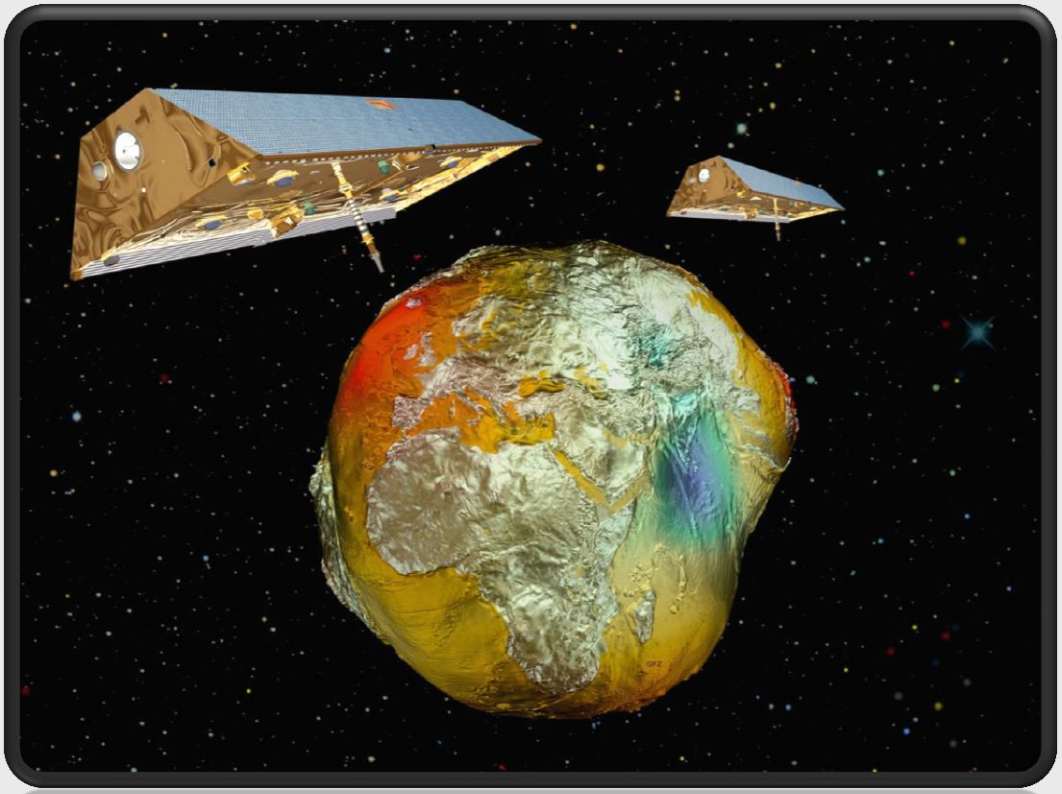
# Mass variations in the Siberian permafrost region based on new GRACE results & auxiliary modeling



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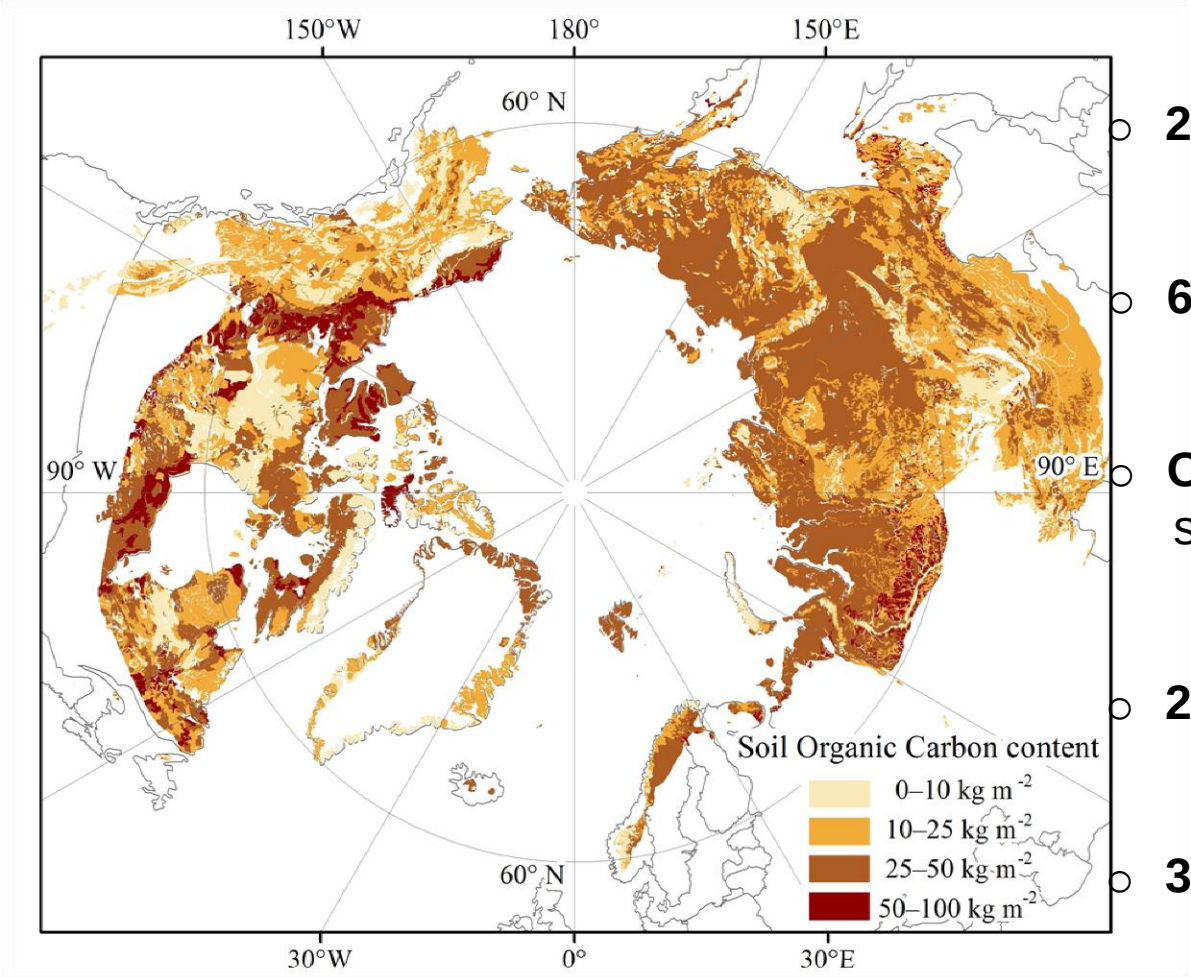
# Motivation

- Since **2002**, monthly solutions are available: more than **12** years of data
  - **GRACE products** are provided by **different analysis centers (e.g. GFZ, UT-CSR and JPL)**
  - **(Surface) mass variations** based on **GRACE** products
  - **Focusing** on **regional/local** patterns of mass variations
- **Constraining** mass variations using complementary models/data e.g. from hydrology, satellite altimetry and satellite imagery
- **The permafrost** region is one of the most challenging areas for **climate change**!

