GLIMS

Global Land Ice Measurements from Space

Annual satellite imaging of the world's glaciers

Assessment of glacier extent and change

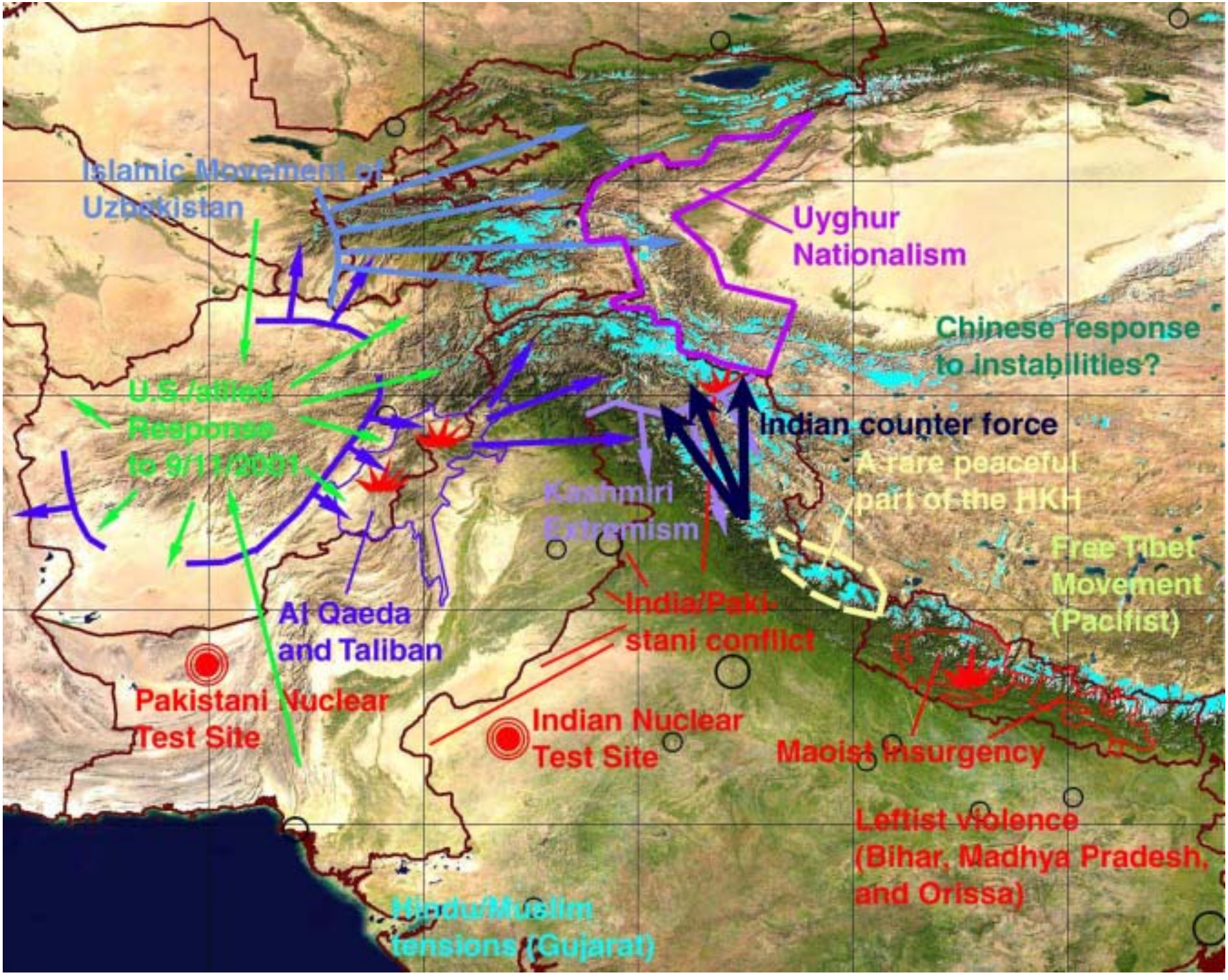
Development and population of a digital glacier data inventory

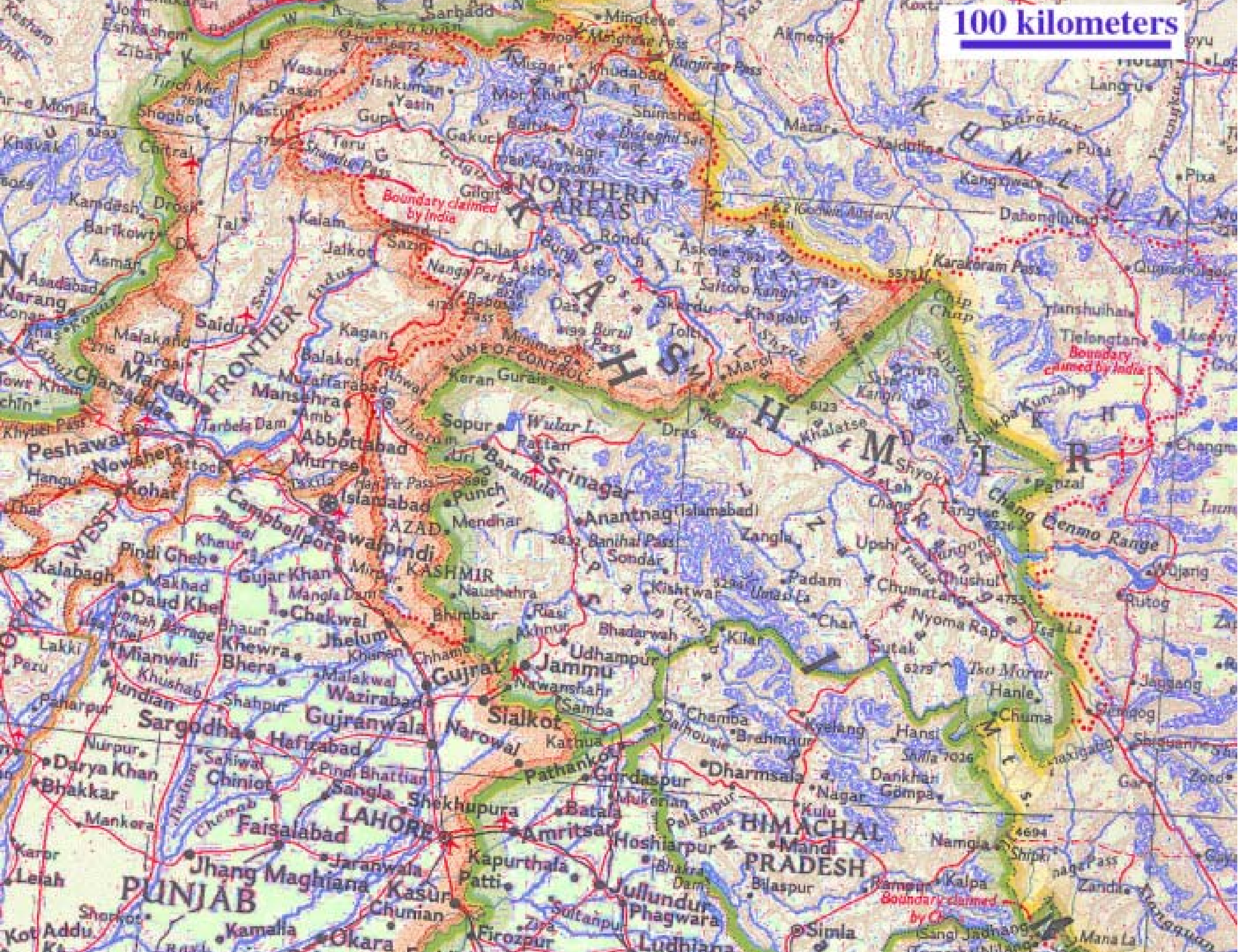
HIGH ICE

High Asia Institutes for Glaciology: Hydrology, Ice, Climate, and Environment

"Science for Peace for the High Asia Region of Chaos"

