Exploiting Synthetic Aperture Radar to map and observe landslides

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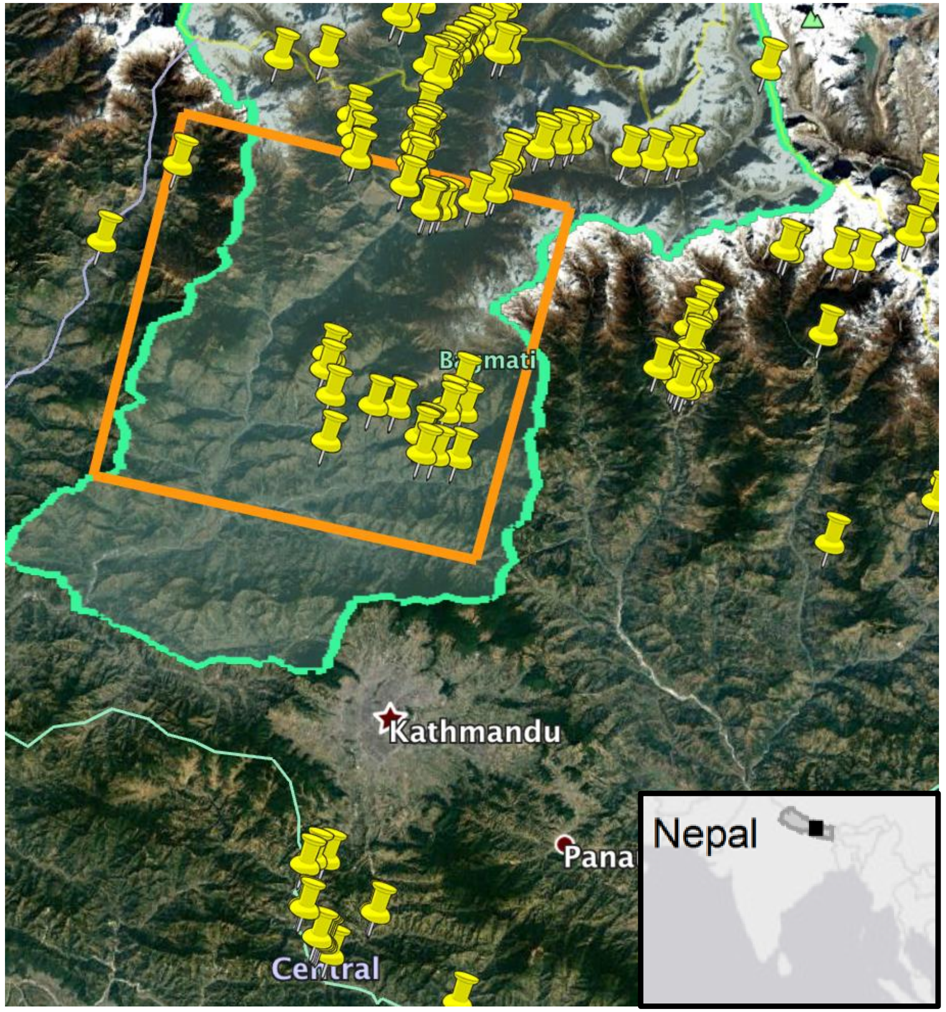
Landslides impacting road-corridors

- Thousands of people are impacted each year by landslides
- Poorly designed roads are more prone to landslides
- Local economies are highly vulnerable to inaccessible road networks

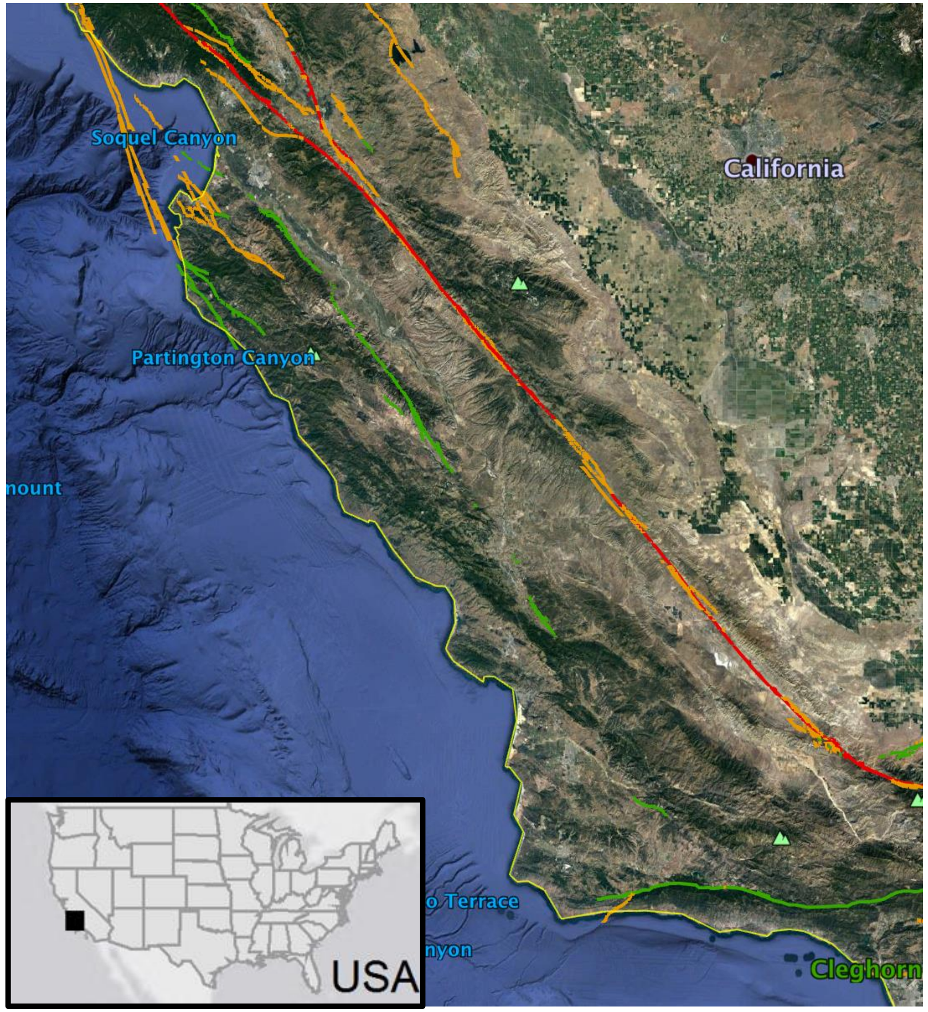
Improved understanding on causes & correlation with physical processes requires dense spatio-temporal landslide catalogues

Landslide mapping study areas

Trishuli highway in Nepal



California Pacific Highway-1



Detection of Landslides using Synthetic Aperture Radar

1. SAR change detection *(amplitude/intensity), InSAR (coherence)* — **Example: Nepal**

- SAR resolution (+ coherence estimation window) <-> landslide spatial extent
- Thresholding
- Separate false positives (scattering change e.g. precip, snow, EQ etc.)

- Critical failure (surface no longer preserved)

2. *Pixel/feature offset tracking* — **Example: USA**

- Needs preserved surface features
- SAR resolution and correlation window <-> landslide spatial extent

- Fast moving slides (rates > 10^{th} of SAR pixel size)

3. Time-series InSAR — **Examples: Nepal and USA**

- Only sensitive to Line of Sight motion
- SAR resolution <-> landslide spatial extent

- Slow moving slides (i.e. non-aliased rate)

All sensitive to:

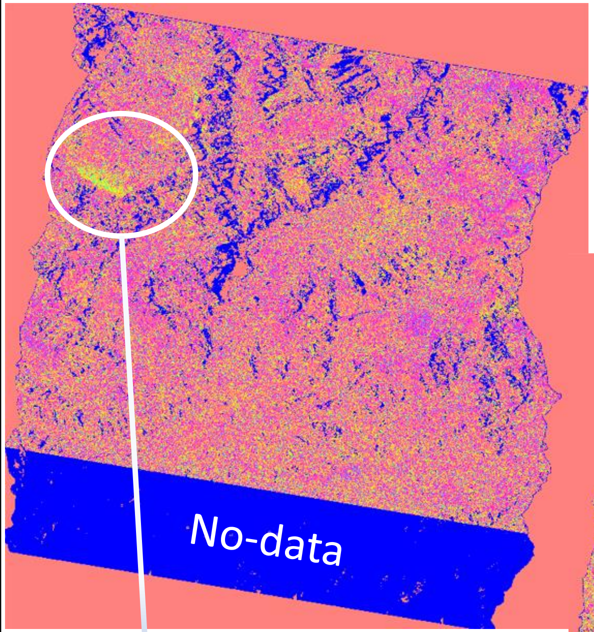
- Geometry (shadow and layover)
- Noise (snow, vegetation, precip., atmos.)