# Permafrost regions




- **22 Million** km$^2$ (circumarctic)
- **65%** of the Russia land area
- **Organic Carbon** storage in soils **(~1.700 Gt)**
- **2 times** of all **$CO_2$** in atmosphere
- **3 times** of all **$CO_2$** in plants

Courtesy: http://bolin.su.se/

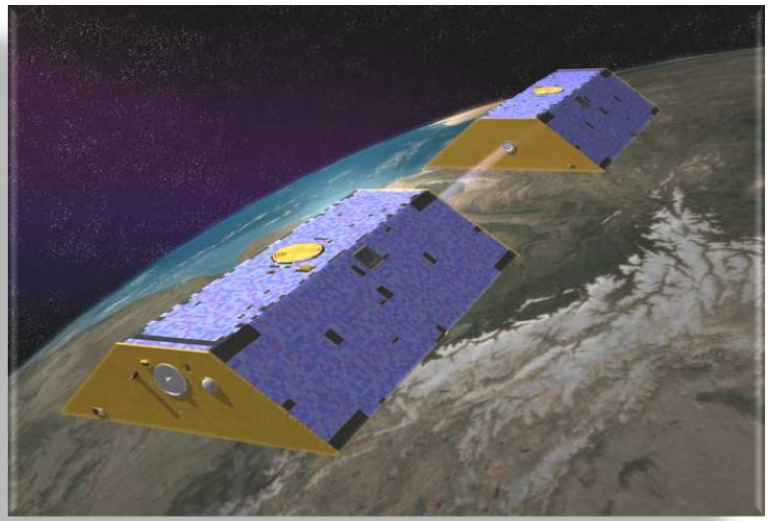
**Climate change (warming) and air pollution!**

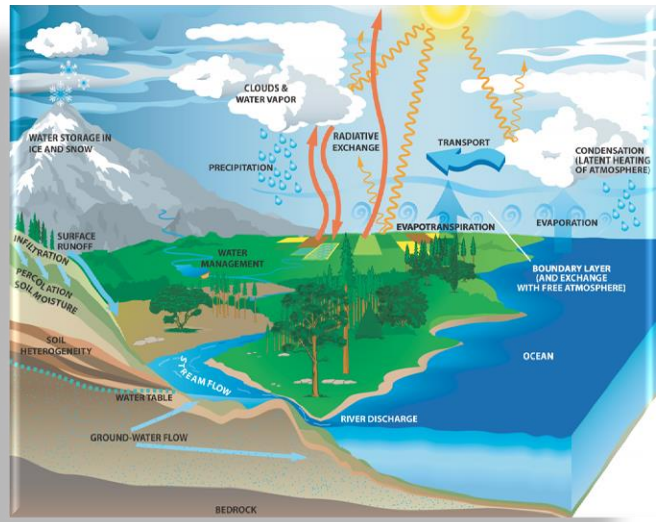
# Permafrost in Siberia (Russia)

- **Region of interest**
  - Siberian permafrost
  - 80% of Siberia is covered by frozen layers!

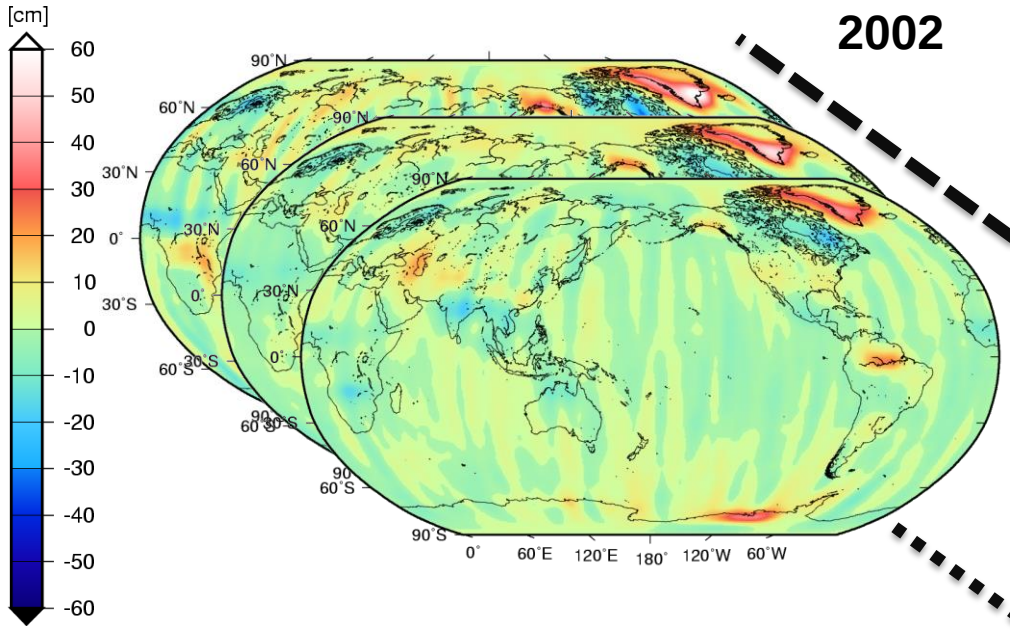
- **Hydrological mass variations (e.g. GLDAS)**
  - Precipitation
  - Evapotranspiration
  - Run-off

- **(Surface) mass variations**
  - GRACE products





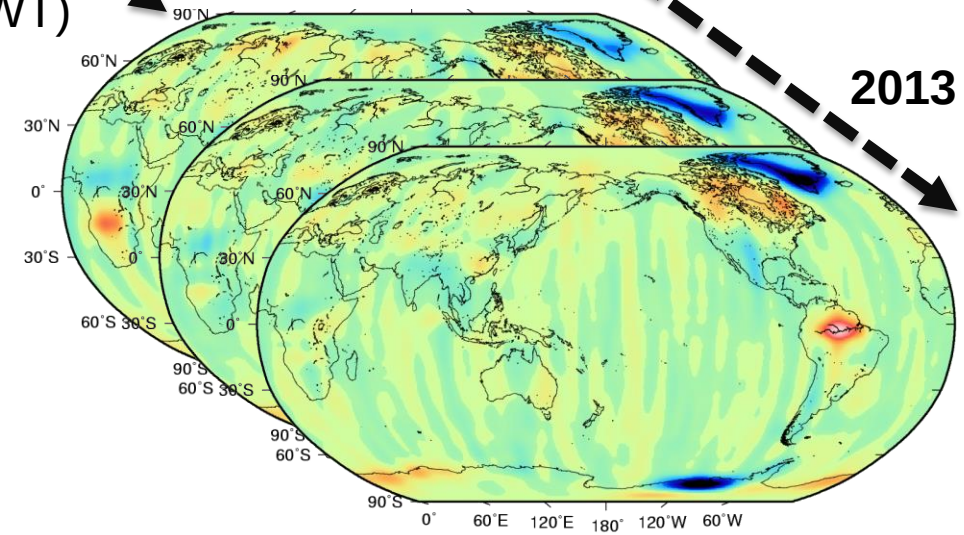
# Time variable Earth gravity field




2002

- Temporal variations of
  - **Hydrosphere**
  - **Geosphere**
  - **Atmosphere**

