Remote Sensing of Lake Dynamics in the Context of Global Change: A Global Perspective

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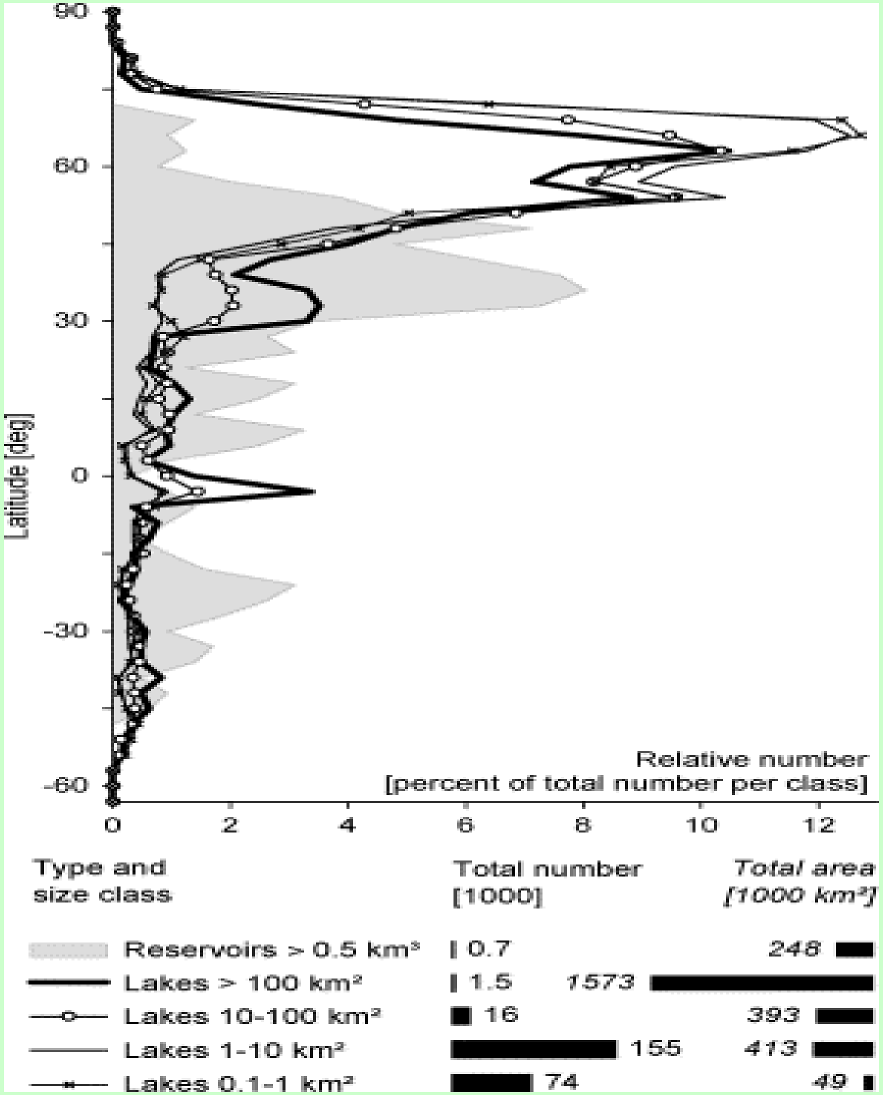
Global Lake Distribution from GLWD

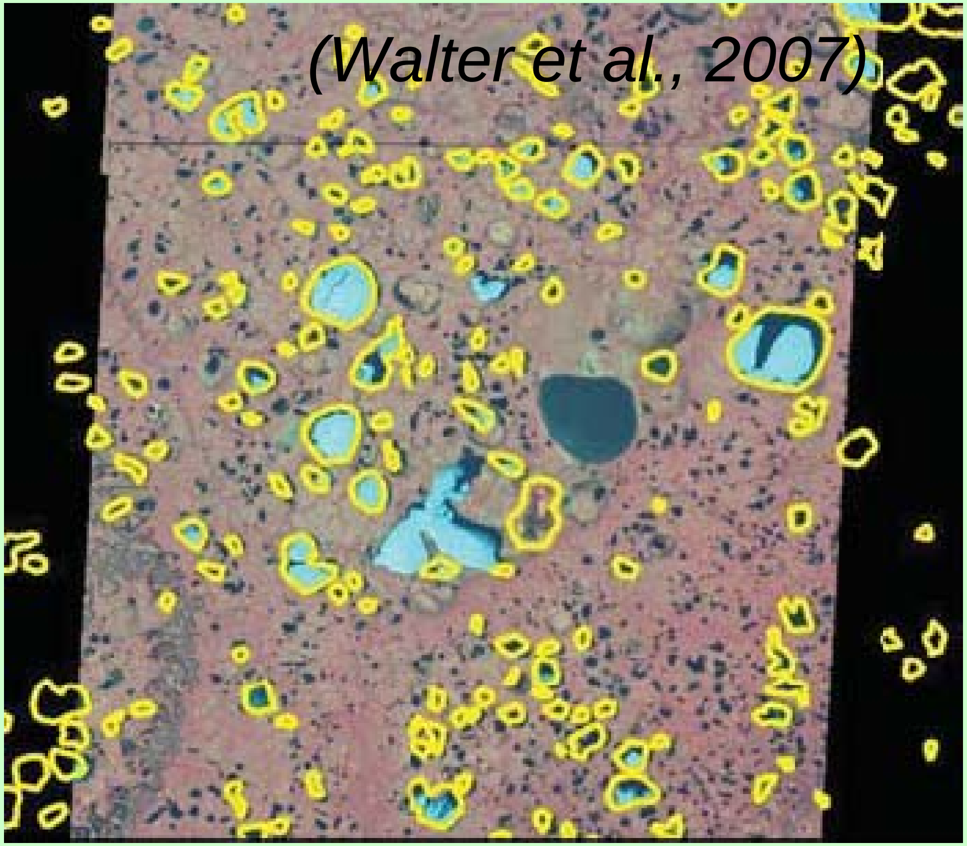


Source: GLWD (Lehner and Doll, 2004)

- ☑ ~250,000 lakes (>0.1 km^2)
- ☑ Largest group of lakes:
  - high-latitudes (> 45°N);
- ☑ Second largest:
  - 27 -- 42°N;
- ☑ … …
- ☑ Complied from various sources (1 : 1 to 3M):
  - DCW (1970s to 1990s);
  - Arc World (1992);
  - WCMC Wetlands map -- World Conservation Monitoring Center (1993)
- ☑ Currently best available data sets.

Problems of GLWD

- ☑ A good reference:
  - 250k lakes;
  - 2.4 million km²;
  - 1.8% density.
- ☑ Miss a lot of small lakes:
- ☑ Not a systematic inventory;
- ☑ Not addressing lake dynamics.



Another global lake estimate (Downing et al, 2006):

- Lake abundance: >300 million lakes;
- Total lake area: 4.6 million km^2;
- Lake area density: >3%.

Lake Dynamics

- Water & energy cycling;
- "measure, monitor, and forecast the US and global supplies of fresh water." (OSTP, 2004)
- Global warming:
  - How much have lakes changed?
  - What are the mechanisms?
  - What are the possible consequences?
- But, How?
  - Remote Sensing!

Our Current Critical Regions for Lake Dynamics Remote Sensing

- ☑ West Siberia (~ 0.5 M km^2);
- ☑ Pan-Arctic (~ 40 M km^2);
- ☑ Tibetan Plateau (~ 1.5 M km^2);
- ☑ All remote, under-populated, climate-sensitive.

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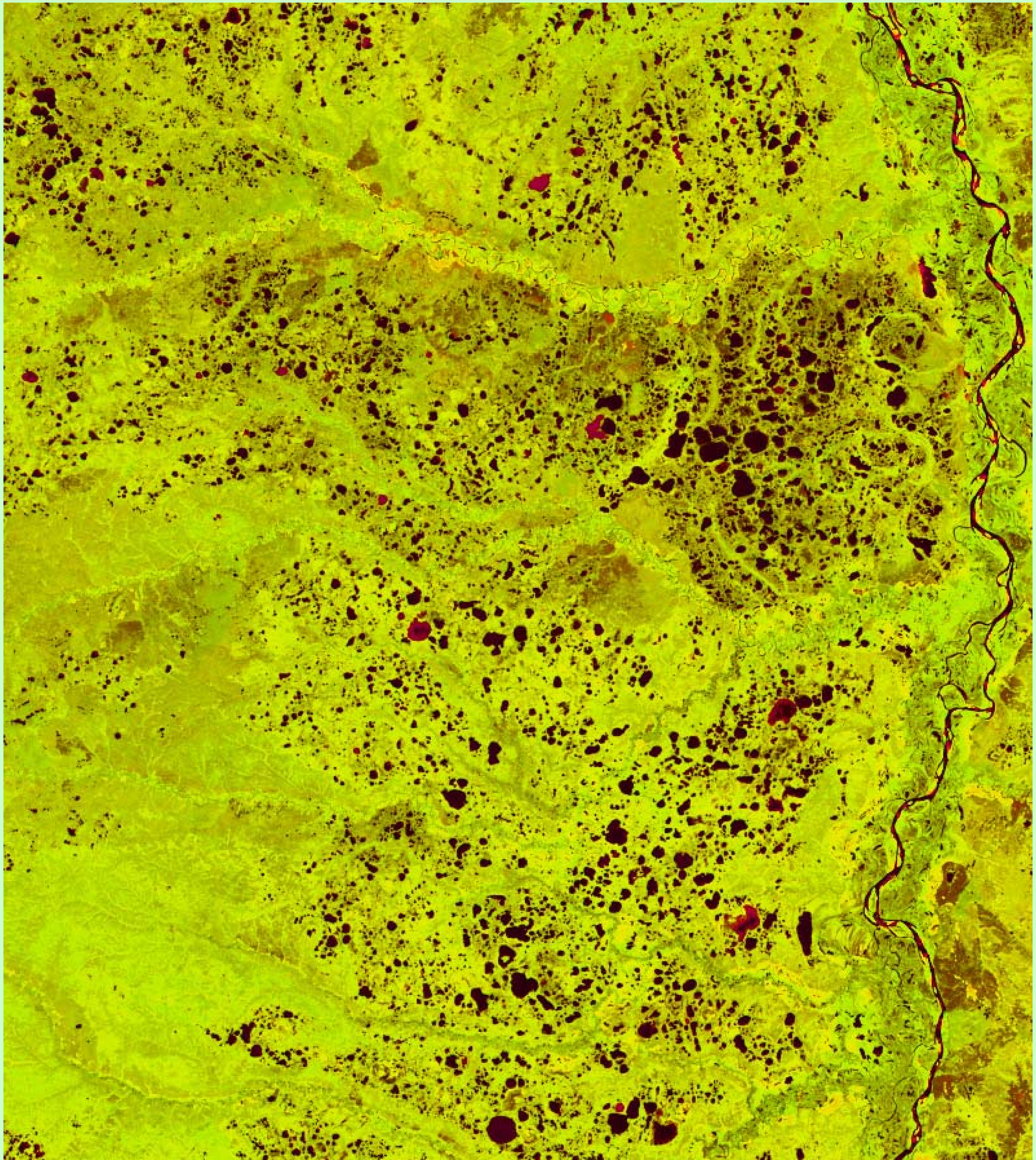
Local-Scale Arctic Lake Dynamics

