Permafrost Monitoring

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Contents

1、Permafrost and its role in climate system

Definition

The soil or rock layer whose temperature is lower than 0℃

With ice

Frozen ground

Duration

Permafrost:

more than 2 years

Seasonally frozen ground:

less than 2 years

Without ice

Gelisol

Water content

Dry gelisol

no ice and gravity water

Wet gelisol

With brine

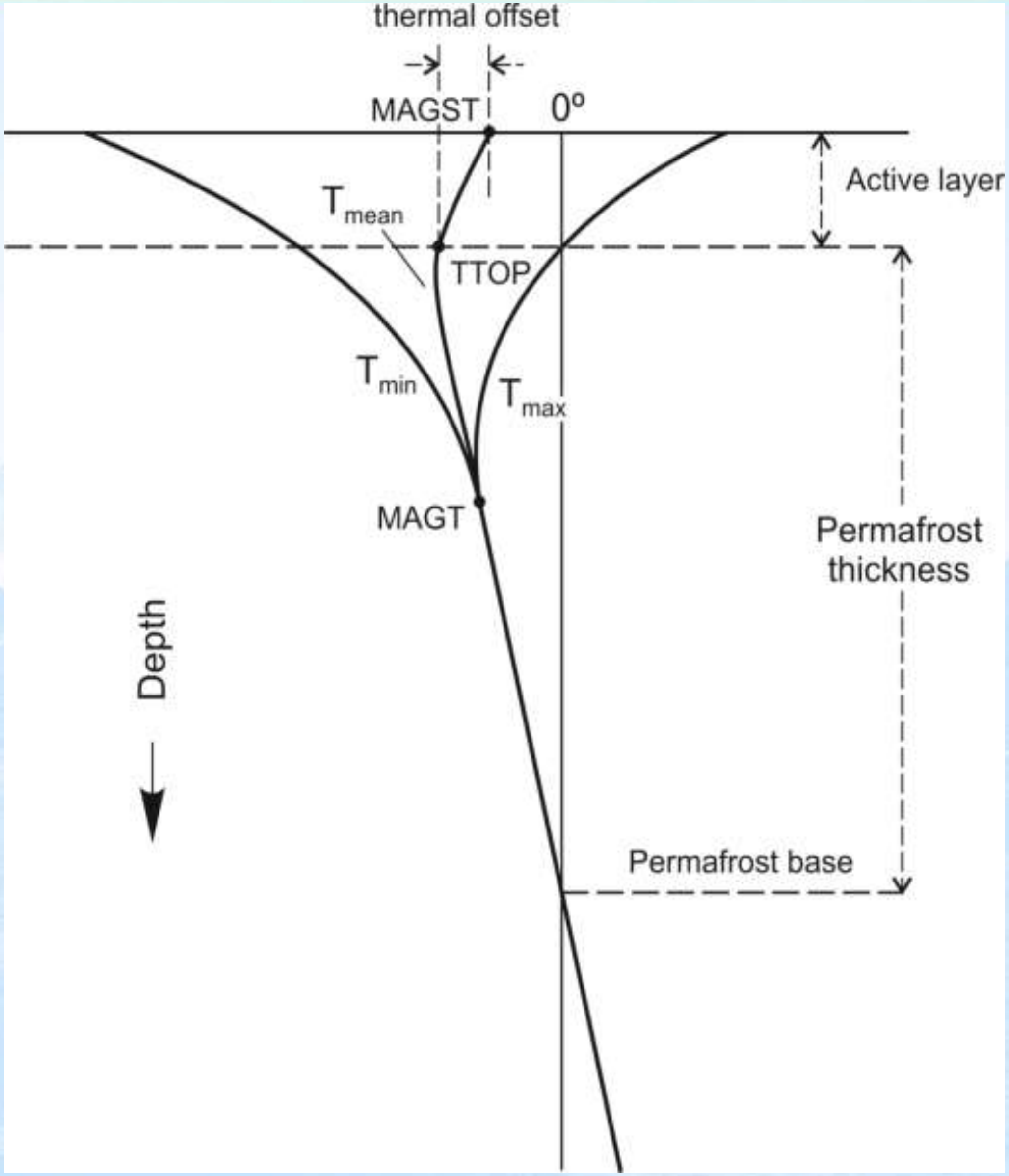
What is Permafrost

PERMAFROST IS A THERMAL CONDITION OF EARTH MATERIAL

- **- *Permafrost* is ground that remains at or below 0ºC for two or more years**
- **- *The active layer* is the layer of ground above permafrost that freezes and thaws each year.**

Active layer	Thaw in summer and freeze in winter
Permafrost	Below 0℃ Ground ice More than 2 years

Ground temperature is a linear function of depth




次整理岩心票

DISCONTINUOUS PERMAFROST

Churchill , northern Manitoba; The tree line; the southern limit of continuous permafrost


CONTINUOUS PERMAFROST
Tuktoyaktuk, NWT; MAGST -7ºC

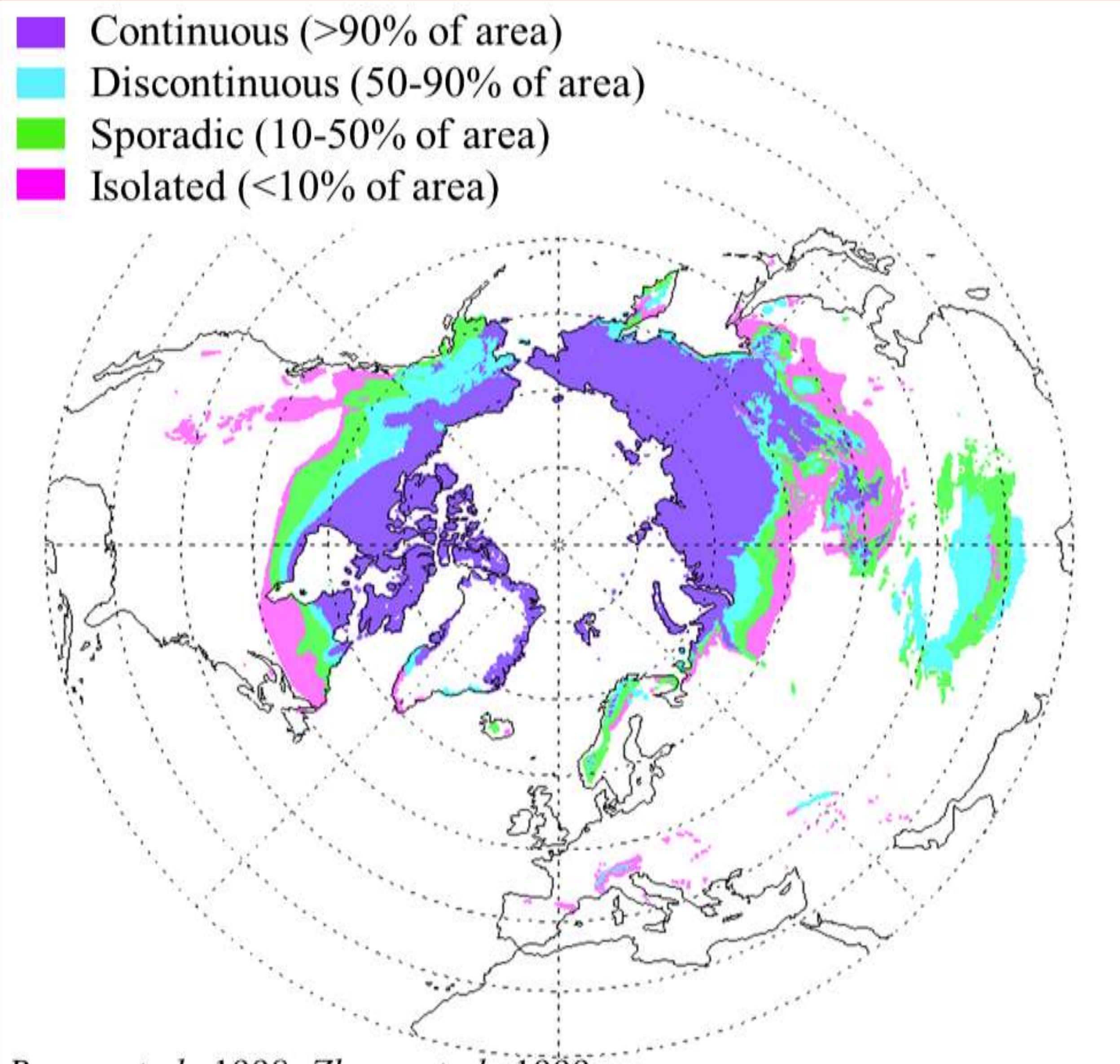
Massive ground ice along Tuktoyaktuk coast, NWT.

Exposed ice in a typical periglacial landform-pingo

Permafrost classification

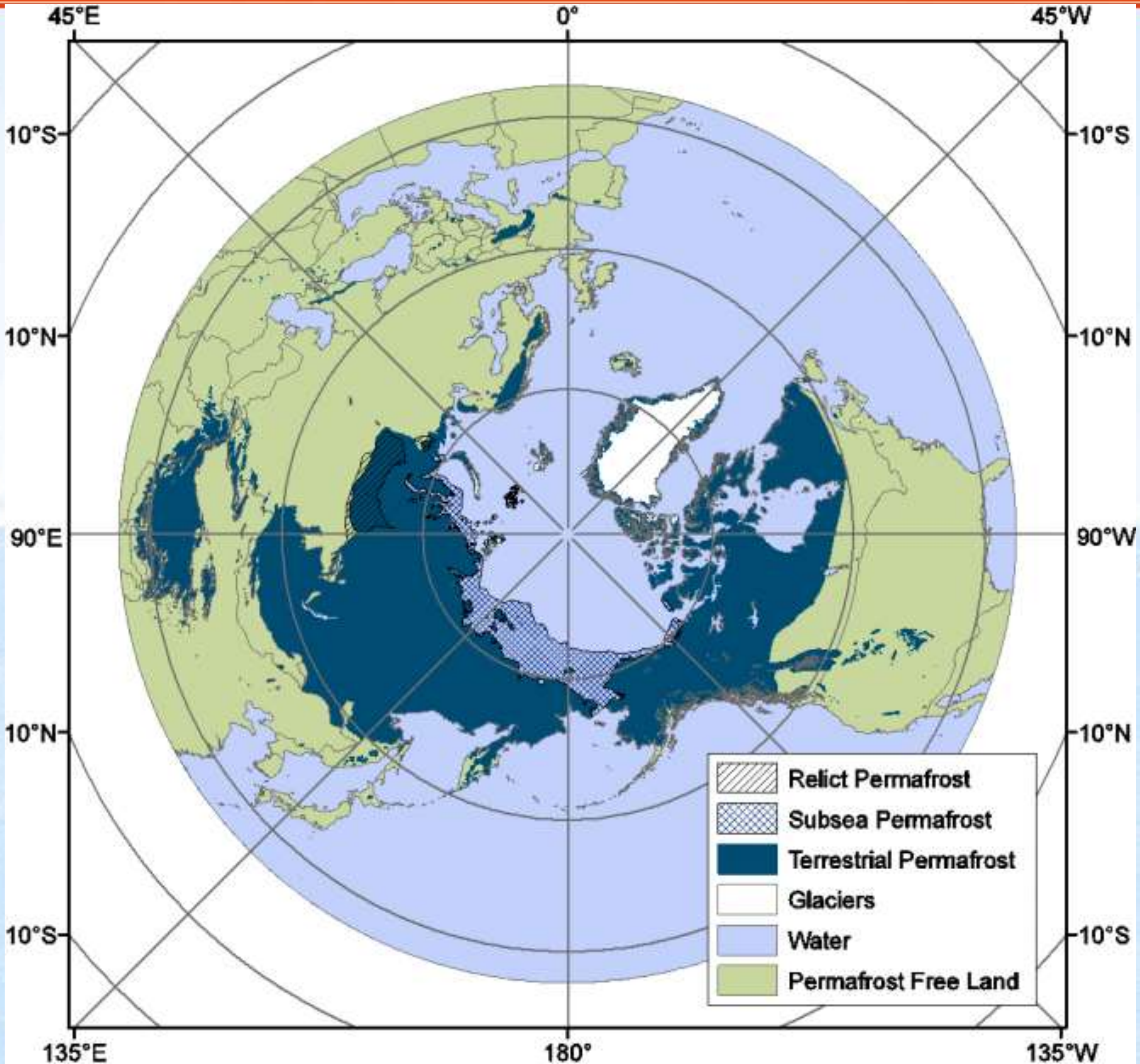
- **By area coverage**
  - Continuous (>90% of area)
  - Discontinuous (50-90% of area)
  - Sporadic (10-50% of area)
  - Isolated (<10% of area)
- **By Location:**
  - Terrestrial
  - Sub-ice
  - Sub-sea
  - Relic
- **By Coupling with climate:**
  - Exposed (terrestrial)
  - Submerged (sub-ice, sub-sea, and relic)

Permafrost Classification by Area



Brown et al., 1998; *Zhang et al.*, 1999

Permafrost Classification

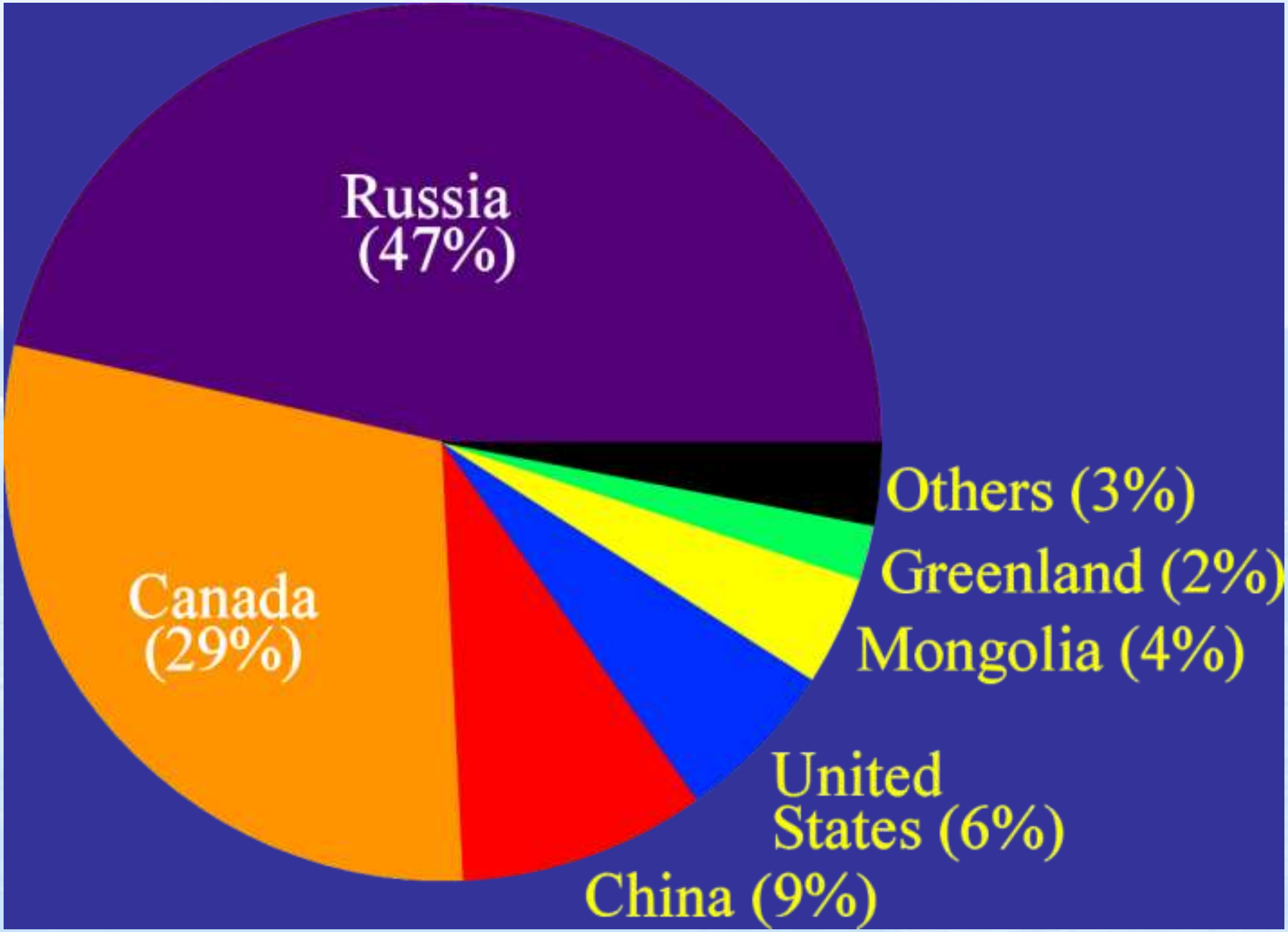


Controls over the distribution of permafrost

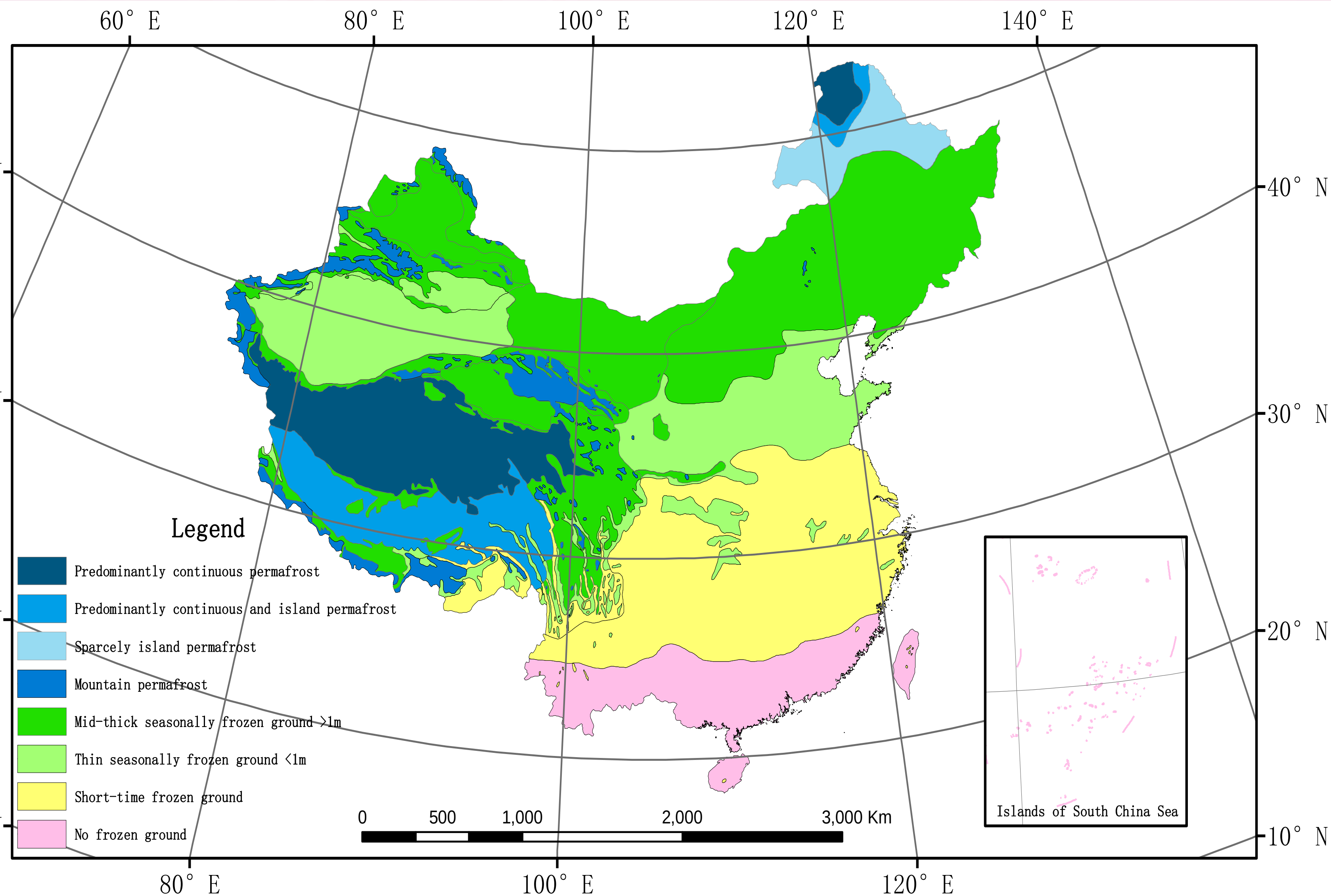
- **1. REGIONAL CLIMATE**.......
- 2. Permafrost may be **RELICT** and unrelated to current climate.....
- 3. Local site-specific factors:
- - aspect, lithology and thermal conductivity, vegetation cover, snow cover, drainage

Permafrost Distribution by Country

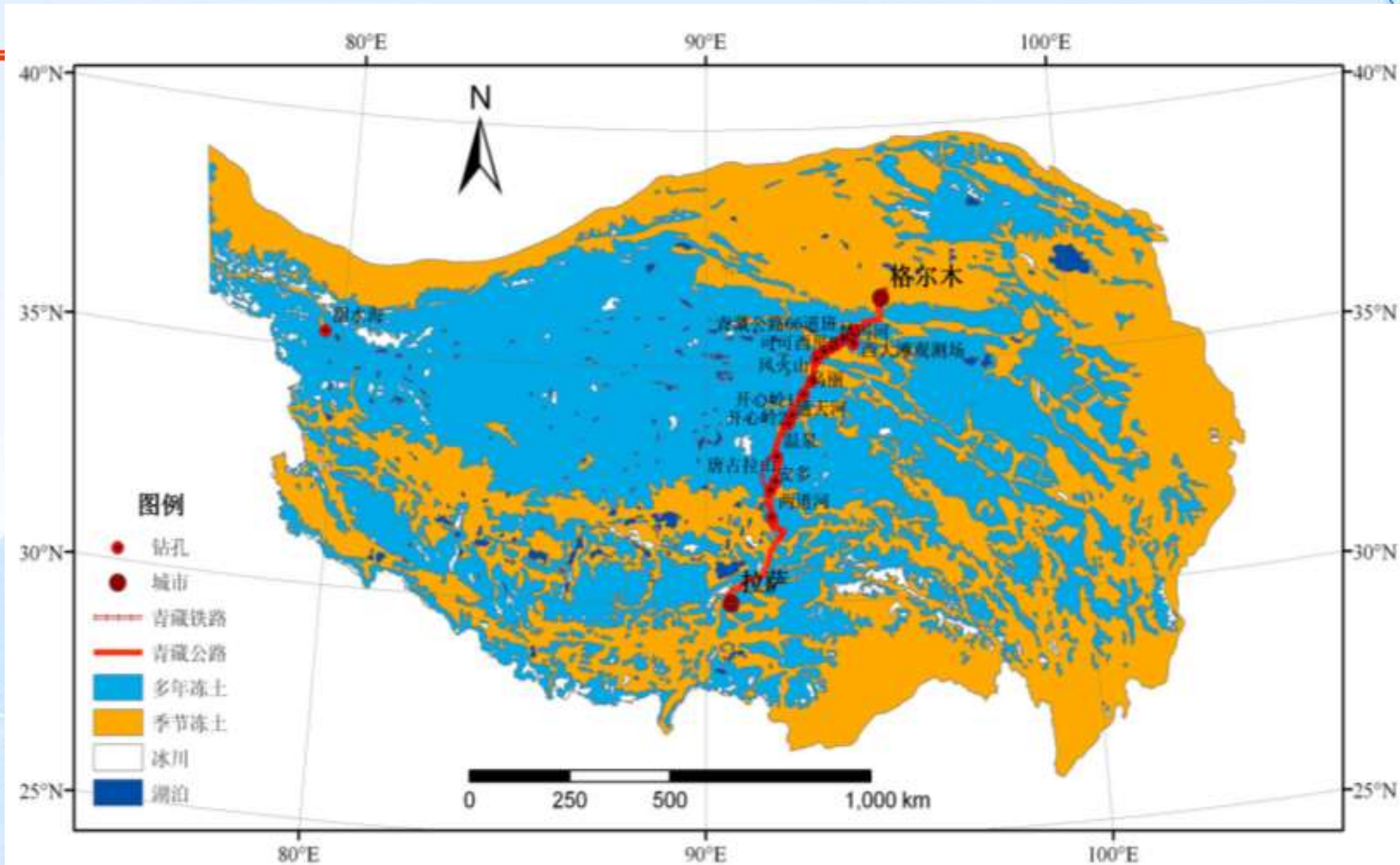
- Permafrost underlies approximately 22.79 million square kilometers (about 24 percent of the exposed land surface) of the Northern Hemisphere.
- It occurs as far north 84° N in northernmost Greenland, and as far south as 26° N in the Himalayas



Distribution of frozen ground in China



- In China, the area of permafrost distribution amounts to about 1.5×10^6 km^2.



