Cryospheric Science: present and the future

1921

2007

2023

(NIEER)

(http://www.weather.com.cn/climate/qhbhyw/12/1570550.shtml?p=3)

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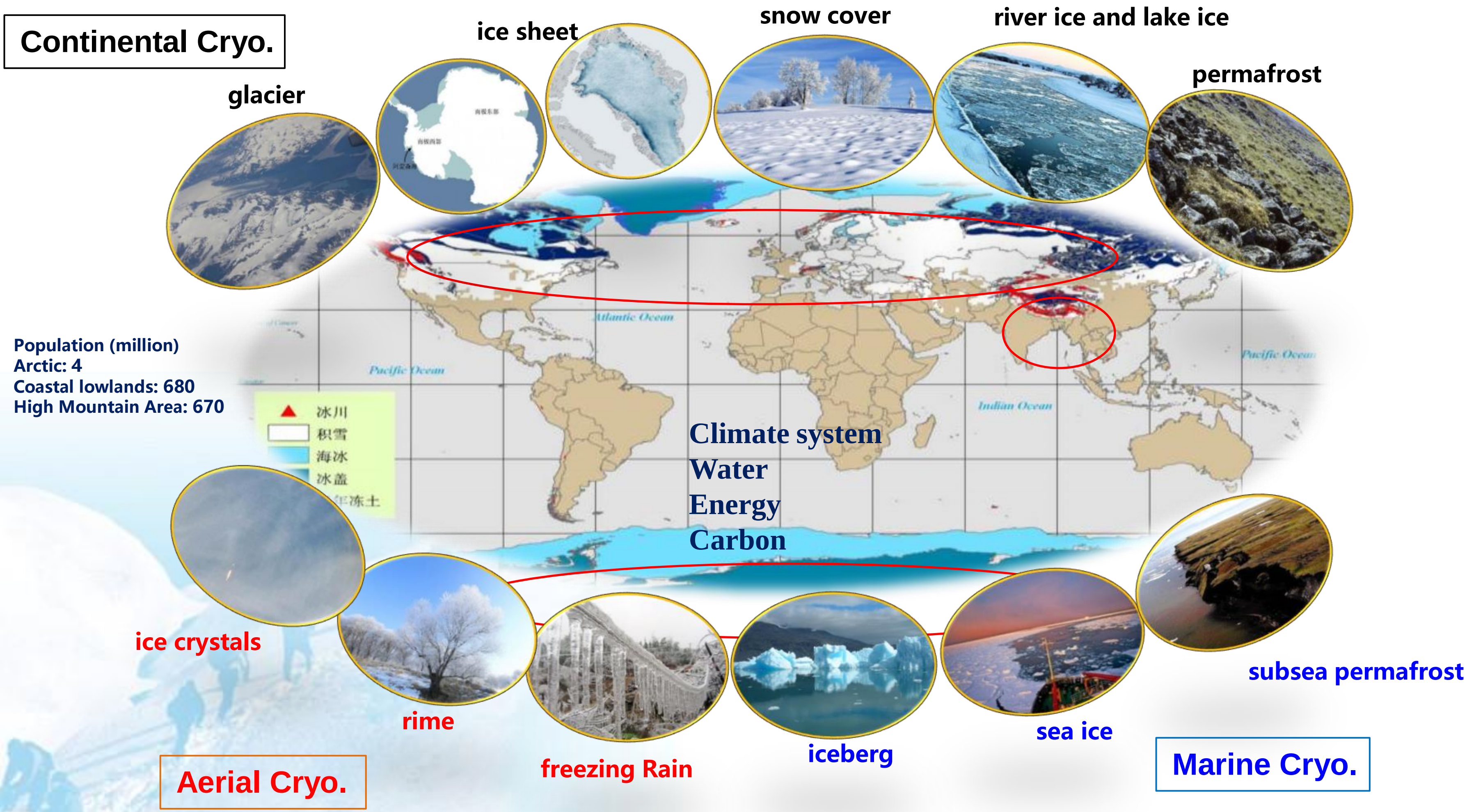
Outline

SKLCS

- Development of Cryospheric Science
- Climate Change Drives the Development of Cryospheric Science
- The Earth System Promotes Cryospheric Science

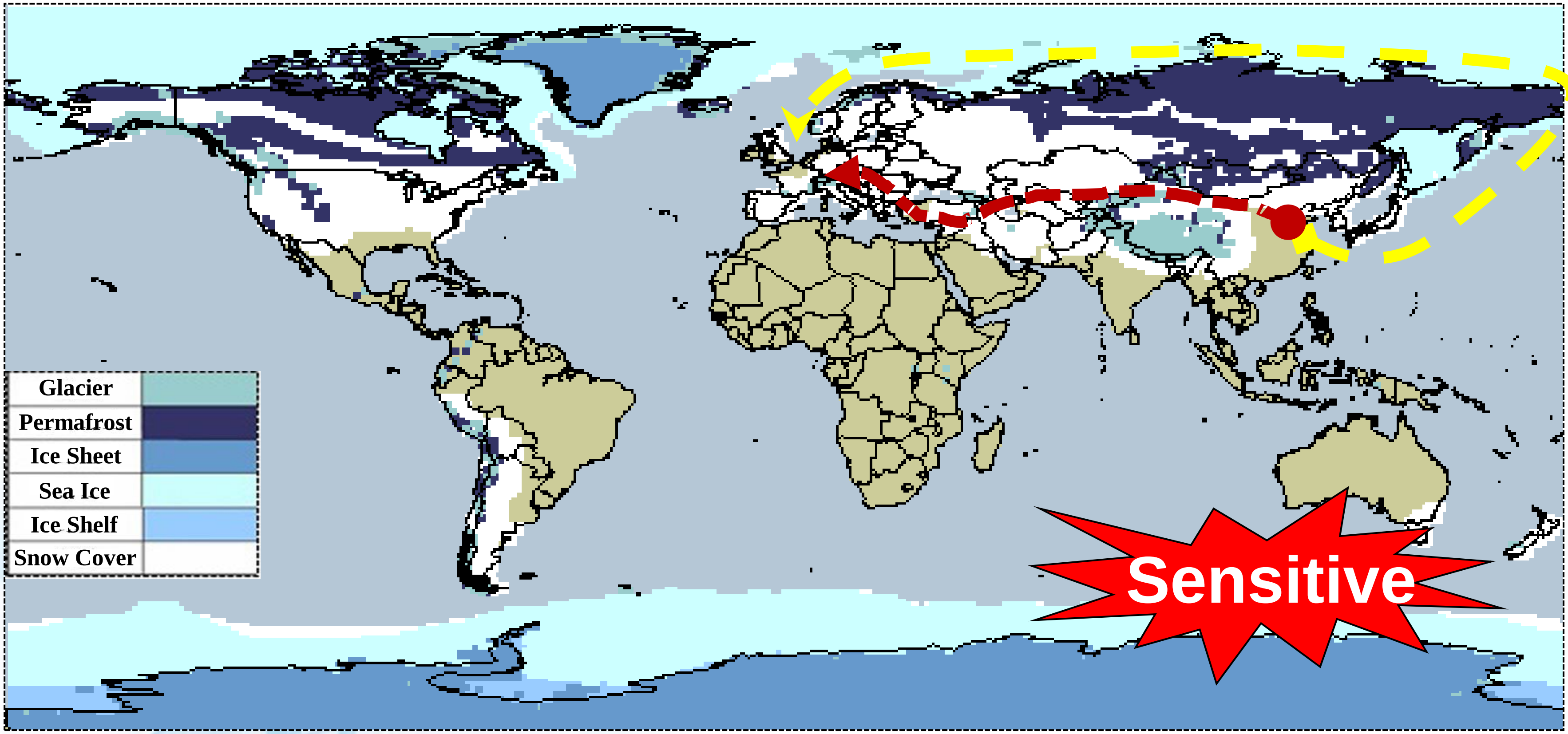
Cryosphere

The frozen parts of the planet, are subject to temperatures below 0°C for at least part of the year



Cryosphere

Spatial distribution

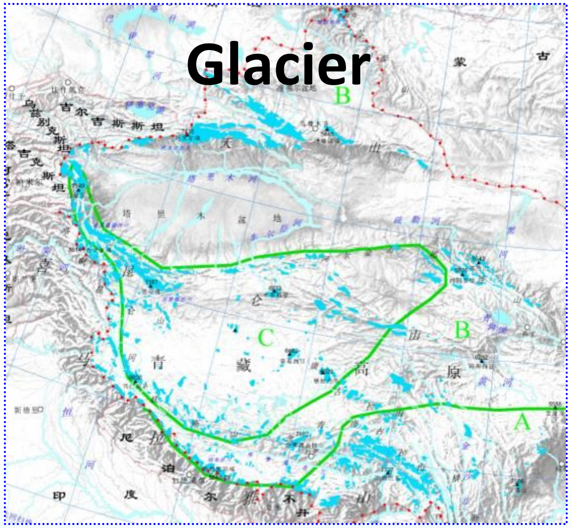


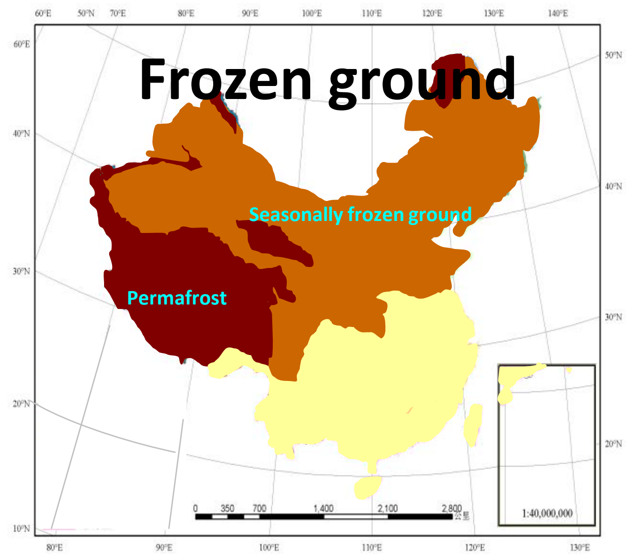
- **Glacier** (Antarctic Ice Sheet, Greenland Ice Sheet and Ice cap): 10% of the land area
- **Frozen soil** (Seasonally frozen soil and Permafrost): 2/3 and 1/4 of the land area
- **Snow cover**: 30% of the land area in January
- **Sea ice**: 7% of the ocean area

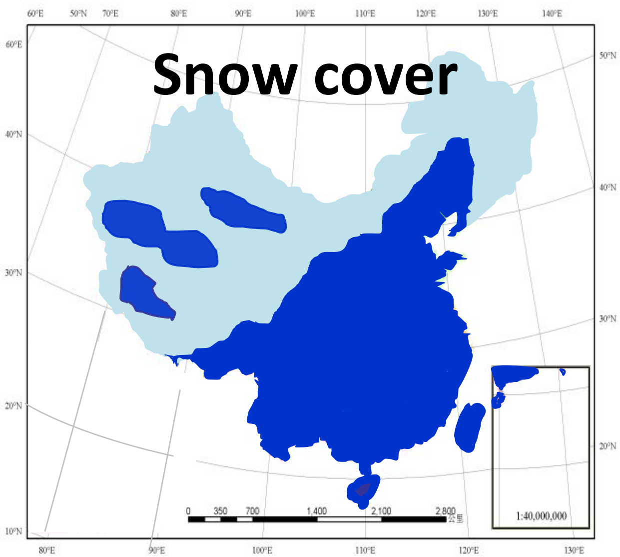
(IPCC AR5, 2013)

Cryosphere

Cryosphere in China







Number： 48571

Area： 51766km^2

Ice storage: 4500 billion m^3

Area： Permafrost 2.2 million km^2

Ground ice storage： 9500 billion m^3

Area: Stable snow cover 4.2 million km^2

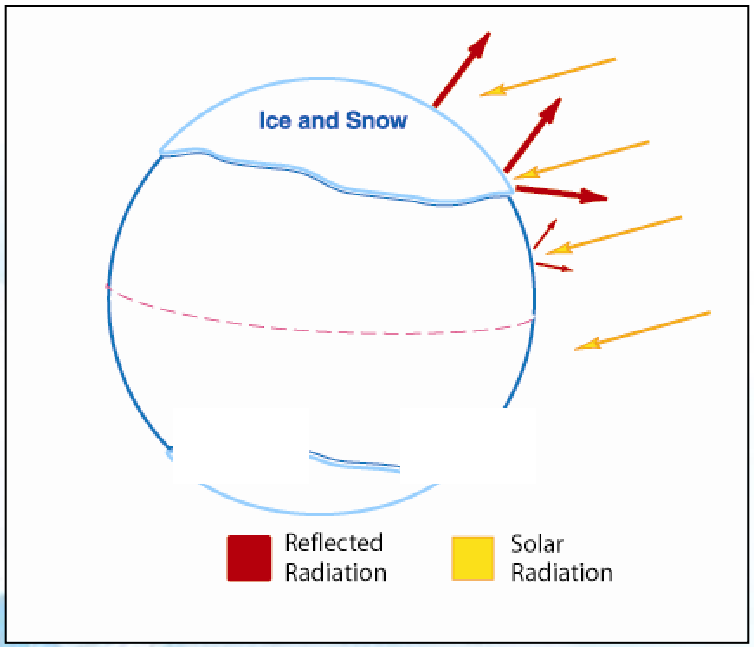
Equivalent water： 75 billion m^3

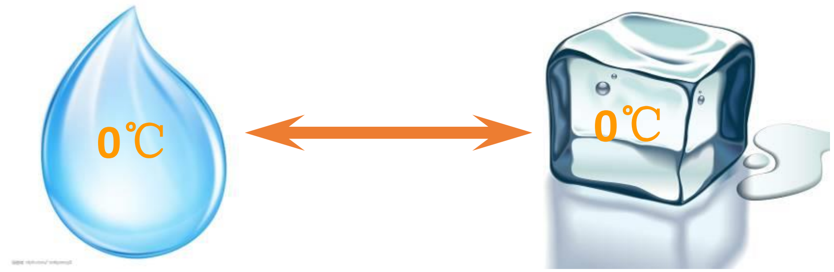
Cryosphere's role globally — albedo and energy

albedo

soil— 10%， water— 30%

pure snow— 90%

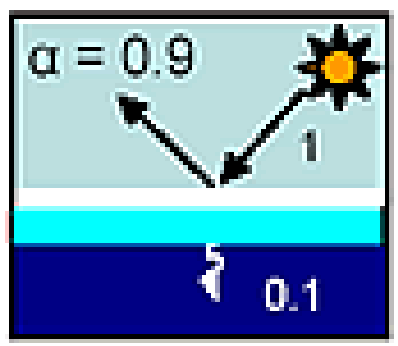




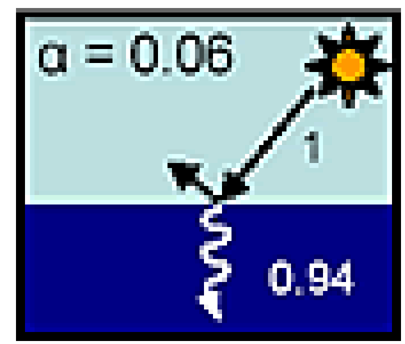
Energy in phase change：

80 cal/g (liquid-solid)

597 cal/g (liquid-vapor)

