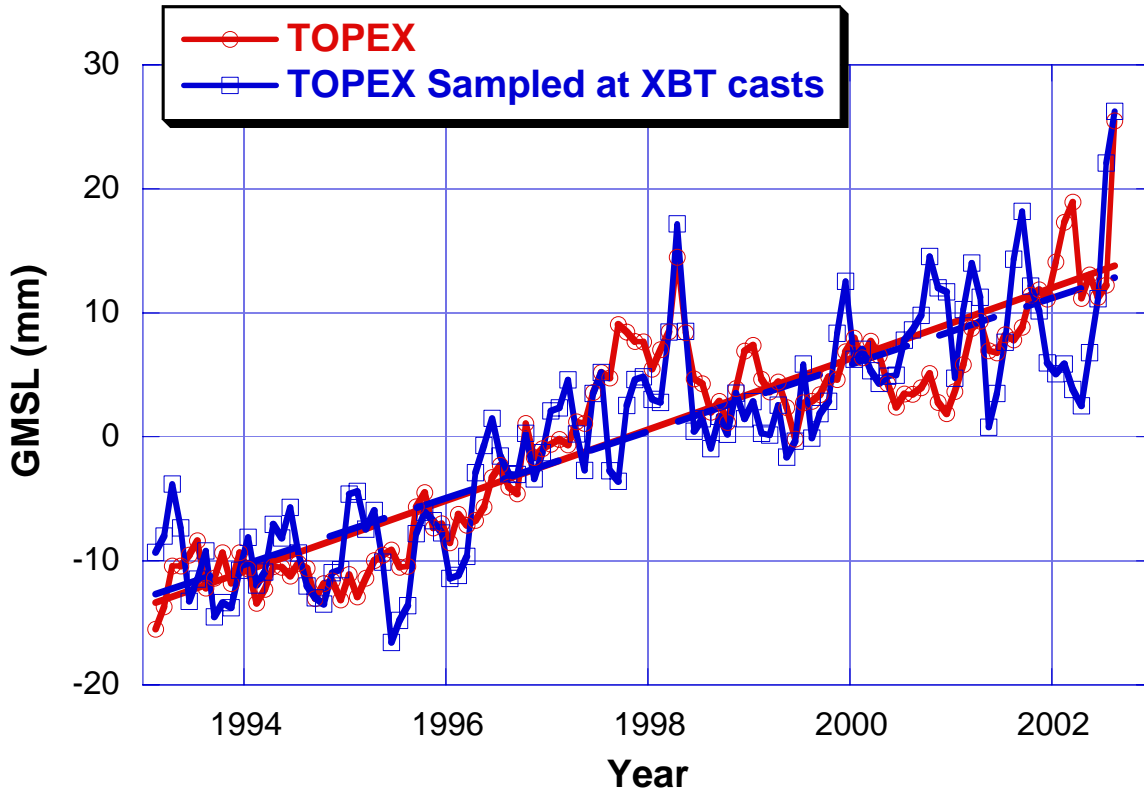
Thermosteric MSL



Error bars are σ of estimated sampling error for steric and σ of tide gauges calibration for TOPEX