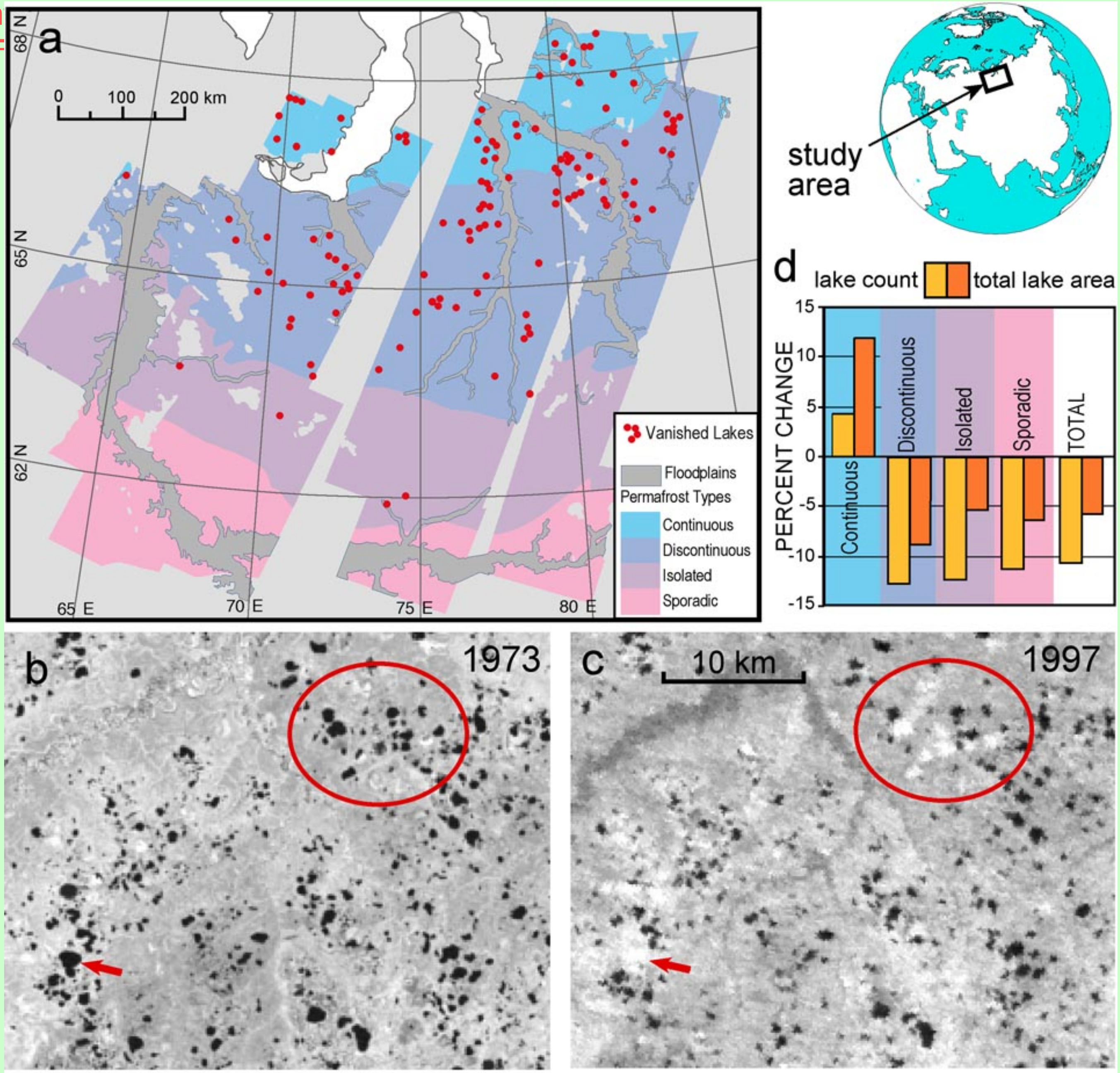
- Studies have recently used remote sensing, field work, and historical records to examine Arctic/sub-Arctic lakes changes during recent decades:
  - *Osterkamp et al., 2000*
  - *Jorgenson et al., 2001*
  - *Yoshikawa and Hinzman, 2003*
  - *Christensen et al., 2004*
  - *Payette et al., 2004*
  - *Stow et al., 2004*
  - *Marsh et al 2005.*
- Most of them are done at local scale.
- Does lake dynamics exhibit a pattern?

Regional-scale Lake Dynamics in West Siberia

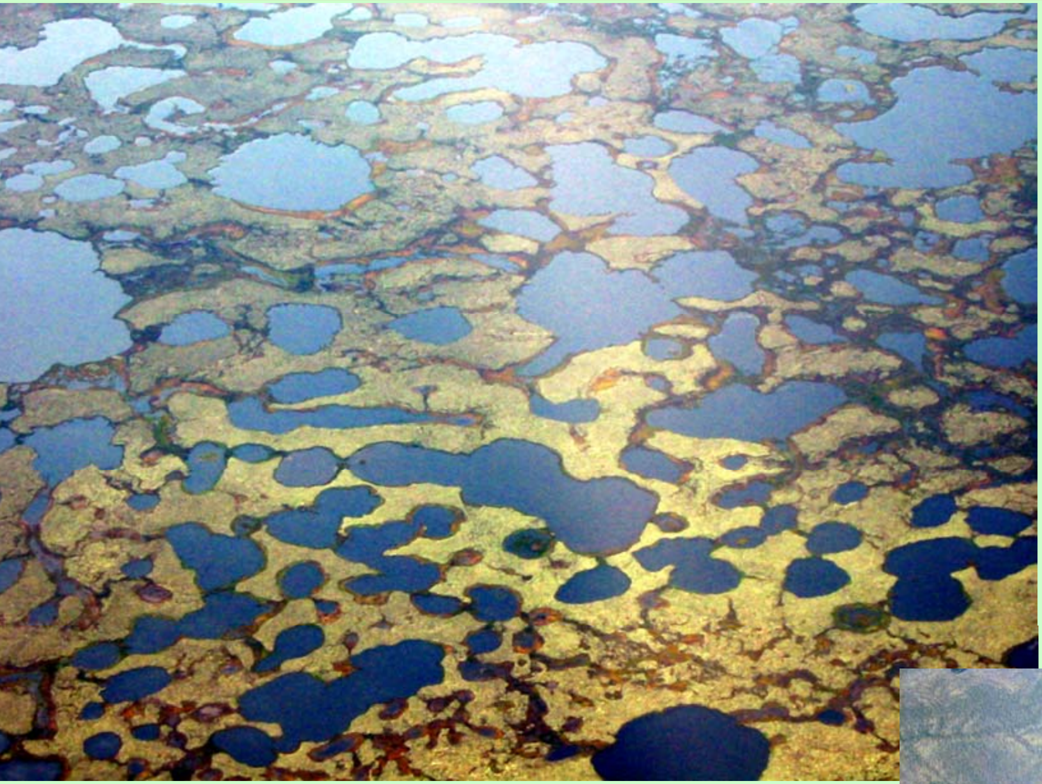
- ☑ Satellite-based inventory of an area > 0.5 million km².
- ☑ 1973 MSS imagery vs. 1997/98 RESURS imagery.



Inventory of ~10,000 large Siberian lakes (1973-1998) reveals lake growth in continuous permafrost but disappearance in discontinuous, isolated and sporadic permafrost



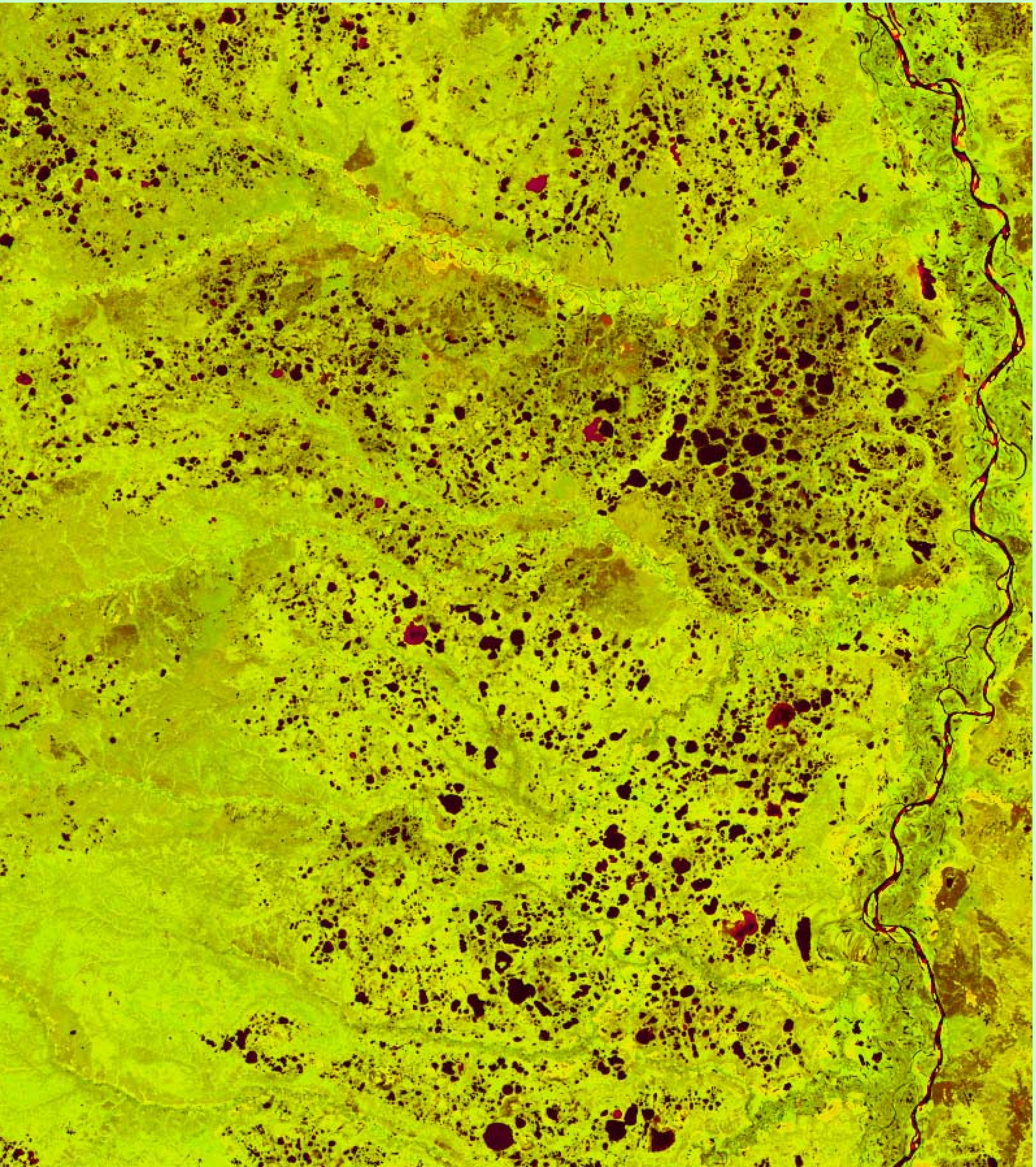
("Disappearing Arctic Lakes," Smith et al., Science, 2005)



Ground Confirmation

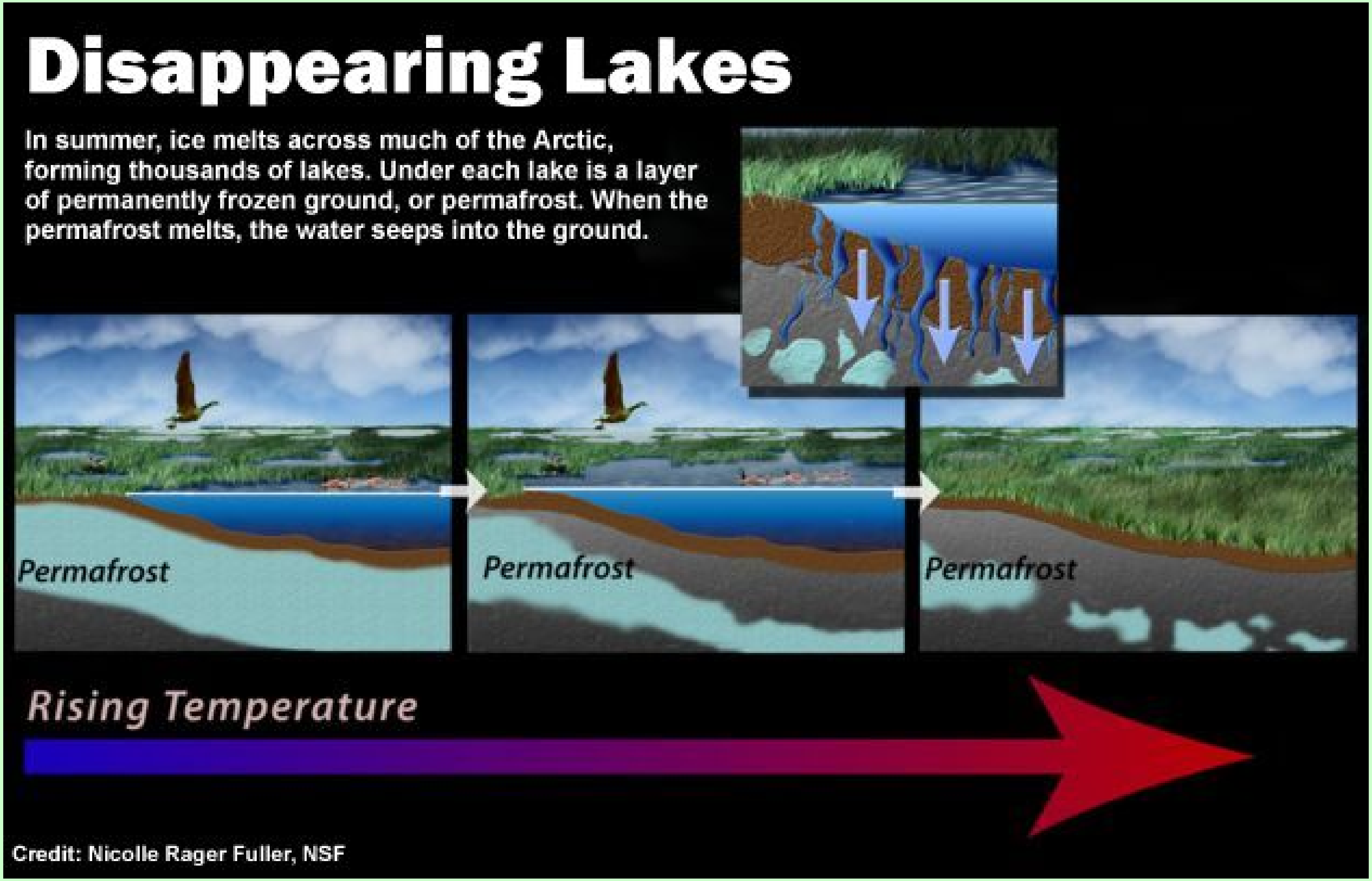
lake expansion (northern, continuous permafrost)

