Trends of Sea Level Rise in the Regional Seas around Taiwan

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Outlines

1. **Research Background**
   - Issues of global sea level rise (GSLR)
   - SLR background studies in the vicinity of Taiwan
2. **Data Analysis**
3. **Results**
   - Data quality
   - Long term sea level rise trends around Taiwan
   - Rate of sea level rise
   - Recent sea level rise trends
   - Possible mechanisms (Ocean heat content, tectonic influences)
4. **Summary and conclusion**

1.Research Background

Warming of the World Ocean

Heat content (1955 to 1998)

Increase by 14.5×10^{22}J (0-3000m)

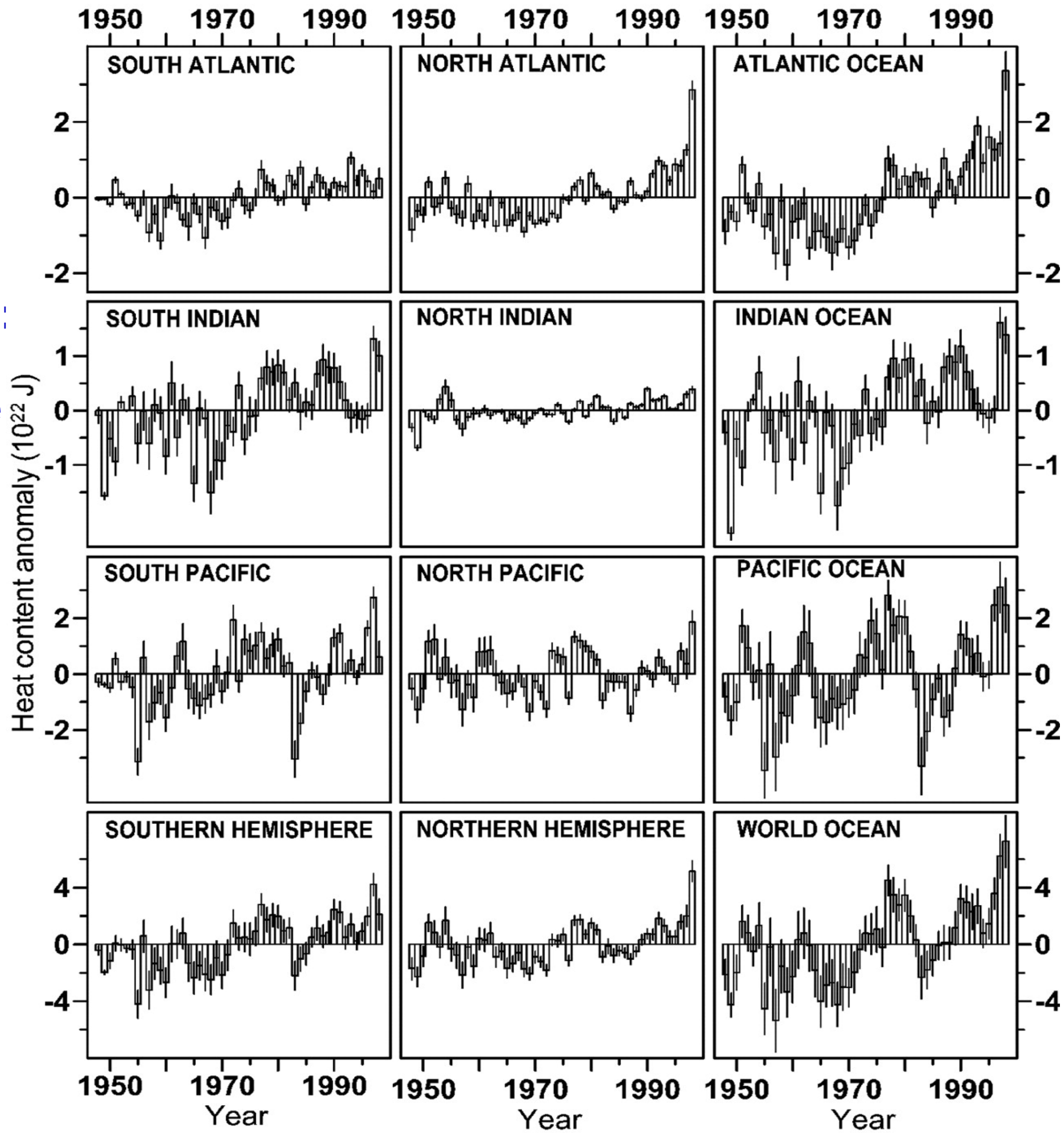
-Mean temperature increase : 0.037℃

-Global mean temp. increase from 0 to 300m : 0.171 ℃

-Warming rate : 0.2W/m^2

→The Pacific Ocean has been warming since 1950s

→ substantial change : 0 to 300m in each ocean (the North Atlantic in depth greater than 1000m)



(Levitus et al., 2000 and 2005)

1.Research Background

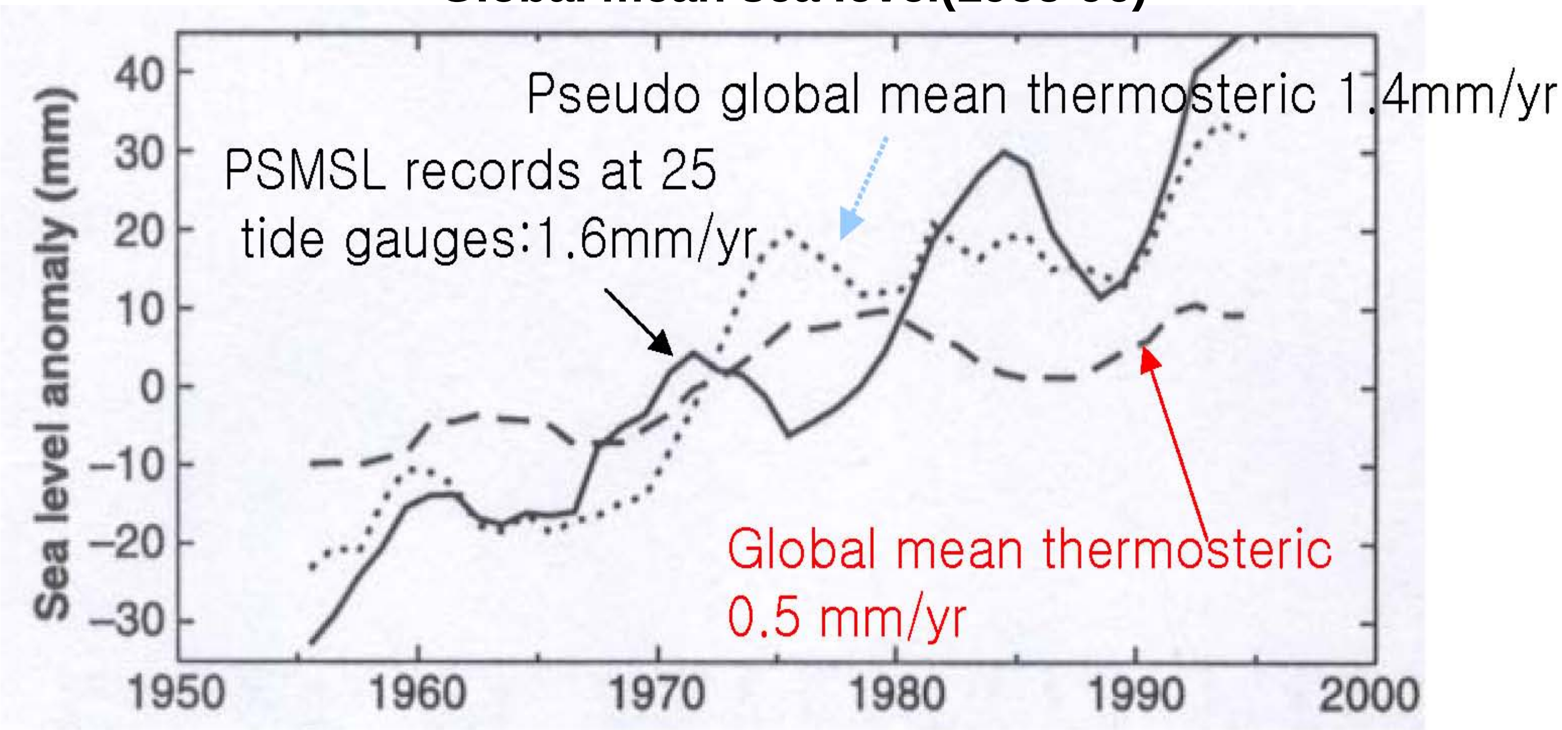
The rate of Global Sea Level Rise(GSLR) and its cause (Enigma)

1. What is the rate of 20th Century GSLR?
   0.5-0.7mm/yr or
   1.5-2.0mm/yr ?
2. What is the causes of GSLR ?
   Thermal expansion?
   Freshwater exports from continents?

