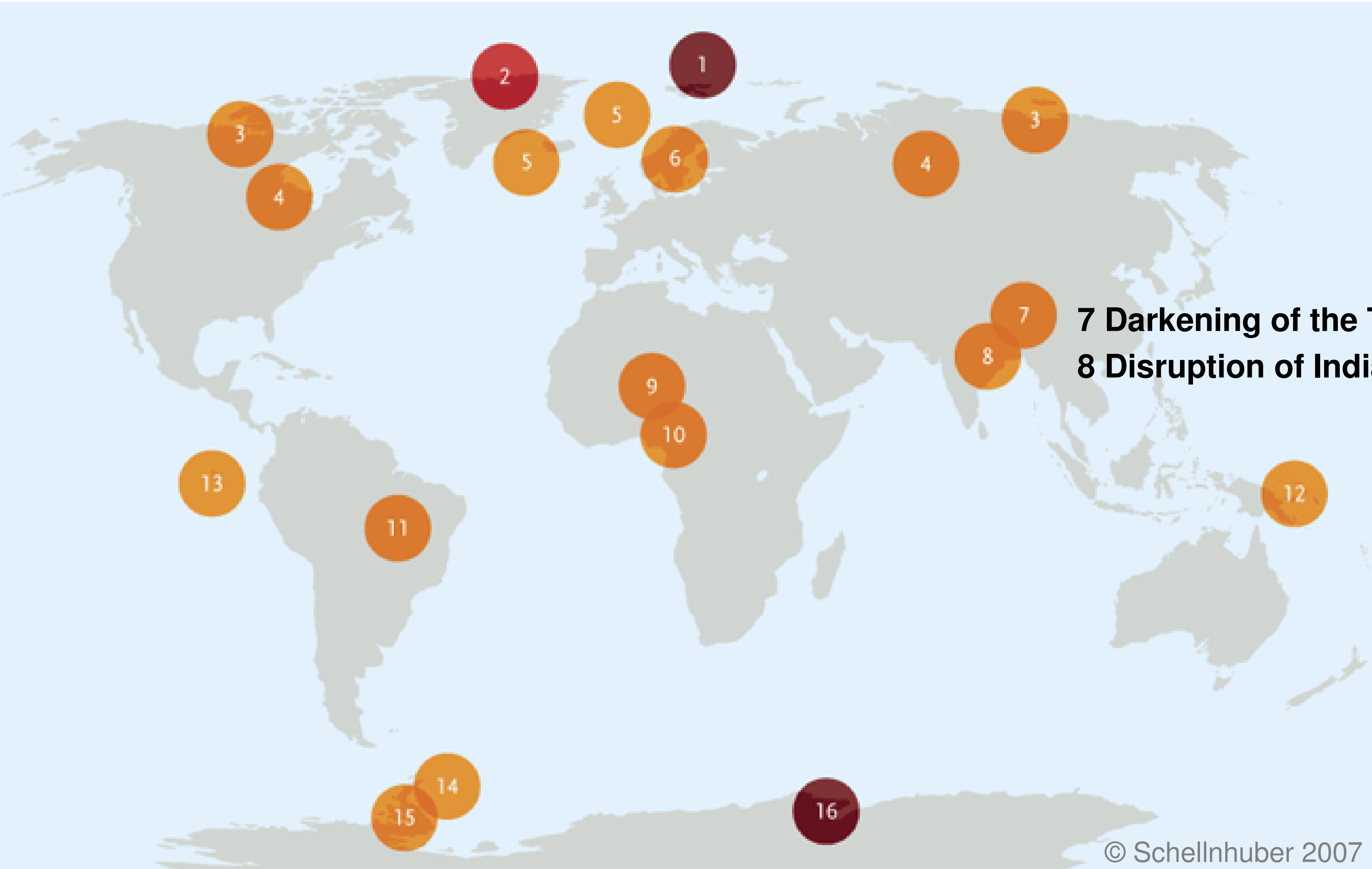
# Climate variability and glacier response on the Tibetan Plateau

## with focus on recent changes in the western Nyainqentanglha Mountains

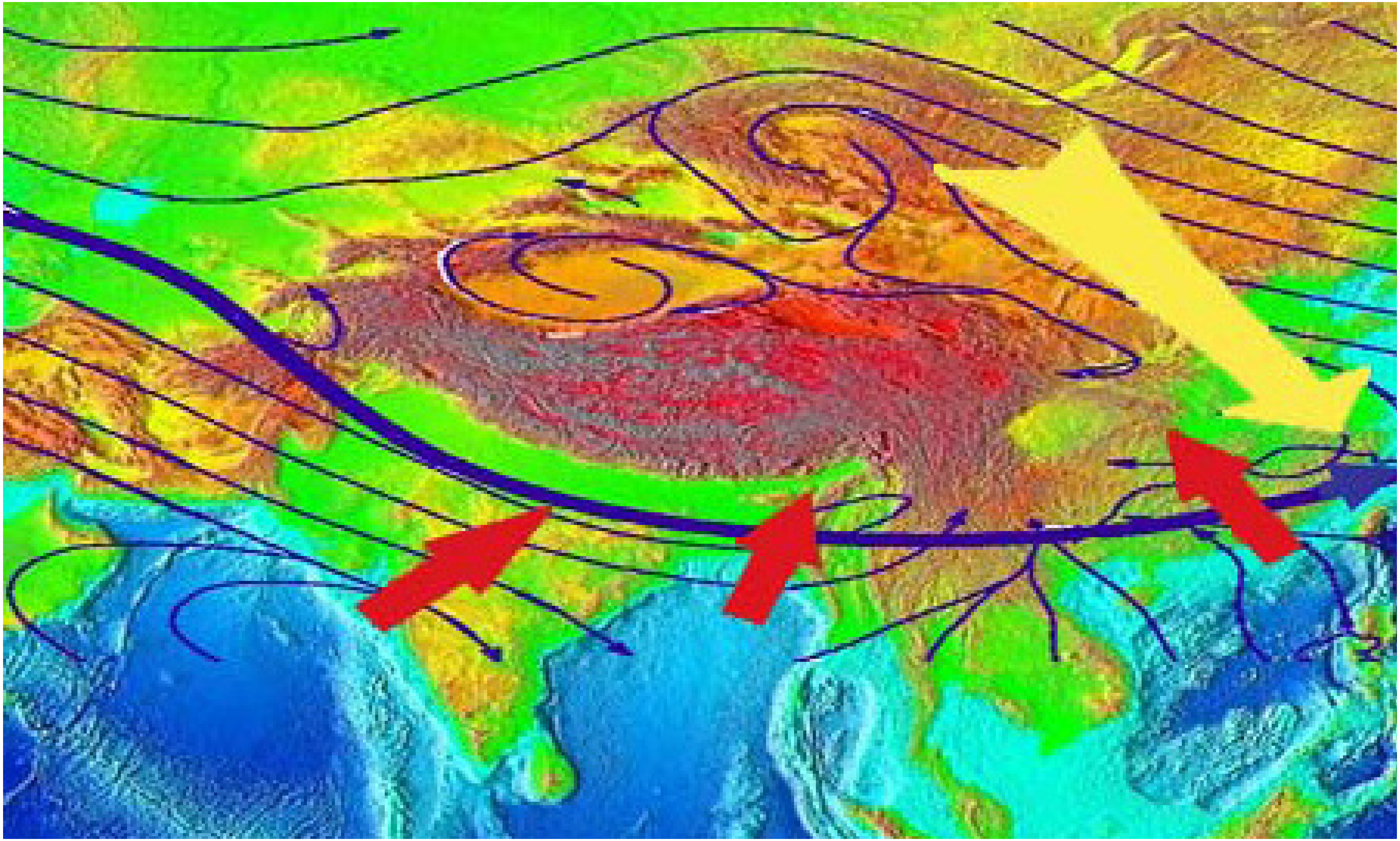
**Dieter Scherer**[1], Christoph Schneider[2], Manfred Buchroithner[3], Tobias Bolch[3], Eva Huintjes[2], Fabien Maussion[1], Tino Pieczonka[3], Jochen Richters[3]

*[1]Institut für Ökologie, TU Berlin*
*[2]Geographisches Institut, RWTH Aachen*
*[3]Institut für Kartographie, TU Dresden*

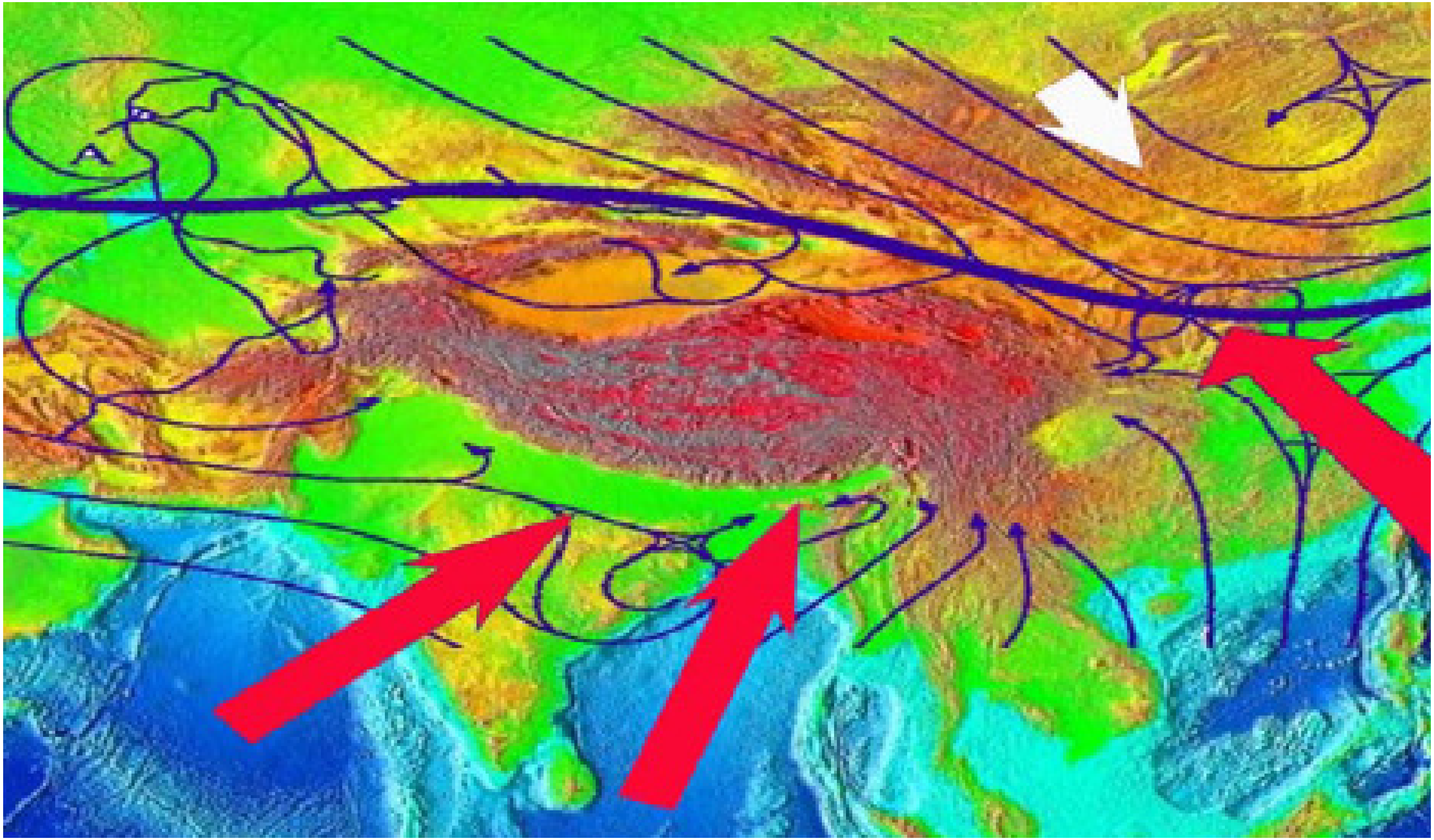
# Potential anthropogenic tipping elements in the Earth system




**7 Darkening of the Tibetan Plateau**
**8 Disruption of Indian Monsoon**

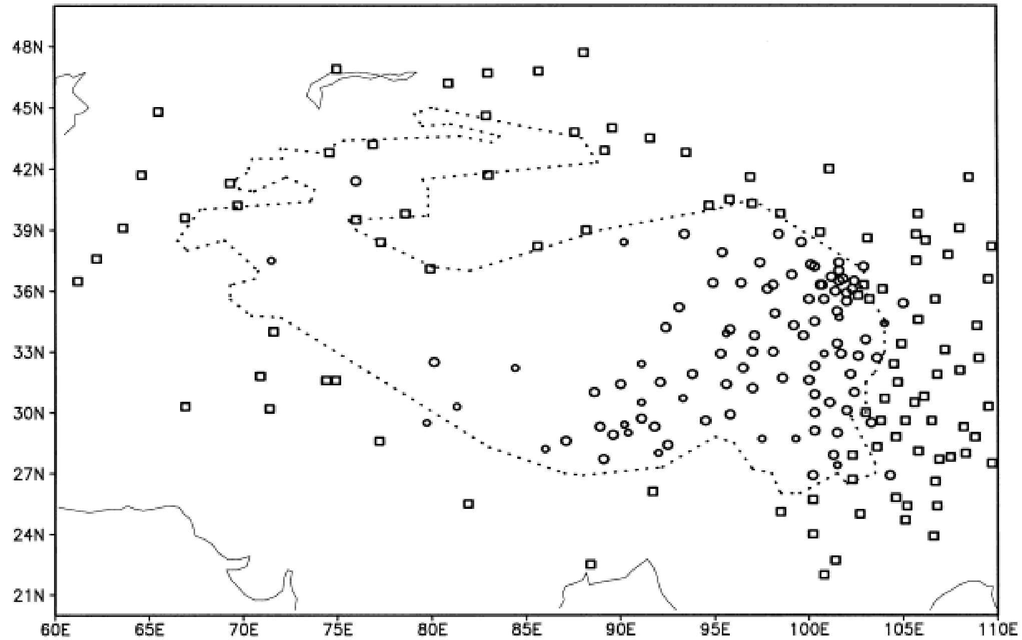


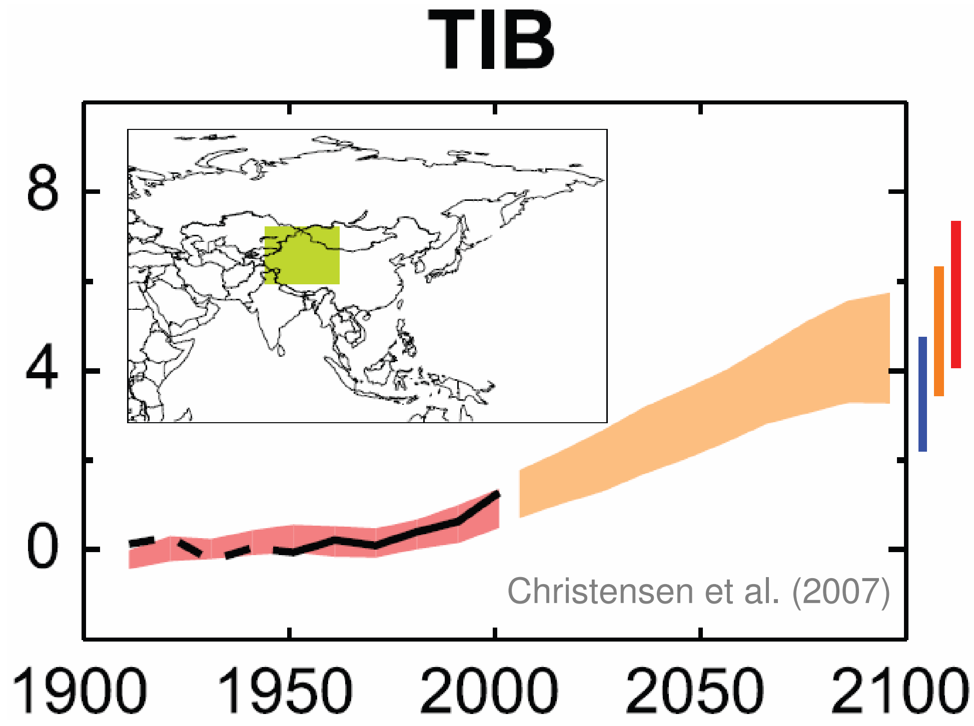
Yao (2008)



Yao (2008)

# IPCC AR4 regional climate projections for Tibet



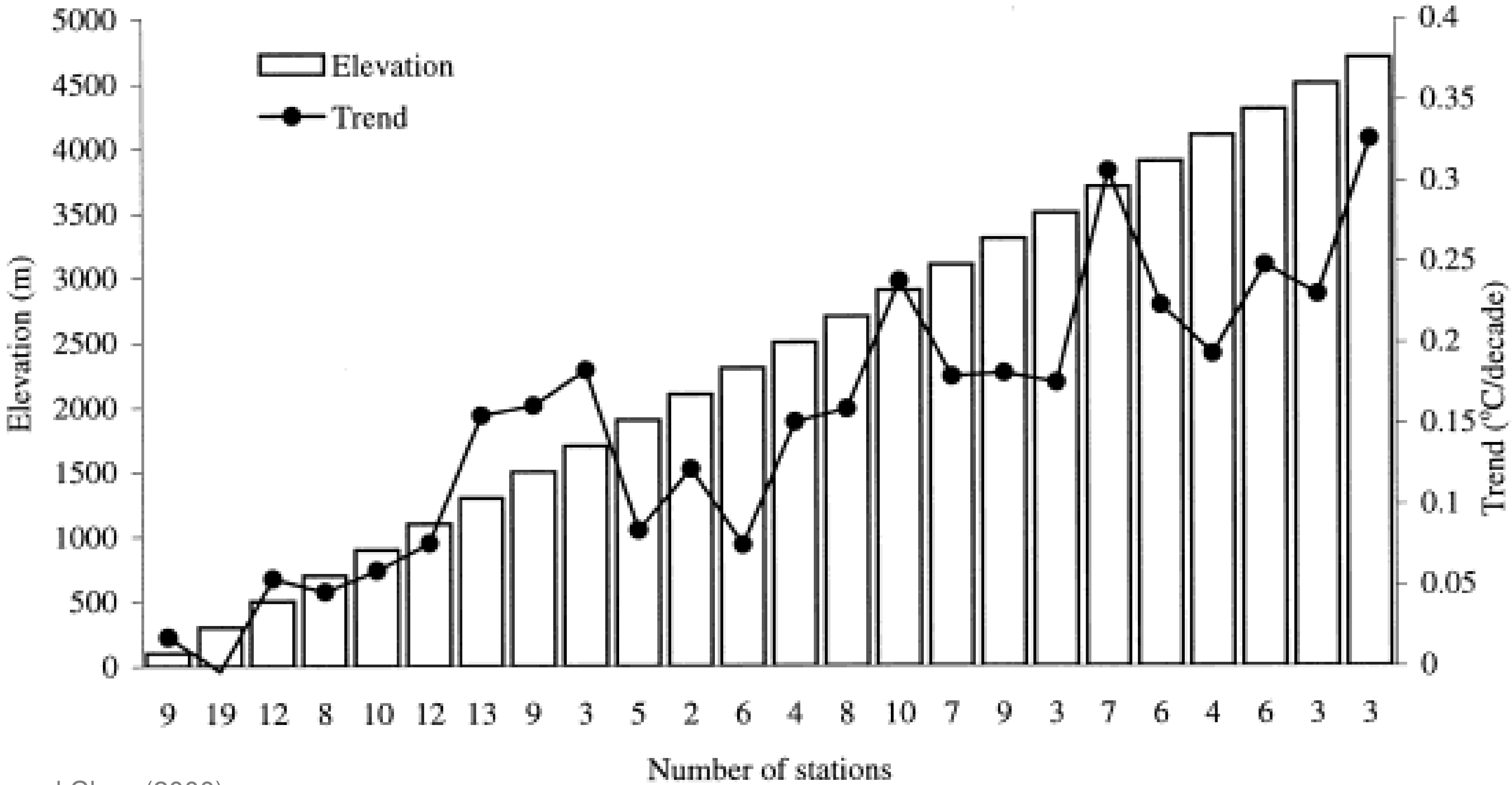




sparse and biased observational data

no station is higher than 4800 m a.s.l.