Equivalent Water Thicknesses (EWT)




2013

**Separation** problem!

# Analysis of monthly GRACE solutions

- **Computation** of grid values in terms of Equivalent Water Thicknesses (**EWT**) from monthly spherical harmonic coefficients up to **D/O 60**

- Estimation of **bias**, **secular trend** and **periodic terms** for the periods of **161** days, **1**, **2.5** and **3.7** years.

$$EWT(t) = a + bt + \sum_{f=1}^{4} A_f \sin\left(\omega_f t + \phi_f\right)$$

# Mass variations - GRACE

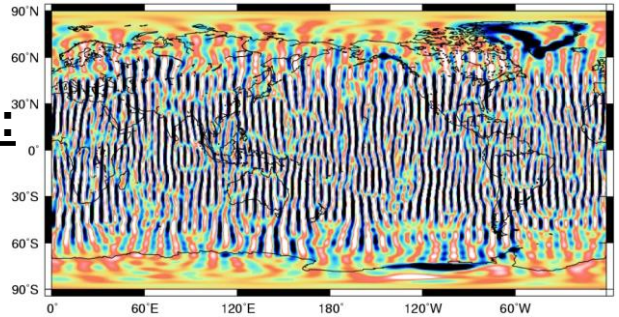
- Monthly solutions show well known "**North-South**" striping due to lower accuracy in the high frequencies and correlations in the high degree & orders (**filtering = de-correlation and de-striping**)
- There are many **filter techniques**!
  - **degree dependent**: Isotropic (Gaussian, 1D)
  - **degree and order dependent**: (non)-isotropic (modified Gaussian, 2D)
    - Han and Fan Filter (2D Gaussian, Han 2005)
    - Hypothesis testing (Sasgen et al. 2005)
  - **Full non-isotropic**
    - Combination of de-correlation and de-striping (Swenson 2006)
    - Empirical error de-correlation (DDK) and Tikhonov smoothing (Kusche 2007)
- Filters should be tested for
  - **de-striping** property (performance issue)
  - **damping** of amplitudes and **phase** shifts
  - **removing** of signals

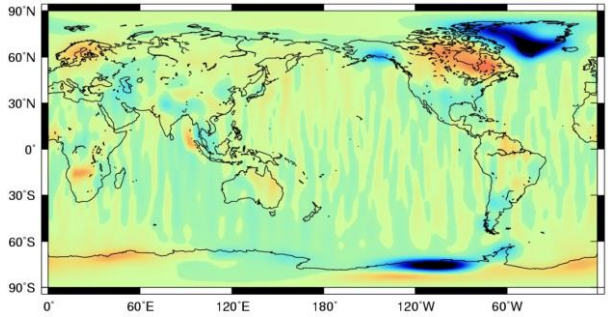
# Filters (Gaussian)

**Secular trend** in terms of EWT [**2003-2013**]

**Radius:**

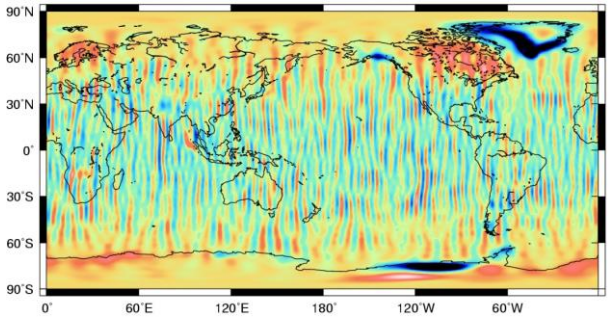
**100 km**

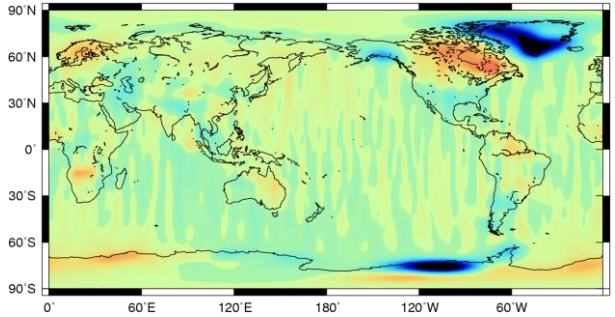



**350 km + $C_{20}$ from SLR**

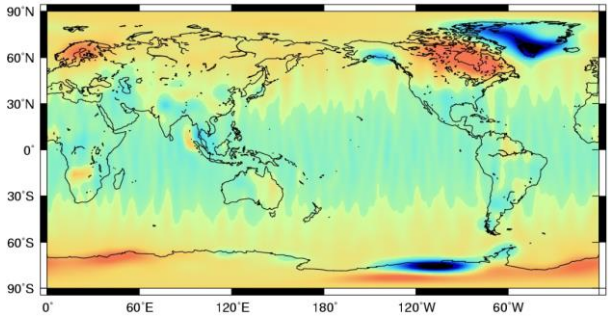
**200 km**




**350 km + $C_{20}$ from SLR + de-striping**

**350 km**

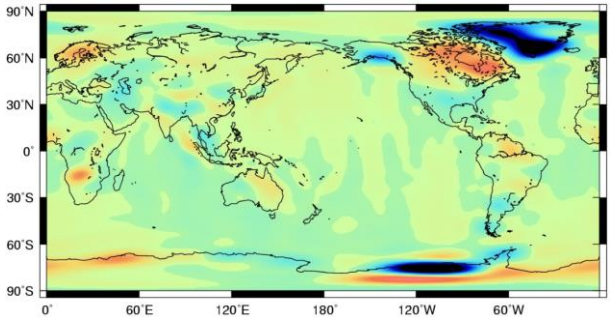



**Removes errors & signals**

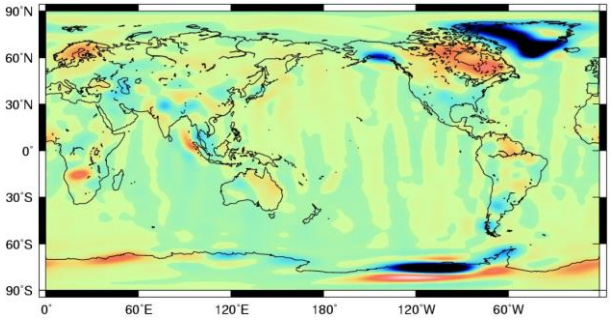
# Filters (de-correlation (DDK) and Fan)

