DUAL-FREQUENCY REMOTE SENSING RADAR OBSERVATIONS OF DEEP SNOWPACK IN GRAND MESA, COLORADO

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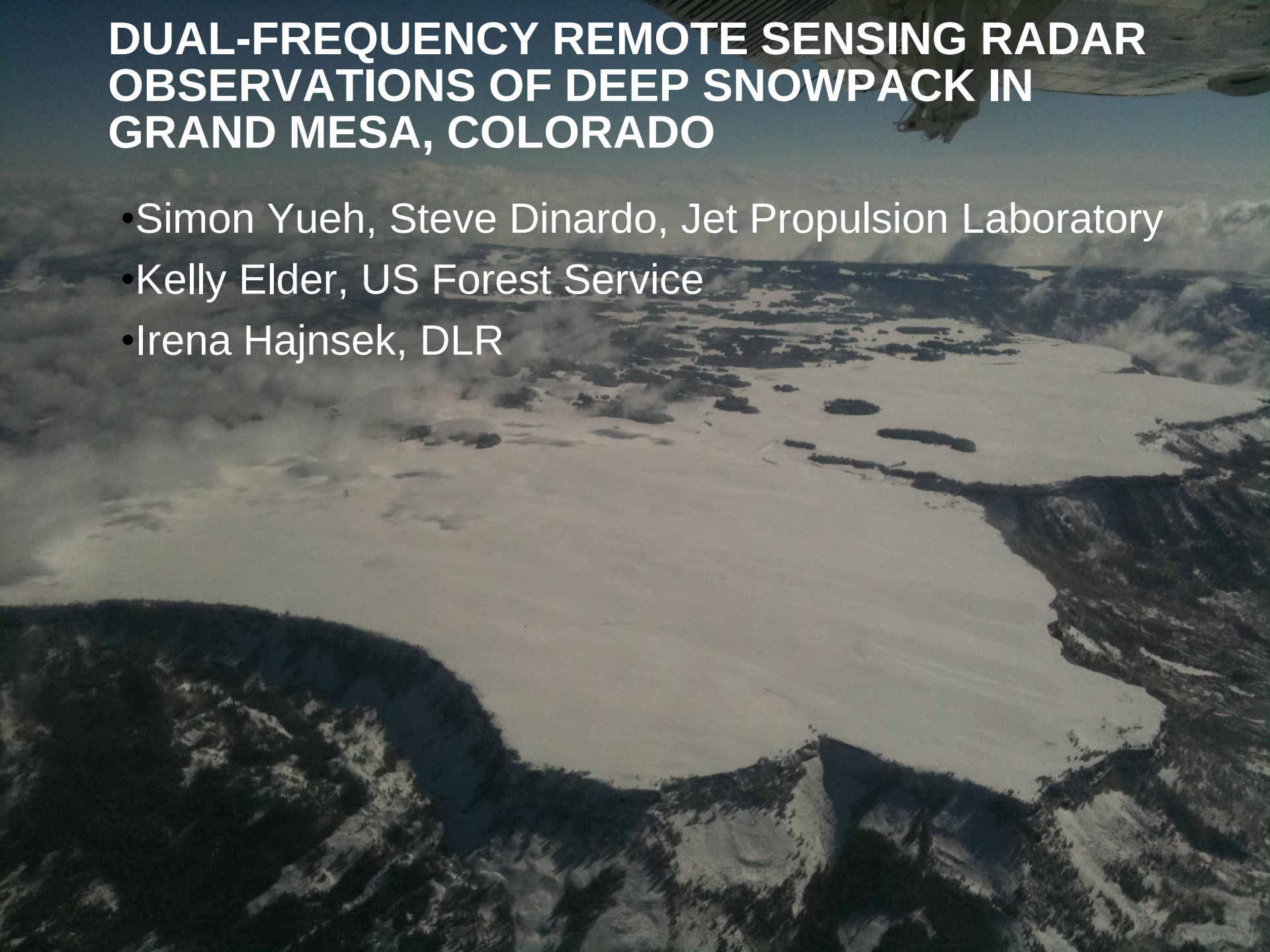
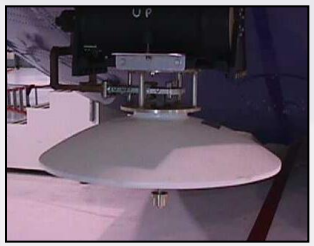


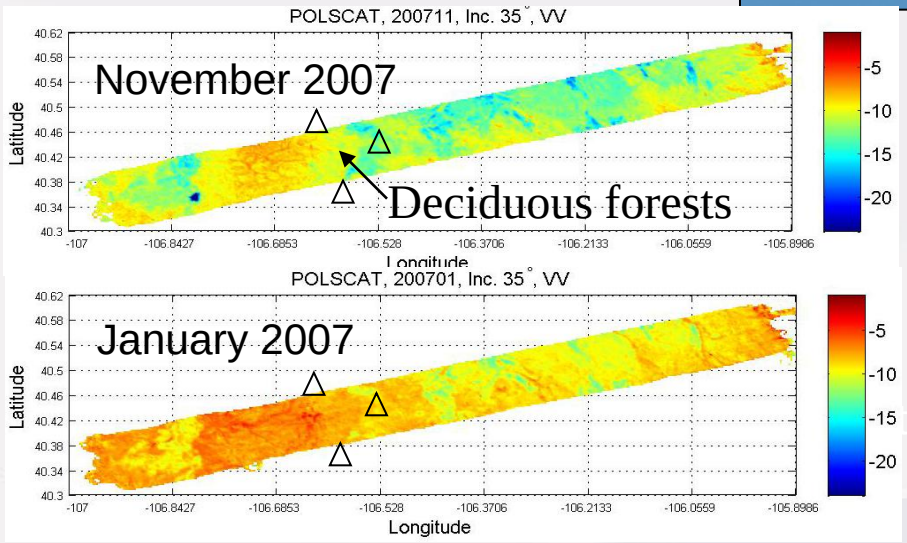
Outline

- Overview
- Cold Land Processes Experiment – 3
- Data Characteristics for Vegetation, Thin Snow and Melt/Sublimation
- Layering effects
- Snow over tree canopy
- Summary

