FACULTY OF SCIENCE
Charles University

Are changes of endorheic lakes on the Tibetan Plateau a valid climate indicator?

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Mountain environment on a wall painting in Sera Monastery close to Lhasa

overview

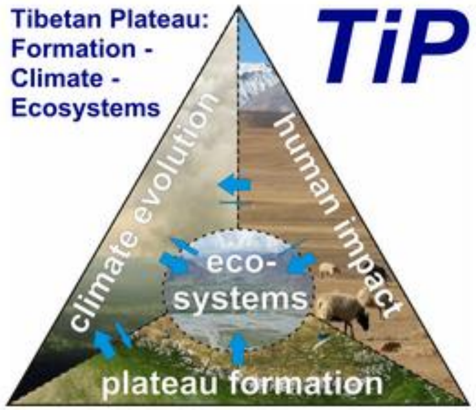
- Background
- Measurements of lake level oscillations
- Mass balance of glaciers
- Lake ice cycle and water recycling
- Wide range of remote sensing methods: satellite altimetry, historical reconnaissance satellites, passive microwave

Tibetan Plateau: Formation - Climate - Ecosystems (TiP)

-Priority program of DFG (German Science Foundation)

20 projects on three different time scales:

- Plateau formation
- Late Cenozoic climate evolution
- Human impact and Global Change phase



Projects in which I took part:

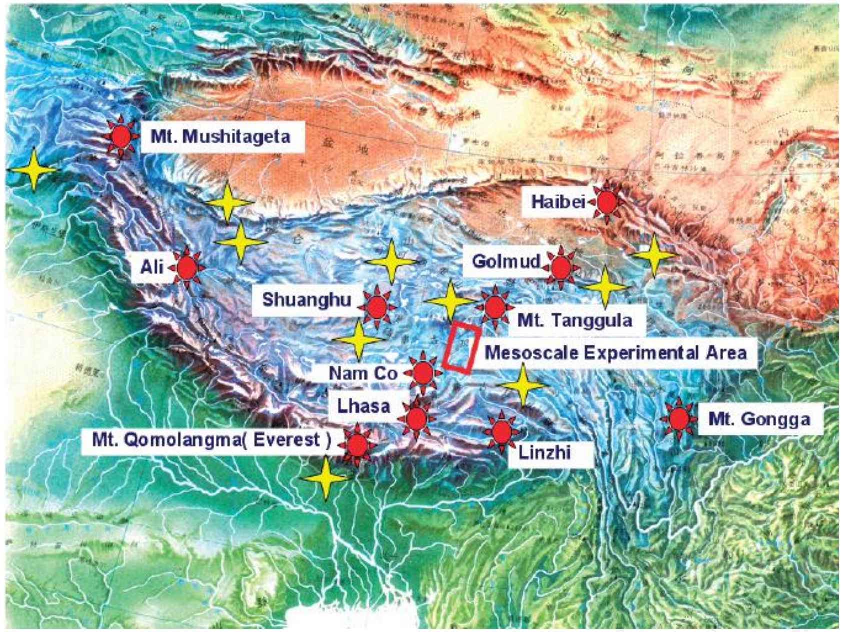
1. Integrated System Analysis to Understand the Implications of the Asian Monsoon System on the **Tibetan Hydrology with Focus on Nam Co Basin** (Uni Tübingen)
2. Dynamic **Response of Glaciers** on the Tibetan Plateau to Climate Change (TU Dresden)

10th Sino-German Workshop of Tibetan Plateau Research in Berlin, 10-11 Dec 2014

Institute of Tibetan Plateau Research, CAS

- founded by the Chinese Academy of Sciences (CAS) in 2003 in collaboration with Max Planck Society
- > 230 permanent employees
- 3 campuses in Beijing, Lhasa and Kunming

Namco station, 4750 m a.s.l.



Field stations on the Tibetan Plateau:

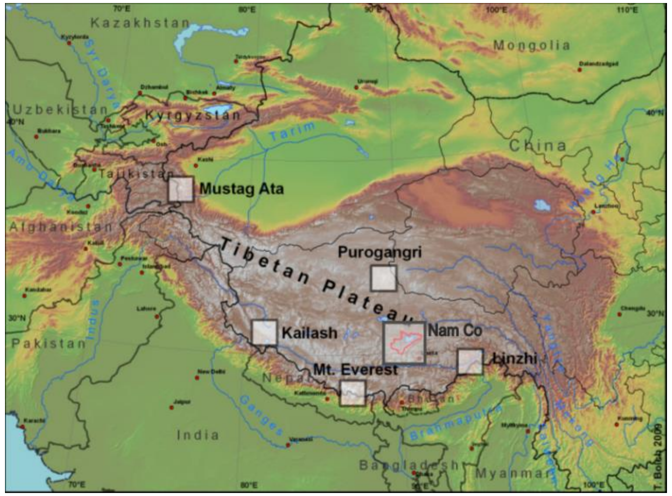
1. Namco Monitoring and Research Station for Multispheric Interactions
2. Southeast Tibet Observation and Research Station for the Alpine Environment
3. Qomolangma Atmospheric and Environmental Observation and Research Station
4. Muztagh Ata Westerly Observation and Research Station
5. Ngari Desert Observation and Research Station

Variability and trends in water balance components of benchmark drainage basins on the Tibetan Plateau (WET)

- One of 10 projects of the BMBF program CAME „Central Asia: Monsoon dynamics and geo - ecosystems“

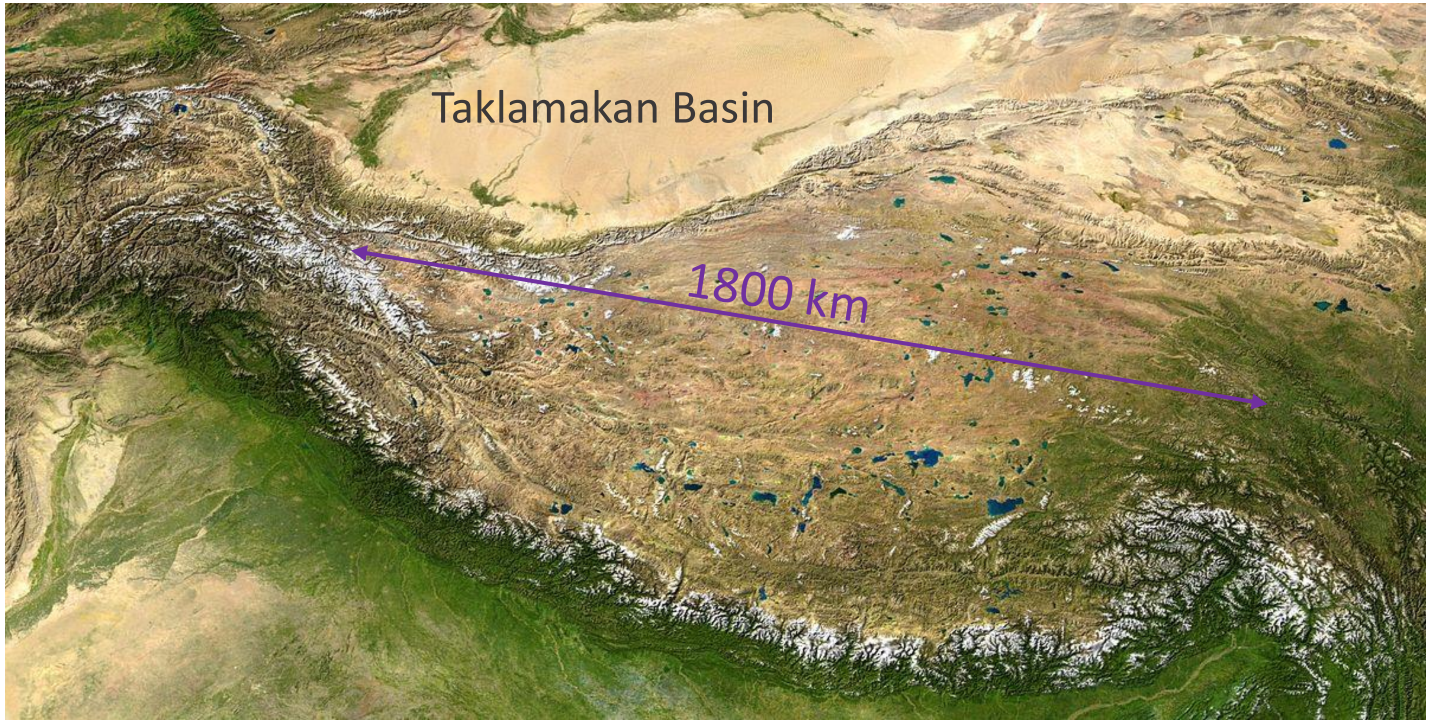
- TU Berlin, Uni Marburg, Uni Jena, Uni Tübingen, RWTH Aachen, TU Dresden

Main goal: Investigation of the **coupling of climate and hydrological cycle** on the example of benchmark drainage basins on the Tibetan Plateau



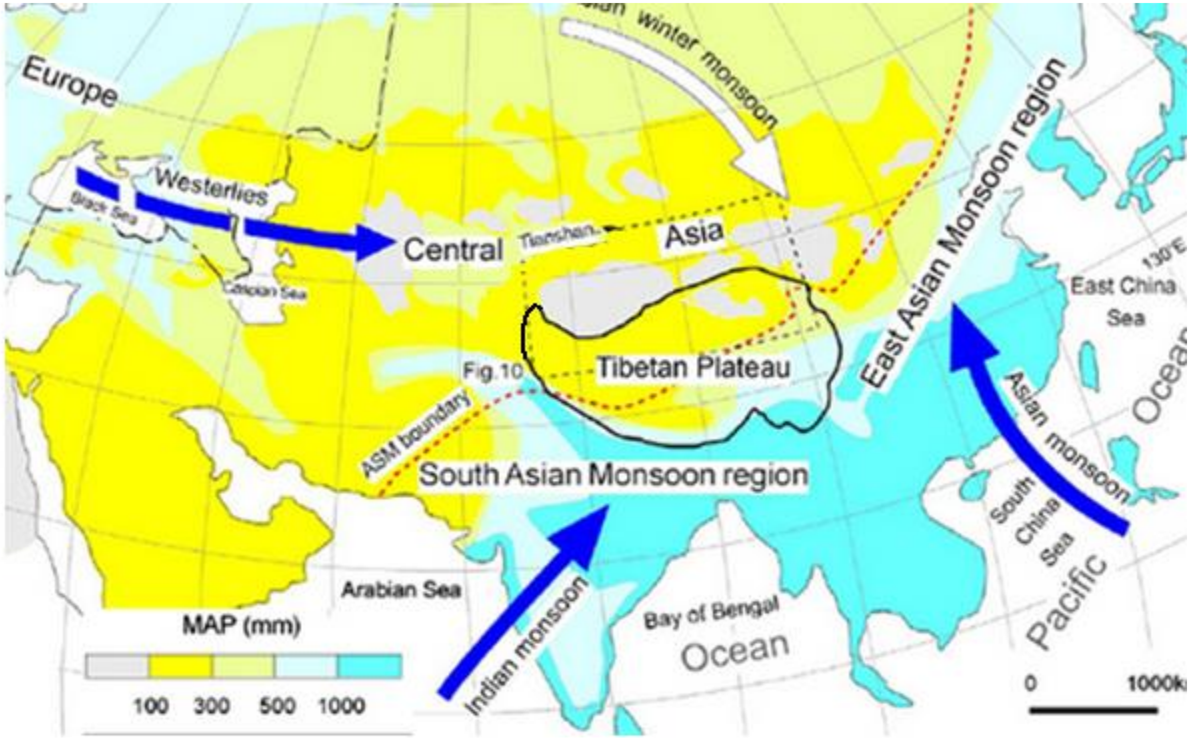
Tibetan Plateau

- Mean elevation > 4500 m a.s.l.
- Role in regional climate: barier to southward flow (the role as heat source disputed)
- Highest concentration of glaciers out of polar regions
- Numerous endorheic lakes
- Dominated by grasslands (Kobresia)
- Sparse snow cover



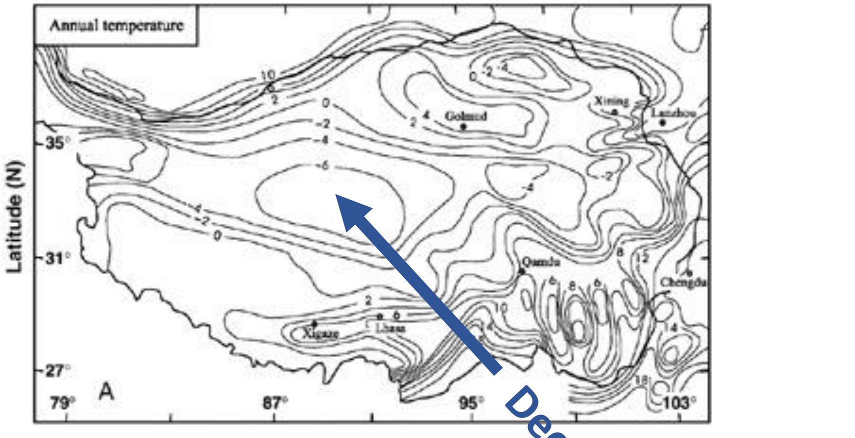
Molnar, Peter, William R. Boos, and David S. Battisti. "Orographic controls on climate and paleoclimate of Asia: thermal and mechanical roles for the Tibetan Plateau." *Annual Review of Earth and Planetary Sciences* 38 (2010): 77-102.