1. Change Detection InSAR

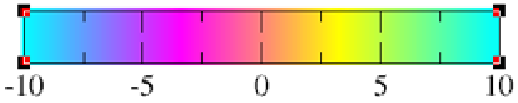
Critical failure (surface no longer preserved)

Coherence-Index (April-November)

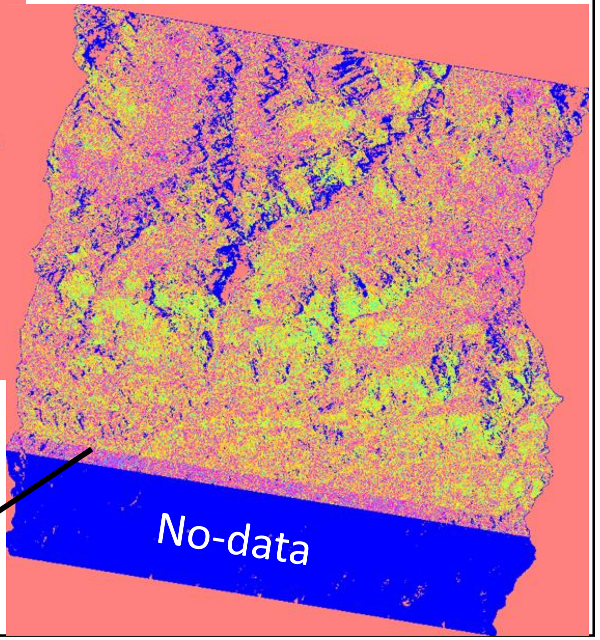
7-19-31 Oct 2014



$10 \log 10 \left(\frac{coh1}{coh2}\right)$



5-17-29 Apr 2015

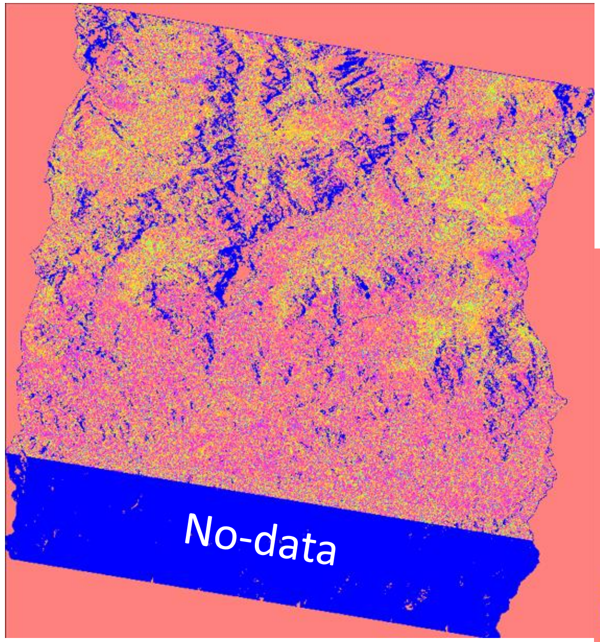


Snow?

How to separate from Gorka EQ on 25 Apr 2015?

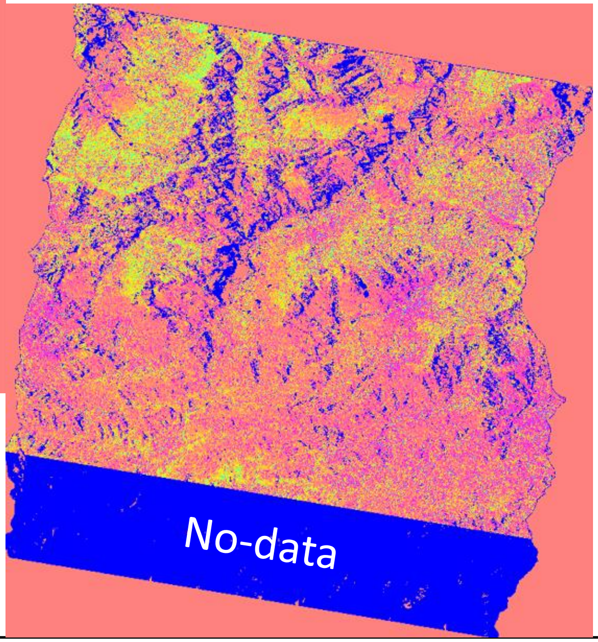
Coherence-Index (Winter/spring)

19-31 Oct, 12 Nov 2014



decorrelation for winter images

19-31 Dec 2016, 12 Jan 2017



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2. Feature/pixel offset tracking

Fast moving slides

Needs preserved surface features

Requires motion >10% of pixel size

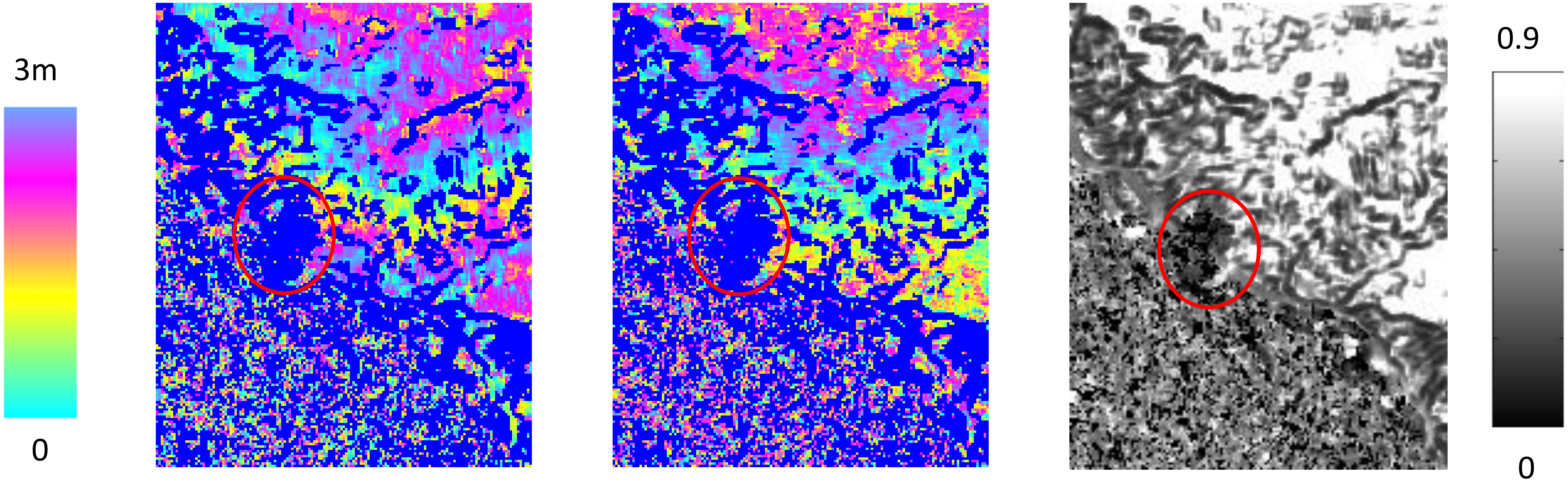
CA Mudcreek landslide (20 May 2017)

PRE (2017-05-16)

POST (2017-05-31)

Data accessible for free under Planet's Open California Initiative

Pixel offsets



Y-direction

X-direction

Correlation

- Landslide completely decorrelated after failure
- Correlation of 0.7-0.8 at least needed for reliable estimates
- Orthorectification artifacts also visible in the offset estimates

Detection of Landslides using Synthetic Aperture Radar

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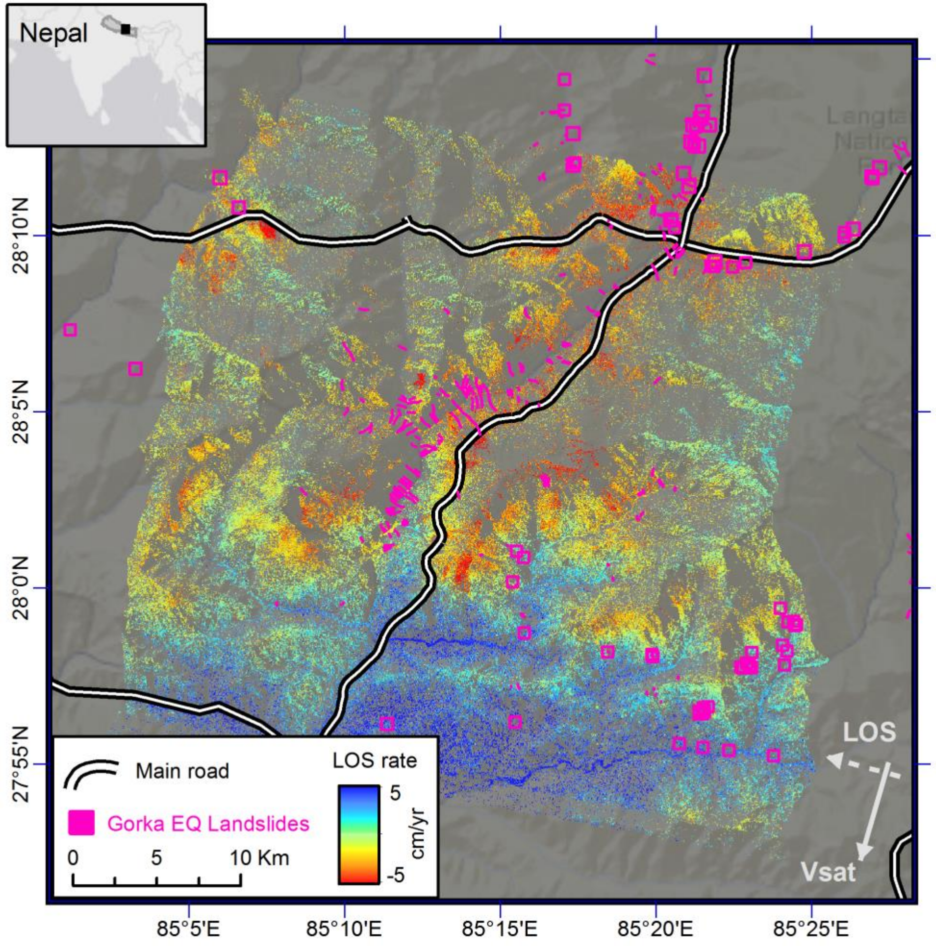
Regional rate maps are difficult to interpret

3. Time-series InSAR

Techniques include: PSI, PS, SBAS, SqueeSAR etc.