lake shrinking further south



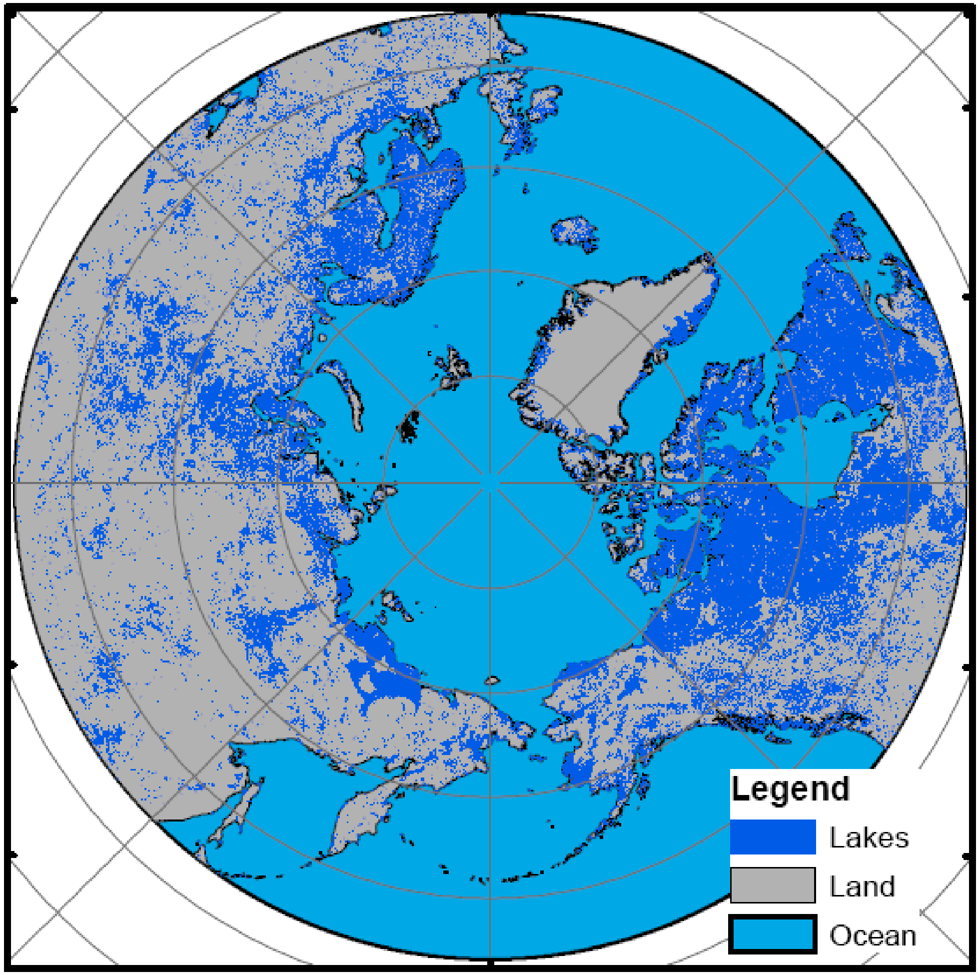
- ☑ 125 disappeared lakes (> 0.4 km^2) were detected!
- ☑ No new lakes.

Mechanism for Arctic Disappearing Lakes



Remote Sensing of Pan-Arctic Lakes

- ☑ *~200,000 lakes (sized 0.1 – 50 km², GLWD) northwards of 45°N*
- ☑ *Regional scale studies:*
  - *5,400 km² lake change detection in western Arctic coast of Canada (Marsh et al, 2005);*
  - *34,570 km² lake mapping in North Slope of Alaska (Frohn, Hinkel et al, 2005; Hinkel et al, 2007);*
  - *515,000 km² lake change detection in West Siberia (Smith, Sheng et al., 2005).*



Lake Changes at Pan-Arctic Scale

- 45°N and north:
  - Peak in the global lake distribution;
  - 45°N: about the southern limit of permafrost zones;
  - Coverage:
    - 73 million km^2, 1/7 of the Earth's surface;
    - 41 million km^2 of land, ~1/4 of the Earth's land surface.
- So far only <2.5% of the high-latitude land surface has been studied for lake change-detection.
- ***"How have northern lakes responded to rising Arctic temperatures?"***
- Arctic lake changes would have significant ramifications for hydrology, ecology, carbon cycle, and so on.

Requirements to Arctic Lake Remote Sensing

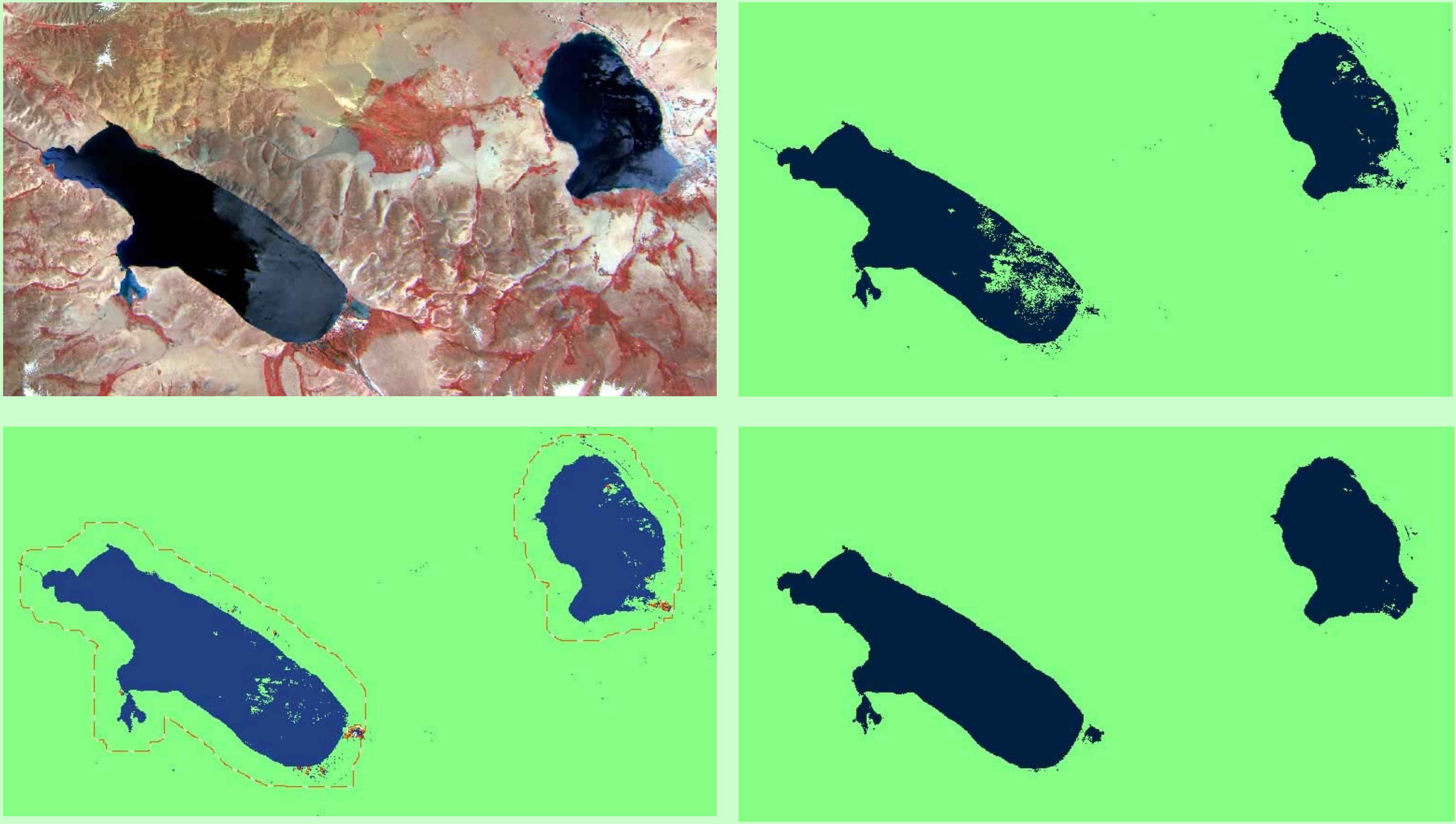
- Characteristics of Arctic lakes:
  - Abundant in number;
  - Small in size;
  - Shallow in depth;
  - Frozen most of the time;
  - Low-relief landscapes.
- Requirements to remote sensing:
  - Many, high-resolution, summer images!
  - Pan-Arctic lake mapping requires ~1,800 scenes of cloud-free Landsat images acquired in summer season for each change detection episode.
  - Automation!

Critical Technologies and Automation

- ☑ Precise image co-registration;
- ☑ Accurate lake mapping;
- ☑ Detailed change detection.

