Basics, methods & applications

ACTIVE MICROWAVE REMOTE SENSING OF LAND SURFACE HYDROLOGY

Annett.Bartsch@polarresearch.at

Active microwave remote sensing of land surface hydrology

- Landsurface hydrology:
  - Near surface water storage: soil, snow, water bodies

- Introduction
  - Why microwave remote sensing?
  - Why active?

Annett.Bartsch@polarresearch.at

Why microwave remote sensing

- Cloud independent
- Therefor frequent acquisitions possible, what is of interest when we study fast changes
- Complements optical and thermal
- For climate modelling interesting regional to global products available

- Aim
  - Basic understanding on what radar based products can offer with respect to land surface hydrology

Annett.Bartsch@polarresearch.at

Why active systems (radar)

- Systems available which cover different scales and part of the electromagnetic spectrum
- Specific techniques available which offer unique insight into landsurface processes such as **movements** or **surface structure**
- Several relevant satellite launches in 2014
- Sentinel-1 as part of copernicus is a radar system! + Future Biomass mission
- To some extent similar application potential like passive microwave sensors

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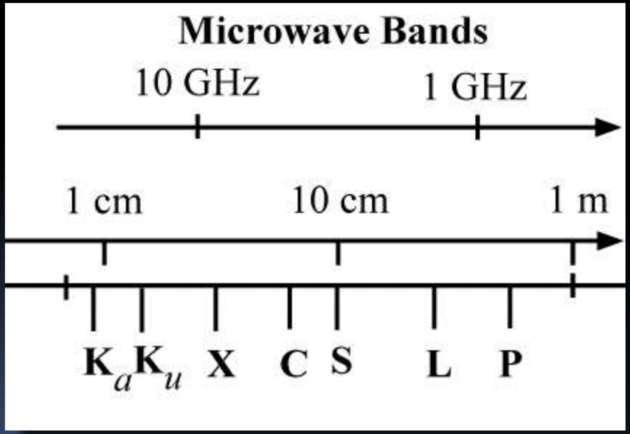
Basics

- Microwaves ~1cm – 1m
- But (spaceborne) systems work on ~ 2 - 23cm



Jensen 2005

Basics

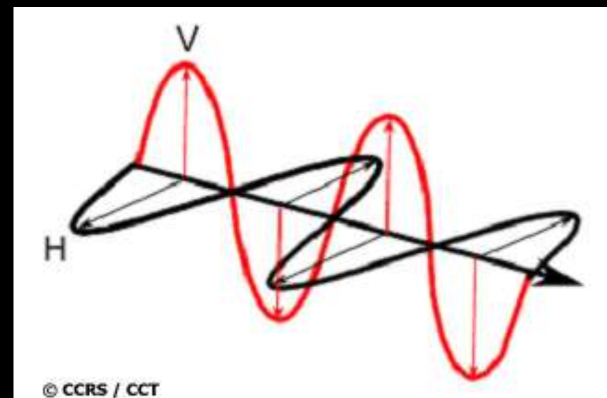
X C L Ku P S

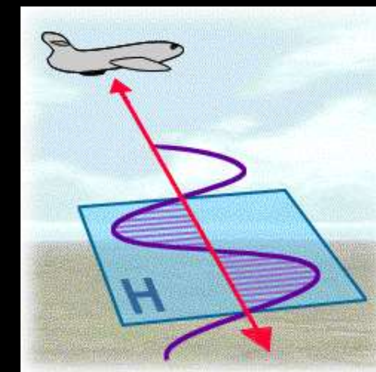
- ✓ Wavelength – Bands
- Polarization
  - Single, dual, cross …

HH VV HV VH

Basics - Polarization

- Send – Received
  - HH or VV
  - HV or VH





single polarized	- HH or VV (or possibly HV or VH)
dual polarized	- HH and HV, VV and VH, or HH and VV
alternating polarization	- HH and HV, alternating with VV and VH
polarimetric	- HH, VV, HV, and VH

- Polarimetry analyses polarization state of an electromagnetic field

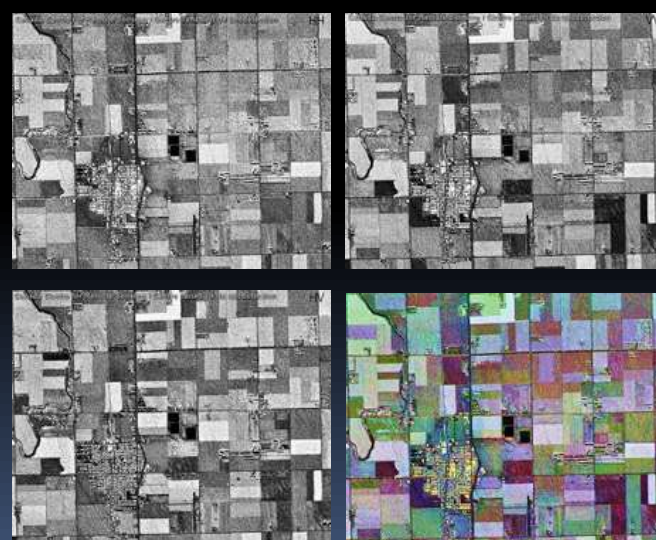
http://www.ccrs.nrcan.gc.ca

Basics - Polarization

- Cross polarisation modes detect the amount of backscatter whose polarisation has changed as a result of surface interaction
- Polarisation determines the penetration depth (beside the actual wavelength)