Skeletal remains of what was a debris-covered glacier near Mt. Everest


Islamic Movement of Uzbekistan
Uyghur Nationalism
Chinese response to instabilities?
U.S./allied Response to 9/11/2001
Indian counter force
A rare peaceful part of the HKH
Kashmiri Extremism
Free Tibet Movement (Pacifist)
India/Pakistani conflict
Al Qaeda and Taliban
Pakistani Nuclear Test Site
Indian Nuclear Test Site
Maoist insurgency
Leftist violence (Bihar, Madhya Pradesh, and Orissa)
Hindu/Muslim tensions (Gujarat)



100 kilometers
NORTHERN AREAS
Boundary claimed by India
KASHMIR
LINE OF CONTROL
FRONTIER
AZAD KASHMIR
HIMACHAL PRADESH
PUNJAB
KUNLUN
Chang Chenmo Range
Karakoram Pass
Gilgit
Chitral
Drosh
Saidu
Malakand
Mardan
Charsadda
Peshawar
Nowshera
Attock
Kohat
Hangu
Khyber Pass
Tarbela Dam
Mansehra
Abbottabad
Murree
Muzaffarabad
Balakot
Kagan
Islamabad
Rawalpindi
Campbellpore
Pindi Gheb
Kalabagh
Daud Khel
Chakwal
Gujar Khan
Mangla Dam
Mirpur
Jhelum
Khewra
Bhera
Mianwali
Kundian
Khushab
Sargodha
Shahpur
Malakwal
Gujrat
Wazirabad
Gujranwala
Hafizabad
Sialkot
Narowal
Jammu
Samba
Kathua
Pathankot
Gurdaspur
Batala
Amritsar
LAHORE
Shekhupura
Sangla
Chiniot
Faisalabad
Jhang Maghiana
Jaranwala
Kasur
Patti
Kapurthala
Jullundur
Phagwara
Hoshiarpur
Mandi
Bilaspur
Simla
Kulu
Nagar
Dharmsala
Chamba
Dalhousie
Kyelang
Udhampur
Bhadarwah
Kishtwar
Anantnag (Islamabad)
Banihal Pass
Srinagar
Baramula
Sopur
Wular L.
Punch
Mendhar
Naushahra
Bhimbar
Akhnur
Uri
Keran
Gurais
Dras
Kargil
Khalatse
Leh
Shyok
Zangla
Padam
Upshi
Chushul
Chumatang
Nyoma Rap
Hanle
Chuma
Tso Morari
Skardu
Khapalu
Tolti
Marol
Nanga Parbat
Astor
Chilas
Rondu
Askole
Saltoro Kangri
Baltit
Nagir
Gakuch
Gupis
Yasin
Ishkuman
Mastuj
Shandur Pass
Tirich Mir
Kalam
Jalkot
Sazin
Kunjirap Pass
Mintaka Pass
Misgar
Khudabad
Shimshal
Distaghil Sar
Rakaposhi
K2 (Godwin Austen)
Chip Chap
Tianshuihai
Tielongtan
Dahongliutan
Kangxiwar
Pusa
Rutog
Shipki
Namgia
Kalpa
Rampur
Zanda
Boundary claimed by China
Darya Khan
Bhakkar
Leiah
Kot Addu
Okara
Ferozpur
Ludhiana
Chunian
Kamalia
Pindi Bhattian
Nurpur
Sahiwal
Mankera

Global Land Ice Measurements from Space

GLIMS

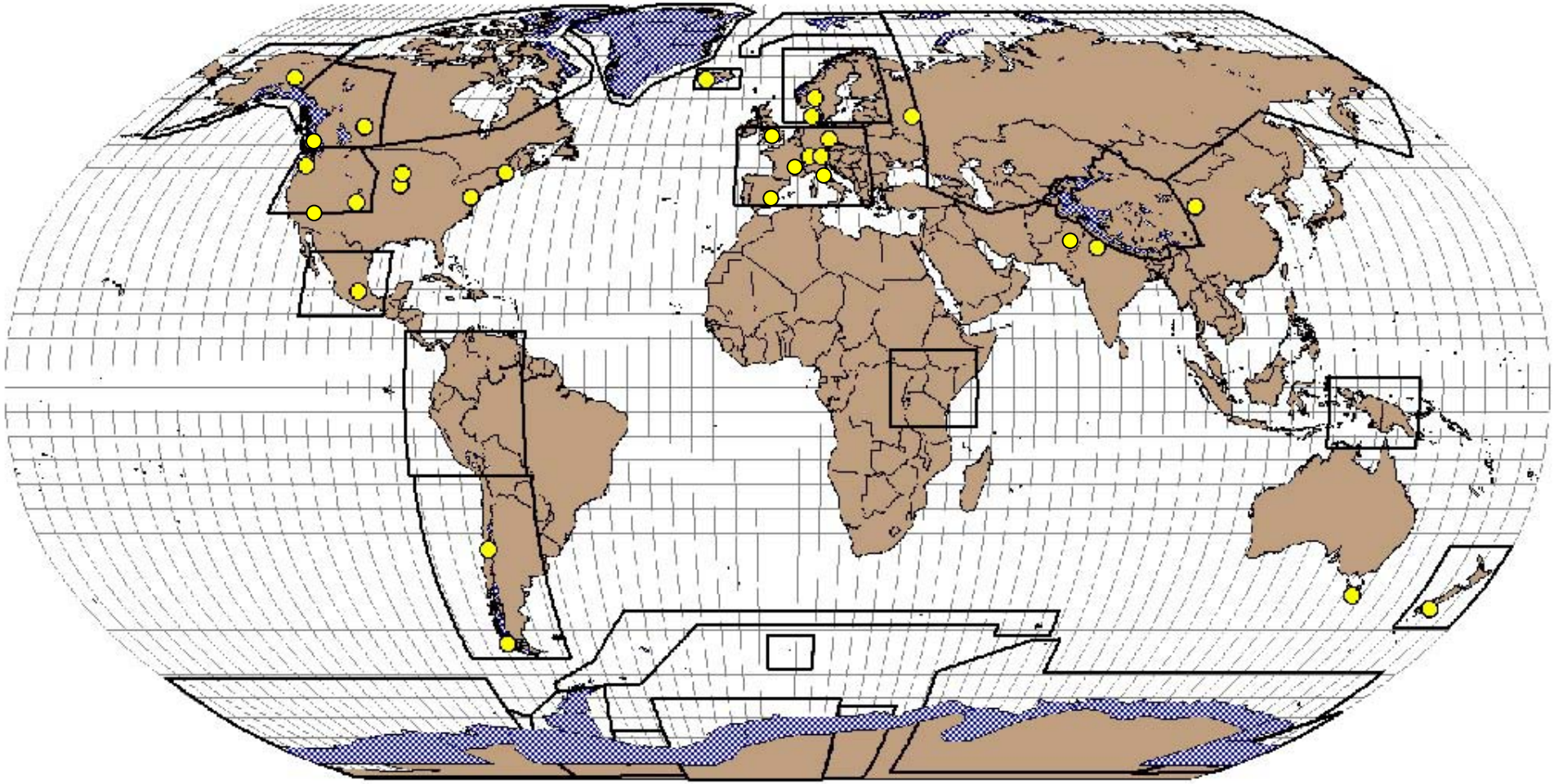
www.GLIMS.org

GLIMS primary goal: to determine the extent of Earth's glaciers and the rate at which they are changing.

