CEOS SAR Calibration/Validation Workshop

Local Incidence Angle Considered Harmful

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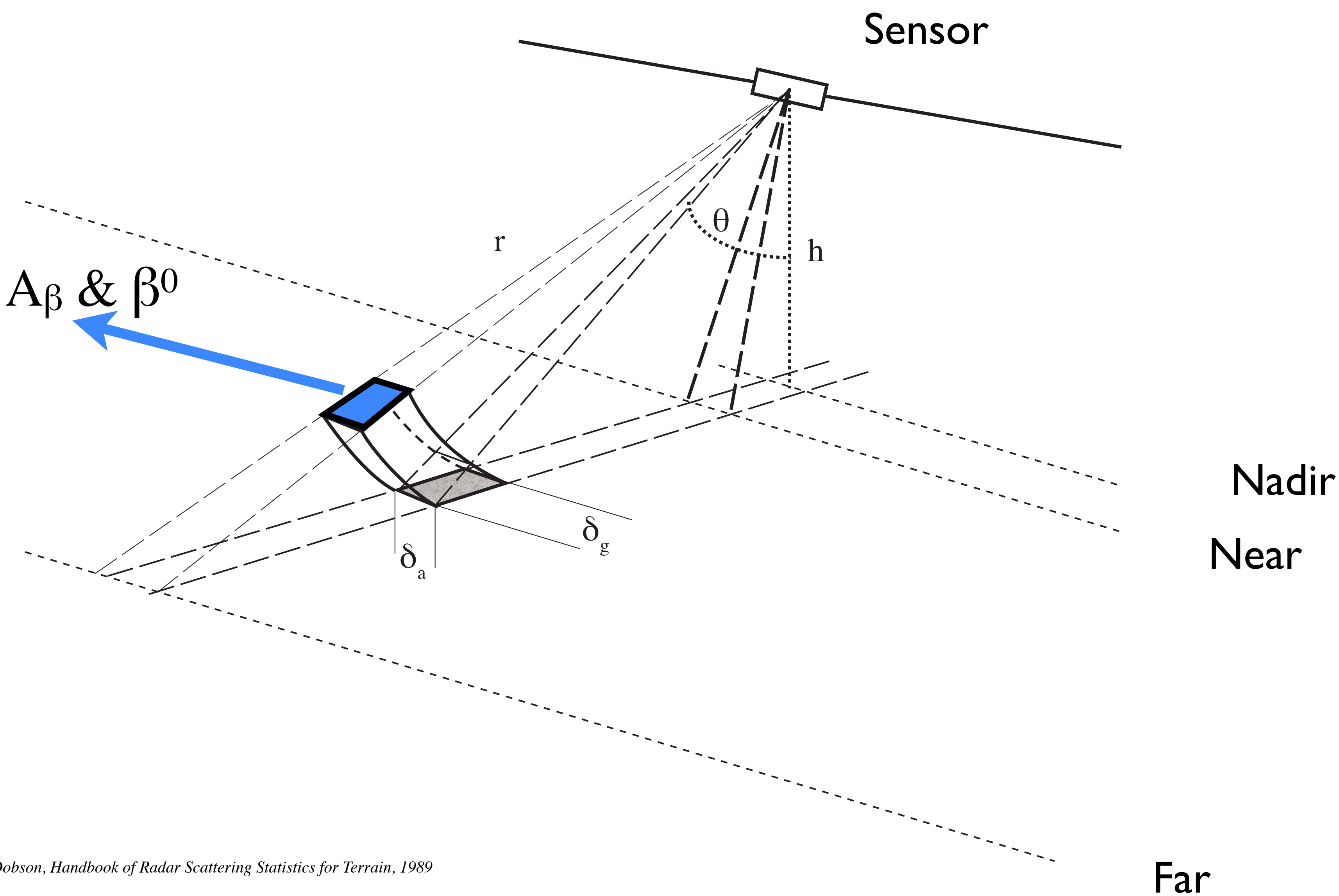
Outline

- Review of Radiometric Normalisation Conventions
- Role of Local Incidence Angle
- Evaluation of Radiometric Terrain Correction Methods
- Examples from PALSAR & ASAR
- Conclusions

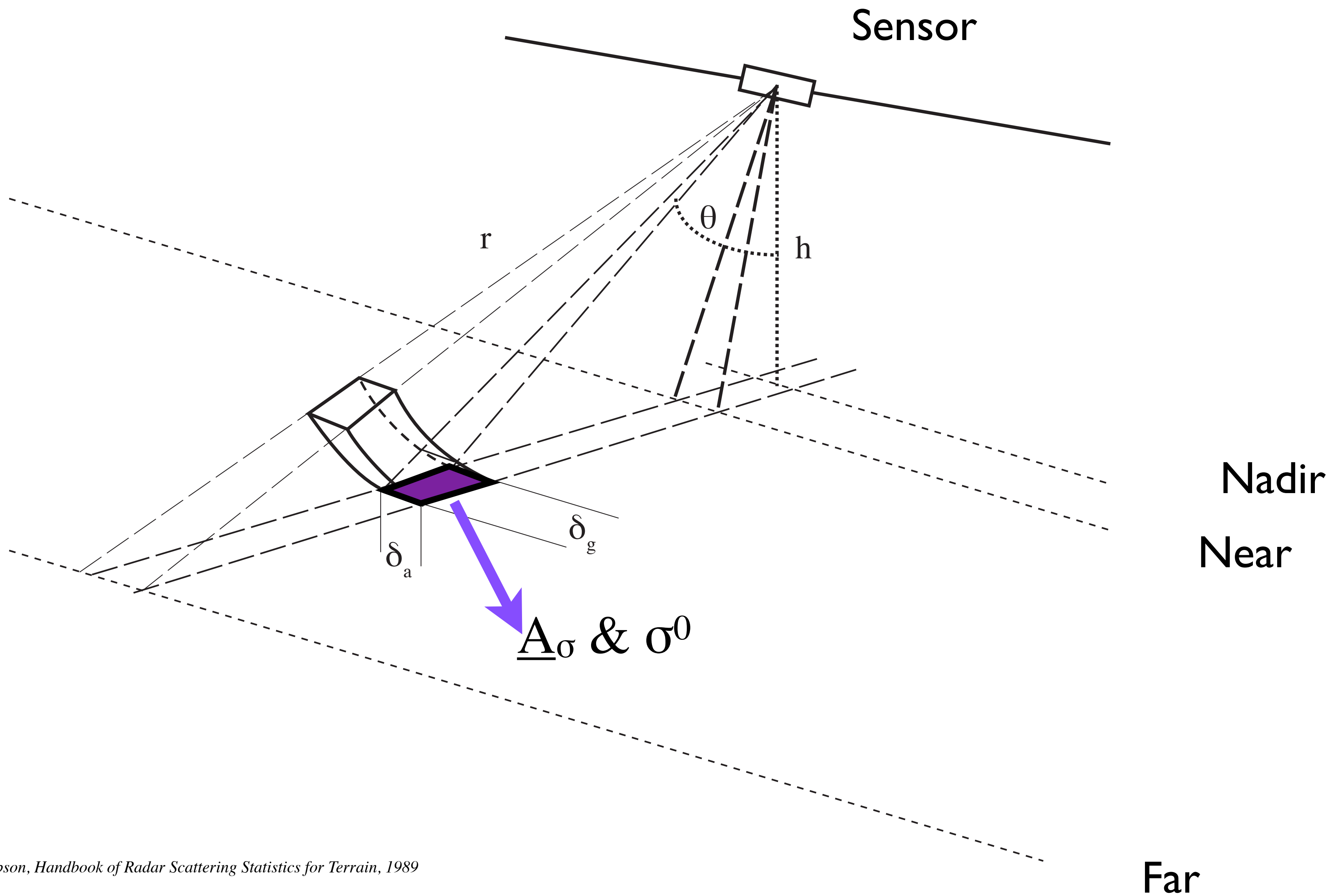
Radiometric Normalisation Conventions

Standard Areas for *Ellipsoid-normalisation*



modified from Ulaby & Dobson, Handbook of Radar Scattering Statistics for Terrain, 1989

Standard Areas for *Ellipsoid-normalisation*



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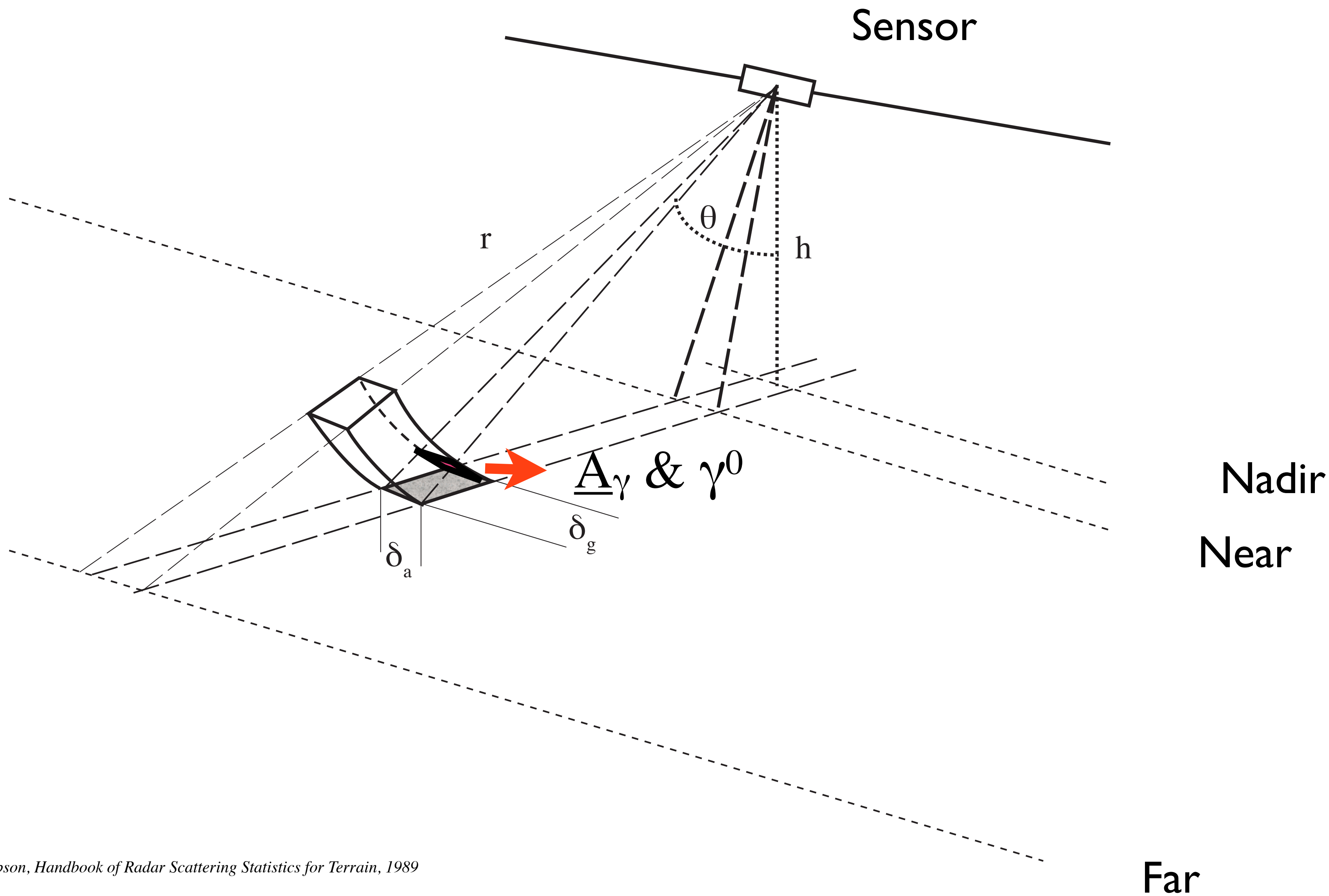
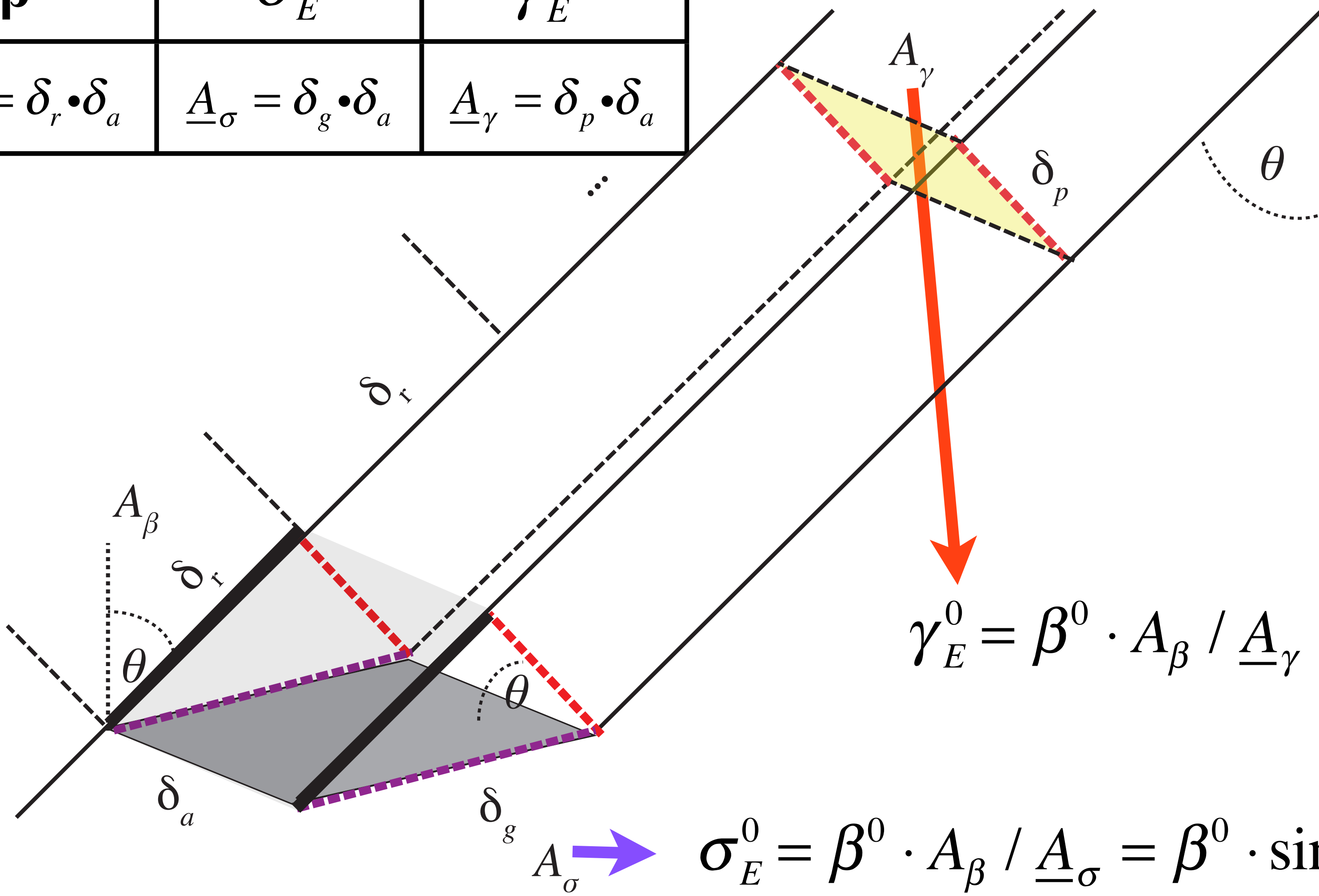
Standard Areas for *Ellipsoid-normalisation*



modified from Ulaby & Dobson, Handbook of Radar Scattering Statistics for Terrain, 1989

Ground Illuminated Area

β^0	σ_E^0	γ_E^0
$A_\beta = \delta_r \bullet \delta_a$	$\underline{A}_\sigma = \delta_g \bullet \delta_a$	$\underline{A}_\gamma = \delta_p \bullet \delta_a$

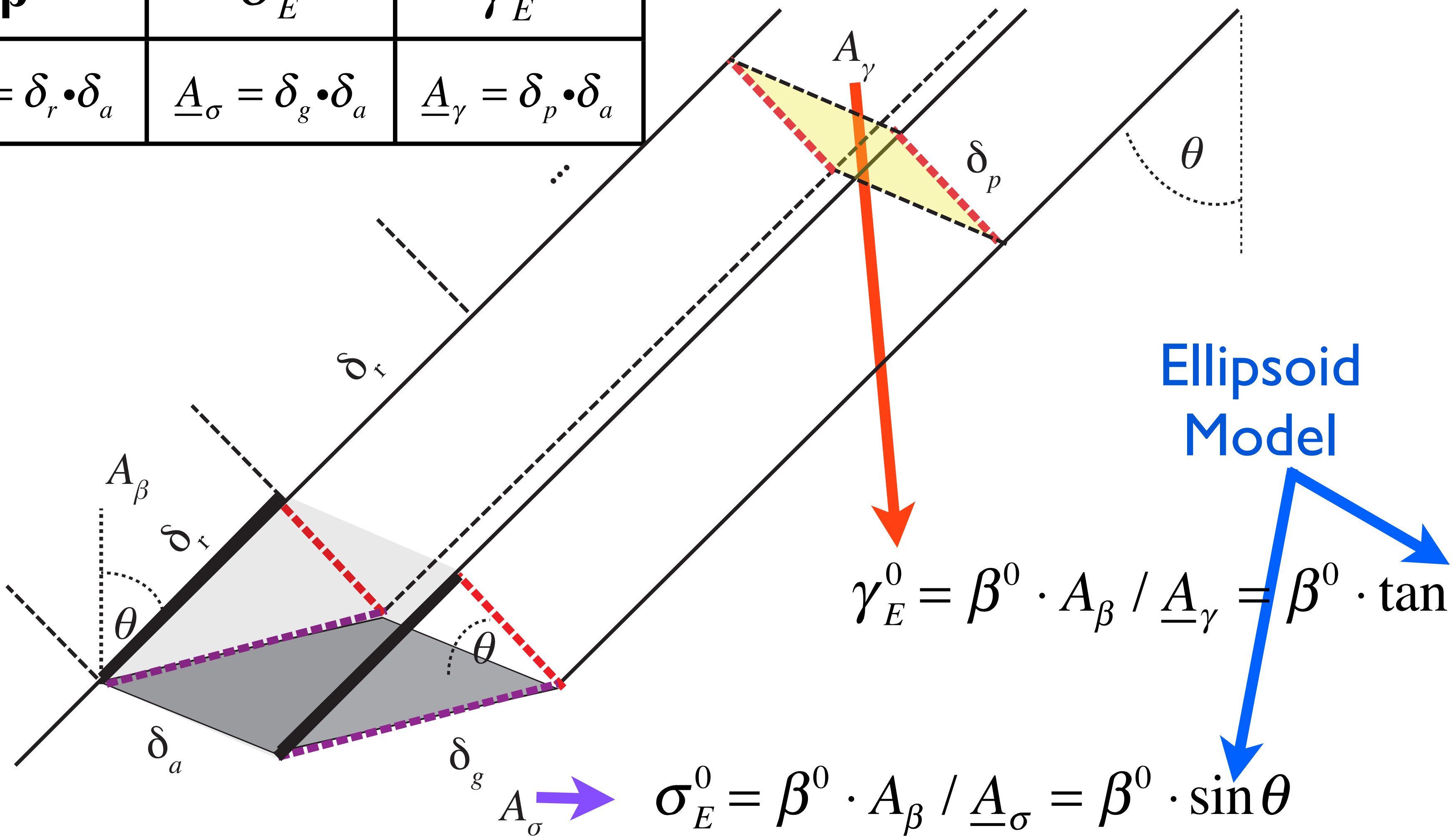


$$\gamma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\gamma = \beta^0 \cdot \tan\theta$$

$$\sigma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\sigma = \beta^0 \cdot \sin\theta$$

Ground Illuminated Area

β^0	σ_E^0	γ_E^0
$A_\beta = \delta_r \bullet \delta_a$	$\underline{A}_\sigma = \delta_g \bullet \delta_a$	$\underline{A}_\gamma = \delta_p \bullet \delta_a$



$$\gamma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\gamma = \beta^0 \cdot \tan\theta$$

$$\sigma_E^0 = \beta^0 \cdot A_\beta / \underline{A}_\sigma = \beta^0 \cdot \sin\theta$$

Radar Equation & Reference Area

- Relating *received* to *transmitted* power:

$$\overline{P}_r = \frac{\lambda^2}{(4\pi)^3} \cdot \int_{\text{area illuminated}} \frac{P_t G^2}{R^4} \cdot \sigma^0 dA$$

Ulaby, Moore, Fung, 1982.