Major climate drivers on the TP

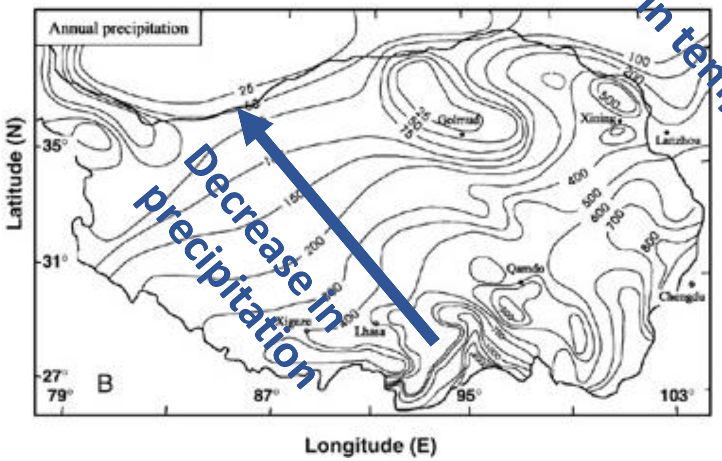


Asian summer monsoon (ASM) limit is shown by a red dashed line (after Gao, 1962)

Mean annual temperature



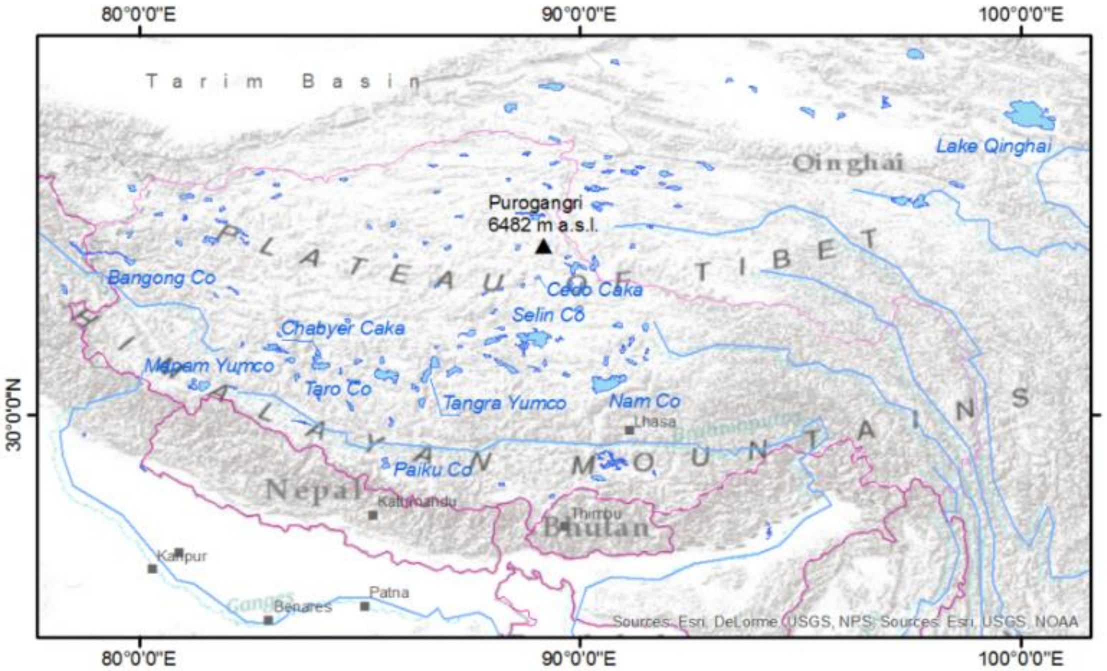
Mean annual precipitation



(Modified from Institute of Geography 1990)

Tibetan lakes

Map of Tibet, Mongolia and Manchuria by John Tallis from the year 1851



- Exploration by Seven Hedin at the beginning of the 20th century: rough outlines of the large lakes

Research of lakes on the Tibetan Plateau

- Restrictions
- Remoteness, altitude above 4500 m a.s.l.
- Limnological study: only handful of lakes
- Few lakes are gauged
- One lake is used for hydropower production

Hydropower plant at Yamdrok Yumco diverts water to Yarlung Cangpo river. The altitude difference is 840 m.

Dynamics of endorheic lakes

Palaeo-beaches at Tangra Yumco
altitude range: ~200m

http://www.tibetarchaeology.com/february-2017/

Decline of lake levels in Holocene

Tangra Yumco lake (luminescence dating of feldspar)

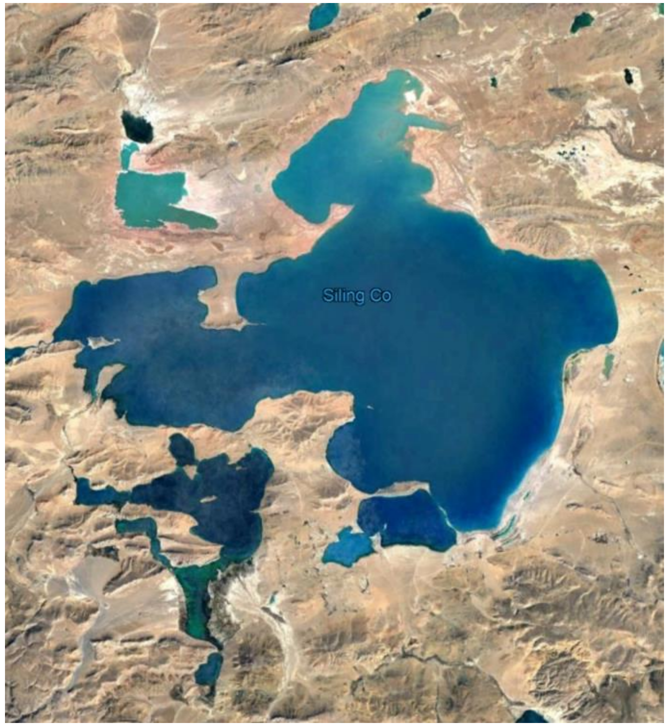
- from ~ 6.4 to ~ 4.5 ka: rapid decline (~ 50 m)
- between ~ 4.5 and ~ 2.0 ka: slow decline (~ 20 m)
- since ~ 2 ka: fast decline by 70 m
- link between a decrease in monsoonal activity and lake-level decline since the early Holocene

Tangra Yumco

Rades, Eike F., et al. "A lake-level chronology based on feldspar luminescence dating of beach ridges at Tangra Yum Co (southern Tibet)." *Quaternary Research* 83.3 (2015): 469-478.

Paleo-beaches at Selin Co Lake

- >100 m than the current level: early stage of the Last Glaciation (67.9 ± 2.4 ka BP)
- Correspond to cold or wet climate periods
- beach ridge groups are almost synchronous with **advances or standstills of Himalayan glaciers**
- consistent with nearby **ice core** records
- supports **no plateau-scale ice sheet** during the Last Glaciation



Li, Dewen, et al. "Lake-level fluctuations since the Last Glaciation in Selin Co (lake), Central Tibet, investigated using optically stimulated luminescence dating of beach ridges." *Environmental Research Letters* 4.4 (2009): 045204.

Recent warming on the TP

- Warming accelerated since the 1950s
- Ice core from Dasuopu Glacier : last 50 years have been the warmest in the last 1000 years (Thompson et al. 2000)
- Station data 1955 – 1996: +0.16 °C/decade
    - mean winter temperature increase: +0.32 °C/decade
- Faster warming than the average for the northern hemisphere
- Warming slow-down in 1999 – 2014 (Zhong et al. 2019)

Sources of precipitation

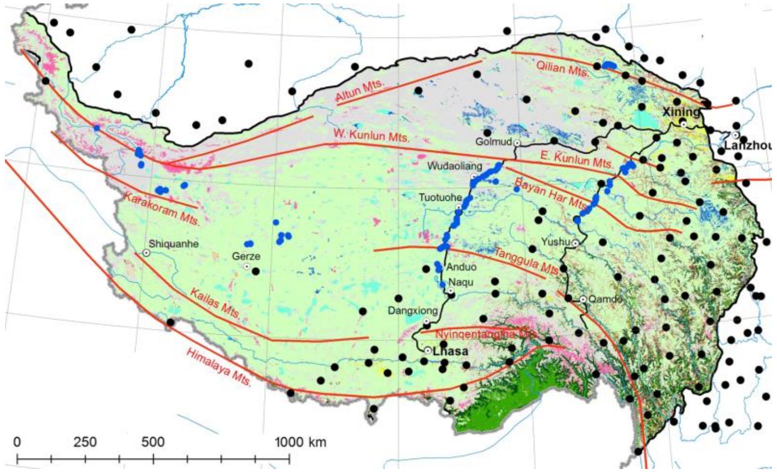
Source of moisture: from SW – Indian Ocean, Westerlies

- 69% from land
- 21% from ocean about 18% of the total precipitation from inside the region - recycling

Trend in precipitation

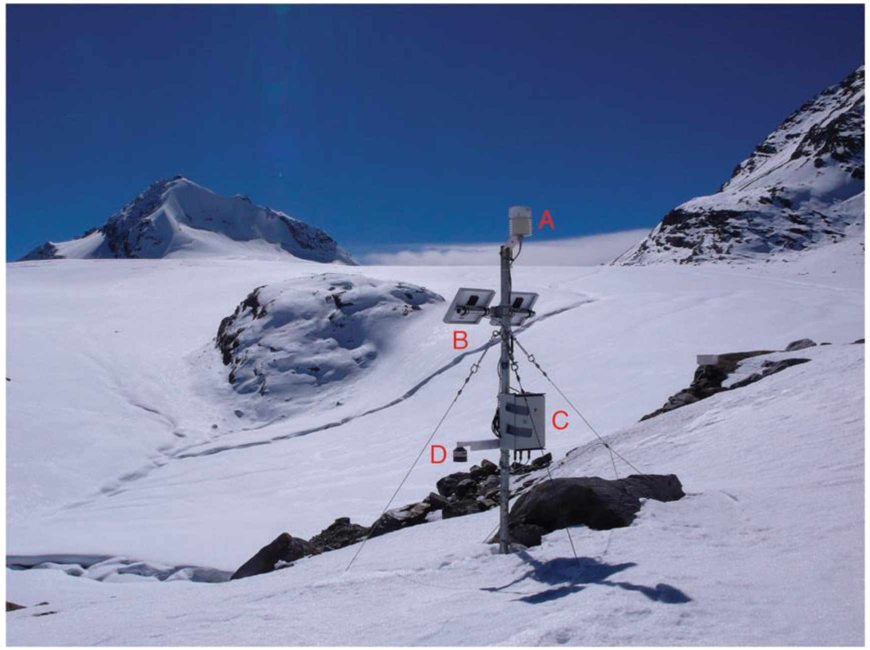
- large uncertainties in this trend due to sparse observations

- Recent precipitation increase (1979-2013) due to:
  - enhanced moisture transport from the Indian Ocean during July and September
  - Intenzification of local hydrological recycling



Asymetric distribution of weather stations (shown as black points) after Ran, Y., Li, X., & Cheng, G. (2018).

Zhang, Chi, Qiuhong Tang, and Deliang Chen. "Recent changes in the moisture source of precipitation over the Tibetan Plateau." *Journal of Climate* 30.5 (2017): 1807-1819.