- Radar geometry leading to pixel distortion
  - Layover and shadowing effects

- Atmospheric noise
  - Long wavelength spatially varying (>20km)
  - Short spatial wavelength turbulent (<2km)
  - Topography correlated (local)
  - Noise more apparent away from InSAR reference
- Tectonic deformation
  - Interseismic, Coseismic, Postseismic, Afterslip
- Anthropogenic deformation
- DEM errors introduced in processing



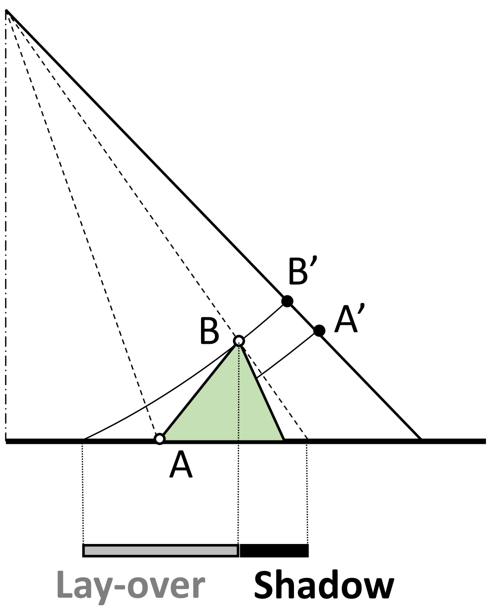
How to handle Radar Geometry?

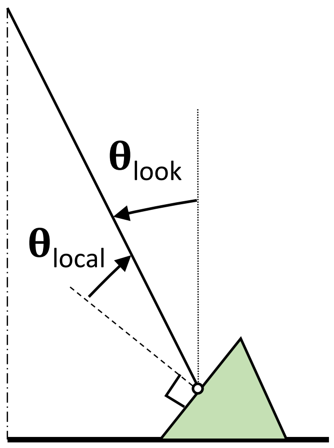
Mask out pixels that have radar distortion:

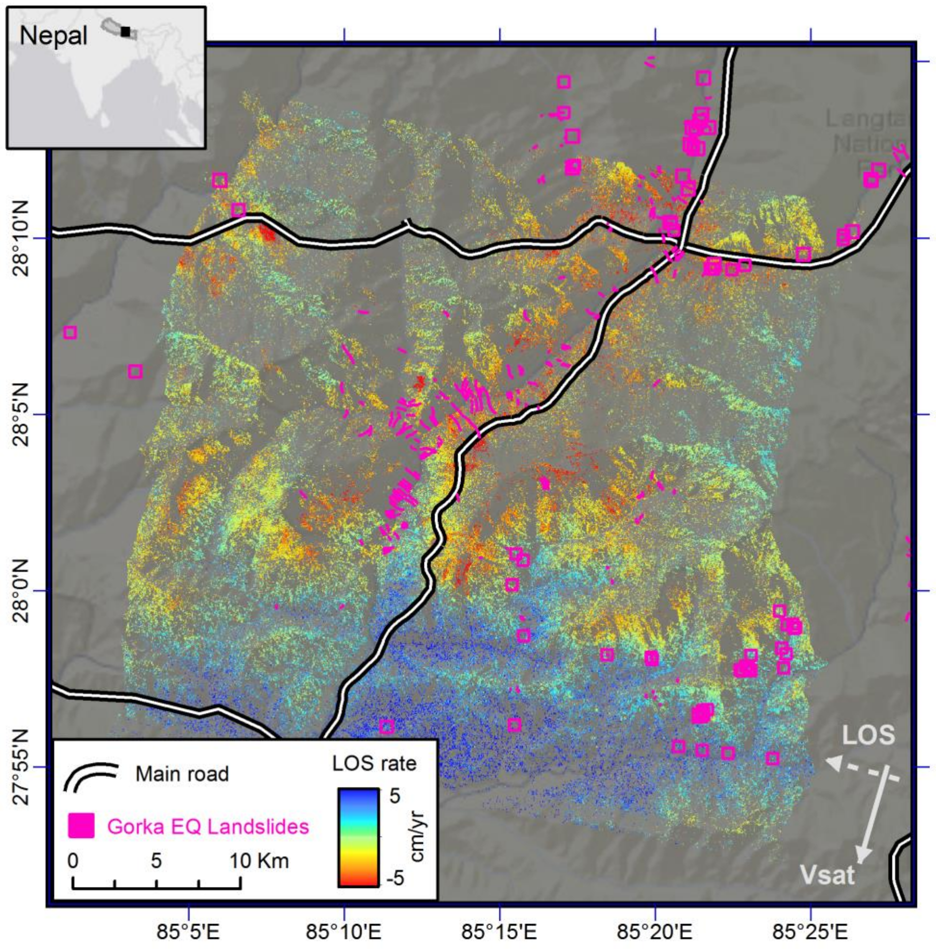
- Shadowing (Feature that does not get illuminated by the radar)
- Lay-over (Top of a feature is received before the base of the feature)

