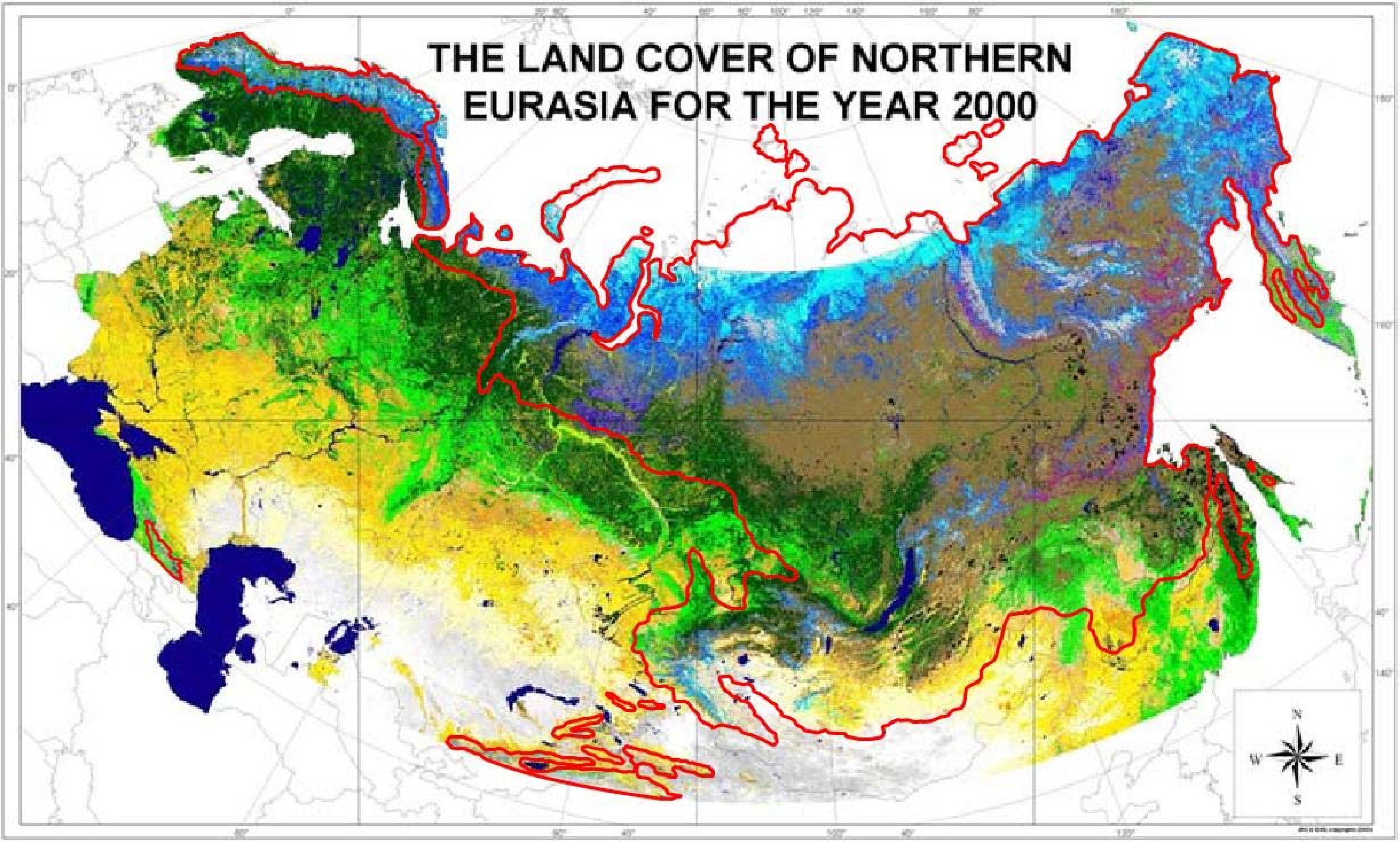
Interagency NEESPI Meeting

Cold Land Processes:
Permafrost, Glaciers, Snow Cover

Vladimir Romanovsky

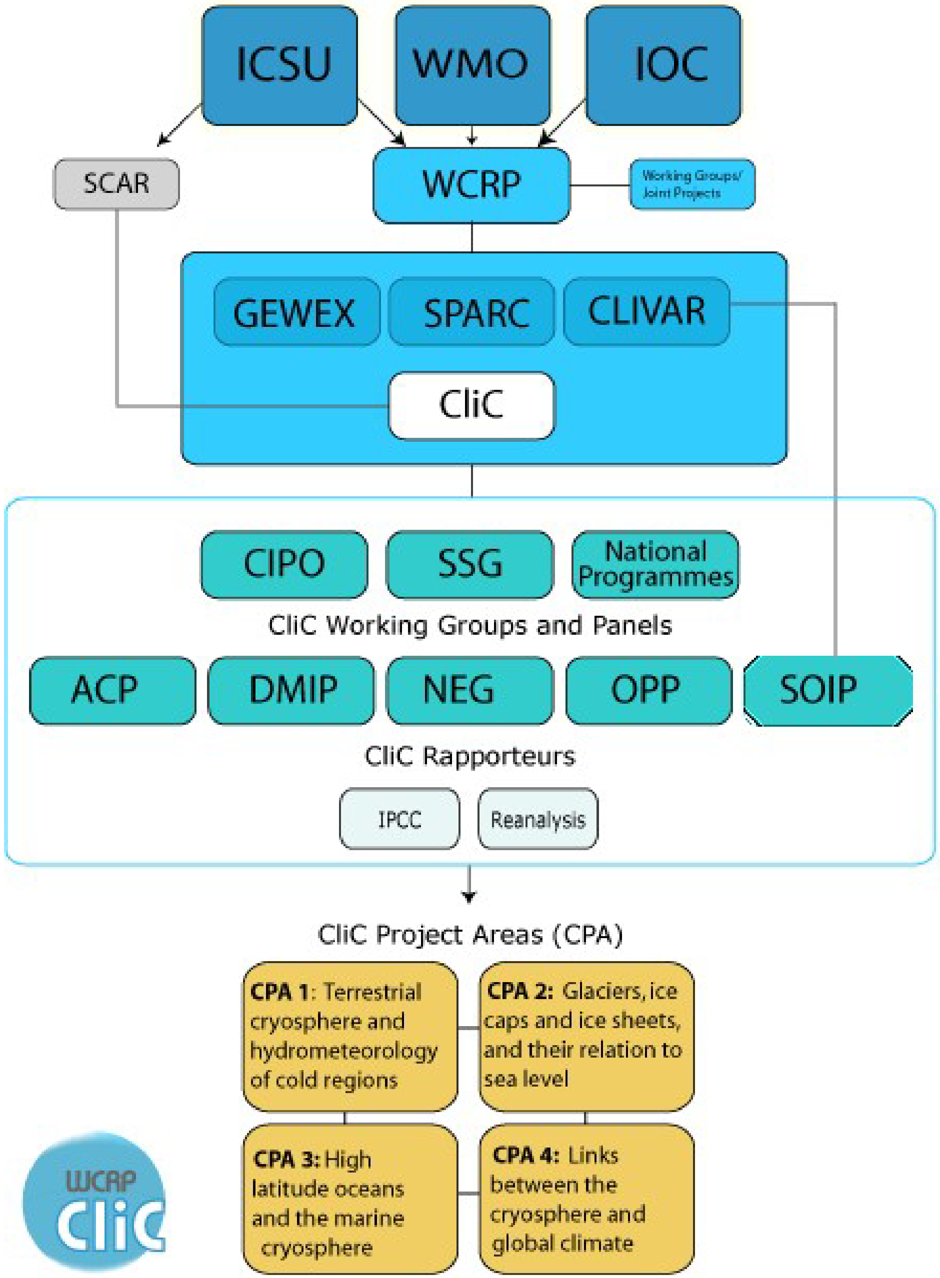
with essential contribution from V. Aizen, R. Barry, M. Durgerov, T. Khromova, S. Marchenko, P. Romanov, A. Bruochkov, and L. Hinzman

Photo by V.Romanovsky



The land cover type distribution and the boundary of the Cold Land Regions in Northern Eurasia

Climate and Cryosphere (CliC) Organizational Structure



Changes in ecosystems will be the largest in Cold Land Regions because of:

- the immense changes here in the atmosphere and soil climate

- the extreme sensitivity of the natural systems in these regions, making them highly vulnerable to rapid natural and anthropogenic changes because of presence of ice on or near the ground surface with temperatures close to its melting point

- the significant amount of excess ground ice in the upper few tens of meters under the ground surface

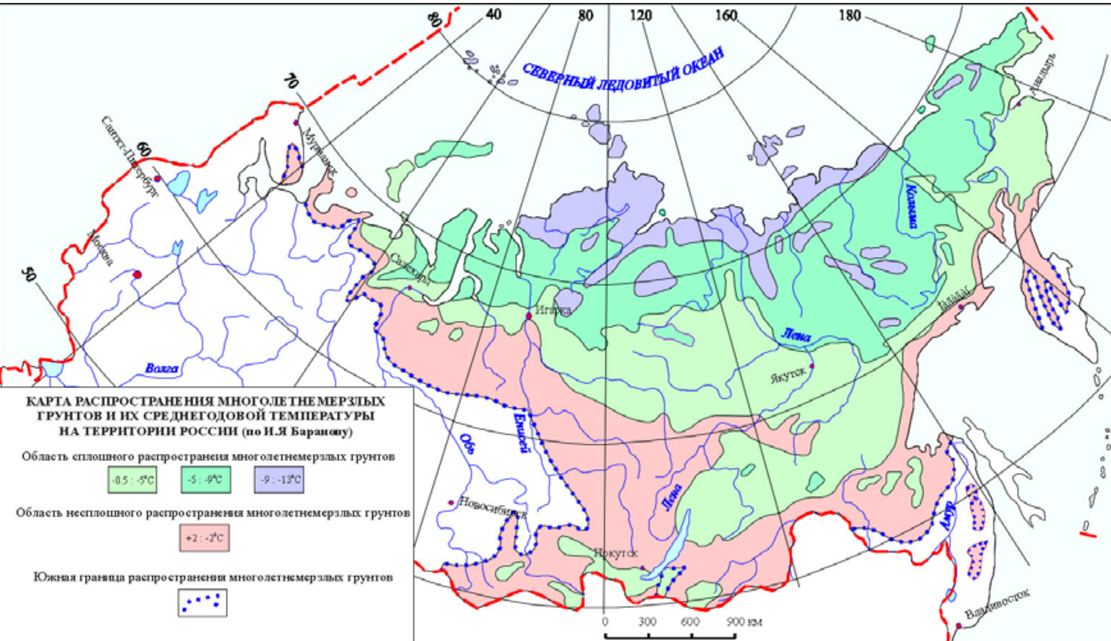
Changes in physical environment will force the Cold Land Region ecosystems to cross several very important thresholds. These are:

- times and locations where the thickening active layer reaches the upper surface of massive ground ice bodies or extremely ice-rich soil horizons
- mean annual temperature at the base of the active layer exceeds 0°C and permafrost starts to thaw from the surface downwards
- the complete, or practically complete, disappearance of glaciers from the mountain watersheds

The stability of the ecosystems in Cold Land Regions relies on the stability of ice that so far holds these systems together.