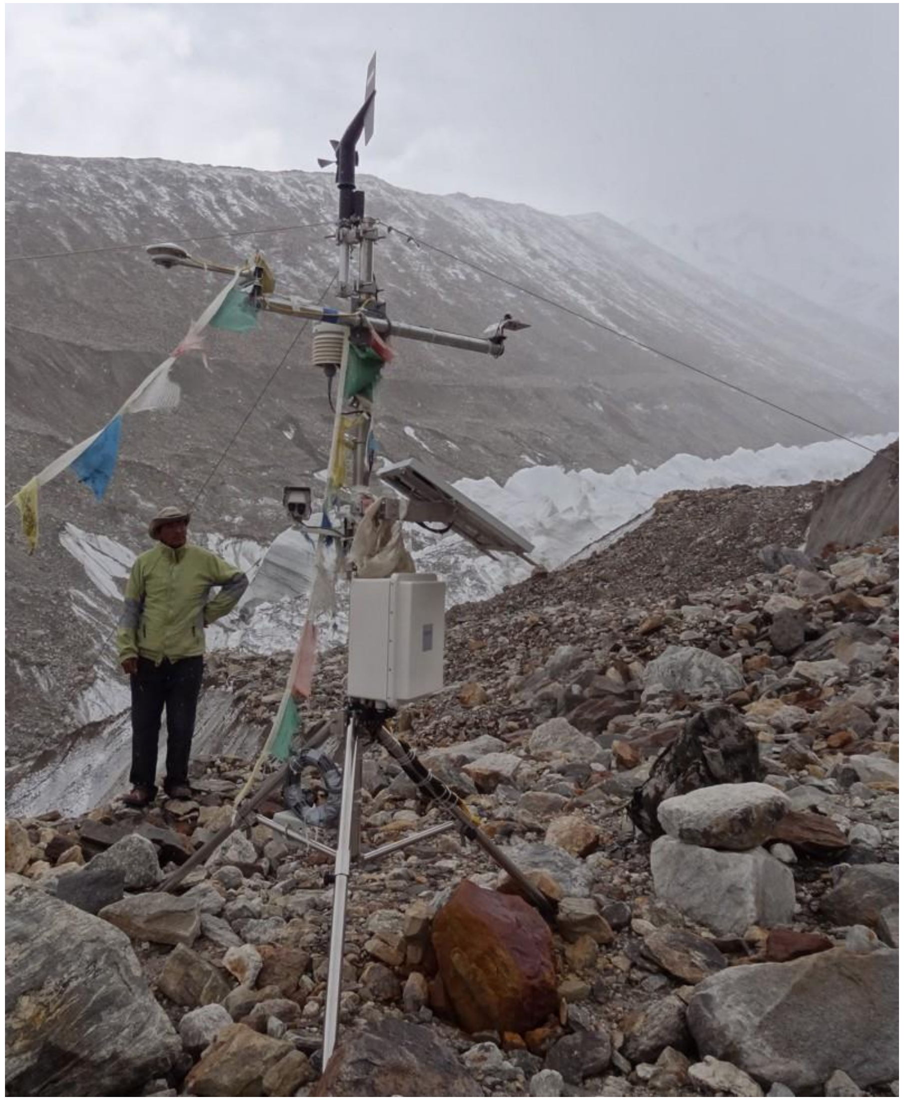
AWS at Halji Glacier, 5350 m a.s.l., Installed in Dec 2013

A CS215 temperature and relative humidity probe;

C pressure sensor TF5004 in data logger case

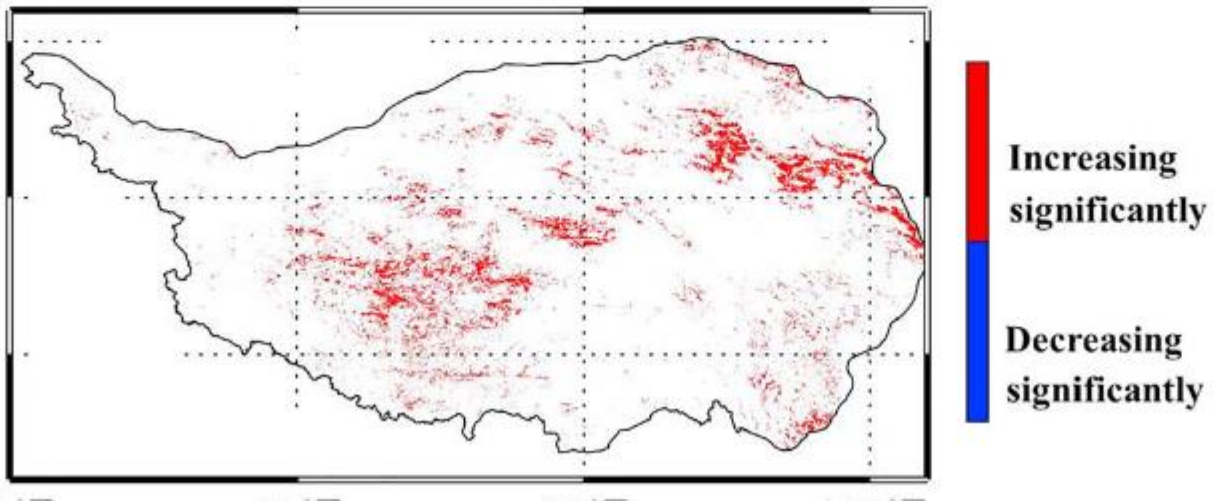
D SR50A snow depth sensor

Automatic weather station at Nyenchen Tanglha, 5500 m a.s.l



Greening

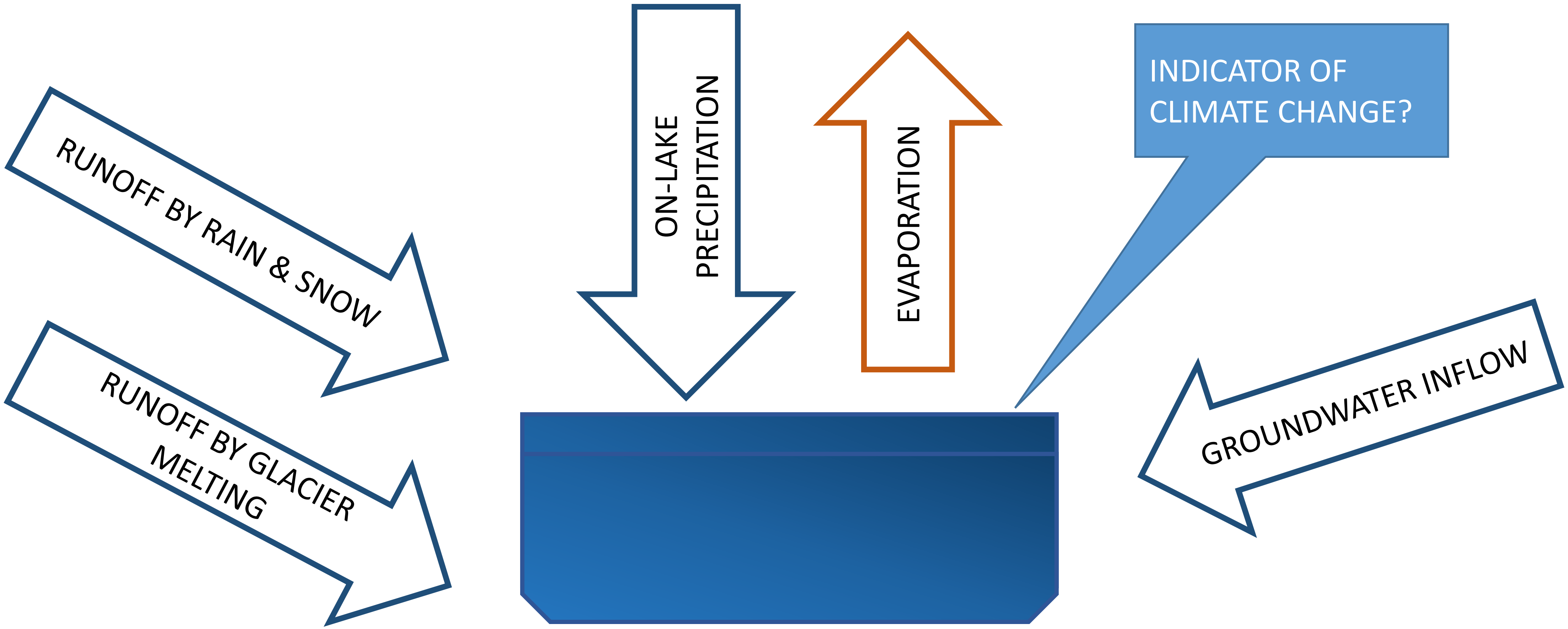
- greening increase from medium resolution satellite data
- 7.63% of TP: significant greening
- reaction on both precipitation and temperature
- reforestation projects



Tree plantation in frames of a reforestation project in Yarlung Cangpo valley

Zhong, Lei, et al. "Climate change trends and impacts on vegetation greening over the Tibetan Plateau." *Journal of Geophysical Research: Atmospheres* 124.14 (2019): 7540-7552.

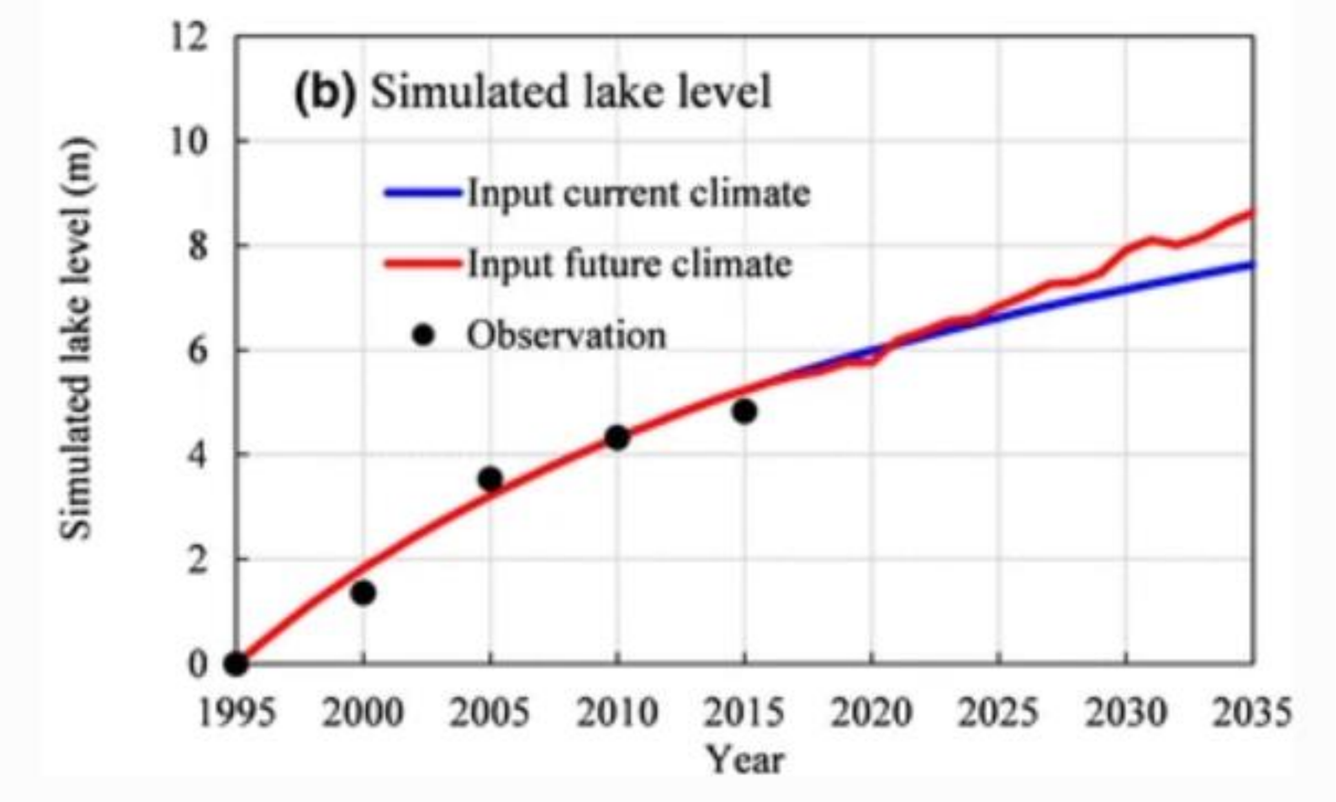
Water balance of an endorheic lake



Preditions based on models

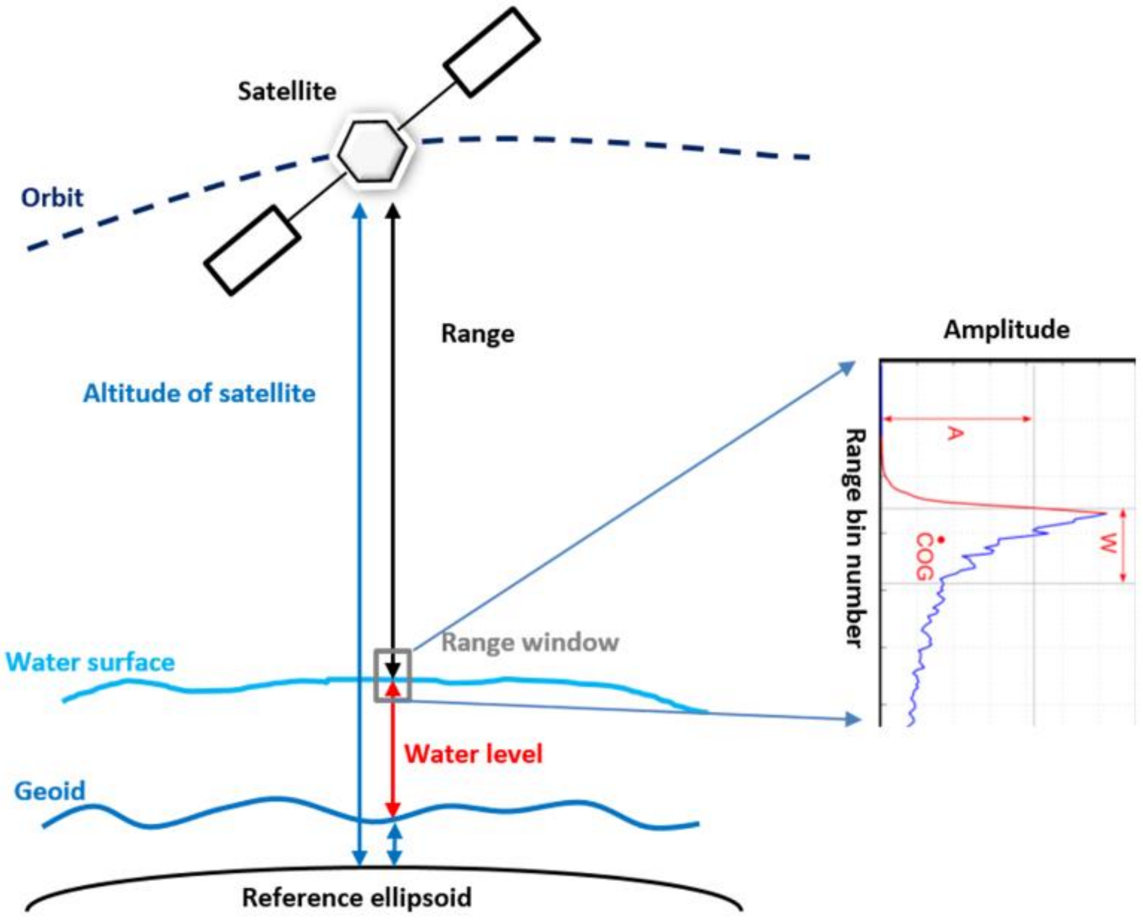
- 1995 to 2025:

average lake level rise by about 6.6 ± 0.3 m



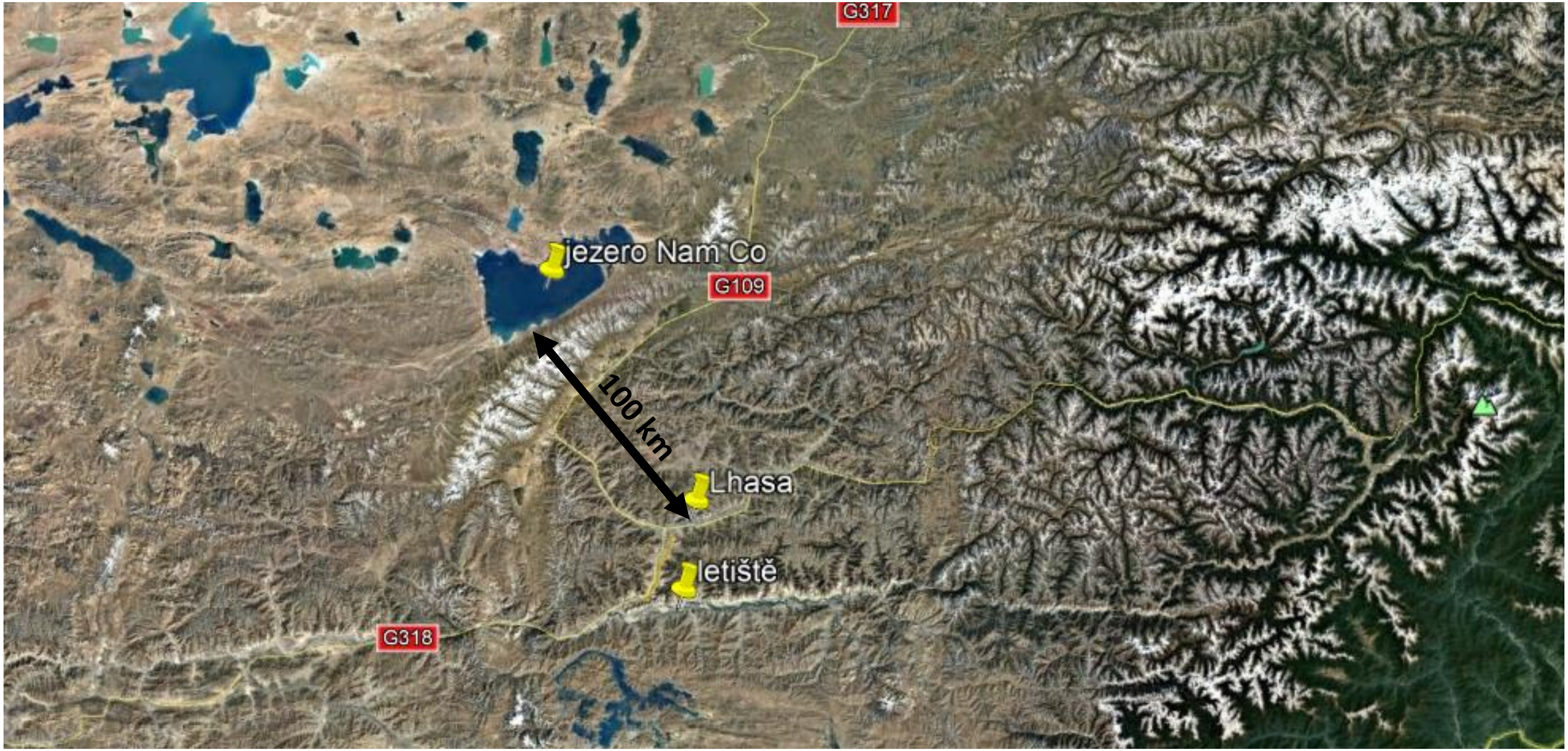
Yang, Kun, et al. "Quantifying recent precipitation change and predicting lake expansion in the Inner Tibetan Plateau." *Climatic change* 147.1-2 (2018): 149-163.

Satellite altimetry – surface elevation from space



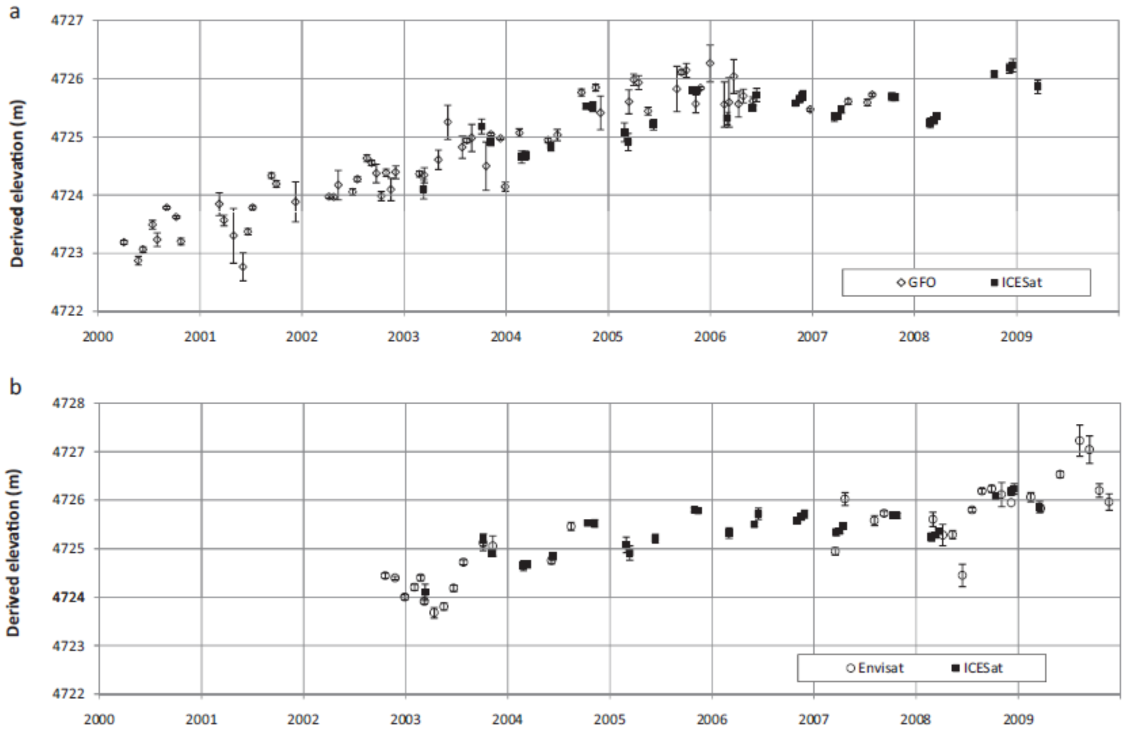
- Range is calculated based on delay of the two way signal travel
- Accurate position of the satellite from SLR – Satellite Laser Ranging
- Geoid – elipsoid: Earth Gravitational Models EGM96 and EGM2008 based on gravitational measurements of GRACE satellite mission

Lake level changes of Nam Co



Lake level rise of Nam Co by satellite altimetry

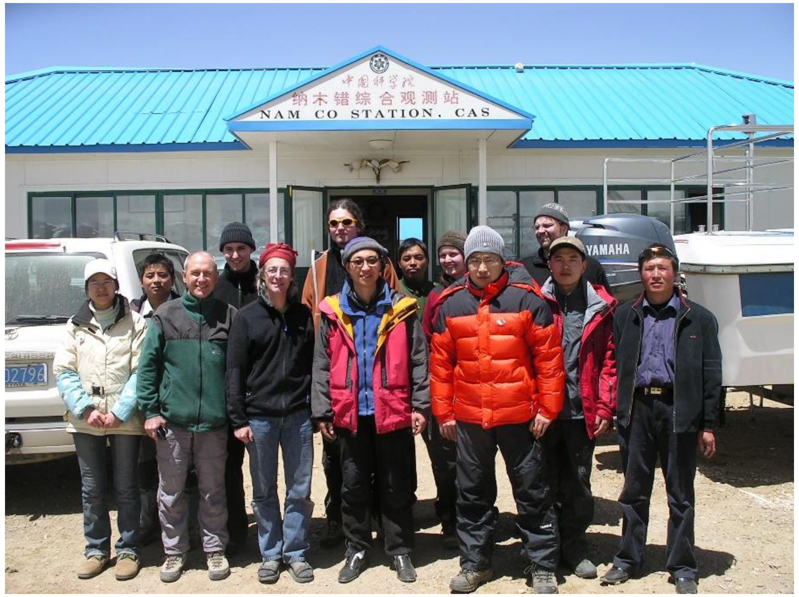
- ENVISAT, ICESat and GFO data for the period 2002 – 2009
- Mean increase rate: **0.31 m/y**
- The first study that combined Laser and radar altimetry for lake level measurements



Kropáček, J., Braun, A., Kang, S., Feng, C., Ye, Q., & Hochschild, V. (2012). Analysis of lake level changes in Nam Co in central Tibet utilizing synergistic satellite altimetry and optical imagery. *International Journal of Applied Earth Observation and Geoinformation*, *17*, 3-11.

Nam Co station

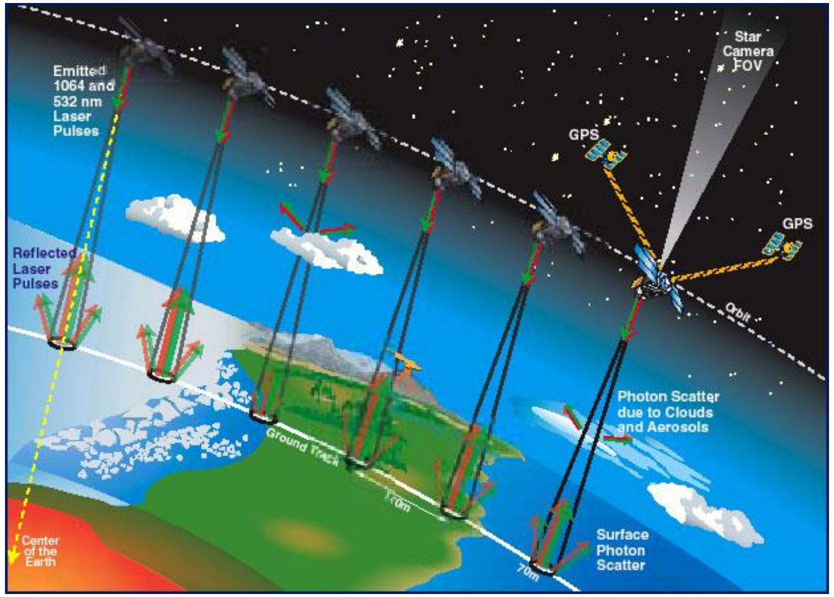
Nam Co station (Nam Co Monitoring and Research Station for Multisphere Interactions – NAMORS), elevation of 4730 m a.s.l.



