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Global Mean Mass Sea-Level Change From 1993 to 2016 Derived by Tongji Temporal Gravity Field Solutions

Yunzhong Shen[1] Qiujie Chen[1] Fengwei Wang[1] Xingfu Zhang[2] Yufeng Nie[1]

[1]Tongji University [2]Guangdong University of Technology

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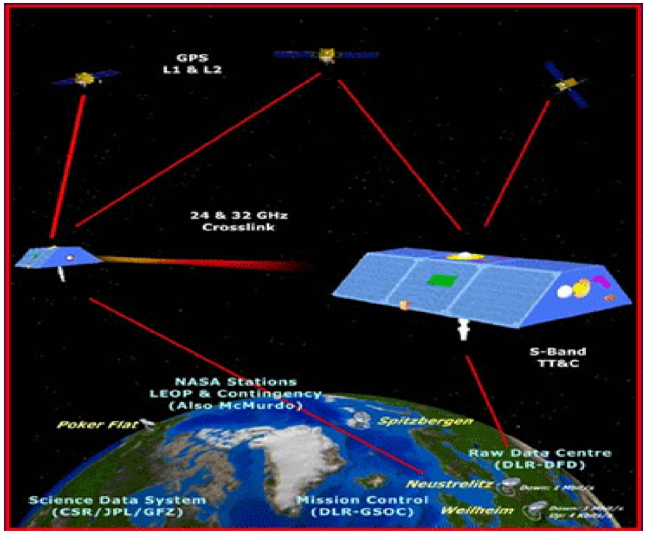
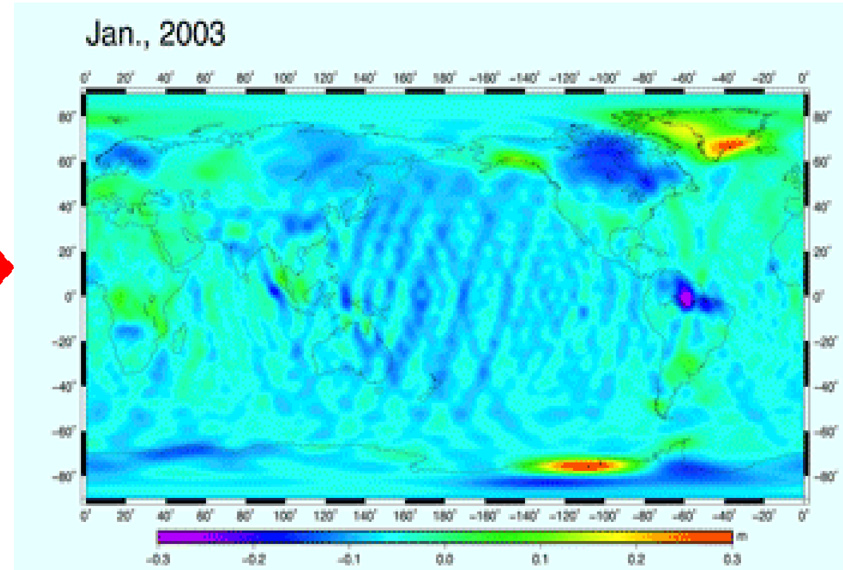
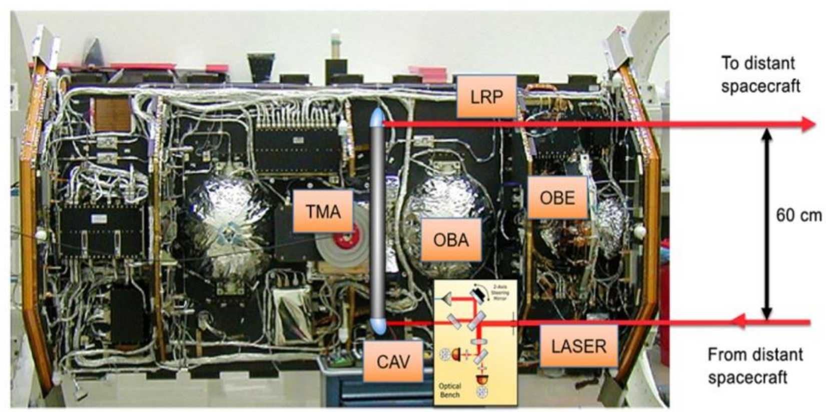
Background — Satellite Gravimetry

