MultiHazard Process Chains: Nepal and other hotspots

Jeffrey S. Kargel
(Thanks to NASA Disasters program and David Green for support)

6 Sep 2016

Glaciers
Glacial Lakes
Seismicity
Meteorological floods
Volcanoes

(1) Future possible CEOS/GEO pilots on high mountain disaster risks

-- Regions proposed for CEOS multihazard extended monitoring/analysis:

i) Nepal Himalaya and transborder areas of Tibet and India: seismic-landslide-glacier-glacial lake-meteorological hazards (major hazard points/examples: Imja Lake, Lower Barun Lake, Rolpa Lake, Kodari Pass, Koshi Tappu wetlands)

ii) Cascades: volcano-seismic-meteorological-landslide-glacier hazards (major hazard points, examples: Mts Rainier, Hood, Baker, and downstream areas)

iii) Northern Andes (Colombia-Ecuador-Peru): volcano-seismic-landslide-glacier-glacial lake-meteorological hazards, imopacts on people, infrastructure, and ecosystems (major hazard points, examples: Cordillera Blanca (glaciers and lakes), Corapuna (Peru), Cotopaxi (Ecuador), Nevado del Ruiz (Colombia), others)

-- Nepal examples:

i) Gorkha earthquake glacier-landslide-river blocking,

ii) Gorkha earthquake-ice avalanche-glacial lake outburst hazard,

iii) Monsoon and construction related landslides and dammed lake outbursts

(2) NASA-supported, CEOS-related high mountain disaster workshops:

-- "Satellite Observations Could Cover Multi-Process Glacier Hazard and Disaster Hotspots: Nepal, Cascades, and Northern Andes," pre-AGU, Dec. 11, San Fran.

-- "Satellite Observations to Cover Multi-Process Glacier Hazards and Disasters Hotspot in the Nepal Himalaya," Kathmandu, Nov. 2, 3, or 4 possible.

(3) HMA team, tool development: Glacier Lake Accelerated Melting (GLAM)

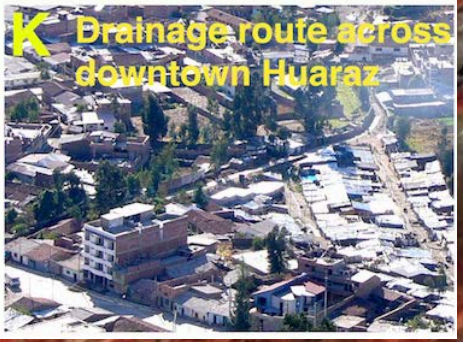
D

E

G

H

J

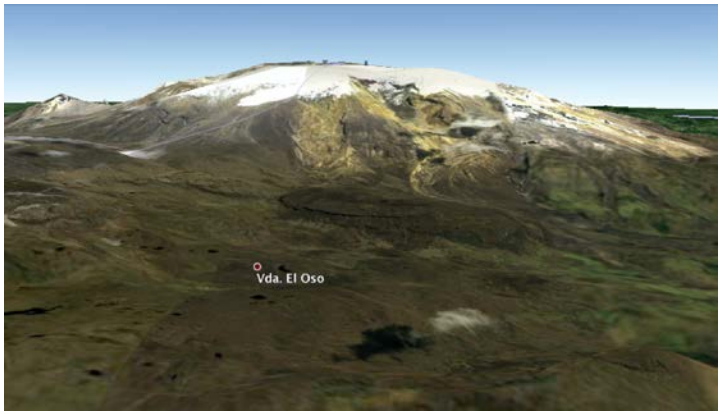


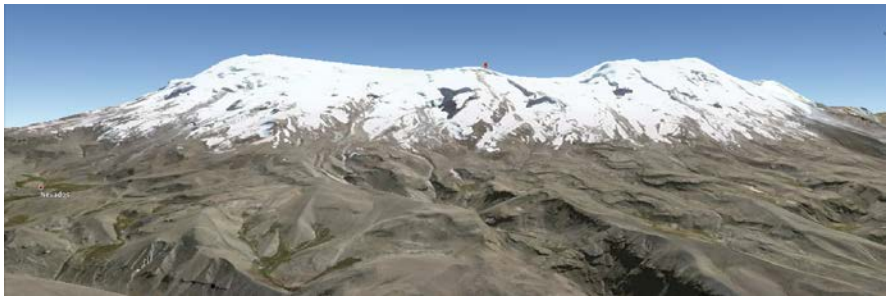
Aluviones in Huaraz:
1702, 1725, 1869, 1941, 1952, 2003

Palcacocha

Huaraz

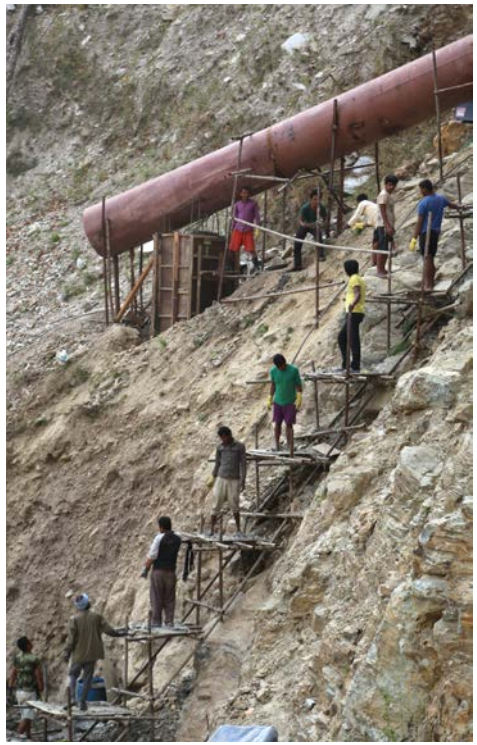
Nevado del Ruiz, Colombia- 1985 lahars, tragedy (23,000 killed) and Coropuna, Peru (6377 m)– seismicity, heat flow, eruption history, next tragedy?





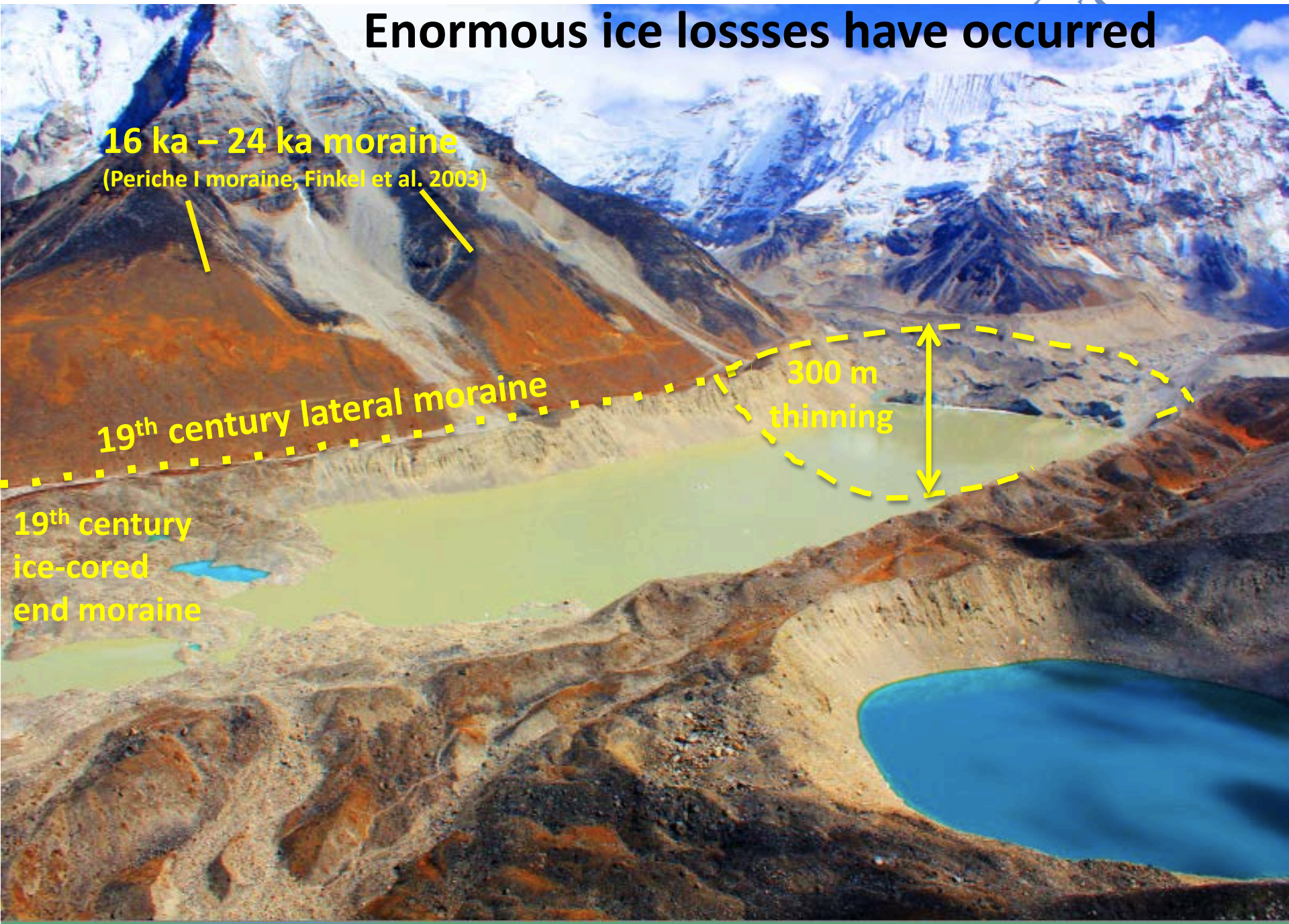
Taplejung landslides, June 10-11, 2015: Steep slopes + monsoon = deadly landslides (57 killed) → blocked river → landslide dammed lake outburst flood → killed fish → wild swings in price of fish

Construction on slopes + Geological weaknesses + monsoon +- earthquake = Landslides + lost hydropower production (economic losses)