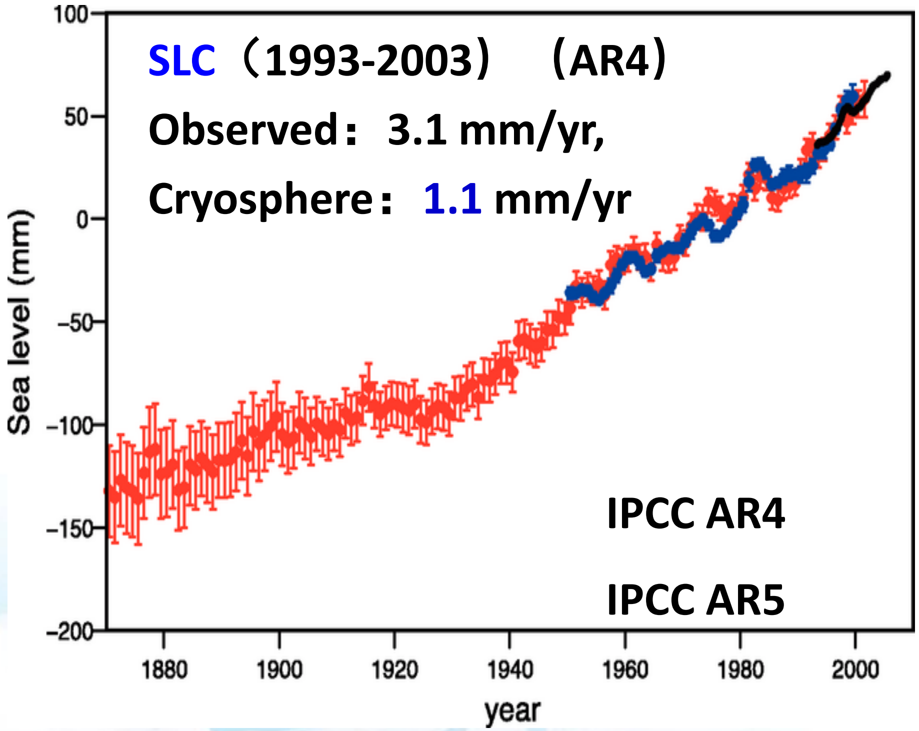


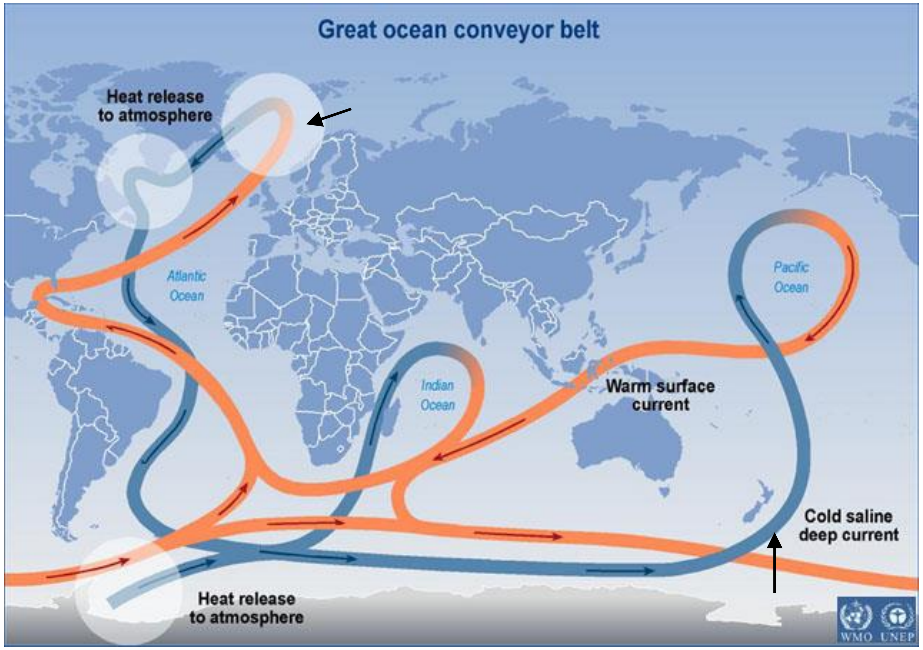
Ice-covered ocean



Ice-free ocean

Cryosphere's role globally —sea level, ocean circulation



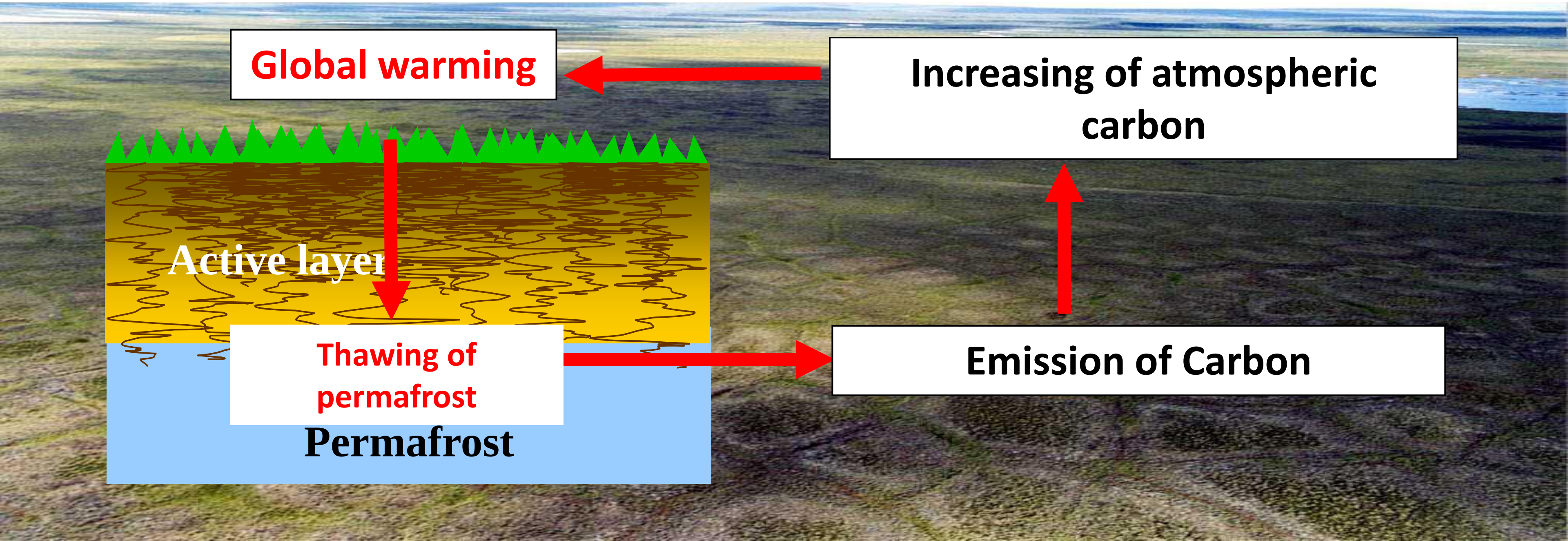


Cryosphere's role globally — carbon cycle

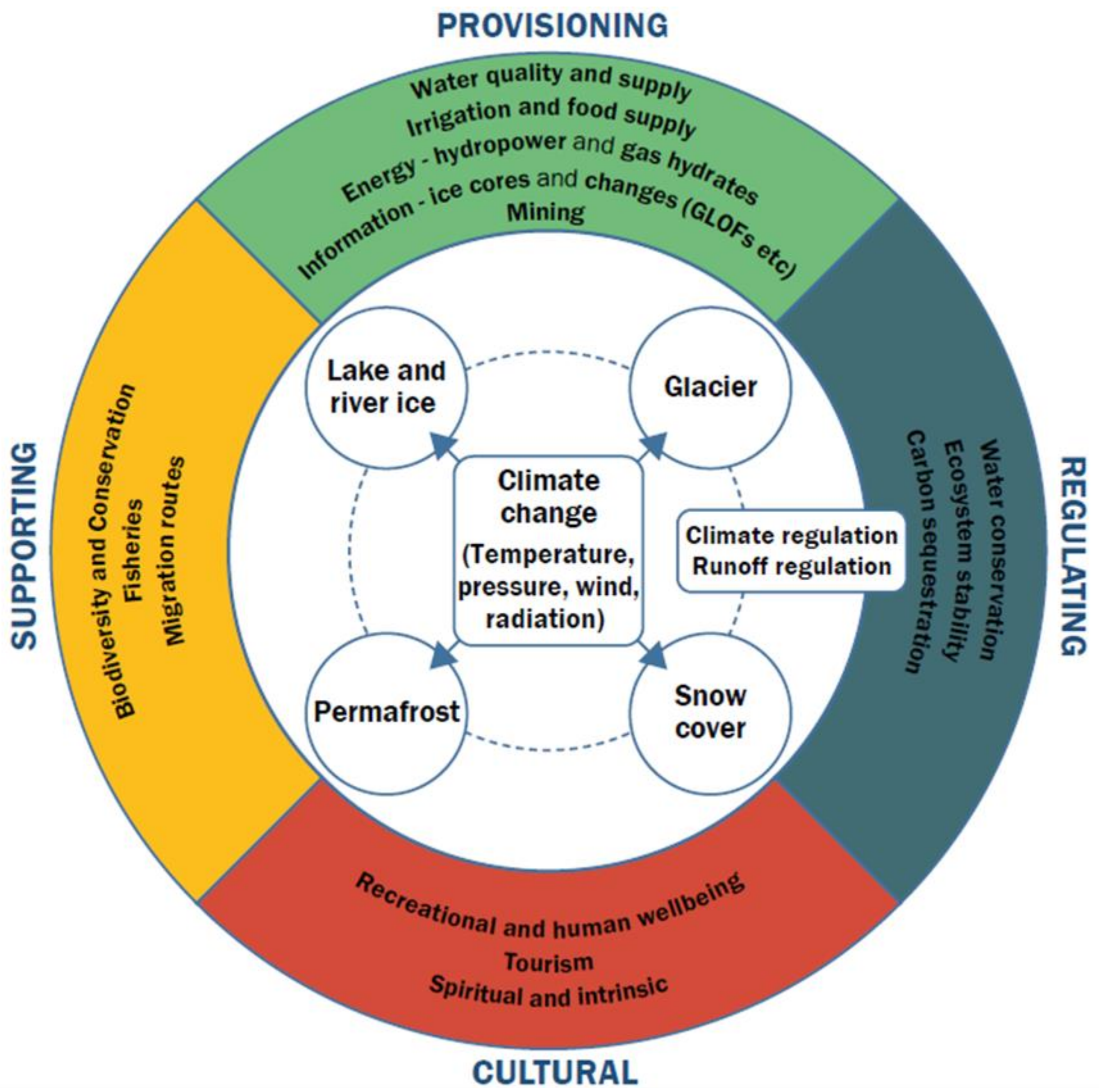
Permafrost 1672 Pg C (1.67×10^{12} ton C)

(projection: future 200a, 2/3 permaf. thawing, 1.9×10^{11}T C emissioon)

Global soil (1m)	1500 Pg C
atmosphere	777 Pg C
Land vegetation	650 Pg C



Cyosphere Services



Provisioning services:
Water resource, irrigation, energy from hydropower, and information (e.g. ice core).

Regulating services:
Water availability, ecosystem stability and carbon sequestration.

Supporting services:
Habitat such as biodiversity and migration routes for people and animals.

Cultural services:
Recreational and human wellbeing, religious, spiritual services, aesthetics, tourism.

Cryospheric Science International Background

Cryosheric Science

Focus on Dynamic of cryospheric changes, their impacts and adaptation, cryospheric service and sustainable development

BELMONT FORUM

ICSU

UNITED NATIONS UNIVERSITY

Future Earth

ISSC

UNESCO

IGFA

UNEP

WMO as an observer

2013 FE

International Association of Cryospheric Sciences IACS IUGG

2007 IACS

WCRP

CliC Climate and Cryosphere

2000 CliC

1920s ICSI

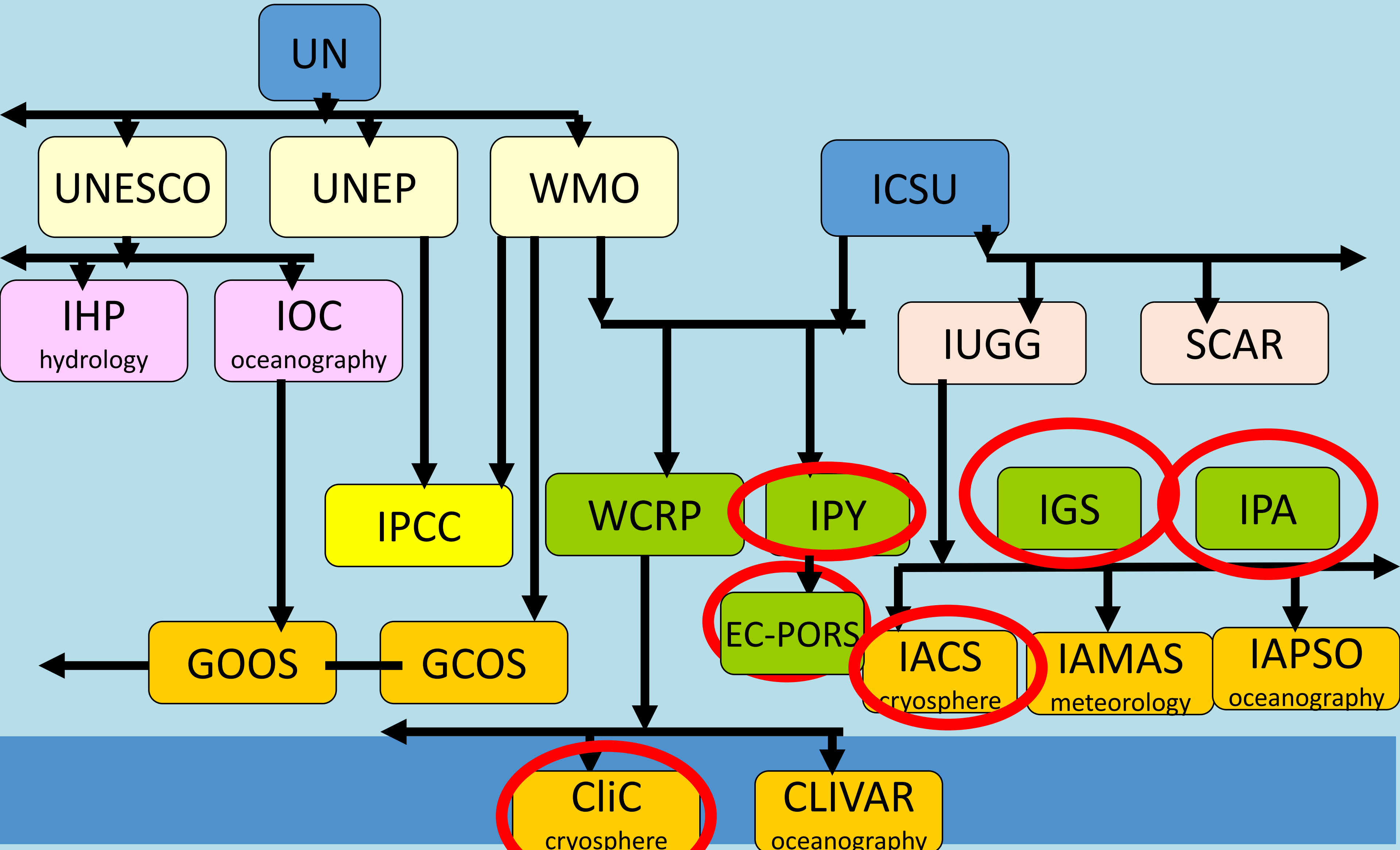
International Commission on Snow and Ice

IAHS AISH

International Union of Geodesy and Geophysics

Union Géodésique et Géophysique Internationale

Cryospheric Science in International Organizations

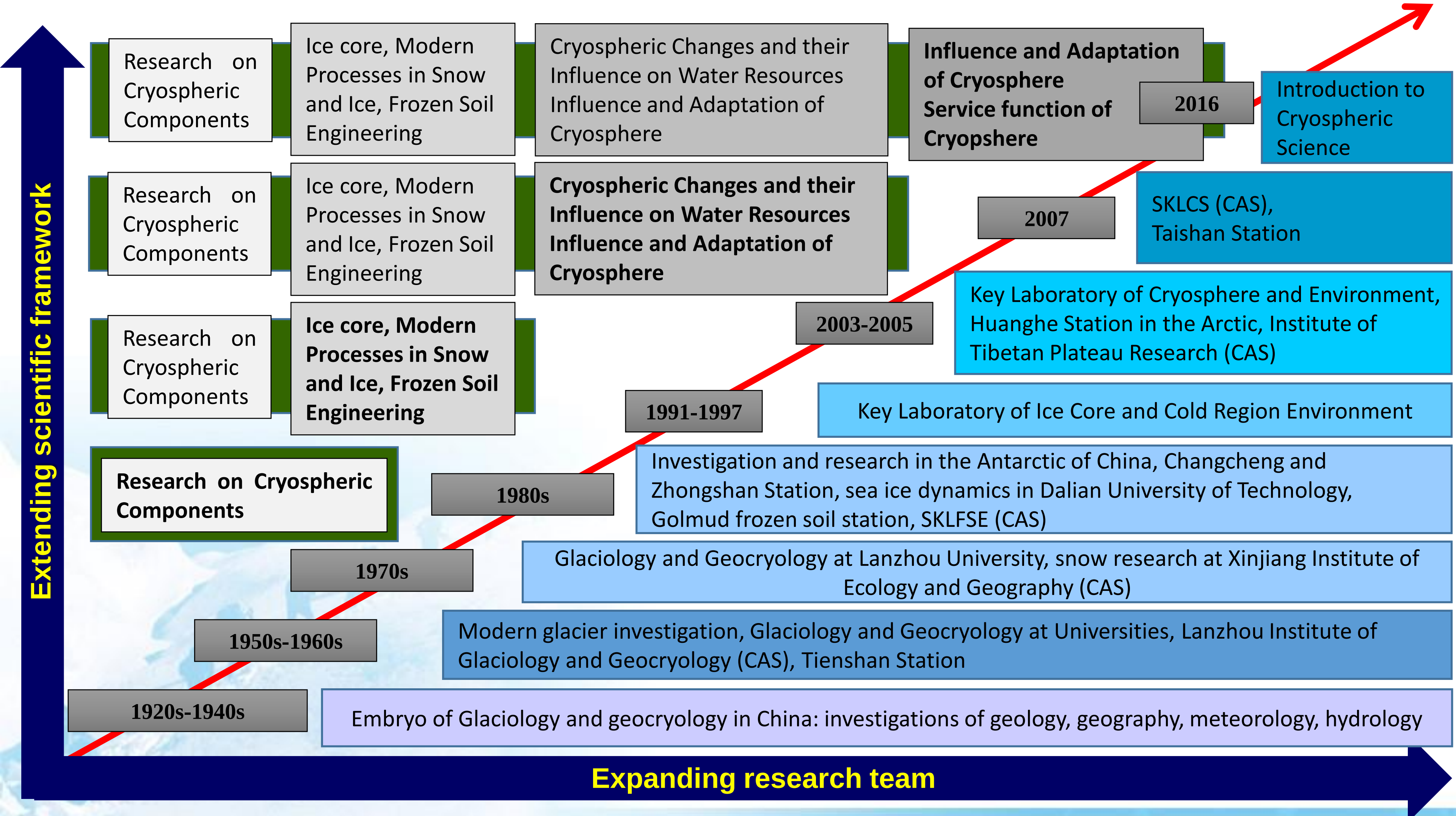


(based on Ian Allison)

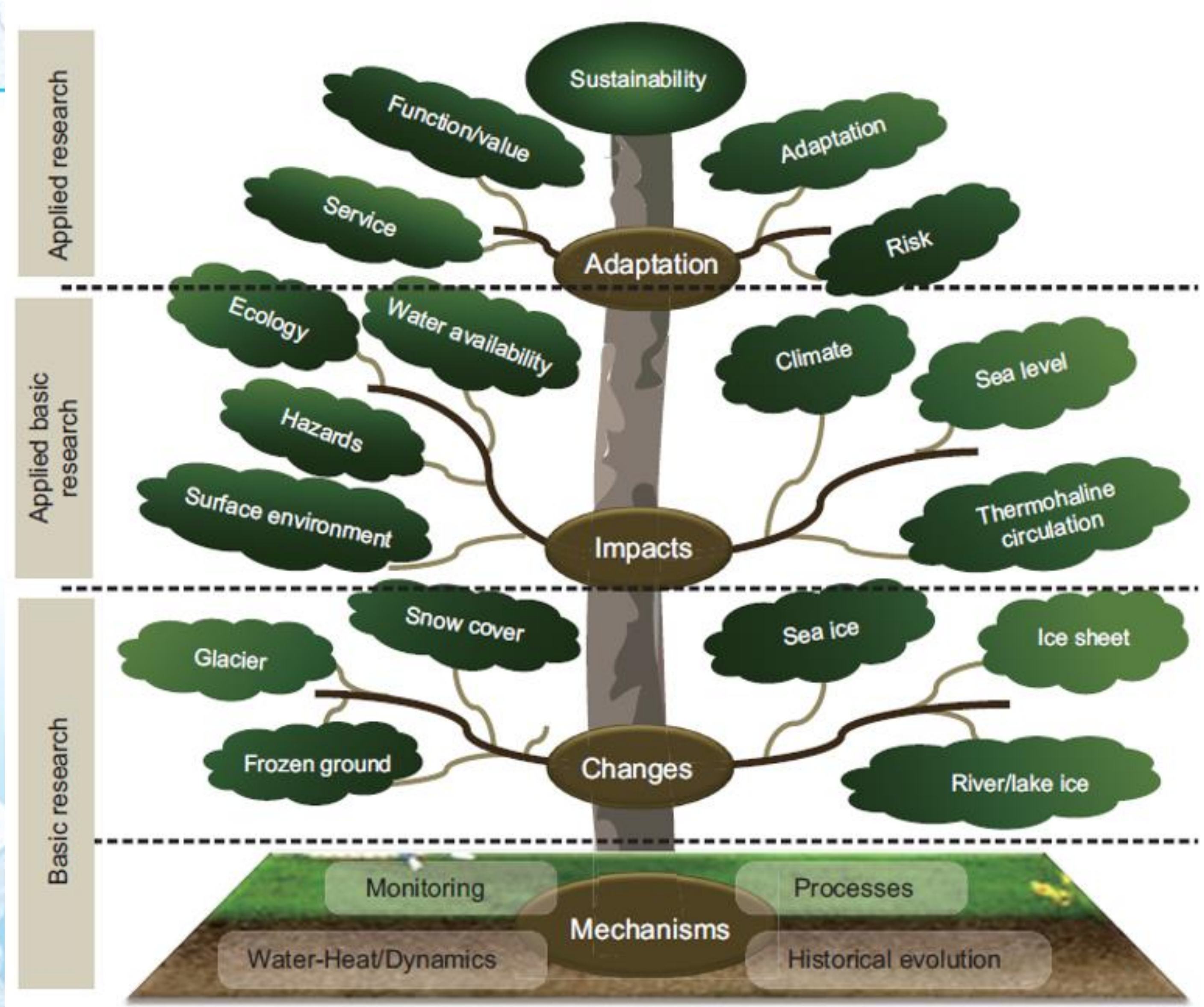
Developing Process of Cryospheric Science in China

