# Incidence Angle Normalization of Backscatter Data

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Feb. 25, 2011

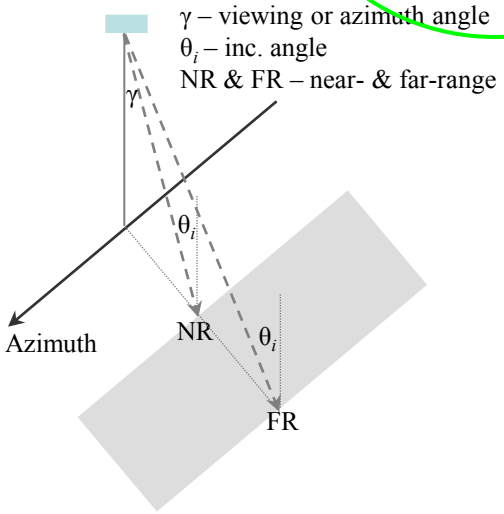
# Introduction

- SMAP: Soil Moisture Active Passive (NASA/JPL, 2014)
- We need backscatter data for algorithm development and validation.
- Aircraft-based SAR are very efficient mapping tools; however, these instruments observe at 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.
- Can we develop an accurate/reliable method of normalizing SAR data to a fixed incidence angle so that it can be exploited for SMAP?

# Backscatter Dependence on Incidence Angle

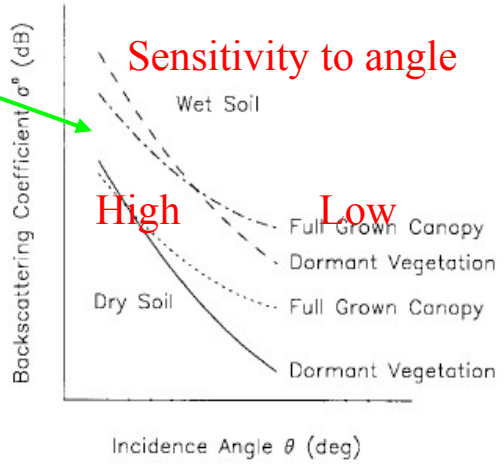
$\sigma^o$ is function of sensor and terrain characteristics

| Sensor | Terrain |
|---|---|
| Frequency (f) | Surface roughness (*h*) |
| Polarization (pp) | Dielectric properties (ε) |
| Viewing geometry (r) | Topography (t) |
| Resolution (r)? | Land cover (lc) |