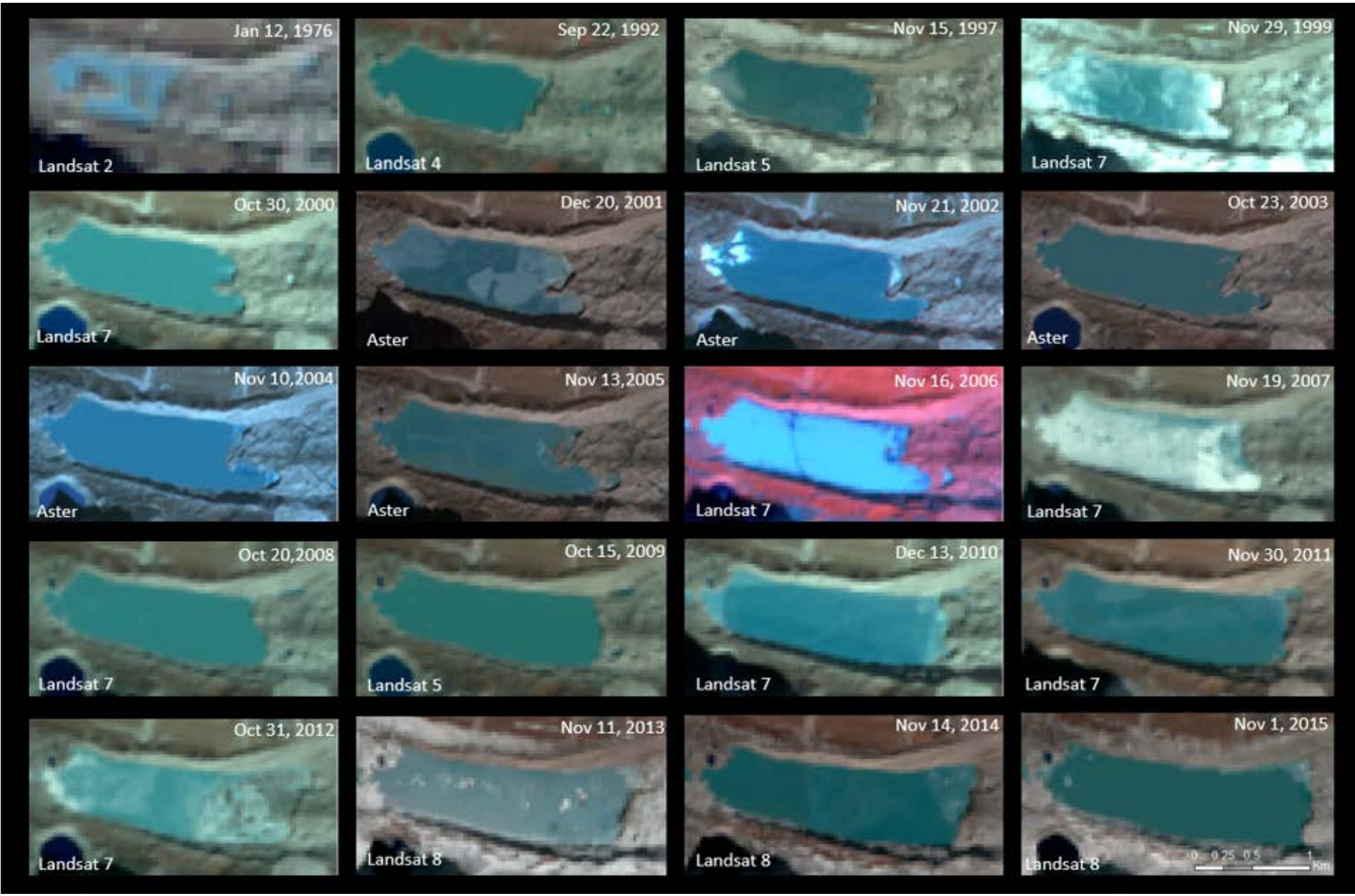


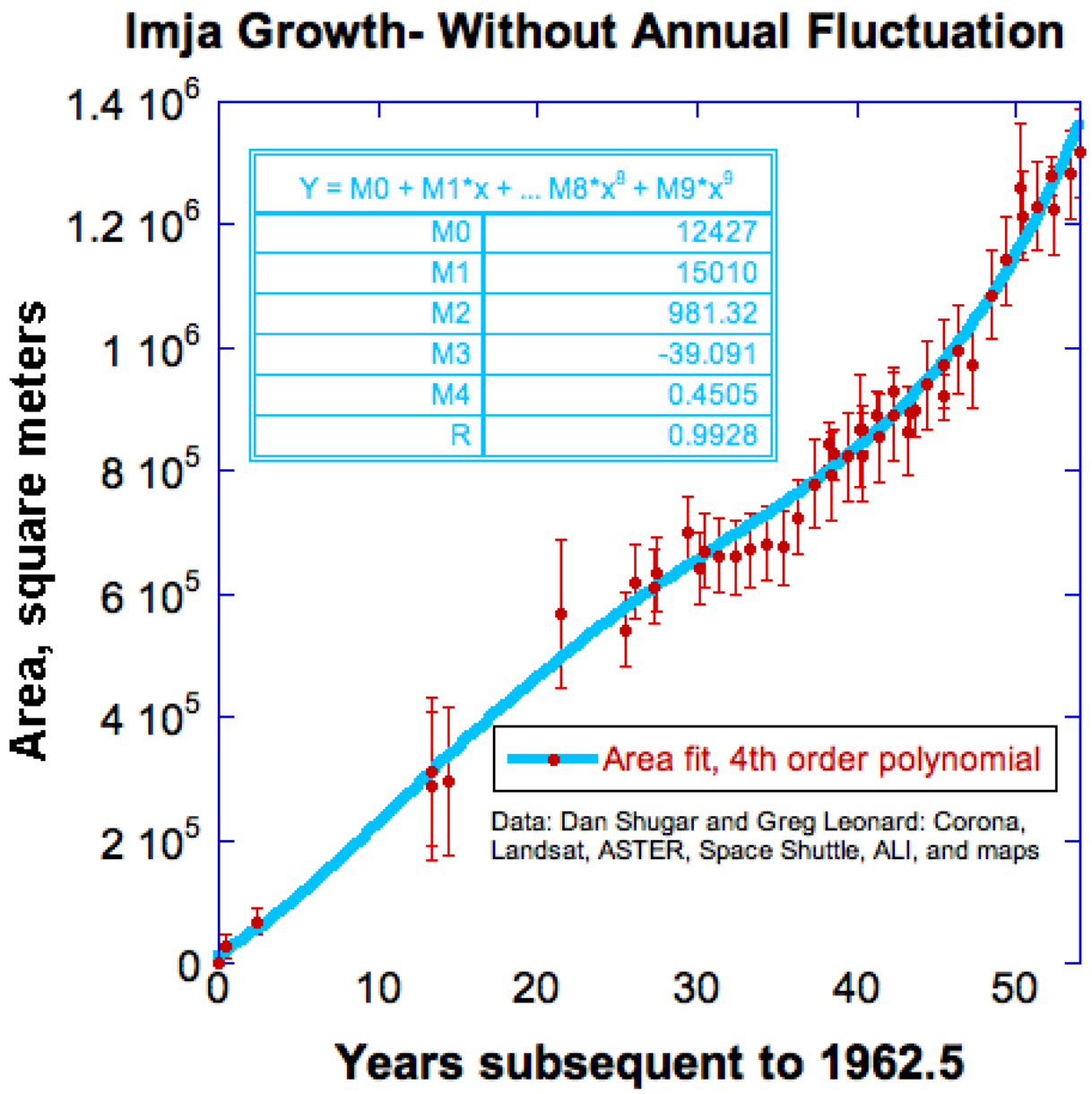
Far Eastern Nepal: 5 MW run-of-the-river hydropower plant construction and recurrent problems with landslides.