POLSCAT ON TWIN OTTER and CLPX-2

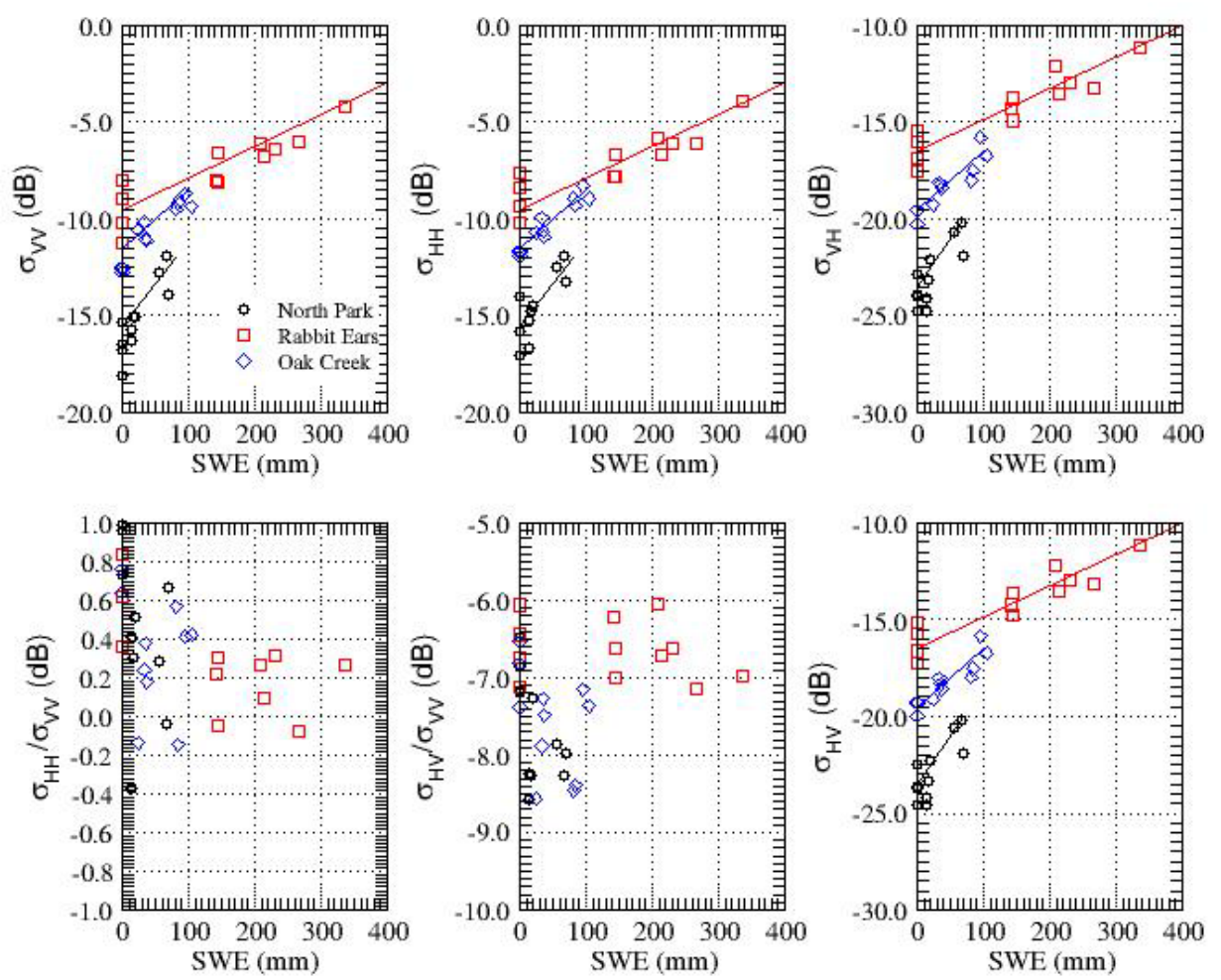
- Ku-band radar with VV, HH, VH and HV polarizations
- Conical scanning imager with variable incidence angle (0-65 degrees)
  - Baseline 35 and 45 degrees for CLPX
- 3-deg beamwidth (80m to 240m spatial resolution for CLPX/CO 2006-2008)





- November 2007 VV data reflect the vegetation types
- Snow accumulation increased the radar backscatter for dry snowpack (December 2006 and January 2007)

POLSCAT/CLPX RESPONSE TO SWE CLPX-2



Radar footprints compared to footprint-scale ("hourglass") observations

- Ku-band radar echoes showed significant correlation with the change of SWE
- All polarizations showed similar response
- VV and HH ratios are close to unity
- HV/VV ratios larger for the Rabbit Ears hourglass sites.

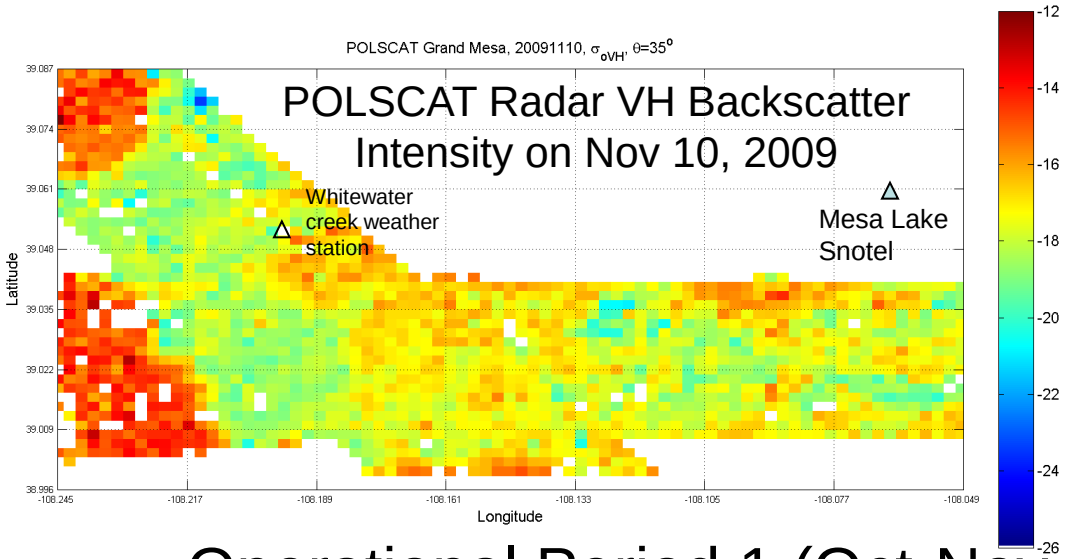
Yueh et al, IEEE TGRS, 2009

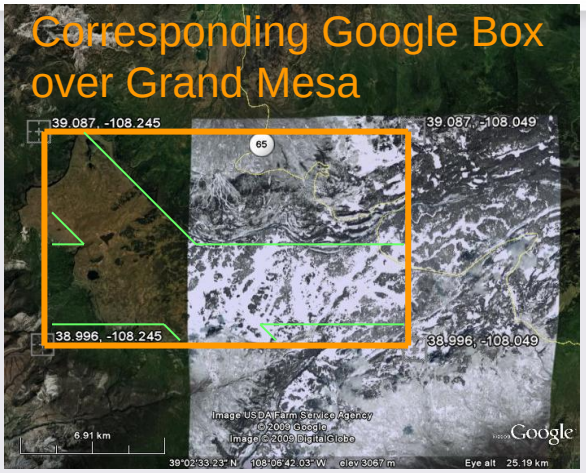
What is the response at X-band?
Data limited to single frequency

Cold Land Processes Experiment-3 Objectives

- Conduct POLSCAT/TerraSAR-X flights over Grand Mesa, Colorado to acquire dual-frequency (X-/Ku-band) radar data for the testing and improvement of forward scattering model
  - Vegetation scattering and background modeling
  - Layering effects
- To support the development of SWE retrieval algorithm with extensive in-situ SWE samples