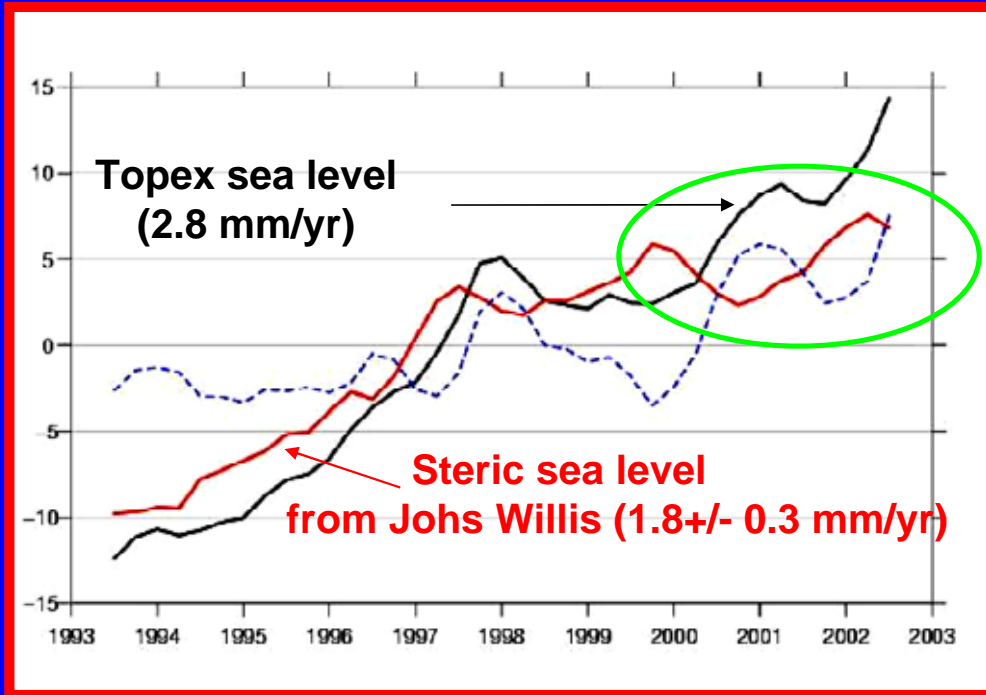
Thermosteric MSL from an independent analysis of in situ temperature profiles at depths of 300m or greater by D. Chambers, Basin-scale thermosteric sea level variations: 1993-2002, presented at EGS-AGU-EUG Joint Assembly, Nice, France, April, 2003

