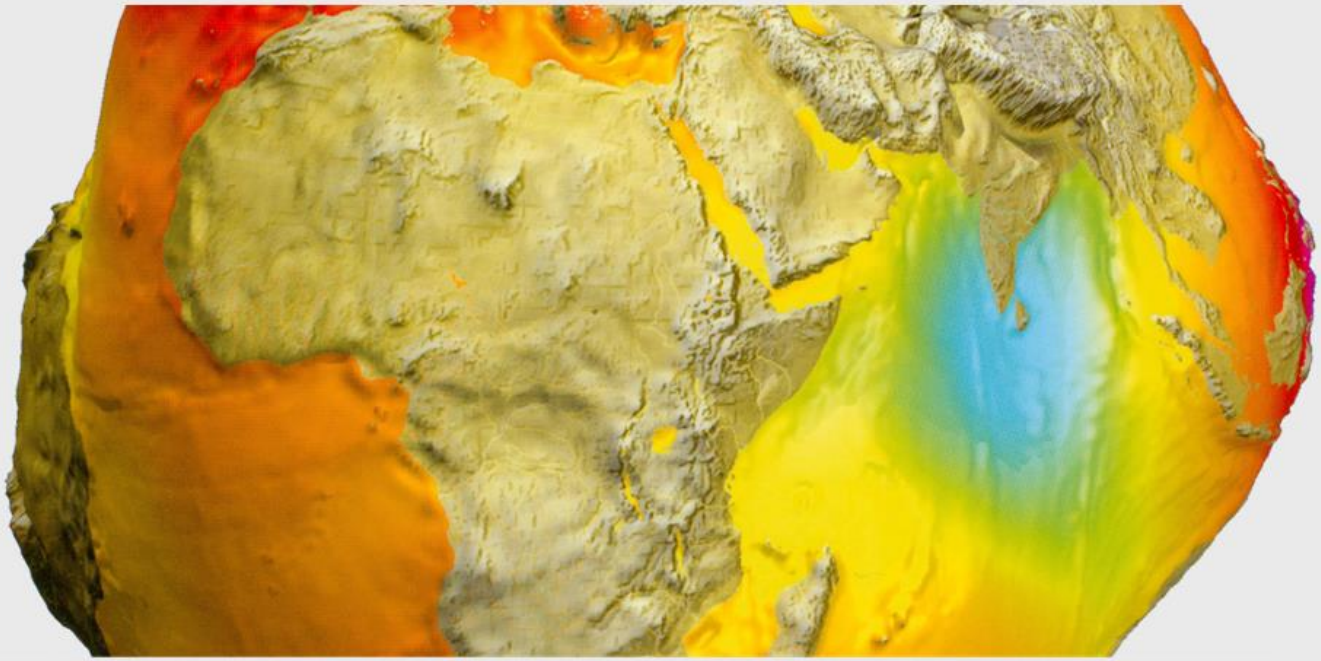
Constraining mass variations in the Siberian permafrost region based on GRACE & Satellite Altimetry



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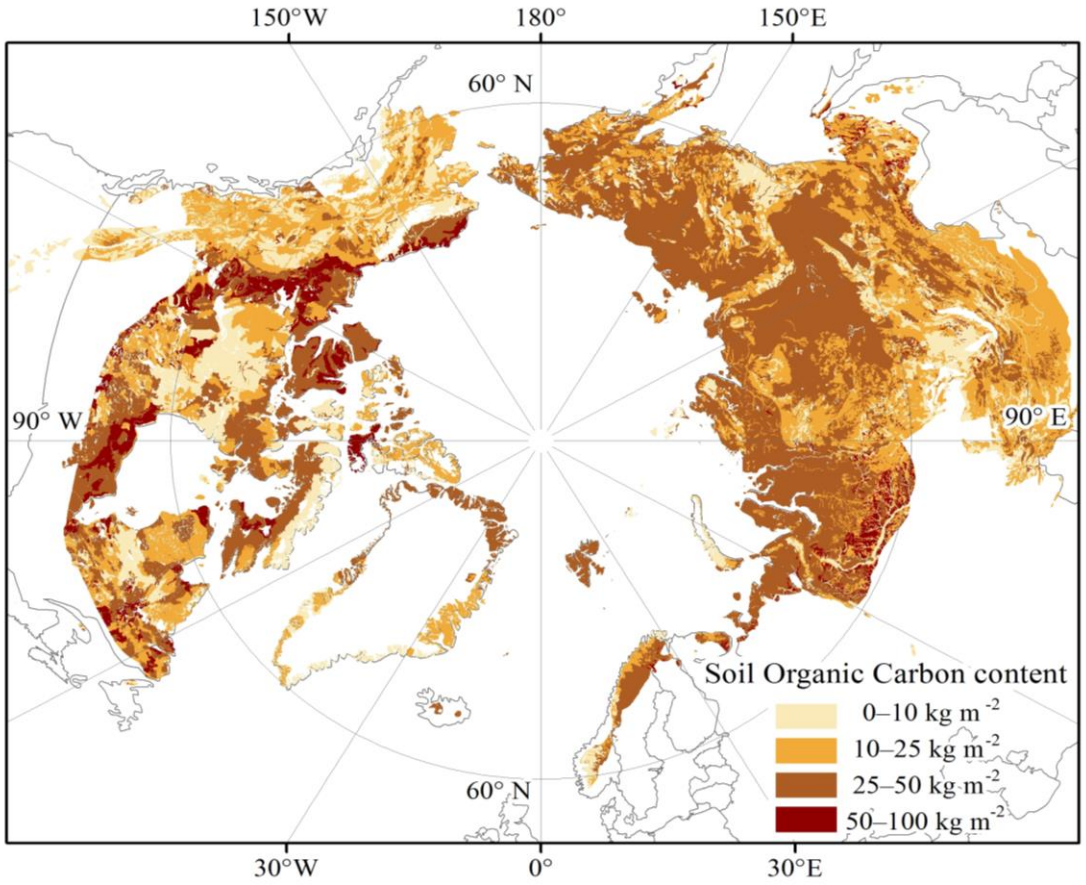
Motivation

- 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
- **Assimilating** surface mass variations using complementary models/data e.g. from **satellite radar/laser altimetry & hydrology** data
- **The permafrost** region is one of the most challenging areas for **climate change**!