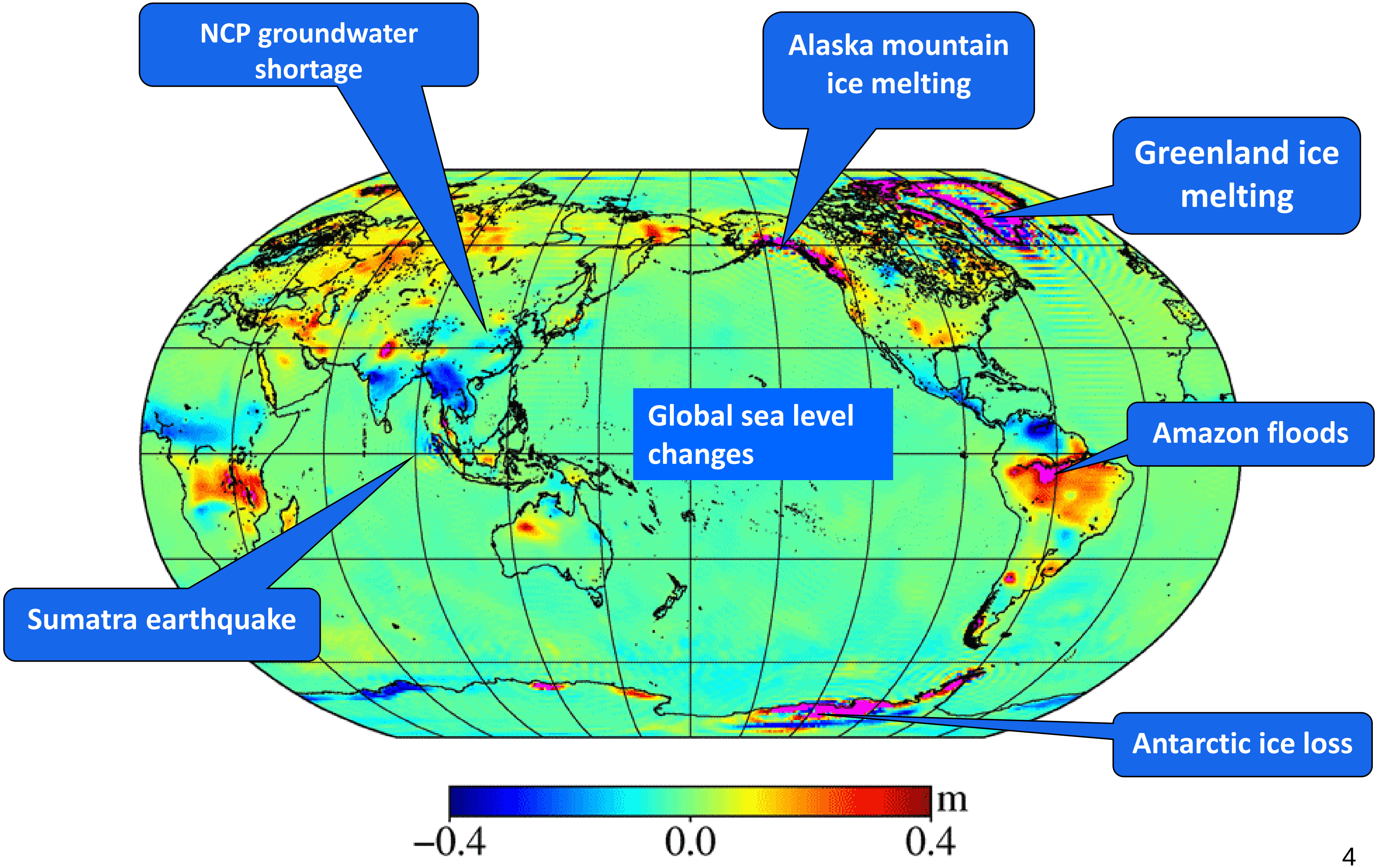




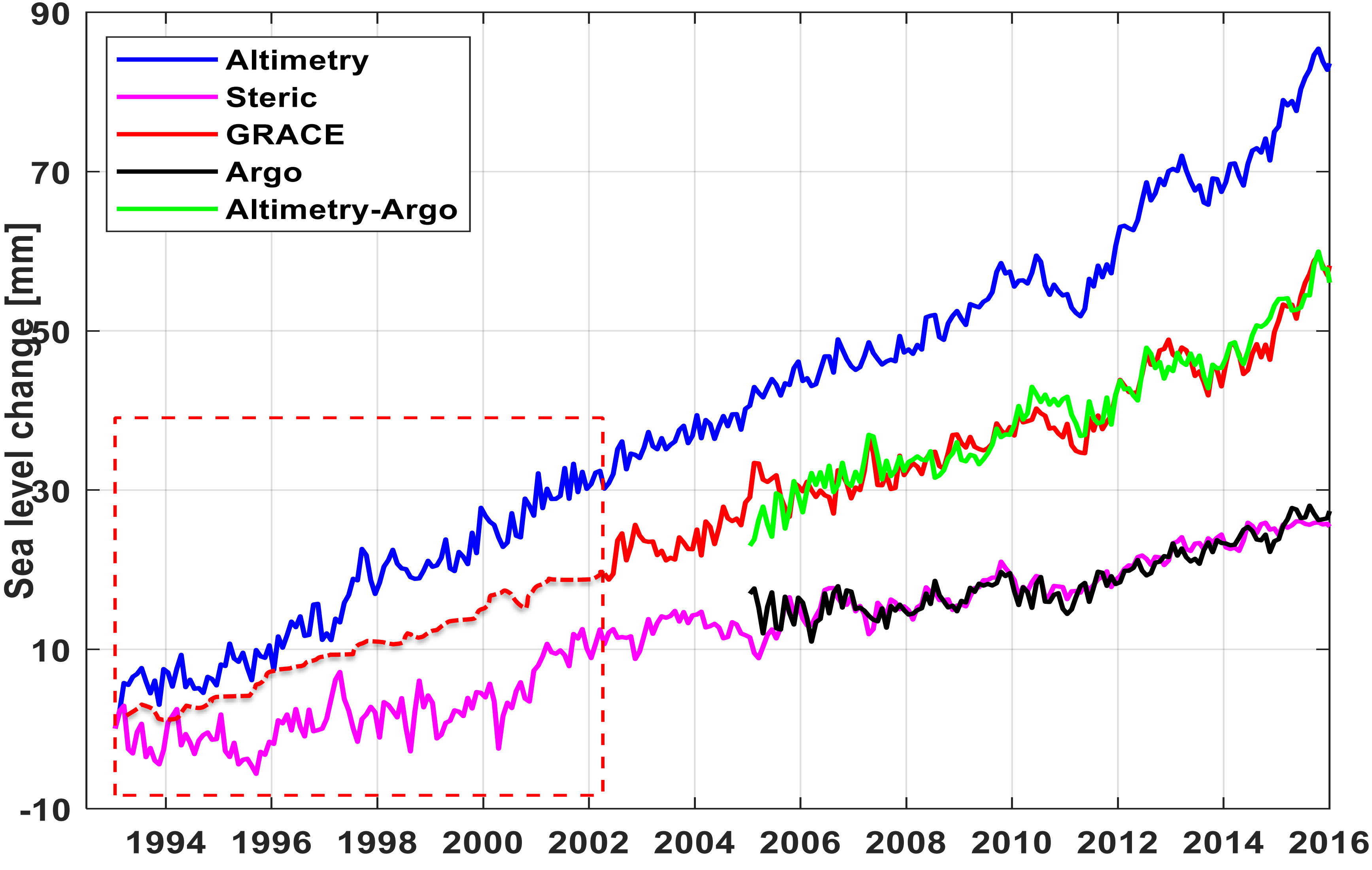


LRI, precision ~1.0nm/s

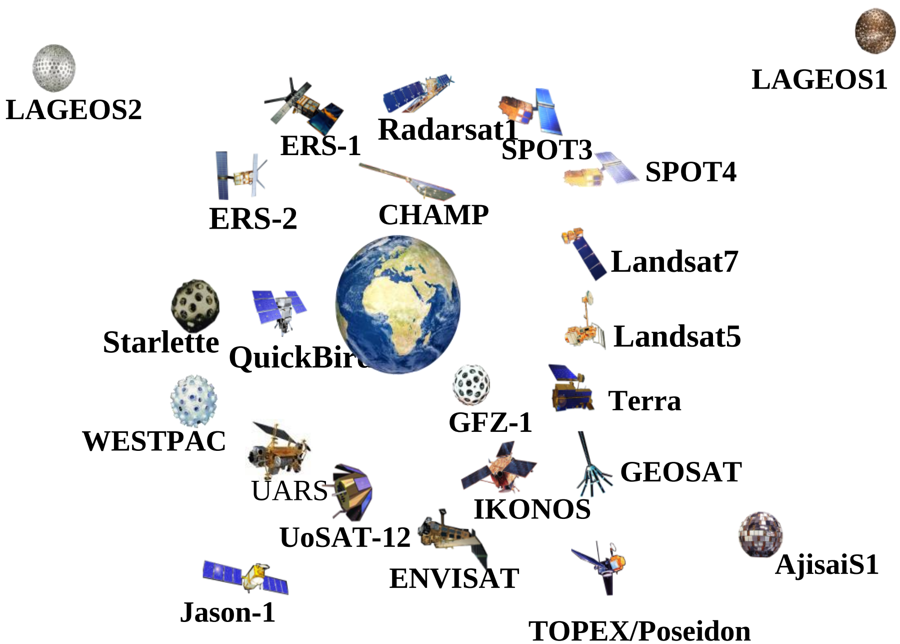
Background — Earth Mass Transport

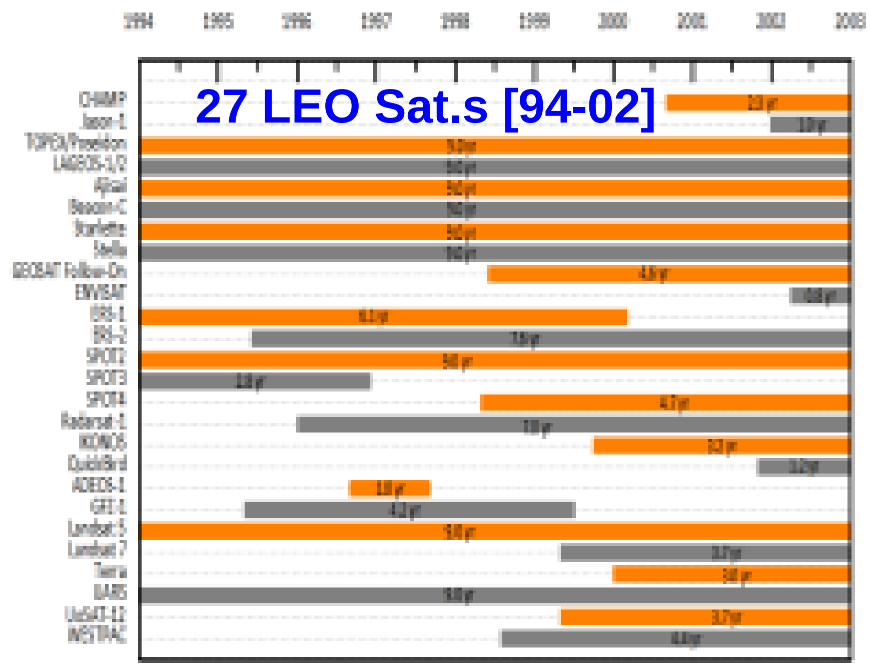


Background — Sea-Level Budget



Background — LEO Satellites





Methodology — Improved Short-arc Approach

$$\boldsymbol{r}(\tau)=\boldsymbol{r}_0(1-\tau)+\boldsymbol{r}_N(\tau)-T^2\int_0^1 K(\tau,\tau')\boldsymbol{a}\left(\boldsymbol{r}(\tau'),\boldsymbol{u},\boldsymbol{p}(\tau')\right)d\tau'$$ **Orbit**

$$\boldsymbol{r}(\tau')=\boldsymbol{r}_k(\tau')+\boldsymbol{v}_r(\tau')$$

$\boldsymbol{p}(\tau')$: Polynomial Model

