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Presentation · September 2021

DOI: 10.13140/RG.2.2.31237.68321

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Characterizing spatio-temporal patterns of ground subsidence as an indicator of permafrost thaw in Tso Kar valley, Ladakh using SAR remote sensing

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ICIMOD Crosphere Forum 2021

Outline of presentation

- Brief introduction and background
- Study area
- Initial Results
- Concluding Remarks and Steps Forward

What is permafrost?

Permafrost is a subsurface earth region below 0°C for two consecutive years. It is considered to be perennially frozen (for many years).

Permafrost classification:

- Continuous: If 90-100 %
- Discontinuous: 50-90 %
- Sporadic: 10-50 %
- Isolated: 0-10%

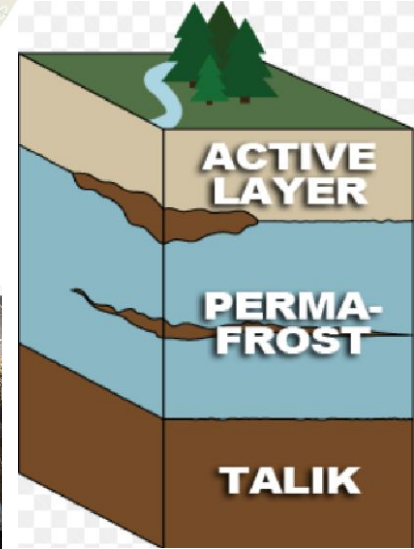
Based on how much of the underlying landscape is permafrost.

Active Layer

Ice-wedges

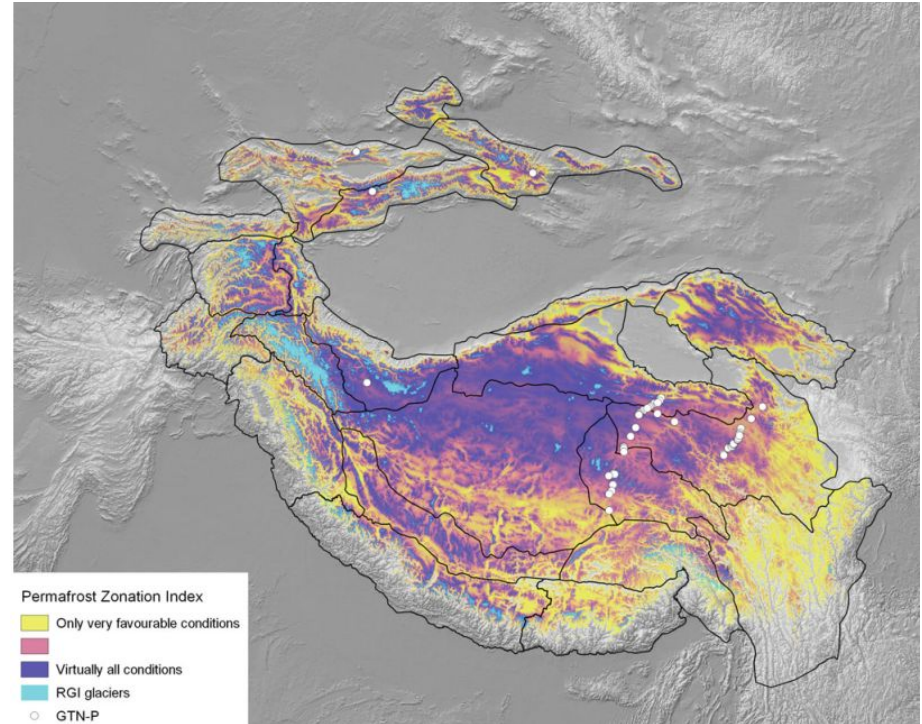


Figure 1. Latitudinal zonation of permafrost. Source: Brown and colleagues (1998).