- 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 θ_e as a **proxy for area**

For radiometric terrain correction, we need to actually ***perform the integration*** on a DEM

Existing SAR Normalisation Conventions: β^0, σ^0, γ^0

Name	Symbol	Normalisation Area	Derivation (ignoring terrain effects!)
Beta	$\boldsymbol{\beta}$	None	Natural radar observable: $\beta = k \cdot P_s / P_i$
Beta Nought	β^0	Sample Interval in Slant Range Plane: $\boldsymbol{A_\beta}$	$\beta^0 = \beta / A_\beta$
Sigma Nought	σ_E^0	Ground Area: $\underline{\boldsymbol{A_\sigma}}$	$\beta^0 \cdot A_\beta / \underline{A}_\sigma = \boldsymbol{\beta^0 \cdot \sin\theta_e}$
Gamma Nought	γ_E^0	Ground Area projected in plane ⊥ to Look Direction: $\underline{\boldsymbol{A_\gamma}}$	$\beta^0 \cdot A_\beta / \underline{A}_\gamma = \boldsymbol{\beta^0 \cdot \tan\theta_e}$

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

Convention	1	2	3	4
	β^0	σ_E^0	γ_E^0	γ_T^0
Earth Model	*None*	*Ellipsoid*		*Terrain*
Reference Area	A_β	$\underline{A}_\sigma$	$\underline{A}_\gamma$	A_γ
Area Derivation	$\delta_r \cdot \delta_a$	$\delta_g \cdot \delta_a$	$\delta_p \cdot \delta_a$	$\int_{DHM} \delta_p \cdot \delta_a$
Normalisation	$\beta^0 = \frac{\beta}{A_\beta}$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\sigma} = \beta^0 \cdot \sin\theta_e$	$\beta^0 \cdot \frac{A_\beta}{\underline{A}_\gamma} = \beta^0 \cdot \tan\theta_e$	$\beta^0 \cdot \frac{A_\beta}{A_\gamma}$

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

Name	Symbol	Normalisation Reference	Derivation
Beta Nought	β^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	σ_E^0	*Ellipsoid* Ground Area	$\sigma_E^0 = \beta^0 \cdot A_\beta \big/ \underline{A}_\sigma$
Gamma Nought	γ_E^0	*Ellipsoid* Ground Area projected in plane ⊥ to Look Direction	$\gamma_E^0 = \beta^0 \cdot A_\beta \big/ \underline{A}_\gamma$
Gamma Taut	γ_T^0	Integrated *Terrain* Area projected in plane ⊥ to Look Direction	$\gamma_T^0 = \beta^0 \cdot A_\beta \big/ A_\gamma$

Definition of *Taut*

Merriam-Webster Dictionary:

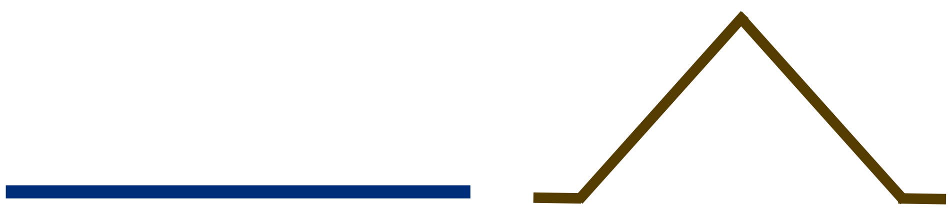
1. *having no give or slack: tightly drawn*
2. *kept in proper order or condition*
3. *not loose or flabby; marked by economy of structure and detail*

Evaluation of Normalisation Methods

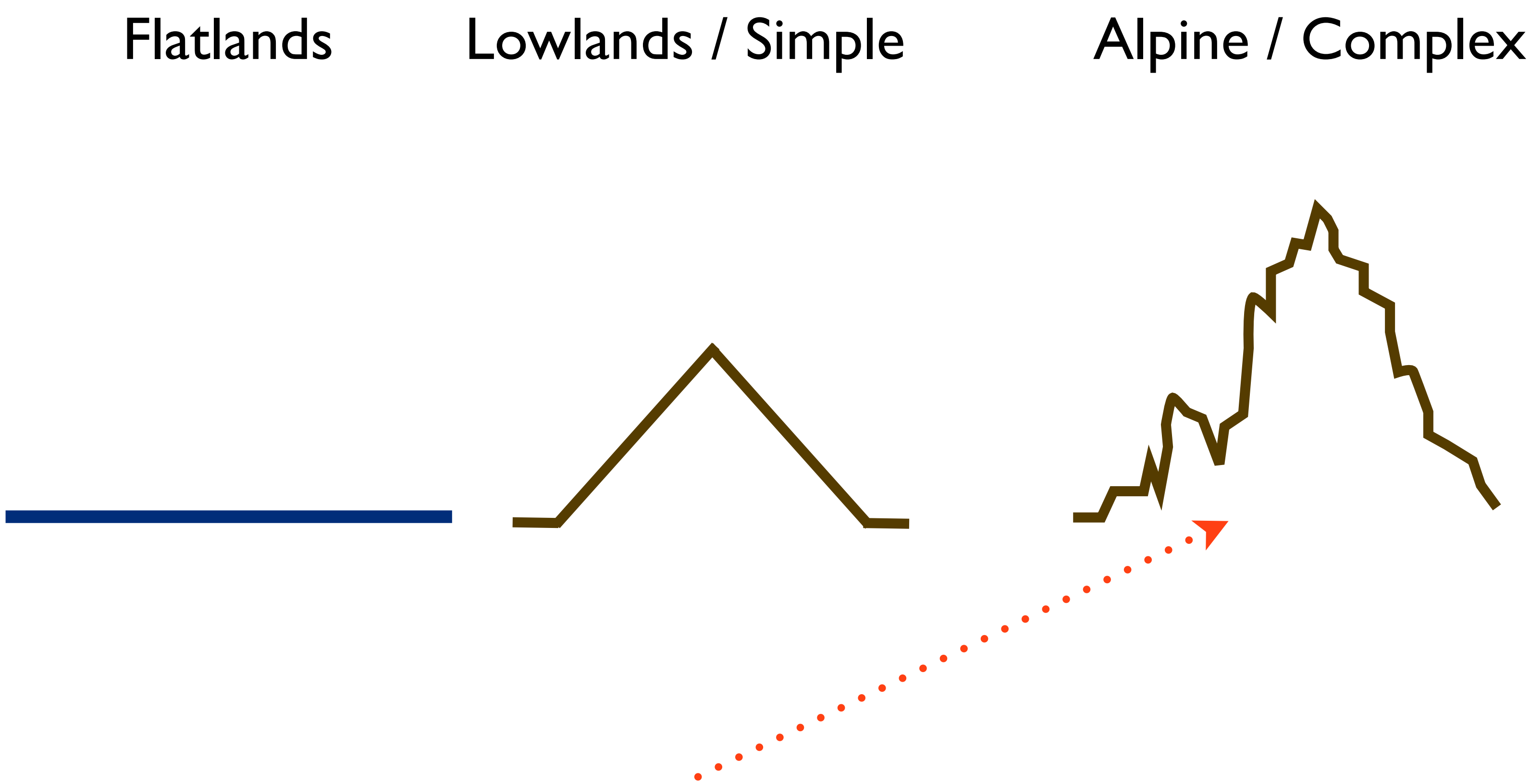
Flatlands Lowlands / Simple

Evaluation of Normalisation Methods

Flatlands Lowlands / Simple



Evaluation of Normalisation Methods



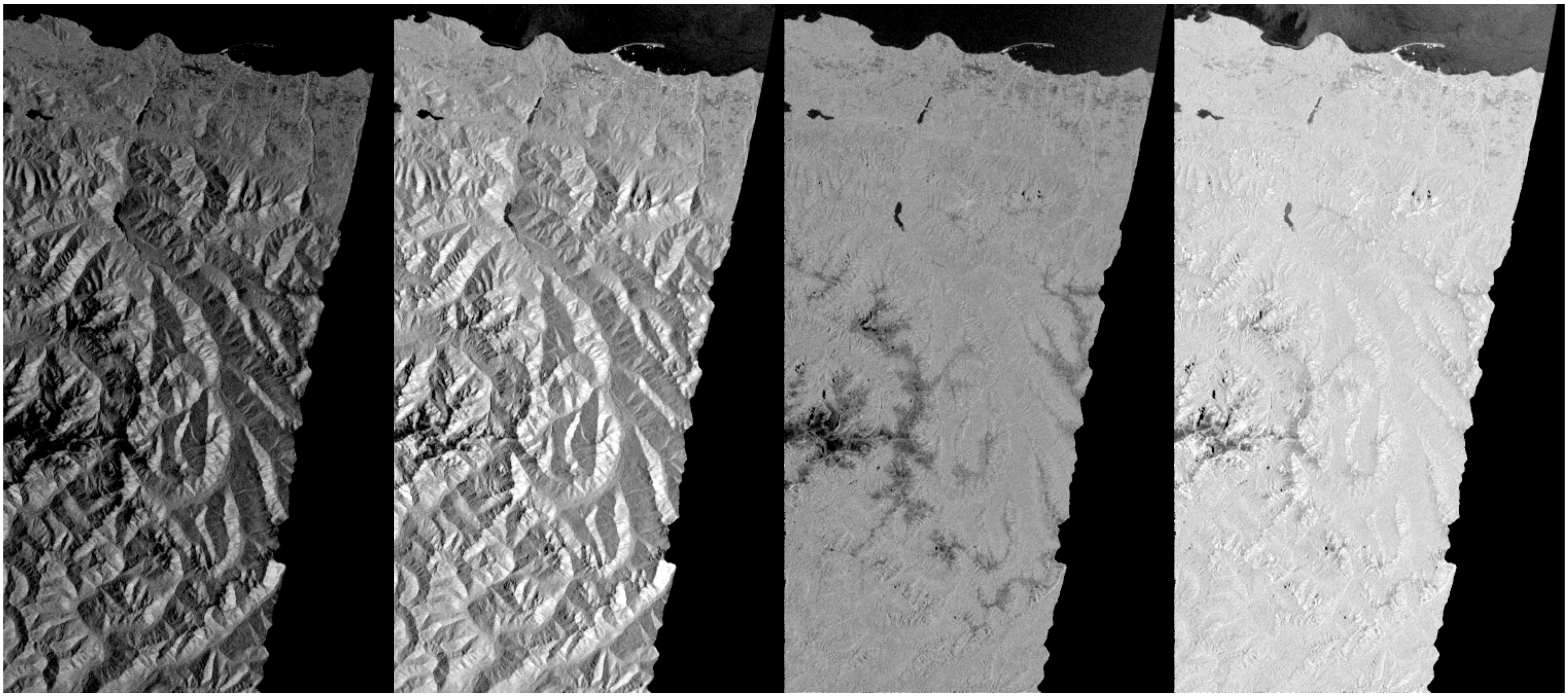
Seek out *complex* (challenging) terrain for RTC testing!