- On the QTP, the area of permafrost distribution amounts to about 1.06×10^6 km^2；
- Lots of studies indicated that permafrost dynamics on the QTP have exerted significant influence on the engineering construction, hydrological cycles, and ecosystem diversity and production in local regions.

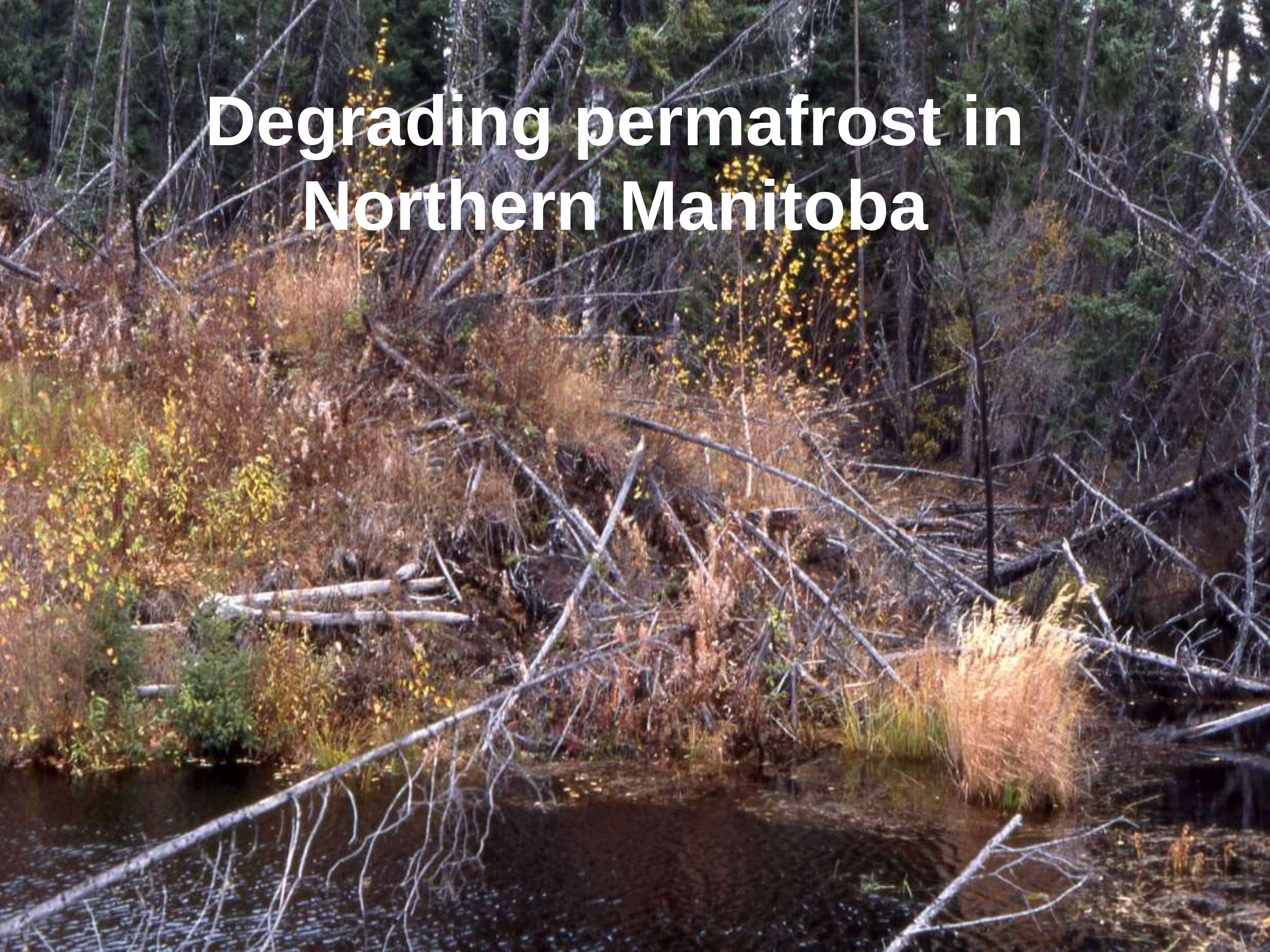
Geomorphic evidence of warming permafrost

In Arctic regions, a thickening of the active layer may result in an increased frequency of active-layer-detachment failures.

In Subarctic regions, the thaw of marginal (warm) permafrost will cause collapse scars and the formation of wetlands and bogs

French, 2013, Lanzhou


Active-layer detachment failure,
Banks Island, Arctic Canada


Degrading permafrost in
Northern Manitoba

GCOS Essential Climate Variables

The 50 GCOS Essential Climate Variables (ECVs) (2010) are required to support the work of the UNFCCC and the IPCC. All ECVs are technically and economically feasible for systematic observation. It is these variables for which international exchange is required for both current and historical observations. Additional variables required for research purposes are not included in this table. It is emphasized that the ordering within the table is simply for convenience and is not an indicator of relative priority.

Domain	GCOS Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:**[1] Air temperature, Wind speed and direction, Water vapour, Pressure, Precipitation, Surface radiation budget. **Upper-air:**[2] Temperature, Wind speed and direction, Water vapour, Cloud properties, Earth radiation budget (including solar irradiance).
Terrestrial	River discharge, Water use, Groundwater, Lakes, Snow cover, Glaciers and ice caps, Ice sheets, Permafrost, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (FAPAR), Leaf area index (LAI), Above-ground biomass, Soil carbon, Fire disturbance, Soil moisture.

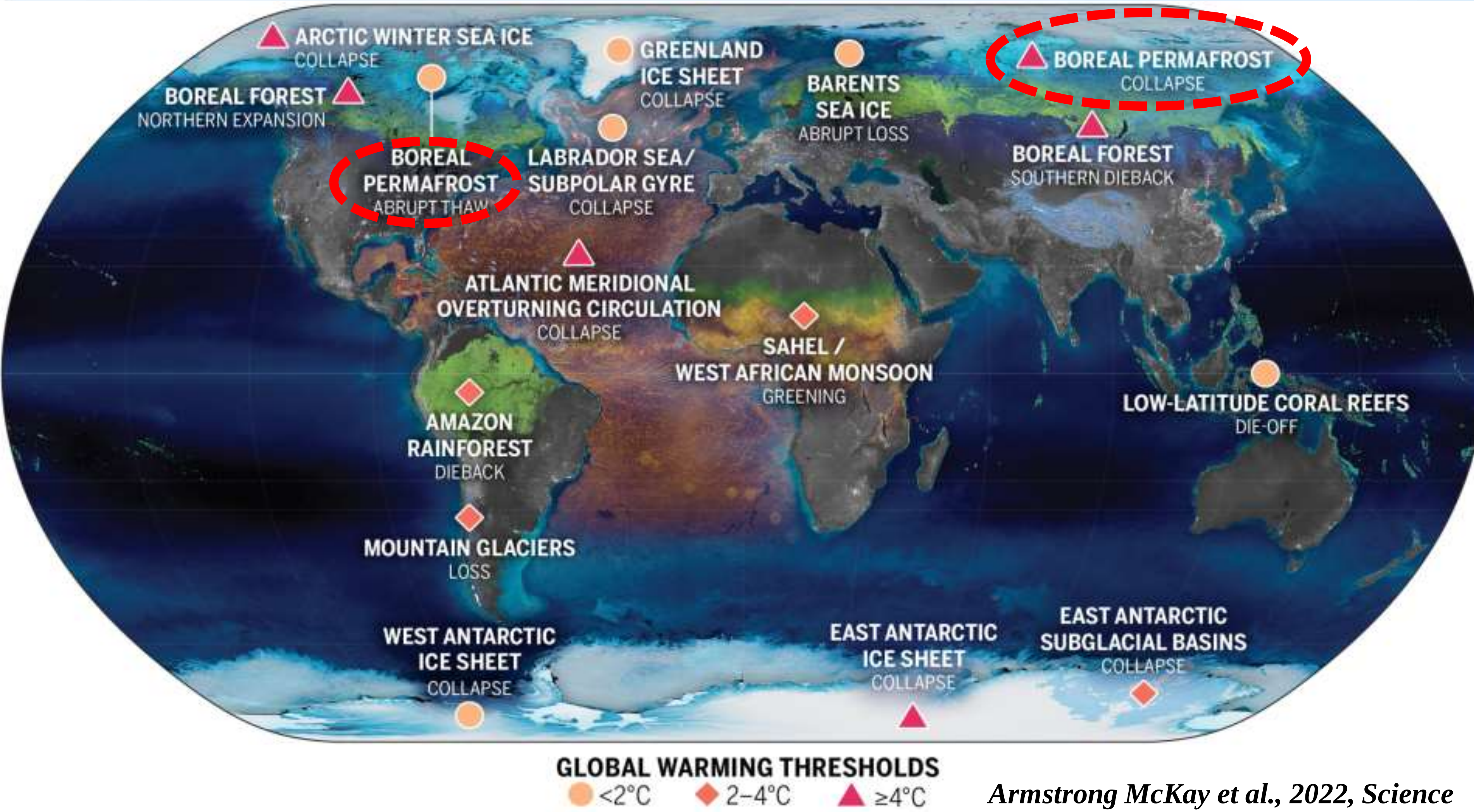
[1] Including measurements at standardized, but globally varying heights in close proximity to the surface.

[2] Up to the stratopause.

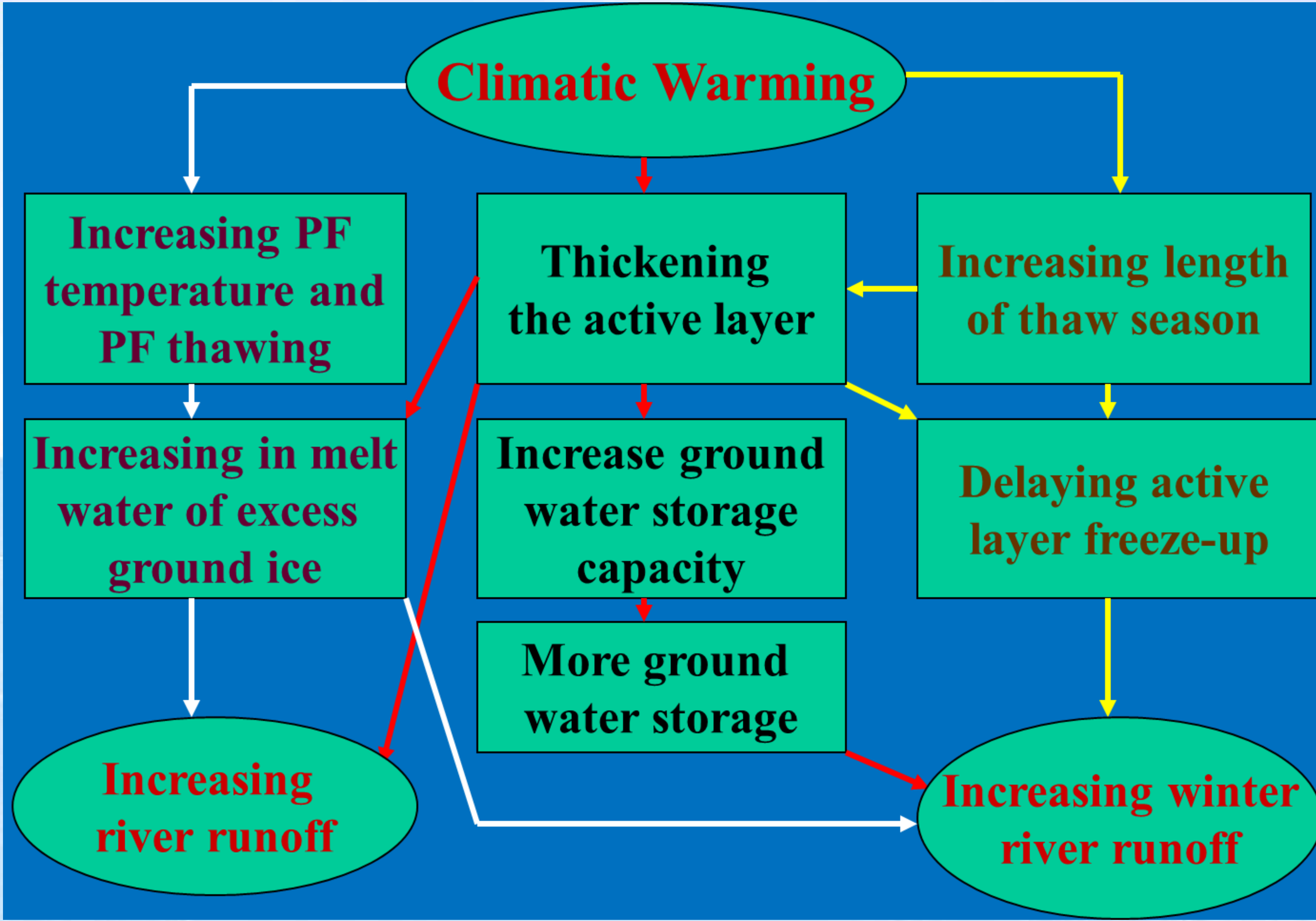
[3] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons

Permafrost – an essential climate variable of the"Global Climate Observing System"

- **The tipping points in earth climate system**



Armstrong McKay et al., 2022, Science


Climatic Warming
Increasing PF temperature and PF thawing
Thickening the active layer
Increasing length of thaw season
Increasing in melt water of excess ground ice
Increase ground water storage capacity
Delaying active layer freeze-up
More ground water storage
Increasing river runoff
Increasing winter river runoff

Permafrost plays a central role in Arctic landscapes

Major influence on **hydrology . . .** and on **water quality**

S**now** greatly influences the permafrost conditions

“Drunken Forests”

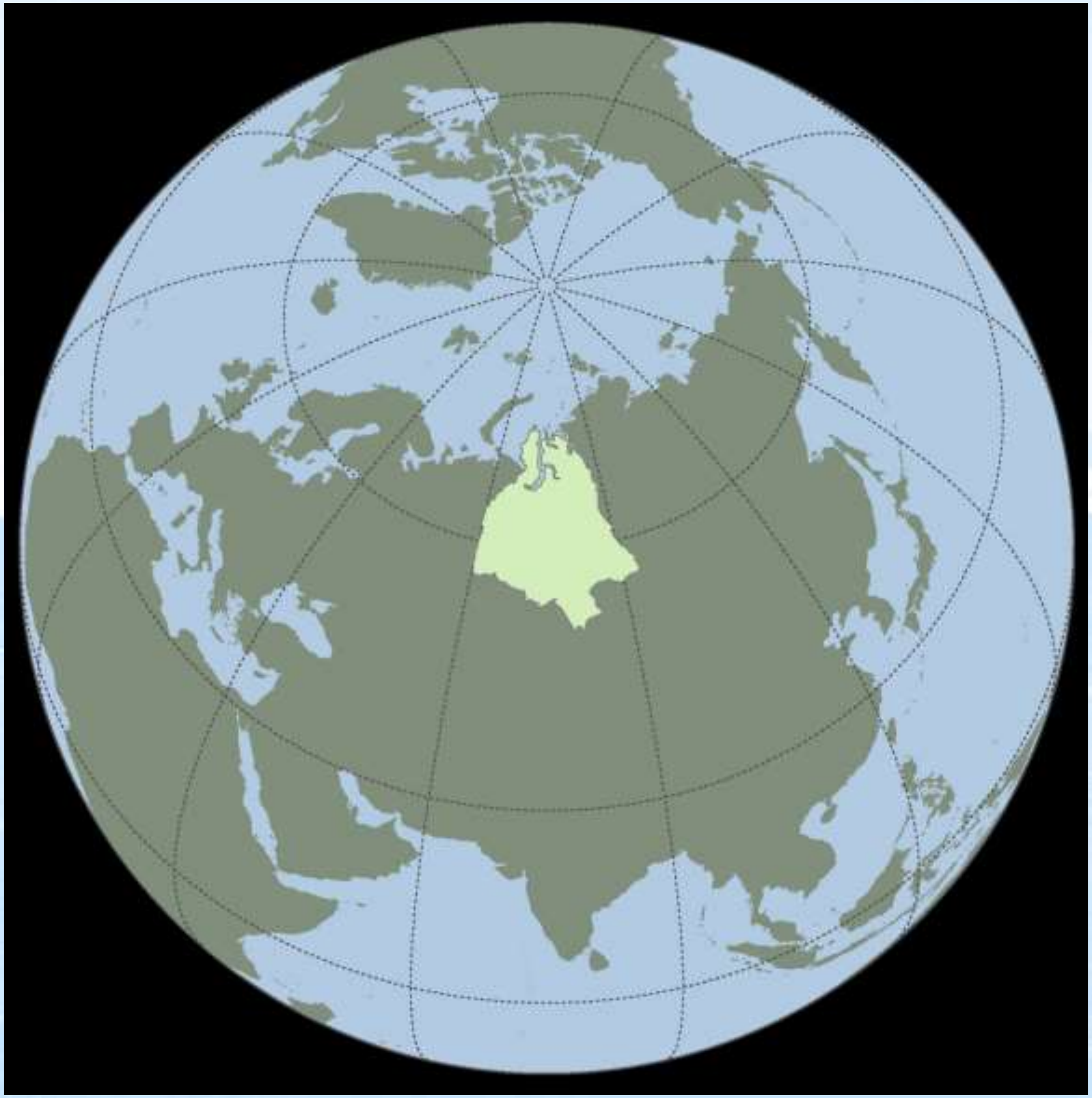
http://gsc.nrcan.gc.ca/landscapes/details_e.php?photoID=509

http://openlearn.open.ac.uk/mod/resource/view.php?id=172095

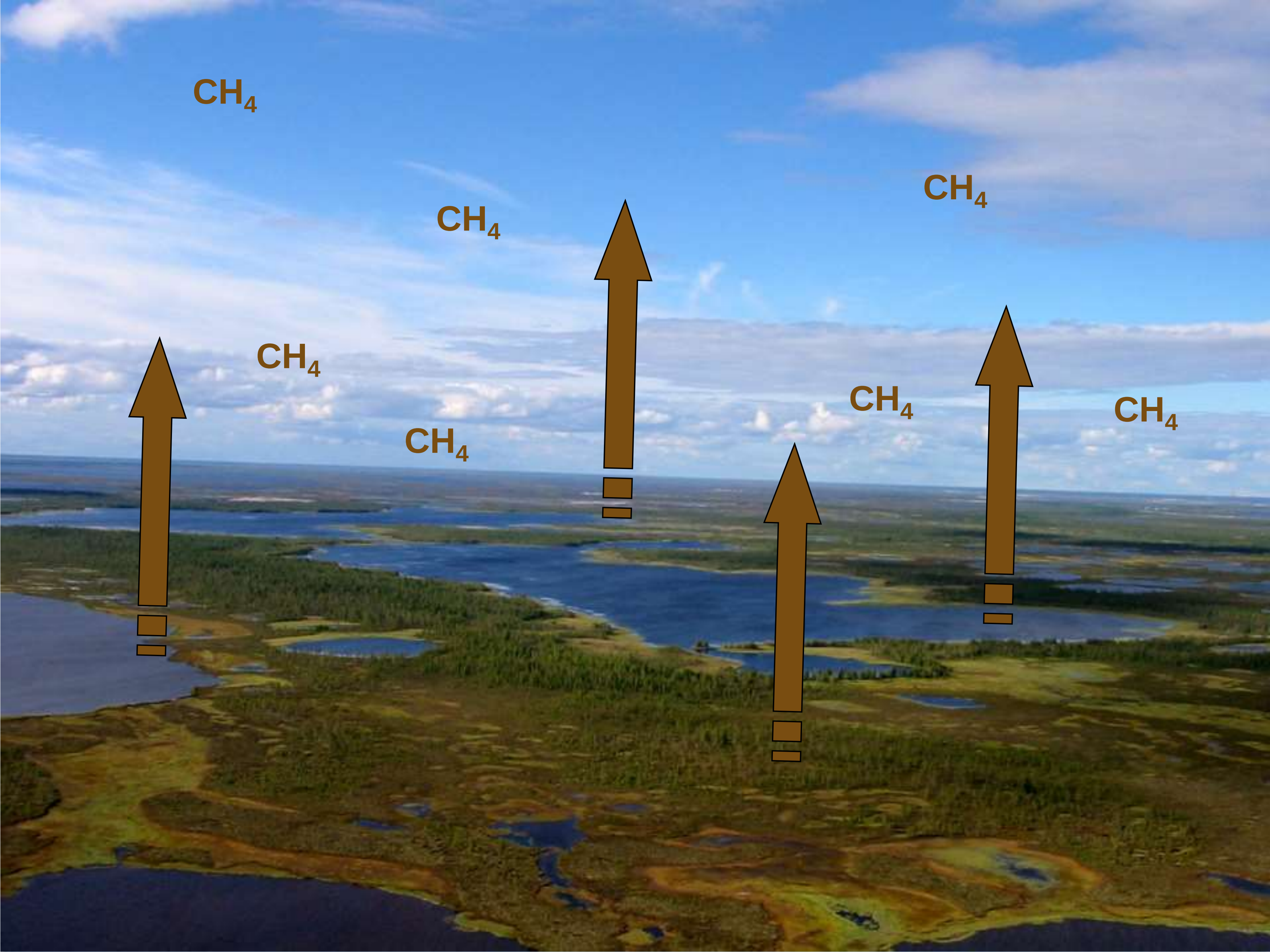
Permafrost plays a central role in Arctic landscapes