Permafrost regions



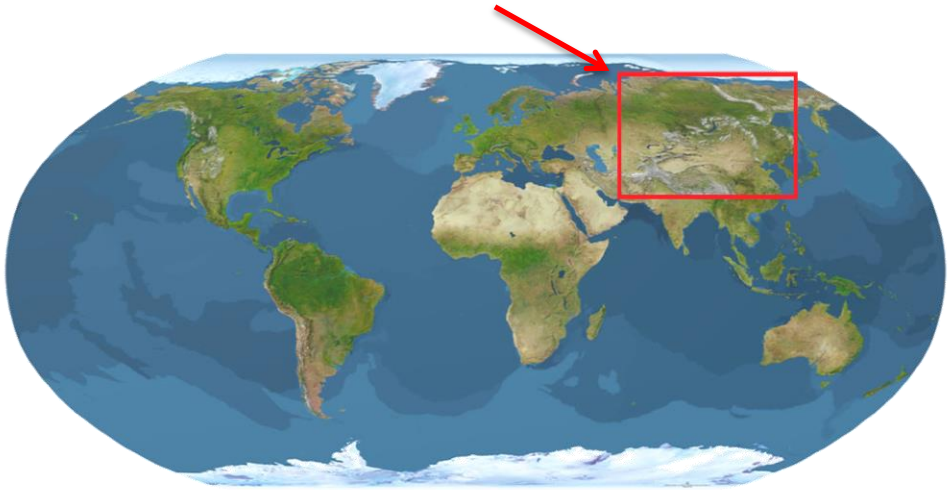
Courtesy: http://bolin.su.se/

- **22 Million km²** (circumarctic)
- **65%** of the Russia land area
- **Organic Carbon** storage in soils **(~1.7 Tt)**
- **2 times** of all CO_2 in atmosphere
- **3 times** of all CO_2 in plants

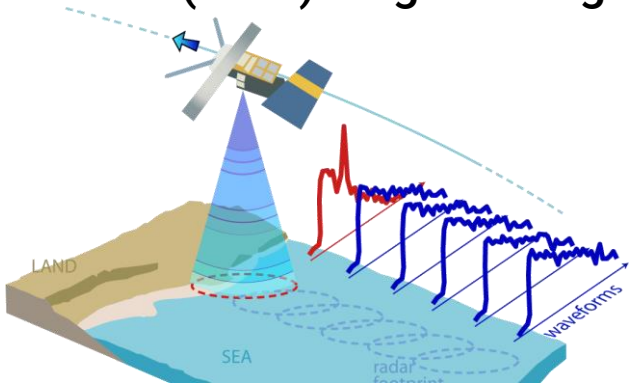
Climate change (warming) and air pollution!

Permafrost in Siberia (Russia)

Region of interest

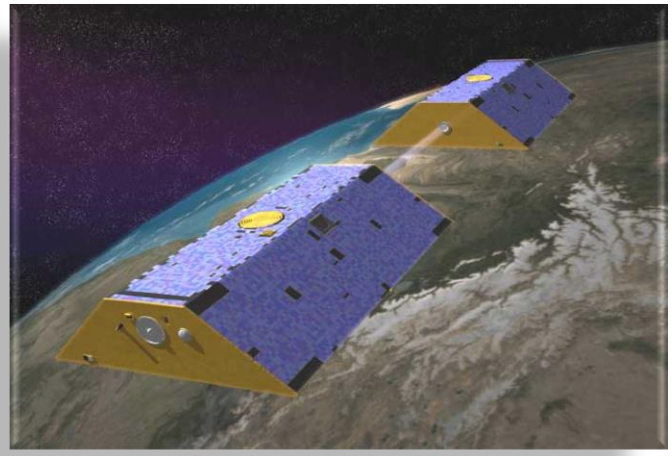


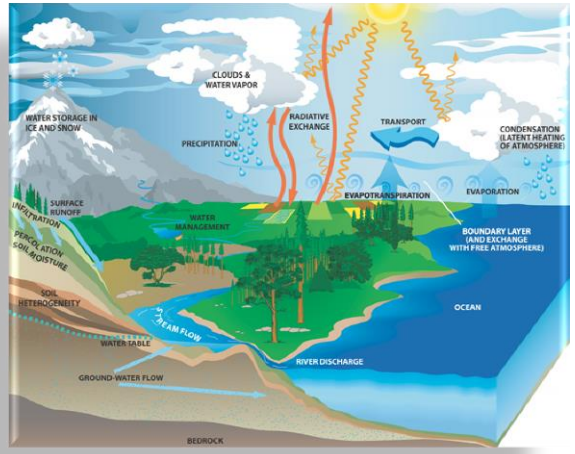
- **Satellite Altimetry**
  - Sea (Lake) height changes