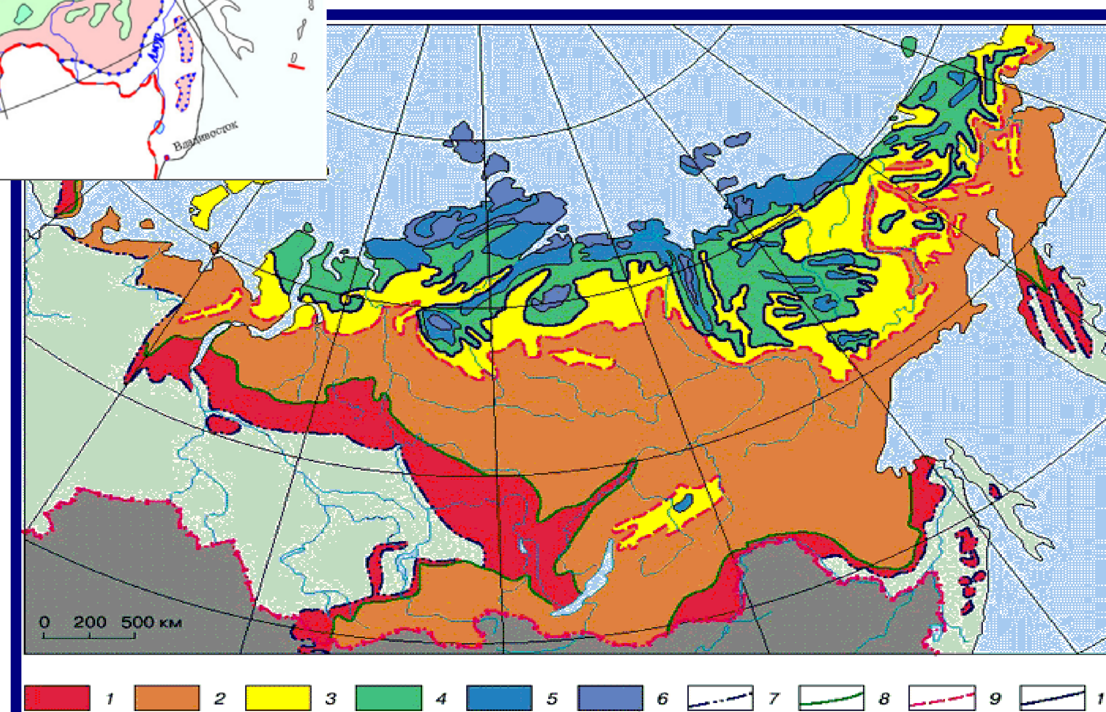
In losing the glacier ice and permafrost we are losing the stability of the systems

Projected changes in permafrost



Present

2100



Possible permafrost change 100 years from now (4-5 deg.C): 1 – permafrost thawing; 2 – "islands" of permafrost; 3 – discontinuous permafrost; 4 – permafrost with temperature –1-2 deg.C; 5 - permafrost with temperature –2-4 deg.C

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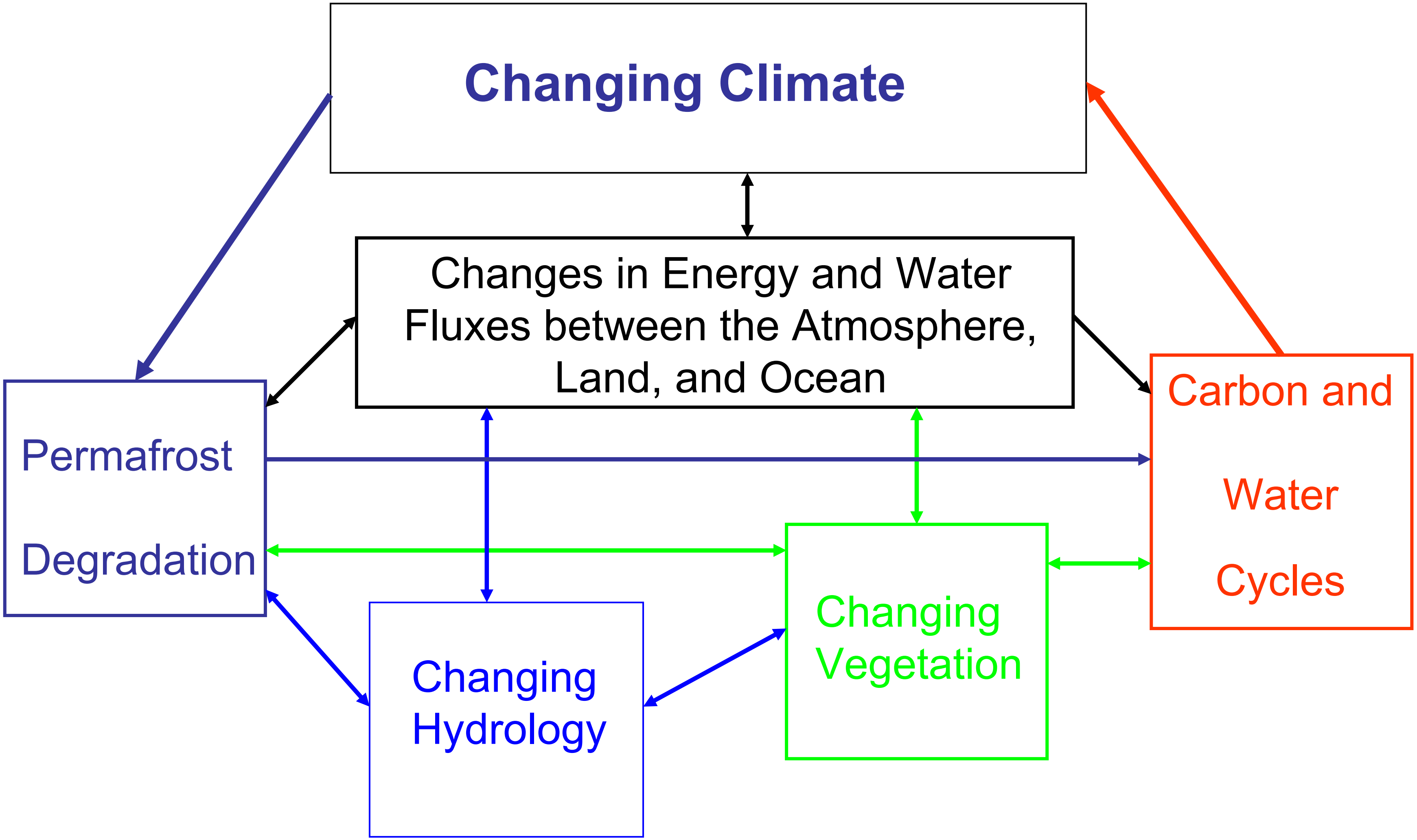