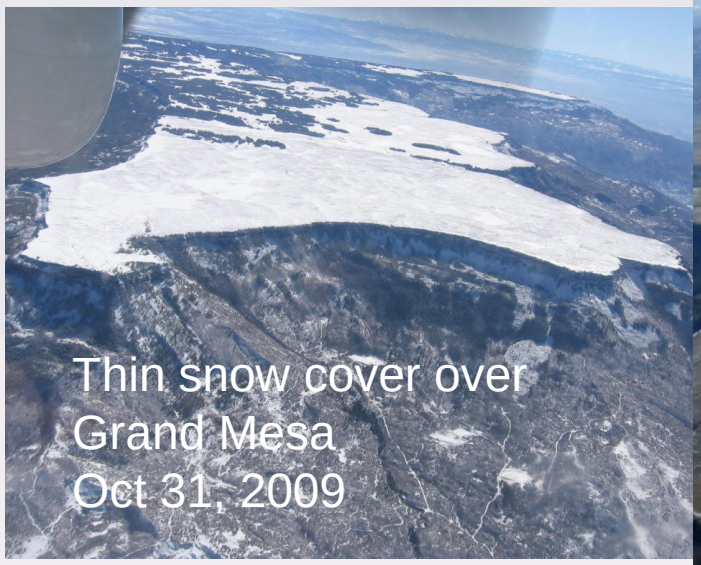
Overview of CLPX-3 Campaign

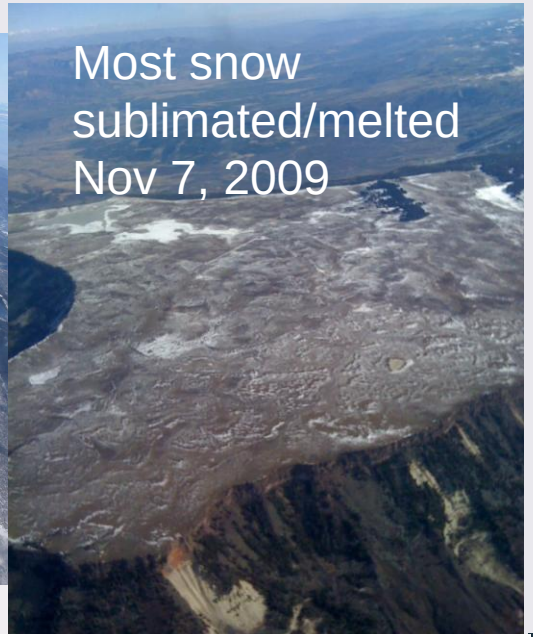


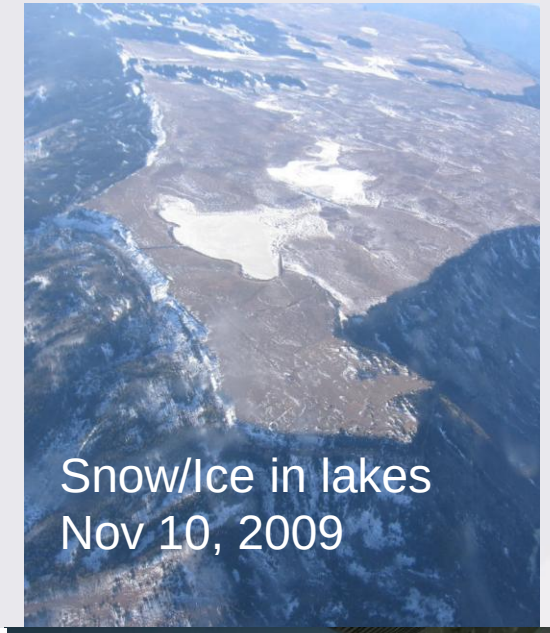


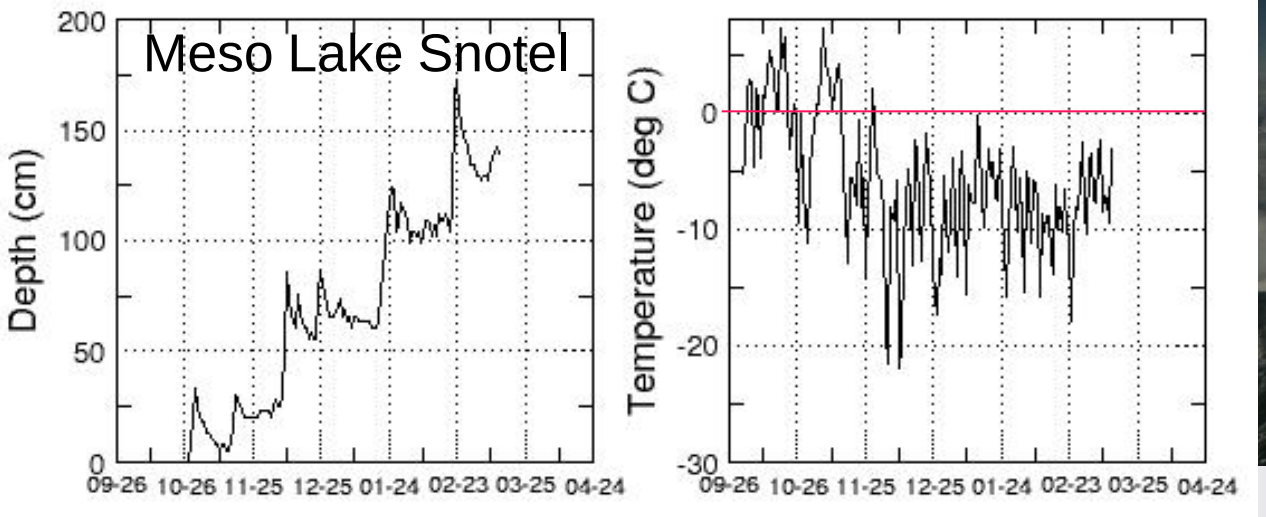
- Operational Period 1 (Oct-Nov 2009)
  - Four POLSCAT flights (35 and 45 degree incidence angles)
  - Five TerraSAR-X acquisitions
    - Two passes at 33.5 deg, two passes at 27.8 deg and one pass at 42.9 deg
- Operational Period 2 (Feb-Mar 2010)
  - Four POLSCAT flights (35 and 45 degrees for all and one pass at 40 deg incidence)
  - Three TerraSAR-X passes (27.8, 33.5 and 42.9 deg)