Enormous ice lossses have occurred

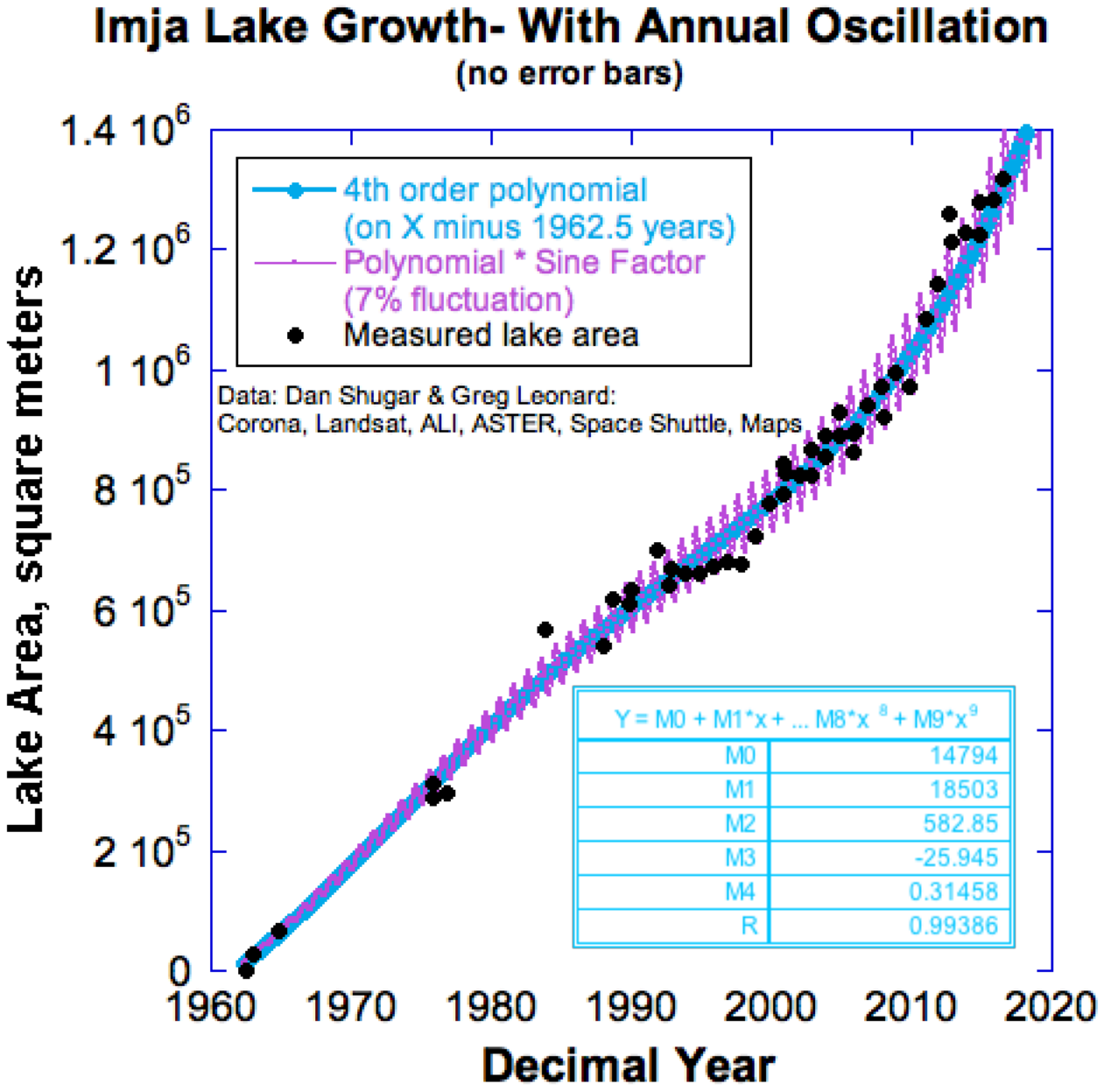


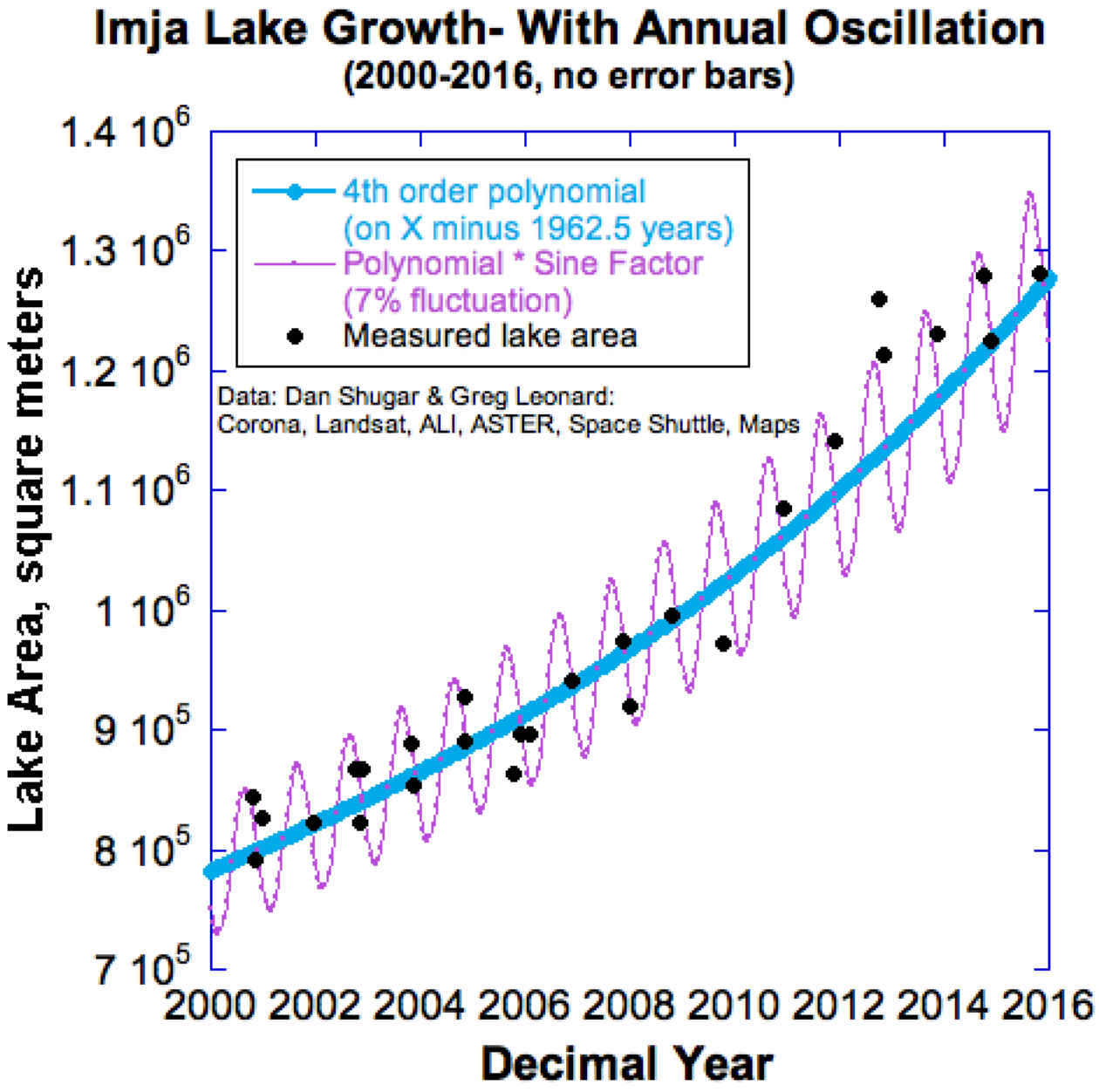
Growth of Imja Lake, Nepal, 1976-2015



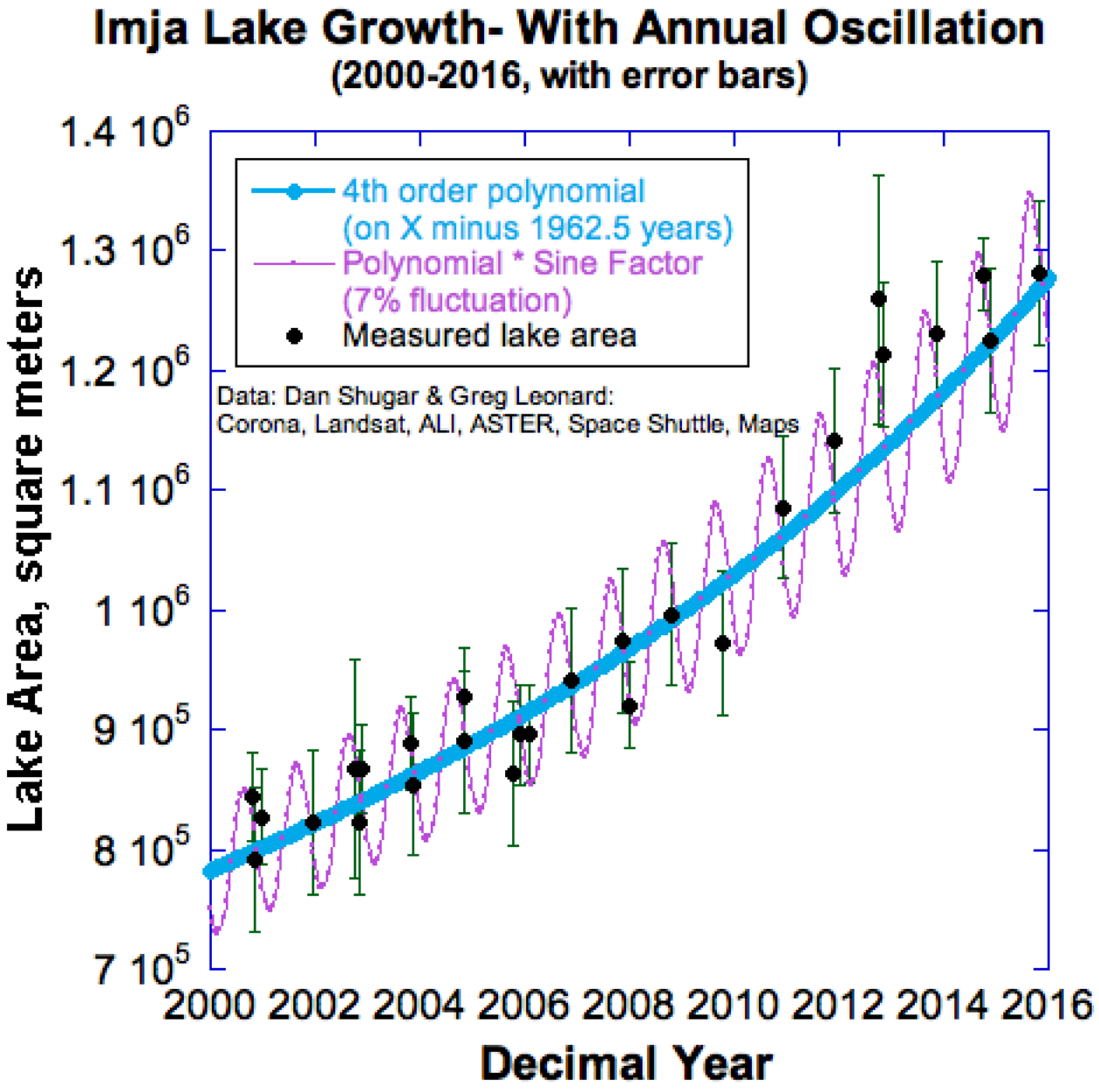

Imja Growth- Without Annual Fluctuation
Area, square meters
1.4 10^6
1.2 10^6
1 10^6
8 10^5
6 10^5
4 10^5
2 10^5
0
0
10
20
30
40
50
Years subsequent to 1962.5
Y = M0 + M1*x + ... M8*x^8 + M9*x^9
M0 12427
M1 15010
M2 981.32
M3 -39.091
M4 0.4505
R 0.9928
Area fit, 4th order polynomial
Data: Dan Shugar and Greg Leonard: Corona, Landsat, ASTER, Space Shuttle, ALI, and maps

The sine function would produce a scattering of points about the polynomial curve that roughly matches the disperson around the curve.