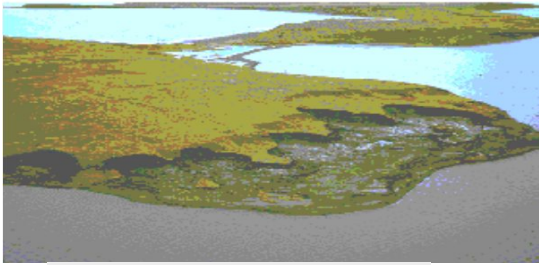


Permafrost in the HKH region

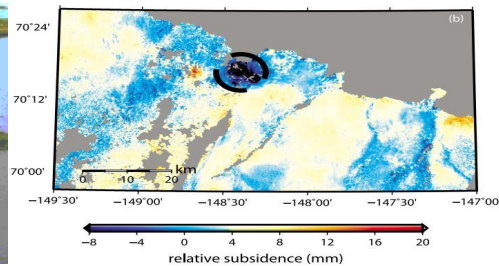
- Middle & Central Asia - largest area of mountain permafrost. (*A.P Gorbunov 1978*)
- Heterogeneity in mountain permafrost region (*Etzelmüller 2013*)
- Major drivers of Climate change in HKH (*The HKH Assessment 2019*)
 - Globalization
 - Infrastructure development
 - Migration
 - Tourism
- Scarce data collections in HKH (*Rastogi & Narayan 1999; Gruber et al 2017; Shiraiwa 1992; Klimeš and Doležal 2010*)



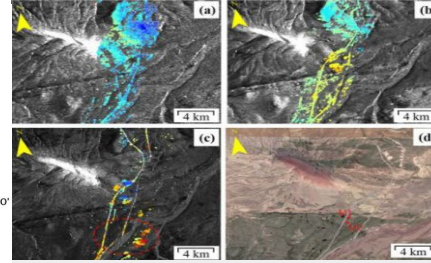
Remote Sensing for Permafrost



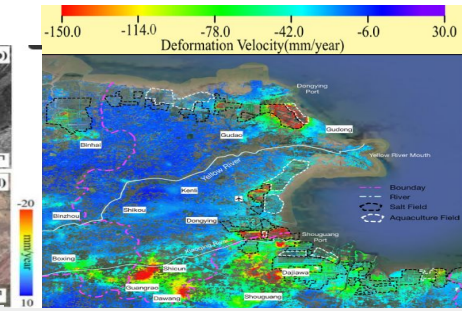
Bylot Island,
Canada ^a



North Slope of
Alaska ^b



Beiluhe region ^c



Vertical subsidence
near river delta ^c

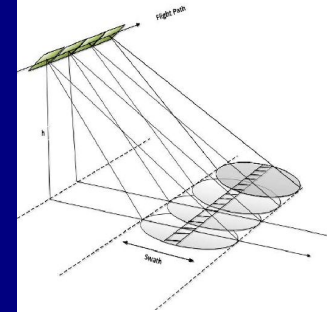
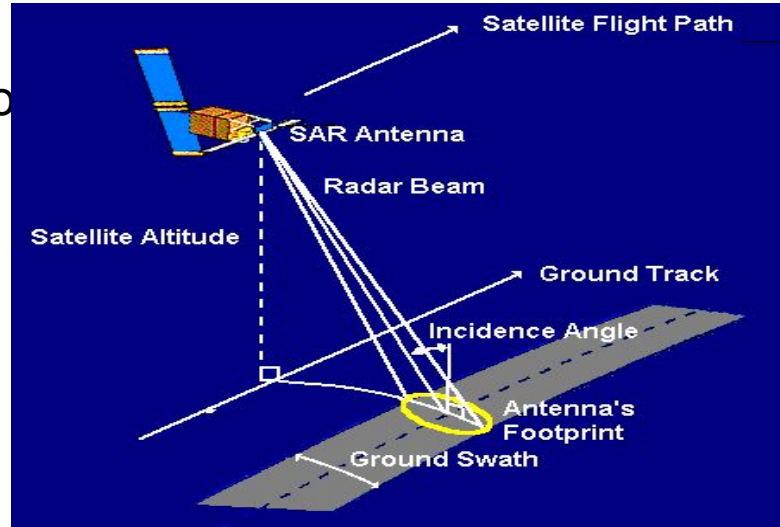
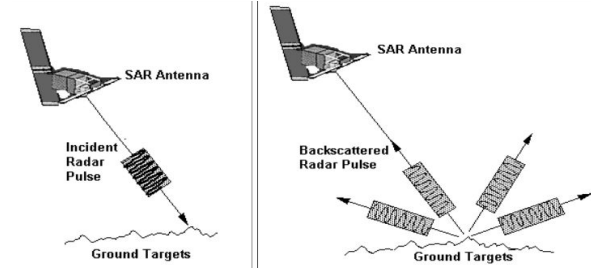
a. Vachon, Paris W., et al. "Measurement of land subsidence due to wasting of tabular massive ground ice using differential JERS-1 SAR interferometry: Bylot Island test site." *JERS-1 Science Program 99* (1997): 27-31.

