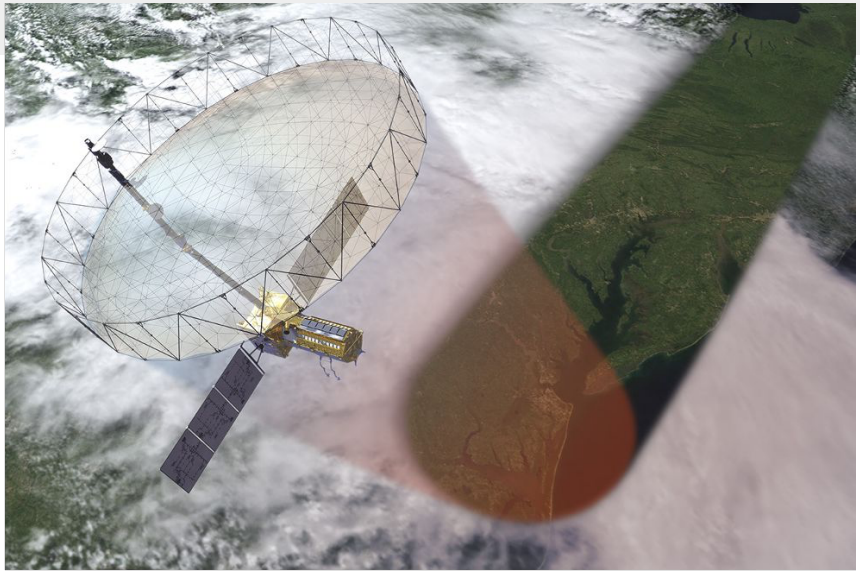
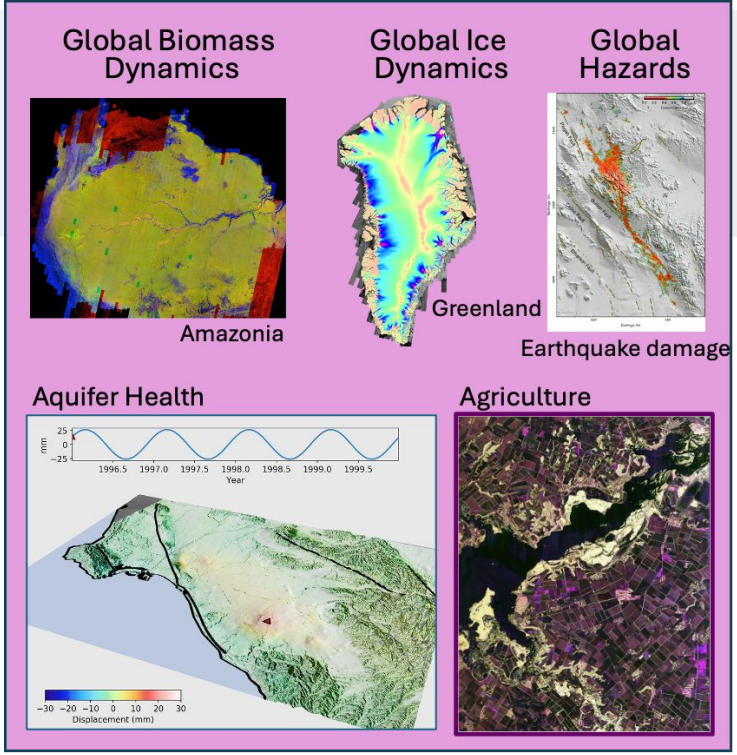
# NISAR: Understanding Climate, Carbon, and Catastrophic Change Resource Management ….and Snow?






- U.S./Indian collaboration; L-band and S-band InSAR (amplitude and phase)
- 80m resolution, global coverage every 12 days with exact repeat
- All weather measurements of surface deformation and change; 6am/6pm overpass


**Hans-Peter Marshall, Boise State University**

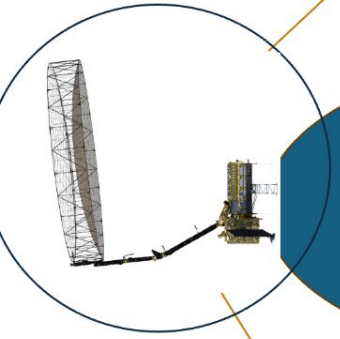
Western Water Action Office

## 2 Major Spaceborne radar SWE retrieval concepts for snow:

**SAR**

Amplitude

- High Frequency : Ku band (1-3cm)
- Volume Scattering
- **TSMM, SnowGlobe**, CLPX, CoreH2O
- [e.g. Tsang et al., 2022]