**Secular trend** in terms of EWT [**2003-2013**]

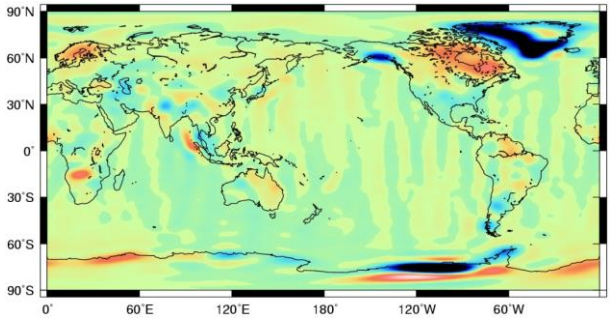
**DDK2**

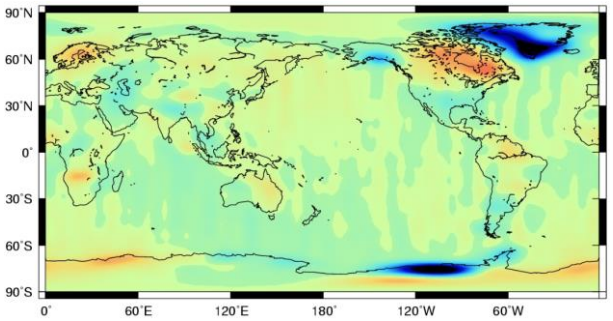



**DDK3**

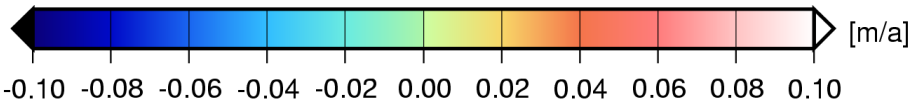



**DDK4**



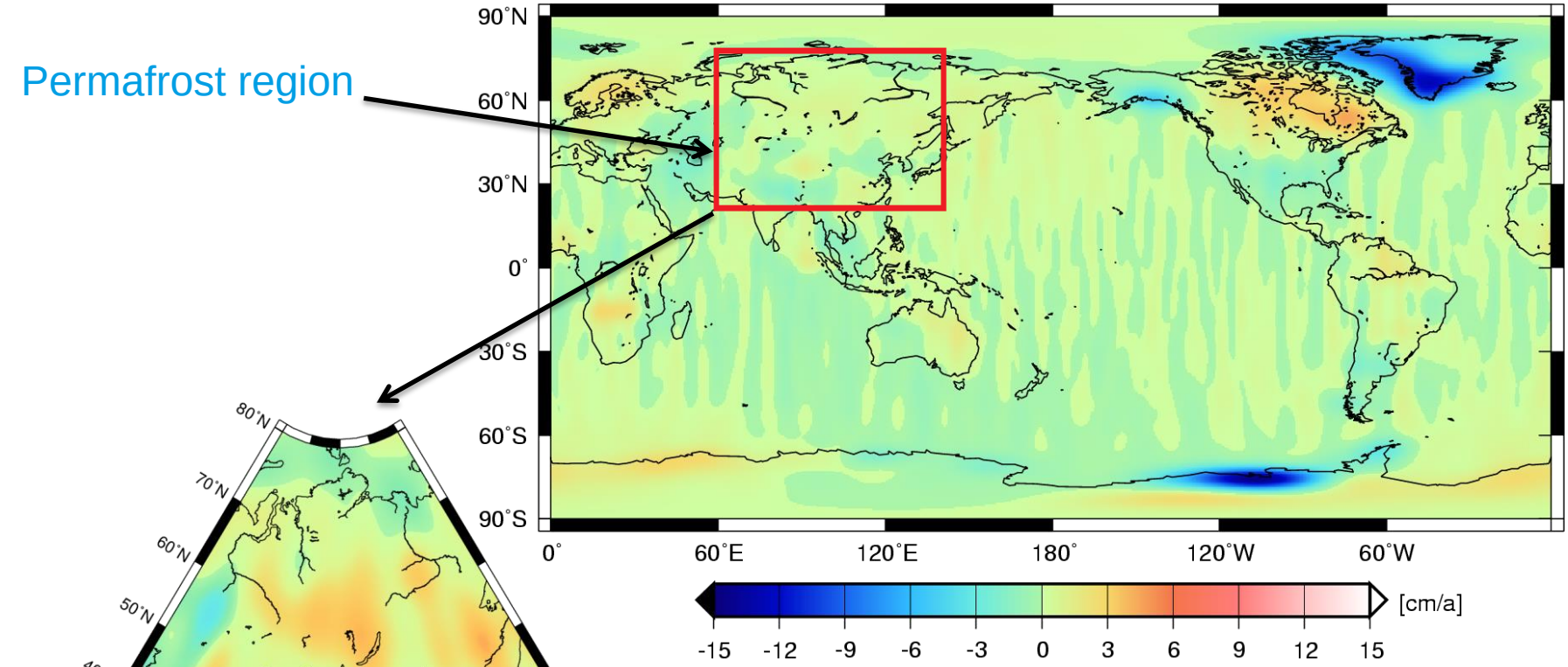



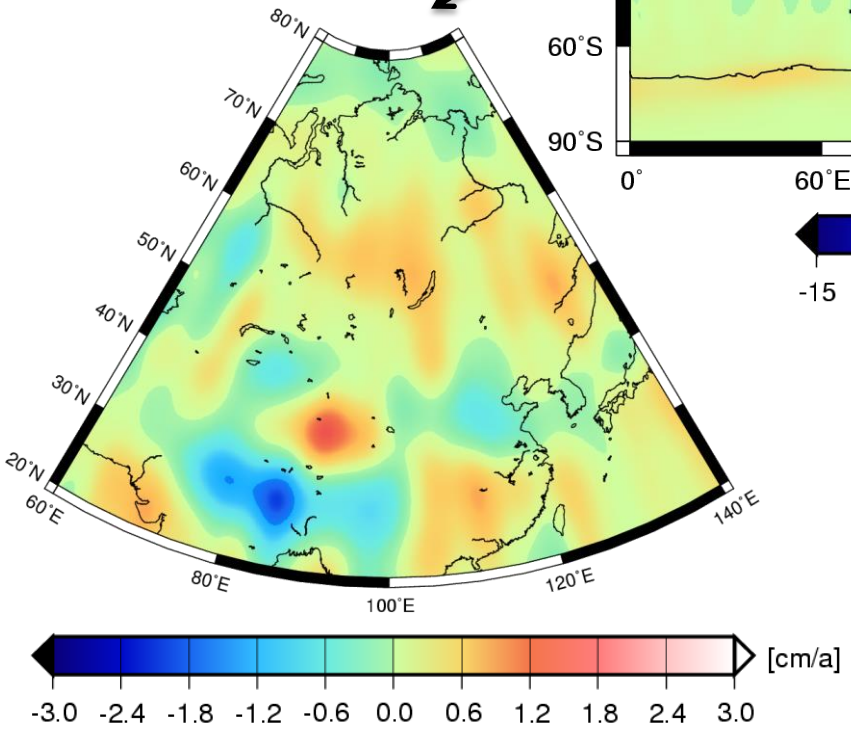

**Fan Filter (350 km) + $C_{20}$ from SLR + de-striping**



# Permafrost in Siberia (Russia)

Permafrost region



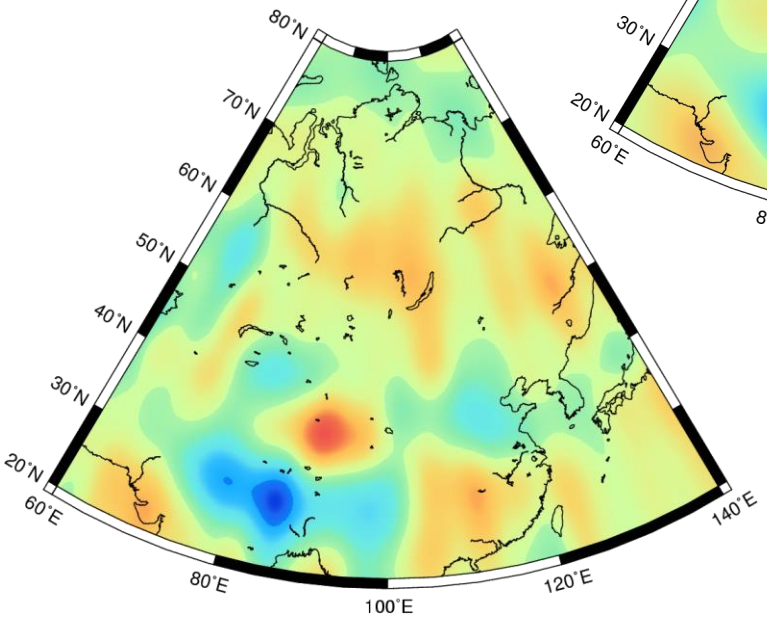



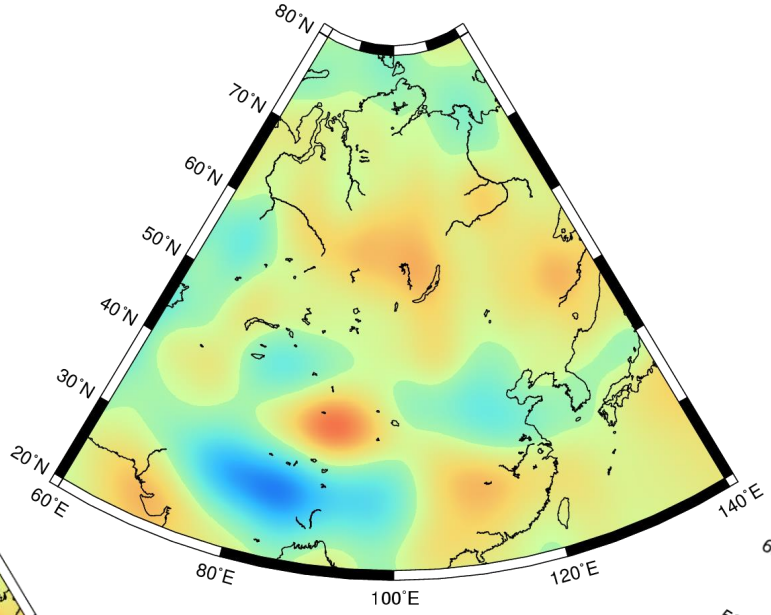

**Secular Trend** [cm/a, EWT]

| | |
|---|---|