Mask out pixels on flat terrain & slopes insensitive to the radar

- Remove pixels for which $|\theta_{look} - \theta_{local}| < 5°$

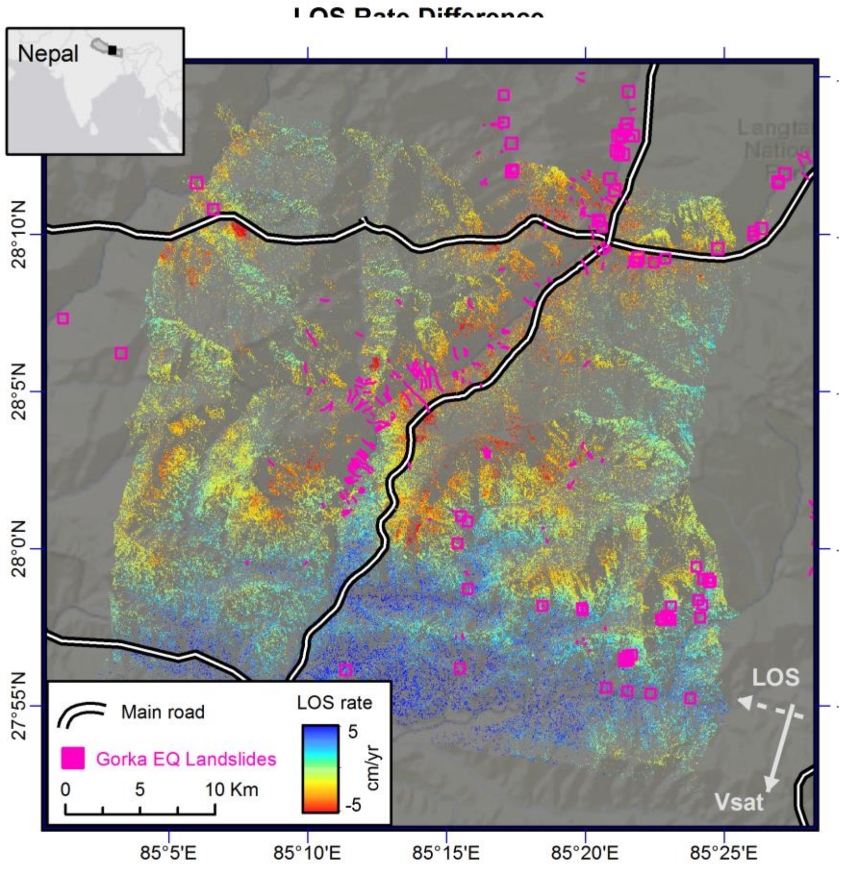


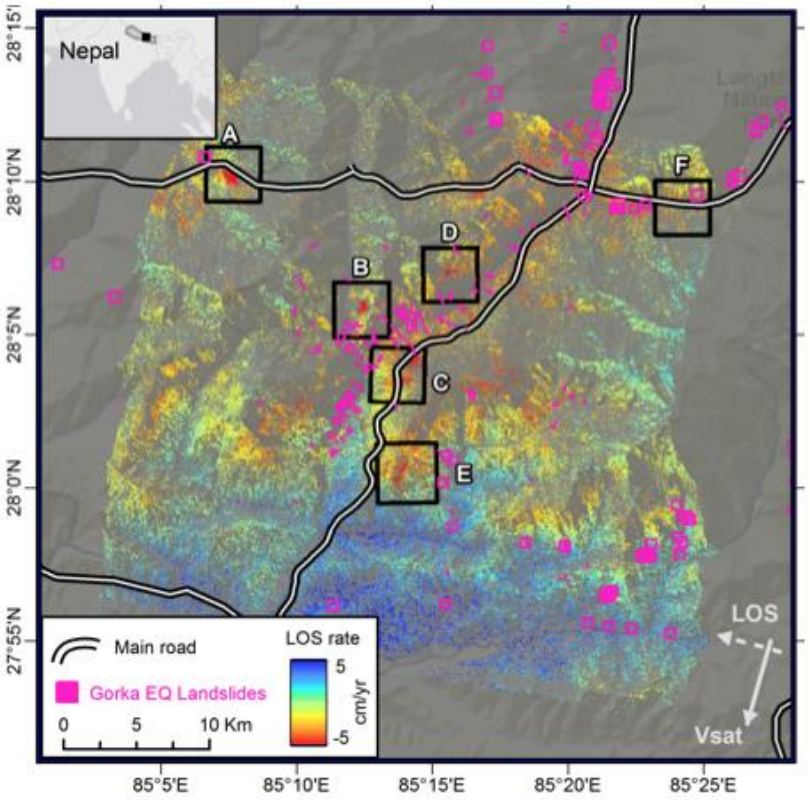


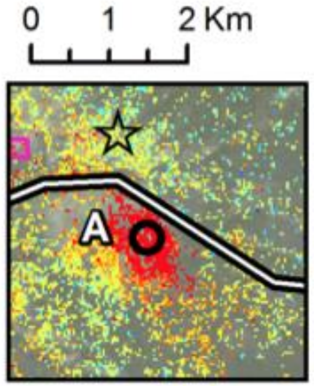


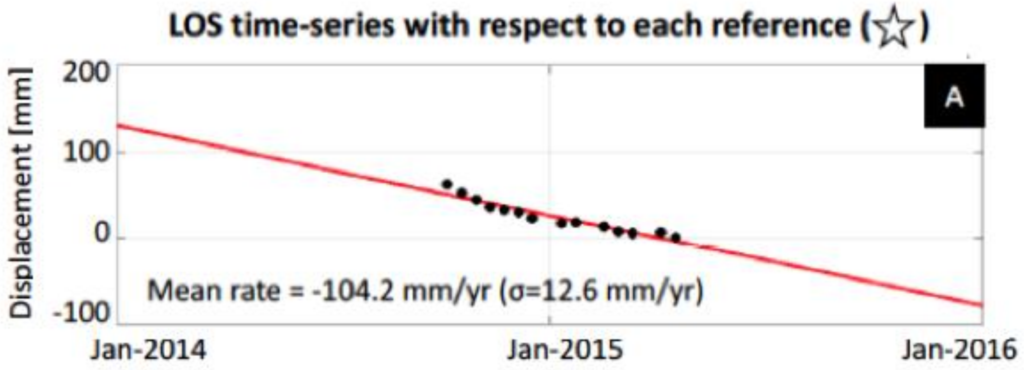
How to distinct noise sources from landslide?

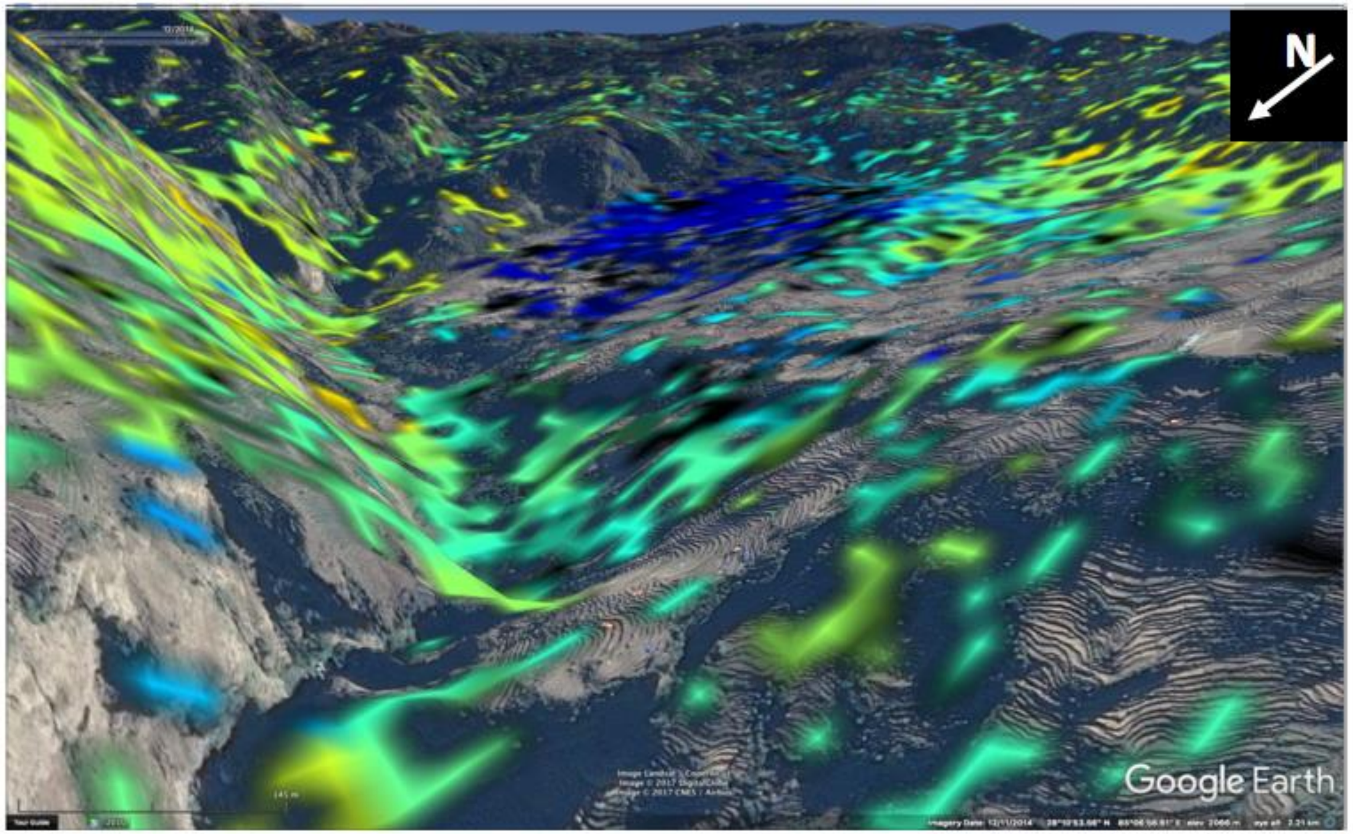
Local double differences cancels out longer wavelength noise signals   -> DETECTOR

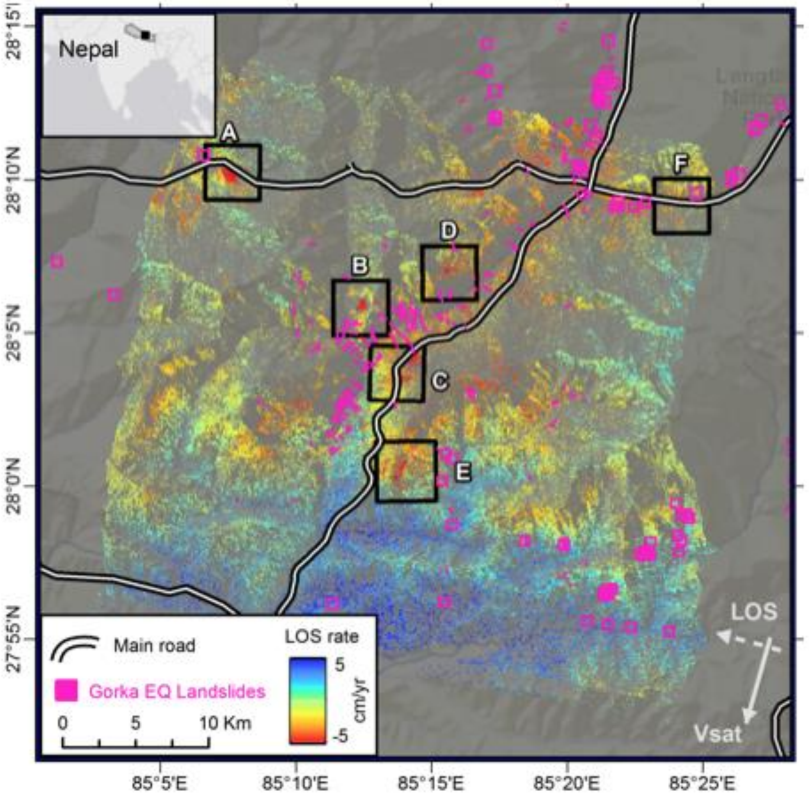



Nepal
A
B
C
D
E
F
28°15'N
28°10'N
28°5'N
28°0'N
27°55'N
85°5'E
85°10'E
85°15'E
85°20'E
85°25'E
Main road
Gorka EQ Landslides
0 5 10 Km
LOS rate
5
-5
cm/yr
LOS
Vsat