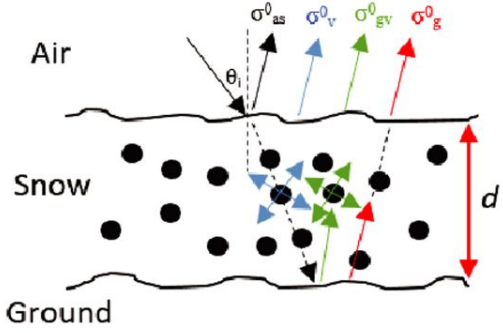
Sentinel-1 : C-band : 6cm

- *Both approaches have shown promise [Lievens et al., 2019, 2022; Ovisigarahan et al., 2023]*

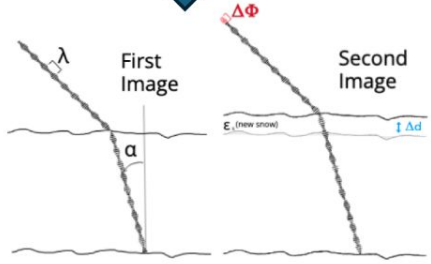
**InSAR**

Phase Change

- Low Frequency: L-band(25cm), P-band (100cm)
- Time-of-flight to snow-ground
- **SnowWatch, NISAR**
- [e.g. Gunnerison et al., 2001; Yueh et al., 2021]

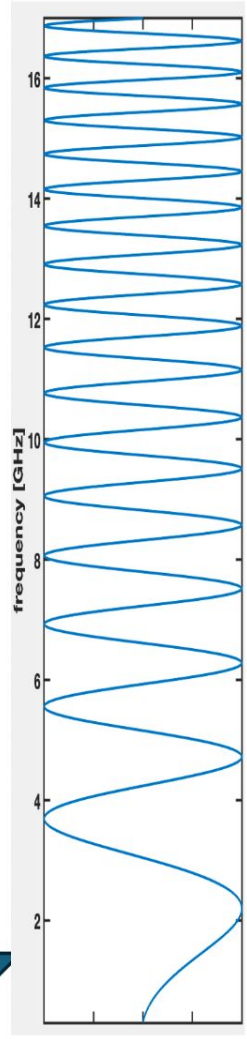



complementary




Amplitude Sensitivity, frequency

Penetration, wavelength



# C41B-05: Progress on L-band InSAR snow retrievals for future NISAR application: *Recent results from the 2020-2021 NASA SnowEx UAVSAR time series experiment*

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**3** U.S. Army CRREL
**4** NASA Jet Propulsion Laboratory
**5** Dept. of Geosciences, Colorado State University
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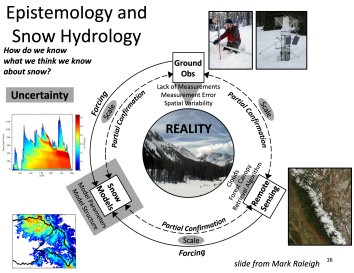
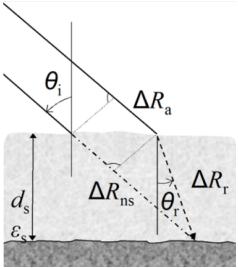
**9** University of Wyoming
**10** Montana State University
**11** NSIDC, University of Colorado Boulder
**12** Dept. of Geography, University of Utah