RESULTS:

- Acquired >30,000 ASTER L1A scenes (of any quality)
  - Of these, we've archived and distributed over 5000 L1B scenes with:
    - Nominal gain settings and seasons for best snow and ice imaging
    - GLIMS uses all ASTER bands (VNIR,SWIR,TIR) for glacier mapping
  - Timely ASTER imaging response to recent glacier hazard events
- Purchased 150+ Landsat ETM+ scenes for RC ftp download
- Currently producing digital maps of glacier change
  - 23 regional centers mapping current extent of exposed land ice
  - Producing high resolution surface displacement fields using ASTER
  - Automating data extraction from ASTER
  - Measuring glacier lake temperature variations using multi TIR bands
- Designed GIS digital database for GLIMS glacier inventory (NSIDC)

GLIMS Regions and Regional Center locations



- **GLIMS is an international consortium of 23 regional centers**
- **Coordinated by U.S. Geological Survey - Flagstaff**

GLIMS

Science Questions from the Research Strategy

Variability	Forcing	Response	Consequence	Prediction
Precipitation, evaporation & cycling of water changing? *	Atmospheric constituents & solar radiation on climate?	Clouds & surface hydrological processes on climate? *	Weather variation related to climate variation? *	Weather forecasting improvement?
Global ocean circulation varying?	Changes in land cover & land use? *	Ecosystem responses & affects on global carbon cycle?	Consequences in land cover & land use?	Transient climate variations?
Global ecosystems changing?	Surface transformation? *	Changes in global ocean circulation? *	Coastal region change? *	Trends in long-term climate? *
Stratospheric ozone changing?		Stratospheric trace constituent responses?		Future atmospheric chemical impacts?
Ice cover mass changing?		Sea level affected by climate change? *		Future concentrations of carbon dioxide and methane?
Motions of Earth & interior processes?		Pollution effects?		

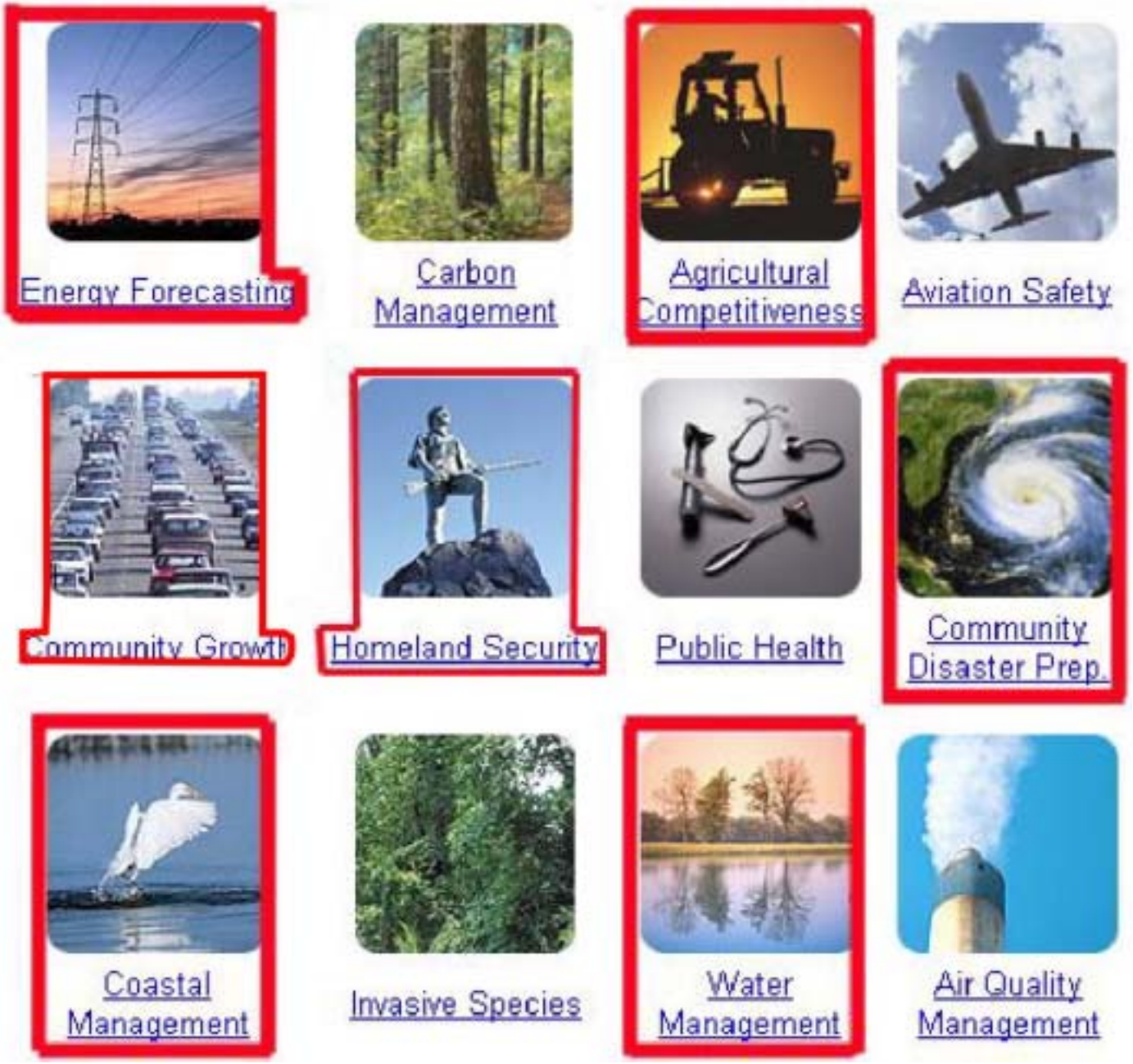
Glacier Relevance to other Science Questions

- *R1. Clouds and surface hydrological processes on climate?*
  - Albedo feedbacks; thermohaline circulation of oceans.
- *R3. Changes in global ocean circulation?*
  - Thermohaline circulation.
- *C3. Coastal region change?*
  - Glacier/ice sheets are melting: effects on sea level.
- *V1. Precipitation, evaporation, and cycling water?*
  - Glaciers/ice sheets store most of Earth's fresh water.
- *F2. Changes in land cover and land use?*
  - Changing glacier cover changes water availability, hence land use in areas downstream.
- *F3. Surface transformation?*
  - Glacial isostacy/rebound and mountain uplift/erosion affect glacier stability.
- *R5. Sea level affected by climate change?*
  - Climate change alters land ice volume and ocean volume.
- *C1. Weather variation related to climate variation?*
  - Albedo and humidity feedbacks due to land ice.
- *P3. Trends in long-term climate change?*
  - Glaciers integrate climate signals in continental regions where other climate records may be lacking.