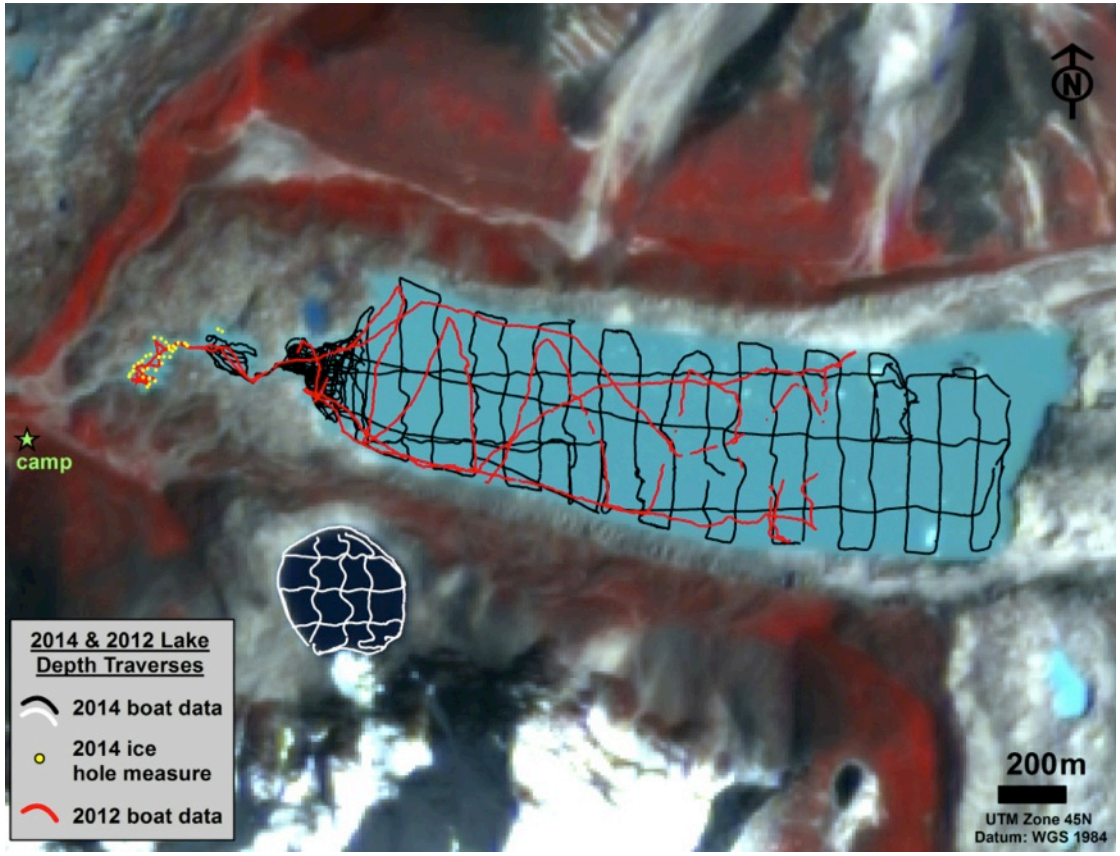



Imja Lake Growth- With Annual Oscillation
(2000-2016, no error bars)
4th order polynomial
(on X minus 1962.5 years)
Polynomial * Sine Factor
(7% fluctuation)
Measured lake area
Data: Dan Shugar & Greg Leonard:
Corona, Landsat, ALI, ASTER, Space Shuttle, Maps
Lake Area, square meters
1.4 10^6
1.3 10^6
1.2 10^6
1.1 10^6
1 10^6
9 10^5
8 10^5
7 10^5
2000 2002 2004 2006 2008 2010 2012 2014 2016
Decimal Year

Measurement errors are probably overestimated



Imja / Amphulapcha Lakes, Nepal: 2014 & 2012 Data

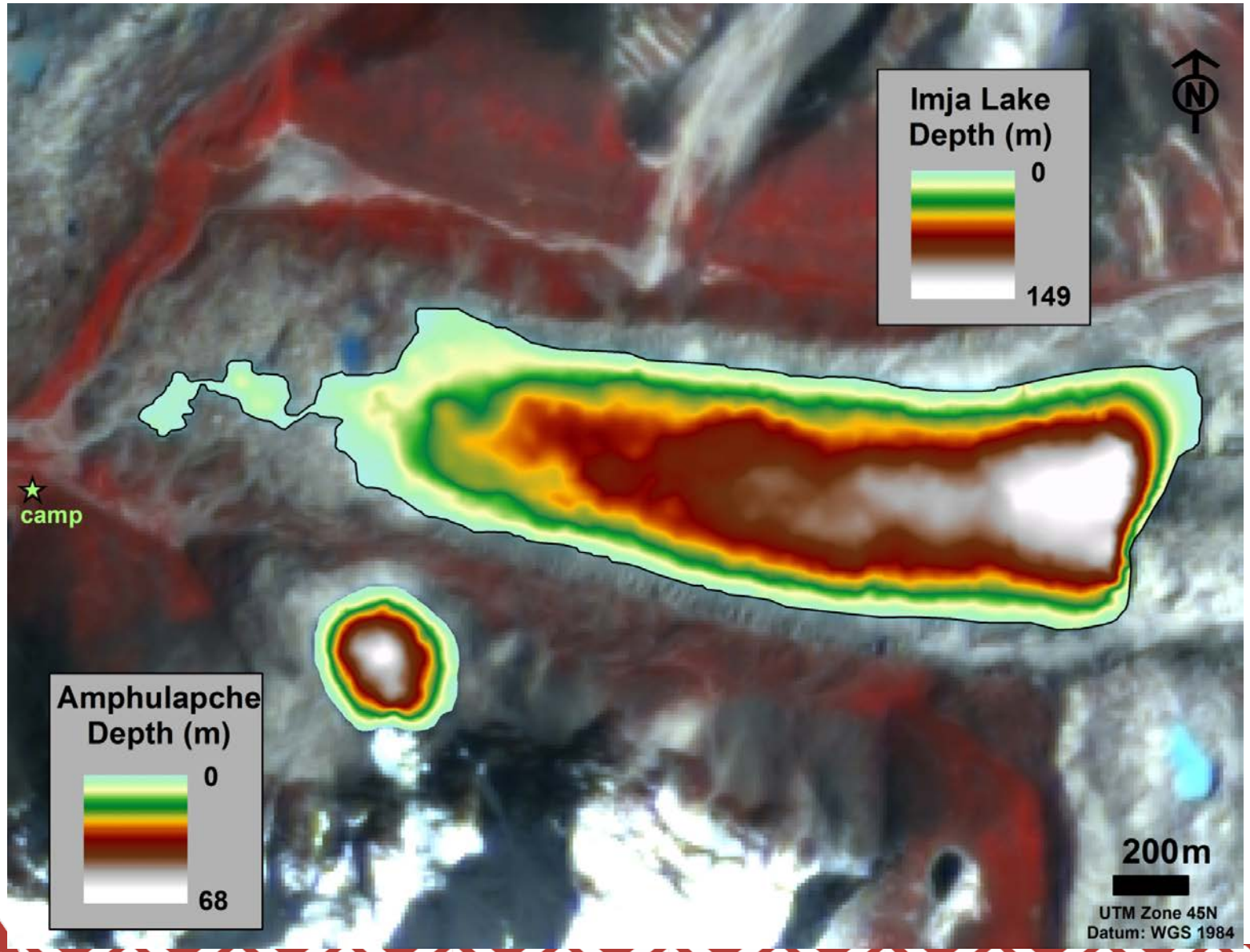


2014 Total (kayak-mount)	53,878	4221
Omitted points:	(-30,354)	(-886)
Kayak validated points:	**23,524**	**3335**
2014 Total (USV-mount)	9655	-
Omitted points:	(-1338)	-
USV validated points:	**8317**	-
2014 Total (ice bore measure)	61	-
Omitted points:	(-28)	-
Ice bore validated points:	**33**	-
2012 Somos et al. Total (boat-mount)	10,020	-
Omitted points:	(-854)	-
Boat validated points:	9,166	-
TOTAL VALIDATED:		

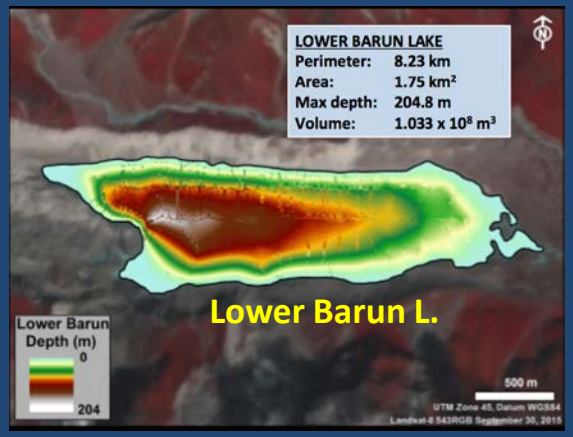
Black: our USV and kayak survey
Red: Somos et al. 2014 (survey date 2012)
Yellow: Our plumb line measurements

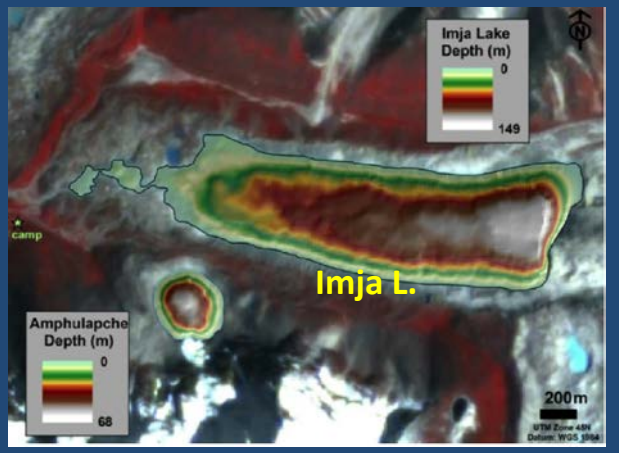
Details at west end of Imja lake and ponds on the end moraine

Imja Lake bathymetry, Oct 2014



Glacier and High Mountain Hazard Dynamics in Nepal





Thulagi Lake bathymetry, glacier dynamical assessment, hydrological and energy balance modeling

Lower Barun Lake bathymetry, glacier flow speed assessment

Imja Lake and glacier dynamics and the Imja Lake lowering project

Community Based Flood and Glacial Lake Outburst Risk Reduction Project (CFGORRP)

Implementing Authority

Nepal Army


Helipad
Ware house
Diversion Channel
Workshop/
community
Hall
Main Channel
Coffer Dam
Imja Lake lower

Water flowing through diversion channel.

