Analysis and modeling of water balance of permafrost regions

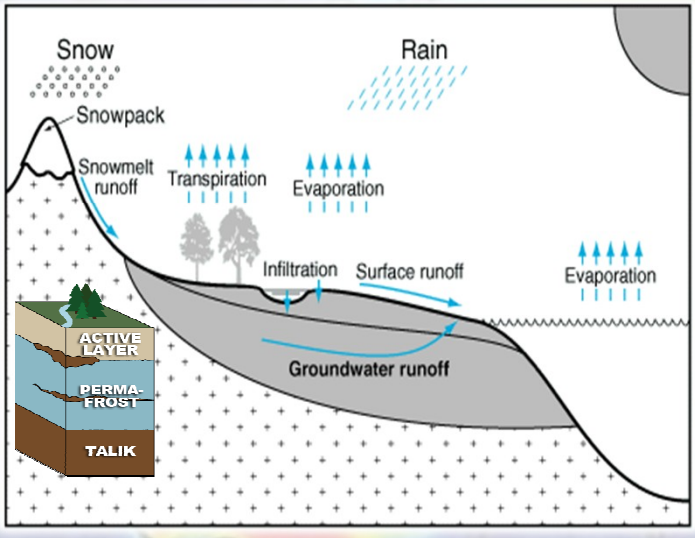
Im Sergei, Institute of Forest SB RAS,
Krasnoyarsk, 2014

Plan

- Water balance (equation)
- Data sources to estimate water balance in permafrost zones (ground, modelled, remote sensing)
- Water mass changes permafrost zone in Siberia (recent results)
- Some results obtained from GRACE data within Megagrant project
- Practical task

Water balance

Water balance equation



$$P = Q + E + \Delta S$$

- P – precipitation = rain + snow;
- Q – runoff = surface water runoff + groundwater runoff;
- E – evapotranspiration = evaporation + transpiration;
- ΔS – water storage variations = surface + ground water.

Data sources

Data sources

$$P = Q + E + \Delta S$$

Free available data for Siberia (permafrost zone; coarse resolution)

1) Ground measurements (station, in-situ – field works)
2) Modelling (GLDAS)
3) Remote sensing data (GRACE, MODIS, AMSR-E, ICESat, ERS, Envisat, Landsat, Topex\Poseidon, SMOS, etc.)

Precipitation

$P = Q + E + \Delta S$

1) CRU TS 3.xx – reanalysis data
2) GPCP – satellite based data
3) GPCC – reanalysis data
4) CMAP – merged reanalysis and satellite data
5) GLDAS – reanalysis data
6) ERA-Iterim – reanalysis data

Centre for Environmental Data Archival
SCIENCE AND TECHNOLOGY FACILITIES COUNCIL
NATURAL ENVIRONMENT RESEARCH COUNCIL

Climatic research unit (CRU) TS (time-series) version 3.22

gridded data 1901-2013

Label	Variable	Units (Multiplying factor for ASCII data ONLY)
cld	Cloud Cover	percentage (x10)
dtr	Diurnal Temperature Range	Degrees Celcius (x10)
frs	Frost Day Frequency	Days (x100)
pet	Potential Evapo-Transpiration (PET)	Millimeters (x10)
pre	Precipitation	Millimeters (x10)
tmp	Daily mean temperature	Degrees Celcius (x10)
tmn	Monthly average daily minimum temperature	Degrees Celcius (x10)
tmx	Monthly average daily maximum temperature	Degrees Celcius (x10)
vap	Vapour pressure	Hecta-Pascals (x10)
wet	Wet Day Frequency (rain days per month)	Days (x100)

http://www.cru.uea.ac.uk/cru/data/hrg/cru_ts_3.22/

Harris, I., Jones, P.D., Osborn, T.J. and Lister, D.H. (2014), Updated high-resolution grids of monthly climatic observations τ the CRU TS3.10 Dataset. Int. J. Climatol., 34: 623-642. doi: 10.1002/joc.3711

Global precipitation climatology project (GPCP)

http://www.gewex.org/gpcp.html, http://www.ncdc.noaa.gov/wdc/wdcamet-ncdc.html
http://www1.ncdc.noaa.gov/pub/data/gpcp/gpcp-v2.2/
George J. Huffman, David T. Bolvin
NASA Goddard Space Flight Center, Mesoscale Atmospheric Processes Laboratory
and Science Systems and Applications, Inc.

- Precipitation data **based on satellite data**
- The GPCP **One-Degree Daily (1DD)** released as an official GPCP product, February 12, 2013.
- The 1DD product provides precipitation estimates on a 1-degree grid over the entire globe at 1-day (daily) for the **period October 1996 - present**.

Data [ftp://rsd.gsfc.nasa.gov/pub/1dd-v1.2/]

Index of ftp://rsd.gsfc.nasa.gov/pub/1dd-v1.2/

Up to higher level directory

Name	Size	Last Modified
1DD_v1.2_doc.pdf	293 KB	04.03.2013 0:00:00
1dd_v1.2.software		18.09.2012 0:00:00
gpcp_1dd_v1.2_p1d.199610.gz	3504 KB	18.09.2012 0:00:00
gpcp_1dd_v1.2_p1d.199611.gz	3486 KB	18.09.2012 0:00:00
gpcp_1dd_v1.2_p1d.199612.gz	3457 KB	18.09.2012 0:00:00

CMAP

http://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html
https://climatedataguide.ucar.edu/climate-data/cmap-cpc-merged-analysis-precipitation

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research

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Climate Datasets: By Category
All
Sub-daily
Daily
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Land
Ocean
Multi-level
Radiation
Arctic
Reanalysis
Climate Indices

On this page: Temporal Coverage | Spatial Coverage | Levels | Update Schedule | Download/Plot Data | Analysis Tools
Restrictions | Details | Caveats | File Naming | Citation | References | Original Source | Contact

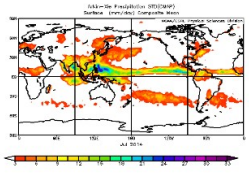
CPC Merged Analysis of Precipitation (CMAP)

Brief Description:

- Monthly and pentad global gridded precipitation means. It includes a standard and enhanced version (with NCEP Reanalysis) from 1979 to near the present.

Temporal Coverage:

- Monthly values 1979/01 to 2014/07
- Pentad values 1979/01 to 2014/06/25
- Long term monthly means, derived from years 1979 to 2000.



Spatial Coverage:

- 2.5 degree latitude x 2.5 degree longitude global grid (144x72).
- 88.75N - 88.75S, 1.25E - 358.75E.

Global Land Data Assimilation System Version 2 (GLDAS-2) Products

Prepared by Hualan Rui, GES DISC
Last revised, November 01, 2012

http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings

The goal of the Global Land Data Assimilation System (GLDAS) is to ingest satellite- and ground-based observational data products, using advanced land surface modeling and data assimilation techniques, in order to generate optimal fields of land surface states and fluxes (Rodell et al., 2004a)

Format	GRIB
Latitude extent	-59.5° to 89.5°
Longitude extent	-179.5° to 179.5°
Spatial resolution	1.0°
Temporal resolution	3-hourly and monthly
Temporal coverage	3Z January 1, 1948 – 21 Z December 31, 2010; 0Z March 1, 2001 - present
Dimension	360 (lon) x 150 (lat)
Origin (1st grid center)	(179.5W, 59.5S)
Land surface models	NOAH 3.3, GLDAS/NOAH

Parameters in the GLDAS-2 Noah model data

1	Surface pressure	Pa	Instantaneous
11	Near surface air temperature	K	Instantaneous
32	Near surface wind magnitude	m/s	Instantaneous
51	Near surface specific humidity	kg/kg	Instantaneous
57	Total evapotranspiration	kg/m^2/s	Past 3-hr average
65	Snow water equivalent	kg/m^2	Instantaneous
223	Total canopy water storage	kg/m^2	Instantaneous
85	Average layer soil temperature	K	Instantaneous
86	Average layer soil moisture	kg/m^2	Instantaneous
99	Snowmelt	kg/m^2/s	Past 3-hr average
111	Net shortwave radiation	W/m^2	Past 3-hr average
112	Net longwave radiation	W/m^2	Past 3-hr average
121	Latent heat flux	W/m^2	Past 3-hr average
122	Sensible heat flux	W/m^2	Past 3-hr average
161	Snowfall rate	kg/m^2/s	Past 3-hr average
162	Rainfall rate	kg/m^2/s	Past 3-hr average
148	Average surface temperature	K	Instantaneous
155	Ground heat flux	W/m^2	Past 3-hr average
204	Surface incident shortwave radiation	W/m^2	Past 3-hr average
205	Surface incident longwave radiation	W/m^2	Past 3-hr average
234	Subsurface runoff	kg/m^2/s	Past 3-hr average
235	Surface runoff	kg/m^2/s	Past 3-hr average

CISL Research Data Archive
Managed by NCAR's Data Support Section
Data for Atmospheric and Geosciences Research

RDA

Go to Dataset: nnn.n

Home | Find Data | Ancillary Services | About/Contact | Data Citation | Web Services | For Staff

ERA-Interim Project, Monthly Means
ds627.1

For assistance, contact Dave Stepaniak (303-497-1343).

http://rda.ucar.edu/datasets/ds627.1/

Air Temperature	Albedo	Cloud Amount/Frequency	Cloud Liquid Water/Ice
Convergence/Divergence	Dew Point Temperature	Evaporation	Geopotential Height
Gravity Wave	Heat Flux	Humidity	Hydrostatic Pressure
Ice Extent	Incoming Solar Radiation	Longwave Radiation	Outgoing Longwave Radiation
Potential Temperature	Precipitable Water	Precipitation Amount	Runoff
Sea Level Pressure	Sea Surface Temperature	Shortwave Radiation	Skin Temperature
Snow	Snow Density	Snow Depth	Snow Melt
Snow/Ice Temperature	Soil Moisture/Water Content	Soil Temperature	Streamfunctions
Sunshine	Surface Air Temperature	Surface Pressure	Surface Roughness
Surface Winds	Terrain Elevation	Tropospheric Ozone	Upper Level Winds
Vegetation Cover	Vegetation Species	Vertical Wind Motion	Vorticity
Water Vapor	Wind Stress		

Model name[a]	Model time step	Meteorological forcing variables[b]	Energy balance	ET scheme[c]	Runoff scheme[d]	Snow scheme	Reference(s)
GWAVA	Daily	P, T, W, Q, LW_{net}, SW, SP	No	Penman–Monteith	Saturation excess/ beta function	Degree-day	Meigh et al. 1999
H08	6 h	R, S, T, W, Q, LW, SW, SP	Yes	Bulk formula	Saturation excess/ beta function	Energy balance	Hanasaki et al. 2008a
HTESSEL	1 h	R, S, T, W, Q, LW, SW, SP	Yes	Penman–Monteith	Infiltration excess/ Darcy	Energy balance	Balsamo et al. 2009
JULES	1 h	R, S, T, W, Q, LW, SW, SP	Yes	Penman–Monteith	Infiltration excess/ Darcy	Energy balance	Cox et al. 1999; Essery et al. 2003
LPJmL	Daily	P, T, LW_{net}, SW	No	Priestley–Taylor	Saturation excess	Degree-day	Bondeau et al. 2007; Rost et al. 2008
MacPDM	Daily	P, T, W, Q, LW_{net}, SW	No	Penman–Monteith	Saturation excess/ beta function	Degree-day	Arnell 1999; Gosling and Arnell 2010
MATSIRO	1 h	R, S, T, W, Q, LW, SW, SP	Yes	Bulk formula	Infiltration and saturation excess/ groundwater	Energy balance	Takata et al. 2003; Koirala 2010
MPI-HM	Daily	P, T	No	Thornthwaite	Saturation excess/ beta function	Degree-day	Hagemann and Gates 2003; Hagemann and Dümenil 1998
Orchidee	15 min	R, S, T, W, Q, SW, LW, SP	Yes	Bulk formula	Saturation excess	Energy balance	De Rosnay and Polcher 1998
VIC	Daily/3h	P, T_{max}, T_{min}, W, Q, LW, SW, SP	Snow season	Penman–Monteith	Saturation excess/ beta function	Energy balance	Liang et al. 1994
WaterGAP	Daily	P, T, LW_{net}, SW	No	Priestley–Taylor	Beta function	Degree-day	Alcamo et al. 2003