Major influence on **tundra ecology:** Vegetation and Fauna

Also affected by **snow** and **liquid water**



Thawing permafrost forecast to release CO_2 and CH_4 -- huge areas of Siberia are a gigantic source of additional green house gases, as across many parts of the Arctic

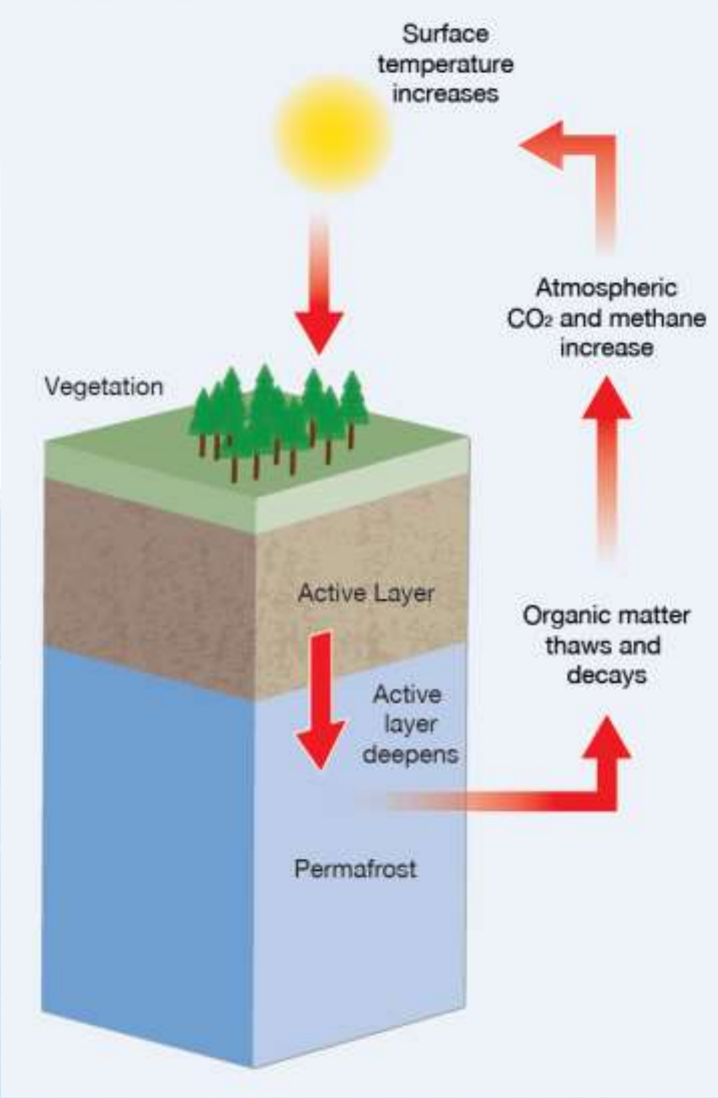

CH_4
CH_4
CH_4
CH_4
CH_4
CH_4
CH_4

Impact of Thawing Permafrost on Global Climate

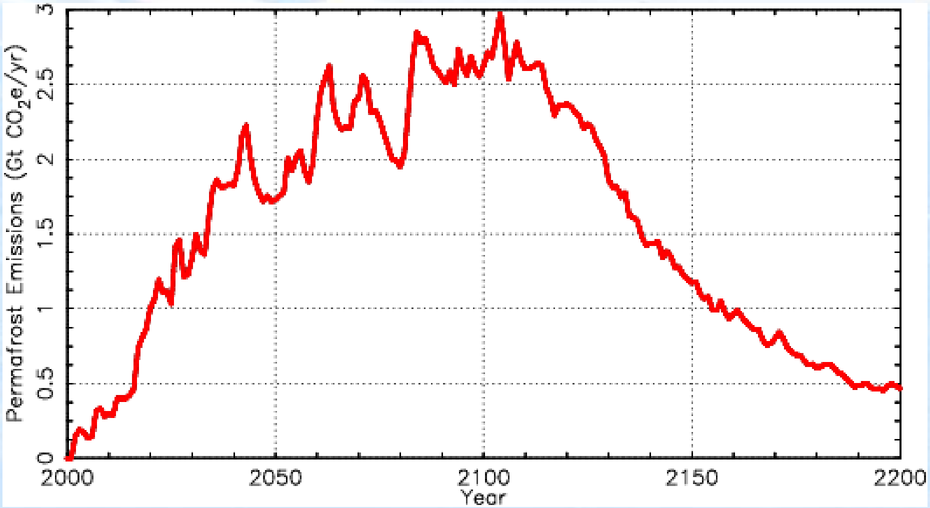
- ~1700 Gt of carbon in permafrost as frozen organic matter
- Thawing permafrost will release CO_2 and methane into atmosphere

(Tarnocai et al. 2009. GBC 23, GB2023)

The Permafrost Carbon Feedback



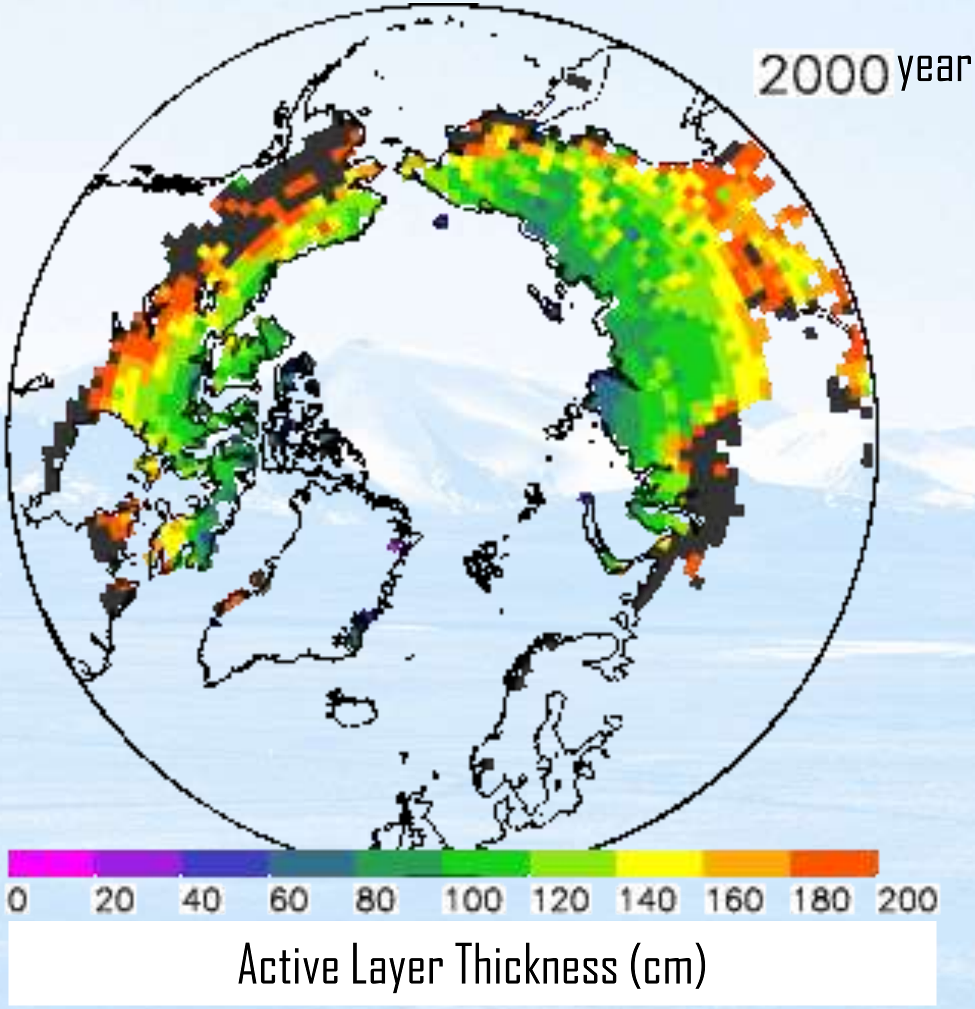
- Amplifies surface warming
- Irreversible
- Emissions for centuries



Projected annual permafrost emissions for A1B scenario

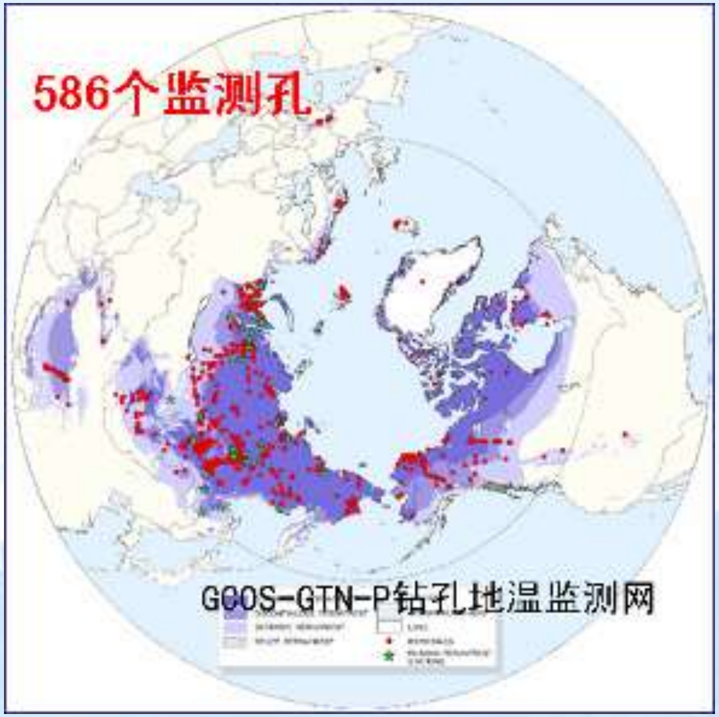
Permafrost will continue to thaw

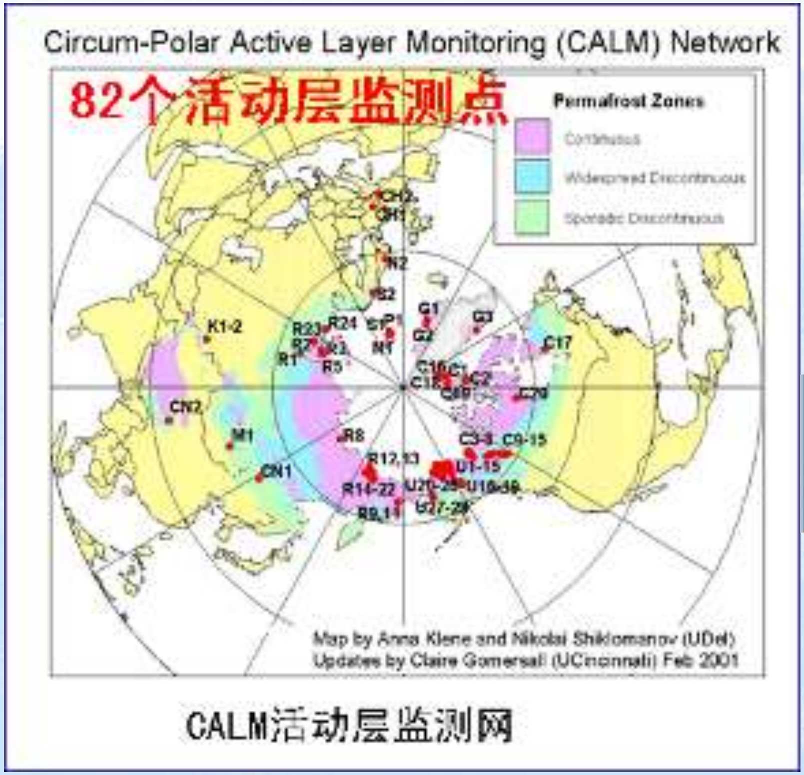
Projection of active layer thickness for A1B scenario



Permafrost observation network in the NH

- ► CALM
- ► GTN-P





World Meteorological Organization
Global Cryosphere Watch

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

2、Permafrost monitoring

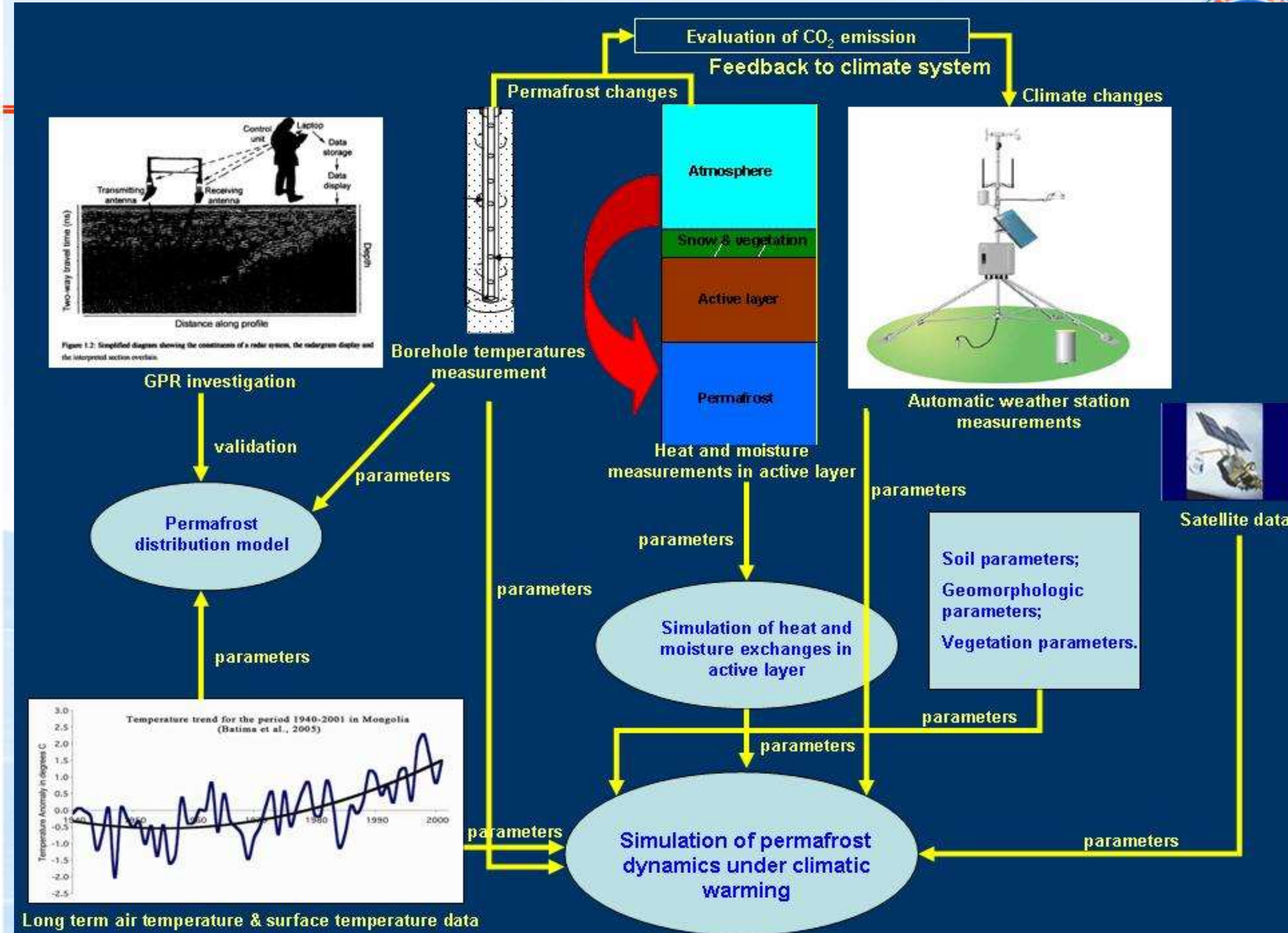
Permafrost monitoring

-Drilling

-Measuring ground temperatures

-Observation of active layer

-Geophysics and Remote Sensing



Evaluation of CO_2 emission
Feedback to climate system
Permafrost changes
Climate changes
Control unit
Laptop
Data storage
Data display
Transmitting antenna
Receiving antenna
Two-way travel time (ns)
Depth
Distance along profile
Atmosphere
Snow & vegetation
Active layer
Permafrost
GPR investigation
Borehole temperatures measurement
Heat and moisture measurements in active layer
Automatic weather station measurements
Satellite data
validation
parameters
Permafrost distribution model
Simulation of heat and moisture exchanges in active layer
Soil parameters;
Geomorphologic parameters;
Vegetation parameters.
Simulation of permafrost dynamics under climatic warming
Temperature trend for the period 1940-2001 in Mongolia (Batima et al., 2005)
Temperature Anomaly in degrees C
Long term air temperature & surface temperature data