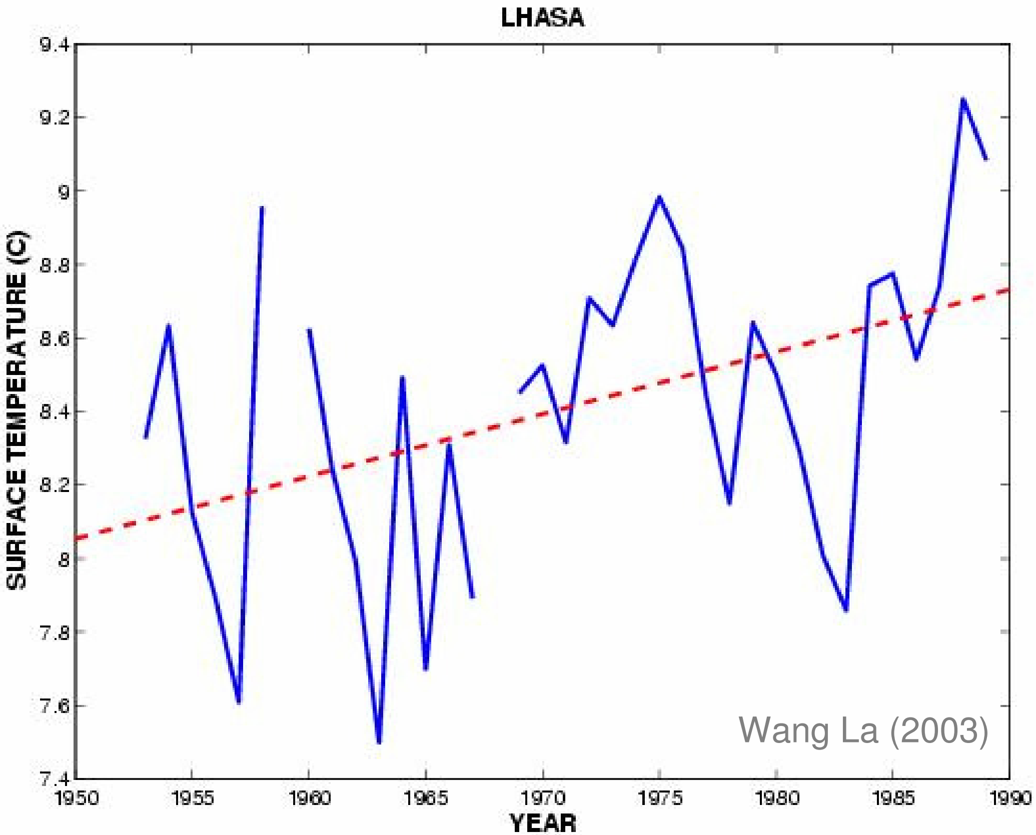
warming higher than global average

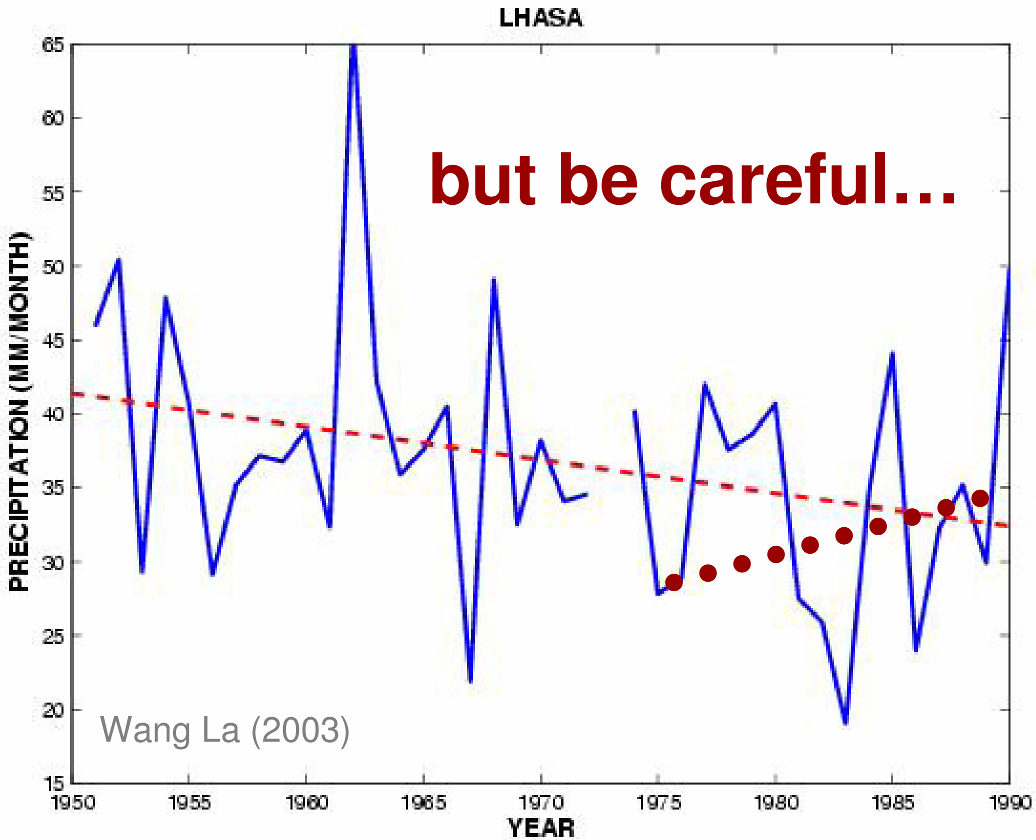
# Mean annual air temperature trends in Tibet




Liu and Chen (2000)

# Air temperature and precipitation trends in Lhasa




Liu and Chen (2000):
- warming stronger in the E and at high altitudes
- warming started already in the 1950s

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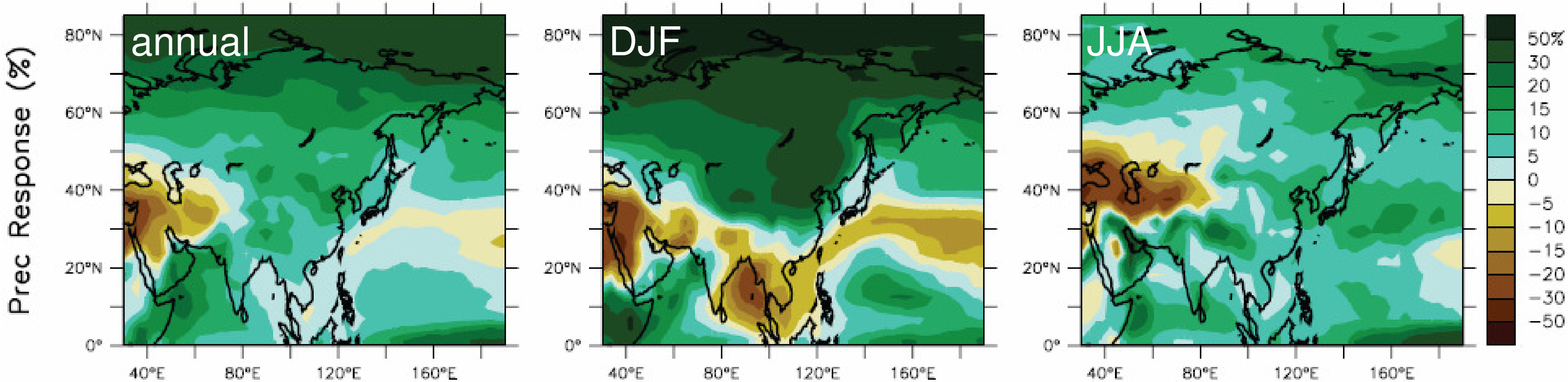
# IPCC AR4 regional climate projections for Tibet




Christensen et al. (2007)

Increasing winter precipitation

Decreasing summer precipitation

GCM precipitation up to six times too high

RCM better, but still up to two times too high

# Regional mean length variations of glaciers

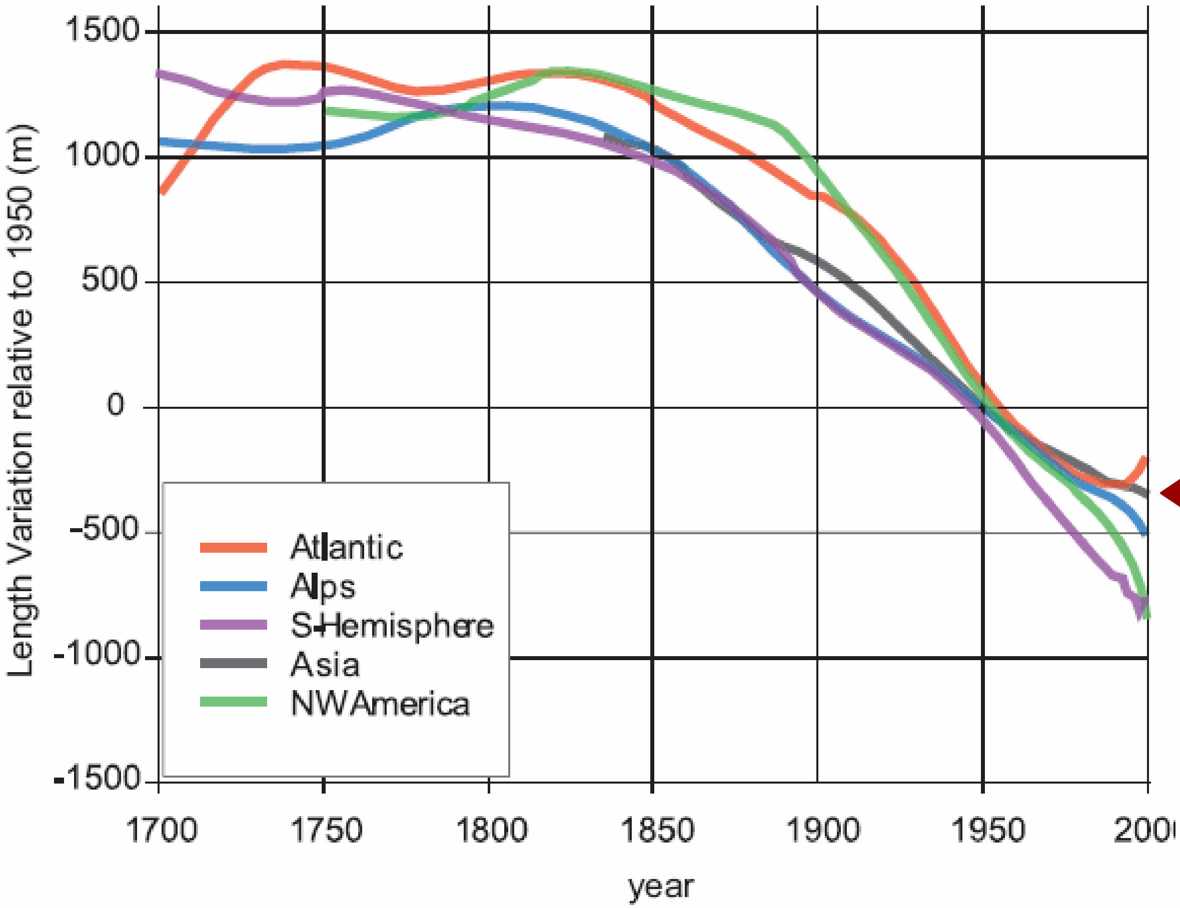



**Figure 4.13.** *Large-scale regional mean length variations of glacier tongues (Oerlemans, 2005). The raw data are all constrained to pass through zero in 1950. The curves shown are smoothed with the Stineman (1980) method and approximate this. Glaciers are grouped into the following regional classes: SH (tropics, New Zealand, Patagonia), northwest North America (mainly Canadian Rockies), Atlantic (South Greenland, Iceland, Jan Mayen, Svalbard, Scandinavia), European Alps and Asia (Caucasus and central Asia).*

Asian glaciers retreated about 300 m since 1950

Complex spatio-temporal patterns: retreating, advancing and even surging glaciers

Lemke et al. (2007), IPCC AR4 WG I, Ch. 4

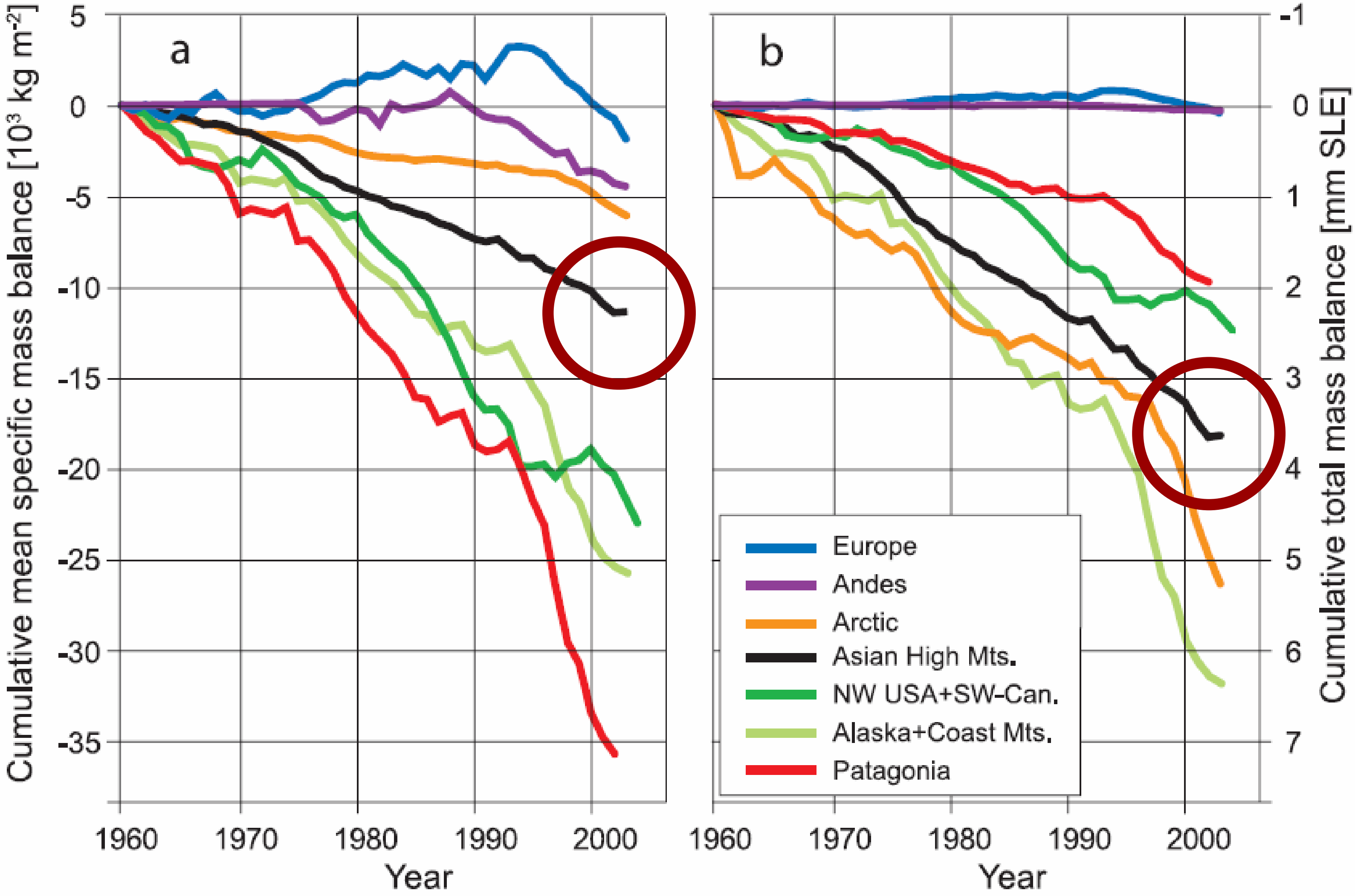



**Figure 4.15.** *Cumulative mean specific mass balances (a) and cumulative total mass balances (b) of glaciers and ice caps, calculated for large regions (Dyurgerov and Meier, 2005). Mean specific mass balance shows the strength of climate change in the respective region. Total mass balance is the contribution from each region to sea level rise.*

Lemke et al. (2007), IPCC AR4 WG I, Ch. 4

# *DynRG-TiP*

## Dynamic Response of Glaciers on the Tibetan Plateau to Climate Change

### German project partners:

**Dieter SCHERER**, Prof. Dr.
Department of Ecology, Chair of Climatology, Technische Universität Berlin (TU Berlin)

**Christoph SCHNEIDER**, Prof. Dr.
Department of Geography, Physical Geography and Climatology, RWTH Aachen University

**Manfred BUCHROITHNER**, Prof. Dr.
Institute for Cartography (IfC), Dresden University of Technology (TU Dresden)

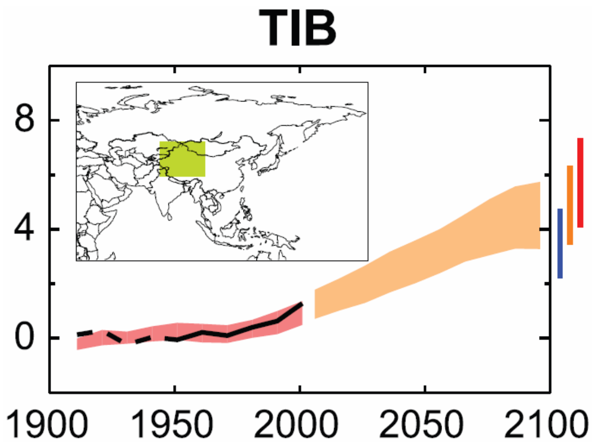
### Chinese project partners:

**YAO Tandong**, Ph.D., Prof., Director

**KANG Shichang**, Ph.D., Prof. Glaciology and Climatology
Institute of Tibetan Plateau Research (ITP), Chinese Academy of Sciences (CAS)