0 1 2 Km
A


LOS time-series with respect to each reference (☆)
A
Displacement [mm]
200
100
0
-100
Mean rate = -104.2 mm/yr (σ=12.6 mm/yr)
Jan-2014
Jan-2015
Jan-2016


N
Google Earth


Nepal
A
B
C
D
E
F
28°15'N
28°10'N
28°5'N
28°0'N
27°55'N
85°5'E
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85°15'E
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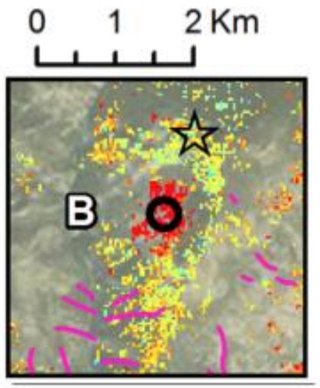
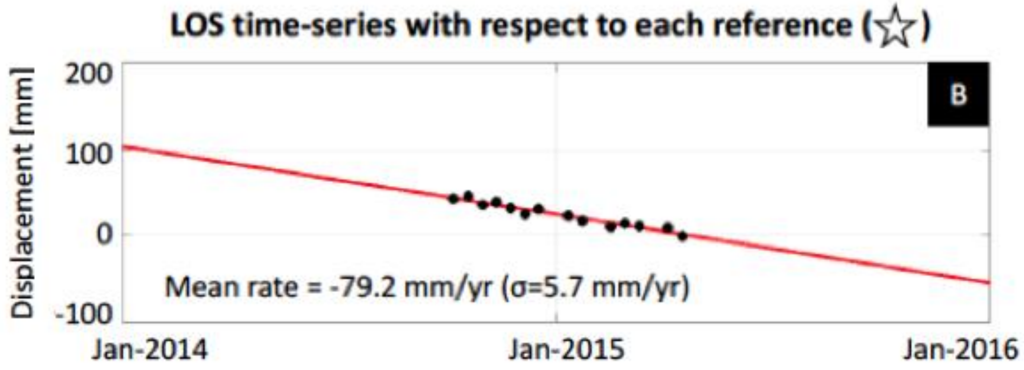
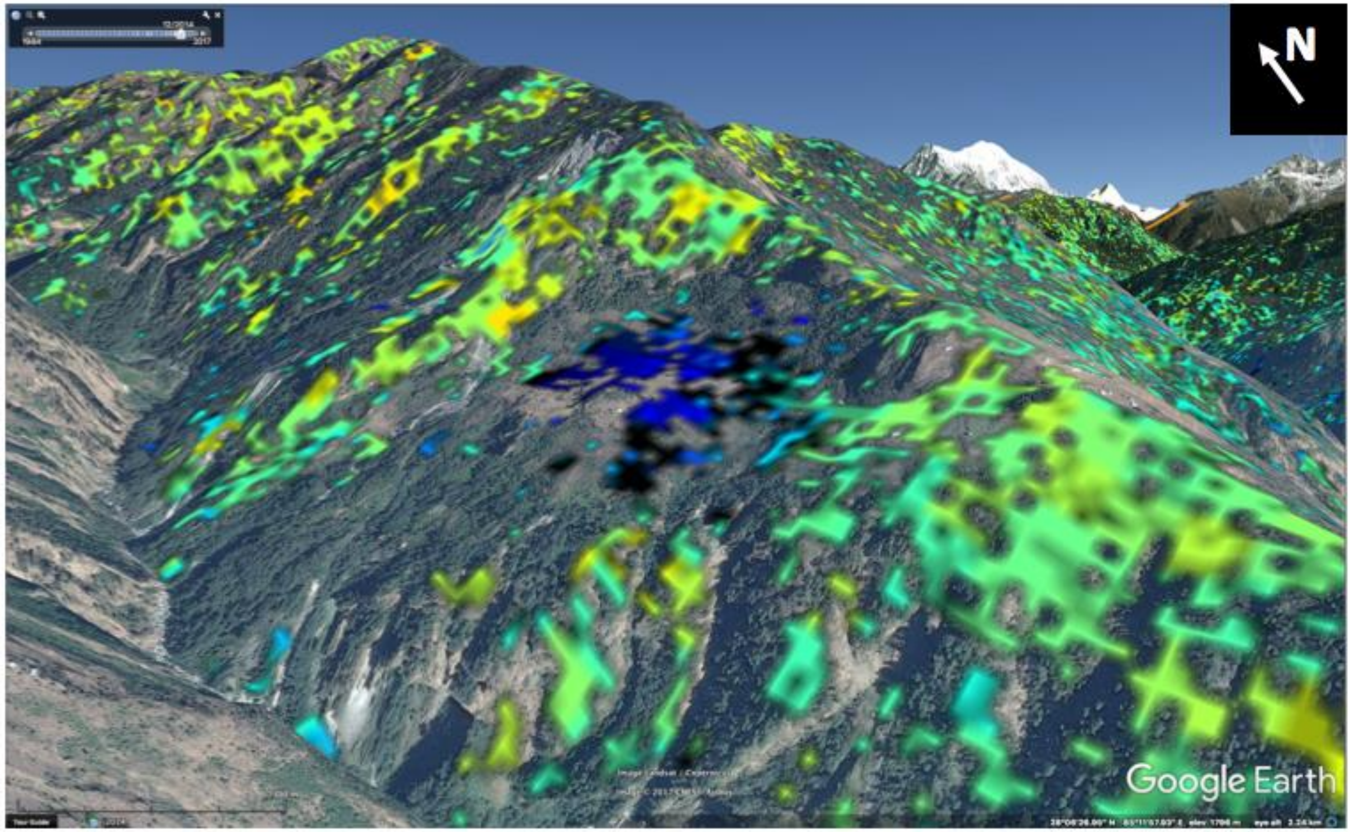
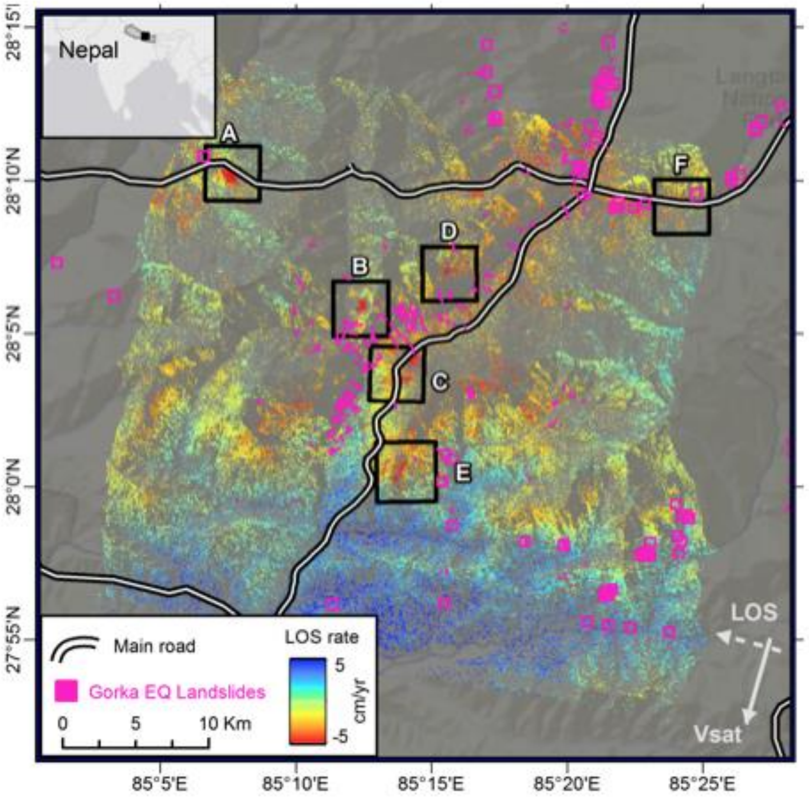

0 1 2 Km
B


LOS time-series with respect to each reference (☆)
B
Displacement [mm]
200
100
0
-100
Mean rate = -79.2 mm/yr (σ=5.7 mm/yr)
Jan-2014
Jan-2015
Jan-2016