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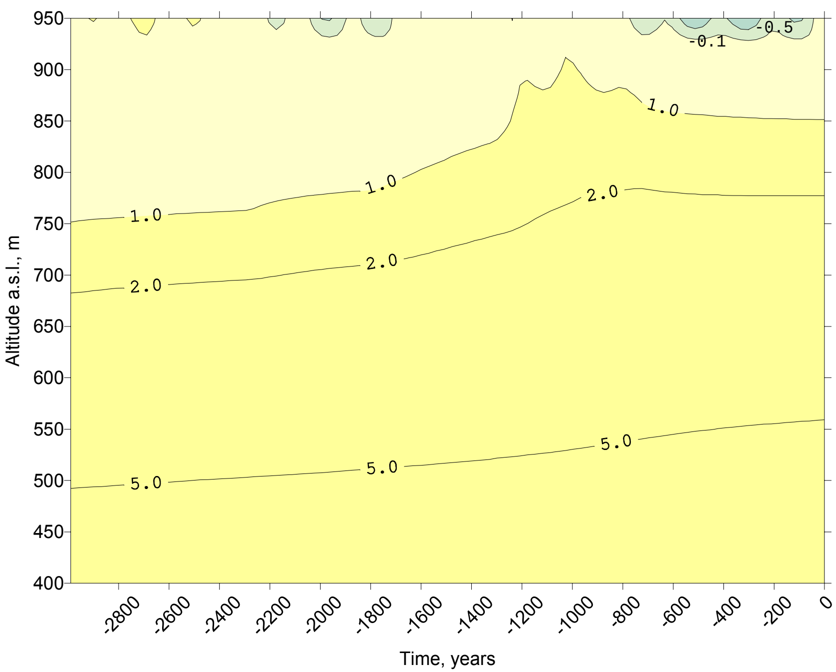
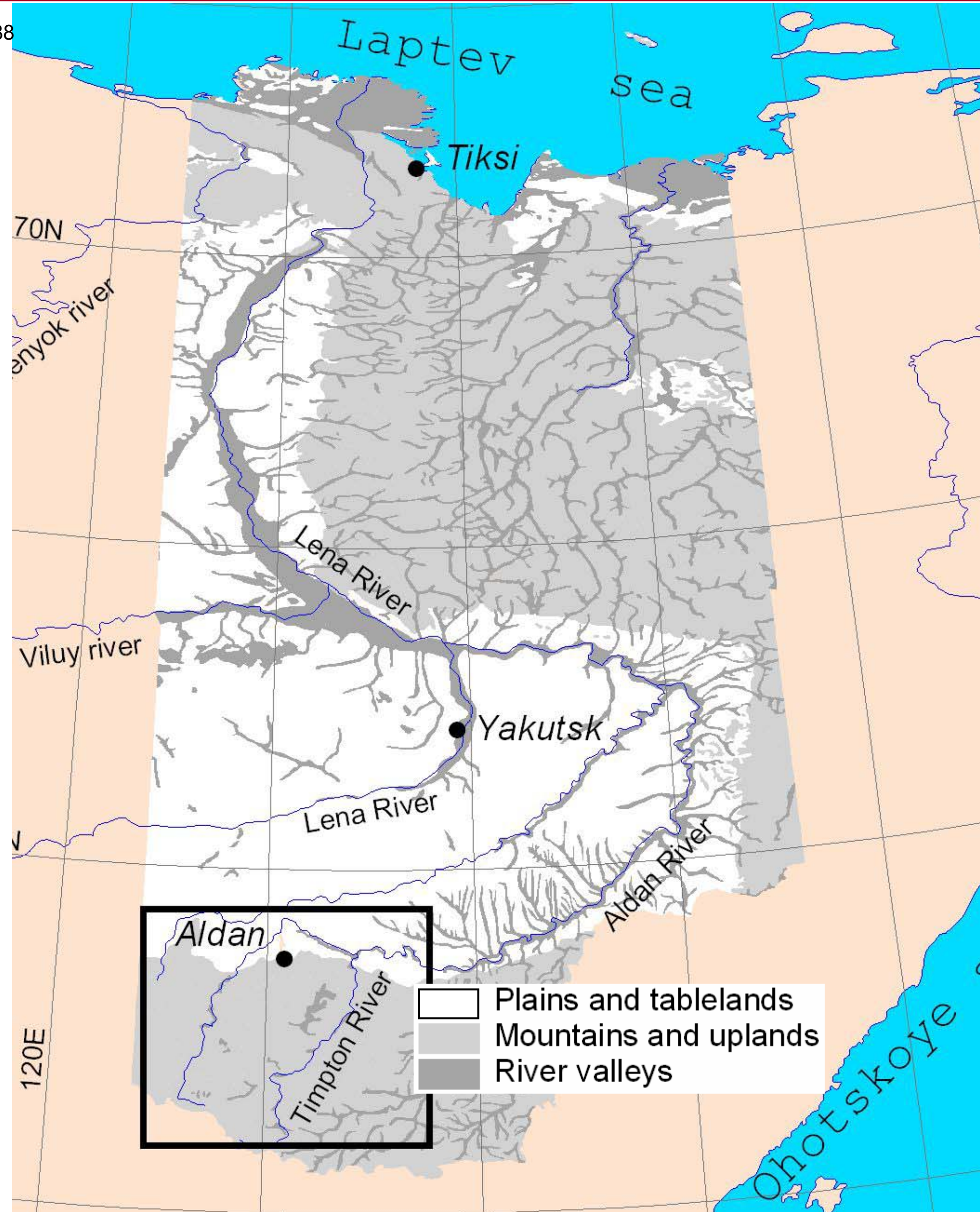
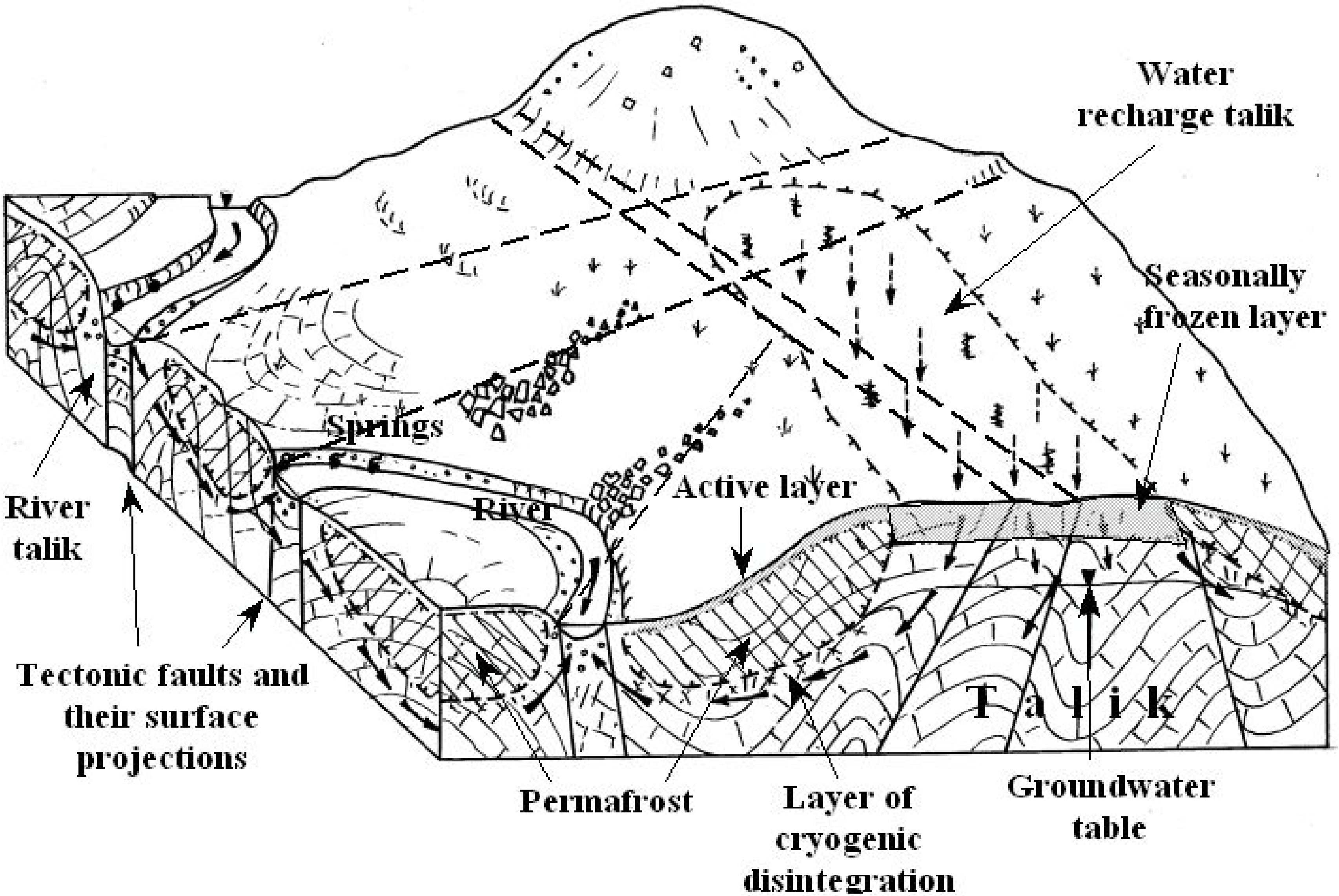
Ground temerature dynamics at the divide (deg.C; scenario from Maximova & Romanovsky, 1988 - plus 1500 and 208 year cycles adding).





During the last several thousand years permafrost appeared and disappeared several times from the watersheds of this region. Hydrology of the area was also changing accordingly.


Water recharge talik
Seasonally frozen layer
Springs
Active layer
River
River talik
Tectonic faults and their surface projections
Permafrost
Layer of cryogenic disintegration
Groundwater table
T a l i k

Impact of permafrost degradation on surface hydrology and vegetation

Thawing of ice-rich permafrost, triggered by the forest fire in Central Yakutia, transforms boreal forest into steppe-like habitats (photo by V. Romanovsky)

Impact of permafrost degradation on surface hydrology and vegetation

Photograph by T. Jorgenson

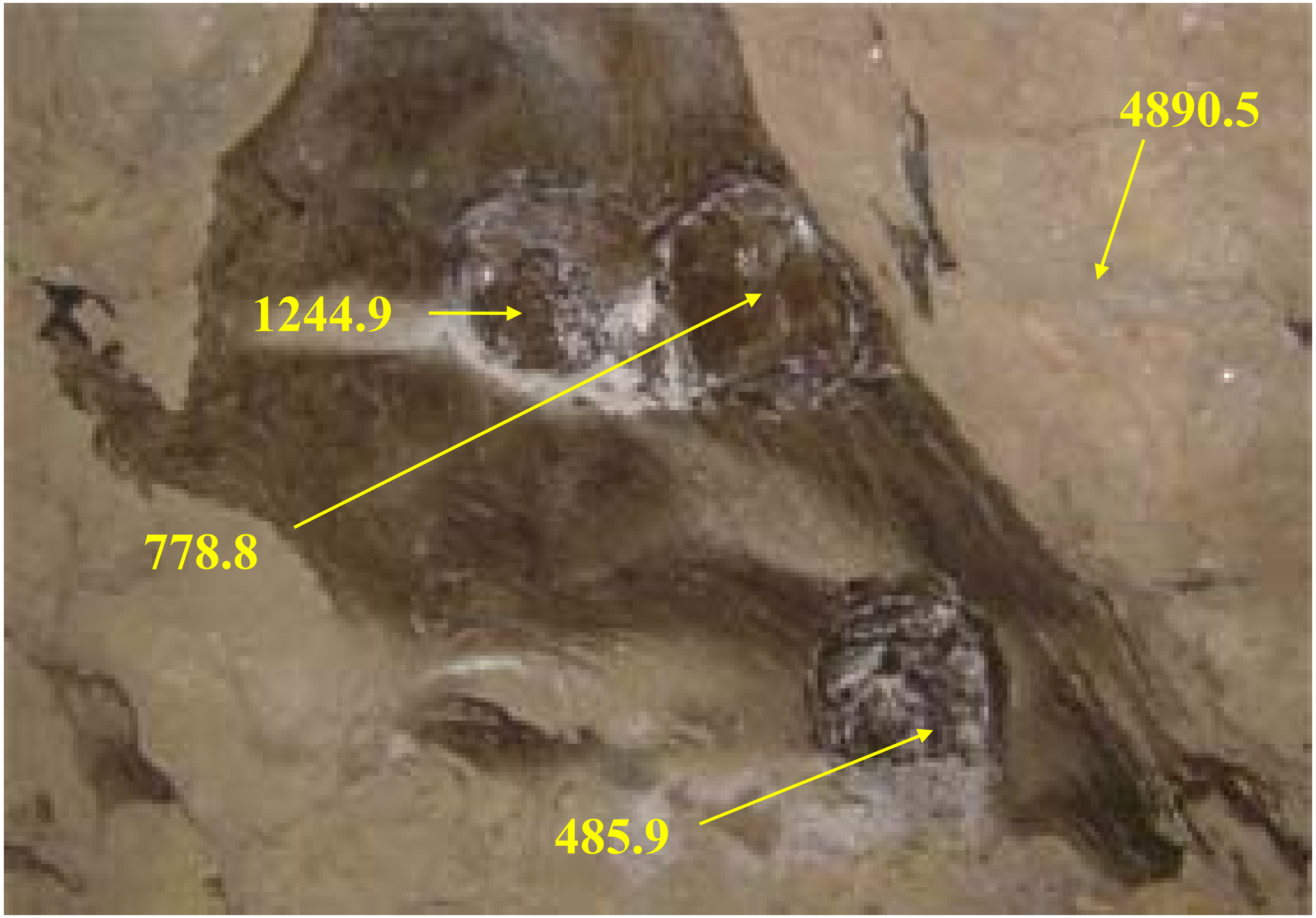
The ground will become over-saturated, which could cause trees to die