1.Research Background

Cabanes et al.(2001, Science)

Global mean sea level(1955-96)



PSMSL GSLR seems to be overestimated!!!
Miller and Douglass (2004) argued this

Steric effects: caused by volume change
- Thermosteric: (temperature change)
- Halosteric: (salinity change)

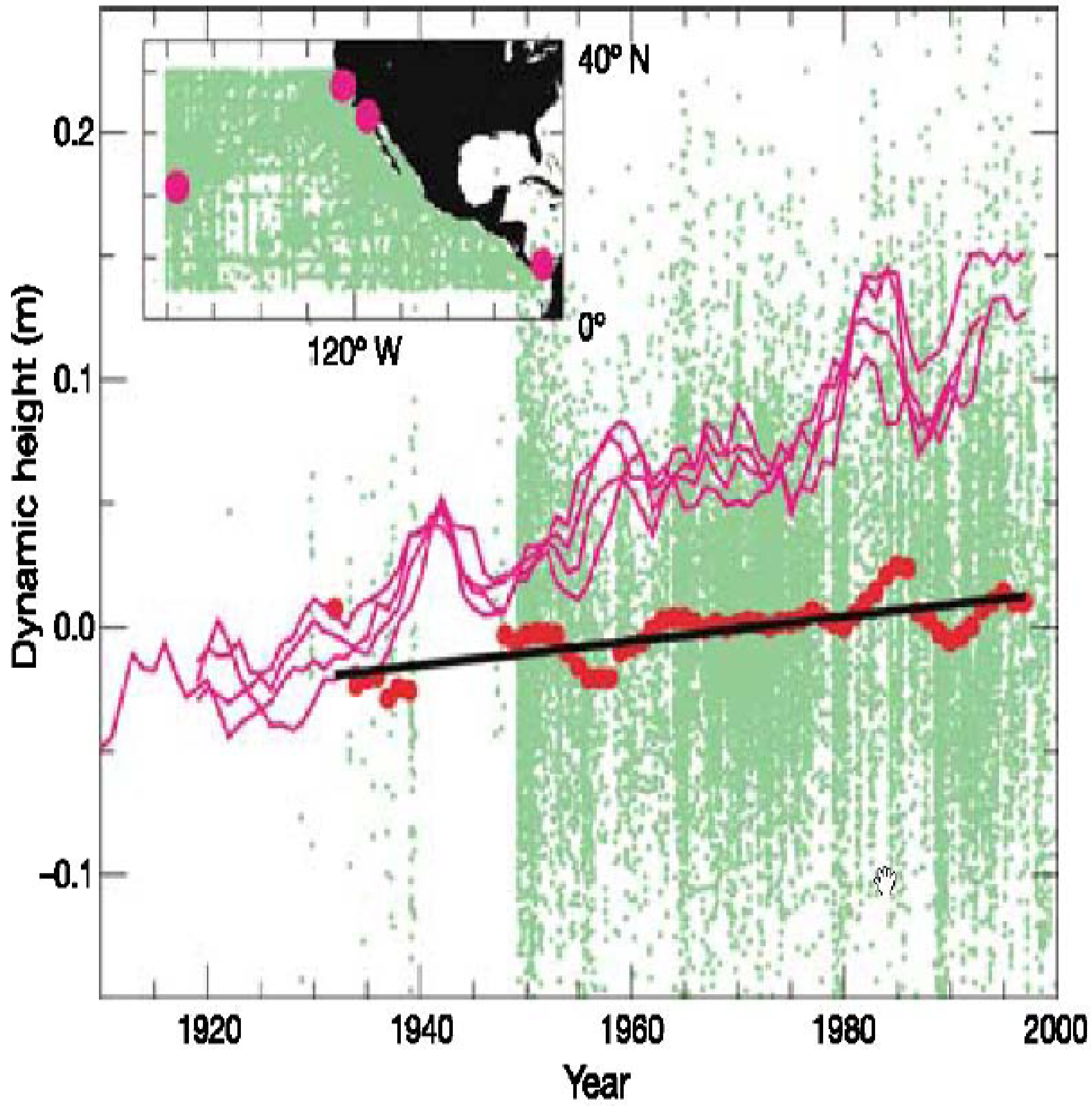
Eustatic effects: caused by mass change

1.Research Background

Pacific region; SF,SD,HO,BB

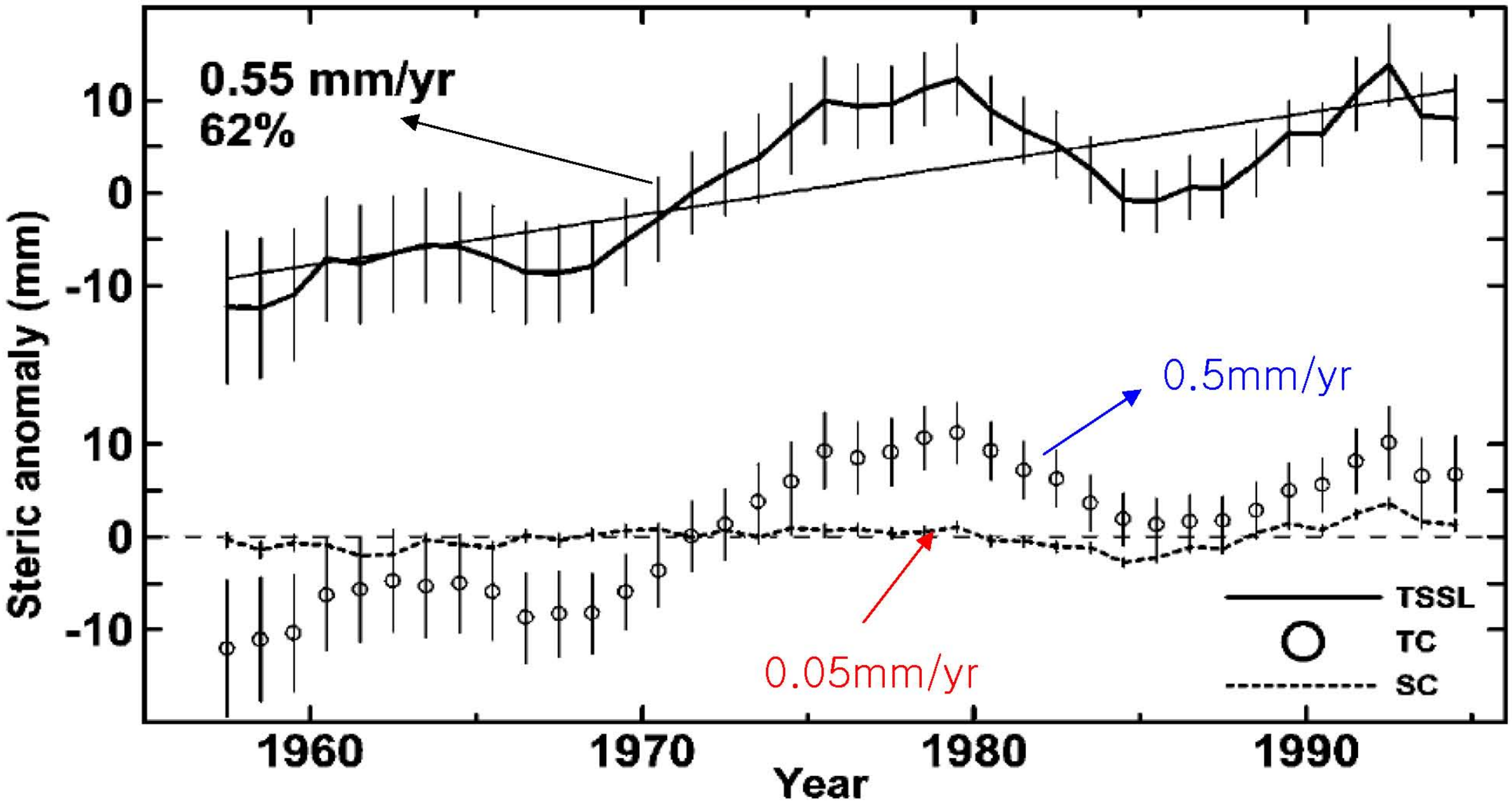
Miller and Douglas (2004)

- -Volume change accounts for only a fraction of SLR
- -1.5~2.0mm/yr for GSLR
- -Mass change play a dominant role



1.Research Background

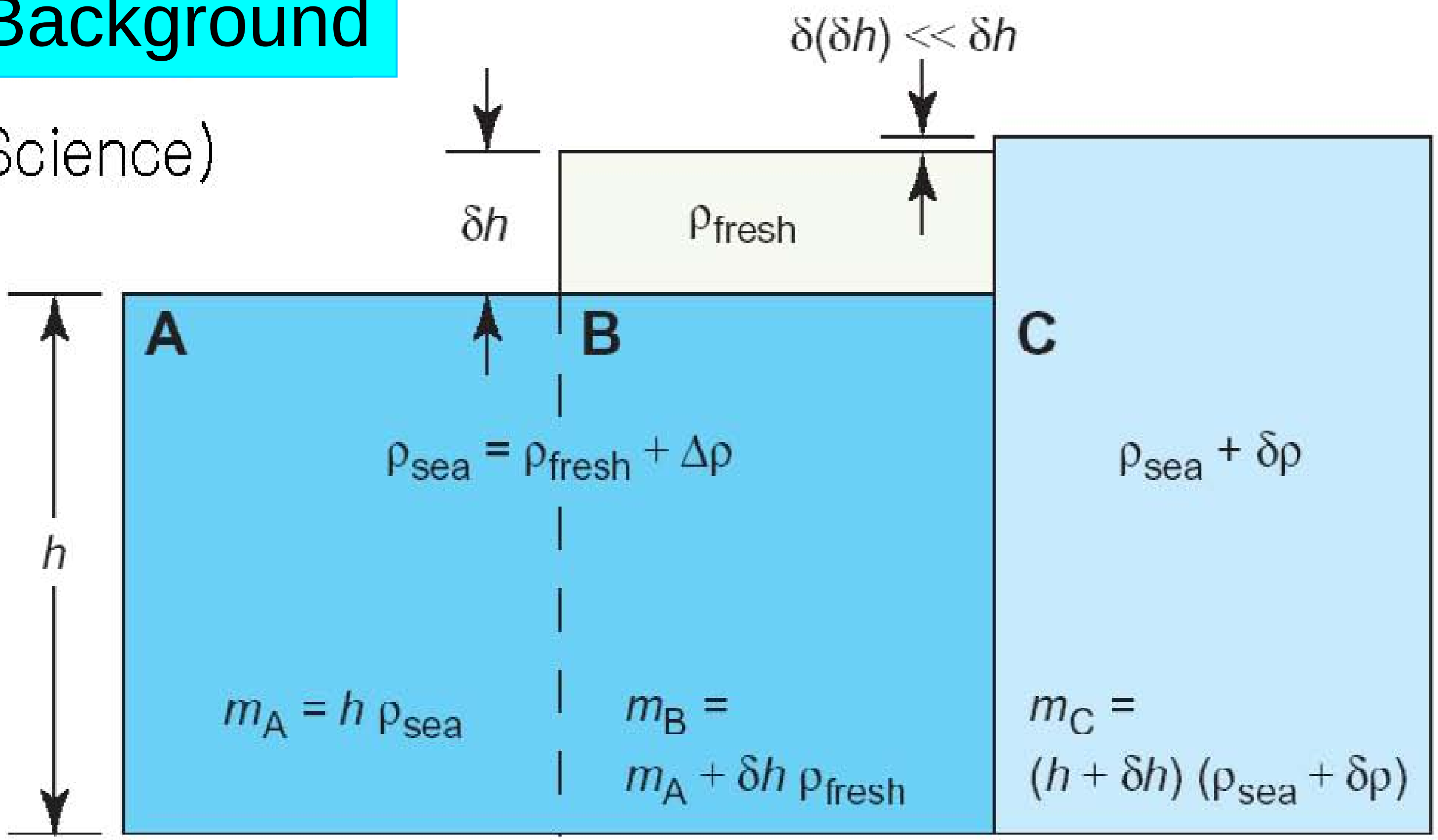
Antonov et al.(2002, JGR) **Spatially averaged(50°S-65°N)5-year running mean**