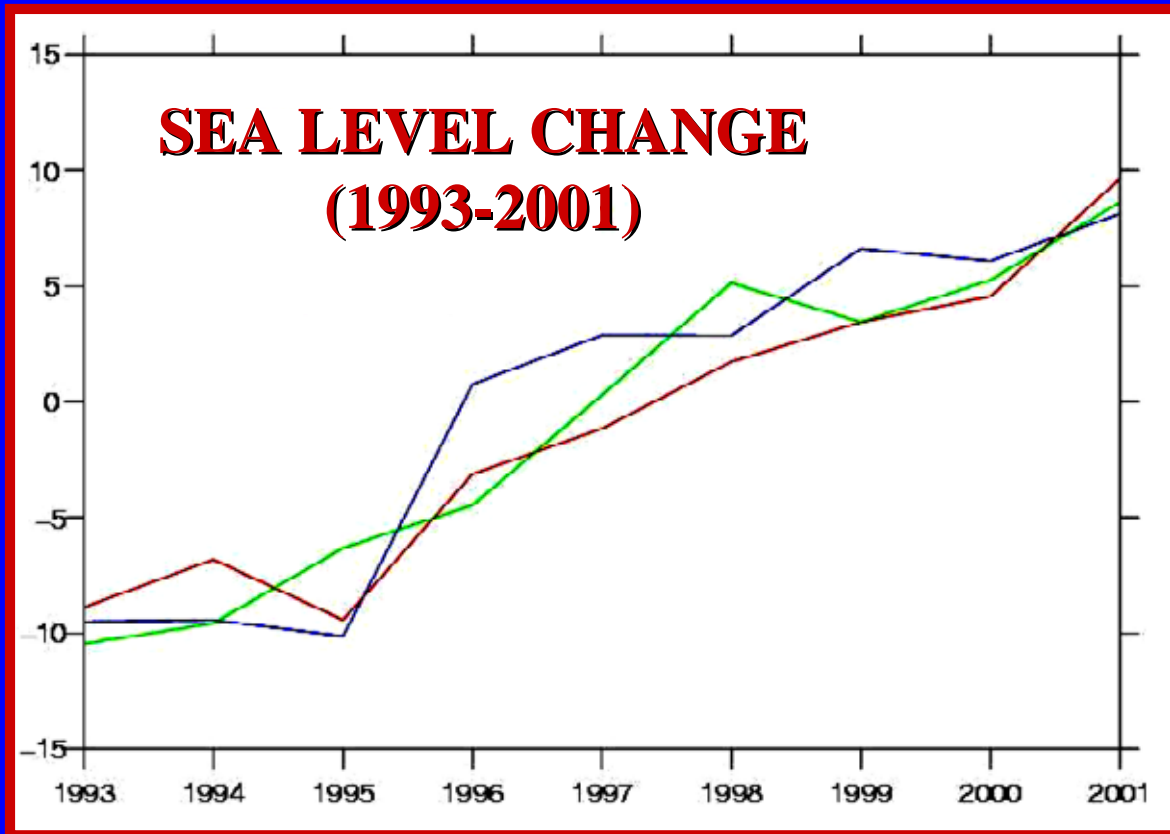
Sampling Error



Standard deviation between “truth” and sampled = 5 mm

Steric Sea Level from ARGO data (J. Willis, 2003)





In situ data from Sismar/Coriolis (WOCE, etc.) : 2.5 mm/yr
Satellite data interpolated at in situ stations : 2.3 mm/yr
Satellite data - global mean : 2.5 mm/yr

Steric sea level rise based on *in situ* hydrographic data

D. Chambers; 1993-2002 : 3.7 +/- 1.5 mm/yr

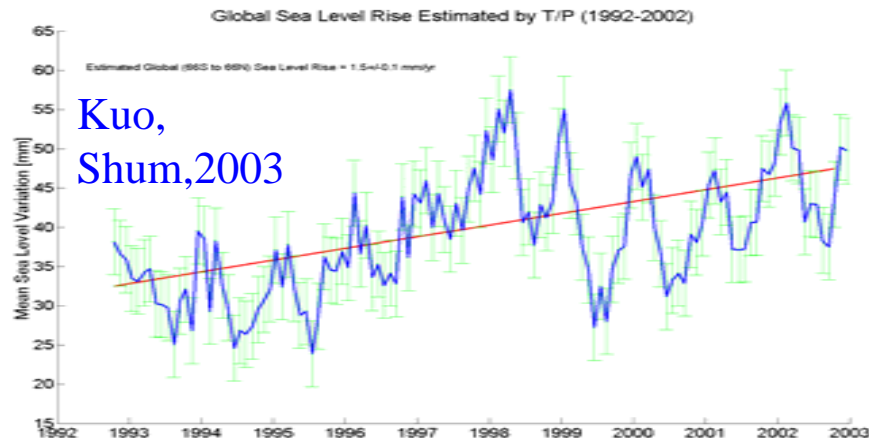
J. Willis; 1993-2002 : 1.8 +/- 0.3 mm/yr