Drilling

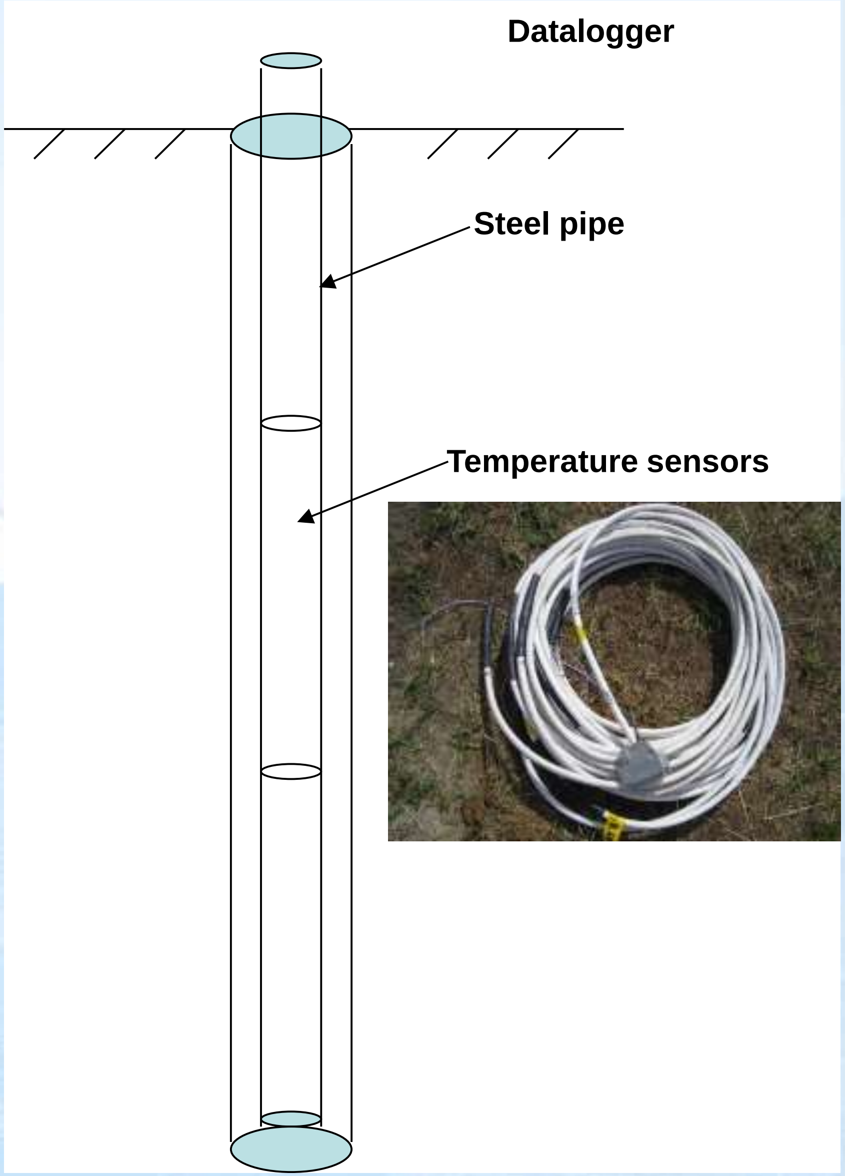
1

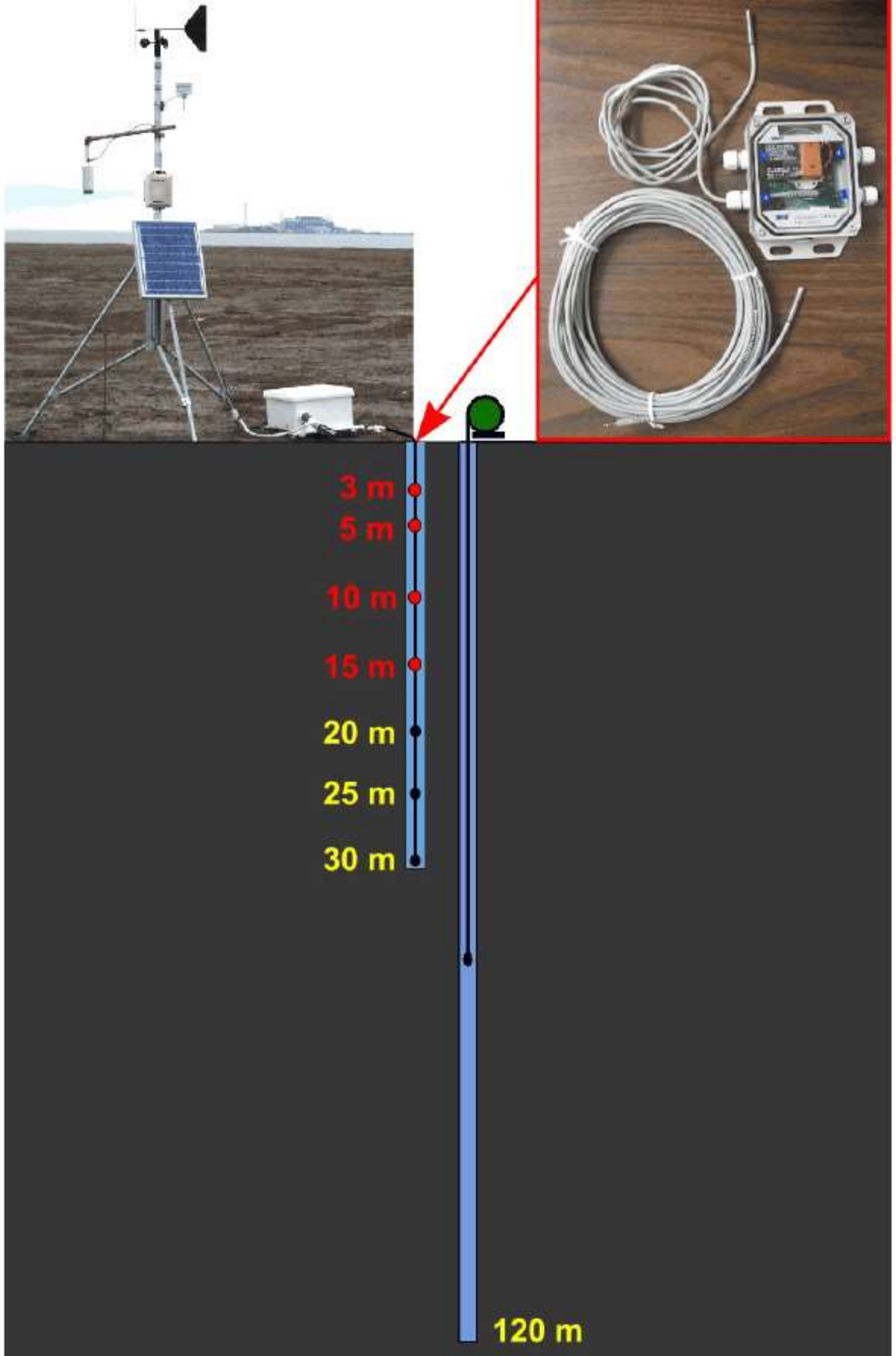
2

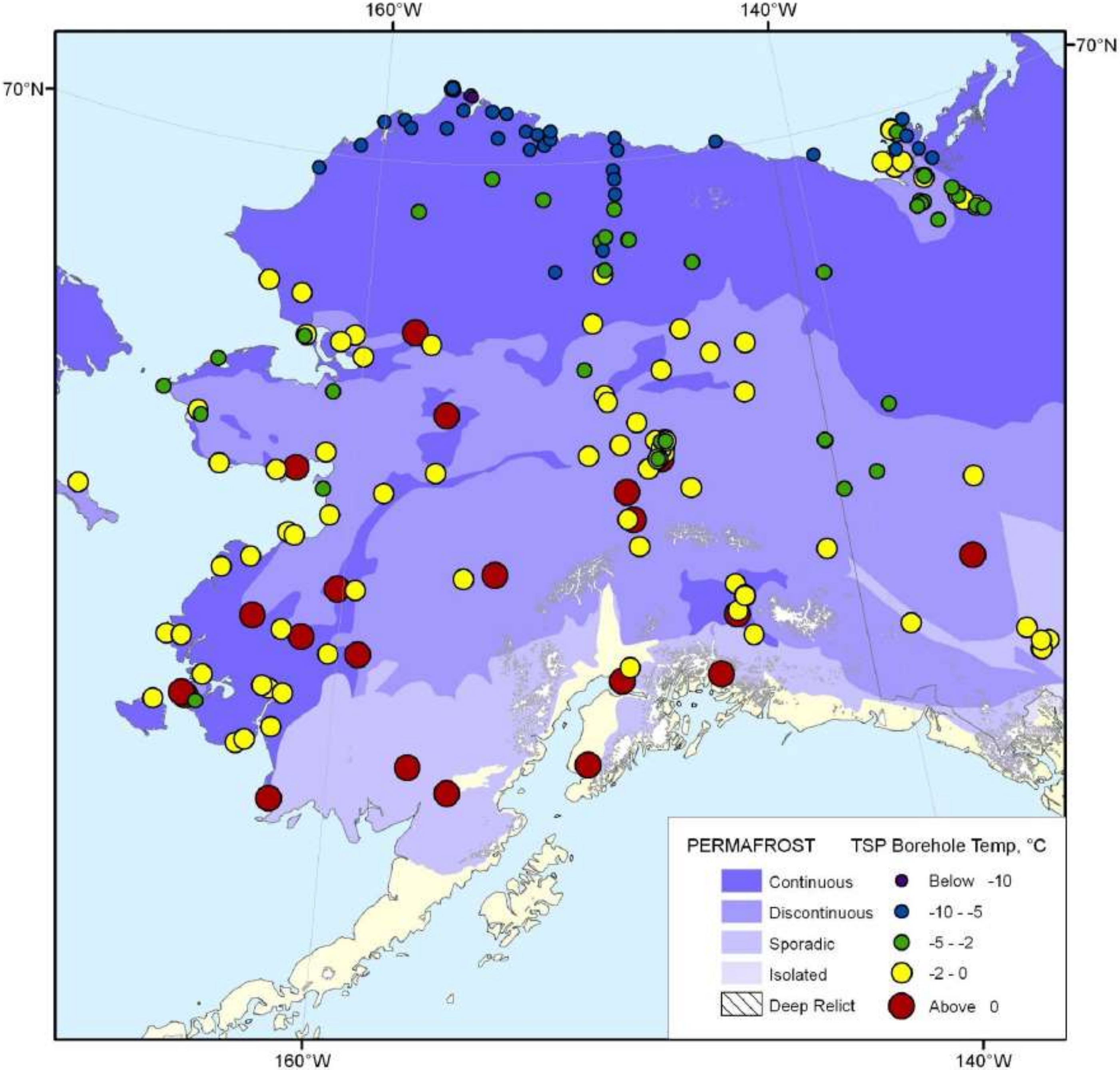
The drilling facilities include two equipment for:

- 1) deep borehole (more than 20 m)
- 2) shallow borehole (up to 15 m).