$$\dot{\boldsymbol{r}}(\tau)=(\boldsymbol{r}_N-\boldsymbol{r}_0)/T+T\int_0^1\frac{\partial K(\tau,\tau')}{\partial\tau}\boldsymbol{a}\left(\boldsymbol{r}(\tau'),\boldsymbol{u},\boldsymbol{p}(\tau')\right)d\tau'$$

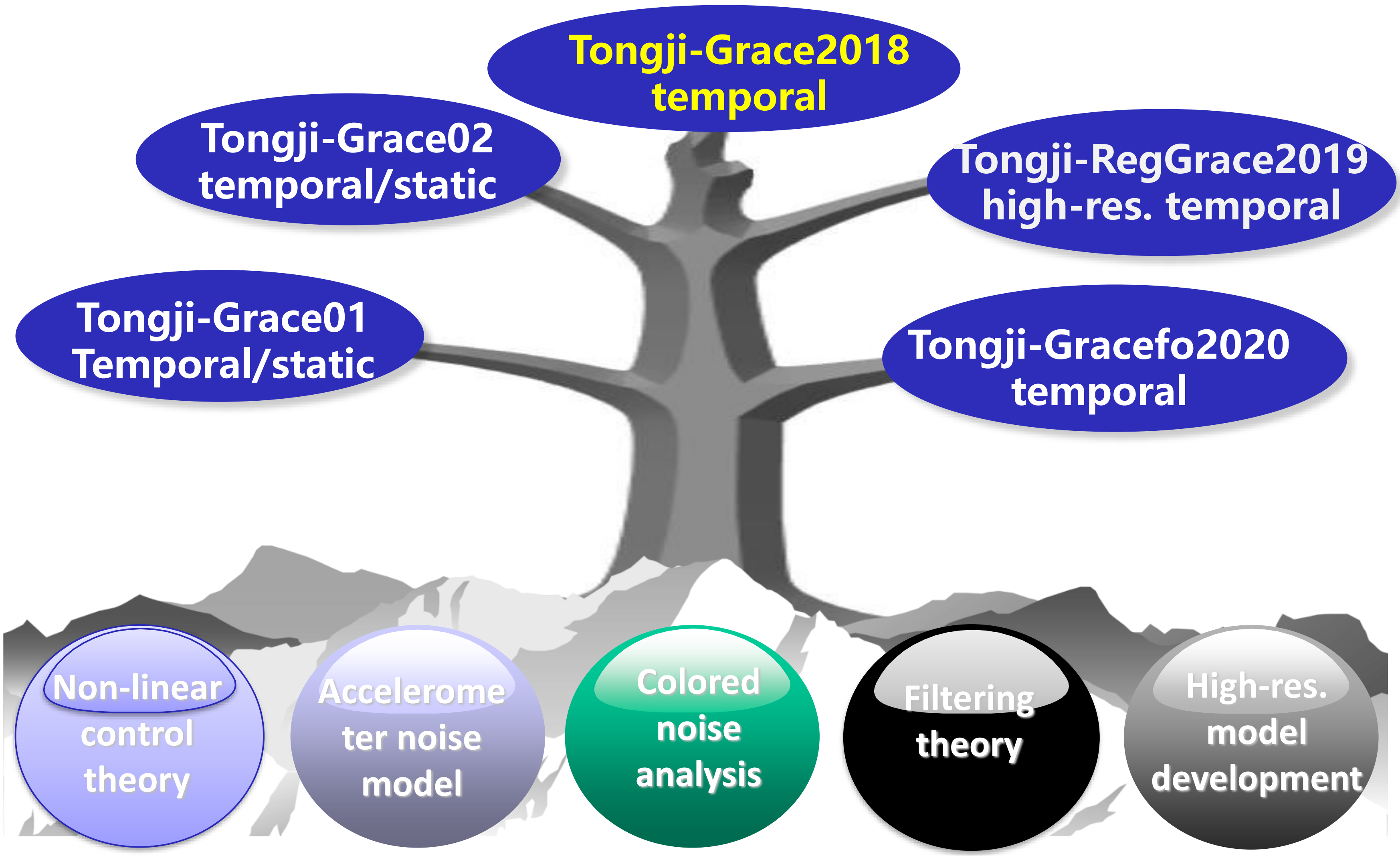
$$\dot{\rho}(\tau)+v_{\dot{\rho}}(\tau)=\left(\dot{\boldsymbol{r}}_B(\tau)-\dot{\boldsymbol{r}}_A(\tau)\right)\bullet\boldsymbol{e}_{AB}(\tau)$$ **Range Rate**

Tongji-GRACE01 Model: Modelling Orbit and KBR Obs. Errors

Tongji-GRACE02 model: Further Modelling Acc. and Attitude Obs. Errors

Tongji-GRACE2018 model: 6 hour Arc Length, Optimized Algorithm

Tongji Solutions — GRACE Solutions



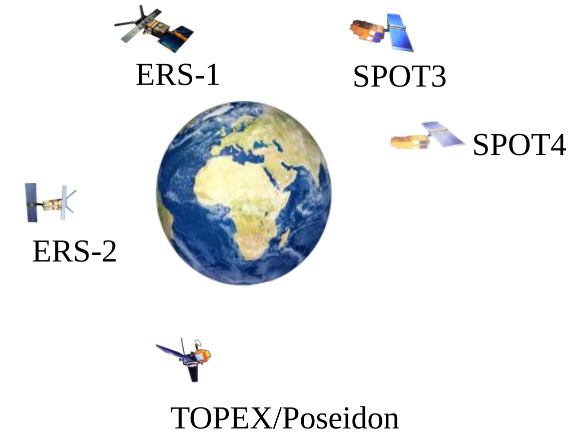
Methodology — Gravity Recovery from LEOs