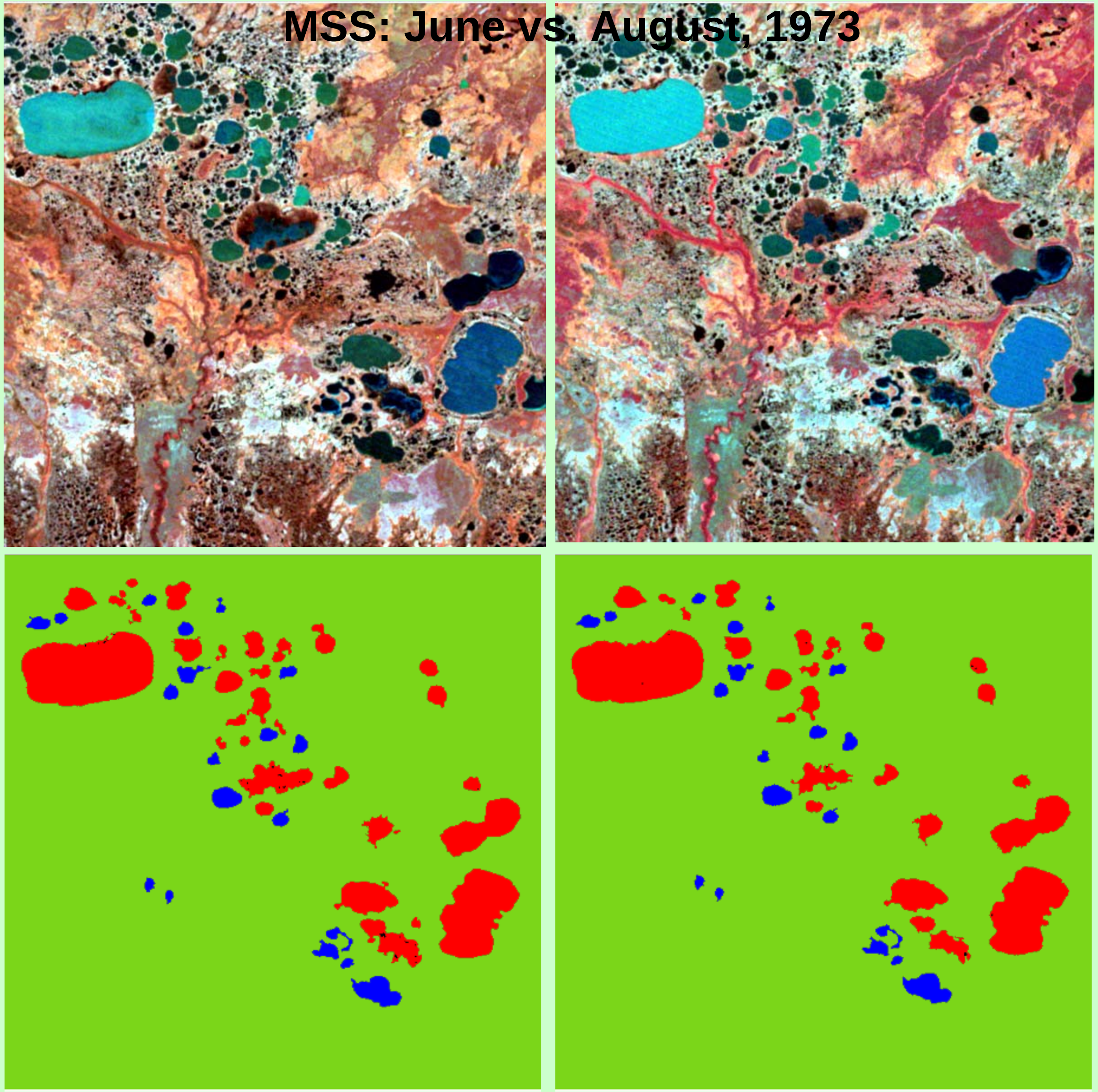
Hierarchical Lake Mapping

☑ Global segmentation and local adjustment

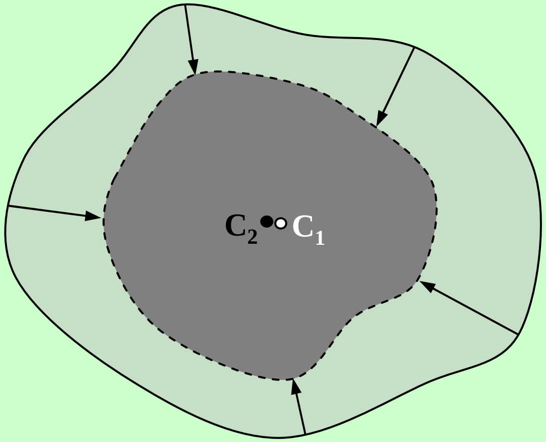


Automated PIF-based Image Co-registration

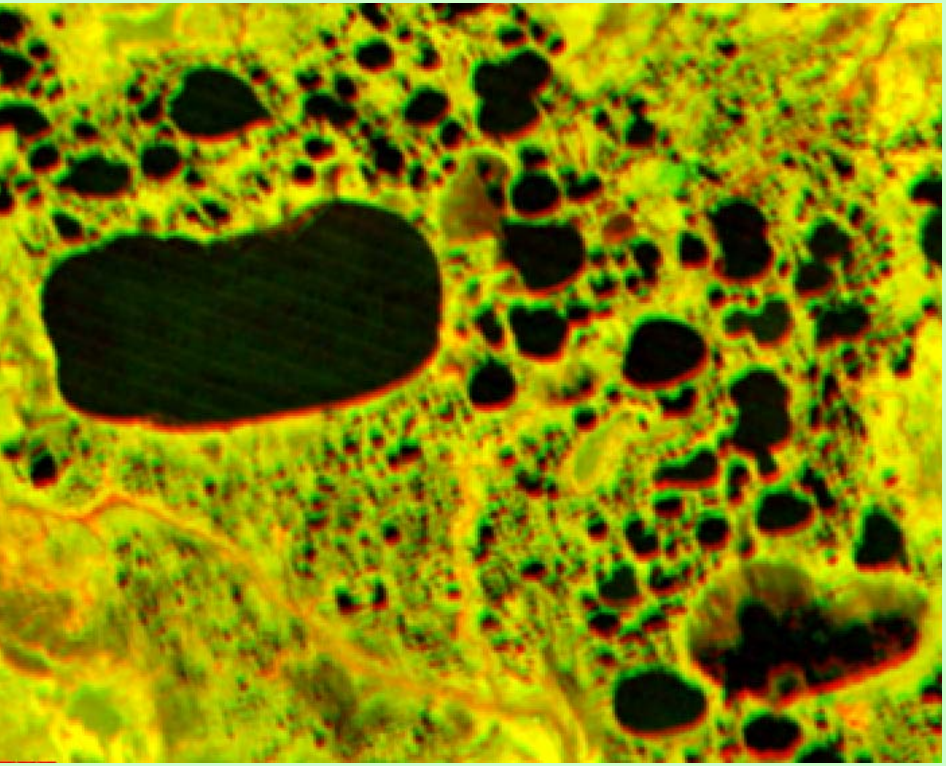
MSS: June vs. August, 1973



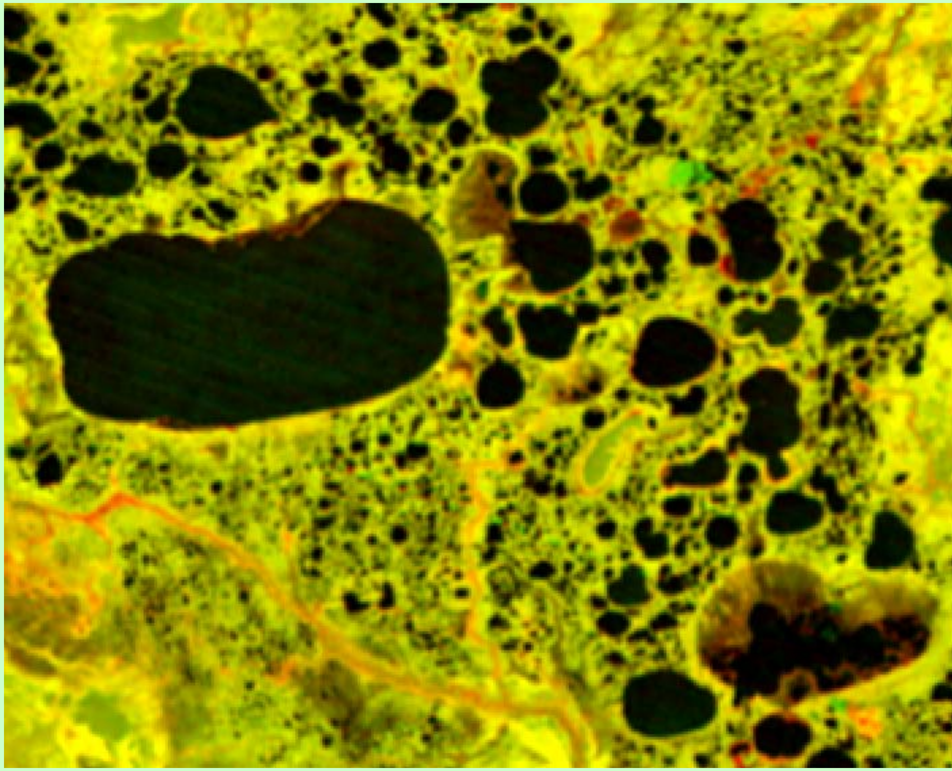
PIF: pseudo invariant features



RMSE = 0.27 pixel

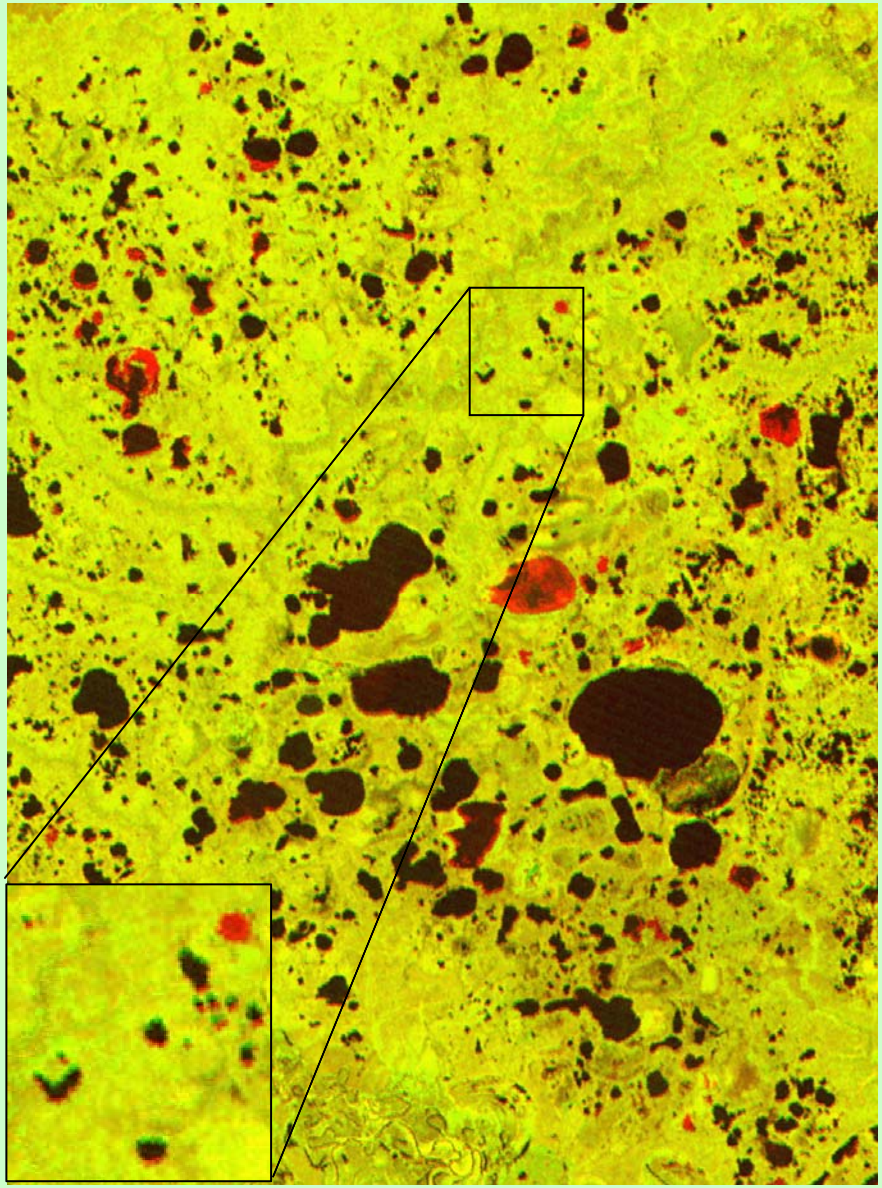


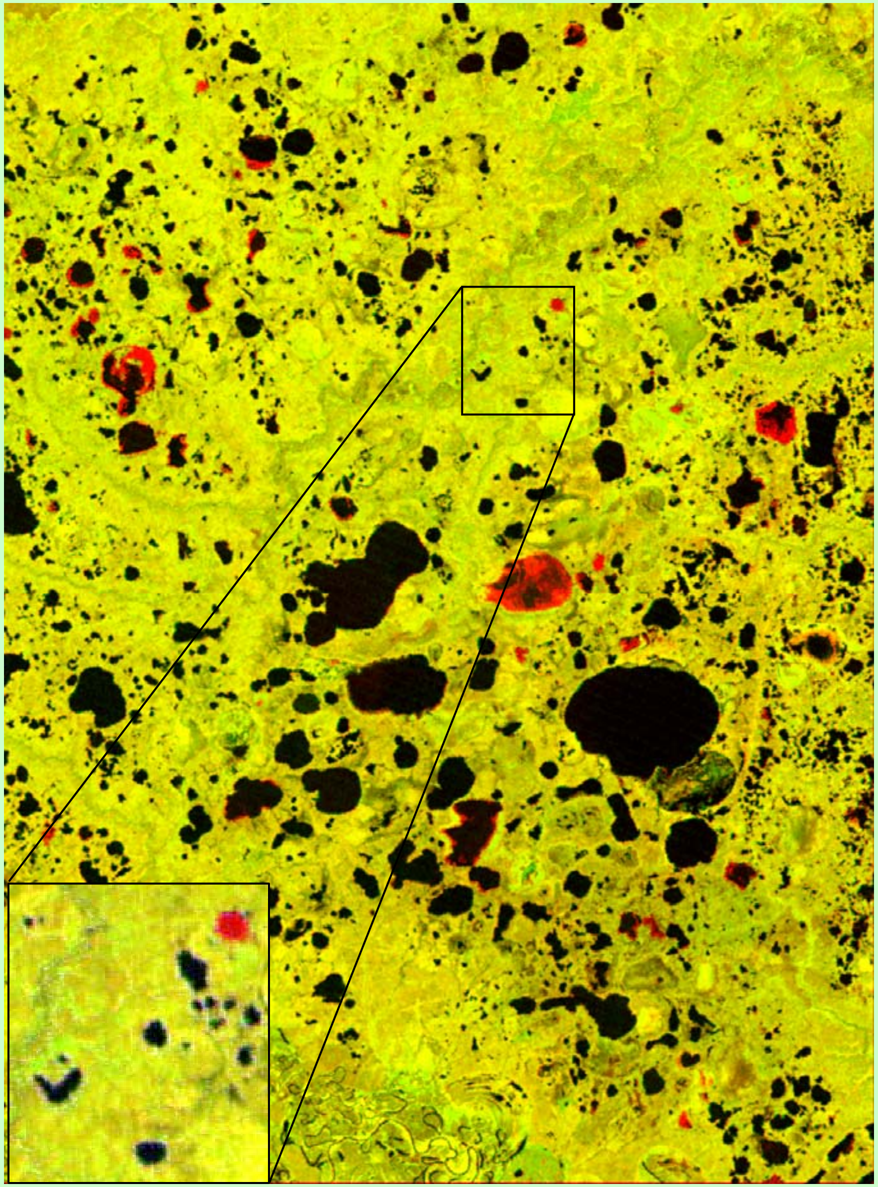
Before



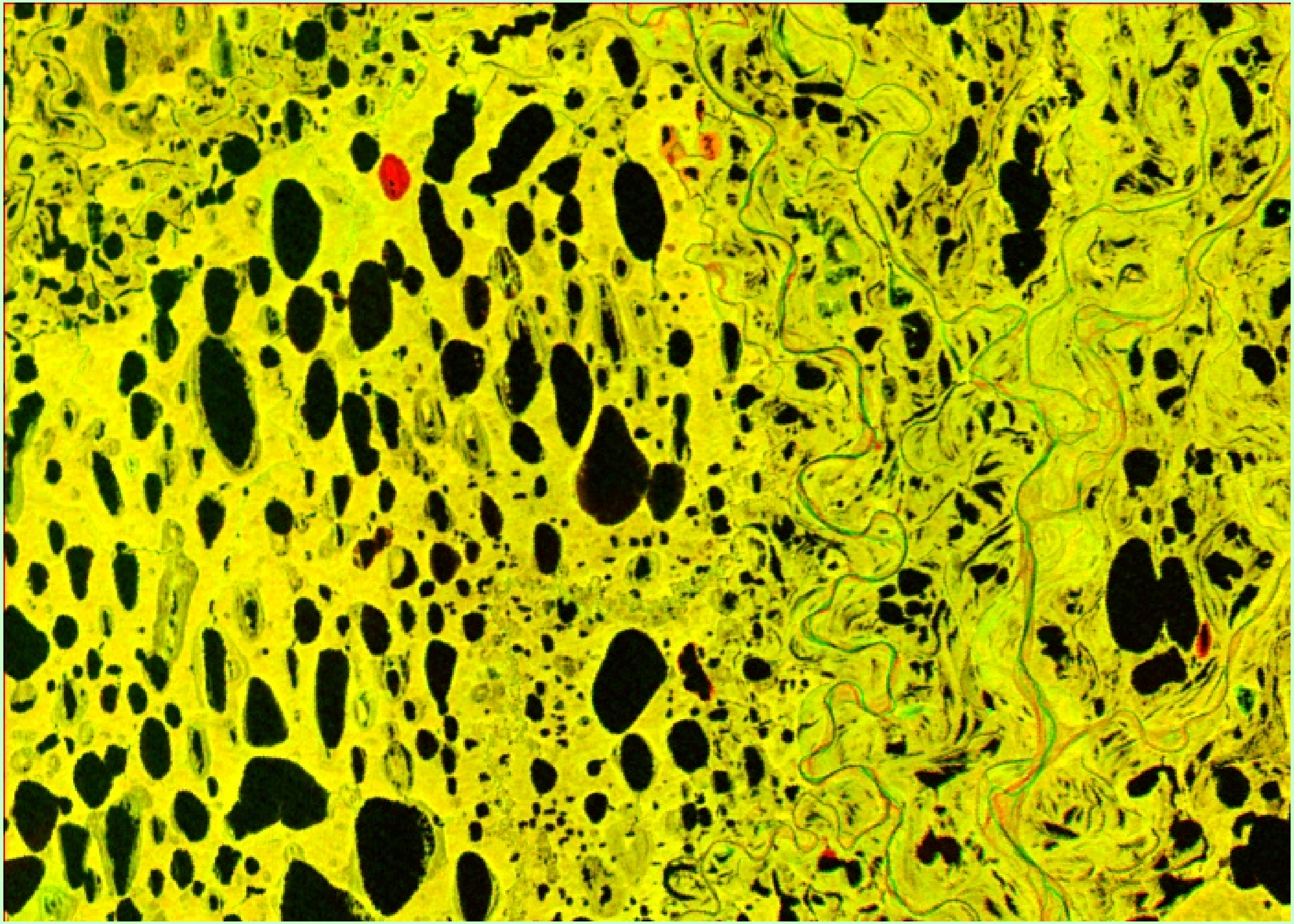
After

MSS with TM

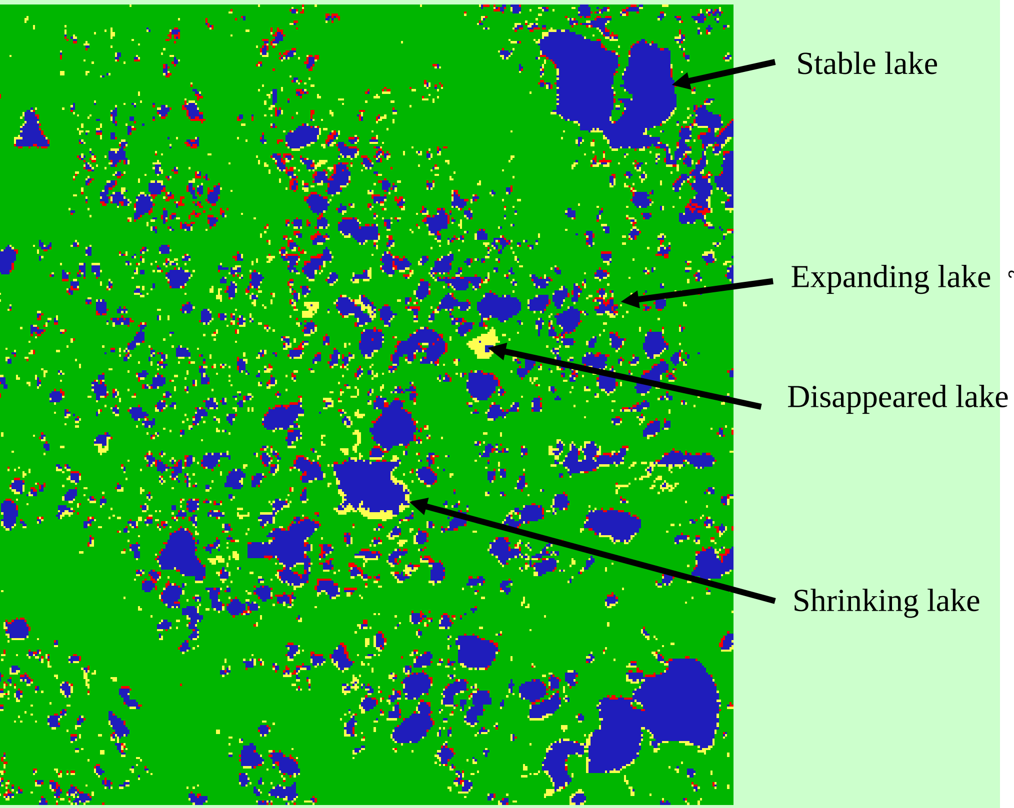


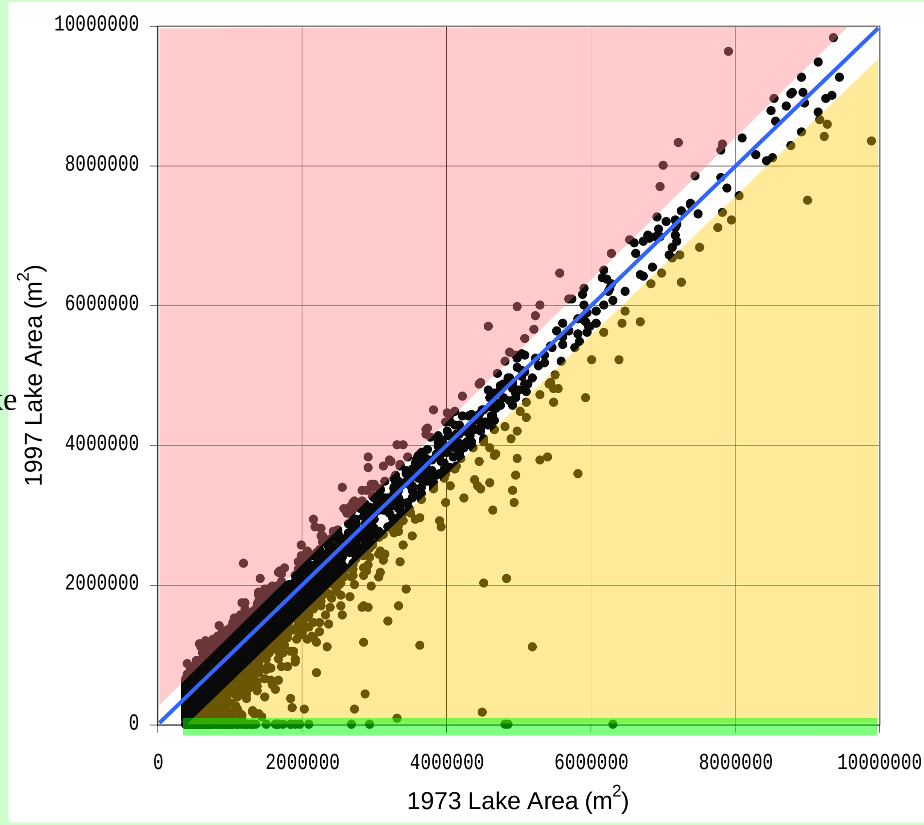


1974 MSS and 2002 ETM+ (0.24 pixel) Alaskan ACP (70.46°N, 155.25°W)



Multi-Decadal Lake Change Record

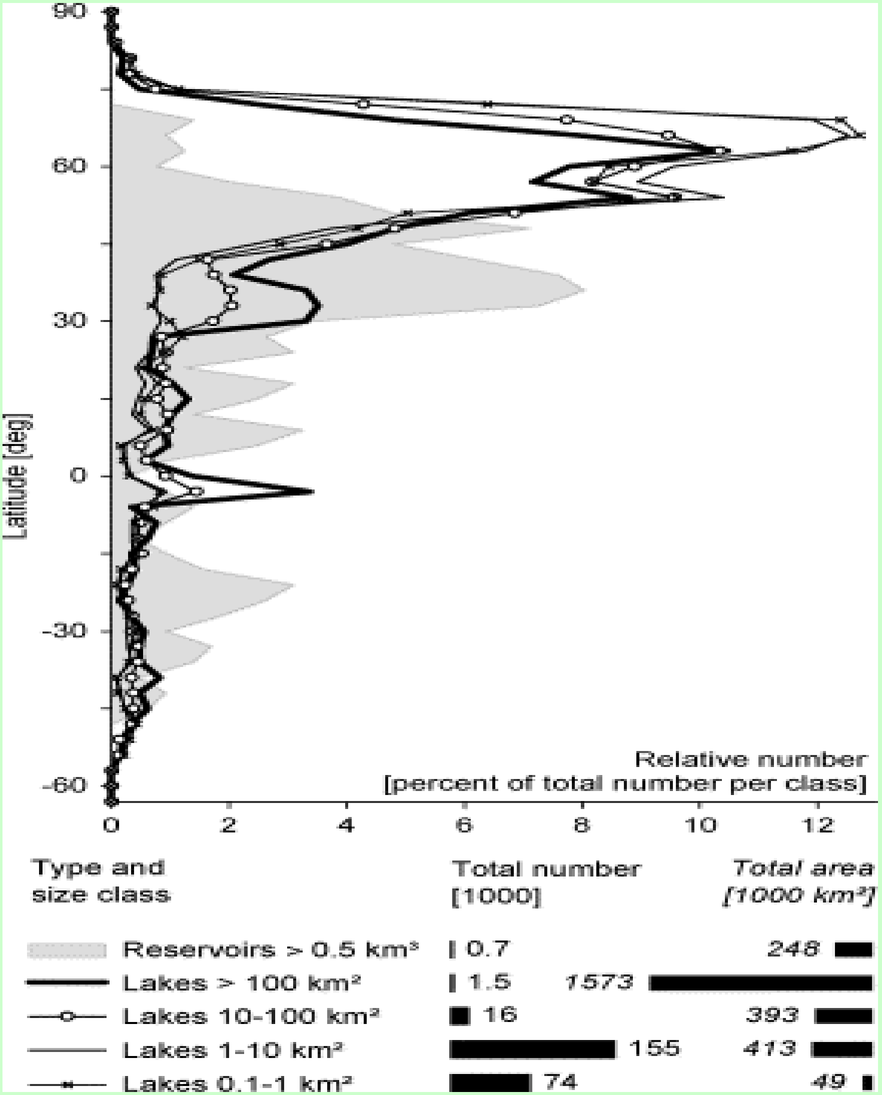




Expected Results from Pan-Arctic Studies