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



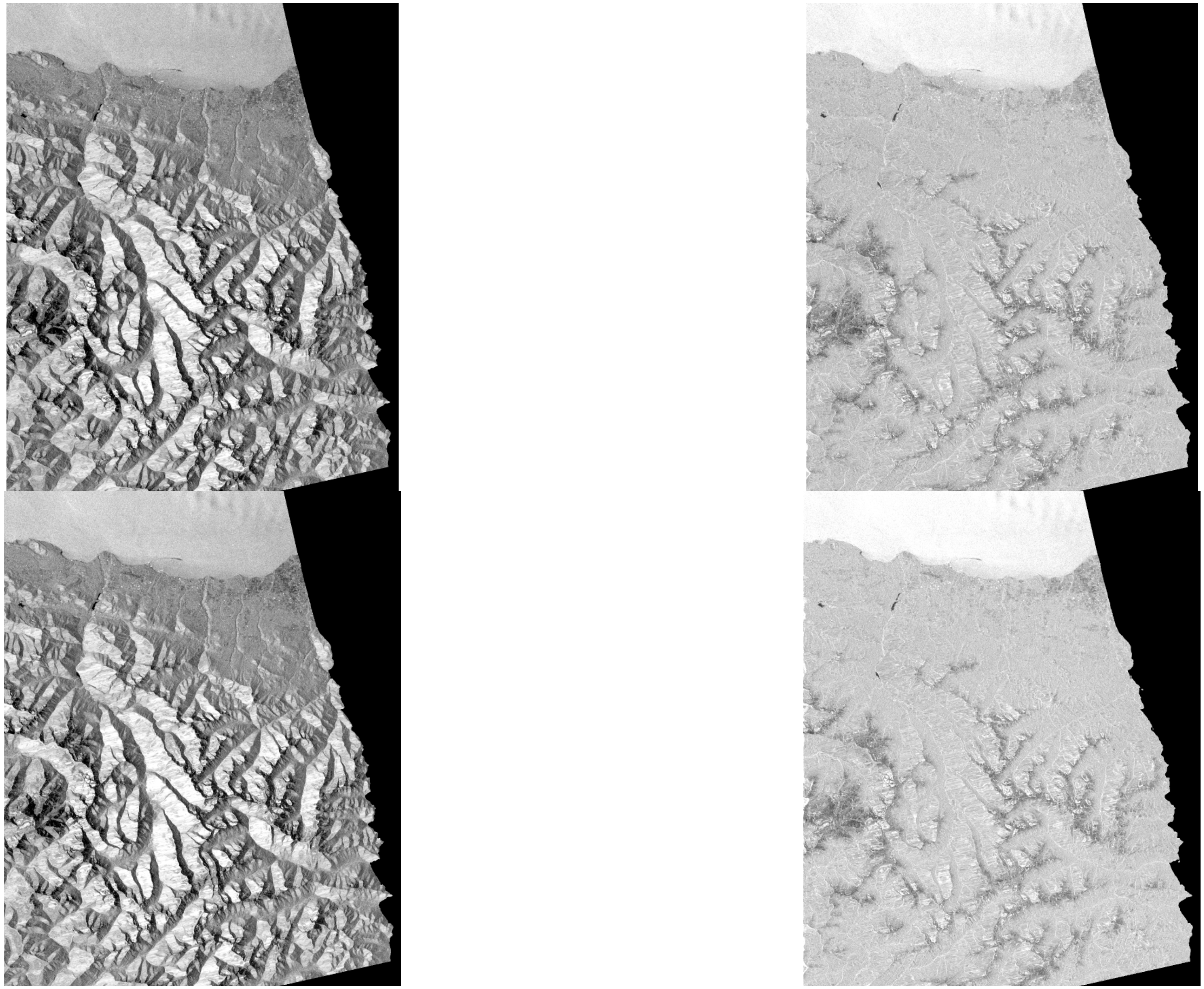
VH *VV* *VH* *VV*

GTC *RTC*

ASAR AP 2006.04.29 IS1 - scaled -20 to +5 dB/m^2

HH

VV

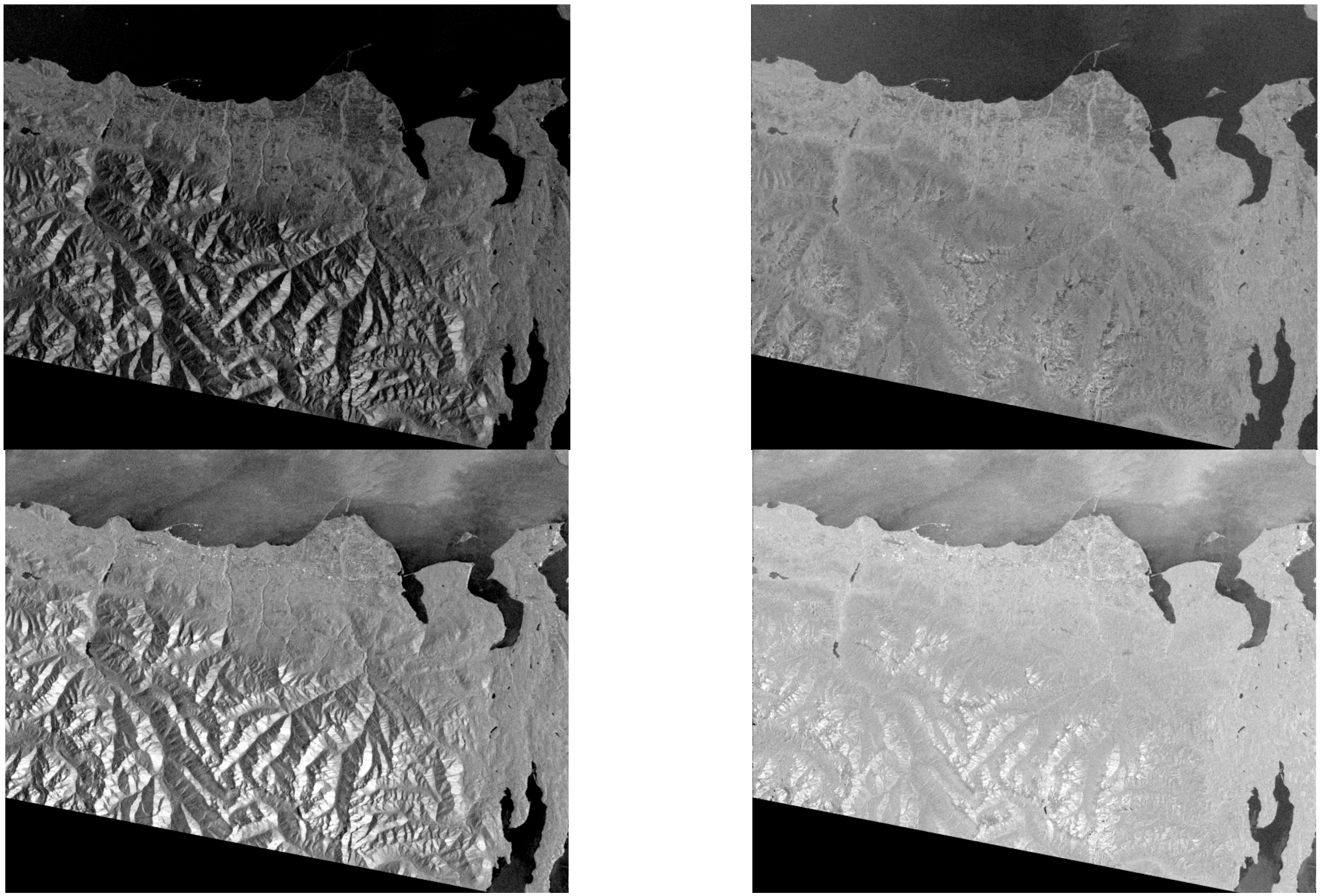


GTC

RTC

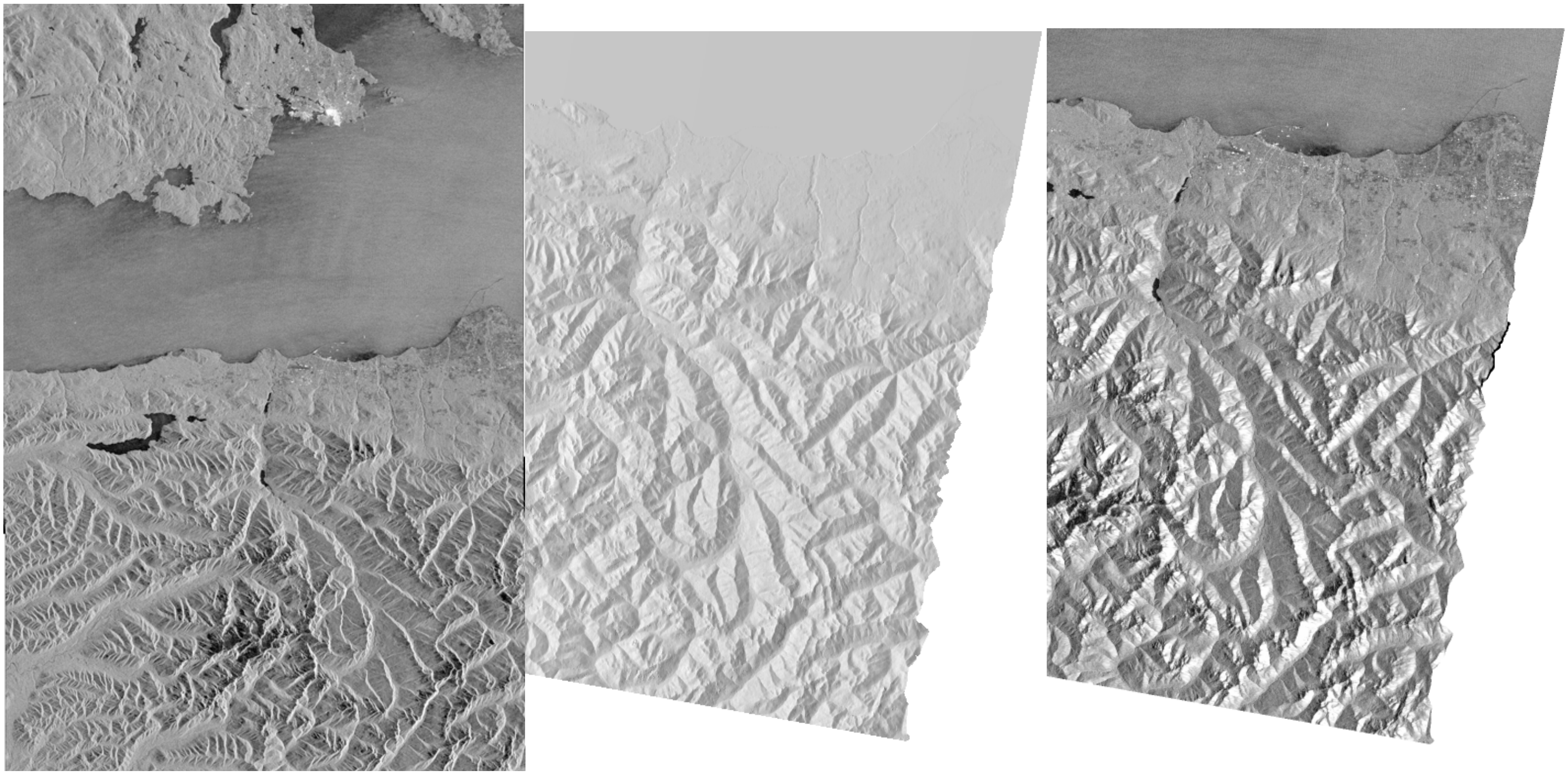
Olympic Peninsula - GTC vs. RTC

ASAR AP 2007.12.230 IS4 - scaled -20 to +5 dB/m^2



Olympic Peninsula - ASAR IM

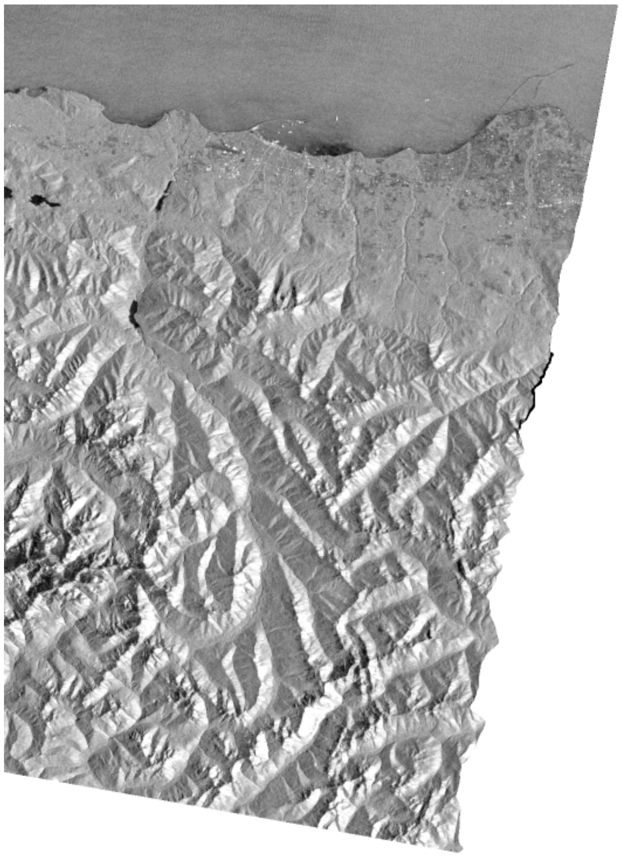
ASAR IMP 2007.10.18 IS6



Ground Range LIM GTC

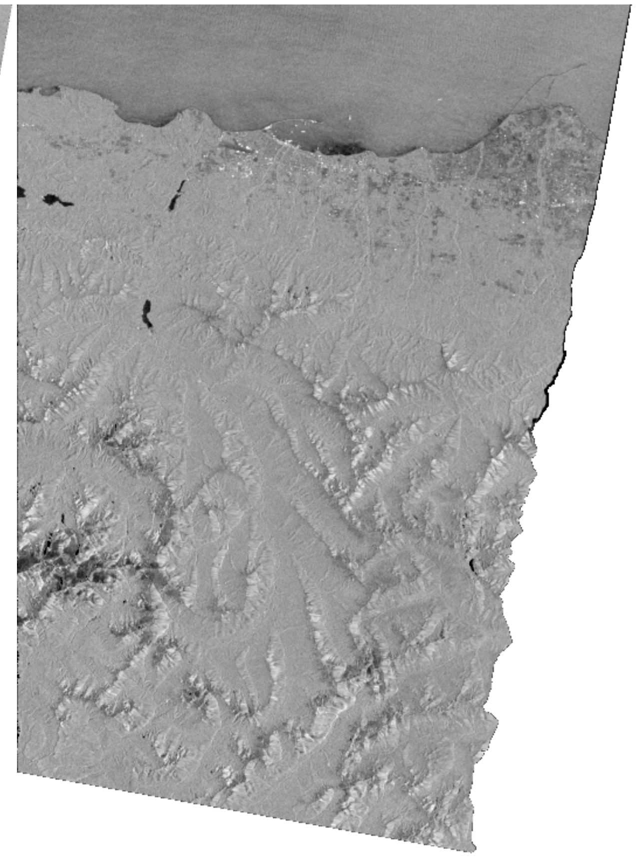
Olympic Peninsula - GTC vs. LIM vs. RTC

ASAR IM 2007.10.18 IS6 - 25dB dynamic range



GTC

NORLIM

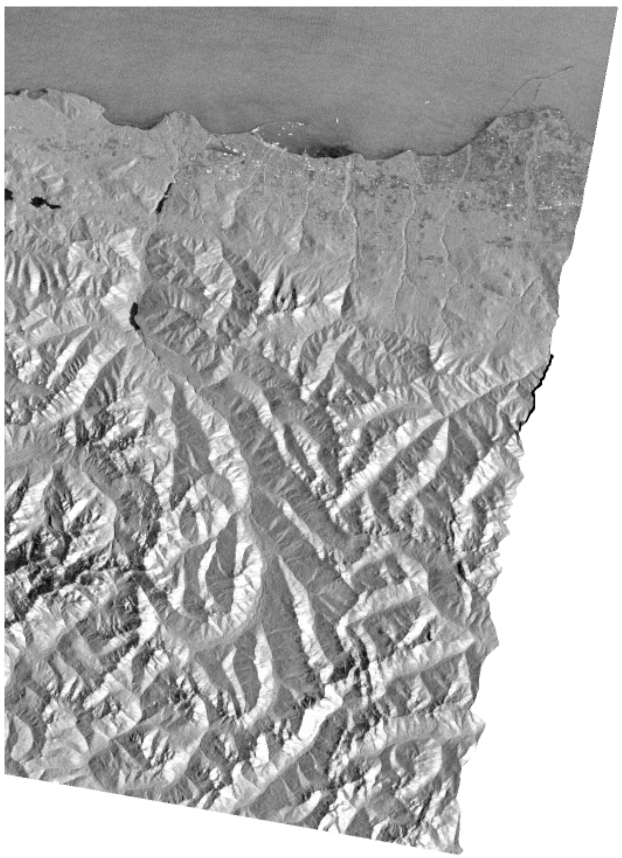


RTC

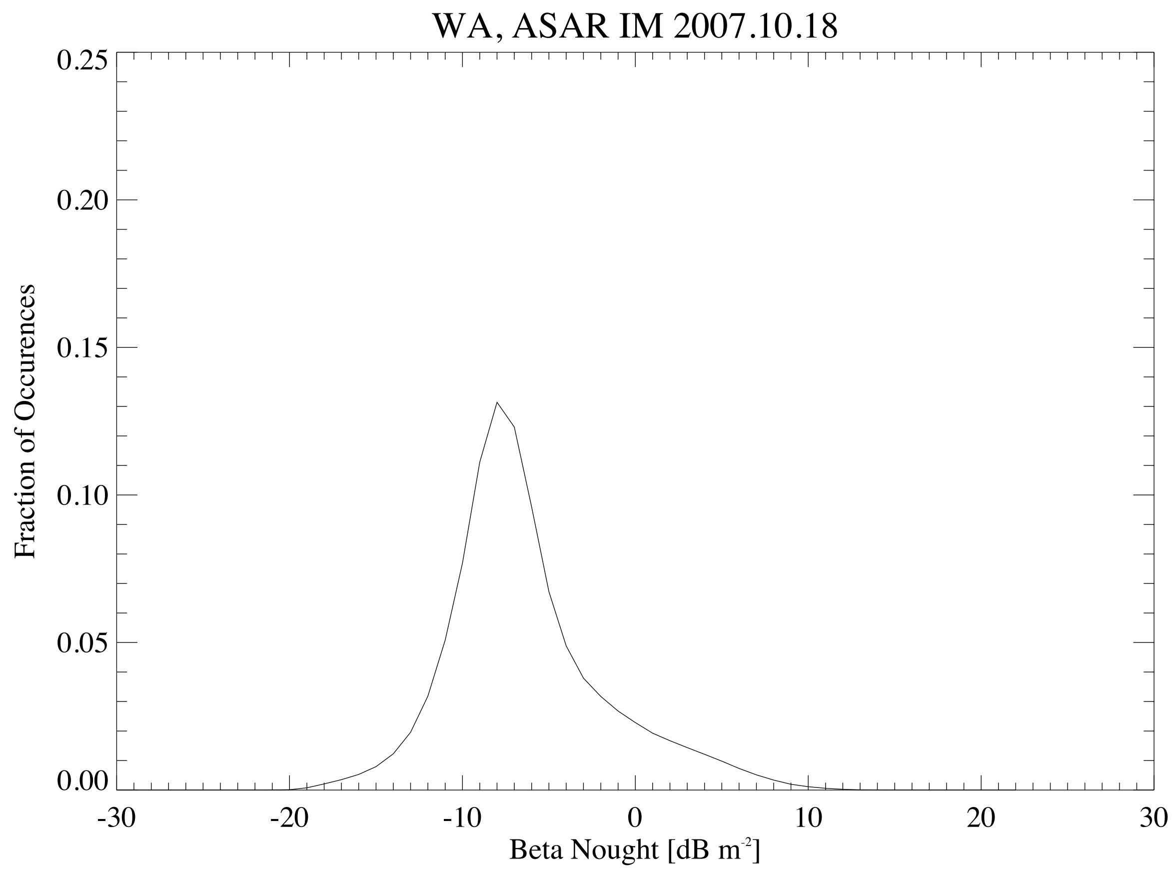
Tests of Flatness

- GTC vs. RTC
- Histograms of backscatter for GTC/RTC

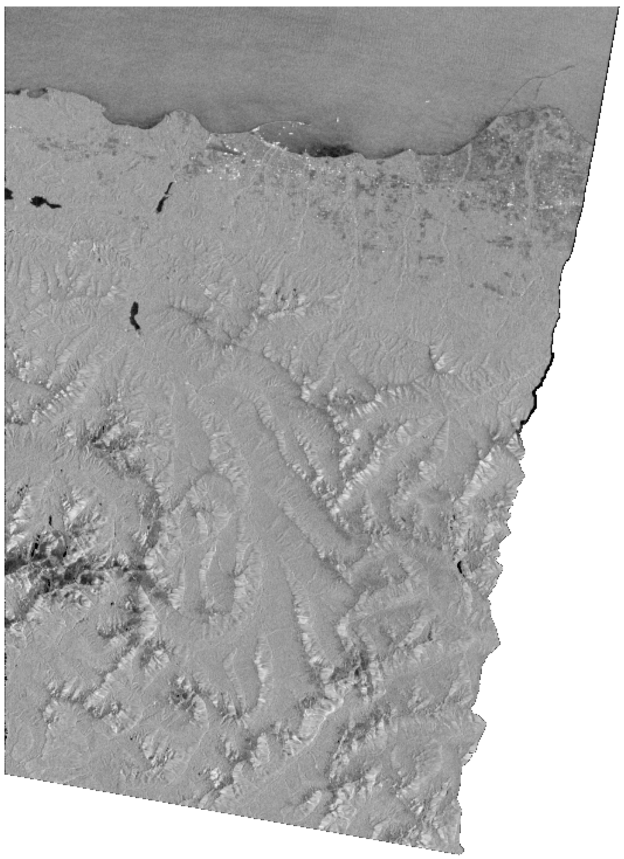
GTC - Olympic Peninsula: ASAR IM IS6D VV



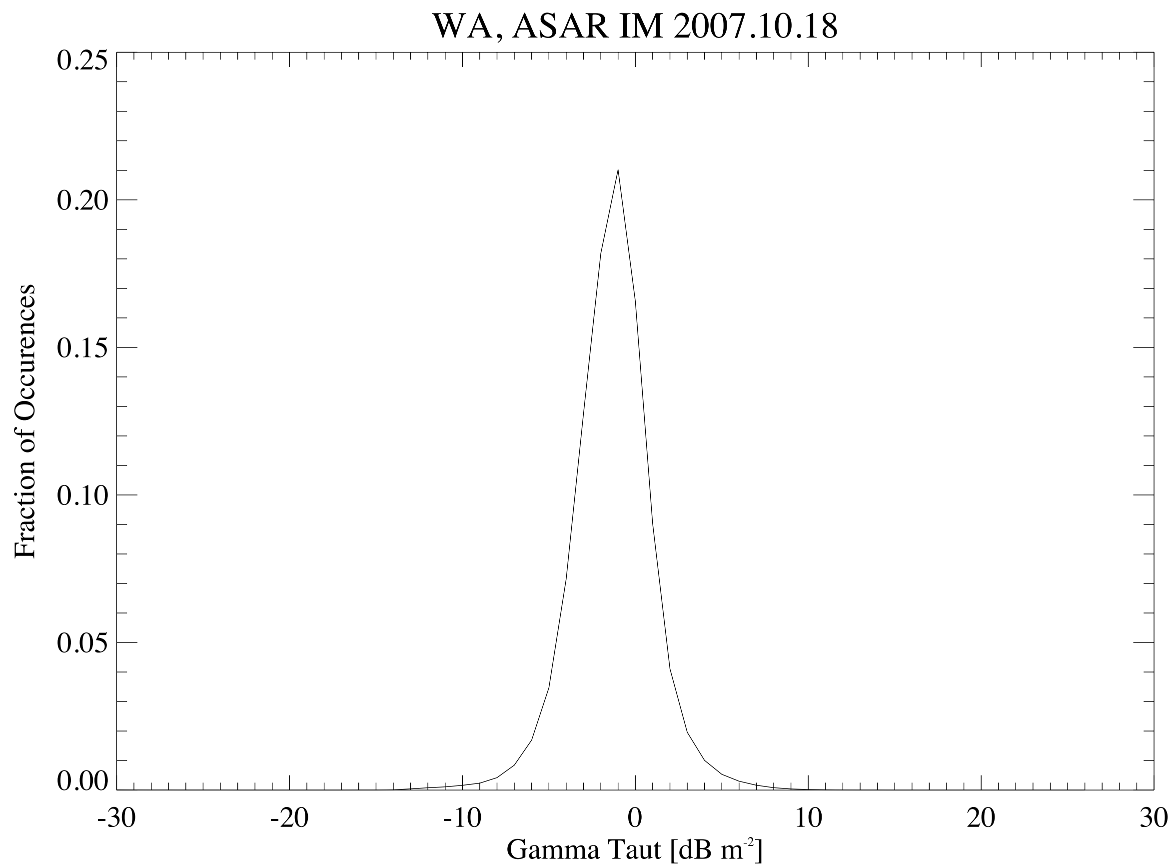
GTC



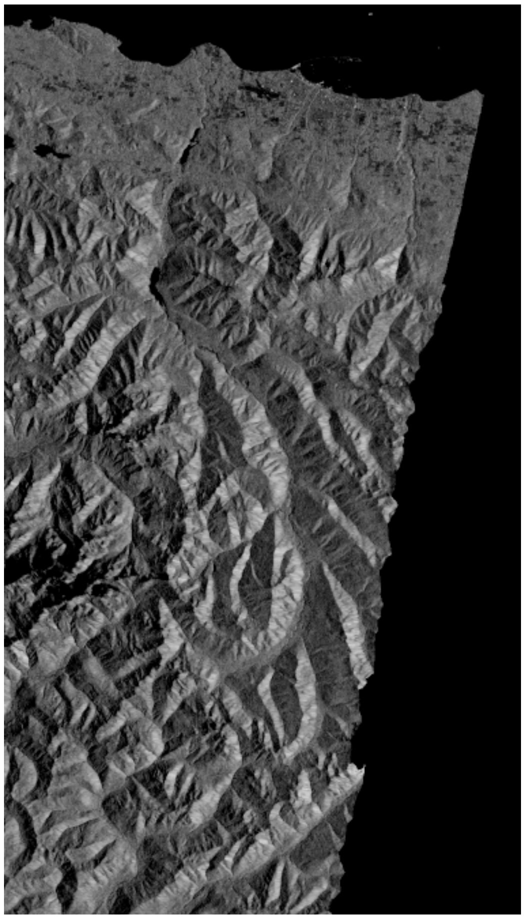
RTC - Olympic Peninsula: ASAR IM IS6D VV



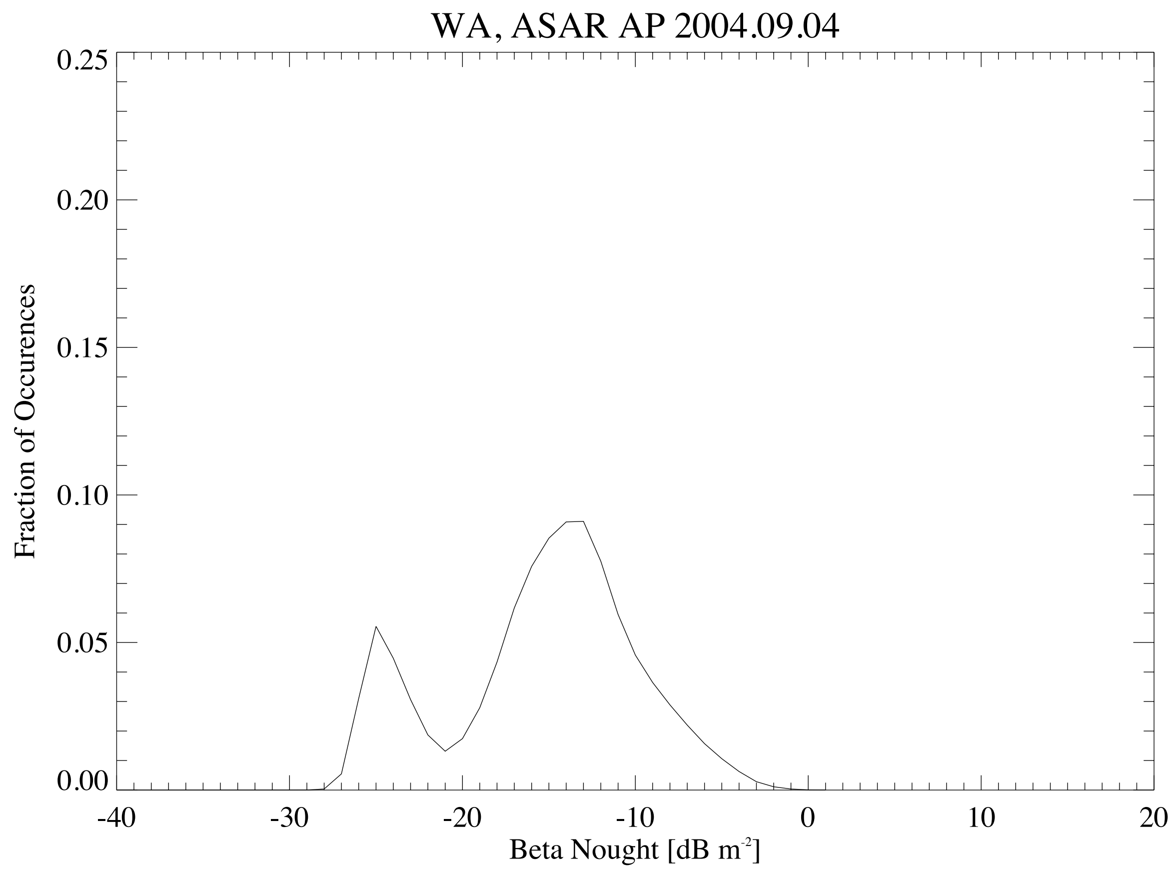
RTC



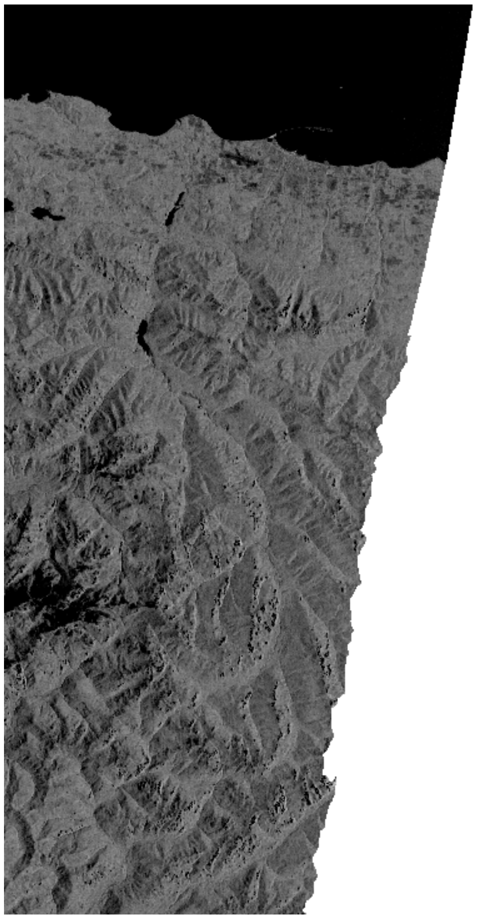
GTC - Olympic Peninsula: ASAR AP IS7D HV



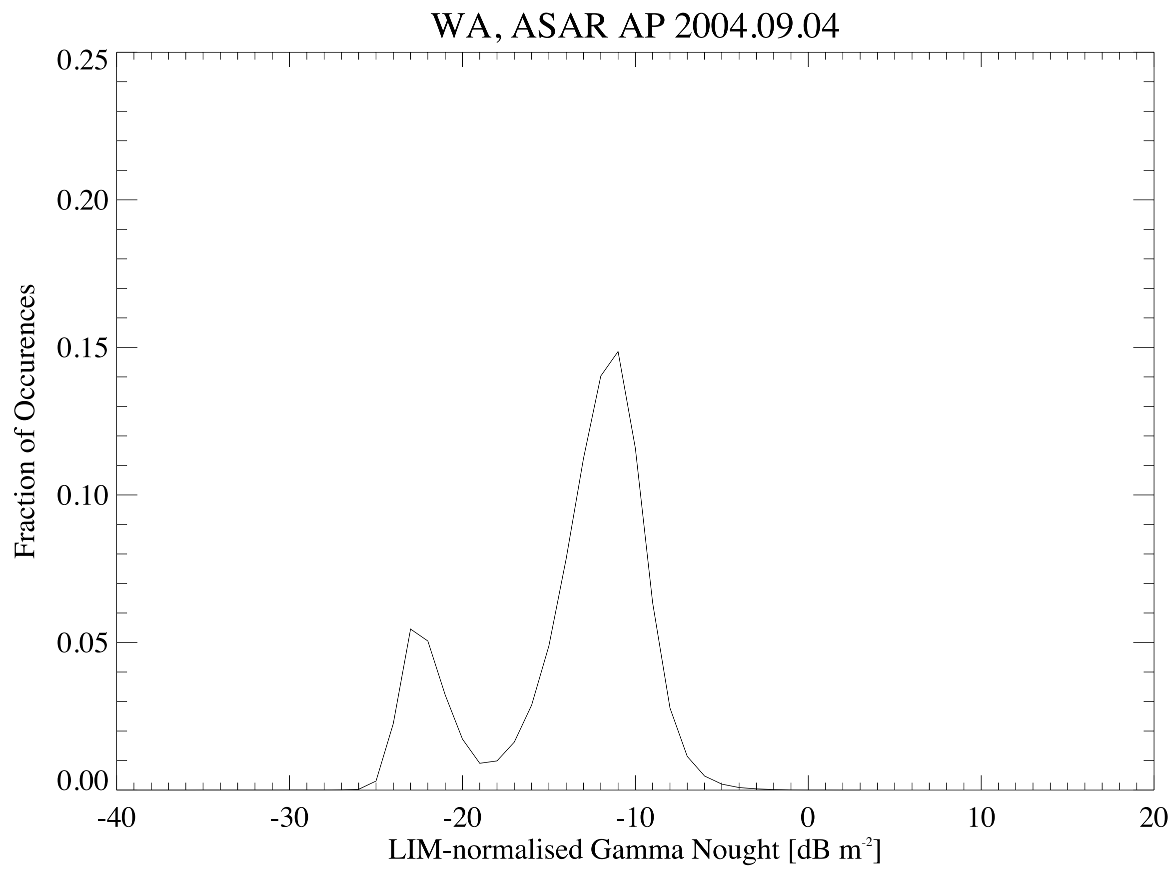
GTC



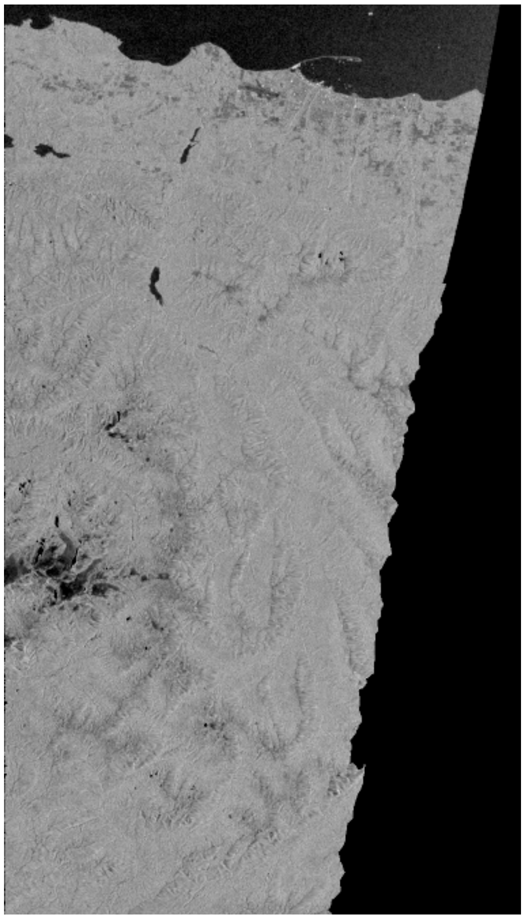
NORLIM - Olympic Peninsula: ASAR AP IS7D HV



