MultiHazard Process Chains: Nepal and other hotspots

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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, impacts 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 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)
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)

Enormous ice losses have occurred.

16 ka – 24 ka moraine (Periche I moraine, Finkel et al. 2003)

19th century lateral moraine

19th century ice-cored end moraine

300 m thinning
Imja Growth - Without Annual Fluctuation

\[ Y = M_0 + M_1 x + \ldots + M_8 x^8 + M_9 x^9 \]

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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 dispersion around the curve.
Measurement errors are probably overestimated
### Imja / Amphulapcha Lakes, Nepal: 2014 & 2012 Data

**2014 Total (kayak-mount)**
- Total: 53,878
- Omitted points: (-30,354, -886)
- Kayak validated points: 23,524, 3335

**2014 Total (USV-mount)**
- Total: 9655
- Omitted points: (-1338)
- USV validated points: 8317

**2014 Total (ice bore measure)**
- Total: 61
- Omitted points: (-28)
- Ice bore validated points: 33

**2012 Somos et al. Total (boat-mount)**
- Total: 10,020
- Omitted points: (-854)
- Boat validated points: 9,166

**TOTAL VALIDATED:**
- Total: 41,040
- Kayak validated points: 23,524
- USV validated points: 8317
- Ice bore validated points: 33

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

Map showing debris and ice deposit, Langtang, Mundu, Singdum, Gumba, Kyangjin Ghompa, Langtang Khola, and Supraglacial lake. Legends indicate landslides and deposits, villages, and rivers.
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

Pre-earthquake 2012
Devastating landslide, Langtang village
Photos by David Breashears/GlacierWorks
Before/after image pair

Post-earthquake 2015
Devastating landslide, Langtang village
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Photos by David Breashears/GlacierWorks
Before/after image pair

Post-earthquake 2015
Proximal deposit, 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.
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 epicenter and hypocenter.