- **A decrease in global mean salinity has occurred**
- **This increase of freshwater causes SLR at rate of 1.3±0.5mm/yr**

1.Research Background

Munk (2003, Science)



$\delta_{heustatic} = (\rho / \Delta\rho)\,\delta_{hsteric} = 36.7\,\delta_{hsteric}$ **=1.8mm/yr, Ocean area=3.6×10⁸km²**

If SLR by salinity change is known, SLR due to mass input can be calculated
Eustatic rise due to mass input corresponds to 515km³/year or 1.4mm/year

- **20th-century SL remains an enigma**
- **We don't know warming or melting was dominant**

1.Research Background

- **Sea level Rise and Warming of the ECS and SCS**
  - **+11.3 mm/yr (1993-2000) and -11.8 mm/yr (2001-2005) SLR rate in SCS (Cheng and Qi, 2007)**
  - **~+2-3 mm/yr relative SLR along the coast of China (Wang, 1998)**

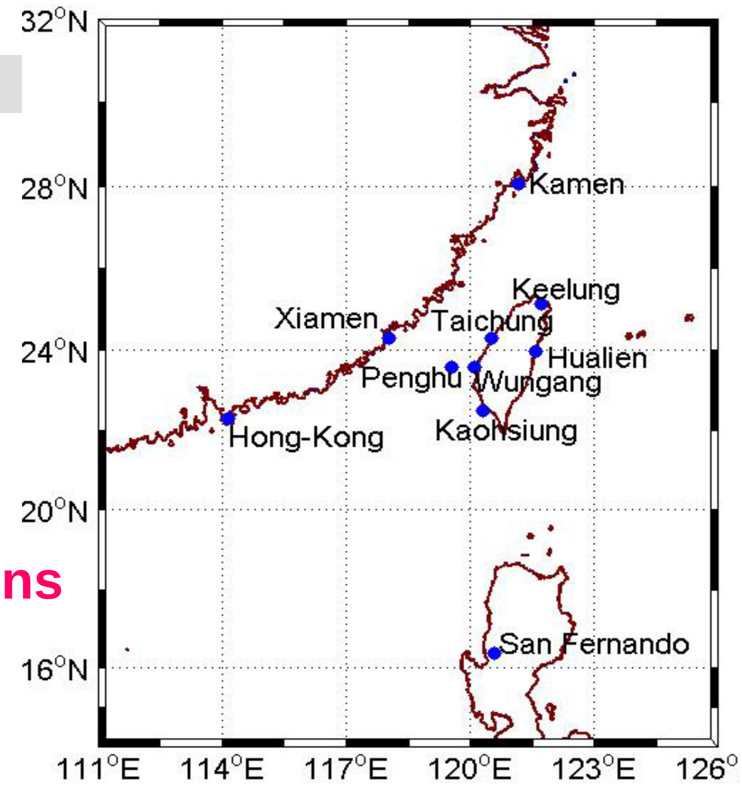
- **Present study background**

→Interest in examining what the rate of SLR is in marginal seas around Taiwan and what the cause of SLR is?

→If it is due to warming, is it due to deep or upper water warming ?

2.Data Analysis

Data sources: tide gauges



Stations

**WRA: Data from Water Resources Agency, Ministry of Economic Affairs

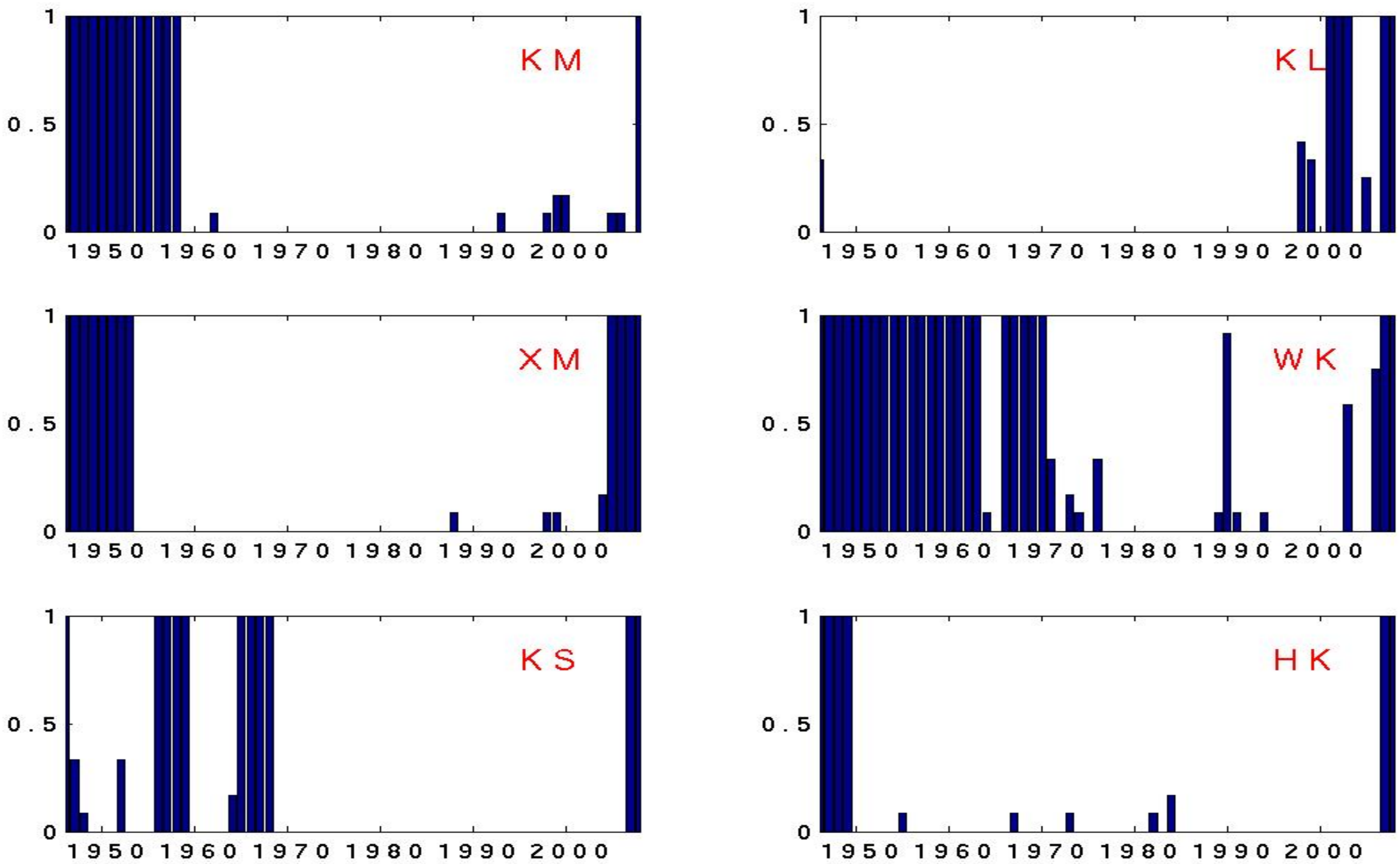
***Final data time series is the same as the data period

Stations	Codes	Location	Time	Source	Final Series
Kanmen (KM)	610/016	28°08'N 121°17'E	195901~200712	PSMSL	***
Keelung (KL)	1212	*Keelung Harbor	194605~199012	CWB*	194605~ 200612
	151	25°09'N 121°44'E	199503~200012	CWB	
	1511		199101~199503		
	1513		200401~200712		
	1516		200711~200808		
	612/002	25°08'N 121°44'E	195601~199512	PSMSL	***

2.Data Analysis

Stations	Codes	Location	Time	Source	Final Series
Xiamen	610/016	28°05'N 121°17'E	195901~200712	PSMSL	***
Wungkang (WK)	1361	23°28'N120°07'E	196302~196401 197005~200201	WRA**	196302~ 200806
	1365		200301~200501	CWB	
	1366		200306~200801		
Kaohsiung (KS)	148	22°37'N 120°16'E	198701~200807	CWB	194705~ 200612
	1481	22°37'N 120°17'E	199707~199806		
	1482	22°37'N 120°16'E	194705~198612		
	1486	22°37'N 120°17'E	200403~200808		
	612/012	22°32'N 120°19'E	197301~198912	PSMSL	***
Hong Kong (HK) QB	611/010	22°18'N 114°13'E	198601~200612	PSMSL	192901-200612
Hong Kong (HK) NA	611/011	22°18'N 114°12'E	192901~198512		
Hong Kong (HK) TAI (TP)	611/014	22°27'N 114°11'E	196301~200612		***