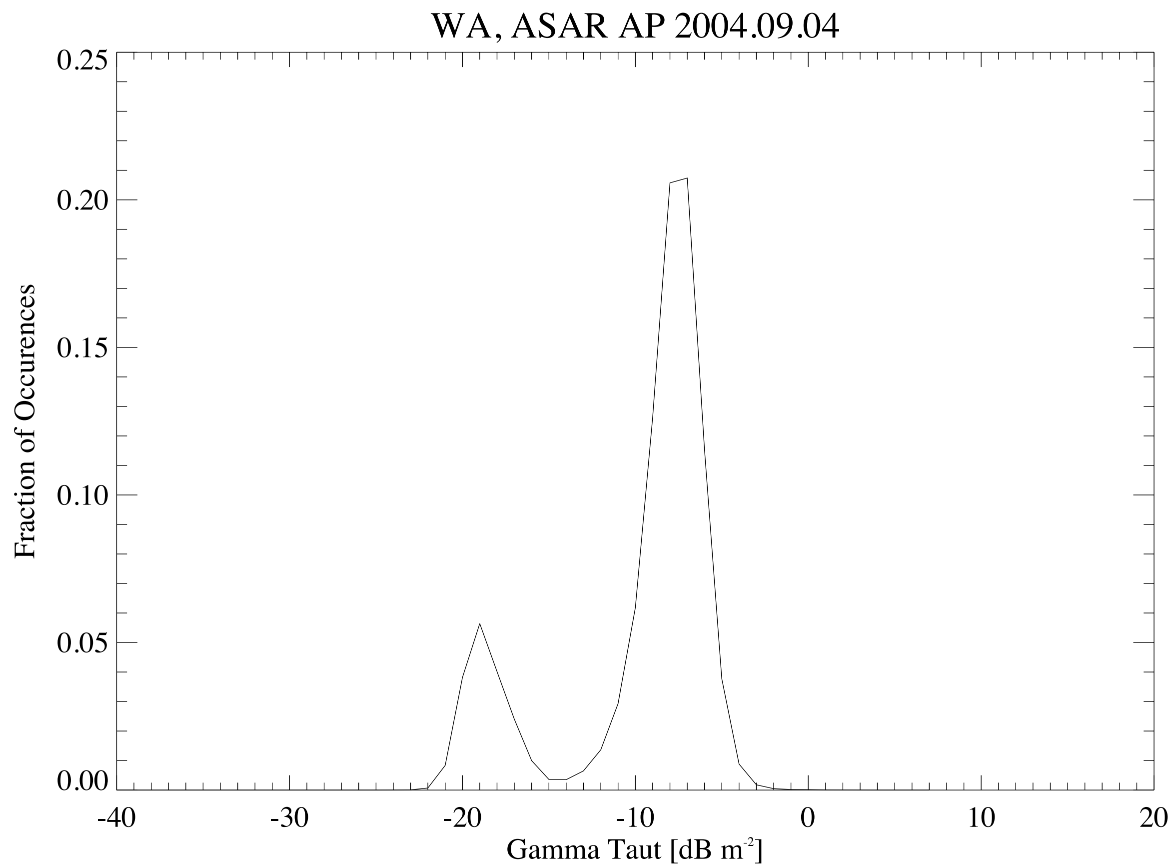
NORLIM



RTC - Olympic Peninsula: ASAR AP IS7D HV



RTC

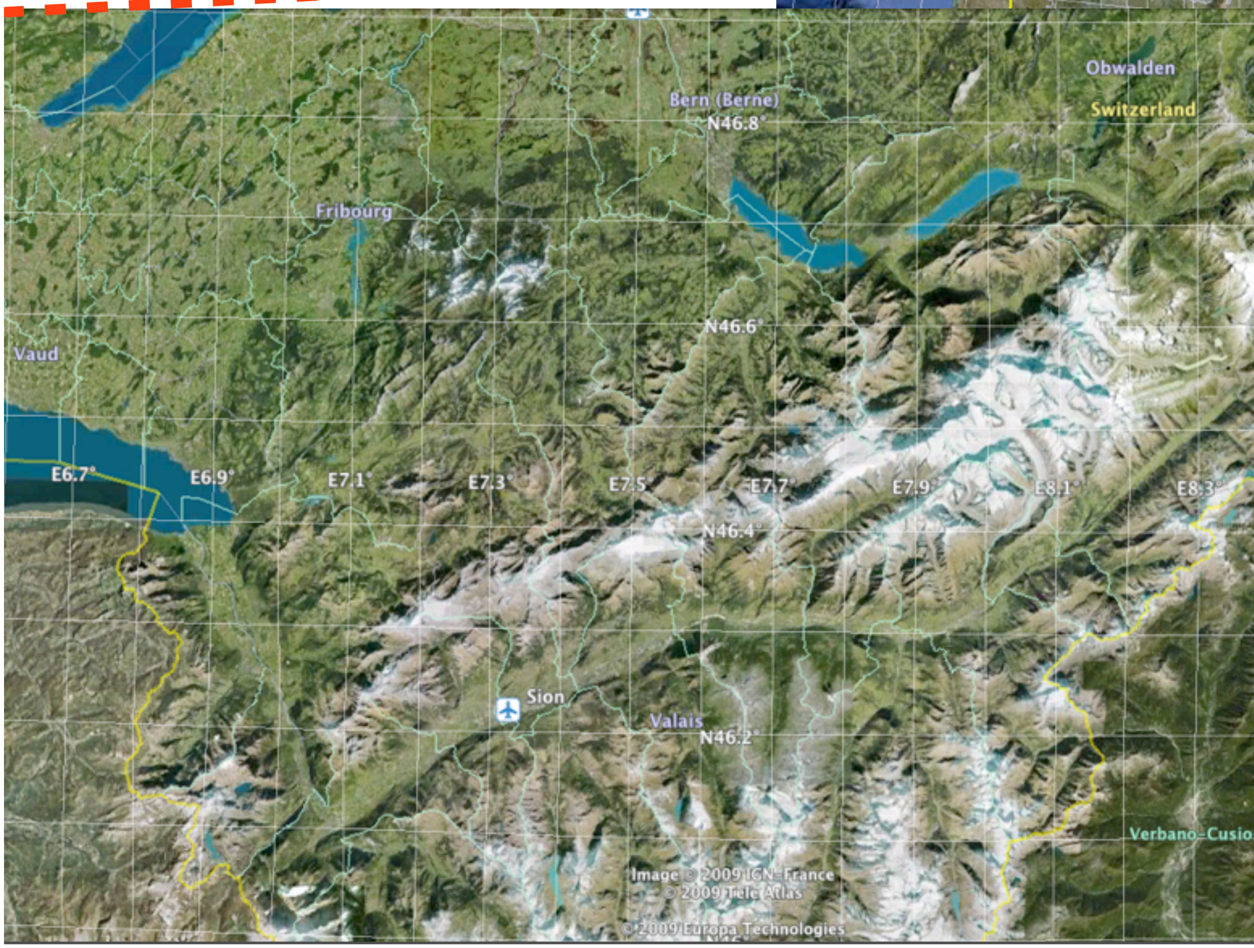


Switzerland: PALSAR FBD

HH & HV polarisations

Switzerland:

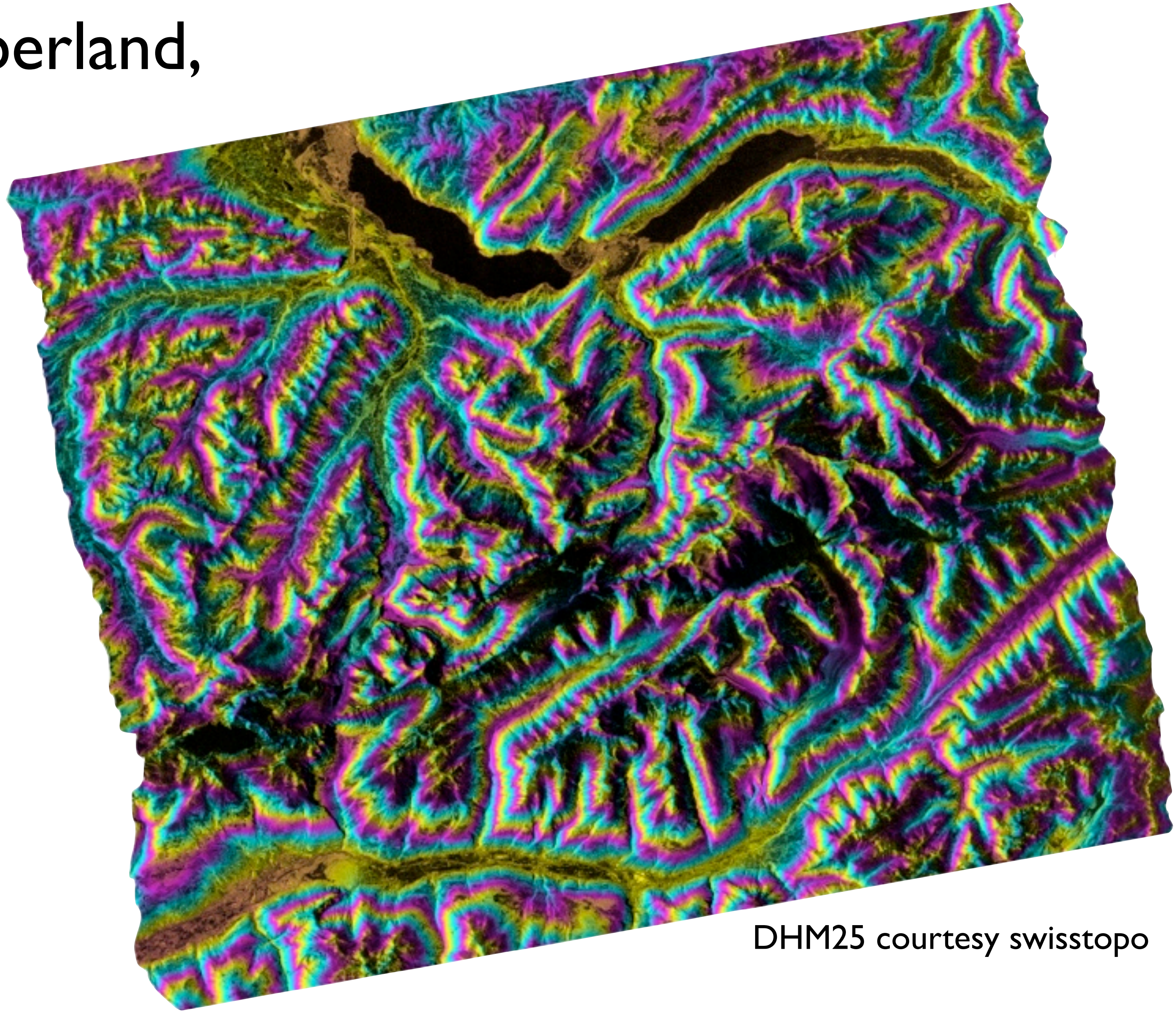
not in Kansas anymore



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

Bernese Oberland, Switzerland

>3000m of in-scene height variations



20dB

1000m Height Cycle

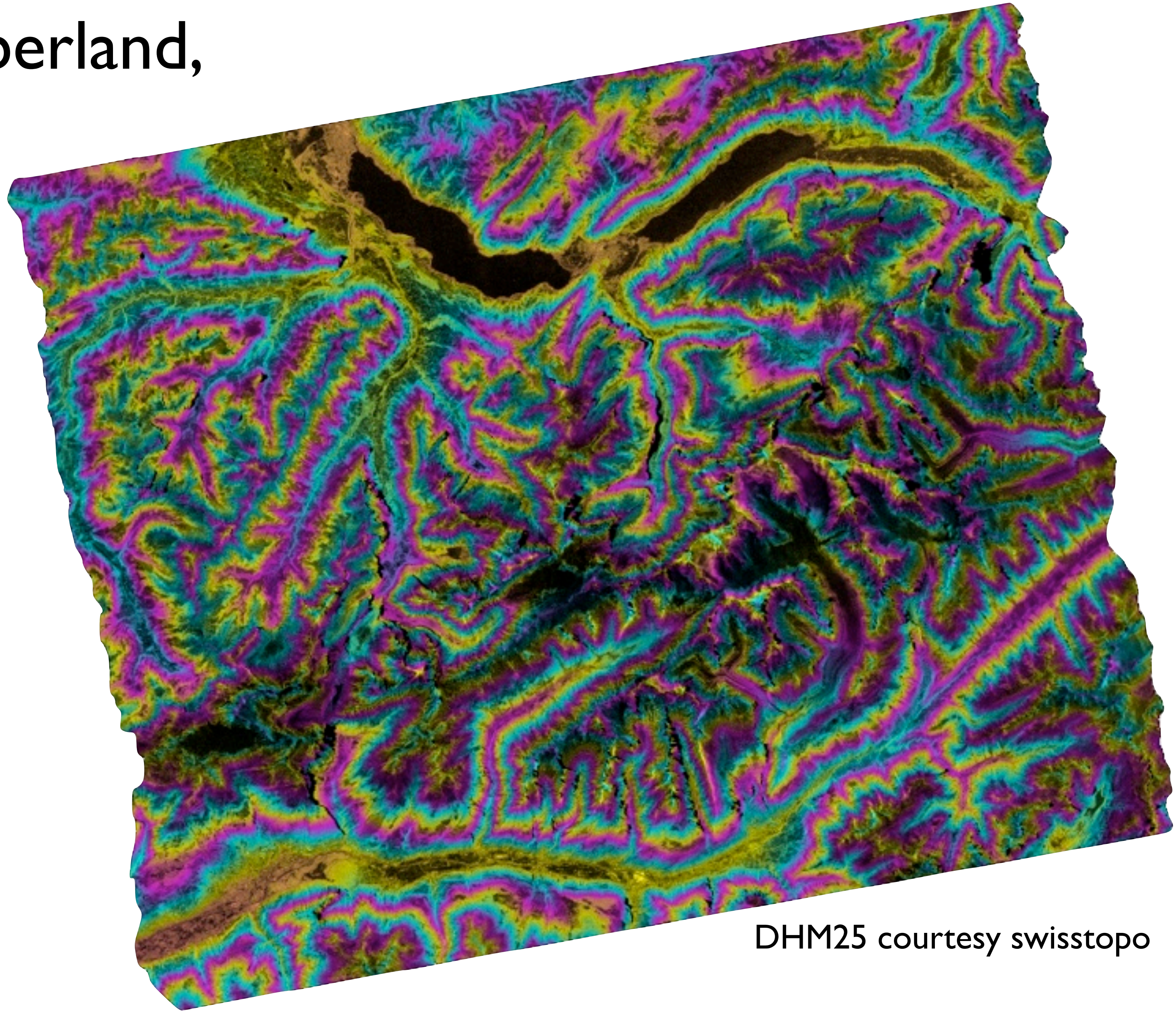
2008.06.02A

GTC

FBD HV

DHM25 courtesy swisstopo

Bernese Oberland, Switzerland



20dB

1000m Height Cycle

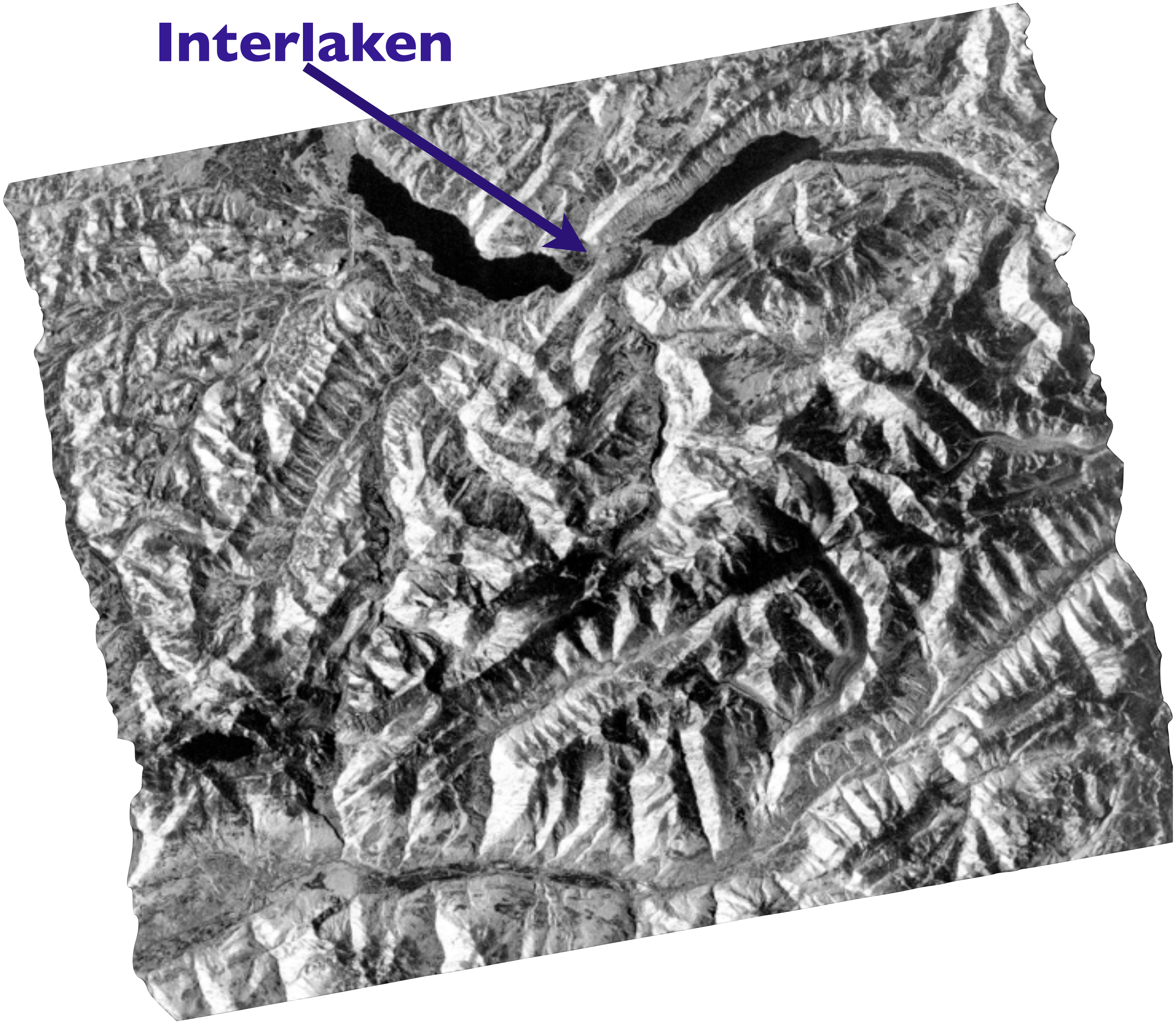
2008.06.02A

RTC

FBD HV

DHM25 courtesy swisstopo

Bernese Oberland, Switzerland



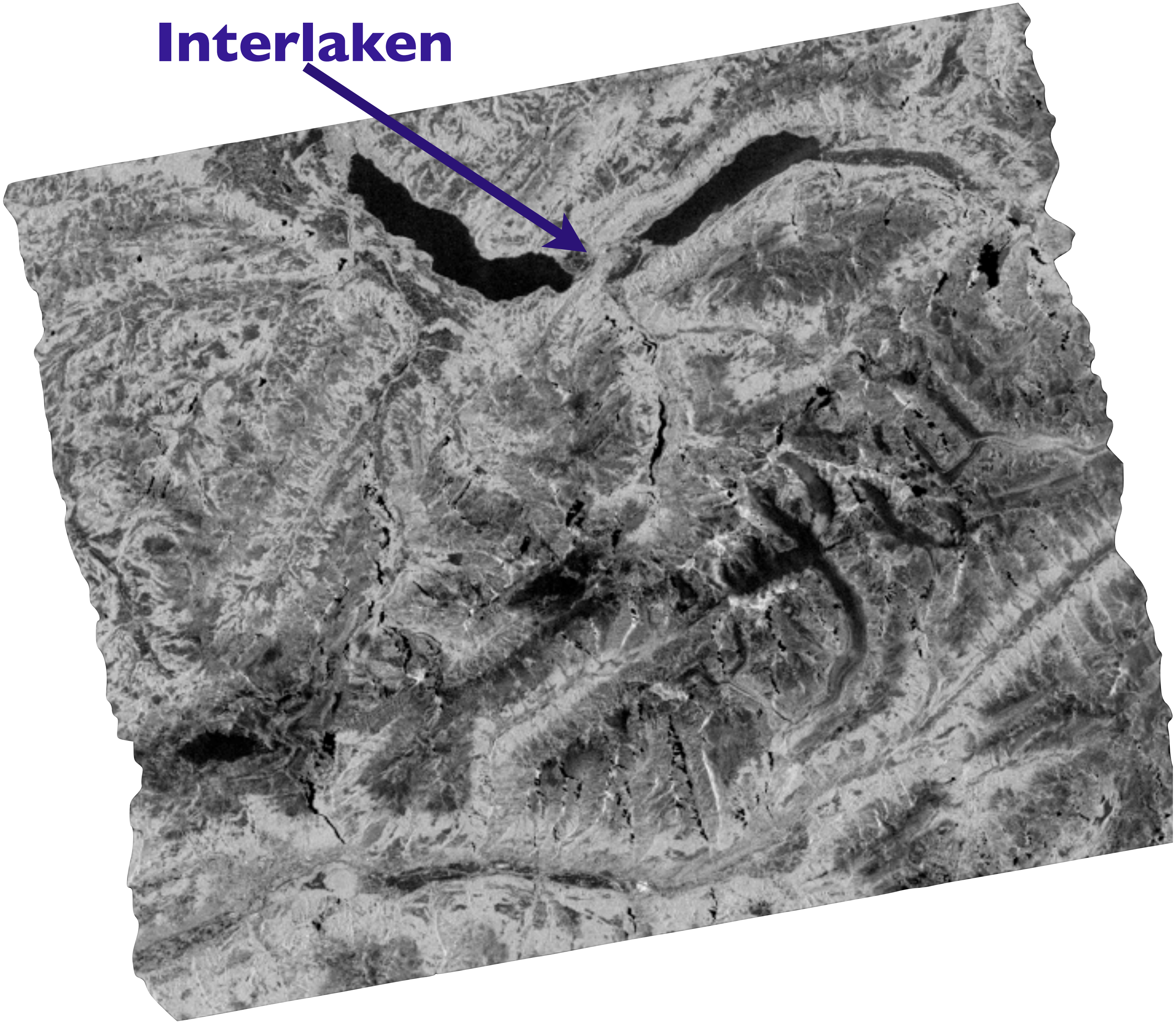
20dB

2008.06.02A

GTC

FBD HV

Bernese Oberland, Switzerland



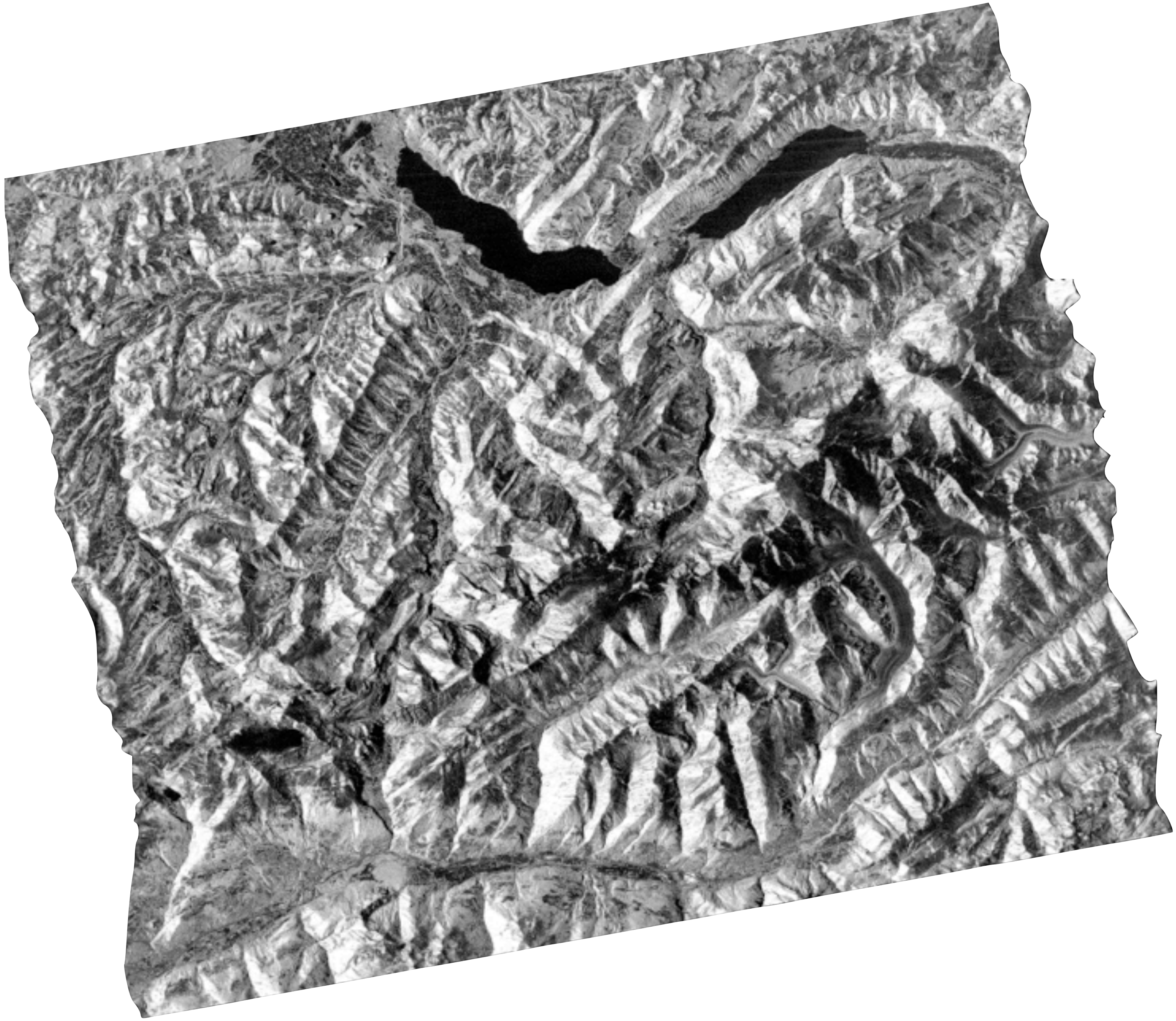
20dB

2008.06.02A

RTC

FBD HV

Bernese Oberland, Switzerland



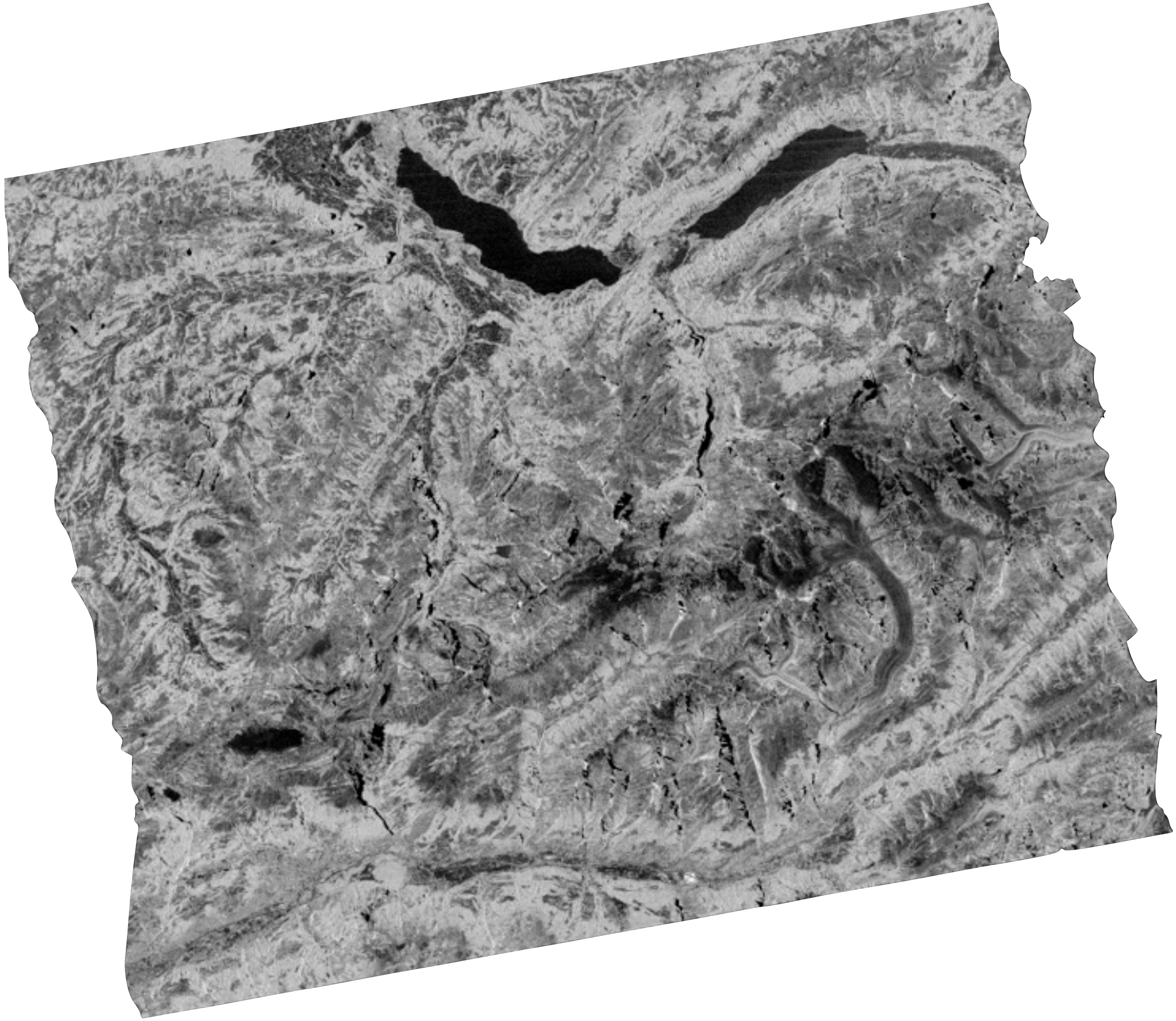

20dB

2008.07.18A

GTC

FBD HV

Bernese Oberland, Switzerland



20dB

2008.07.18A

RTC

FBD HV

Bernese Oberland, Switzerland


20dB

2007.08.14A

GTC

FBD HV

Bernese Oberland, Switzerland

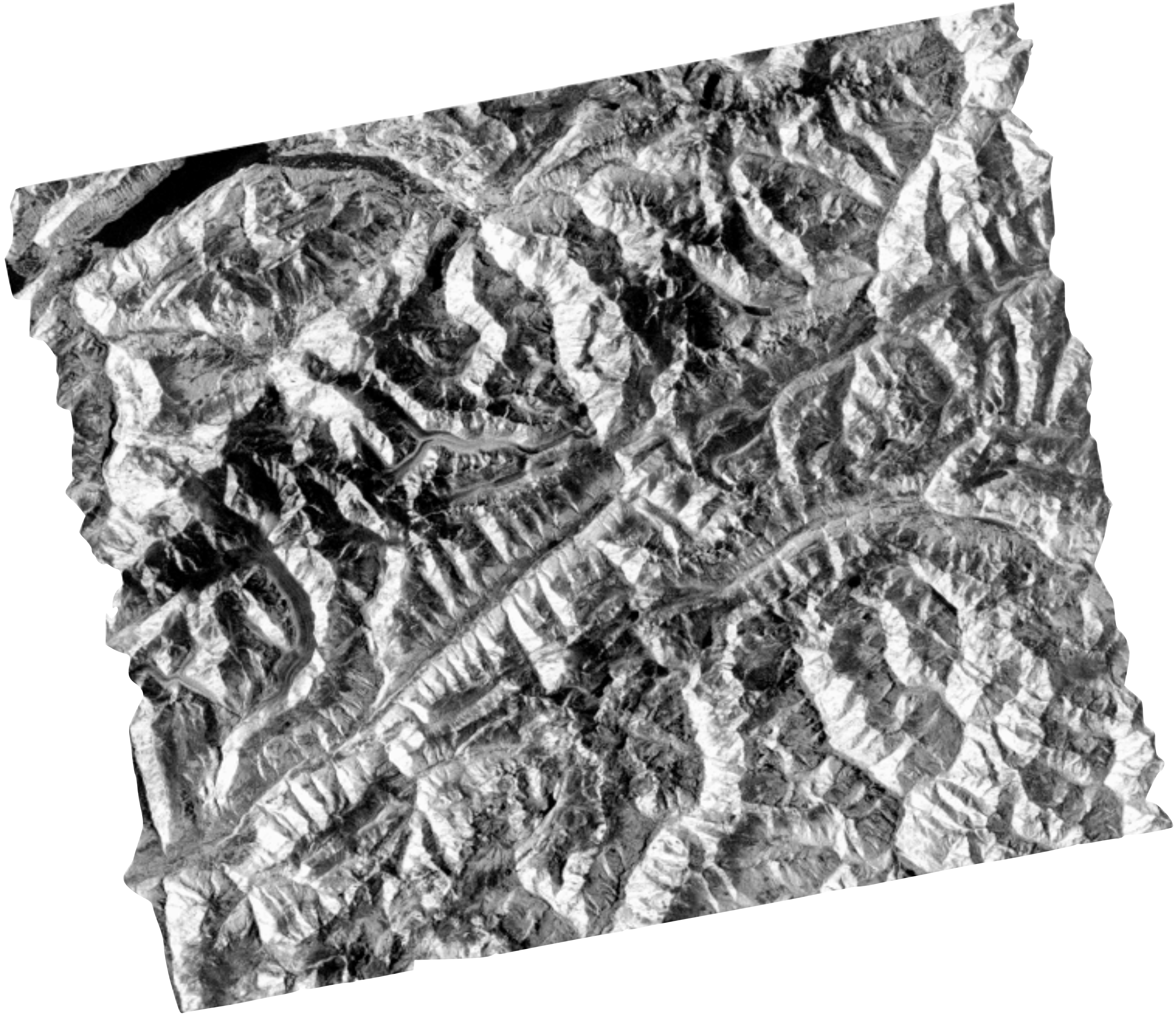
20dB

2007.08.14A

RTC

FBD HV

Bernese Oberland, Switzerland



20dB

2008.07.01A

GTC

FBD HV

Bernese Oberland, Switzerland

20dB

2008.07.01A

RTC

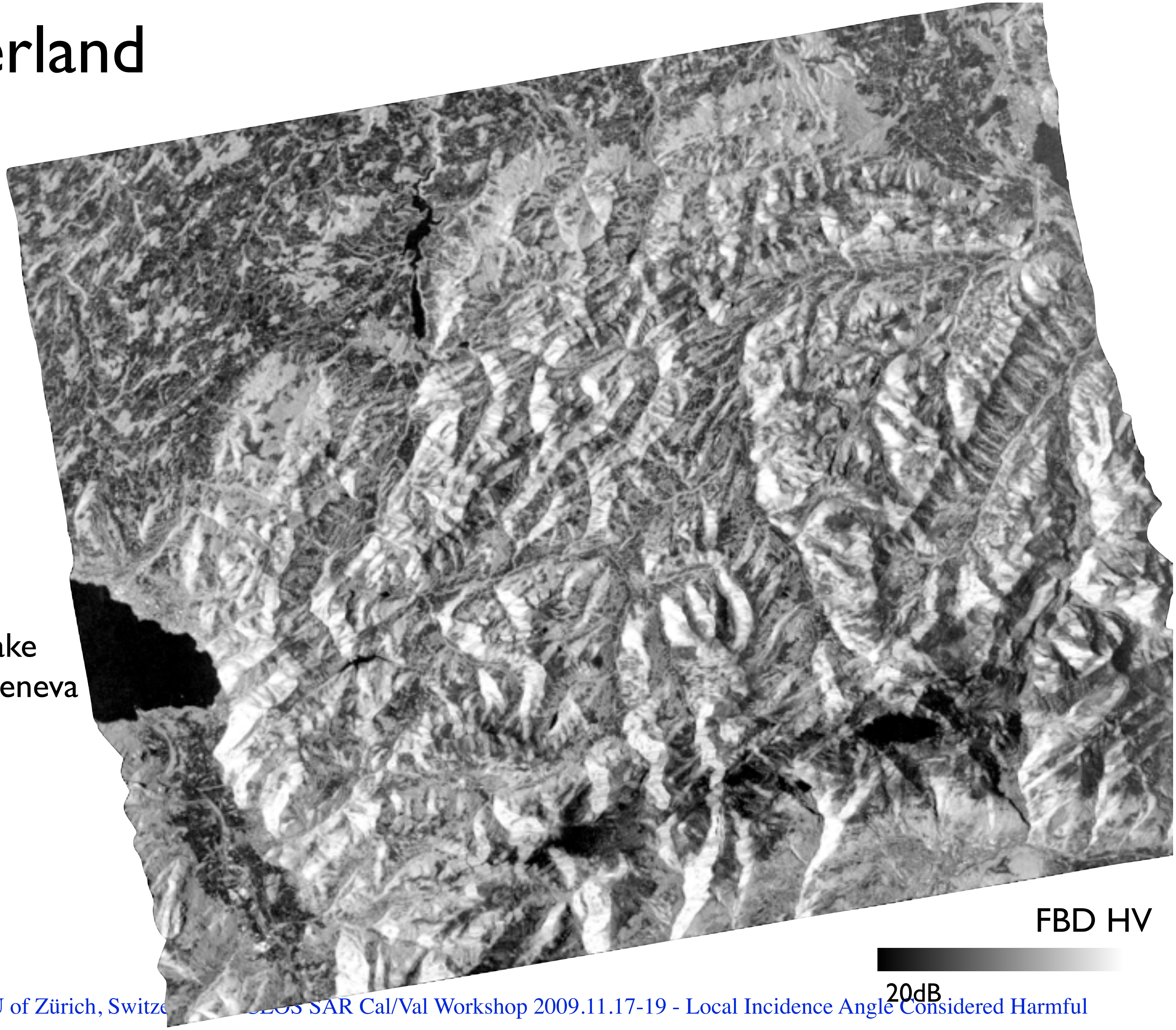
FBD HV

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)