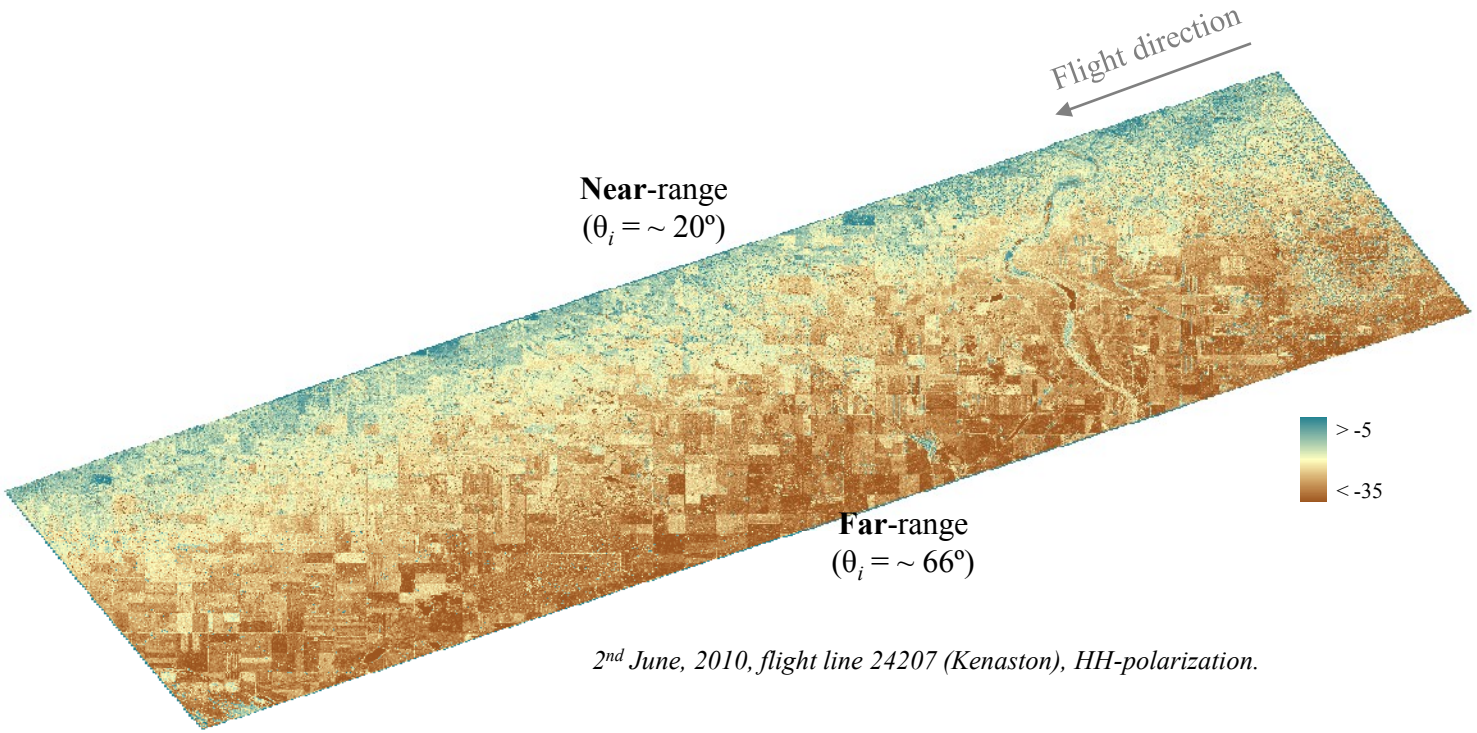

*Viewing geometry of a left-looking SAR system.*

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.



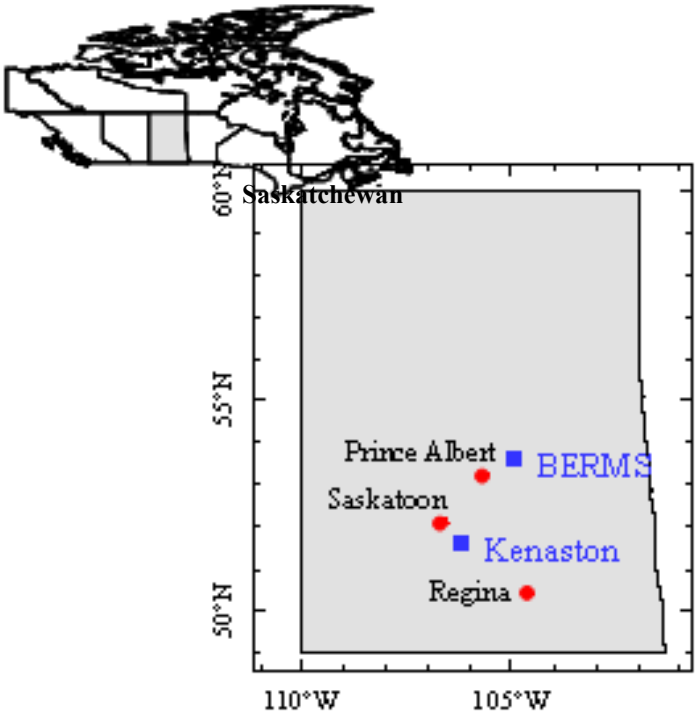

*Characteristic backscatter-incidence angle curves for two soil moisture regimes as a function o f vegetation growth. (image courtesy Wagner et al., 1999)*