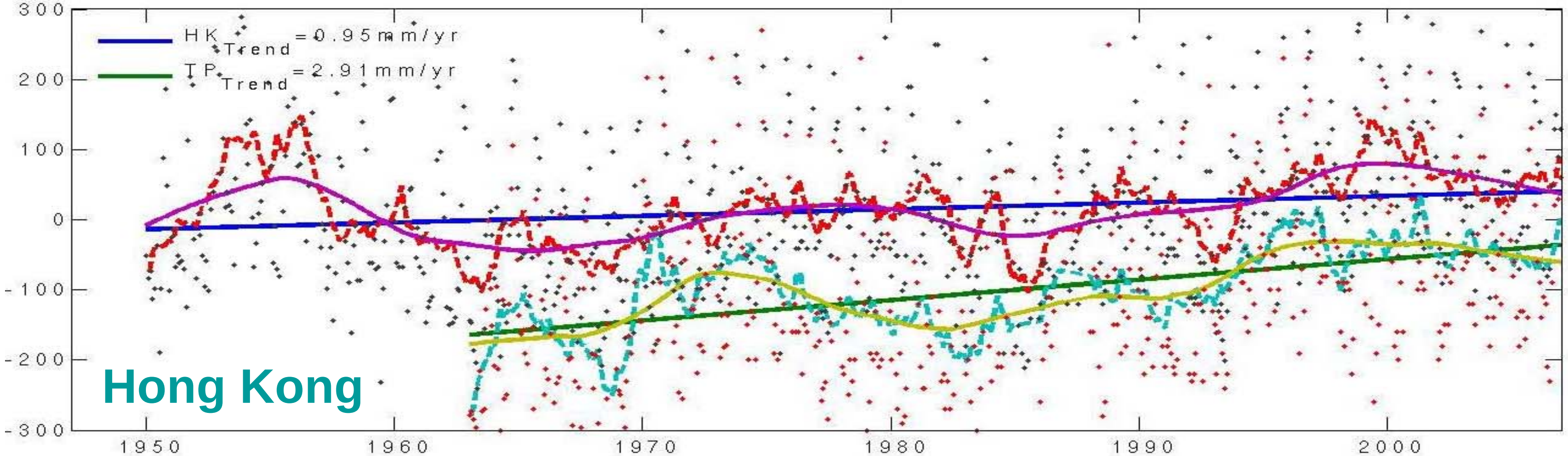
DataCheck

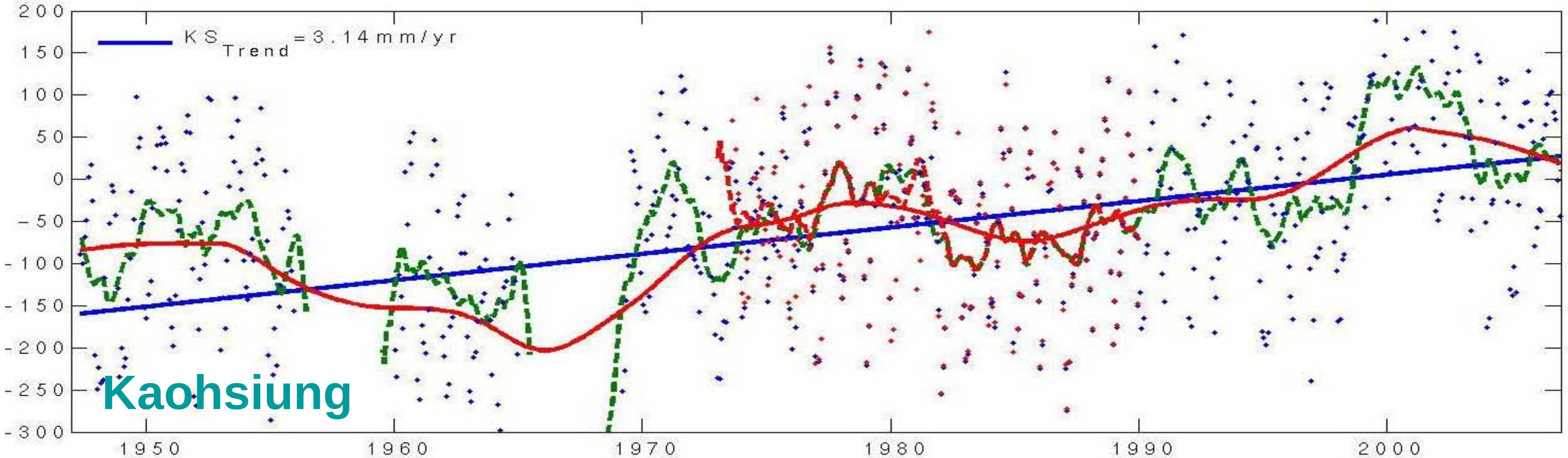


Missing ratio of Stations, 1948~2007

3. Results

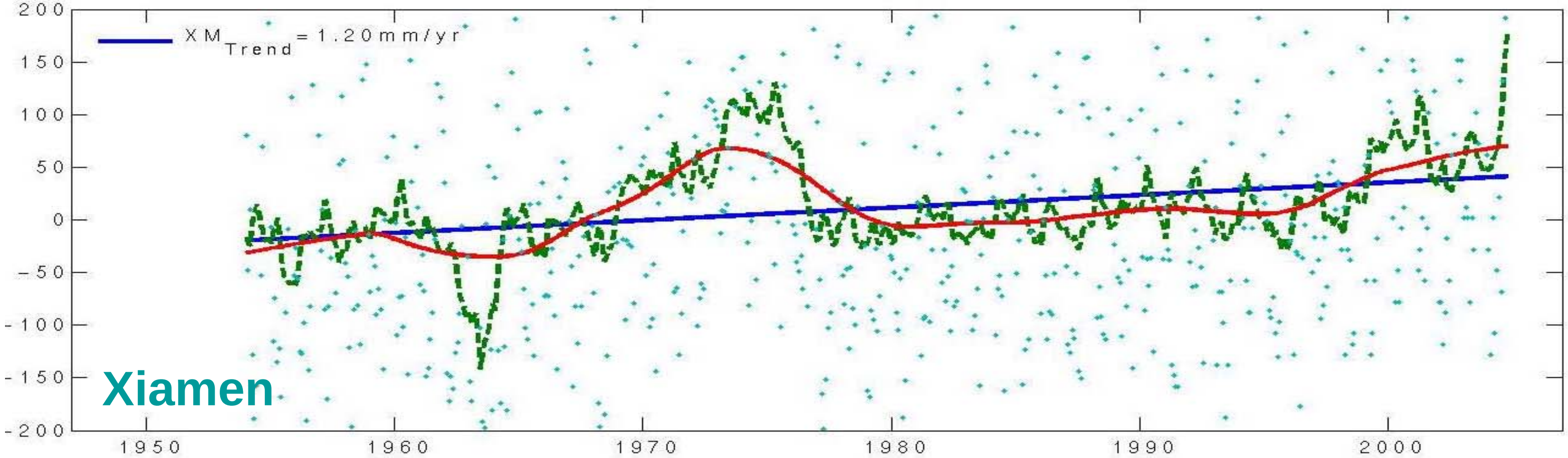
Trend of low-latitude stations

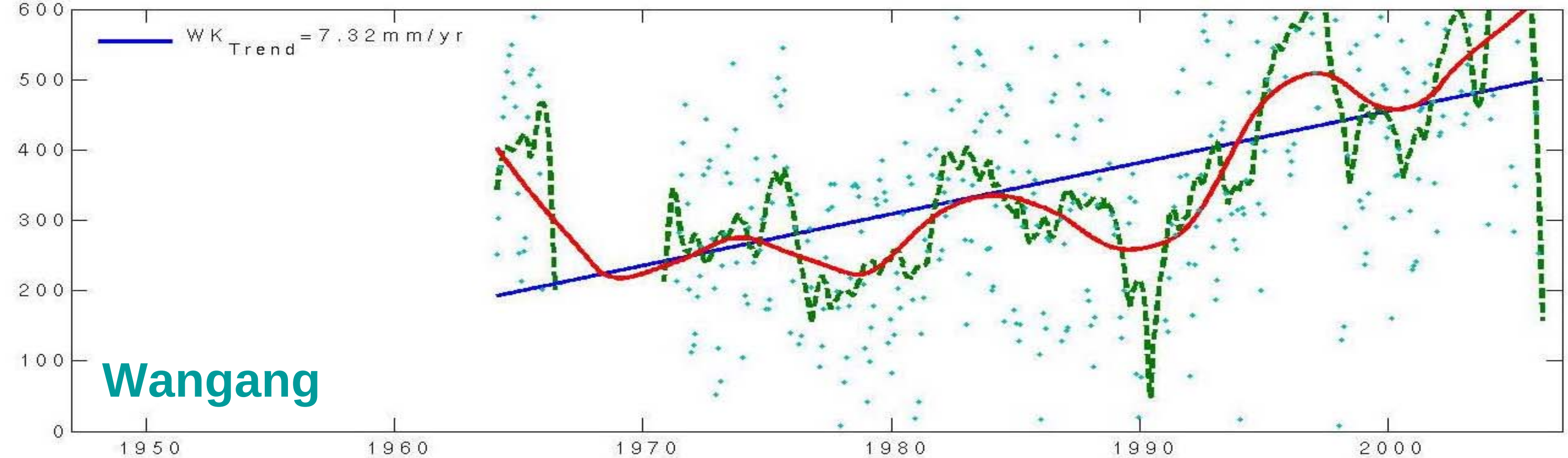




3. Results

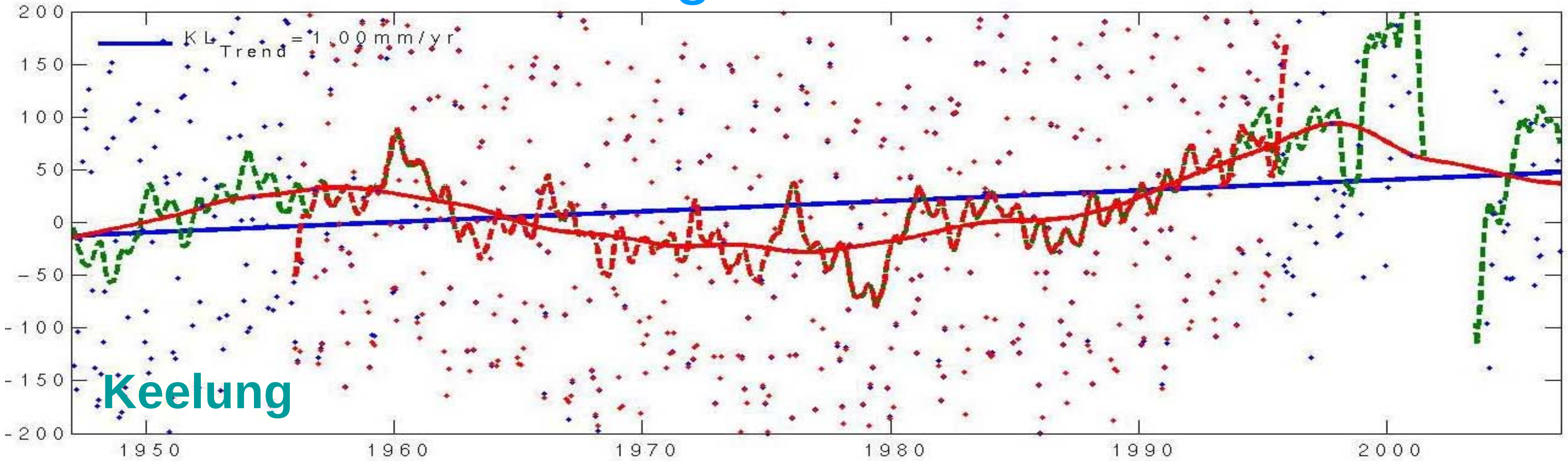
Trend of mid-latitude stations

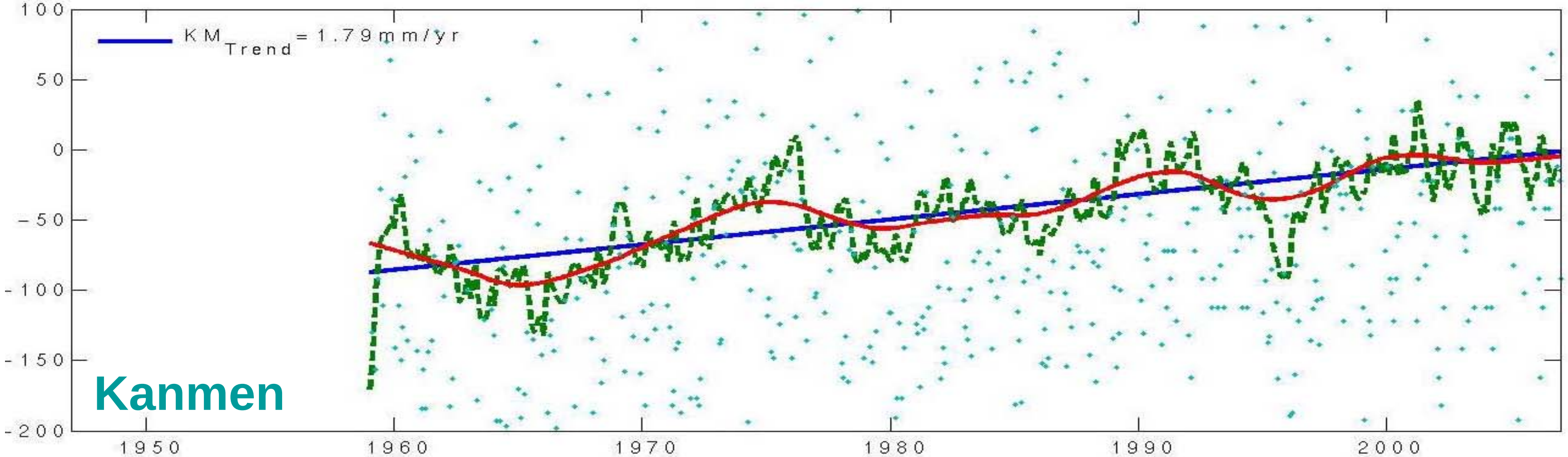




3. Results

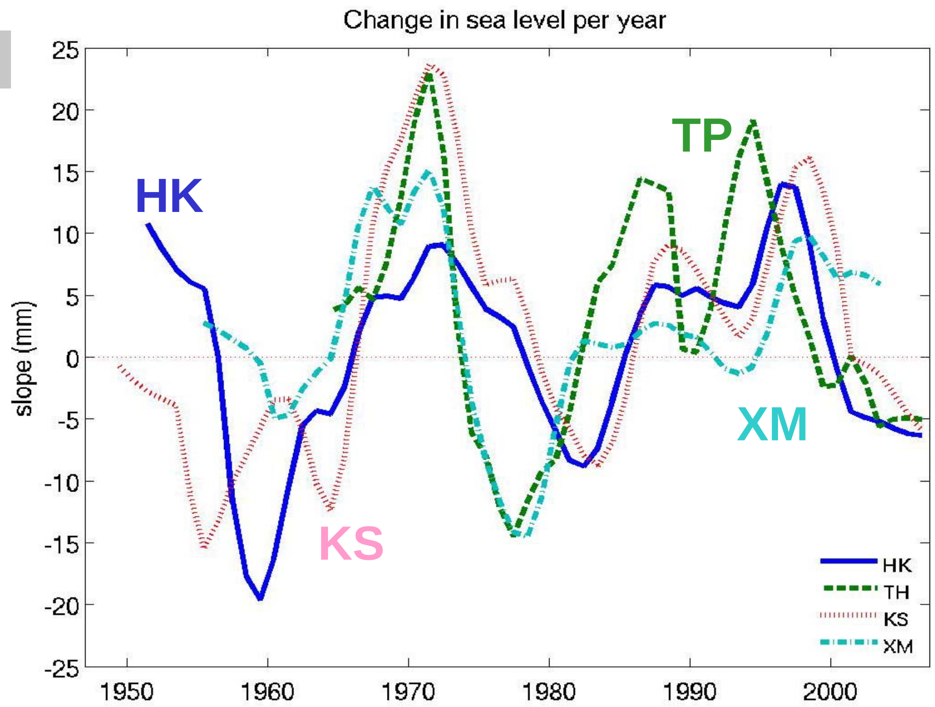
Trend of high-latitude stations



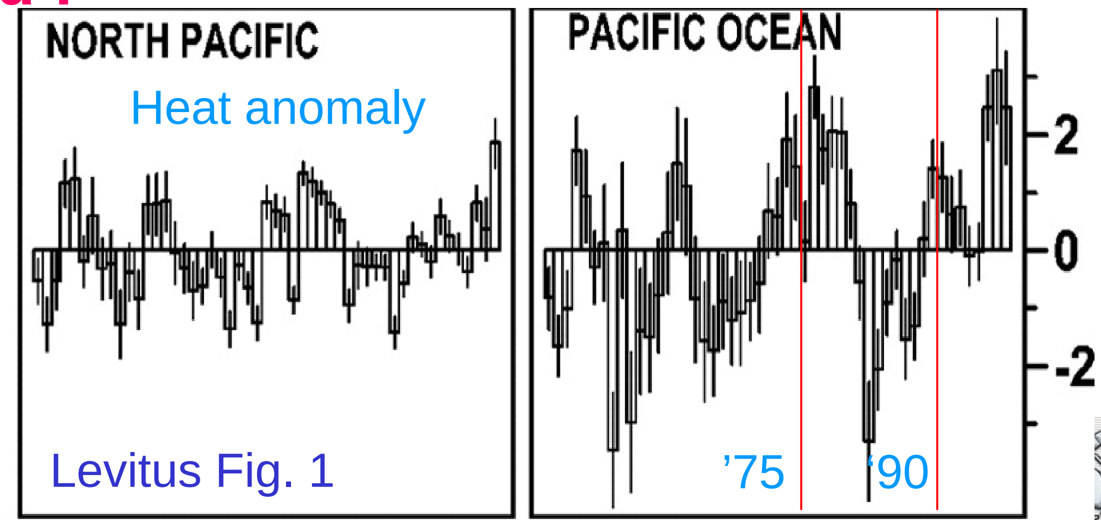


3. Results

Yearly forward difference (mm/yr)



-Recent sea level trend : in increasing phase from 1993



3. Results

	1993~2003	1961~2003	1955~2003	Entire periods
HK	4.97	2.46	0.47	0.73(1951~2006)