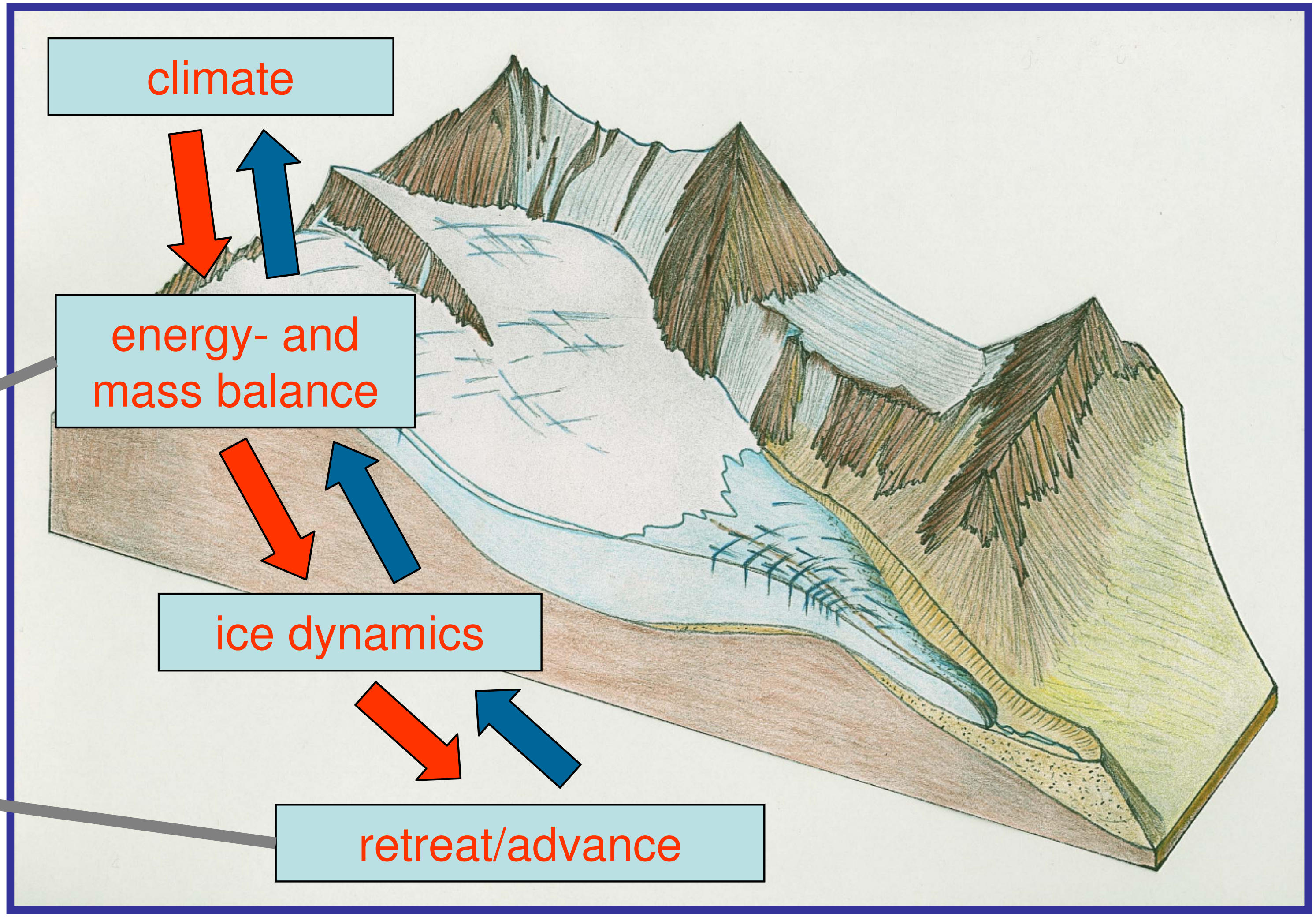


# Glacier response to climate change



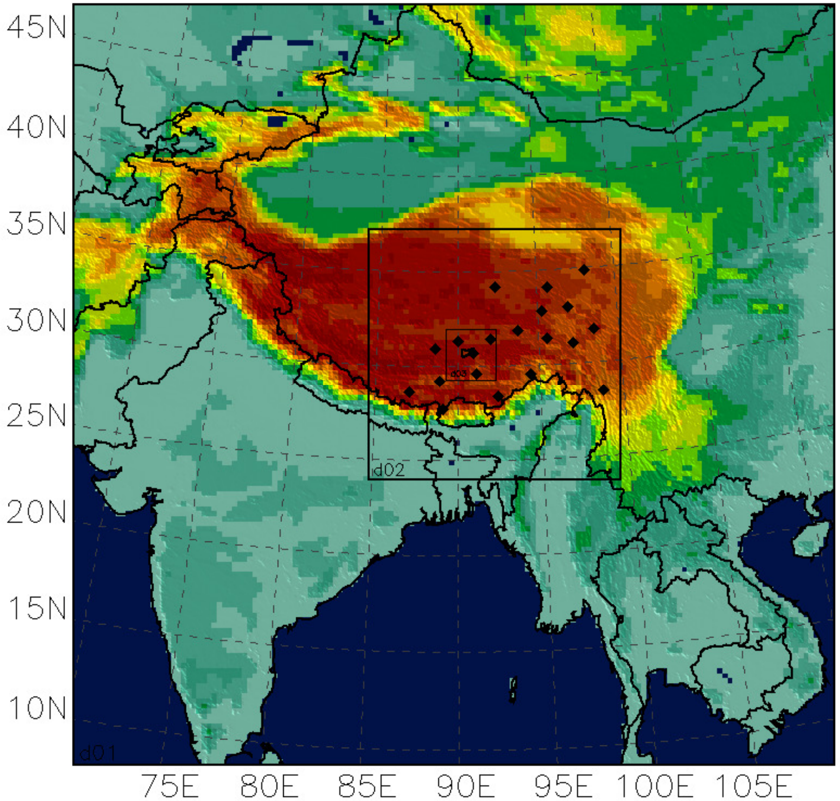

direct signals

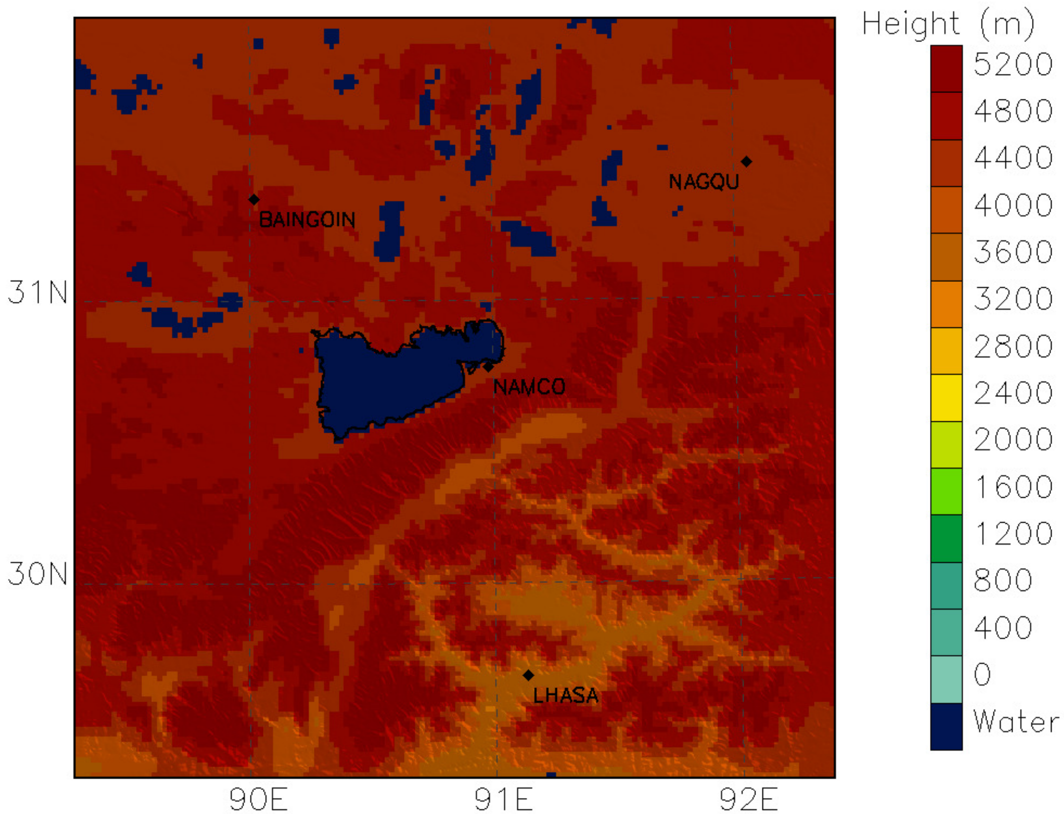
indirect, time-laged, filtered, sometimes enhanced or even reversed signals




modified after Häberli (2003)

# WRF model domains (two-way nesting)

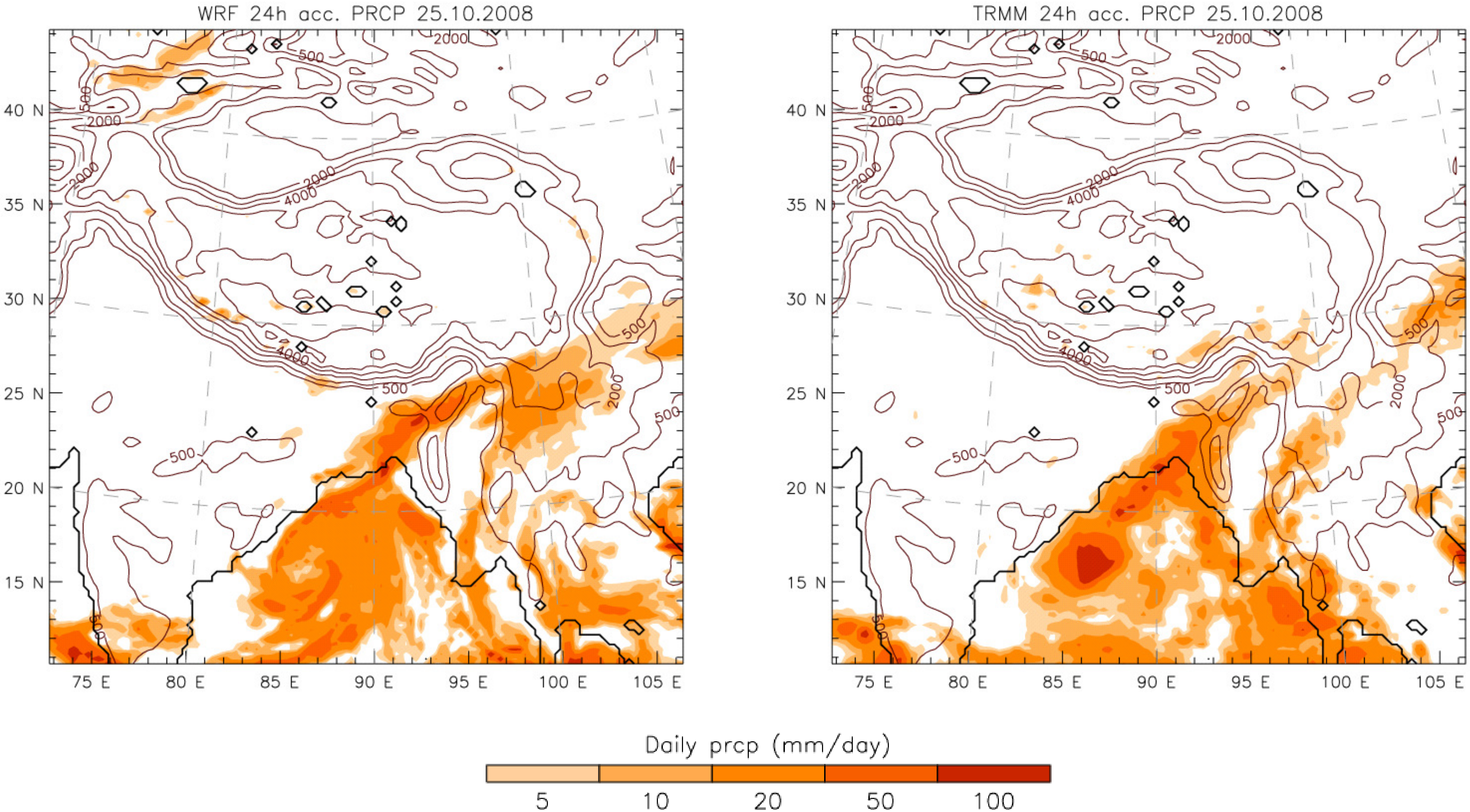


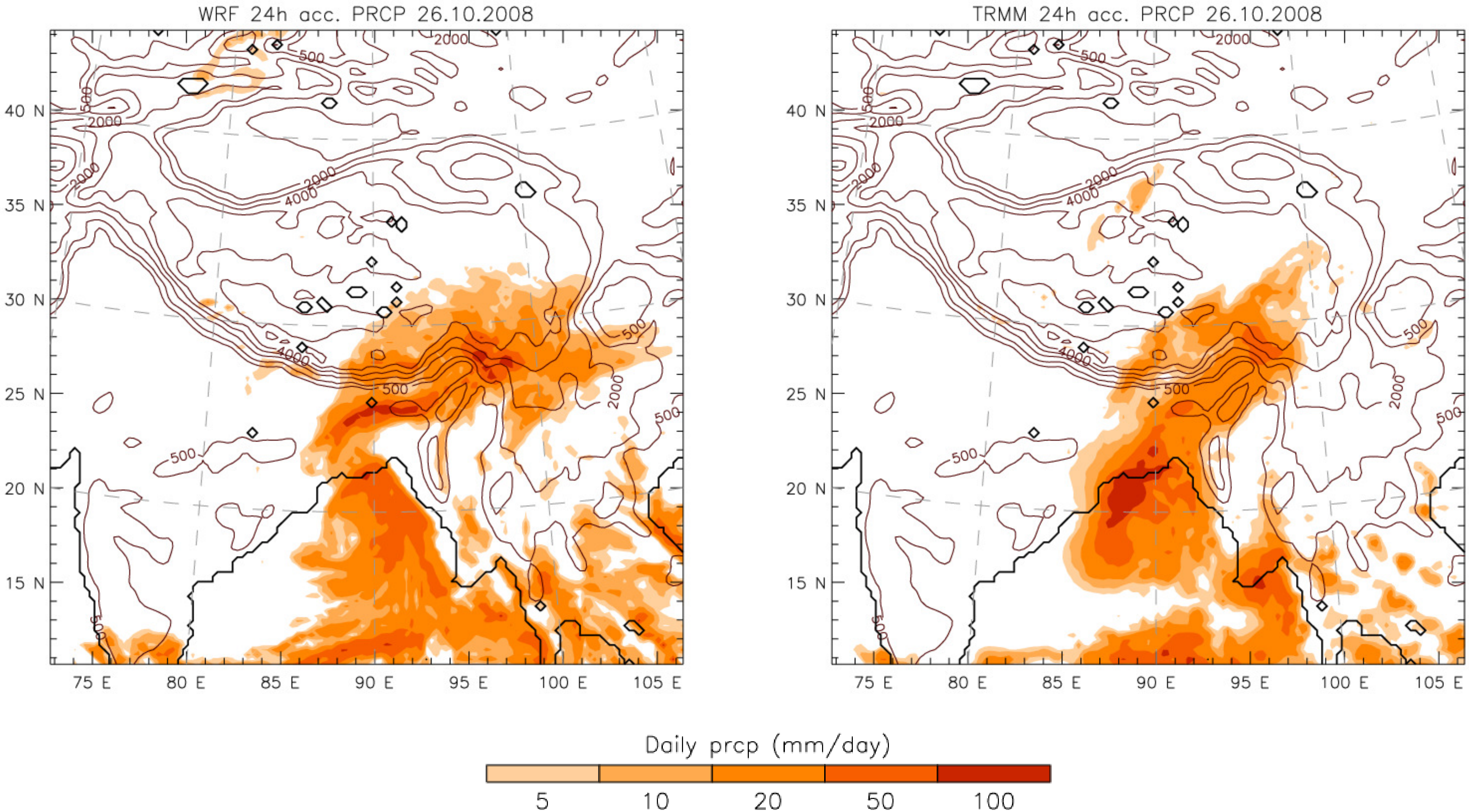

**WRF**: **W**eather **R**esearch & **F**orecasting model (ARW dynamical core)

| | |
|---|---|
| large domain: | 30 km grid |
| medium domain: | 10 km grid |
| small domain: | 2 km grid |

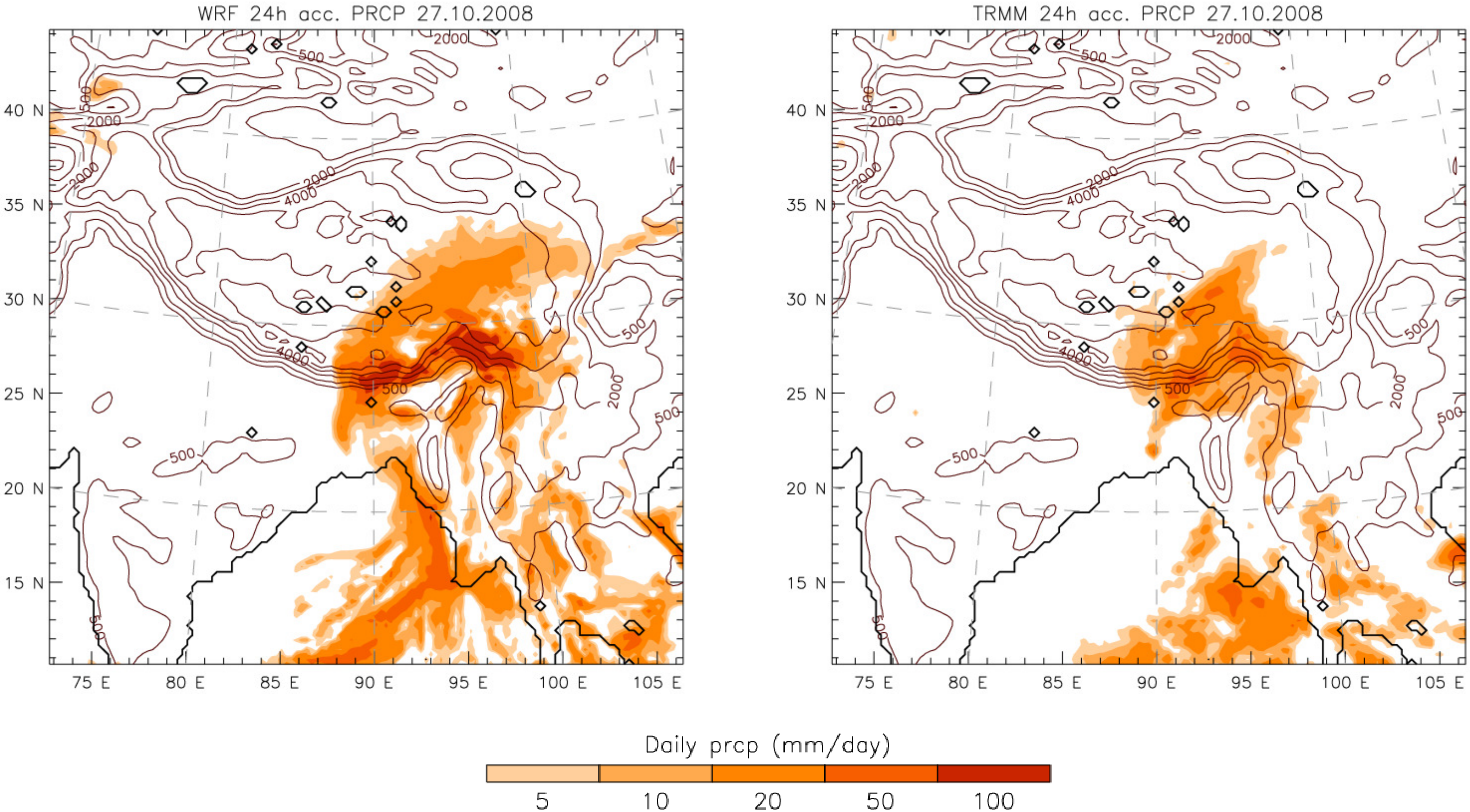
# WRF and TRMM daily precipitation 25.10.2008



