CanEx-SM10: UAVSAR Data Set

Incidence Angle Normalization of Backscatter Data

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Introduction

- **SMAP**: Soil Moisture Active Passive (NASA/JPL, 2014)
  - 3 soil moisture products (passive, active and combined).
  - Need of comprehensive data sets that
    - Are compatible with the SMAP system configuration, and
    - Can be used for algorithms development and validation.

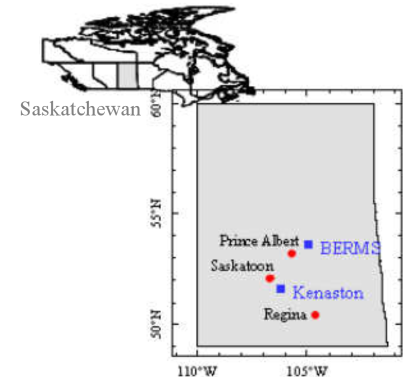
- Canadian Soil Moisture Experiment 2010 (**CanEx-SM10**)
  - Provide data sets suitable for SMAP algorithms testing.

- Aircraft-based SAR instruments are very efficient mapping tools; however, they characterize with a wide range of incidence angles over the swath. SMAP will operate at a fixed incidence angle of 40º.
  - Incidence angle has a significant impact on radar backscatter.

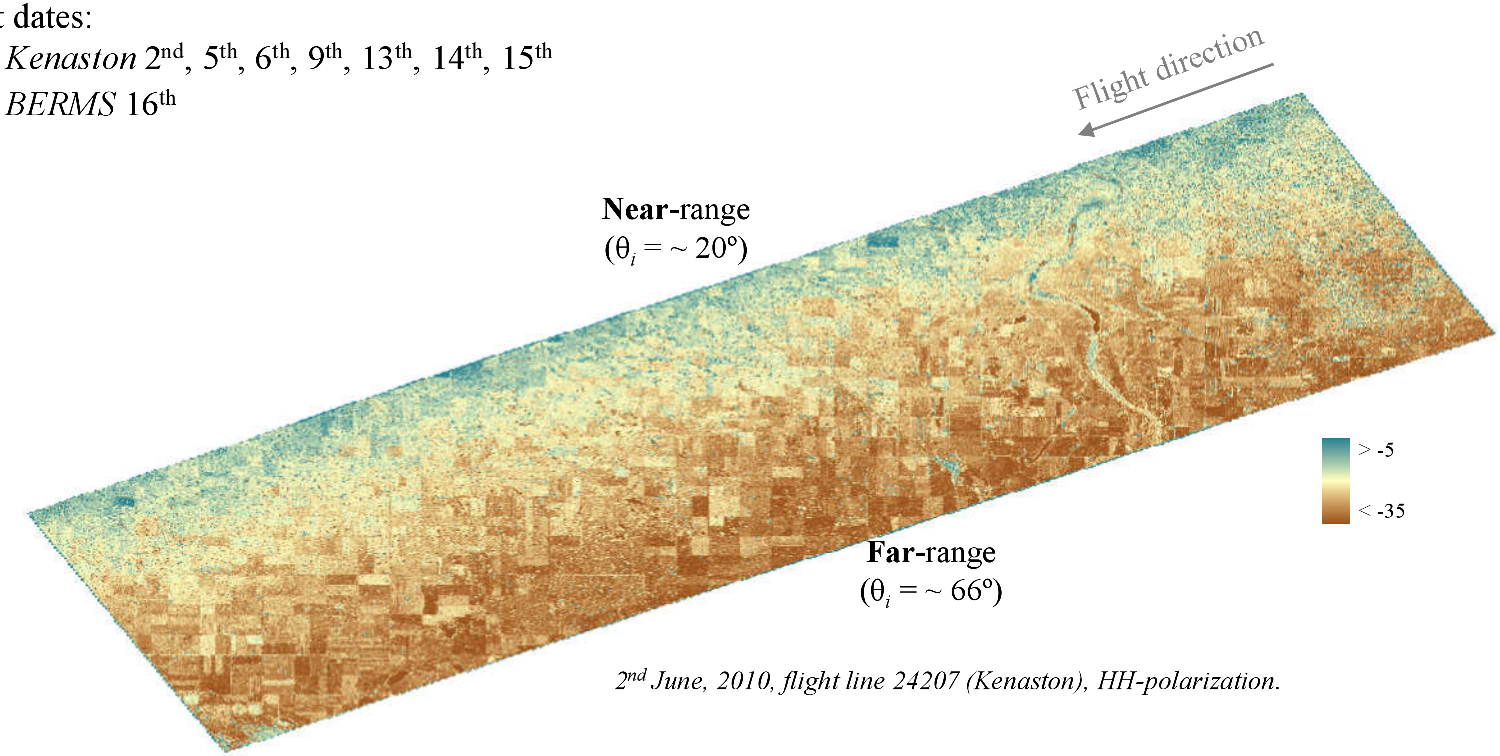
- What is needed is an accurate/robust method for normalizing the multi-incidence UAVSAR backscatter observations to a fixed incidence angle, i.e. 40º, so that the data can be exploited for SMAP.