Evolution of Snow Cover over Grand Mesa CLPX-3

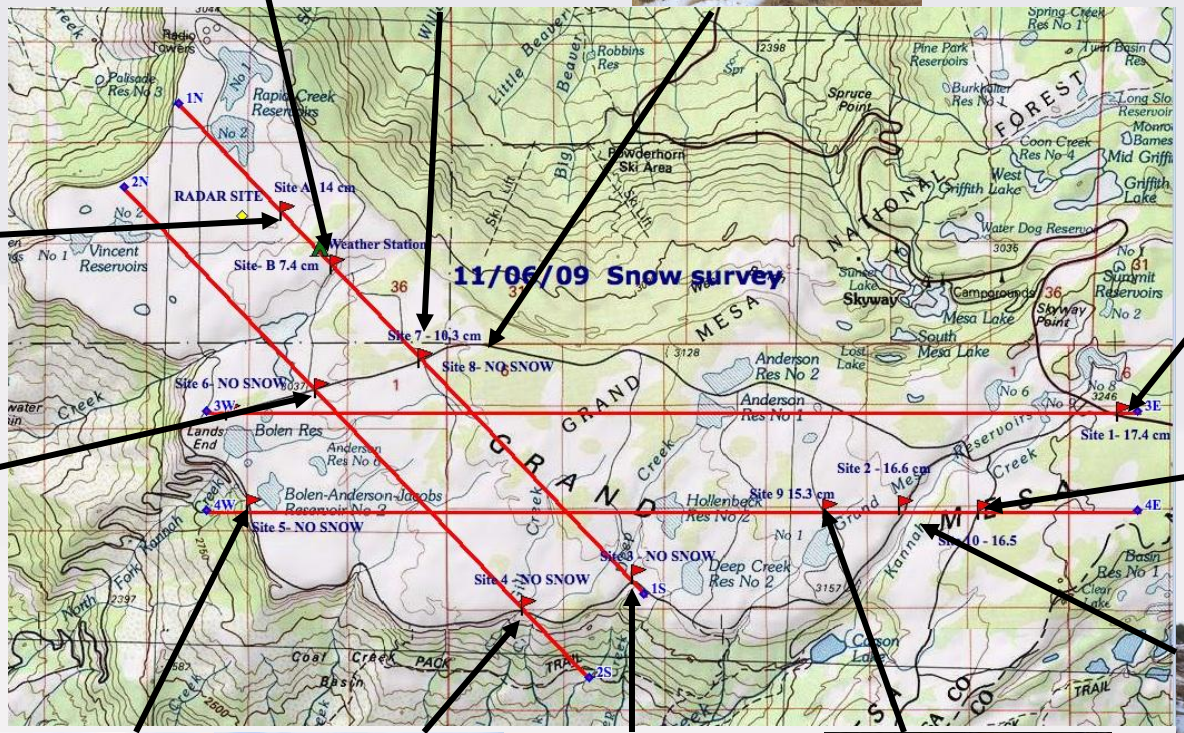








Characteristics of Ground Cover on 9 Nov 2009
Grand Mesa

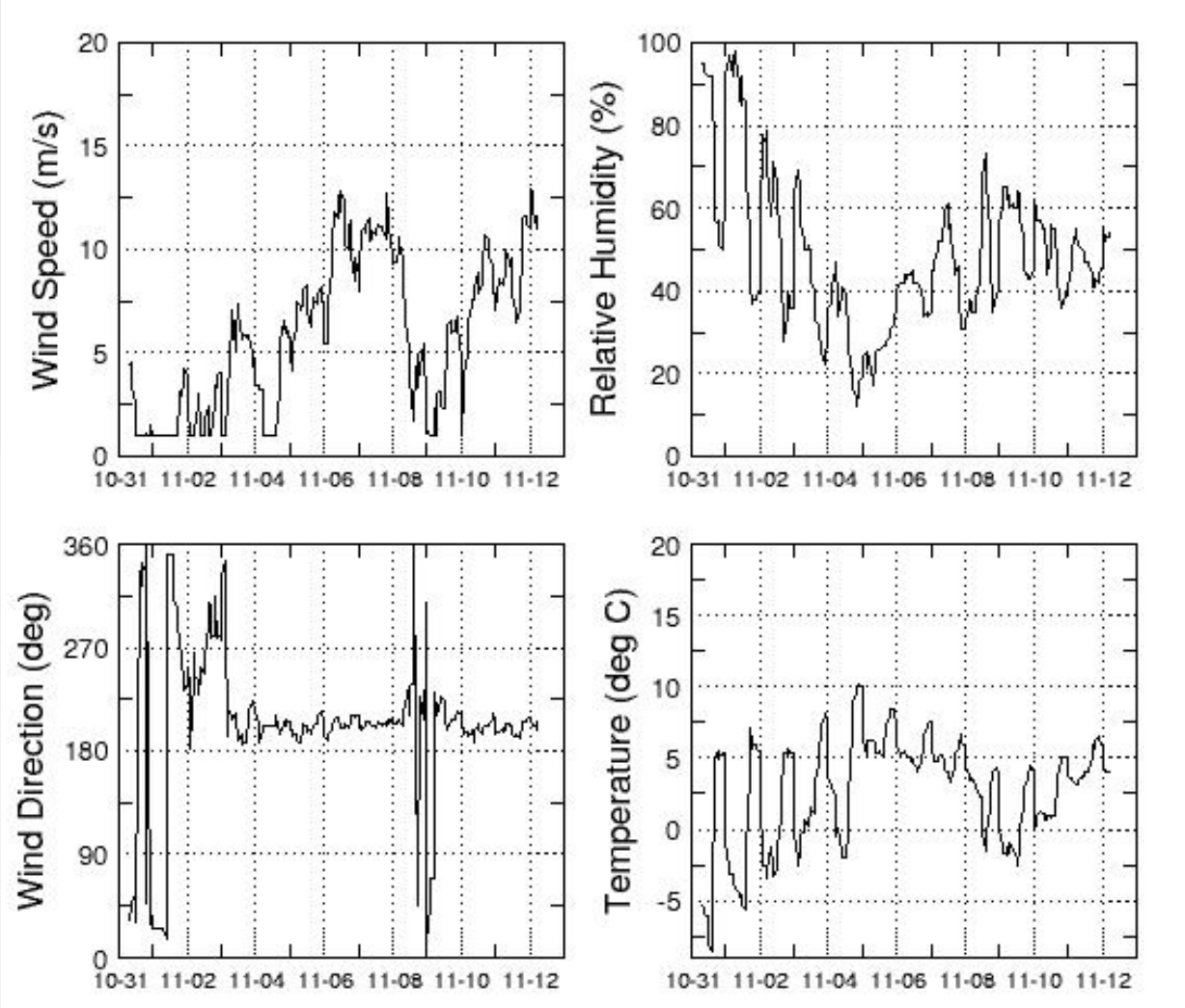


In-Situ Sampling

- Operational Period 1 (Oct-Nov 2009)
  - 12 sites
  - 0-4 cm SWE
- Operational Period 2 (Feb-Mar 2010)
  - Snow pits
  - Transects
  - 10 to 46 cm SWE

