Local Incidence Angle Considered Harmful

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Outline

- Review of Radiometric Normalisation Conventions
- Role of Local Incidence Angle
- Evaluation of Radiometric Terrain Correction Methods
- Examples from PALSAR & ASAR
- Conclusions
Radiometric Normalisation
Conventions
Standard Areas for *Ellipsoid-normalisation*

*modified from Ulaby & Dobson, Handbook of Radar Scattering Statistics for Terrain, 1989*
Standard Areas for *Ellipsoid-normalisation*

Standard Areas for *Ellipsoid-normalisation*


Tuesday, 17 November 2009
Ground Illuminated Area

<table>
<thead>
<tr>
<th>$\beta^0$</th>
<th>$\sigma_E^0$</th>
<th>$\gamma_E^0$</th>
</tr>
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<tr>
<td>$A_\beta = \delta_r \cdot \delta_a$</td>
<td>$A_\sigma = \delta_g \cdot \delta_a$</td>
<td>$A_\gamma = \delta_p \cdot \delta_a$</td>
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$\gamma_E^0 = \beta^0 \cdot A_\beta / A_\gamma = \beta^0 \cdot \tan \theta$

$\sigma_E^0 = \beta^0 \cdot A_\beta / A_\sigma = \beta^0 \cdot \sin \theta$
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Ellipsoidal Model
Radar Equation & Reference Area

• Relating received to transmitted power:
\[
\overline{P_r} = \frac{\lambda^2}{(4\pi)^3} \cdot \int_{\text{area illuminated}} \frac{P_t G^2}{R^4} \cdot \sigma^0 dA
\]

• Standard equation of: \( \sigma^0 = \beta^0 \cdot \sin \theta_e \)

uses an *ellipsoid Earth model* approximation as a standard normalisation area - using ellipsoidal incidence angle \( \theta_e \) as a proxy for area

For radiometric terrain correction, we need to actually perform the integration on a DEM.
## Existing SAR Normalisation Conventions: $\beta^0, \sigma^0, \gamma^0$

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Normalisation Area</th>
<th>Derivation (ignoring terrain effects!)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>$\beta$</td>
<td>None</td>
<td>$\beta = k \cdot \frac{P_s}{P_i}$</td>
</tr>
<tr>
<td>Beta Nought</td>
<td>$\beta^0$</td>
<td>Sample Interval in Slant Range Plane: $A_\beta$</td>
<td>$\beta^0 = \beta / A_\beta$</td>
</tr>
<tr>
<td>Sigma Nought</td>
<td>$\sigma^0_E$</td>
<td>Ground Area: $A_{\sigma}$</td>
<td>$\beta^0 \cdot \frac{A_\beta}{A_{\sigma}} = \beta^0 \cdot \sin \theta_e$</td>
</tr>
<tr>
<td>Gamma Nought</td>
<td>$\gamma^0_E$</td>
<td>Ground Area projected in plane $\perp$ to Look Direction: $A_{\gamma}$</td>
<td>$\beta^0 \cdot \frac{A_\beta}{A_{\gamma}} = \beta^0 \cdot \tan \theta_e$</td>
</tr>
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</table>
Time to Leave Kansas

• “The” Local Incidence Angle a flawed concept:
  • adapted from ellipsoidal incidence angle for flatlands
  • fails to account for:
    • shadow
    • foreshortening
    • layover

• Improve sensor model:
  • use local illuminated area, not angle!
## Summary of Normalisation Conventions