CanEx-SM10: UAVSAR

- June 2010
- Two **study sites** 33 km x 71 km
  - *Kenaston*: agricultural crops and rangelands
  - *BERMS*: forest type of vegetation
- **UAVSAR**
  - Left-looking system
  - L-band radar
  - Quad Pol
  - Swath ~22 km
  - Flight dates:
    - *Kenaston* 2nd, 5th, 6th, 9th, 13th, 14th, 15th
    - *BERMS* 16th



Schematic representation of the locations of the CanEx-SM10 sampling sites within the Saskatchewan province, Canada.



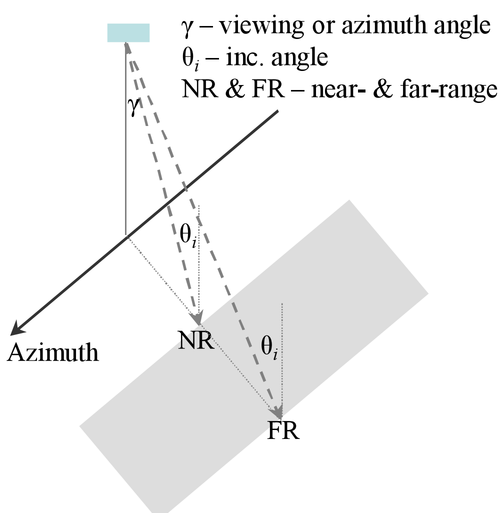
2nd June, 2010, flight line 24207 (Kenaston), HH-polarization.

Example of a UAVSAR data acquisition illustrating incidence angle impact on σ^o

Backscatter Dependence on Incidence Angle

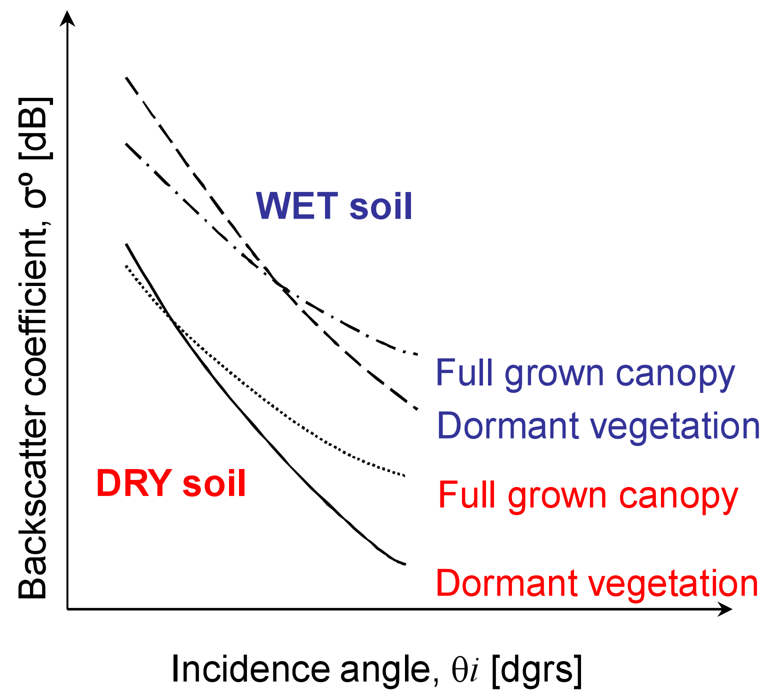
σ° is a function of sensor and terrain characteristics

Sensor	Terrain
Frequency (f)	Surface roughness (*h*)
Polarization (pp)	Dielectric properties (ε)
Viewing geometry (*v*)	Topography (t)
	Land cover (lc)