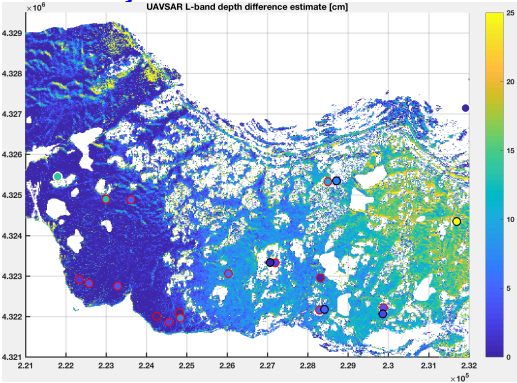



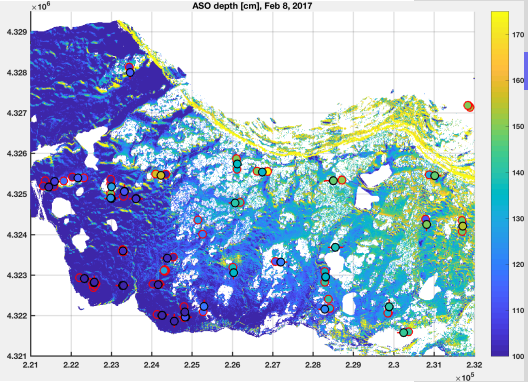

$$\Delta d = -\frac{\Delta\phi\,\lambda}{4\pi}\frac{1}{\cos\theta - \sqrt{\epsilon_s - \sin^2\theta}}$$

$$\Delta SWE = \Delta\phi\frac{2\lambda}{4\pi(1.59 + \theta^{\frac{5}{2}})}$$

- L-band InSAR approach - not holy grail for SWE, but useful tool, global coverage
- Provides information about spatiotemporal patterns in Δ SWE; will require fusion with in-situ observations and snow models
- At L-band, snow is $\sim$ tranparent; reflection is from the snow-ground interface
- Phase change caused by change in travel time; increase due to slower velocity, decrease due to refraction
- Velocity and refraction are f(density,LWC), but SWE change can be estimated directly without density
- (Guneriussen et al., 2001; Deeb et al., 2011; Leinss et al., 2015)

# Pilot survey: SnowEx17



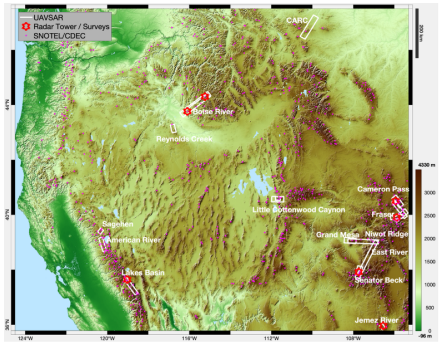

- SnowEx 2017 designed to measure spatial pattern of total SWE, not *changes*
- Few in-situ data for investigating spatial patterns of change in snow depth/SWE
- Very small change occurred during campaign (mean=10 cm depth)
- East-West trend in accumulation consistent with trend in total snow depth
- Machine learning feature importance: #1=phase change (Alabi et al., 2024) *Frontiers in Remote Sensing*