SKLCS

Cryosphere science has become a scientific system combining natural science and sustainable socioeconomic development

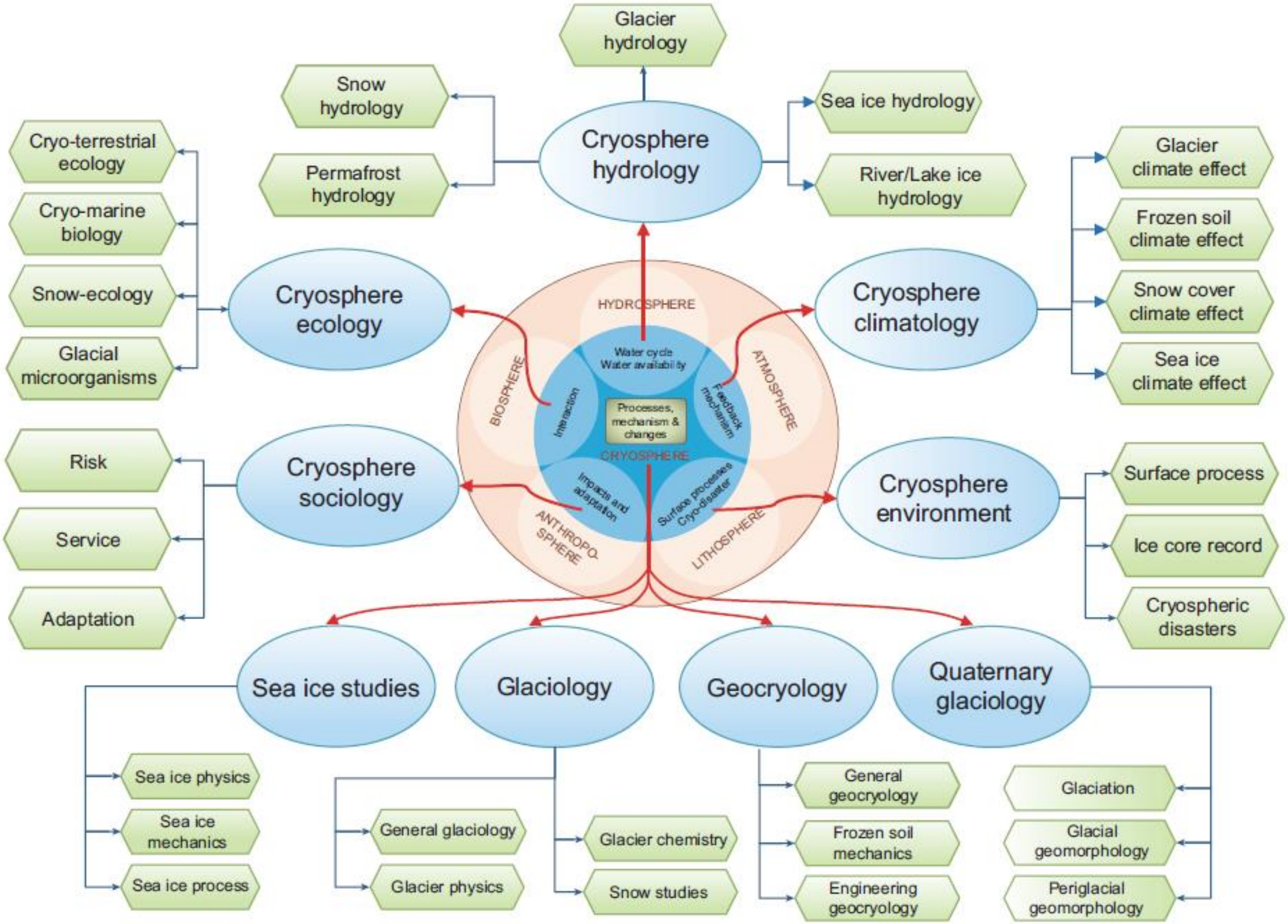


冰冻圈科学国家重点实验室



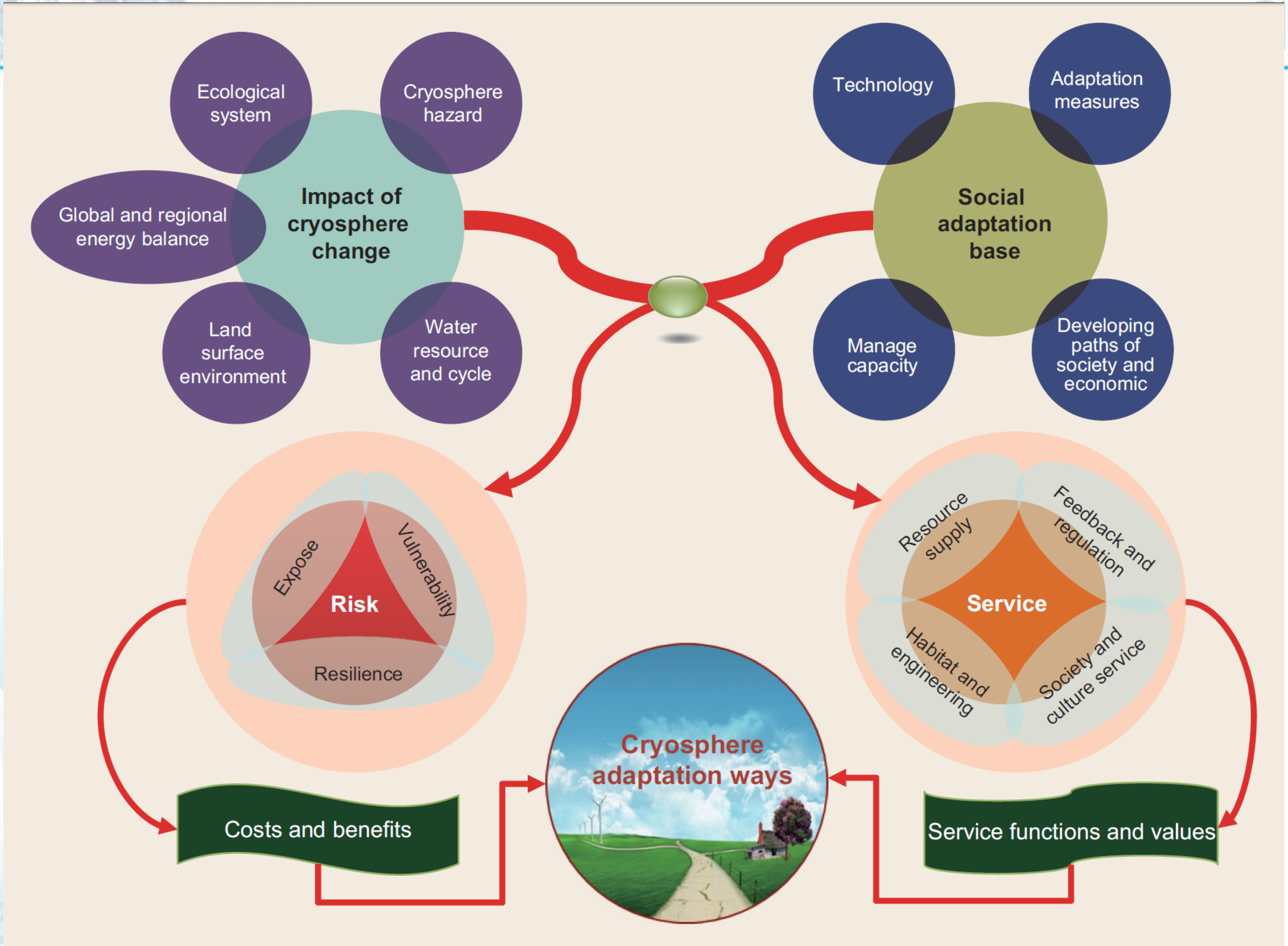
Schematic Tree of Cryospheric Science

(Qin et al., 2017, NSR)



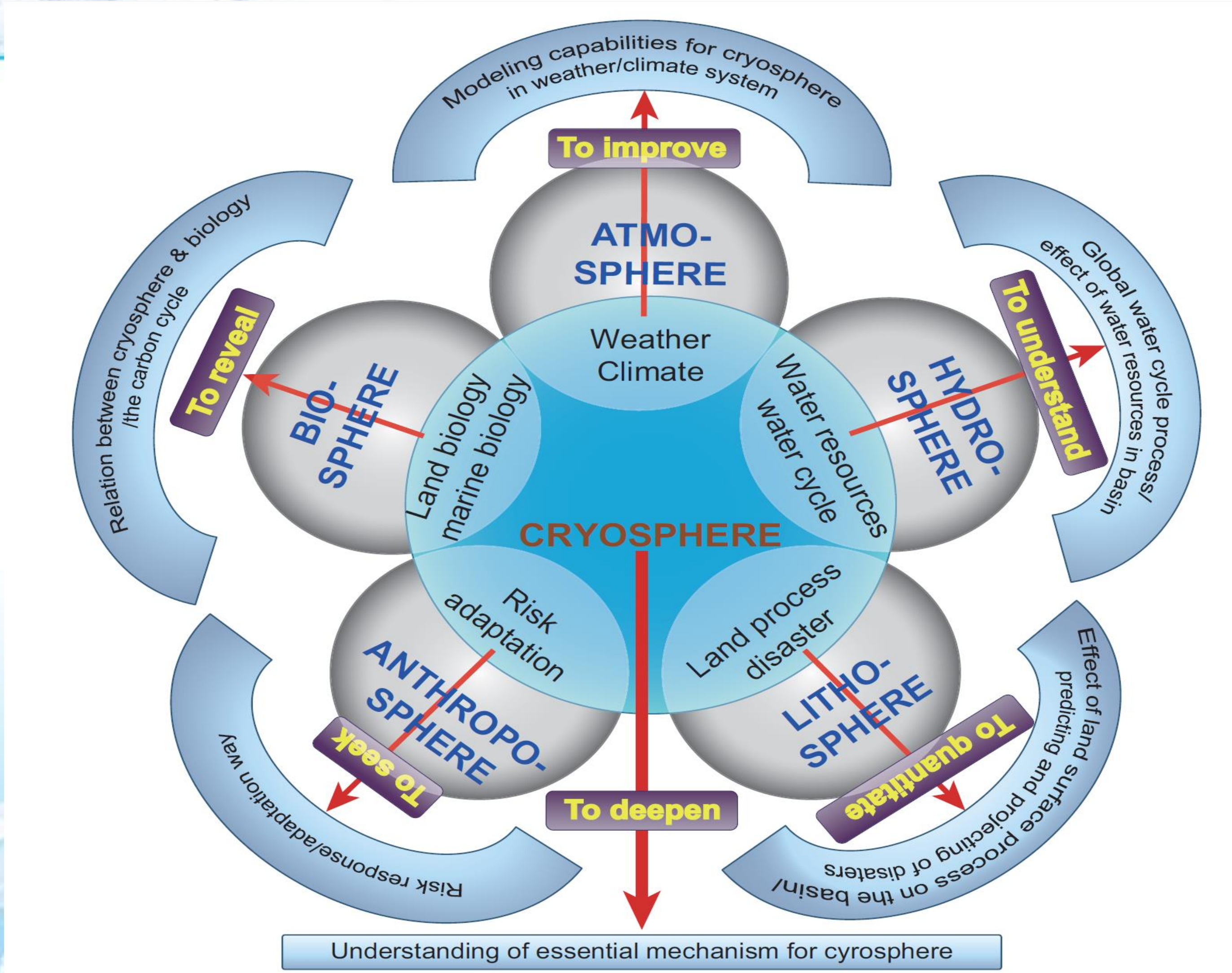
Disciplinary Structure (system) of Cryospheric Science

(Qin et al., 2017, NSR)



Relationship between the cryosphere and sustainable development

(Qin et al., 2017, NSR)

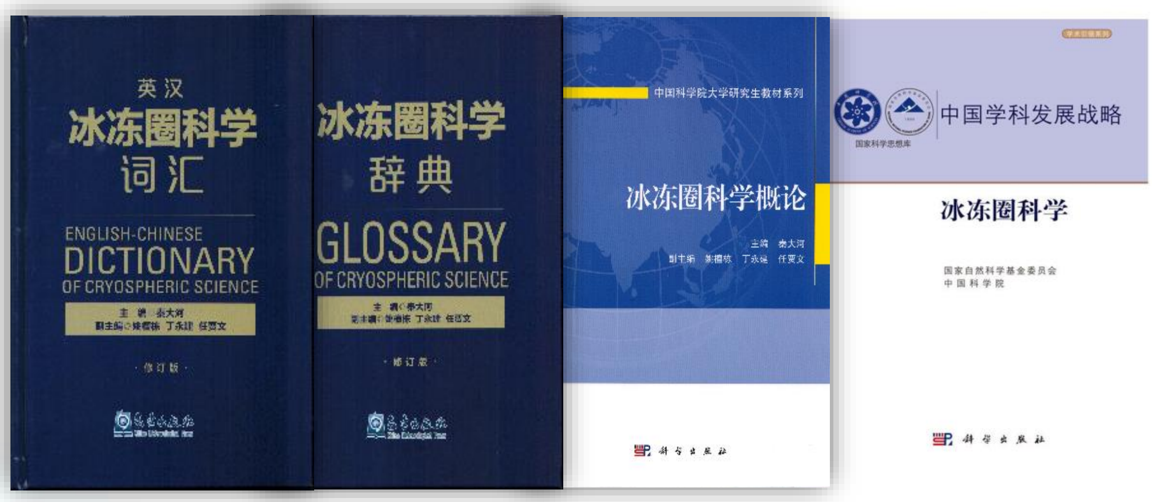


The Frontiers of Cryospheric Science

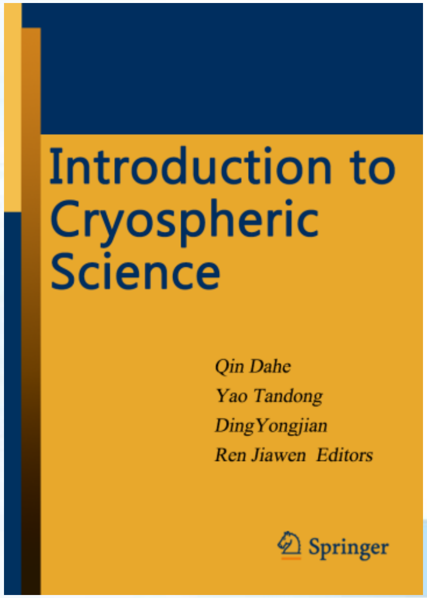
(Qin et al., 2017, NSR)

- **Compiling a series of books on Cryospheric Science**

Published



Preparing



《冰冻圈气候学》
《冰冻圈地理学》
《冰冻圈水文学》
《冰冻圈灾害学》
《行星冰冻圈》
《冰冻圈人文学》
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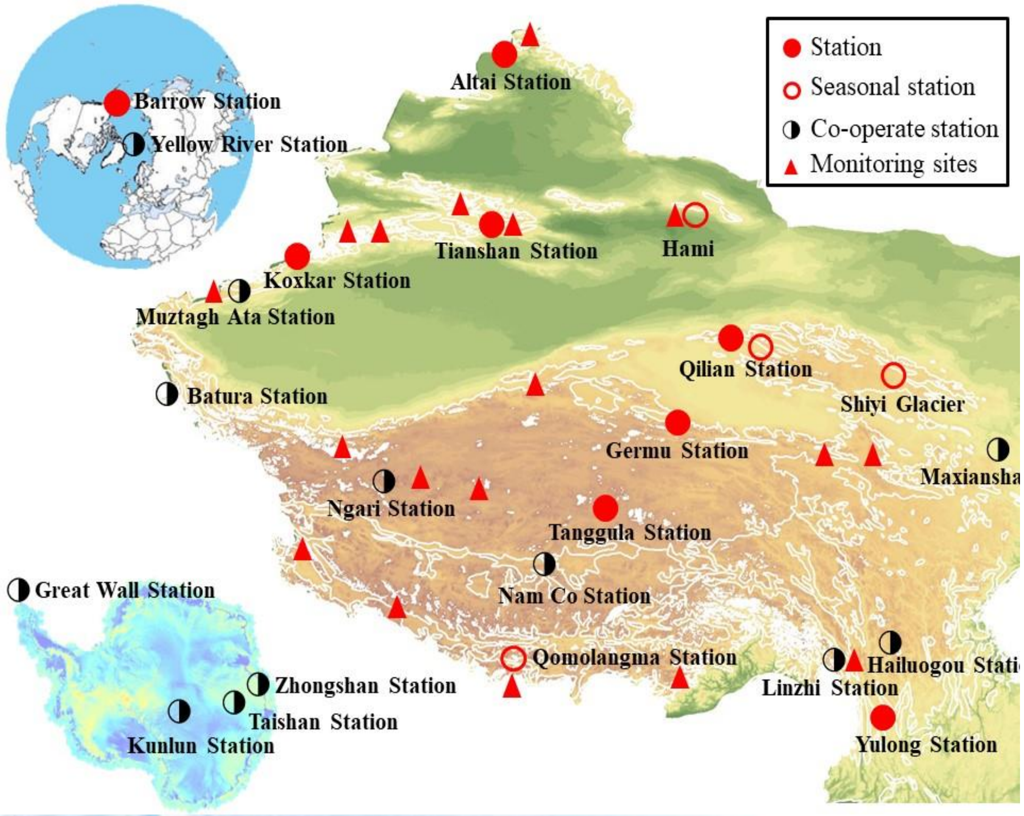
13 Volumes will be published during 2018-2019