# Example of a UAVSAR Data Acquisition Illustrating Incidence Angle Impact on σ°.




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

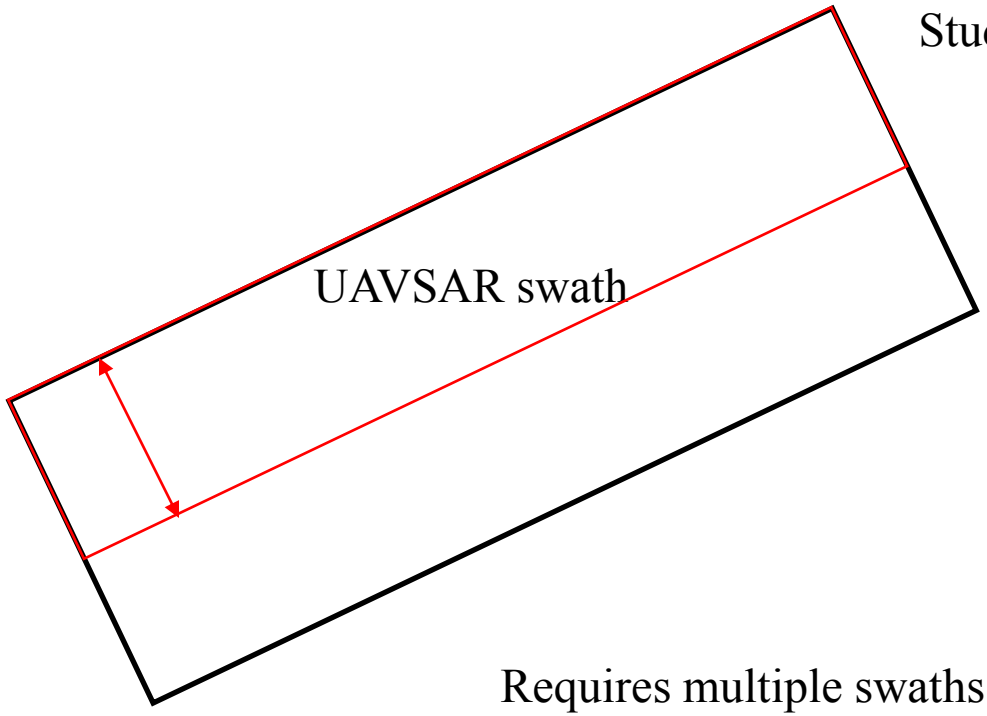
# CanEx-UAVSAR




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

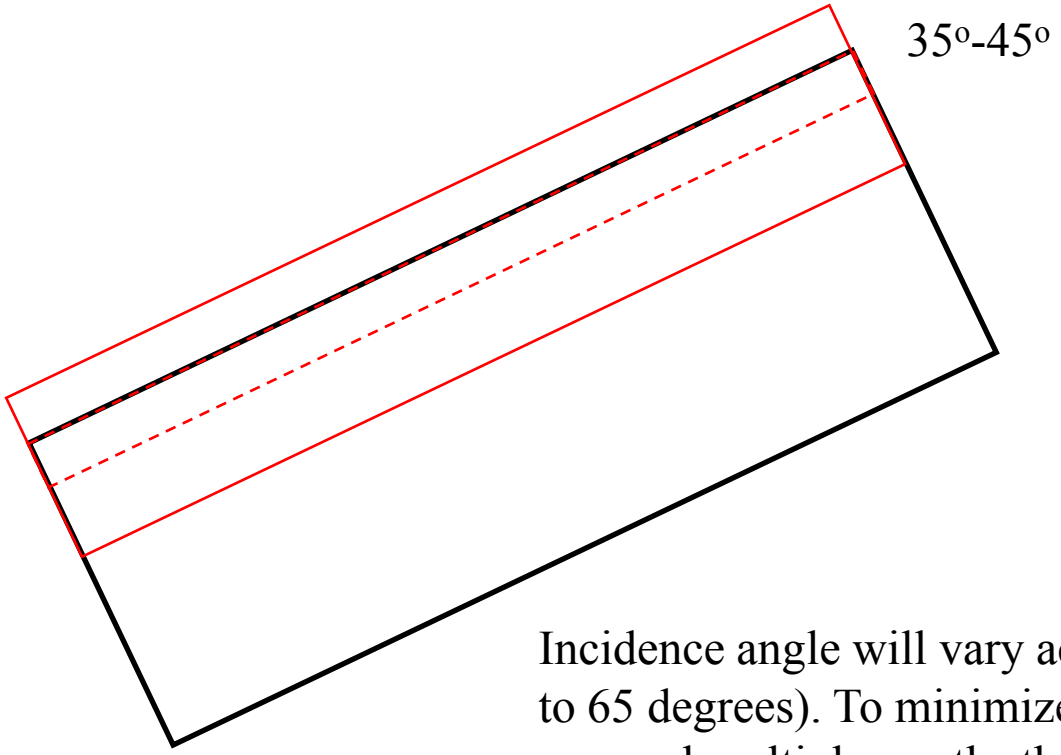
- June 2010
- Two study sites 33 km x 71 km
  - Kenaston (agricultural crops and rangelands)
  - BERMS (forested type of vegetation)
- UAVSAR L-band radar
  - Quad Pol
  - Swath~22 km
  - Resolution~10 m
- Flights
  - Kenaston 2nd, 5th, 6th, 9th, 13th, 14th, 15th
  - BERMS 16th

# UAVSAR and Kenaston Design



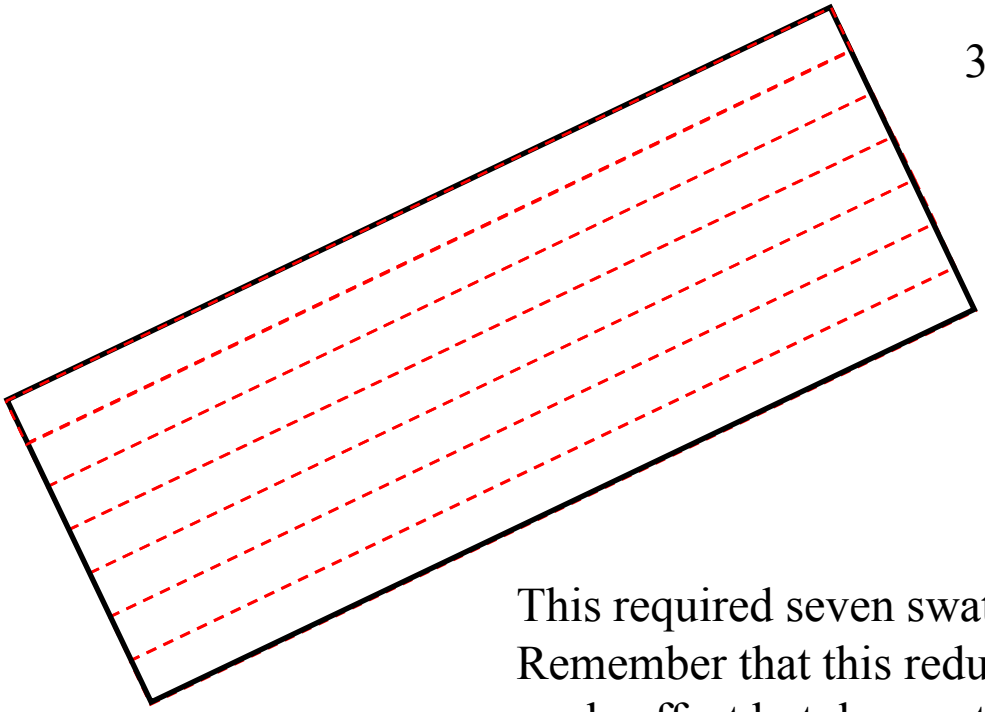

Requires multiple swaths to cover the study area.