- A. Lombard; 1993-2001 (0-500 m): 2.3 mm/yr
(0-700 m): 2.5 mm/yr**

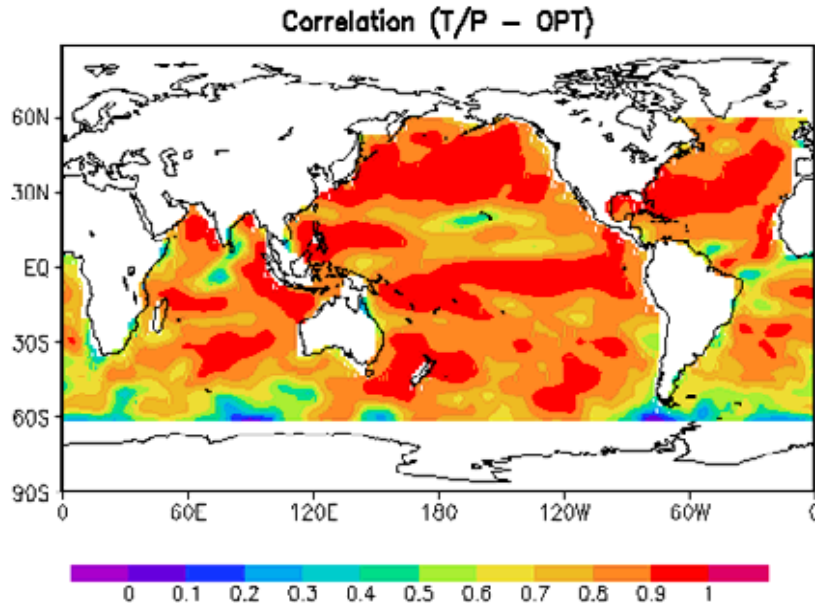
Topex (1993-2002): 2.8 +/- 0.4 mm/yr

GLOBAL STERIC AND EUSTATIC SEA LEVEL RISE 1993-2001

Jens Schröter, Manfred Wenzel, Joanna Staneva



Data assimilation



Data:

T/P SSH anomalies

SST, WOA98

Method:

4DVAR

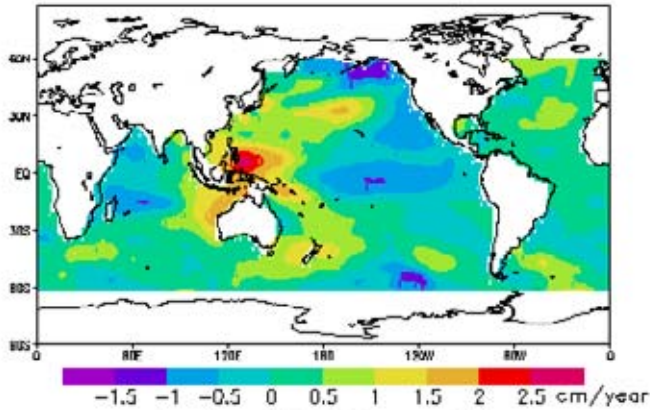
Control:

Forcing,

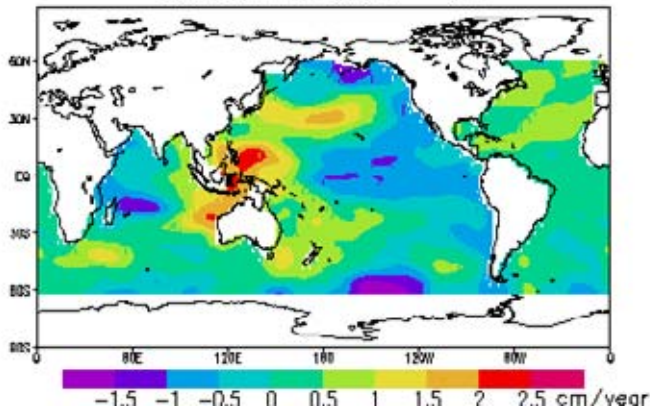
Initial conditions

sea level trends

Local linear trend (1993–2001)
Sea Level Variations – I/P



Sea Level Variations – OPT



OCEAN MODEL:

2° x 2° in the
horizontal,

23 vertical layers

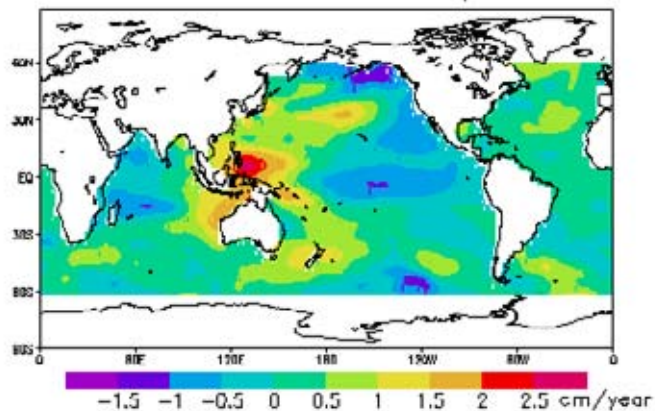
4DVAR assimilation

Conserves SALT

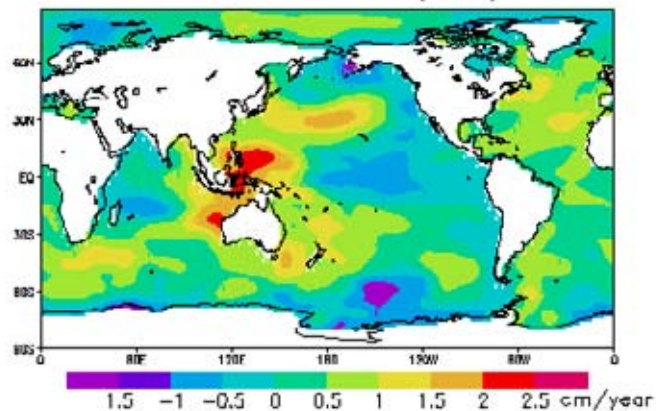
sea level trends

Local linear trend (1993–2001)

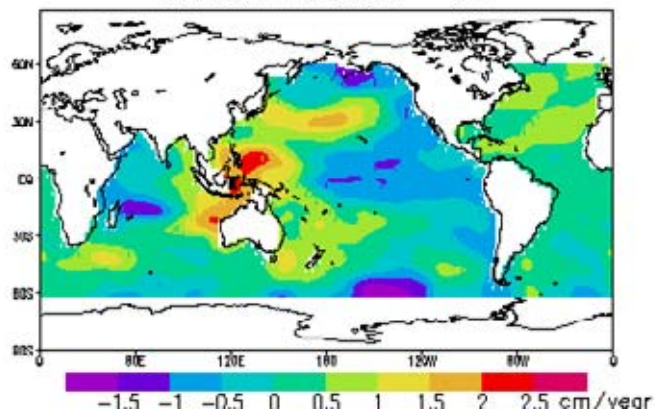
Sea Level Variations – I/P



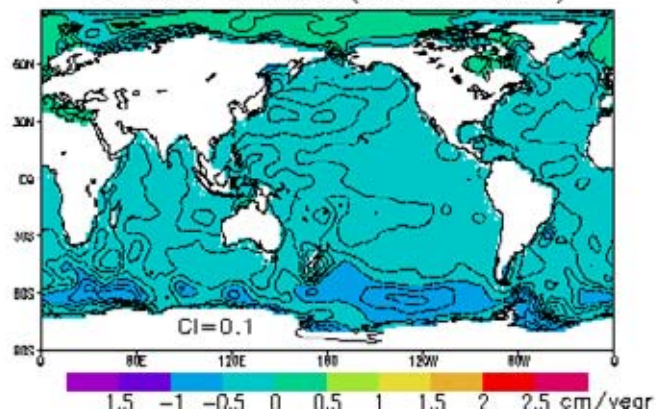
Sea Level Variations (steric)