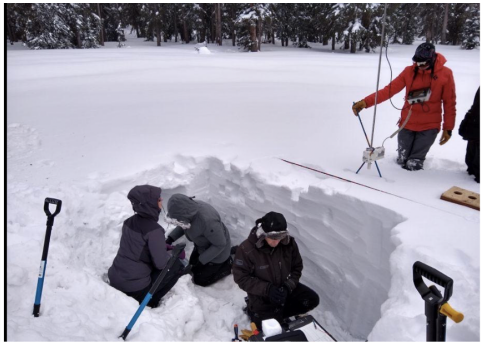

Open science: Hackweek, Working Group

Future Work - NISAR prep

References & Opportunities

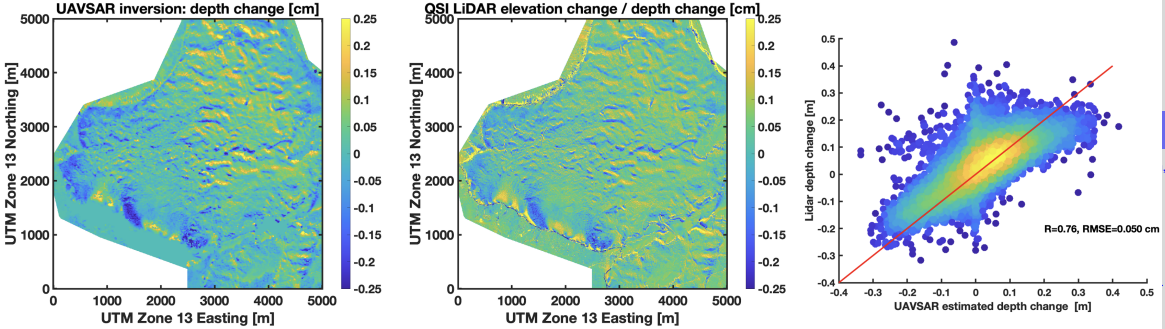
# InSAR time series: SnowEx20/21



- NASA SnowEx 2020-21 focused on UAVSAR repeat-pass interferometry
- Winter 2020: Biweekly spread over different US sites (6 sorties,13 sites, 5 states)
- Winter 2021: Weekly over subset of sites (10 sorties, 6 sites, 4 states)
- Local experienced field teams deployed on the date of each over pass (validation)
- Airborne LIDAR over subdomain at a subset sites (best source for spatial validation)
- coordinated with Sentinel-1 team for 6-day revisit for some SnowEx sites

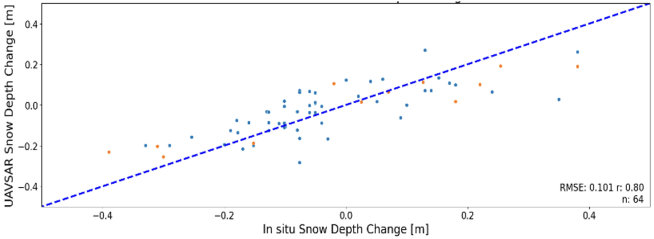
# Grand Mesa, February 2020: Flat terrain, dry snow

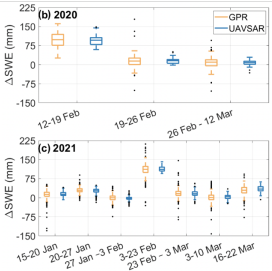


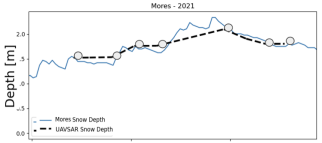


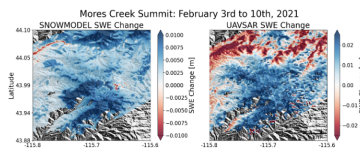

- Retrieved snow depth change using UAVSAR shows a very good agreement with LIDAR over flat 5km x 5 km region on Grand Mesa with dry snow
- Motivated the continuation of the SnowEx UAVSAR time series in 2021
- Airborne Lidar flights aligned with UAVSAR: direct comparison of depth change (Marshall et al., 2021) *IGARSS*
- Palomaki and Sproles (2023) found similar patterns in UAVSAR retrievals and lidar at a prairie site, but shallow snow ($\sim$10 cm) challenged both techniques (*RSE*)

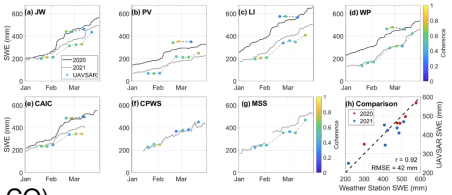
# Boise Mountains, ID and Cameron Pass, CO: Complex Terrain



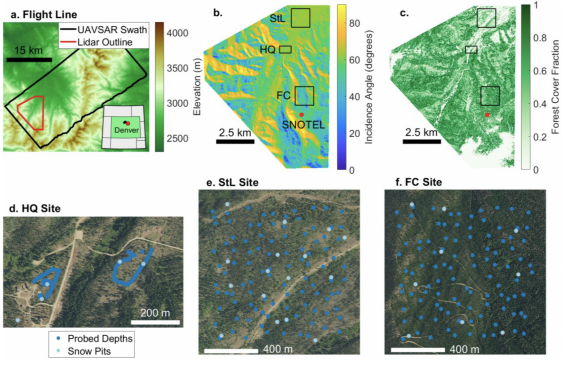



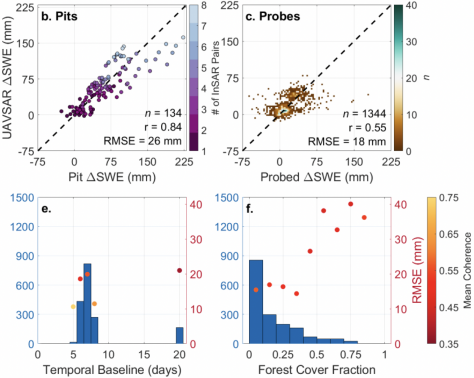




- Agreement w/in-situ depth (R=0.8, RMSE=10cm, ID)
- Temporal changes in depth/SWE agree w/ SNOTEL, GPR (ID, CO)
- Changes in SWE from UAVSAR and SnowModel show similar patterns (ID)
- Disagreement likely due to liquid water in snow (ID)
- Agreement between InSAR SWE and GPR SWE (CO)
- (Hoppinen et al., 2024; Bonnell et al., 2024b) *The Cryosphere*