SW Switzerland

Mixture of *terrain* and thematic *land cover*



Lake Geneva

2008.06.19A

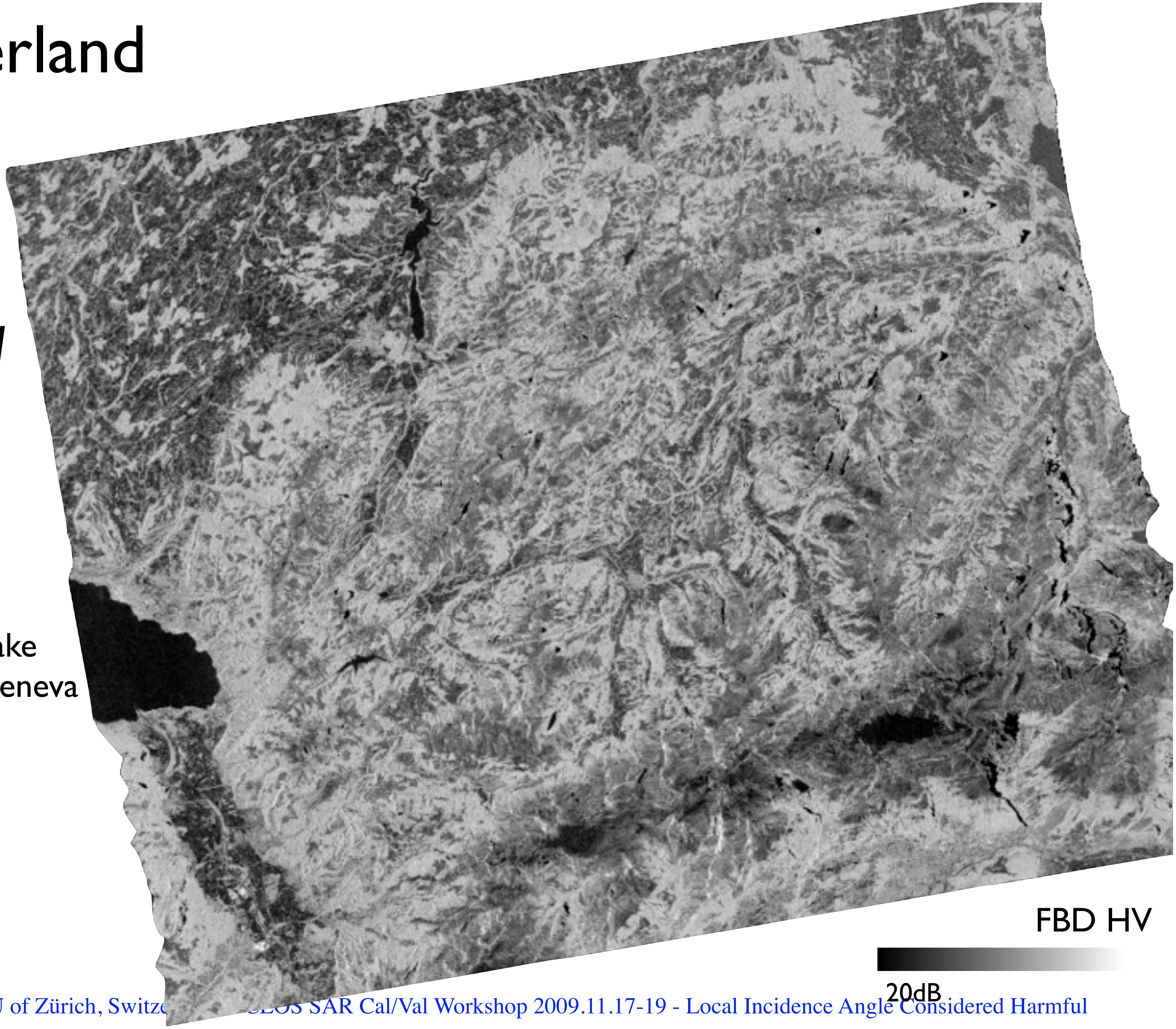
GTC

FBD HV

20dB

SW Switzerland

Thematic *land cover*

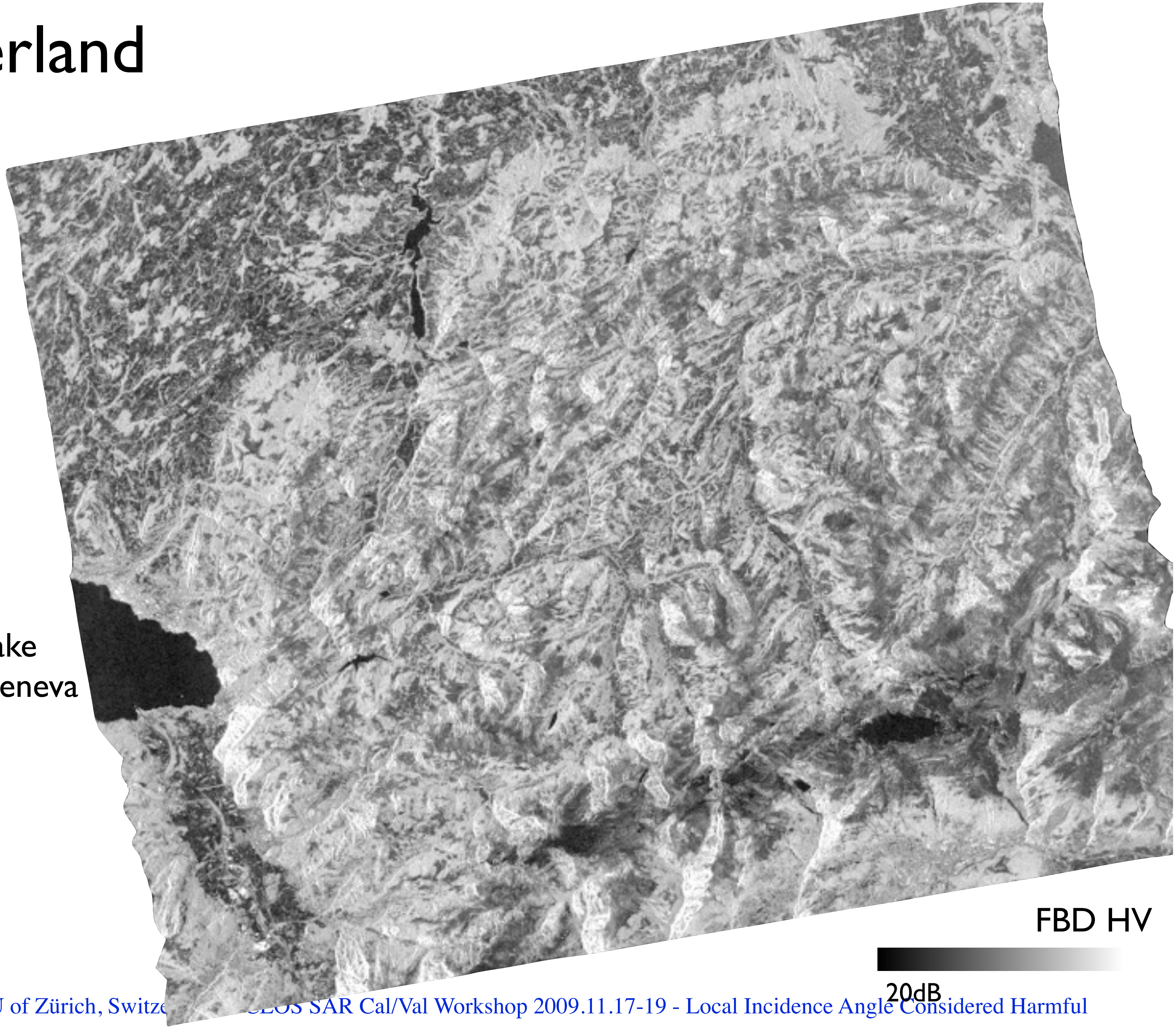


2008.06.19A

RTC

SW Switzerland

Mixture of *terrain (reduced)* and thematic *land cover*



Lake Geneva

2008.06.19A

NORLIM

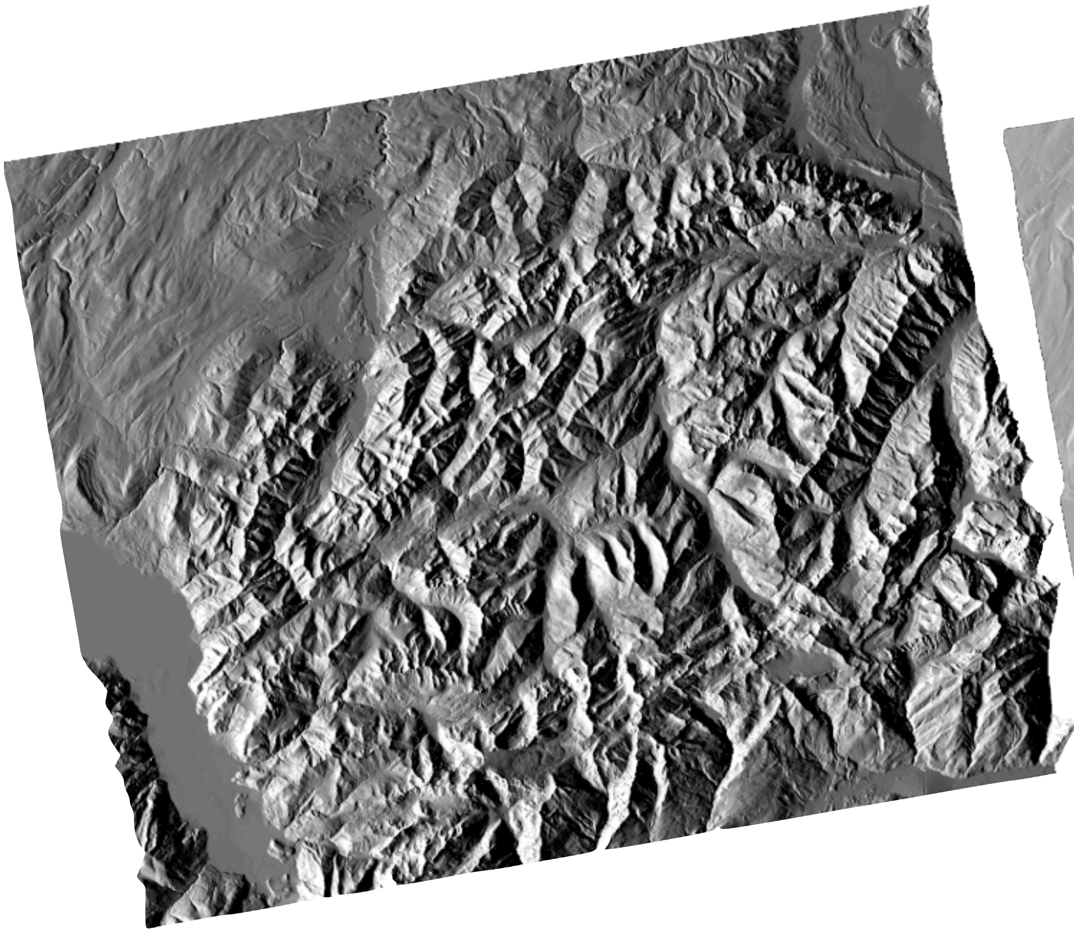
FBD HV

20dB

Bernese Oberland, Fribourg, & Vaud - SW Switzerland

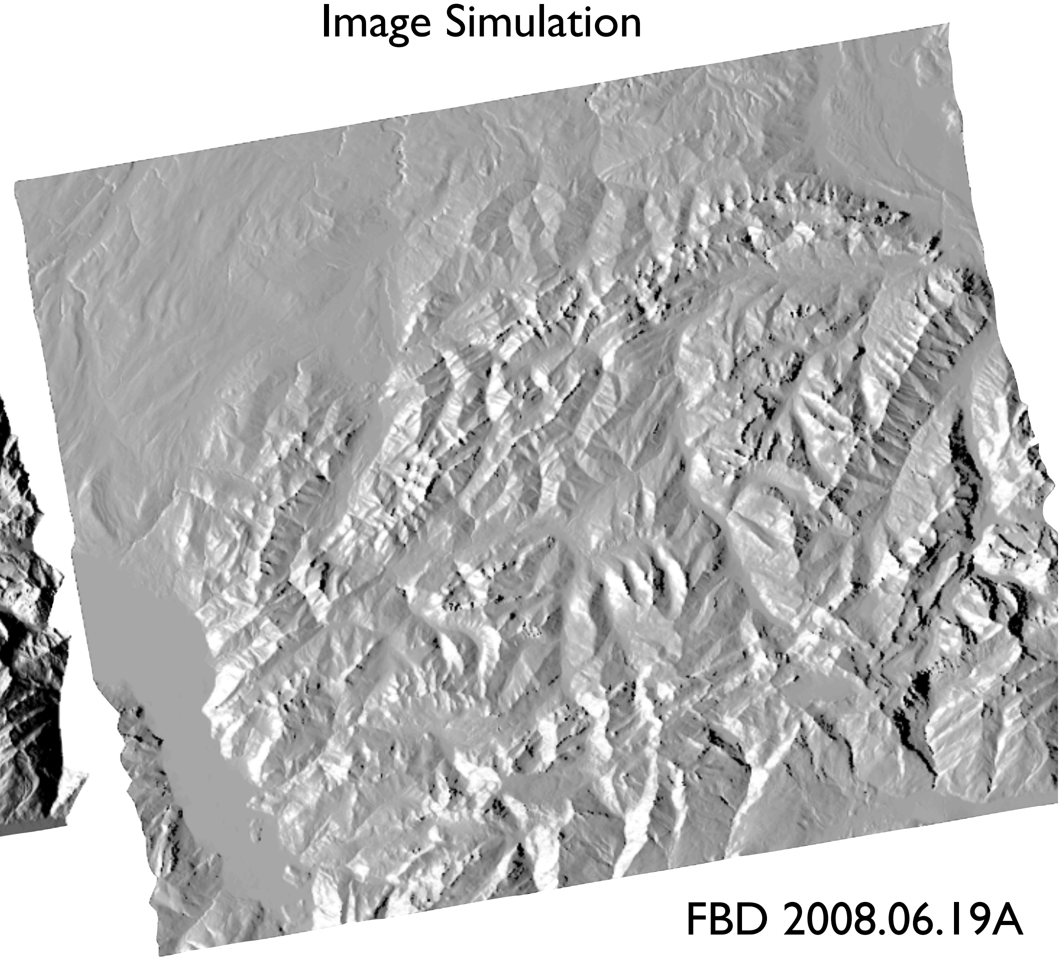
NORLIM

Local Incidence-angle Mask



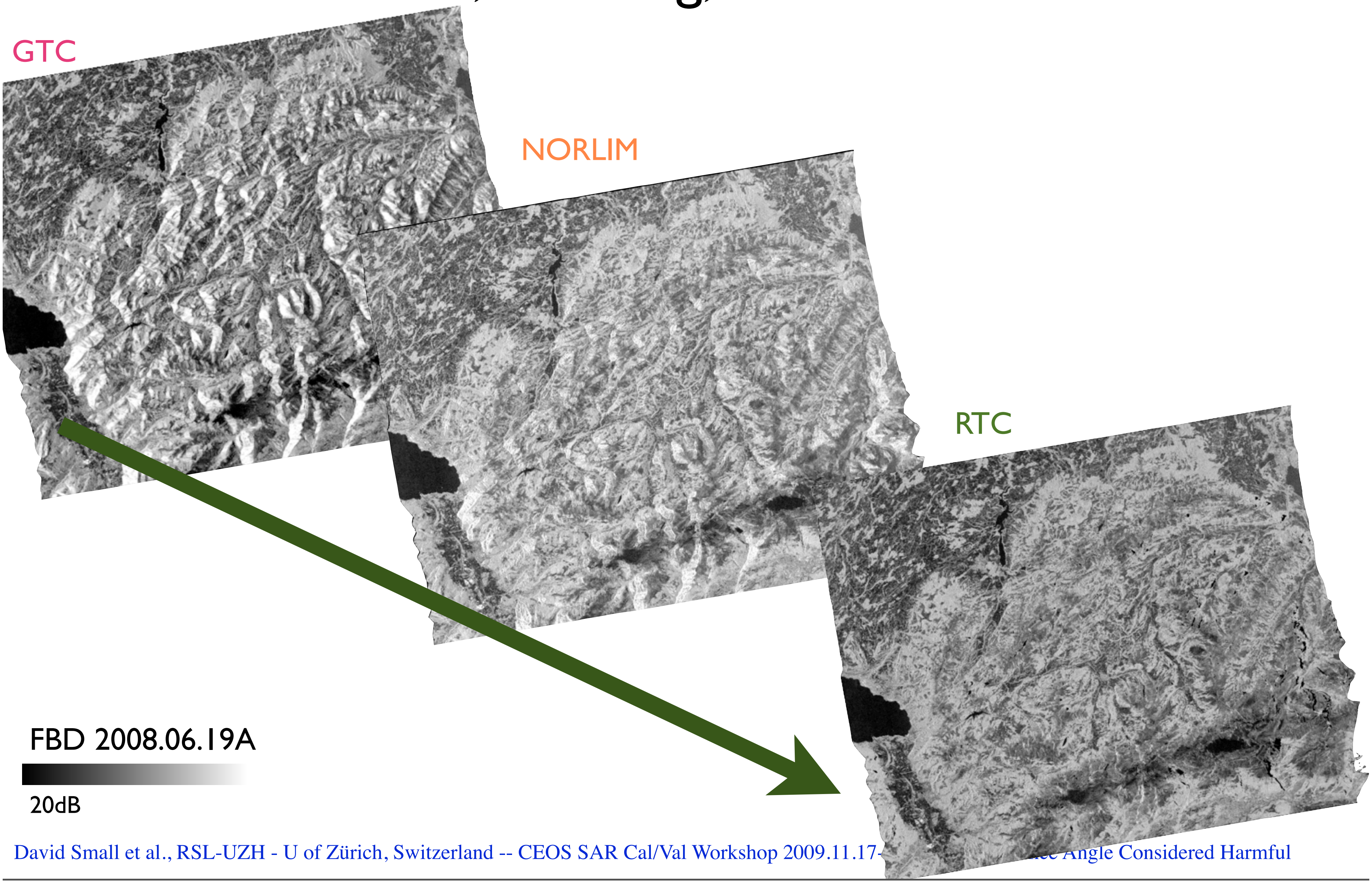
RTC

Image Simulation

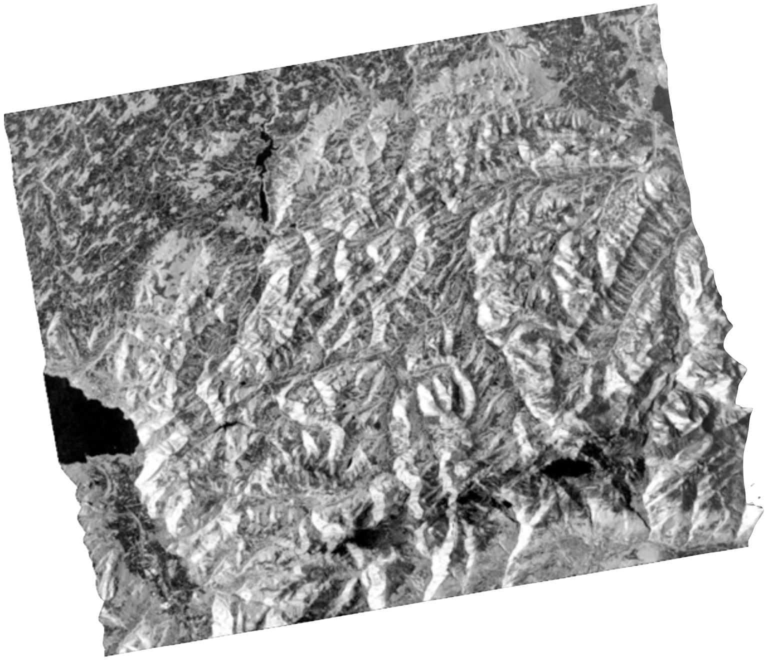


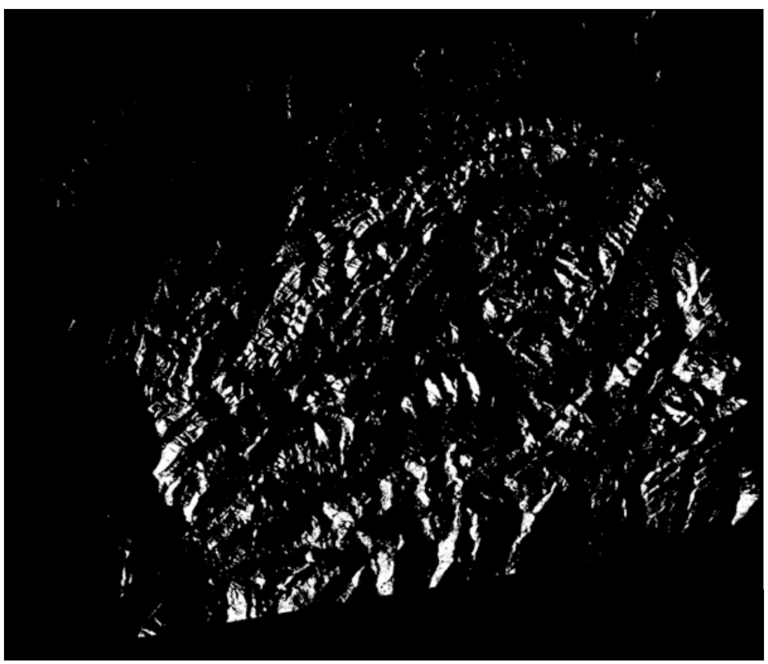
FBD 2008.06.19A

Bernese Oberland, Fribourg, & Vaud - SW Switzerland

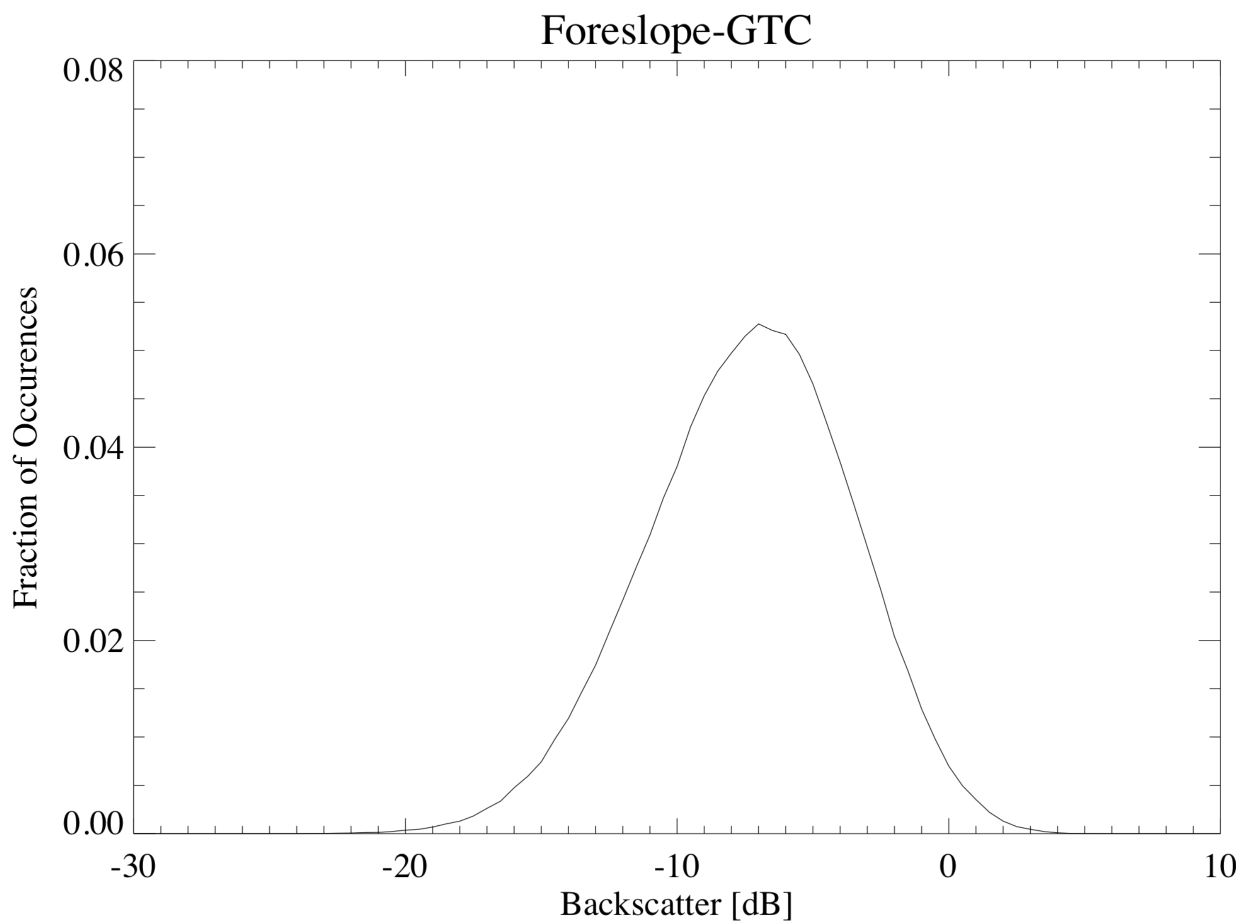


GTC on Foreslopes

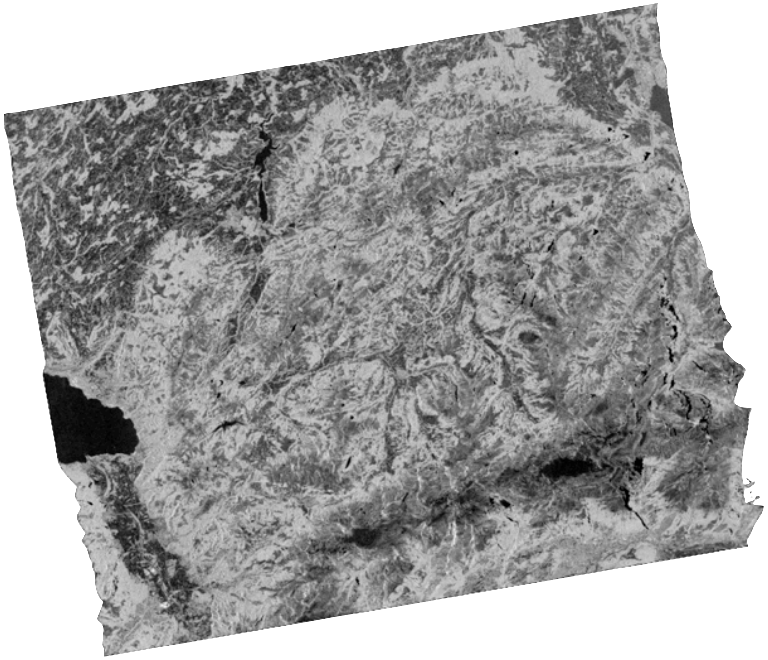




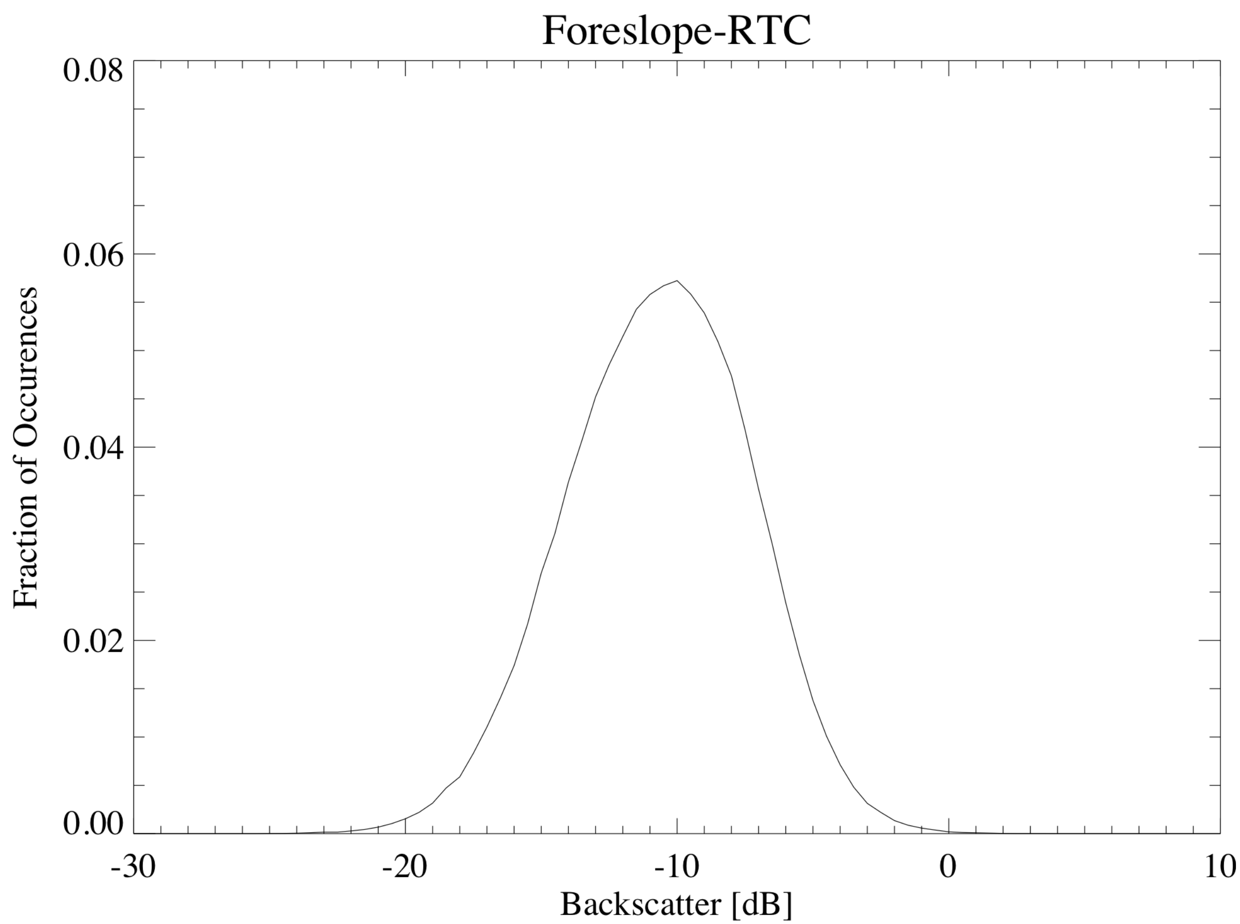