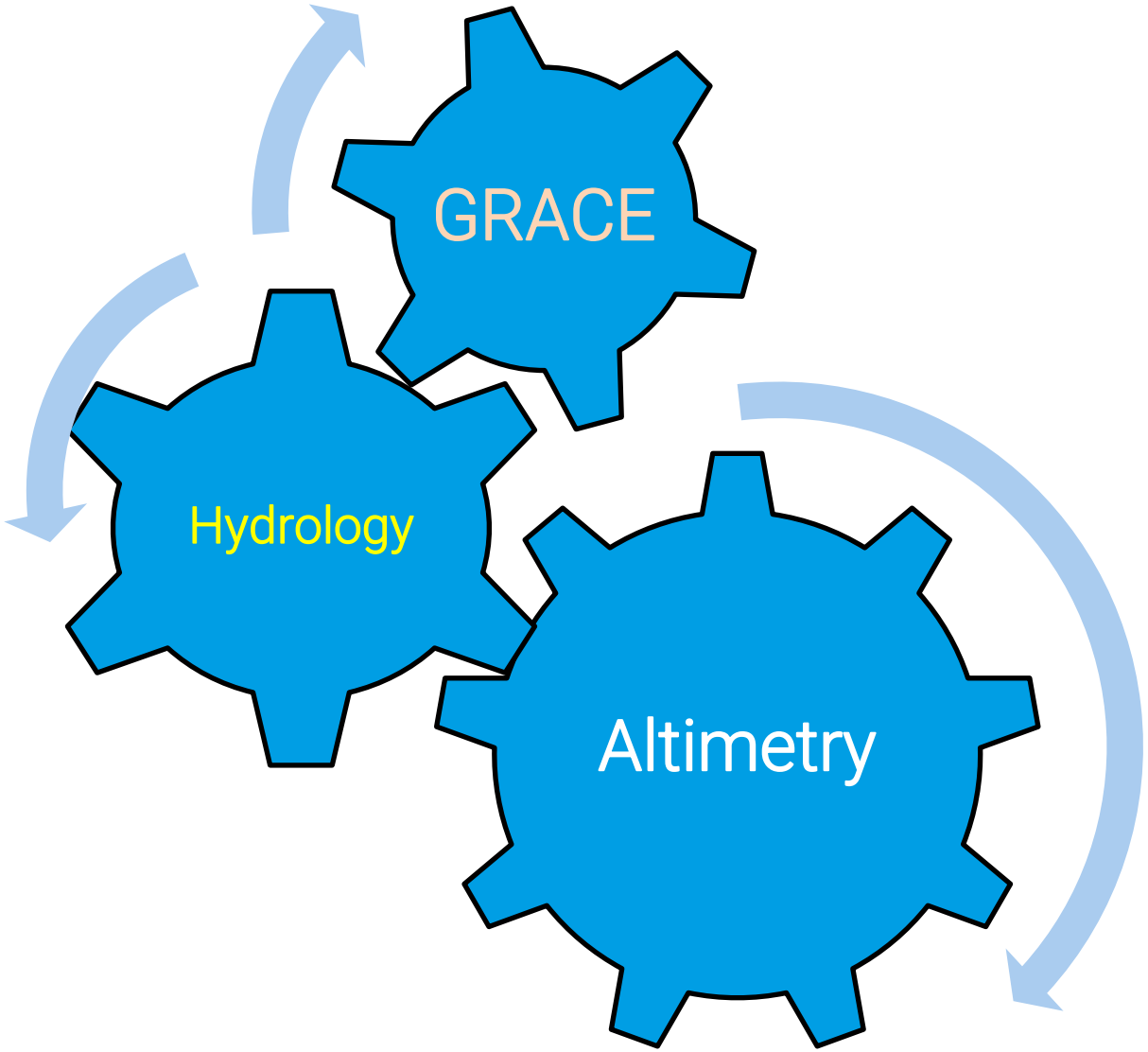
- **Hydrological mass variations (e.g. GLDAS)**
  - **Precipitation,** Evapotranspiration and Run-off