R: Rainfall rate, S: Snowfall rate, P: Precipitation, T: Mean daily air temperature, Tmax: Maximum daily air temperature, Tmin: Minimum daily air temperature, W: Wind speed, Q: Specific humidity, LW: Longwave radiation flux (downward), LWn: Longwave radiation flux (net), SW: Shortwave radiation flux (downward), SP: Surface pressure

Multimodel estimate of the global terrestrial water balance: Setup and first results
I Haddeland, DB Clark, W Franssen, F Ludwig, F VOß... - Journal of Hydrometeorology, 2011

Evapotranspiration

Modelling (reanalysis)

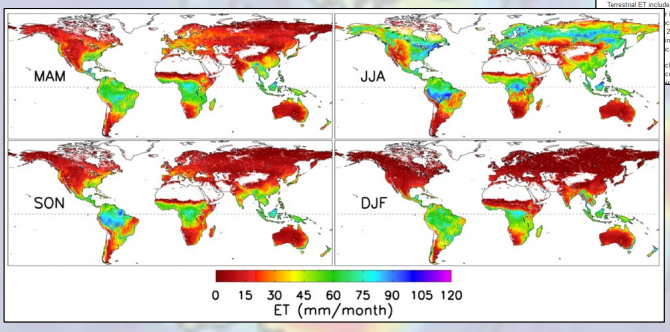
- CRU TS 3.22
- GLDAS
- ERA-Iterim

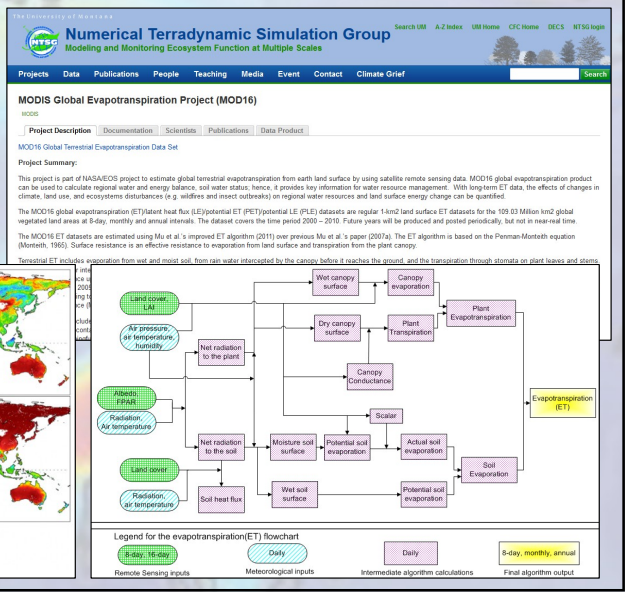
Remote sensing

- MODIS MOD16 http://www.ntsg.umt.edu/project/mod16

MODIS Global Evapotranspiration Project (MOD16)

- 8-day, monthly, annual; mm/month
- Spatial resolution 1 km
- 2000-2013





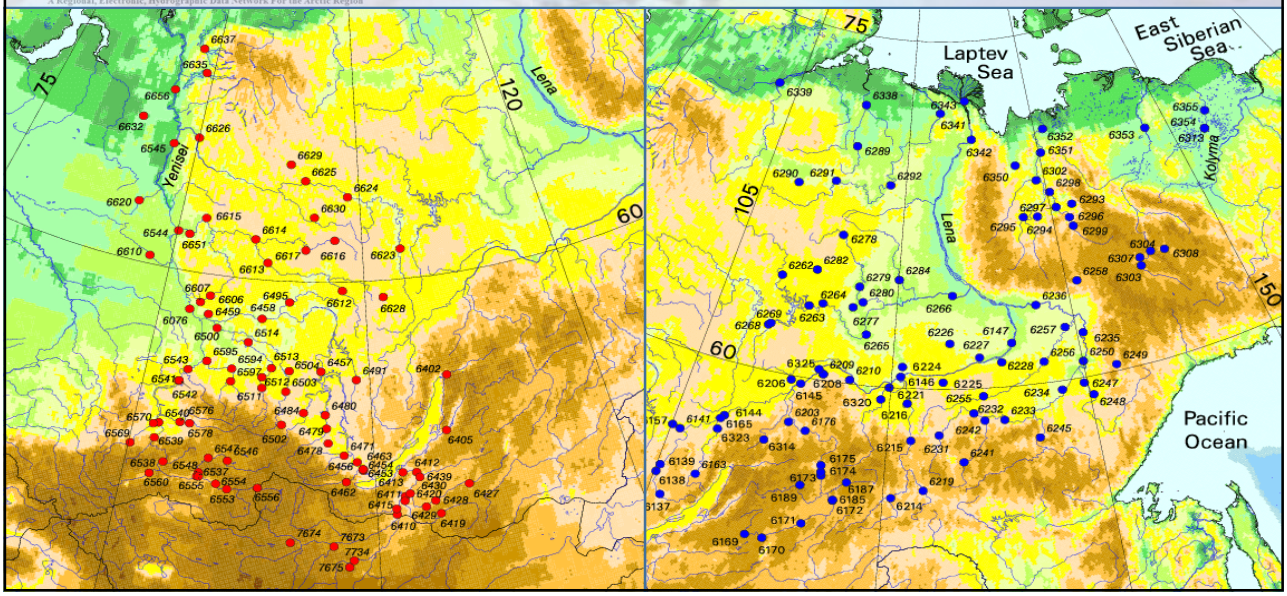
Runoff

1) Arctic RIMS
2) Global Runoff Data Centre (GRDC)
3) River Watch (Satellite River Discharge Measurements)

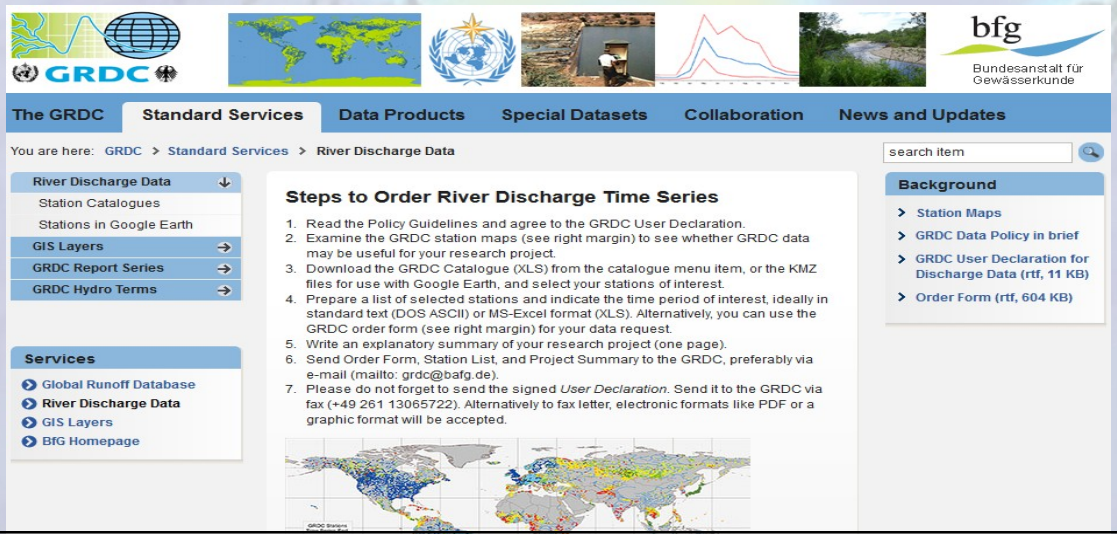
R-Arctic.NET discharge data

http://www.r-arcticnet.sr.unh.edu/v4.0/main.html

Monthly pointed data, m^3 per s



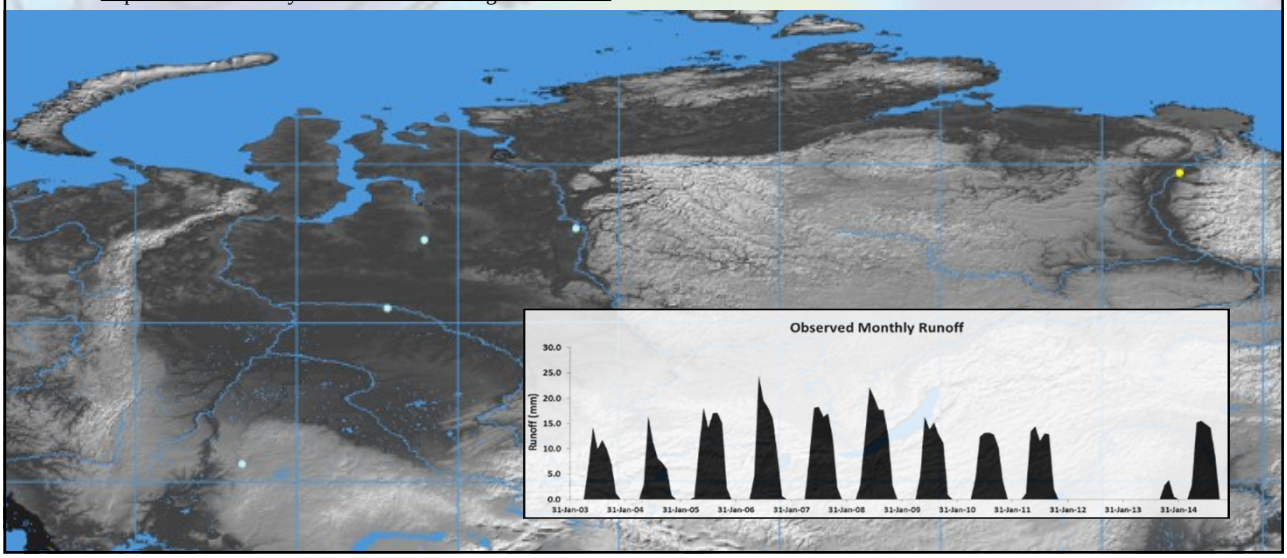
Global Runoff Data Centre (GRDC)



River Watch

(Satellite River Discharge Measurements; AMSR-E, AMSR-2)

http://floodobservatory.colorado.edu/DischargeAccess.html



Total storage variations

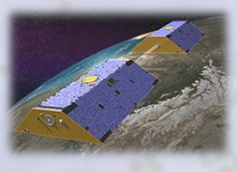
Remote sensing

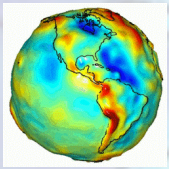
- GRACE (surface+underground water)
- AMSR-E (top layer soil moisture, snow cover)
- Landsat (area of water bodies)
- ICESat (height variations of water bodies)
- Topex\Poseidon (height variations of water bodies)
- ERS, Envisat (area and height variations of water bodies)

Modelling (Land Surface Models)

- GLDAS (surface+underground water, etc)

GRACE





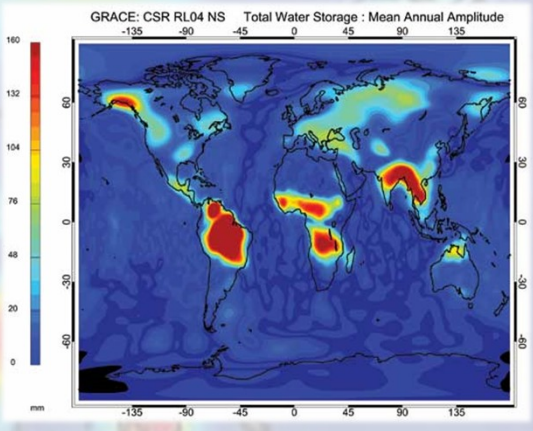
- GRACE – Gravity Recovery and Climate Experiment (NASA)
- Launched in March of 2002, the GRACE mission is accurately mapping variations in Earth's gravity field. Designed for a nominal mission lifetime of five years, GRACE is currently operating in an extended mission phase, which is expected to continue through at least 2015.
- GRACE consists of two identical spacecraft that fly about 220 kilometers (137 miles) apart in a polar orbit 500 kilometers (310 miles) above Earth. GRACE maps earth's gravity field by making accurate measurements of the distance between the two satellites, using GPS and a microwave ranging system.