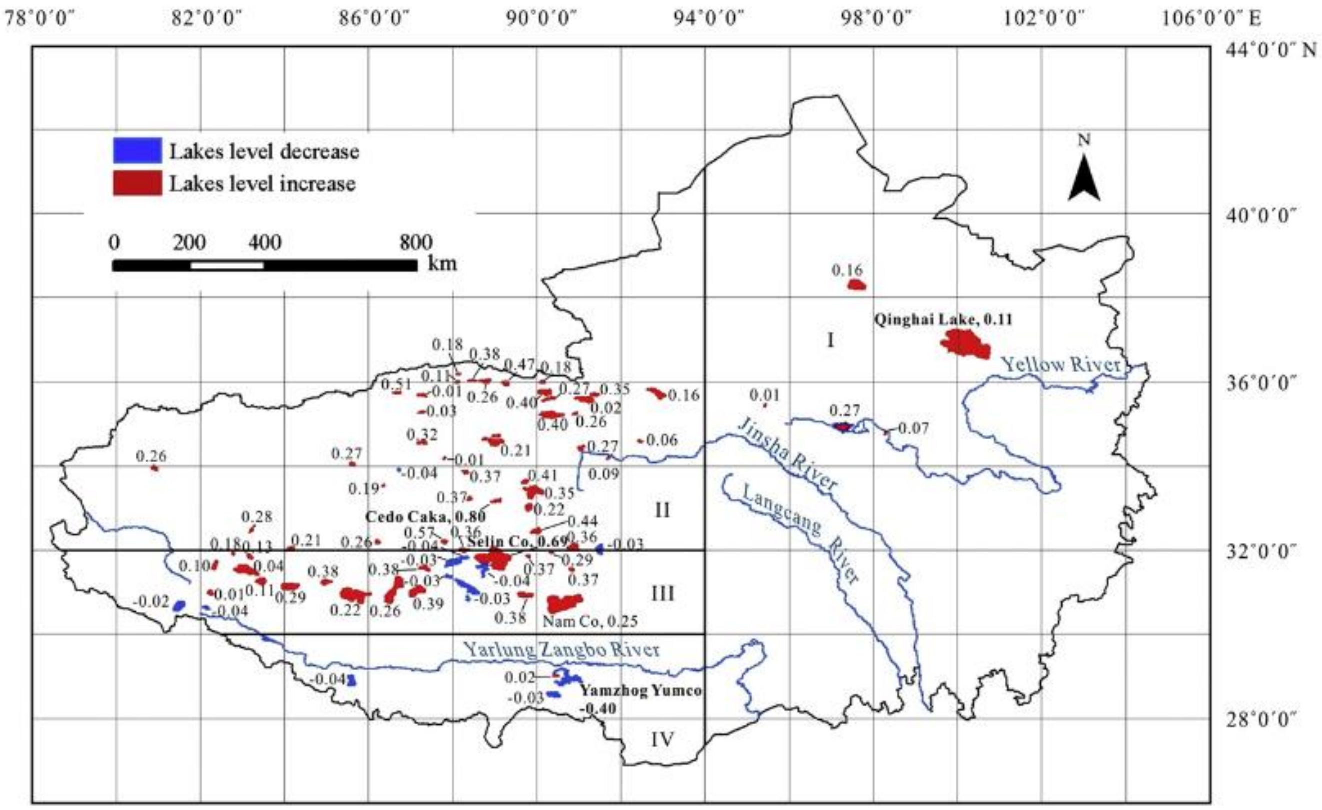
Nomads around Nam Co lake

Satellite Laser altimeter ICESat

- NASA mission, 2003-2010
- Point elevation measurements along the ground track
- Lidar
- Footprint of 70 m diameter each 170 m,
- Effect of cloud cover



Lake level oscillation by satellite Lidar ICESat

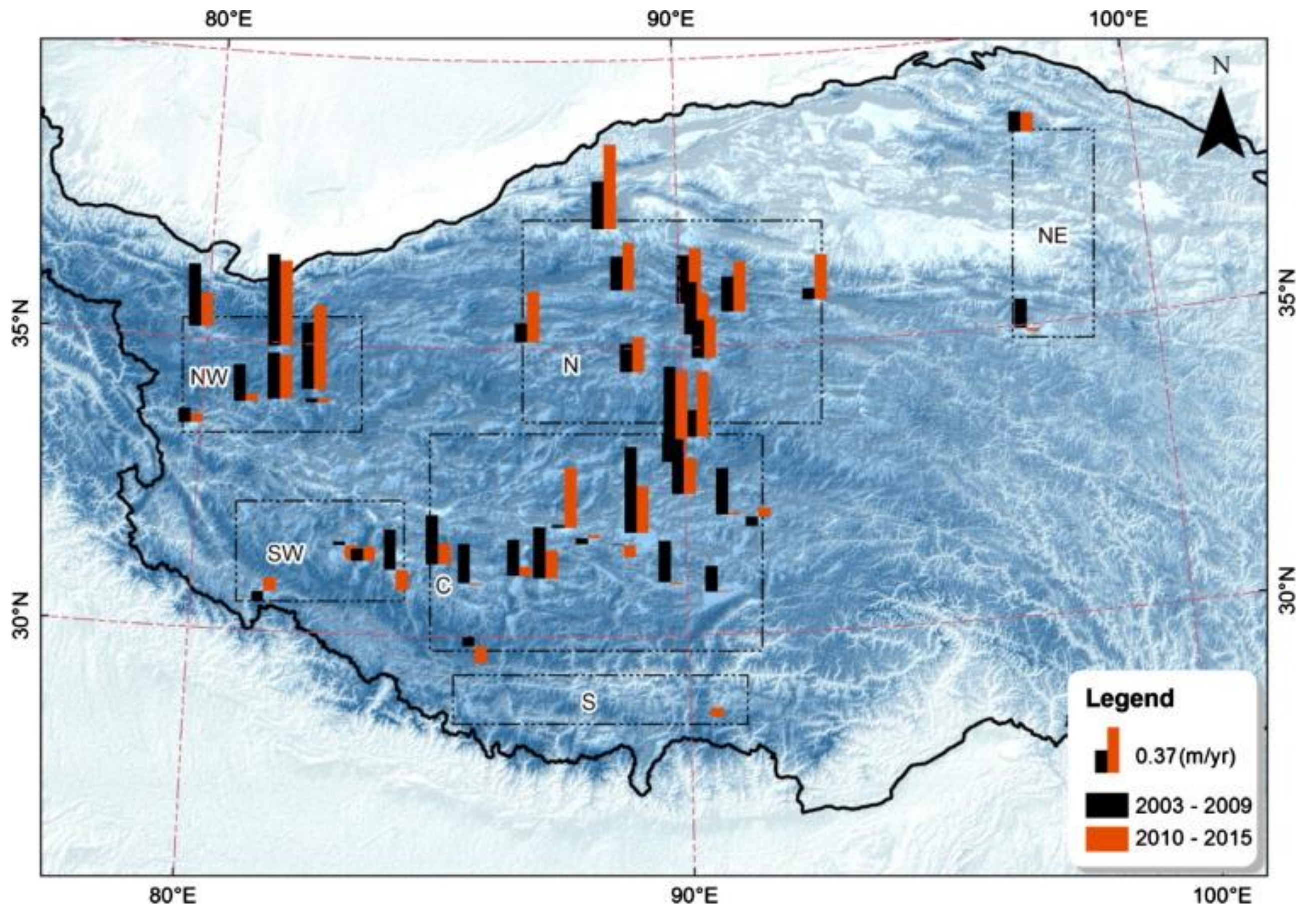


- Period 2003–2009
- 111 lakes on the Tibetan Plateau covered by ICESat footprints
- Lake level of 84% lakes increased
- Accelerated *glacier melting* due to global warming suggested as the most likely cause

Zhang, Guoqing, et al. "Monitoring lake level changes on the Tibetan Plateau using ICESat altimetry data (2003–2009)." *Remote Sensing of Environment* 115.7 (2011): 1733-1742.

Recent trends in lake levels in Tibet

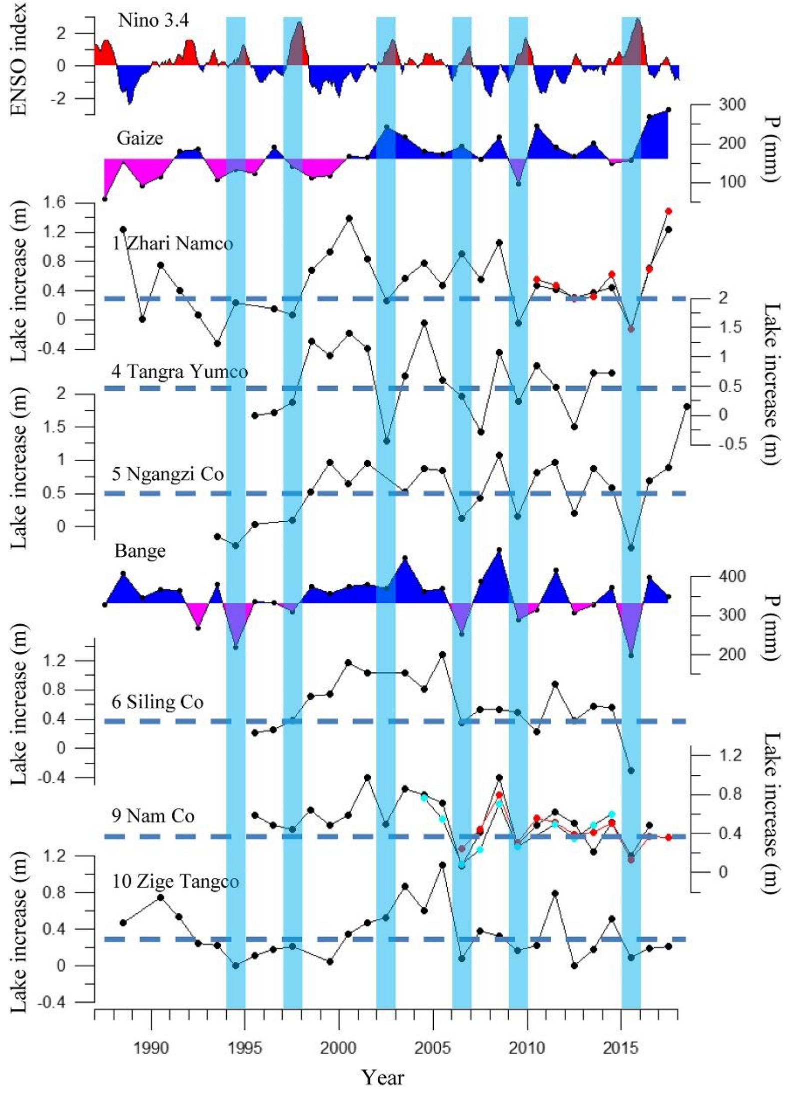
- Comparison of Cryosat (ESA‘s radar altimeter) 2010-2015 with ICESat 2003-2009
- Lakes in the NTP maintin their rising trend
- Lakes in the South slow down or keep decreasing



Jiang, Liguang, et al. "Monitoring recent lake level variations on the Tibetan Plateau using CryoSat-2 SARIn mode data." *Journal of Hydrology* 544 (2017): 109-124.

Reaction of Tibetan lakes to ENSO

El Nino Southern Oscilation



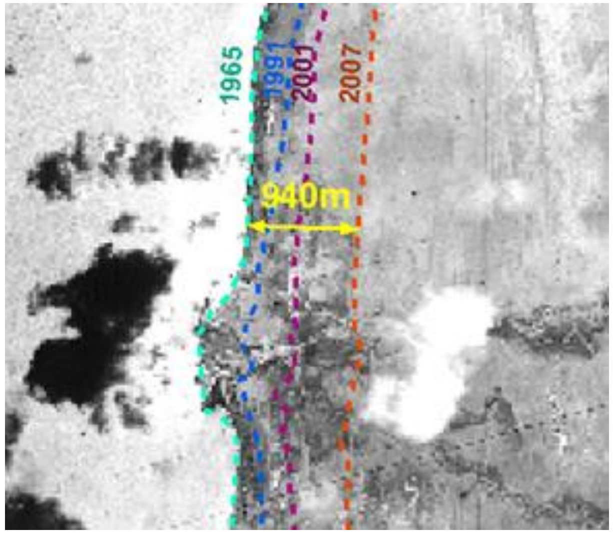
- Increase in ENSO index ->> decrease in precipitation in Tibet
- Followed by years of precipitation abbundance

LEI, Yanbin, et al. Extreme lake level changes on the Tibetan Plateau associated with the 2015/2016 El Niño. *Geophysical Research Letters*, 2019, 46.11: 5889-5898.