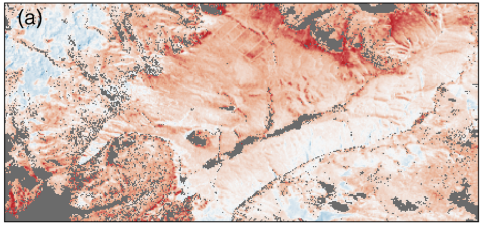
# Fraser Experimental Forest, Colorado: Forest Cover

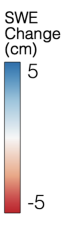


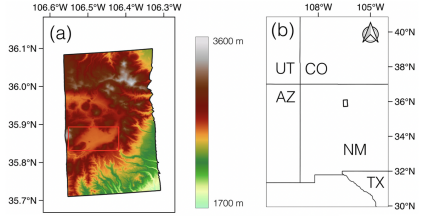



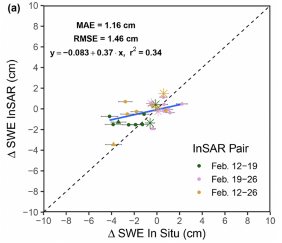

- Spatial in-situ snow depth probing and pits indicate accurate & unbiased InSAR retrievals for forest cover fraction < 0.4
- SWE RMSE=14-17mm for FCF<0.4, and RMSE=33-40 for FCF>0.5
- Snow depth patterns between lidar and InSAR agreed for FCF<0.5
- Retrieval of changes in snow depth and SWE show promise for L-band InSAR in FCF<0.5
- (Bonnell et al., 2024a) *Geophysical Research Letters*

# Jemez River, New Mexico: Early Melt Conditions



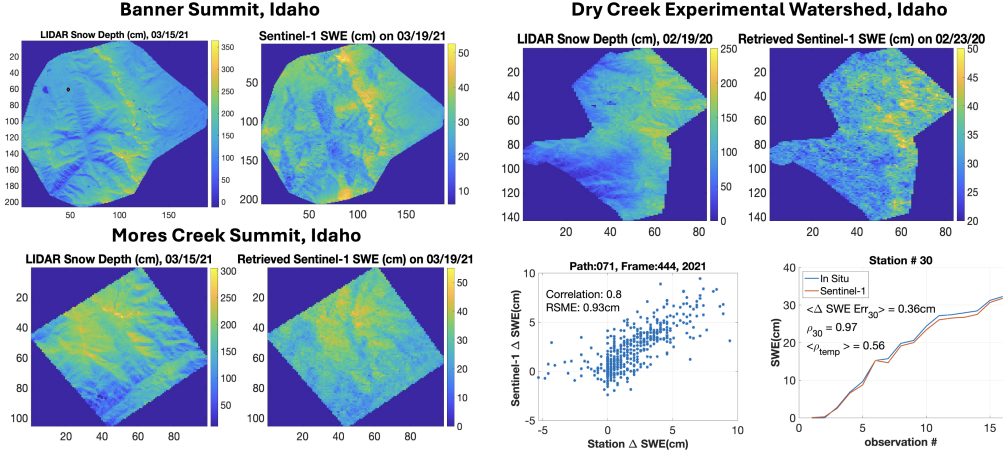



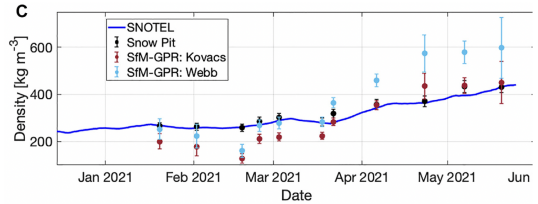

- Coherence maintained after significant melt with early AM overflight in complex terrain
- After removal of atmospheric effect, phase change showed Δ SWE signal
- Both SWE loss and SWE gain measured with InSAR after significant melt
- Δ SWE compared to in-situ and pattern of SWE loss confirmed w/ Δ fSCA
- (Tarricone et al., 2023) *The Cryosphere*