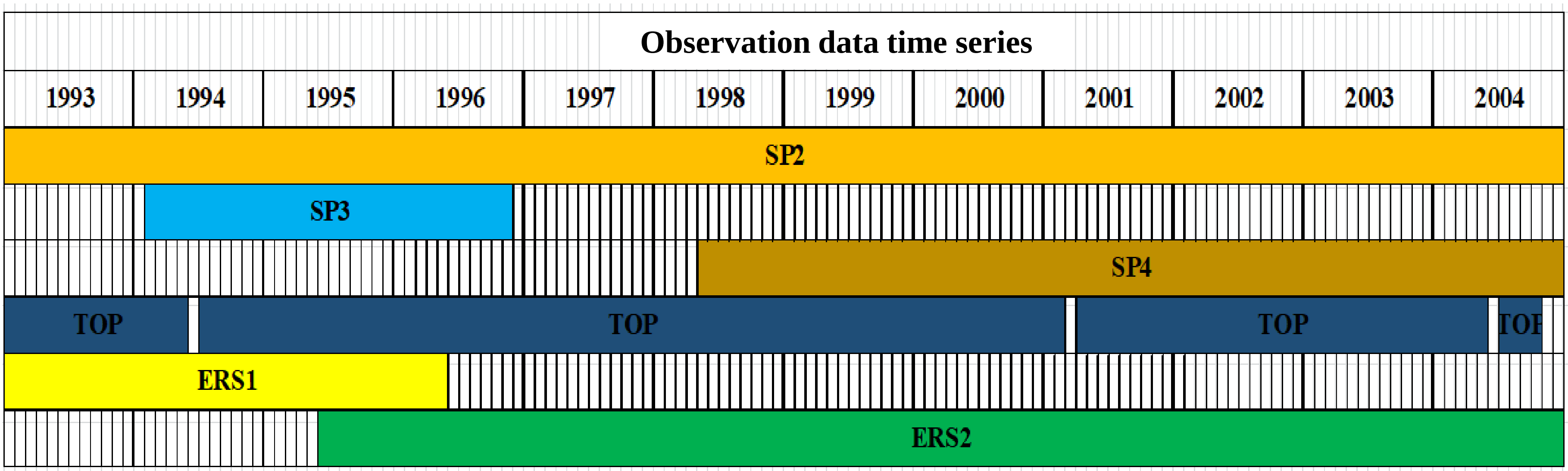
$$\boldsymbol{r}(\tau)=\boldsymbol{r}_0(1-\tau)+\boldsymbol{r}_N(\tau)-T^2\int_0^1 K(\tau,\tau')\boldsymbol{a}\big(\boldsymbol{r}(\tau'),\boldsymbol{u},\boldsymbol{p}(\tau')\big)d\tau'$$

$$\boldsymbol{r}(\tau')=\boldsymbol{r}_k(\tau')+\boldsymbol{v}_r(\tau')$$

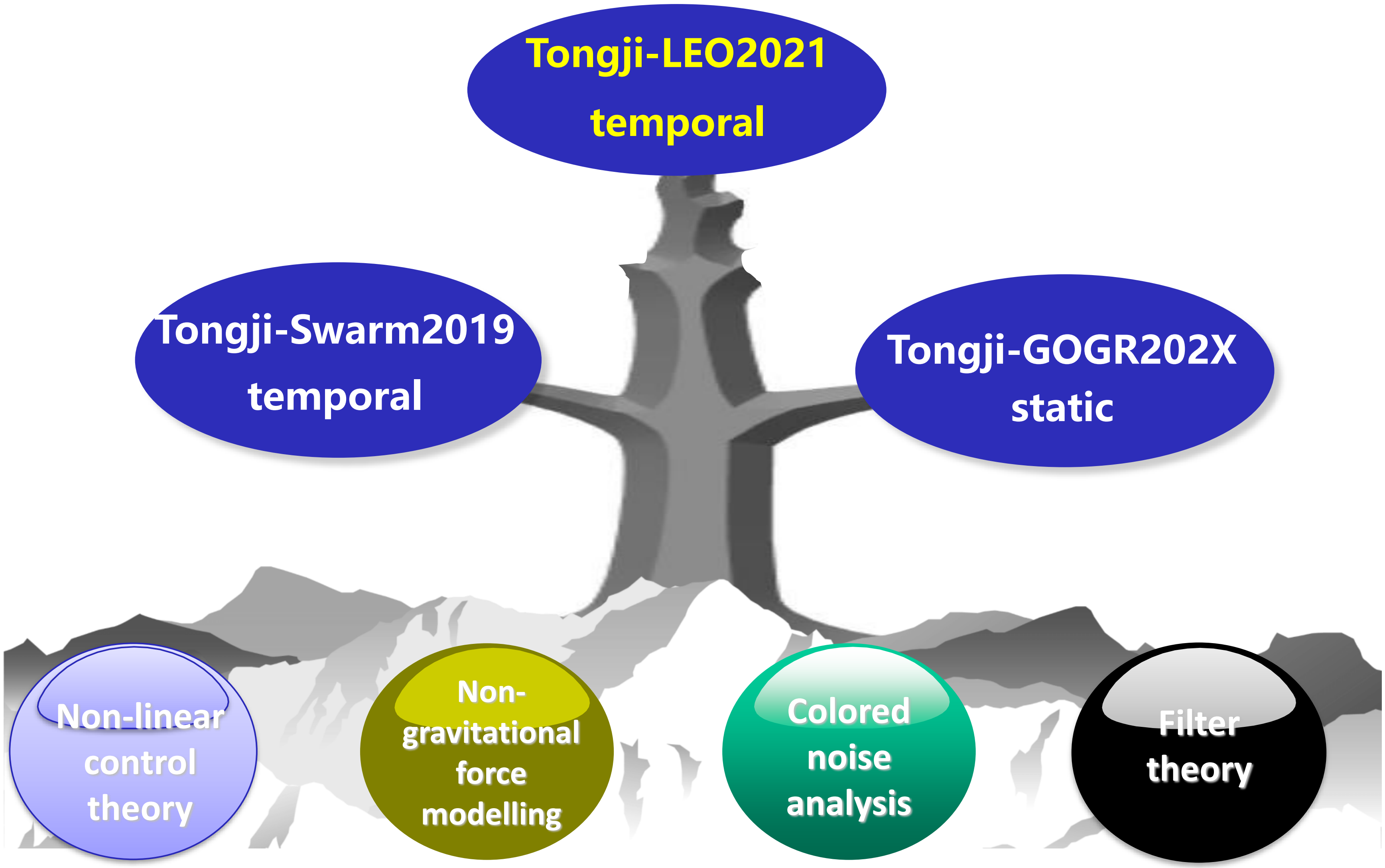
$\boldsymbol{p}(\tau')$: **Empirical forces**

(Montenbruck and Gill, 2000)





Tongji Solutions — Other LEO Solutions



Methodology — Postprocessing

➢ C_{20}, Deg-1 and GIA Correction

– Tongji-LEO2021: **C_{20}** and **Deg-1** with SLR solutions
– Tongji-Grace2018: **C_{20}** and **Deg-1** with TN-14 and TN-13
– GIA corrections with **ICE6G-D** model

➢ Temporal Estimation of Mean Mass Sea-Level

$$\Delta m(\theta,\lambda,t)=\left(\frac{a\rho_{ave}}{3\rho_{water}}\frac{2n+1}{1+k_n}\sum_{n=0}^{N_{\max}}\sum_{m=0}^{n}W_{n,m}\left(\Delta C_{nm}(t)\cos m\lambda+\Delta S_{nm}(t)\sin m\lambda\right)\bar{P}_{nm}(\cos\theta)\right)\times S$$

where: $\Delta C_{nm}=C_{nm}-\bar{C}_{nm}$, $\Delta S_{nm}=S_{nm}-\bar{S}_{nm}$

W_{nm}: **P4M6+Gauss 300** for Tongji-Grace2018
Gauss1000 for Tongji-LEO2021

➢ Mean Mass Sea-Level Change

$$\Delta m(\theta,\lambda,t)=\beta_0(\theta,\lambda)+\boxed{\beta_1(\theta,\lambda)}(t-t_0)+\beta_2(\theta,\lambda)\cos(2\pi(t-t_0)+\varphi_1(\theta,\lambda))$$
$$+\beta_3(\theta,\lambda)\cos(4\pi(t-t_0)+\varphi_2(\theta,\lambda))$$