Utilization of Corona reconnaissance photographs

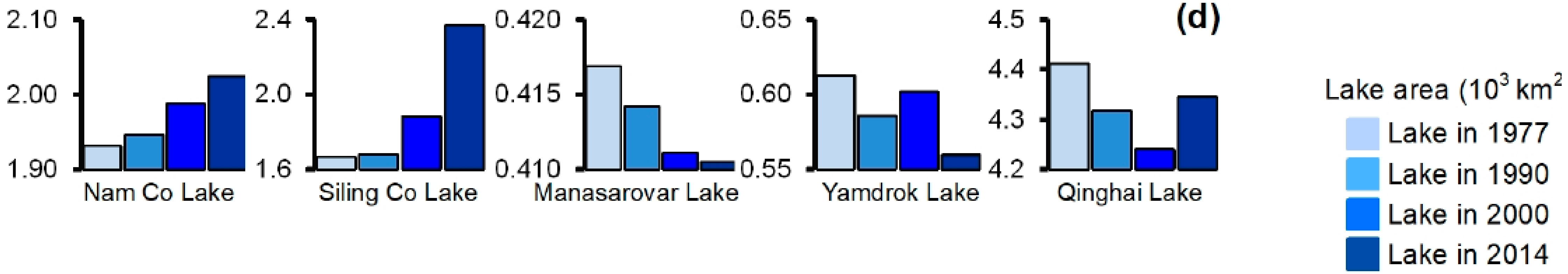
detail

(?) Connection between Mapam Yumco and Langa Co



Shoreline displacements at Nam Co from Corona and Landsat images

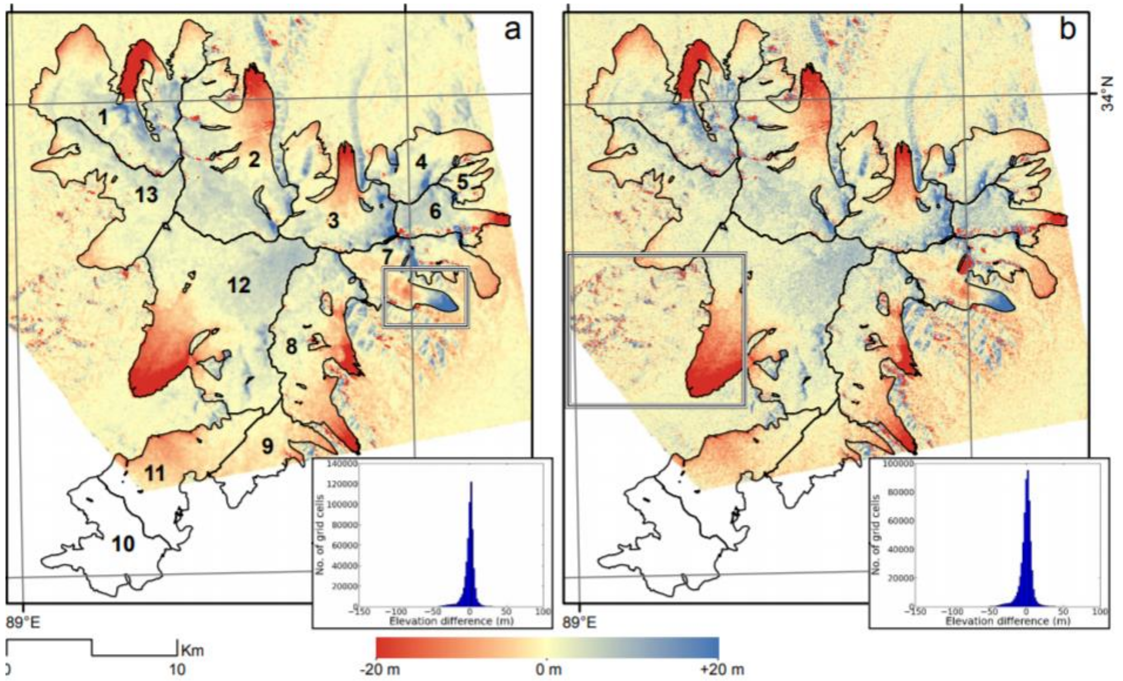
Changes of aerial extent from satellite images



- Analysis of Landsat images
- Shrinking lakes: drier climate or permafrost degradation

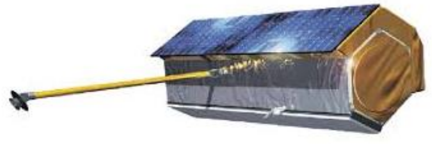
Mao, Dehua, et al. "Impacts of climate change on Tibetan lakes: Patterns and processes." *Remote Sensing* 10.3 (2018): 358.

Mass balance of the Purogangri Ice Cap by differential X-band SAR interferometry



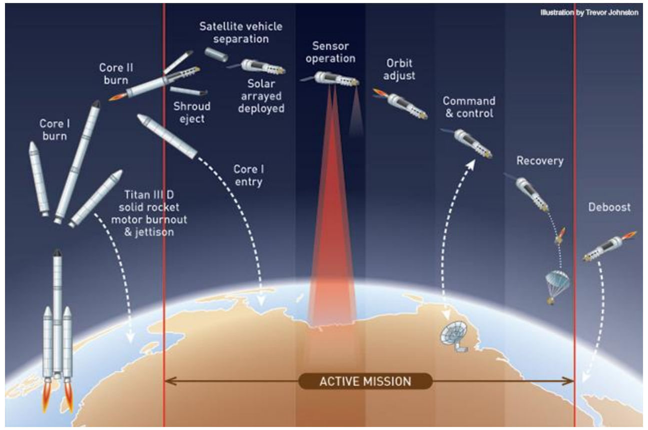
- SRTM-X and TanDEM-X, 2000 and 2012
- Two methods
  - DInSAR
  - DEM differencing
- Slightly negative mass budget
- −44 ± 15 and −38 ± 23 mm w.eq. a−1

Neckel N, Braun A, Kropácek J, et al. Recent mass balance of the Purogangri Ice Cap, central Tibetan Plateau, by means of differential X-band SAR interferometry[J]. The Cryosphere, 2013, 7(5): 1623.



TerraSAR-X, DLR

Glacier mass wasting in Kunlun from KH-9

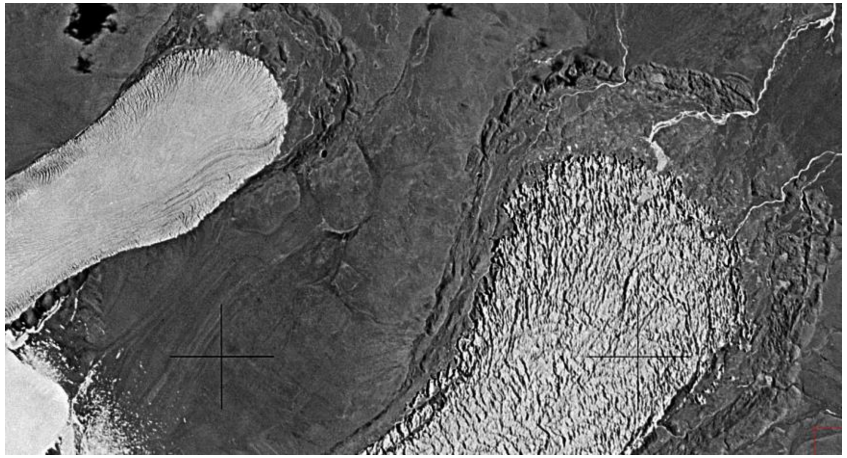


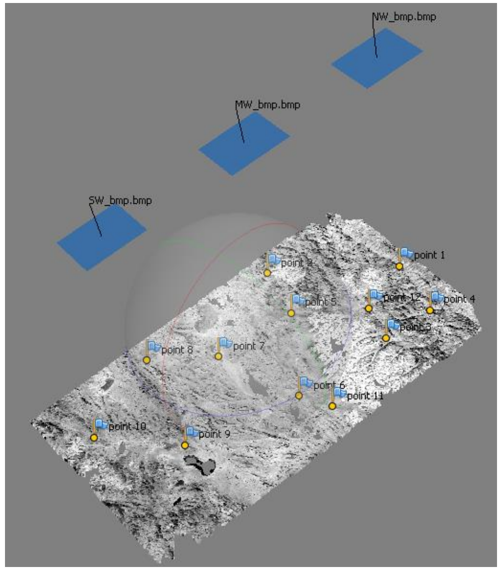
How it worked

Film recovery

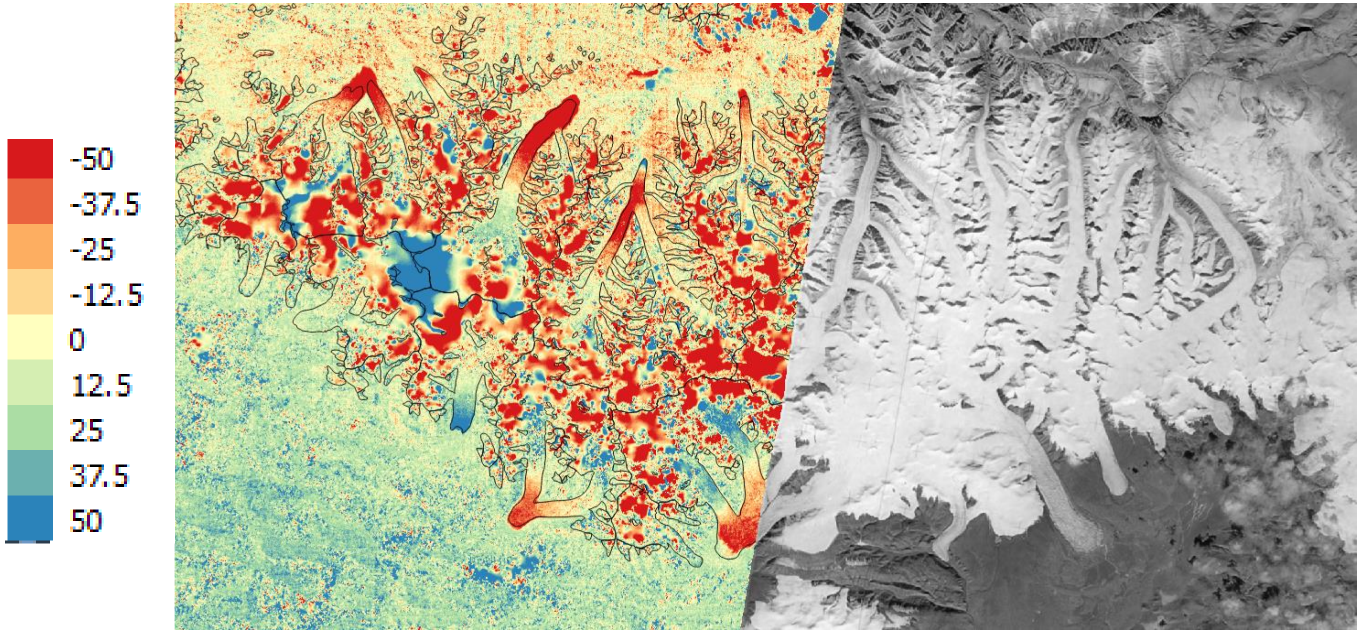
- 6 KH-9 images from 1973 and 1974
- Resolution 3 m
- SfM processing

- Reconnaissance program in 1973-1980
- Declassified in 2002
- 29 000 photos, 12 campaigns
- F = 305 mm
- 9x18 inches, 3600 dpi



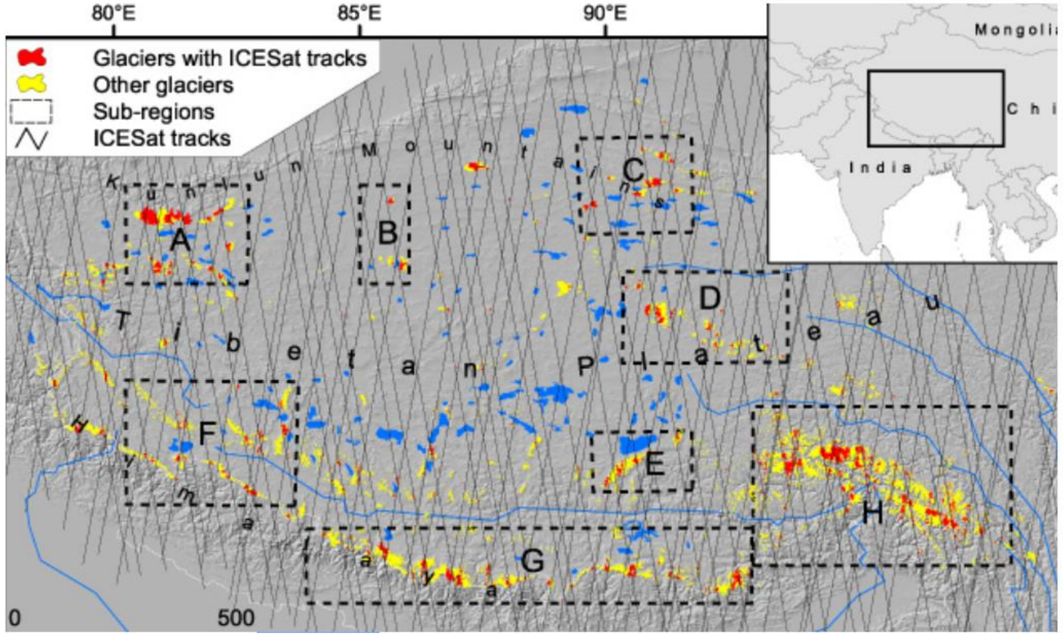


Glacier mass wasting in Kunlun from KH-9

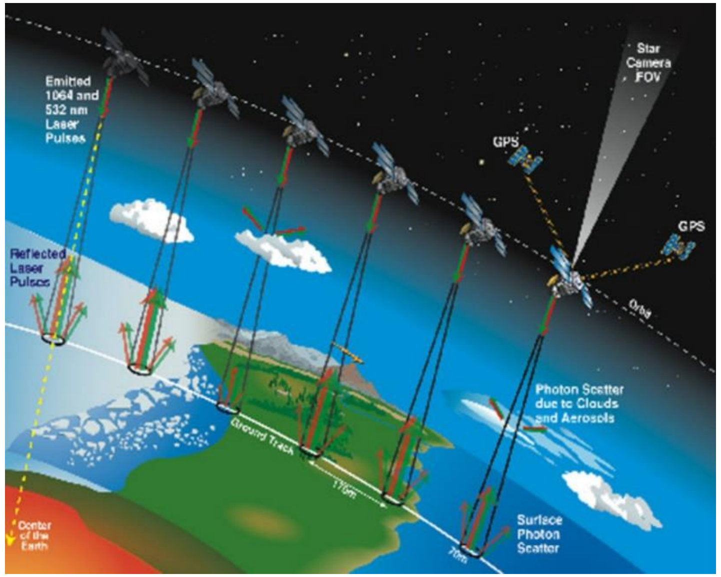


- DEM resolution = 7 m
- DEM differencing (SRTM, TanDEM-X)
- Artifacts in accumulation areas
- Thinning up to about -50m in ablation areas
- Several surges