Excavated main channel

Manual breaking of the big rocks

Breaking of stone for aggregate collection

Dressing of stone for workshop.

Collection of sand for construction

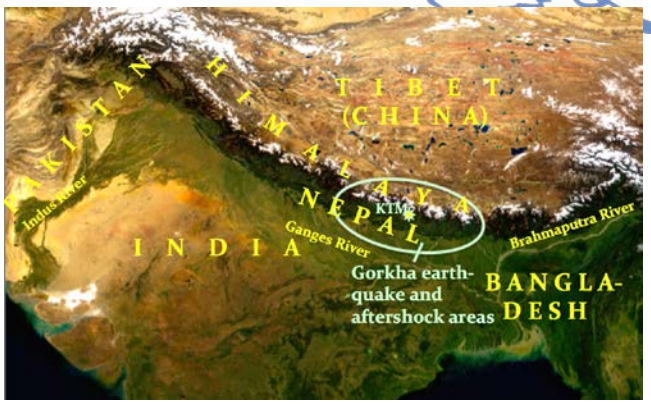
Excavation work of cutoff.

Reno mattress work in d/s of gate.

M25 Concrete in column section,

Gorkha earthquake– multihazard process chains

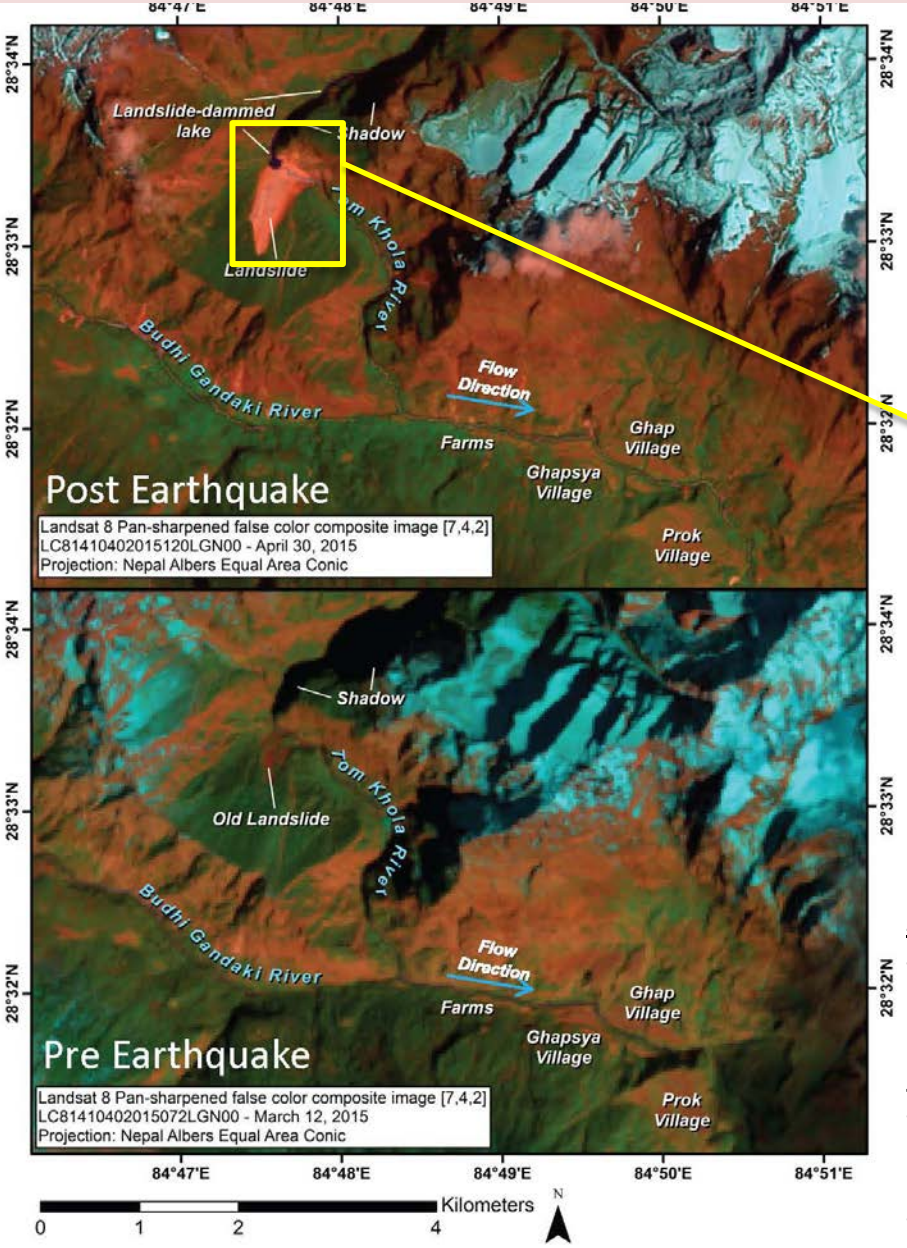
- M7.8 quake on April 25, 2015, epicenter west of Kathmandu, ~12 km deep, blind fault
- M7.3 aftershock on May 12, 2015.
- ~9000 killed, 97% of fatalities in Nepal. Others in India, China, and Bangladesh.
- >4300 significant landslides/ice avalanches.
- Some dangerous river blockages, upstream inundation floods, and landslide dammed lake outburst floods
- Many glacial lakes are in the heavily shaken zone: but no seismic aluviones!



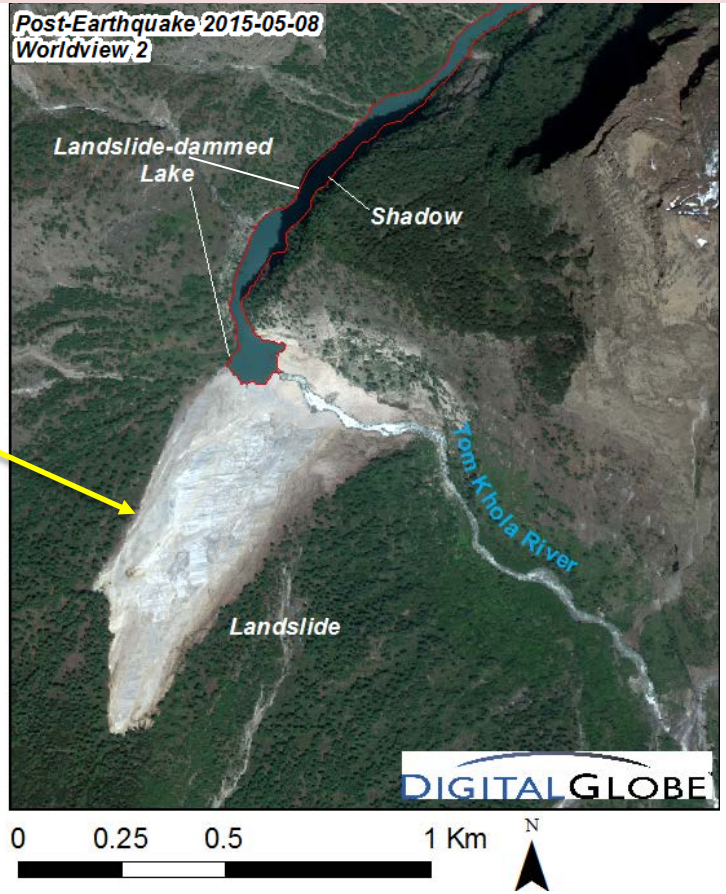

Destroyed temple in Kathmandu

Earthquake-triggered snow, ice and debris avalanche and potential river blocking, starting with ridge-top failure (PGA ~0.12 g)

Landslide-dammed lake in the Manaslu trekking region of Nepal



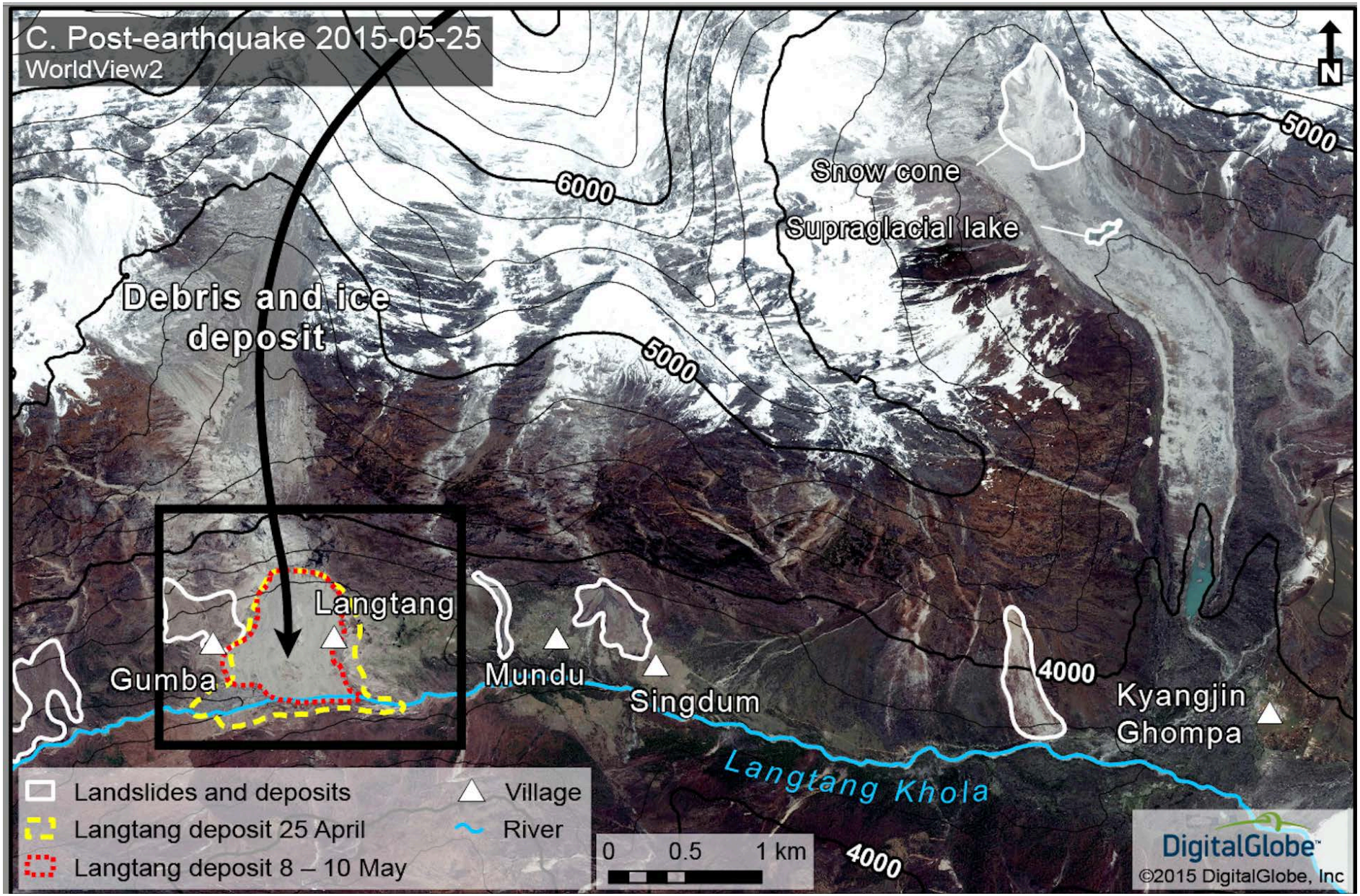
Post- and pre-earthquake image pair. The landslide is bright red.