HH

VV



HV

colour composite

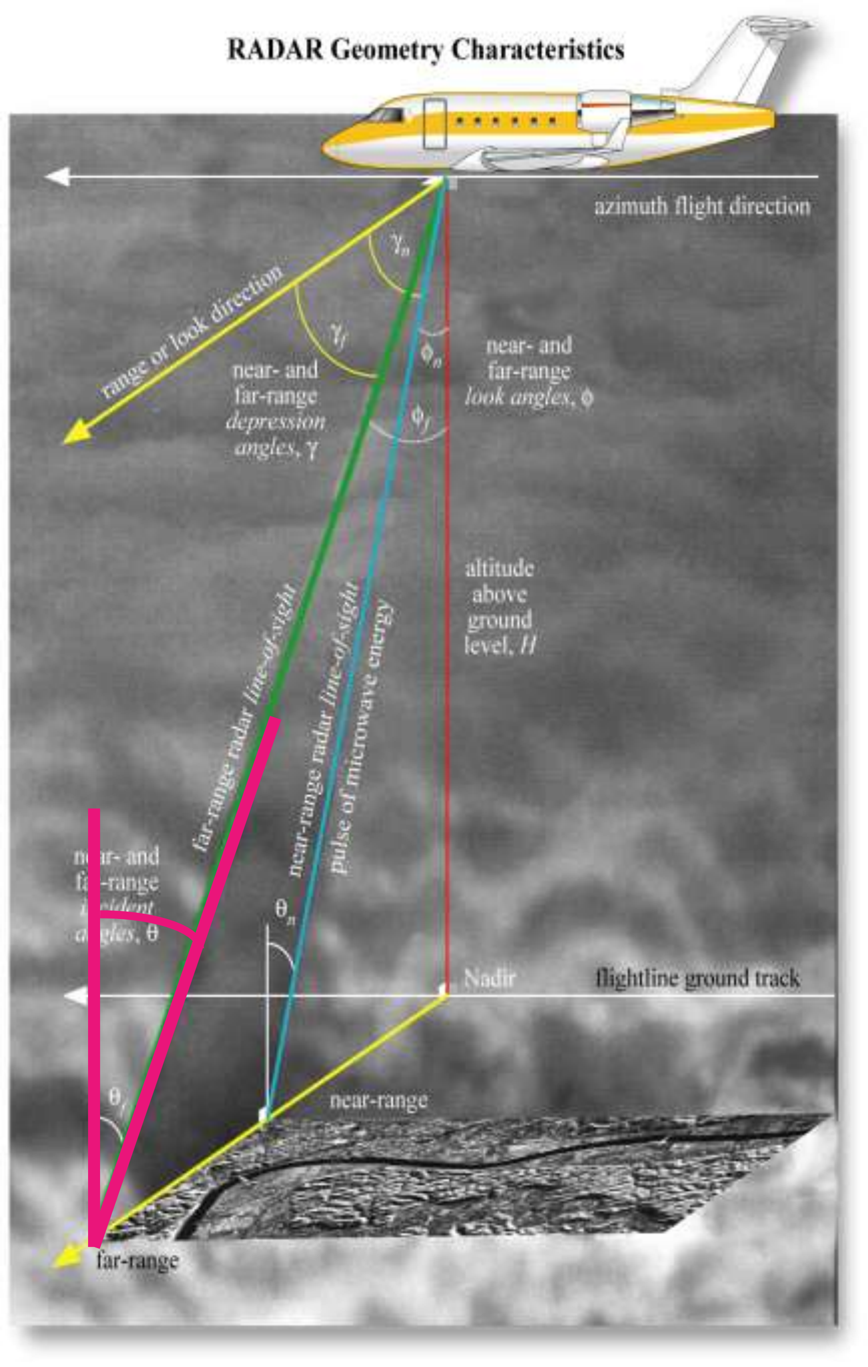
http://www.nrcan.gc.ca/earth-sciences/geography-boundary/remote-sensing/fundamentals/1025

Basics

X C L Ku P S

- ✓ Wavelength – Bands
- ✓ Polarization
  - Single, dual, cross …
- Incidence angle
- Range
- Azimuth