- ☑ Systematic inventory of high-latitude lakes;
- ☑ Metrics on lake dynamics.
- ☑ Science questions and Hypotheses:
  - “How have northern lakes and wetlands responded to rising Arctic temperatures, and what does their future hold with respect to continued warming in the region?”
  - High-latitude lakes are in a disequilibrium state since the 1970’s.
  - Lake changes are significantly influenced by other factors besides climate, such as permafrost state.
  - The ultimate “endgame” for a hotter Arctic is a shift from above-ground to below-ground storage of water.

Global Lake Distribution

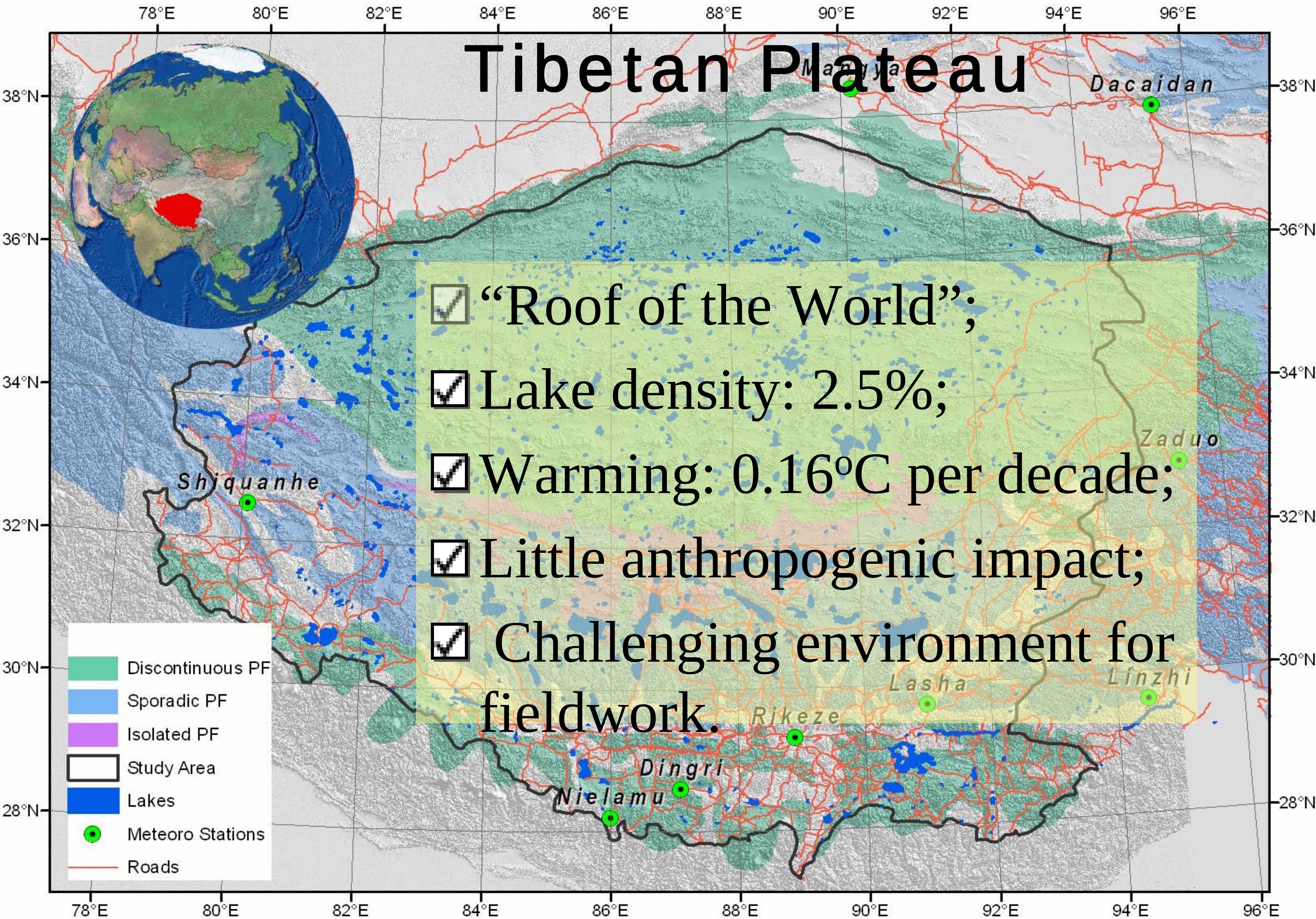


Source: GLWD (Lehner and Doll, 2004)

- ☑ Largest group of lakes:
  - high-latitudes;
- ☑ Second largest:
  - 27 -- 42ºN
  - Where are they?