TH	4.79	3.56	-	2.86(1964~2006)
KS	6.79	4.70	2.96	1.79(1949~2006)
XM	5.32	2.11	1.88	1.94(1955~2003)
~~WK~~	~~16.54~~	~~6.10~~	~~-~~	~~6.52(1966~2005)~~
KL	0.49	0.67	0.59	0.86(1948~2006)
KM	1.27	1.56	-	1.37(1960~2007)
	3.93	2.51	1.47	

Unit: mm/yr

ea level trends from different studies.

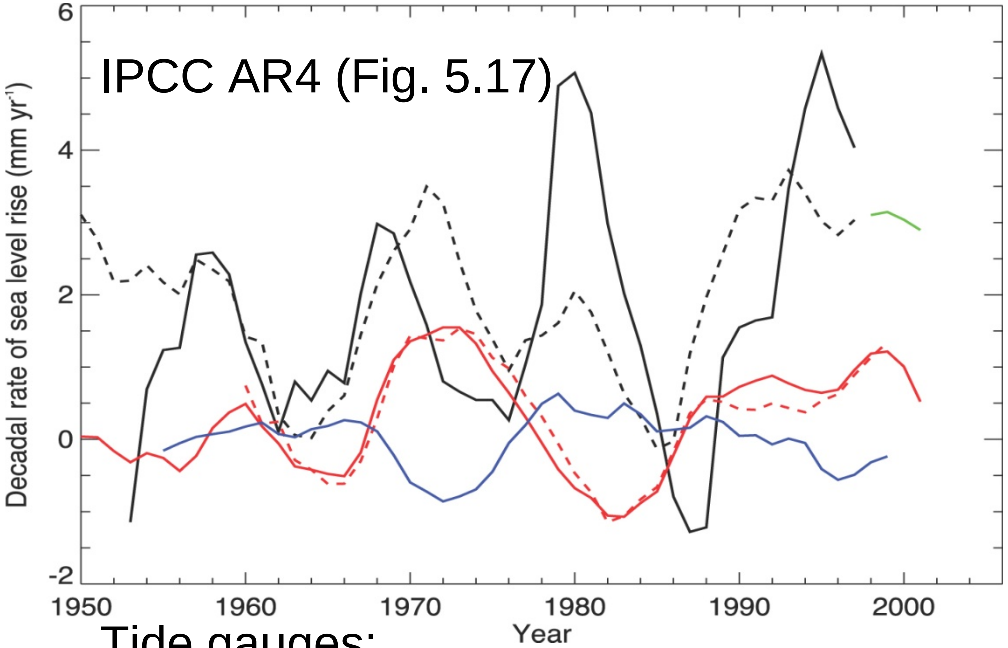
Steric sea level change with errors (mm yr-1)	Period	Depth range (m)	Data Source
0.40 ± 0.09	1955–1998	0–3,000	Levitus et al. (2005b)
0.33 ± 0.07	1955–2003	0–700	Levitus et al. (2005b)
0.36 ± 0.06	1955–2003	0–700	Ishii et al. (2006)
1.2 ± 0.5	1993–2003	0–700	Levitus et al. (2005b)
1.2 ± 0.5	1993–2003	0–700	Ishii et al. (2006)
1.6 ± 0.5	1993–2003	0–750	Willis et al. (2004)
1.8 ± 0.4	1993-2003	0-700	Guinehut et al. (2004)