# WRF and TRMM daily precipitation 26.10.2008

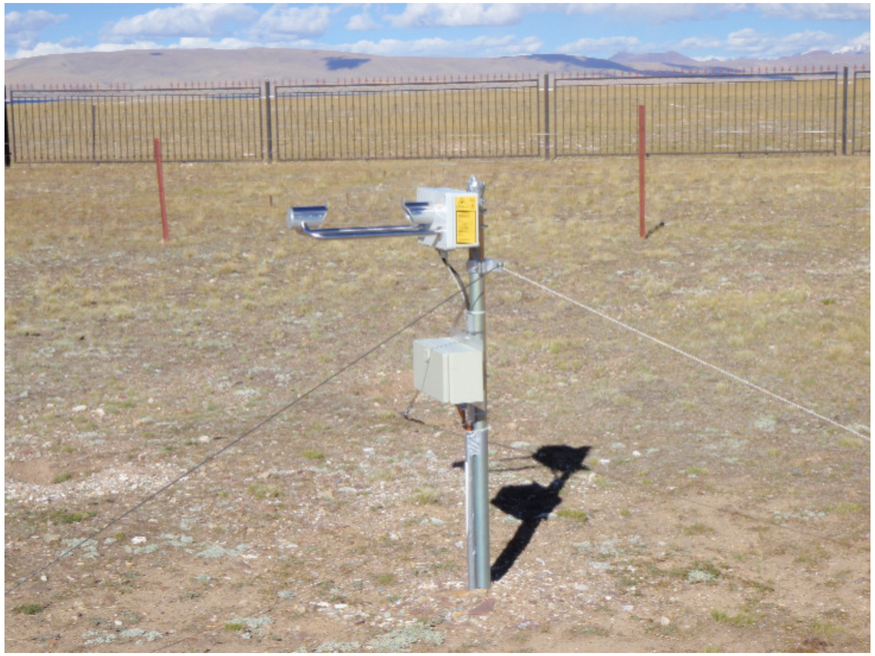


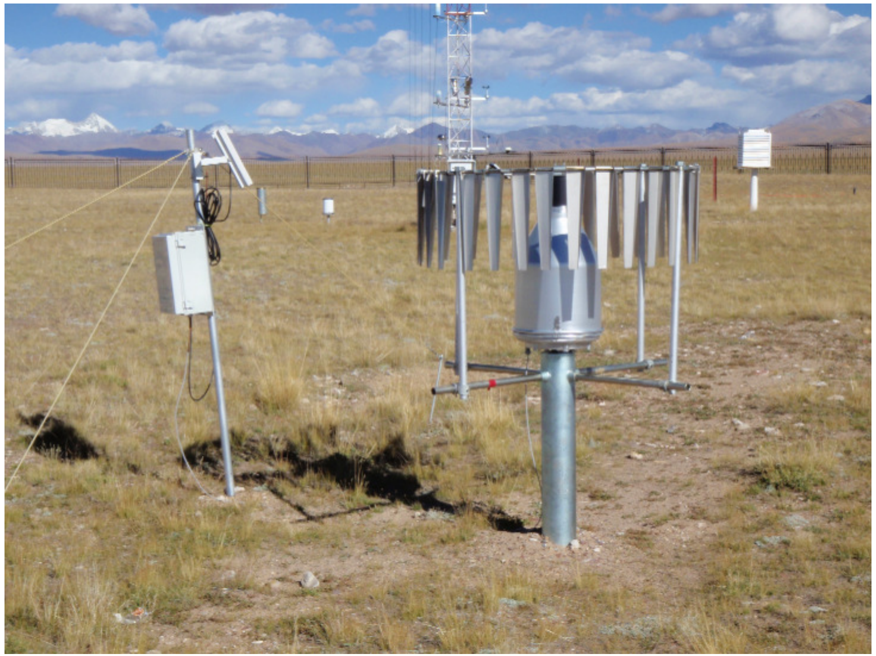
# WRF and TRMM daily precipitation 27.10.2008





# Future plans for WRF-based atmospheric modelling





1. Optimising the WRF set-up.
2. WRF runs for two mass-balance years.
3. Validation of WRF output.
4. WRF runs for whole period since 2000.
5. Final post-processing, quality control.

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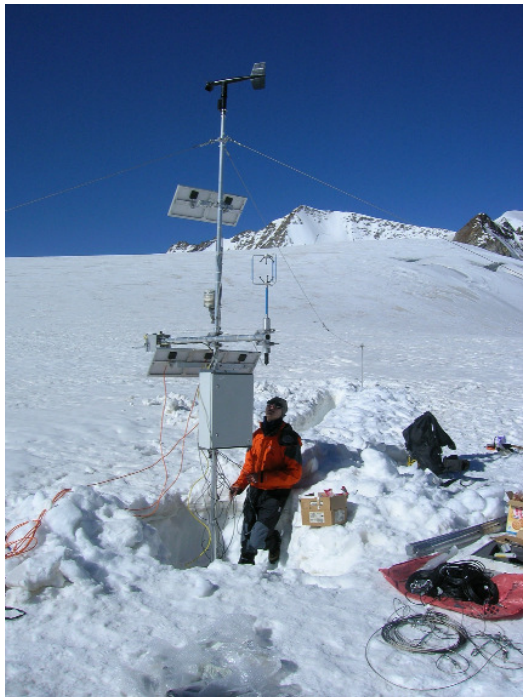
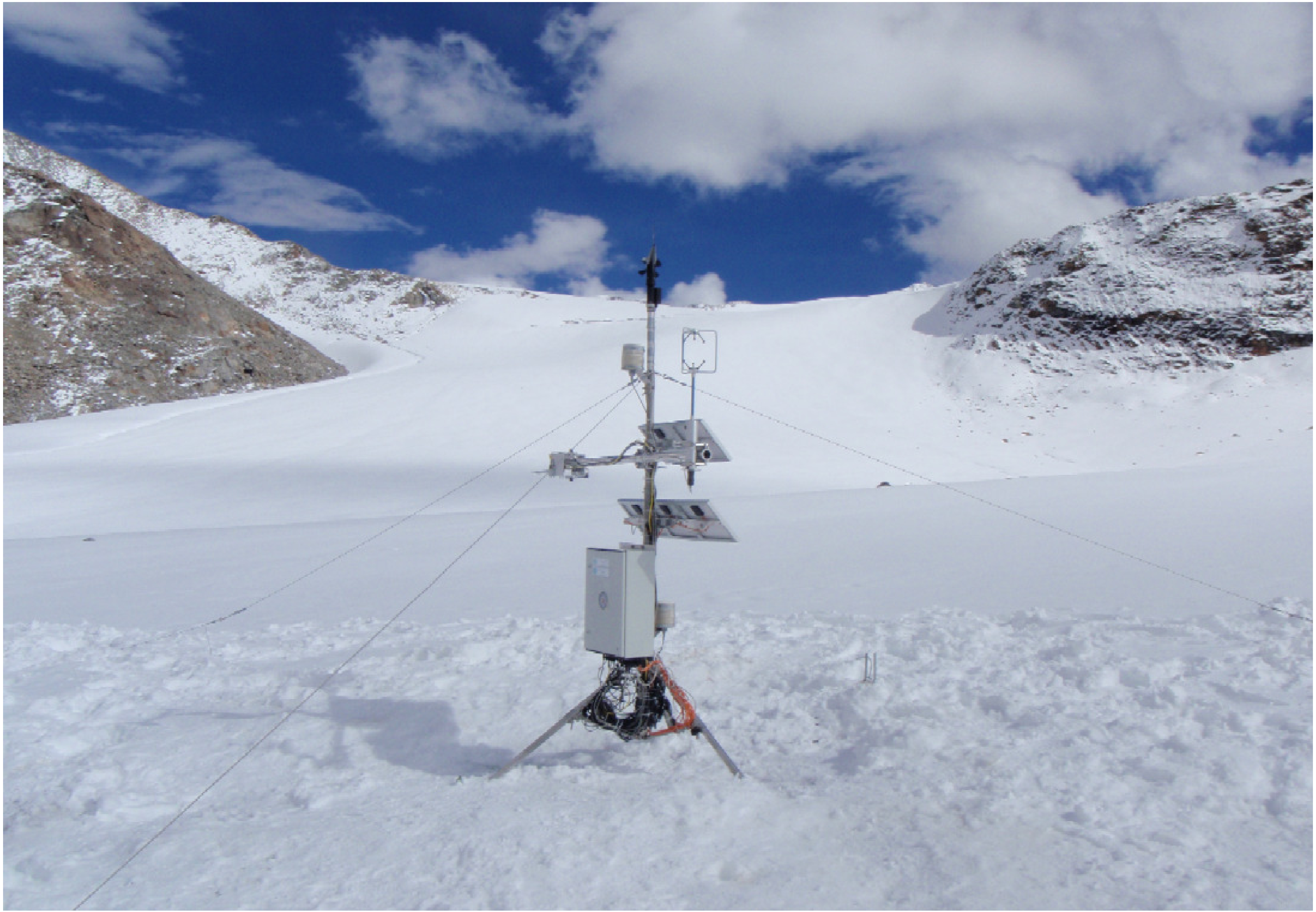






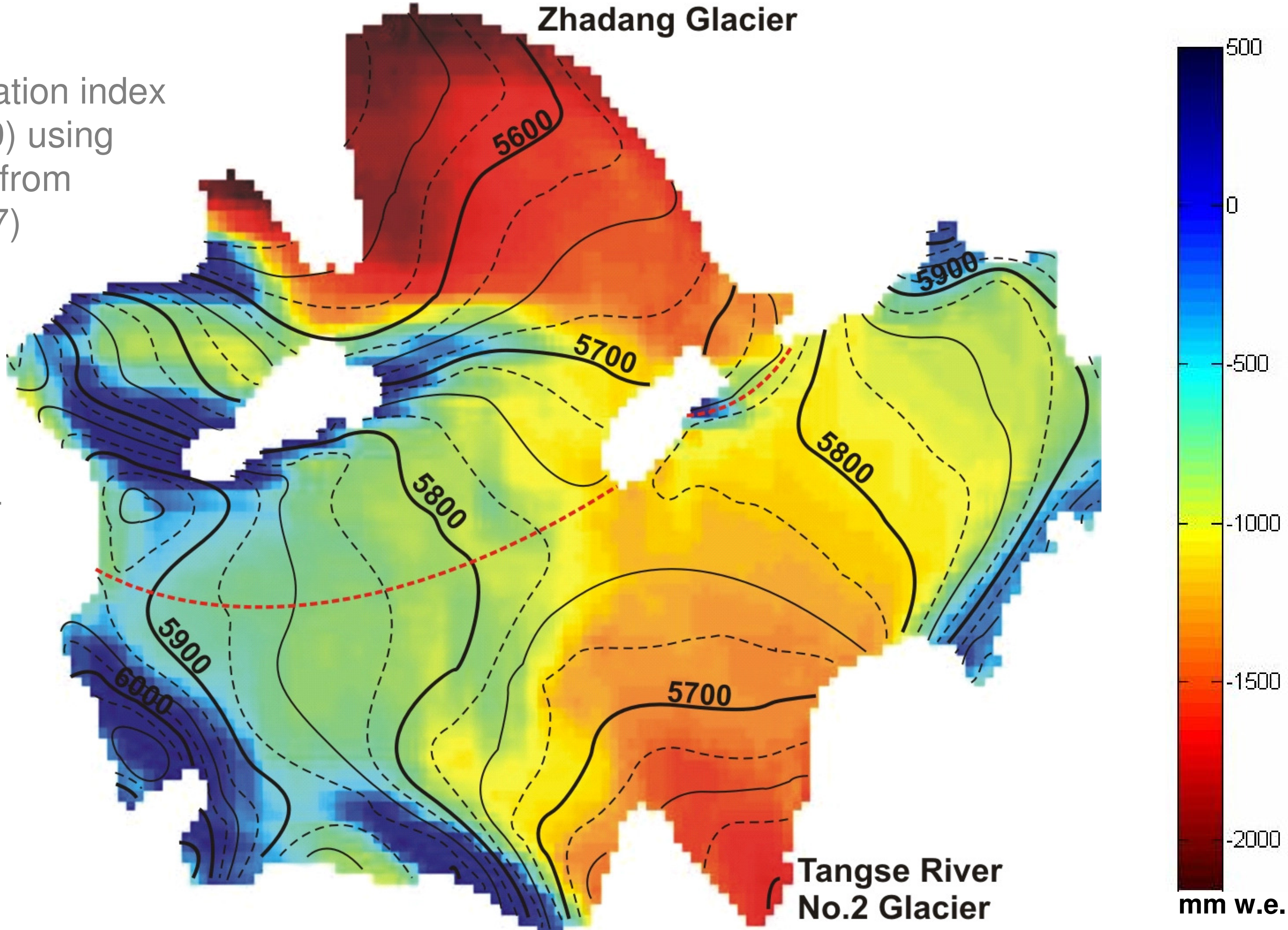




# Modelled annual mean surface mass balance 2005/06

Temperature-radiation index model (Hock 1999) using a radiation model from Kumar et al. (1997)

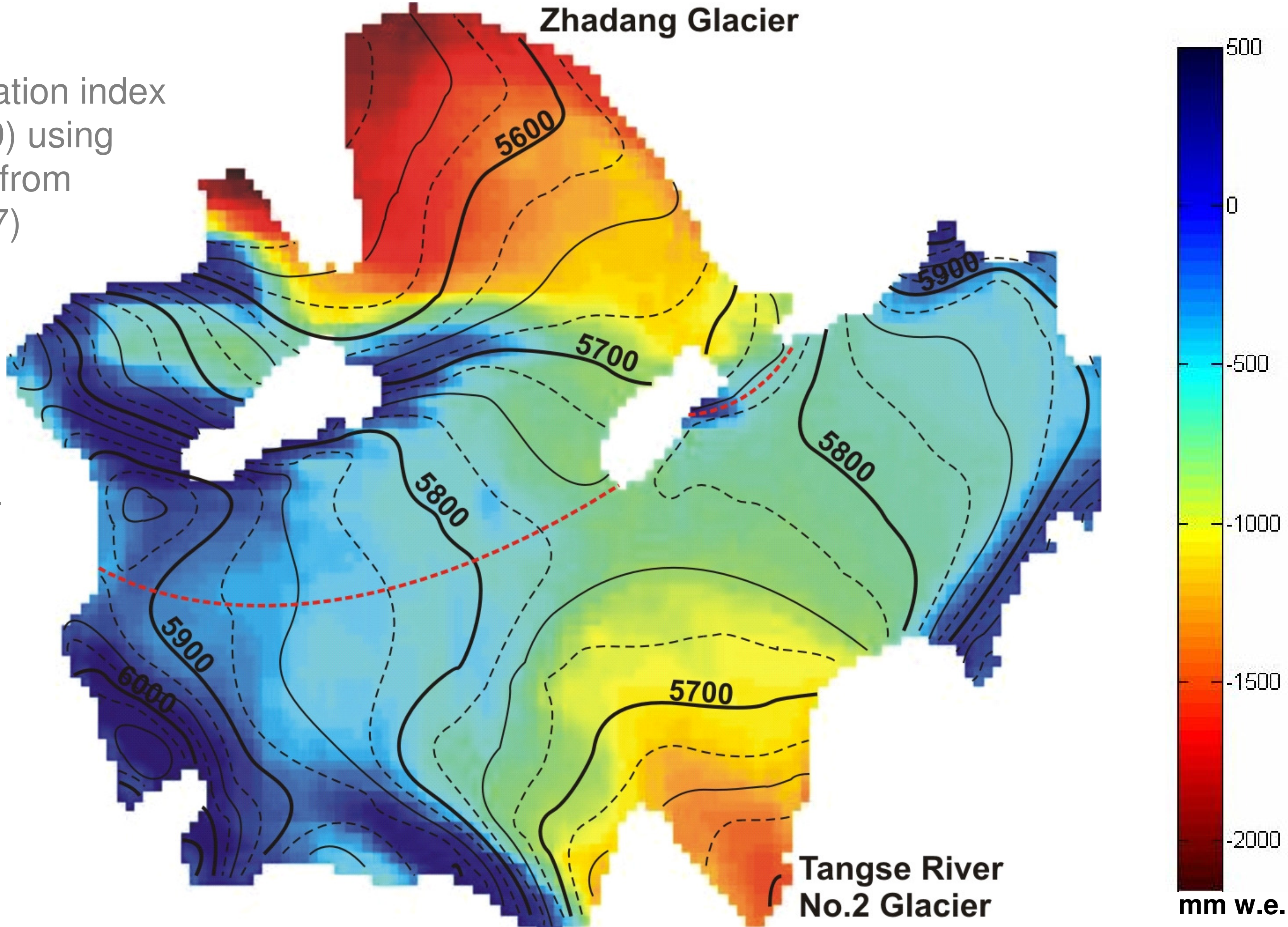
Daily air temperature and precipitation values from Baingoin station (31°22‘ N, 90°01‘ E 4701 m a.s.l.), adapted to Zhadang Glacier



# Modelled annual mean surface mass balance 2006/07

Temperature-radiation index model (Hock 1999) using a radiation model from Kumar et al. (1997)

Daily air temperature and precipitation values from Baingoin station (31°22‘ N, 90°01‘ E 4701 m a.s.l.), adapted to Zhadang Glacier