- It is providing scientists from all over the world with an efficient and cost-effective way to map earth's gravity field with unprecedented accuracy. The results from this mission are yielding crucial information about the distribution and flow of mass within earth and its surroundings.
- The gravity variations studied by GRACE include: changes due to surface and deep currents in the ocean; runoff and ground water storage on land masses; exchanges between ice sheets or glaciers and the ocean; and variations of mass within earth. Another goal of the mission is to create a better profile of earth's atmosphere. GRACE results are making a huge contribution to the goals of NASA'S science mission directorate, Earth Observation System (EOS) and global climate change studies.

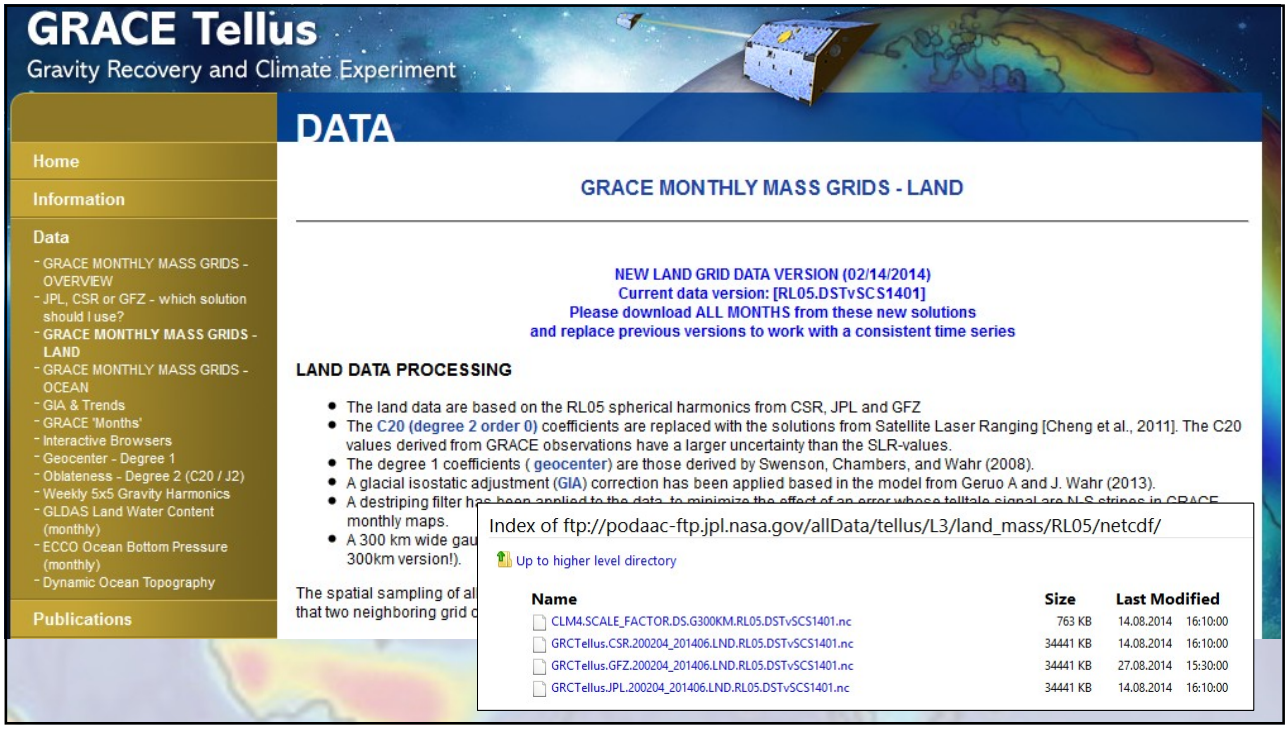
Three centers are part of the GRACE ground system):

1. **CSR** (U. Texas / Center for Space Research);
2. **GFZ** (Geoforschungszentrum Potsdam);
3. **JPL** (Jet Propulsion Laboratory)

- **Grid size 1x1 degrees** = 71 x 111 km at 50°N
- **Time from 04.2002 to 06.2014** excluding some dates.
- The units of the '**equivalent water thickness anomalies**' grids are cm of water thickness



http://grace.jpl.nasa.gov


GRACE Tellus
Gravity Recovery and Climate Experiment
DATA
Home
Information
Data
- GRACE MONTHLY MASS GRIDS - OVERVIEW
- JPL, CSR or GFZ - which solution should I use?
- GRACE MONTHLY MASS GRIDS - LAND
- GRACE MONTHLY MASS GRIDS - OCEAN
- GIA & Trends
- GRACE 'Months'
- Interactive Browsers
- Geocenter - Degree 1
- Oblateness - Degree 2 (C20 / J2)
- Weekly 5x5 Gravity Harmonics
- GLDAS Land Water Content (monthly)
- ECCO Ocean Bottom Pressure (monthly)
- Dynamic Ocean Topography
Publications
GRACE MONTHLY MASS GRIDS - LAND
NEW LAND GRID DATA VERSION (02/14/2014)
Current data version: [RL05.DSTvSCS1401]
Please download ALL MONTHS from these new solutions
and replace previous versions to work with a consistent time series
LAND DATA PROCESSING
The land data are based on the RL05 spherical harmonics from CSR, JPL and GFZ
The C20 (degree 2 order 0) coefficients are replaced with the solutions from Satellite Laser Ranging [Cheng et al., 2011]. The C20 values derived from GRACE observations have a larger uncertainty than the SLR-values.
The degree 1 coefficients (geocenter) are those derived by Swenson, Chambers, and Wahr (2008).
A glacial isostatic adjustment (GIA) correction has been applied based in the model from Geruo A and J. Wahr (2013).
monthly maps.
300km version!).
The spatial sampling of al
that two neighboring grid c
Index of ftp://podaac-ftp.jpl.nasa.gov/allData/tellus/L3/land_mass/RL05/netcdf/
Up to higher level directory
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Size
Last Modified
CLM4.SCALE_FACTOR.DS.G300KM.RL05.DSTvSCS1401.nc 763 KB 14.08.2014 16:10:00
GRCTellus.CSR.200204_201406.LND.RL05.DSTvSCS1401.nc 34441 KB 14.08.2014 16:10:00
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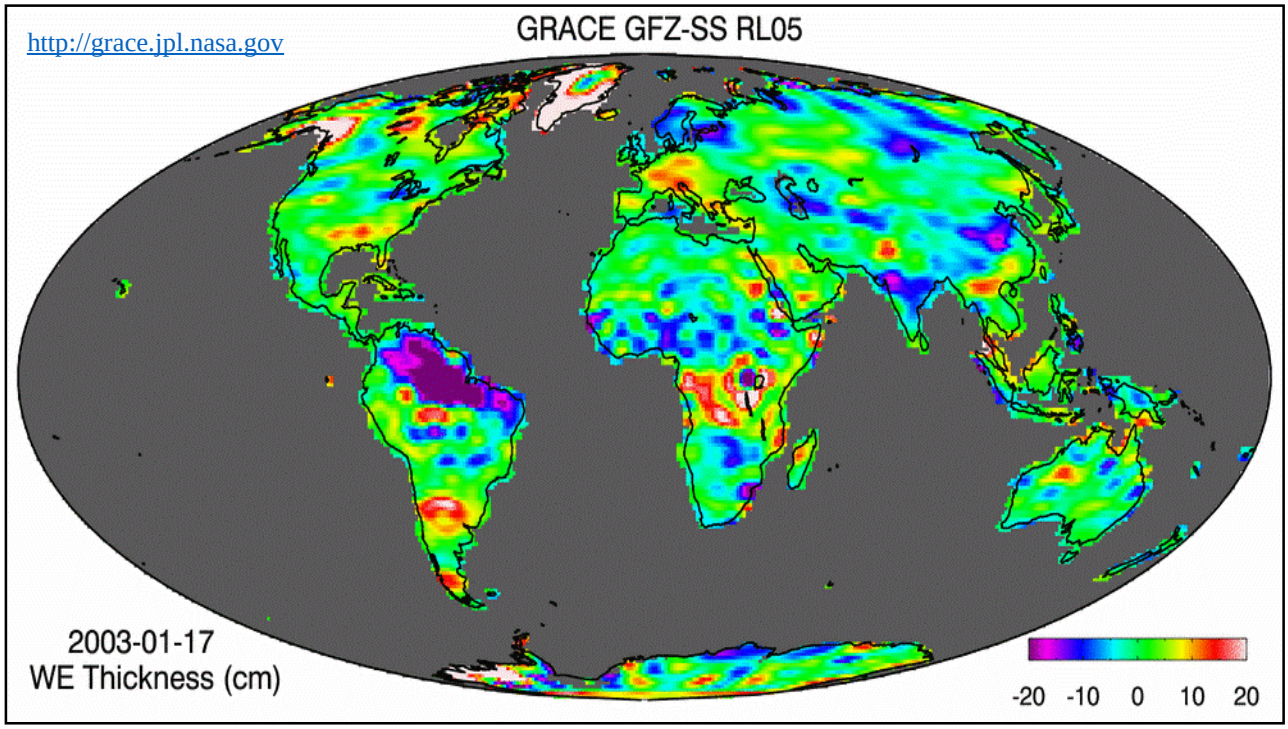
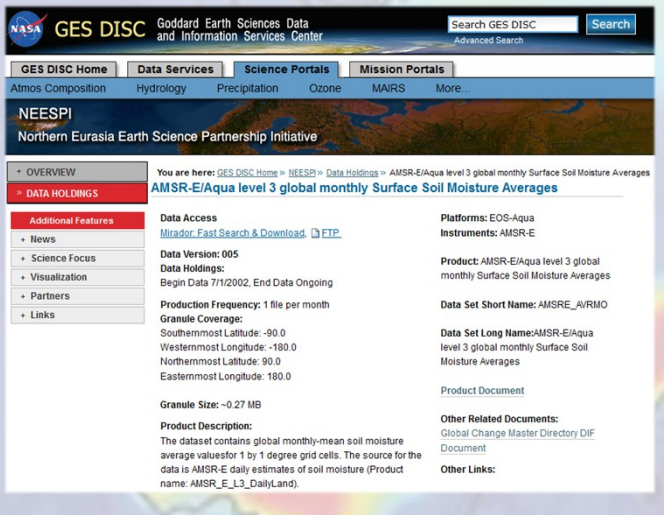

http://grace.jpl.nasa.gov
GRACE GFZ-SS RL05
2003-01-17
WE Thickness (cm)
-20 -10 0 10 20

Global monthly AMSR-E-derived soil moisture (NEESPI)

http://disc.Sci.Gsfc.Nasa.Gov/neespi/data-holdings/amsre_avrmo.Shtml



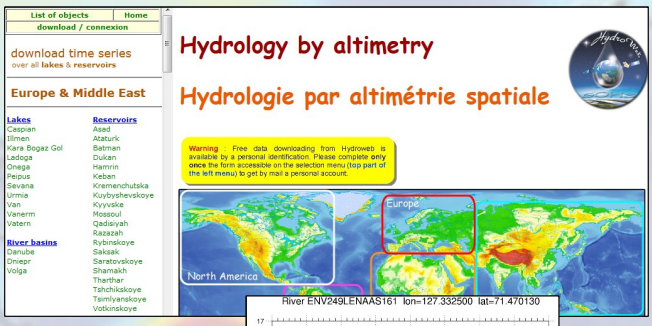
- 1 degree grid cells
- The source for the data is AMSR-E daily estimates of soil moisture (product name: amsr_e_l3_dailyland).
- The dataset covers the time period starting july 2002 - 2011.
- Data files contain 180 lines with 360 pixels per line. The projection is latitude-longitude with the upper left corner of the first pixel of the first line positioned at 90N 180W.
- Units: 1000*g/cm^3 = mm
- Soil moisture in the top ~1 cm of soil is averaged over the retrieval footprint

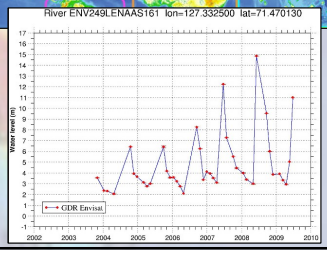
Global Reservoir and Lake Monitor

Lake water variation (m) based on microwave remote sensing data from Envisat/ASAR and Topex/Poseidon

HydroWeb (LEGOS, Hydrology by altimetry)

- Envisat, ERS-1, ERS-2
- Need registration

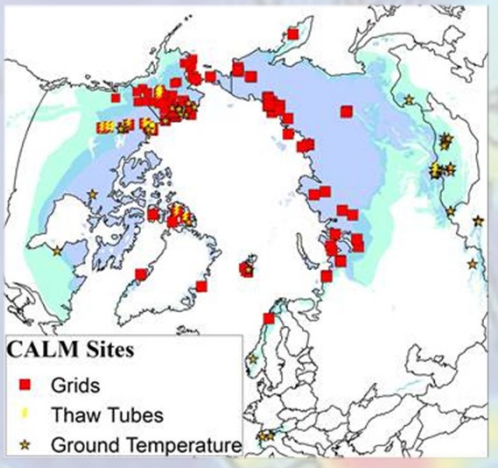




Additional data sets

Active layer, soil moisture, water level, soil moisture, temperature, DEM, etc.