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

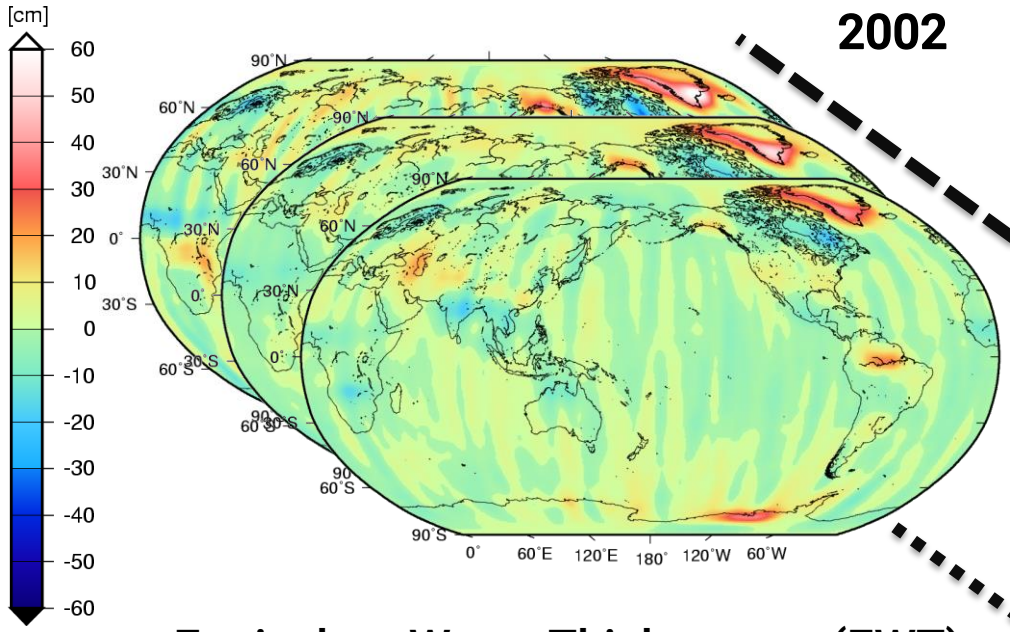




Constraining of mass variation results



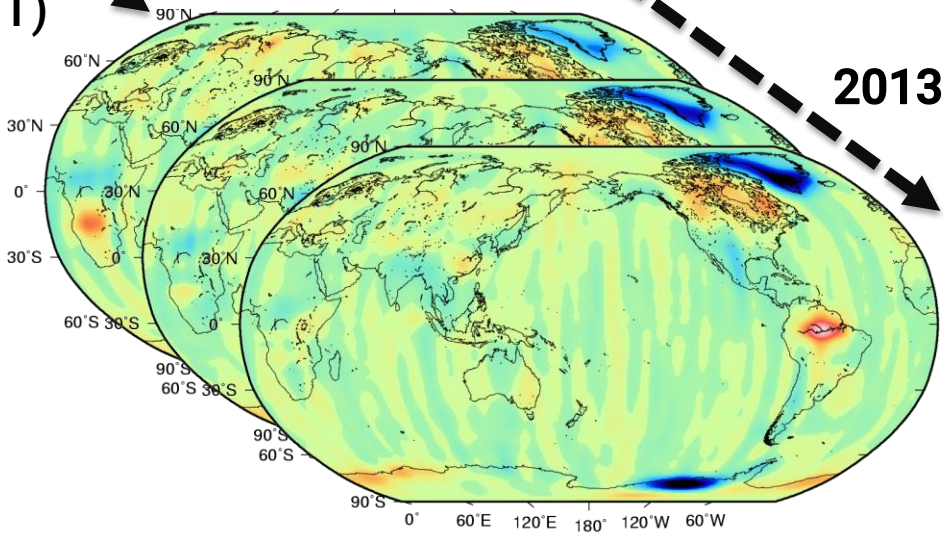
Time variable Earth gravity field



2002

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

Equivalent Water Thicknesses (EWT)



2013

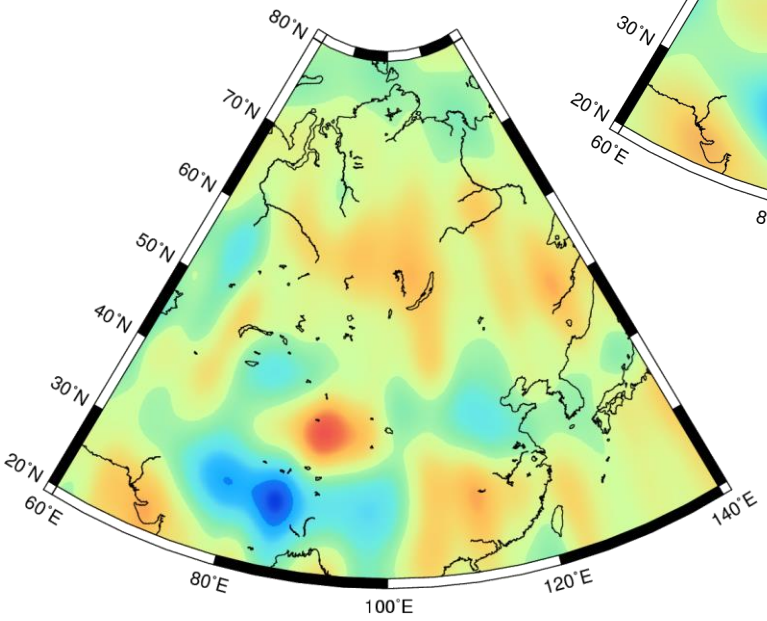
Separation problem!

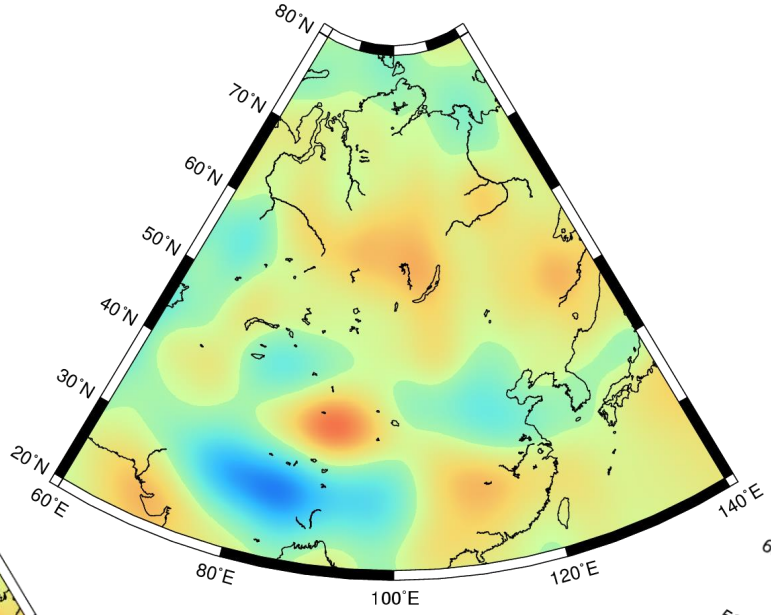
Mass variations - GRACE

- 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** play a key role for estimating regional (surface) mass variations based on GRACE products

Filters (performance test) – GFZ RL05a

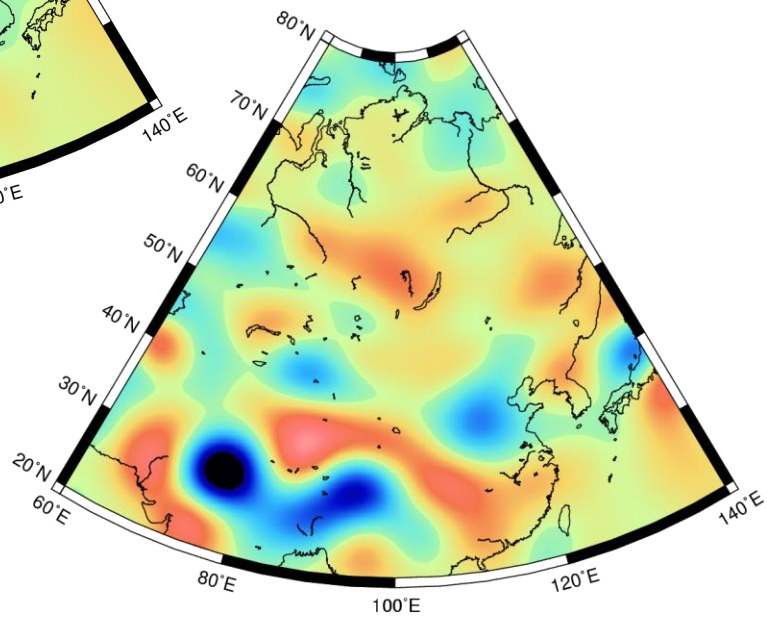
Product : GFZ-RL05a
Filter : 1D-Gaussian
$C_{2,0}$: Replaced
De-correlation : Yes
Period : 2003-2013