Sea-level Change — Area and Data

Study Area

Buffer Zone 300km & ±66°

Excluding: Caspian Sea, Black Sea & Mediterranean Sea

Data

Altimetry：

AVISO [0.25°×0.25°] Converted to [1°×1°]

1993.01~2016.12

Steric：

EN4 (Good et al., 2013) (1993.01~2016.12)

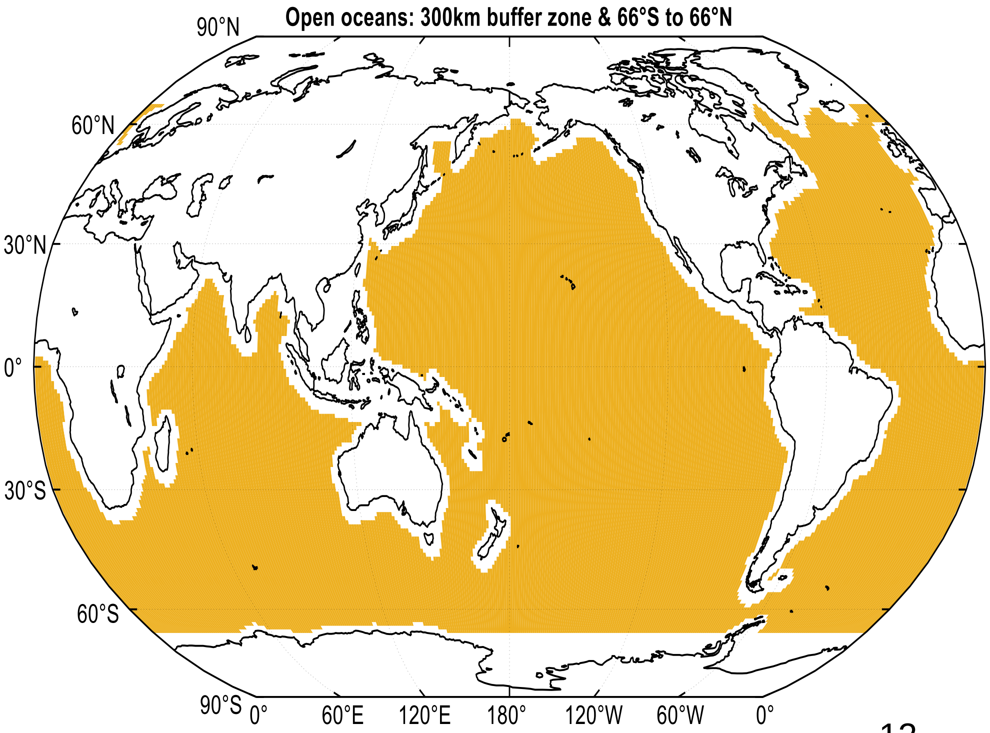
IK09 (Ishii &Kimoto, 2009) (1993.01~2016.12)

Argo (IPRC, CSIO, SIO) (2005.01~2016.12)

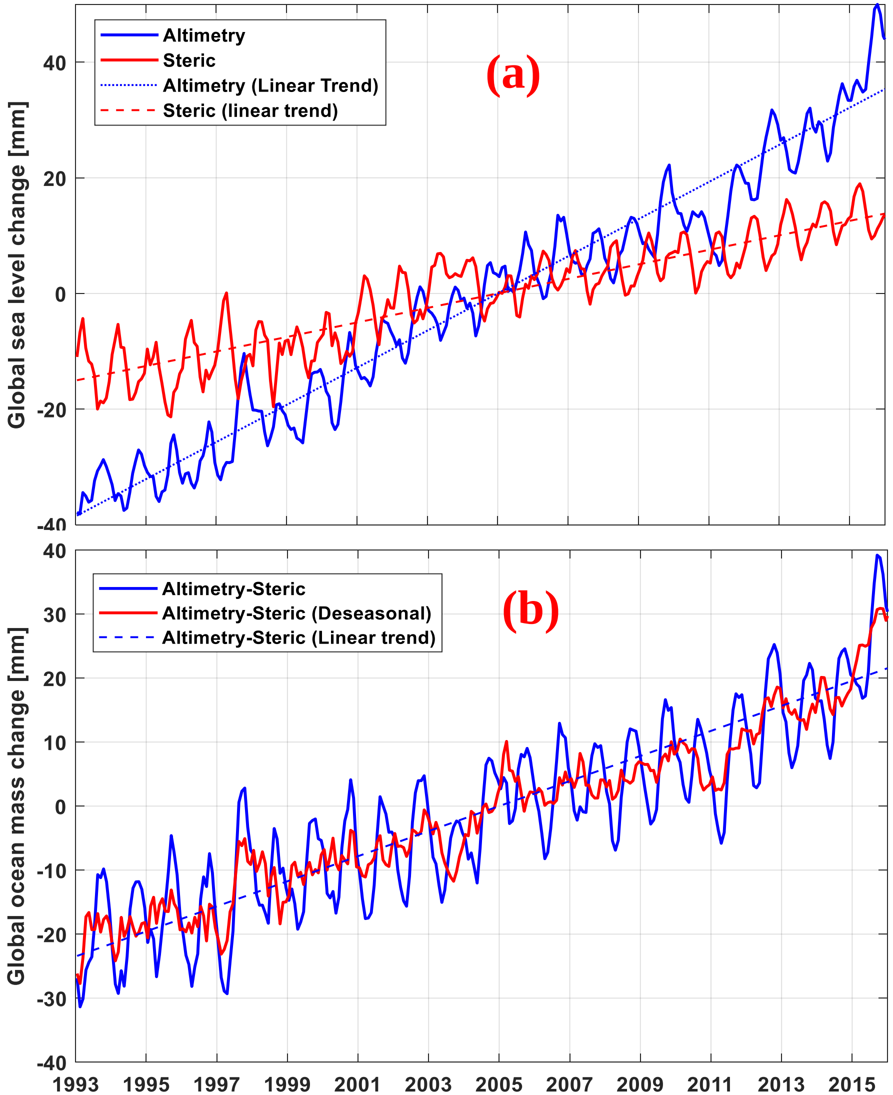
Satellite Gravimetry:

Tongji-LEO2021 (d/o 40) (1993.01~2004.12)

Tongji-Grace2018 (d/o 60) (2002.4~2016.12)