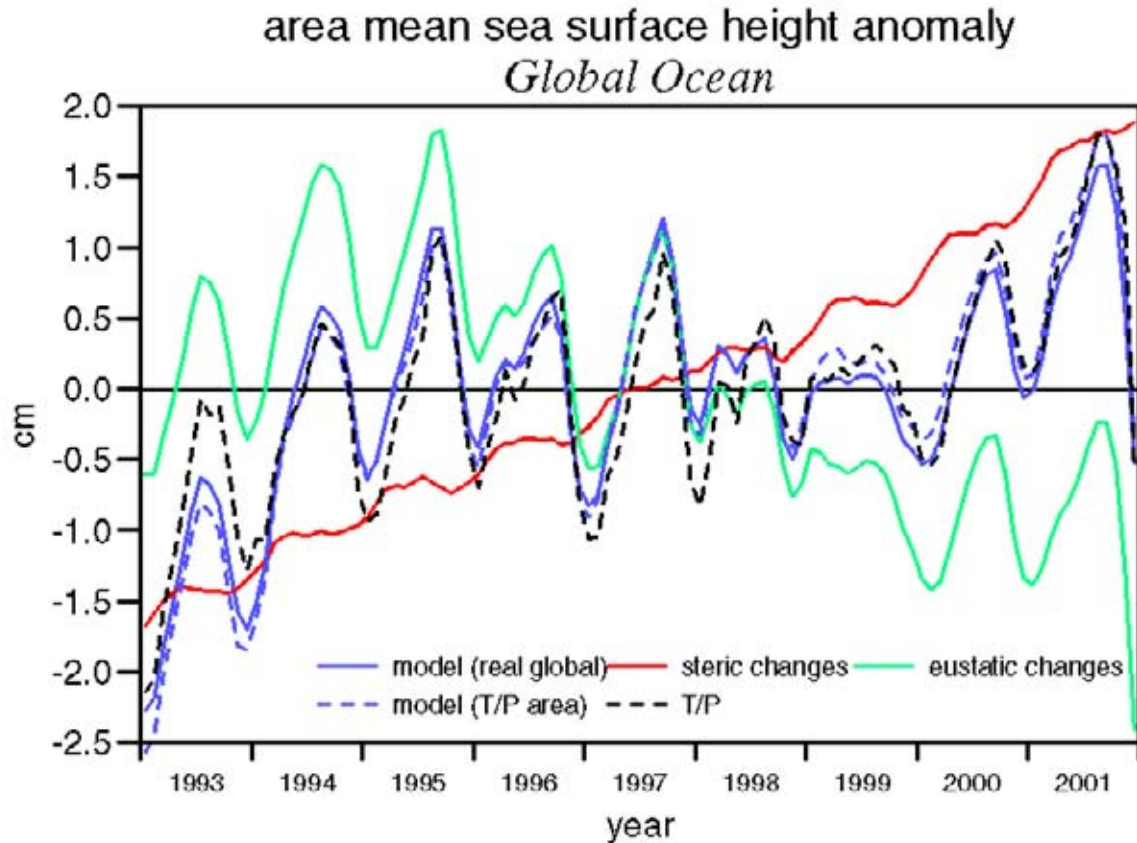
Sea Level Variations – OPT



Sea Level Variations (total non-steric)



temporal evolution of area mean sea level



Question:

**What are the respective contributions
of
thermal expansion and water mass change
to last decade sea level rise?**

EUSTATIC CONTRIBUTIONS
From
LAND WATERS,
MOUNTAIN GLACIERS
AND ICE SHEETS
Recent results

Eustatic Contributions of Land Ice and Waters (last decade)

■ **MOUNTAIN GLACIERS** : > 0.5 mm/yr

(Meier and Dyurgerov, 2002; Arendt et al., 2002; Rignot et al., 2003)

■ **ICE SHEETS** :

Greenland : +0.13 mm/yr (Krabill et al., 2000)

Antarctica : +0.16 +/- 0.05 mm/yr (WA)

0 +/- 0.07 mm/yr (EA)

Total (G+A): + 0.3 mm/yr (Rignot and Thomas, 2002)