N
Google Earth


Nepal
A
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28°15'N
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Main road
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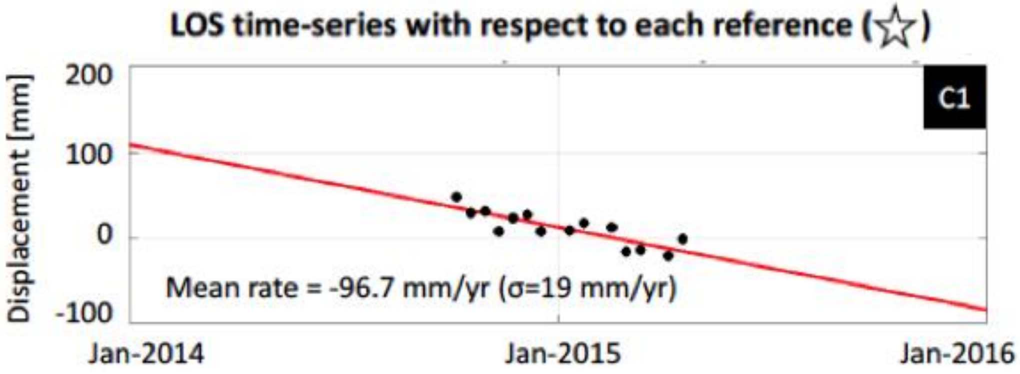
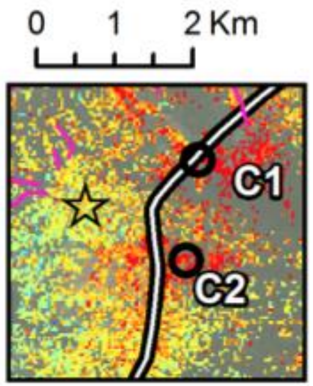
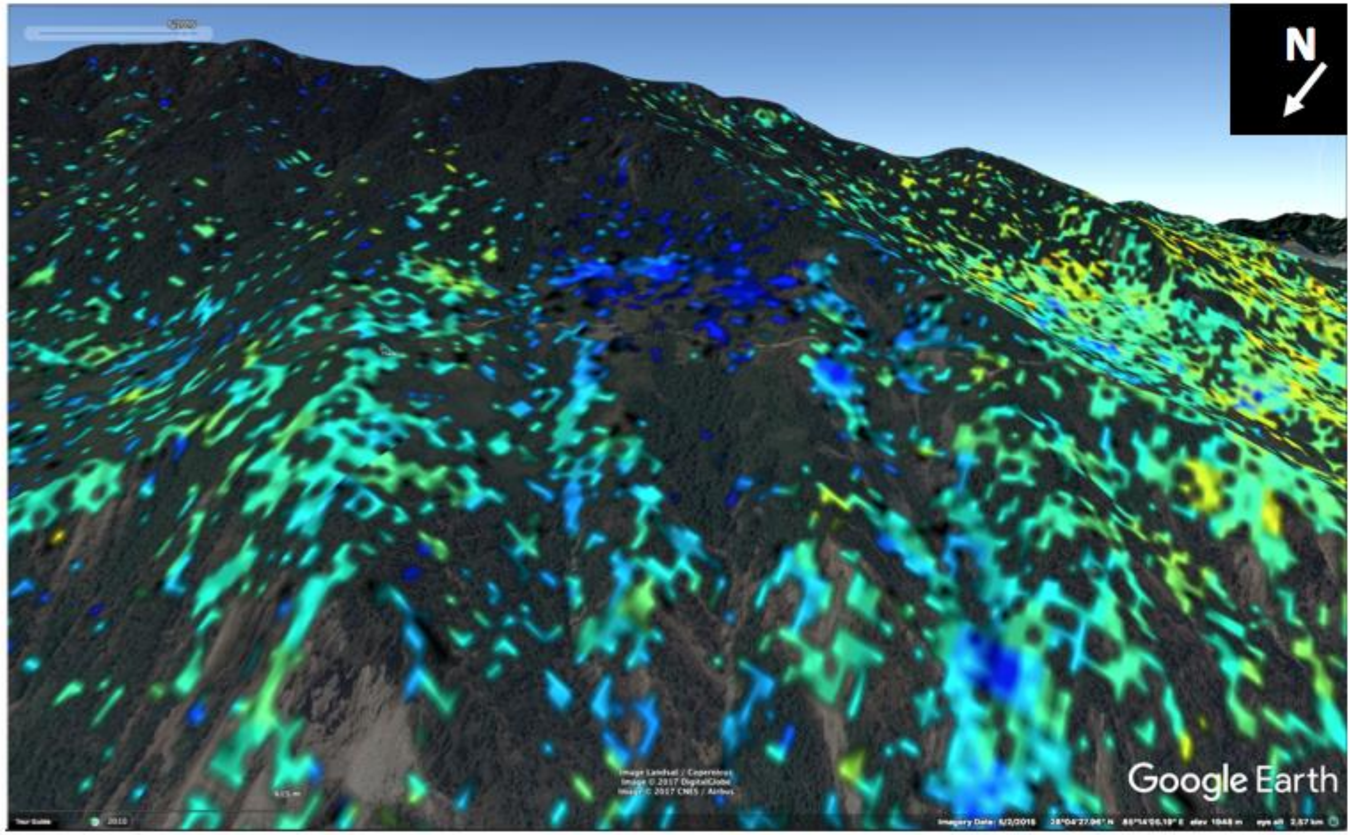
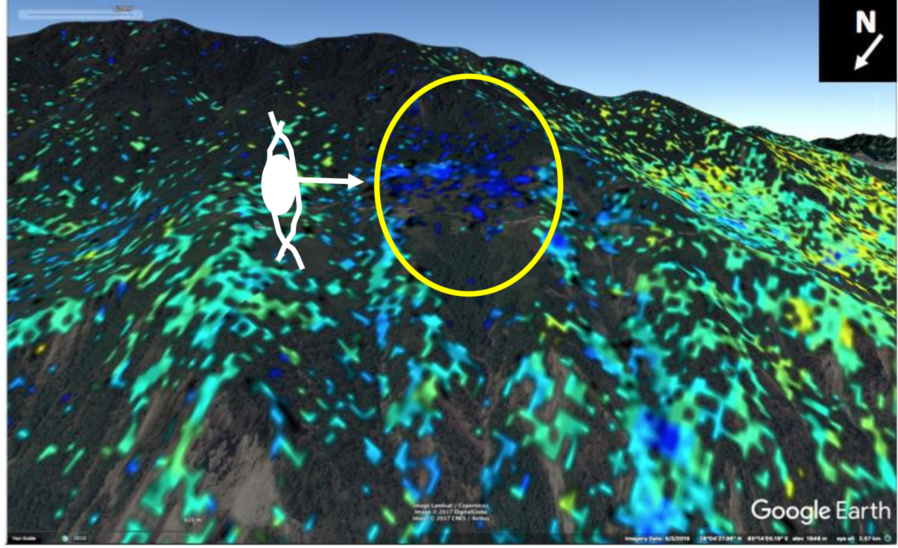
LOS
Vsat


LOS time-series with respect to each reference (☆)
C1
Displacement [mm]
200
100
0
-100
Mean rate = -96.7 mm/yr (σ=19 mm/yr)
Jan-2014
Jan-2015
Jan-2016