CALM - Circumpolar active layer monitoring network-calm: *long-term observations of the climate-active layer-permafrost system*
http://www.gwu.edu/~calm/



The primary goal of the circumpolar active layer monitoring (CALM) program is to observe the response of the active layer and near-surface permafrost to climate change over long (multi-decadal) time scales.

The CALM observational network, established in the 1990s, observes the long-term response of the active layer and near-surface permafrost to changes and variations in climate at more than 200 sites in both hemispheres.

CALM data on Russia

Russia

Russian European north

Site Code	Site Name	Location LAT	Location LONG	Method	SITE AVERAGES OF THE ANNUAL END-OF-SEASON THAW DEPTH (cm) 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
R2	Ayach-Yakha, Vorkuta	67° 35' N	64° 11' E	100/T	-	-	-	-	-	-	70	63	65	64	69	73	76	77	78	81	84	89	87	86	89	88	91	93
R23	Talnik	67° 20' N	63° 44' E	100	-	-	-	-	-	-	-	76	91	111	111	110	113	125	131	137	138	152	144	138	144	161	156
R24	Bolvansky	68° 18' N	54° 30' E	100	-	-	-	-	-	-	-	-	89	106	106	104	113	120	115	114	125	124	112	104	107	>135[2]	117
R24 A	Kashin Island	68° 14' N	53° 51' E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	58	64	88	87
R44	Umbozero; Kola Peninsula	67.7723958 N	34.1820458 E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	160	160	165

West Siberia

Site Code	Site Name	Location LAT	Location LONG	Method	SITE AVERAGES OF THE ANNUAL END-OF-SEASON THAW DEPTH (cm) 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
R1	Nadym; West Siberia	65° 20' N	72° 55' E	100/T/B10	-	-	-	-	-	-	-	119	134	129	126	132	143	126	134	141	129	129	136	101[3]	114	129	134	136
R3	Marre Sale, Yamal Peninsula	69° 43' N	66° 45' E	1000/T/B10	-	-	-	-	-	131	110	92	93	92	106	111	115	109	114	116	116	114	114	85[4]	98	102	127	115
R4	Parisento, Gydan Peninsula	70° 07' N	75° 35' E	1000	-	-	82	91	-	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R5	Vaskiny Dachy, Yamal Peninsula	70° 17' N	68° 54' E	100/T/B10	-	-	-	84	85	95	89	81	93	87	92	92	92	*	94	97	94	92	93	76[5]	87	87	102	103
R5 A	Vaskiny Dachi, Yamal Peninsula	70°16'31.8" N	68°53'29.9" E	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	72	75	47[6]	67	67	77	80
R5 B	Vaskiny Dachi, Yamal Peninsula	70°17'43.8" N	68°53'00.5" E	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	72	73	81[7]	65	65	77	78
R5 C	Vaskiny Dachi, Yamal Peninsula	70°18'05.0" N	68°50'28.7" E	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	112	113	82[8]	106	114	128	126
R50a	Urengoy Gas Field GP5	66.31537 N	76.90772 E	100/T/B10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84	65[9]	77	72	87	70
R50b	Urengoy Gas Field GP15	67.4779100 N	76.6952900 E	100/T/B10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	84	65[10]	80	82	95	92
R33 A	Yubileynoe 2 WET	66°00'34.1" N	75°46'46.5" E	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R33 B	Yubileynoe 2 DRY	66°00'36.2" N	75°46'48.8" E	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R34 A	Yubileynoe 3 WET	65°57'01.2" N	75°52'18.7 E	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R34 B	Yubileynoe 3 DRY	65°57'3" N	75°52'20.6 E	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Central Siberia

Site Code	Site Name	Location LAT	Location LONG	Method	SITE AVERAGES OF THE ANNUAL END-OF-SEASON THAW DEPTH (cm) 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
R6	Labaz Lake, Taimyr	72° 23' N	99° 30' E	100/T	-	-	-	-	42	50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R7	Levinson Lessing Lake, Taimyr	74° 32' N	98° 36' E	100/T	-	-	-	-	36	42	34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
R8	Tiksi (Game), Lena Delta	71° 35' N	128° 47' E	1000/T	-	-	-	-	-	-	-	40	40	42	47	-	-	-	-	-	-	-	-	-	-	-	-	-
R28	Svjatoy Nos cape (East Siberian sea)	72° 51,42' N	141° 00,61' E	100	-	-	-	-	-	-	-	-	-	-	-	38	-	-	-	-	-	-	-	-	-	-	-	-
R29 A	Bykovsky (Lena delta) (edoma)	71° 47.13' N	129° 25.15' E	100	-	-	-	-	-	-	-	-	-	-	-	27	-	35	25	33	35	44	38	28	38	39	33	26
R29 B	Bykovsky (Lena delta) (alas)	72° 47.13' N	130° 25.15' E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	26	33	32	44	37	25	28	35	30	24
R32	Talnah (Norilsk Region)	69° 26' N	88 28' E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	81	91	90	94	94	94	96	104	86
R40	Igarka	67° 28'56" N	86° 26'08" E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	74	71	67	70	69	72
R42	Tuymada (Yakutsk region)	62.013306 N	129.656991 E	50/TT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	203	199	197	201	201	201
R43	Neleger (Yakutsk region)	62.316255 N	129.499661 E	50/TT	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	124	122	123	123	124	129
R46	Chara Belenky	56.76038 N	118.18903 E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	59
R47	Chara Most	56.906264 N	118.280672 E	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	55

North East Siberia

Site Code	Site Name	Location LAT	Location LONG	Method	SITE AVERAGES OF THE ANNUAL END-OF-SEASON THAW DEPTH (cm) 1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
R12 A	Kuropatochya River; Kolyma	70° 55' N	156° 38' E	100/T/B15	-	-	-	-	-	-	37	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Active layer data (Samoylov Island)

http://doi.pangaea.de/10.1594/pangaea.806202

PANGAEA®
Data Publisher for Earth & Environmental Science

Not logged in (log in or sign up)

Always quote citation when using data!

Data Description

Show Map | Google Earth

Citation: Boike, J et al. (2013): Thaw depth measured on Samoylov Island, 2002-2010. doi:10.1594/PANGAEA.806202,
In Supplement to: **Boike, Julia; Kattenstroth, Britta; Abramova, Katya; Bornemann, Niko; Chetverova, Antonina; Fedorova, Irina; Fröb, Katrin; Grigoriev, Mikhail N; Grüber, Maren; Kutzbach, Lars; Langer, Moritz; Minke, Merten; Muster, Sina; Piel, Konstanze; Pfeiffer, Eva-Maria; Stoof, Günter; Westermann, Sebastian; Wischnewski, Karoline; Wille, Christian; Hubberten, Hans-Wolfgang (2013):** Baseline characteristics of climate, permafrost and land cover from a new permafrost observatory in the Lena River Delta, Siberia (1998-2011). *Biogeosciences*, **10(3)**, 2105-2128, doi:10.5194/bg-10-2105-2013

Project(s): **Periglacial Dynamics @ AWI** (AWI_PerDyn)

Coverage: *Median Latitude:* 72.369812 * *Median Longitude:* 126.481106 * *South-bound Latitude:* 72.369664 * *West-bound Longitude:* 126.480654 * *North-bound Latitude:* 72.369959 * *East-bound Longitude:* 126.481556
Date/Time Start: 2002-07-10T00:00:00 * *Date/Time End:* 2010-09-27T00:00:00
Minimum ELEVATION: 9.3 m a.s.l. * *Maximum ELEVATION:* 10.0 m a.s.l.

Event(s): **Samoylov_02-10_Thaw_depth** * *Latitude Start:* 72.369660 * *Longitude Start:* 126.480650 * *Latitude End:* 72.369950 * *Longitude End:* 126.481550 * *Date/Time Start:* 2002-07-10T00:00:00 * *Date/Time End:* 2010-09-27T00:00:00 * *Location:* Samoylov Island, Lena Delta, Siberia * *Device:* Multiple investigations

Parameter(s):

#	Name	Short Name	Unit	Principal Investigator	Method	Comment
1	DATE/TIME	Date/Time				Geocode
2	LATITUDE	Latitude				Geocode
3	LONGITUDE	Longitude				Geocode
4	ELEVATION	Elevation	m a.s.l.			Geocode
5	Identification	ID		Boike, Julia		
6	Description	Description		Boike, Julia		1 = typical Centre, high Waterlevel, C. aquatilis, +/- dense Mosses; 2 = Rim (Slope), very dense Mosses, Aulacomnium sp. among others; 3 = high Rim, C. aquatilis small, Salix, Dryas, rel. flat Moss layer Hylocomium; 4 = flat Rim, C. aquatilis, dense Hylocomium; 5 = Crack, dense Moss layer Hylocomium among others, partly Water no vegetation
7	Thaw depth of active layer	Thaw depth	cm	Boike, Julia		

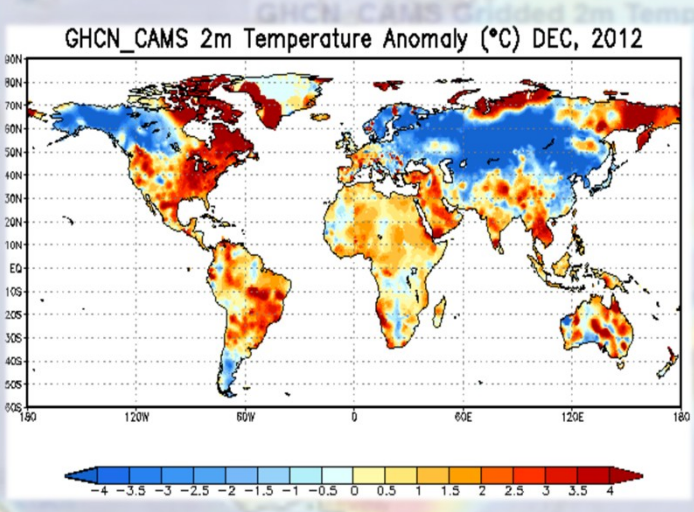
License: Creative Commons Attribution 3.0 Unported

Size: 34650 data points

Date/Time	Latitude	Longitude	Elevation [m a.s.l.]	ID	Description	Thaw depth [cm]
2002-07-10	72.369759	126.480654	9.460	1/1	2	15

NCEP GHCN gridded 2m temperature (land)

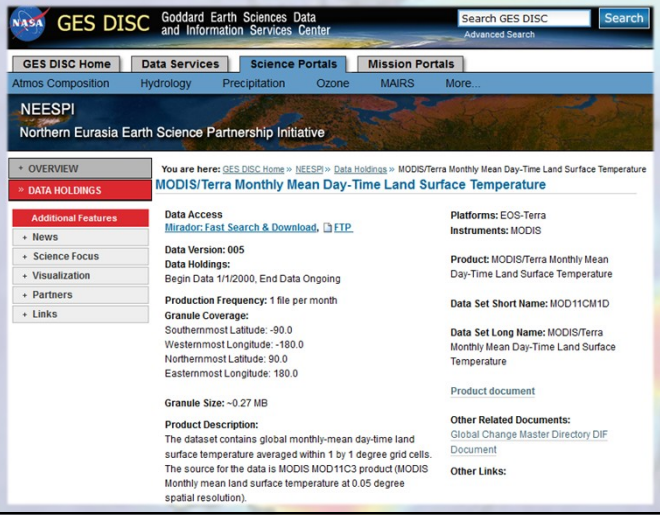
http://www.esrl.noaa.gov/psd/data/gridded/data.ghcncams.html
ftp://ftp.Cdc.Noaa.Gov/datasets/ghcncams