Ice wedges

Aldan river exposure, about 40 m above water level (left) and Sirdah lake exposure, about 10 m above water level (right). Ice wedges are different: Aldan and Sirdah sites do not contain methane, but carbon dioxide. Neleger site contain a lot of methane

(*A. Broushkov)*

Ice wedges



Methane concentrations (ppmv) in an ice wedge inside of a gold mine, Fairbanks, Alaska (*A. Broushkov)*

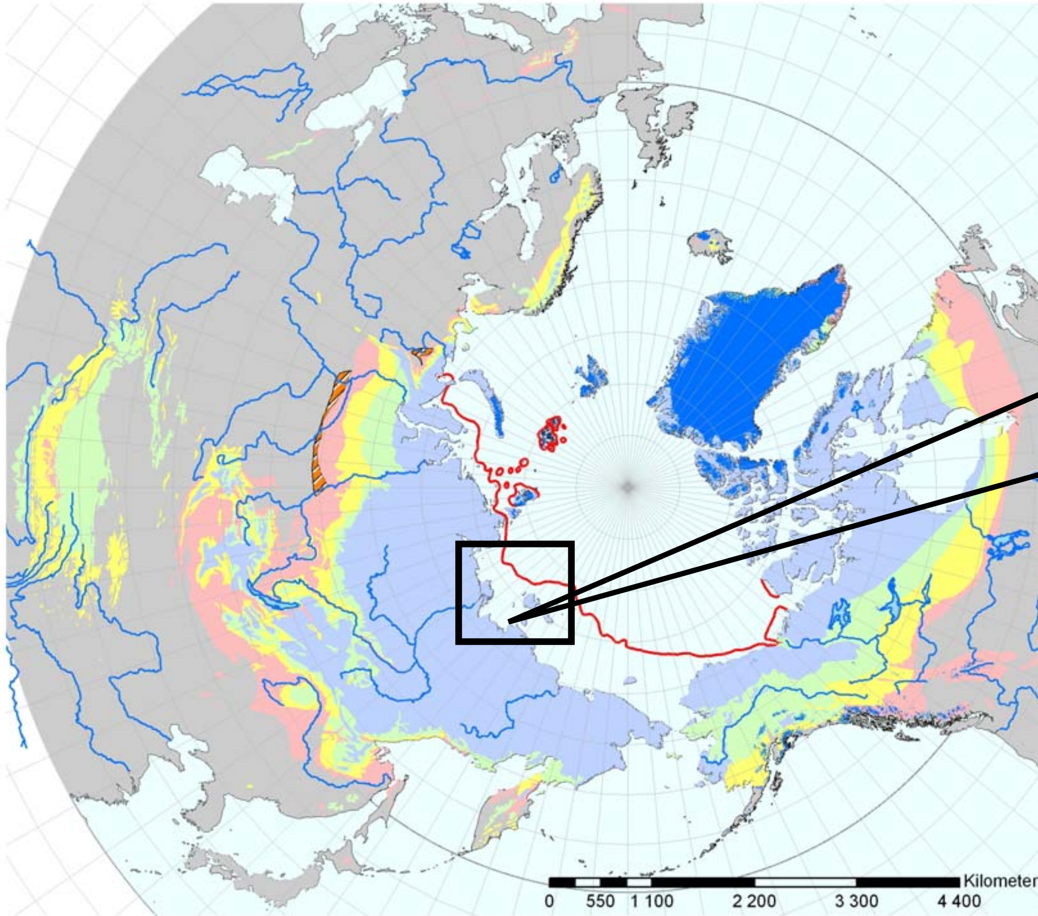
In the area of “wet thermokarst” formation, new and significant sources of CH_4 production will be developing. There will be a considerable difference in greenhouse production from degrading permafrost depending on a different type of substrate and soil carbon quantity and quality.

Impact of permafrost degradation on carbon cycle:

Significant amounts of carbon are now sequestered in perennially frozen soils (permafrost).
A thicker, warmer and dryer active layer will be much friendlier for microbial activities during the summer.
Significantly later freeze-up of this layer in winter and warmer winter temperatures (that means much more unfrozen water in it) will considerably enhance the microbial activities during the winter.
So, the arctic and sub-arctic ecosystems will turn into a source of CO_2 or CH_4 (especially on an annual basis) very soon.
Further permafrost degradation and formation of taliks will only amplify these changes because a layer that will not freeze during the entire winter (talik) will appear above the permafrost where microbial activities will not cease during the winter.

Circumpolar permafrost extent

Permafrost Lab., GI UAF, 2003



Coastal erosion and subsea permafrost degradation

Legend

Permafrost extent

- Continious (90-100% of area)
- Discontinious (50-90% of area)
- Sporadic (10-50% of area)
- Isolated (0-10% of area)

Subsea cryosphere

- Subsea permafrost limit

Relict permafrost

Geograpic objects

- Glaciers
- Lakes
- Ocean and Seas
- Land
- Rivers
- 10 x 10 Degree Graticule

This map was prepared by using an electronic version of the "Circum-Arctic Map of Permafrost and Ground-Ice Condition", J.Brown, O.J. Ferrians, Jr., J.A. Heginbottom, & E.S.Melnikov, 1997, U.S.Geological Survey, ISBN 0-607-88745-1.

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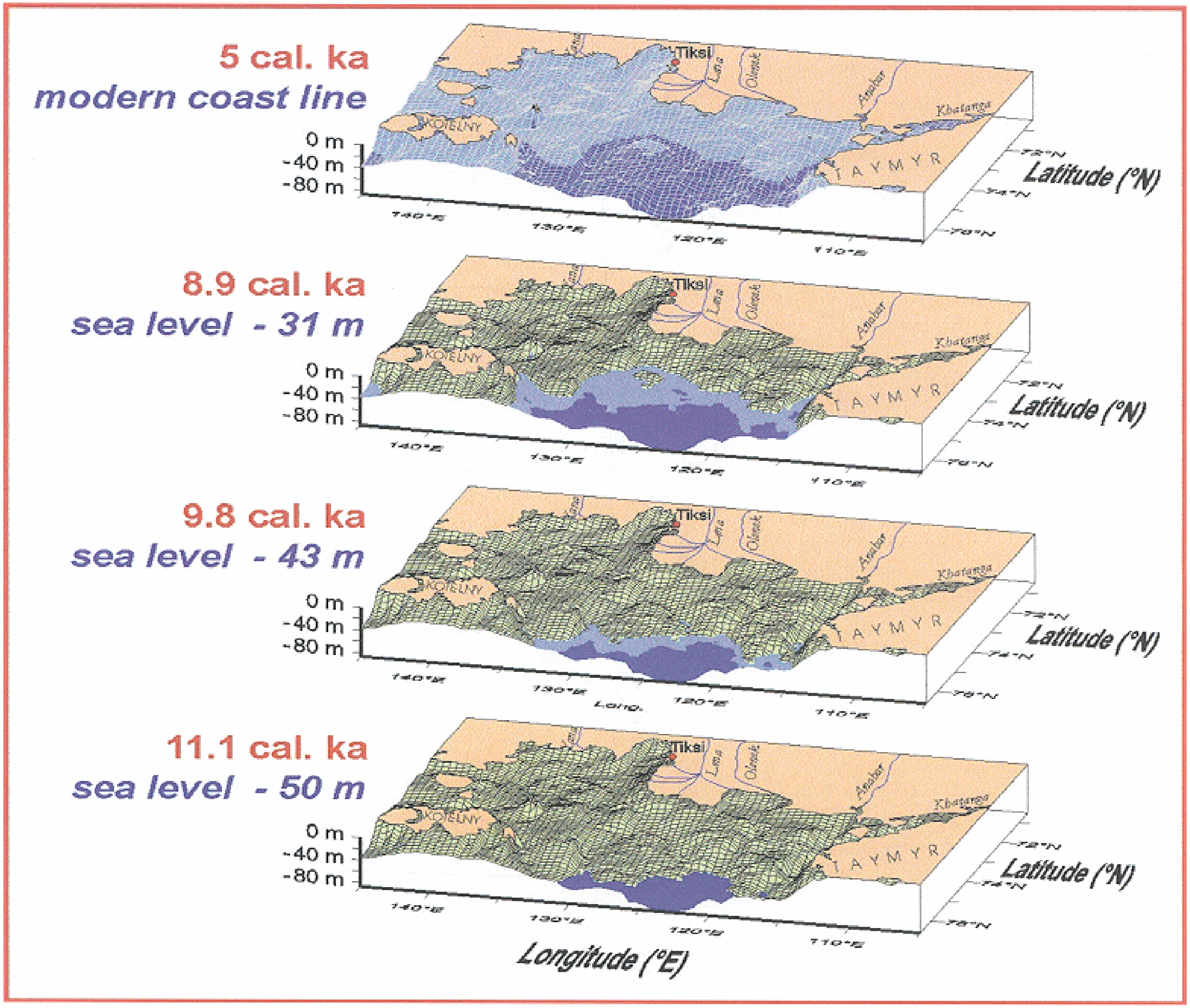
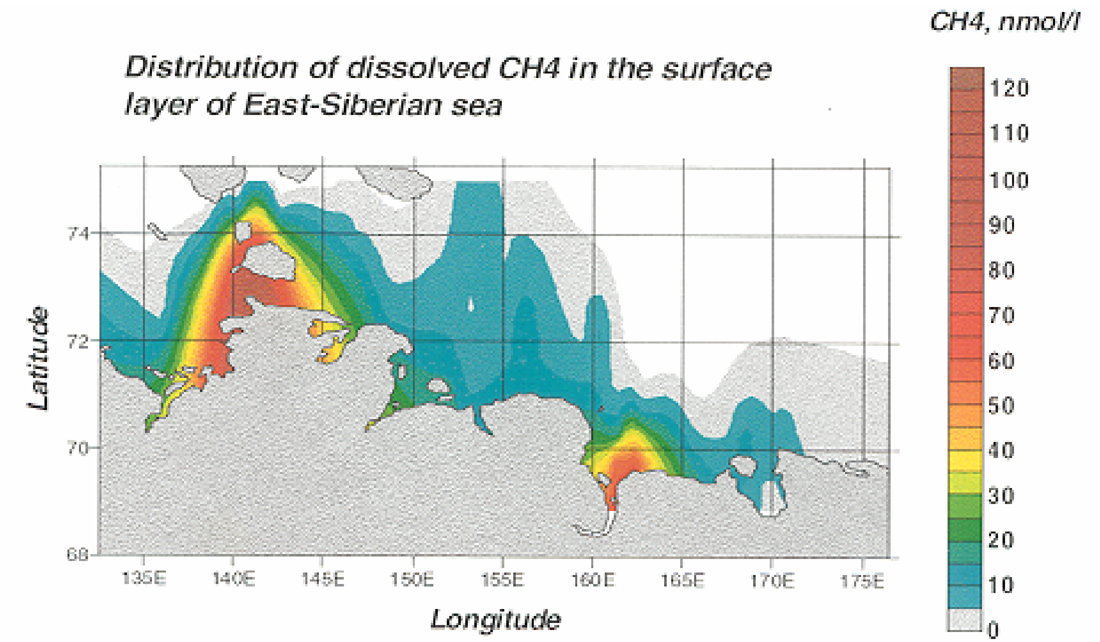
Extremely ice-rich permafrost cliff (22 m high) retreats with an average rate of 11 m/year at this location on the Muostakh Island. Significant amount of organic-rich material is being supplied to the near-shore ocean