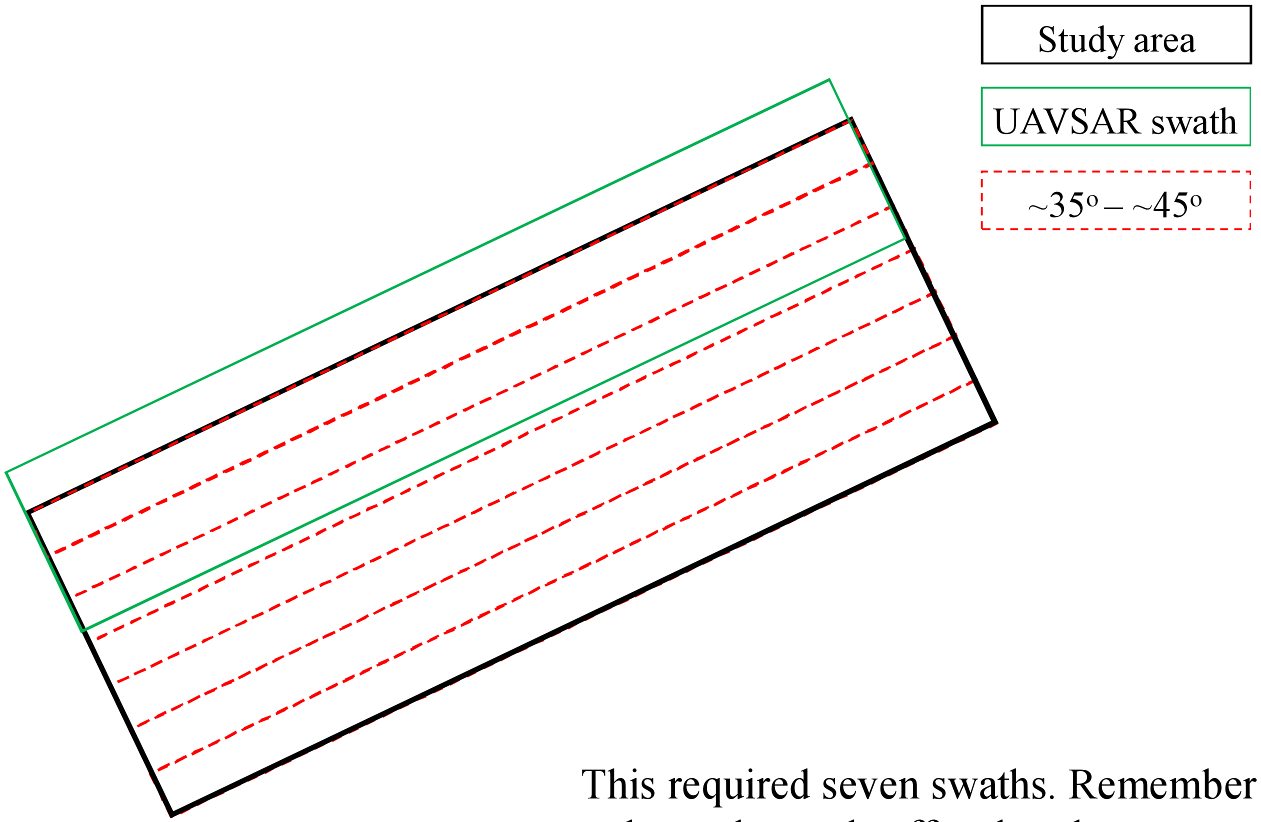
Viewing geometry of a left-looking SAR system.

Radar backscatter return will be stronger at smaller incidence angles and will decrease towards the far-range. Rate of decrease depends mostly on roughness conditions and land cover.



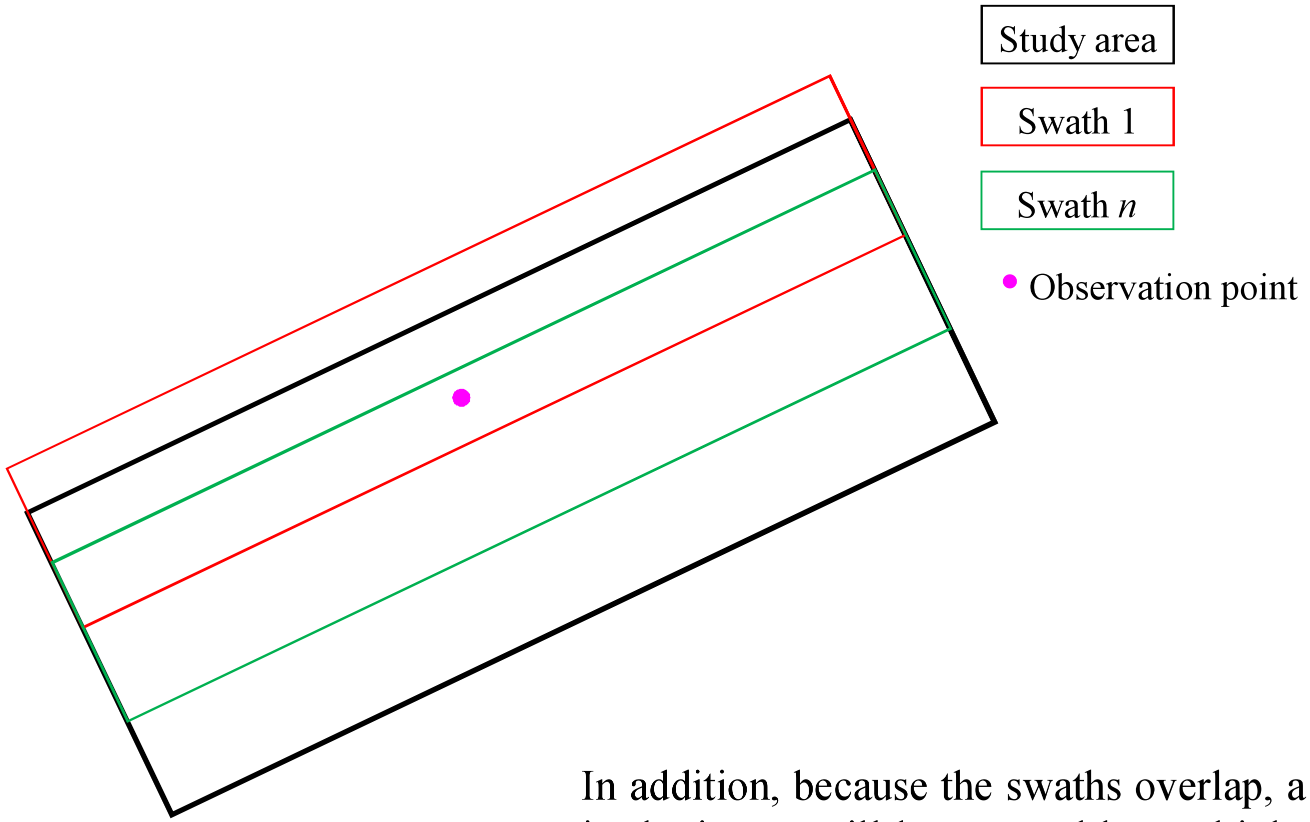
Characteristic backscatter-incidence angle curves for two soil moisture regimes as a function o f vegetation growth; image courtesy Wagner et al. (1999).