The cryosphere observation network in China

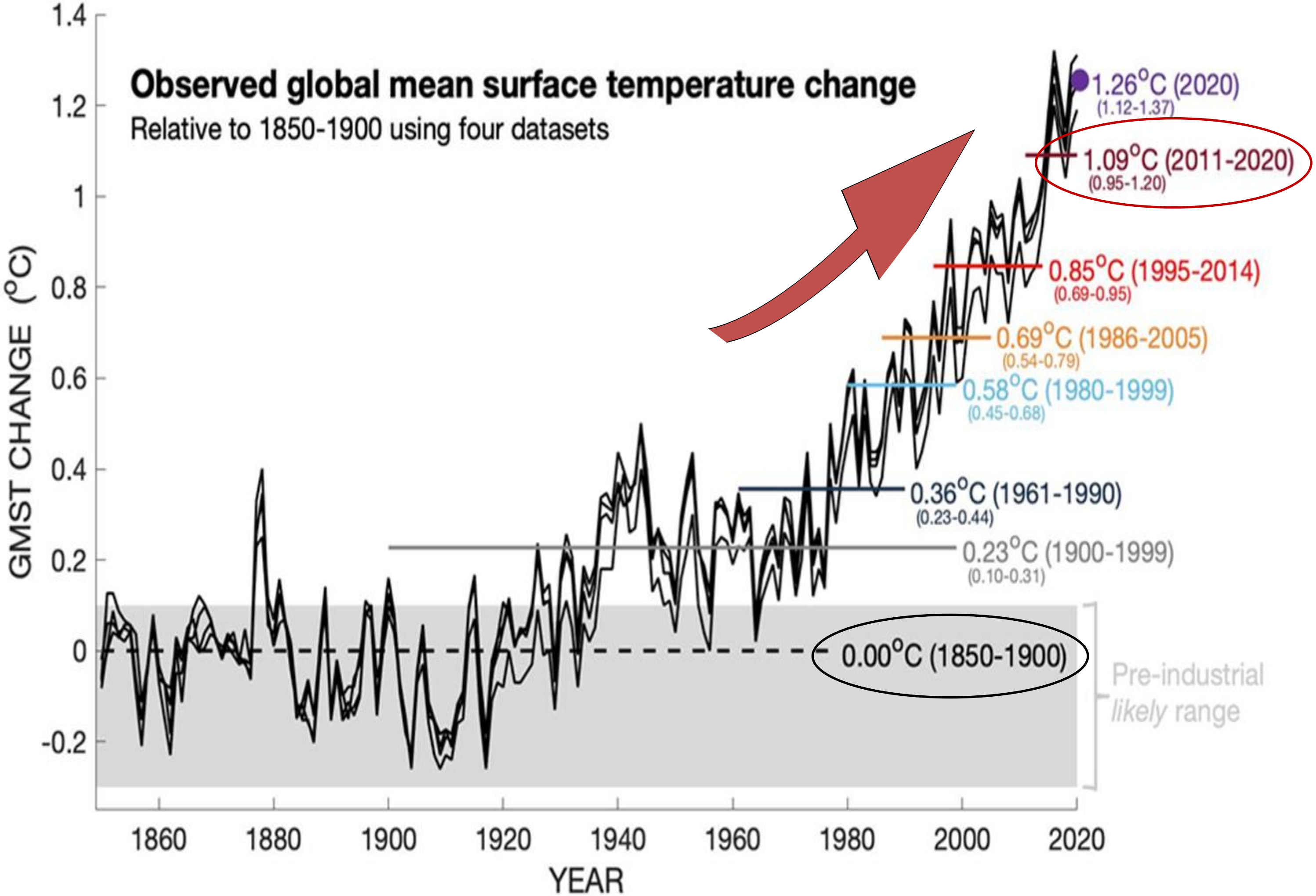


Field observation stations

17 comprehensive stations

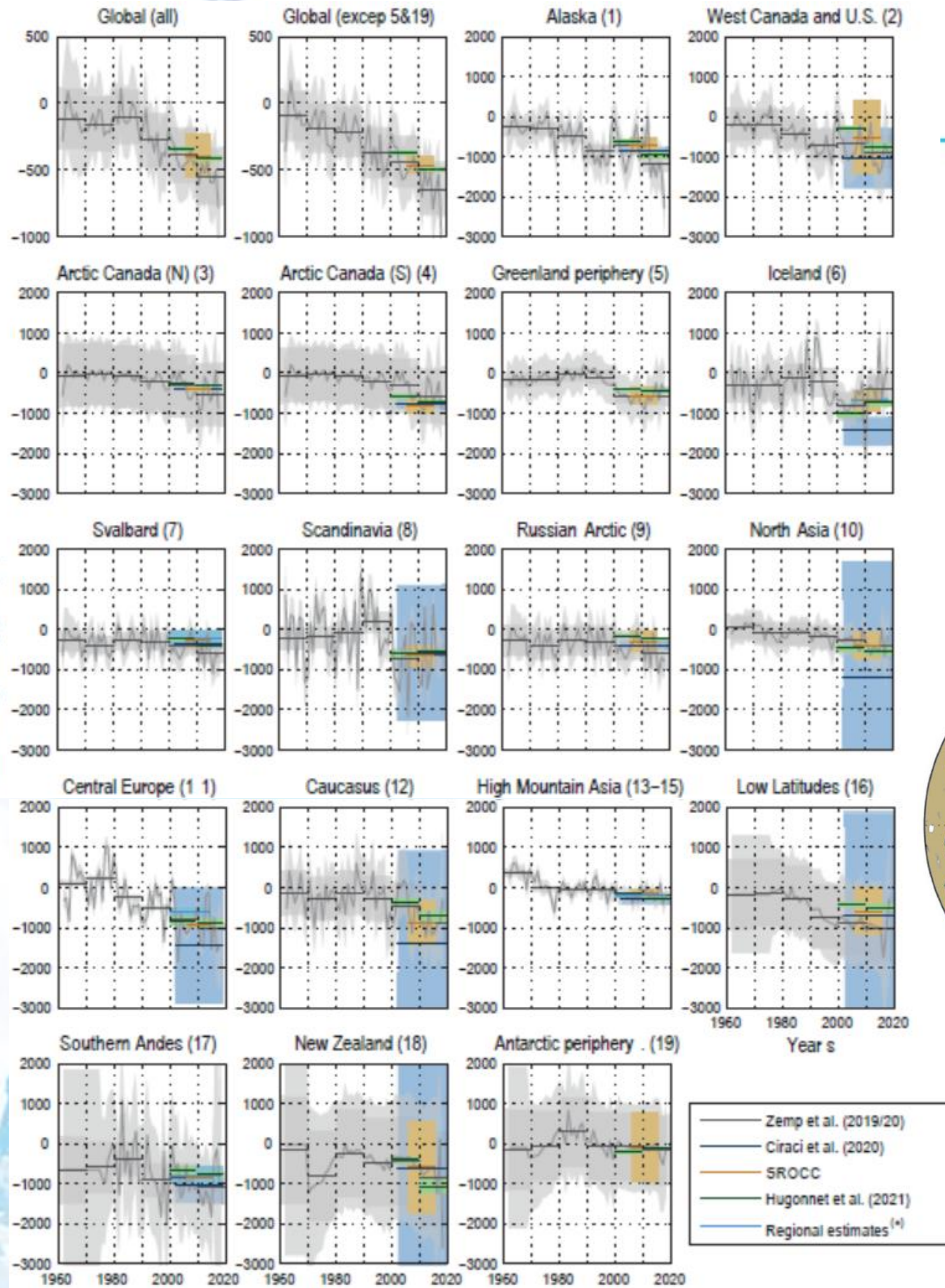
18 observed sites

- Development of Cryospheric Science
- **Climate Change Drives the Development of Cryospheric Science**
- The Earth System Promotes Cryospheric Science

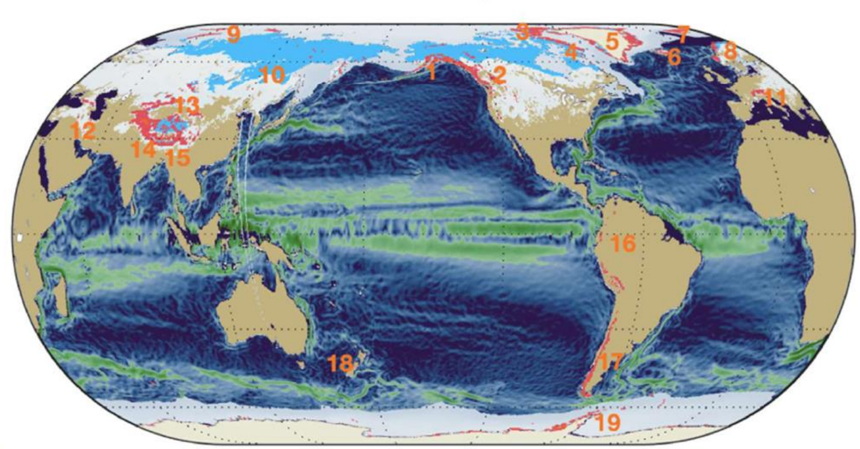


The total increase between the average of the 1850–1900 and the 2001–2020 period is 0.99℃. The total increase between the average of the 1850–1900 and the 2011–2020 period is 1.09℃.

(IPCC, 2021)

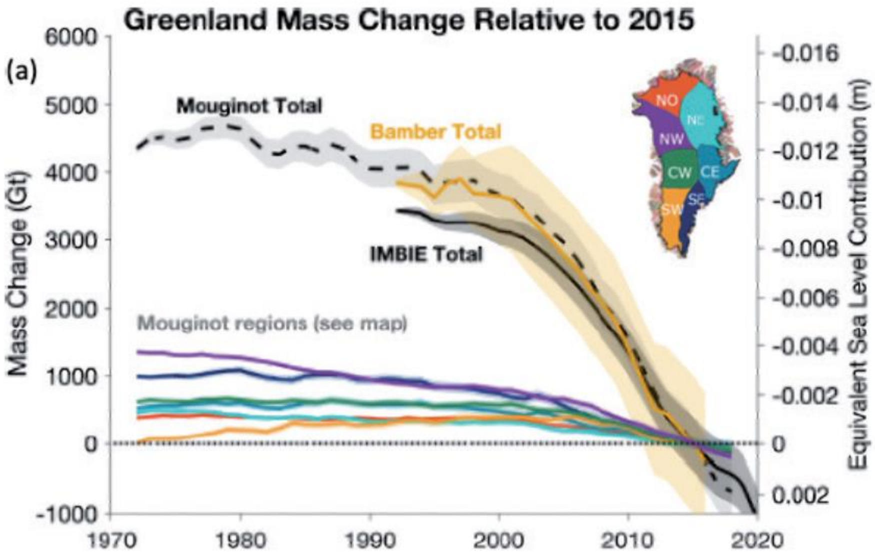


Global and regional glacier mass change rate between 1960 and 2019



(IPCC, 2021)

Greenland and Antarctic ice sheets have been losing mass



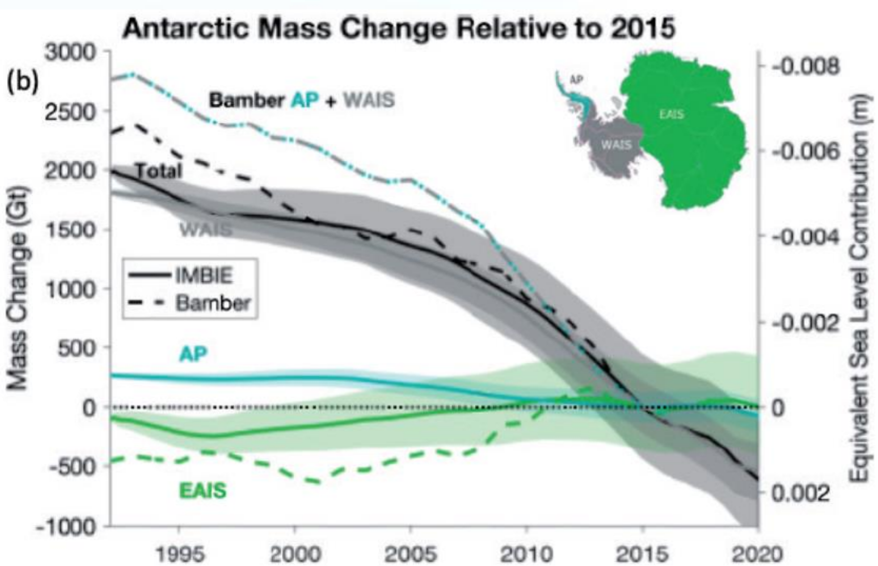
Greenland ice sheet

34 [−6 - 74] Gt/yr 1992–2001

215 [157 - 274] Gt/yr 2002–2009

278 ± 11 Gt/yr 2006–2015

243 [197 - 290] Gt/yr 2010–2019



Antarctic ice sheet

30 [−37 - 97] Gt/yr 1992–2001

147[72 - 221] Gt/yr 2002–2011

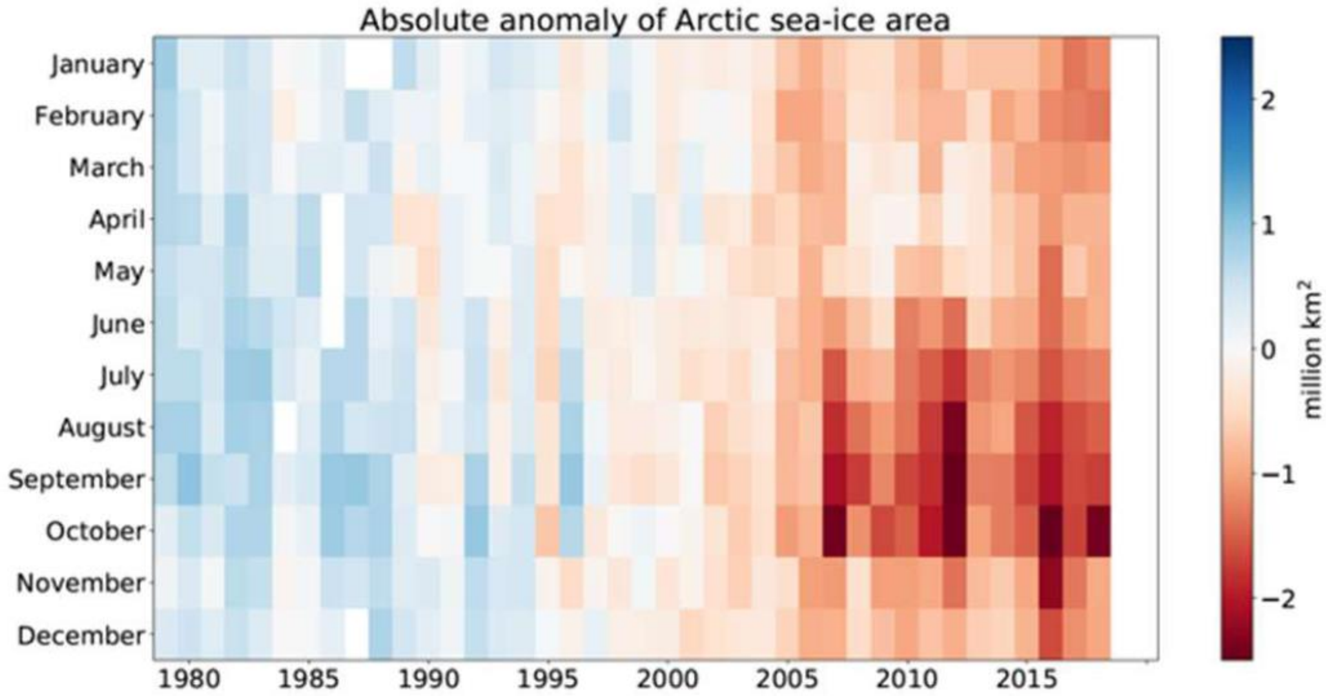
155 ± 19 Gt/yr 2006–2015

148 [94 - 202] Gt/yr 2010–2016

(IPCC, 2021)

Arctic sea ice area has decreased since 1979

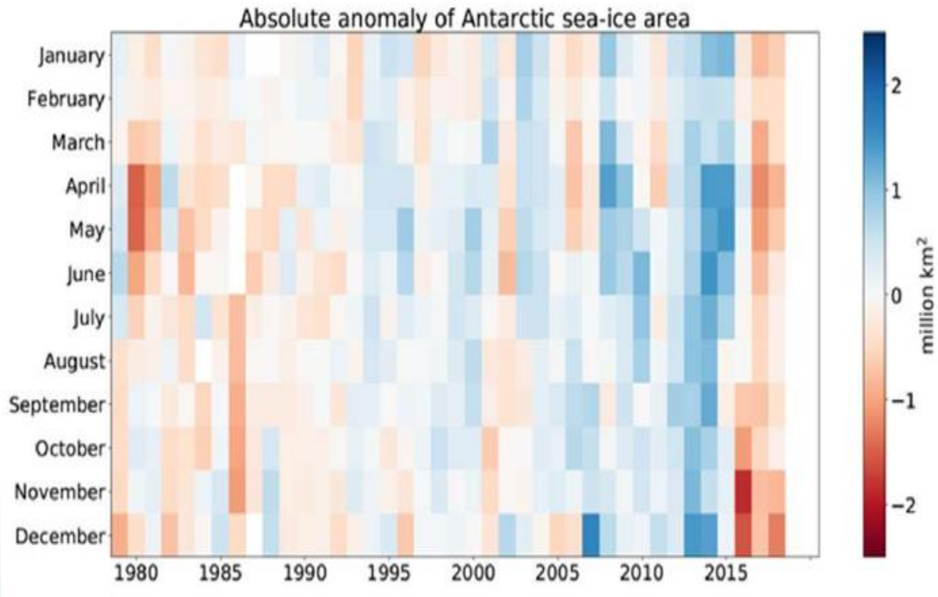
Absolute anomaly of monthly-mean Arctic sea-ice area during the period 1979 to 2018 relative to the period of 1979-2008

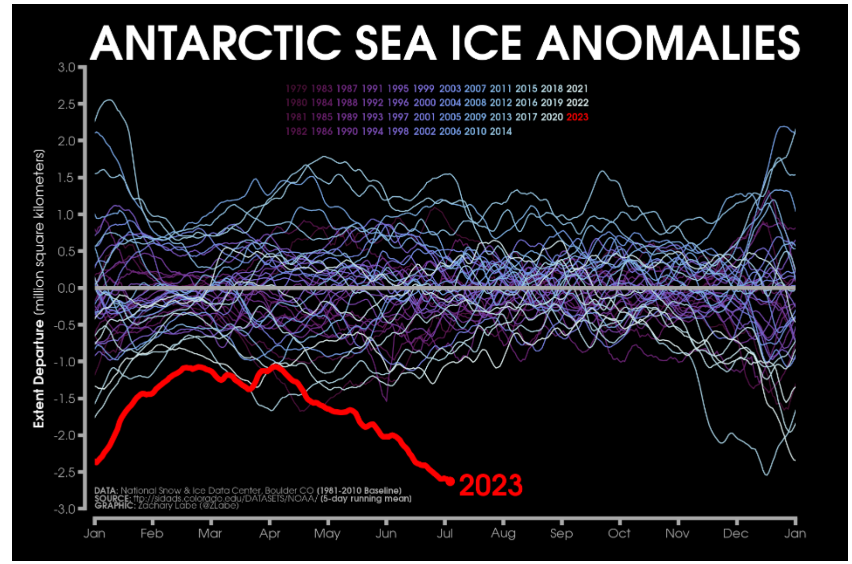


(IPCC, 2021)