- Spatial resolution 0.5 degrees
- Time coverage 1948-2012
- Reanalysis data

Global monthly MODIS-derived land surface temperature (NEESPI)

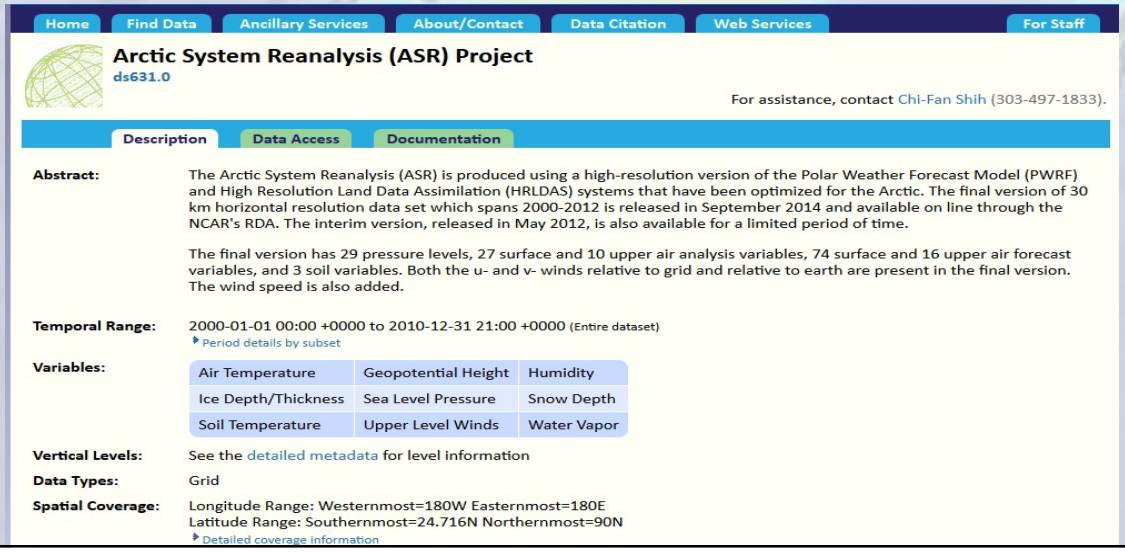
http://disc.sci.gsfc.nasa.gov/neespi/data-holdings/mod11cm1d.shtml



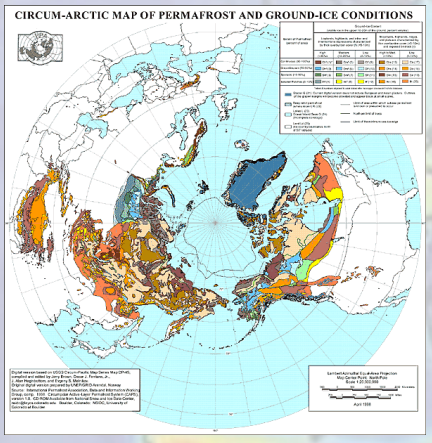
- 1 by 1 degree grid cells.
- The source for the data is MODIS MOD11C3 product (MODIS Monthly mean land surface temperature at 0.05 degree spatial resolution)
- Data files contain 180 lines with 360 pixels per line. The projection is latitude-longitude with the upper left corner of the first pixel of the first line positioned at 90N 180W
- 2000-2013 Terra/MODIS (MOD11CM1D, MOD11CM1N)
- 2002-2013 Aqua/MODIS (MYD11CM1D, MYD11CM1N)

Arctic System Reanalysis (ASR) Project

Byrd Polar Research Center/The Ohio State University. 2012. *Arctic System Reanalysis (ASR) Project*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory.



Circum-Arctic Map of Permafrost and Ground-Ice Conditions



Dataset Creator: Brown, J., O.J. Ferrians, Jr., J.A. Heginbottom, and E.S. Melnikov.
Dataset Title: Circum-Arctic Map of Permafrost and Ground-Ice Conditions
Dataset Release Date: 2002-02-01
Dataset Release Place: Boulder, Colorado USA
Dataset Publisher: NSIDC: National Snow and Ice Data Center
Version: 2
Online Resource:
http://nsidc.org/data/ggd318.html

USGS
science for a changing world

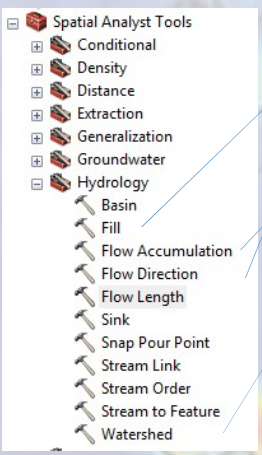
Global multi-resolution terrain elevation data 2010 (GMTED2010)

http://topotools.cr.usgs.gov/gmted_viewer/

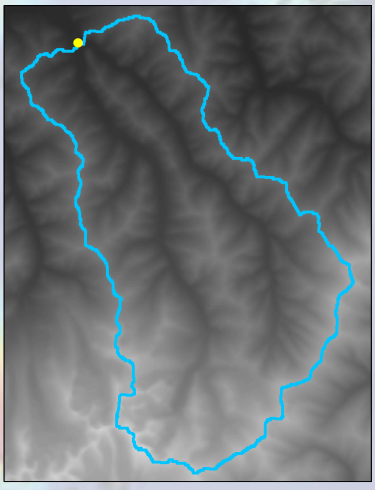
- The U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA) have collaborated on the development of a notably enhanced global elevation model named the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) that replaces GTOPO30 as the elevation dataset of choice for global and continental scale applications.
- Data sources include global Digital Terrain Elevation Data (DTED®) from the Shuttle Radar Topography Mission (SRTM), Canadian elevation data, Spot 5 Reference3D data, and data from the Ice, Cloud, and land Elevation Satellite (ICESat)
- Spatial resolution is 7.5-30 arc-seconds (~1km).
- At 30 arc-seconds, RMSE range is between 25 and 42 meters.
- Covers up to 90°N.
- The global raster data grids are provided in the ESRI ArcGrid format.

How to calculate river watershed based on DEM? Use ArcGIS Hydrology tools

ArcToolBox>Spatial Analyst Tools



1. Use Fill tool to remove anomalies
2. Use Flow Direction tool
3. Use Flow Accumulation tool
4. Create pour point
5. Use Watershed tool
6. Use Rater To Polygon tool



Some recent publications on investigation of Siberian permafrost based on remote sensing data

Some publications

Energy and mass changes of the Eurasian permafrost regions by multi-satellite and *in-situ* measurements

Reginald R. Muskett*, Vladimir E. Romanovsky, Natural Science, vol.3, no.10, 827-836 (2011)

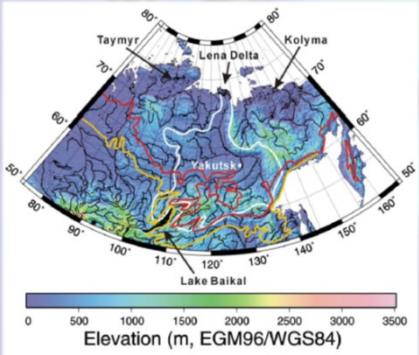


Figure 1. Eurasia centered on the Lena River watershed (white line extent). Permafrost zones are represented by extent lines: the continuous zone (red) and the combined discontinuous and sporadic zones (yellow). Permafrost thaw-lake regions of Kolyma, Lena Delta and Taymyr are identified.

Investigated changes in total water equivalent mass, land-surface temperature and atmospheric CO2 by satellite-based measurements (2002-2008).

Region of interest 75° to 165°E and 50° to 80°N.

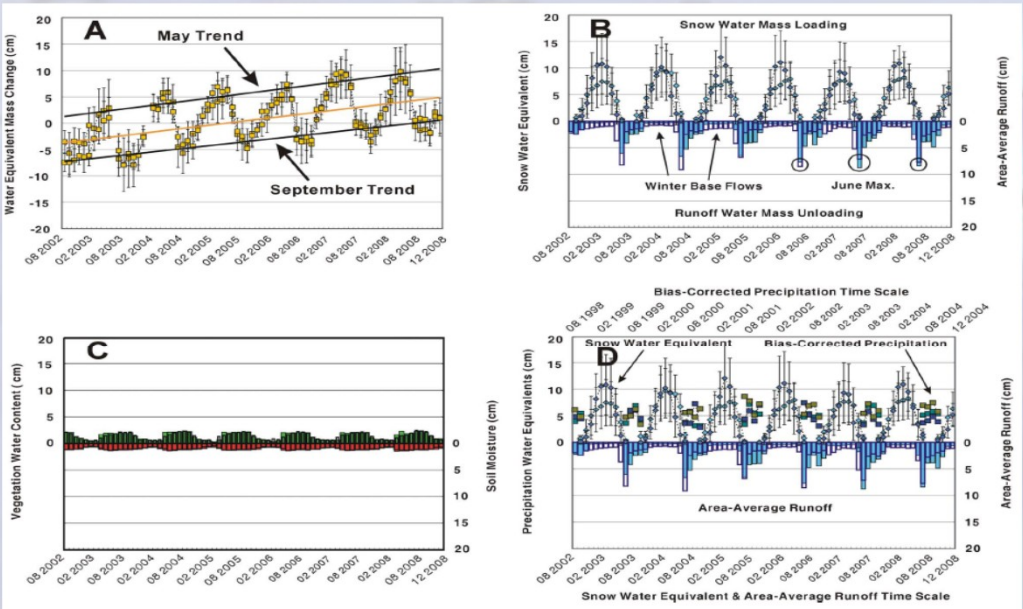


Figure 3. Regionalized time series of water mass changes in the Lena and Yenisei River watersheds. (A) GRACE water equivalent mass series and least squares trends, (B) SSM/I-AMSR-E snow water equivalent series (top) area-average runoff (below), (C) AMSR-E vegetation water content series (top) and soil moisture (below), (D) same as B with summertime bias-corrected precipitation series.

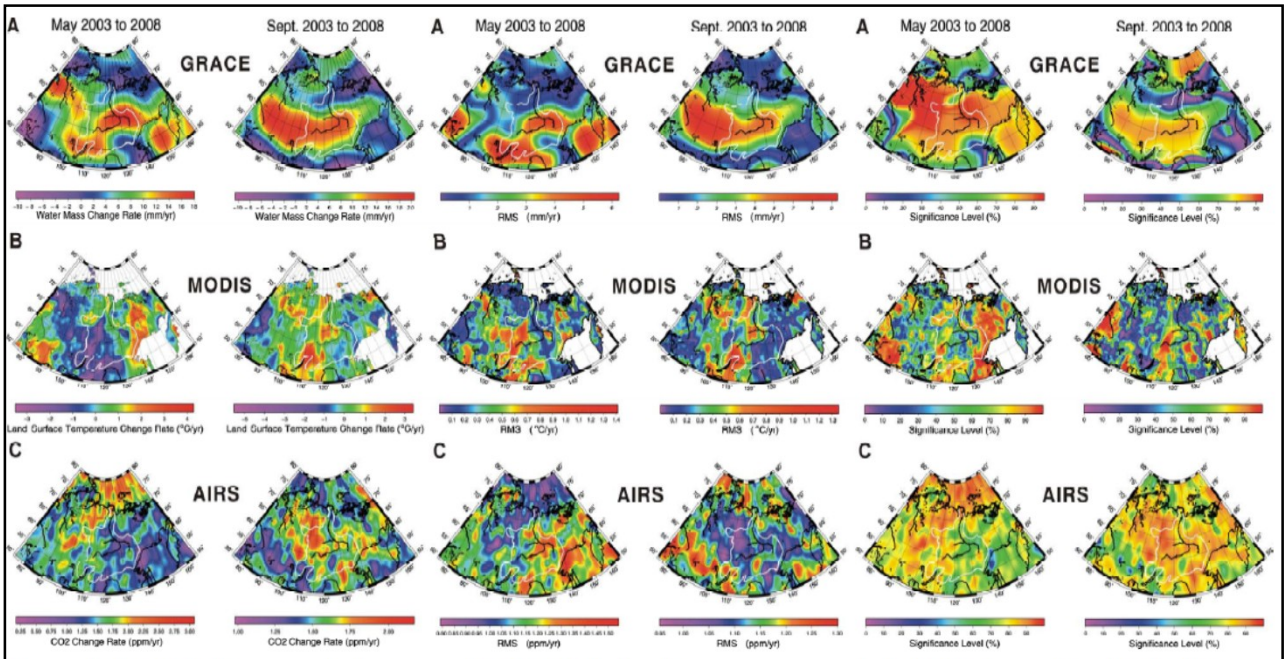


Figure 4. (A) GRACE water equivalent mass, (B) MODIS land-surface temperature and (C) AIRS CO_2 gradient fields (left), error estimates by Root Mean Squares (RMS, center) and significance levels (right).