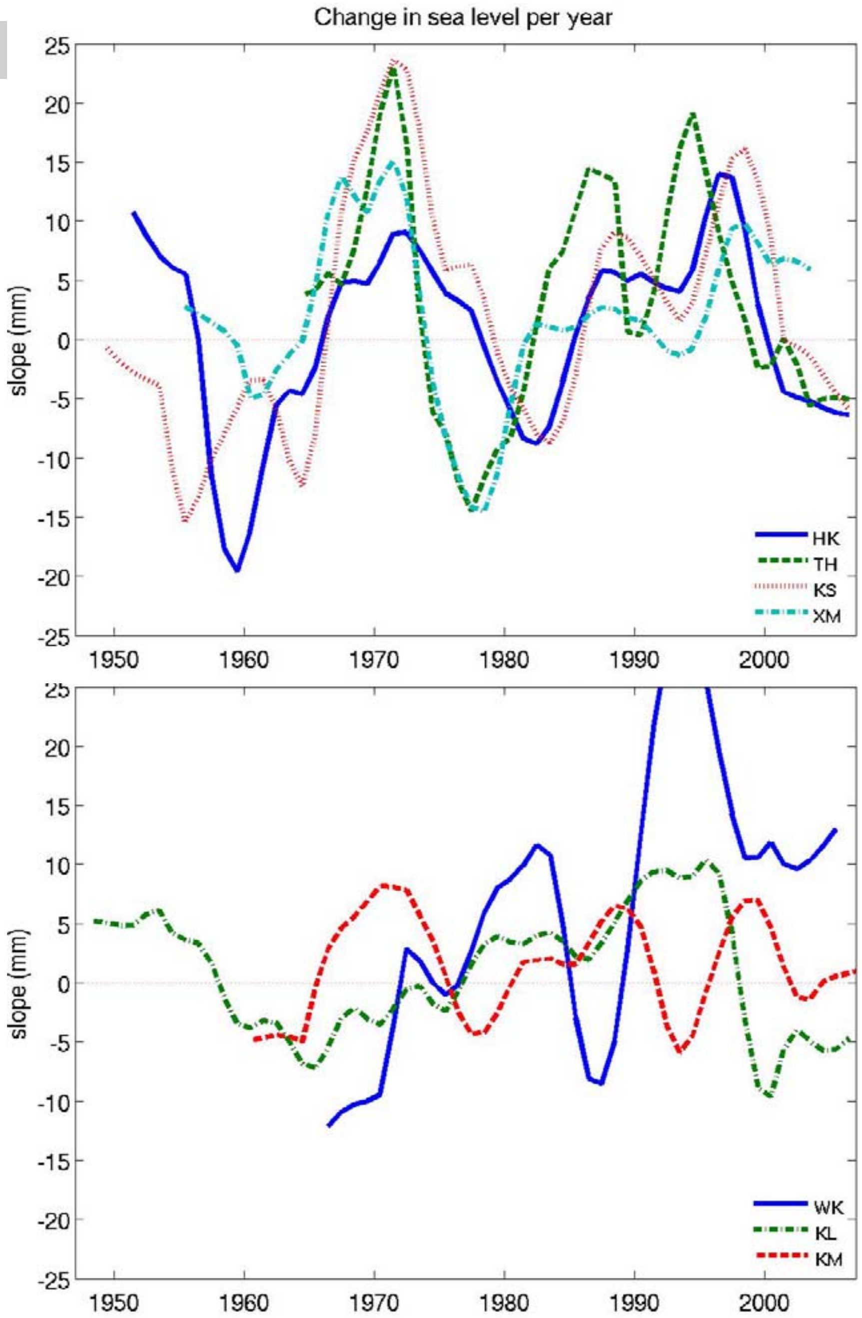
Source	Sea Level Rise (mm yr-1) 1961–2003	1993–2003
Thermal Expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and Ice Caps	0.50 ± 0.18	0.77 ± 0.22
Greenland Ice Sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic Ice Sheet	0.14 ± 0.41	0.21 ± 0.35
Sum	1.1 ± 0.5	2.8 ± 0.7
Observed	1.8 ± 0.5	3.1 ± 0.7
Difference (Observed –Sum)	0.7 ± 0.7	0.3 ± 1.0

IPCC AR4 (Table 5.2, 5.3)

3. Results

Comparison with the global trends





Tide gauges:

Holgate and Woodworth (2004), solid black
Church and White (2006), dashed black

Satellite:

Dazenave and Nerem (2004), green

Thermal expansion:

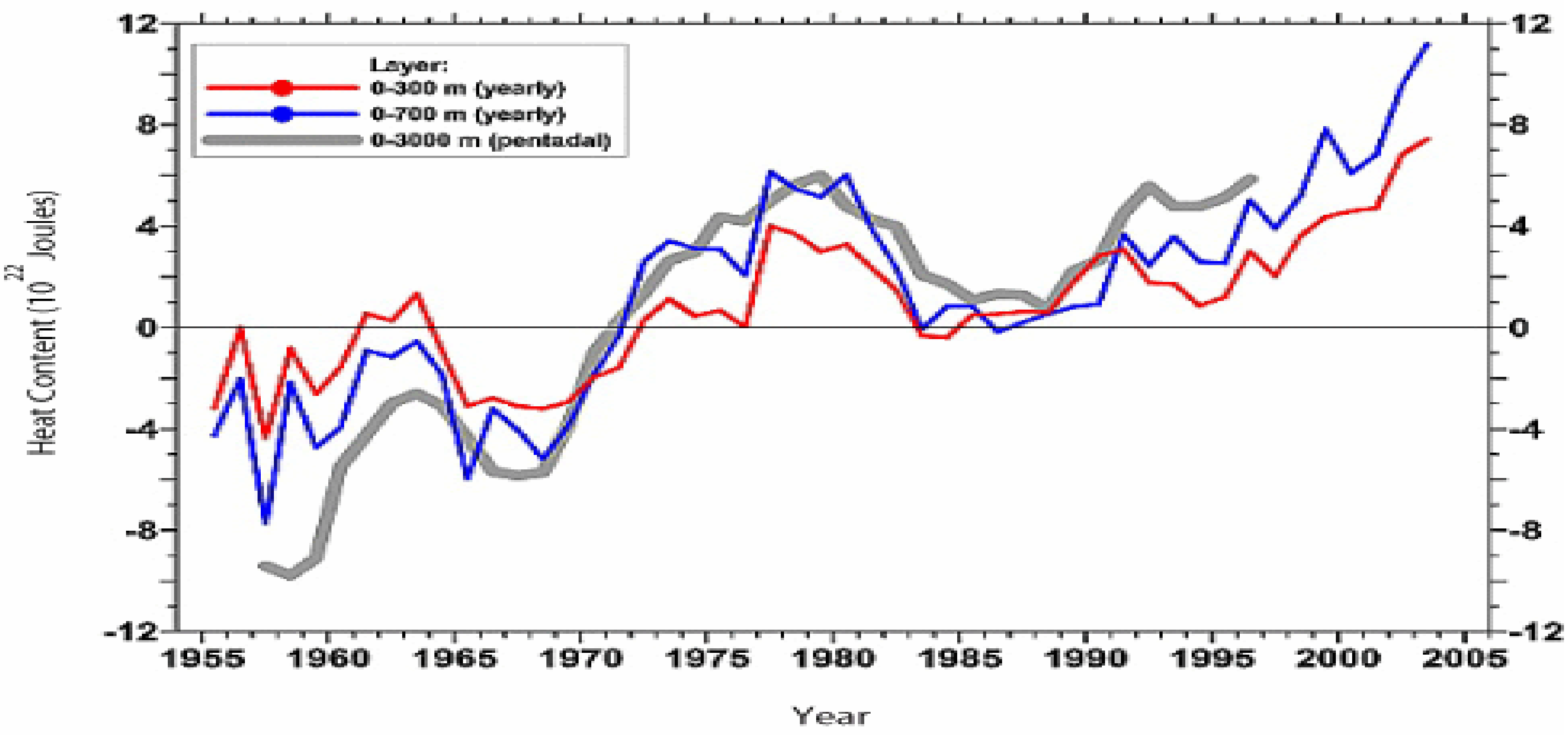
Ishii et al. (2006), solid red
Antonov et al. (2005), dashed red