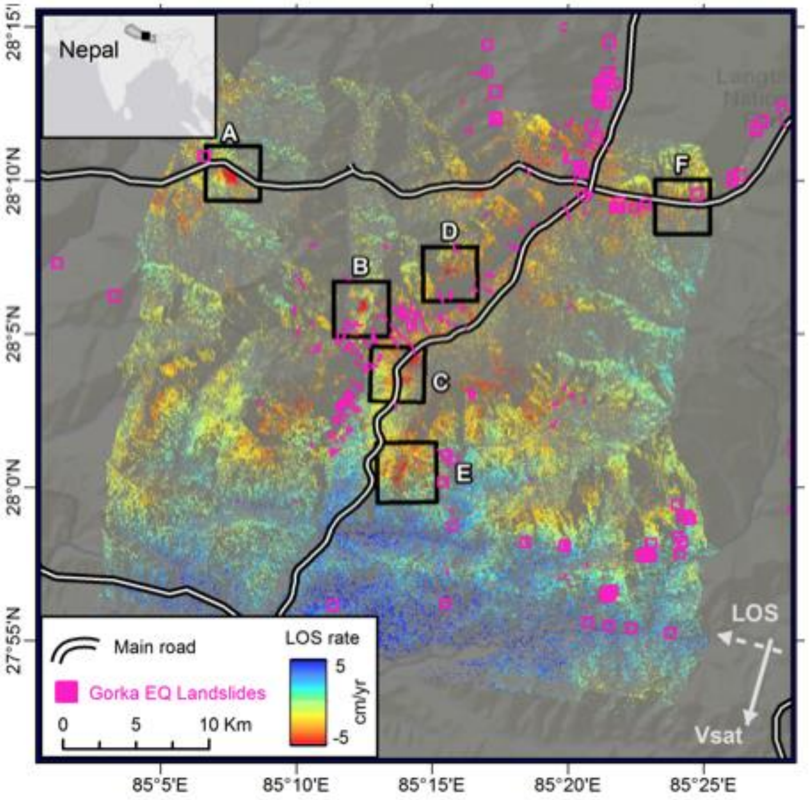

0 1 2 Km
C1
C2


N
Google Earth


N


N
Google Earth


N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A
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28°10'N
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Main road
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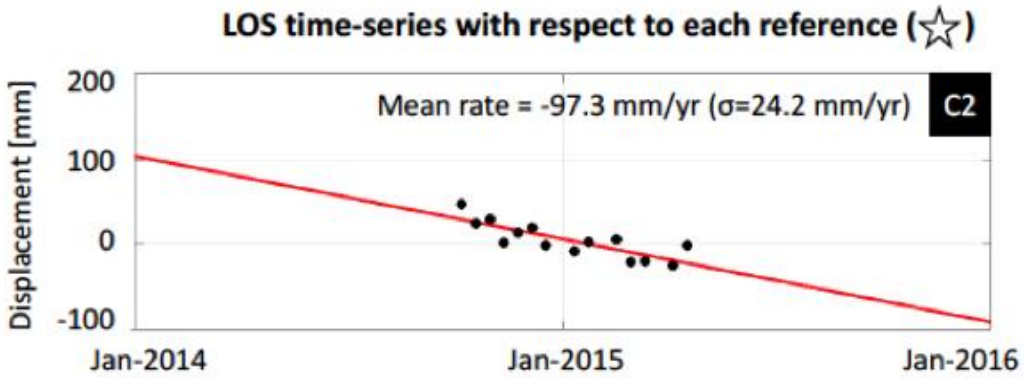
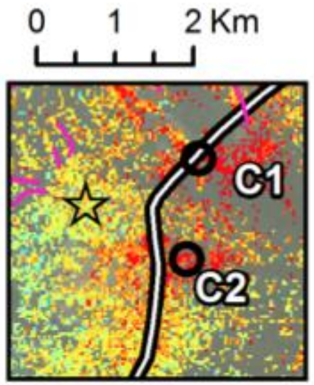
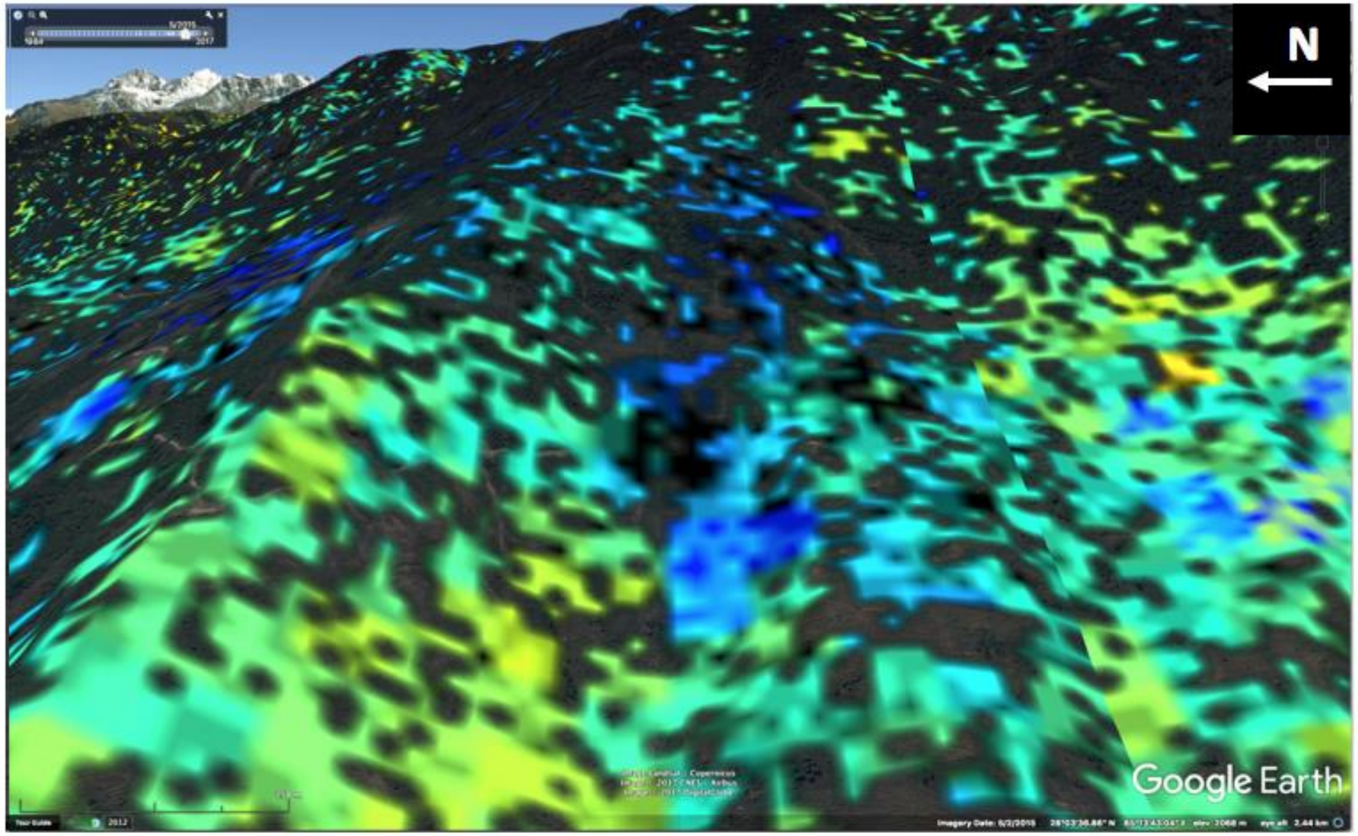
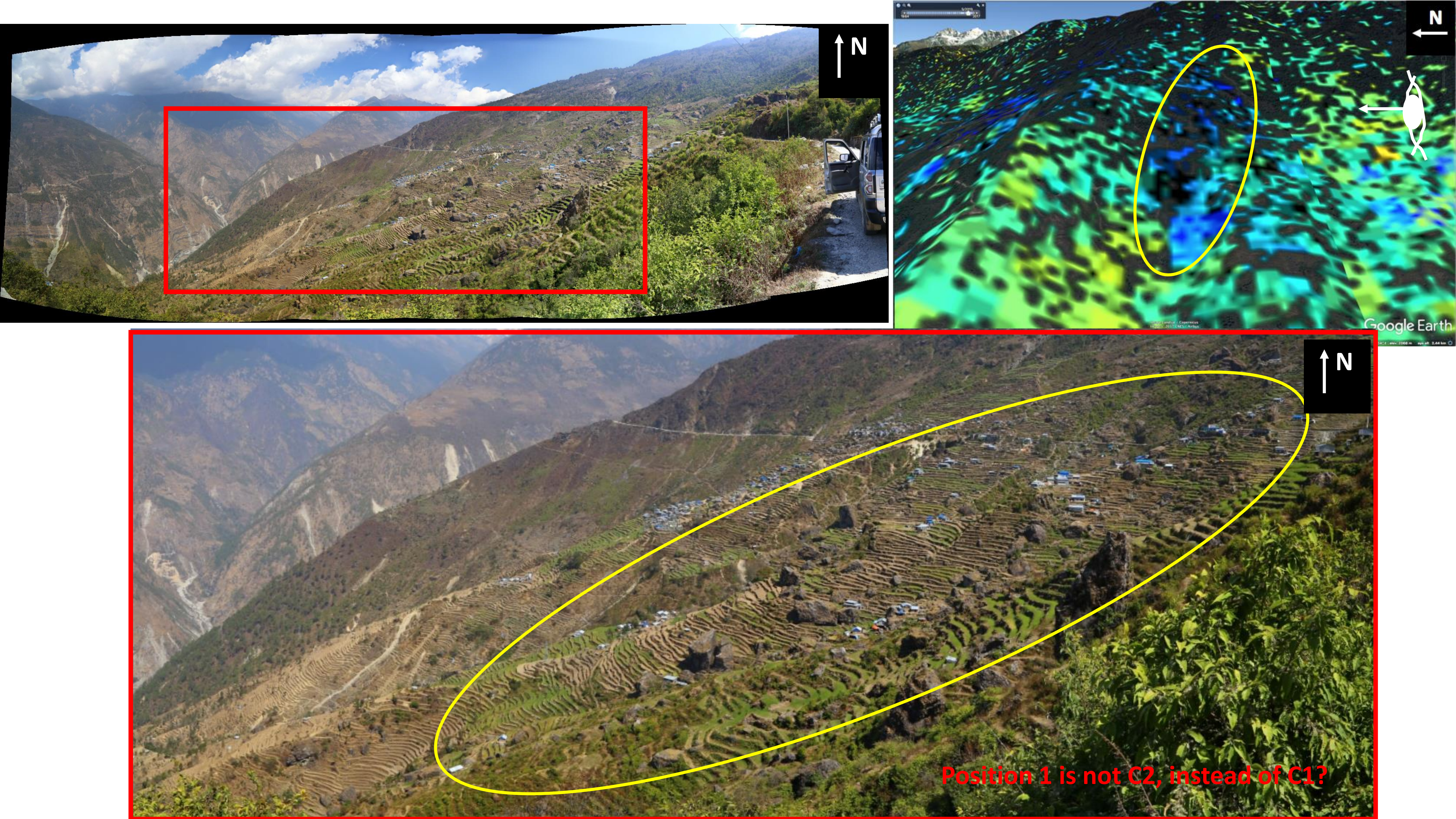
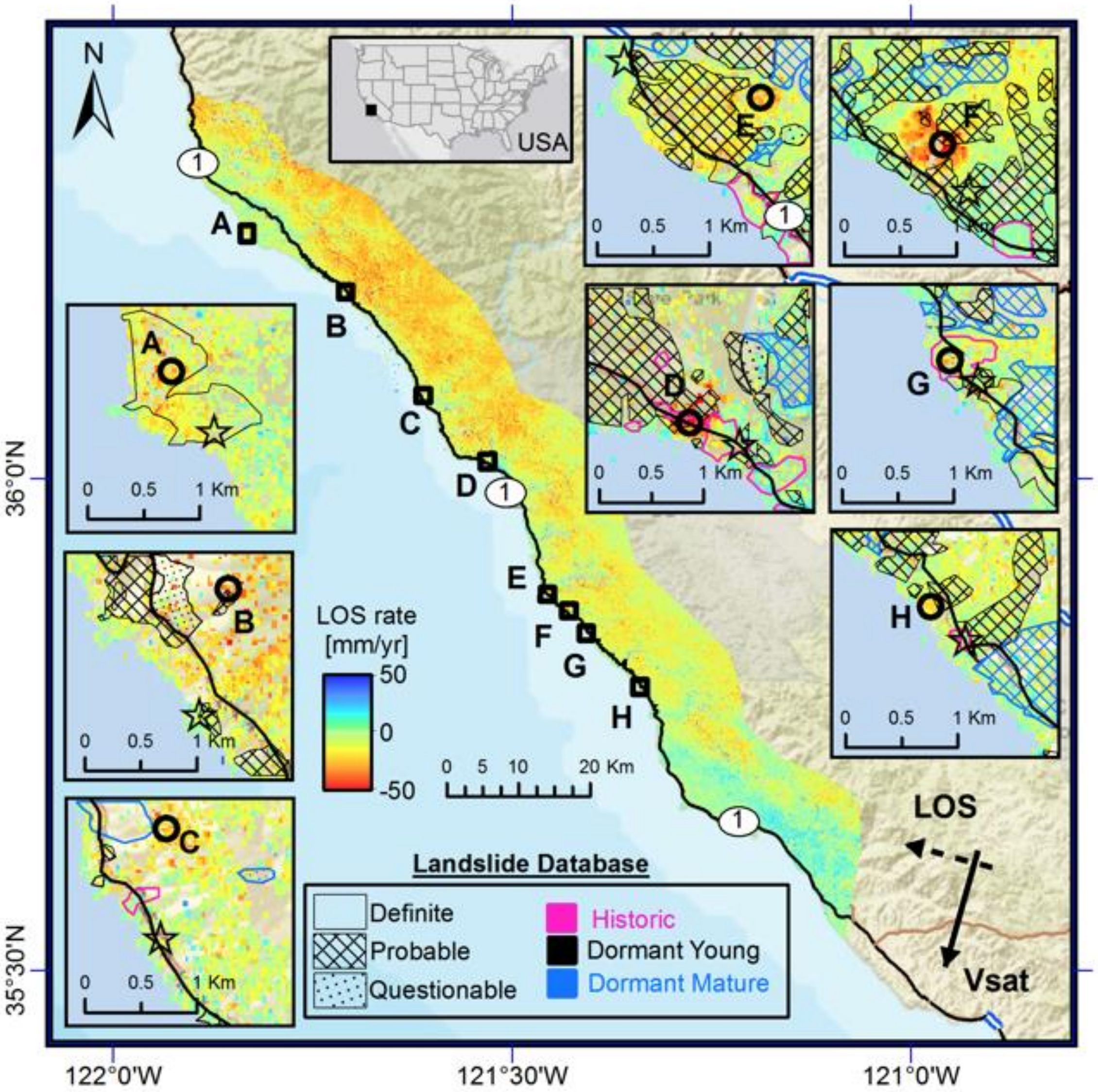