Above: WorldView satellite image, May 8. NDWI technique was used to map the lake (red outline) and distinguish it from shadow.

Societal Concern: The concern was that an outburst flood could reach downstream villages (Ghapsya village 3.1 miles, Ghap village 3.7 miles, terraced agricultural fields 2.5 miles, 3.7 miles Nepal/Tibet border). The lake drained naturally, with little damage.

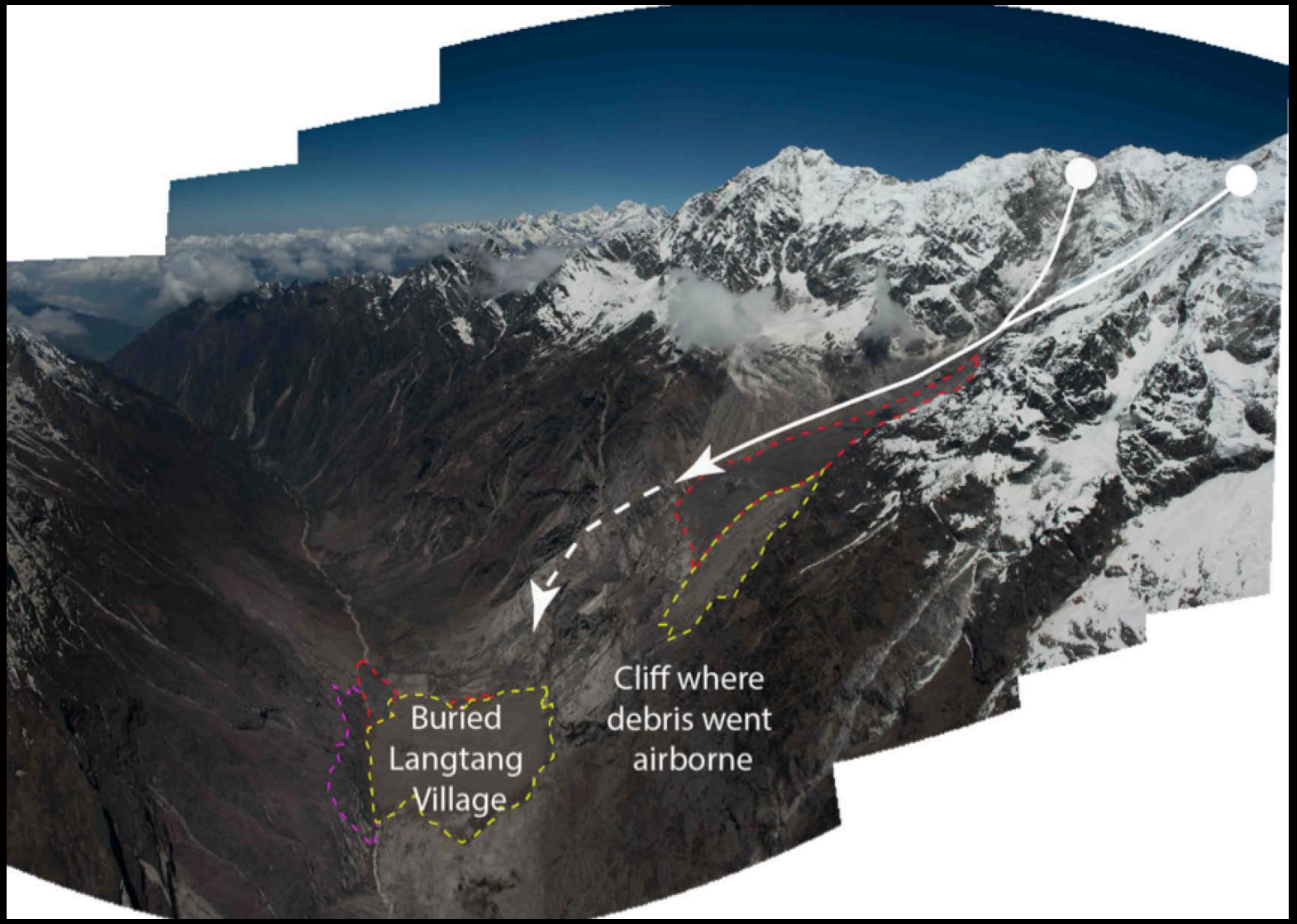
Langtang Valley landslides



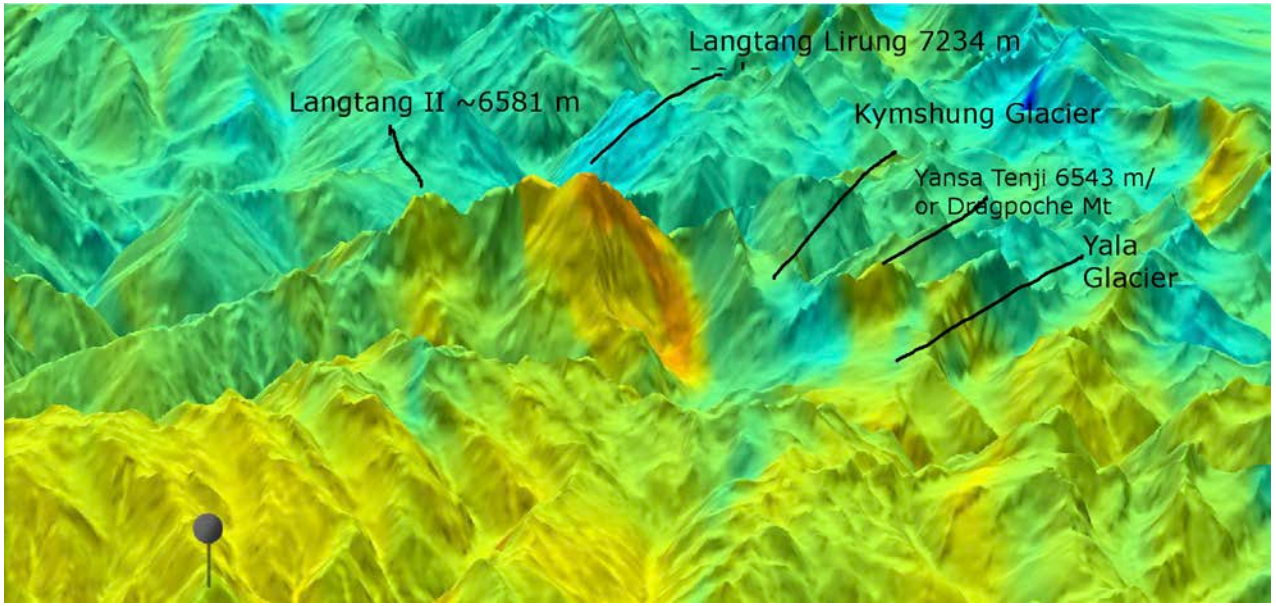
Devastating landslide pathway, Langtang village

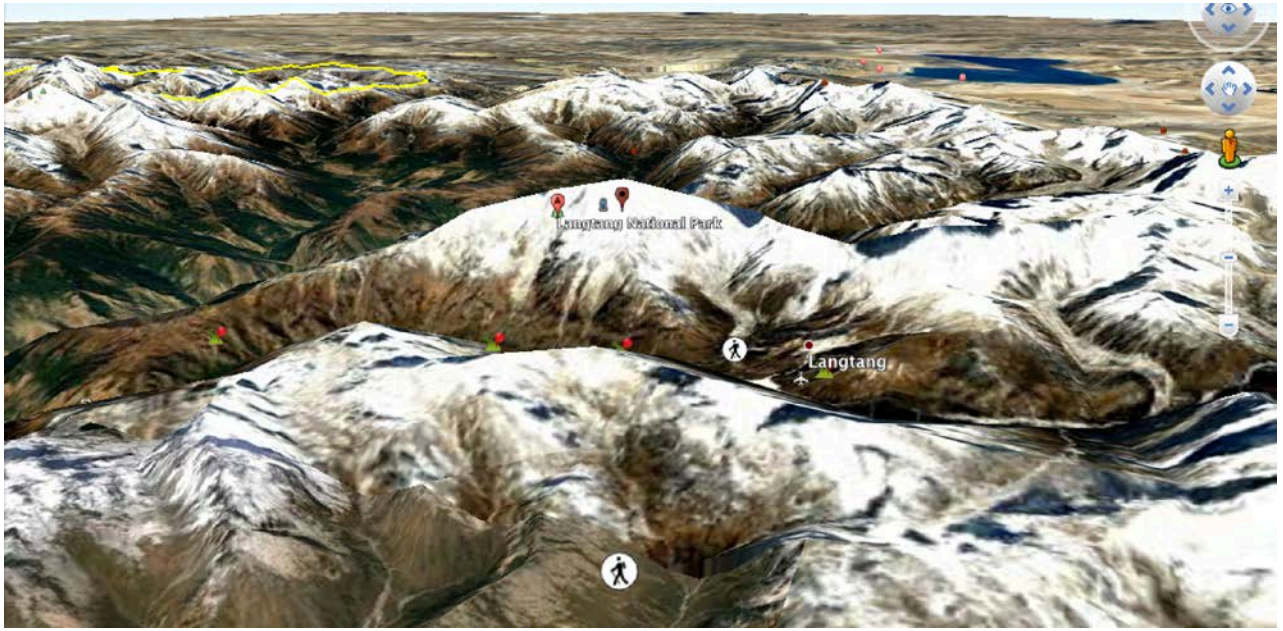
Photos by David Breashears/GlacierWorks, Mosaic by Dan Shugar