Found energy and mass changes on the continuous and discontinuous permafrost zones indicating:

1) **arctic uplands** such as the Siberian Plateau show **strongly positive water equivalent mass** and **strongly negative land-surface temperature gradients during May** months.

2) **arctic lowlands** such as the thaw-lake regions of Kolyma, Lena delta, and Taymyr show **strongly negative water equivalent mass** and **strongly positive land-surface temperature gradients during September** months.

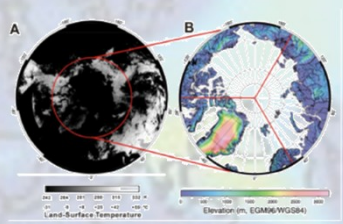
3) **areas with strongly positive water equivalent mass** and **negative land-surface temperature gradients during may** months have **weakly positive CO_2 gradients**

4) **areas with strongly negative water equivalent mass** and **strongly positive land-surface temperature gradients during September** months have **strongly positive CO_2 gradients**.

This indicates that continuous and discontinuous permafrost ecosystem responses are correlated in phase with energy and mass changes over the period. The Laptev and East Siberia sea have increasing trends of CO_2 atmosphere concentration 2.23 ± 0.15 ppm/yr and 2.40 ± 0.21 ppm/yr, respectively. **Increasing trends and strong positive gradients of CO_2 atmosphere concentration during Aprils-Mays are evidence that the arctic ocean is a strong emitter of CO_2 during springtime** lead formation. They hypnotize that the increasing CO_2 from land and ocean regions is from permafrost thawing and degradation and ecosystem microbial activity.

Modis-derived arctic land-surface temperature trends

Reginald R. Muskett, *Atmospheric and Climate sciences*, 2013, 3, 55-60



- Investigated arctic land-surface temperature changes and regional variations derived by the MODIS sensors on NASA Aqua and Terra (2000-2012).
- Detected increase in the number of days with daytime land-surface temperature above 0°C. There are indications of increasing trends of land-surface temperature change. Regional variations of the changes in land-surface temperature likely arise due to surface material types and topography relative to the daytime variation of solar irradiance.

Table 1. Arctic MODIS-derived decadal land-surface temperature change trends.

Regions	MODIS-Terra	MODIS-Aqua
	10:30	13:30
	2000-2010	2002-2012
	D°C PV R^2	D°C PV R^2
Arctic	+2.1 ± 0.20.01 0.95	+0.1 ± 0.2 0.01 0.95
*Eurasia	+1.7 ± 0.30.01 0.93	+2.8 ± 0.3 0.01 0.93
*Western NA	+1.9 ± 0.2 0.01 0.95	−1.5 ± 0.2 0.01 0.95
*Eastern NA-WE	+2.5 ± 0.3 0.01 0.85	−1.5 ± 0.3 0.01 0.87

*120° azimuth sectors of the Arctic. PV = P-Value (ANOVA).

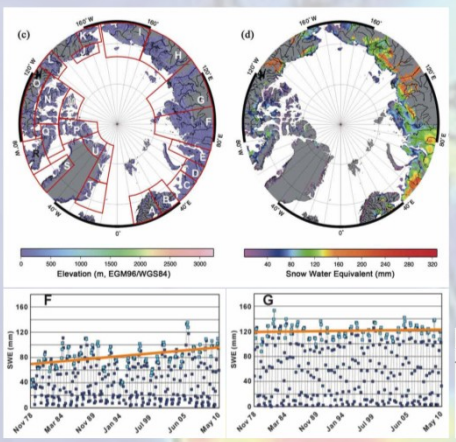
Table 2. Arctic MODIS-derived decadal change of days above 0°C.

Regions	MODIS-Terra	MODIS-Aqua
	10:30	13:30
	2000-2010	2002-2012
	D Days Above 0°C	D Days Above 0°C
Arctic	+14	+14
*Eurasia	+0	+20
*Western NA	+13	+8
*Eastern NA-WE	+31	+23

*120° azimuth sectors of the Arctic. PV = P-Value (ANOVA).

Multi-satellite and sensor derived trends and variation of snow water equivalent on the high-latitudes of the northern hemisphere

Reginald R. Muskett, *International journal of geosciences*, 2012, 3, 1-13



- Investigated regional trends and variations relative to elevation based on the satellite-microwave sensor derived snow water equivalent data on the high-latitudes of the northern hemisphere (1978-2010).
- On the low-elevation tundra regions encircling the arctic - high statistically significant trends of snow water equivalent.
- Across the high arctic Siberia and far east Russia through North America and northern Greenland - increasing trends of snow water equivalent with local region variations in strength.
- Across the high arctic of western Russia through Norway - decreasing trends of snow water equivalent of varying strength.

Region	Longitude	Latitude	Trend	Uncertainty (+/−)	P-Value	Significance Level %
			mm/yr	mm/yr		
F	75 to 110E	65 to 80N	0.85	0.16	1.63E−06	100.0
G	110 to 130	65 to 80N	0.13	0.10	7.61E−09	100.0

Analysis of cryolithozone of Central Siberia based on GRACE remote sensing data

current results
within grant of Russian Federation

The aim of the research

To analyze total water mass dynamics in Central Siberia based on GRACE remote sensing data.

Question to answer

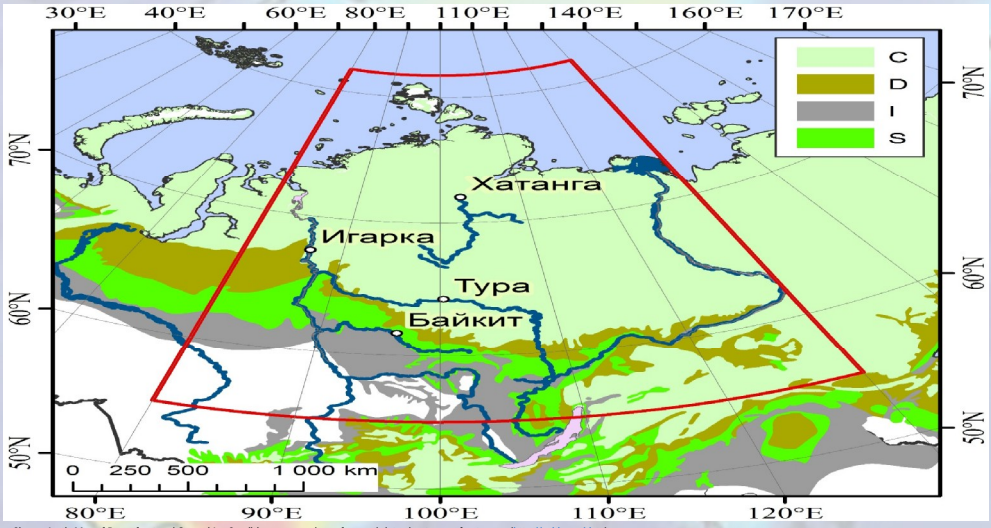
1) Are there any significant trends of total water mass changes in the permafrost zone of the Central Siberia?
2) How climate change is relates to total water mass changes?
3) How water mass anomalies correlates with orography and soil properties?
4) How GRACE data can be used to estimate ground water dynamics?

Materials

- Water thickness anomalies based on GRACE data (http://grace.jpl.nasa.gov/)
- Climate data were obtained from Climatic Research Unit (CRU TS3.21: http://badc.nerc.ac.uk).
- Aster Global Digital Elevation Model (http://gdem.ersdac.jspacesystems.or.jp)
- Harmonized World Soil Database (http://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database)

S1

Study area – Central Siberia
(80°E-130°E, 55°N-82°N)



Circum-Arctic Map of Permafrost and Ground-Ice Conditions was used as referenced data about permafrost zones (http://nsidc.org/data)

Слайд 50

S1 Discontinuous - <300 m.S - sporadic permafrost, I - isolated.