FBD 2008.06.19A

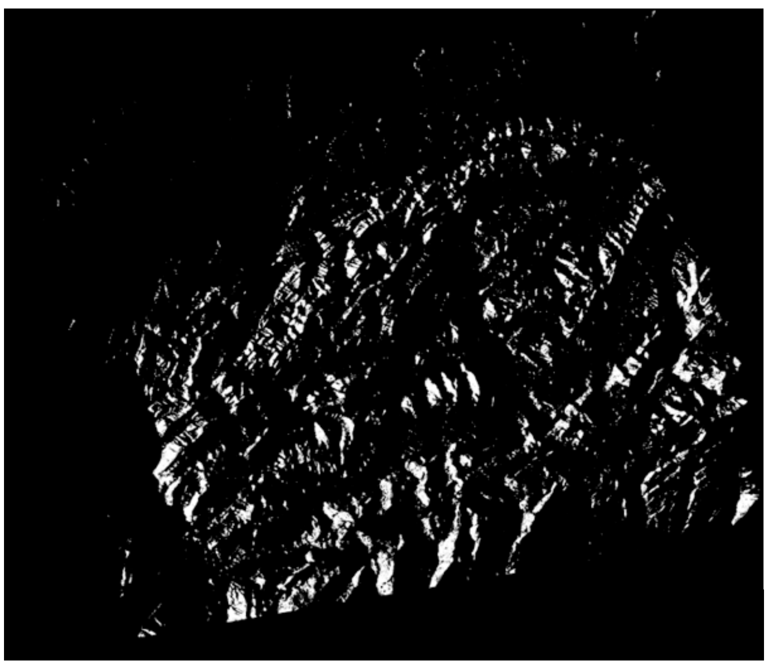


RTC on Foreslopes

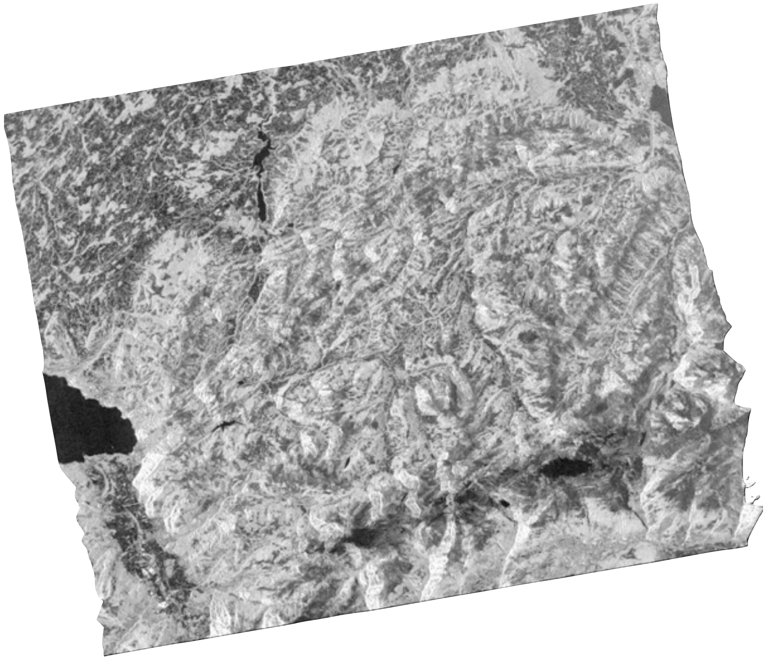


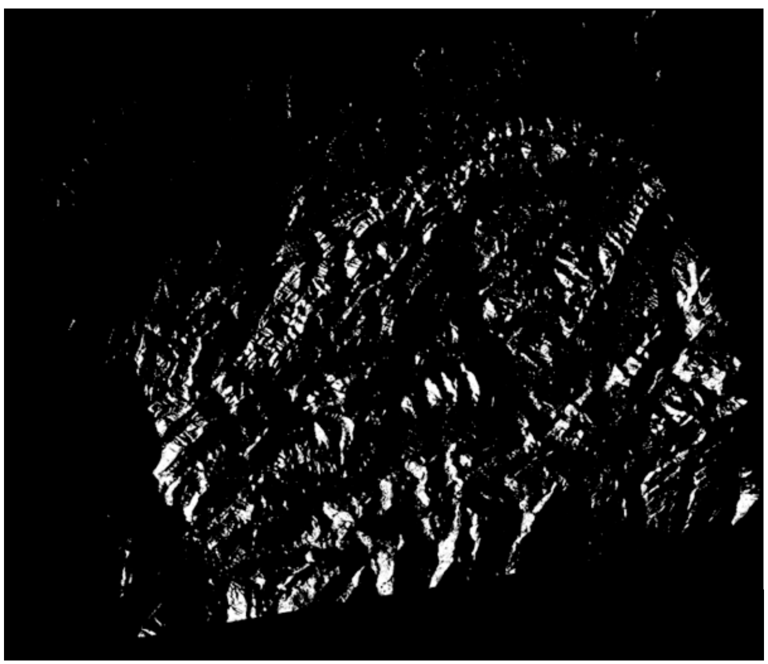
FBD 2008.06.19A



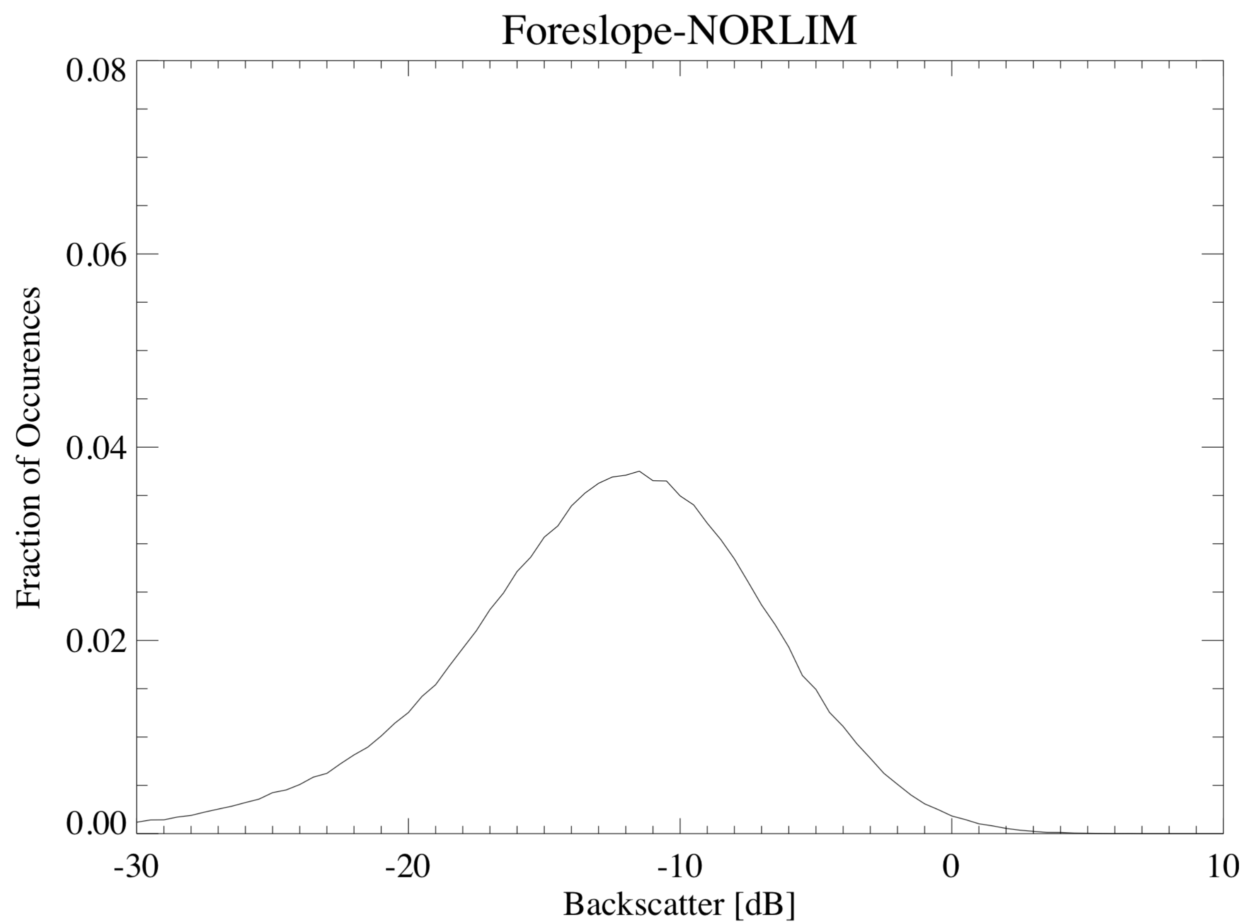


NORLIM on Foreslopes



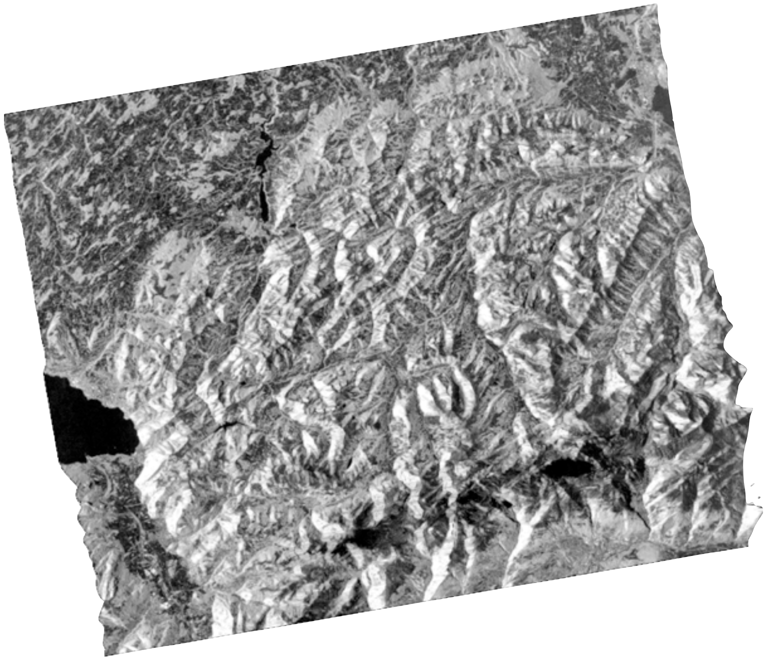


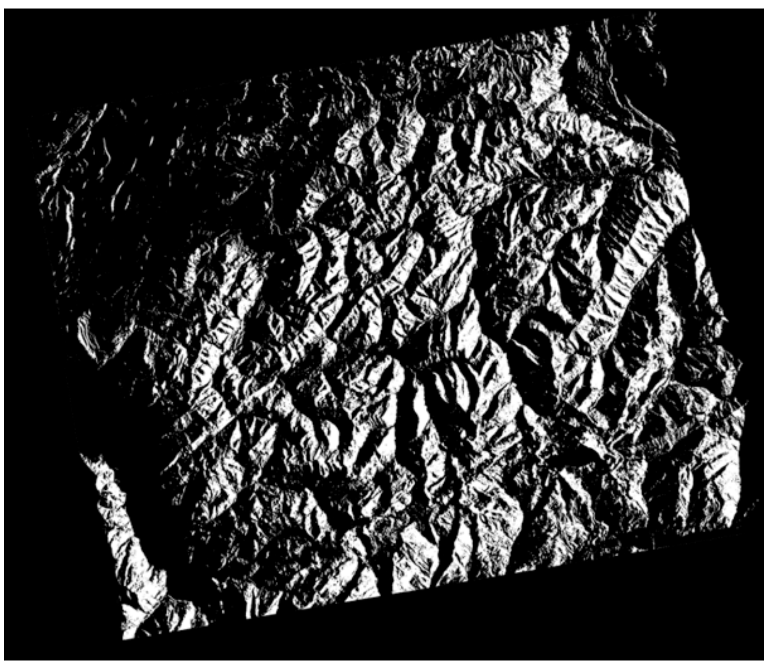
FBD 2008.06.19A



Poor performance: mixture of under- and over-correction

GTC on Backslopes





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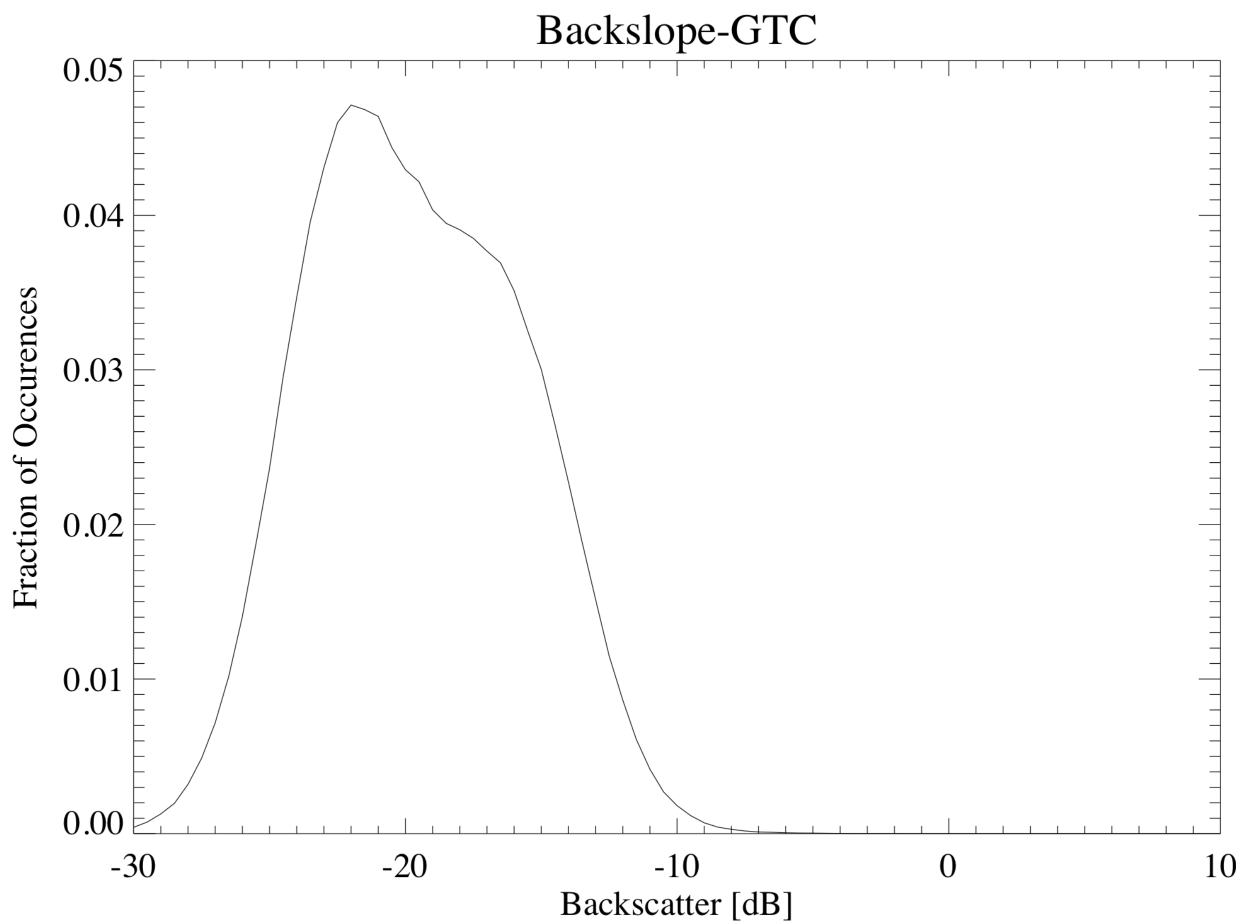
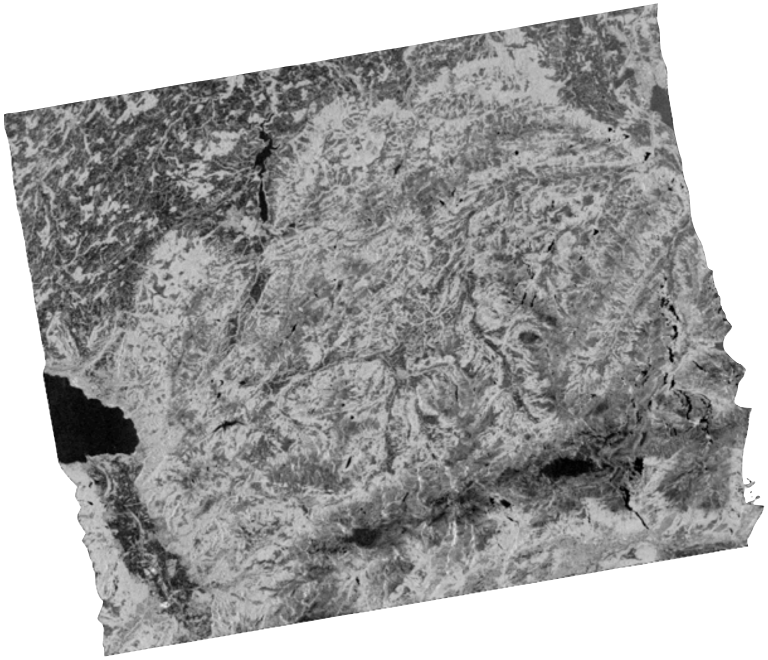
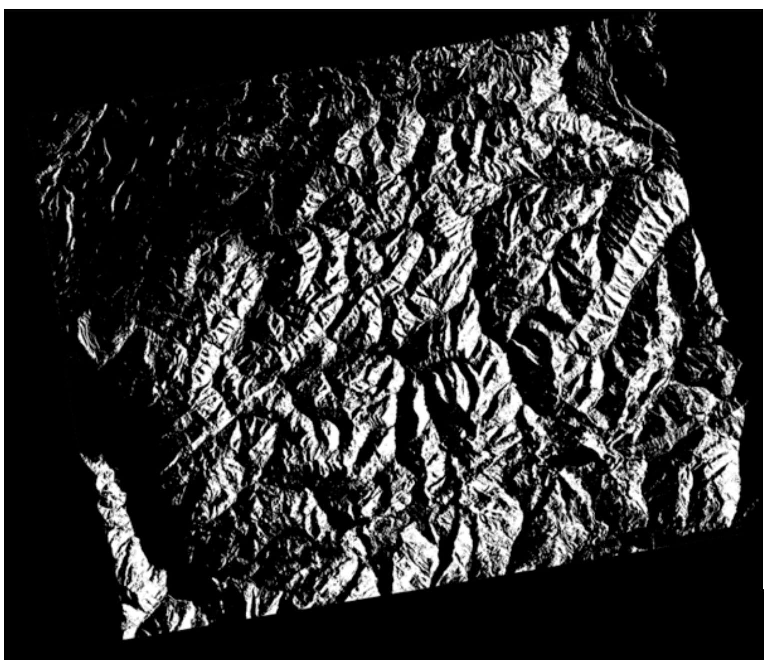
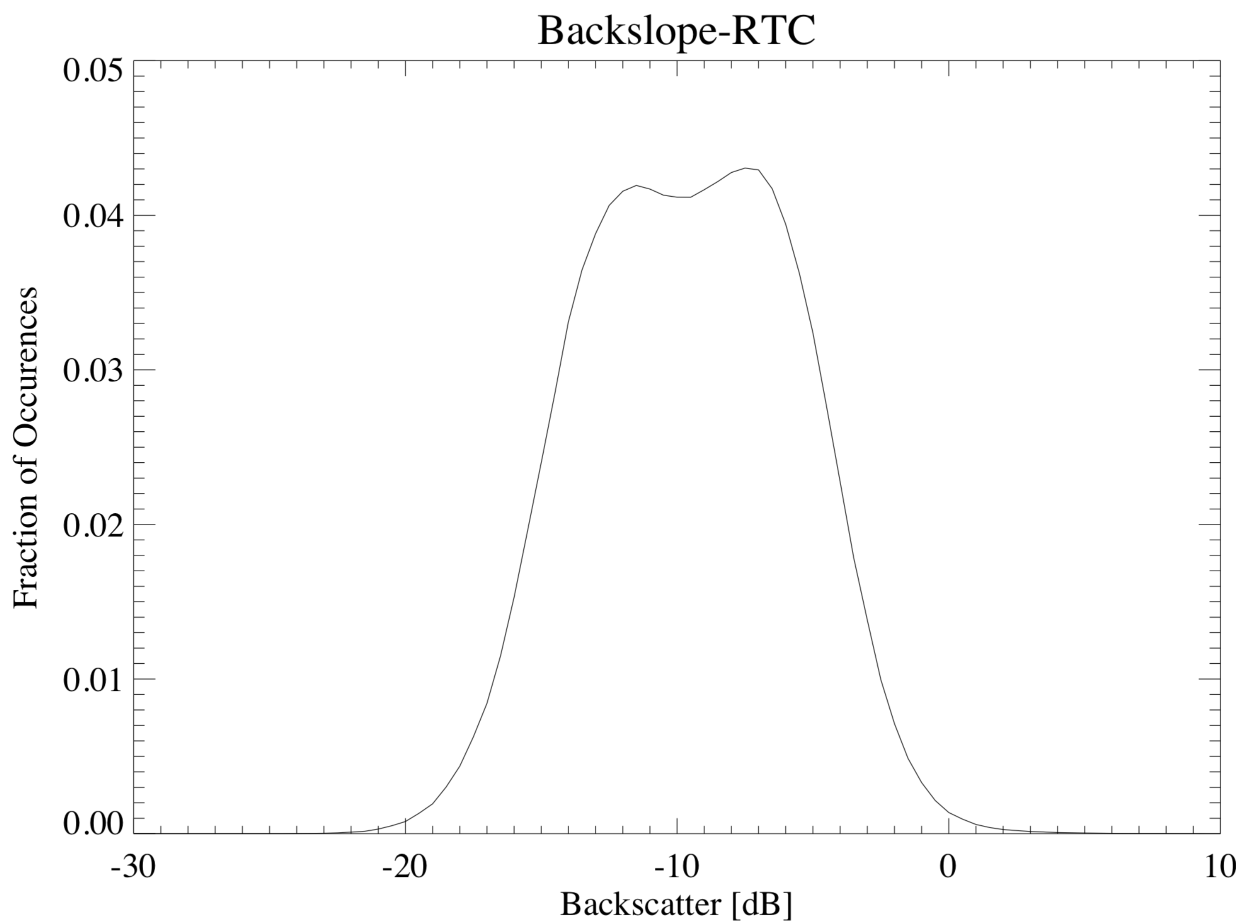


RTC on Backslopes

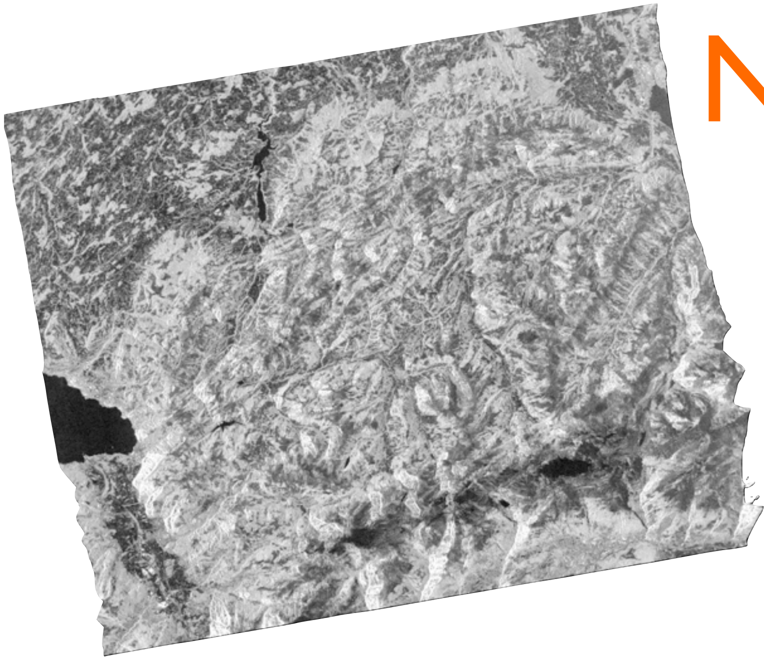


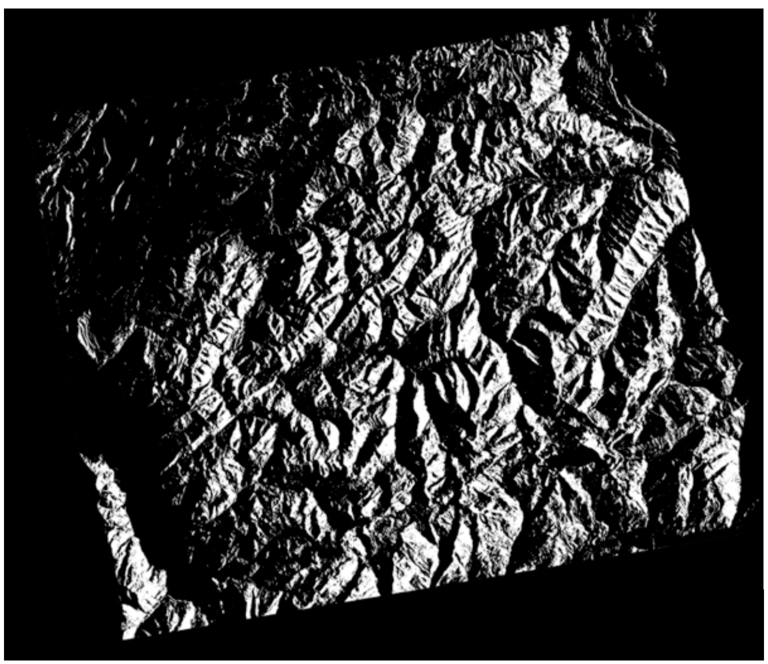


FBD 2008.06.19A



NORLIM on Backslopes





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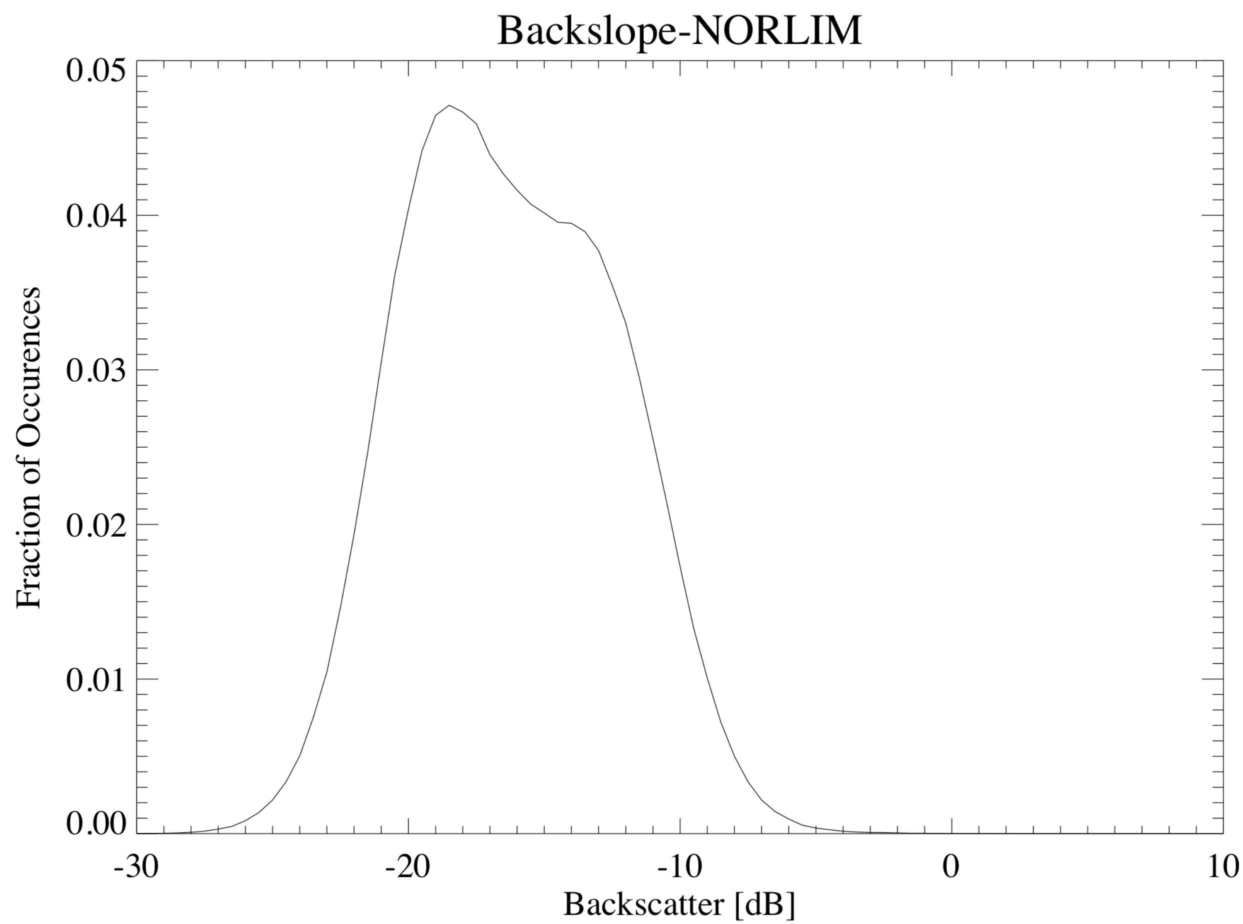