HH VV HV VH



Jensen, 2009

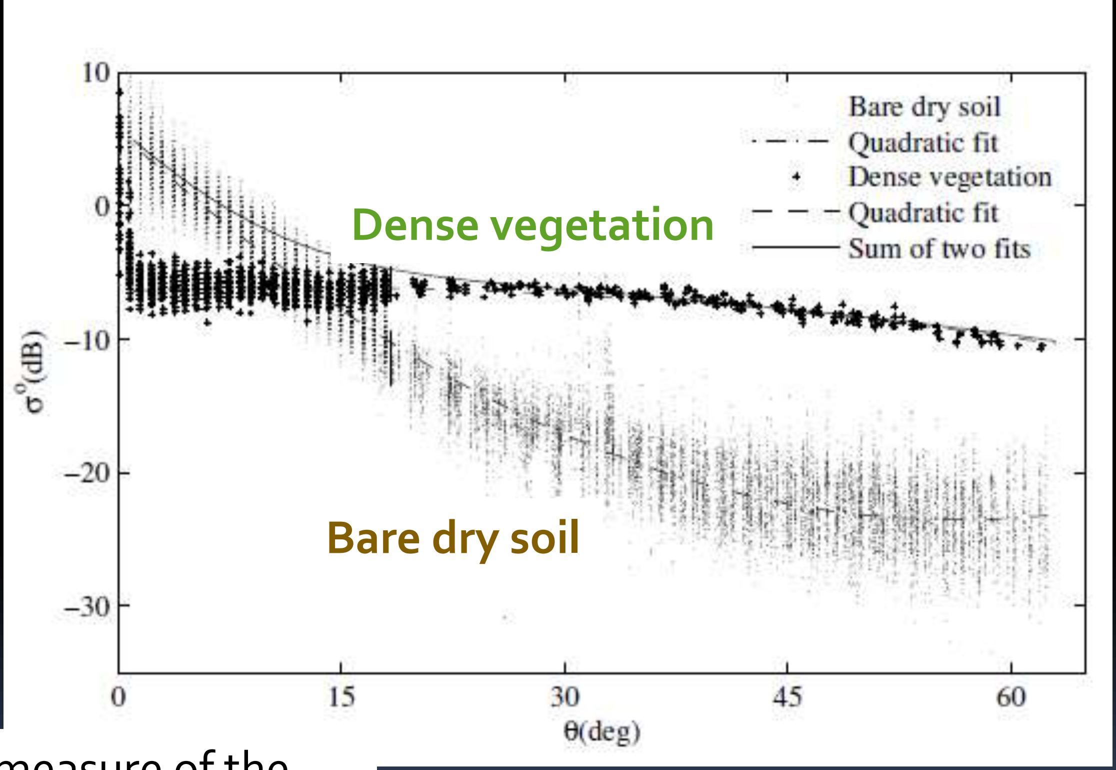
Terminology

- altitude above-ground-level, H
- Nadir
- azimuth flight direction
- range (near and far)
- depression angle (γ)
- look angles (ϕ)
- incidence angle (Θ)

Basics

Backscatter – local incidence angle

Near range far range



Normalized measure of the radar return from a distributed target
ESA Radar Glossary

K_u-Band; Stephen 2006

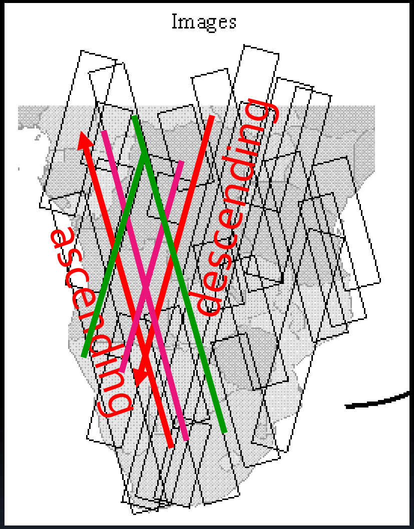
Basics

- Data are acquired
  - At ascending and descending orbit, and
  - in different modes
    - vary in spatial resolution and area covered