Glaciers in the context of 12 major national research applications

Major research applications

Potentially significant research applications



Major Glacier Applications among 12 U.S. National Research Applications:

- **Energy Forecasting: Energy for U.S. Northwest derived partly from hydropower.**

- **Community disaster preparedness: Mt Rainer/Tacoma; Alaska.**

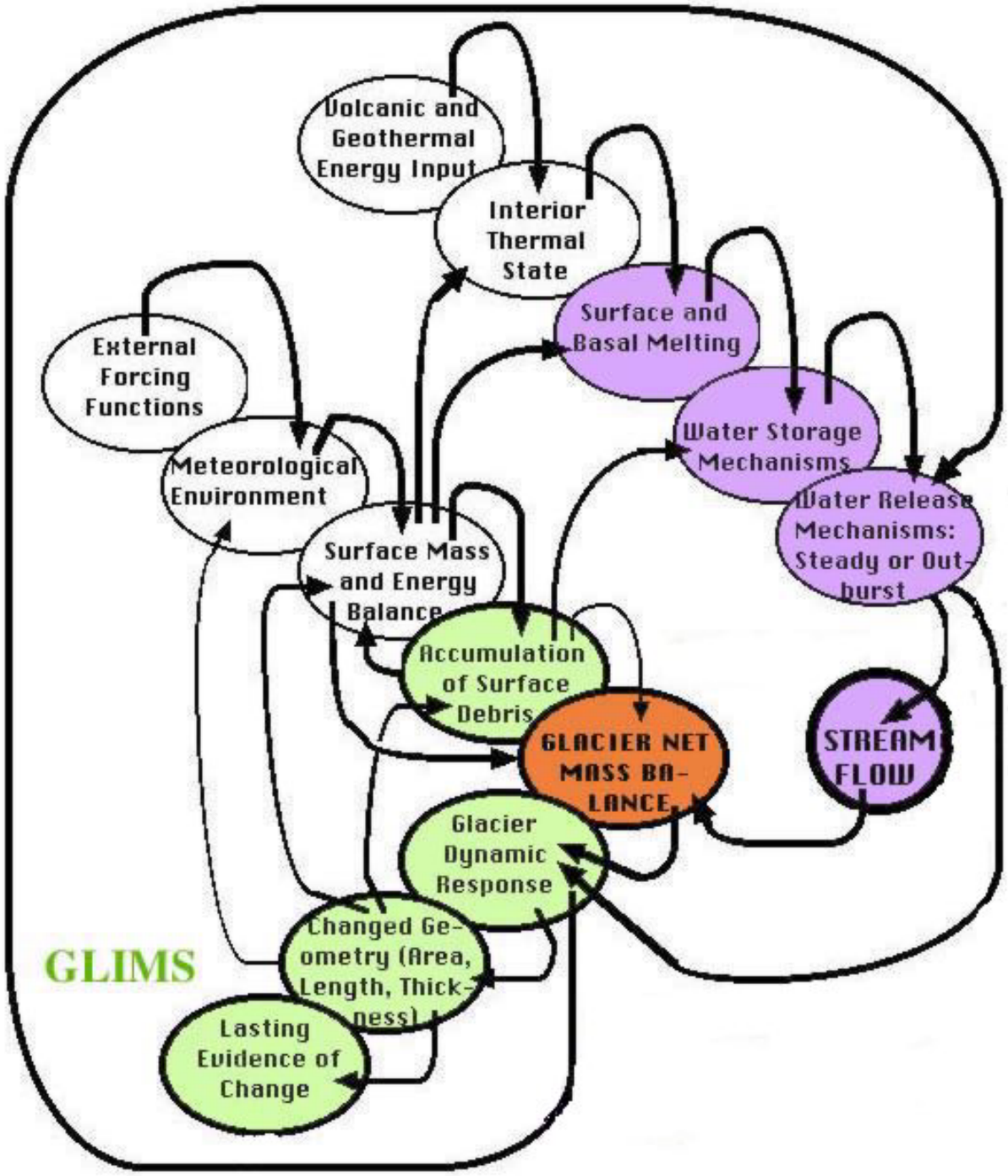
- **Water management: Washington and Oregon partly dependent on glacier meltwater (especially Canadian glacier sources)**

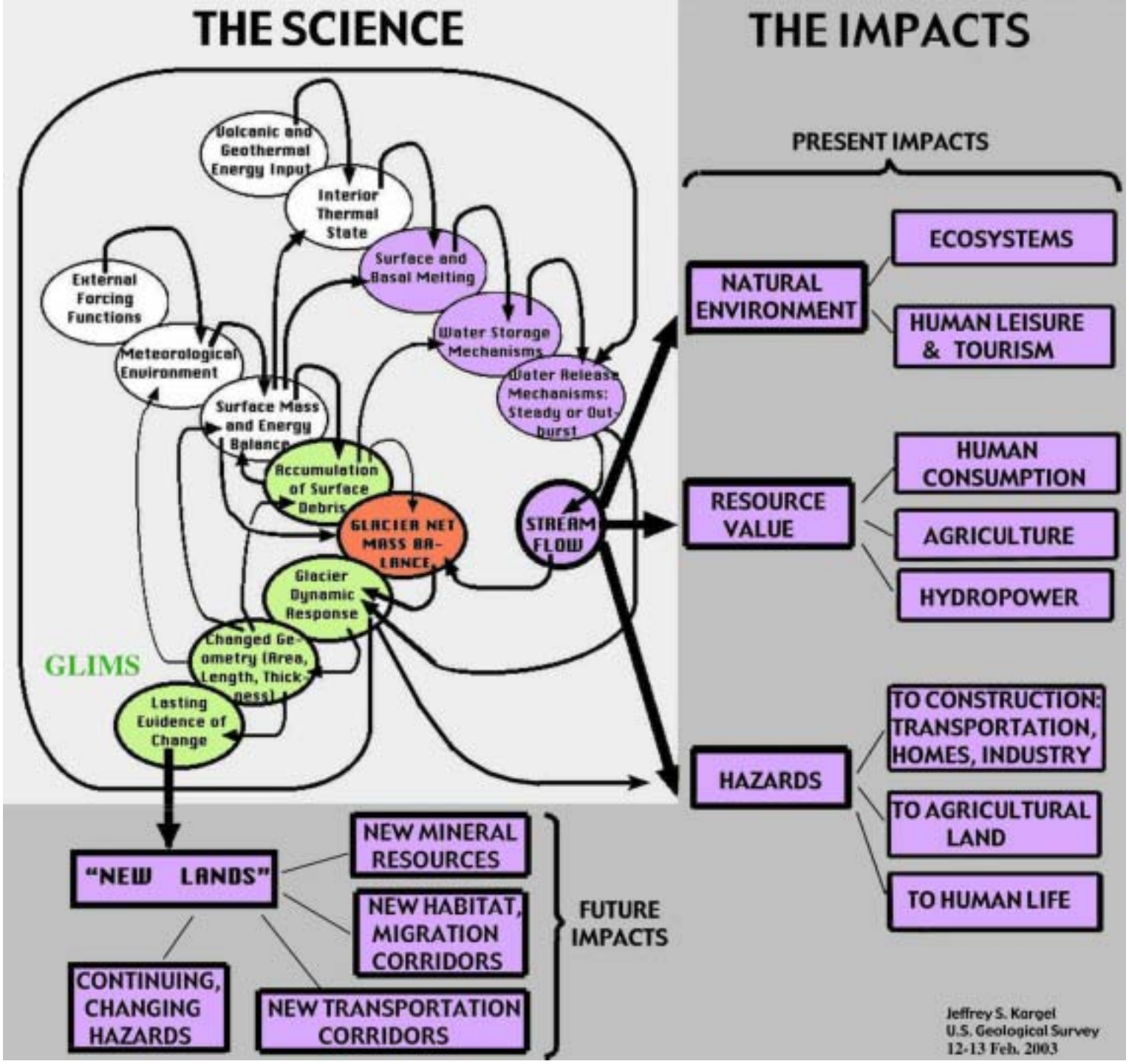
- **Agricultural competitiveness: Dependent on water resources, including glacier meltwater (especially Canadian glacier sources)**