# UAVSAR and Kenaston Design




Incidence angle will vary across the swath (20 to 65 degrees). To minimize the impact of this, we used multiple swaths that were offset to provide coverage of the study area within a narrow range of the SMAP angle of incidence.

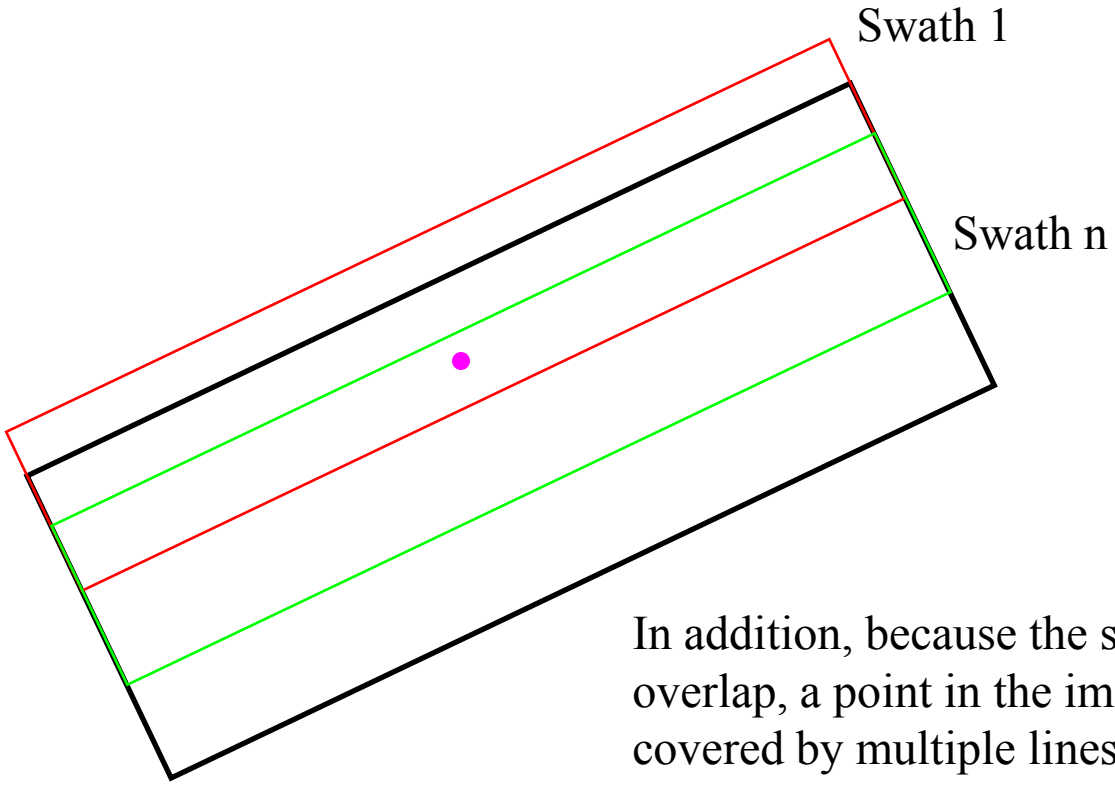
# UAVSAR and Kenaston Design



35°-45°

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

# UAVSAR and Kenaston Design

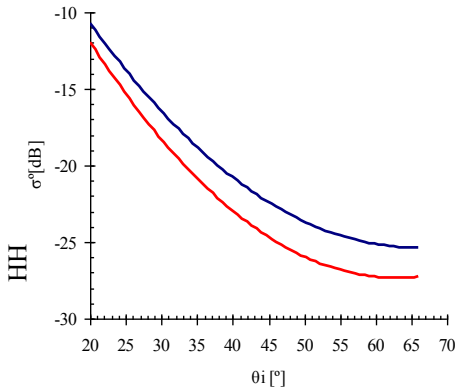



In addition, because the swaths overlap, a point in the image will be covered by multiple lines. Each with a different incidence angle. This allows us to quantify any error introduced in ignoring angle and methods for correction.

# Previous Research

Approaches:

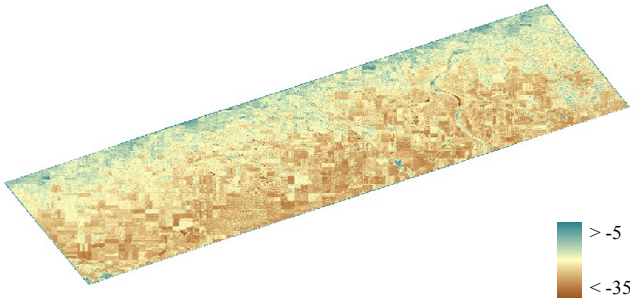
- Ignore when the incidence angle range is small; assume that the backscatter variability due to θi is negligible/minimal.
  - Even as little as 5 inc. angle can have ~3 dB difference between the near- and far-range. For comparison, approximately the same backscatter difference corresponds to ~15% soil 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 n (the power index characterizing surface roughness) should not be constant [Ardila et al. (2010)]; however, the proposed by the authors approach for improved n estimation is regression based.
- Empirical, regression based approaches;
  - Often assume linear dependency of backscatter as a function of inc. angle; more importantly, this set of techniques are site- and sensor-specific.