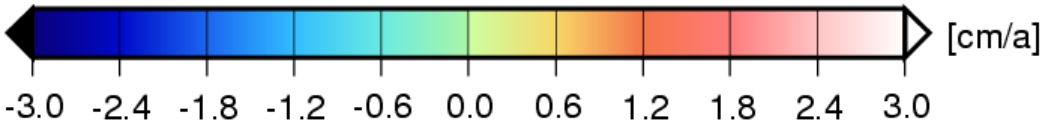


: GFZ-RL05a
: 2D Fan (350 km)
: Replaced
: Yes
: 2003-2013

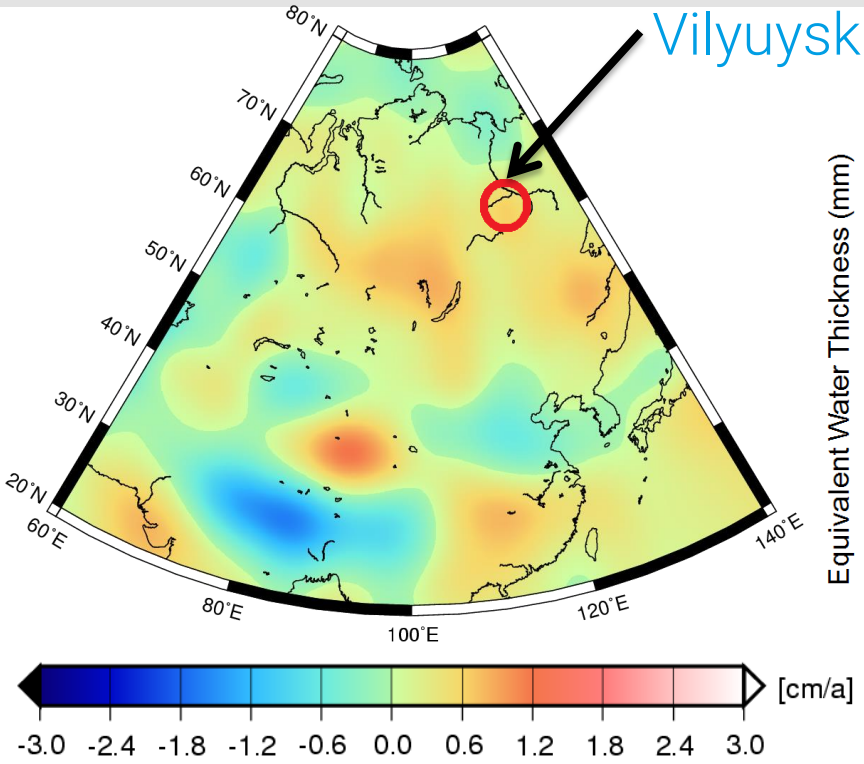
: GFZ-RL05a
: DDK3
: Replaced
: Yes
: 2003-2013