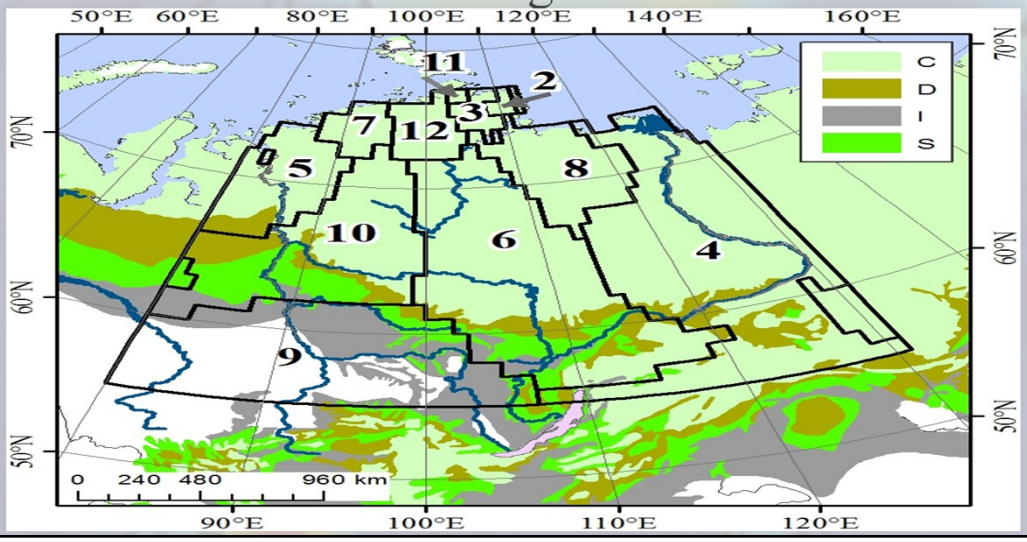
Sergey; 24.03.2014

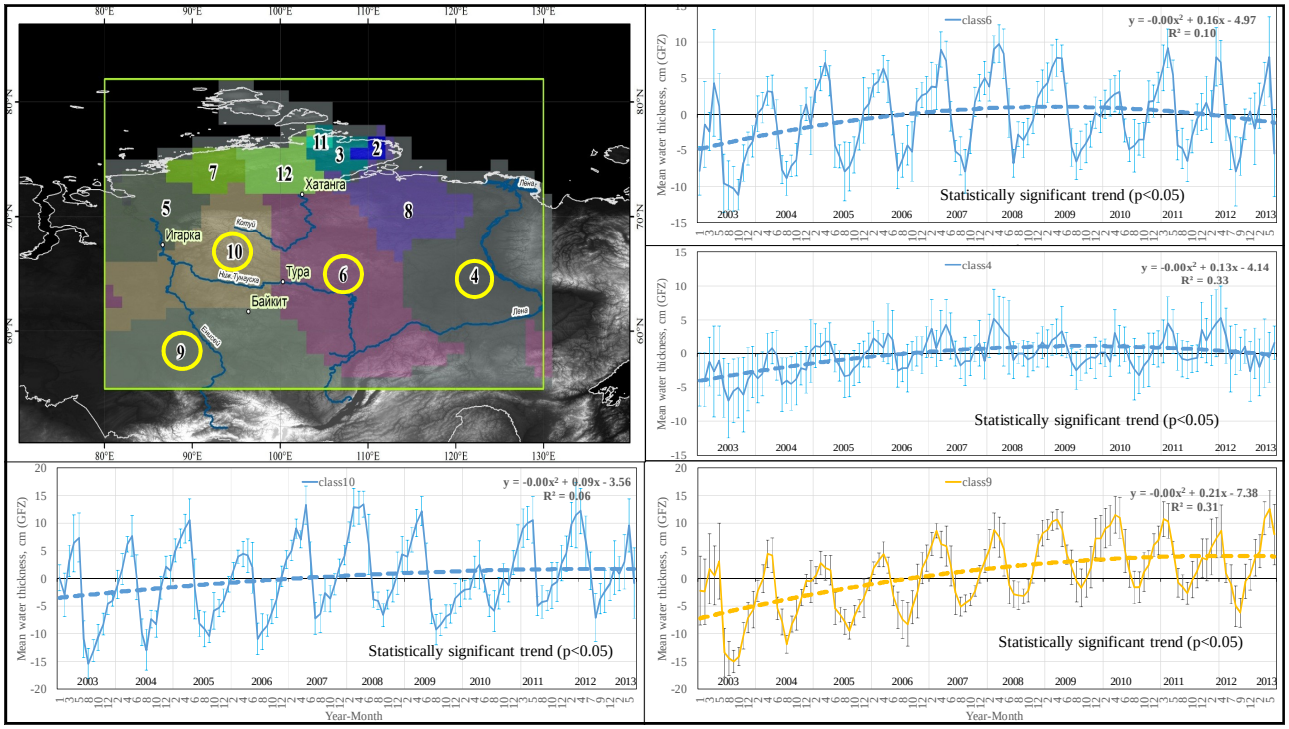
Methods

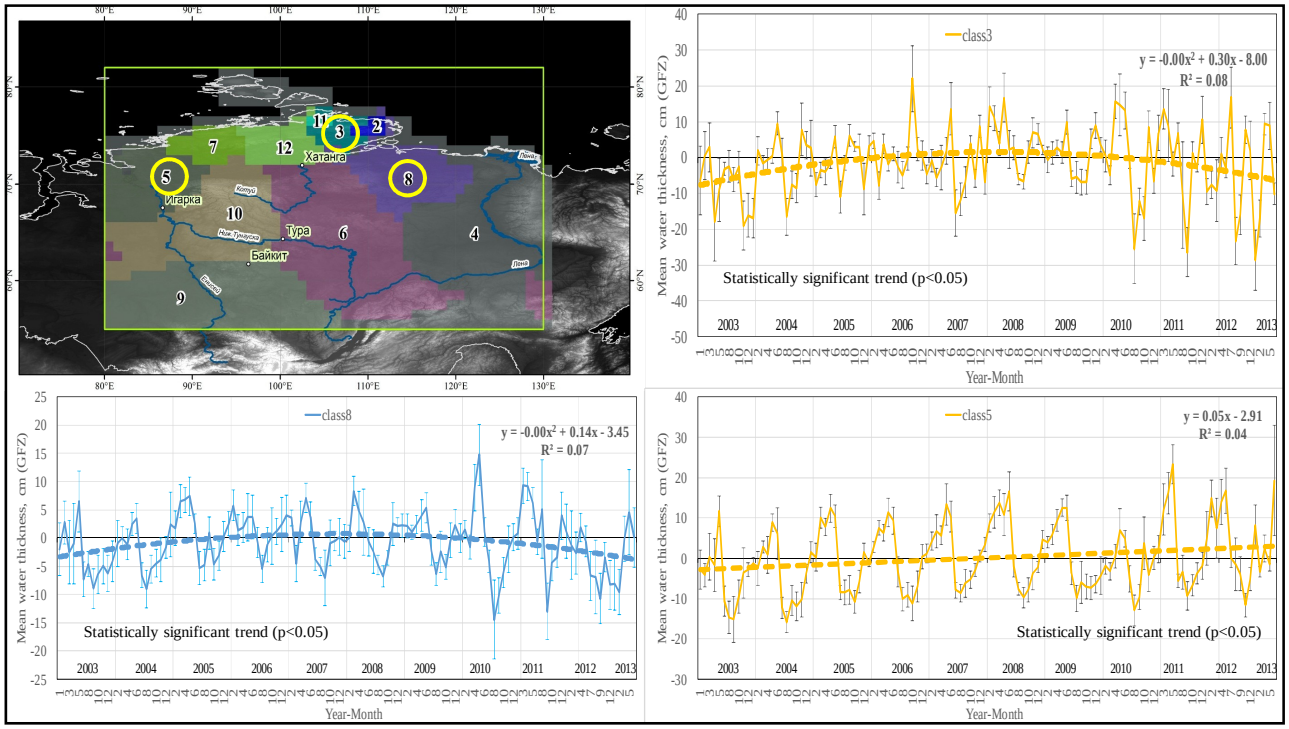
- Uniform regions of total water mass changes were determined using ISODATA classification method.
- Within identified regions trends of total water mass anomalies were estimated.
- Within identified regions trends of total water mass anomalies were compared with temperature and precipitation data.
- A method were suggested and tested to analyze ground water dynamics based on GRACE data.

Results

Determined uniform regions of total water mass changes



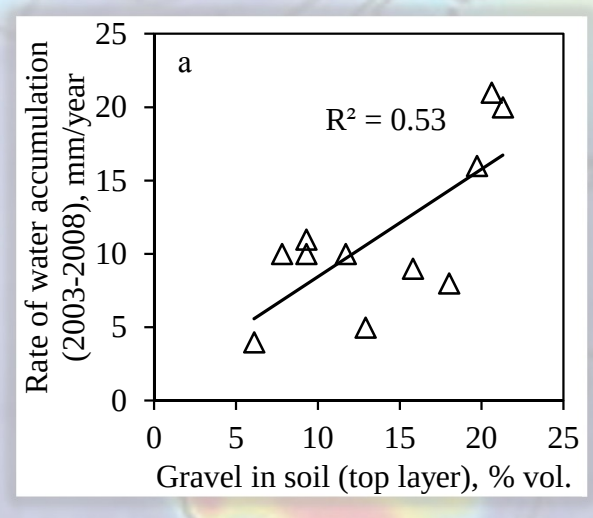

Хатанга
Игарка
Тура
Байкит
class6
y = -0.00x² + 0.16x - 4.97
R² = 0.10
Statistically significant trend (p<0.05)
class4
y = -0.00x² + 0.13x - 4.14
R² = 0.33
Statistically significant trend (p<0.05)
class10
y = -0.00x² + 0.09x - 3.56
R² = 0.06
Statistically significant trend (p<0.05)
class9
y = -0.00x² + 0.21x - 7.38
R² = 0.31
Statistically significant trend (p<0.05)
Mean water thickness, cm (GFZ)
Year-Month

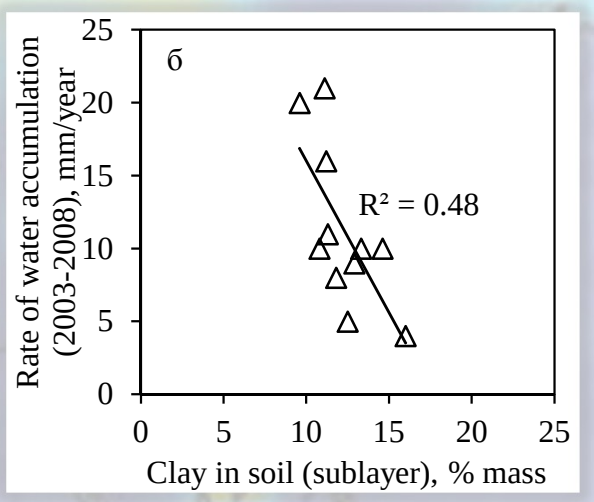

Хатанга
Игарка
Тура
Байкит
class3
y = -0.00x² + 0.30x - 8.00
R² = 0.08
Statistically significant trend (p<0.05)
class8
y = -0.00x² + 0.14x - 3.45
R² = 0.07
Statistically significant trend (p<0.05)
class5
y = 0.05x - 2.91
R² = 0.04
Statistically significant trend (p<0.05)
Mean water thickness, cm (GFZ)
Year-Month

Water mass anomalies vs temperature and precipitation

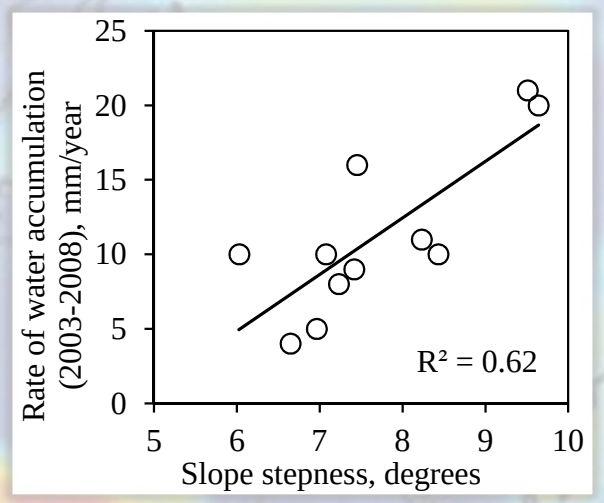
No		Annual precipitation	Summer precipitation	Annual temperature	Summer temperature
4	Summer MEWTA	–	–	–	r^2=0.64
5	Annual MEWTA	r^2=0.67	–	–	–
	Summer MEWTA	r^2=0.73; Spearman-R=0.73	Spearman-R=0.73	–	–
7	Annual MEWTA	r^2=0.66	–	r^2=0.64	r^2=0.66
9	Annual MEWTA	–	Spearman-R=0.73	–	r^2=-0.66

Soil content vs rate of water mass accumulation

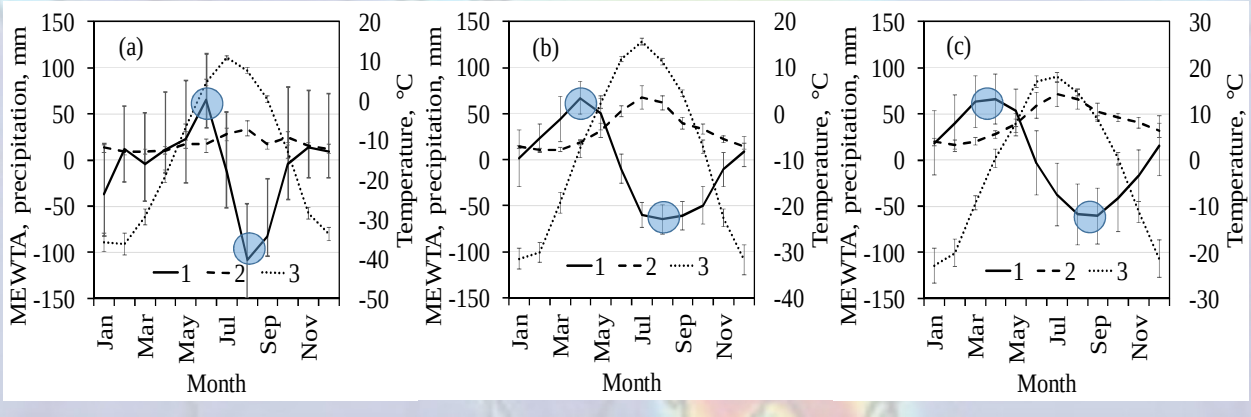




Orography vs rate of water mass accumulation



Seasonal dynamics



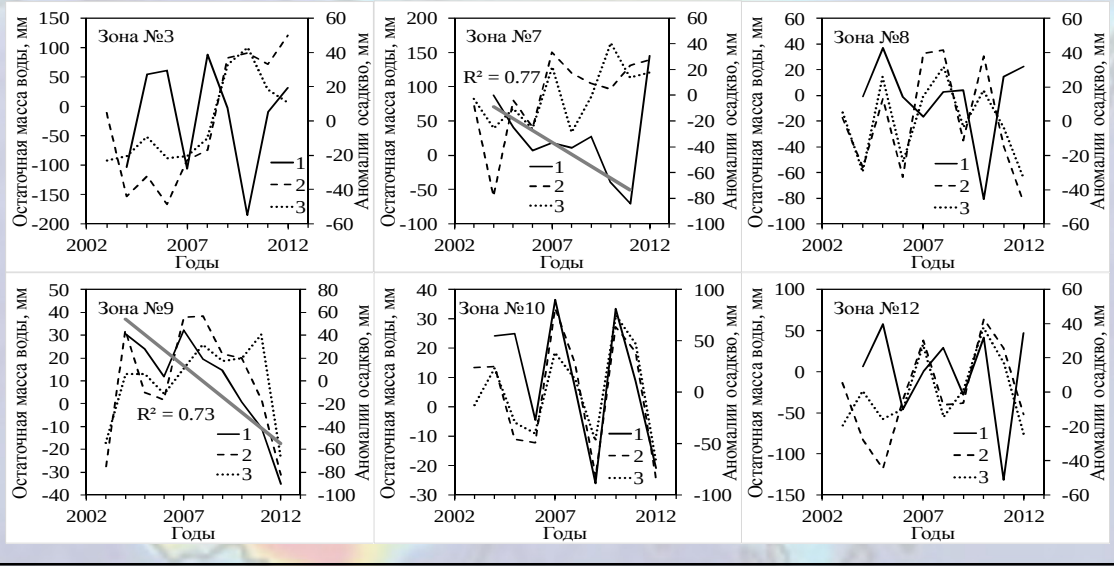
1 – mean equivalent water thickness anomalies (MEWTA),
2 – precipitation, 3 – temperature.
(a) – tundra, (b) – middle zone, (c) – margin zone of permafrost.