Measuring ground temperatures



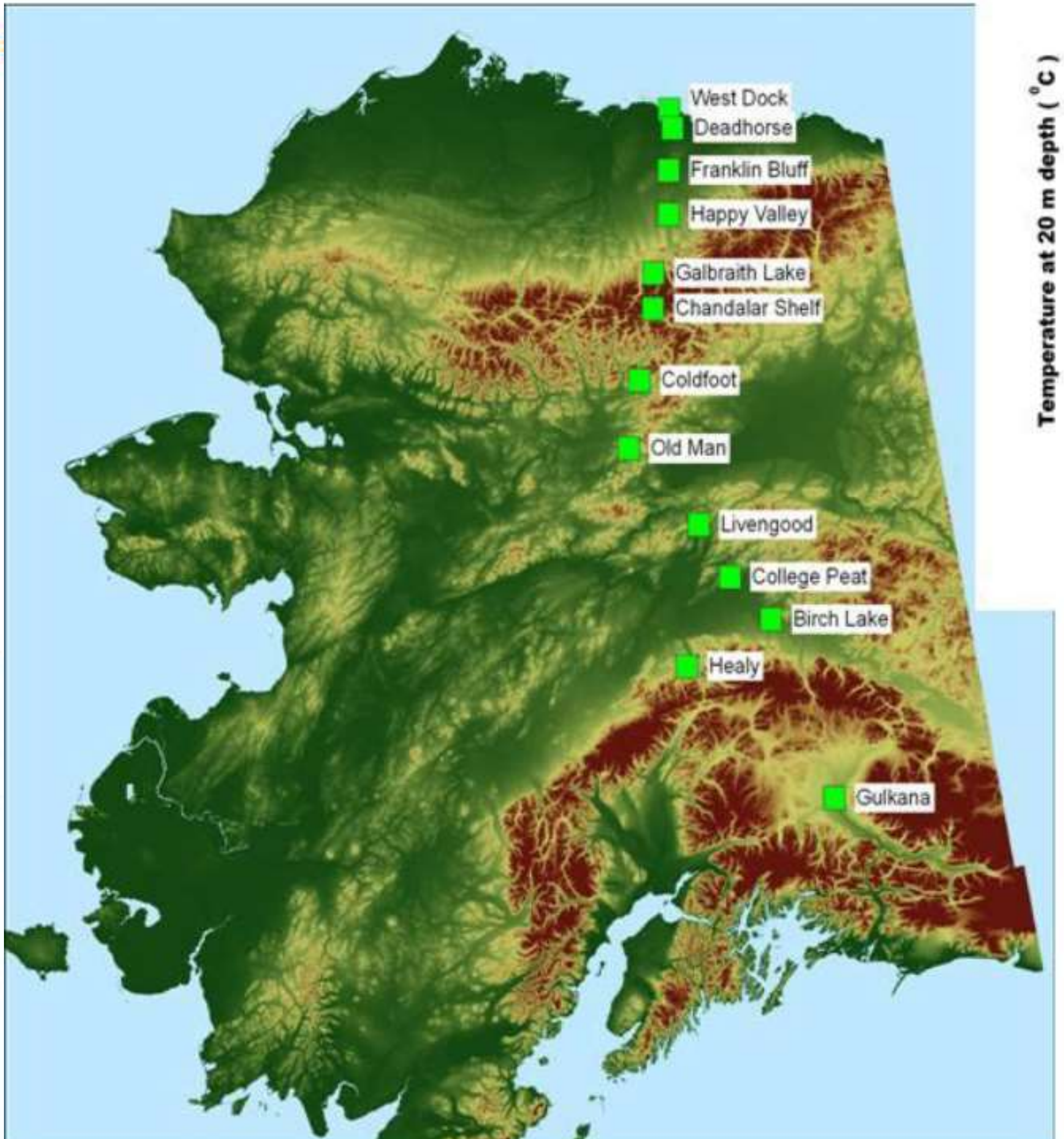

3 m
5 m
10 m
15 m
20 m
25 m
30 m
120 m

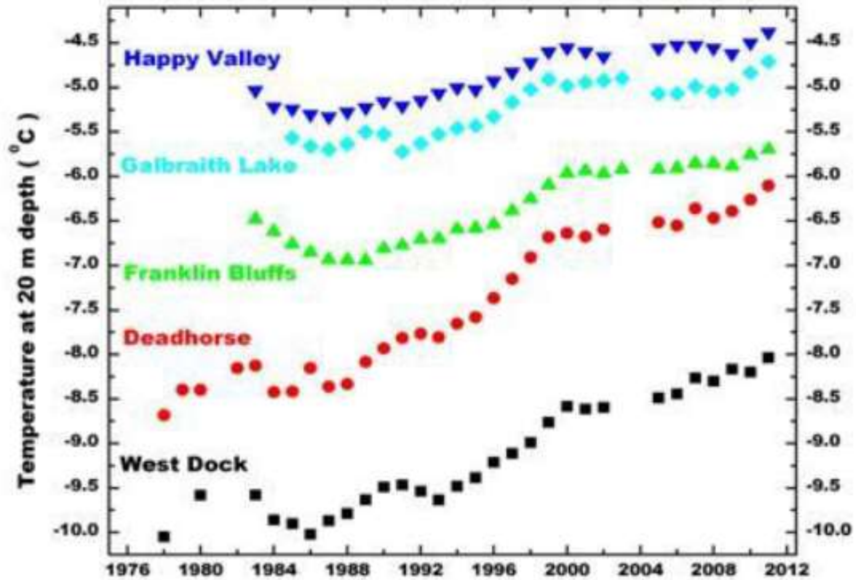


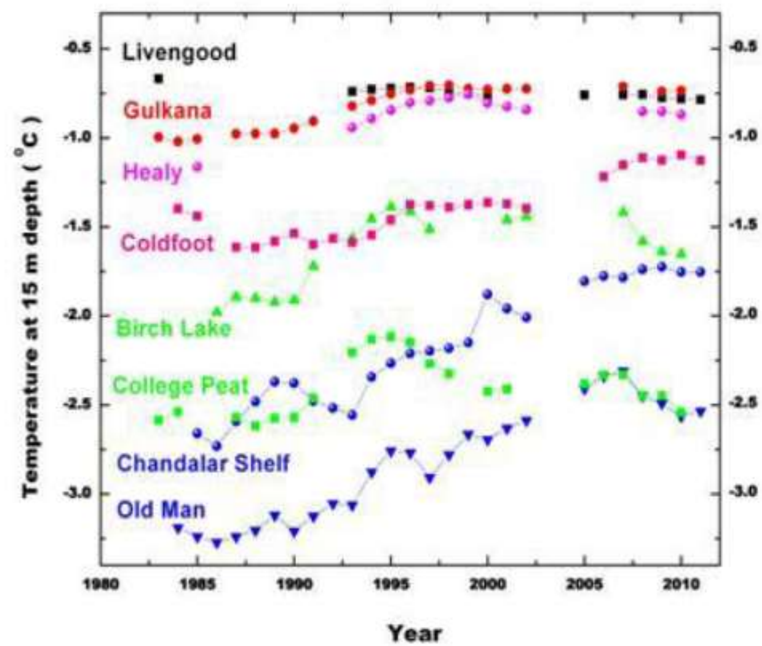
IPY TSP

Snapshot

2007-2009

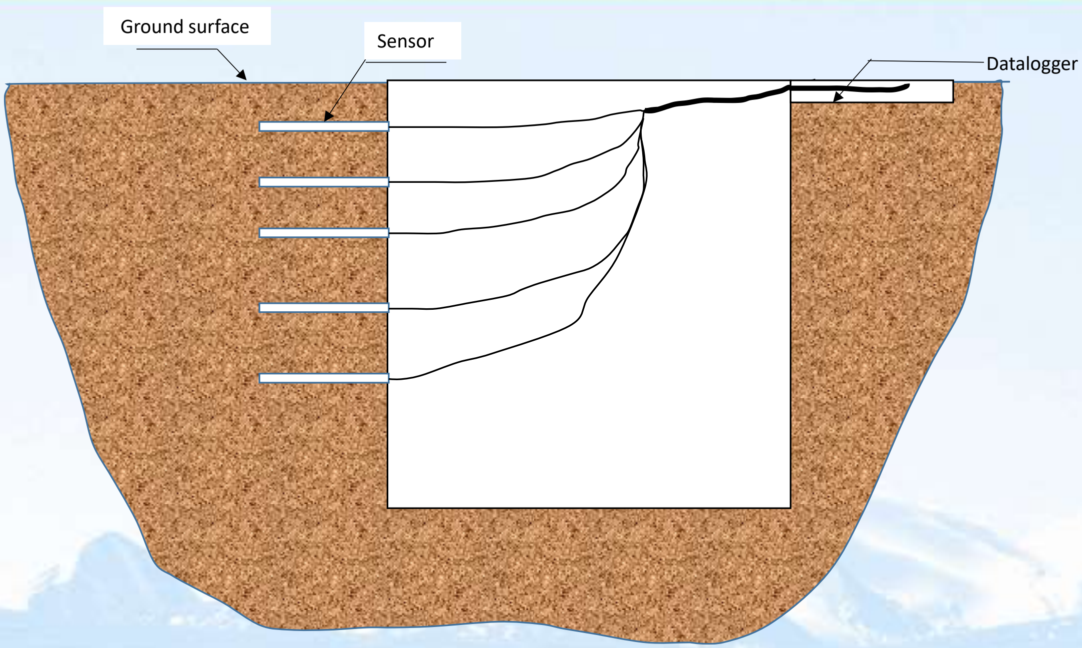


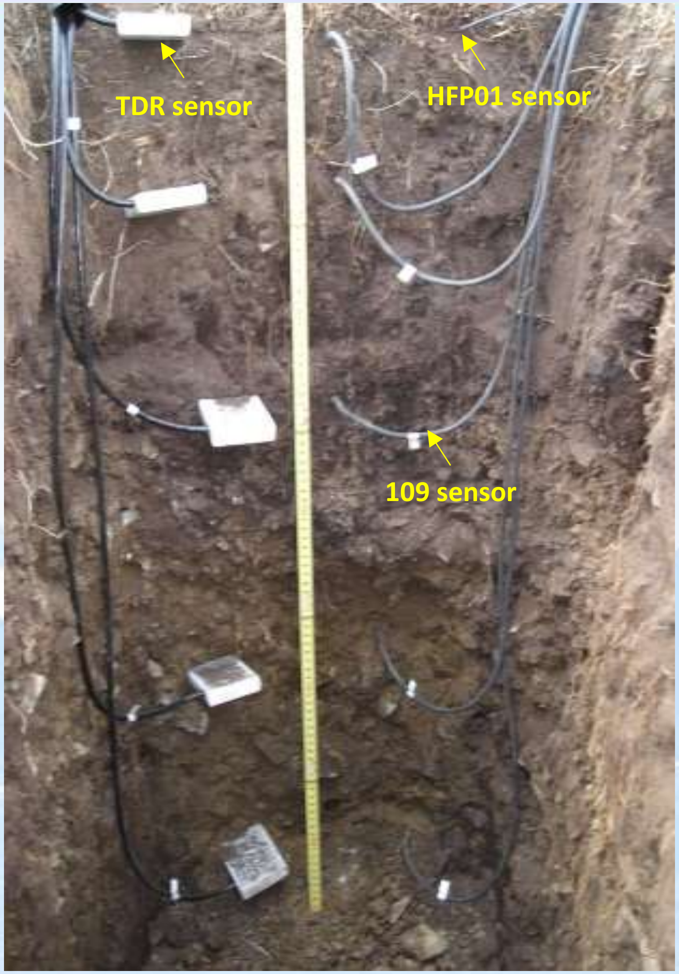




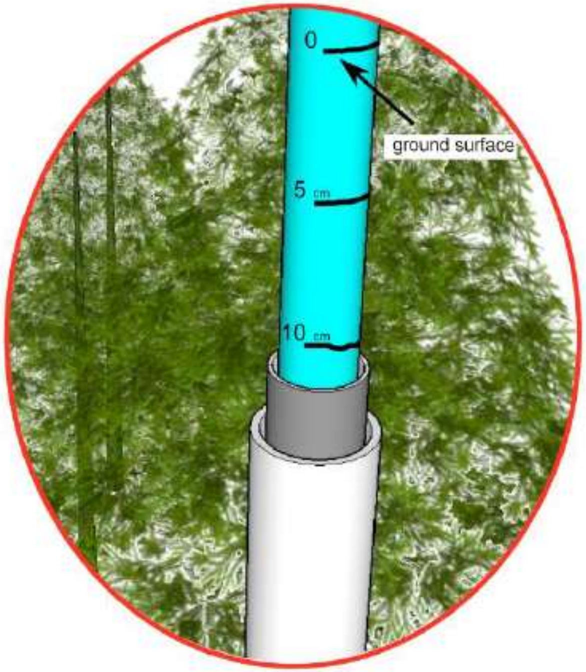
Romanovsky et al, 2012

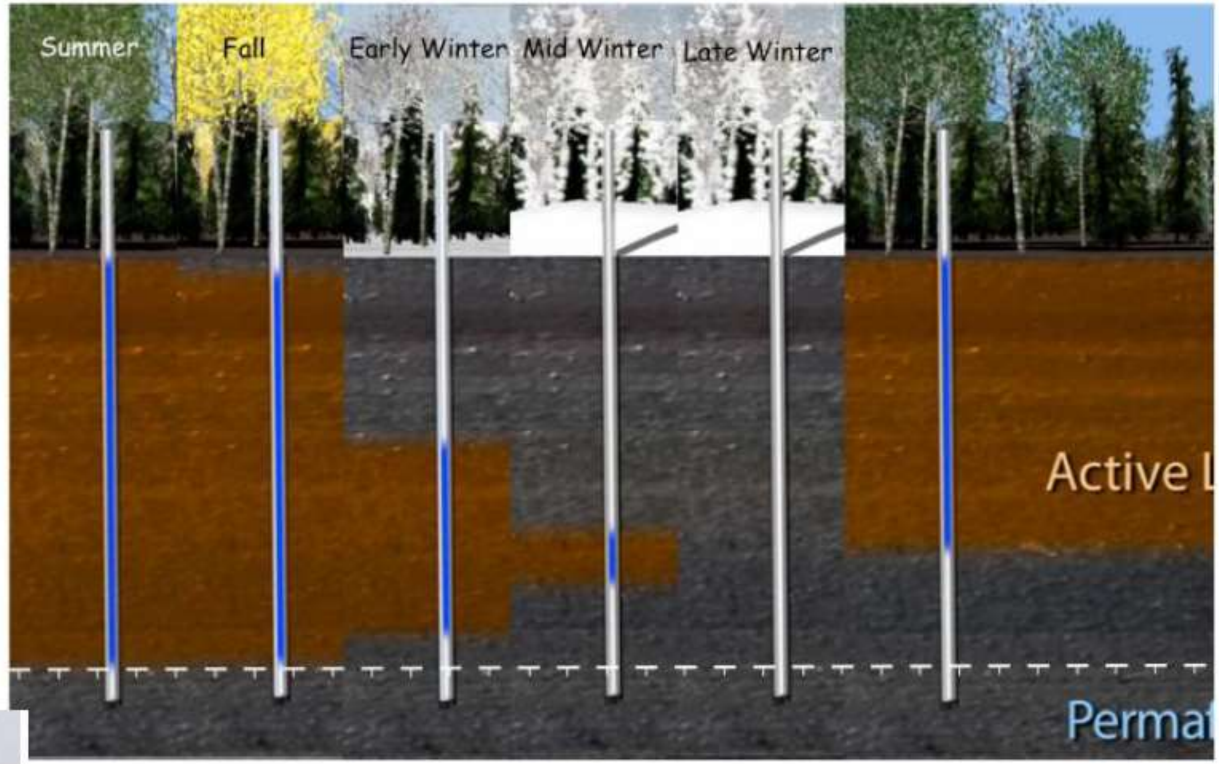
Observation of active layer

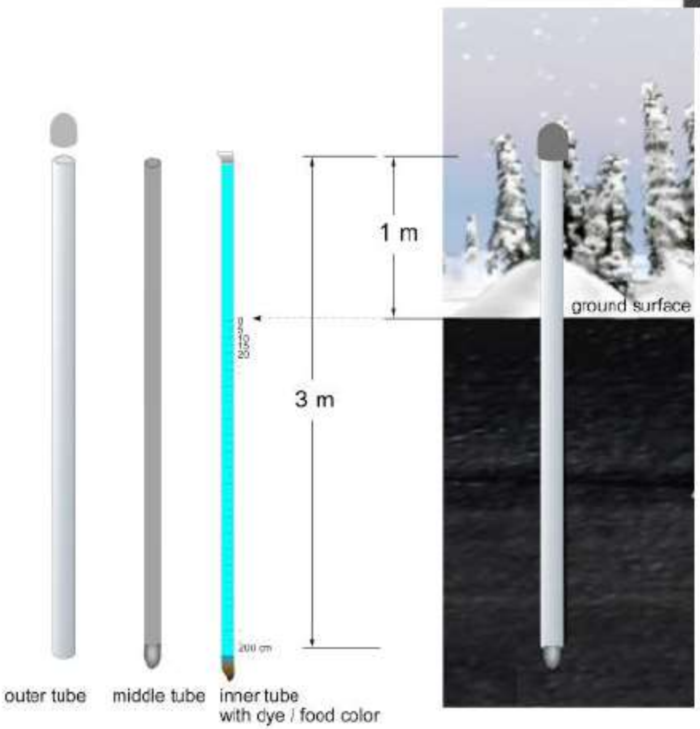




- **Soil temperature, moisture content, and heat flux have been recorded by datalogger at an interval of 30 minutes or 1 hour.**







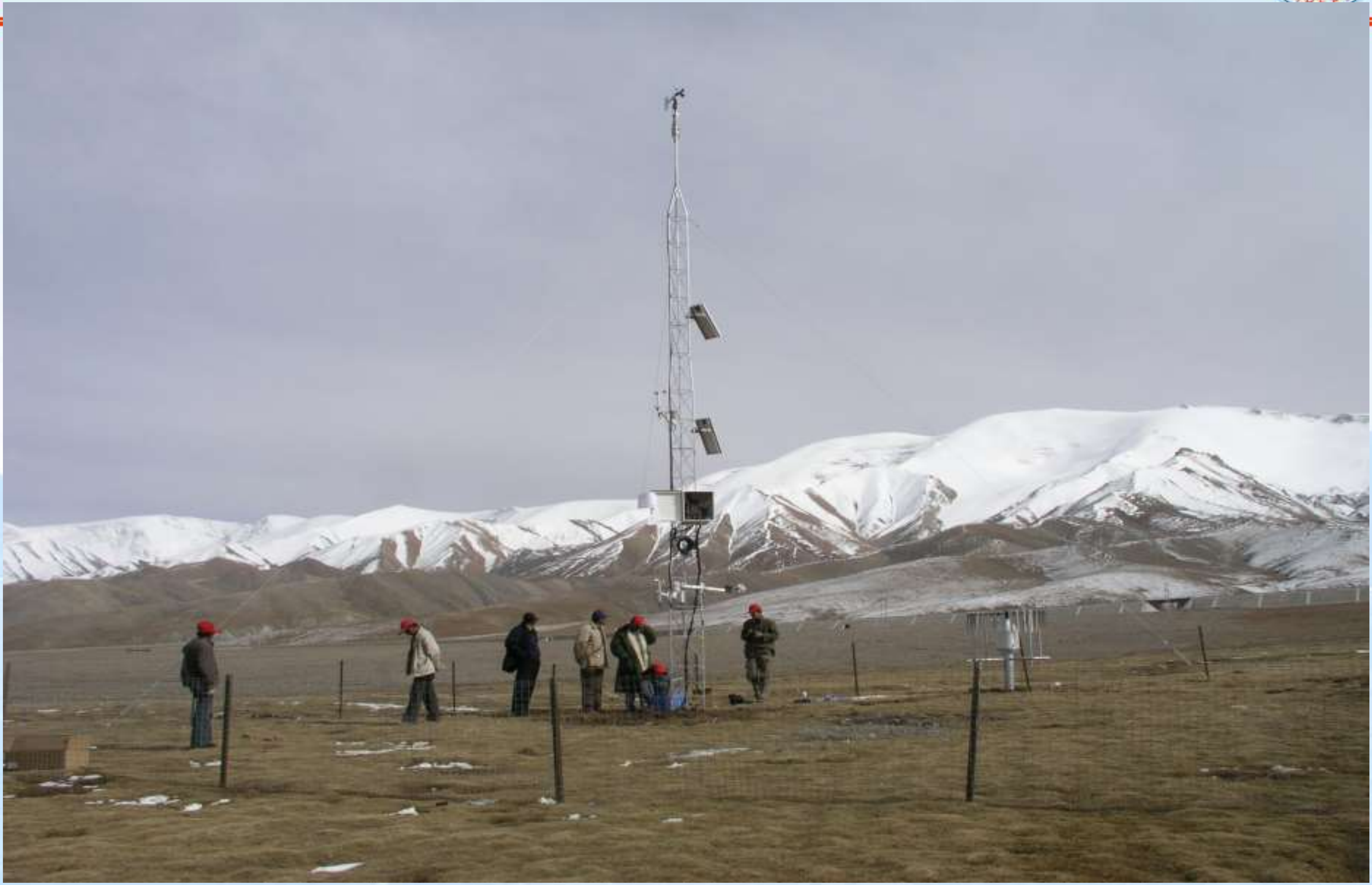
Active Layer Depth Measurements using Frost Tube Method

Frost Tube Protocol, Kenji Yoshikawa, 2011

Eddy Covariance System

- Sensible heat, latent heat, water vapor, and CO_2 flux were measured.

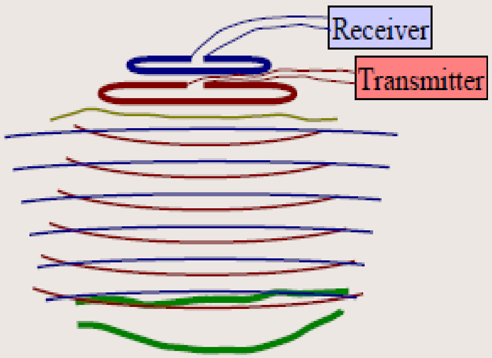
Automatic weather station



Geophysical survey

GPR Principles

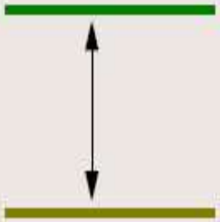
- Uses 30- 1000 MHz electromagnetic waves emitted in short "chirps" for probing
  - Two dipole antennas as source and receiver;
  - Automatically stacks series of pulses for noise reduction.
- Directly produces a zero-offset section;
  - Optionally, can also be used to produced a constant-offset or walkaway sections.
- Sensitive to *dielectric susceptibility* (ε) and *conductivity* (σ).



Geophysical survey

Propagation and reflection of radio waves

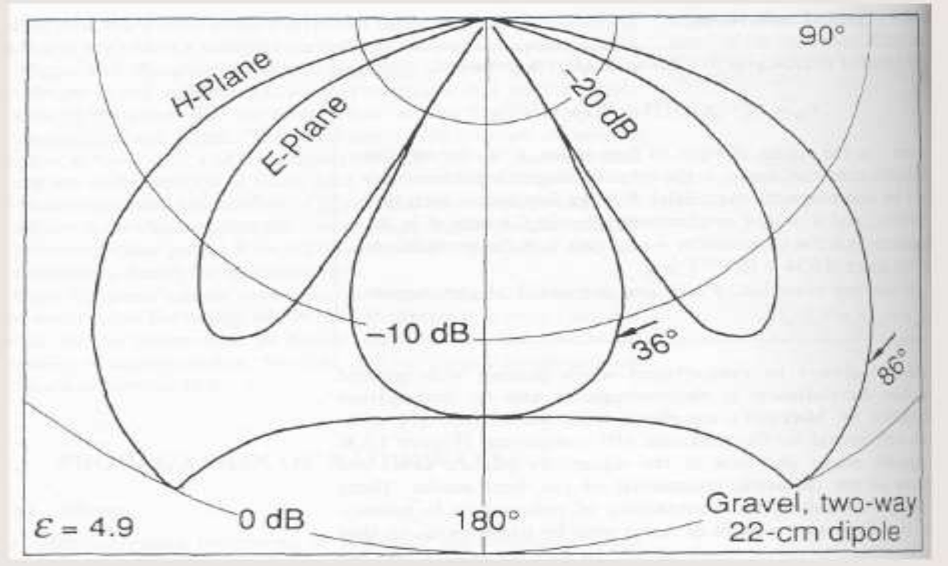
- Velocity: $$c=\frac{c_0}{\sqrt{\varepsilon\mu}}\approx\frac{c_0}{\sqrt{\varepsilon}}.$$
    - the fastest for the 'air' wave;
    - generally decreases with depth.
- Impedance: $$Z=\sqrt{\frac{\mu}{\varepsilon}}\approx\sqrt{\frac{1}{\varepsilon}}[Ohms].$$
- Amplitude reflection coefficient: $$R=\frac{Z_2-Z_1}{Z_2+Z_1}.$$
- Two-way travel times:
    - Air: 6 ns/m;
    - Unsaturated sand: 12-18 ns/m;
    - Saturated sand: 18-27 ns/m.



Geophysical survey

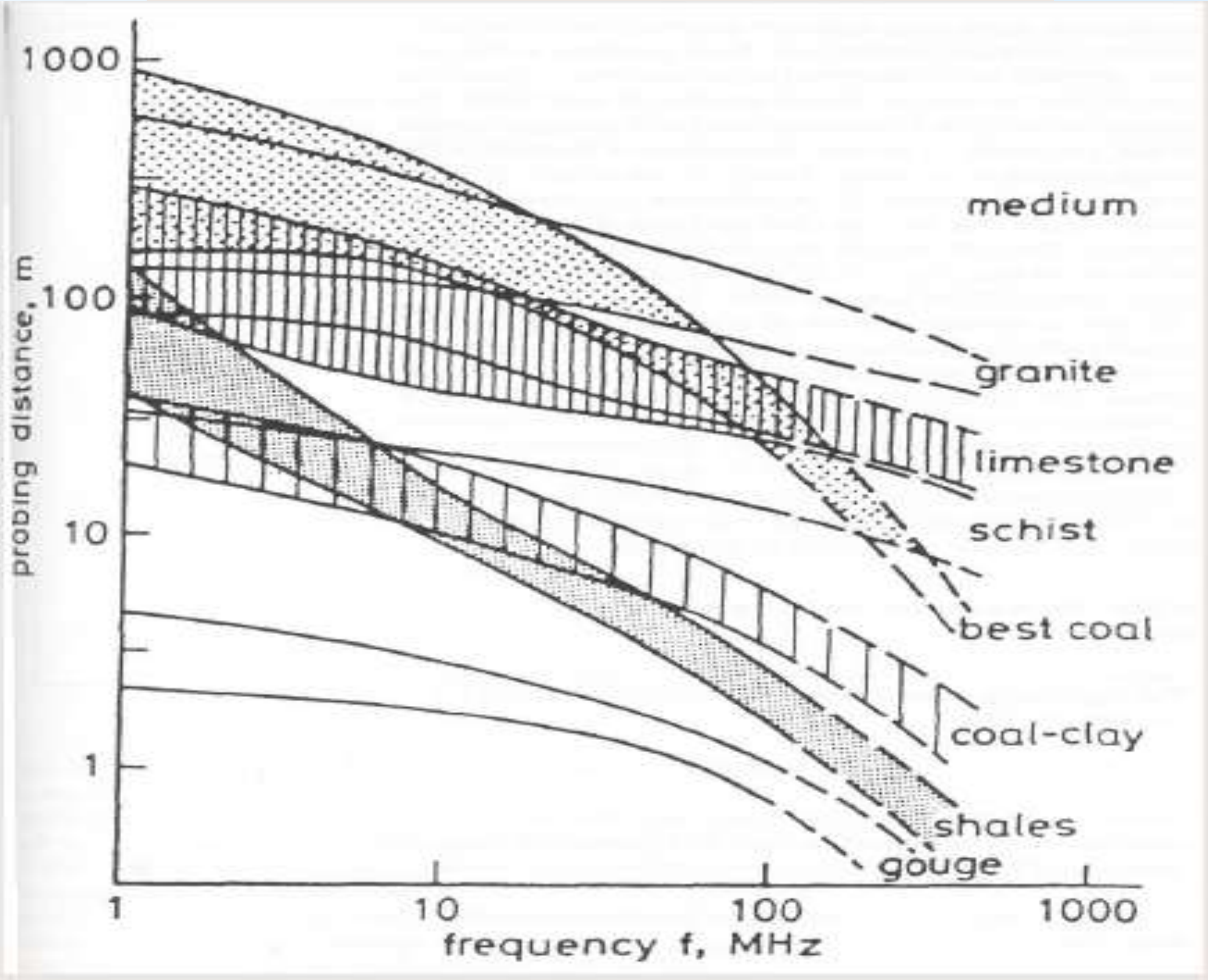
Antenna directivity patterns

- GPR antenna focuses energy in a beam directed downward;
- Receiver antenna has a similar sensitivity pattern.



Geophysical survey

Depth penetration of GPR waves



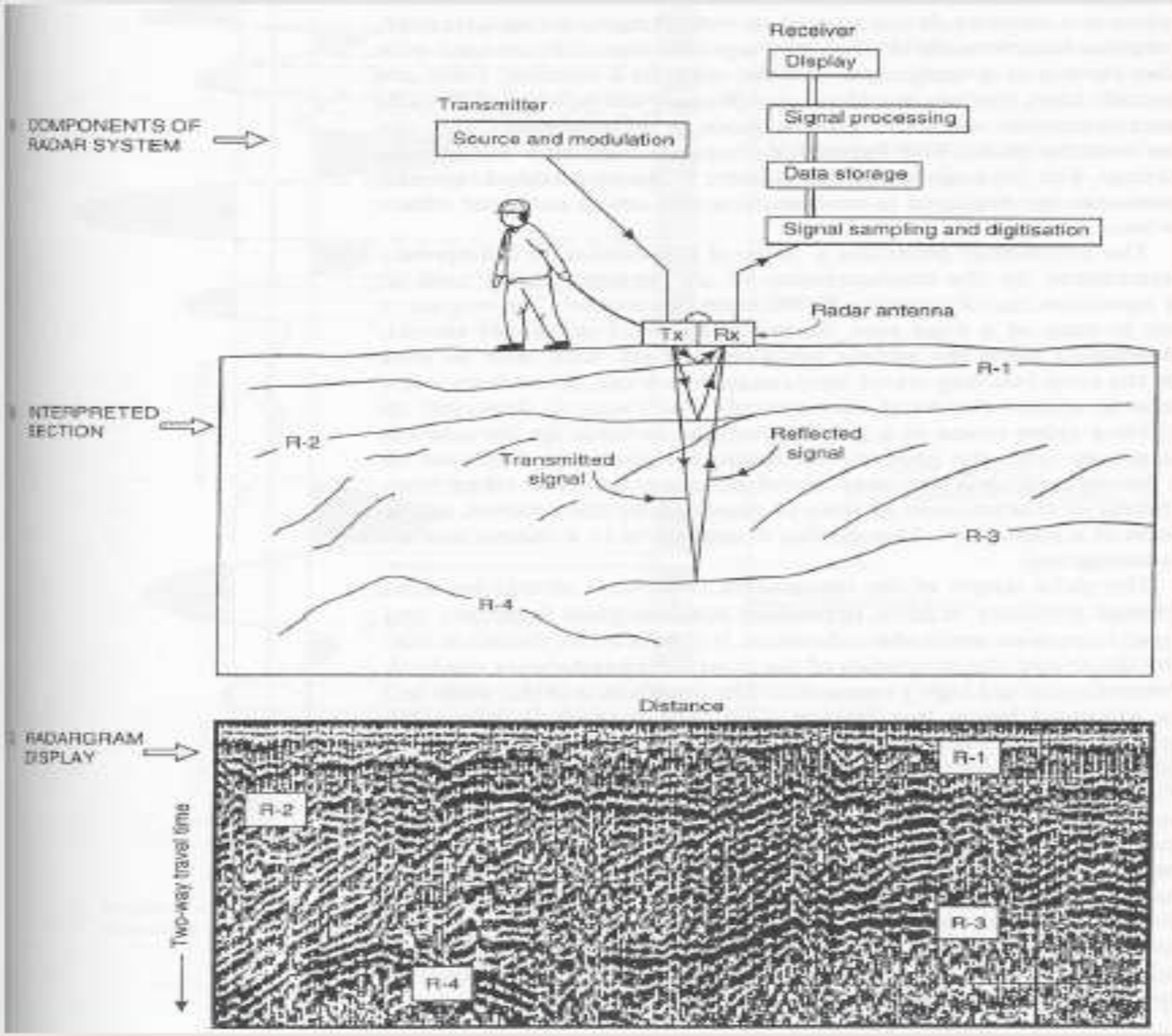
Geophysical survey

Relation to Reflection Seismics

- Similarities:
  - Processing procedures (filtering, stacking, migration);
  - Appearance of the zero-offset section;
  - Resolution-frequency relationships;
  - Interpretation techniques.
- Differences:
  - Nanoseconds (*ns*) instead of milliseconds (*ms*);
    - Sub-meter vertical resolution and ~10-100 m penetration.
  - Electrical properties instead of acoustic impedance;
    - Very sensitive to buried metallic objects.
  - Velocities decrease with depth
    - Rays bend *toward* the vertical;
    - Free-air arrival is the *fastest;*
    - Faster attenuation;
    - Large velocity contrasts.
  - Sub-meter resolution.

Thus, GPR is a a valuable complementary technique to shallow seismics.

Geophysical survey



Geophysical survey

Electrical methods:

DC resistivity soundings (also called vertical electrical soundings, VES) and electrical resistivity tomography(ERT)

C. Kneisel and C. Hauck, 2008

1.2 Measurement principles

Resistivity surveys are conducted by injecting a direct electrical current (I) into the ground via two current electrodes (A and B in Figure 1.1). The resulting voltage difference (ΔV) is measured at two potential electrodes (M and N). The overall purpose of resistivity measurements is to determine the subsurface resistivity distribution. From the current (I) and voltage difference values (ΔV) the resistivity ρ is calculated using

$$\rho_a = K\frac{\Delta V}{I}, \tag{1.1}$$

where K is a geometric factor that depends on the arrangement of the four electrodes. This calculated resistivity value is not the 'true' resistivity of the subsurface, but a so-called 'apparent resistivity' ρ_a, which equals the 'true' (or specific) resistivity only for a homogeneous subsurface. For heterogeneous

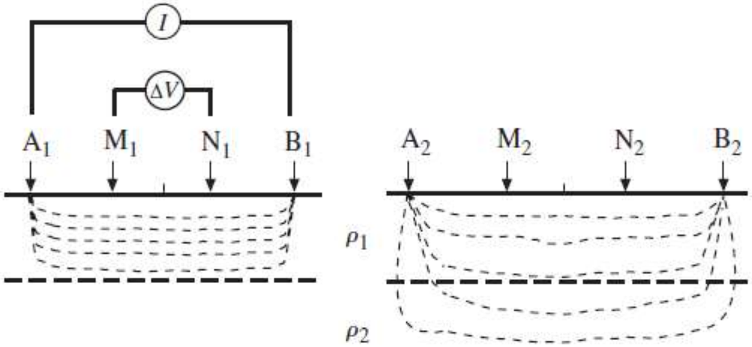


Figure 1.1. Conventional four-electrode configuration in resistivity surveys.