- **The sea-ice area has decreased from 1979 to the present every month of the year.**
- **The absolute and relative ice losses are highest in late summer-early autumn.**
- **Averaged over the decade 2010-2019, the monthly average Arctic sea-ice area in August, September and October has been around 2 million km^2 (about 25%), smaller than that during 1979-1988.**

Antarctic sea ice area has no trend since 1979

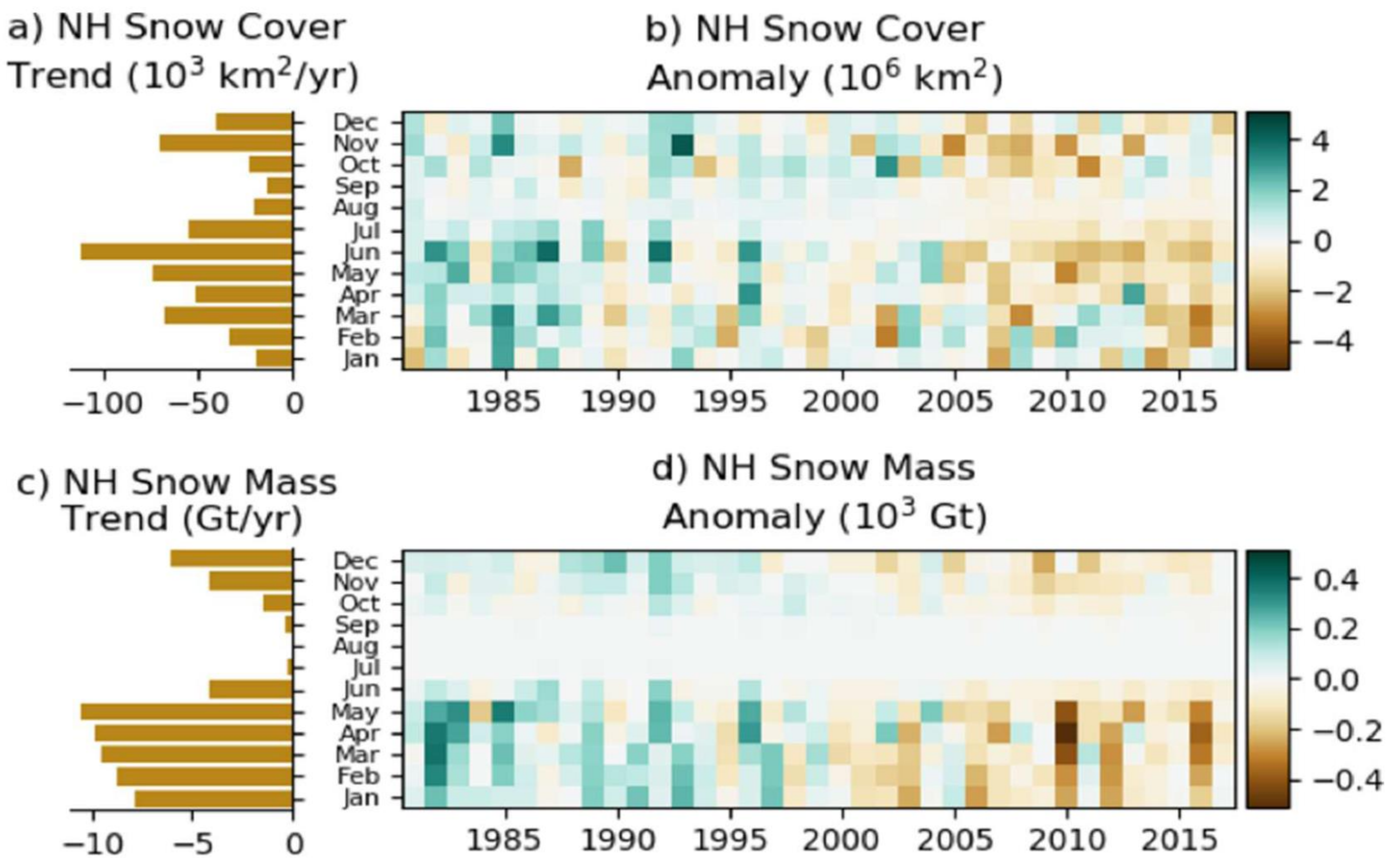




(IPCC, 2021)

For Antarctic sea ice, regionally opposing trends and large interannual variability resulted in no significant trend in satellite-observed sea ice area from 1979 to 2020 in both winter and summer. However, it decreases sharply in 2023.

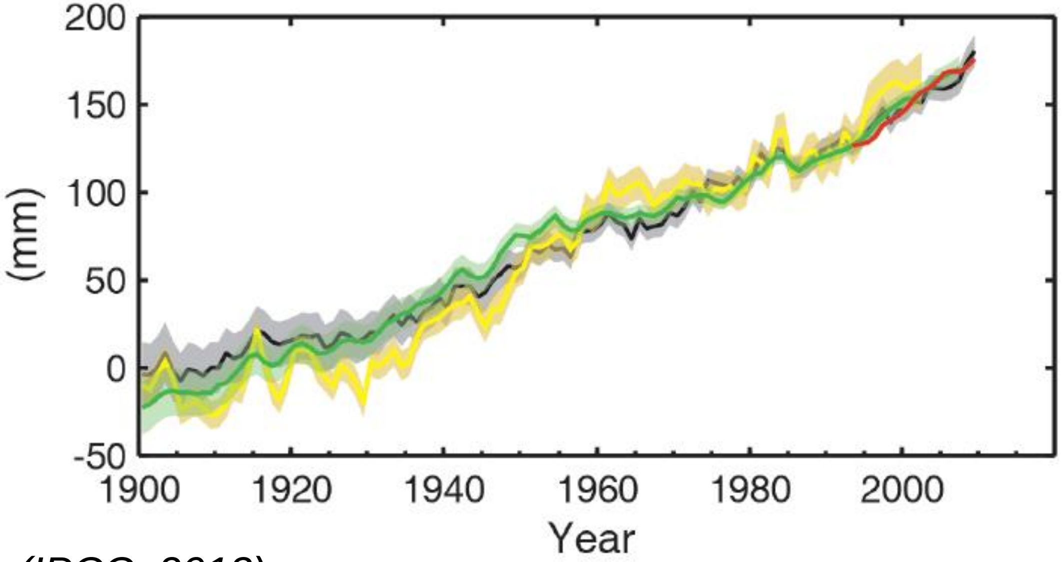
Observed monthly northern hemisphere snow cover changes



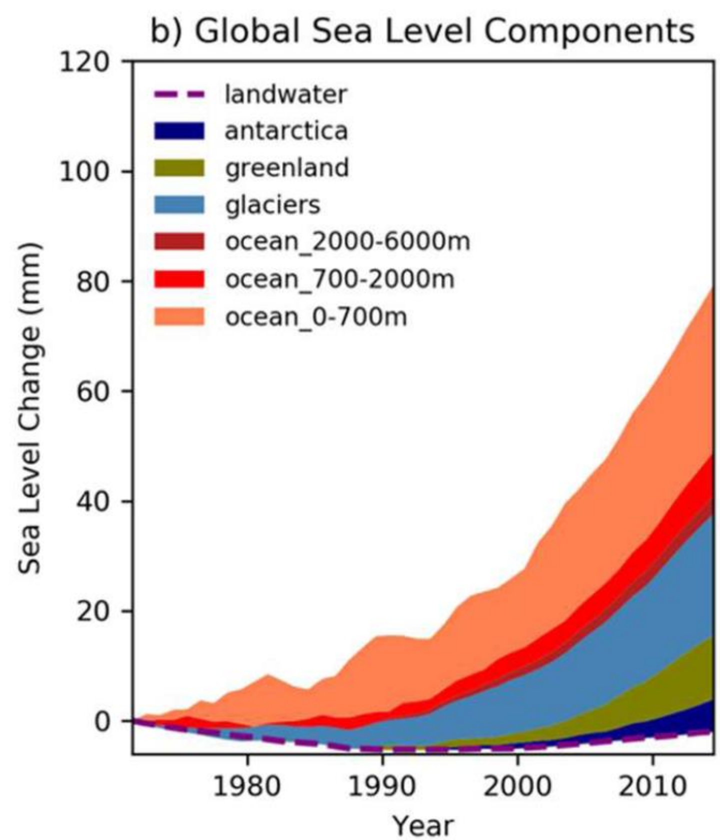
(IPCC, 2021)

There are negative NH SCE trends in all months between 1981 and 2018, exceeding -50 × 10^3 km^2 yr^{-1} in November, December, March and May.

Global mean sea level has risen by 0.19 m (1901-2010)



(IPCC, 2013)



Observed changes in global mean sea level components for 1971-2015

1901-2010 1.7 [1.5 to 1.9] mm/yr

1971-2010 2.0 [1.7 to 2.3] mm/yr

1993-2010 3.2 [2.8 to 3.6] mm/yr

1971-2018 2.3 [1.6 to 3.1] mm/yr

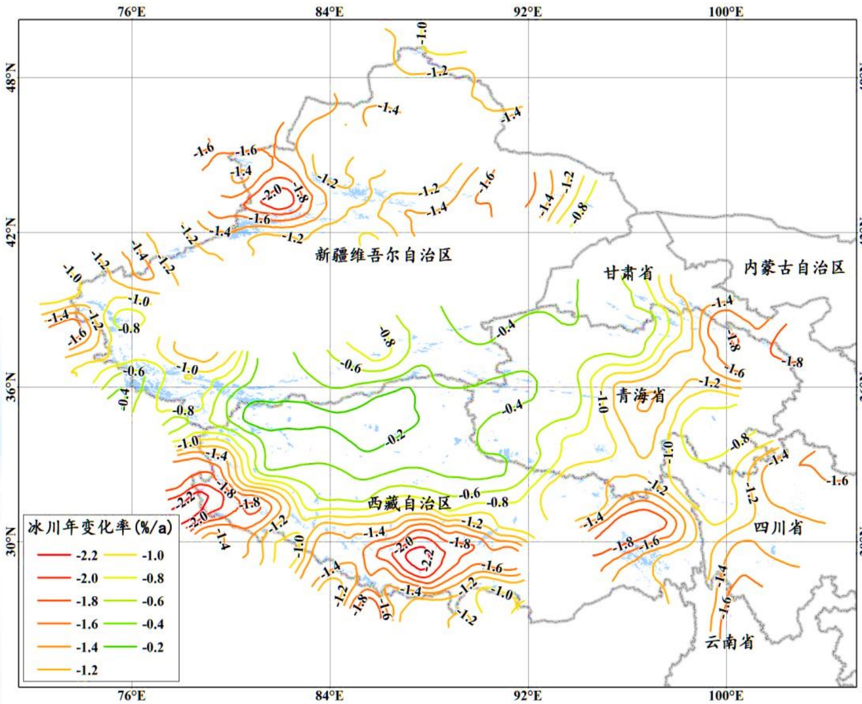
2006-2018 3.7 [3.2 to 4.2] mm/yr

(IPCC, 2021)

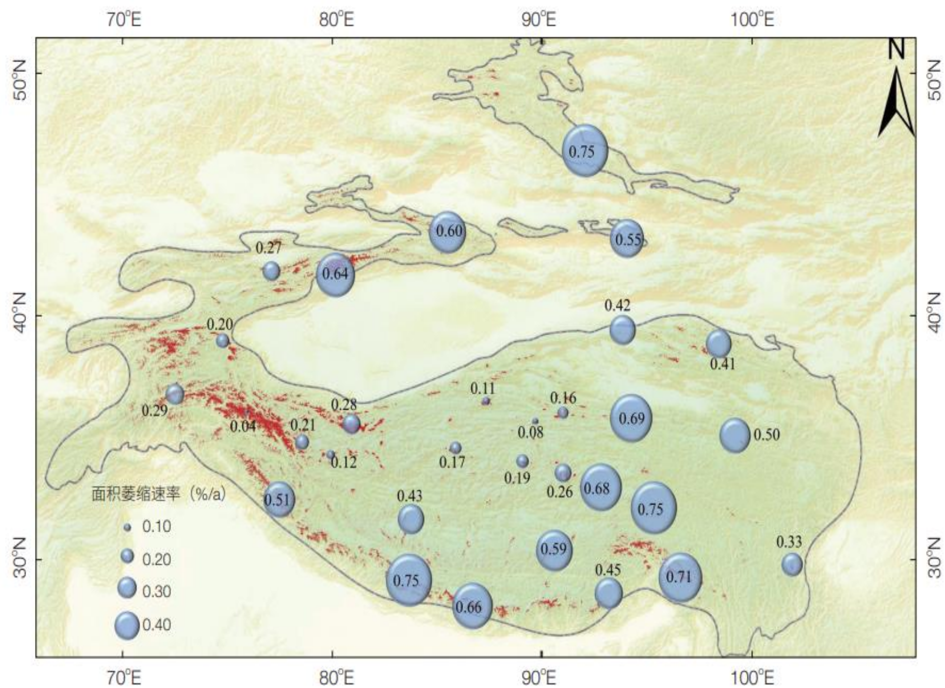
Glacier number: 48571
Aera：51,766 km²
Volume: 4,500 km³

Rapid shrinking

- **South and east of TP**
- **Tanshan and Altai**



Guo et al., 2015 JOG



Wang et al., 2019

Mean annual glacier area change rate (%/year) during the last decades

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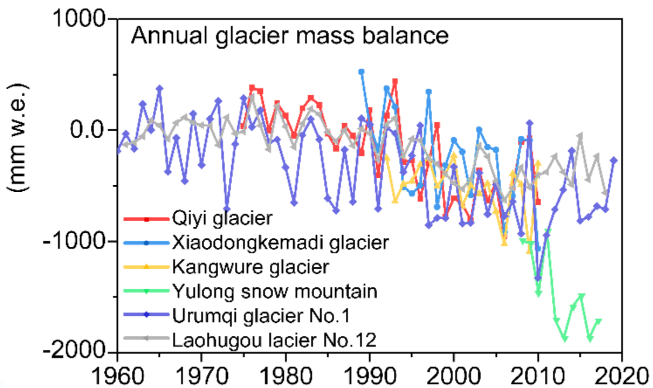
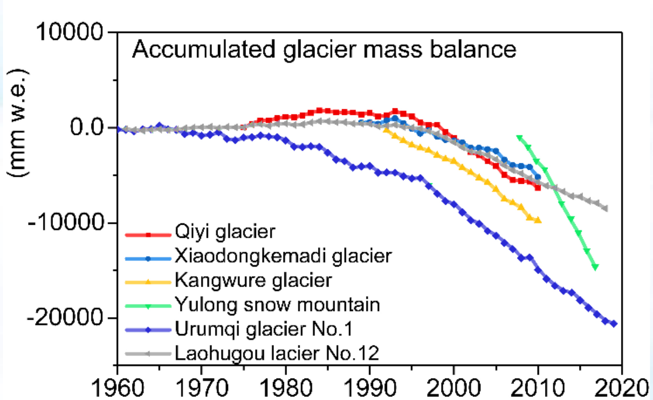
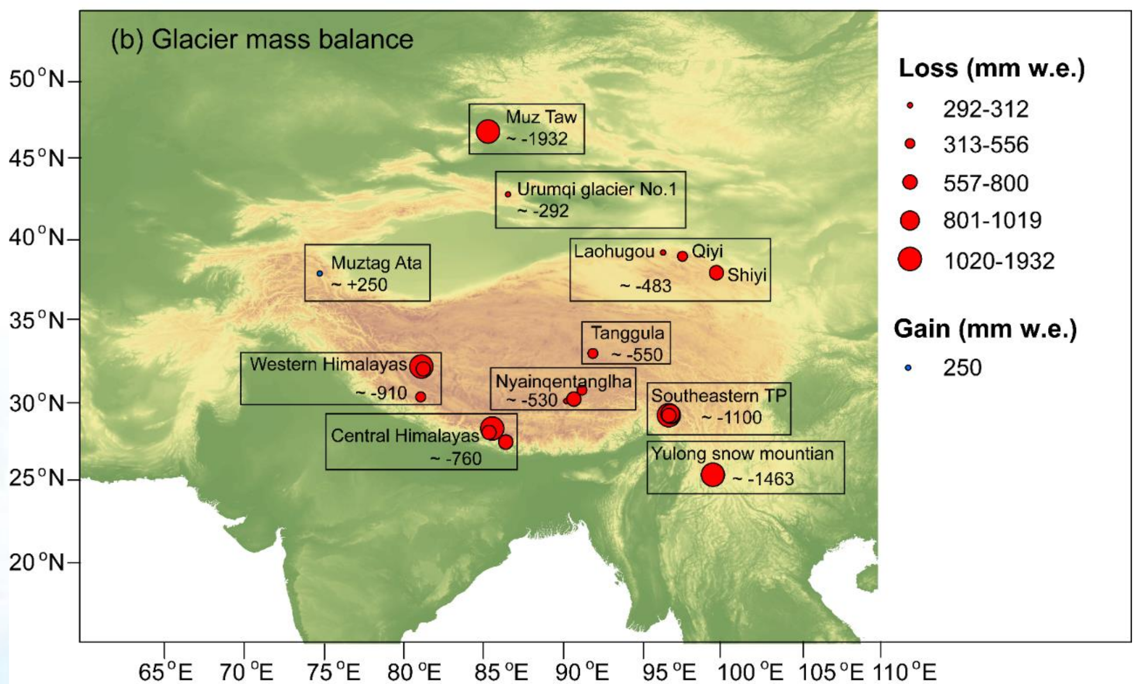
In-situ observed glacier mass balance changes