Sea-level Change — Altimetry & Steric



Total Sea-Level Change from Altimetry

TOPEX drift correction: **1.50 mm/year**

1993.01~1998.12

Trend: **2.98±0.07 mm/year**

Steric Sea-level Change

Deep steric (>2000m): **+0.10 mm/year**

EN4 & IK09: **1.25±0.07 mm/year**

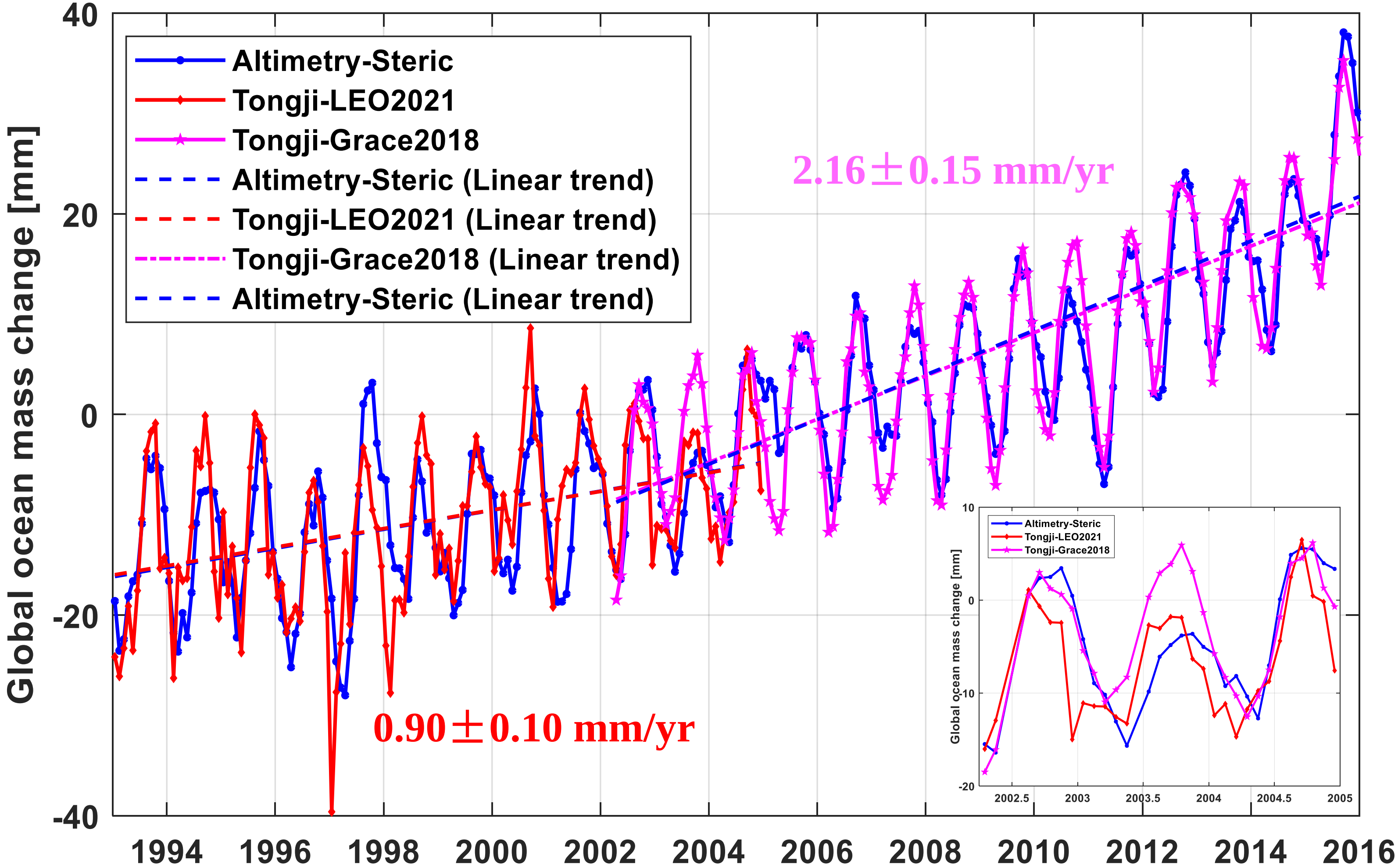
Sea-level Change of Altimetry-Steric

Altimetry-Steric: **1.73±0.08 mm/year**

After removing the data as GRACE gaps

Altimetry-Steric: **1.68±0.08 mm/year**

Sea-level Change — Tongji Solutions



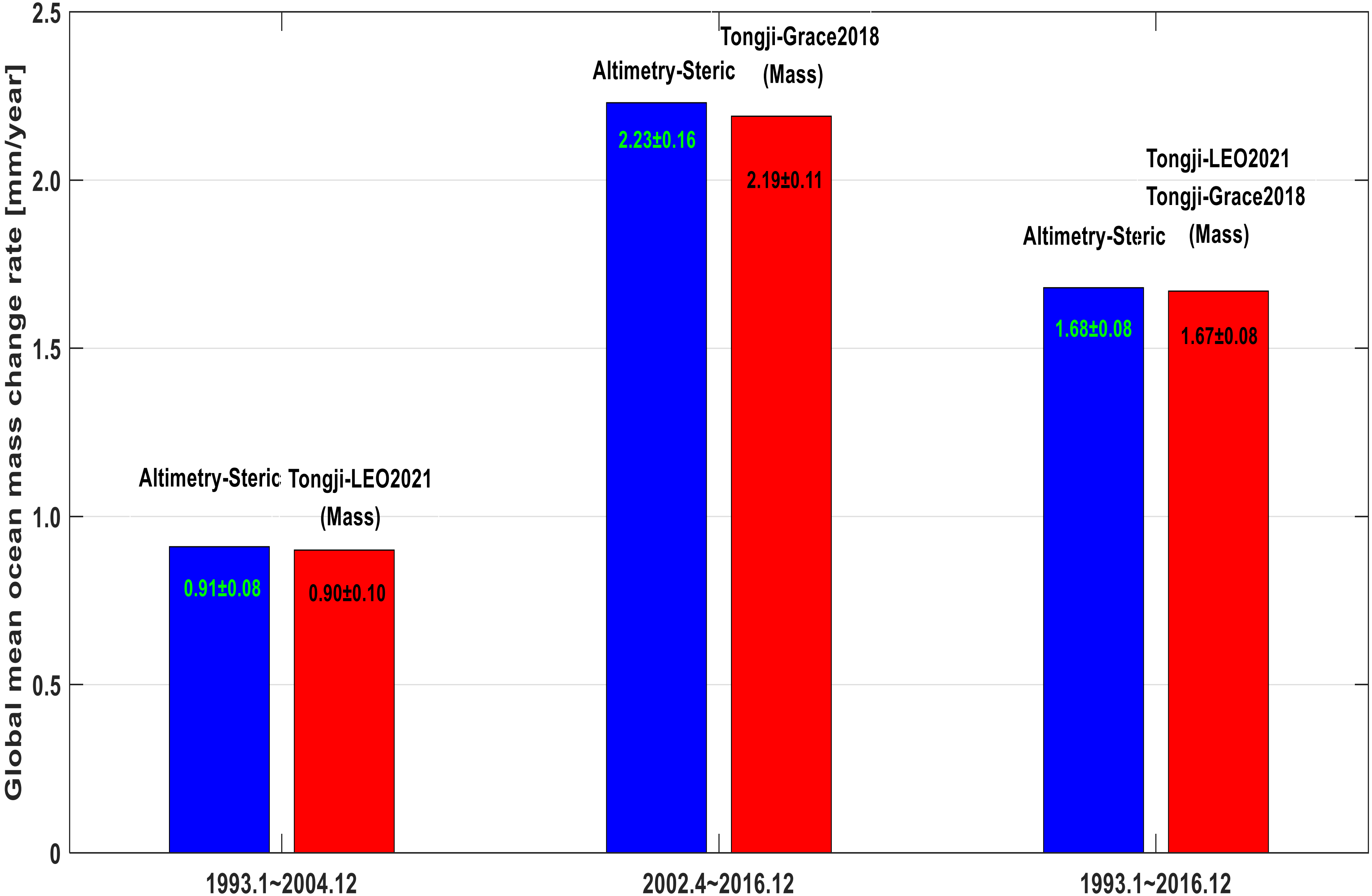
Tongji-LEO2021 (1993-2004): Gauss1000km

Tongji-Grace2018 (2002-2016): P4M6 + Gauss300km

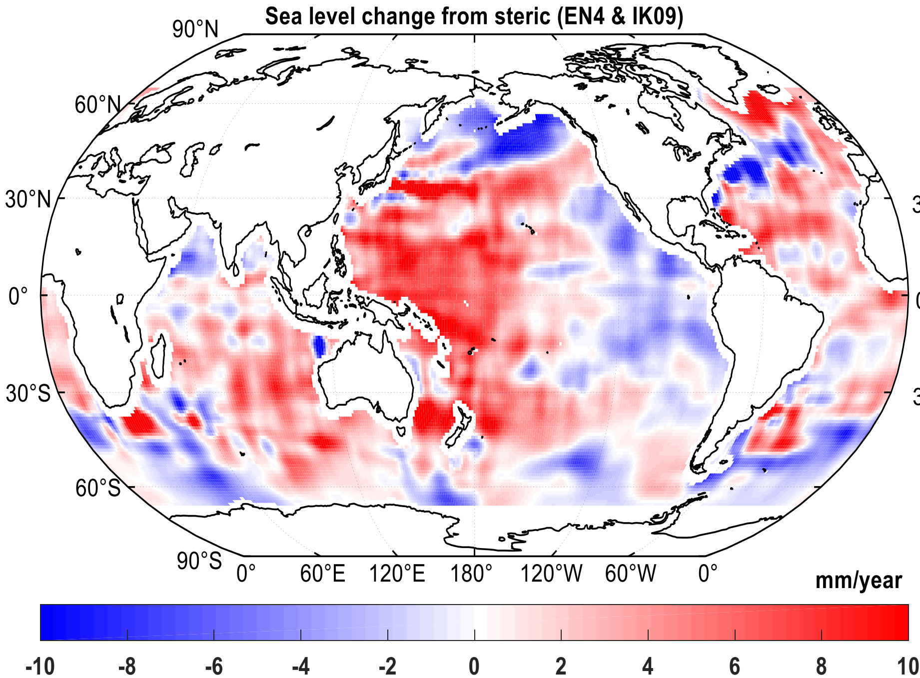