Accumulated water mass estimation

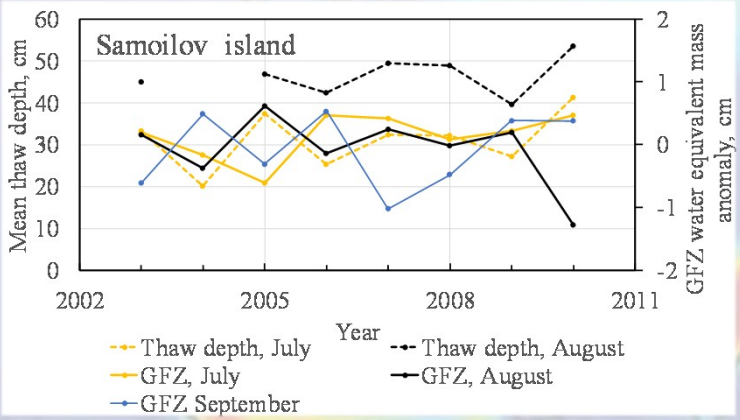
$$W_{ac} = [(\Delta+) - (\Delta-)]$$

- W_{ac} – residual (accumulated) water mass
- (Δ+) (input mass) = difference between maximal (March-June) value of equivalent water mass in the previous year and minimal value of equivalent water mass (August-October) in the current year.
- (Δ–) (run-out mass) = difference between maximal (March-June) and minimal values of equivalent water mass (August-October) in the current year.
- W_{ac}>0 => water accumulated; W_{ac}<0 => water run off.

W_{ac} – residual (accumulated) water mass dynamics

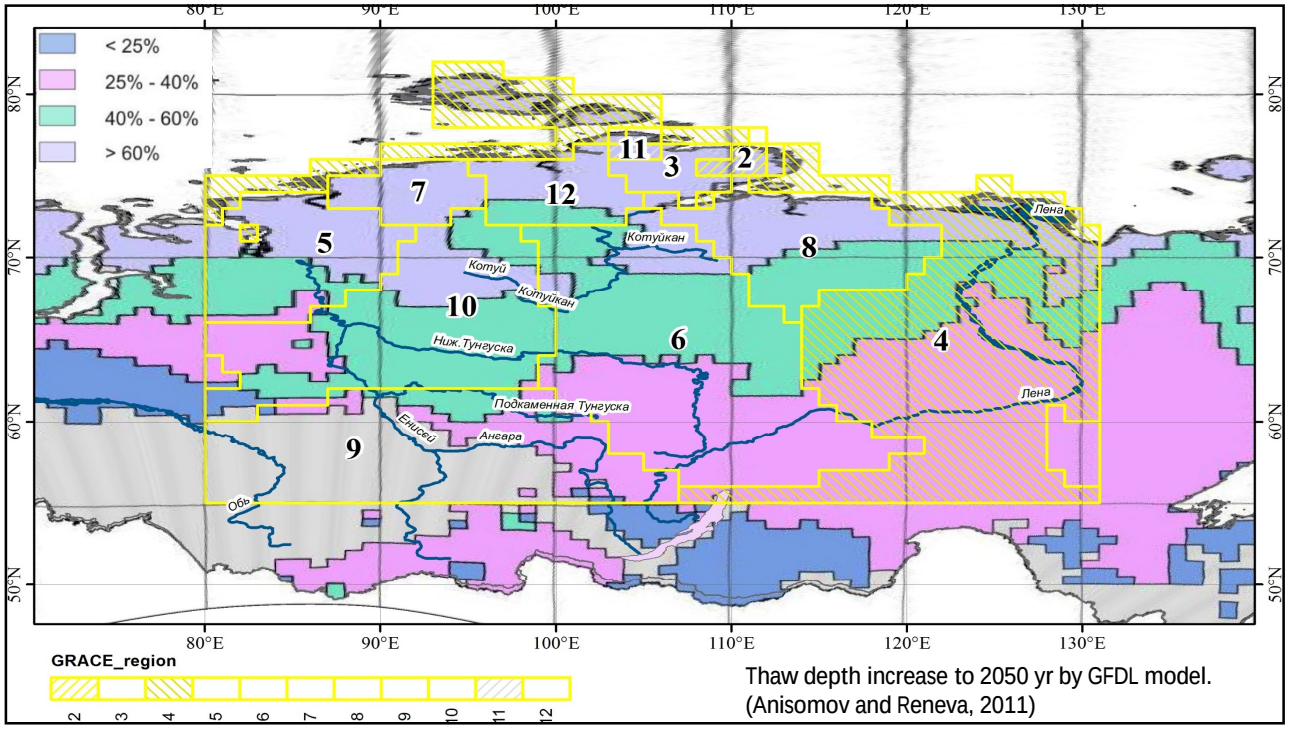


Thaw depth vs equivalent water thickness anomalies (Samoilov Island)



Thaw depth	GFZ		
	July	August	September
July	r^2=0.01	r^2=0.92	
August		r^2=-0.55	r^2=-0.83

1) August GFZ (2003-2008) correlates with thaw depth in July
2) September GFZ (2003-2008) correlates with thaw depth in August
More data is required to analyze



Thaw depth increase to 2050 yr by GFDL model. (Anisomov and Reneva, 2011)

Conclusions

- In the permafrost zone of Central Siberia eleven uniform regions with similar patterns of water mass changes were determined. Statistically significant trends of water mass changes were found for seven zones only. These zones are located in the marginal areas of permafrost (transition between continuous and discontinuous permafrost) and in mountainous regions.
- There are positive trends of water mass changes during 2003-2008 yr (p-level>0.05). An increase of soil water content during this period can be attributed to increase of thawing depth.

- Increased variation of total water mass in tundra zones is typical and begins from 2010. It can be related to increase of thaw depth and soil water storage capacity.
- Rate of water mass changes are correlates with soil properties (R^2=0.48-0.53) and slope steepness (R^2=0.62).
- GRACE data can be used to estimate residual (accumulated) water mass dynamics.

Other problems to solve

Active layer is a layer in ground which thawing and freezing seasonally.

• Can we estimate active layer thickness dynamics from GRACE data?

We can estimate ground water dynamics from GRACE.
Ground water dynamics connected to active layer thickness dynamics .

Comparison of water mass dynamics with water height variations and precipitation dynamics

Practical task students

The aim

(1) to study how GRACE data can be used to estimate water mass dynamics,

(2) how these data can be compared with other data (on example of precipitation and water level variations),

(3) obtained some practical knowledge about what happens with water mass in the selected regions.

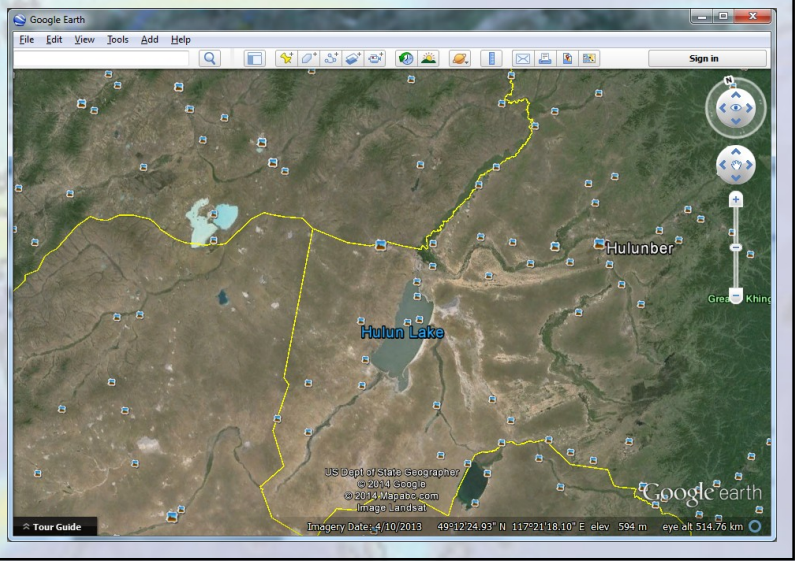
- ***Lakes (regions, variants of task)***: (1) Hulun Lake, (2) Hovsgol Lake, (3) Baikal Lake, (4) Zeyskoe; (5) Lake Barun-Torey.

Basic steps (on example of Hulun Lake)

1. *Find coordinates* of the Hulun Lake (Mongolia).

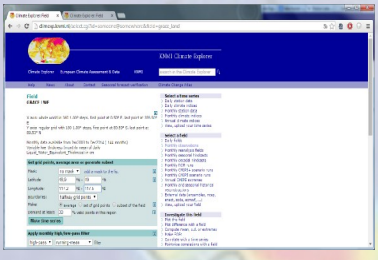
You can use Google Earth or online Google Maps service or other tools.

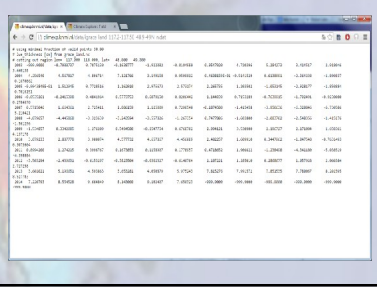
Write down coordinates of the lake.



2. Download GRACE data

- Use coordinates you found.
- Use the following link http://climexp.knmi.nl/select.cgi?id=someone@somewhere&field=grace_land.
- In this case GRACE data are estimated in cm.



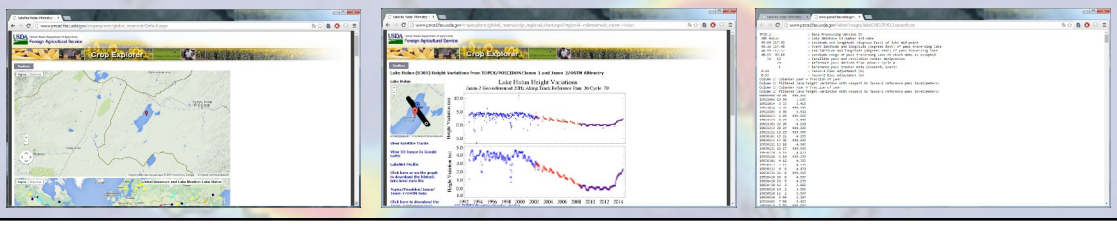


3. Download precipitation data

- Do the same steps (as in the #2) to download precipitation data from the following link http://climexp.knmi.nl/select.cgi?id=someone@somewhere&field=cru_pre_10
- Precipitations are estimated in mm.

4. Download water height variation data

- Use the following link
  http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/Default.aspx
  or
  http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/Default_env.aspx
- Water height variation are in meters.



5. Use Microsoft Excel of other statistical software to ***estimate trends of water mass changes***, water height variations and precipitation.

6. ***Compare water mass dynamics*** (monthly, annual, summer) ***with precipitation and water height variations*** based on correlation analysis.

7. ***Interpret you results and make some conclusions. Make short report***.