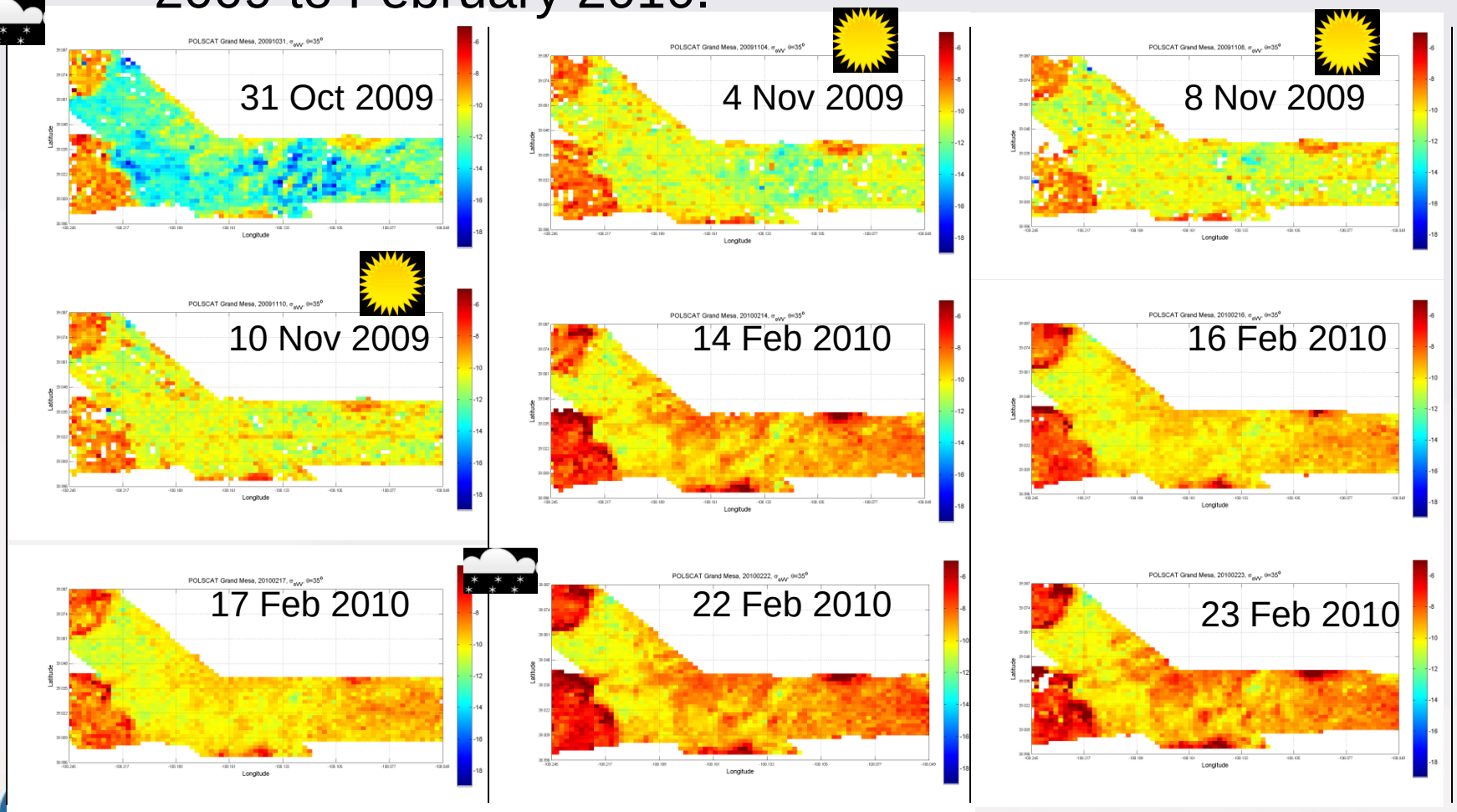
This chart shows the sampling plan. The actual number of sampling sites was slightly less.

Whitewater Creek Weather Station During Operation Period 1 (Oct-Nov 2009)



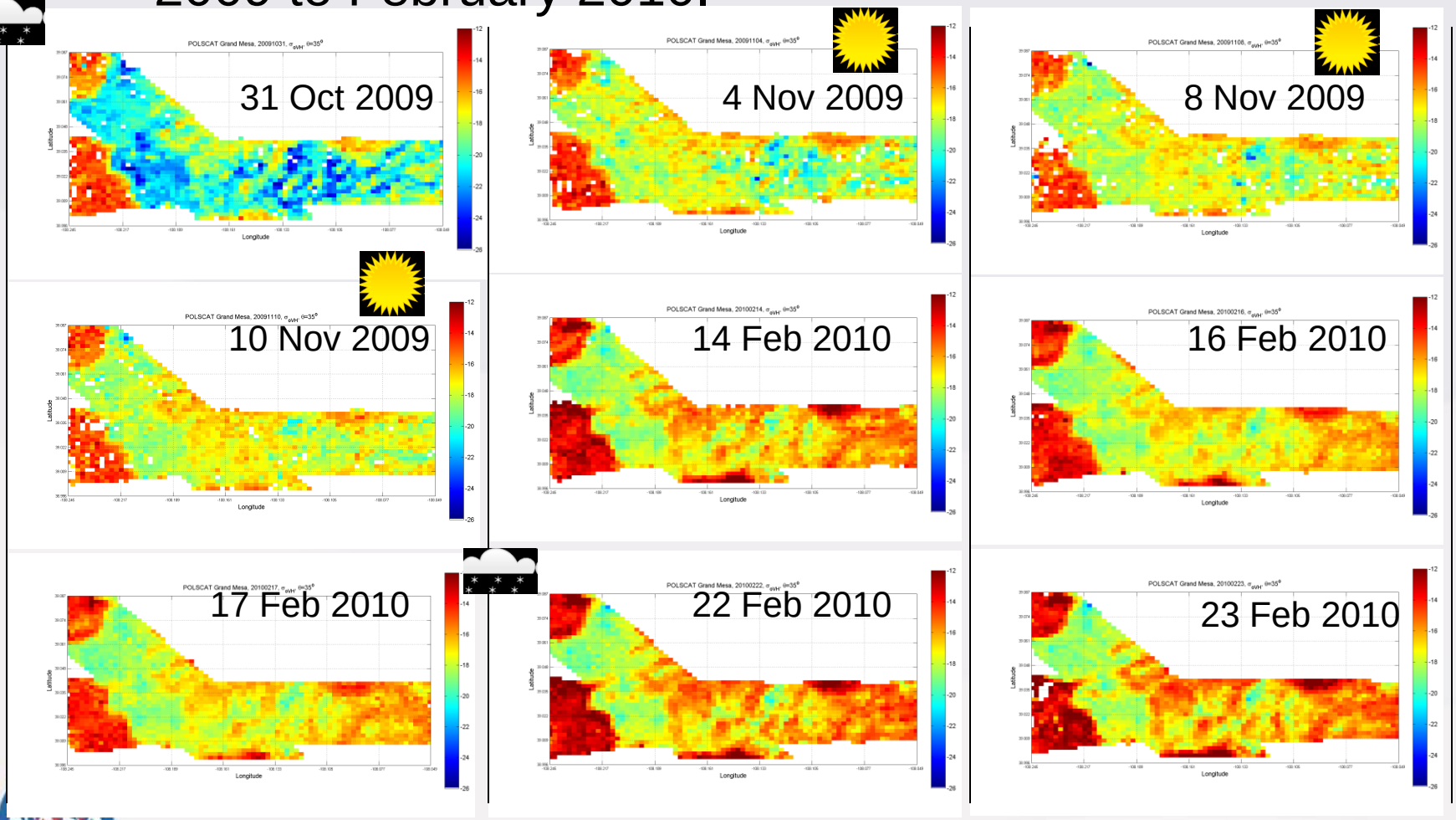
POLSCAT VV Response to Snow Accumulation over Grand Mesa, Colorado

- VV backscatter at 35 deg incidence from November 2009 to February 2010.



POLSCAT VH Response to Snow Accumulation over Grand Mesa, Colorado

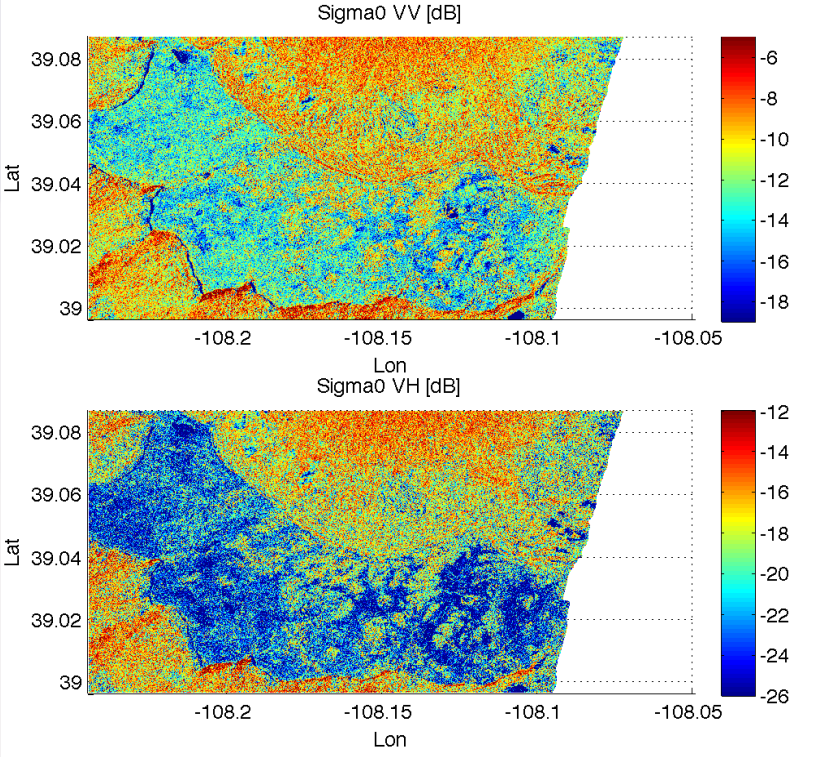
- VH backscatter at 35 deg incidence from November 2009 to February 2010.