b. Liu, Lin, Tingjun Zhang, and John Wahr. "InSAR measurements of surface deformation over permafrost on the North Slope of Alaska." *Journal of Geophysical Research: Earth Surface* 115.F3 (2010).

c. Zhang, Z.; Wang, M.; Wu, Z.; Liu, X. Permafrost Deformation Monitoring Along the Qinghai-Tibet Plateau Engineering Corridor Using InSAR Observations with Multi-Sensor SAR Datasets from 1997–2018. *Sensors* **2019**, *19*, 5306. <https://doi.org/10.3390/s19235306>

How SAR Interferometry works

- EM waves (microwaves) are emitted through the source which are backscattered due to topography. These waves are captured by the sensor.
- SAR produces fine-resolution images owing to its working principle. A sequence of acquisitions from a shorter antenna are combined to simulate a much larger antenna, thus providing higher resolution data.



SAR- Synthetic Aperture Radar

SAR interferometry in mapping permafrost subsidence

- Phase: Number of cycles of oscillation between two points (satellite and ground).
- Phase as a measurement of distance.

Measured phase difference:

$$\Delta\phi = -\frac{2\pi}{\lambda}\delta\rho$$

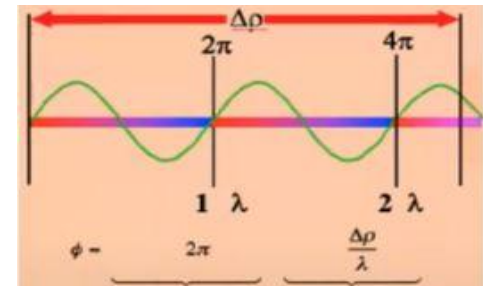
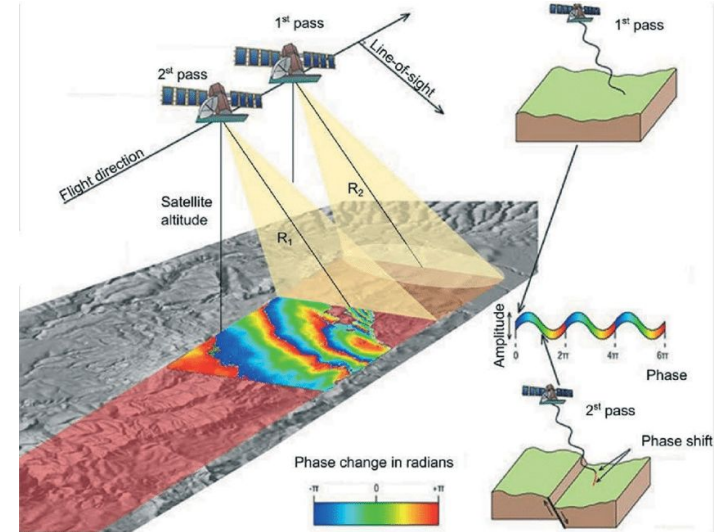
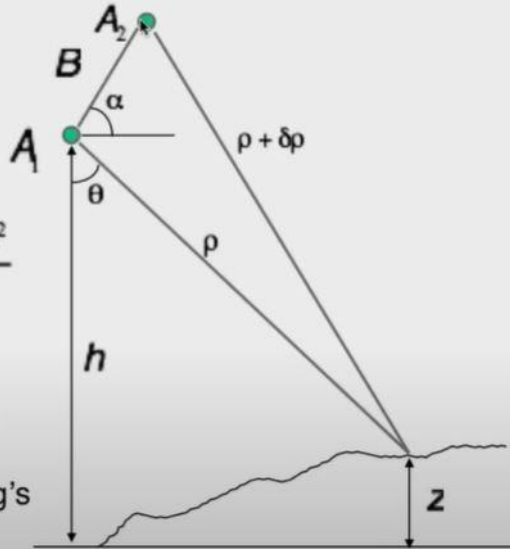
Triangulation:

$$\sin(\theta - \alpha) = \frac{(\rho + \delta\rho)^2 - \rho^2 - B^2}{2\rho B}$$

$$z = h - \rho \cos\theta$$

Critical Interferometer Knowledge:

- Baseline, ($B\alpha$) to mm's
- System phase differences, to deg's



Radians per wavelength

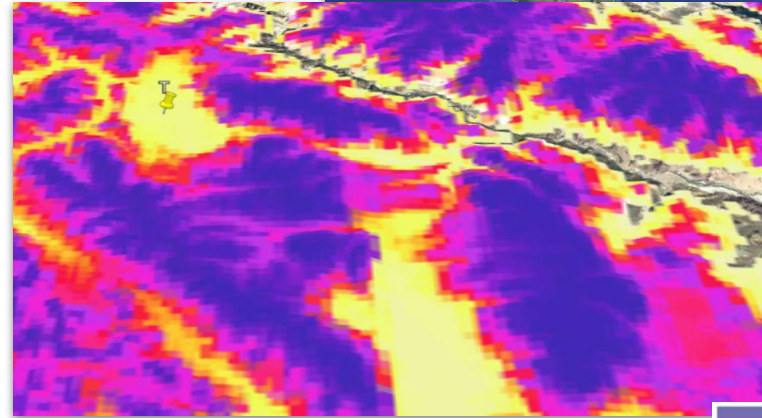
Number of wavelengths

Objectives of the Study

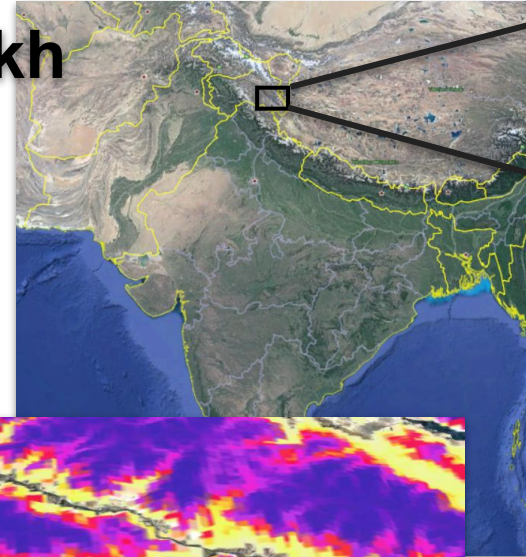
- Map land subsidence as a consequence of permafrost thaw using SAR interferometry.
- Quantify variation of land subsidence intra and interannual during a period of 2015 - 2021
- Investigate relationships between climatic parameters such as land surface temperature, precipitation with rate of change in land subsidence.

Study Area: Tso Kar in Ladakh

- Tso Kar Area, 33.31° N, 77.99° E, Ladakh, India
- Permafrost classification: Discontinuous
- Elevation: 3000 - 6500 m.a.s.l
- Areal span : 3160 sq km



Blue: In nearly all conditions
Yellow: Only in favourable conditions



"The Climate Data Guide: Global Permafrost Zonation Index Map." Retrieved from <https://climatedataguide.ucar.edu/climate-data/global-permafrost-zonation-index-map>.

SAR Data Processing workflow in SNAP

The screenshot displays the SNAP (Sentinel Applications Platform) interface with several key components highlighted:

- Products Menu:** A tree view on the left showing a list of SAR products, including metadata, vector data, and various SAR data files like 'Intensity_IW1_VV' and 'Phase_IW1_VV'.
- Image viewer:** The main central window displaying a SAR image of a mountainous region.
- Graph Builder:** A window for creating processing graphs, showing 'Read' and 'Write' buttons and a 'Source Product' dropdown menu.
- World View:** A satellite map at the bottom left showing the geographical context of the SAR data, with labels for regions like 'Kabul', 'Peshawar', and 'Srinagar'.

The interface also includes a top menu bar (File, Edit, View, Analysis, Layer, Vector, Raster, Optical, Radar, Tools, Window, Help), a toolbar with various processing tools, and a 'Pin Manager' window at the bottom.

<https://scihub.copernicus.eu/>

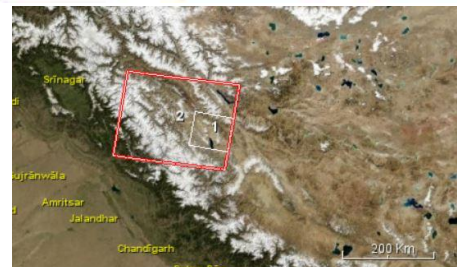
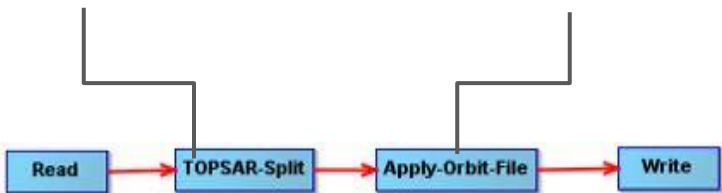
SAR Data Processing workflow in SNAP