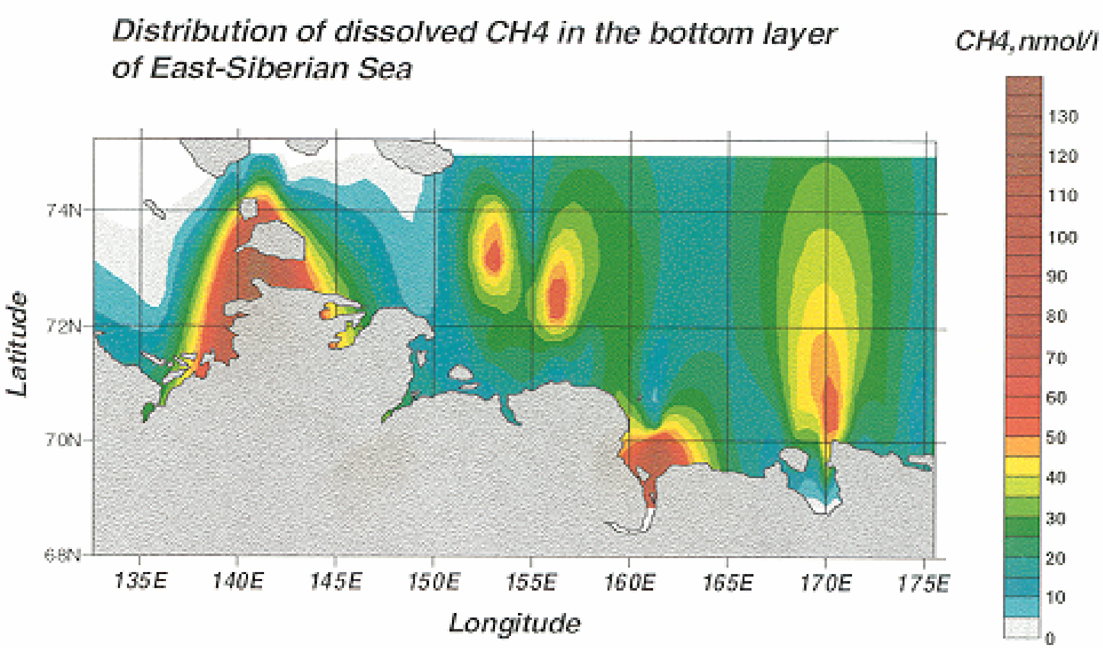
This lighthouse on Bykovskiy Peninsula has to be moved regularly from the cliff inland to save it from falling down

Sea level rise in the Laptev Sea (by Robie Macdonald)





Data from I. Semiletov, Summer 2004 Joint Russia – USA Cruise (Far Eastern Branch of the Russian Academy of Sciences and International Arctic Research Center, UAF)



Distribution of dissolved methane in the area near to the Bolshoi Lakhovsky Island demonstrates an extremely high concentration of CH_4 from the bottom to the top of the water column (up to 120 nmol/l). This can be an indication of active methane ebullition from the sea floor.

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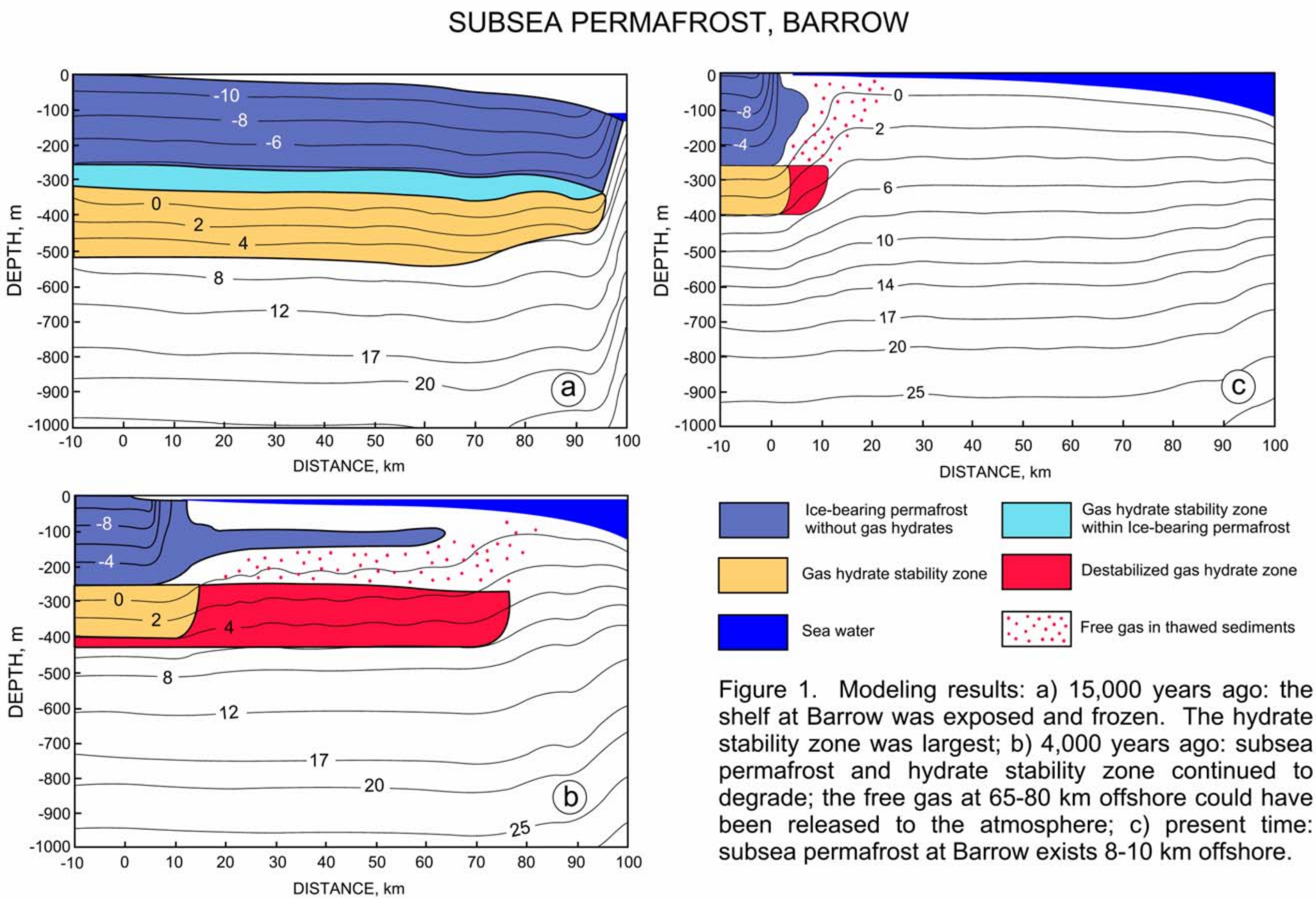
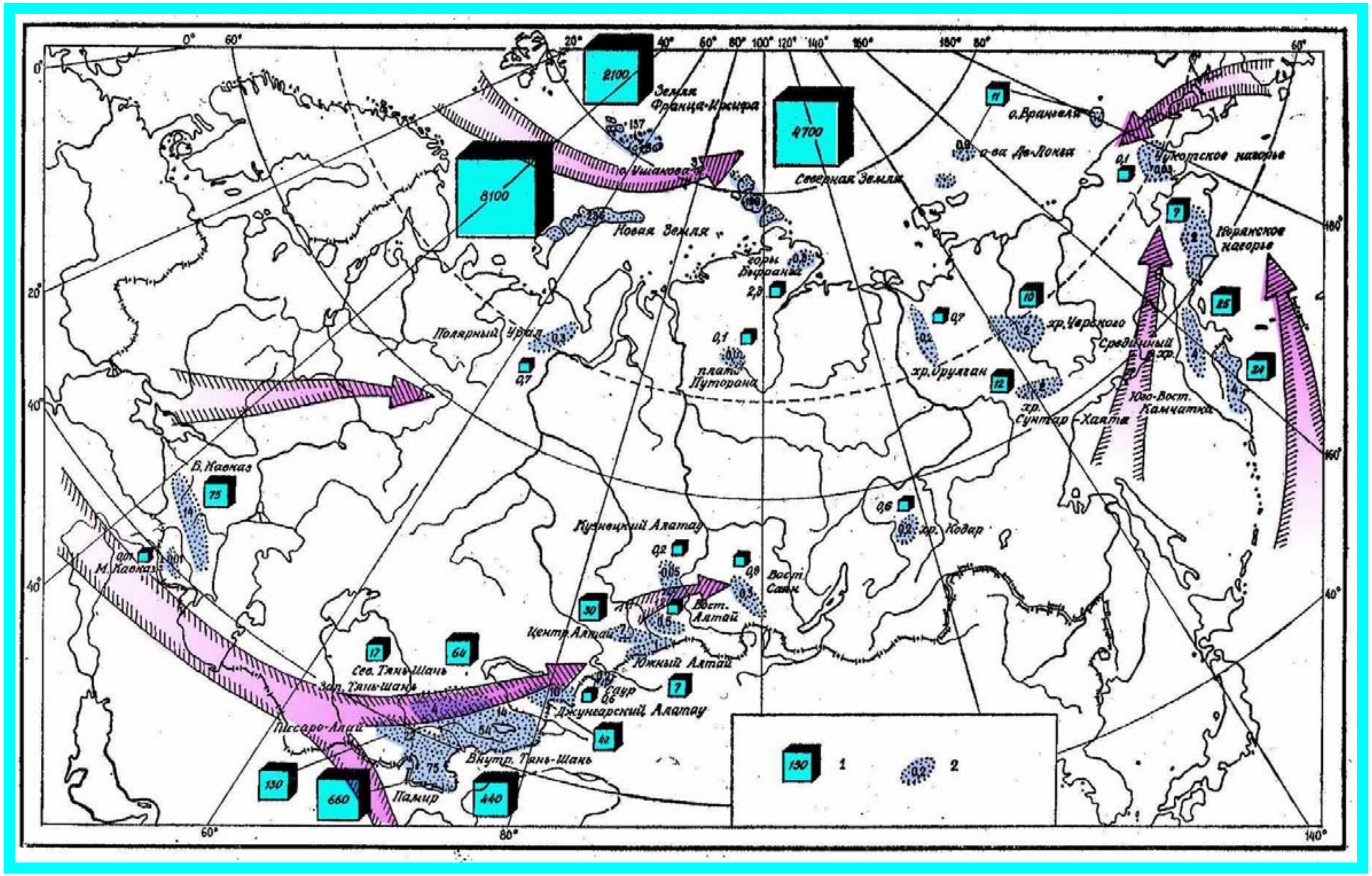


Figure 1. Modeling results: a) 15,000 years ago: the shelf at Barrow was exposed and frozen. The hydrate stability zone was largest; b) 4,000 years ago: subsea permafrost and hydrate stability zone continued to degrade; the free gas at 65-80 km offshore could have been released to the atmosphere; c) present time: subsea permafrost at Barrow exists 8-10 km offshore.