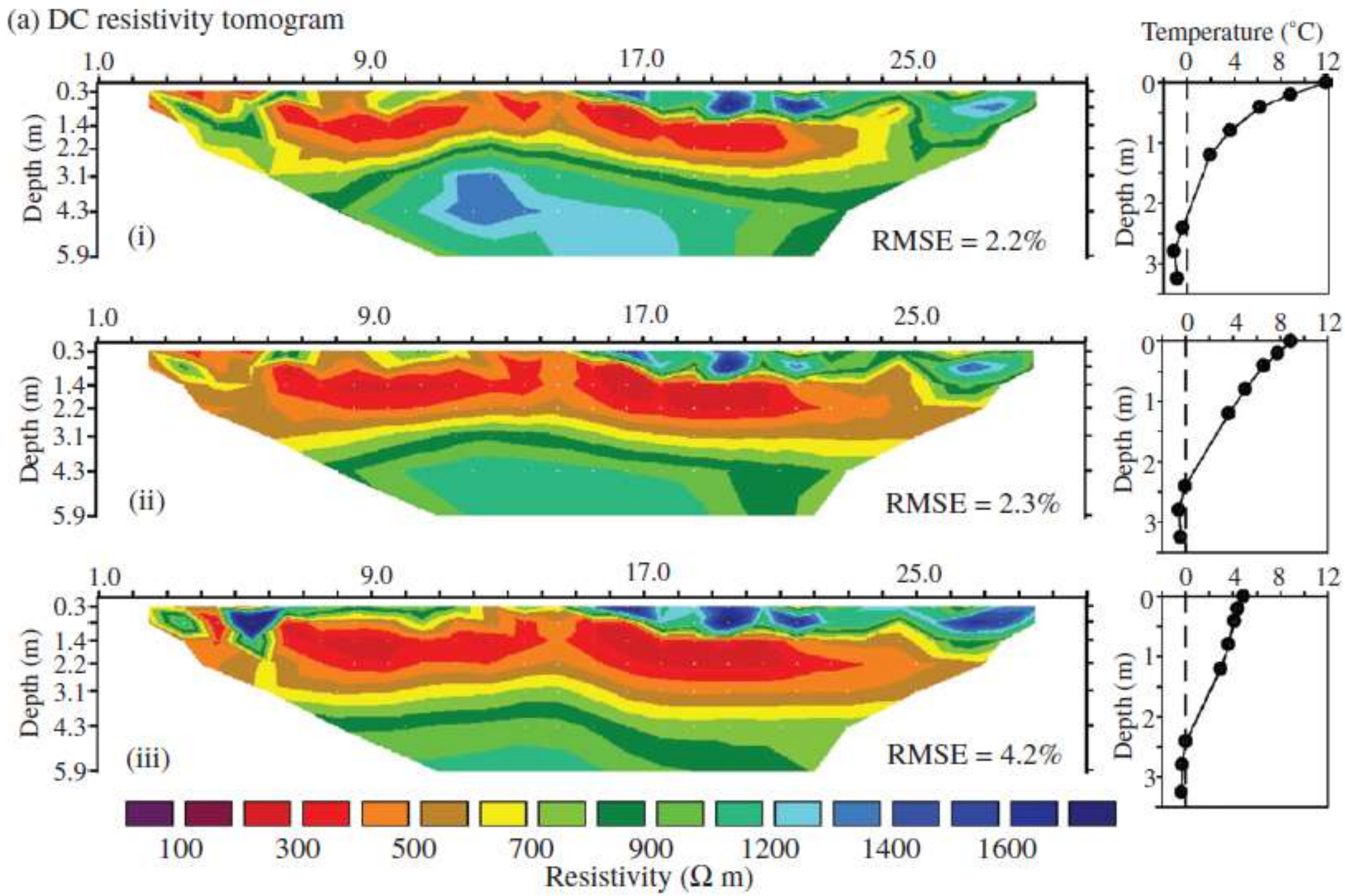


Plate 7 (Figure 6.5). Inversion results of ERT imaging at the permafrost-underlying talus slope, northeast Mongolia. (a) DC resistivity (Ω m) tomogram on (i) 1 July, (ii) 24 August and (iii) 20 September 2003. Daily means of ground temperatures on the respective days are also shown. Unit electrode spacing was 1m and total number of electrodes was 30. (b) Plots of anomaly index for two consecutive resistivity measurements, showing resistivity changes (i) between 1 July and 24 August, and (ii) between 24 August and 20 September 2003.

Geophysical survey

Checklist of the operation procedures

- Fieldwork should be thoroughly planned especially in remote high mountain areas, e.g. estimation of time available for the field measurements (efficiently using good weather conditions) and battery capacity.
- What is the minimum expected number of profiles/surveys?
- Is the equipment in working order, are the batteries charged?
- Always bring spare batteries if possible.
- Choose layout and electrode configuration according to estimated complexity of subsurface layering and ground resistance – compose and/or upload configuration files for the planned measurements.
- Perform contact resistance check for each electrode.
- In the case of rough surface conditions with high ground resistance, use water or sponges soaked with water attached to the electrodes to improve electrical contact – another possibility is to use additional electrodes in parallel.
- Is there any information on the expected subsurface conditions based on geomorphological and geological setting and interpretation?
- Is there any information about expected depth of layers?
- Is there any possibility of shallow layers that might not be resolved?
- Are there any other critical factors (air-filled voids, water flow at the electrodes etc.) influencing the current flow?
- Note electrodes that are badly coupled.
- Note topography for the following interpretation of the data.
- Make whenever possible or necessary for the scientific question cross-checks using complementary geophysical methods.
- Note location of the electrodes for possible repetition or time-lapse measurements (monitoring).
- After the survey: recharge batteries and save data.

Geophysical survey

Electromagnetic methods:
Electromagnetic techniques include frequency-domain EM systems (FEM), time-domain electromagnetic systems (TDEM), systems using
very low frequencies (VLF) and the so-called radiomagnetotelluric method
(RMT).

C. Kneisel and
C. Hauck, 2008

2.2.1 Measurement principle

Electromagnetic methods are based on electric currents that are induced in the earth by a time-varying current in a transmitter (Figure 2.1). The currents in the earth depend on the electrical conductivity distribution in the subsurface, and cause their own EM field called the secondary field, which superimposes on the primary field generated by the respective instrument transmitter. From the EM field measured by a receiver, the spatial distribution of electrical conductivity may be determined. As indicated in Figure 2.1, loops or coils are commonly used as transmitters or receivers. The confined body used in the sketch may be replaced by a conducting halfspace (a term used to describe the non-conducting air layer over a conducting earth), or any other conductivity distribution, in which case the current flow will be more complicated.

Depending on the time variation of the transmitter current, EM methods operate either in the frequency domain or in the time domain. Frequency-domain electromagnetic (FEM) methods use a sinusoidal current with a specific single frequency at a time. The signal observed at the receiving sensor, which has the

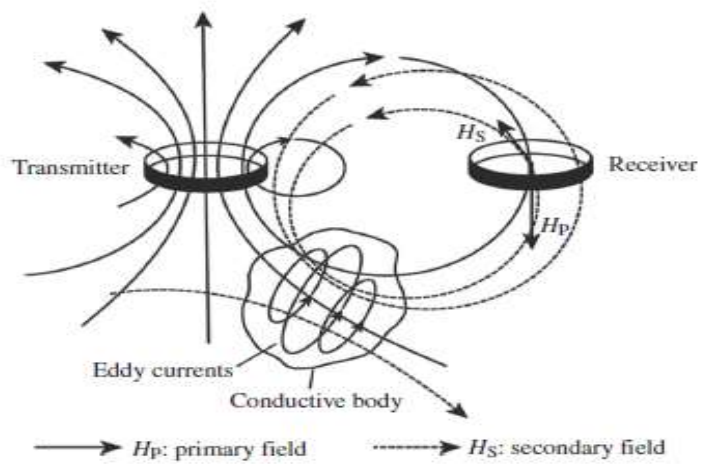


Figure 2.1. Principle of electromagnetic methods (after Militzer and Weber 1985). The varying magnetic field of the transmitter induces currents in the conductor. The induced currents have a secondary field that is superimposed on the primary field.

Geophysical survey

A. Hördt and C. Hauck

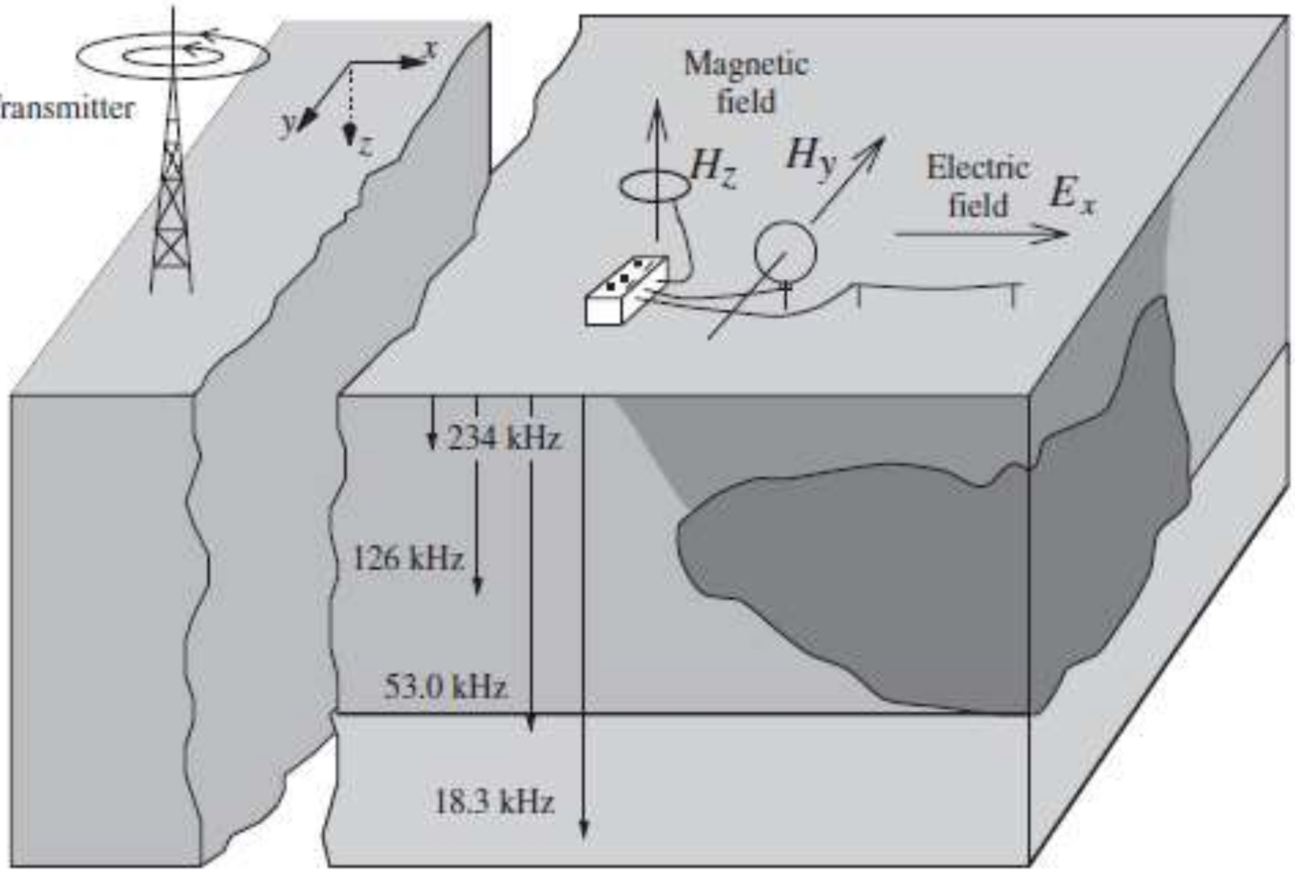


Figure 2.7. Schematic sketch of VLF and RMT methods (modified from Zacher *et al*. 1996). VLF measures the ratio of vertical to horizontal magnetic fields. VLF-R and RMT measure the ratio of horizontal electric and magnetic fields. RMT uses a broad frequency range, with penetration increasing with decreasing frequency.

Transient electromagnetic systems (TDEM)

GDP—32 II Multifunctional Receiver

Geophysical survey

Checklist of the operation procedures

Before starting a survey:

- Is the method used adequate to answer the scientific question?
- Are there any other useful complementary methods?
- What is the minimum expected number of profiles/soundings?
- What is the required line spacing for mapping surveys and how does this relate to the spatial extent of expected anomalies? What is the expected time required for the planned survey?
- Is there any information on the expected subsurface condition based on geomorphological and geological setting and interpretation?
- Is there any information about expected depth of anomalies?
- Is there any possibility of hidden metallic objects, cables etc.?
- Are there any other critical factors (power lines, other EM noise, surface heterogeneities, water, snow etc.) influencing the EM signal?
- Can the weather conditions influence the EM instrument outputs (temperature/radiation changes)?

During the survey:

- Mark carefully the edges of the survey grid and the locations of the proposed survey line (for FEM mapping).
- Conduct a drift experiment for EM instruments.
- TEM soundings: stack individual sounding curves as appropriate.
- Make backup copies of output data at regular intervals.

After the survey:

- Use postprocessing software that offers different inversion tools (e.g. smooth inversion *and* layered inversion).
- Make (whenever possible) cross-checks using complementary geophysical methods.
- Try to avoid the misinterpretation of critical data sets and repeat the survey if necessary.

Geophysical survey

Refraction seismics

There are two types of seismic waves that travel through the ground. While *longitudinal* or *primary (P-) waves* are characterised by deformation parallel to direction of wave propagation, the particle motion of *transverse* or *secondary (S-) waves* takes place at a right angle to the direction of wave propagation. Based on the different types of deformations the proportionality constant between strain and stress varies. In the case of P-waves the elongational modulus j is appropriate and for S-waves the shear modulus μ.

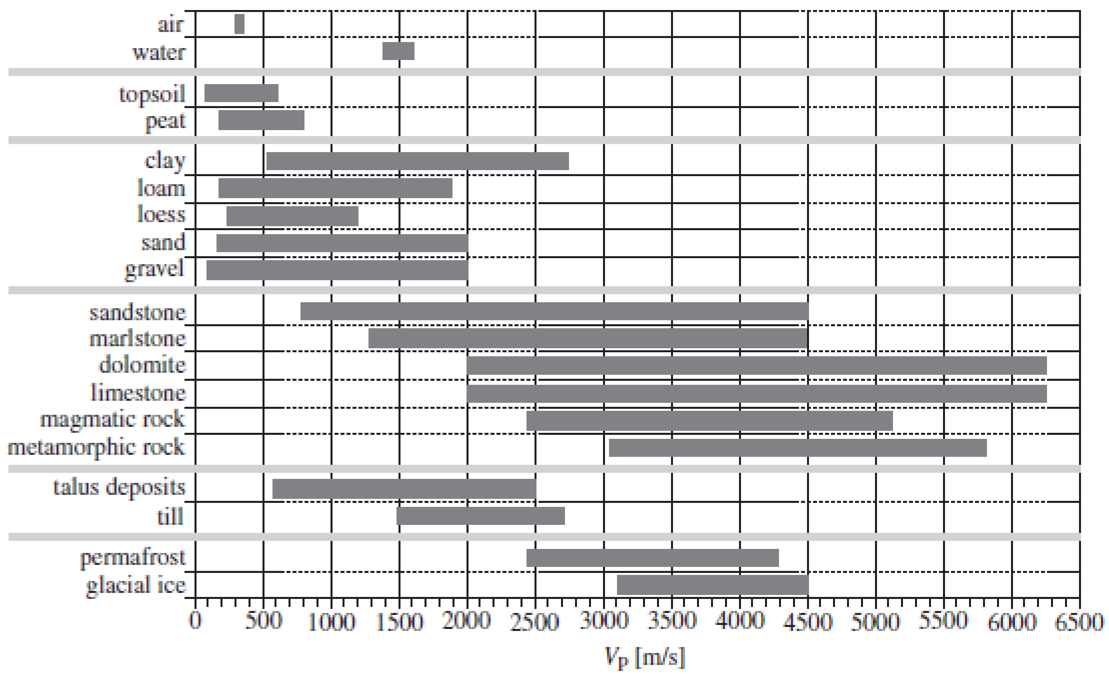
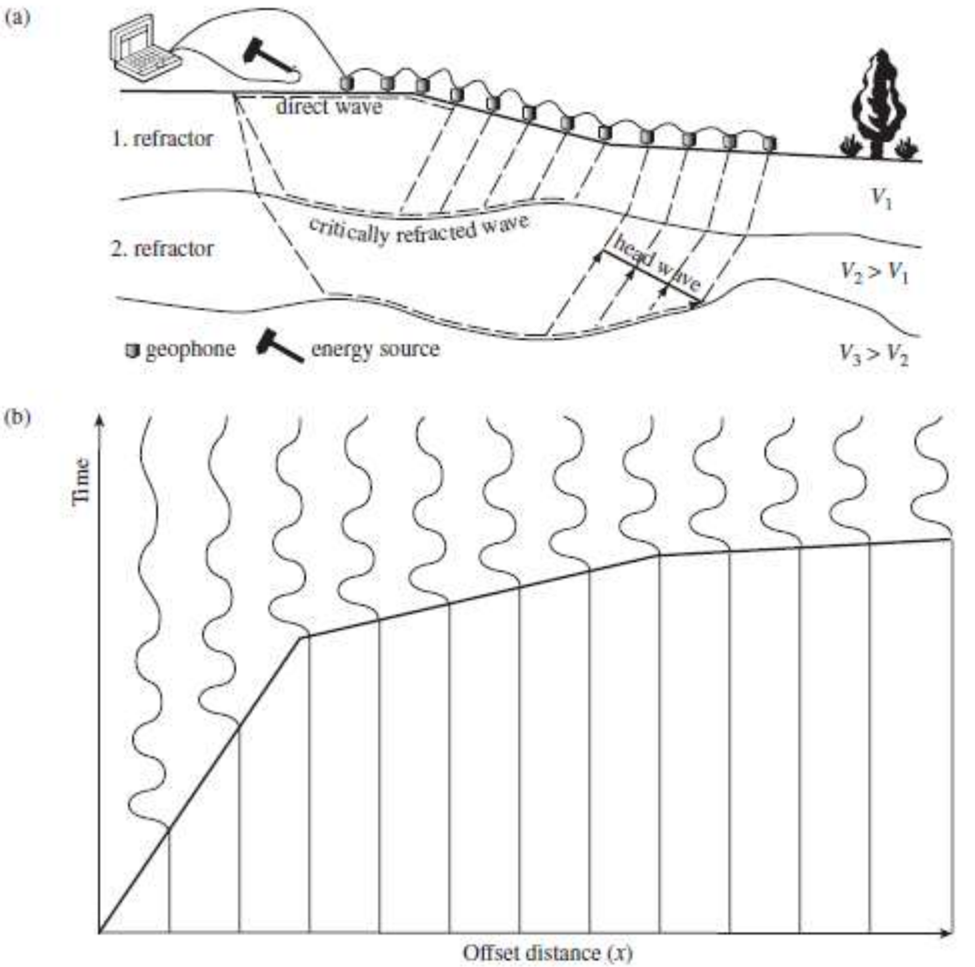


Figure 3.1. Ranges of P-wave velocities of rocks and sediments common in high mountainous terrain (modified after Hecht 2000).

Geophysical survey

3 *Refraction seismics*



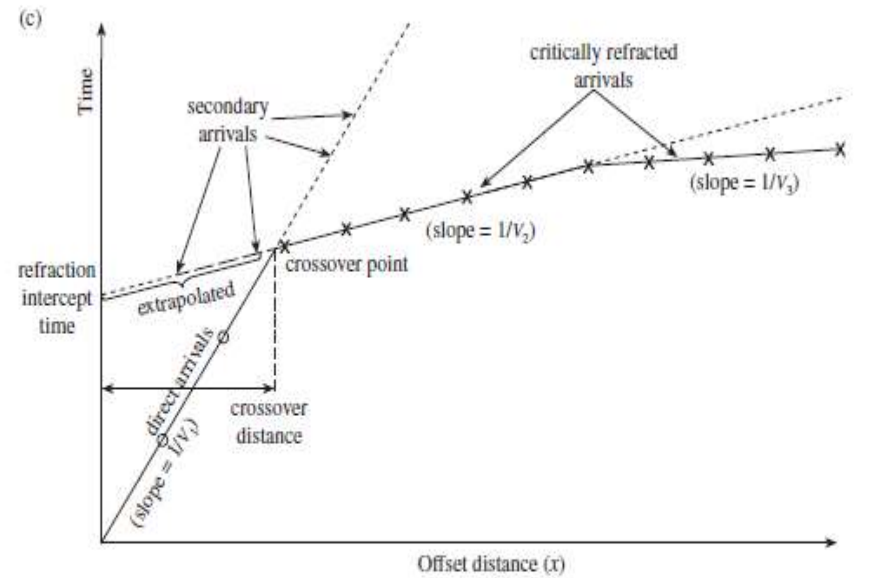


Figure 3.2. (a) Design of a seismic survey and simplified raypath geometry in a layered subsurface with three layers. (b) Corresponding seismogram resulting from a forward shot close to the first geophone. (c) Time–distance plot of traveltimes of the first arrivals extracted from the seismogram above.

Limitations on detecting subsurface layers based on seismic refraction are caused by the following problems:

(i) velocity inversion with depth,
(ii) lack of velocity contrast,
(iii) the existence of thin beds, and
(iv) inappropriate geophone spacing.