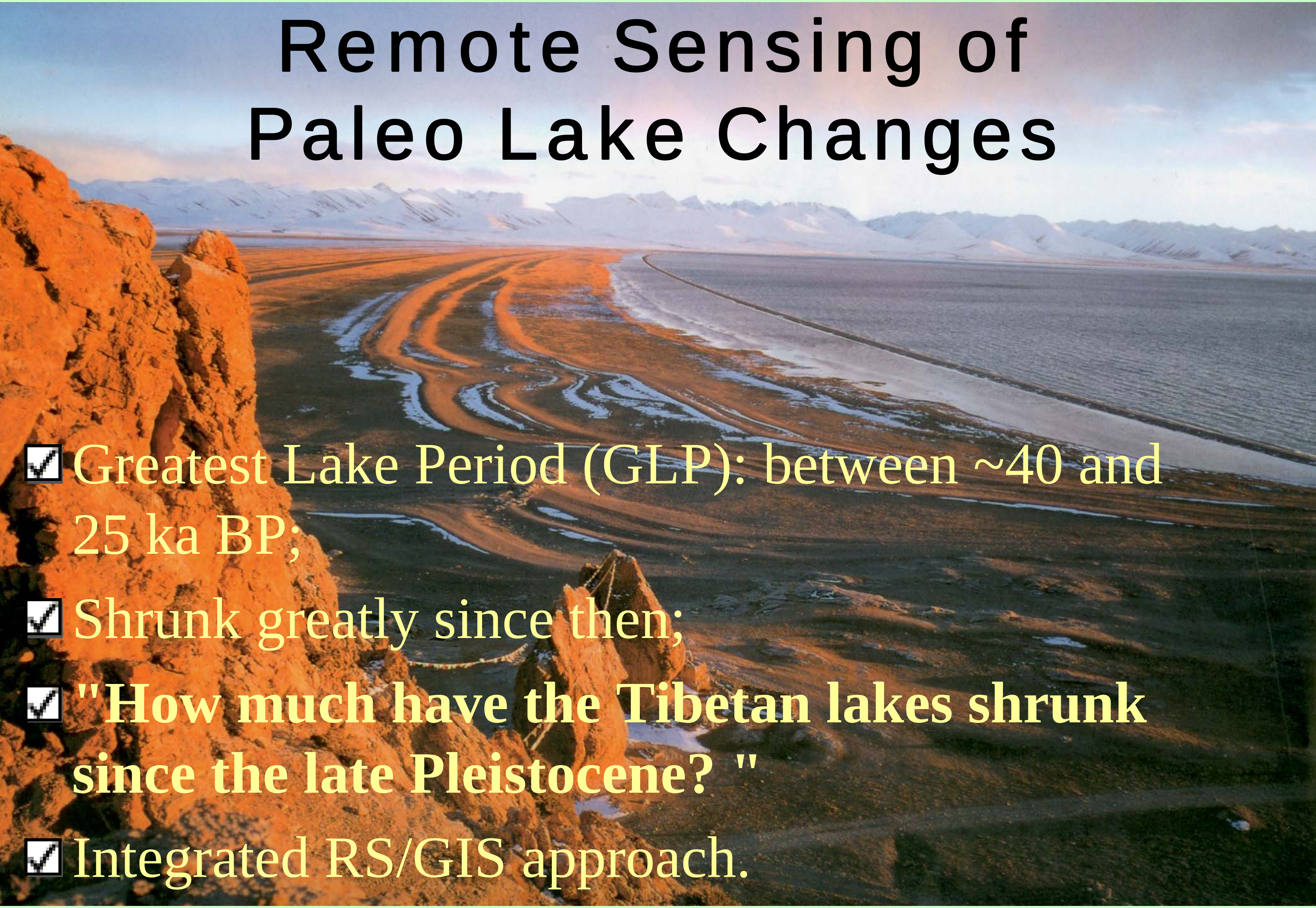
Tibetan Plateau

- ☑ "Roof of the World";
- ☑ Lake density: 2.5%;
- ☑ Warming: 0.16ºC per decade;
- ☑ Little anthropogenic impact;
- ☑ Challenging environment for fieldwork.



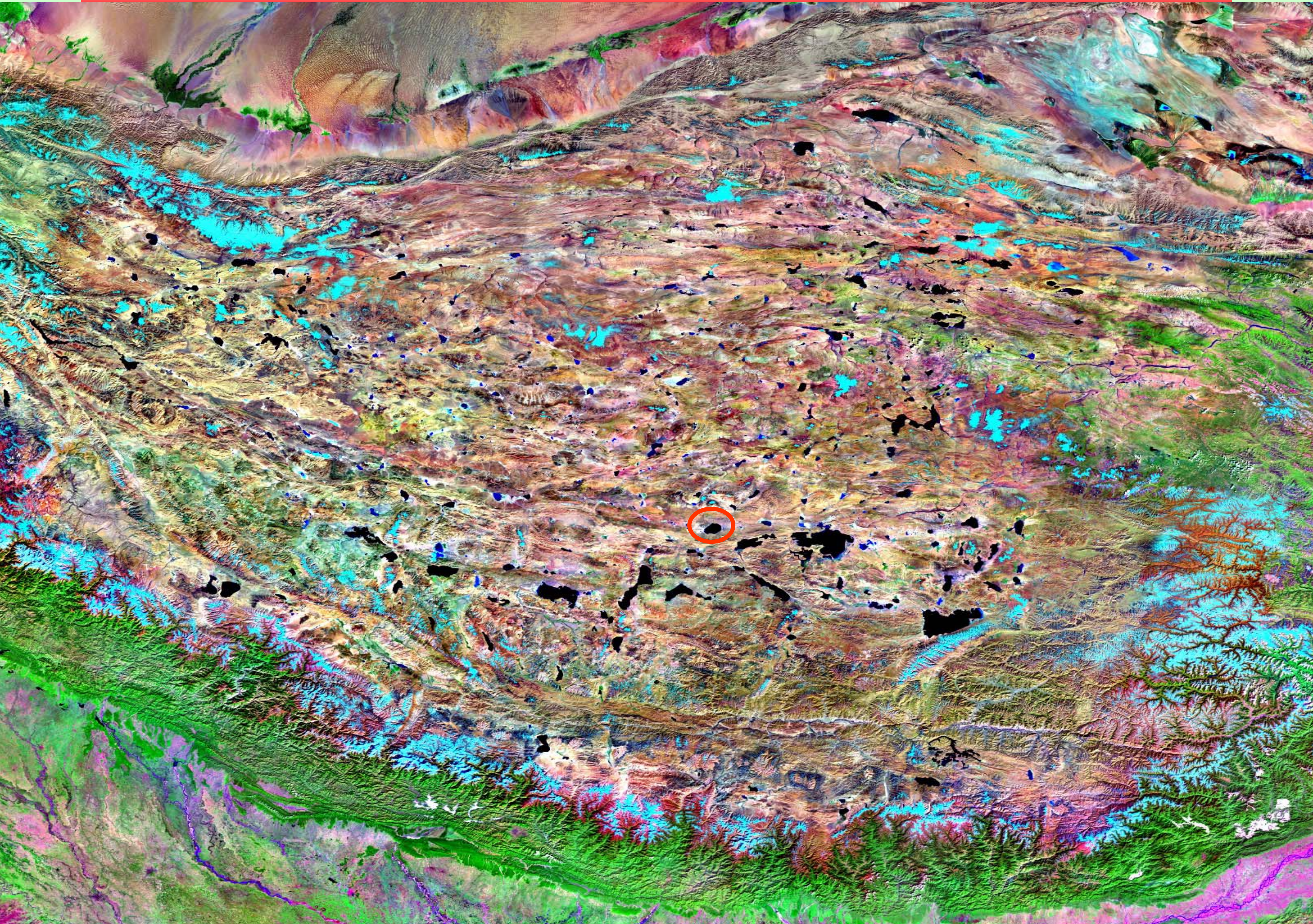
Science Questions

- ☑ **How do present-day lake areas compare with maximum lake extents during the GLP period in the late Pleistocene, as evidenced by paleo-shoreline data?**
- ☑ **How have areas and distributions changed over the past 30 years, an interval of pronounced warming in the region?**
- ☑ **What are the driving mechanisms underlying the observed lake changes?**