Selection of region of interest

Satellite Velocity and position

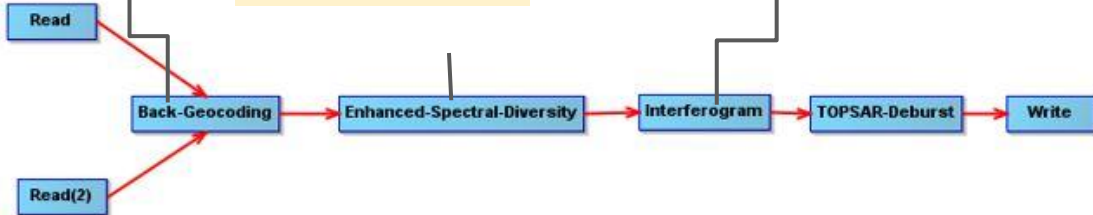
DEM generation

Creation of Interferogram

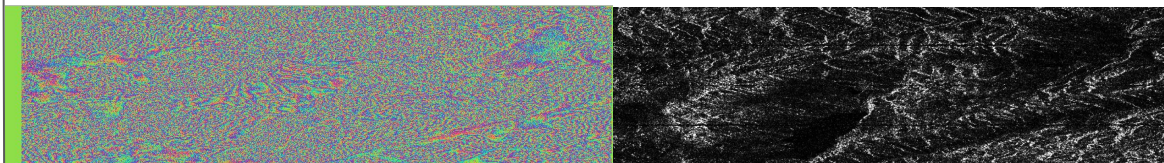
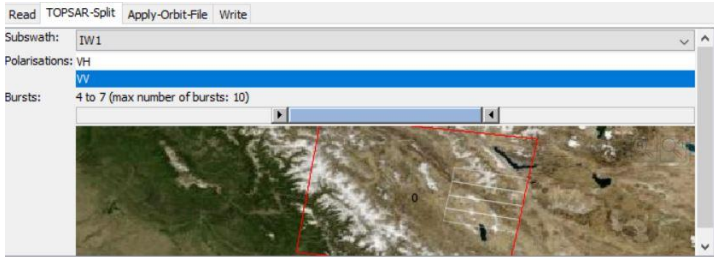


Process 1

Correction factors



Process 2



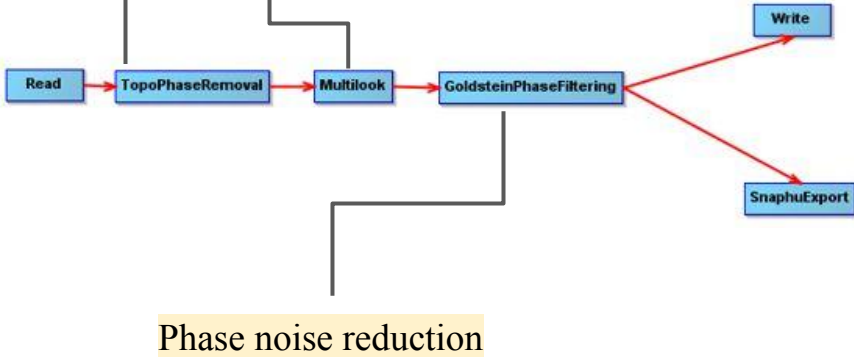
Phase

Intensity

SAR Data Processing workflow in SNAP

Removal of phase caused due to topography.

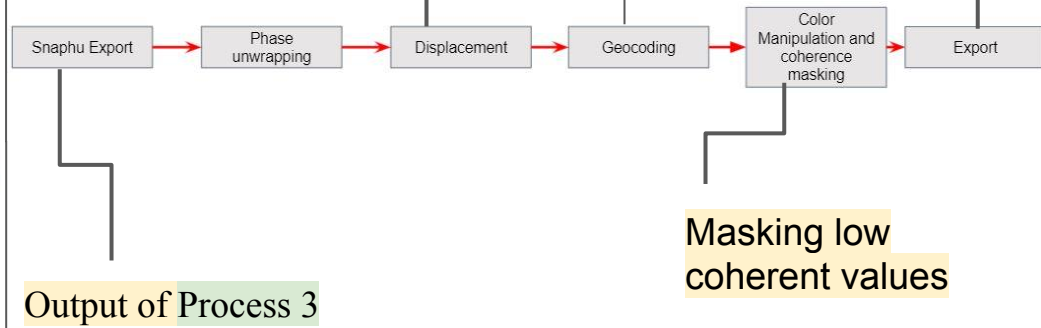
Speckle noise reduction.