Example
ENVISAT ASAR
Right looking
Varying length of frame

Far range

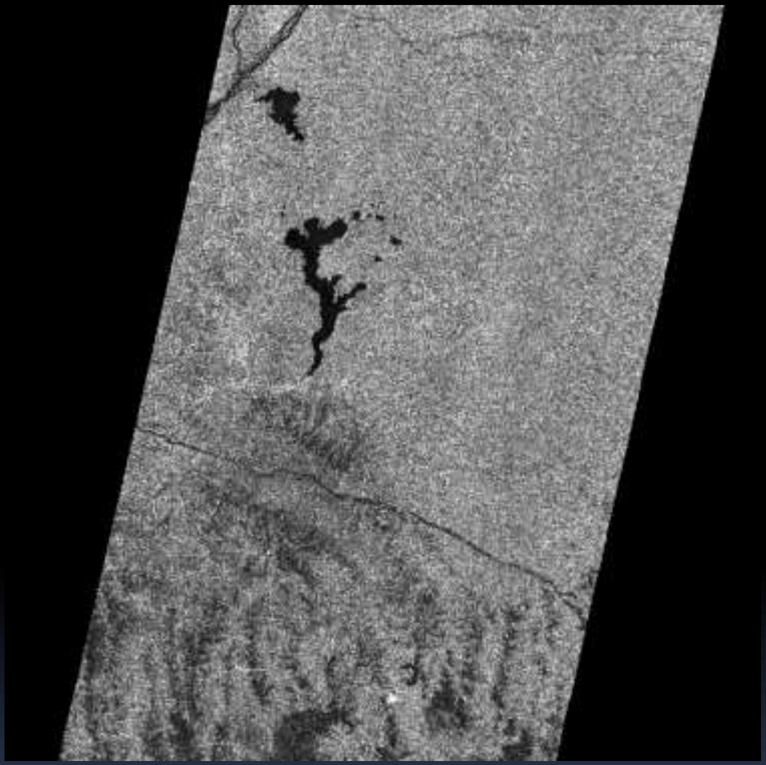
Near range



Basics – preprocessing

Normalization

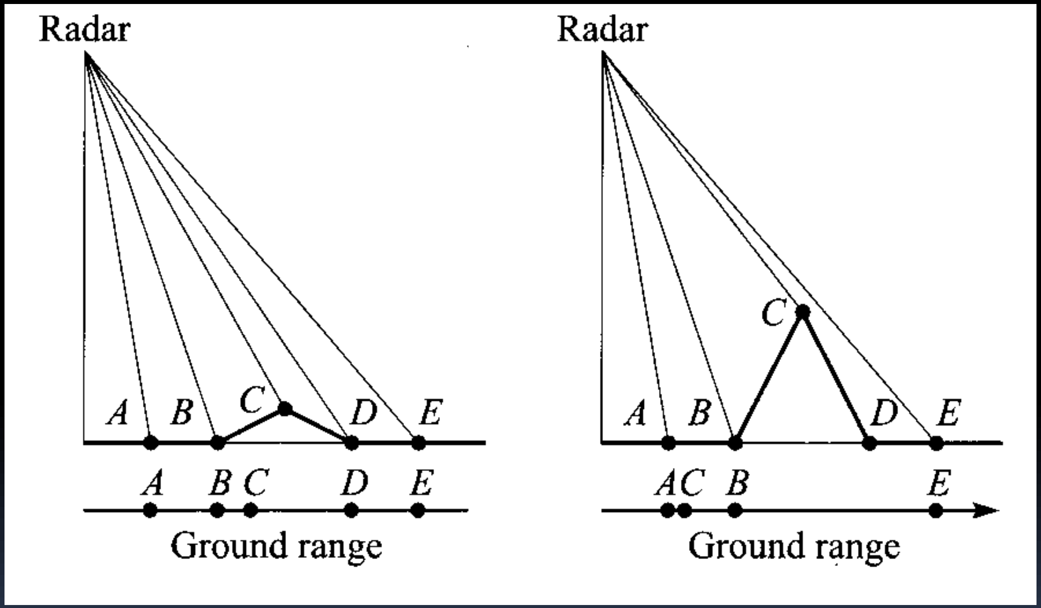
before normalization



after normalization

Basics – preprocessing

Distortion phenomena



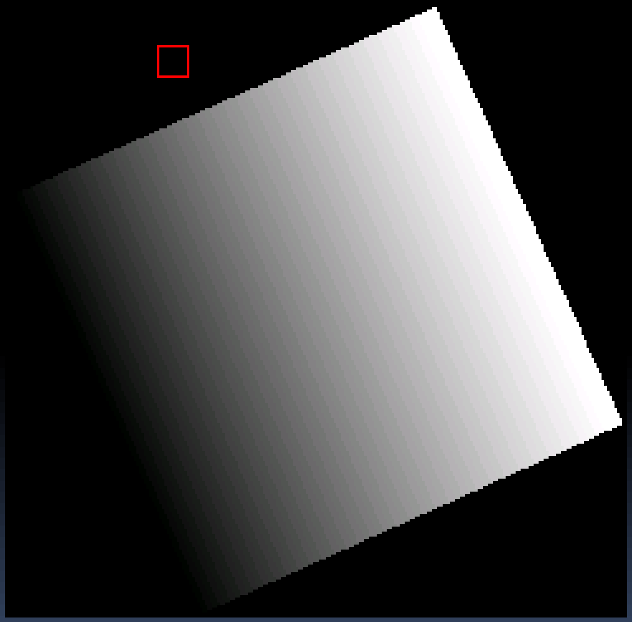
Rees 2001

Image distortion phenomena in side-looking radar imaging:
(left) **Foreshortening** and (right) **Layover & shadowing**