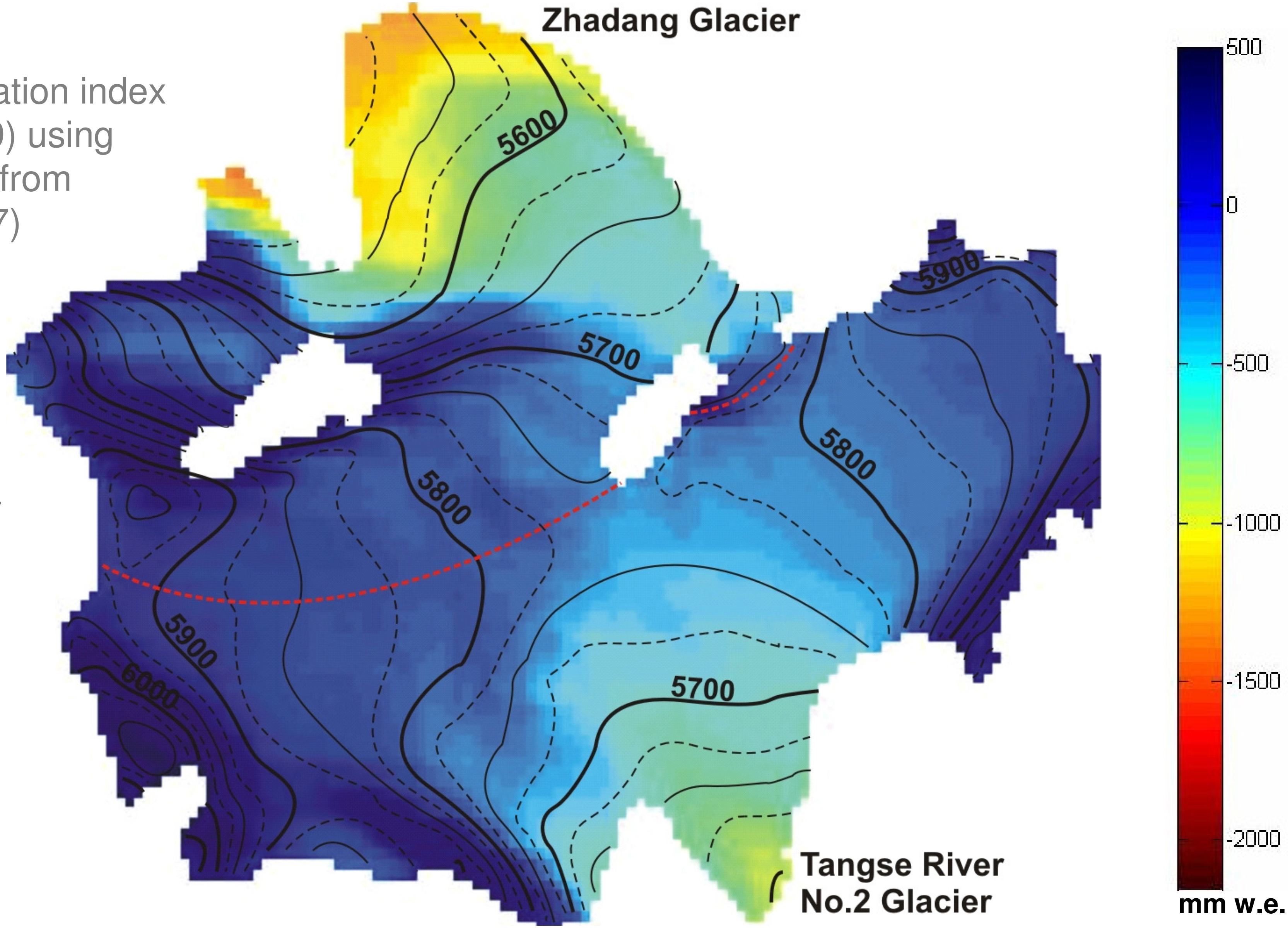




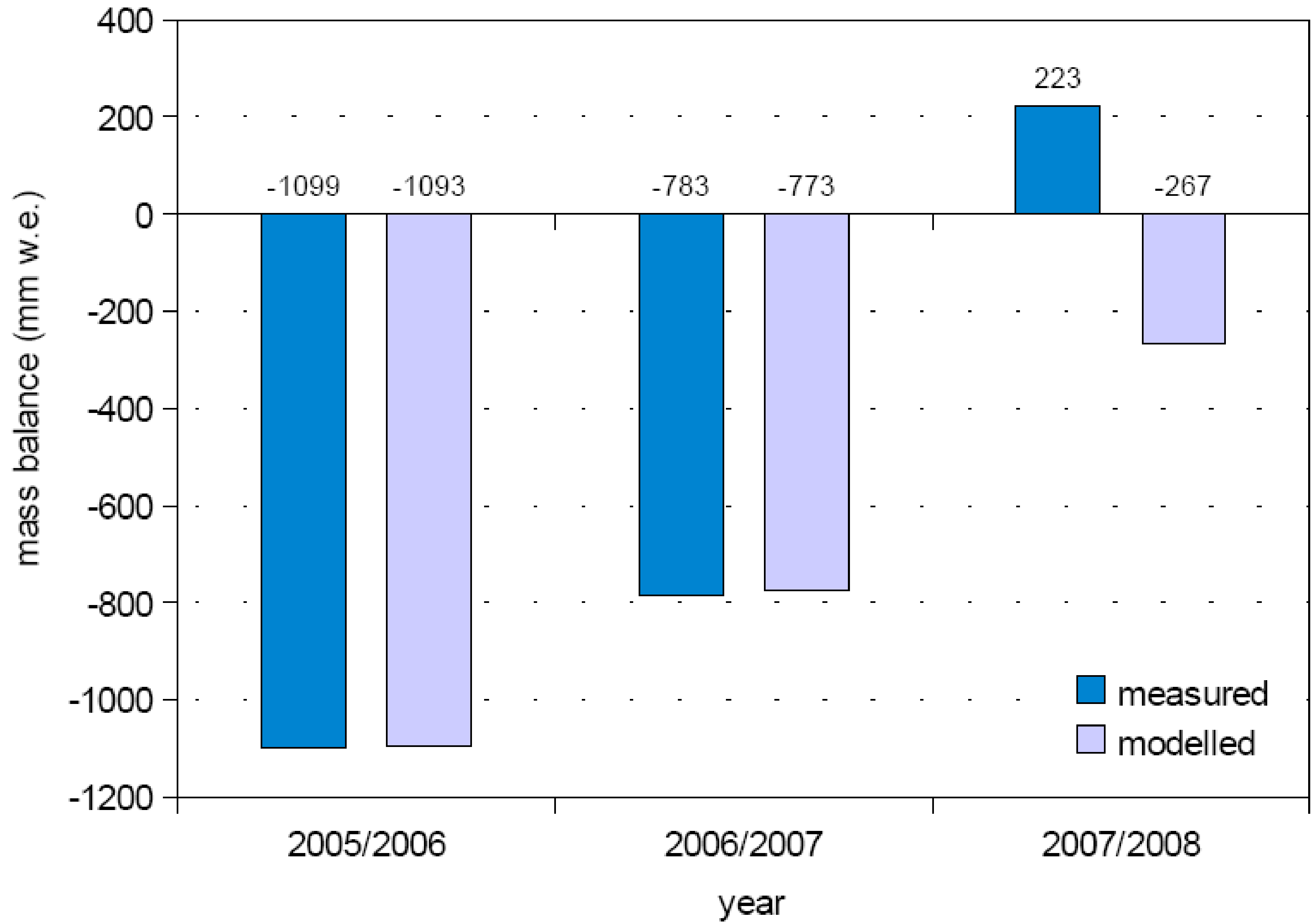
# Modelled annual mean surface mass balance 2007/08

Temperature-radiation index model (Hock 1999) using a radiation model from Kumar et al. (1997)

Daily air temperature and precipitation values from Baingoin station (31°22‘ N, 90°01‘ E 4701 m a.s.l.), adapted to Zhadang Glacier

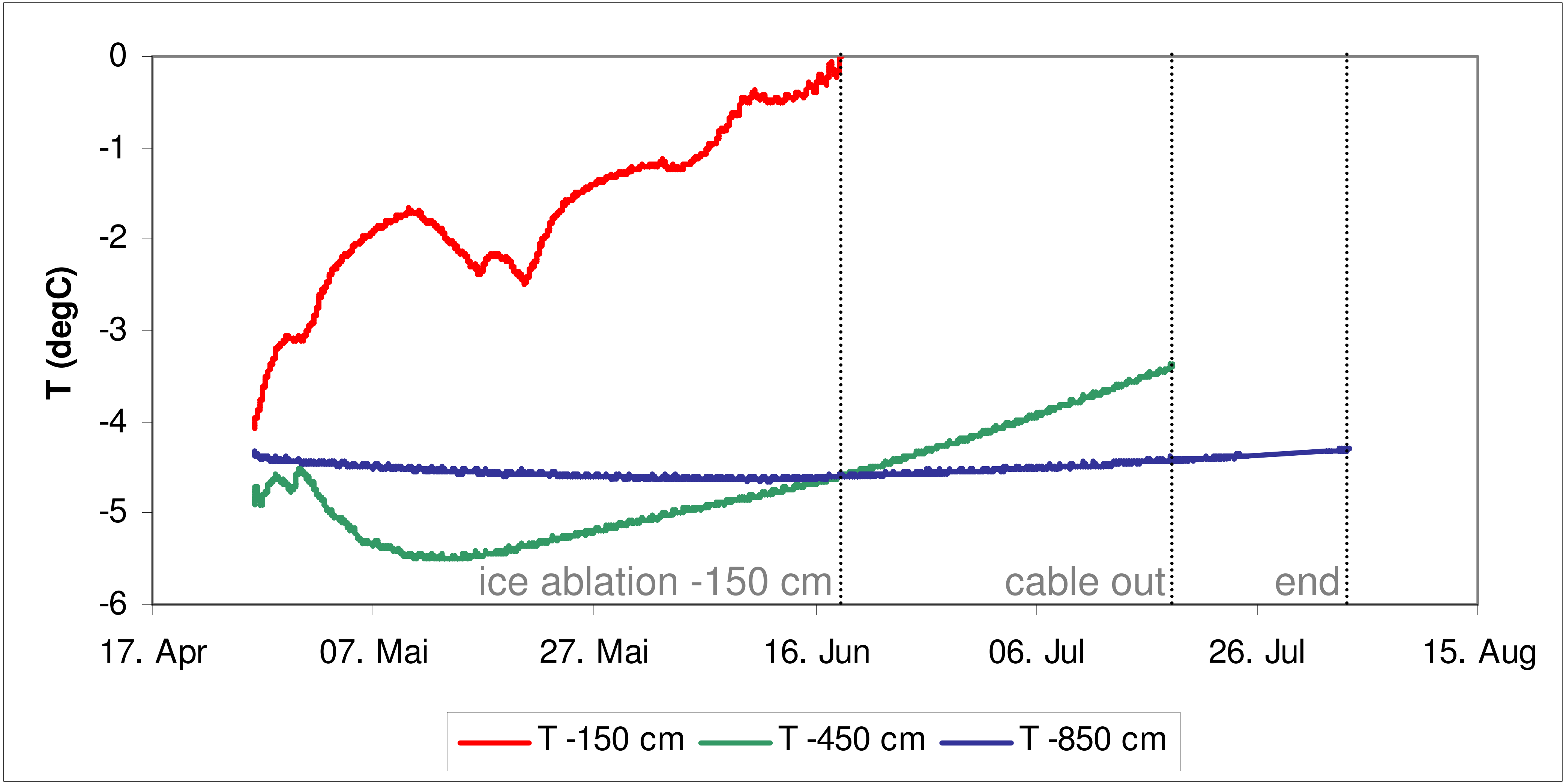


# Annual mean surface mass balance Zhadang Glacier



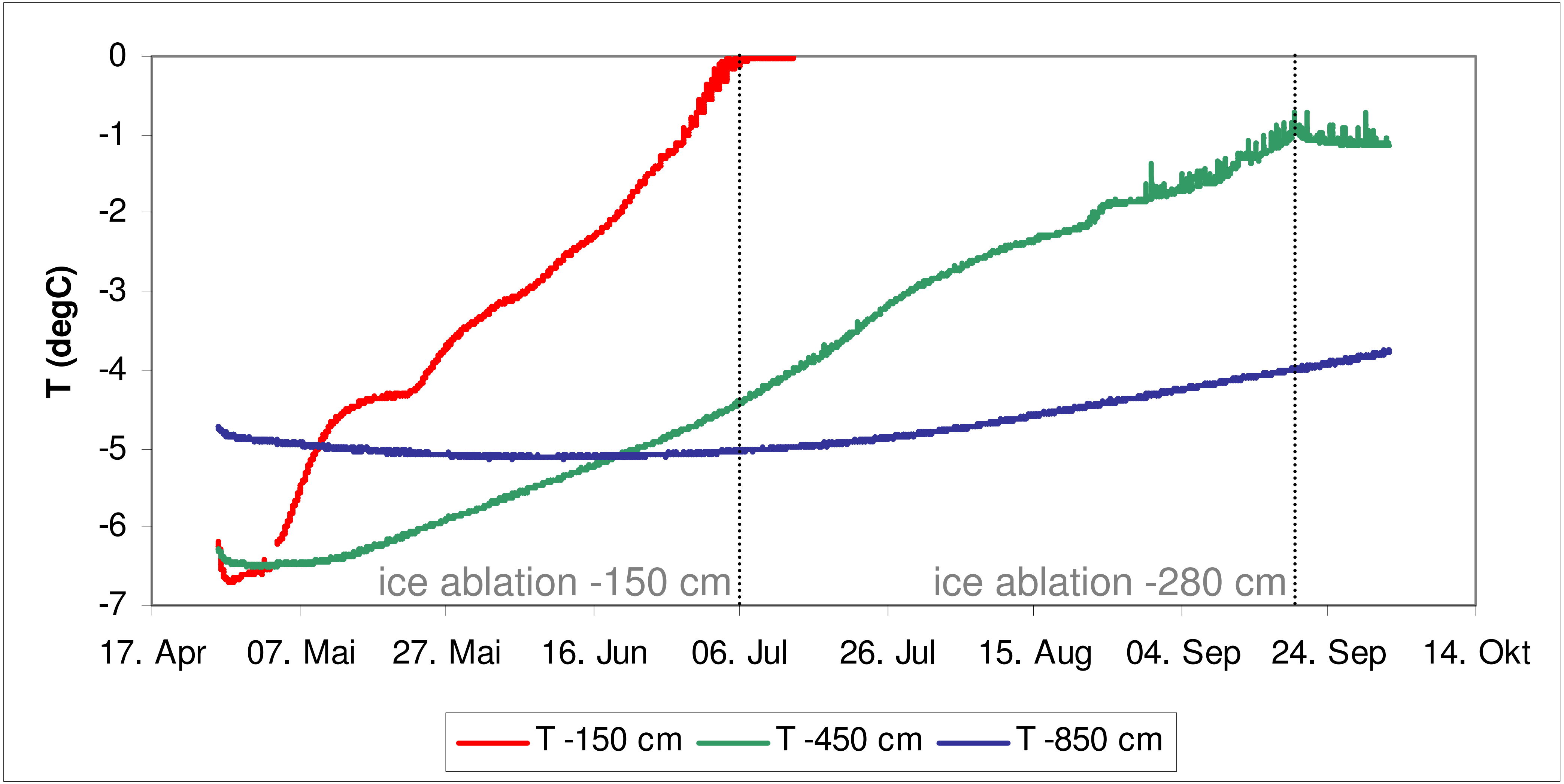

measured values from Kang et al. (2009)

# Ice temperatures at AWS 1 (5680 m a.s.l.)



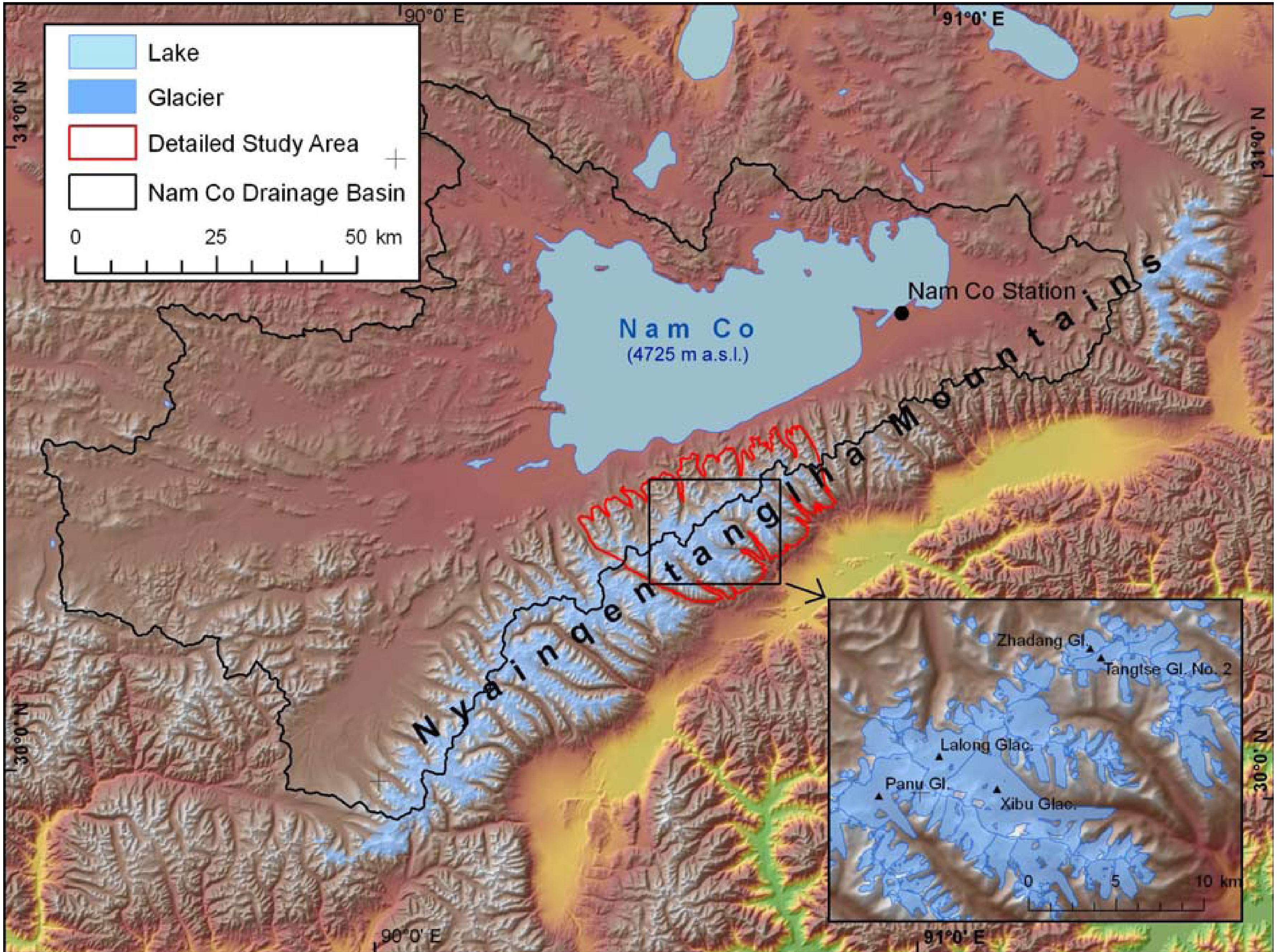

ice ablation end of September: -400 cm

# Ice temperatures at AWS 2 (5730 m a.s.l.)

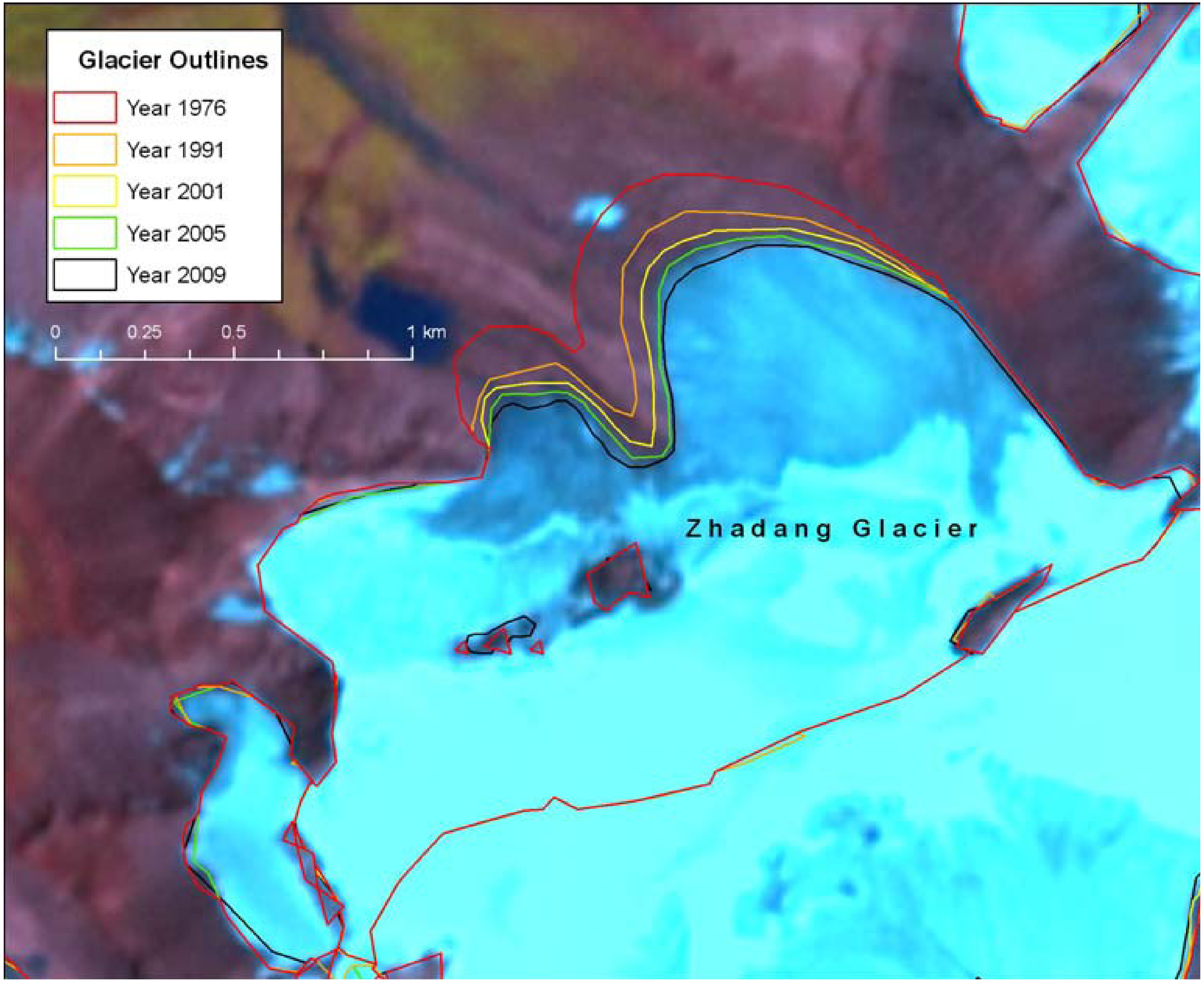



ice ablation end of September: -280 cm




Lake
Glacier
Detailed Study Area
Nam Co Drainage Basin
0 25 50 km
90°0' E
91°0' E
31°0' N
30°0' N
Nam Co
(4725 m a.s.l.)
Nam Co Station
Nyainqentanglha Mountains
Zhadang Gl.
Tangtse Gl. No. 2
Lalong Glac.
Panu Gl.
Xibu Glac.
0 5 10 km