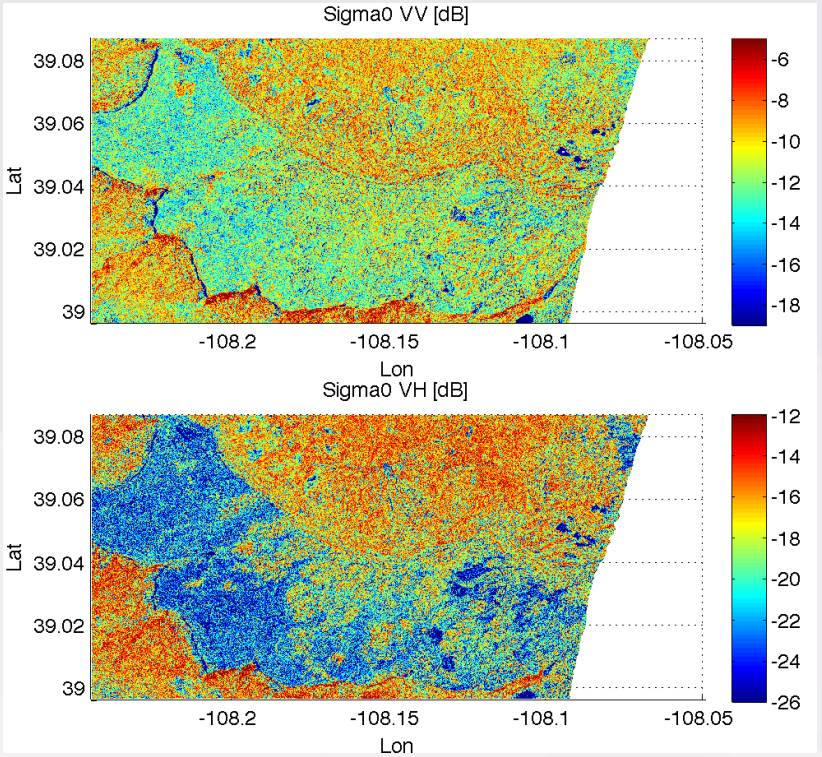
TerraSAR-X Changes from Oct 31 to Nov 11, 2009
Melt and Vegetation Effects

•Backscatter generally lower on Oct 31 – similar to POLSCAT data

Oct 31, 2009



Nov 11, 2009



•What caused the increase?

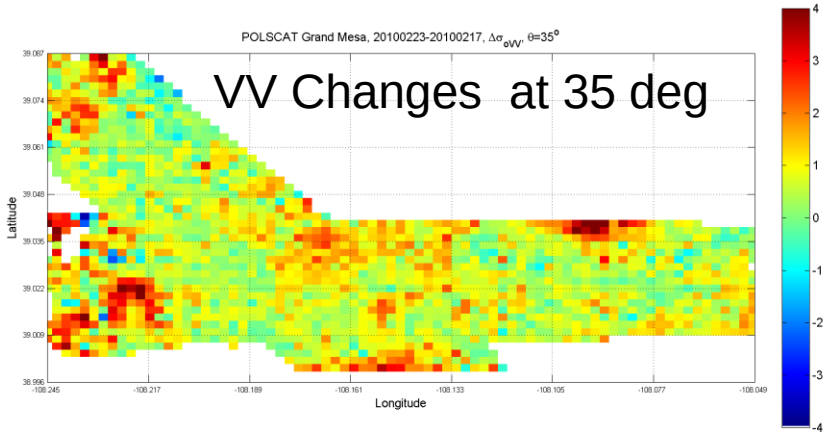
•Wet snow on the western part?

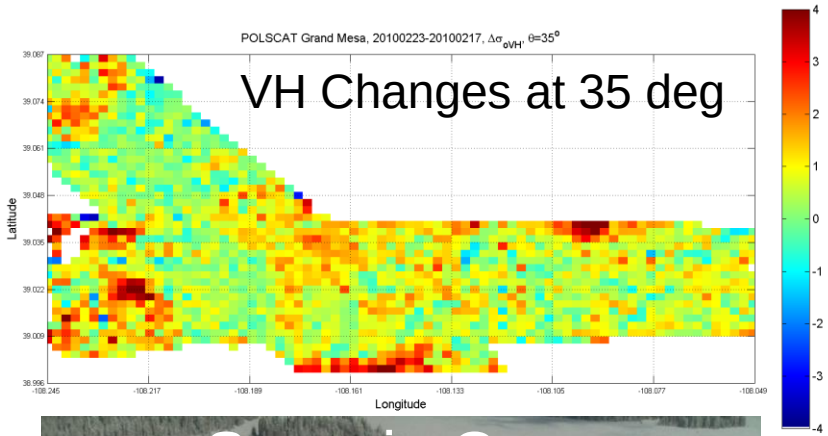
•Hw about eastern part? There was still some snow (wet).

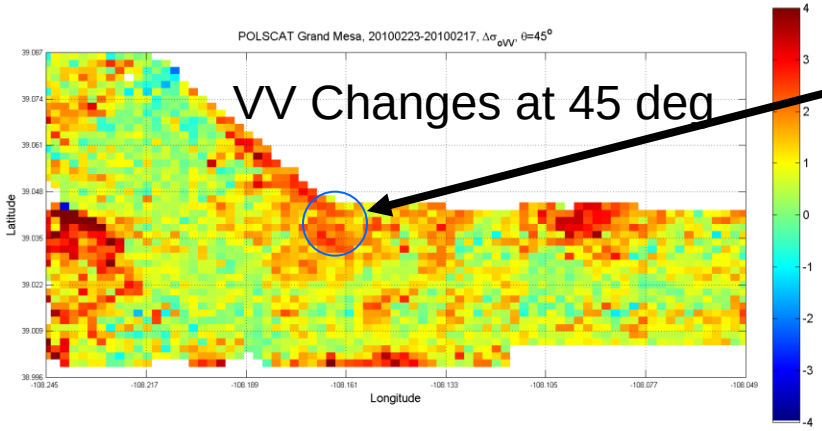
•Mean incidence angle over Grand Mesa about 33.5 degrees

POLSCAT VV and VH Changes from Feb 17 to 23, 2010
Impact of New Snow

- Backscatter increased in some regions, but decreased in some other regions
- VV and VH changes were generally similar.
- VV at 45 degree had larger positive changes, particular over forested areas.