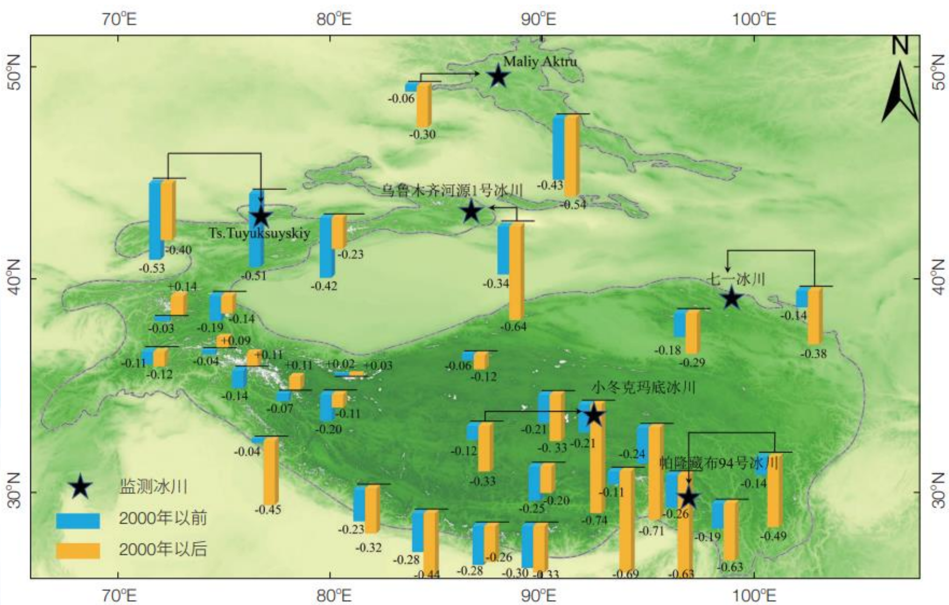




Zhang & Kang* et al., 2021 ESR

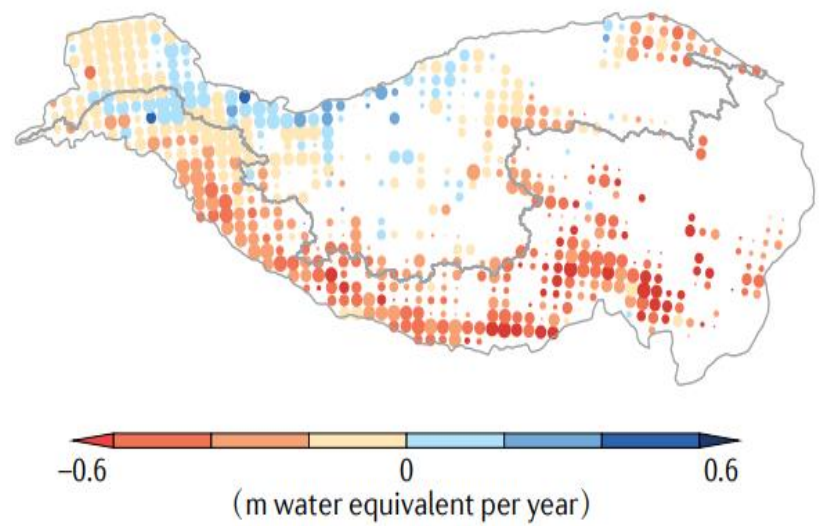
Observed glacier mass balance changes

Since 2000, a total glacier mass loss is –19.0±2.5Gt a^{-1}



Average glacier mass balance before and after 2000

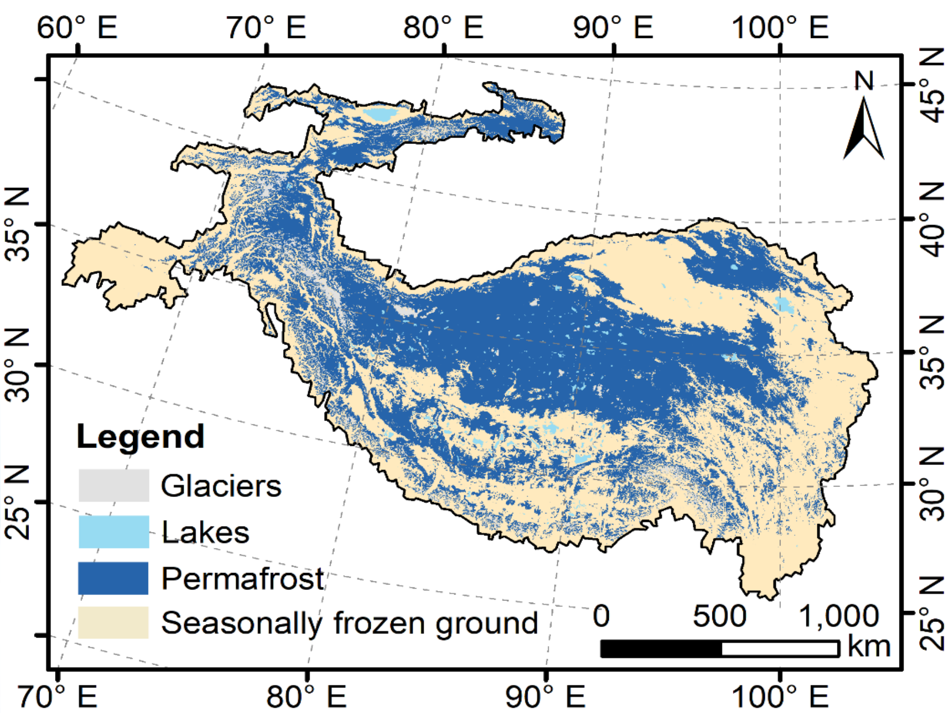
Wang et al., 2019



Average glacier mass balance by RS since 2000

Yao et al., 2022

Permafrost changes in the Third Pole



The spatial distribution of the permafrost area in the Third Pole region for the period of 2000–2016 (Ran et al., 2021).

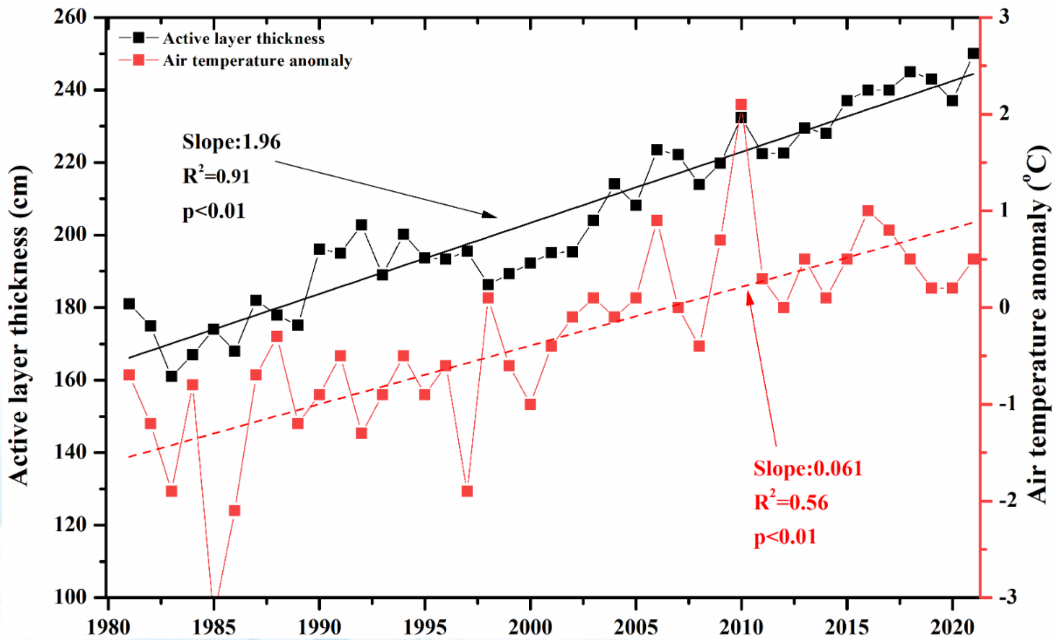
- **The total area of permafrost in the Third Pole for the period of 2000–2016 is approximately 159.70×10^4 km^2;**
- **The total permafrost area has decreased significantly from 1960s to 2000s at a rate of approximately 9.52×10^4 km^2 per decade.**

The area statistics of the permafrost types over the Third Pole in the past 50 years (×10^4 km^2).

Permafrost type	Net change (1960s to 2000s) Area	Percent (%)	Change rate ($\times 10^4$ km^2 decade^{-1})
Very cold	−8.99	−72.79	−2.09
Cold	−27.06	−70.12	−6.15
Cool	−9.30	−27.24	−2.14
Warm	−1.18	−4.77	−0.29
Very warm	3.99	9.02	1.06
Likely thawing	0.90	4.34	0.09
Total area	−41.66	−23.84	−9.52

Ran et al. (2018)

Permafrost changes in the Third Pole

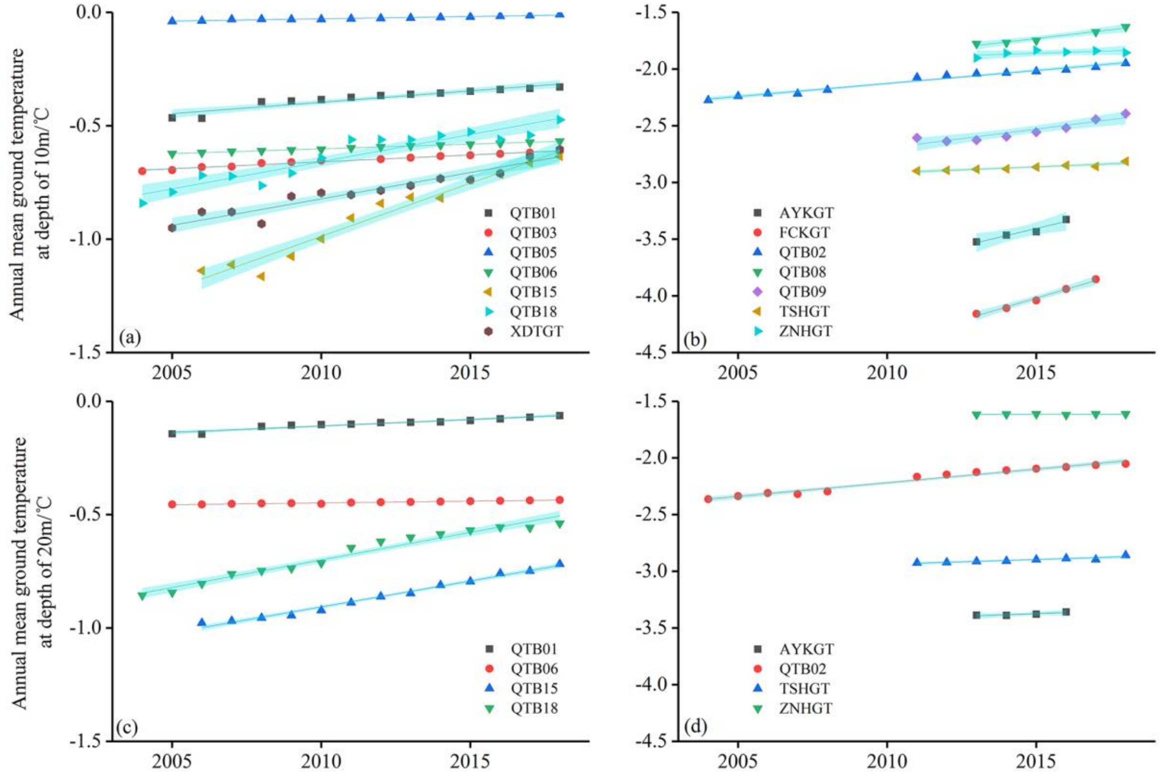


The activity layer thickness and air temperature anomaly in the permafrost region along the Qinghai-Tibet Highway through the time period 1981 to 2021

- **The active layer thickness was thickened (1.96 cm/a)**
- **The average air temperature showed a significant warming trend (0.61℃/10a)**

Permafrost changes in the Third Pole

Permafrost temperature



The relationship between warming rate and multiyear mean ground temperature during the observation period from the (a) active layer monitoring site and the (b) borehole site.

- **The ground temperature showed significant linearly increasing trends, and the permafrost has warmed at different rates**

- **The warming rates at a depth of 10 m ranged from 0.02 °C per decade to 0.78 °C per decade but varied between 0 °C per decade and 0.24 °C per decade at a depth of 20 m.**

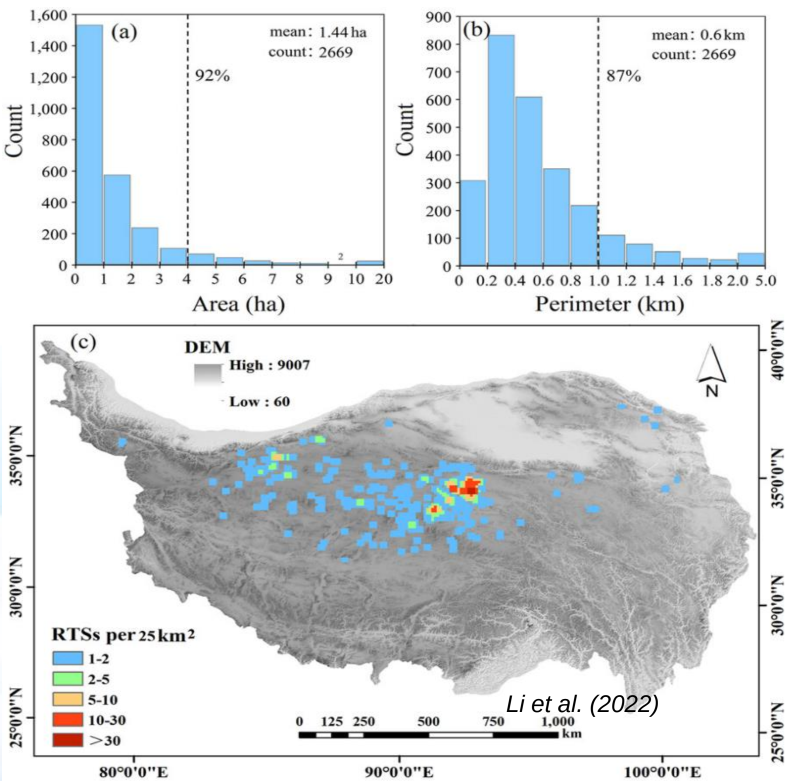
Permafrost changes in the Third Pole

Permafrost degradation

The warming of permafrost and deepening of the active layer in ice-rich permafrost regions of the Third Pole have resulted in widespread thermokarst formation that includes thaw slumps and thermokarst lakes.

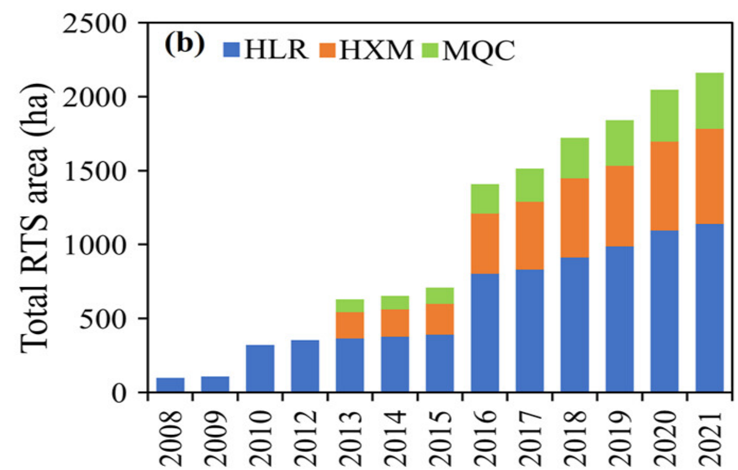
Permafrost changes in the Third Pole

Thaw Slumps



Frequency distribution of active Retrogressive thaw slumps (RTSs) on the Qinghai–Tibet Plateau

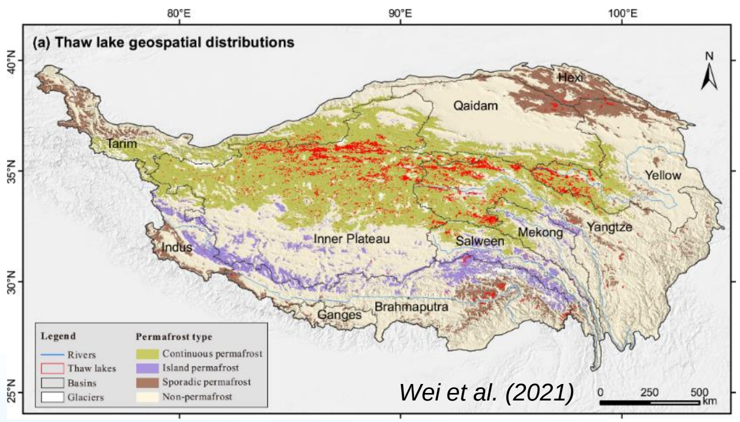
- **In total, 2669 active retrogressive thaw slumps (RTSs) were identified in the permafrost regions of the QTP between 2018 and 2020;**
- **The number of RTSs increased and RTSs covered a wider surface area from 2008 to 2021. The increases mainly occurred in 2010 and 2016.**



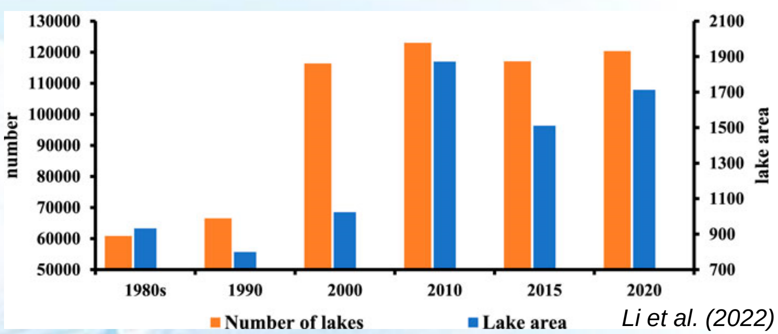
Changes in the number of Retrogressive thaw slumps (RTSs) from 2008 to 2021

Permafrost changes in the Third Pole

Thermokarst Lakes



Geospatial distribution of thaw lakes on the Third Pole permafrost regions



Number and area of thermokarst lakes in the Third Pole, 1980s–2020.