# Changes in glacier geometry (1976-2001)




***A*** **(1976):**
2.75 km²

**Δ*A*** **(1976-2001):**
-0.27 km² (-9.8%)
-0.011 km²/a

**Δ*A*** **(2001-2009):**
-0.12 km²
-0.015 km²/a

**Δ*L*** **(1976-2001):**
-210 m
-8.4 m/a

**Δ*L*** **(2001-2009):**
-85 m
-10.6 m/a

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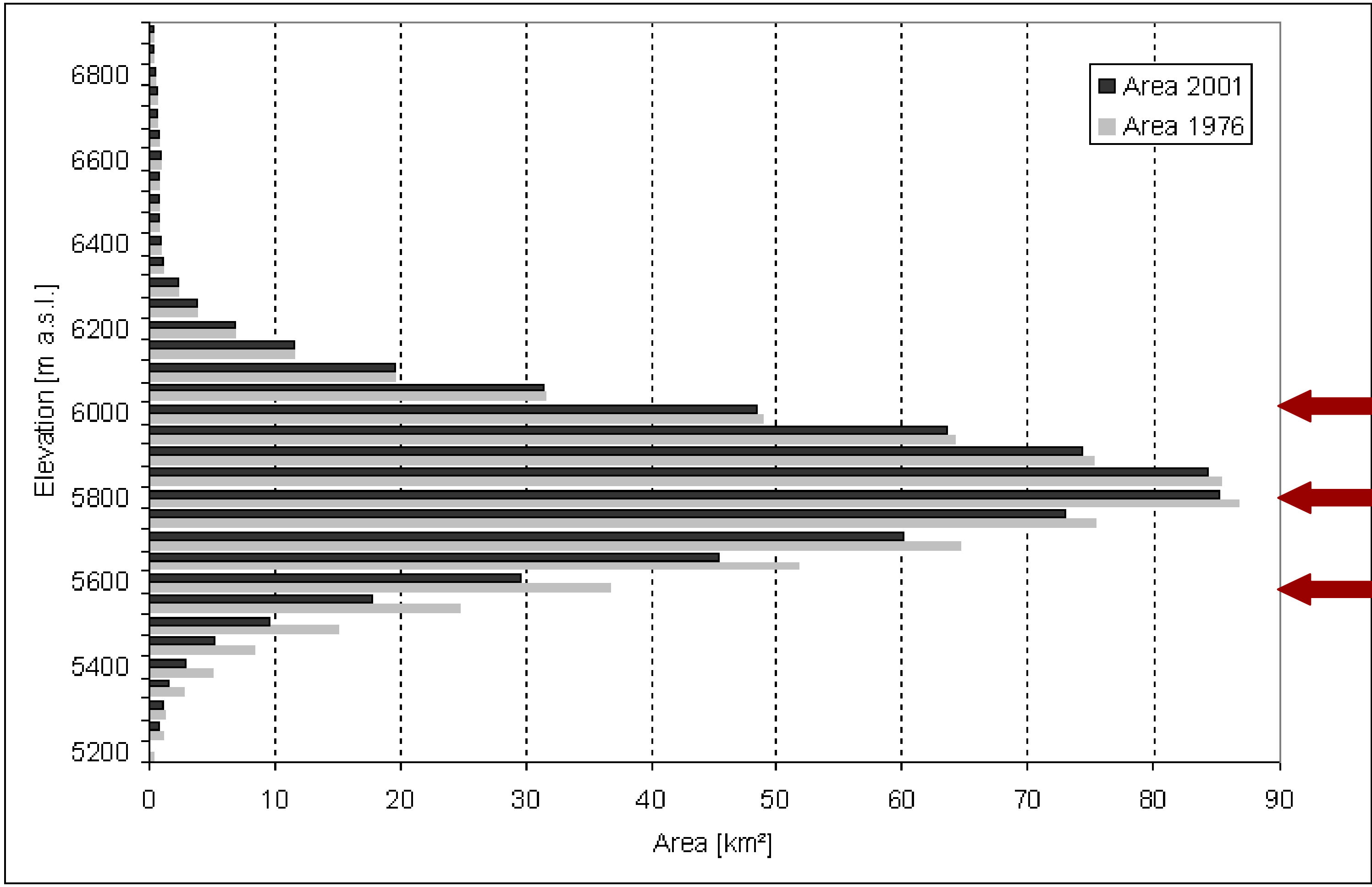
# Changes in glacier hypsometry (1976-2001)

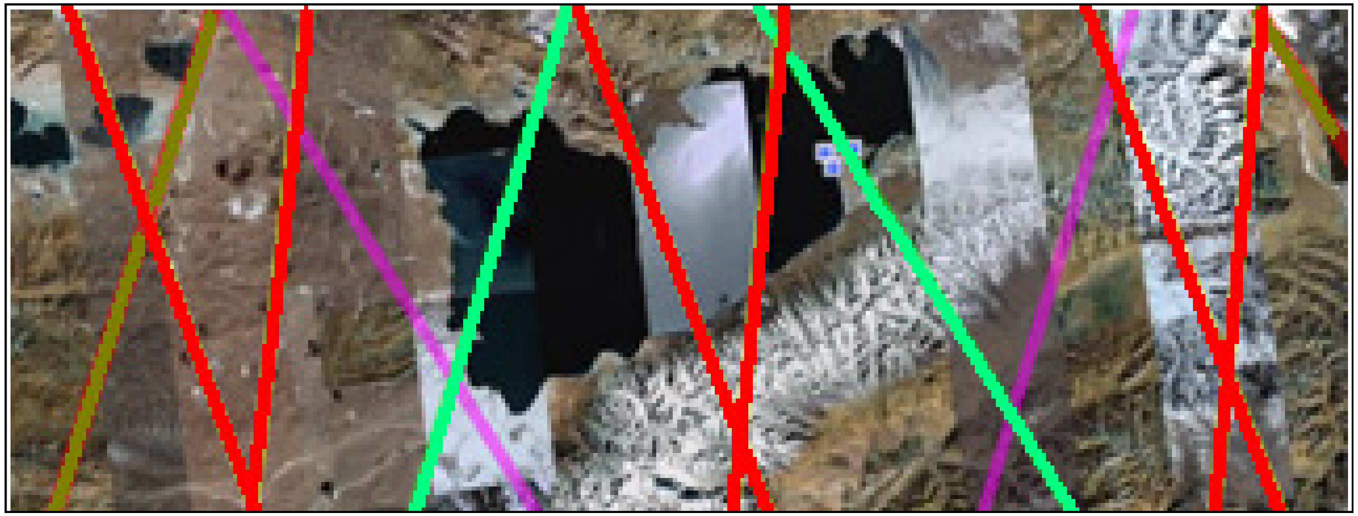



no shrinkage above

approximate ELA

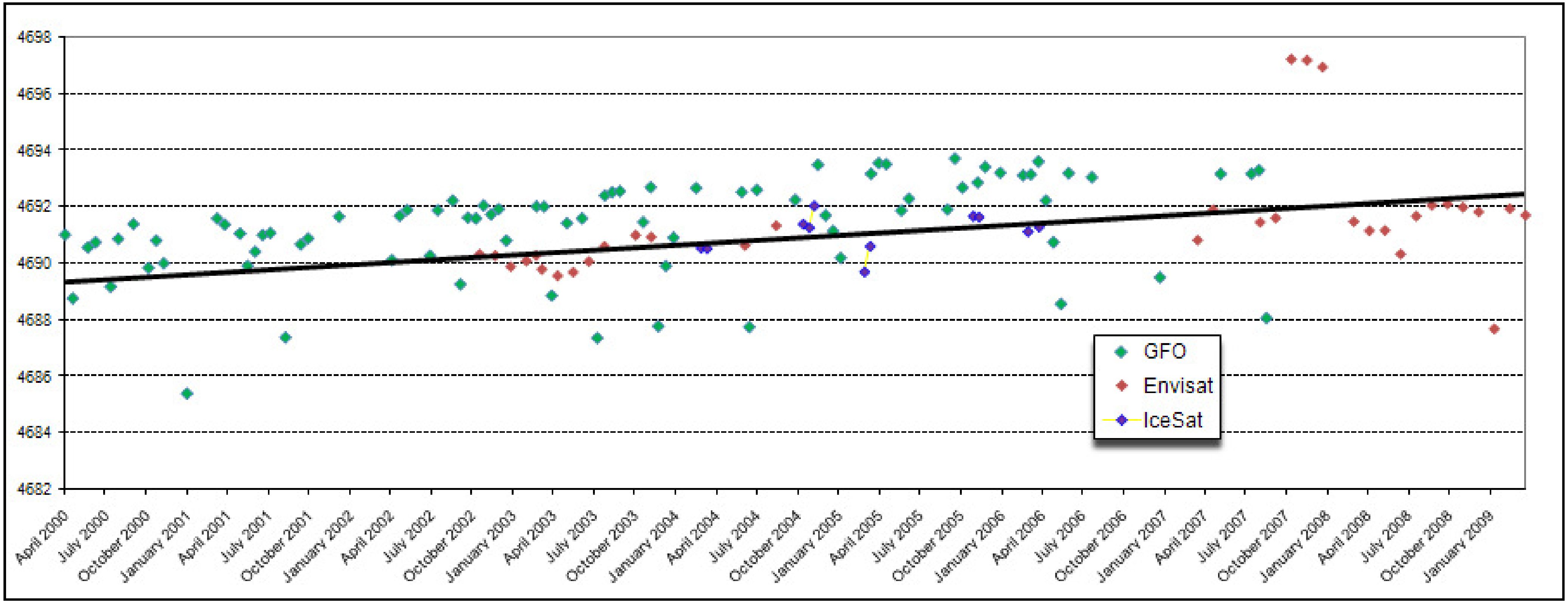
termini of most glaciers

Total area: 1976: 734.1 ± 25.7 km² ; 2001: 692.4 ±19.4 km²
Shrinkage: -41.7 ± 22.4 km² or 5.7 ± 3.1% (0.23 ± 0.12%/a)

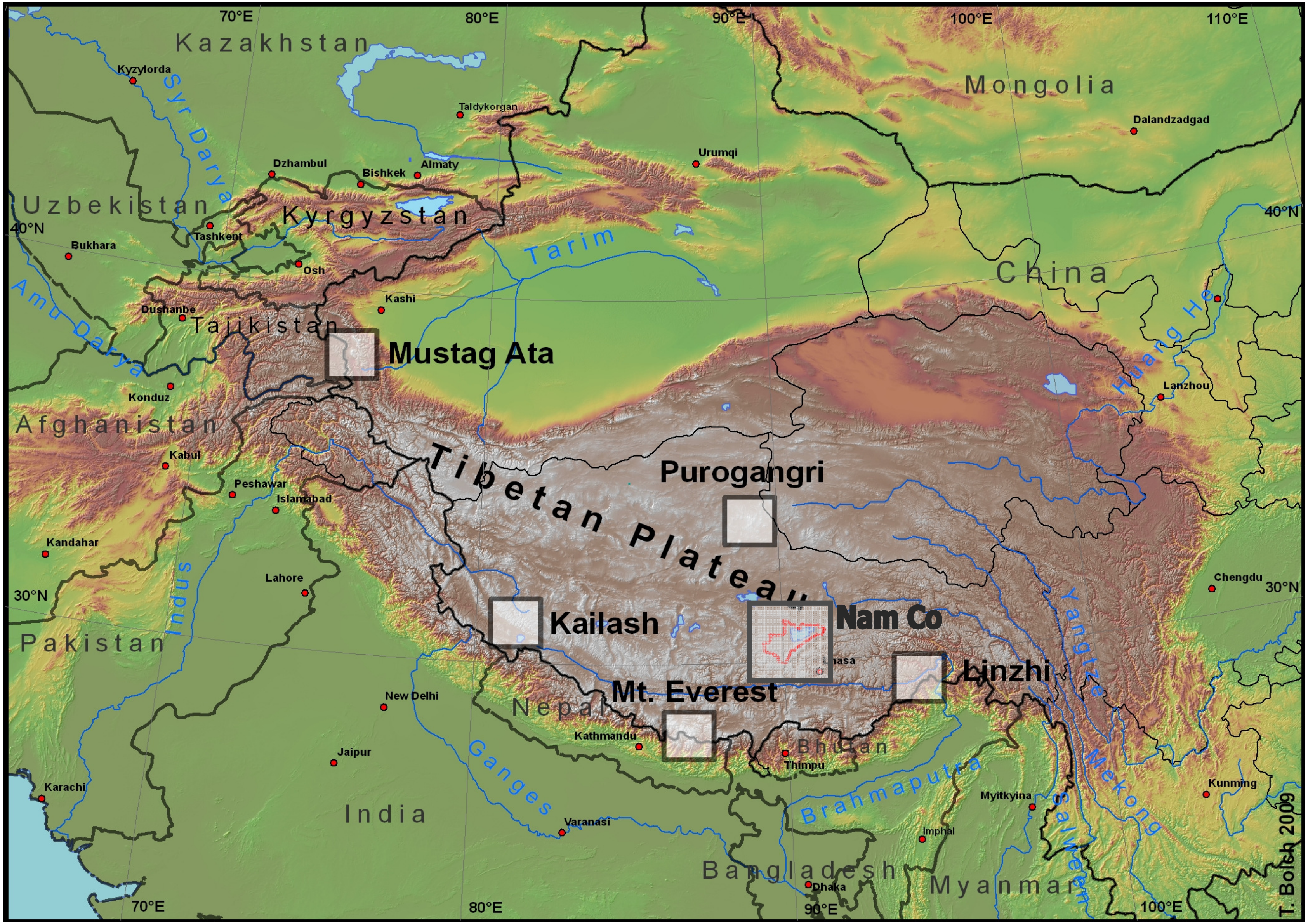


# Lake level rise Nam Co from satellite altimetry

Courtesy J. Kropacek, V. Hochschild



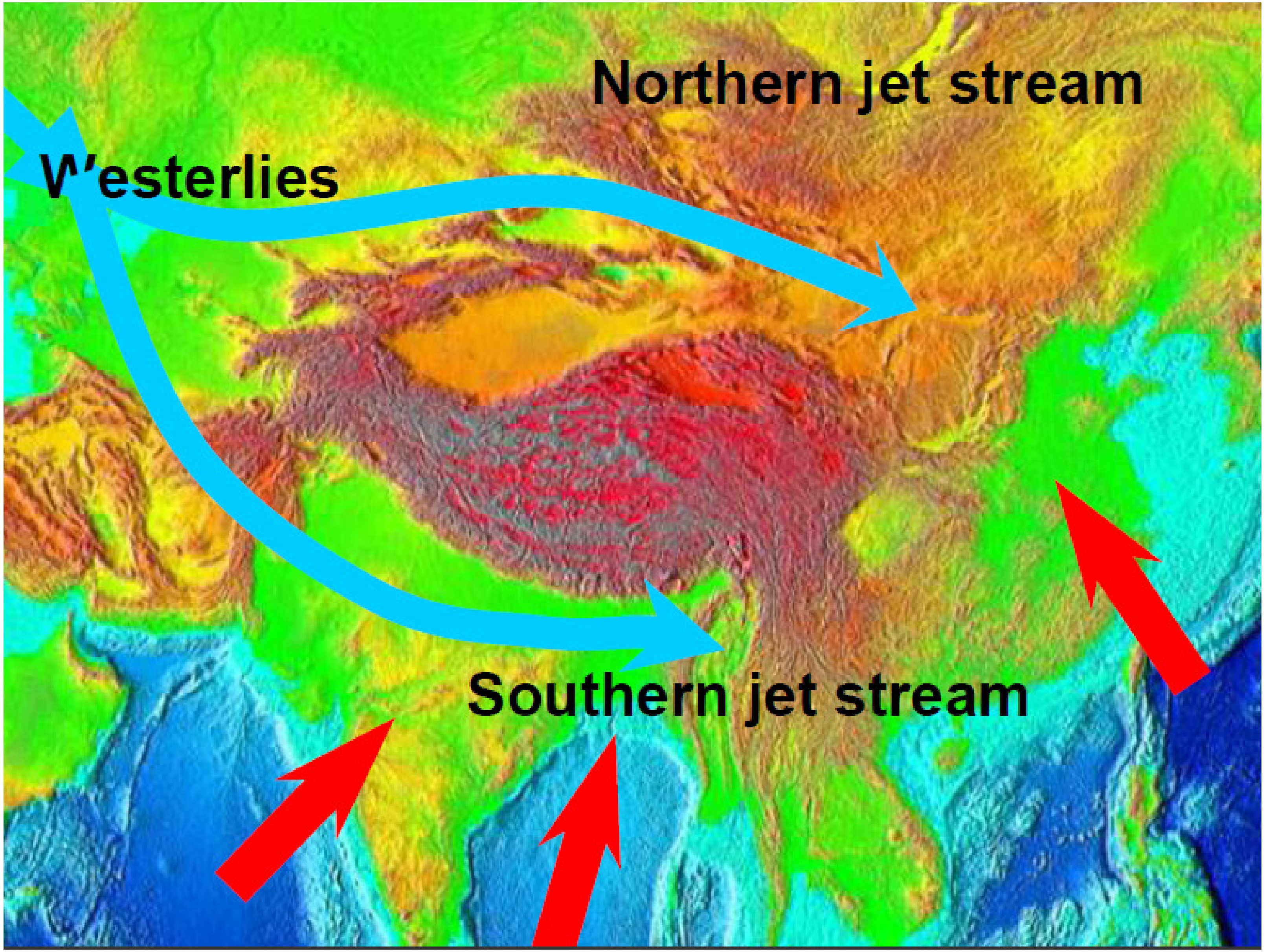
# Proposal for extended research on the TiP