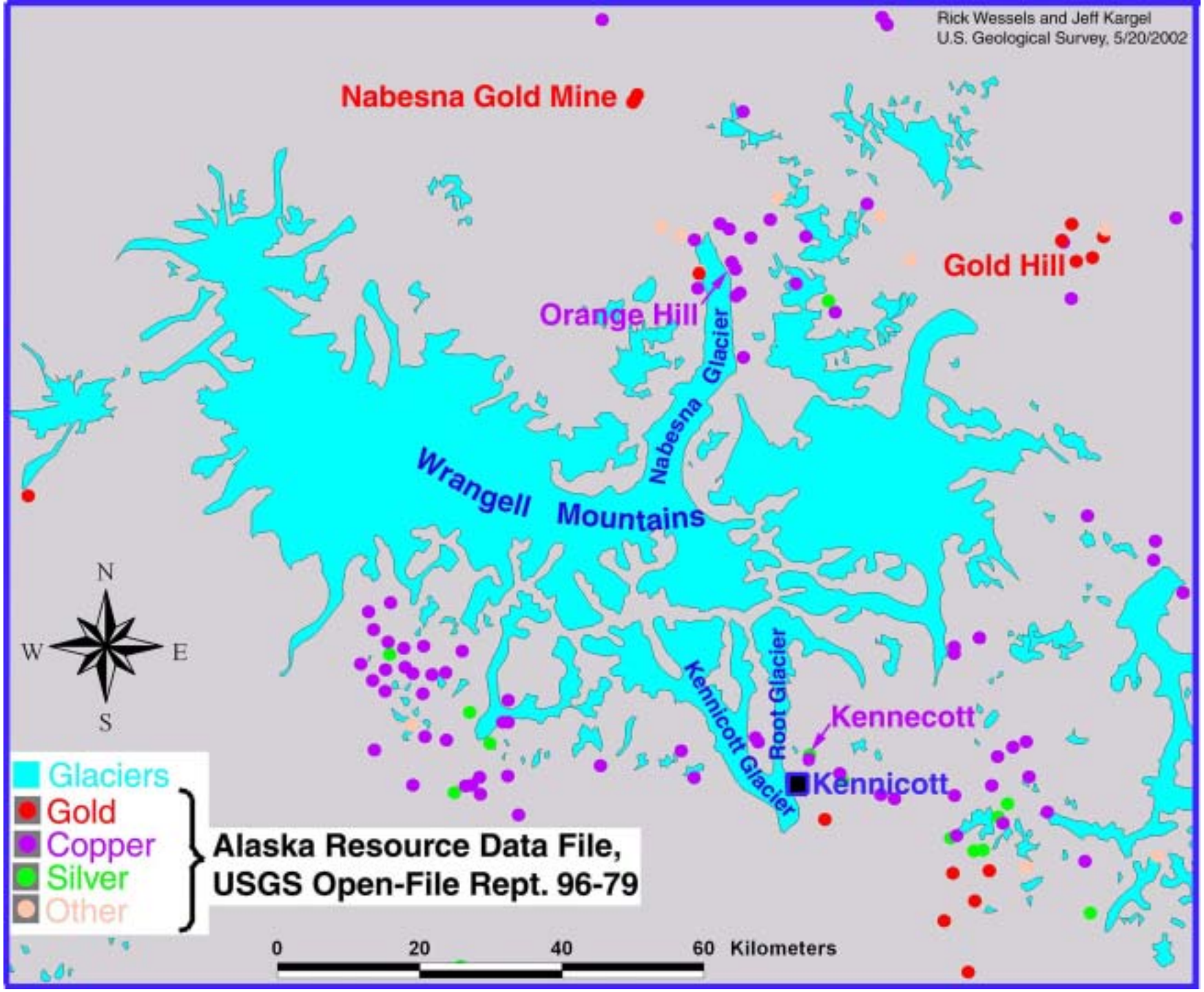
- **Coastal management: Sea level issues related to global melting of glaciers and ice sheets.**

Every U.S. research application has an international dimension and specifically an application in nations of High Asia. Glacier applications to energy, agriculture, and water management are of order magnitude greater importance to High Asia than to U.S. The issues are of critical economic interest to several nations, and hence, to regional and U.S. national security interests.

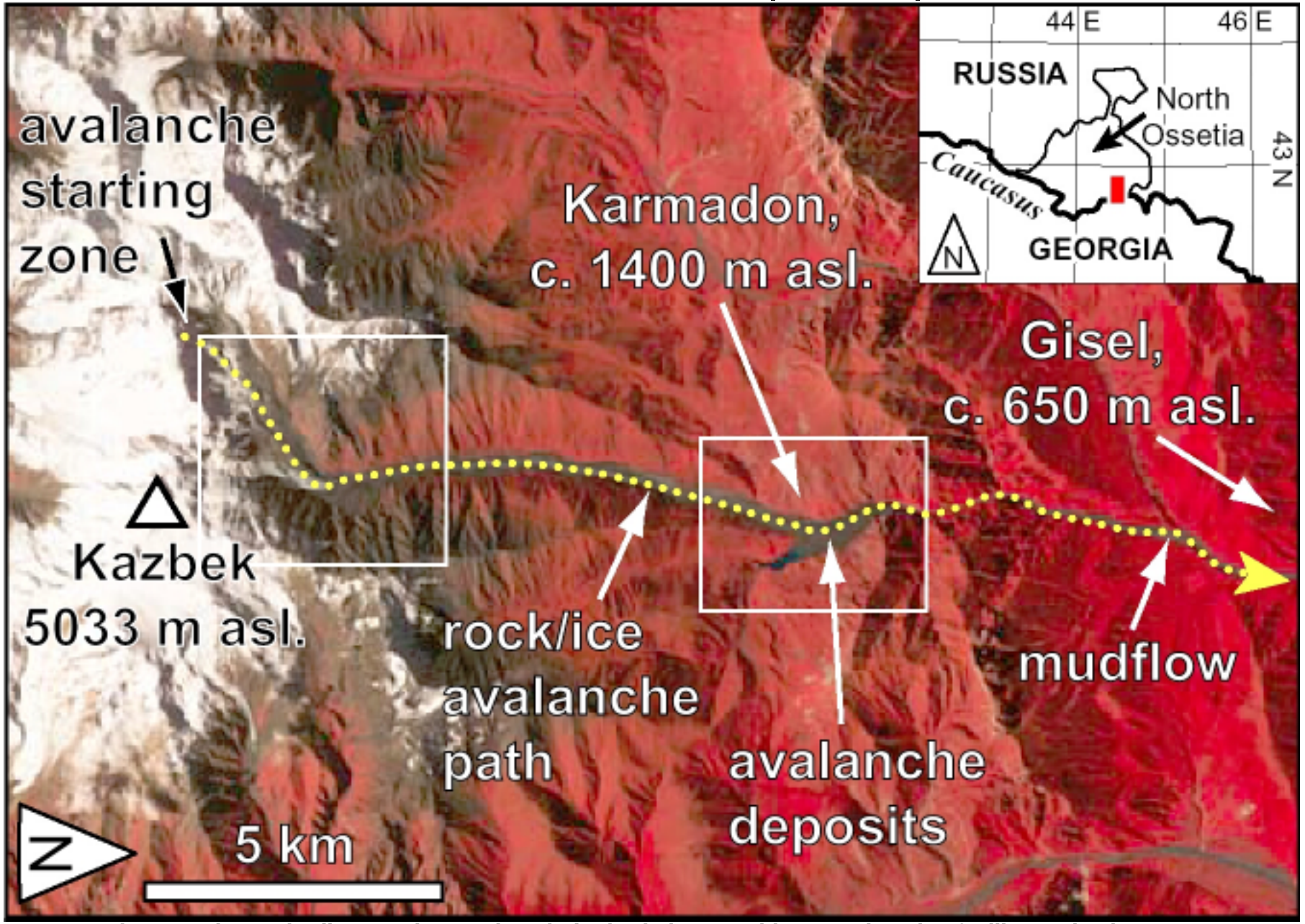
Science of glaciers




THE SCIENCE
THE IMPACTS
Volcanic and Geothermal Energy Input
Interior Thermal State
Surface and Basal Melting
External Forcing Functions
Water Storage Mechanisms
Meteorological Environment
Water Release Mechanisms: Steady or Outburst
Surface Mass and Energy Balance
Accumulation of Surface Debris
GLACIER NET MASS BALANCE
STREAM FLOW
Glacier Dynamic Response
Changed Geometry (Area, Length, Thickness)
GLIMS
Lasting Evidence of Change
PRESENT IMPACTS
NATURAL ENVIRONMENT
ECOSYSTEMS
HUMAN LEISURE & TOURISM
RESOURCE VALUE
HUMAN CONSUMPTION
AGRICULTURE
HYDROPOWER
HAZARDS
TO CONSTRUCTION: TRANSPORTATION, HOMES, INDUSTRY
TO AGRICULTURAL LAND
TO HUMAN LIFE
"NEW LANDS"
NEW MINERAL RESOURCES
NEW HABITAT, MIGRATION CORRIDORS
NEW TRANSPORTATION CORRIDORS
CONTINUING, CHANGING HAZARDS
FUTURE IMPACTS
Jeffrey S. Kargel
U.S. Geological Survey
12-13 Feb. 2003