Basics – preprocessing

Local Incidence Angle - LIA

LIA for flat area



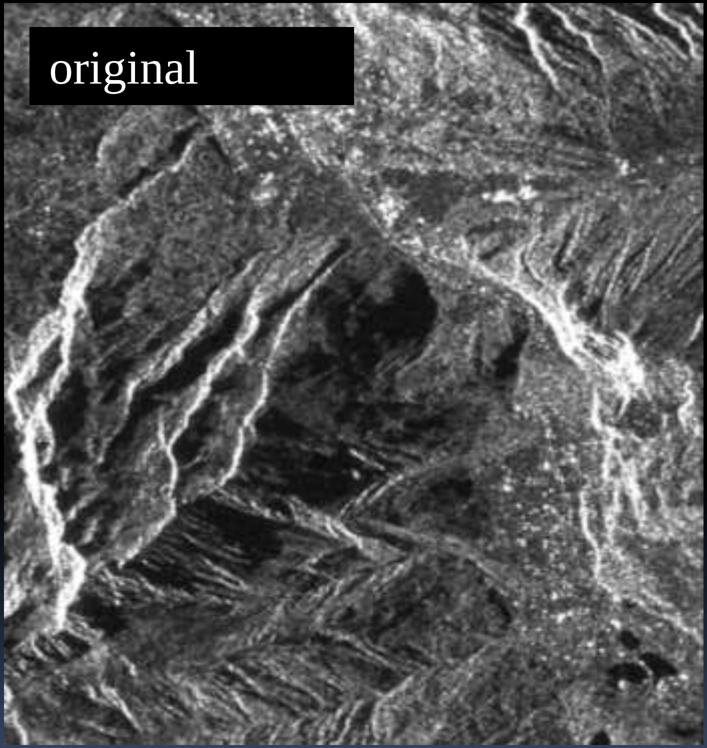
LIA for Hochschwab, eastern Alps

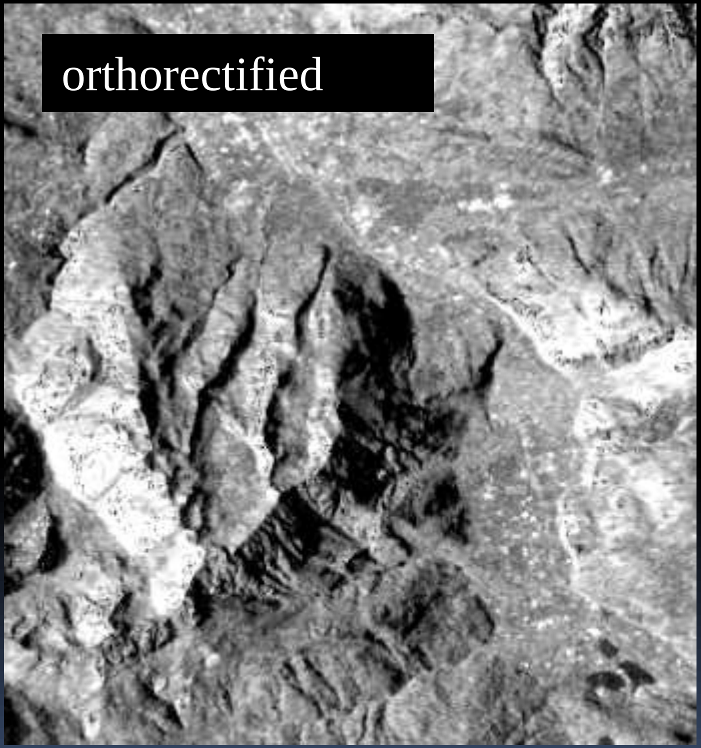
ENVISAT ASAR WS examples

Basics – preprocessing

Orthorectification of SAR – terrain correction

ENVISAT Synthetic Aperture Radar (SAR)





Source: W. Wagner

Basics - SAR Pre-processing

- ✓ Radiometry and geometric distortions
  - Orthorectification
  - Normalization

- Speckle reduction
  - Multilooking
  - Adaptive filtering

Speckle:
caused by random constructive and destructive interference from the multiple scattering returns that will occur within each resolution cell

Basics

X C L Ku P S

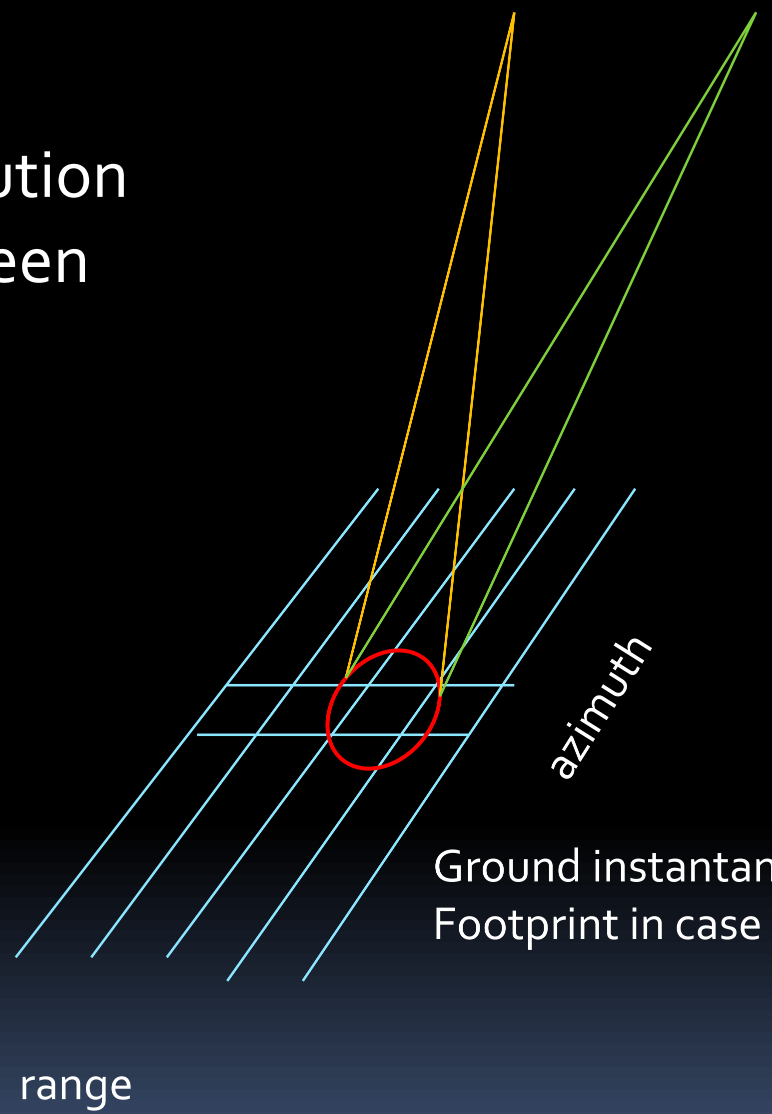
- ✓ Wavelength – Bands
- ✓ Polarization
  - Single, dual, cross …
- ✓ Incidence angle
- ✓ Range
- ✓ Azimuth
- Beam
  - A certain area on the surface is illuminated
  - Spatial resolution?
  - The product grid is ‚nominal resolution'