| Product | : **GFZ-RL05a** |
| Filter | : **1D-Gaussian (350 km)** |
| $C_{2,0}$ | : **Replaced** |
| De-correlation | : **Yes** |
| Period | : **2003-2013** |

# Filters (performance test) – GFZ RL05a

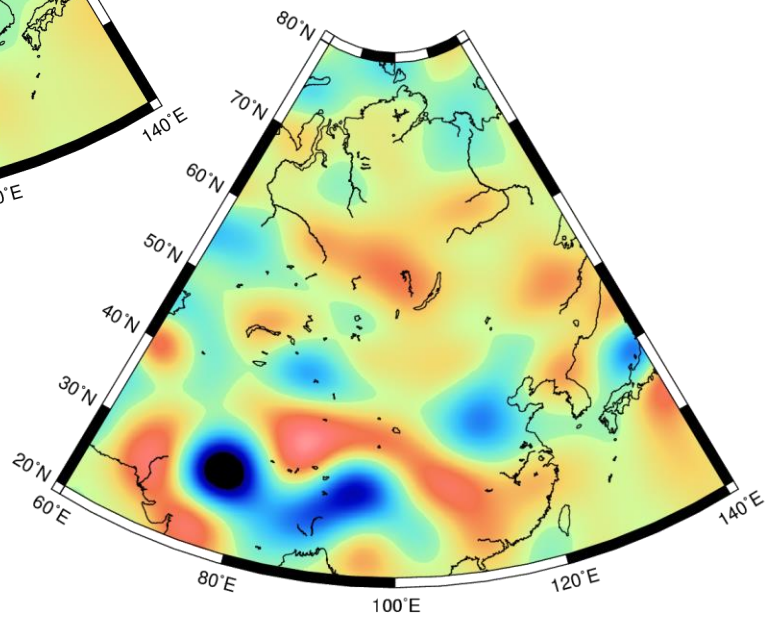
Product : GFZ-RL05a
Filter : 1D-Gaussian
$C_{2,0}$ : Replaced
De-correlation : Yes
Period : 2003-2013



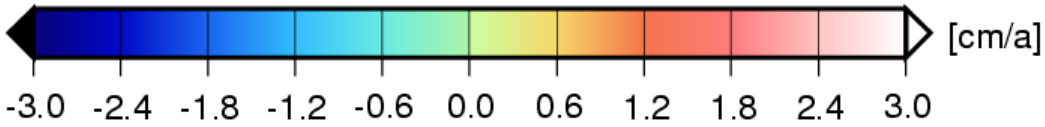




: GFZ-RL05a
: 2D Fan (350 km)
: Replaced
: Yes
: 2003-2013

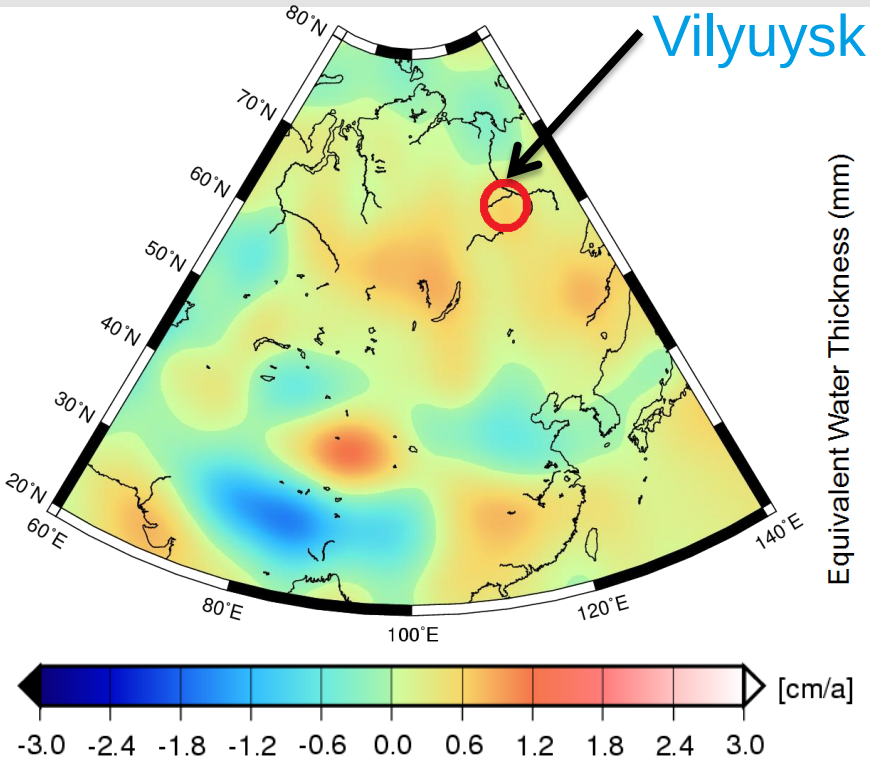
: GFZ-RL05a
: DDK3
: Replaced
: Yes
: 2003-2013