– wet SM conditions
– dry SM conditions

*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.*

**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.***

# Proposed Approach: Histogram-based Normalization

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

$$\sigma_{..orm} = \sigma_{..ef} + \hat{\sigma}_{..ef}\frac{(\sigma_{..ct} - \sigma_{..ct})}{\hat{\sigma}_{..ct}}$$

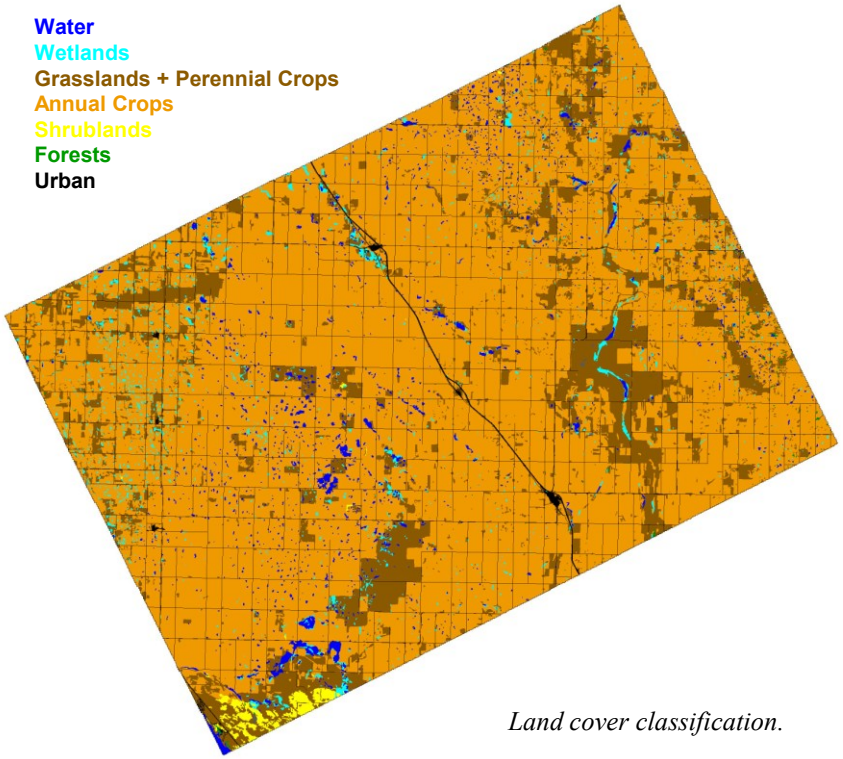
$\sigma^\circ_{norm}$ – ormalized backscatter