Variabilität und Trends der Wasserhaushalts-komponenten in Benchmark-Einzugs-gebieten des Tibet-Plateaus (WET)

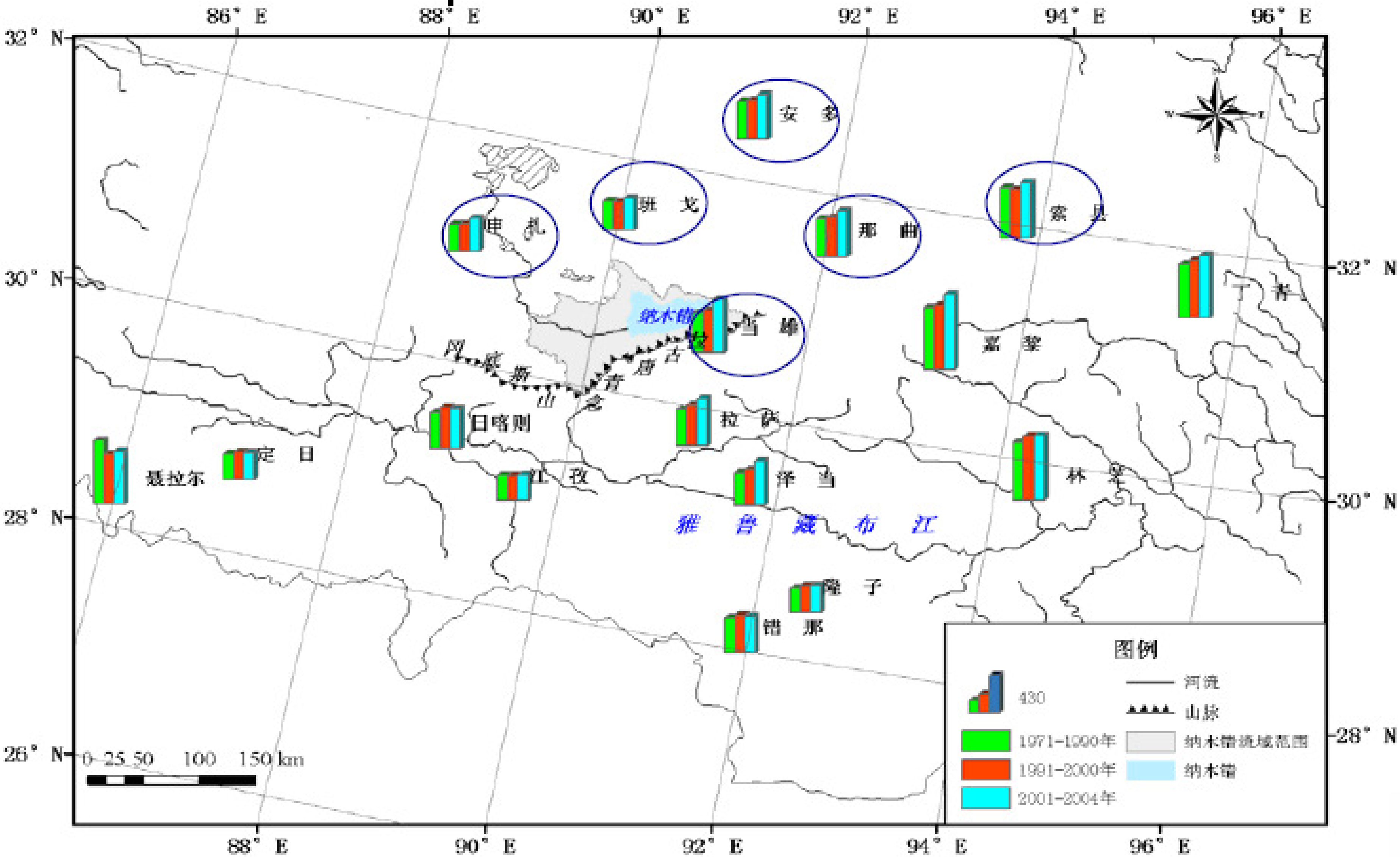
# Conclusions

- Our understanding of climate variability and subsequent climate-glacier interactions on the TiP is still limited
- New data and improved research methods are required
- Thermal regimes of glaciers should be considered in detail
- The contribution of glaciers to hydrologic processes may be overestimated but needs to be quantified




Yao (2008)

# Precipitation trends in Tibet




from: Zhu Liping (2008)

# Research concept

**Model input:** existing gridded data sets (reanalyses, spatially interpolated data)

**Model calibration and validation:** field and remote sensing data

Large-scale atmospheric processes

↓

Meso- and local-scale atmospheric processes

↕

Glacier surface energy and mass balance

↕

Glacier mass balance and dynamics

**Model input:** GFS/ECMWF analyses, output from GCM/RCM runs

**Model application:** Sensitivity studies, regional projections

Spatial resolution ↓

Spatial extend ↑

| Model validation | Observation and model calibration | Model application |
|---|---|---|
| Past (since 1960) | Present situation | Future (decades) |

# WRF case study

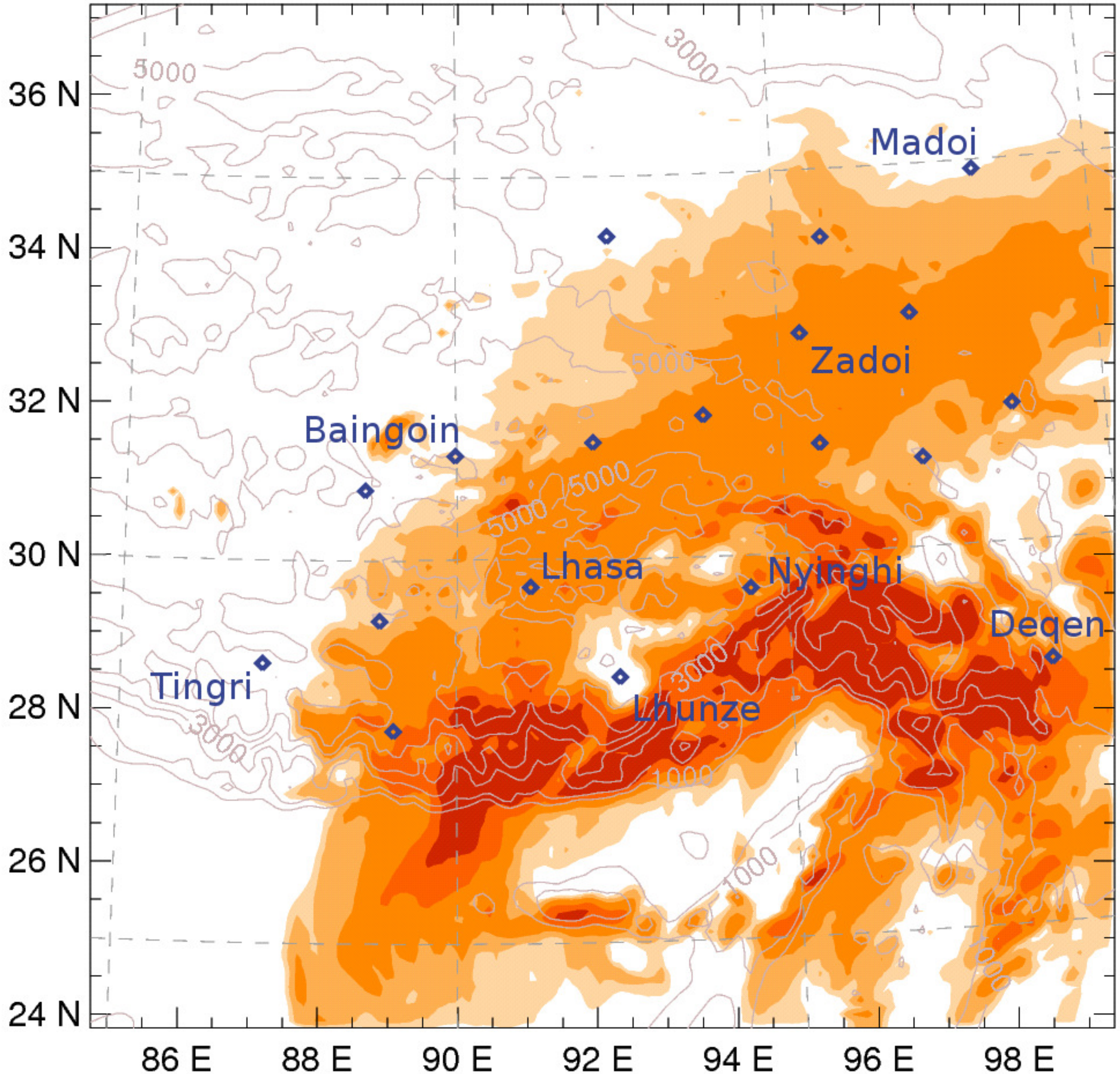
**Tropical cyclone Rashmi**
modelling period:
24. - 28. October 2008
five 36 h runs (12 h spin-up)

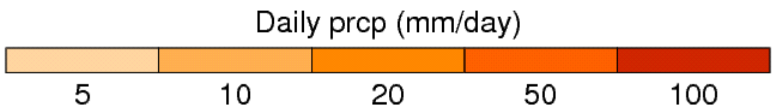
**Sensitivity study** testing various parameterization schemes, input data sets and model configurations

**Validation** by meteorol. station and TRMM data

TRMM (Tropical Rainfall Measuring Mission):
3-hourly, 0.25 deg. grid precipitation rates
(trmm.gsfc.nasa.gov/3b42.html)

WRF 24h acc. total PRCP 27.10.2008



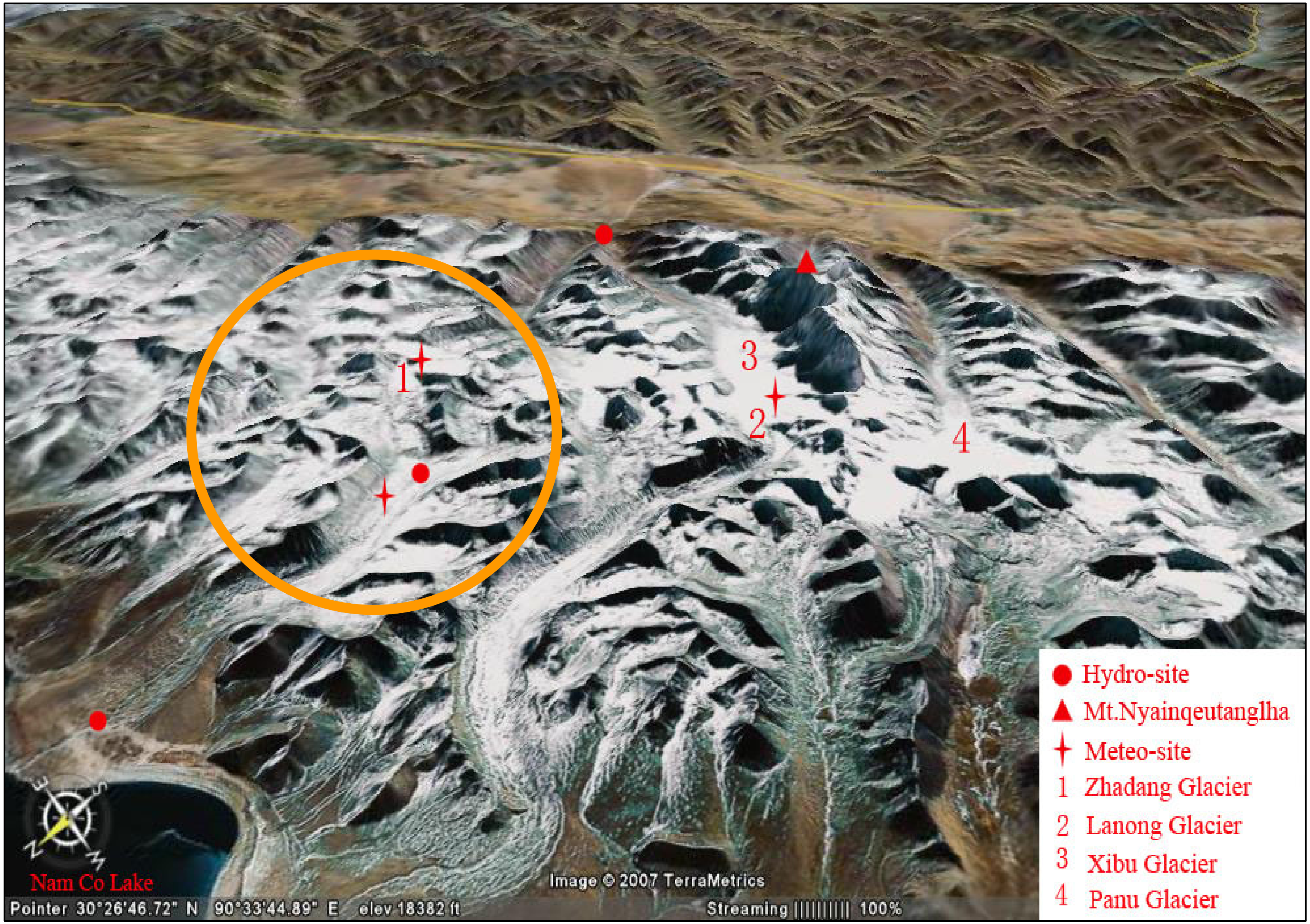



# Validation example for WRF results on 27.10.2008

| Station | Lon. (deg) | Lat. (deg) | Elev. (m a.s.l.) | Obs. (mm/day) | Type | TRMM (mm/day) | WRF 30 km (mm/day) | WRF 10 km (mm/day) | WRF 2 km (mm/day) |
|---|---|---|---|---|---|---|---|---|---|
| **Baingoin** | 90.02 | 31.37 | 4701 | **6** | ❄ | **8** | **6** | **6** | **5** |
| **Dege** | 98.57 | 31.80 | 3185 | **7** | 💧 | **1** | **20** | **18** | |
| **Dengqen** | 95.60 | 31.42 | 3874 | **17** | ❄ | **10** | **31** | **31** | |
| **Deqen** | 98.88 | 28.45 | 3320 | **52** | 💧 | **1** | **55** | **41** | |
| **Lhasa** | 91.13 | 29.67 | 3650 | **6** | 💧 | **27** | **30** | **28** | **27** |
| **Lhunze** | 92.47 | 28.42 | 3861 | **17** | ❄ | **36** | **3** | **0** | |
| **Madoi** | 98.22 | 34.92 | 4273 | **5** | ❄ | **3** | **4** | **3** | |
| **Nagqu** | 92.07 | 31.48 | 4508 | **22** | ❄ | **13** | **18** | **17** | **17** |
| **Nyingchi** | 94.47 | 29.57 | 3001 | **38** | 💧❄ | **13** | **45** | **22** | |
| **Pagri** | 89.08 | 27.73 | 4300 | **34** | ❄ | **19** | **71** | **68** | |
| **Qamdo** | 97.17 | 31.15 | 3307 | **15** | 💧❄ | **2** | **13** | **12** | |
| **Qumarleb** | 95.78 | 34.13 | 4176 | **6** | ❄ | **4** | **13** | **10** | |
| **Sog Xian** | 93.78 | 31.88 | 4024 | **25** | 💧❄ | **56** | **28** | **28** | |
| **Tingri** | 87.08 | 28.63 | 4300 | **0** | | **2** | **0** | **0** | |
| **Tuotuohe** | 92.43 | 34.22 | 4535 | **1** | ❄ | **1** | **4** | **5** | |
| **Xainza** | 88.63 | 30.95 | 4670 | **2** | ❄ | **6** | **2** | **2** | |
| **Xigaze** | 88.88 | 29.25 | 3837 | **6** | ❄ | **14** | **12** | **9** | |
| **Yushu** | 97.02 | 33.02 | 3682 | **12** | 💧❄ | **3** | **29** | **27** | |
| **Zadoi** | 95.30 | 32.90 | 4068 | **15** | ❄ | **23** | **23** | **22** | |

TRMM (Tropical Rainfall Measuring Mission): 3-hourly, 0.25 deg. grid (trmm.gsfc.nasa.gov/3b42.html)

WRF: WSM-6 microphysics, Grell 3D cumulus parameterization, NOAH land-cover scheme, CAM radiation schemes




Courtesy KANG Shichang

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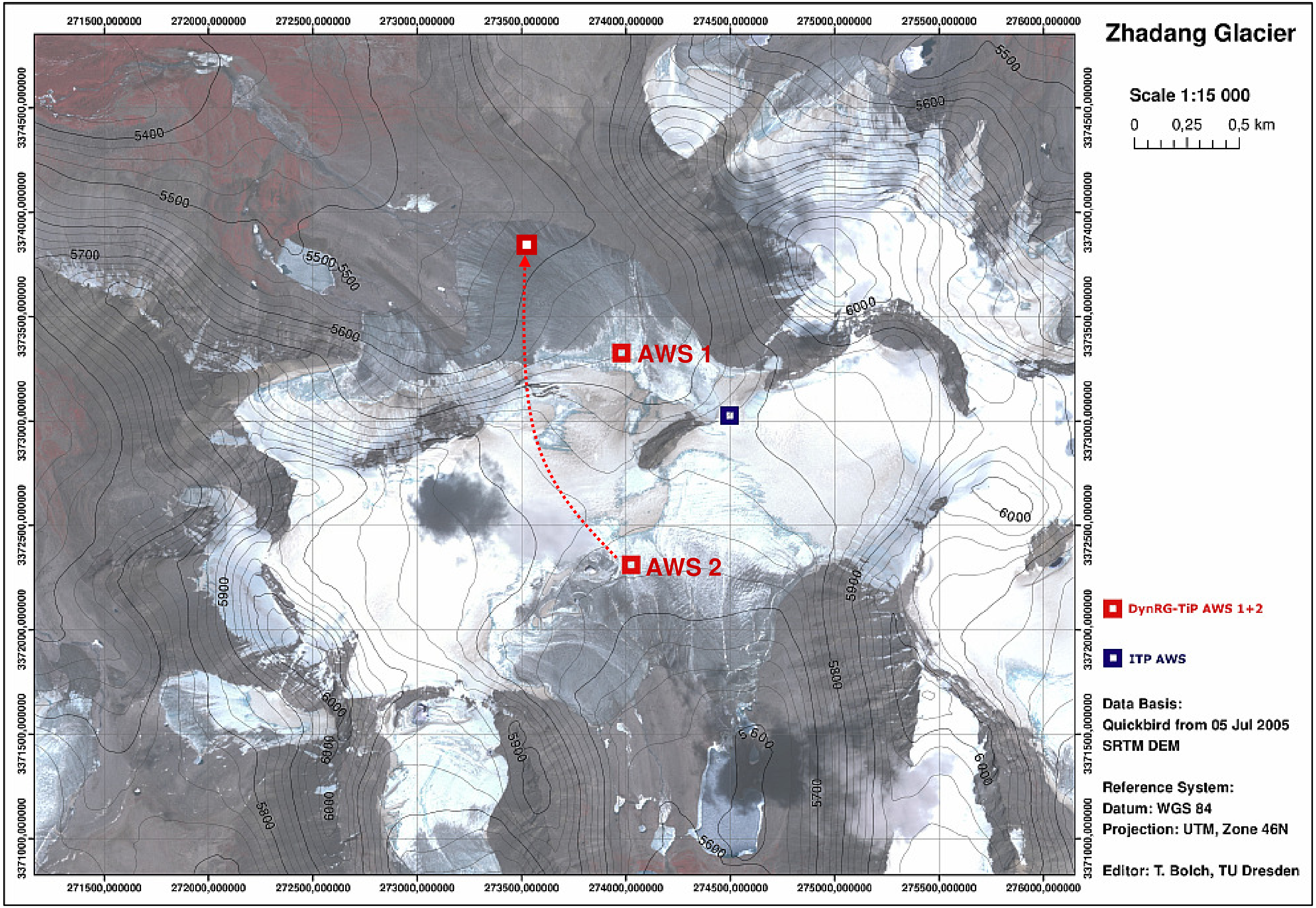