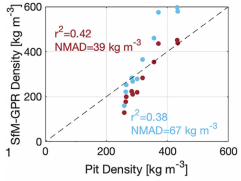
# Boise Mountains, Idaho: Sentinel C-band InSAR: Sum △ SWE = total SWE

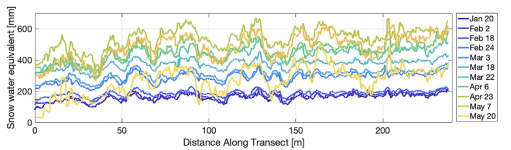


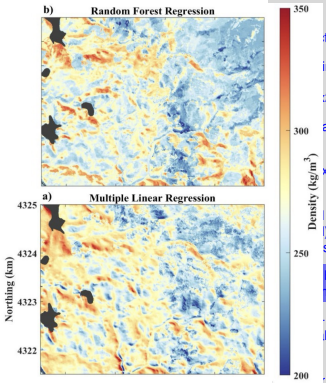

- High coherence allows complete time series from snow-free conditions for first time
- ΣΔ SWE compared well with SNOTEL (RMSE 0.93cm, r=0.8)
- 9 stations had SWE error < 2cm, 15 stations with higher error but similar trends
- ΣΔ SWE from InSAR shows similar pattern to total depth from lidar
- (Oveisgharan et al., 2024) *The Cryosphere*

# Ground based L-band experiments



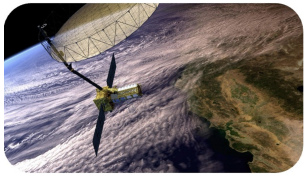



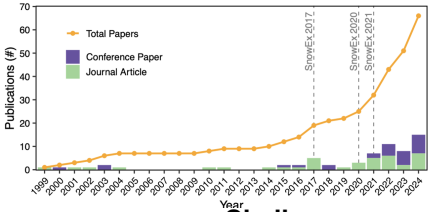




- Combining radar time-of-flight and lidar/SfM depth allows permittivity estimate
- In dry snow, first high-resolution spatial maps of density
- In wet snow with in-situ density: liquid water content estimates
- CarSAR and UAV-based L-band InSAR allows more frequent observations
- Ground-based radar during NISAR will be key for retrievals in spring
- (McGrath et al., 2022; Meehan et al., 2024; Bonnell et al., 2023; Webb et al., 2020)

# NISAR - Potential for Snow





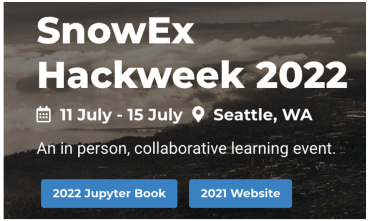

## Advantages

- change in SWE and depth, every 12 days @ 80m, in dry snow conditions
- limited impact of forests for FCF<0.5; all weather conditions
- suprising $\Delta SWE$ loss signal for AM overpass (Tarricone et al., 2023)
- future L-band InSAR missions (NISAR, ALOS-4, ROSE-L,SDC, HydroTerra+, Tandem-L)

## Challenges

- Wet snow - LWC limit unknown
- Possible coherence loss at 12-day intervals, 80m resolution
- Atmospheric delays need to be estimated; reference $\Delta\phi$ requires some in-situ obs (e.g. SNOTEL)
- Snow is not a deliverable for NISAR - no standard product; But 5 THP'24 projects (CRREL, JPL, Goddard, UCLA, UAF) + robust L-band WG

# Why was the SnowEx Time Series so successful? Hackweek, Working Group, Open Science




- **Time series** for 2 winter seasons, during Covid, with no major issues
- Dedicated aircraft, facility instrument with mature technology
- Local experienced field teams in 14 sites in the Western U.S.
- SnowEx Hackweek (2021,2022,2024) built momentum and a culture of open science
- Open science software: e.g. uavsar-pytools, swesarr-pytools, phase-o-matic, spicy-snow, crunchy-snow
- Early career scientists leading the way
- Strong L-band InSAR Working Group, meeting monthly since 2021 (email Eli/Jack/HP)

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