$\sigma^\circ_{ref}$ – eference backscatter

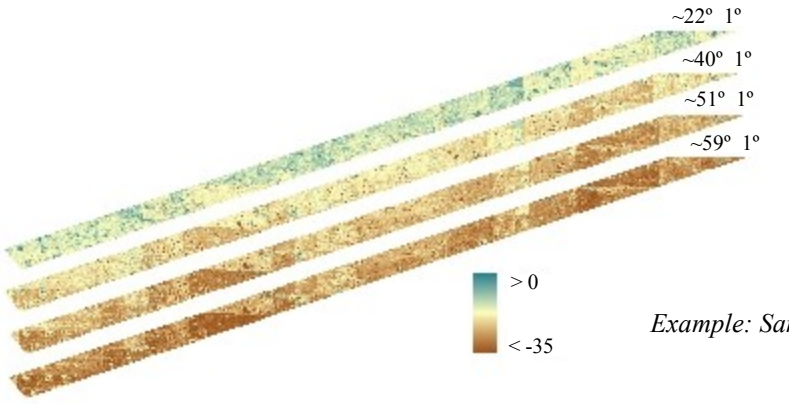
$\bar{\sigma}^\circ$ - nean

$\hat{\sigma}^\circ$ - tandard deviation

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



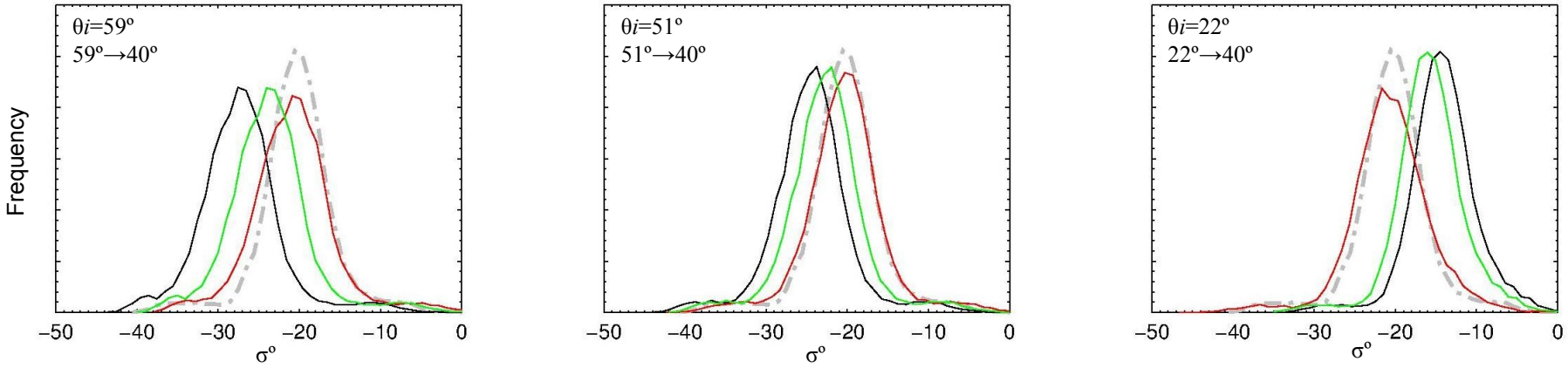

*Land cover classification.*




*Example: Same area was observed by different lines at different angles.*

# Evaluation of Histogram-based Normalization: Histograms Example

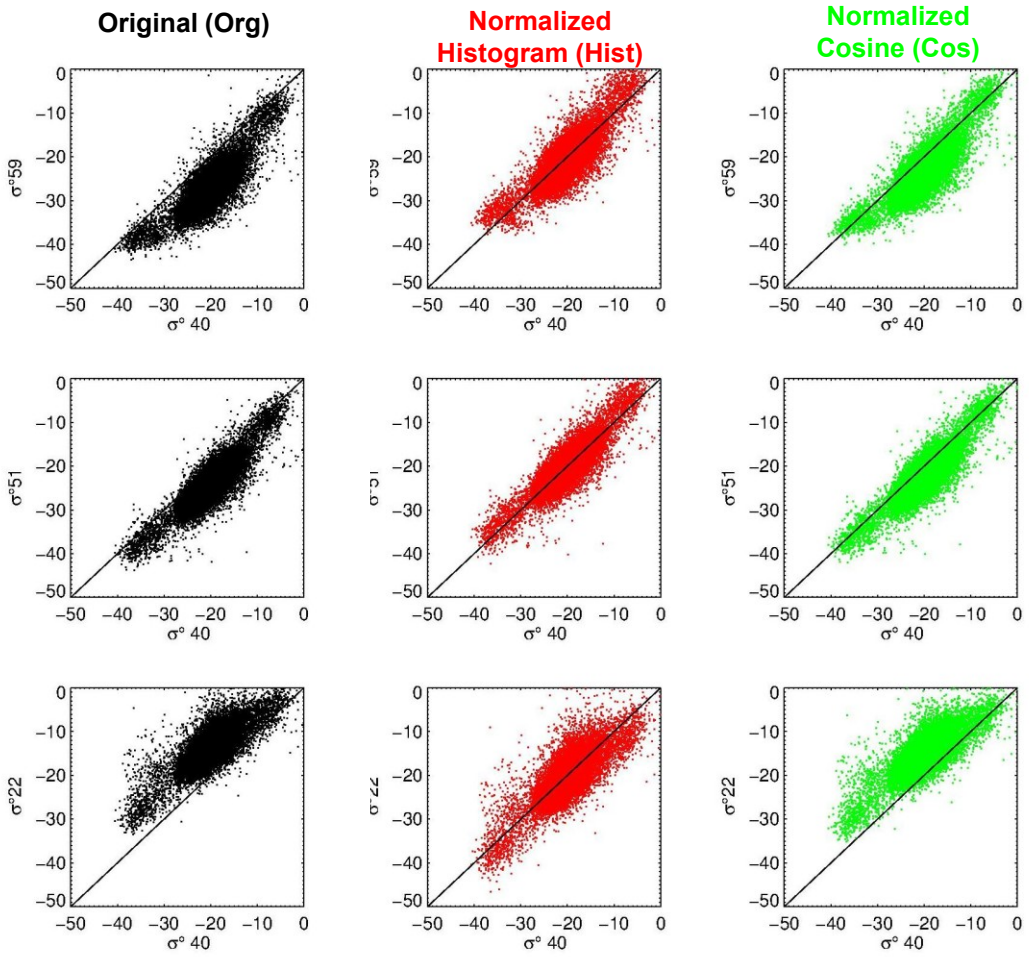
- UAVSAR, HH-pol
- Kenaston, One flight line-5th of June, 2010
  - Reference line: 24204; subset: 40º±0.02º
- Veg.: grasslands+perennial crops