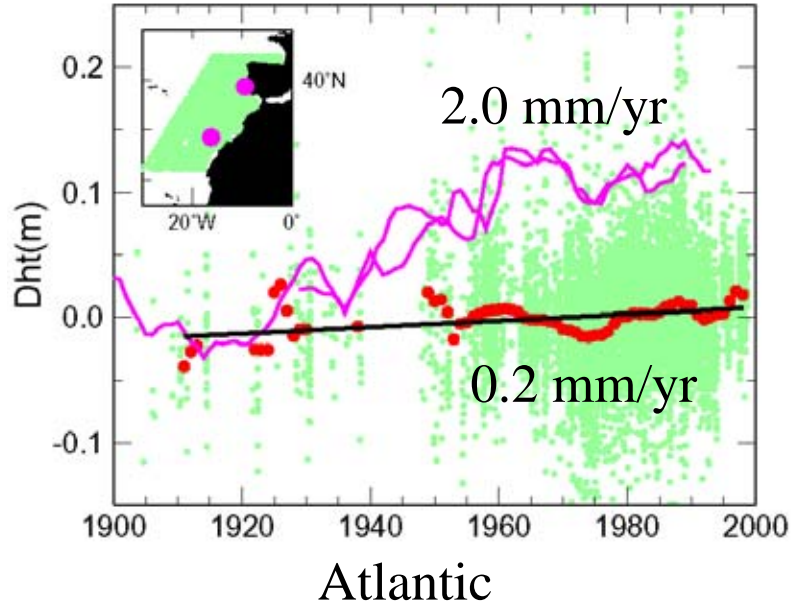
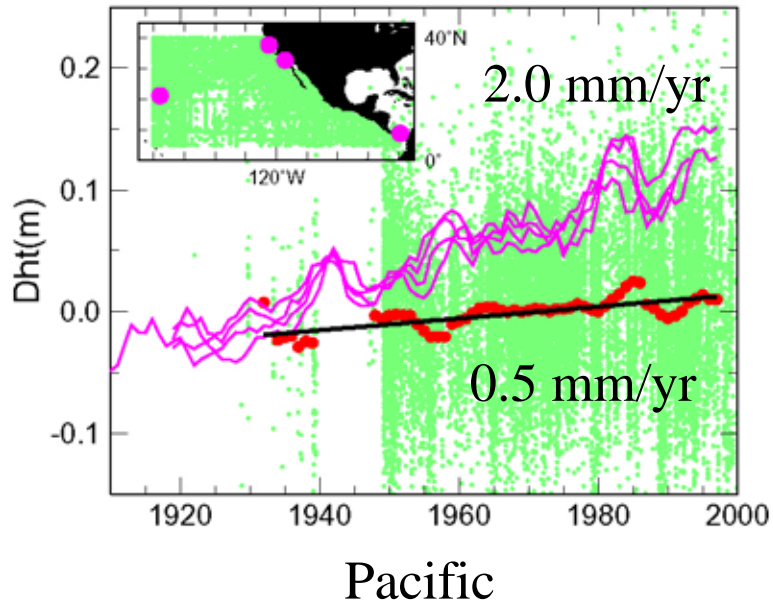
■ **LAND WATER** : +0.2 mm/yr (Milly et al., 2003)