LOS time-series with respect to each reference (☆)
Mean rate = -97.3 mm/yr (σ=24.2 mm/yr)
C2
Displacement [mm]
200
100
0
-100
Jan-2014
Jan-2015
Jan-2016

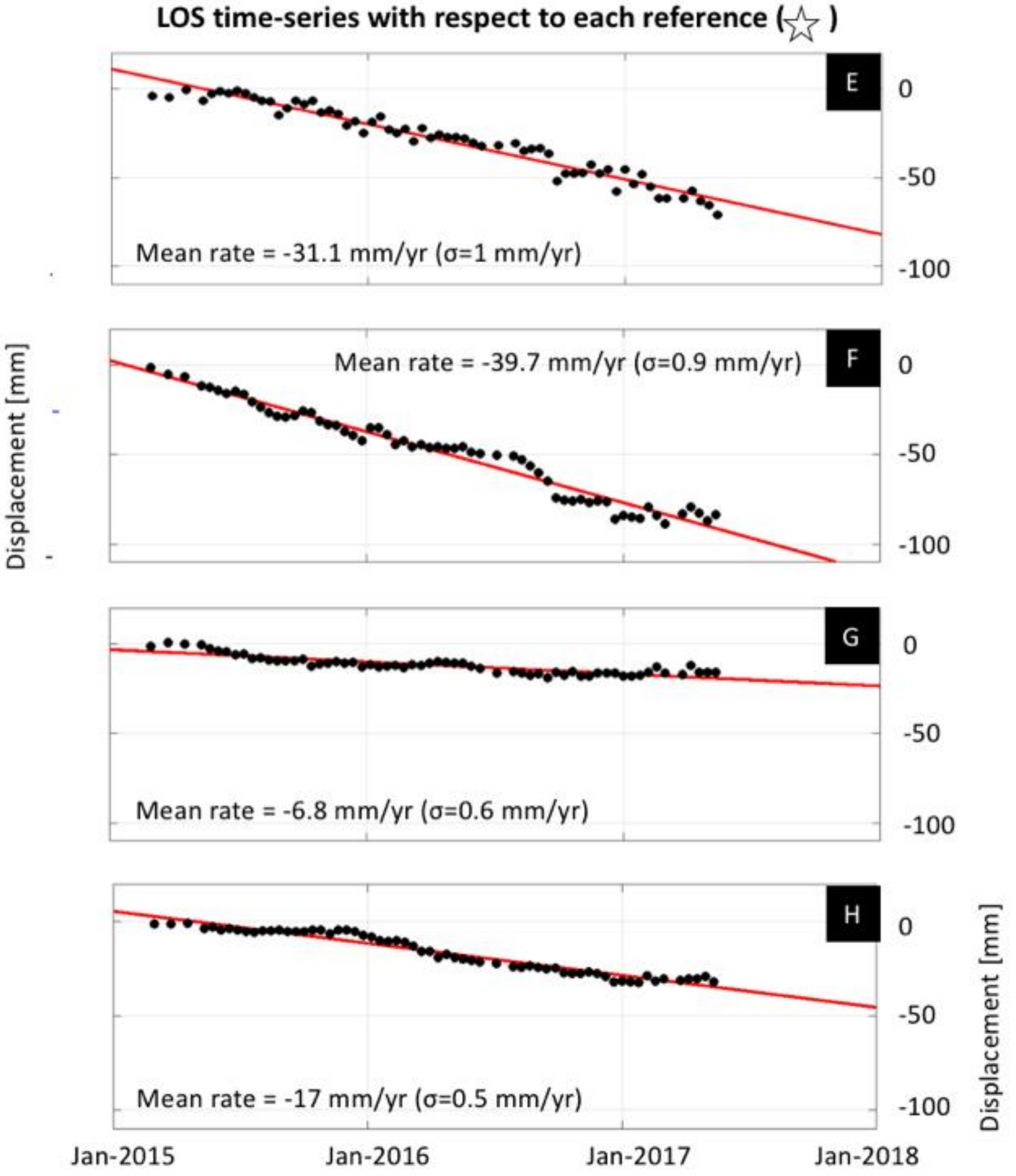

0 1 2 Km
C1
C2


N
Google Earth


N
N
Google Earth
N
Position 1 is not C2, instead of C1?

CA Sentinel-1 InSAR time-series





Sentinel-1 available for free under Copernicus program

Summary

- SAR data can be used in a variety of ways to map landslides
- Detection success rate for SAR strongly related to:
  - Sensor resolution
  - Landslide orientation vs satellite acquisition geometry
  - Scattering changed from snow, precip, vegetation
- There is not a one-fit all SAR technique towards landslide mapping
  - Fast moving landslides
  - Slow moving landslides
  - Critical failure landslides
- Time-series InSAR capable of mapping slowly moving slides
  - Local detector successfully applied on regional processing to identity slowly moving landslide area's from superimposed noise sources

Jet Propulsion Laboratory
California Institute of Technology