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

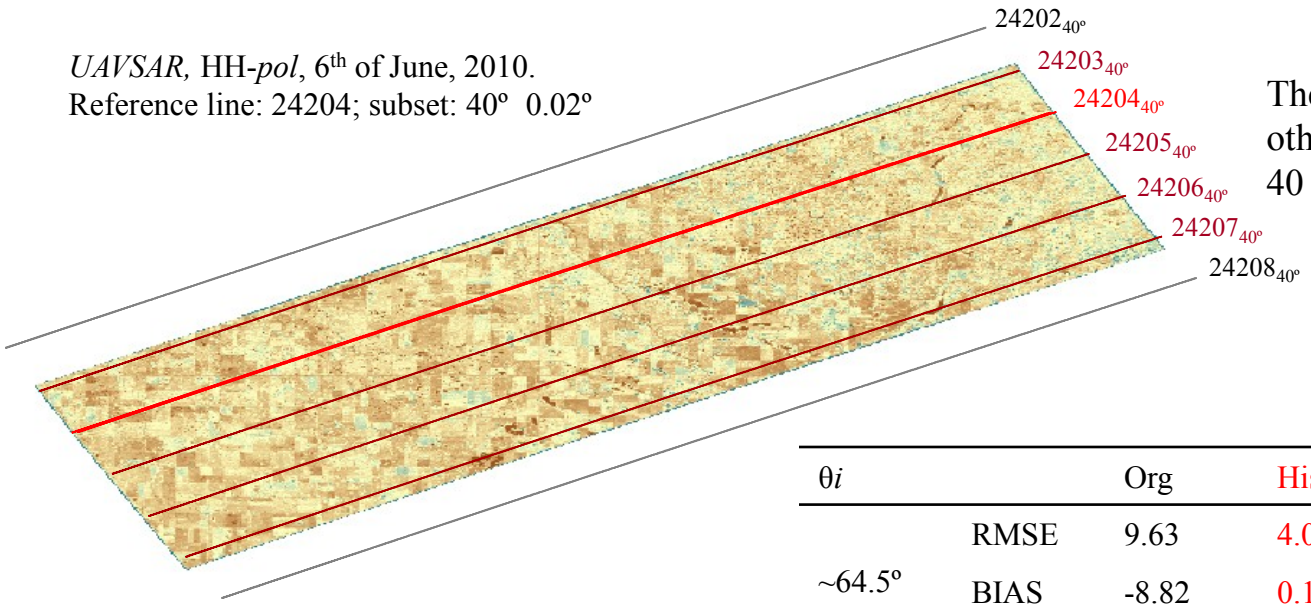
| | Org | Hist | Cos |
|---|---|---|---|
| RMSE | 6.86 | 3.25 | 5.46 |
| BIAS | 6.17 | -0.30 | 4.57 |

*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



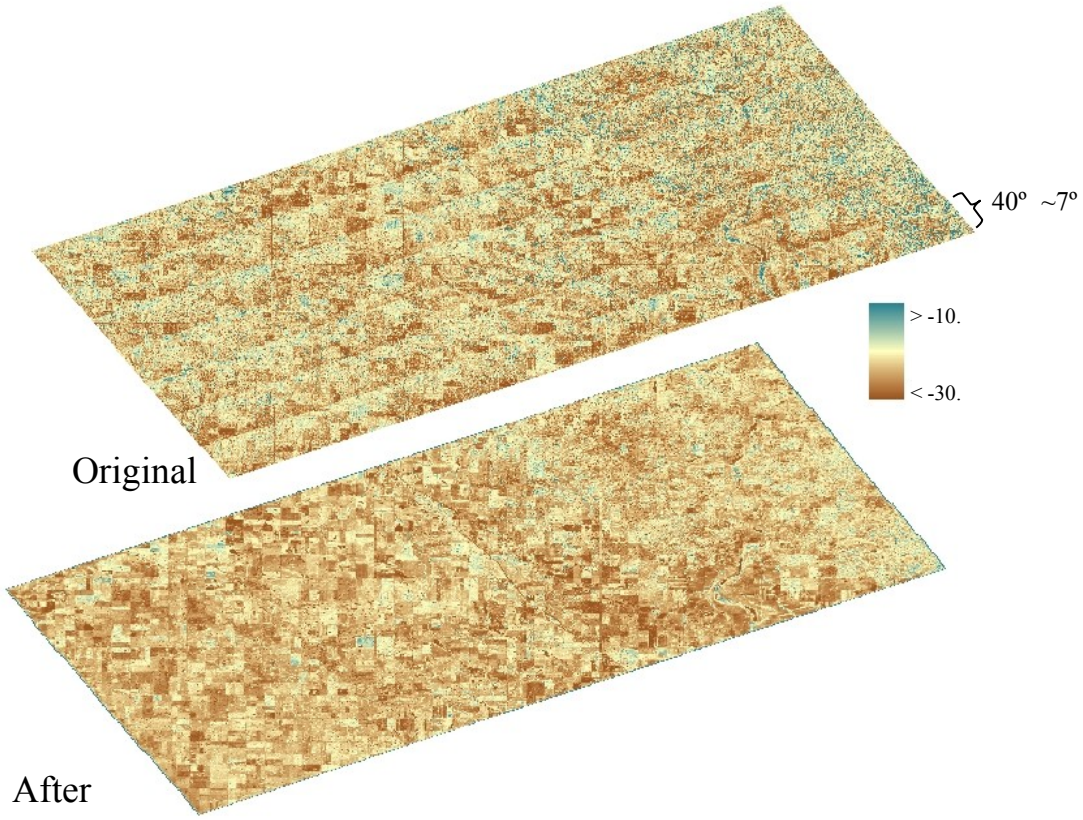

This is the normalized swath.