HH VV HV VH

Basics

- spatial resolution

(distance between distinguishable objects)



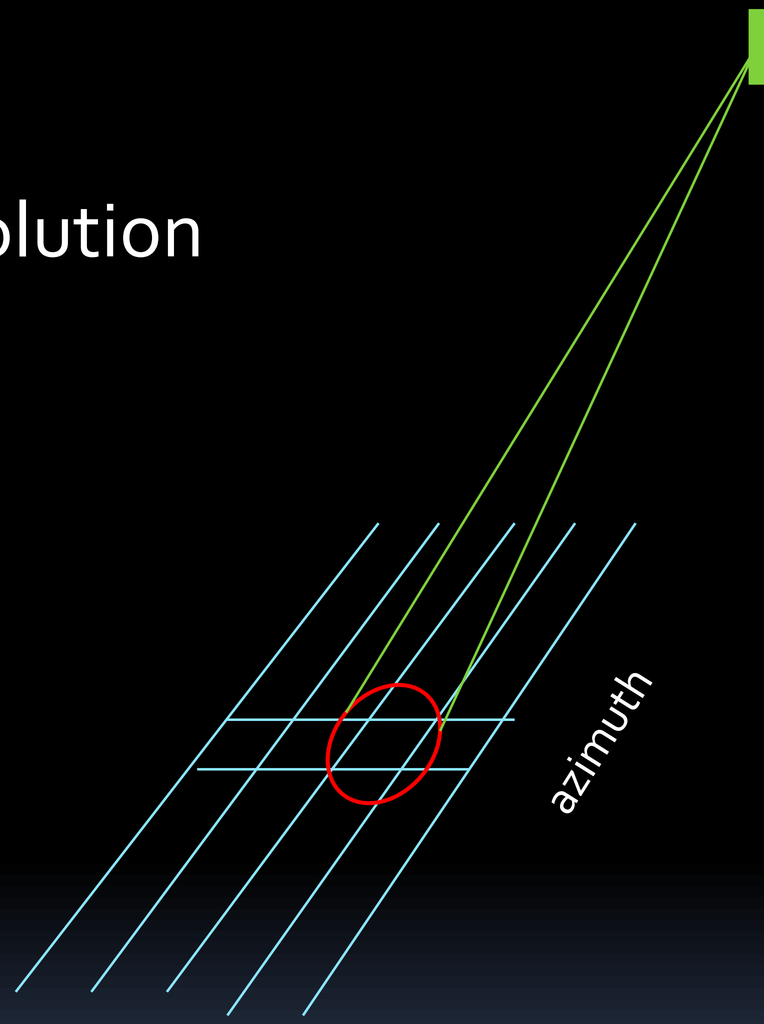
Ground instantaneous field of view
Footprint in case of non-imaging sensors