Sea-level Change — 1993.01 – 2016.12

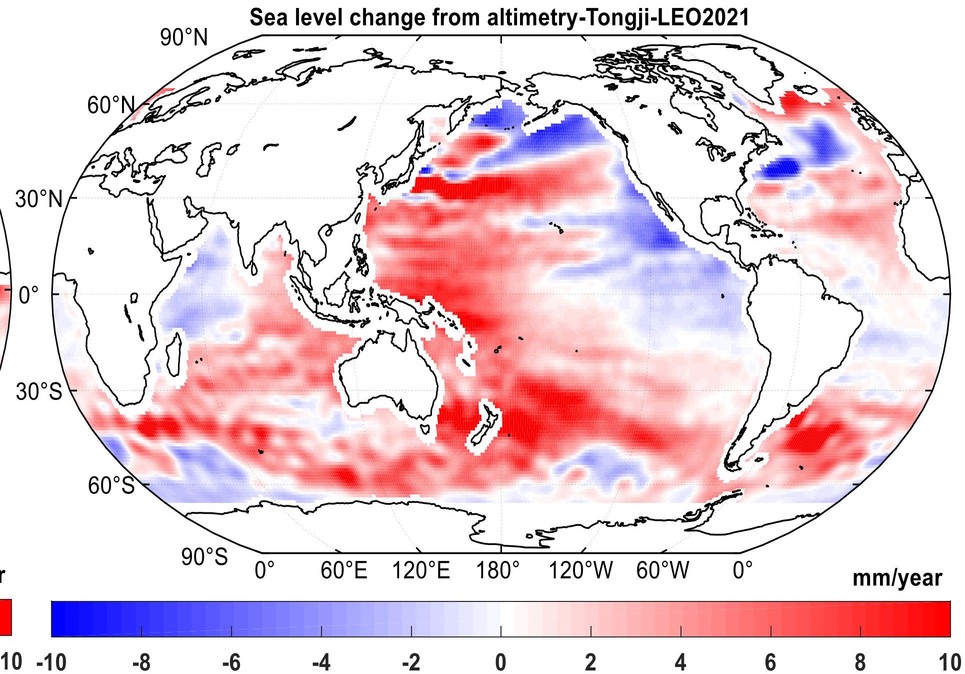
Time span	GMSL(mm)	Annual Amp. [mm] Phase[o]	Semiannual Amp.[mm] Phase[o]	Trend [mm/year]
1993.01 ~ 2004.12	Altimetry-Steric	[8.28±0.40] [276.3±2.8]	[0.92±0.40] [105.1±25.0]	0.91±0.08
	Tongji-LEO2021	[8.03±0.50] [246.6±3.5]	[2.02±0.49] [149.0±14.0]	0.90±0.10
2002.04 ~ 2016.12	Altimetry-Steric	[7.51±0.47] [283.1±3.6]	[1.69±0.47] [85.9±16.1]	2.23±0.16
	Tongji-Grace2018	[9.16±0.31] [270.7±2.0]	[1.08±0.31] [39.2±15.1]	2.19±0.11
1993.01 ~ 2016.12	Altimetry-Steric	[7.81±0.37] [278.6±2.7]	[1.38±0.37] [92.5±15.6]	1.68±0.08
	Tongji-LEO2021 Tongji-Grace2018	[8.45±0.39] [259.7±2.6]	[0.93±0.39] [109.9±24.0]	1.67±0.08