Impact on Infrastructure

Glaciers in Northern Eurasia

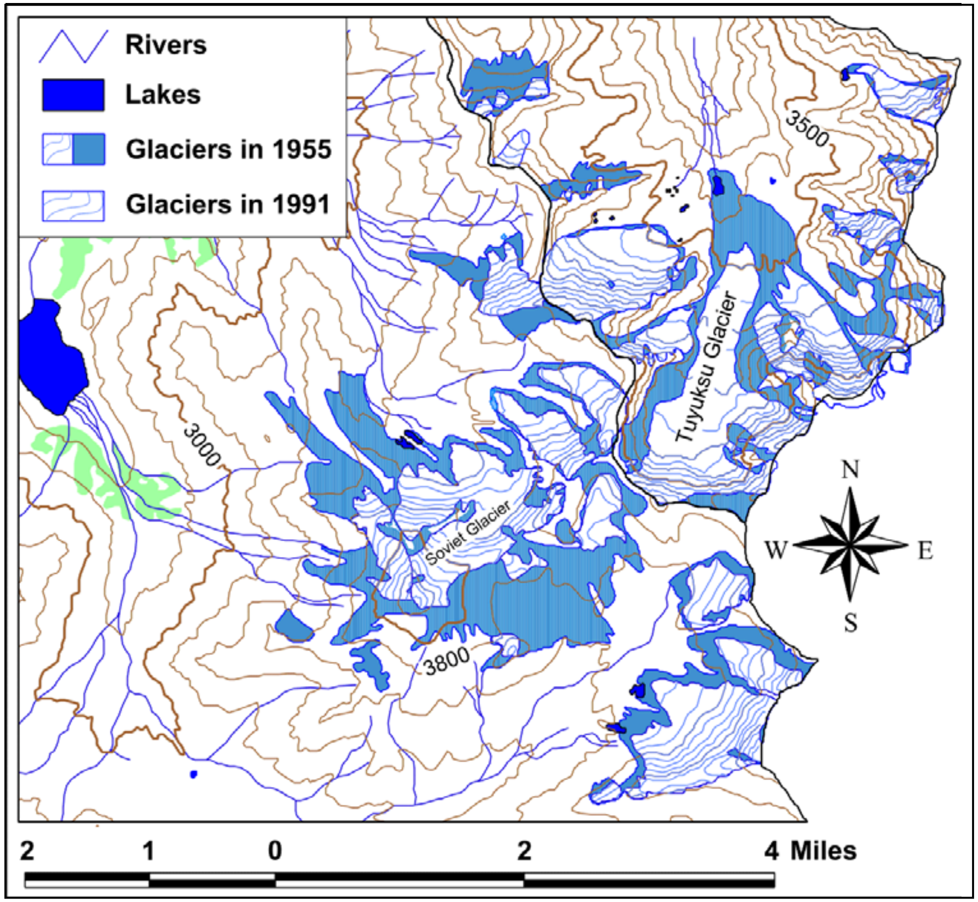


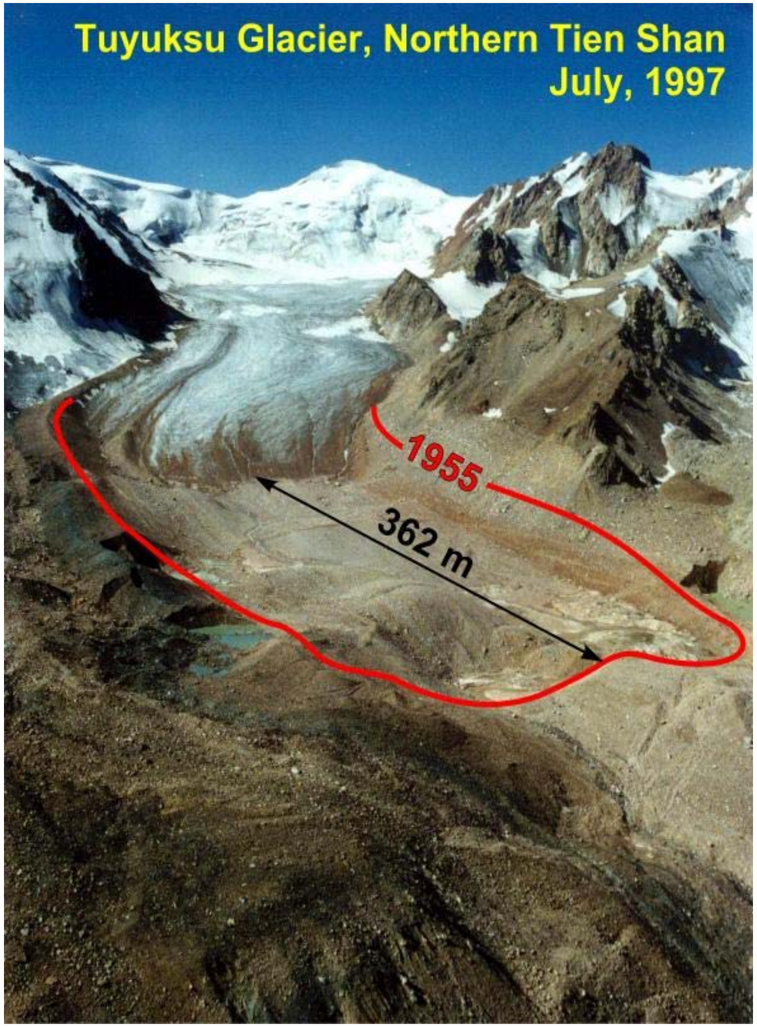
Glacier regions of northern Asia. Ice volume in km^3 is shown as cubes, arrows show major low-pressure tracks (Krenke, 1982).

Contemporary changes in the Cold Land Regions glaciers

Example of a central Tien Shan glacier recession. Petrova Glacier in the Akshiyrak area, ASTER image, September 2002 (A), and instrumental topographic data (B) (Aizen and Kuzmechonok, 2003)

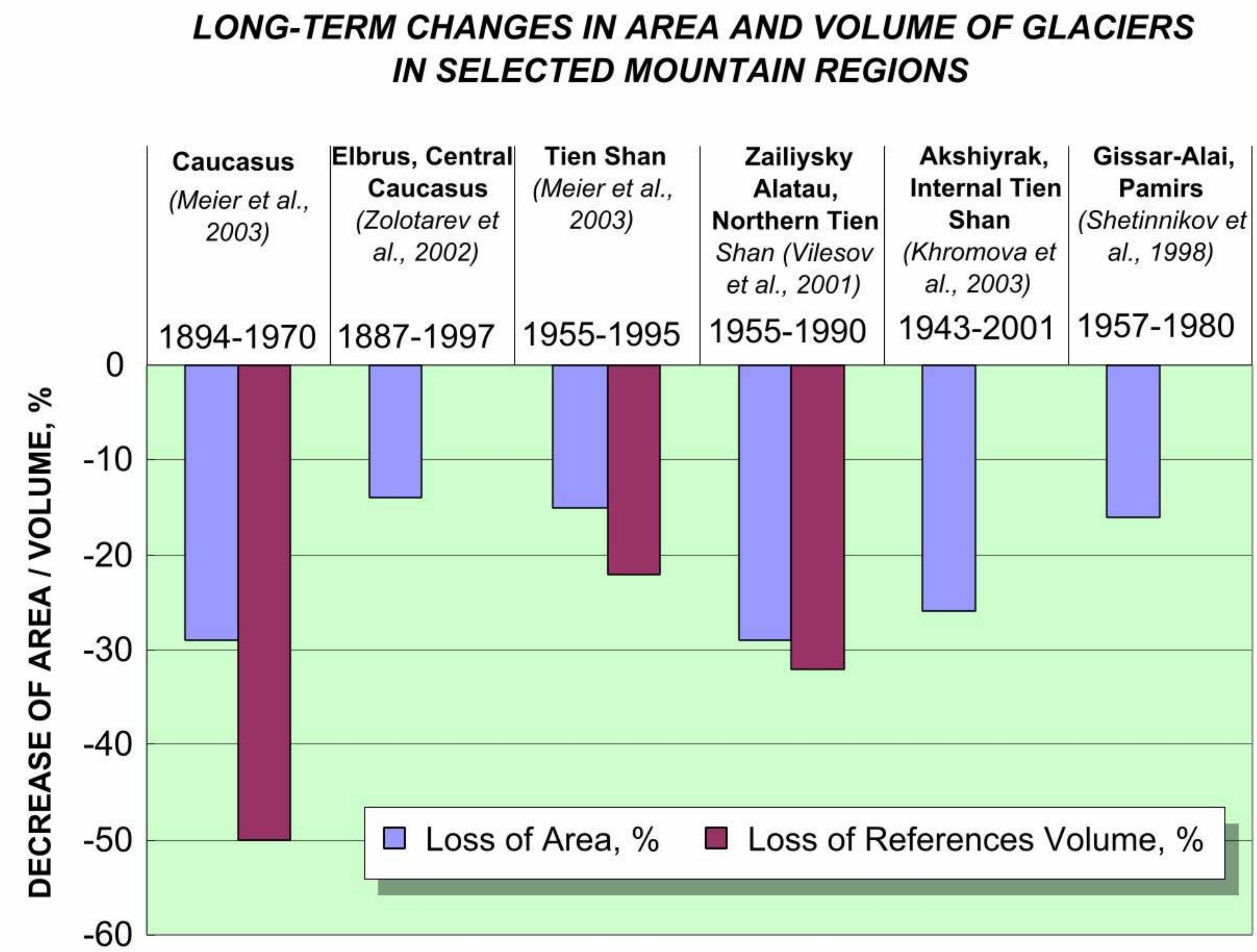
Contemporary changes in the Cold Land Regions glaciers