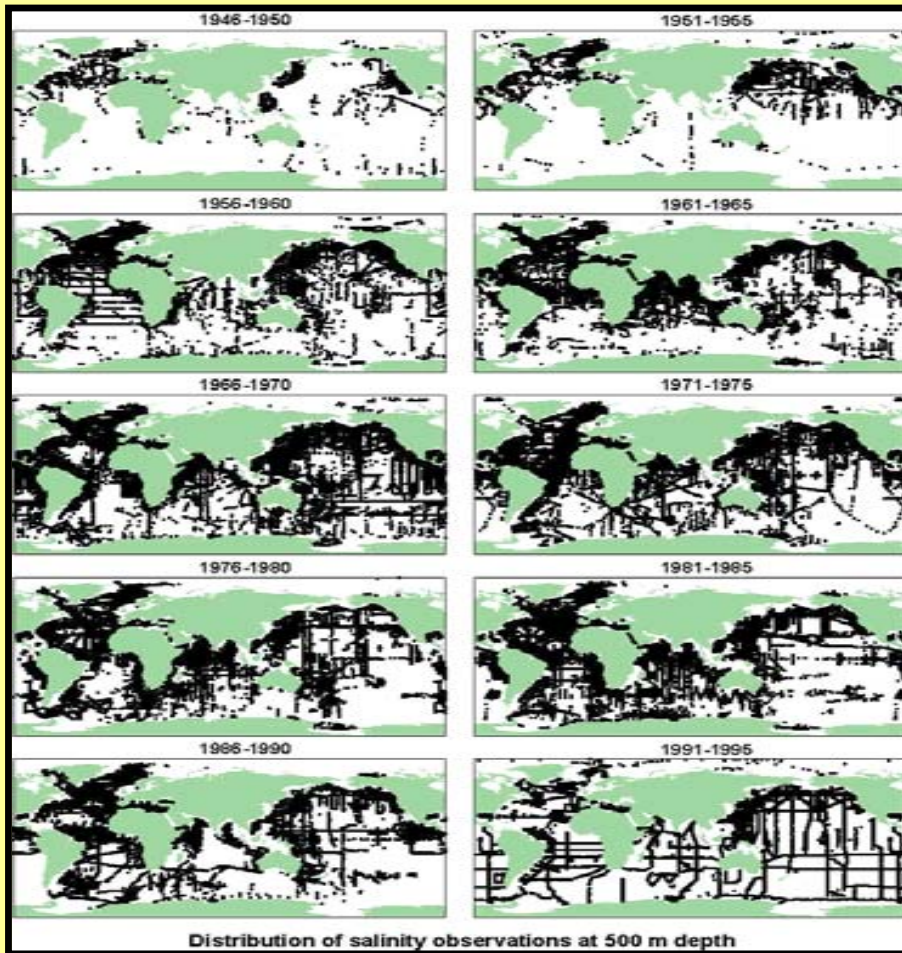
TOTAL : ~1 mm/yr

**WHAT ABOUT
THE PAST FEW DECADES?**

20th Century Sea Level Rise:

Tide gauges vs. Dynamic Height (0/1000 m)





**Distribution
of
Salinity data
at 500 m depth**

Sea Level Rise (1995-1995)

Contribution of salinity:

0.05 mm/yr

(thermal expansion: 0.5 mm/y)

W. Munk (Science, 2003): Ocean Freshening, Sea Level Rising

- Salinity-induced steric sea level rise : **0.05 +/- 0.02 mm/yr**
(Antonov et al., 2002)
- Corresponds to **650 +/- 250 km³/yr** fresh water input (Munk, 2003)
- Equivalent to **1.8 +/- 0.7 mm/yr** eustatic sea level rise
if sea ice melting is neglected
- Rate of sea ice melting still poorly known:
estimates vary from **60 km³/yr** (Johanessen et al., 2003)
to **600 km³/yr** (Wadhams, 2000) of equivalent fresh water
- Either case corresponds to **1.5 mm/yr** or **almost zero**
eustatic sea level contribution

Melting Sea Ice is important!

Anthropogenic contributions to sea level change (mm/yr)

Ground water mining (G)	0.2 +/- 0.1
Urbanization (U)	0.34 +/- 0.04
Combustion of fossil fuels (C)	0.01 +/- 0.06
Deforestation (D)	0.09 +/- 0.02
Reservoirs and dams (R)	- 0.98 +/- 0.2
Irrigation (I)	- 0.56 +/- 0.06

TOTAL : - 0.91 +/- 0.45 mm/yr

Unsolved Problems & Remaining Questions

- **Is sea level rise accelerating?**
- **Need for improved estimates of thermal expansion**
- **Causes of regional variability of thermal expansion?**
- **Salinity change and amount of fresh water added to the oceans?**
- **Need for improved estimates of terrestrial water storage due to anthropogenic activities**