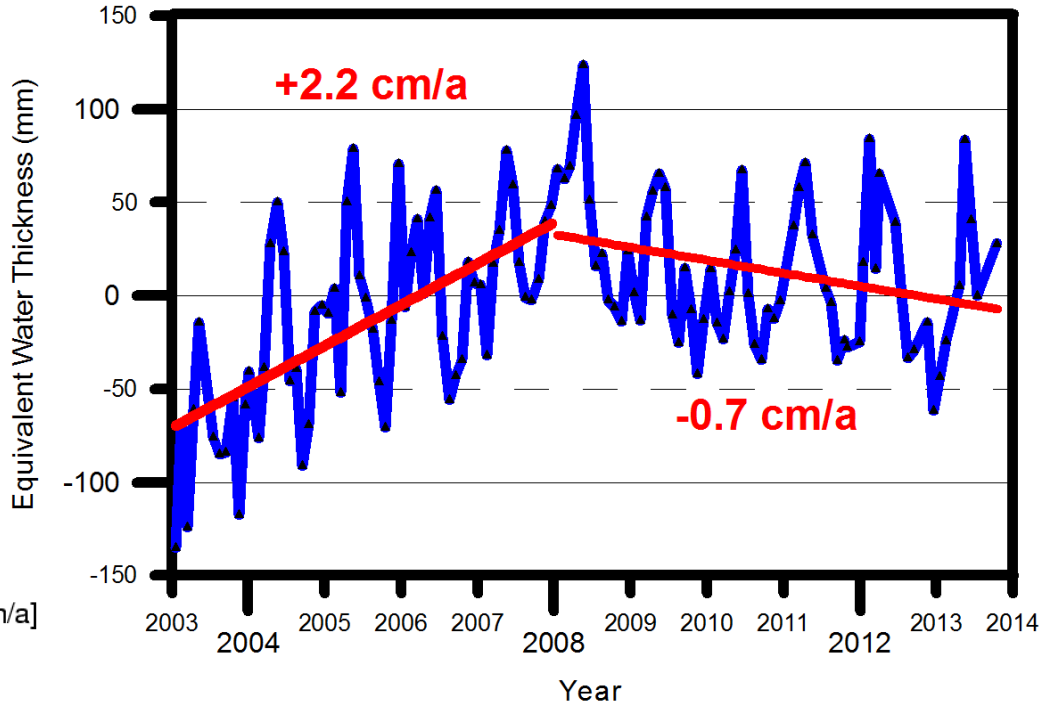



## Secular Trend

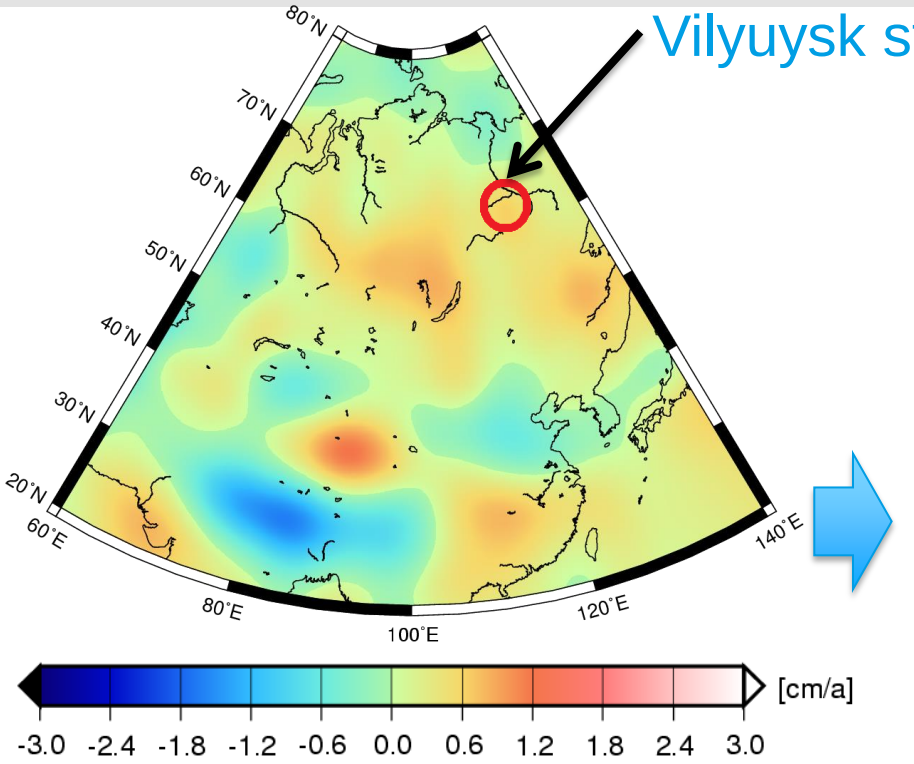


# Mass variation (Siberian permafrost region)



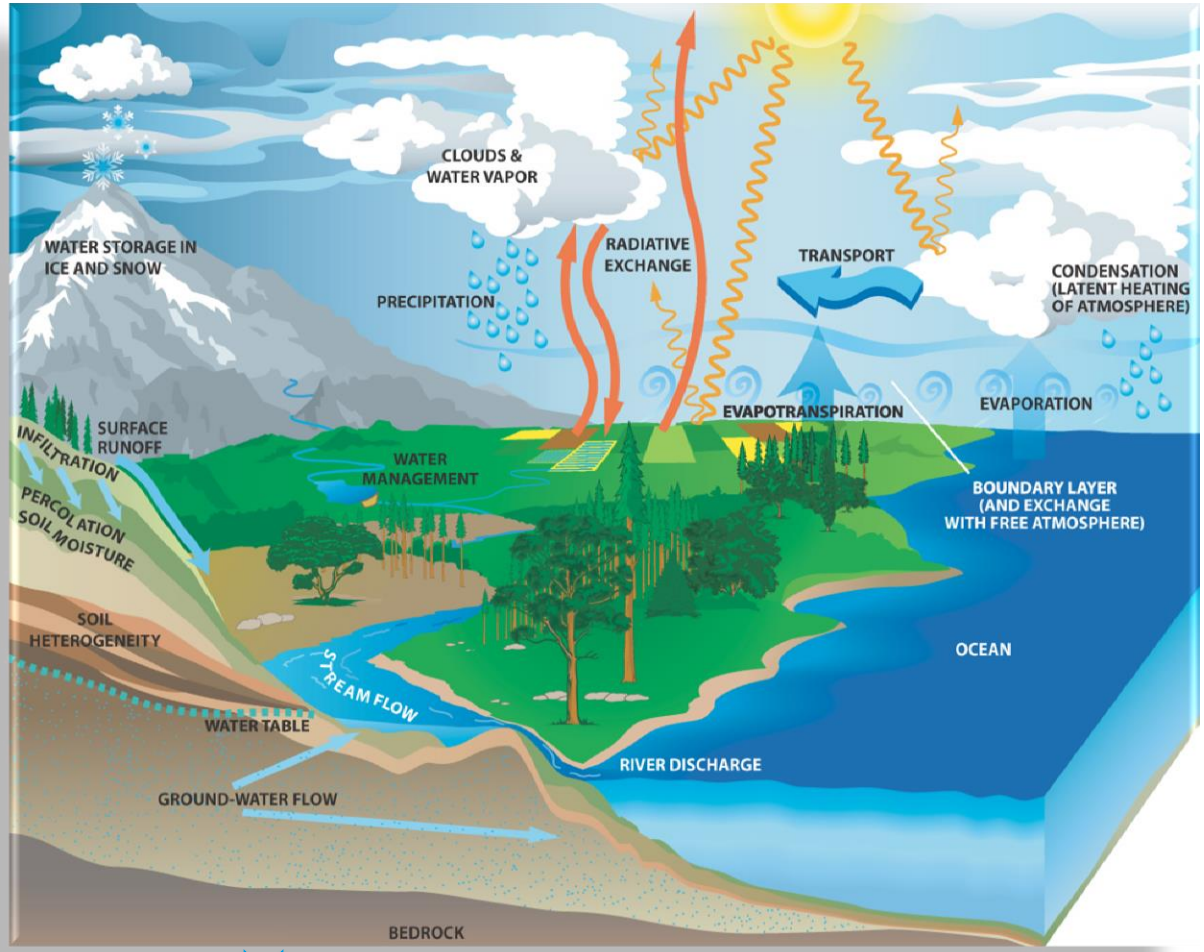
# Mass variation (Siberian permafrost region)




**Statistical** values of **secular trend** estimation for **different filters** using **GFZ-RL05a** over permafrost region for the period of **2003-2013**

| | **Gaussian (350 