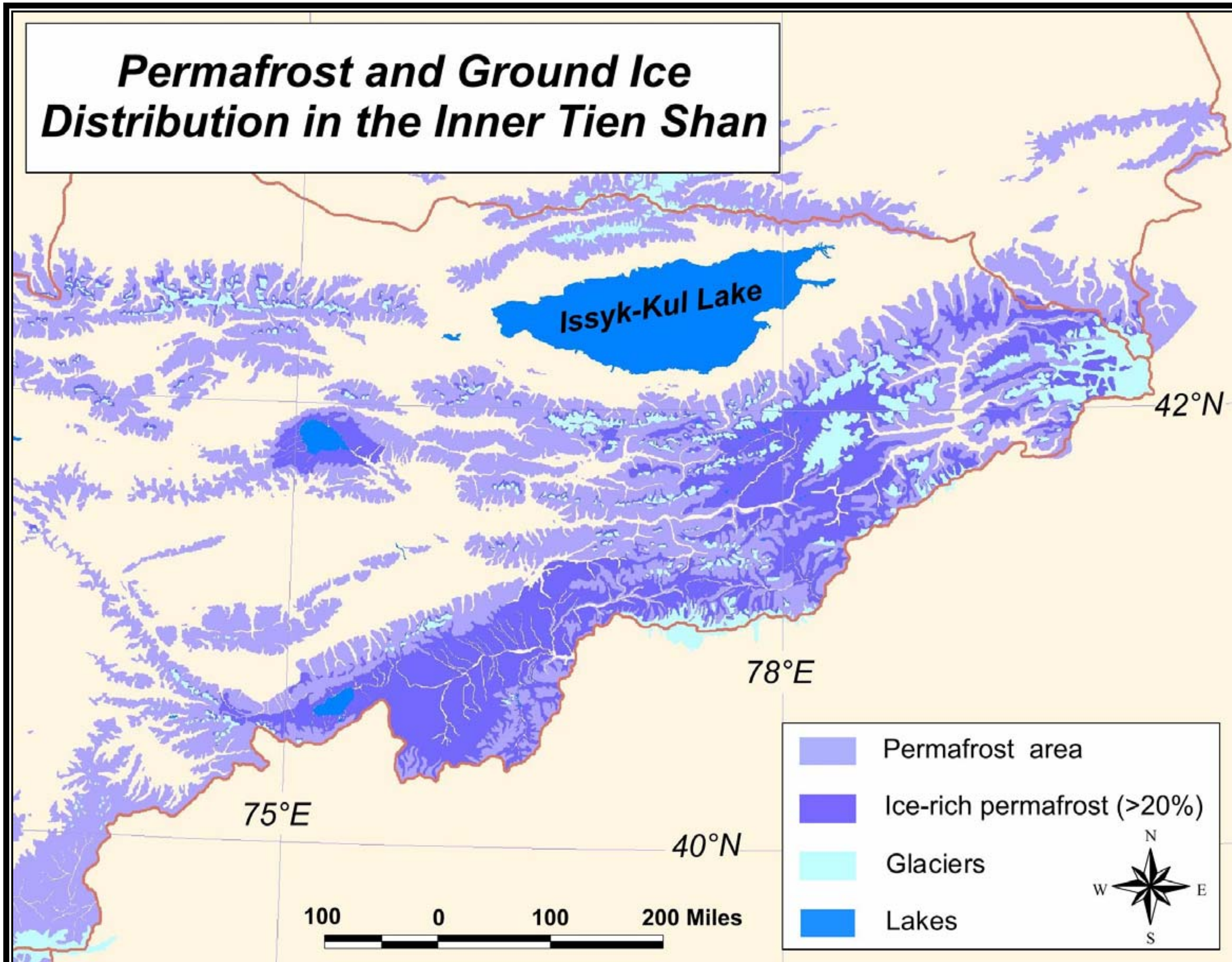


An example of glaciers' recession in the Northern Tien Shan (Tuyuksu Glacier in the Transili Alatau Range) (*V. Uvarov and S. Marchenko)*

Contemporary changes in the Cold Land Regions glaciers

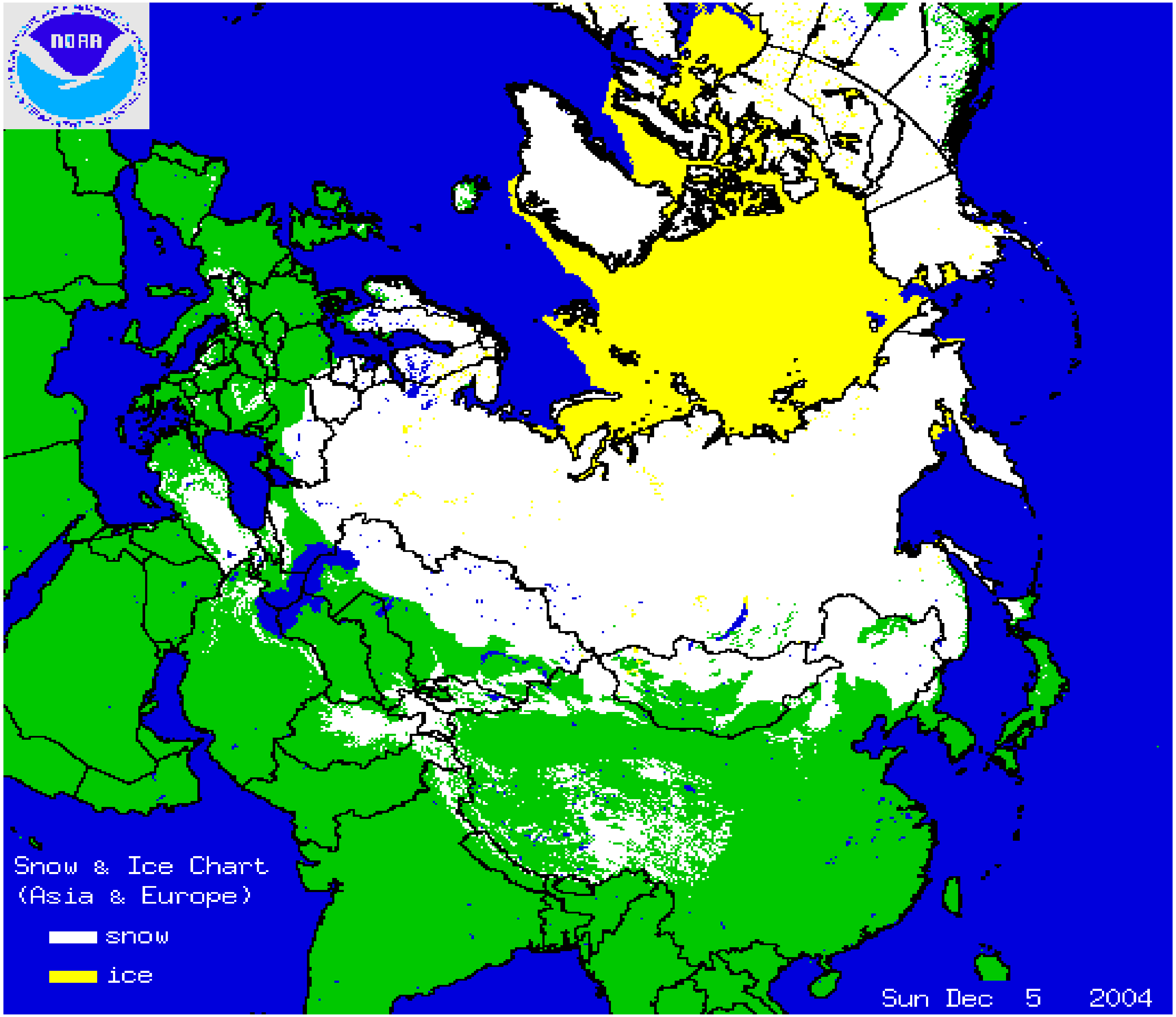


Impact of glaciers and mountain permafrost degradation on surface hydrology



Impact of glaciers and mountain permafrost degradation on surface hydrology

Snow Cover in Northern Eurasia



Satellite-based snow mapping techniques

- **Interactive**

  An analyst examines satellite imagery and draws snow maps by hand. Only snow extent is estimated

- **Automated**

  - *Passive microwave*

    Allow for retrievals of snow extent,
    snow depth, snow-water equivalent

  - *Visible/middle-infrared/infrared*

    Typically only snow cover is derived.
    Potentials also exist to estimate the snow fraction

  - *Active microwave*

    Identify freeze/thaw events
    Not widely used due to high cost of data

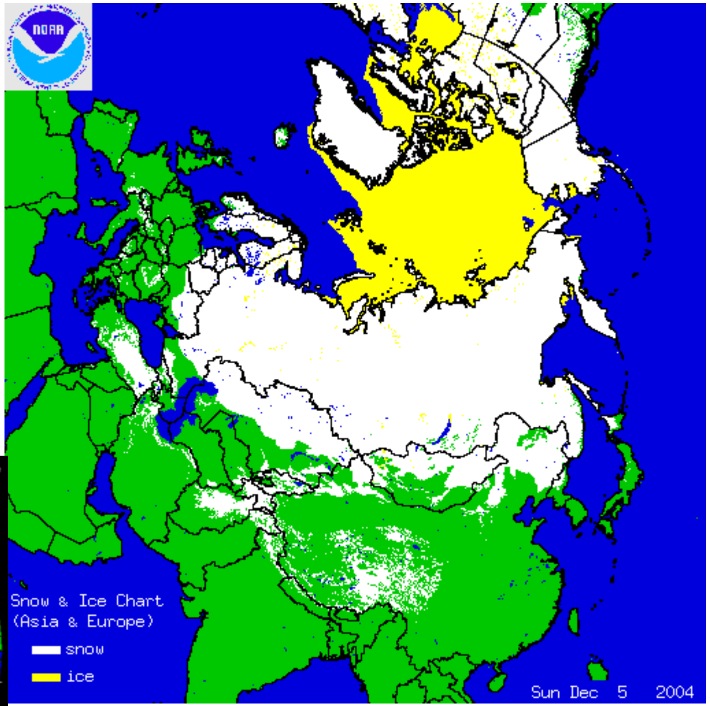
Snow Cover: Available products

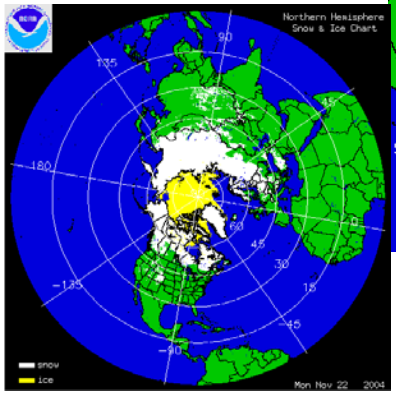
General: No remote sensing snow cover products specifically focused on Northern Eurasia or Eurasia as a whole are available. Monitoring of snow cover in Northern Eurasia is carried out only as part of the global or hemisphere-scale snow cover monitoring.