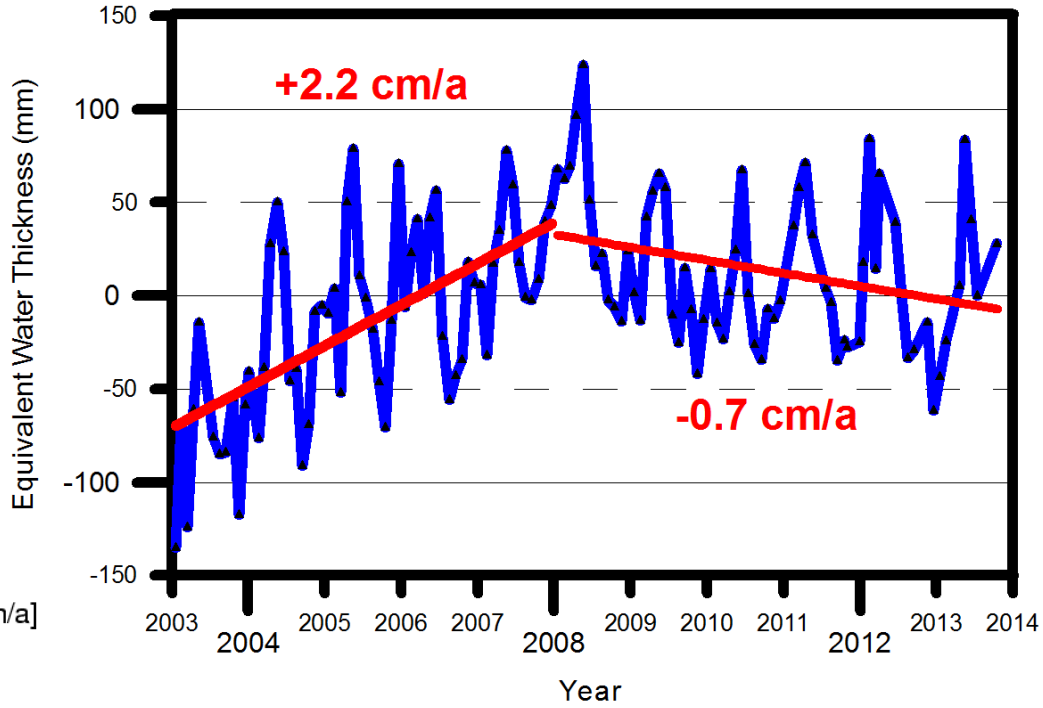


Secular Trend

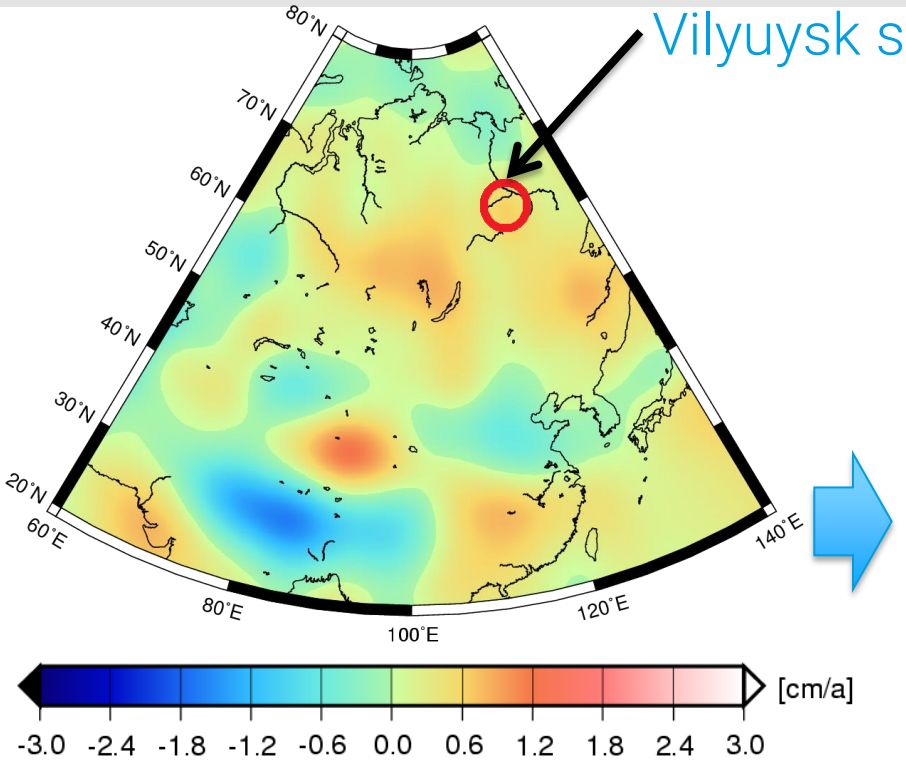


Mass variation (Siberian permafrost region)





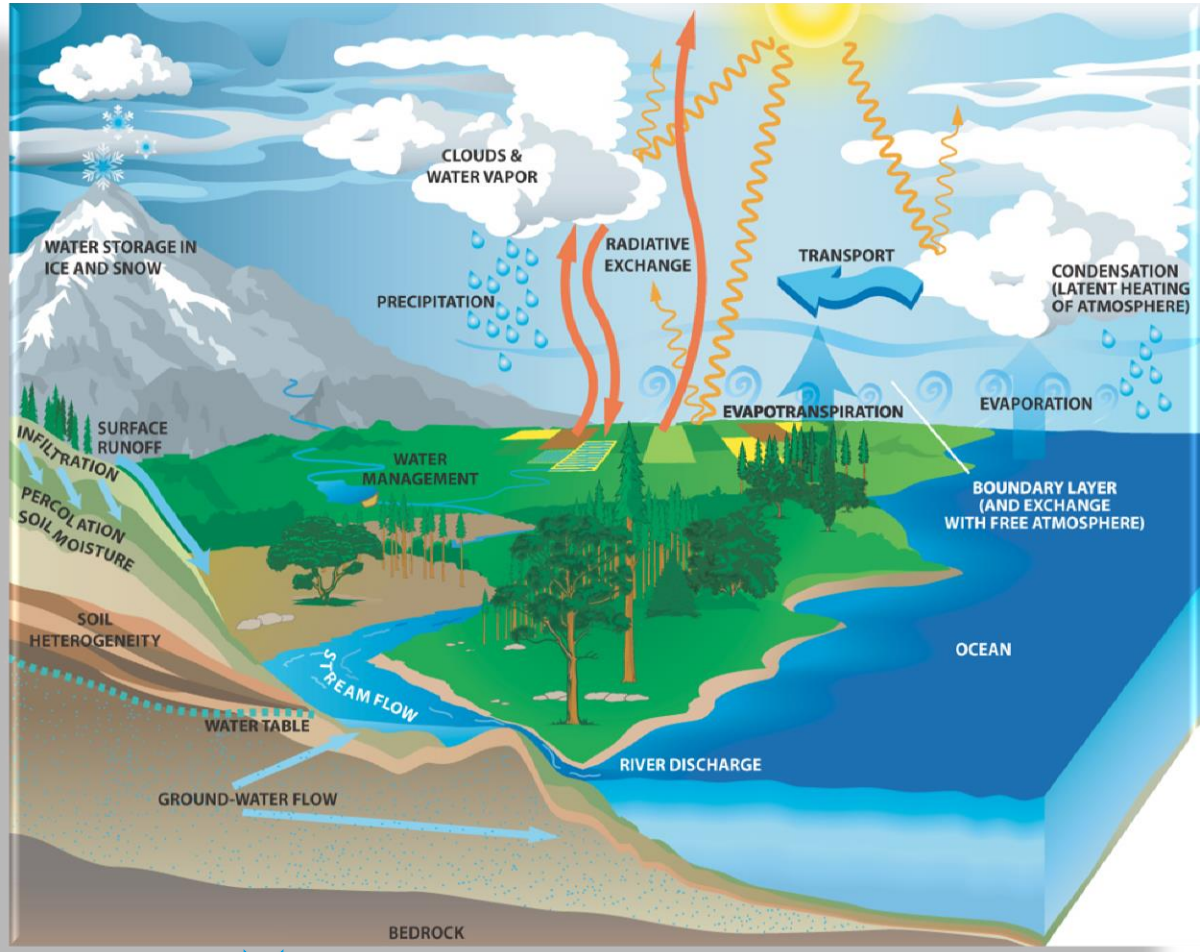
Mass variation (Siberian permafrost region)



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)