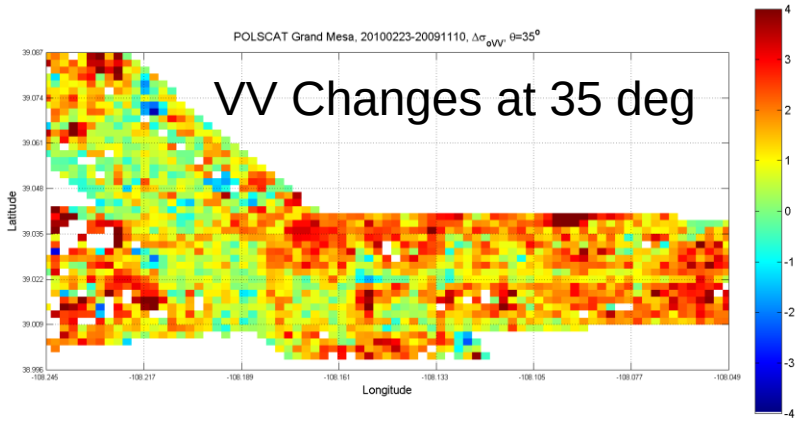


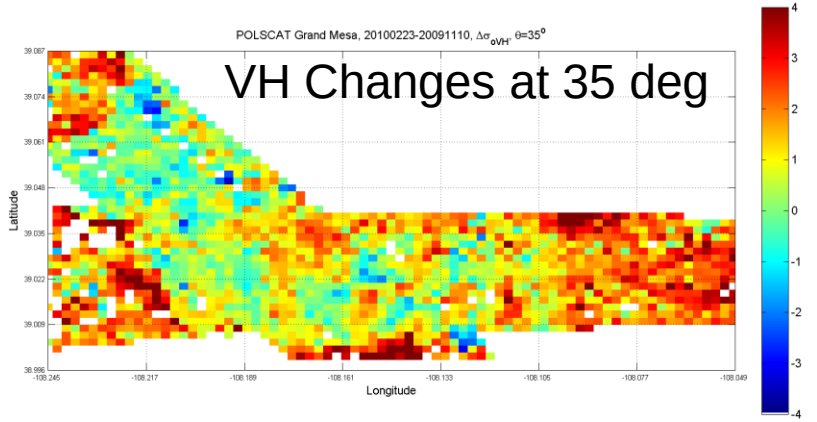


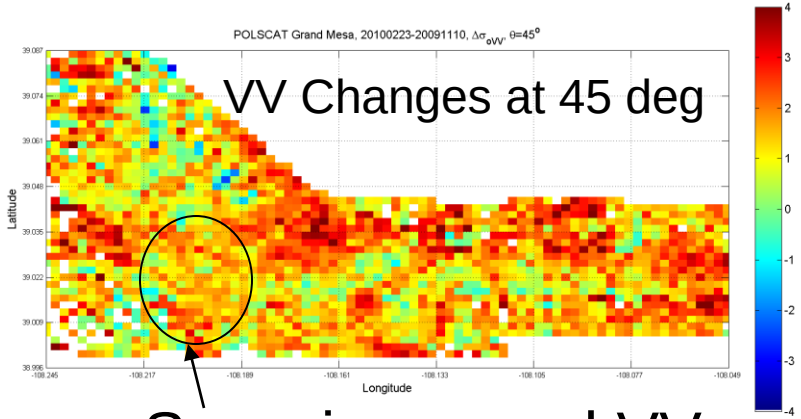


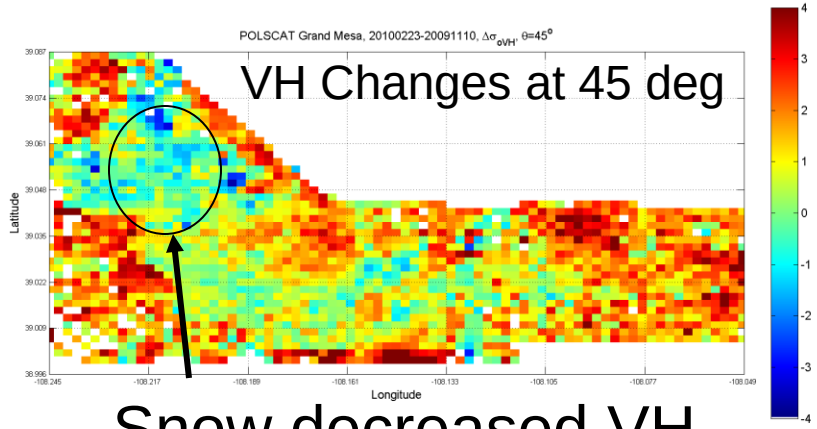
POLSCAT VV and VH Changes from 10 Nov 2009 to 23 Feb 2010 OP1-OP2

- Backscatter increased in some regions, but decreased in some other regions
- VV and VH changes were somewhat different.
- VV at 45 degree had larger positive changes, particular over forested areas.