Climate-driven land water storage

Ngo-Duc et al. (2005), blue

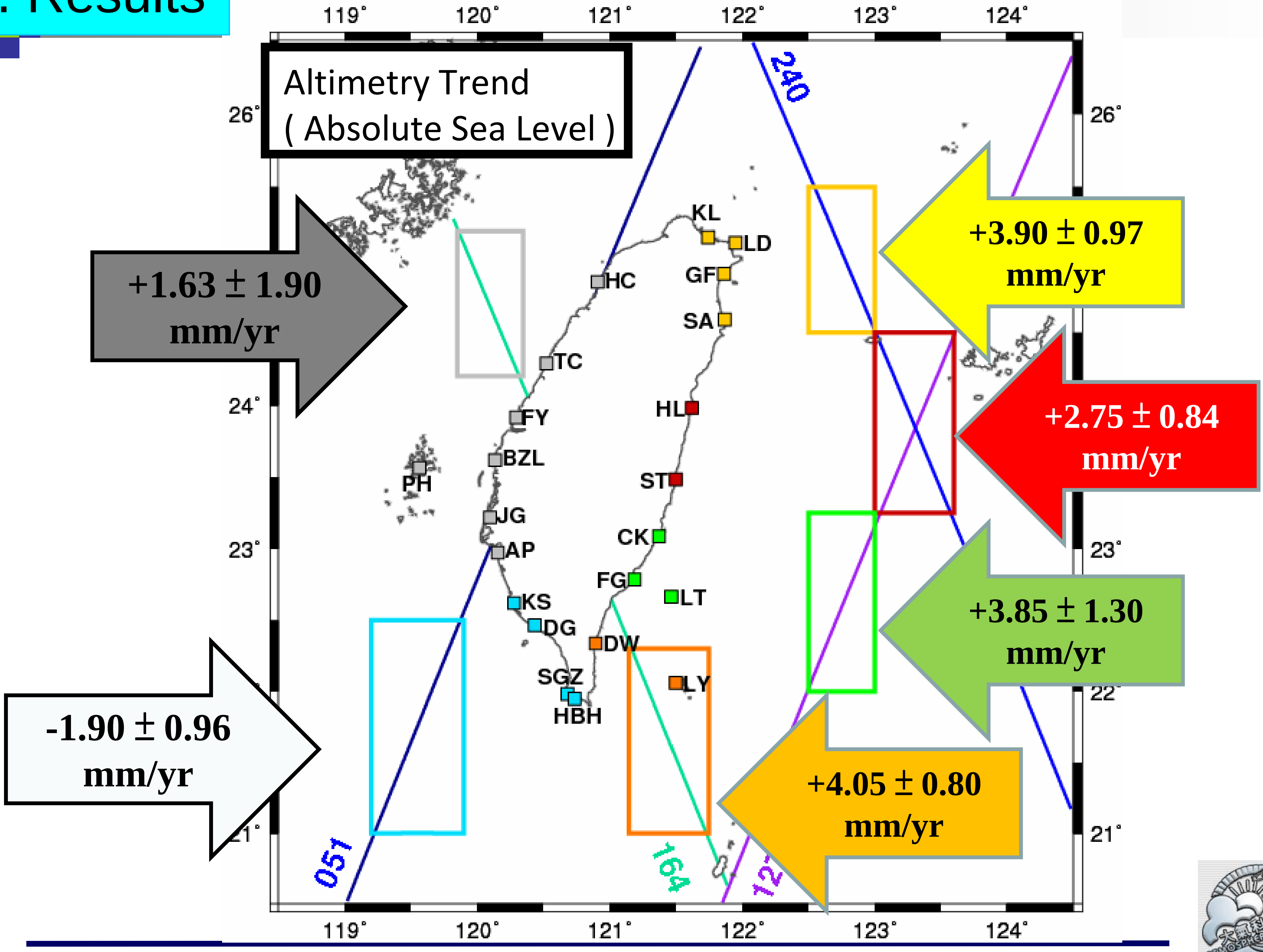
Heat content

Trends in Ocean Heat Penetration



Graph Source: Levitus, S., J. Antonov, and T. Boyer. 2005.

3. Results



Altimetry Trend
(Absolute Sea Level)
+1.63 ± 1.90
mm/yr
-1.90 ± 0.96
mm/yr
+3.90 ± 0.97
mm/yr
+2.75 ± 0.84
mm/yr
+3.85 ± 1.30
mm/yr
+4.05 ± 0.80
mm/yr
KL
LD
HC
GF
SA
TC
FY
HL
BZL
PH
ST
JG
AP
CK
FG
LT
KS
DG
DW
SGZ
LY
HBH
240
051
164
119˚
120˚
121˚
122˚
123˚
124˚
26˚
24˚
23˚
22˚
21˚

3. Results

Comparison between tide gauges and altimetry

ALT		Trend	TG Station		Trend		ALT-TG	Trend
A	+3.9	±1.9	基隆	KL	+24.5	±0.5	-15.8	±1.9
			龍洞	LD	+0.8	±0.9	+3.1	±2.1
			梗枋	GF	-2.3	±0.2	+6.1	±1.9
			蘇澳	SA	+19.5	±0.2	-5.3	±1.9
B	+2.7	±1.6	花蓮	HL	-2.5	±0.2	+5.3	±1.6
			石梯	ST	+15.9	±0.4	-12.3	±1.6
C	+3.8	±2.4	成功	CK	-12.6	±0.4	-5.7	±2.4
			富岡	FG	+8.7	±0.6	-1.8	±2.5
			綠島	LT	+9.2	±0.4	-5.3	±2.4
D	+4.0	±1.6	大武	DW	+6.8	±0.6	-2.7	±1.7
			蘭嶼	LY	-1.2	±0.5	+5.3	±1.7

standard deviation (95% interval confidence)

Unit：mm/year

ALT trend - TG trend
= Vertical Land motion

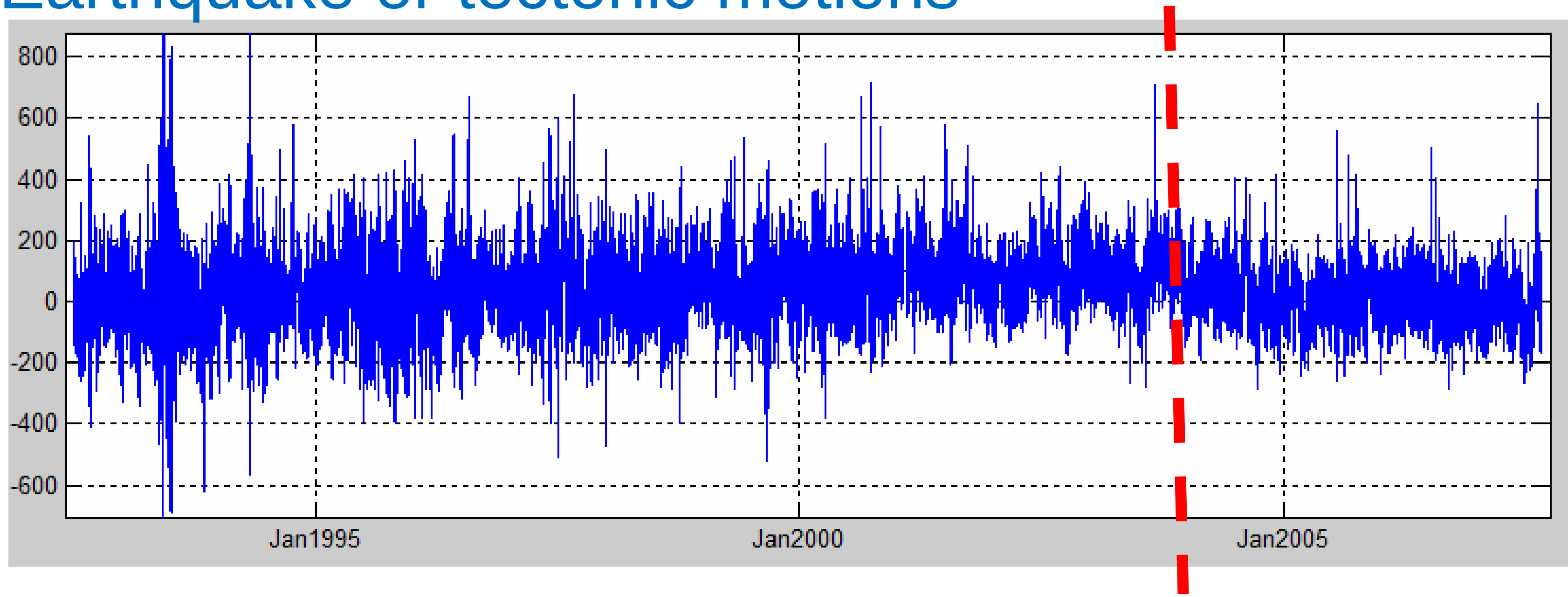
ALT Trend			TG Station		Trend		ALT-TG	Trend
F	+1.63	±1.90	新竹	HC	-7.62	±1.97	+9.25	±2.74
			台中港	TC	-38.93	±2.50	+40.56	±3.14
			芳苑	FY	+13.74	±1.25	-12.11	±2.27
			箔子寮	BZL	+32.86	±1.87	-31.23	±2.67
			將軍	JG	+11.02	±0.51	-9.39	±1.97
			安平	AP	+15.96	±0.52	-14.33	±1.97
			澎湖	PH	-1.05	±0.41	+2.68	±1.94
E	-1.90	±0.96	高雄	KS	-3.44	±0.26	+1.54	±0.99
			東港	DG	+22.09	±0.42	-23.99	±1.05
			蟳廣嘴	SGZ	-12.78	±0.22	+10.88	±0.98
			後壁湖	HBH	+33.69	±0.13	-35.59	±0.97

對於西岸的驗潮紀錄，因爲各段的趨勢有很大的不同，故不用Step fuction連接前後時間序列，而選取各驗潮紀錄最後一段，估計近幾年的陸地升降趨勢。

同樣將結果圖示如左，數字的紅色代表抬藍色代表下降。

3. Results

Earthquake or tectonic motions



Least-Square fitting

$$TG_{raw}(t) = a_0 + a_1 t + \sum_{i=1}^{15} \{A_i \sin(\omega_i t) + B_i \cos(\omega_i t)\} + n(t)$$