Rick Wessels and Jeff Kargel
U.S. Geological Survey, 5/20/2002
Nabesna Gold Mine
Gold Hill
Orange Hill
Nabesna Glacier
Wrangell Mountains
N
W
E
S
Kennicott Glacier
Root Glacier
Kennecott
Kennicott
Glaciers
Gold
Copper
Silver
Other
Alaska Resource Data File,
USGS Open-File Rept. 96-79
0
20
40
60 Kilometers

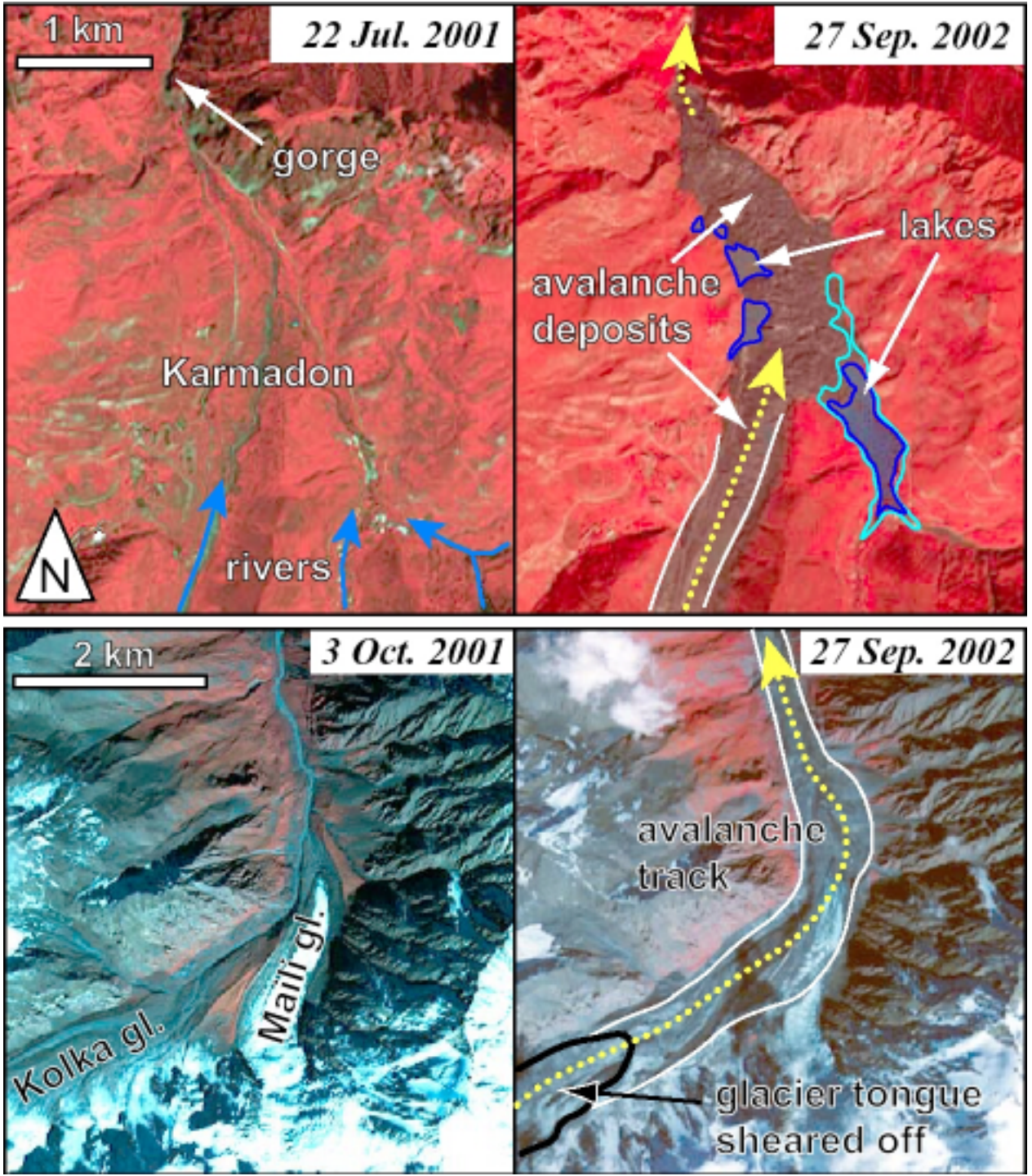
Kolka Glacier disaster - ASTER rapid response



From: Kääb, Wessels, Haeberli, Huggel, Kargel, and Singh Khalsa. Rapid ASTER imaging facilitates timely assessment of glacier hazards and disasters, in press, EOS

Kolka Glacier disaster

- 80 million cubic meter rock/ice avalanche and subsequent debris/mud flows on September 20, 2002
- Overran Karmadon village 18 km down valley
- Over 120 killed
- Mudflow continued 15km further down valley
- Rapid ASTER imaging response over several days following emergency.
- ASTER data used by emergency response teams