UAVSAR Flight Lines Design



This required seven swaths. Remember that this reduces the angle effect but does not remove it.

UAVSAR Flight Lines Design



In addition, because the swaths overlap, a point in the image will be covered by multiple lines, each with a different incidence angle. This allows us to quantify any error introduced in ignoring angle and methods for correction.

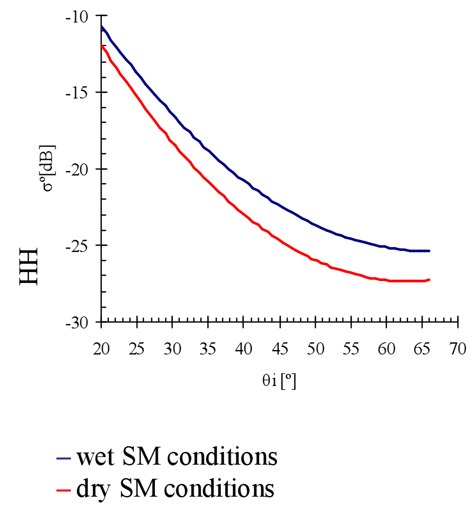
Previous Research

Approaches:

- Ignore when the incidence angle range is small; assume that the backscatter variability due to θ_i is negligible/minimal.
  - Even as little as 5° inc. angle can have ~3 dB difference between the near- and far-range. For comparison, approximately the same backscatter difference corresponds to ~0.15 m^3/m^3 soil moisture change [Oh et al., 1992].
- Cosine normalization based on the Lambert's Law of optics $\sigma^o_\theta = \sigma^o_0(\cos\theta)^n$, where $n = 2$
  - It has been suggested that in order to improve the cosine approach that *n* (the power index characterizing surface roughness) should not be constant [Ardila et al. (2010)]; however, the proposed approach for improved *n* estimation is regression based.
- Empirical, regression based approaches;
  - Often assume linear dependence of backscatter as a function of inc. angle; more importantly, this set of techniques are site- and sensor-specific.

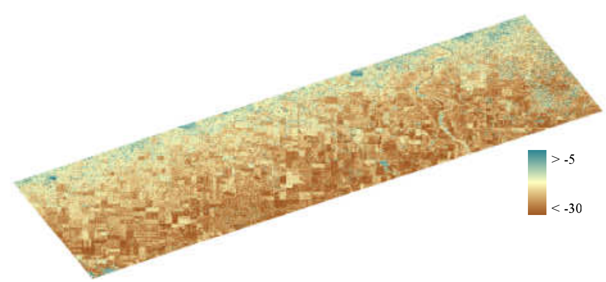
Overall, the available techniques are often sensor-specific and applicable to a limited range of ground/terrain conditions (i.e. not transferable).

What is needed is a robust technique that can be applied to any area and that is able to adequately correct throughout the whole incidence angle range.



Characteristic backscatter-incidence angle curves for two soil moisture regimes.

The inc. angle effect is still evident in the near-range section of the swath (lower inc. angles).



An example of cosine-based normalization for line 24207, June 2nd, 2010, HH-pol.

Proposed Approach: Histogram-based Normalization

- Based on 1° inc. angle
- Derived for each vegetation class

$$\sigma^\circ_{norm} = \overline{\sigma}^\circ_{ref} + \hat{\sigma}^\circ_{ref} \frac{(\sigma^\circ_{act} - \overline{\sigma}^\circ_{act})}{\hat{\sigma}^\circ_{act}}$$