# Stochastic forcing of nonlinear processes

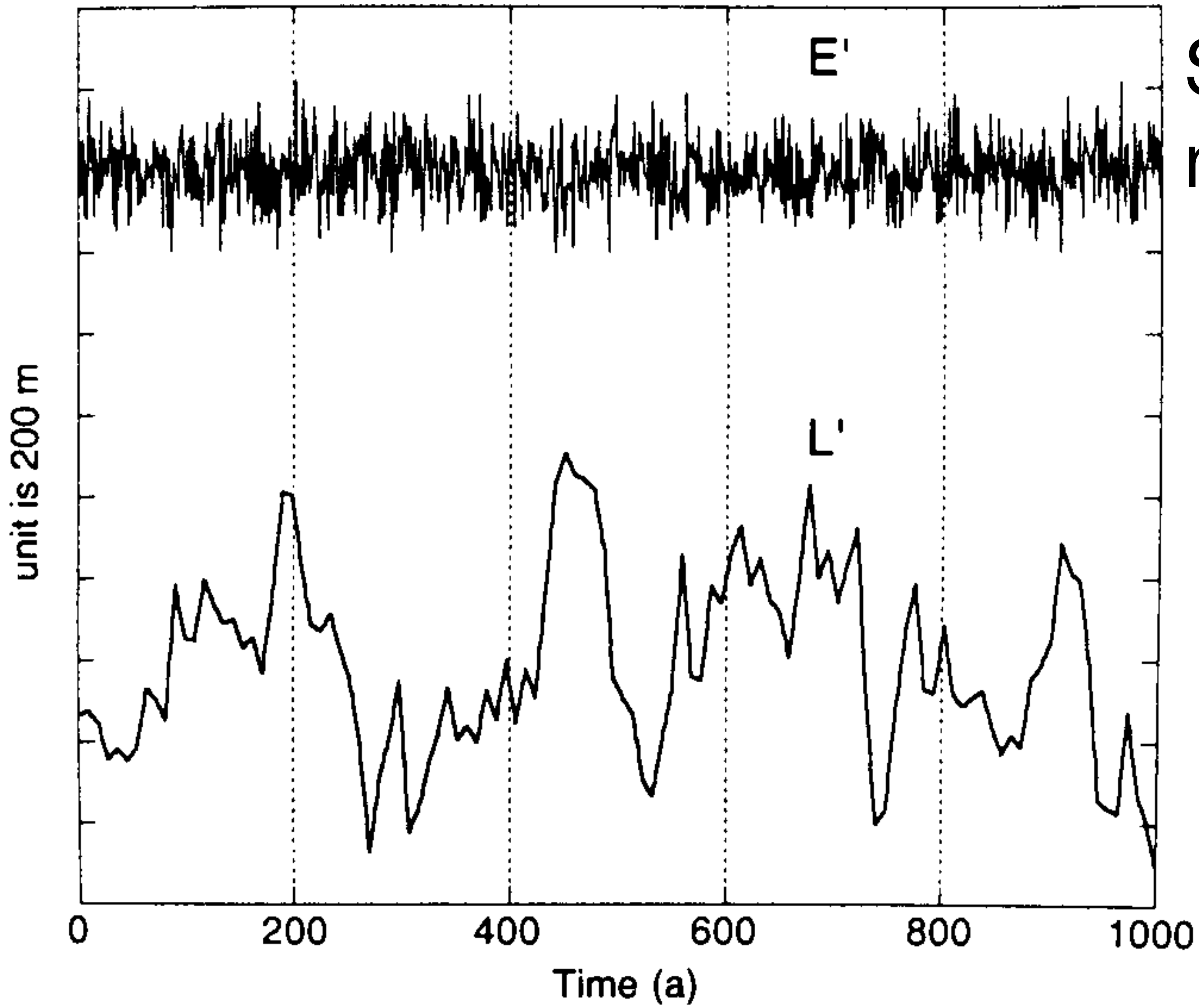
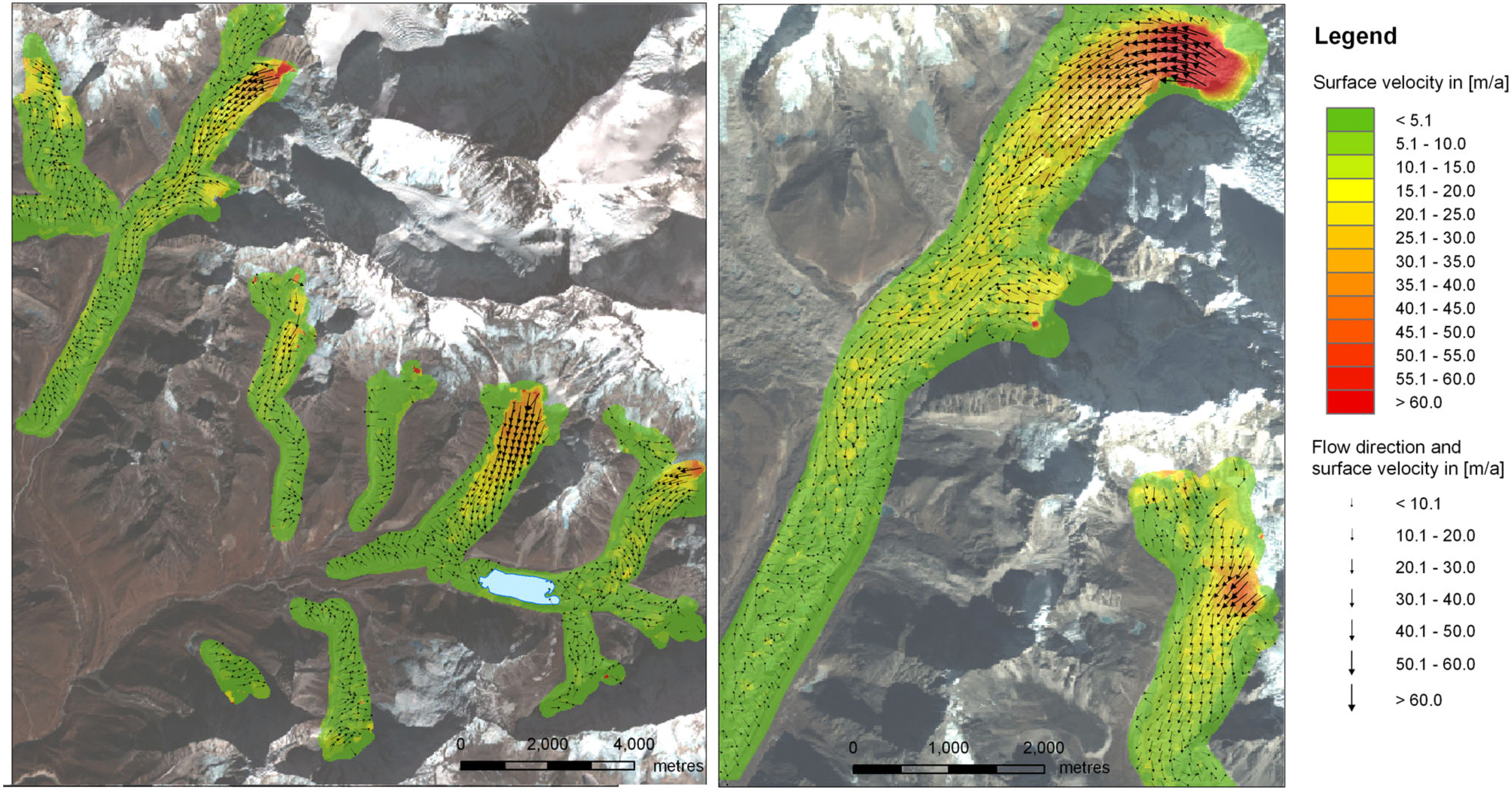



**Figure 9.9.** A synthetic glacier record obtained by integrating eq. (9.2) with white-noise forcing (E' has a standard deviation of 75 m). Model parameters: $c = 35$, $t_{rL} = 50$ a.

Oerlemans (2001)

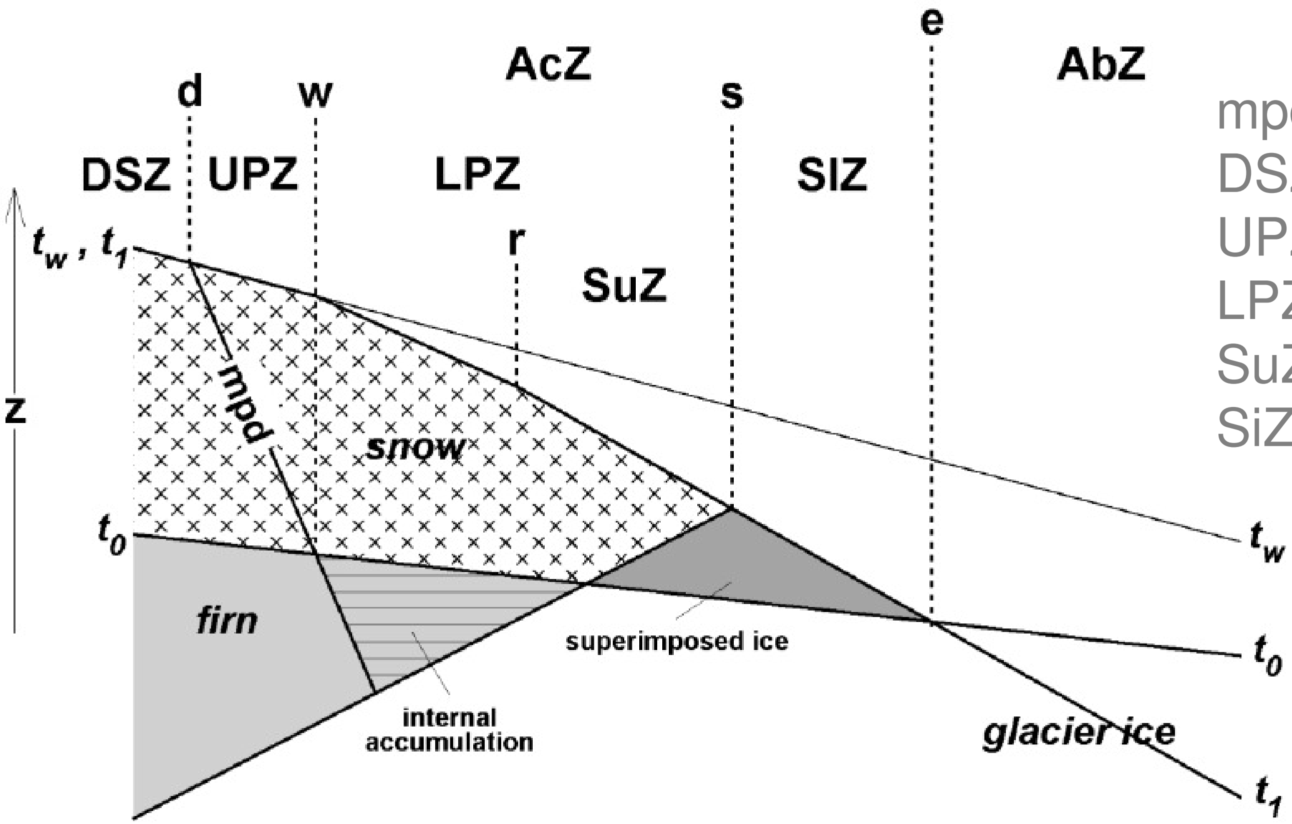





Bolch et al. (2008)



# Glacier zones on a cold glacier

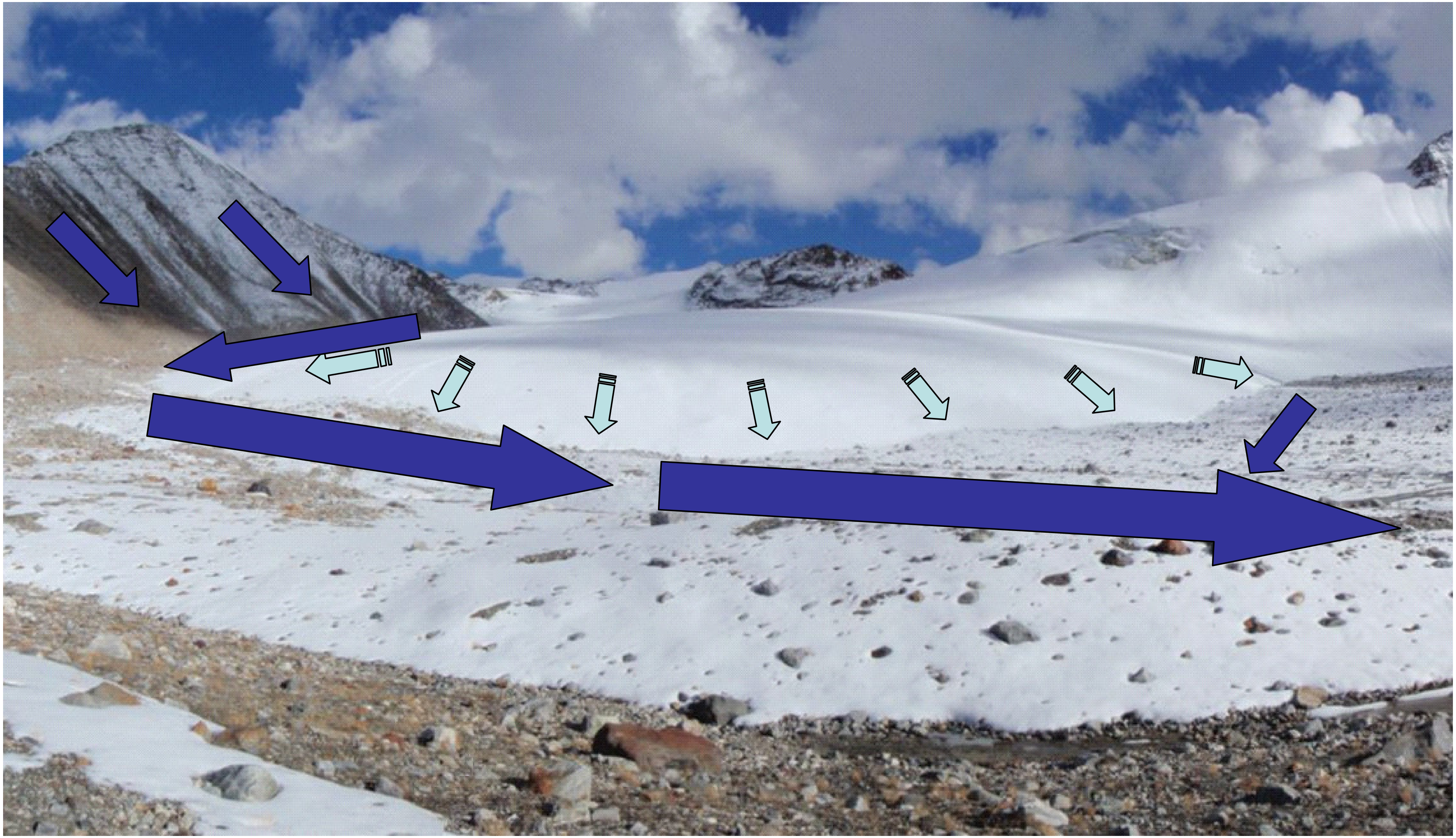




| | |
|---|---|
| mpd | maximum percolation depth |
| DSZ | dry-snow zone |
| UPZ | upper percolation zone |
| LPZ | lower percolation zone |
| SuZ | slush zone |
| SiZ | superimposed ice zone |

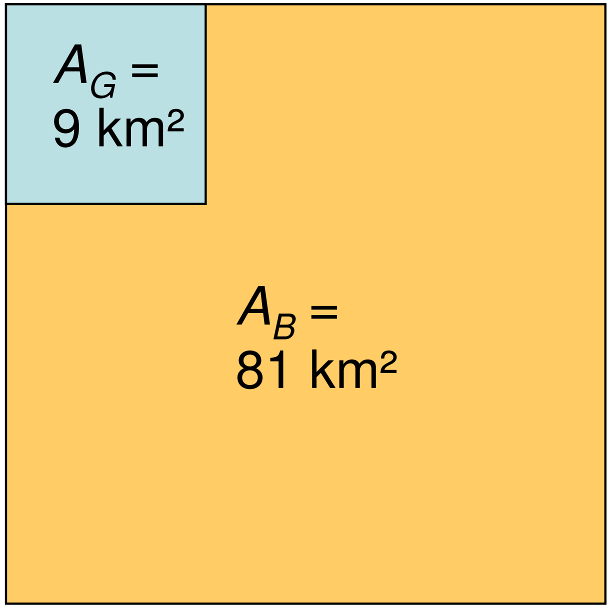
| | |
|---|---|
| $t_0 - t_0$ | summer surface (start of mass-balance year) |
| $t_w - t_w$ | winter surface (end of accumulation season) |
| $t_1 - t_1$ | summer surface (end of mass-balance year) |
| AbZ | ablation zone (zone below e) |
| AcZ | accumulation zone (zone above e) |

| | |
|---|---|
| s | snowline |
| r | runoff (slush) limit |
| e | equilibrium line |
| w | wet-snow line |
| d | dry-snow line |



# Glaciers as water resource

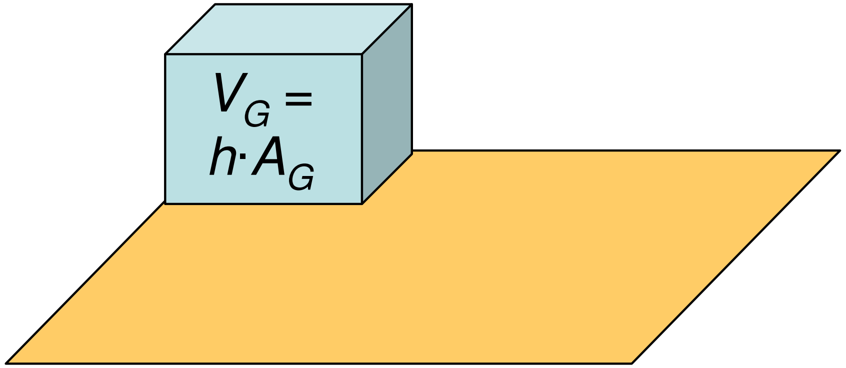
Steady state and uniform precipitation:
annual glacier discharge is about 11.1% of annual precipitation in basin




the glacier may have above-average precipitation

runoff from glacier ensures water availability in times of no precipitation

Melting glacier:
annual glacier discharge is increased but only for a limited time depending on the glacier's volume




while $A_G$ is easily measured, the depth $h$ is more difficult to quantify

when $V_G$ is getting smaller, runoff from glacier will be reduced also

# Glacier Lake Outburst Floods (GLOF)

**FIGURES A–C**

A) Location map of the study areas in the Chinese Himalayas (digital elevations are derived from Shuttle Radar Topography Mission (SRTM) data);

B) villages and towns most likely to be affected by the outburst flood (contours in meters, adapted from Chinese topographic maps at 1:50,000);

C) Longbasaba Lake and its natural dam. (Maps by authors; Photo by J. Ma, Greenpeace).

Wang et al. (2008)
www.bioone.org/doi/pdf/10.1659/mrd.0894