Poor performance: varying "visible" area not modelled

Foreslopes vs. Backslopes

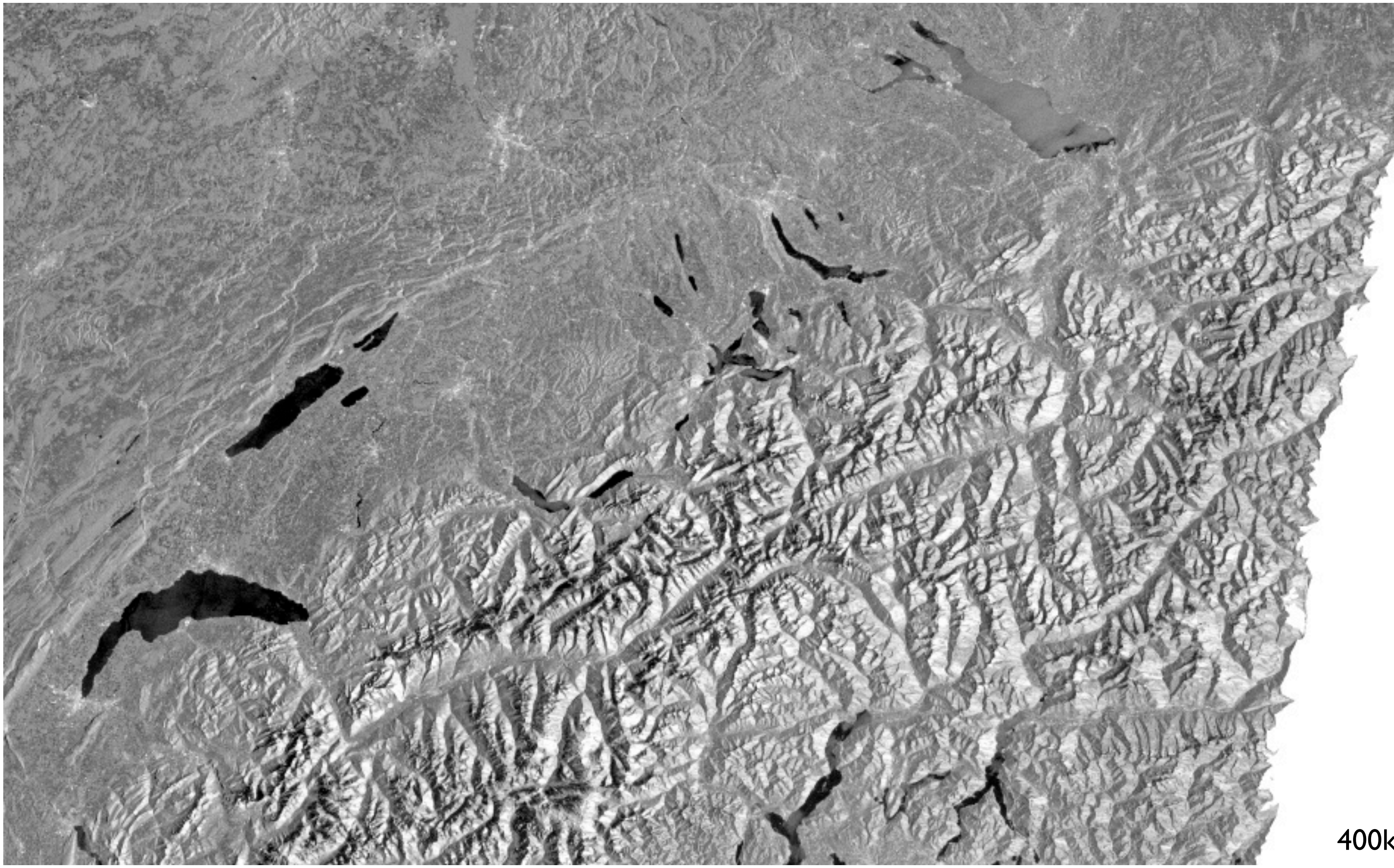
- *Image simulation*-based RTC is *superior* to Local Incidence-angle Mask (LIM) methodology
  - Non neighbouring DEM-samples considered
  - Shadow modelled
  - Varying "visible" area modelled (highly significant on backslopes)
- Foreslopes poorly normalised using LIM (less refined sensor model)
- Use of RTC recommended for thematic interpretation in variable terrain

ASAR Wide Swath (WS)

Snow Melt in Switzerland

ASAR WS GTC 2007.05.06D

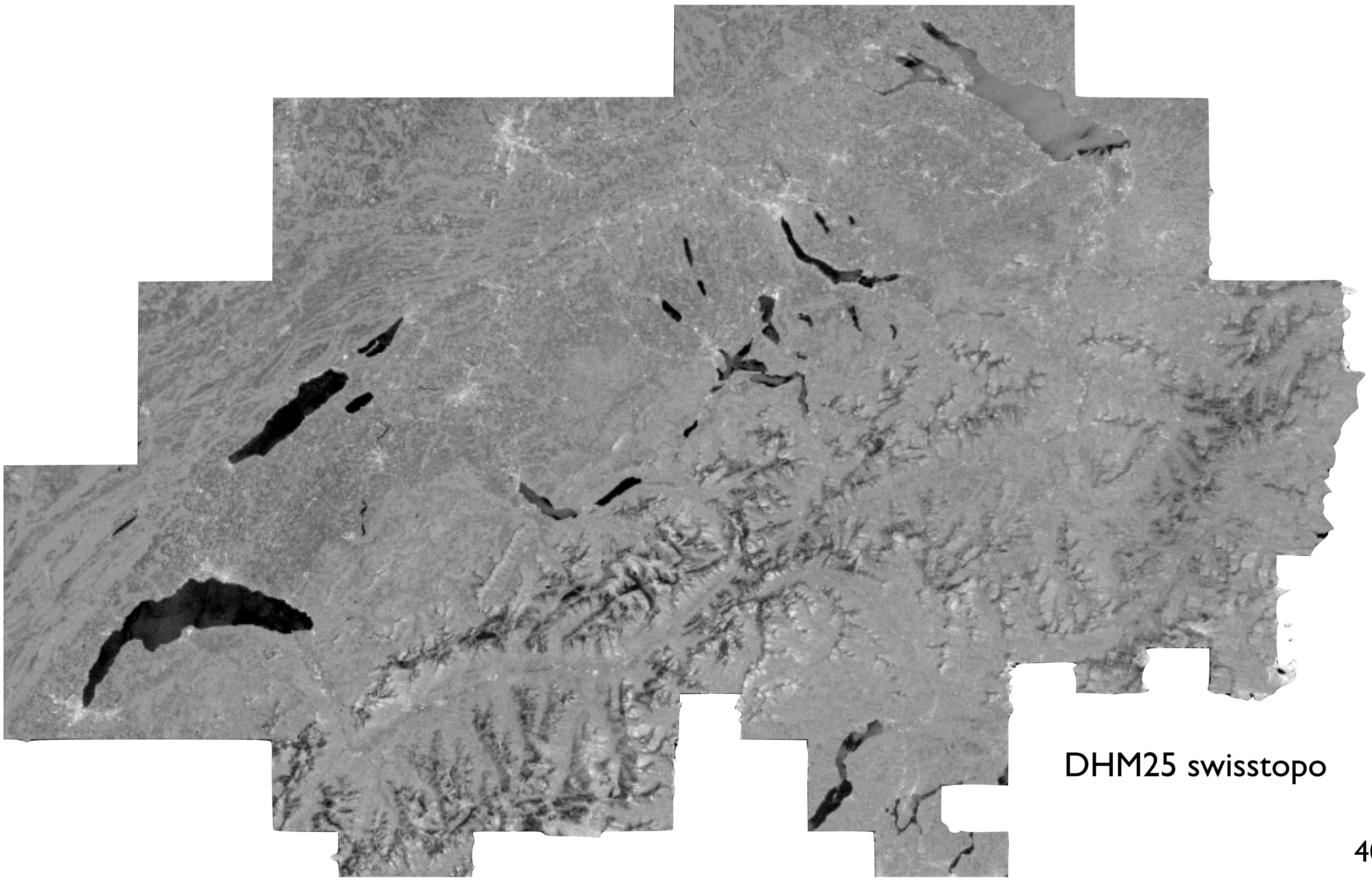
Mix of Terrain Variations + Thematic Land Cover



400km swath

ASAR WS RTC 2007.05.06D

Thematic Land Cover (snow melt)

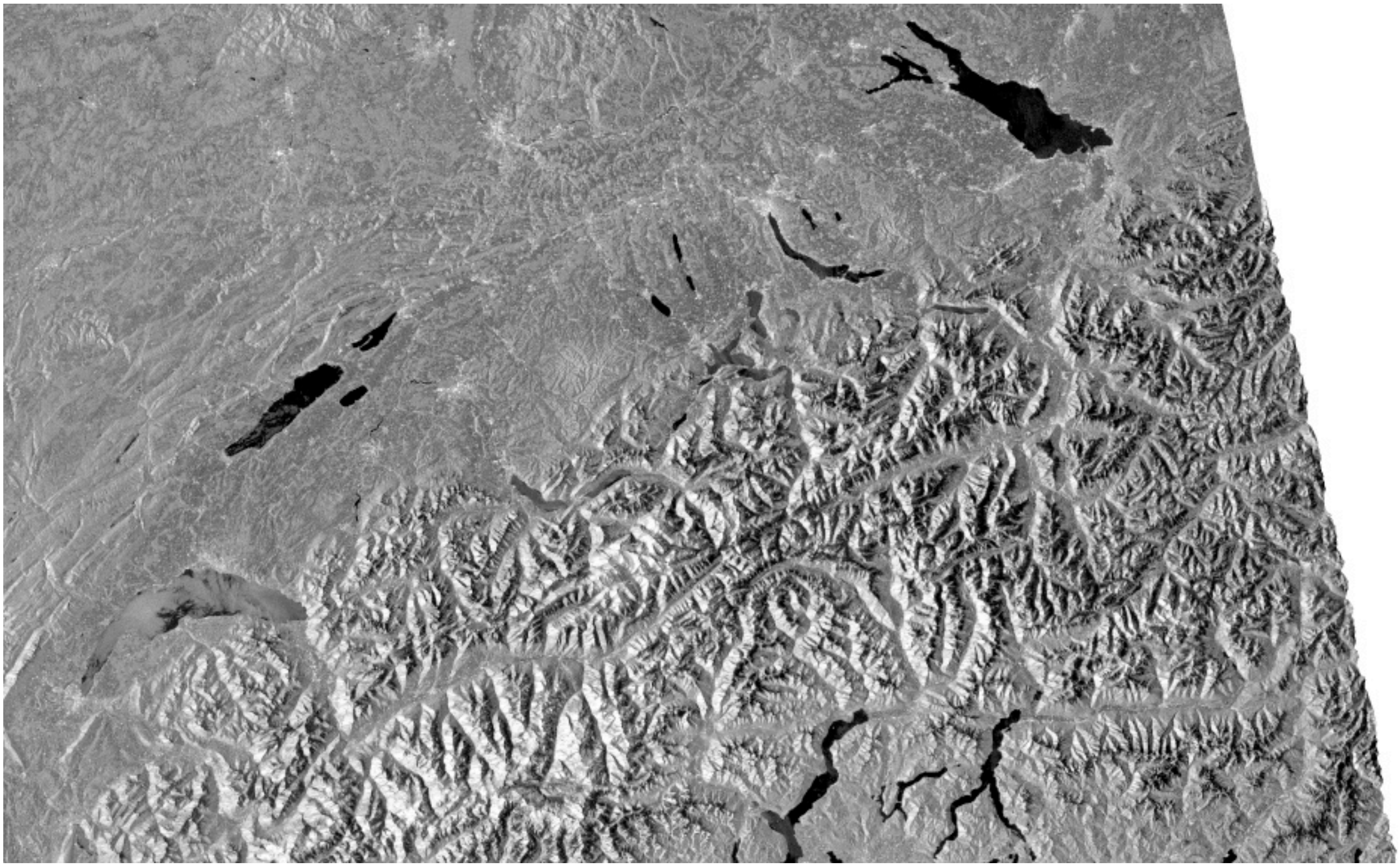


DHM25 swisstopo

400km swath

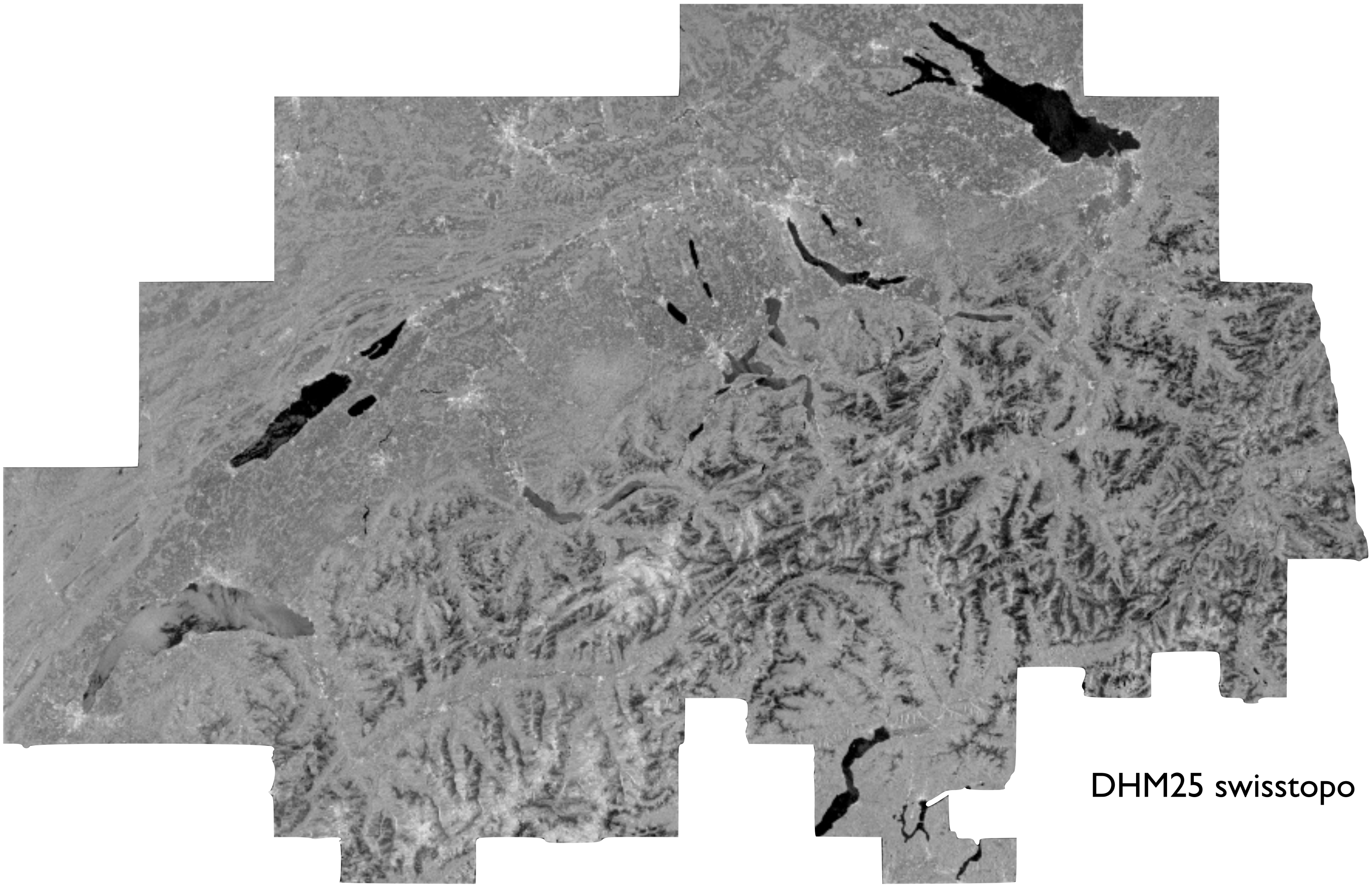
ASAR WS GTC 2009.04.11A

Mix of Terrain Variations + Thematic Land Cover



ASAR WS RTC 2009.04.11A

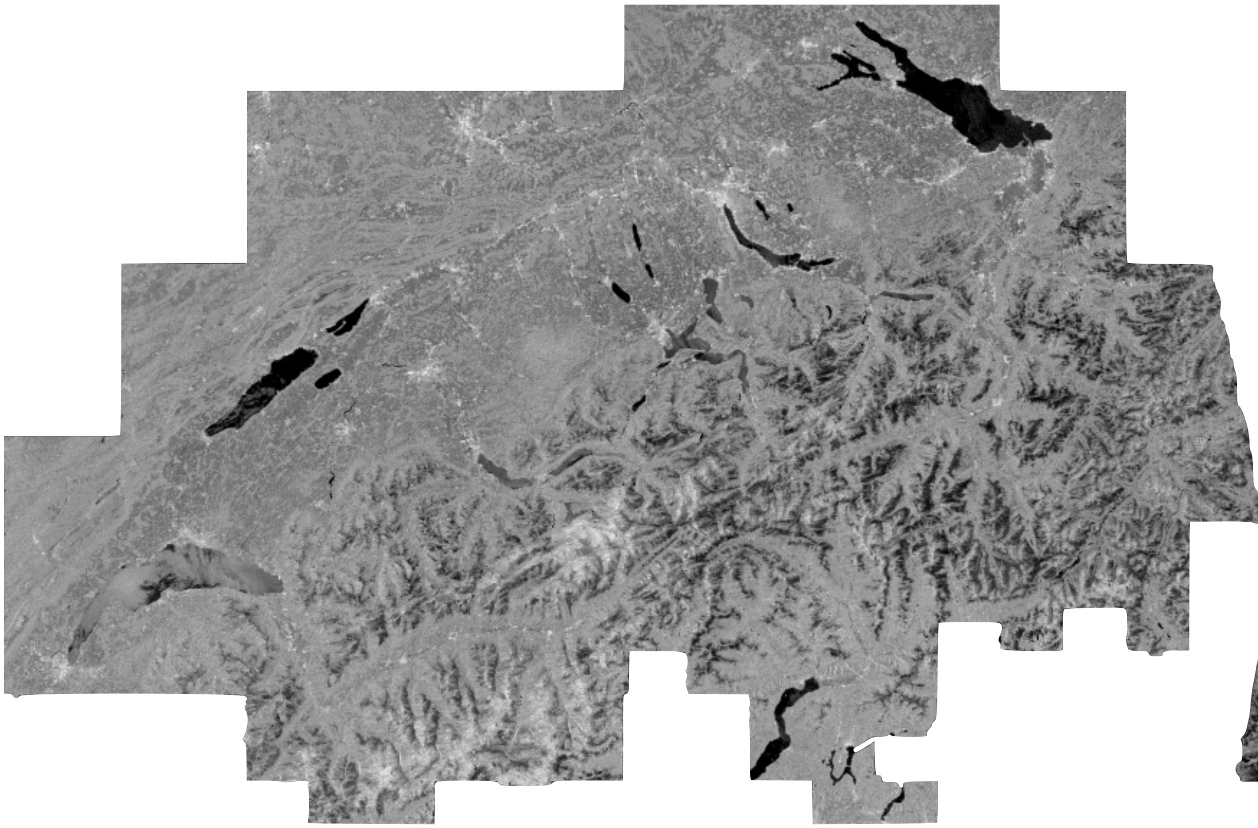
Thematic Land Cover (snow melt)



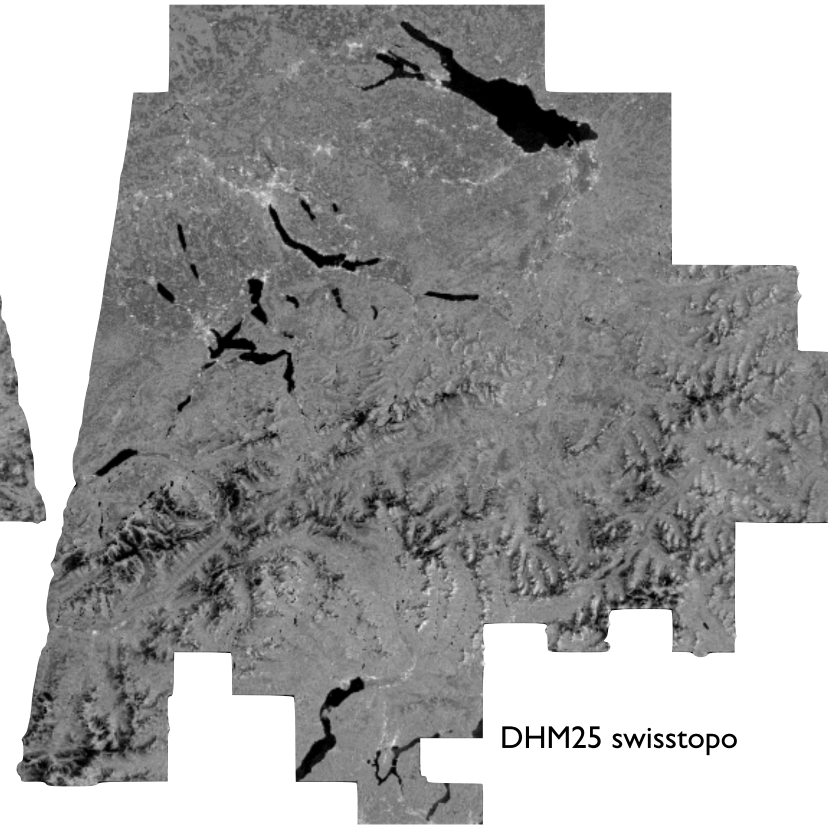
DHM25 swisstopo

ASAR WS Asc/Desc RTC

2009.04.11A



2009.06.08D



Height-dependency in seasonal snow-melt

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?