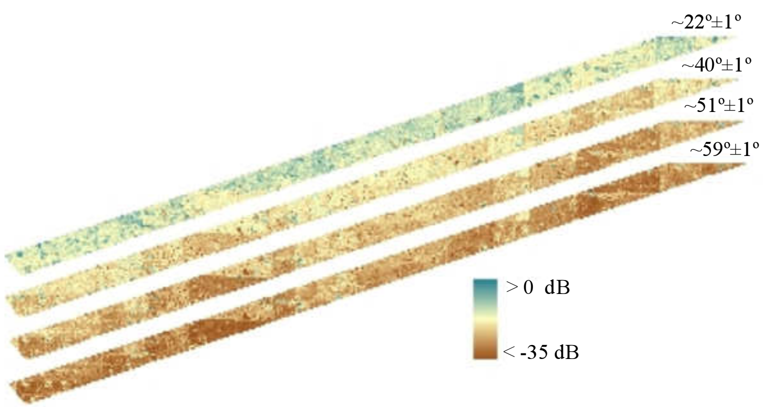
σ°_{norm} – normalized backscatter

σ°_{ref} – reference backscatter

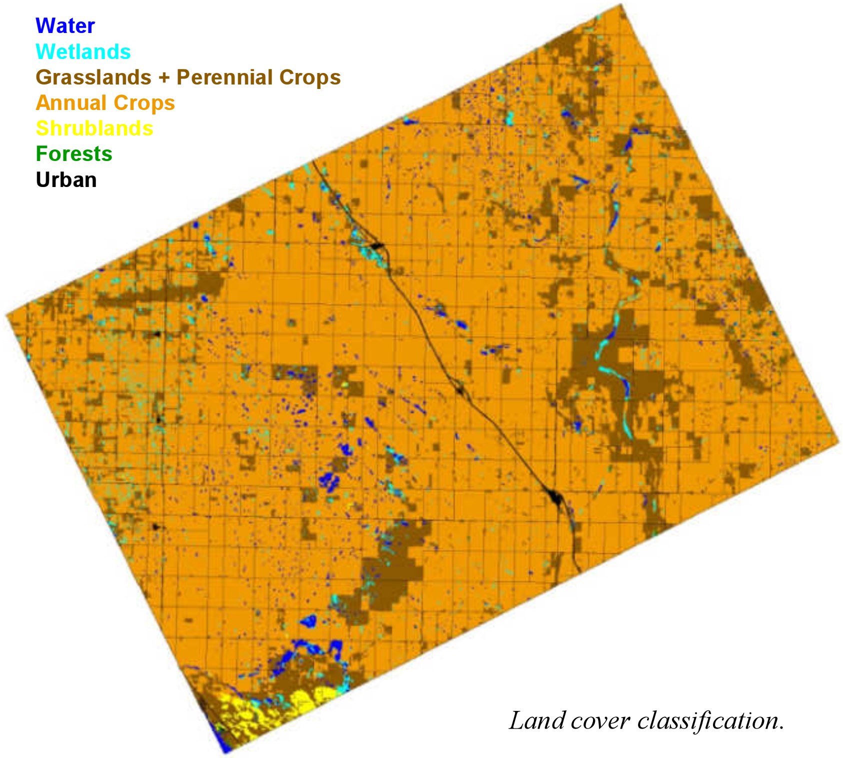
$\overline{\sigma^\circ}$ – mean

$\hat{\sigma}^\circ$ – standard deviation

- Data range constraints: Noise equivalent value < σ° > +3 dB
- Evaluation based on actual $\sigma^o_{40^o}$



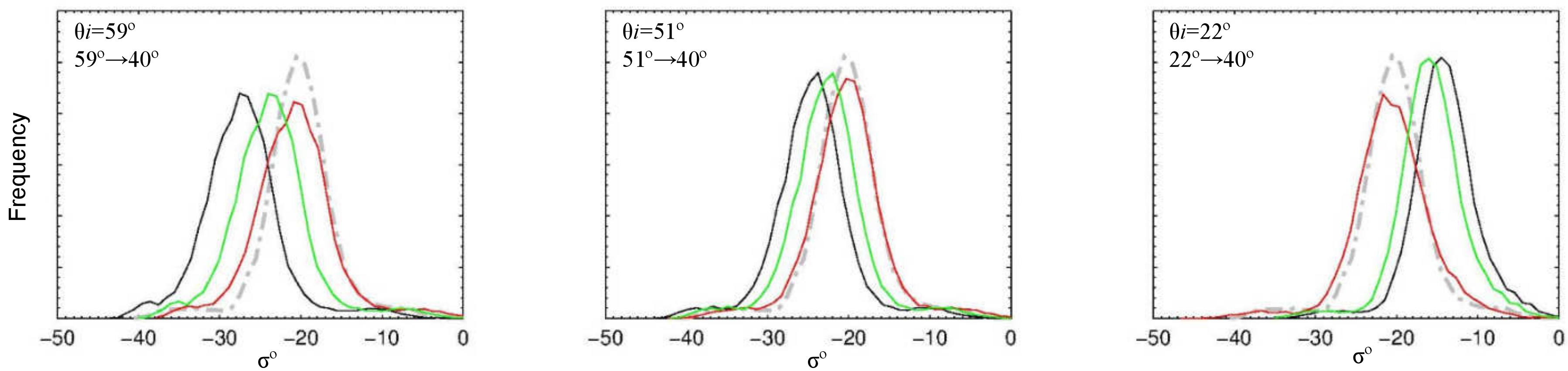
Example: The same area was observed on different lines at different angles.



Land cover classification.