Glacier mass wasting on the TP in 2003-2009 from satellite altimetry by ICESat-1

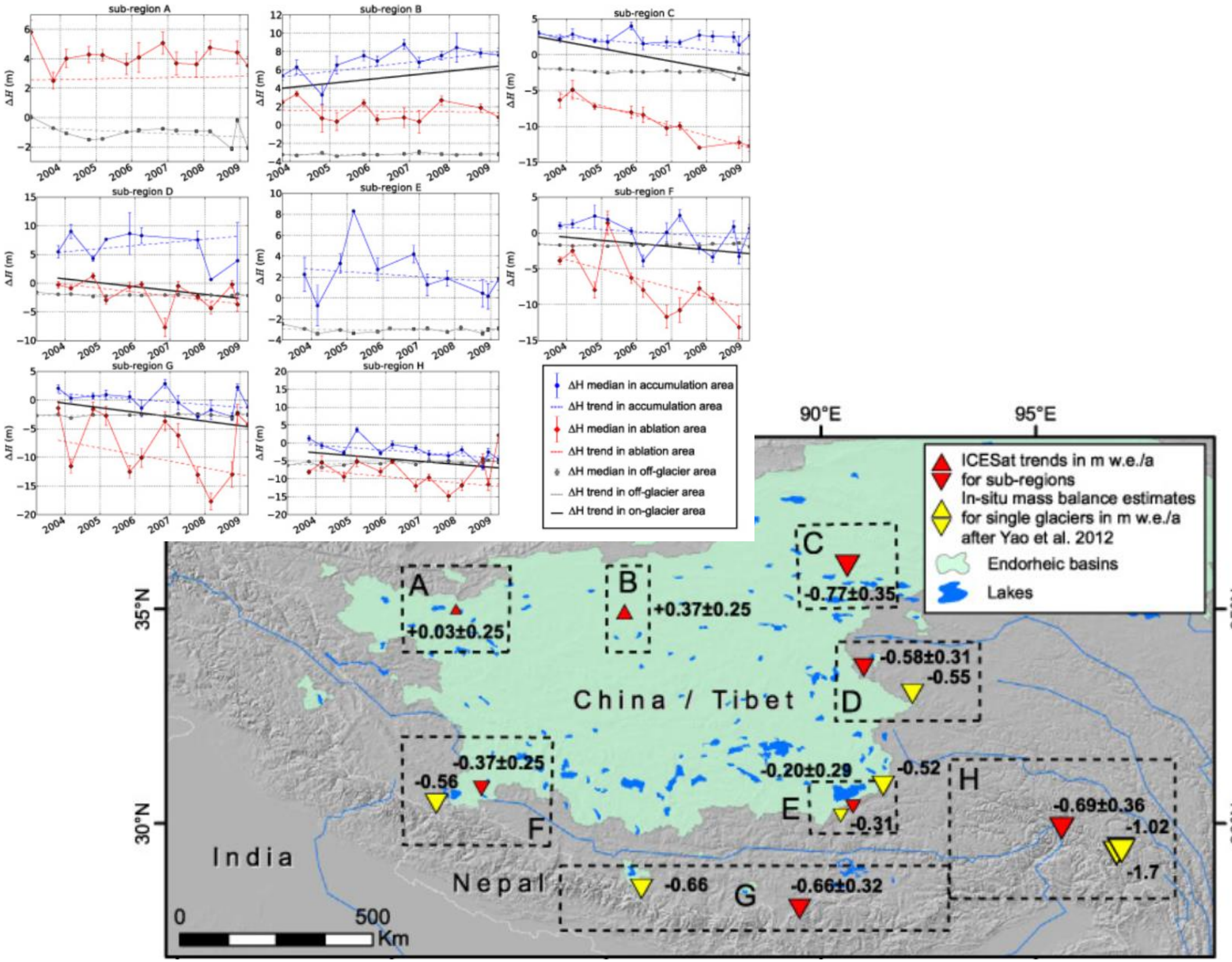


- ICESat-1 (NASA)
- Operational 2003 – 2010
- Surface elevation measurements by orbital LIDAR



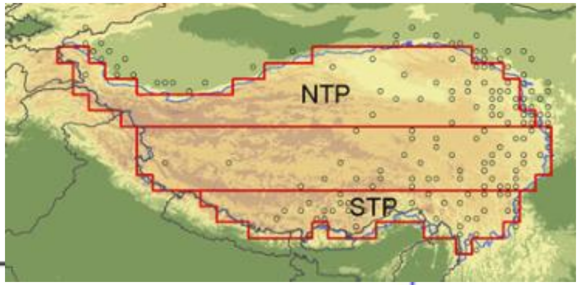
Neckel N, Kropáček J, Bolch T, et al. Glacier mass changes on the Tibetan Plateau 2003–2009 derived from ICESat laser altimetry measurements[J]. Environmental Research Letters, 2014, 9(1): 014009.

Glacier mass wasting on the TP in 2003-2009 from satellite altimetry by ICESat-1 - RESULTS

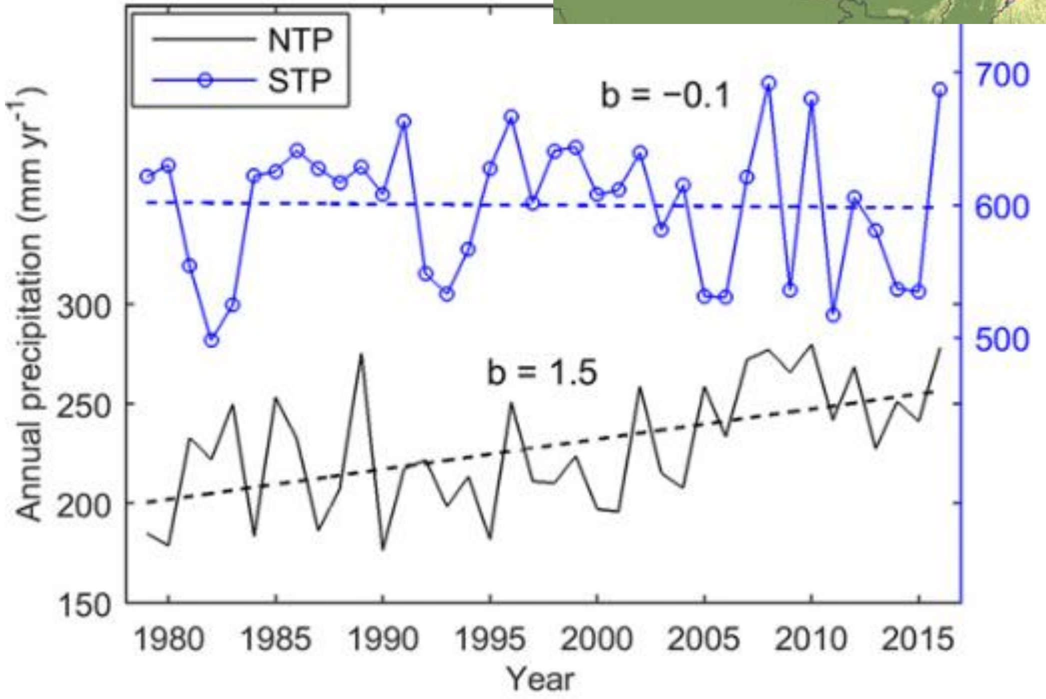


- total annual mass budget of − 15.6 ± 10.1 Gt a^{-1} ~80% of glacier area on the TP
- About 11% is drained to the endorheic lakes
- Larges mass lost in E
- Slight mass gain in NW
- Comprehensive idea of glacier dynamics on the TP

Variation in precipitation trends

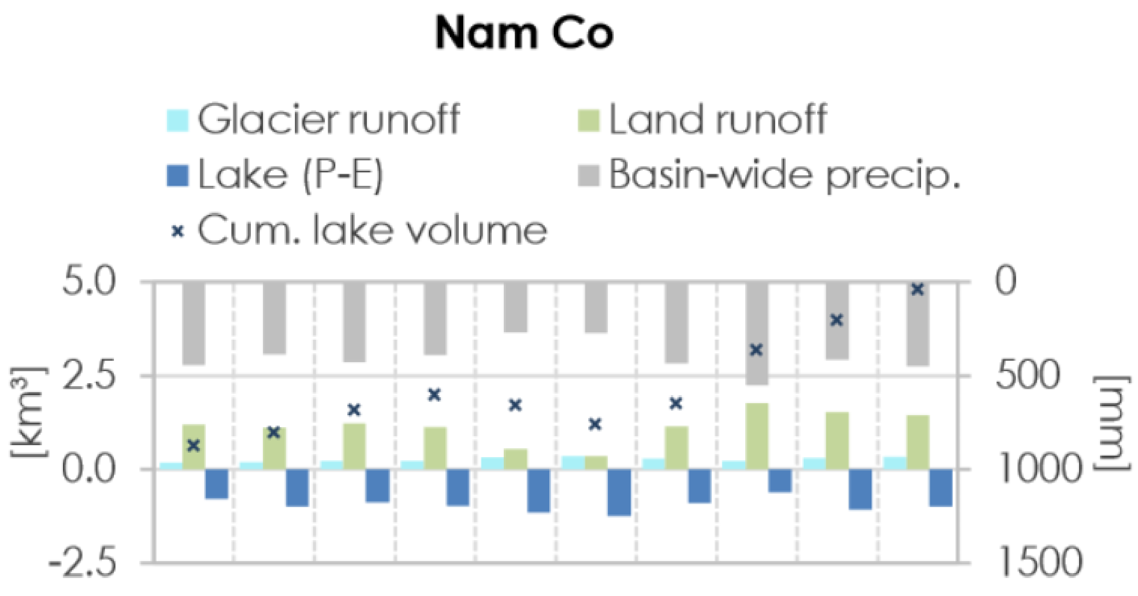


- STP: dominated by Summer Indian Monsoon
- NTP: dominated by Westerlies



ZHANG, Chi, et al. Moisture source changes contributed to different precipitation changes over the northern and southern Tibetan Plateau. *Journal of Hydrometeorology*, 2019, 20.2: 217-229.

Hydrological modelling

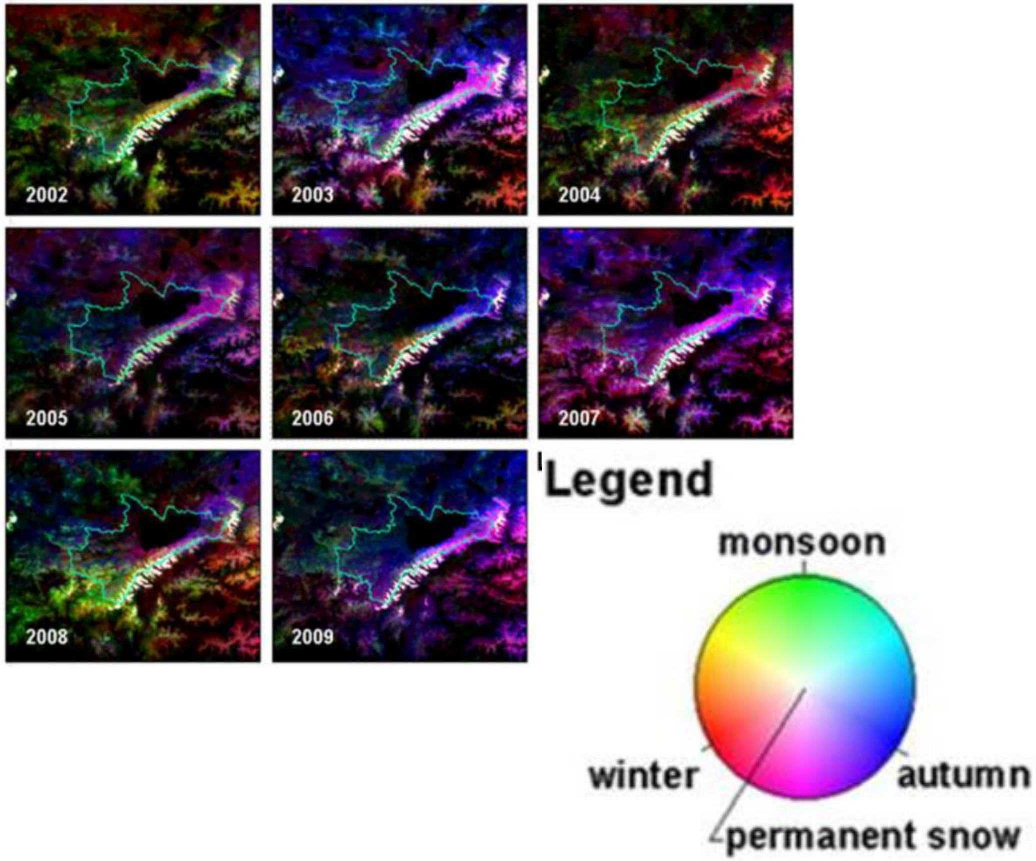


Contribution of components to cummulative lake volume change (Biskop et al.)