TG = Sea level measured per hour by Tidal Gauge

t = Time

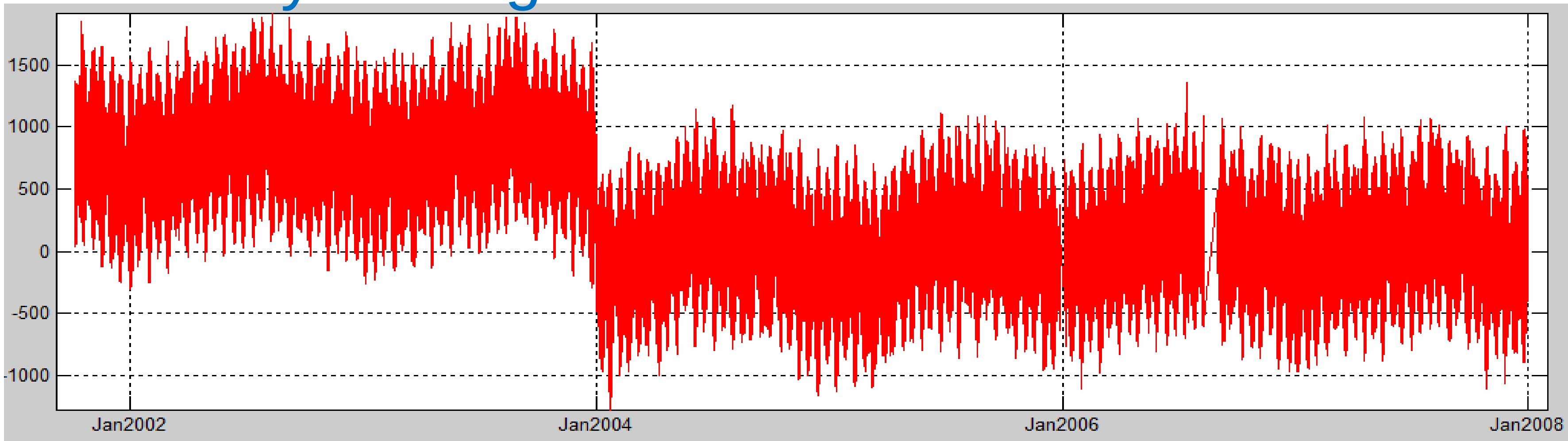
ω_i =frequency of Ocean Tide and Seasonal Signals components

n = The residual values and random errors

3. Results

Artificially shifting

LuTao (6 years)



Least-Square fitting

$$TG_{raw}(t) = a_0 + a_1 t + a_2 S(t) + \sum_{i=1}^{15} \{A_i \sin(\omega_i t) + B_i \cos(\omega_i t)\} + n(t)$$

TG = Sea level measured per hour by Tidal Gauge

S = Step Function

t = Time

ω_i =frequency of Ocean Tide and Seasonal Signals components

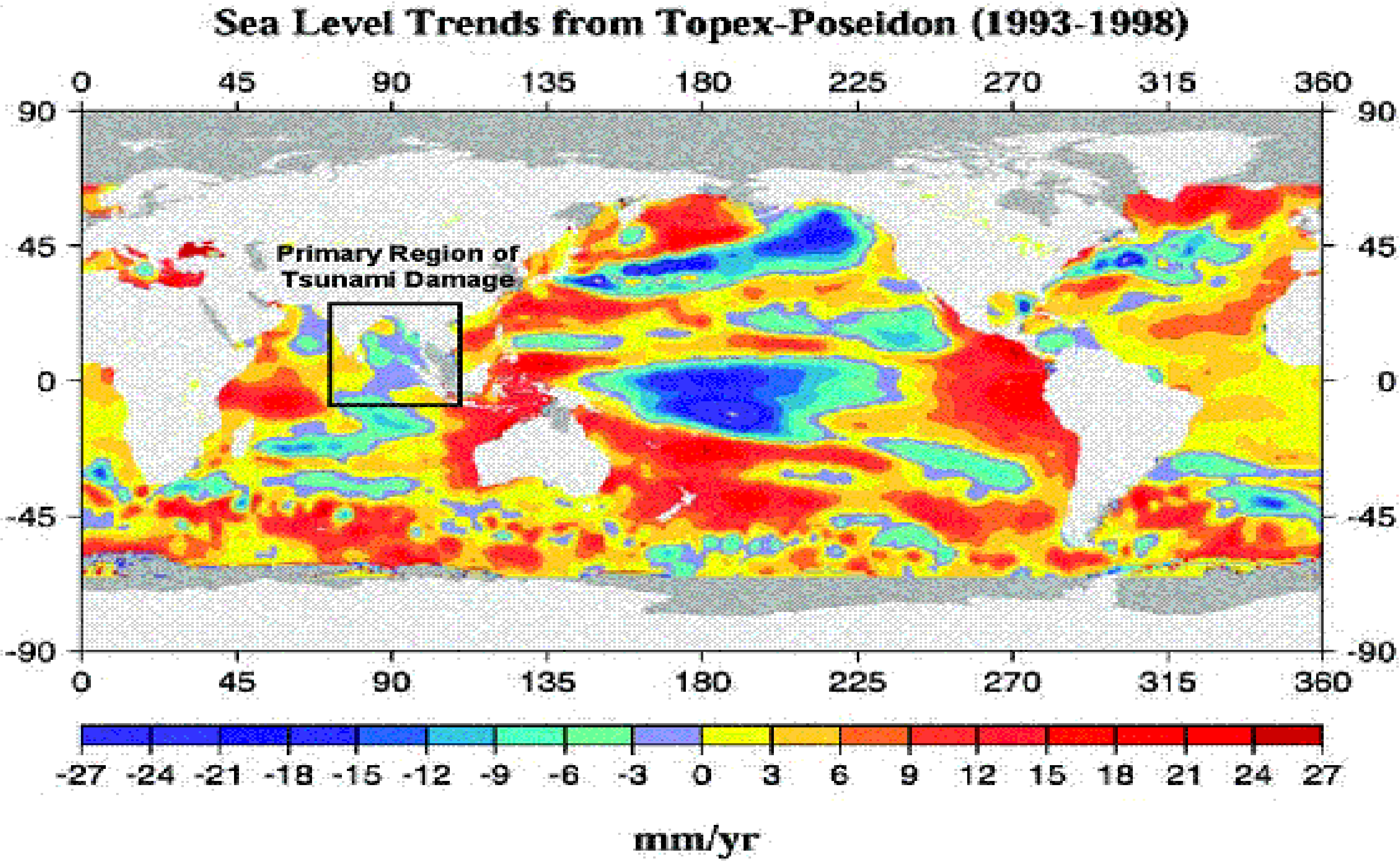
n = The residual values and random errors

3. Results

global SLR (1993-2000)

Regional trend pattern around Taiwan reflects feature in the northwestern Pacific (T/P)

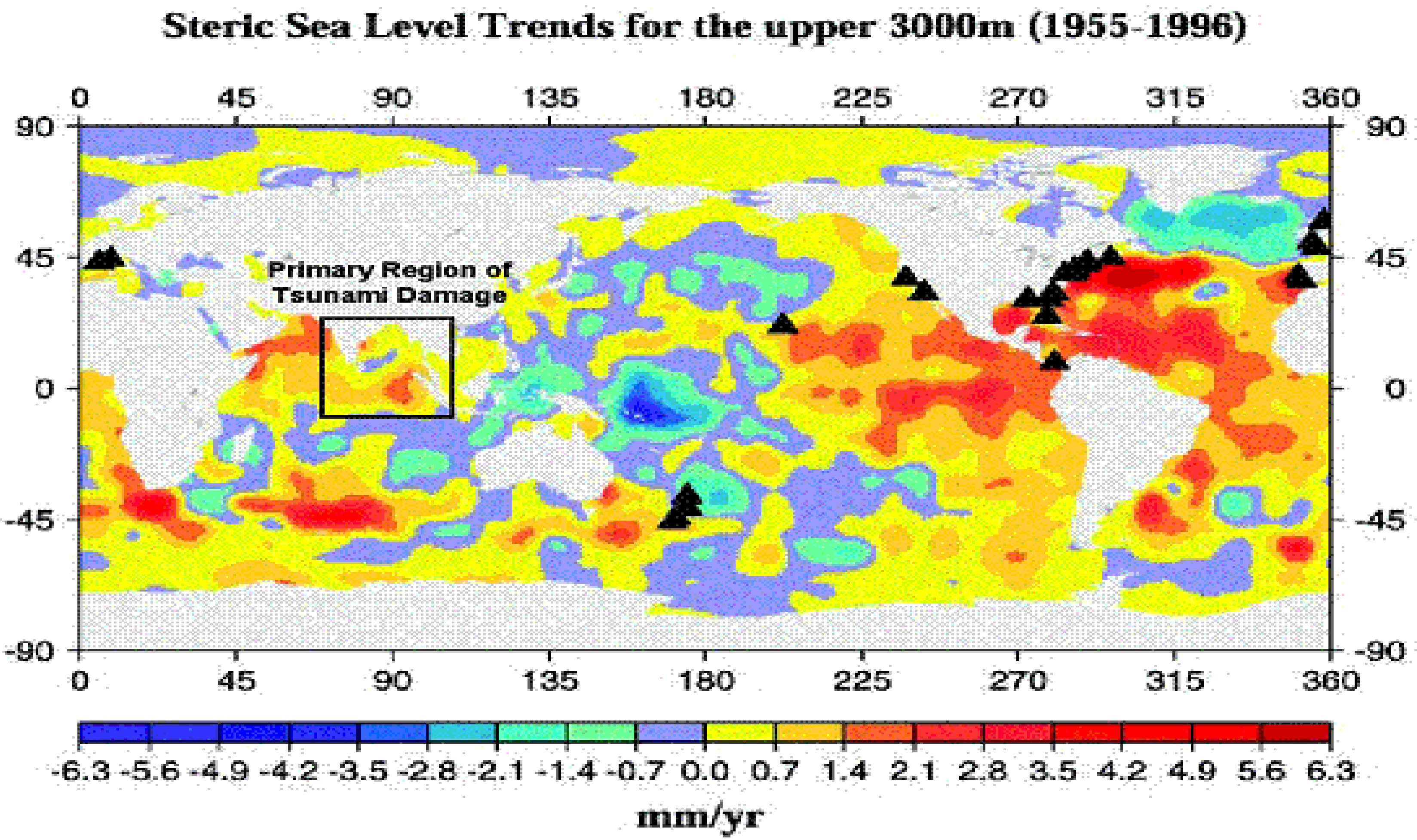
Cabanes et al.(2001)



3. Results

global SLR (TSL) ~ 0.5mm/yr (1961-2000)

Cabanes et al.(2001)



Summary & Conclusion

- Inhomogeneous trends and patterns of SLR around Taiwan
- SLR is larger than the global mean
- Larger SLR can be mainly explained by larger thermal expansion
- Vertical motions of land may play a role in the overestimation
- Further studies are needed……