<table>
<thead>
<tr>
<th>Convention</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Model</td>
<td>None</td>
<td>Ellipsoid</td>
<td>Terrain</td>
<td></td>
</tr>
<tr>
<td>Reference Area</td>
<td>$A_\beta$</td>
<td>$A_\sigma$</td>
<td>$A_\gamma$</td>
<td>$A_\gamma$</td>
</tr>
<tr>
<td>Area Derivation</td>
<td>$\delta_r \cdot \delta_a$</td>
<td>$\delta_g \cdot \delta_a$</td>
<td>$\delta_p \cdot \delta_a$</td>
<td>$\int_{DHM} \delta_p \cdot \delta_a$</td>
</tr>
<tr>
<td>Normalisation</td>
<td>$\beta^0 = \frac{\beta}{A_\beta}$</td>
<td>$\beta^0 \cdot \frac{A_\beta}{A_\sigma} = \beta^0 \cdot \sin \theta_e$</td>
<td>$\beta^0 \cdot \frac{A_\beta}{A_\gamma} = \beta^0 \cdot \tan \theta_e$</td>
<td>$\beta^0 \cdot \frac{A_\beta}{A_\gamma}$</td>
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Local Incidence Angle Mask (LIM)

• The most common slope-normalisation methodology found in the literature is best placed between the ellipsoid- and terrain-based normalisation conventions.

• Normalisation for local variation of scattering area:

\[ \sigma^0_{NORLIM} = \sigma^0_E \cdot \frac{\sin \theta}{\sin \theta_{mid}} \]

Kellndorfer et al., TGRS, Sept. 1998.
## Introducing Terrain-Normalisation

<table>
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<th>Name</th>
<th>Symbol</th>
<th>Normalisation Reference</th>
<th>Derivation</th>
</tr>
</thead>
</table>
| Beta Nought           | $\beta^0$ | Area formed by Sample Intervals in Slant Range / Azimuth Plane | $\beta = k \cdot P_s/P_i$  
$\beta^0 = \beta/A_\beta$ |
| Sigma Nought          | $\sigma^0_E$ | Ellipsoid Ground Area                                       | $\sigma^0_E = \beta^0 \cdot A_\beta/A_\sigma$ |
| Gamma Nought          | $\gamma^0_E$ | Ellipsoid Ground Area projected in plane $\perp$ to Look Direction | $\gamma^0_E = \beta^0 \cdot A_\beta/A_\gamma$ |
| Gamma Taut            | $\gamma^0_T$ | Integrated Terrain Area projected in plane $\perp$ to Look Direction | $\gamma^0_T = \beta^0 \cdot A_\beta/A_\gamma$ |

*Note: $k$, $P_s$, $P_i$, $A_\beta$, $A_\sigma$, $A_\gamma$ are constants and variables related to the normalisation process.*
Definition of **Taut**

*Merriam-Webster Dictionary:*

1. *having no give or slack: tightly drawn*

2. *kept in proper order or condition*

3. *not loose or flabby; marked by economy of structure and detail*
Evaluation of Normalisation Methods

Flatlands  Lowlands / Simple
Evaluation of Normalisation Methods

Flatlands  Lowlands / Simple
Evaluation of Normalisation Methods

Flatlands  Lowlands / Simple  Alpine / Complex

Seek out complex (challenging) terrain for RTC testing!
Olympic Peninsula - Washington, USA

- Located at NW corner of continental USA - terrain ranging from sea level to mountainous
- DEM: SRTM3 v4 CGIAR
- **ASAR** beam-diverse **IM** & **AP** acquisitions
Olympic Peninsula - GTC vs. RTC

ASAR AP 2004.10.09 IS7 - scaled -20 to +5 dB/m²
ASAR AP 2006.04.29 ISI - scaled -20 to +5 dB/m²
Olympic Peninsula - GTC vs. RTC

ASAR AP 2007.12.230 IS4 - scaled -20 to +5 dB/m²
Olympic Peninsula - GTC vs. LIM vs. RTC

ASAR IM 2007.10.18 IS6 - 25dB dynamic range

GTC
c
NORLIM
c
RTC
Tests of Flatness

• GTC vs. RTC

• Histograms of backscatter for GTC/RTC
RTC - Olympic Peninsula: ASAR IM IS6D VV

RTC

WA, ASAR IM 2007.10.18

Fraction of Occurrences

Gamma Taut [dB m^{-2}]