L. Schrott and T. Hoffmann, 2008

Geophysical survey

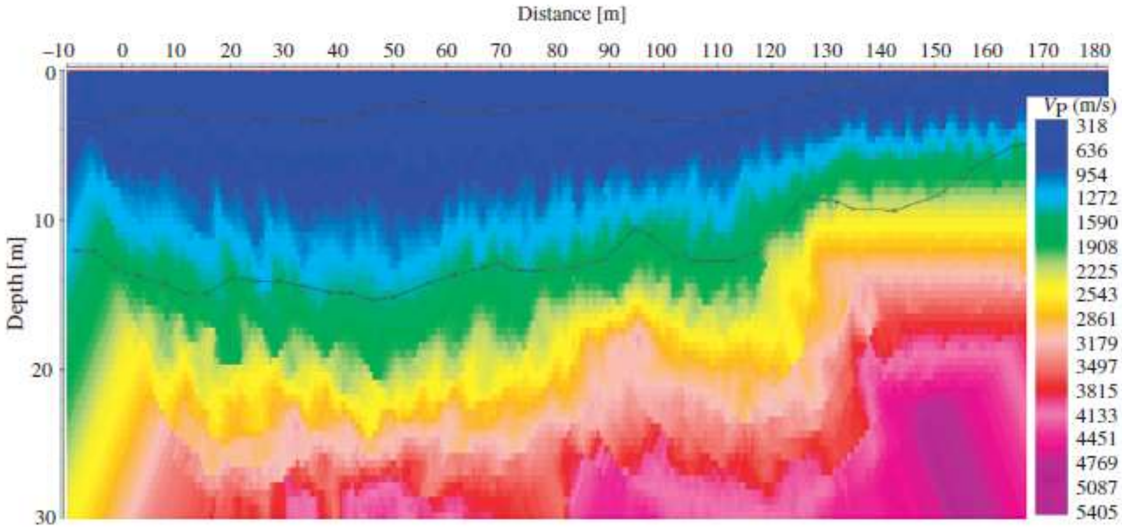


Plate 4 (Figure 3.9). Tomography model of traveltimes measured on a rectilinear slope in the Turtmann Valley, Swiss Alps (traveltimes are shown in Figure 3.6b).

Geophysical survey

Checklist of the operation procedures

L. Schrott and T. Hoffmann, 2008

Before starting a survey:

- Is the method used adequate to answer the scientific question?
- Are there any other useful complementary methods?
- What is the minimum expected number of profiles/surveys?
- Is there any information on the expected subsurface condition based on geomorphological and geological setting and interpretation?
- Is there any information about expected depth of refractors?
- Is there any possibility of hidden layers?
- Are there any other critical factors (groundwater, hollows etc.) influencing the seismic signal?

During the survey:

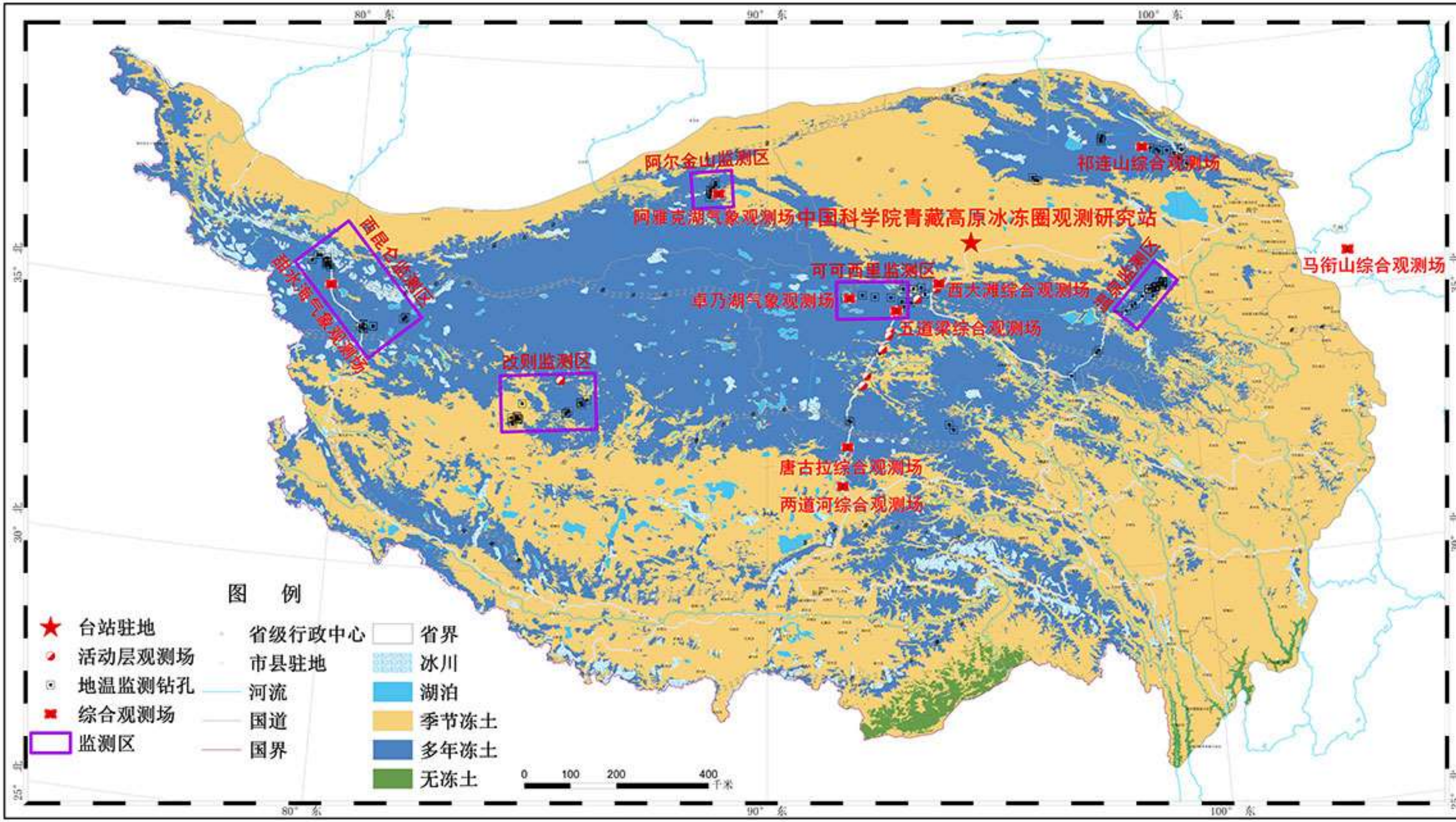
- Check carefully the coupling of each geophone.
- Check carefully (visually) any shot and repeat single shots if necessary.
- If a sledgehammer is used as an impact source, stack several shots (at least 3–5) to improve the signal-to-noise ratio.
- Check if the total spread and the geophone distance are appropriate in terms of resolution and/or possible depth of the lowermost refractor. Change the geophone distance if necessary.
- Make hard copies (printouts) of seismograms.

After the survey:

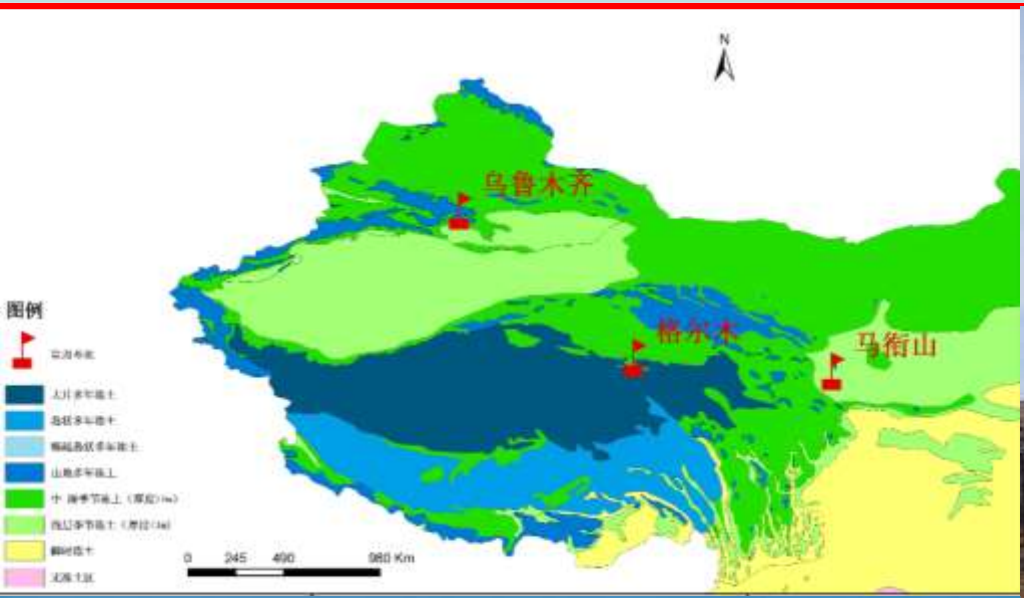
- Discuss your results carefully with experienced geomorphologists and geophysicists before drawing major conclusions.
- Use postprocessing software that offers different interpretation tools (e.g. Reflex).
- Make (whenever possible) cross-checks using complementary geophysical methods.
- Try to avoid the misinterpretation of critical data sets and repeat the survey if necessary.

3、Some cases on permafrost monitoring in the Qinghai-Tibet Plateau and Mongolian Plateau

Permafrost monitoring network on the QTP



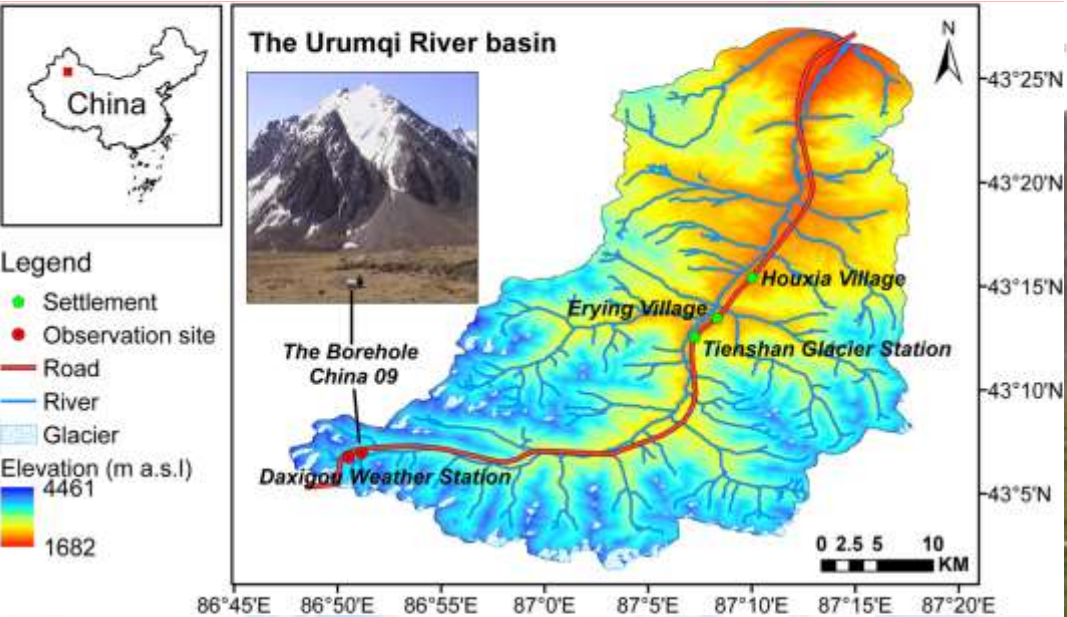
Permafrost observation in the northeast of QTP



Maxianshan site（2009 to present）

- AWS
- Boreholes
- Active layer observation sites
- Vegetation sampling sites

Permafrost observations in the Tienshan Mts.



Urumqi River site（1997 to present）

——AWS

——Boreholes

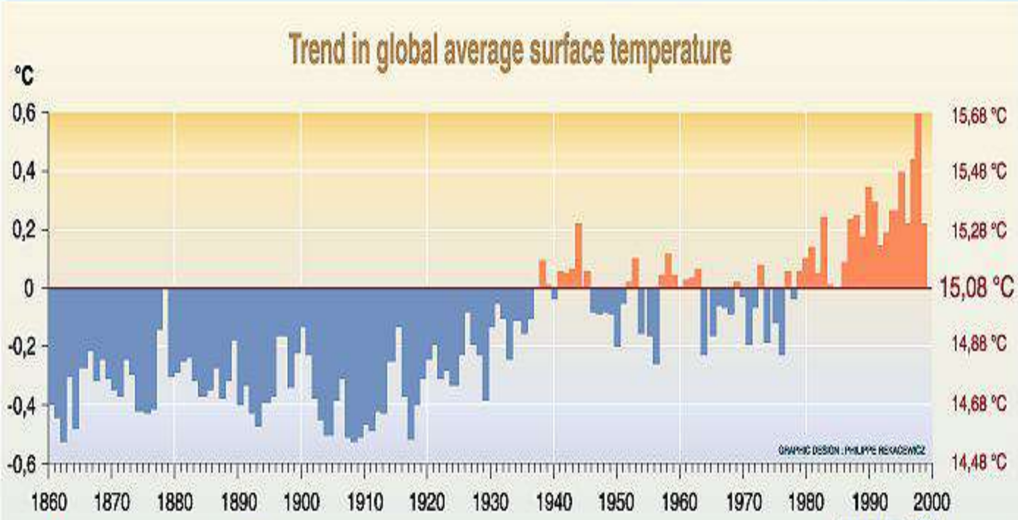
——Active layer observation site

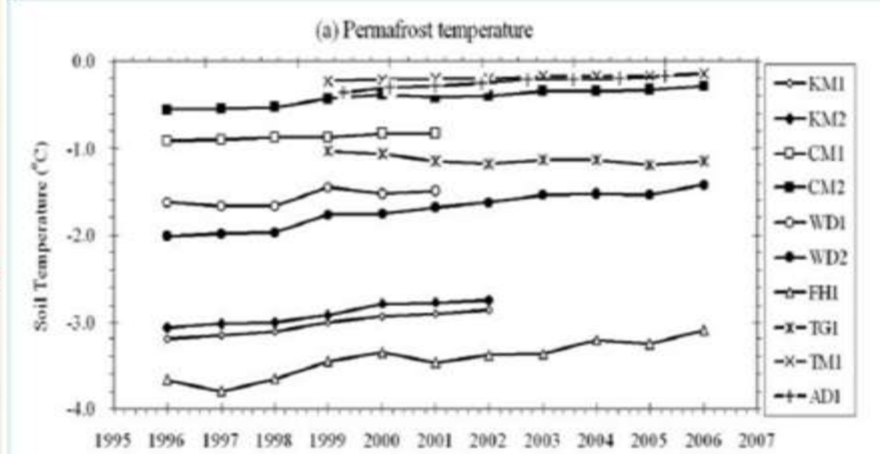
• Permafrost monitoring network on the QTP

Main Equipments

No.	Apparatus	Set	Contents
1	AWS	7	Regular meteorological factors
2	Eddy covariance system	3	CO_2、heat and moisture flux
3	Boreholes with datalogger	16	Ground temperatures
4	Active layer observation system	18	Soil temperature and moisture
5	Mala-Ramac GPR	1	Permafrost table
6	GDP-32	1	Thickness of ice

The impacts of climatic warming in the northern limit of permafrost regions on the QTP





Wu and Zhang, 2008, JGR

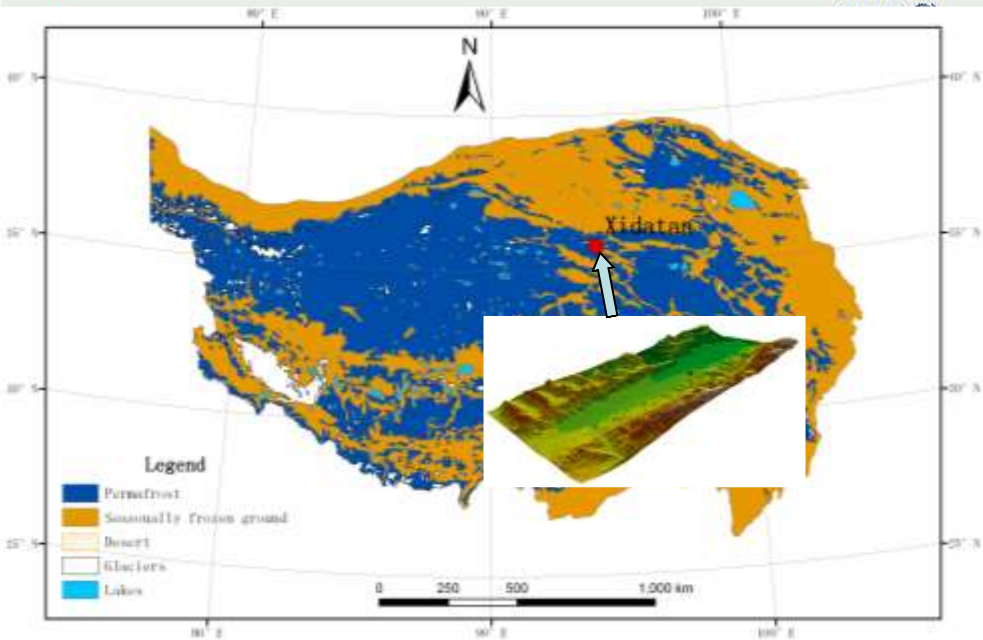
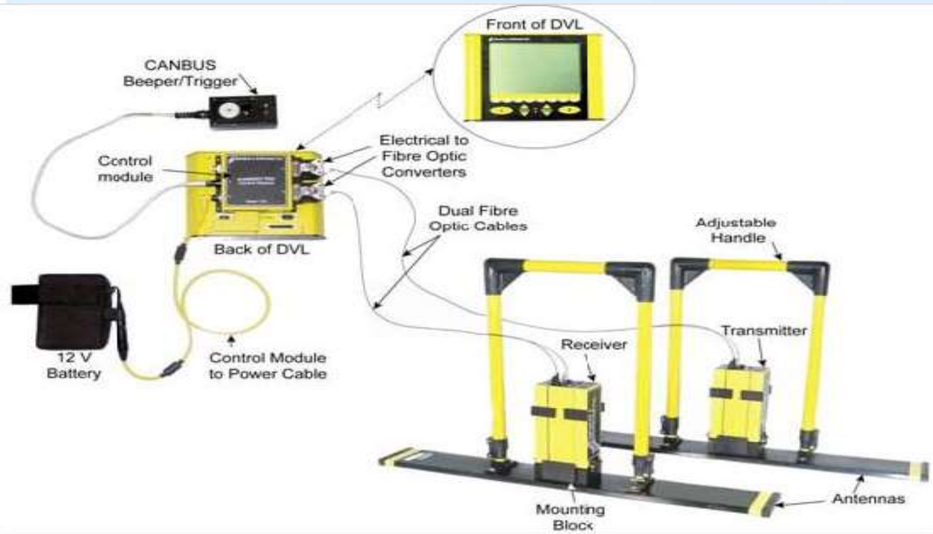
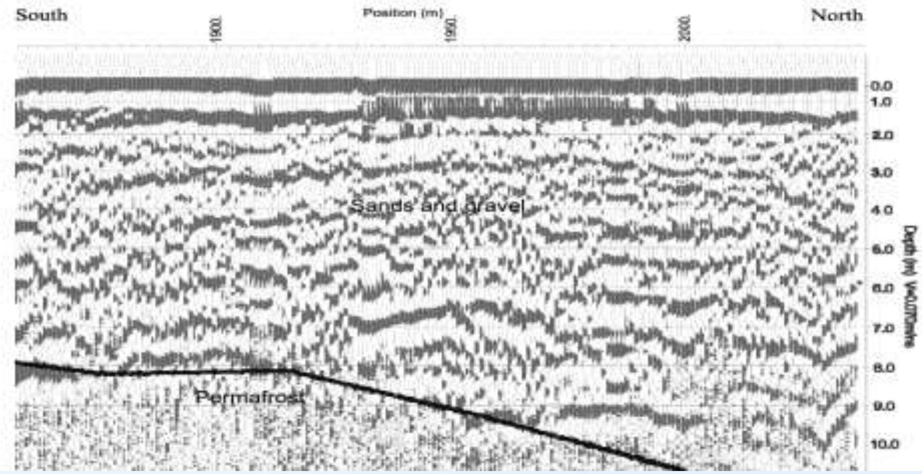
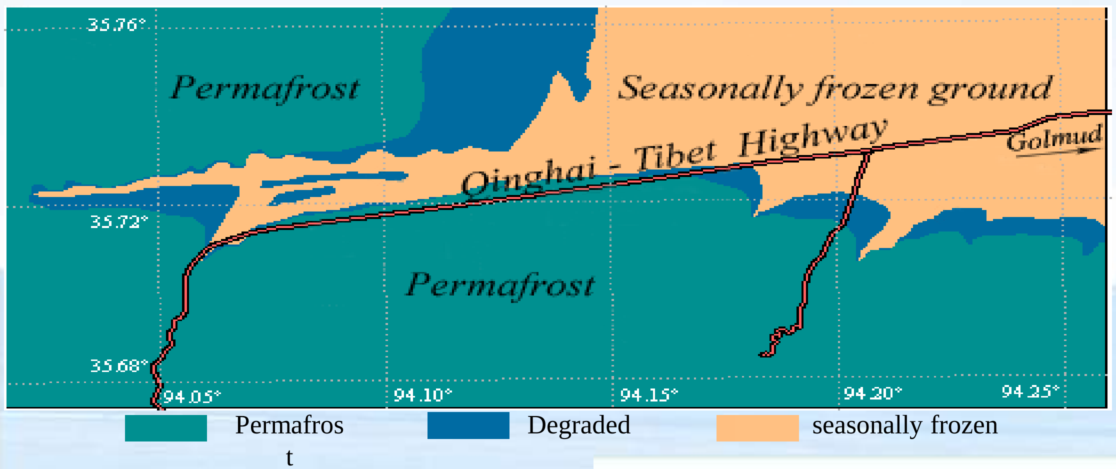


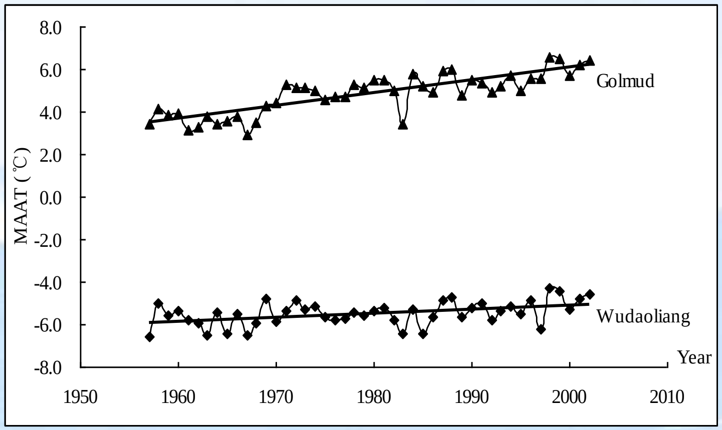
表 2-5　上世纪 60-90 年代以来高原多年冻土下界的升高幅度(引自 Zhao, et al, 2000）

地区	西大滩	安多南山	橡皮山	拉脊山	河卡南山	玛多	西门错北	祁连山
60 年代的冻土下界(masl.)	4300	4640	3700	3700	3840	4220	4070	3420
90 年代的冻土下界(m a.s.l.)	4350	4680	3780	3760	3900	4270	4140	3500
升高值 (m)	25	40	80	60	60	50	70	80









The GPR has been applied to identify the permafrost degradation at the boundary regions of permafrost in Northern QTP (Wu et al., 2005)。

measurements indicate that the lowermost occurrences of permafrost on the Tibetan Plateau have moved up by 25 m in the north during the last 30 years and between 50 and 80 m in the south over the last 20 years. Furthermore, the thickness of the active layer has increased by 0.15 to 0.50 m and ground temperature at a depth of 6 m has risen by about 0.1 °C to 0.3 °C between 1996 and 2001 (Cheng and Wu, 2007). Permafrost temperature monitoring in 10 boreholes up to 10.7 m depth was conducted every 2 weeks during the 1996–2006 period along the Qinghai–Tibetan Highway. The primary results show that the long-term mean annual permafrost temperatures at 6.0 m depth vary from −0.19 °C at the Touerjiu Mountains site to −3.43 °C at Fenghuo Mountain, with an average of about −1.55 °C from all 10 sites over the period of their records, confirming that permafrost is relatively warm on the Plateau (Wu and Zhang, 2008).