Basics

- spatial resolution

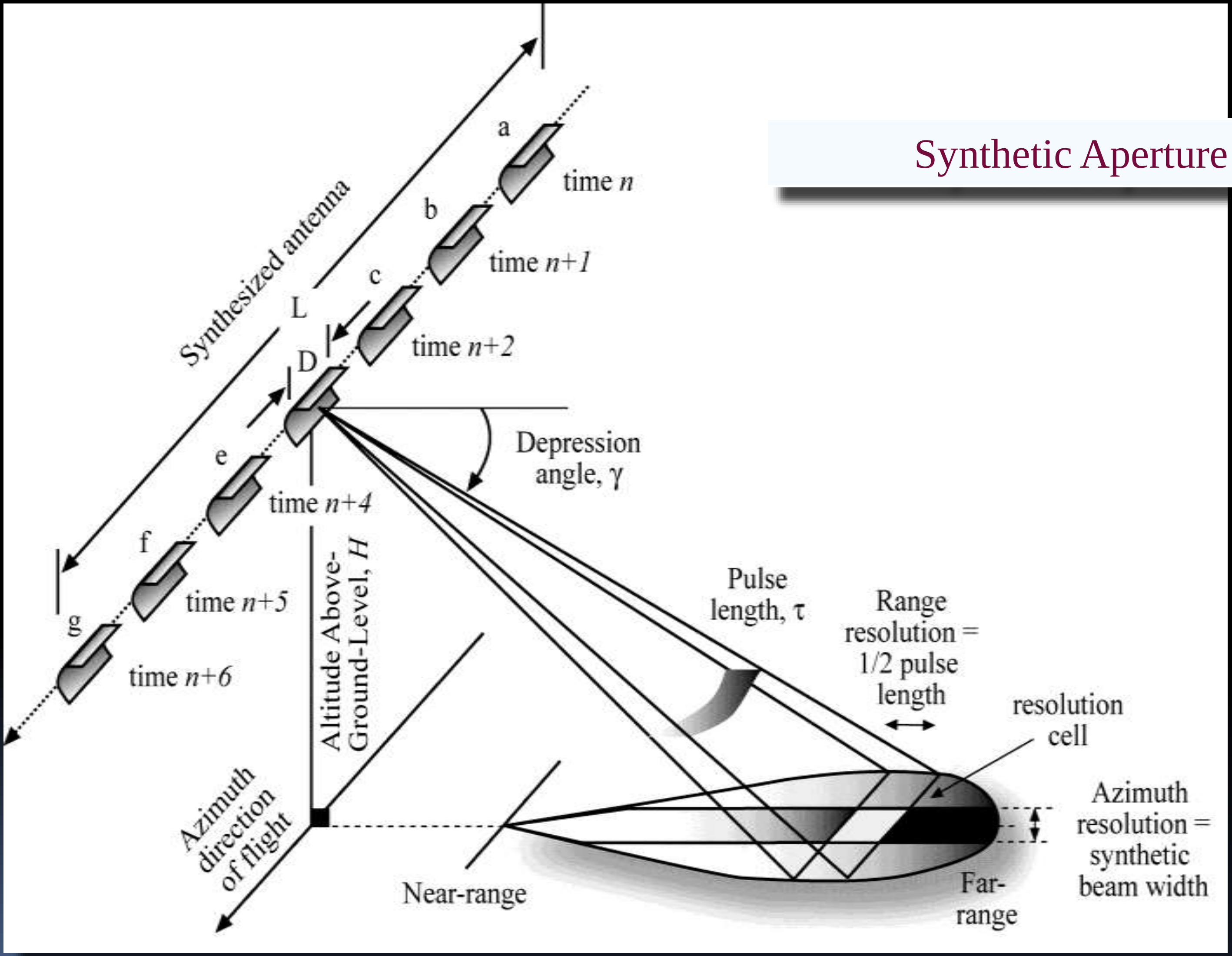
$$R_a = \frac{S \times \lambda}{L}$$

S - Slant range distance
γ - Wavelength
L - Antenna length



Resolution for real aperatures – coarse from space!

Basics – spatial resolution



Synthetic Aperture Radar

Jensen, 2009

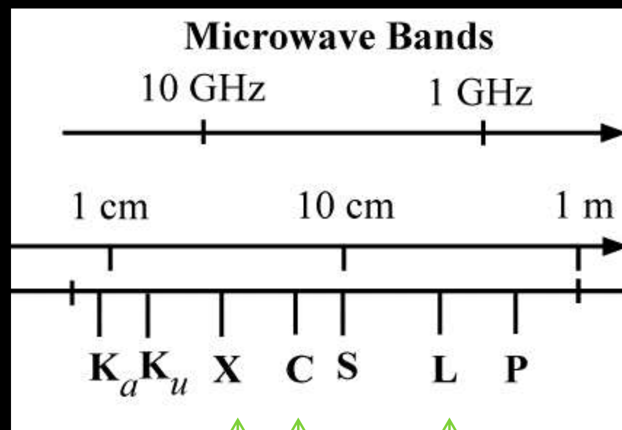
Basics – instruments and applications

- real aperatures instruments
  - scatterometer
  - gridding required
- Used for global applications
  - Frequent acquisitions
  - Operational (designed for ocean applications)

Basics – instruments and applications

- SAR – synthetic aperture radar
  - A technique to overcome the resolution problem, but local to regional applications
  - Resolution – azimuth and range difference
  - Data availability a matter of request and priority