GLOF-wrecked bridge and replacement near Nepal/China border

Tsho Rolpa, Nepal, GLOF threat and engineering mediation

Credit: ICIMOD

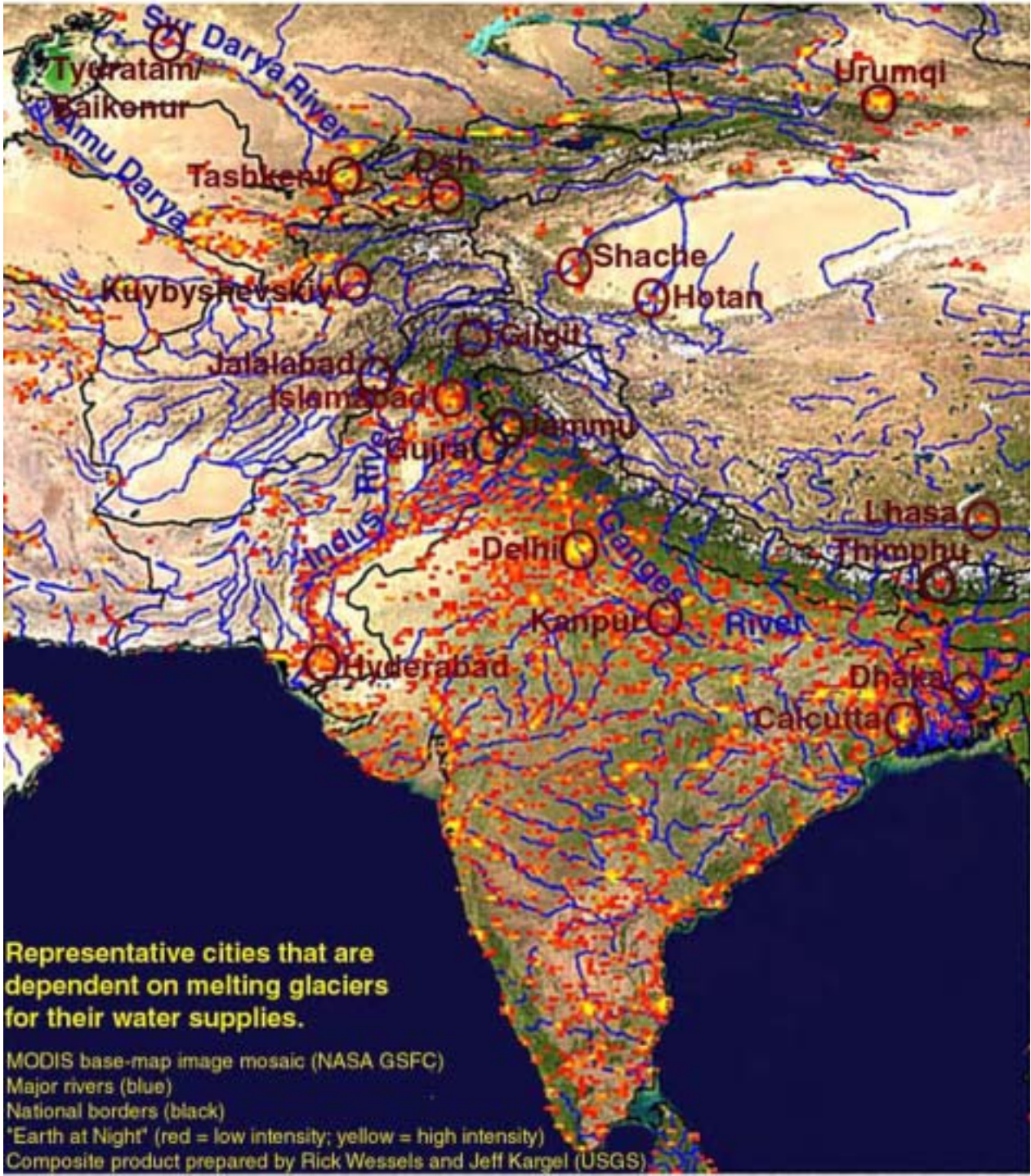
Glacier impact on regional water resources