Sea-level Change — Trend Comparison



Sea-level Change — Spatial Patterns

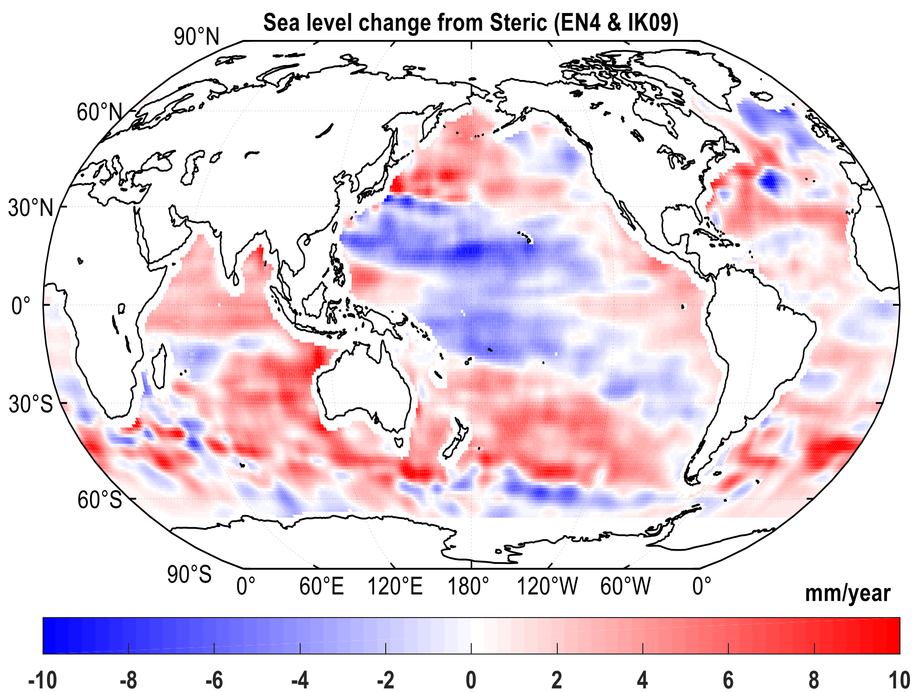


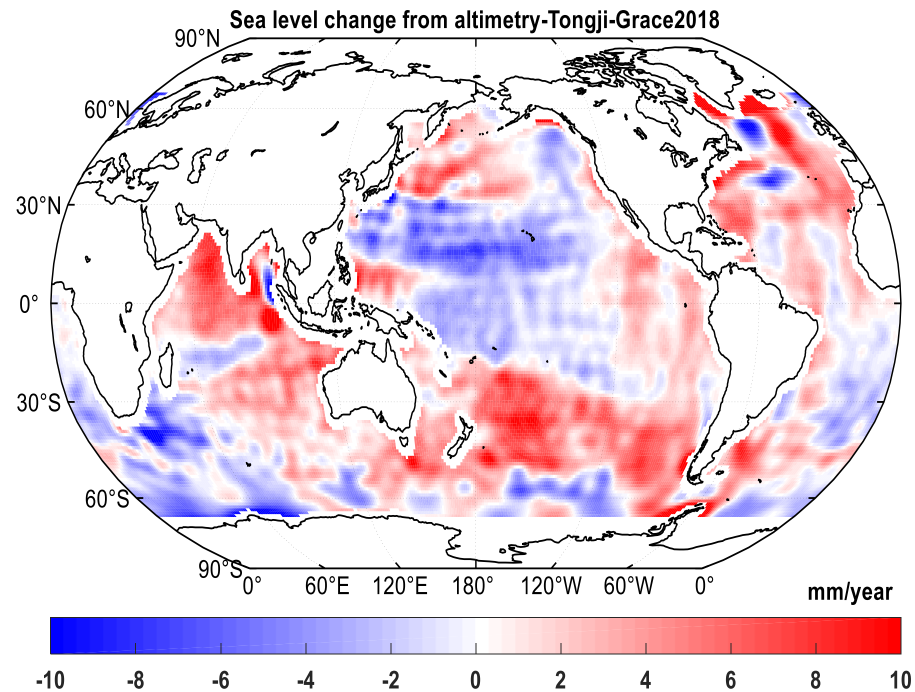


Steric sea level change rates (1993.1~2004.12)

(Observed) **(Altimetry -Tongji-LEO2021)**

Sea-level Change — Spatial Patterns

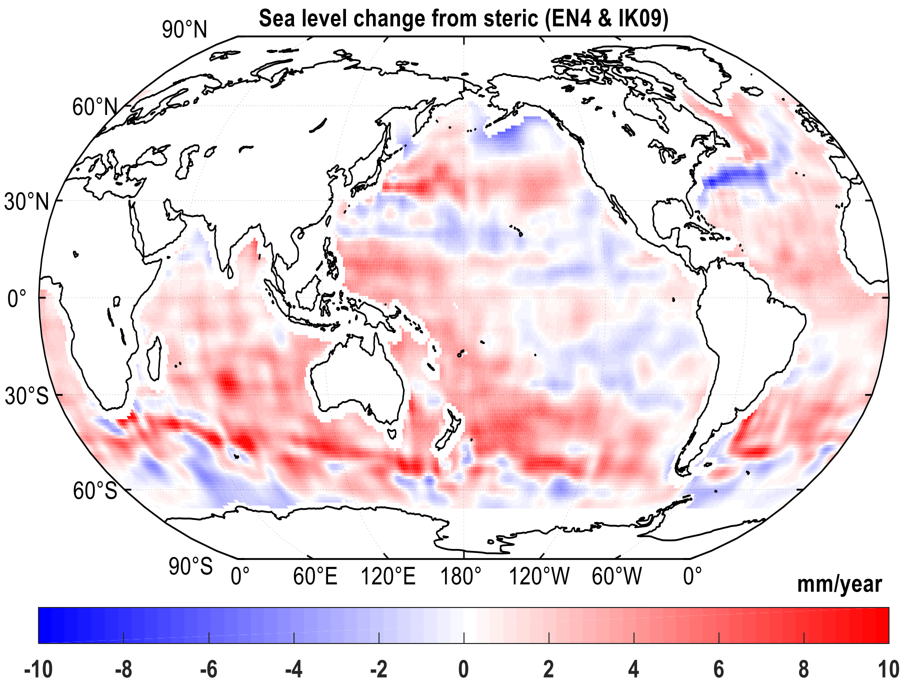


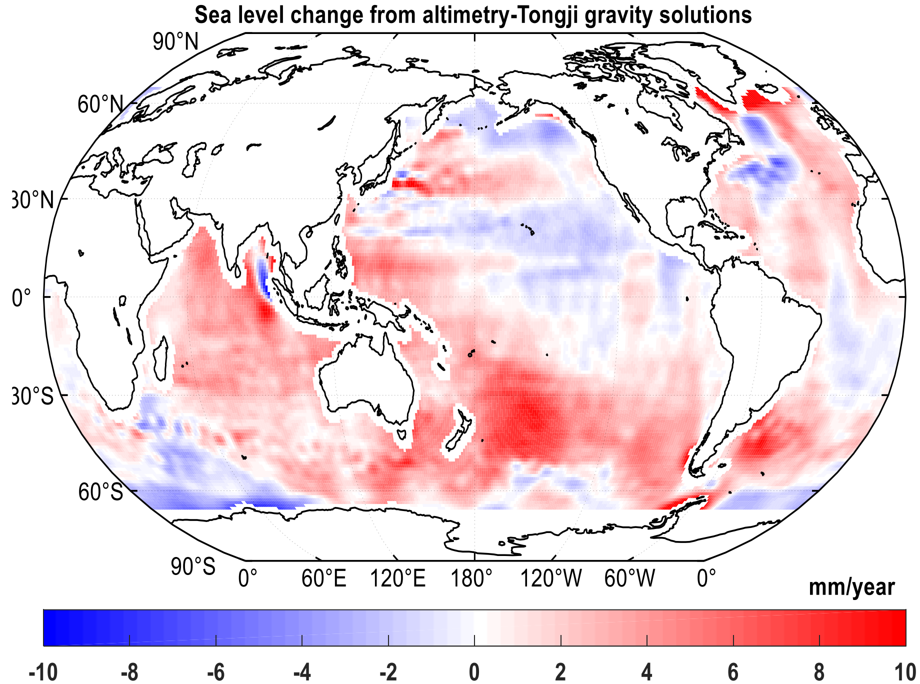


Steric sea level change rates (2002.4~2016.12)

(Observed) **(Altimetry -Tongji-Grace2018)**

Sea-level Change — Spatial Patterns





Steric sea level change rates (1993.1~2016.12)

(Observed) **(Altimetry –Tongji Solutions)**

Conclusion

- Tongji-Grace2018 gives global mean mass sea-level change trend from 2002.04 to 2016.12 to be **2.19±0.11 mm/yr**, consistent with **2.23±0.16 mm/yr** from altimetry-steric;
- Tongji-LEO2021 is the first global temporal gravity model series from 1993 to 2004, it estimates global mean mass sea-level change trend as **0.90±0.10 mm/yr,** closed to **0.91±0.08 mm/yr** from altimetry-steric;
- The global mean mass sea-level change trend from Tongji-LEO2021&Tongji-Grace2018 is **1.67±0.08 mm/yr** from 1993.01 to 2016.12, and **1.60±0.08 mm/yr** from 1993.01 to 2015.1 that is consistent with Chamber et al. (2016) of **1.80±0.46 mm/yr** and Dieng et al. (2017) of **1.87±0.14 mm/yr.**

Thank You
for Your Attention !