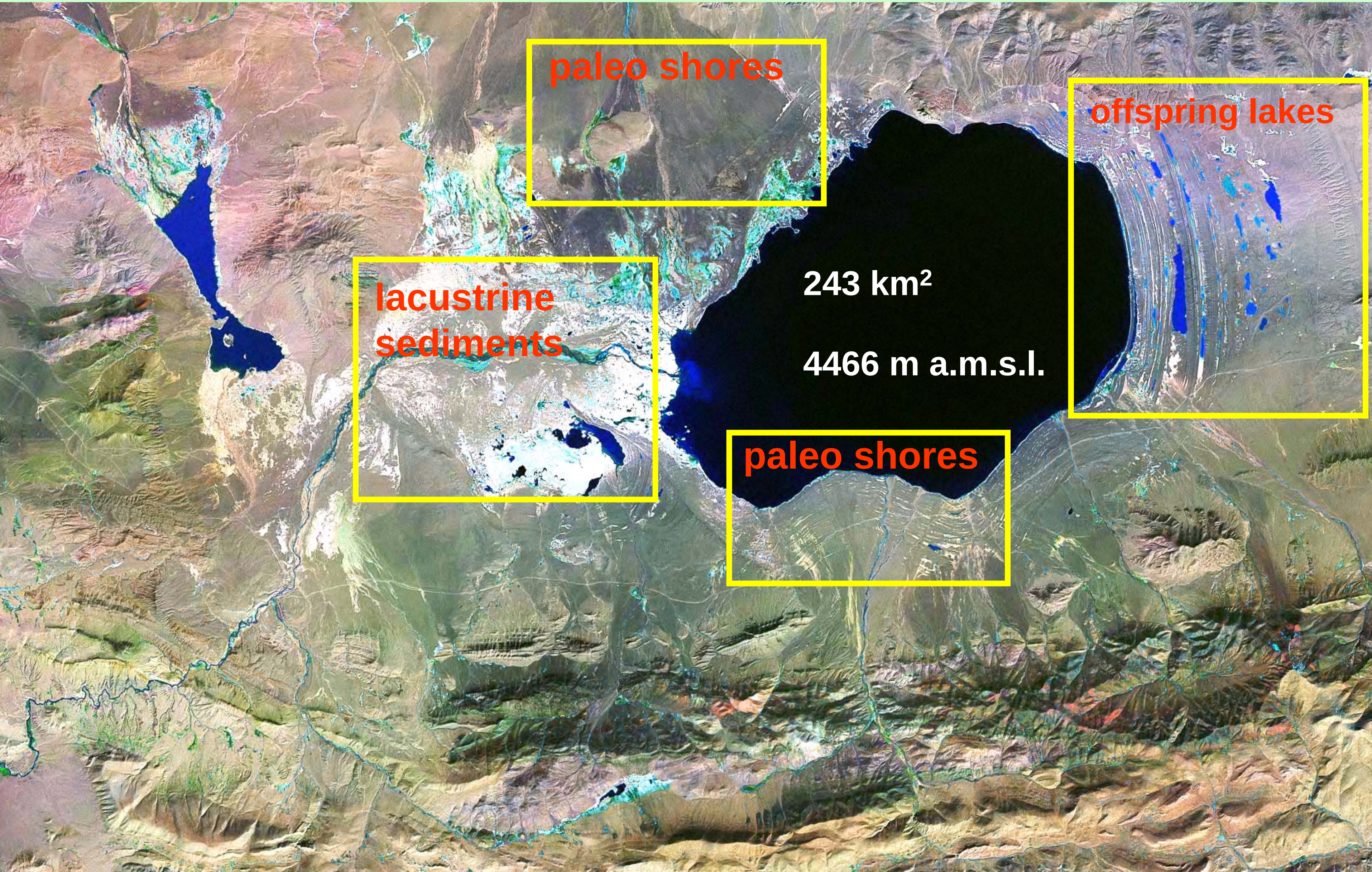


Remote Sensing of Paleo Lake Changes

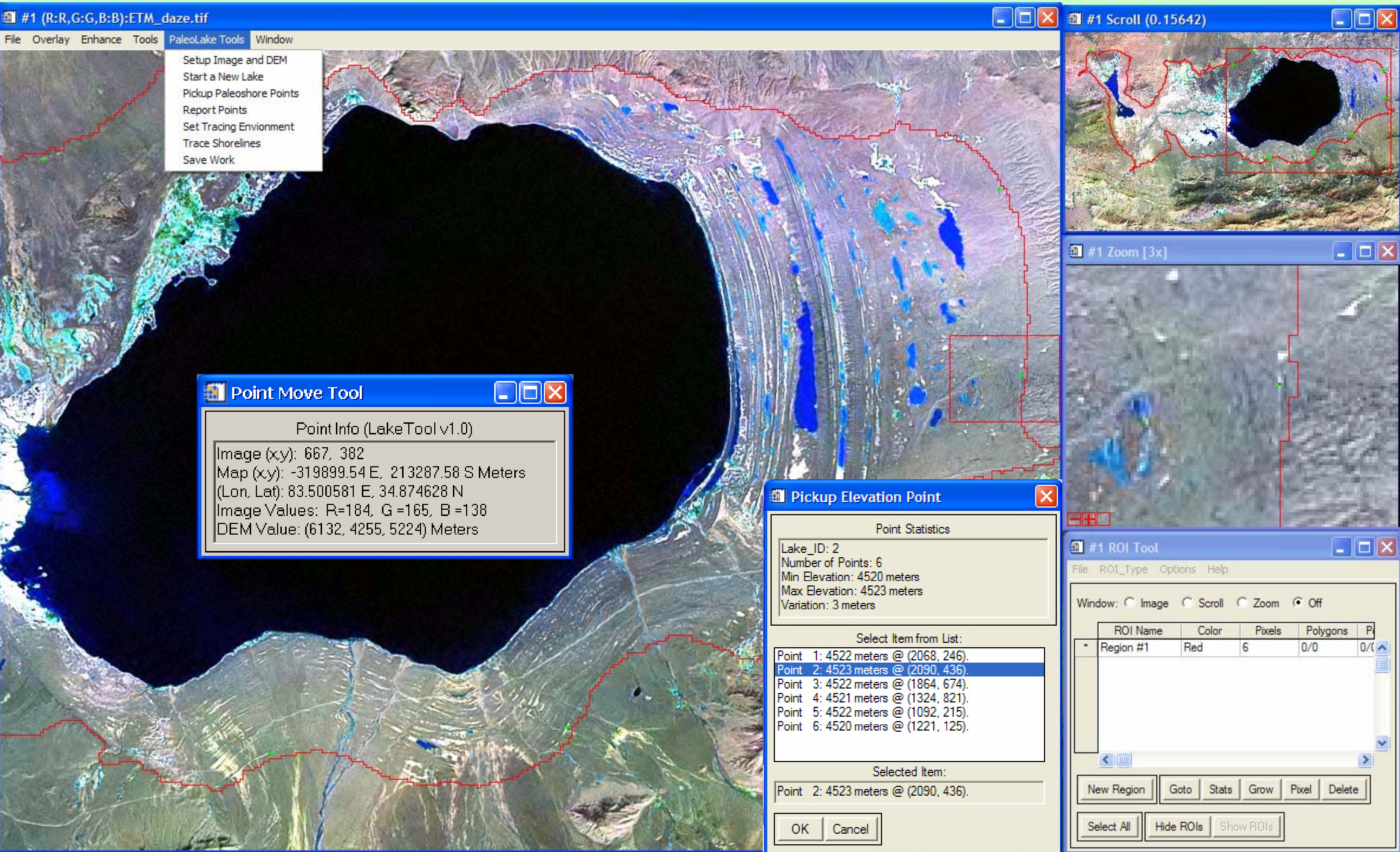
- ☑ Greatest Lake Period (GLP): between ~40 and 25 ka BP;
- ☑ Shrunk greatly since then;
- ☑ **"How much have the Tibetan lakes shrunk since the late Pleistocene? "**
- ☑ Integrated RS/GIS approach.



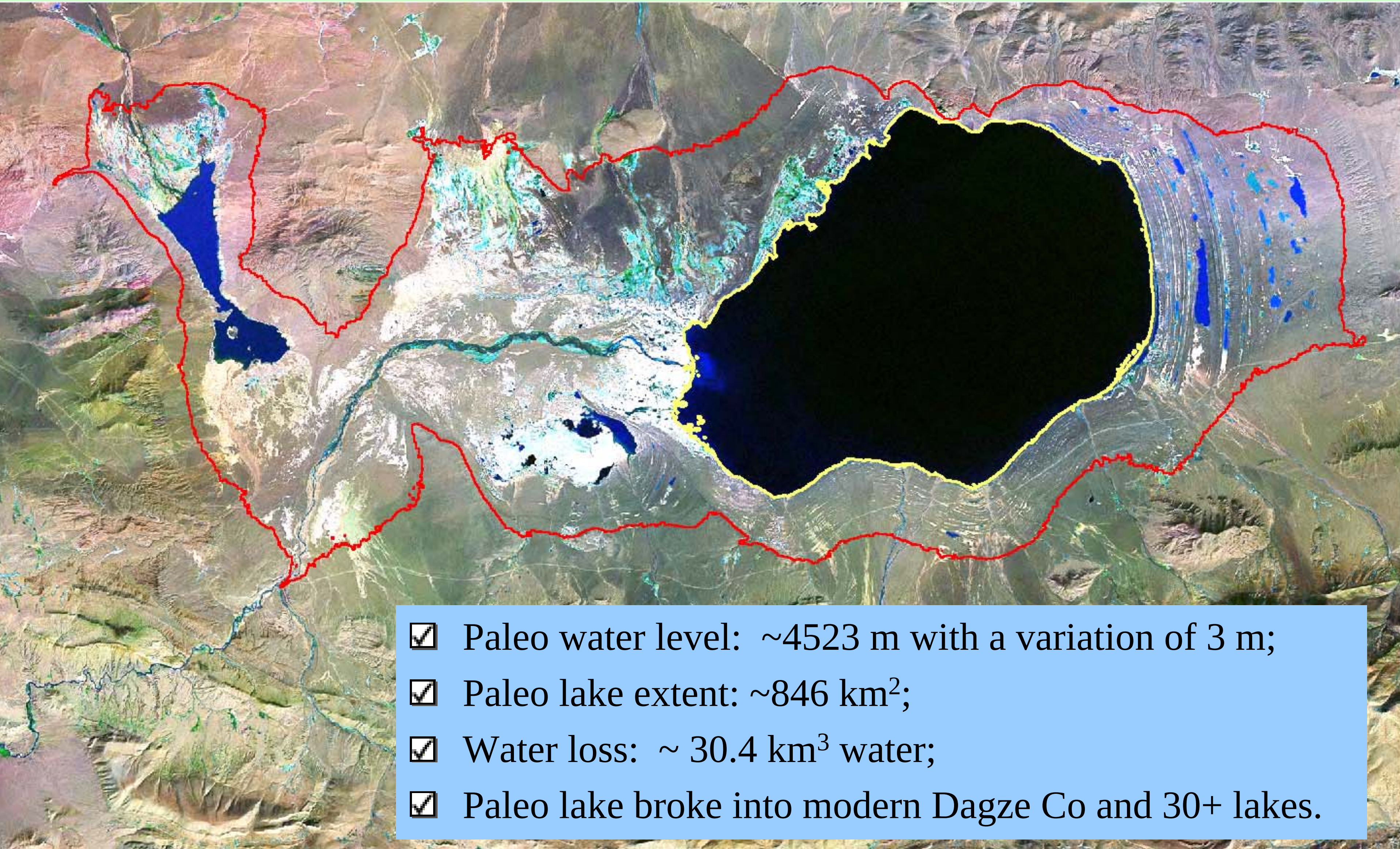
Dagze Co: A Typical Tibetan Lake



Interactive Paleo Lake Mapping Environment



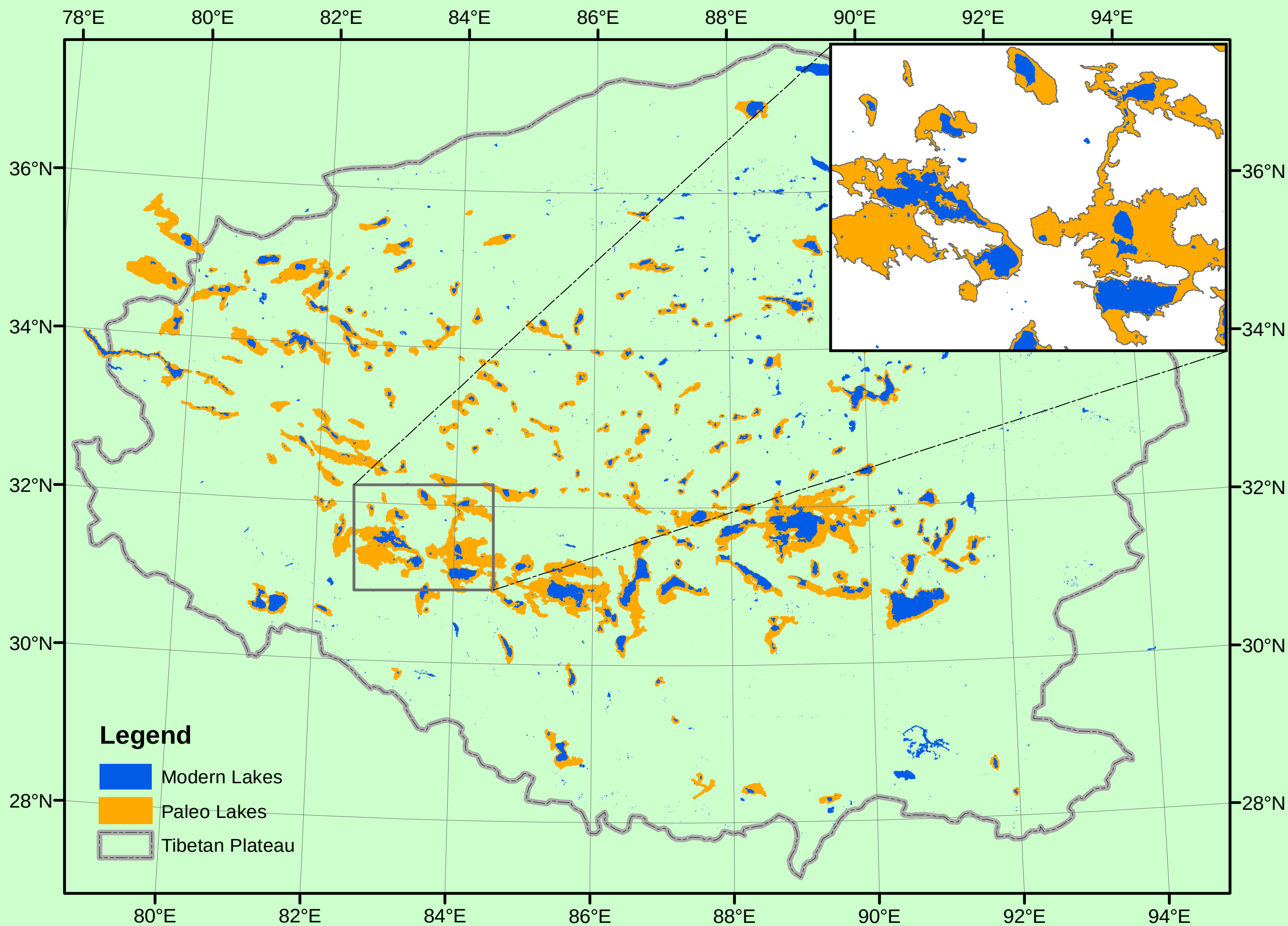
Recovered paleo lake extent matching lake features



- ☑ Paleo water level: ~4523 m with a variation of 3 m;
- ☑ Paleo lake extent: ~846 km^2;
- ☑ Water loss: ~ 30.4 km^3 water;
- ☑ Paleo lake broke into modern Dagze Co and 30+ lakes.