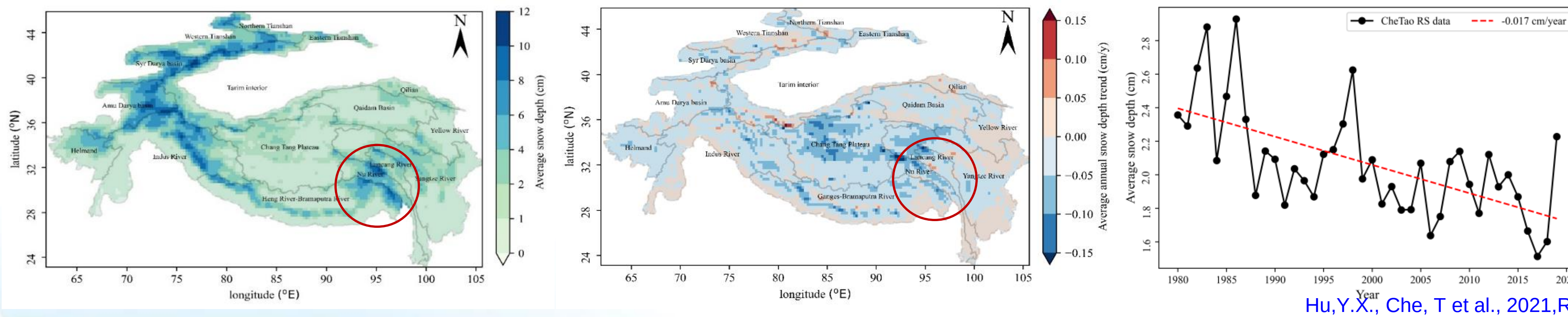
- **The number of thermokarst lakes continued to increase from the 1980s to 2010, but showed a slight downward trend from 2010 to 2020**

- **From the 1980s to 1990, the area of the lakes decreased from 932.5 km^2 to 799.25 km^2, and in 2010, the area of the lakes had increased to a peak of 1871.94 km^2, more than double the area in the 1980s**

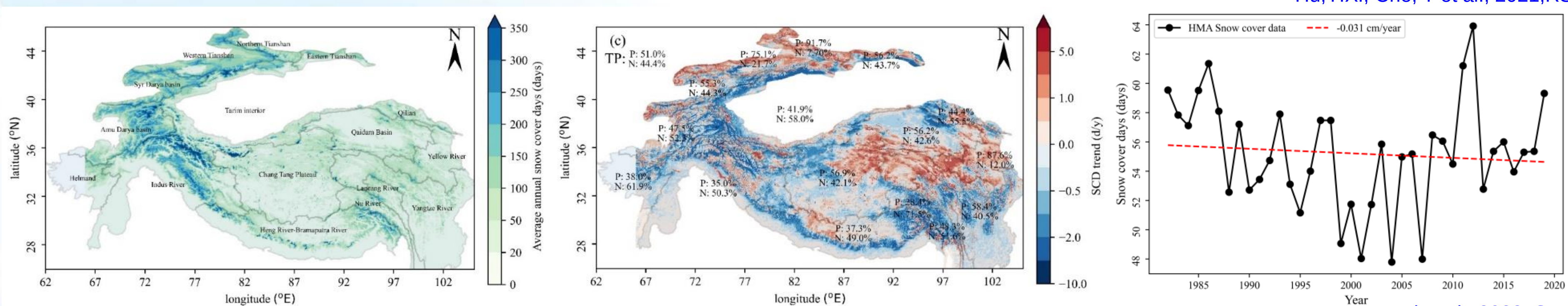
- **From 2010 to 2015, the area of the lakes decreased to 1511.12 km^2 and then increased to 1703.56 km^2 in 2020**

Snow cover changes in the Third Pole

- **Snow cover mainly distributed in the mountain regions.**
- **Snow depth and snow cover days decreasing during last 40 years.**



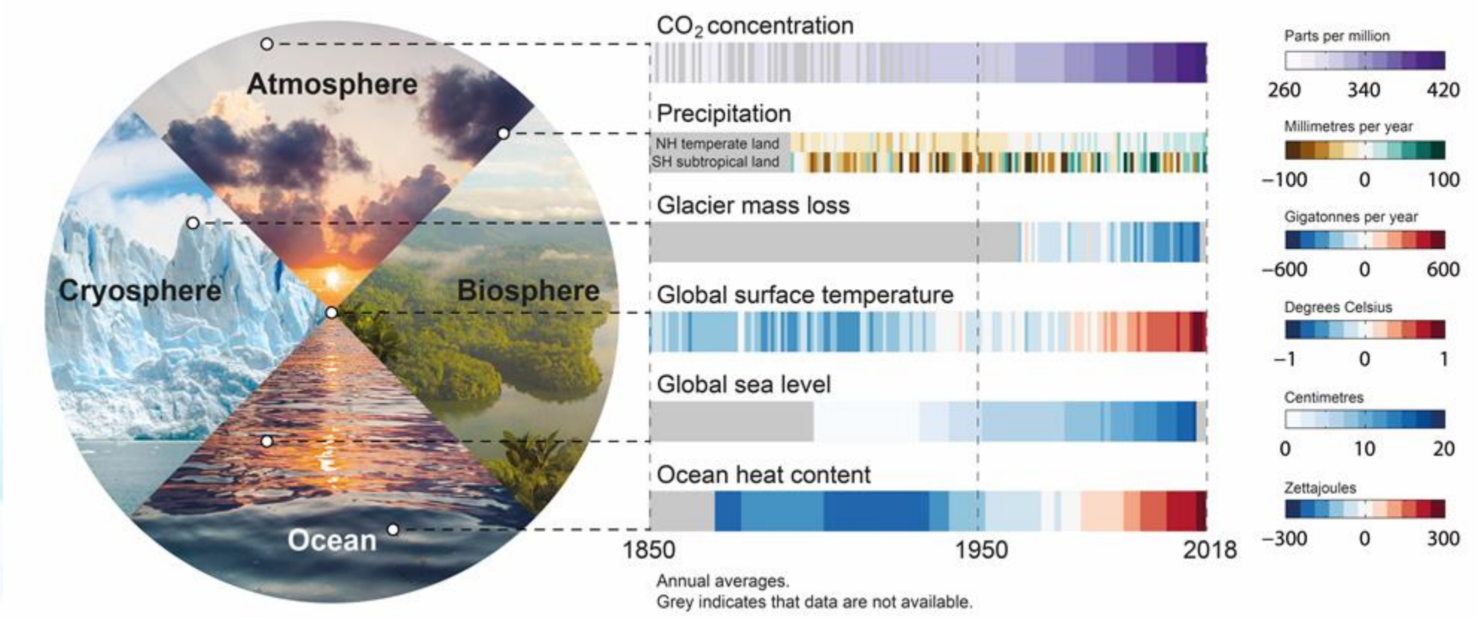
Hu,Y.X., Che, T et al., 2021,RS



Li et al., 2023, SB

Warming of the climate system is unequivocal

Recent changes in the climate system are widespread, rapid, intensifying, and unprecedented in thousands of years.



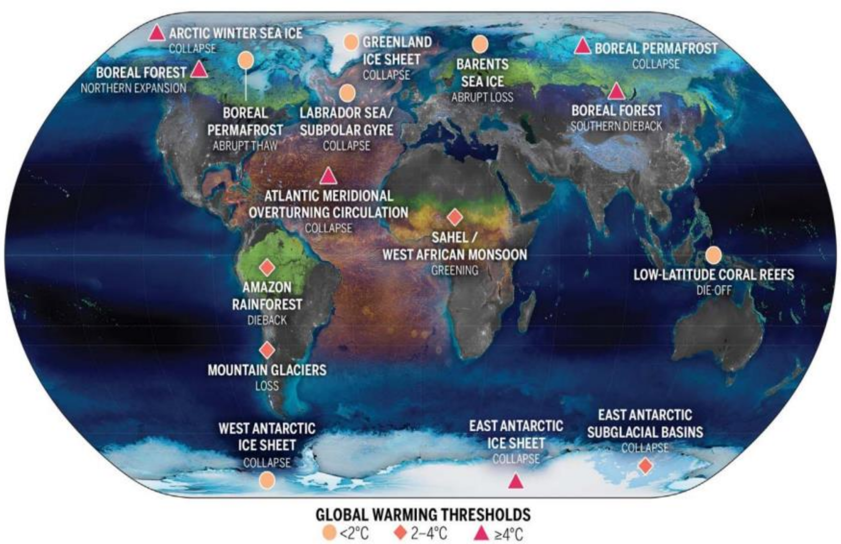
- **CO_2 (2 Ma)**
- **CH_4 and N_2O (0.8 Ma)**
- **Global surface temperature (2000 a)**
- **Ocean warming rate (11 ka)**
- **Glacier (2000a)**
- **Arctic sea ice (1000 a)**
- **Global sea level (3000 a)**

What happens if all the ice on the planet melts?

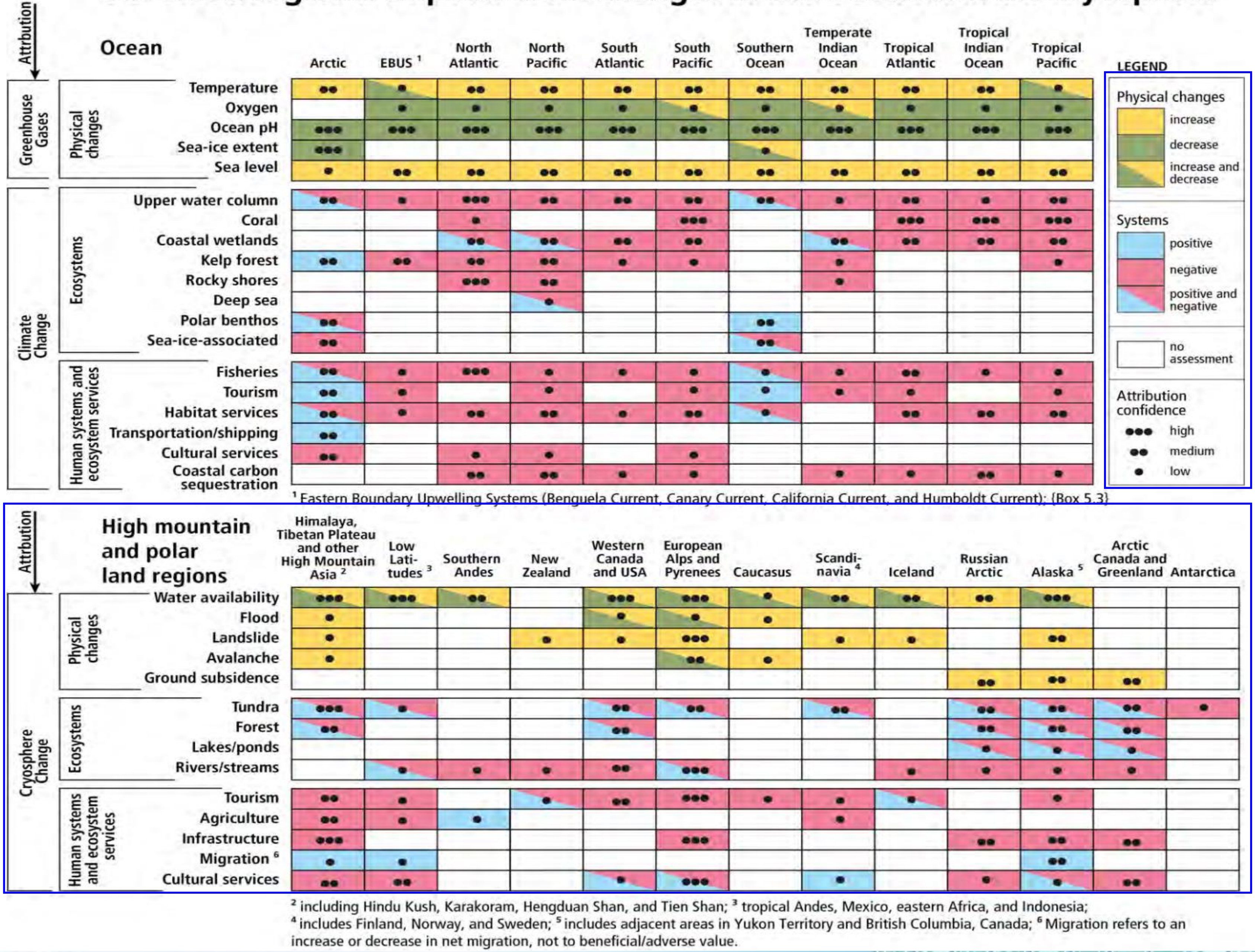
If all the ice on the planet melts, sea level will rise 70 meters (230 feet), and every coastal city on the planet will flood.

Climate tipping elements 16
Cryospheric related elements 9

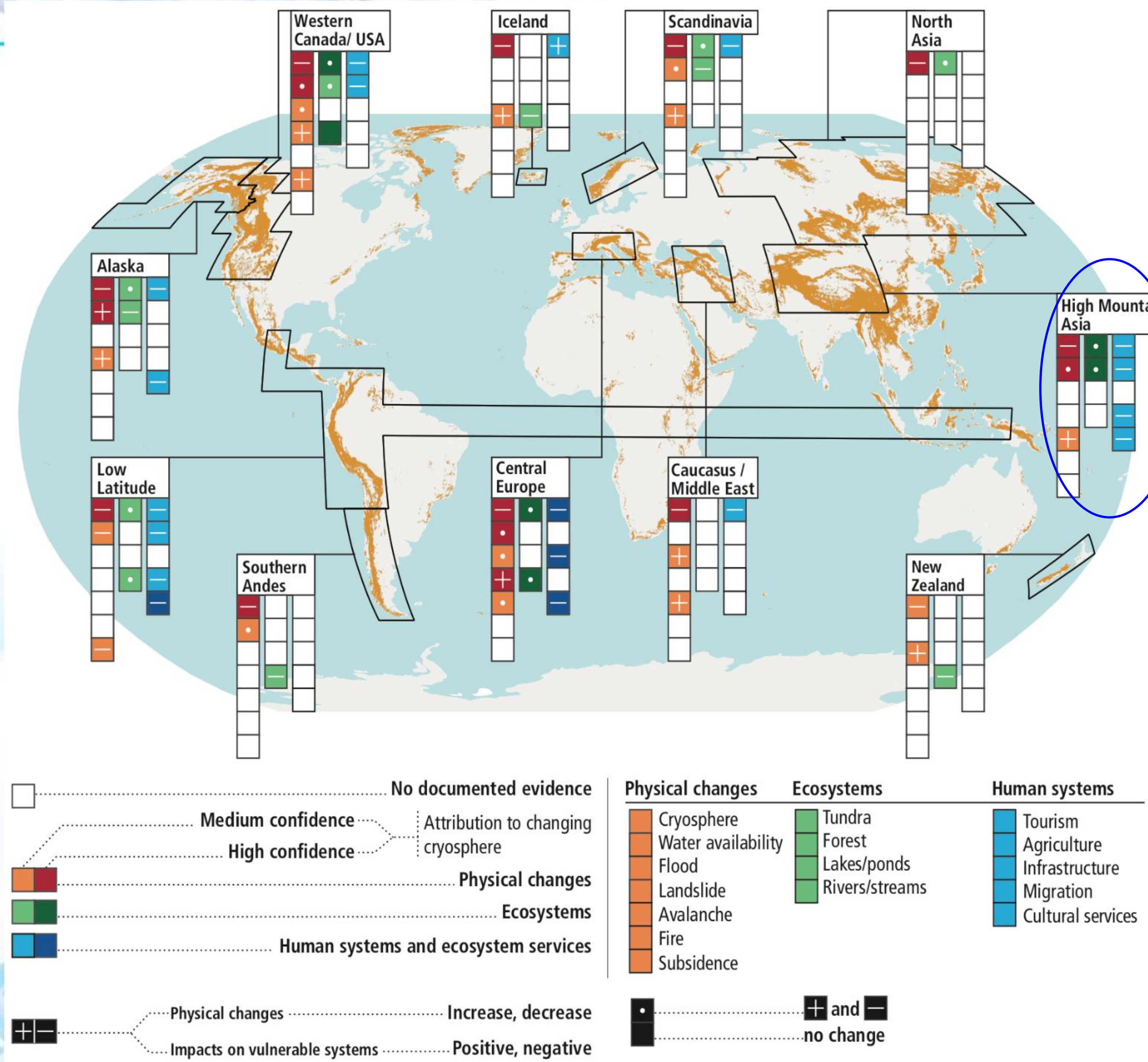
The location of climate tipping elements in the cryosphere (blue), biosphere (green), and ocean/atmosphere (orange), and global warming levels at which their tipping points will likely be triggered. Pins are colored according to our central global warming threshold estimate being below 2°C, i.e., within the Paris Agreement range (light orange, circles); between 2 and 4°C, i.e., accessible with current policies (orange, diamonds); and 4°C and above (red, triangles).



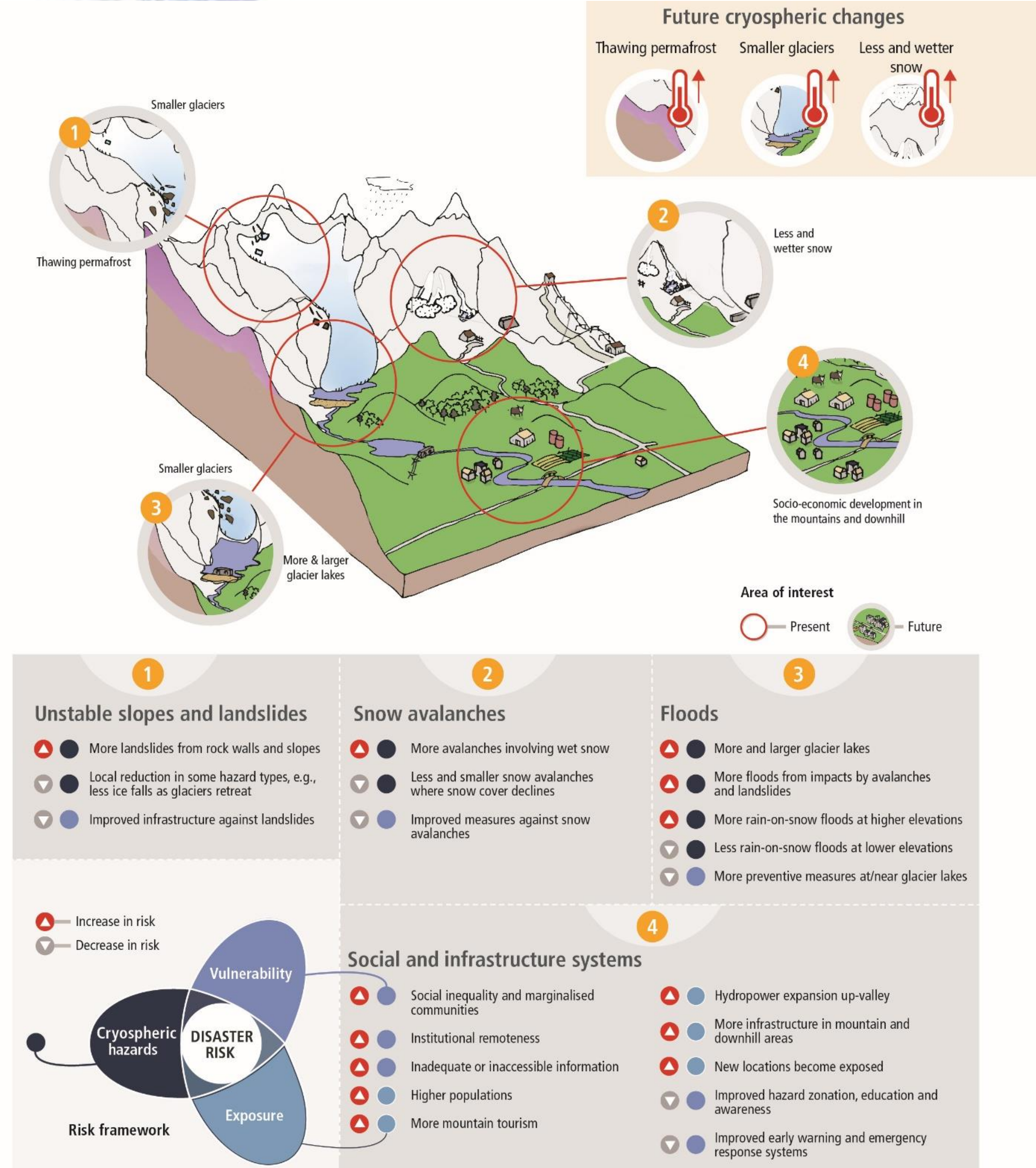
Observed regional impacts from changes in the ocean and the cryosphere



IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, B. Rama, N. Weyer (eds.)]. In press.