Evaluation of Histogram-based Normalization: Histograms Example

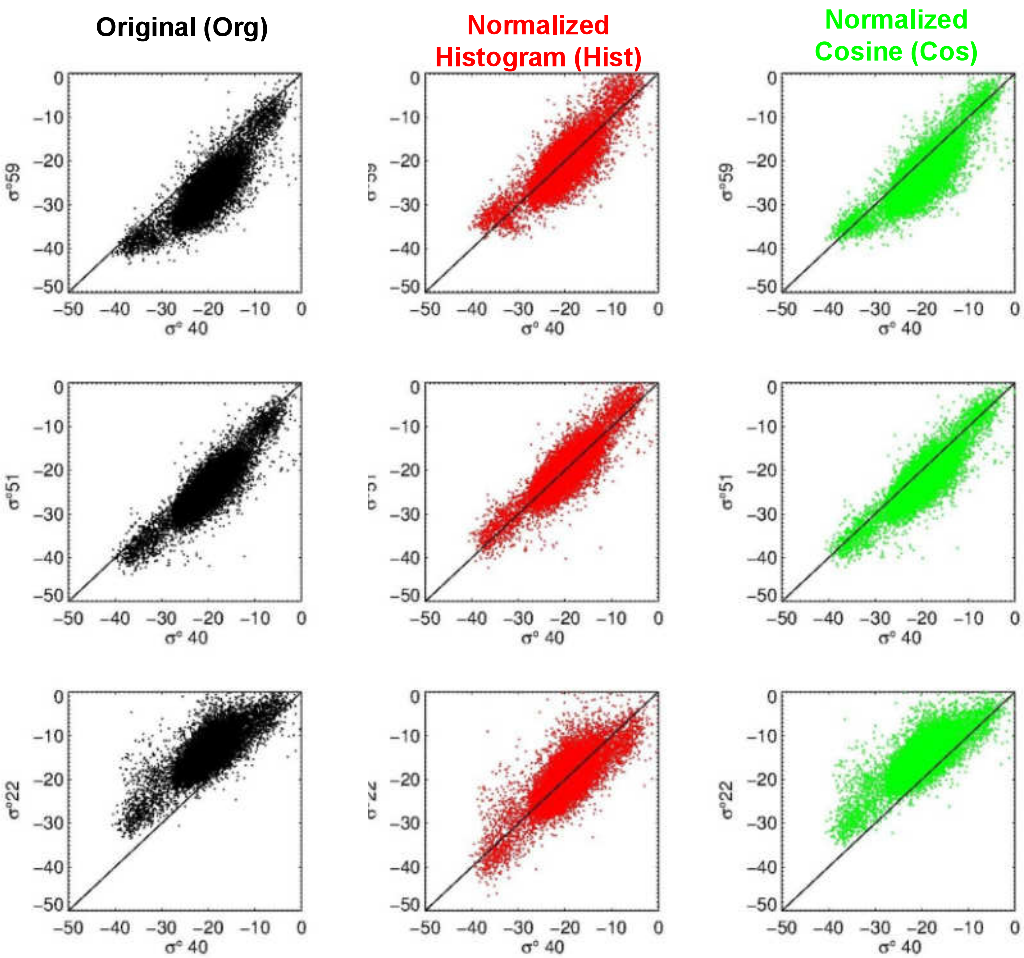
- UAVSAR, HH-pol
- Kenaston, one flight line, 5^{th} of June, 2010
  - Reference line: 24204; subset: 40°±0.02°
- Veg.: grasslands+perennial crops



Original observed at 40°
Original observed at θ*i*
Scaled to 40° using *Histogram*-based normalization approach
Scaled to 40° using *Cosine*-based normalization approach