In J. Kargel and 63 others, SCIENCE (2016)



Sentinel 1 InSAR displacement, pre- and post-quake





Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Devastating landslide, Langtang village

Photos by David Breashears/GlacierWorks

Before/after image pair

Proximal deposit, Langtang village

Photo by David Breashears/GlacierWorks

Airblast zone, Langtang village

Photo by David Breashears/GlacierWorks

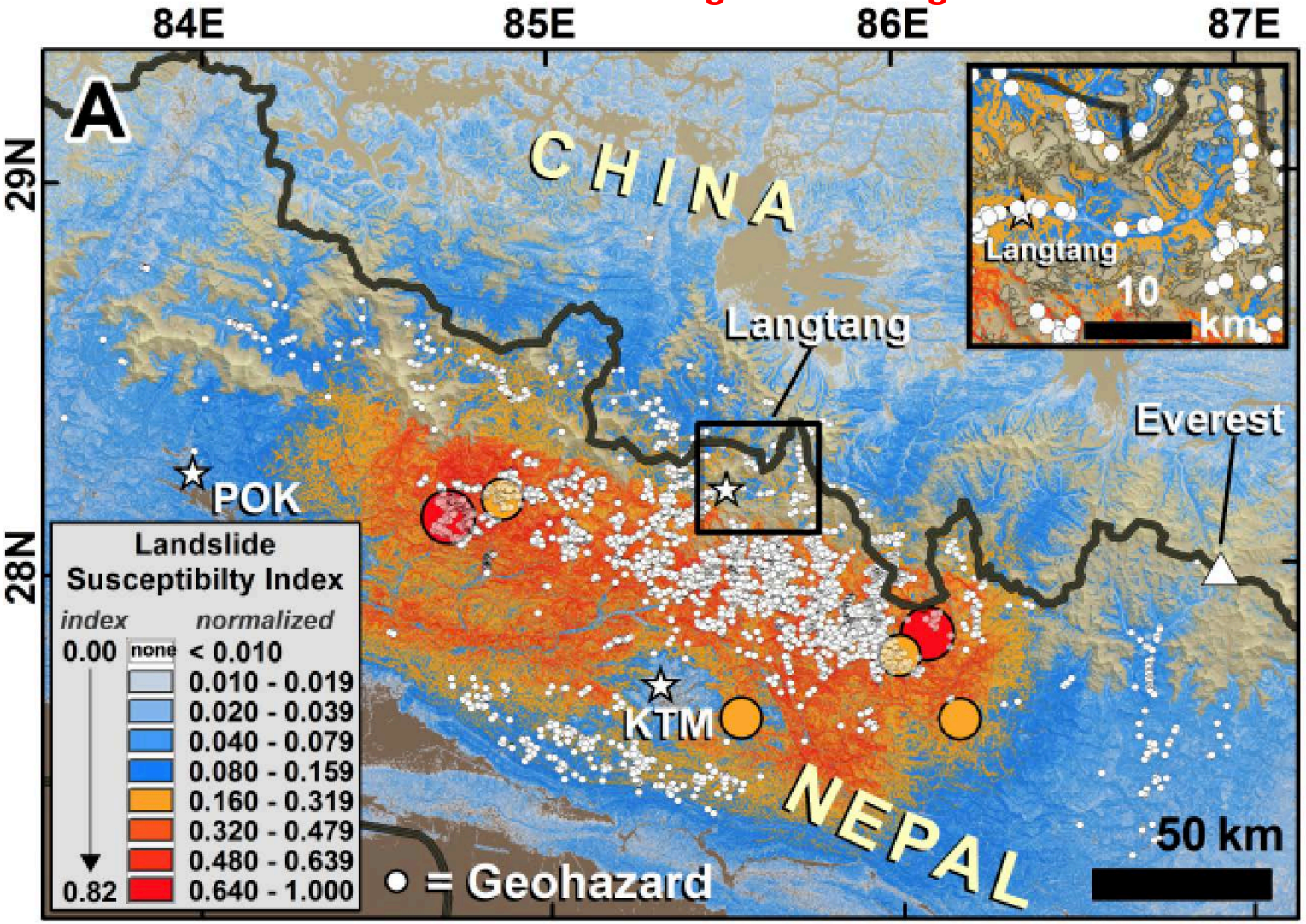
Airblast zone, blown-down forest, Langtang Valley

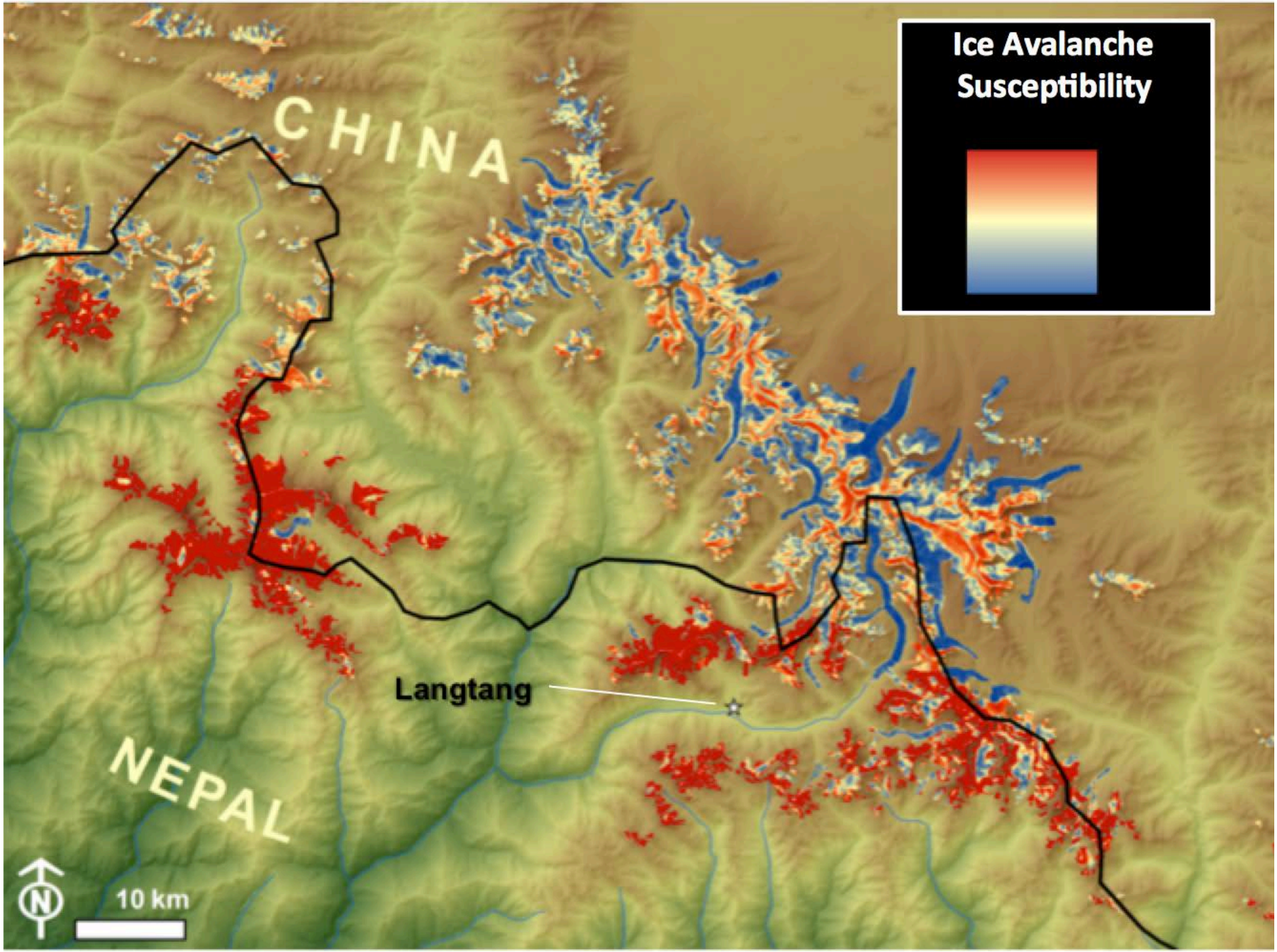
Photo by Randall Jibson/USGS

4312 landslides mapped by a large volunteer team of satellite image analysts (Kargel et al. 2016).

Their distribution is 'bookended' by the primary M7.8 shock and the largest aftershock (M7.3).

98% of landslides occurred where shaking PGA > 0.16 g.




Ice Avalanche Susceptibility
CHINA
Langtang
NEPAL
N
10 km

Glacial lakes show very few effects.
No evidence of seismically and landslide triggered drainage.