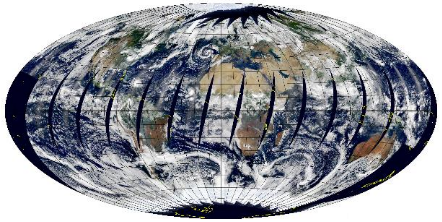
- Four lakes in 2001-2010
- High Asia Refined analysis (HAR)
- Major driver is precipitation
- Contribution of glacier-meltwater to the total basin runoff volume is 14 - 30 %

Biskop, S., et al. "Differences in the water-balance components of four lakes in the southern-central Tibetan Plateau." *Hydrology & Earth System Sciences* 20.1 (2016).

Snow cover patterns in Nam Co basin



- RGB composites made from MODIS data divided in three seasons – new approach
- Color represents the dominant snow cover period
- Allows analysis of snow cover patterns

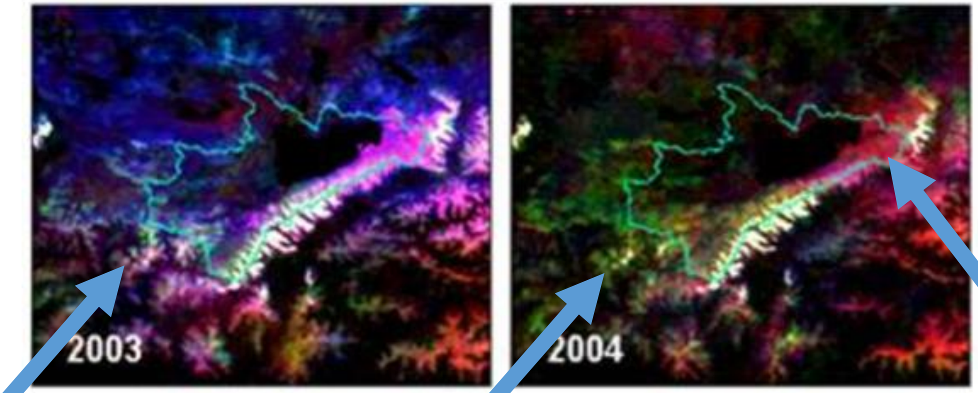


One cycle of MODIS data

Terra satellite

Kropacek, J., Feng, C., Alle, M., Kang, S., & Hochschild, V. (2010). Temporal and spatial aspects of snow distribution in the Nam Co Basin on the Tibetan Plateau from MODIS data. *Remote Sensing*, *2*(12), 2700-2712.

Snow cover patterns in Nam Co Basin



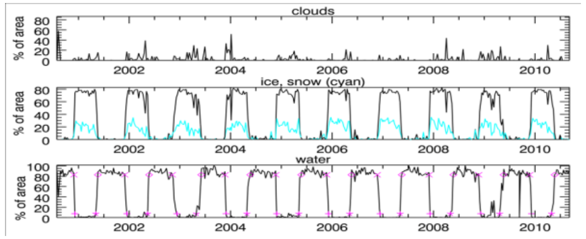
lake effect

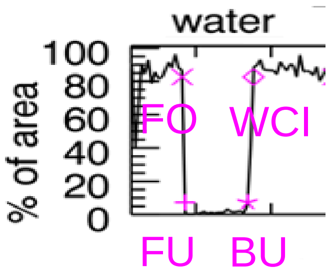
periodicity of snow cover: two years

Corresponds to oscillation of the Indian monsoon

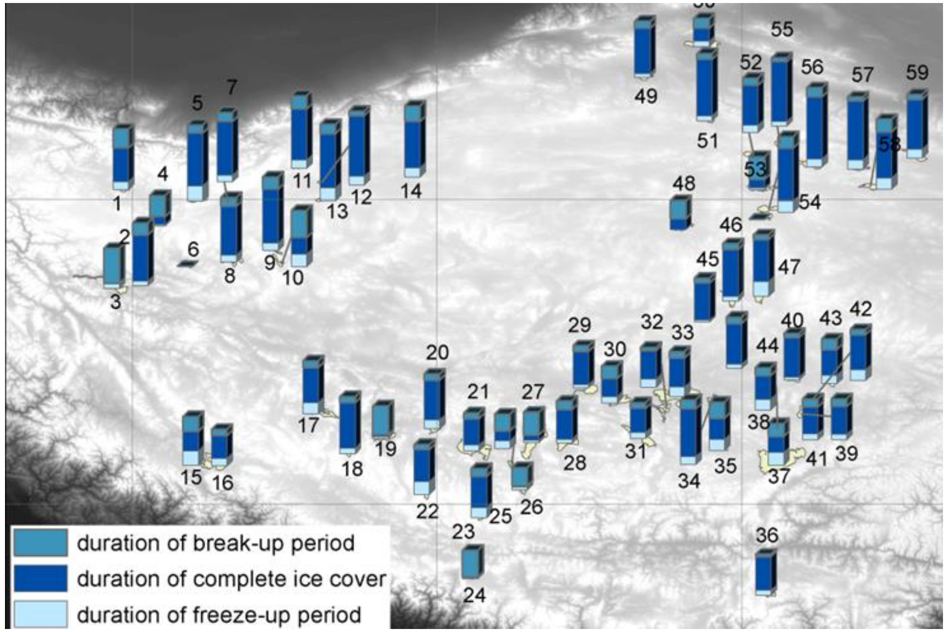
Lake ice phenology on the TP in 2001-2010

MODIS 8-day composites



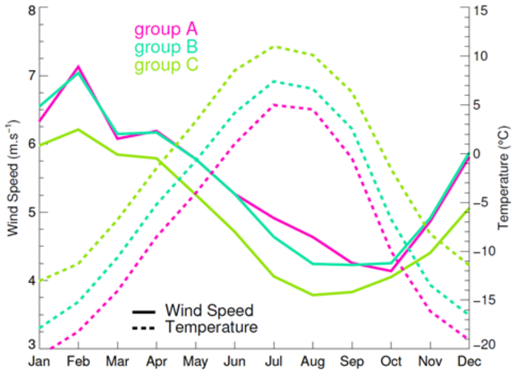


FO: Freeze onset
FU: freeze-up
BU: Break up
WCI: water clear of ice



Freeze onset and water clean of ice day are more thermally determined than freeze-up and break-up dates

Frozen Nam Co, April 2009

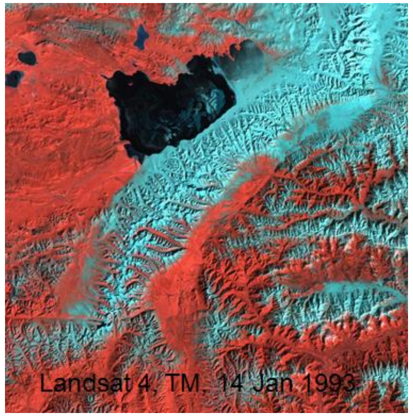


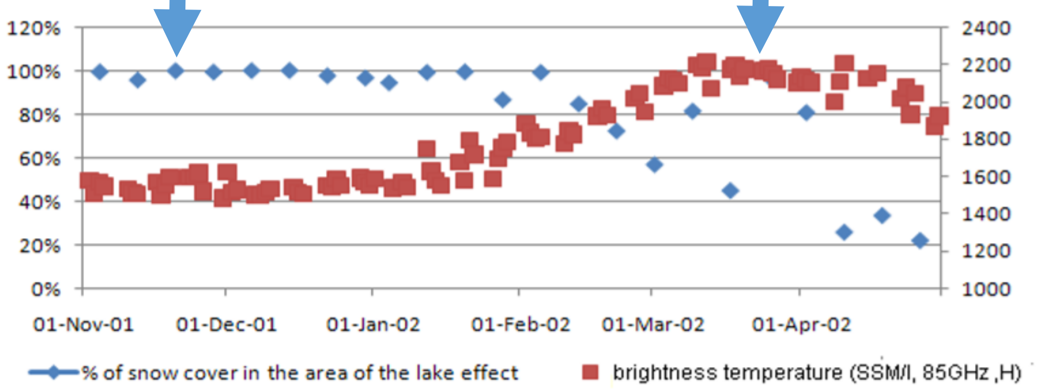
J. Kropáček, F. Maussion, F. Chen, S. Hoerz, and V. Hochschild, Analysis of ice phenology of lakes on the Tibetan Plateau from MODIS data, The Cryosphere, 7, 287–301, 2012

Lake effect in Nam Co Basin

Snow cover from MODIS, East of Nam Co

Lake ice from passive microwave satellite data SSMI, 85 GHz

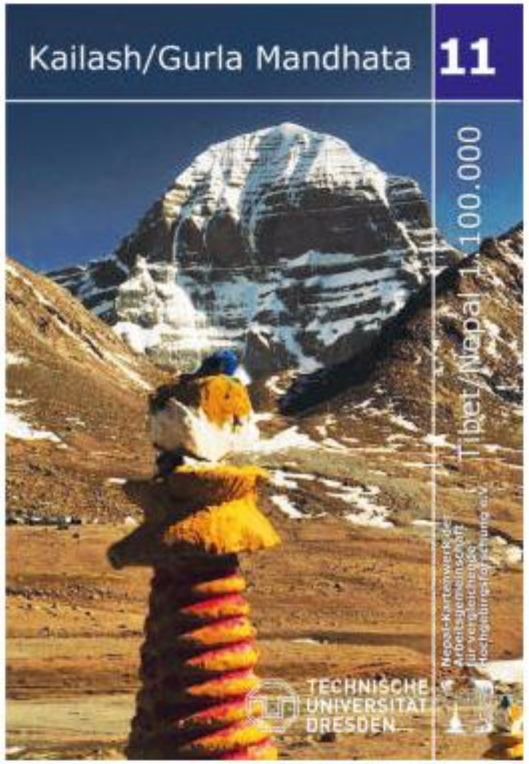




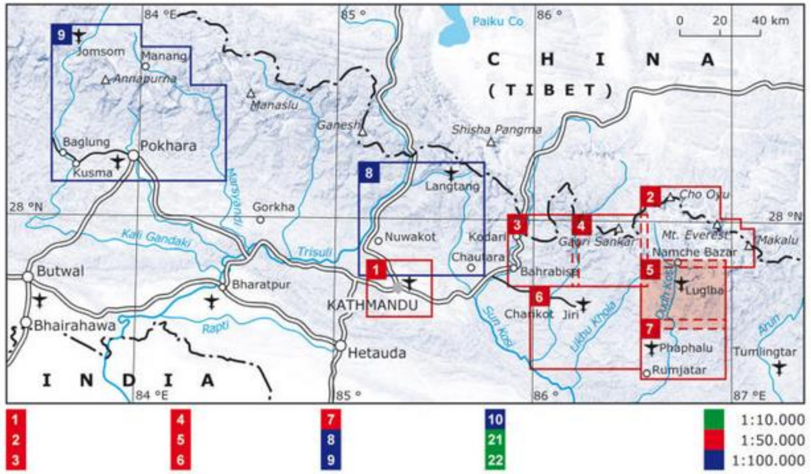
- Lake effect is limited to autumn and early winter
- It disappears due to freeze over of the lake

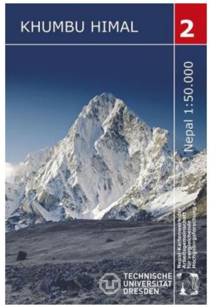
Kropacek, J., Feng, C., Hoerz, S., Hochschild, V., 2011, Analysis of icing cycle and snow distribution in a basin on the Tibetan Plateau from passive microwave and optical data, 31st EARSeL Symposium and 35th General Assembly 2011, May 2011, Prague, Czech Republic.

Trekking Map 11, Kailash/ Gurla Mandhata 1:100.000



Nepal-Kartenwerk der Arbeitsgemeinschaft für vergleichende Hochgebirgsforschung e.V., Verlag: Technische Uni Dresden





- Side product of WET project
- Master thesis of Jacob Trültsch, TU Dresden

Further reading

Kang, Shichang, et al. "Review of climate and cryospheric change in the Tibetan Plateau." *Environmental research letters* 5.1 (2010): 015101.

Zhang, Guoqing, Wenfeng Chen, and Hongjie Xie. "Tibetan Plateau's lake level and volume changes from NASA's ICESat/ICESat-2 and Landsat Missions." *Geophysical Research Letters* 46.22 (2019): 13107-13118.

Song, Chunqiao, et al. "Remote sensing of alpine lake water environment changes on the Tibetan Plateau and surroundings: A review." *ISPRS Journal of Photogrammetry and Remote Sensing* 92 (2014): 26-37.

Song, Chunqiao, Bo Huang, and Linghong Ke. "Modeling and analysis of lake water storage changes on the Tibetan Plateau using multi-mission satellite data." *Remote Sensing of Environment* 135 (2013): 25-35.

The Tibetan Plateau, University of California Television: https://www.youtube.com/watch?v=bLtVI8lhQ20