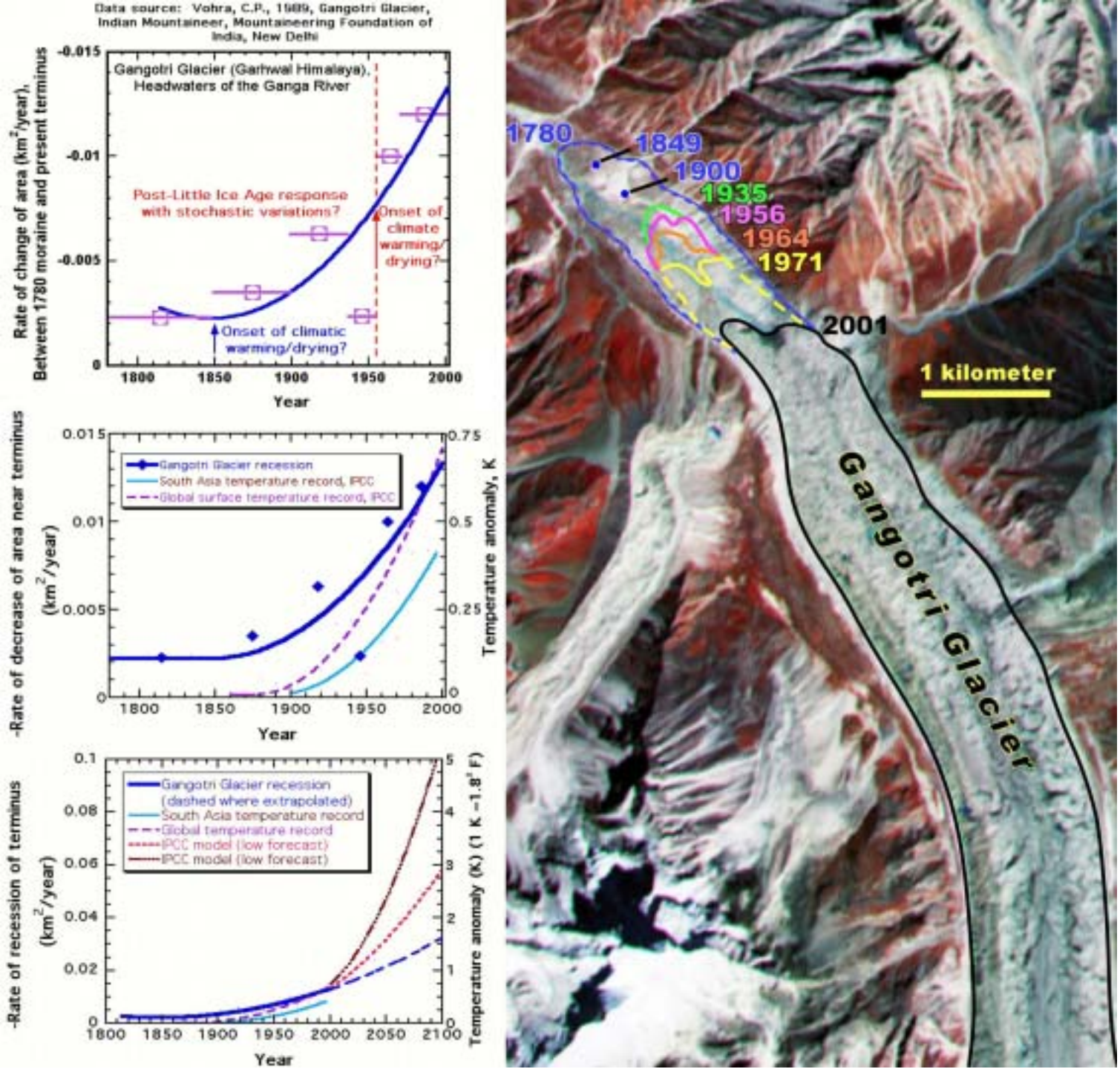
Hindu Kush Himalaya Glaciers

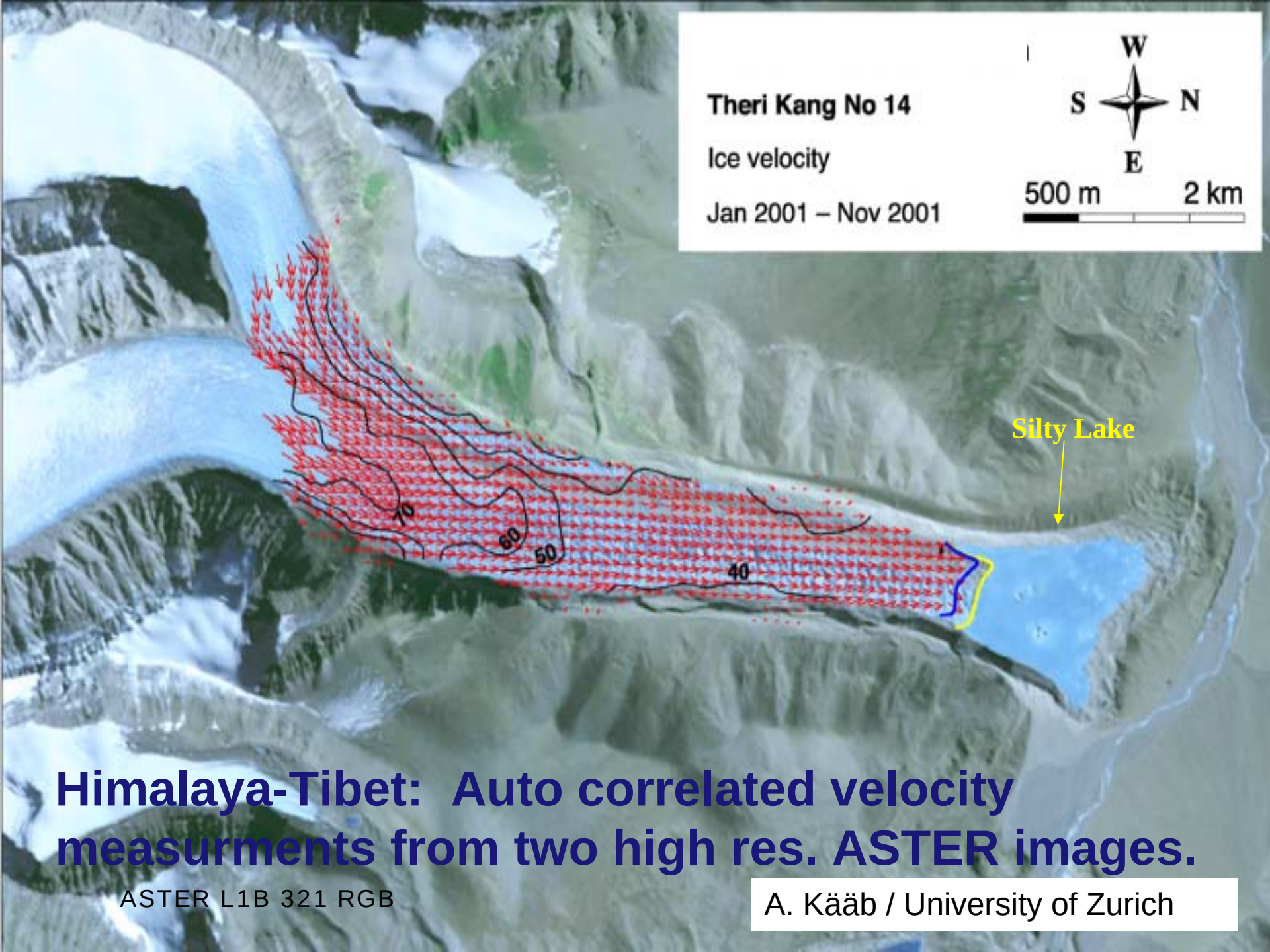
Fast glacier recession and wasting through most of the region

Impacts on South and Central Asia

500 million people partly depend on glacial meltwater




Data source: Vohra, C.P., 1989, Gangotri Glacier, Indian Mountaineer, Mountaineering Foundation of India, New Delhi
Gangotri Glacier (Garhwal Himalaya), Headwaters of the Ganga River
Rate of change of area (km²/year), Between 1780 moraine and present terminus
-0.015
-0.01
-0.005
0
Post-Little Ice Age response with stochastic variations?
Onset of climatic warming/drying?
Onset of climate warming/drying?
1800
1850
1900
1950
2000
Year
-Rate of decrease of area near terminus (km²/year)
Gangotri Glacier recession
South Asia temperature record, IPCC
Global surface temperature record, IPCC
0.015
0.01
0.005
0
0.75
0.5
0.25
0
Temperature anomaly, K
Year
-Rate of recession of terminus (km²/year)
Gangotri Glacier recession (dashed where extrapolated)
South Asia temperature record
Global temperature record
IPCC model (low forecast)
IPCC model (low forecast)
0.1
0.08
0.06
0.04
0.02
0
1800
1850
1900
1950
2000
2050
2100
5
4
3
2
1
0
Temperature anomaly (K) (1 K = 1.8° F)
Year
1780
1849
1900
1935
1956
1964
1971
2001
1 kilometer
Gangotri Glacier



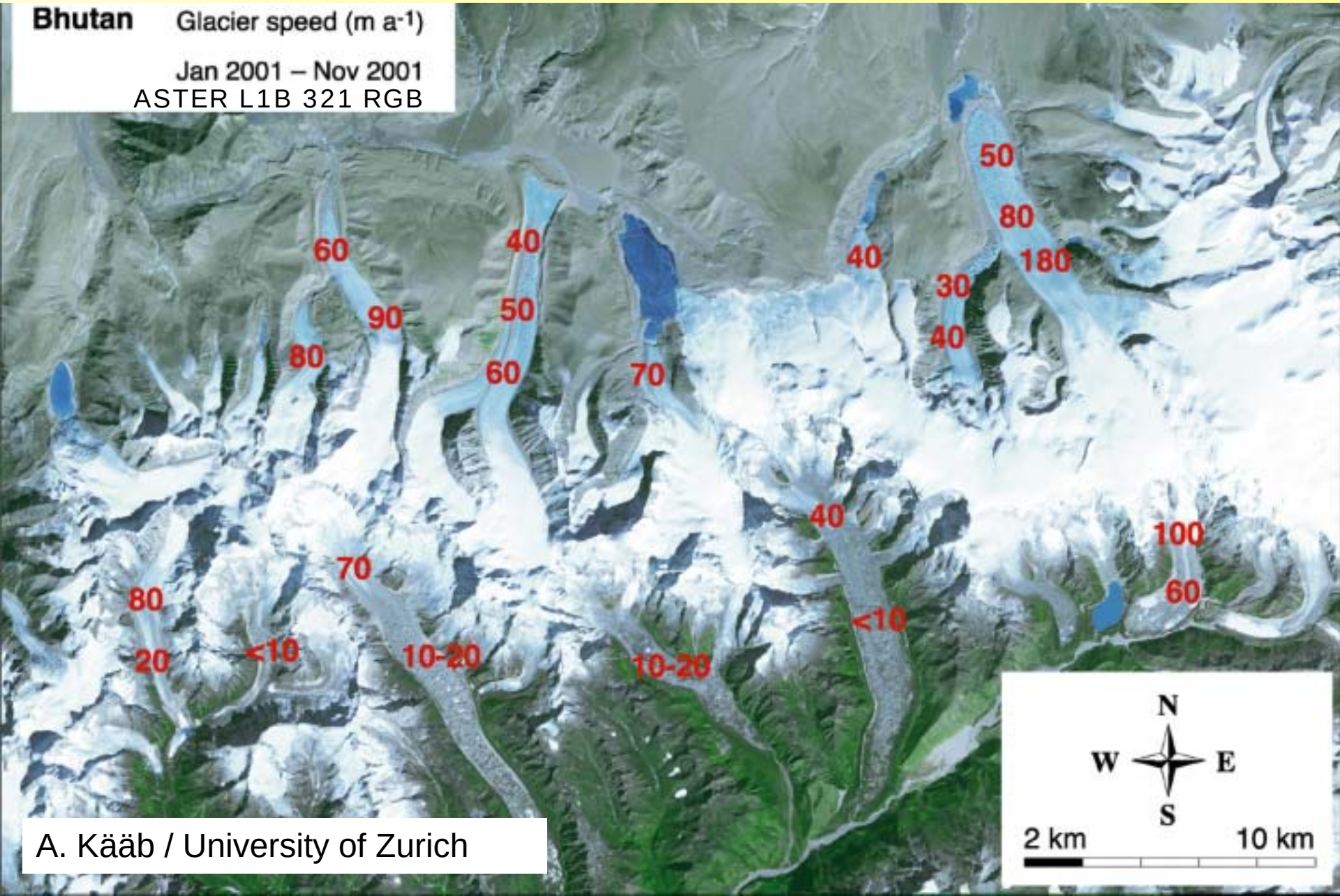
Himalaya-Tibet: Auto correlated velocity measurments from two high res. ASTER images.

ASTER L1B 321 RGB

A. Kääb / University of Zurich

Himalayas

Bhutan - Tibet



A. Kääb / University of Zurich

Glacier Hazard Monitoring and Response: Ice Dam Threat