Ground-penetrating radar (GPR) technology has been used recently on the Tibetan Plateau to detect permafrost degradation. Wu et al. (2005b) used 50-MHz GPR to delimit the extent of permafrost in the Xidatan region (35.7 N, 94.2 E), at the northern margin of sporadic permafrost on the Plateau. The lower altitudinal extent of permafrost was interpreted from nine radar profiles. The locations of the permafrost table along the nine profiles facilitated determination of a characteristic altitudinal permafrost "limit," and assessment of permafrost distribution in the study area. Comparison of these results with those from permafrost surveys conducted in

Drilling

Sampling soil cores

Measuring temperature

GPR investigation

GDP investigation

Sampling soil carbon

Sampling soil moisture

Sampling granularity

Isotope soil samples

Sampling snow

Sampling surface water

Sampling ground ice

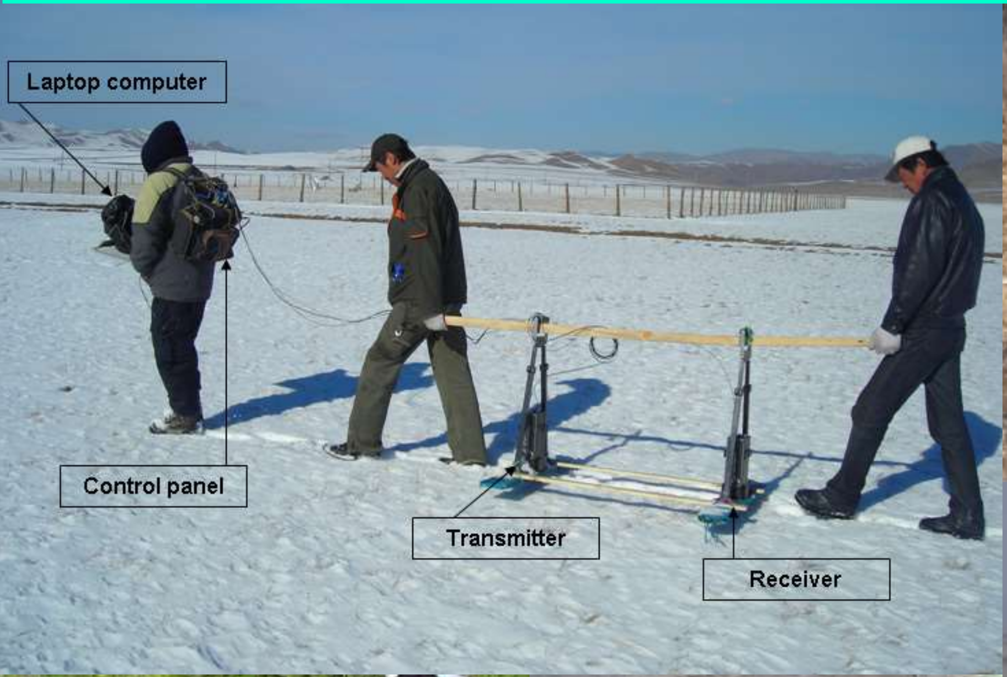

GPR
2012-08-17


GDP


Soil profiling

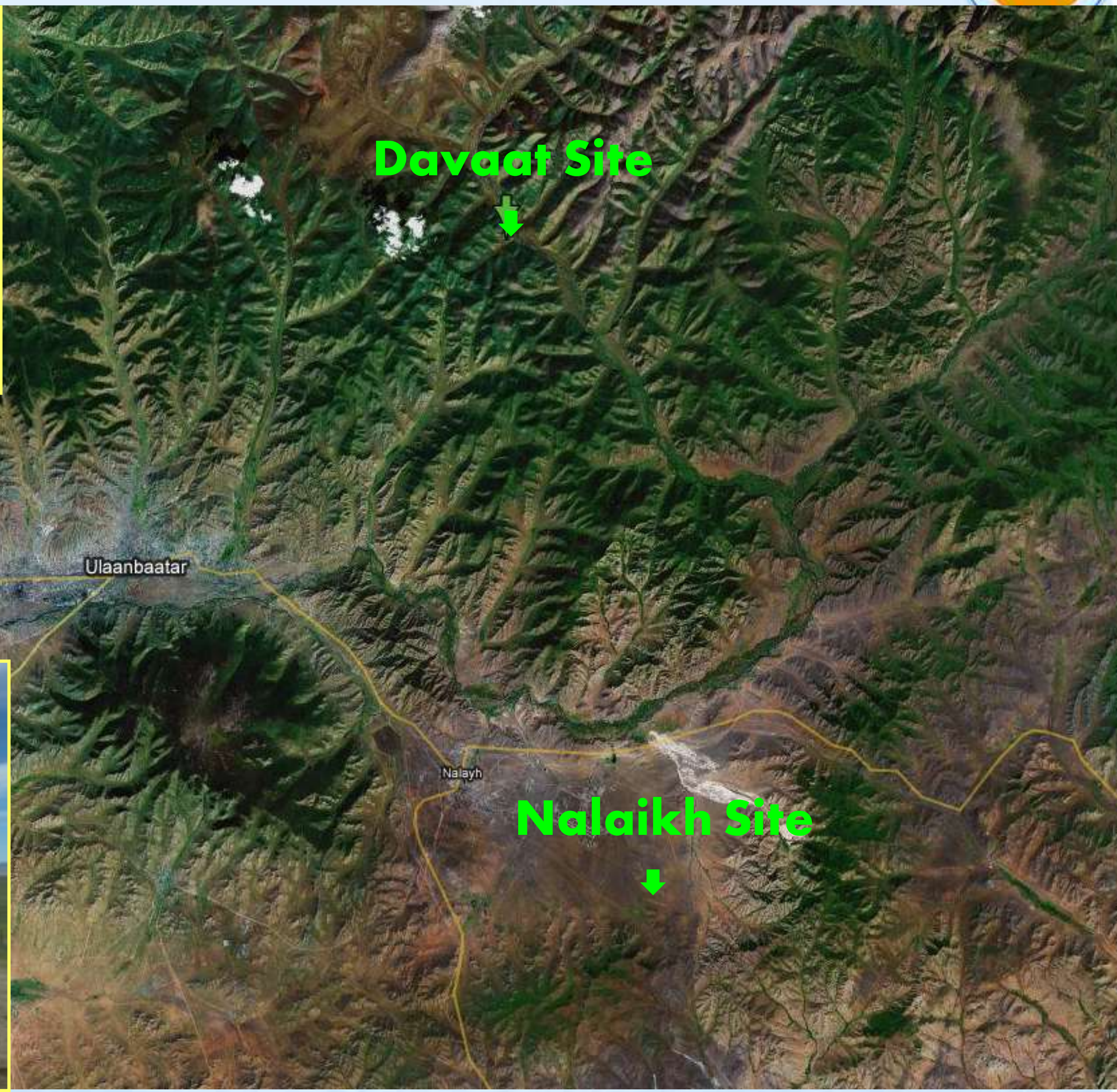

Investigating of vegetation

Permafrost monitoring network on the QTP



We conducted a GPR survey for mapping the permafrost distribution in Davaat Valley and to detect the permafrost in Nalaikh plain in October of 2006.

In order to calibrate the estimation result, two stations have been established in Mongolia for monitoring permafrost changes.



2006.8 Site determination

2006.10 GPR investigation

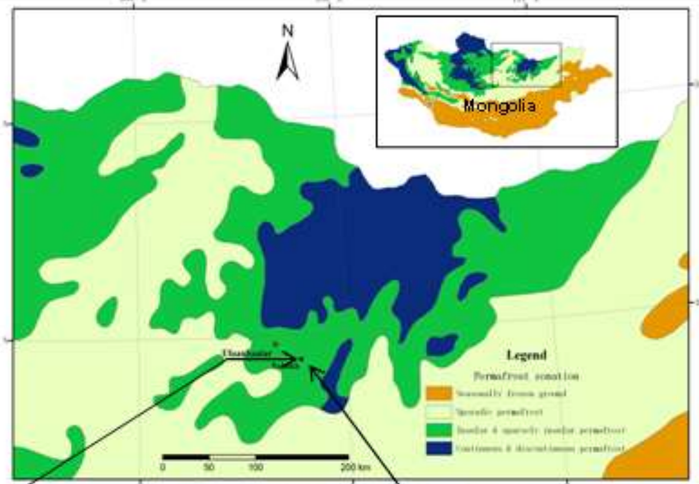
2007.6 Establishment of Davaat site

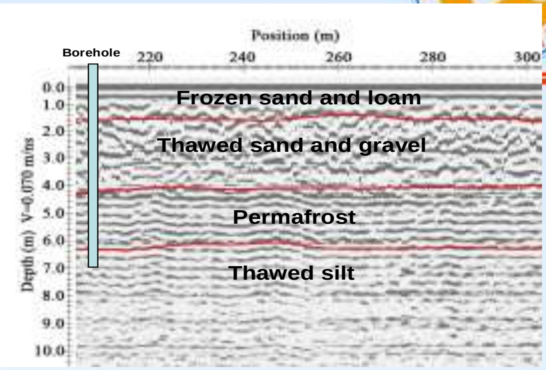
2008.8 Establishment of Nalaikh site

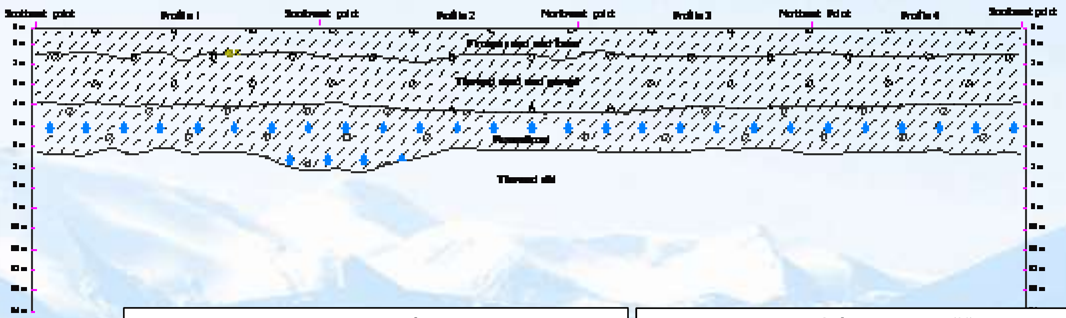
2009.6 Geophysical investigation near Ulaanbaatar

2010.8 Installation of sensors

Permafrost investigation at the Nalaikh AWS site

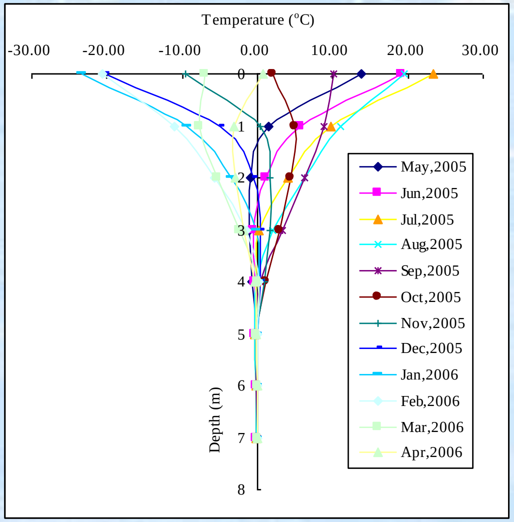


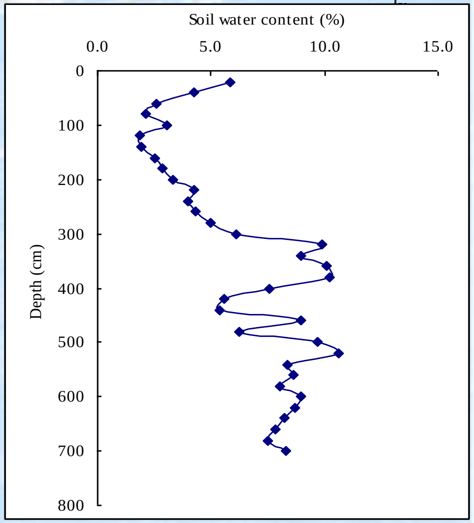




The GPR interpretation results indicated that the permafrost table was located at a depth of 3.8 m to 4.1 m and that the permafrost base at a depth of 6.0 m to 6.8 m in the Nalaikh site. The discontinuous permafrost in the study site was of a small thickness and undergoing severe degradation.

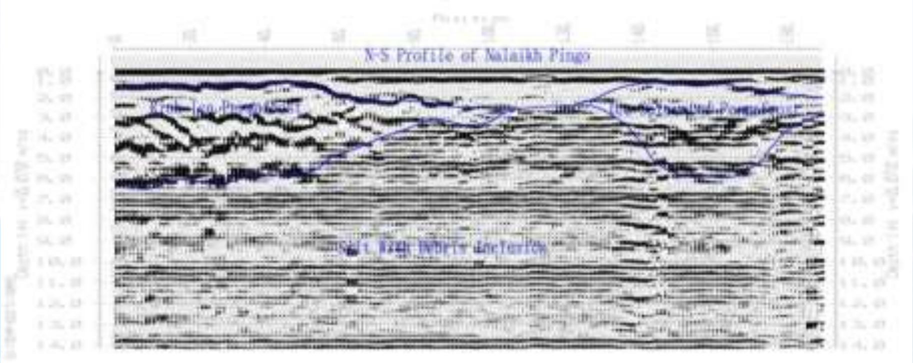
(Wu et al., 2009)

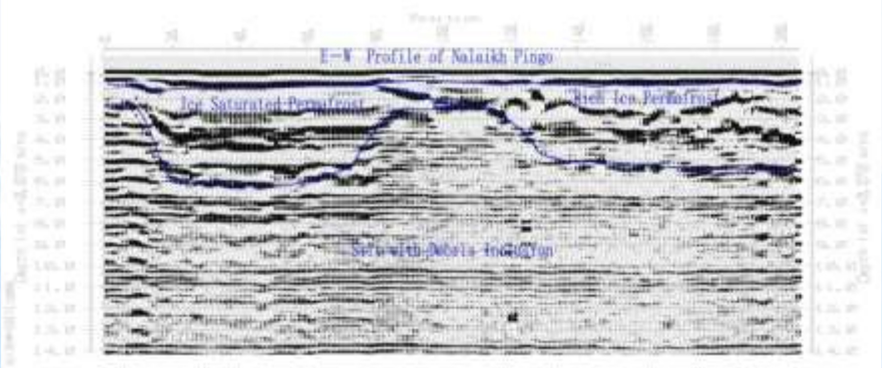




The corroboration of GPR results

GPR investigation at the Nalaikh pingo

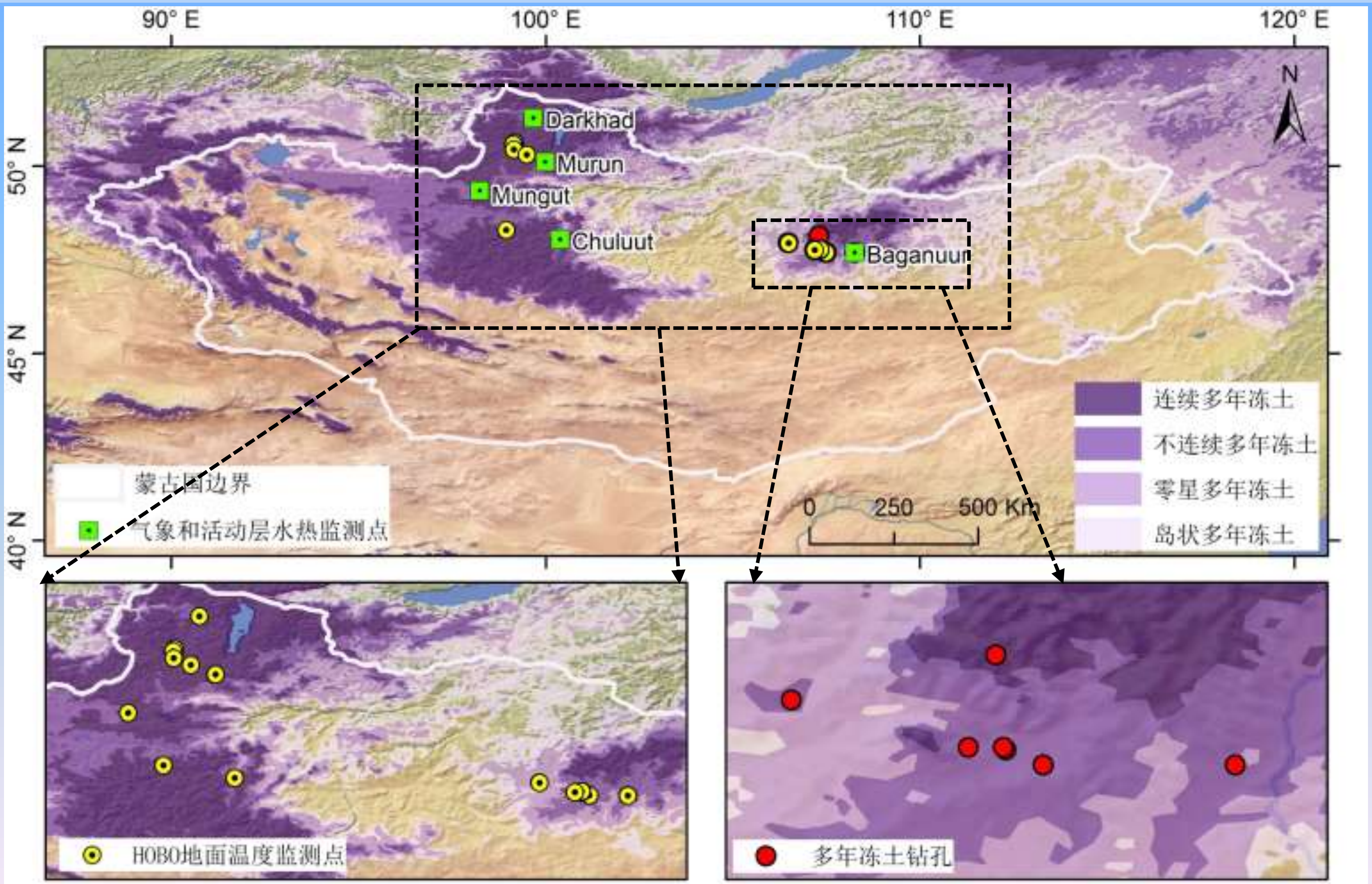




The GPR investigation at the Nalaikh pingo indicated that the active layer thickness was 1.5 m in depth and ground ice was 4 m~6 m in thickness. Compared to the results of previous studies at this site, the active layer thickness has increased 10~15 cm and the thickness of massive ground ice has decreased 1~2 m during the last 8 years. The ground ice is in severe degradation which leads to apparent lowering of lake water level because of the disappearance of permafrost as an aquifuge(非透水層).

Permafrost monitoring network on the QTP

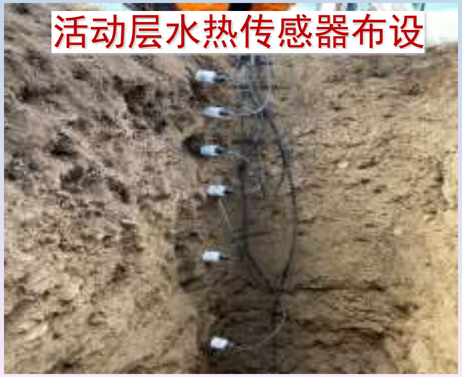
- Five AWS and ALT monitoring sites has been set up in 2023 in Henti and Hangai Mts..



The established permafrost monitoring sites in Mongolia in 2023

Permafrost monitoring network on the QTP

Elements	Parameters
Meteorological factors	Ta, Precipitation, Wind speed and direction, Relative humidity, Air pressure, Radiation
Ground surface temperature	HOBO temperature sensors at 5 cm below ground surface
Active layer thickness	Soil temperature, moisture, themal conductivity
Permafrost temperatures	Permafrost temperature （10～60m boreholes）



Thanks！

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