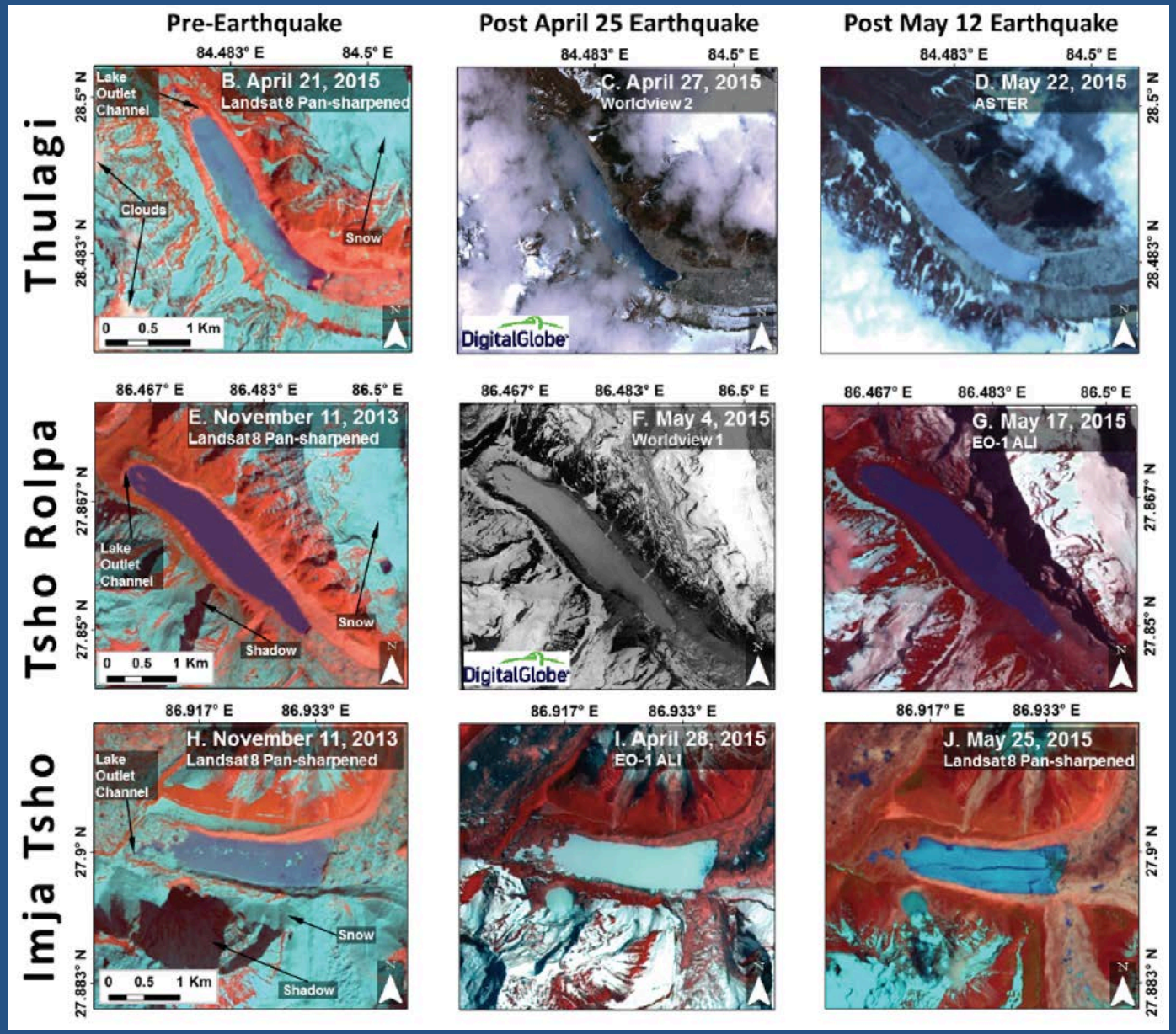
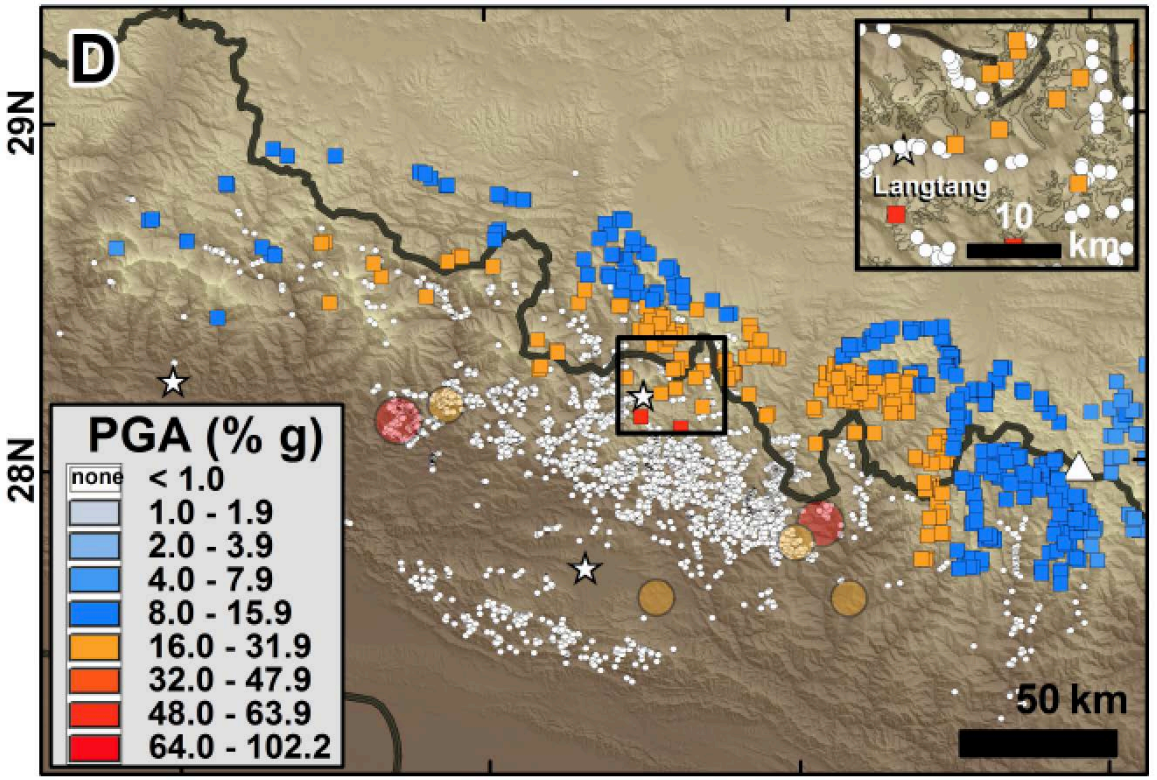
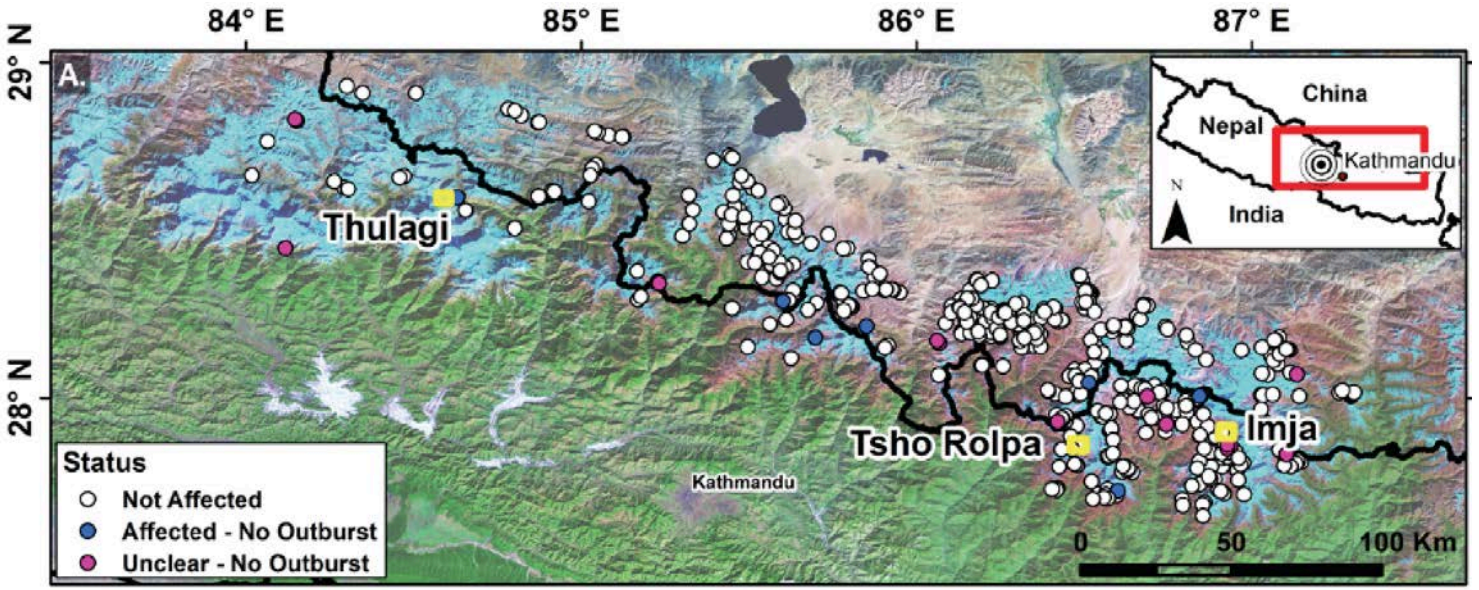


Fig. 12 in Kargel and 63 others, 2016, *SCIENCE*

Detailed systematic survey for damage done by shaking of glacial lakes

-- 491 lakes observed
  -- Koji Fujita/students
  -- Umesh Haritashya/students
-- 9 had some minor rockfalls
-- No lakes experienced
  an observable outburst





Gorkha earthquake effects on glacial lakes

- Prior expectations were that a M7.8 earthquake and M7.3 aftershock situated near glacial lakes would have caused damage and aluviones (glacial lake outburst floods)
- Minor damage (cracking) observed on engineered parts of the Tsho Rolpa moraine dam.
- No aluviones occurred!
- Why?

  -- Fewer landslides than anticipated = fewer potential triggers

  -- Topography shielding (scattering and absorption of seismic waves).

  -- Seismic wave attenuation in valleys
- Number and severity of seismically induced geohazards depend on earthquake details, specific geometry of mountain slopes and glacial lakes relative to the quake epicnter and hypocenter.


Thank you!