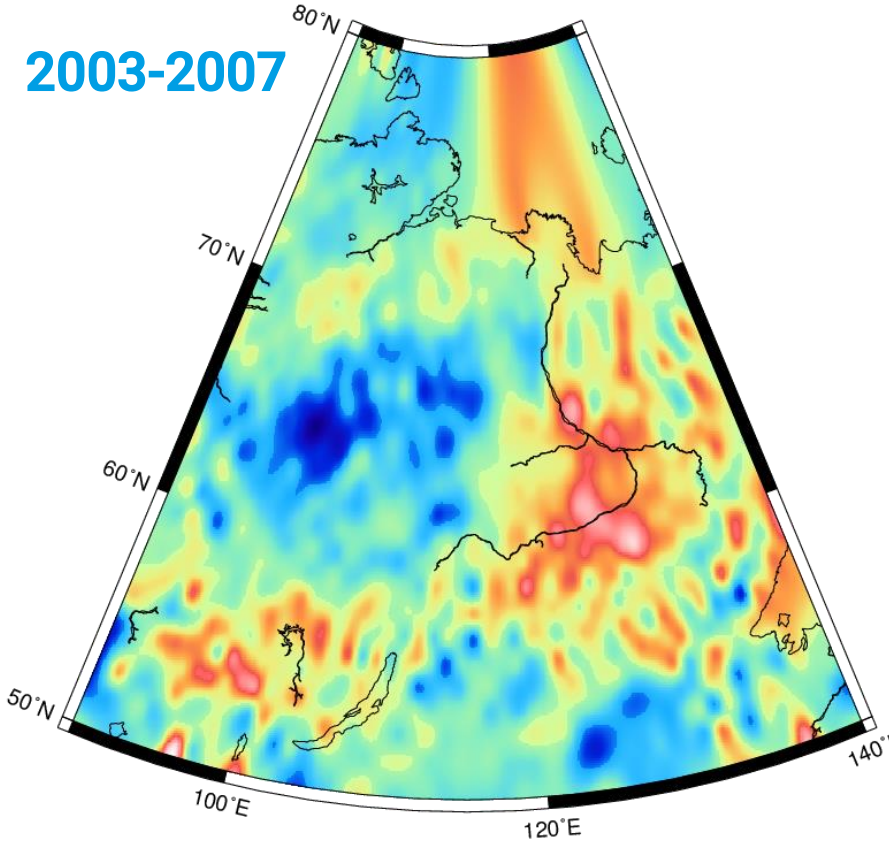
- **Precipitation (*P*)**
- Evapotranspiration (*ETa*)
- Run-off (*R*)

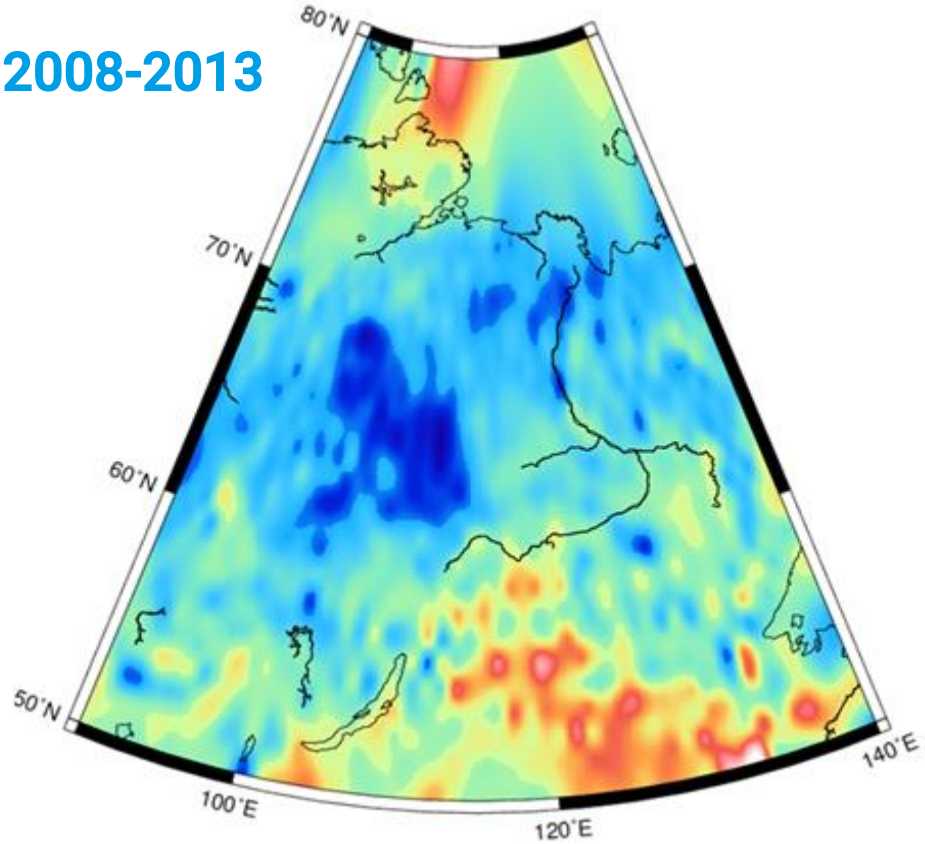
GLDAS

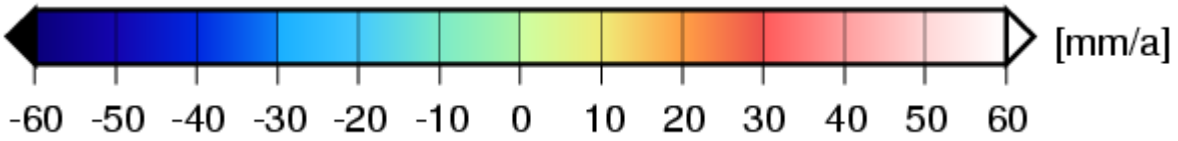
$$TWSC = \frac{d(TWS)}{dt} = P - ETa - R \sim \frac{d(EWT)}{dt}$$