km) + $C_{2,0}$ + de-correlation** | **Fan-filter (350 km) + $C_{2,0}$ + de-correlation** | **DDK3 + $C_{2,0}$** |
|---|---|---|---|
| Min. (cm/a) | -1.9 | -1.6 | -3.9 |
| Max. (cm/a) | 1.5 | 1.2 | 2.0 |
| RMS (cm/a) | 0.4 | 0.4 | 0.7 |
| Avg. (cm/a) | **1.3** | 1.3 | 1.2 |

# Total Water Storage Change (TWSC)



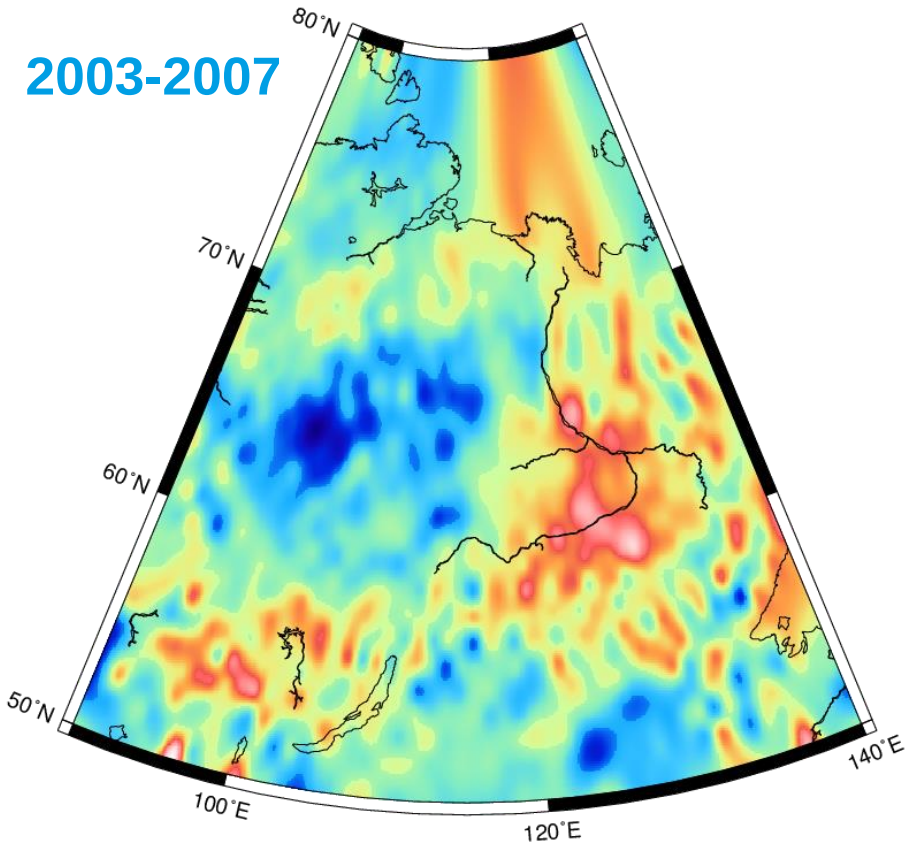

- Precipitation (***P***)
- Evapotranspiration (***ETa***)
- Run-off (***R***)