Observed changes in the cryosphere and impacts on ecosystems, other natural systems and human systems over past decades that can at least partly be attributed to changes in the cryosphere. Only observations documented in the scientific literature are shown, but impacts may also be experienced elsewhere. Shading denotes mountainous areas. Confidence levels (*high* shown by filled; *medium* shown by unfilled tetrix boxes) refer to confidence in attribution to cryospheric changes.



Anticipated changes in high mountain hazards under climate change, driven by changes in snow cover, glaciers and permafrost, overlay changes in the exposure and vulnerability of individuals, communities, and mountain infrastructure.

- Development of Cryospheric Science
- Climate Change Drives the Development of Cryospheric Science
- **The Earth System Promotes Cryospheric Science**

Earth System:

SKLCS

Earth System: as the suite of interlinked physical, chemical, biological and human processes that cycle (transport and transform) materials and energy in complex, dynamic ways within the system *(Steffen et al., 2006)*.

1. Forcings and feedbacks within the system, including biological processes, are as important to its functioning as external drivers.
2. Human activities are an integral part of system functioning *(Steffen et al., 2020)*.

Amsterdam Declaration (2001): **the focus was on recognizing the earth as a single system with its own inherent dynamics and properties at the planetary level, all of which are threatened by human-driven global change. The declaration concluded that:**

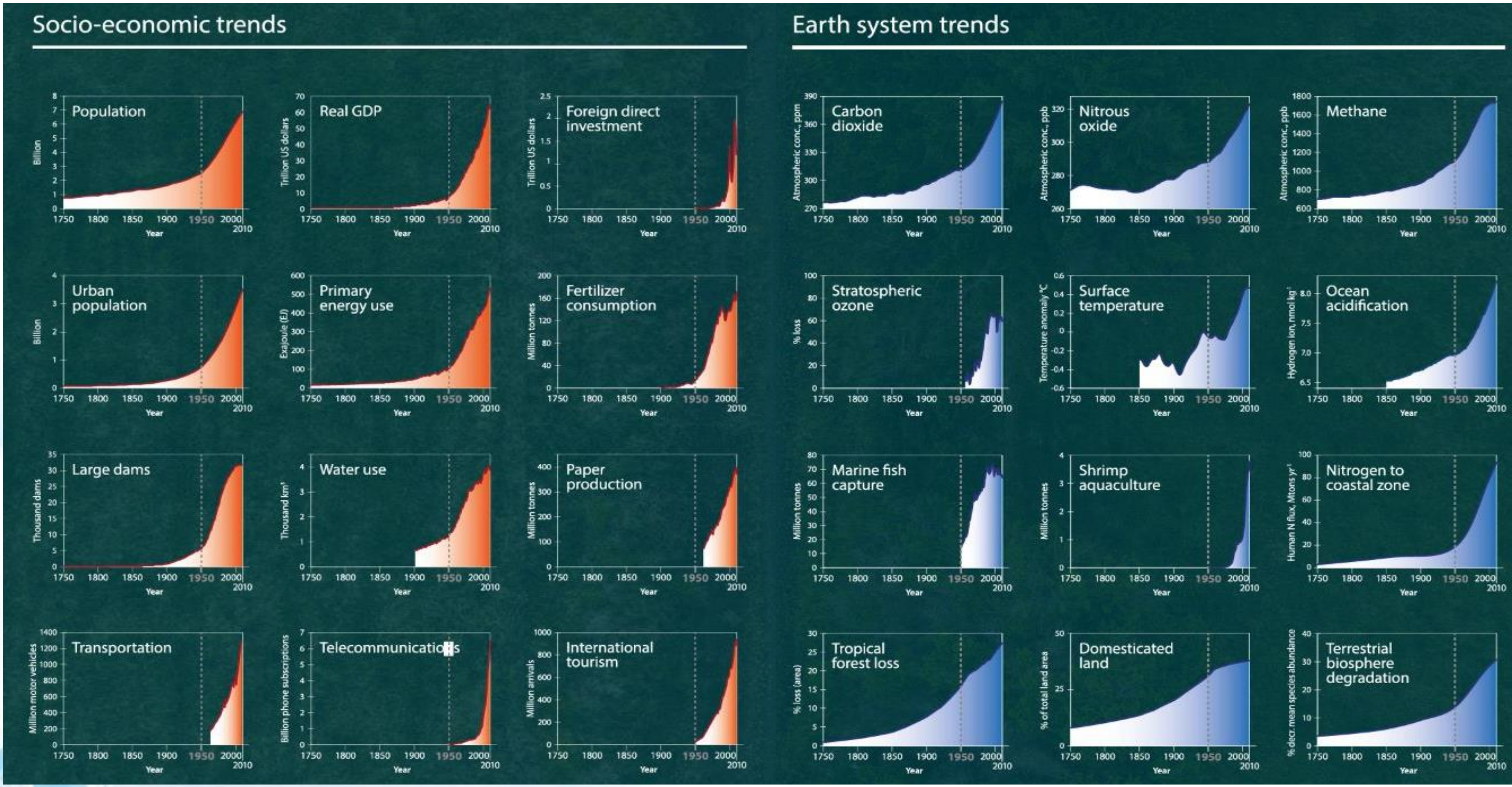
1. **The Earth System behaves as a single, self-regulating system *comprised of physical, chemical, biological and human components*, with complex interactions and feedbacks between the component parts.**
2. **Global change is real and it is happening now. Human-driven changes to Earth's land surface, oceans, coasts and atmosphere, and to biological diversity, are equal to some of the great forces of nature in their extent and impact.**
3. **Global change cannot be understood in terms of a simple cause–effect paradigm. Human-driven changes cause multiple, complex effects that cascade through the Earth System.**
4. **Earth-System dynamics are characterized by *critical thresholds and abrupt changes*. Human activities could inadvertently trigger such changes and potentially switch the Earth system to alternative modes of operation that may prove irreversible and less hospitable to humans and other forms of life.**
5. **The nature of changes now occurring simultaneously in the Earth System, as well as their magnitudes and rates of change, are unprecedented. *The Earth System is currently operating in a no-analogue state.***

Large acceleration！！！

Anthropocene！？

SKLCS

Other elements of the Earth system have also undergone significant changes



In January 2023 at the Davos Winter Forum, Earth Commission co-chairs Prof. Johan Rockström and Prof. Joyeeta Gupta presented the framework and scientific detail of Earth system boundaries in their presentation, *'Leading the Charge through Earth's New Normal'.*

《Safe and just Earth system boundaries》

The result of our work with over 50 scholarly colleagues from across the globe - some of whom are pictured here at our recent Swedish Royal Academy of Sciences launch - is a suite of “Safe and Just Earth System Boundaries”.

Article

Safe and just Earth system boundaries

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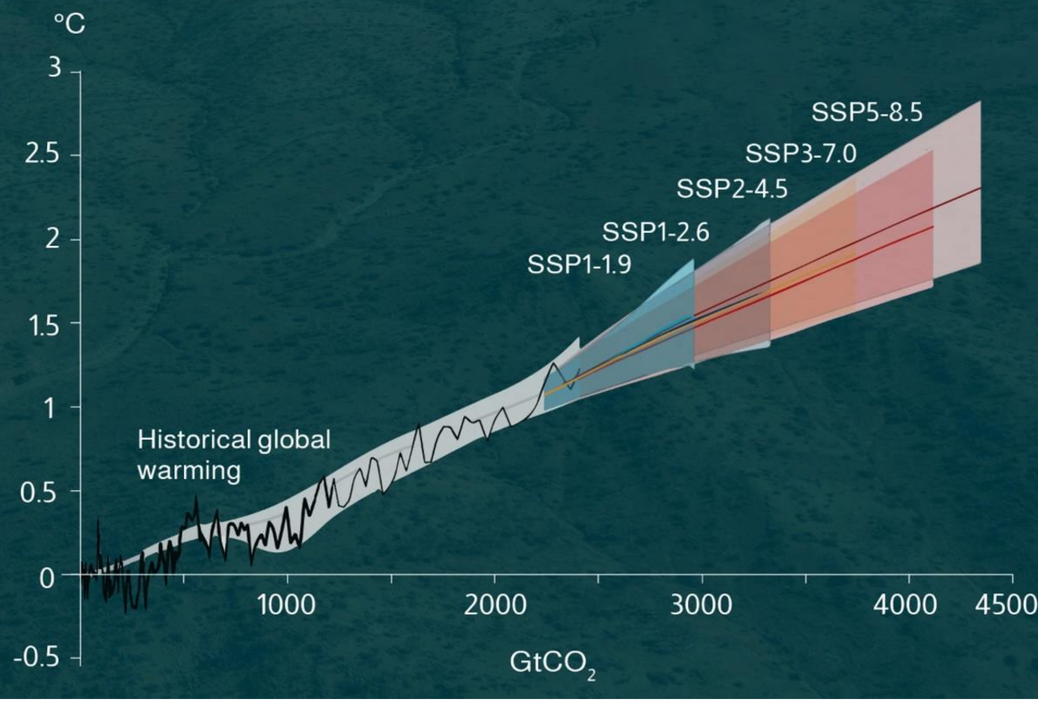
The stability and resilience of the Earth system and human well-being are inseparably linked[1–3], yet their interdependencies are generally under-recognized; consequently, they are often treated independently[4,5]. Here, we use modelling and literature assessment to quantify safe and just Earth system boundaries (ESBs) for climate, the biosphere, water and nutrient cycles, and aerosols at global and subglobal scales. We propose ESBs for maintaining the resilience and stability of the Earth system (safe ESBs) and minimizing exposure to significant harm to humans from Earth system change (a necessary but not sufficient condition for justice)[4]. The stricter of the safe or just boundaries sets the integrated safe and just ESB. Our findings show that justice considerations constrain the integrated ESBs more than safety considerations for climate and atmospheric aerosol loading. Seven of eight globally quantified safe and

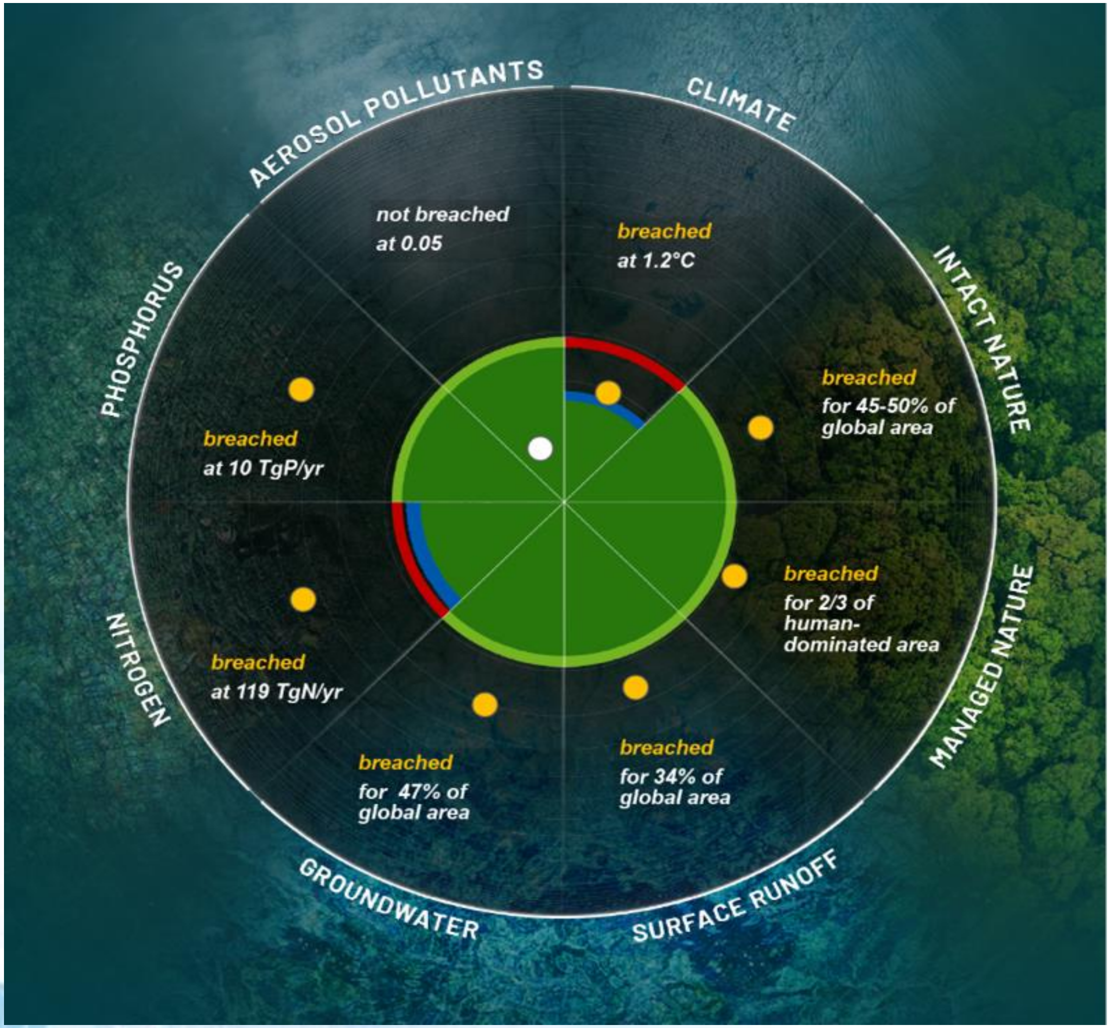
GLOBAL SURFACE TEMPERATURE INCREASE SINCE 1850-1900



Science shows that global warming of 1.5 ℃ and 2 ℃ will be exceeded this century unless deep reductions in CO_2 and other greenhouse gasses occur rapidly in the coming decades.

Achieving global net zero CO_2 emissions is a requirement for stabilizing the global surface temperature.

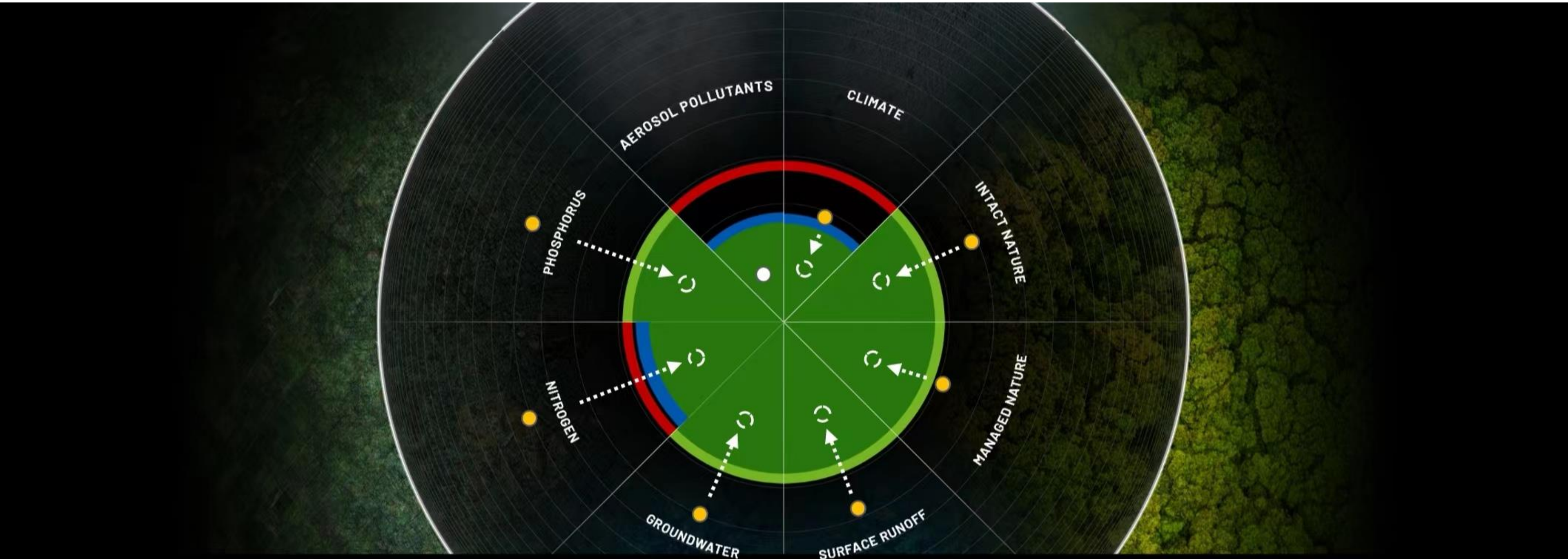
Current status of global Earth system boundaries



The sobering news: the assessment identifies that human activities have pushed seven Earth system boundaries beyond their thresholds and into the risk zone.

The good news: The safe and just *boundaries* account for Earth system resilience and human wellbeing in an integrated framework to help actors meet these challenges.

We have a short period of time - a window of opportunity - to take responsibility and urgent action, and start moving towards the "safe and just space".



HOW CAN WE LIVE *WITHIN* THE SAFE AND JUST EARTH SYSTEM BOUNDARIES?

The science calls on leaders-ministers, mayors and CEOs, to do three things:

1) Think beyond climate- take a whole-earth approach to sustainability, understand impacts, and set targets across Earth system domains.

2) Factor in people - measure impacts on people as well as the planet, and take action to improve wellbeing and reduce inequalities.

3) Finally, work together - Our upcoming analysis shows the top 200 large emitter cities and top 500 emitter companies often co-locate. But they are not necessarily working together. There is a large, untapped opportunity for these cities and companies to bring their target ambition abreast.

Take home message

- ☐ Cryospheric Science is transdisciplinary and integration
- ☐ Take action around the Earth system beyond climate change
- ☐ Do not miss the window of opportunity
- ☐ Integrating natural and social sciences, strengthening "export"

Thank you！