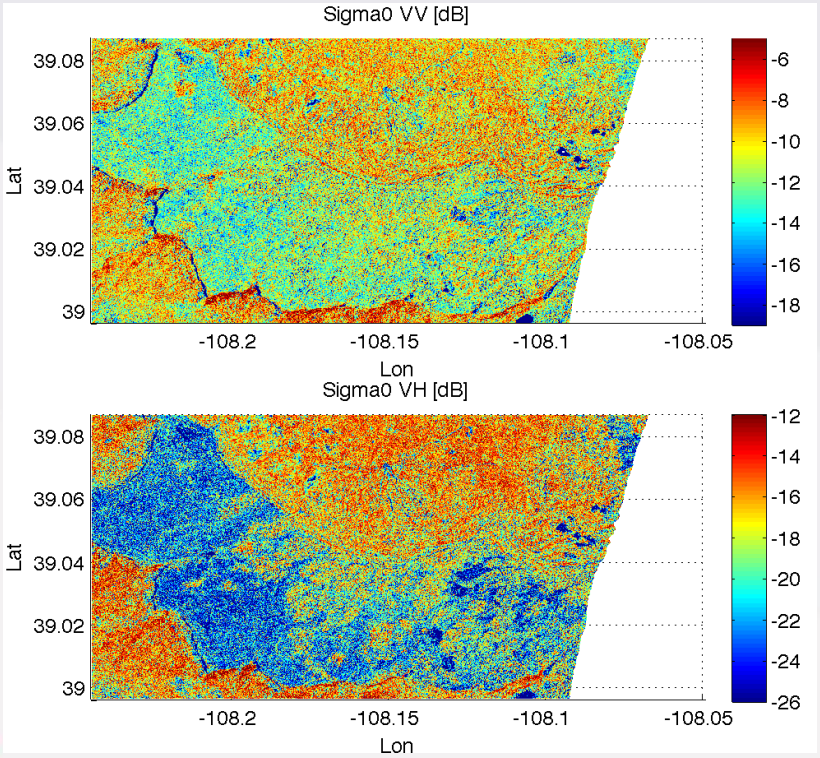




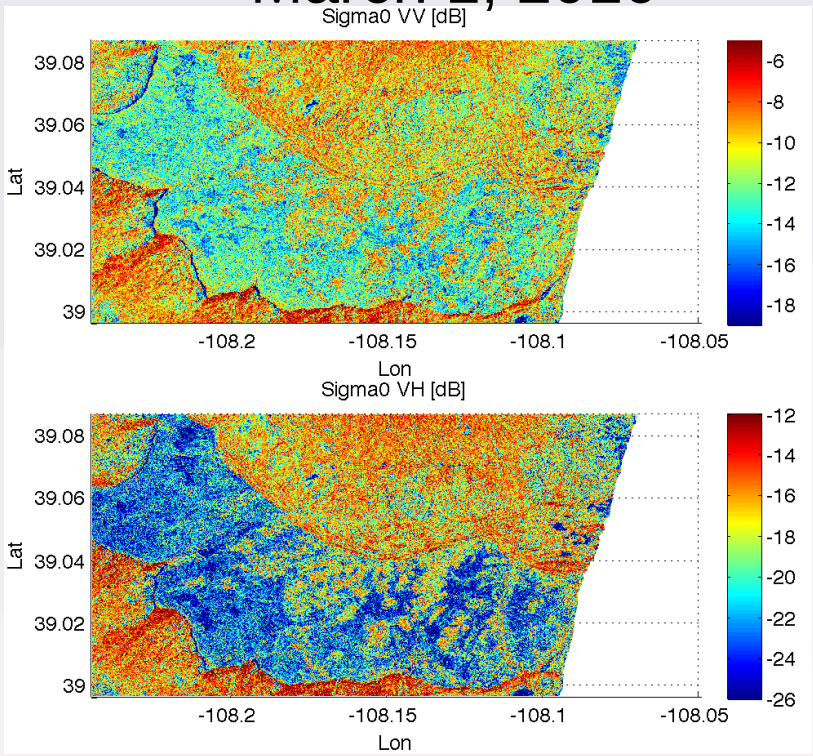
TerraSAR-X, Changes from 11 Nov 2009 to 1 March 2010 OP1-OP2

- Increase over forested areas
- Decrease over short vegetated areas

Nov 11, 2009



March 1, 2010

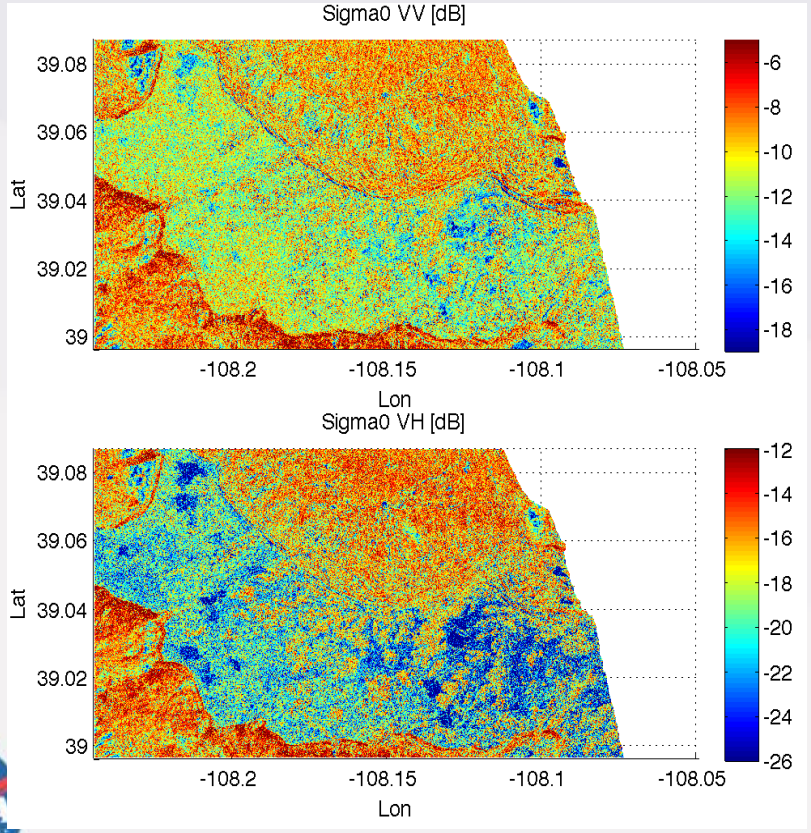


- Mean incidence angle over Grand Mesa about 33.5 degrees

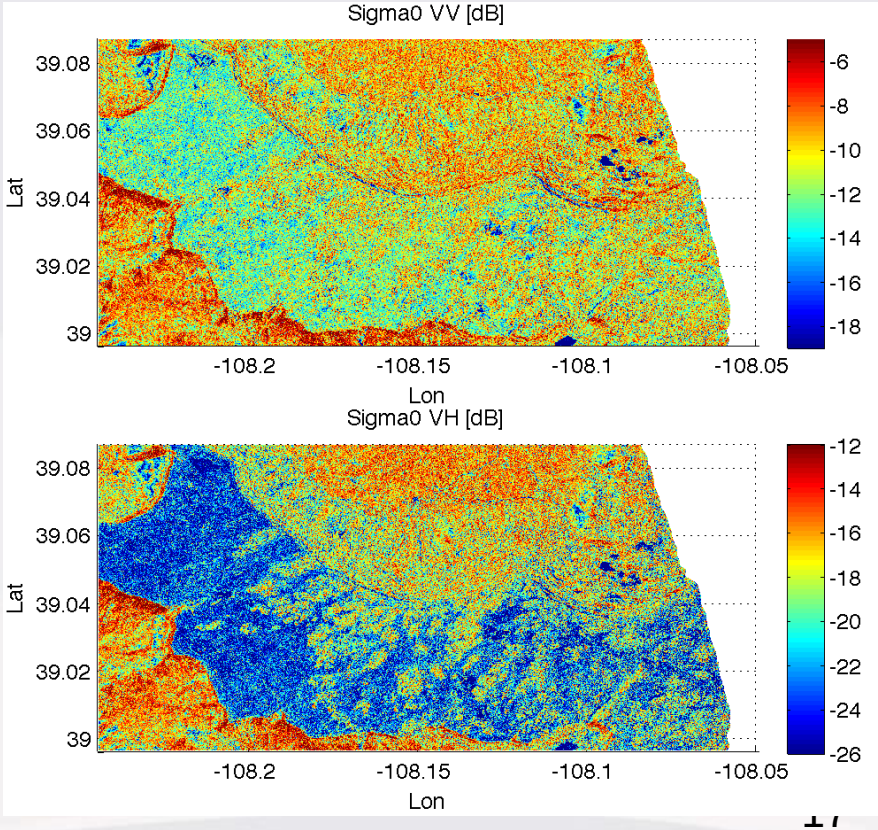
TerraSAR-X, Changes from Nov 3 to Nov 14, 2009

- Backscatter generally decreased from Nov 3 to Nov 14.
  - Could this be caused by soil moisture changes?
- Mean incidence angle over Grand Mesa about 27.8 degrees

Nov 3, 2009



Nov 14, 2009



Summary

- CLPX-3 Deep Snowpack Campaign 2009-2010 Completed
  - 9 POLSCAT flights (35 and 45 degrees); The flight on Feb 17 had additional 40 deg observations
  - 8 TerraSAR-X passes
- Various changes were observed. X- and Ku-band appeared to have different response to the presence of snowpack. Some interesting features:
  - After snow sublimated and/or melted, radar backscatter increased in early November 2009
  - Snow over tree canopies increased the radar backscatter by a few dBs. This was evident in Feb 2010 observations after snwofall.
- More detailed analysis using in-situ data to be conducted.

Mesa Lake Snotel