Process 3

Phase to displacement

Radar coordinates to geographic coordinates.



Output = Results

Output of Process 3

Masking low coherent values

Process 4

Initial Results: Subsidence during May - Sept, 2020

May-June

June-July

Red: subsidence

Blue: uplift

- Areas of elevation between 3850 m - 6000 m show subsidence, both near the peaks and the valley.
- The maximum subsidence observed is 5.5 cm

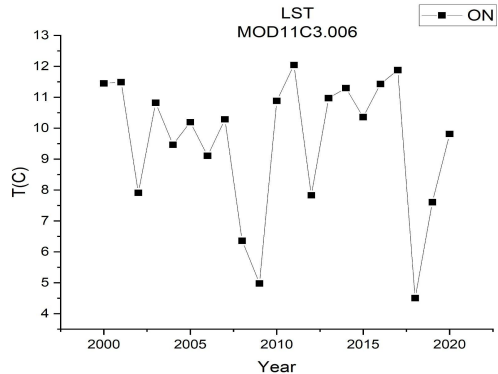
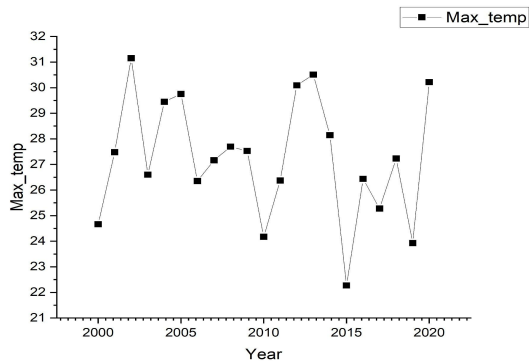
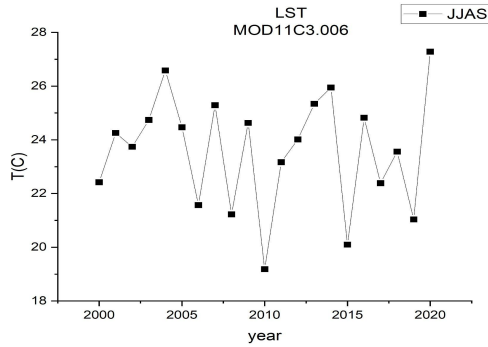
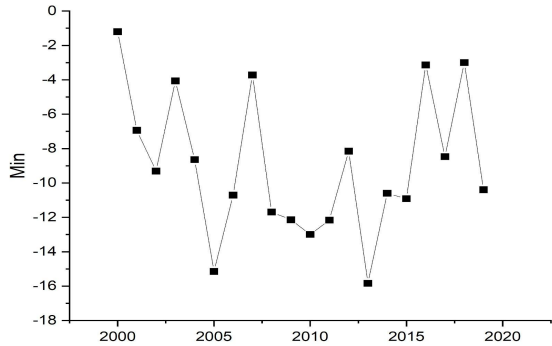
July-Aug

Aug-Sept

Initial Results: Subsidence during May - Sept, 2020

Period	Max. subsidence (m)	Max. uplift (m)	uplift percentile	subsidence percentile
May- June 2020	0.055	0.062	98	2
June- July 2020	0.037	0.053	74	26
July- Aug 2020	0.036	0.064	99	1
Aug- Sept 2020	0.009	0.036	99	1

Land Surface Temperature didn't show any specific trends



Data obtained for June-July-August-September from 2000-2021(May)

Data Used: MOD11C3

Concluding Remarks and Way Forward

Observations:

- Our initial analysis shows that Tso Kar region is seeing ground subsidence.

Next Steps:

- Identification of inter and intra annual behaviour of ground subsidence.
- Investigate areas that show subsidence to analyze its effect.
- Explore other climate parameters to define permafrost degradation for arid alpine region.

Challenges:

- Lack of field data investigations to support the existing modelled and processed data.
- Widespread variability of local climate in mountain regions accompanied by scarcity of meteorological stations affects the reliability of the study.



Thank You!!