These are the portions of the other flightlines that provide 40 deg. obs.

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

| θ*i* | | Org | Hist | Bias | *n* |
|---|---|---|---|---|---|
| ~64.5º | RMSE | 9.63 | 4.04 | 5.43 | 21675 |
| | BIAS | -8.82 | 0.15 | -3.82 | |
| ~59º | RMSE | 7.77 | 2.82 | 4.72 | 21698 |
| | BIAS | -7.18 | 0.33 | -3.67 | |
| ~51º | RMSE | 5.14 | 2.67 | 3.76 | 21777 |
| | BIAS | -4.31 | 0.32 | -2.51 | |
| ~22.6º | 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 continuous map of the area?



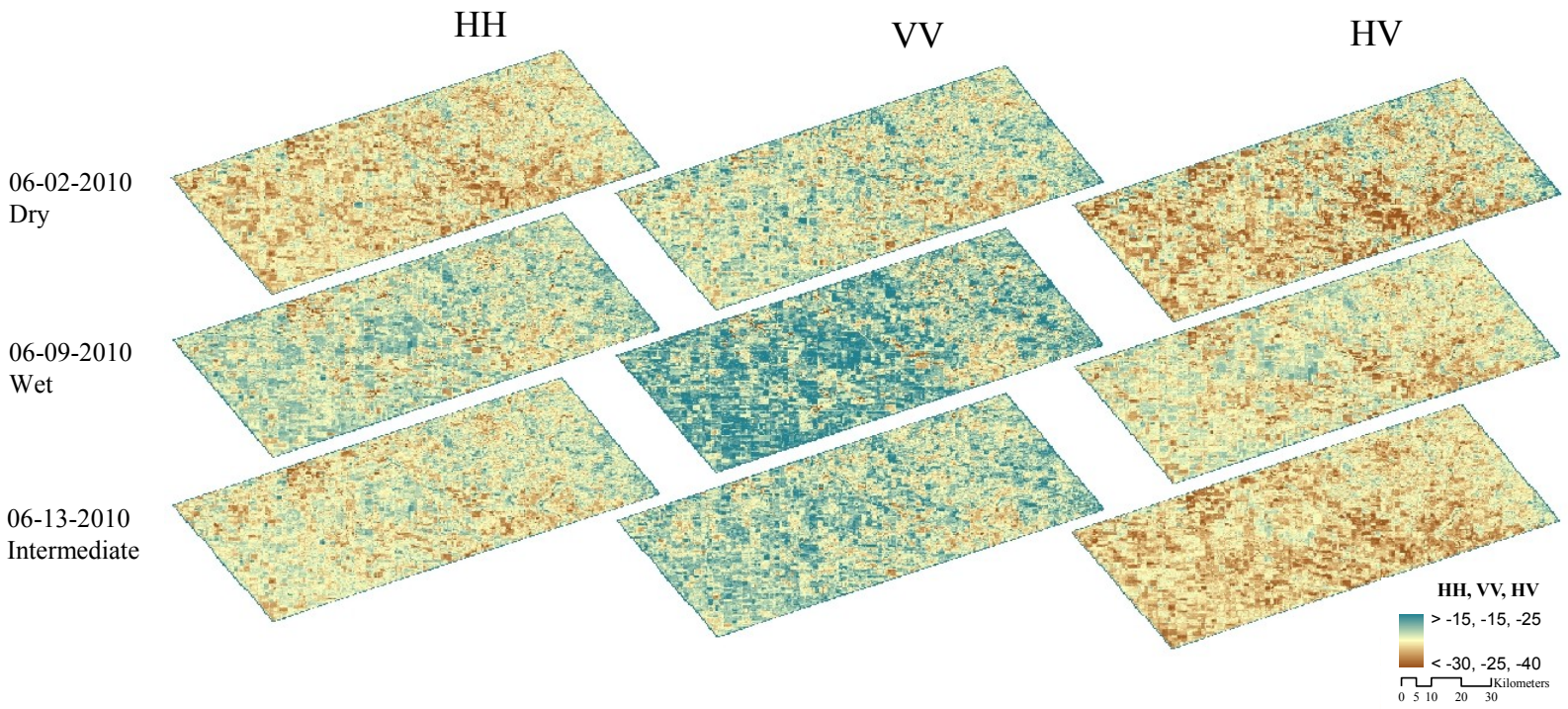

An example of mosaic map using the original UAVSAR backscatter data. The strips clearly noticeable in the upper image correspond to the individual flight lines where the width of each strip is equivalent to ~15º incidence angle range (40º 7º). Even though the inc. angle range of the individual subsets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

Mosaic map generated after applying the proposed histogram normalization.

- Whole study area, 02 June, 2010

# Results of Histogram-based Normalization

- Selected dates for all polarizations



# Summary

- Incidence angle induced variability needs to be taken into account
- The proposed histogram-based normalization technique is easy to be applied and requires little prior knowledge/ancillary information (land cover).
- Evaluation with actual observed data at 40º demonstrated that the technique adequately accounts for the incidence angle effect.
- Further analyses are ongoing.
- Would be applicable to PLIS.