Evaluation of Histogram-based Normalization

- Observed vs. Adjusted backscatter



θ*i*=~59°

	Org	Hist	Cos
RMSE	7.49	3.04	4.48
BIAS	-6.86	-0.42	-3.33
n=21752			

θ*i*=~51°

	Org	Hist	Cos
RMSE	4.82	2.53	3.40
BIAS	-4.12	0.02	-2.31
n=21769			

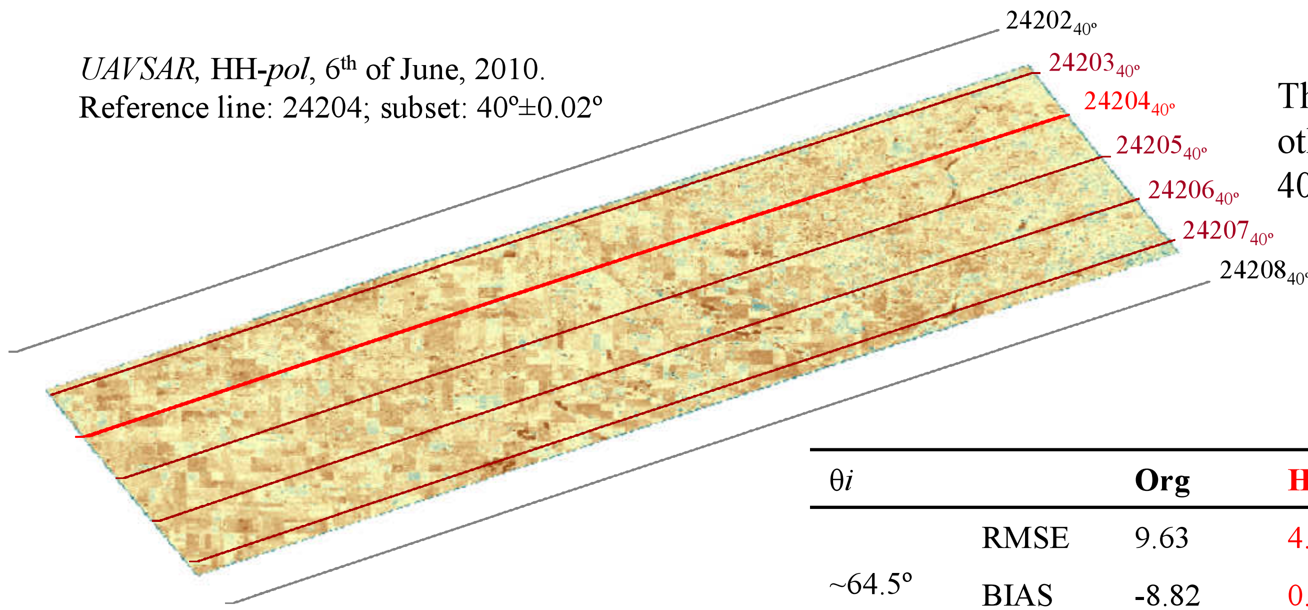
θ*i*=~22°

	Org	Hist	Cos
RMSE	6.86	3.25	5.46
BIAS	6.17	-0.30	4.57
n=21790			

- Correcting lower angles is more difficult.
- Cosine model might work for small ranges and higher angles.

Notation:
ORG - Statistics computed using original σ° data observed at θ*i* and σ° observed at 40°
HIST - Statistics computed using histogram normalized σ° data and σ° observed at 40°
COS - Statistics computed using cosine normalized σ° data and σ° observed at 40°

Evaluation of Histogram-based Normalization: Single Swath Example



This is the normalized swath.

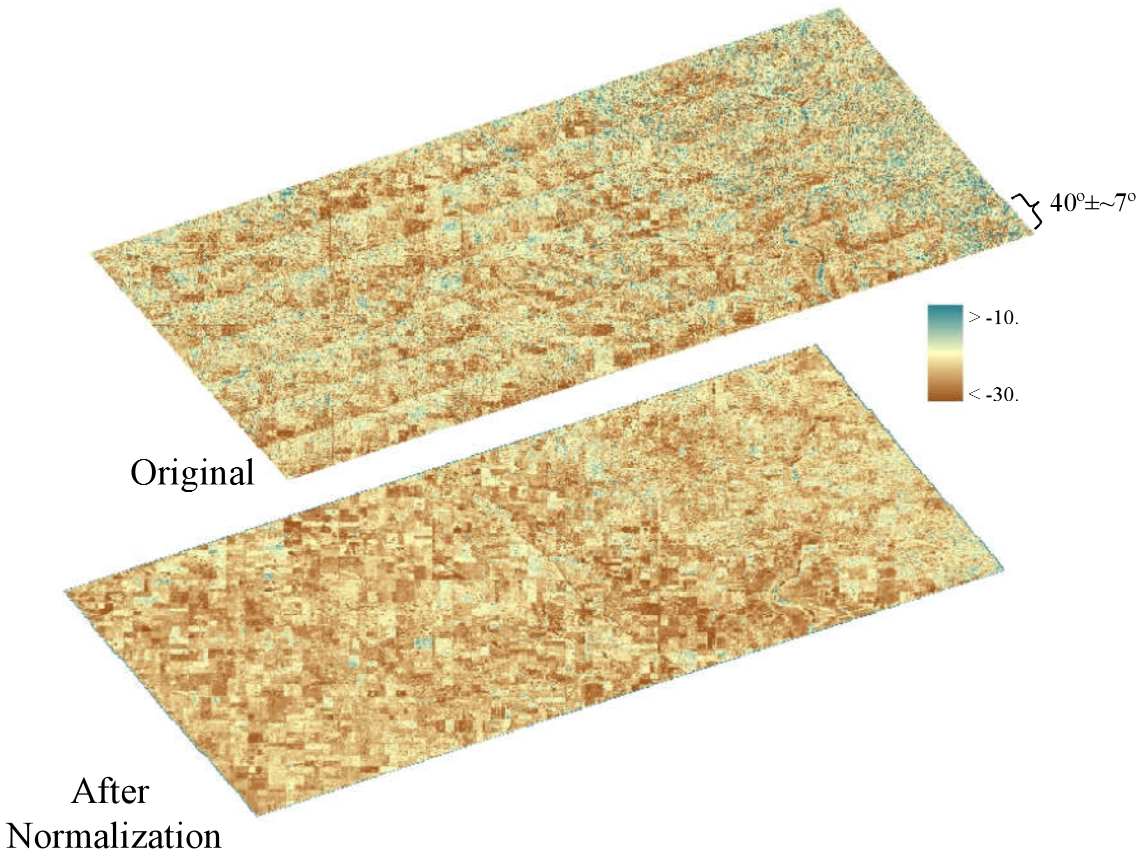
These are the portions of the other flight lines that provide 40° obs.

The Org. error is the comparison of the uncorrected data from line 24204 to the 40° data from the line that covers that location.

Hist. is the comparison of the corrected data. to the 40° data from the line that covers that location.