-30 -20 -10 0 10 20 30

0.25
0.20
0.15
0.10
0.05
0.00

-30 -20 -10 0 10 20 30

Gamma Taut [dB m^{-2}]

0.25
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GTC - Olympic Peninsula: ASAR AP IS7D HV

Fraction of Occurrences vs. Beta Nought [dB m⁻²]

WA, ASAR AP 2004.09.04

GTC

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NORLIM - Olympic Peninsula: ASAR AP IS7D HV
Switzerland: PALSAR FBD

HH & HV polarisations
Switzerland: 
not in Kansas anymore

FBD tests in Bernese Oberland: 
GTC vs. NORLIM vs. RTC

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Bernese Oberland, Switzerland

>3000m of in-scene height variations

2008.06.02A

GTC

FBD HV

DHM25 courtesy swisstopo

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Bernese Oberland, Switzerland

2008.06.02A

RTC
FBD HV

DHM25 courtesy swisstopo

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Bernese Oberland, Switzerland

Interlaken

2008.06.02A

RTC FBD HV

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Bernese Oberland, Switzerland
Bernese Oberland, Switzerland

2008.07.18A

RTC

FBD HV

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Bernese Oberland, Switzerland
Bernese Oberland, Switzerland

2008.07.01A

RTC

FBD HV

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PALSAR: Forest vs. Non-Forest

- Forest boundary ambiguous in GTC imagery (influence of terrain interferes)

- Forest boundary relatively clear in RTC imagery (terrain influence largely eliminated)
Mixture of terrain and thematic land cover

Lake Geneva

2008.06.19A
GTC

SW Switzerland

FBD HV

20dB
SW Switzerland

Thematic land cover

Lake Geneva

2008.06.19A

RTC

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SW Switzerland

Mixture of terrain (reduced) and thematic land cover

Lake Geneva

2008.06.19A

NORLIM

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Bernese Oberland, Fribourg, & Vaud - SW Switzerland

NORLIM
Local Incidence-angle Mask

RTC
Image Simulation

NORLIM
FBD 2008.06.19A

RTC

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GTC on Foreslopes
RTC on Foreslopes

FBD 2008.06.19A

Fraction of Occurrences

Backscatter [dB]

0.00 0.02 0.04 0.06 0.08

-30 -20 -10 0 10
NORLIM on Foreslopes

Poor performance: mixture of under- and over-correction
GTC on Backslopes

Backslope-GTC

Fraction of Occurrences

Backscatter [dB]

0.00 0.01 0.02 0.03 0.04 0.05
-30 -20 -10 0 10

FBD 2008.06.19A

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RTC on Backslopes
Poor performance: varying “visible” area not modelled
Foreslopes vs. Backslopes

- *Image simulation*-based RTC is *superior* to Local Incidence-angle Mask (LIM) methodology
  - Non neighbouring DEM-samples considered
  - Shadow modelled
  - Varying “visible” area modelled (highly significant on backslopes)

- Foreslopes poorly normalised using LIM (less refined sensor model)

- Use of RTC recommended for thematic interpretation in variable terrain
ASAR Wide Swath (WS)
Snow Melt in Switzerland
Mix of Terrain Variations + Thematic Land Cover
Thematic Land Cover (snow melt)
Mix of Terrain Variations + Thematic Land Cover
Thematic Land Cover (snow melt)
ASAR WS Asc/Desc RTC

Height-dependency in seasonal snow-melt

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Conclusions

• Seek out highly variable complex terrain for testing RTC

• Local Incidence Angle Mask (LIM) a poor proxy for true radar equation-based area normalisation:
  • Radar simulation approach is preferable to conventional LIM-based normalisation in variable terrain
  • DHM’s with resolutions even higher than radar imagery can be harnessed in the simulation’s sensor model

• Time to leave Kansas: use integrated areal measures not angle!

• Standardised test sites & CEOS-test for RTC?