Snow Cover: Available products

NOAA INTERACTIVE MULTISENSOR SNOW AND ICE MAPPING SYSTEM (IMS)

Primary product: daily map of snow cover over Northern Hemisphere





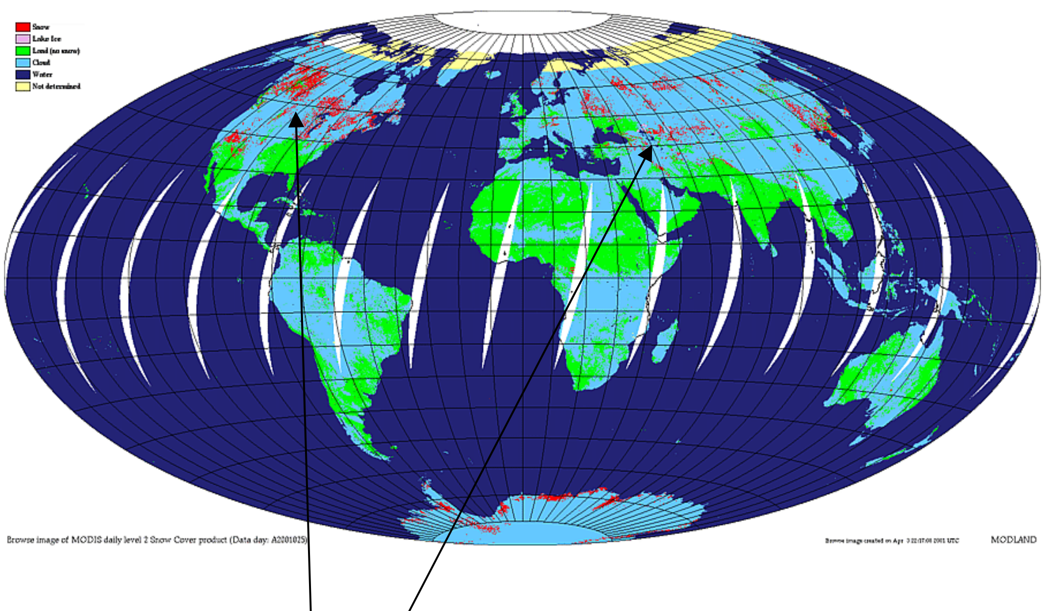
Spatial resolution:

25 km since 1999

4 km since 2004

Snow Cover: Available products

MODIS* snow cover map (NASA)



"Red" is identified snow cover

Global daily product at 500 m spatial resolution

Available since 2000

Since 2002 two maps a day are generated (from Terra and Aqua satellites)

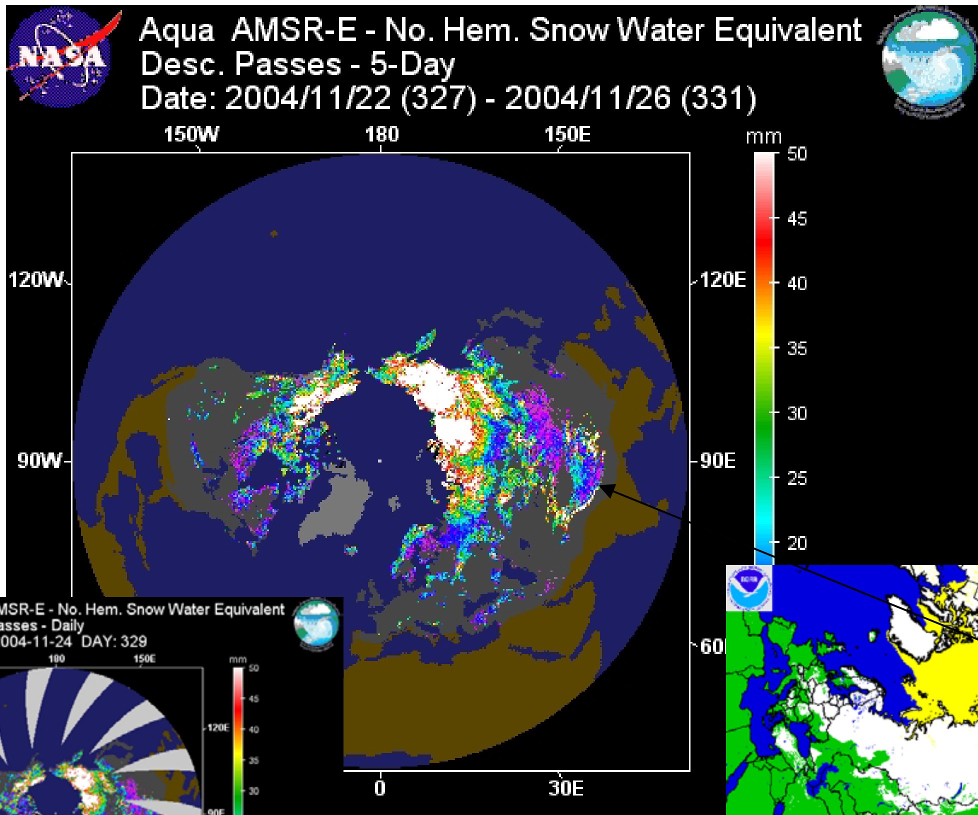
Accuracy of snow mapping as compared with surface observations ranges from 92% to 98%

Clouds prevent from continuous snow mapping on a daily basis.

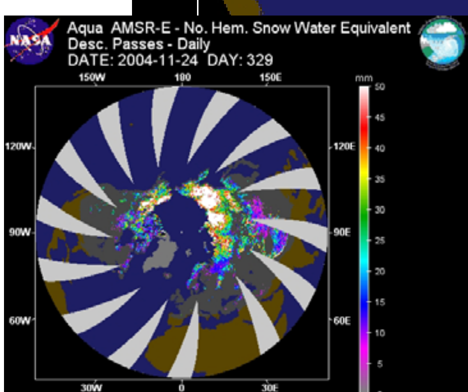
*MODIS: Moderate Resolution Imaging Spectroradiometer

Snow Cover: Available products

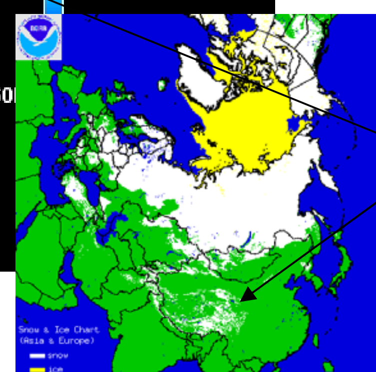
AMSR-E*/Aqua snow water equivalent map (NASA)



5-day composite



Daily map



IMS snow cover map

Global daily product at 12.5 km spatial resolution

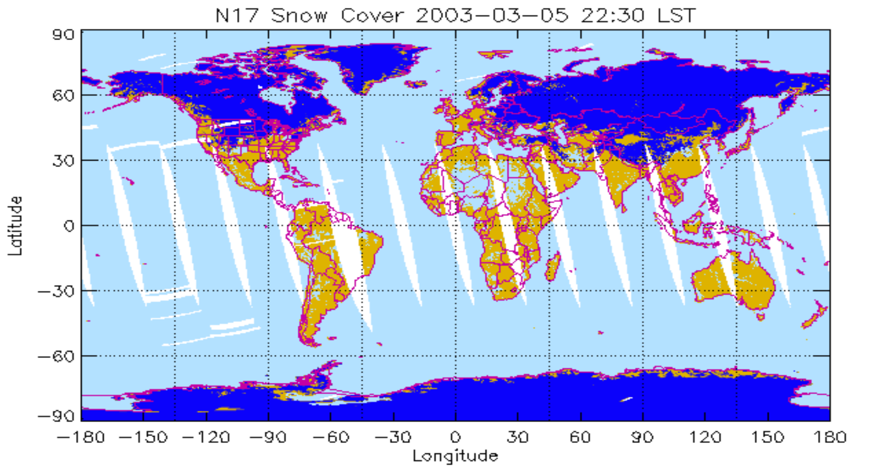
Product has not yet been extensively validated. The accuracy of a similar product from other microwave instruments ranges from 30% to 100%

Mountains is a problem area, where microwave techniques tend to overestimate the snow cover

*AMSR-E:Advanced Microwave Scanning Radiometer - EOS

Snow Cover: Available products

AMSU* snow cover and water equivalent map (NOAA)

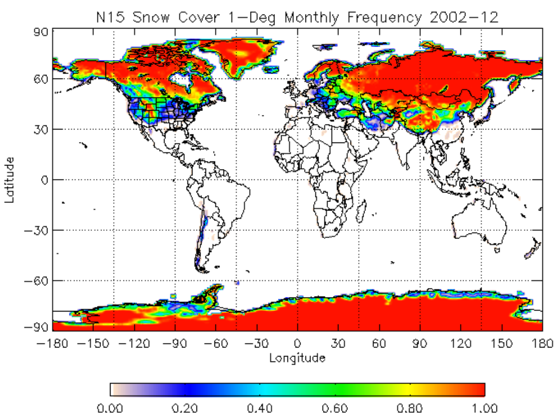


Blue is snow, yellow is land without snow, light blue is undetermined (rain, desert, water, etc.)

Global daily product at 50 km spatial resolution. Six maps are generated daily from asc and desc nodes of AMSU onboard NOAA-15, -16 and -17

Validation results are not available. Accuracy is unknown.

Gaps are due to precipitating clouds



NOAA/AMSU monthly snow frequency

*AMSU: Advanced Microwave Sounding Unit

Applications of snow remote sensing data

General: Except for the IMS interactive snow cover analysis available snow remote sensing products find very limited use in meteorological, hydrological and climate studies. Most of these products simply do not satisfy the requirements of current environmental numerical models. The primary reasons for the lack of application are

- Gaps in the area coverage (typical to snow data in vis/IR)

- Low or unknown accuracy of retrievals (both vis/IR and microwave)

- Inadequate spatial resolution (typical to microwave data)

- Unavailability of sufficiently long homogeneous time series of observations from one instrument.


Thank you very much !