θ*i*		**Org**	**Hist**	**Cos**	*n*
~64.5°	RMSE	9.63	4.04	5.43	21675
	BIAS	-8.82	0.15	-3.82	
~59°	RMSE	7.77	2.82	4.72	21698
	BIAS	-7.18	0.33	-3.67	
~51°	RMSE	5.14	2.67	3.76	21777
	BIAS	-4.31	0.32	-2.51	
~22.6°	RMSE	7.11	3.23	5.72	21734
	BIAS	6.31	0.33	4.70	

Results: Can we mosaic the 7 flight lines and generate a 40º map of the area?

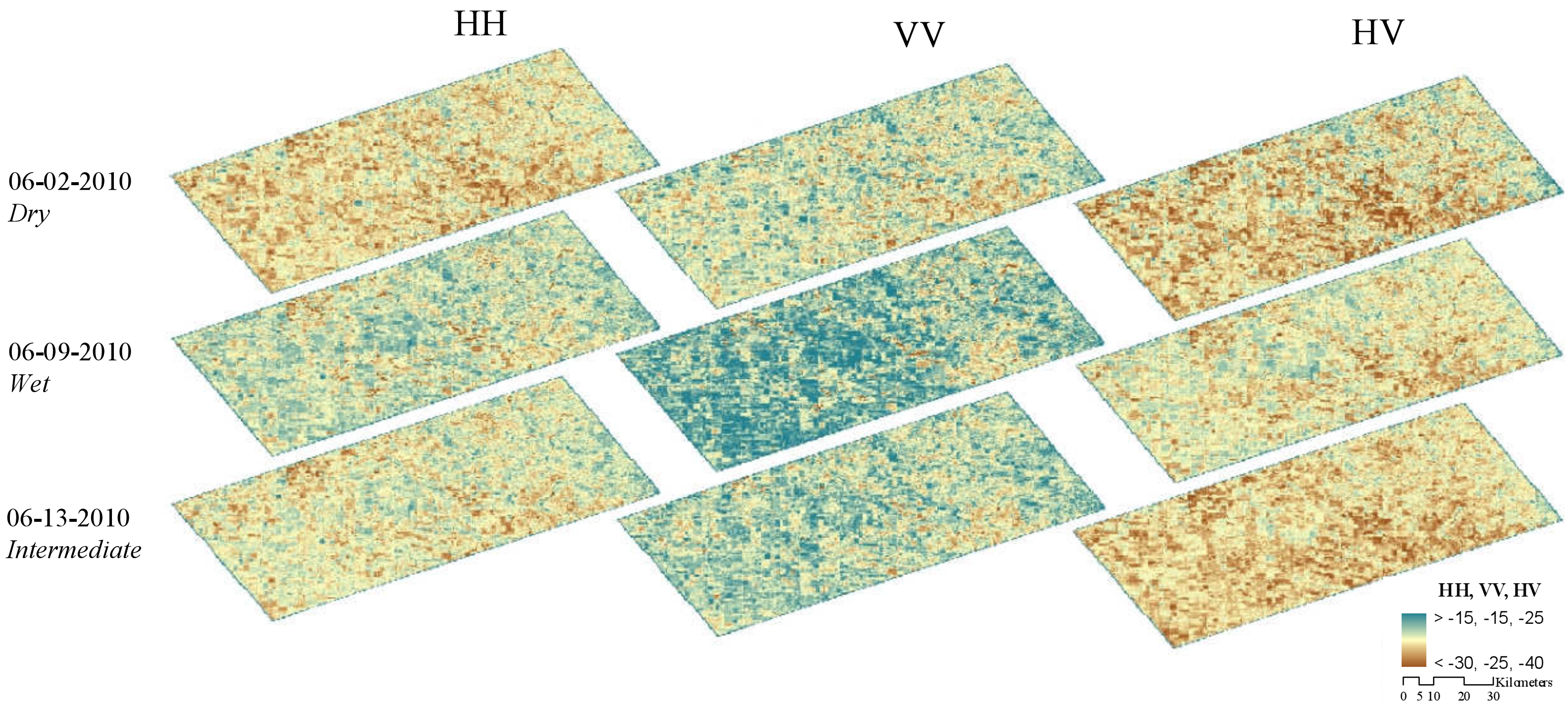


An example of mosaic map using the original UAVSAR backscatter data. The strips that are clearly noticeable in the upper image correspond to the individual flight lines where the width of each strip is equivalent to ~15º incidence angle range (40º±7º). Even though the inc. angle range of the individual subsets is relatively narrow the incidence angle effect is clearly visible.

Mosaic map generated after applying the proposed histogram normalization.

Whole study area, 2nd of June, 2010.

Results of Histogram-based Normalization: Different Soil Moisture Conditions



Selected dates for all polarizations

Summary

- Incidence angle induced variability on σ^{o} needs to be taken into account

- The proposed histogram-based normalization technique is easy to apply and requires little prior knowledge/ancillary information (land cover).

- Evaluation with actual observed data at 40^{o} demonstrated that the technique adequately accounts for the incidence angle effect.

- Further analyses are ongoing.