GRACE

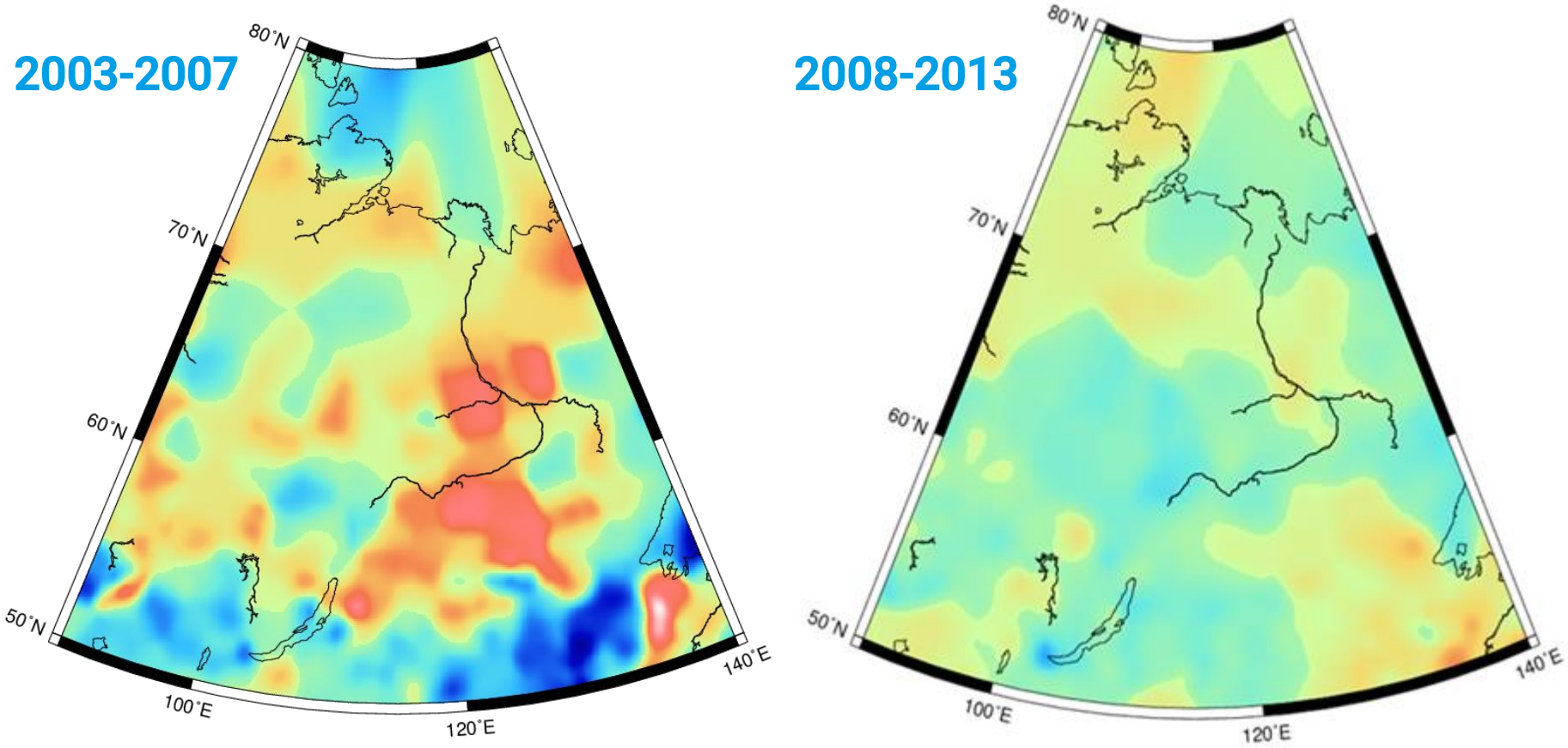
TWSC - GLDAS


2003-2007
80°N
70°N
60°N
50°N
100°E
120°E
140°E


2008-2013
80°N
70°N
60°N
50°N
100°E
120°E
140°E

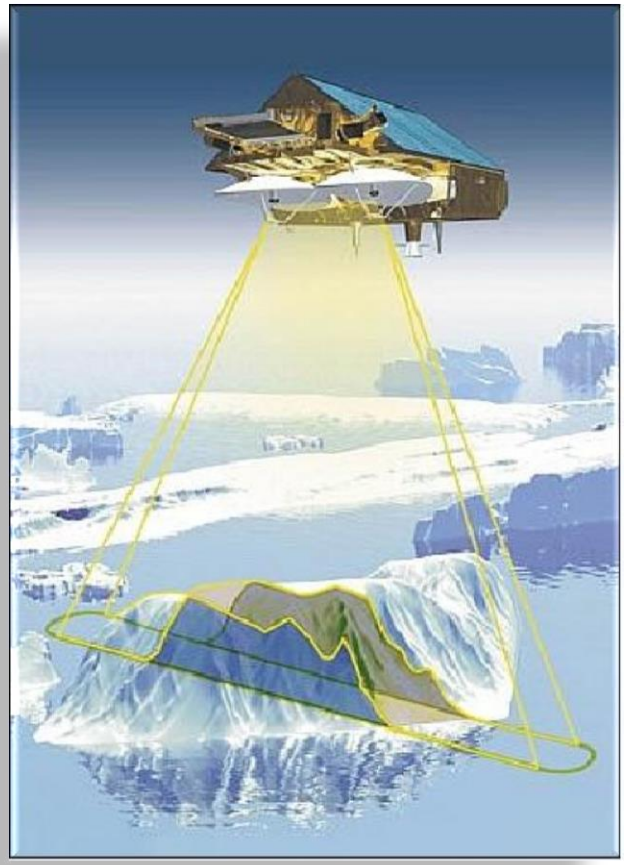

TWSC [mm/a]
[mm/a]
-60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60

Hydrological model, precipitation (GPCC)



Satellite Altimetr

- **CryoSat** altimetry based on SAR Interferometry (SIN) observations @ 20 kHz (one measurement every 300 m).
- In **SIN** mode, two antenna on-board CryoSat are used.
- In **Siberian** area, the SIN mode shall be used for determining hydrological level changes over **sea**, **river** and **Talik** (unfrozen area) with a width bigger than at least **200 m**.
- In Siberia, estimated mass variations based on level changes of Taliks are **uncertain**.
- **Assimilation** of altimetry results over Siberia with GRACE and hydrological data/model should be carefully dealed.



Courtesy: eoportal.org

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 $C_{2,0}$ 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) 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 surface extent changes** from hyper-spectral satellite images.

Thank you for your attention

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