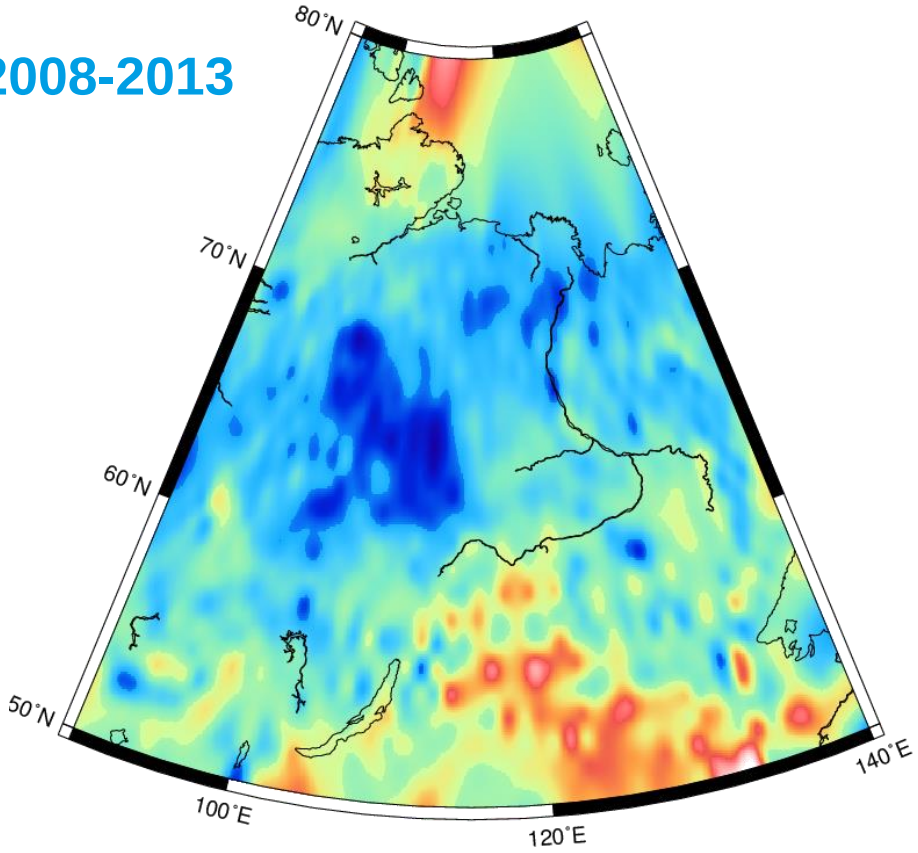
**GLDAS**

$$TWSC = \frac{d(TWS)}{dt} = P - ETa - R \sim \frac{d(EWT)}{dt}$$

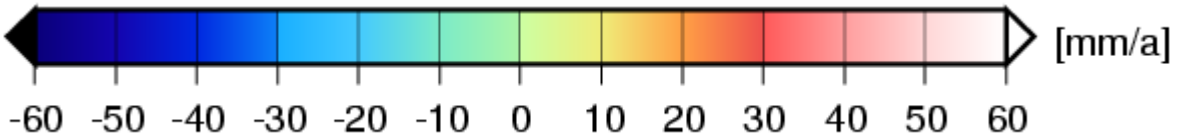
**GRACE**

# TWSC - GLDAS

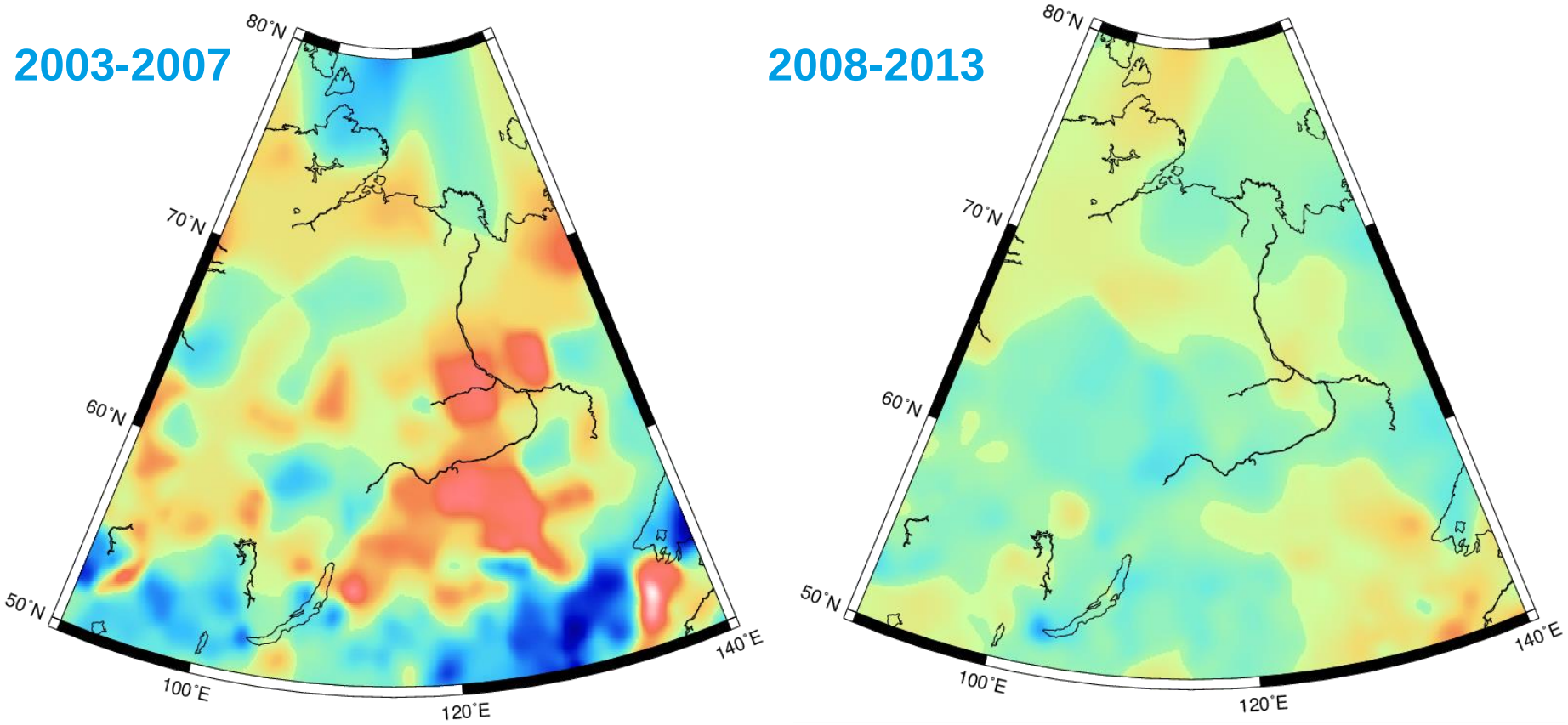



**TWSC** [mm/a]



# Hydrological model, precipitation (GPCC)



# Discussion

- **Filter techniques** play a key role in determination of mass variations.
- The **performance** of different filters depends on the target region.
- **2D Fan-filter** with radius **350 km** after replacing $\mathbf{C_{2,0}}$ from SLR seems to be the optimal filter for Siberia/permafrost.
- **GFZ** and **UT-CSR** GRACE monthly solutions provide similar results for mass variations in the Siberian permafrost region.
- **Mass increase** in the permafrost region of Siberia due to **high precipitation rate** and **thawing** of frozen layers (**other causes?**) in the period of 2003-2007, and **mass decrease** in the period of 2008-2013.
- **Hydrological models (e.g. GLDAS & GPCC)** show similar mass variation patterns in general, but **run-off** and **evapotranspiration** issues are the challenges for this region!
- Vey et al. (2012) attributed **30-60%** of mass variations in the Siberian permafrost region to **surface water storage changes**. Thus, **permafrost** thawing can reach up to **0.4** - **0.8 cm/a** of EWT rate.

# Outlook

- The **separation** (constraining) of mass variations signals should be improved by:
  - **Lake height variations** from satellite altimetry missions, e.g. ENVISAT, JASON 2 and ICESAT (This work is in progress at our institute).
  - **Lake surface extent changes** from hyper-spectral satellite images.

# Thank you for your attention

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