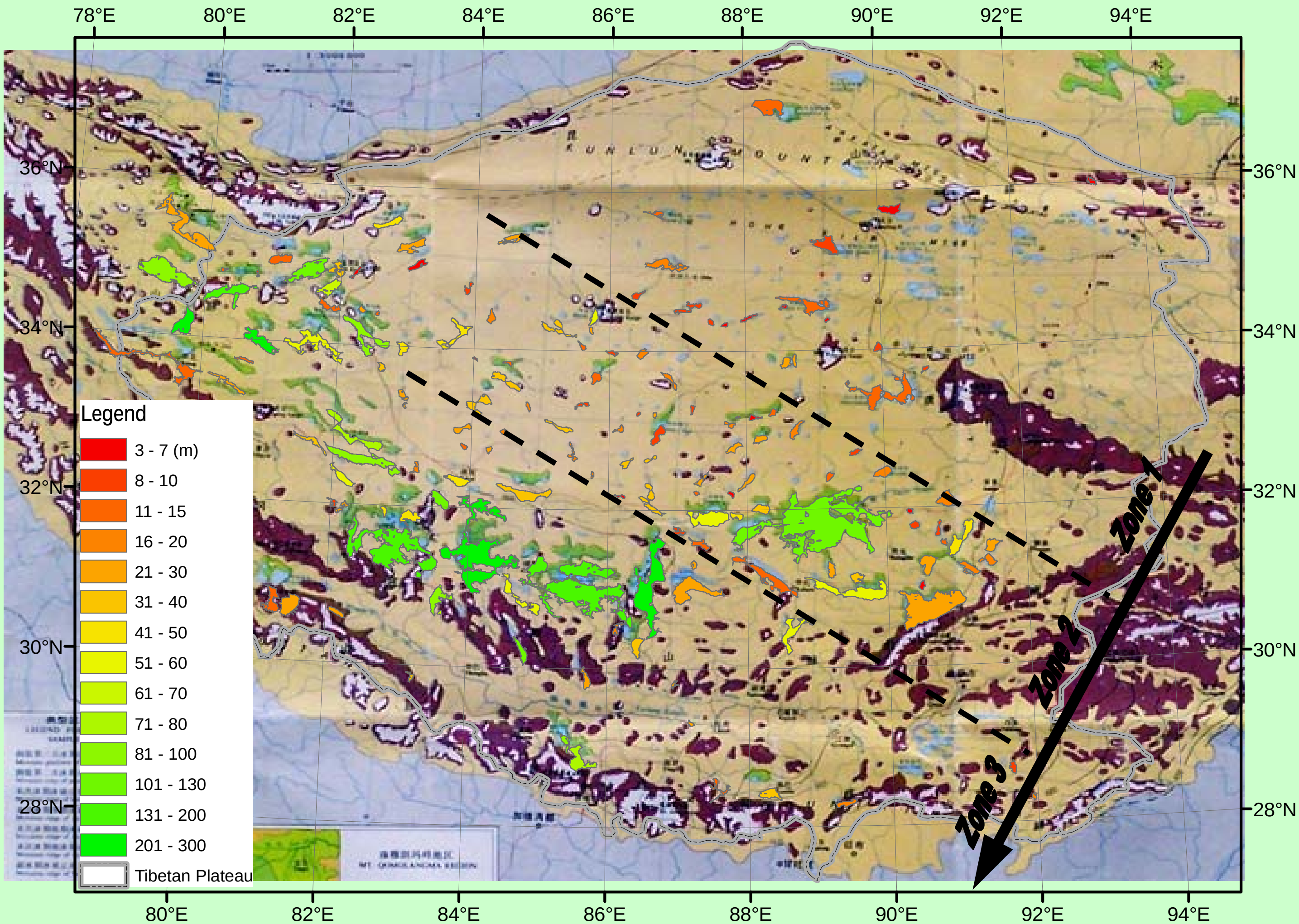
Paleo Lake Recovery Across the Plateau

- ☑ 653 contemporary lakes evolved from 173 paleo mega lakes.
- ☑ Total area shrinkage and water loss are estimated at 42,109 km^2 and 2,936 km^3.



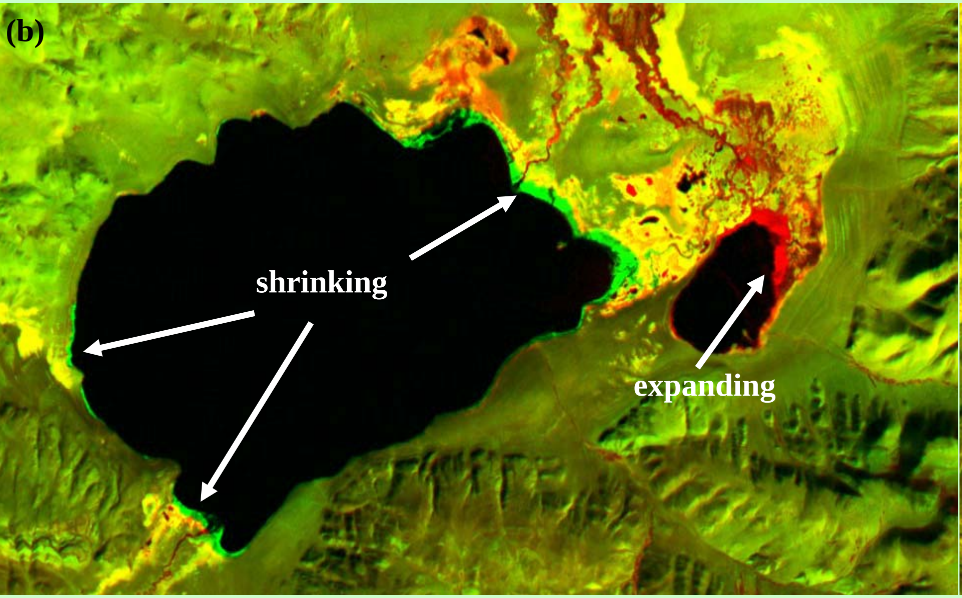
Spatial Pattern of Paleo Lake Change

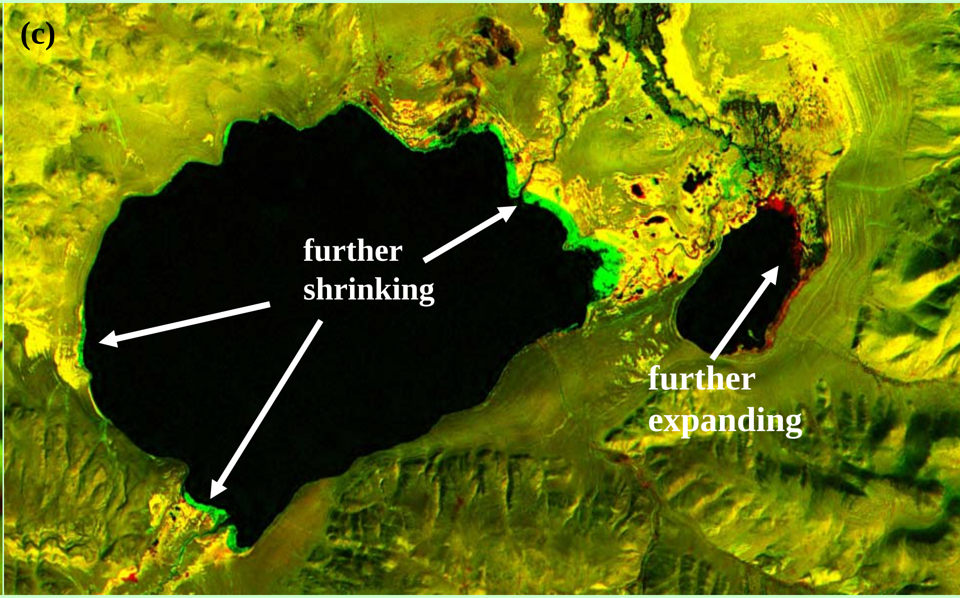
- ☑ Zone 1: minor water-level drop (<20 meters).
- ☑ Zone 2: the moderate zone, with 20-60 meter water level drop.
- ☑ Zone 3: greatest water-level drop, up to 285 meters.



Recent Dynamics of Dawa Co

(a) ETM image of 10/28/2000;
(b) Lake change between 11/15/1976 MSS and 11/10/1990 TM image;
(c) Lake change between 10/10/1990 TM and 10/28/2000 ETM+ image.





Challenges in Global Lake Dynamics

- ☑ Adequate lake change detection:
  - Precise image co-registration at sub-pixel accuracy;
  - Accurate lake identification;
- ☑ Automation:
  - Accurate lake identification and sub-pixel accuracy co-registration;
- ☑ Satellite image acquisition;
- ☑ Addressing seasonal variation;
- ☑ Understanding the mechanism of lake changes.

Critical Techniques

- Algorithms have been tested in Arctic and Tibetan Plateau:
  - Image co-registration;
  - Lake identification;
  - Change detection.
- Automation!

Challenge to satellite image acquisition

Suitable 1970's Landsat coverage is not comprehensive.

Possible Solutions

- ☑ Making a large budget for projects;
- ☑ Calling for institutional attention;
- ☑ Coordinating among researchers;
- ☑ Encouraging data sharing and trading.

Challenge to addressing seasonal variation

- ☑ Seasonal variation vs. Long-term changes;

Possible Solutions

- ☑ Narrow the lake mapping episode to the best season;
- ☑ Avoid the snow melting and flood periods;
- ☑ Leave blanks rather than include images in unwanted seasons;
- ☑ Use overlap area of neighboring scenes to quantify seasonal variations.

Challenge to understanding the mechanism behind lake changes

- ☑ Involved various factors.

Possible Solutions

- ☑ Collecting various data sources:
  - Topographic data;
  - Environmental data;
  - Hydrological data;
  - Climatological data;
- ☑ Establishing GIS database;
- ☑ Using comprehensive GIS analysis;

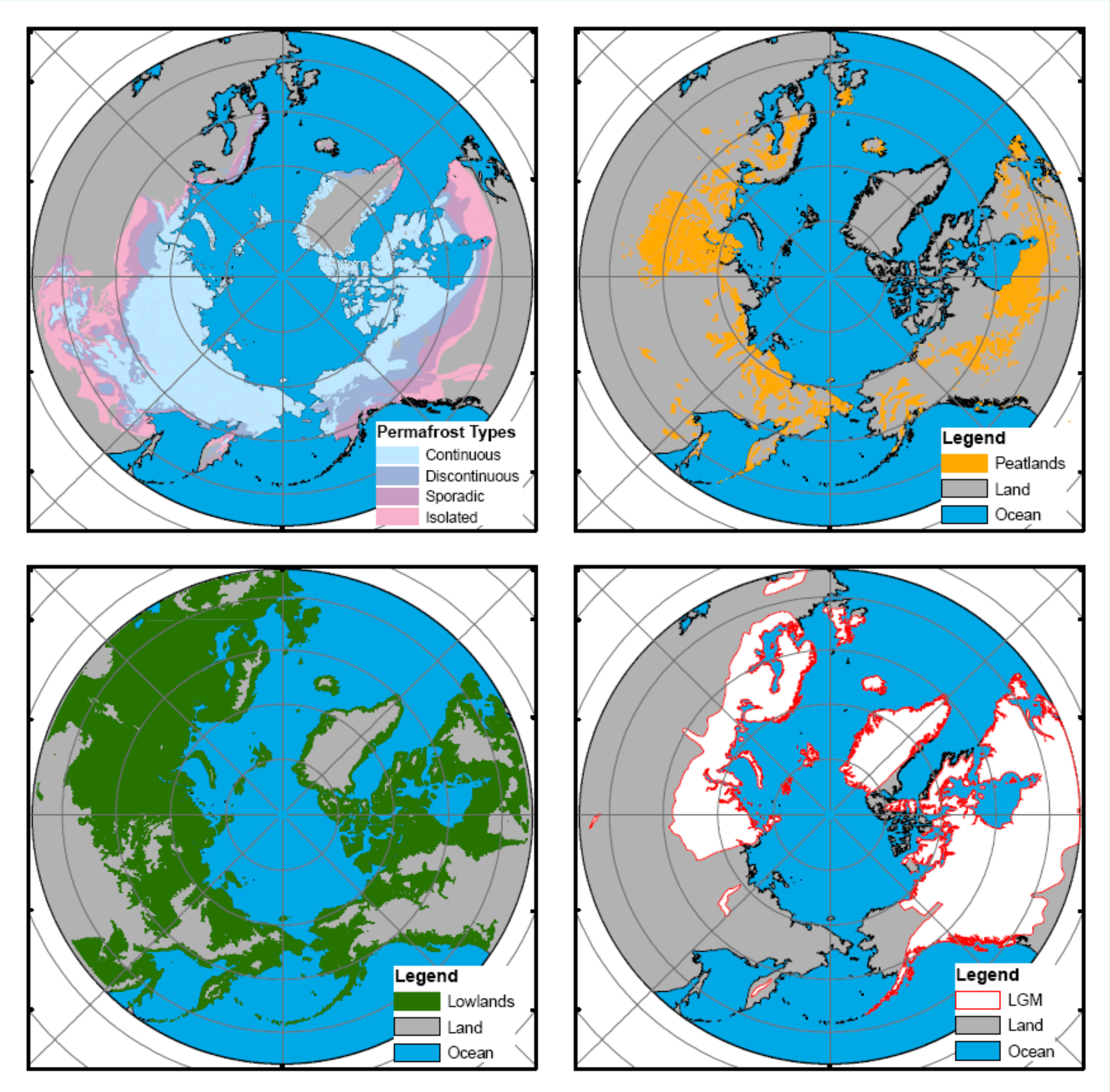
GIS-Based Mechanism Analysis

(Brown et al.,1997)

(Mac-Donald et al.,2006)

GTOPO30 <300 m

(Ray and Adams, 2001)



Conclusions

- ☑ **Remote sensing of lake dynamics:**
  - **On-going efforts;**
  - **Global-scale;**

- ☑ **A lot of work!**

- ☑ Acknowledgement:
  - NASA THP;
  - NSF Arctic Science Program;
  - NASA NIP.


Thank You!