Currently in space, a selection



Jensen 2005

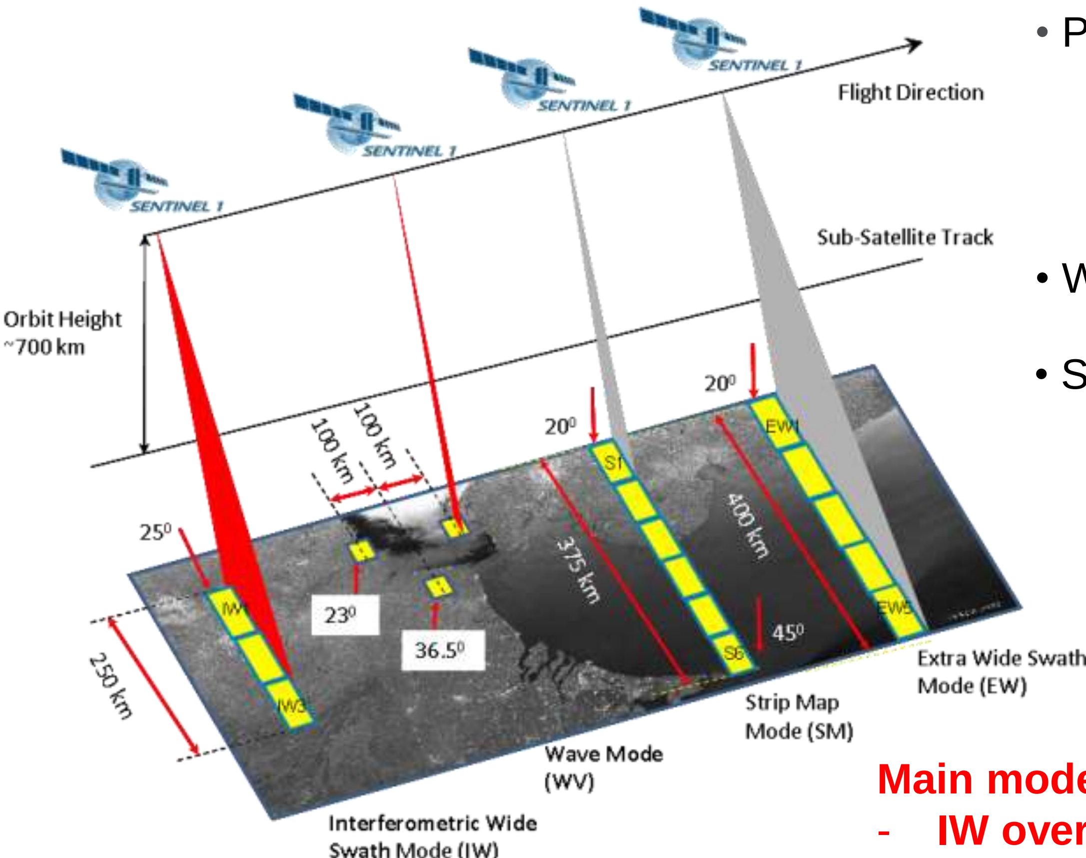
ALOS2 PALSAR

Sentinel 1, Radarsat, ASCAT

TerraSAR-X

Currently in space, a selection

- Sentinel – 1 (launched April 2014)



- Polarisation schemes for IW, EW & SM:
  - ✓ single polarisation: HH or VV
  - ✓ dual polarisation: HH+HV or VV+VH
- Wave mode: HH or VV
- SAR duty cycle per orbit:
  - ✓ up to 25 min in any of the imaging modes
  - ✓ up to 74 min in Wave mode

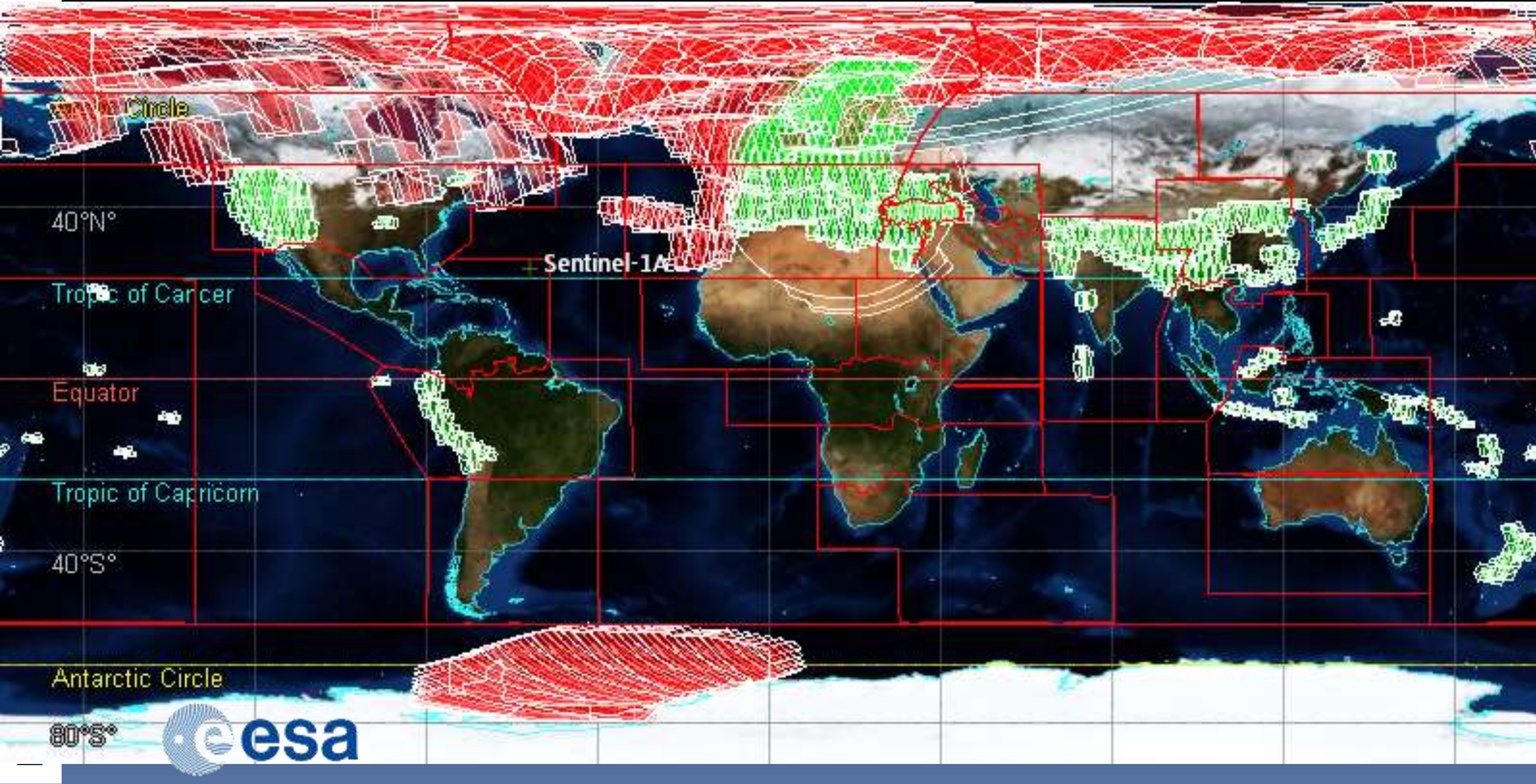
Main modes of operations:

- **IW over land and coastal waters**
- **EW over extended sea and sea-ice areas**
- **WV over open oceans**

esa

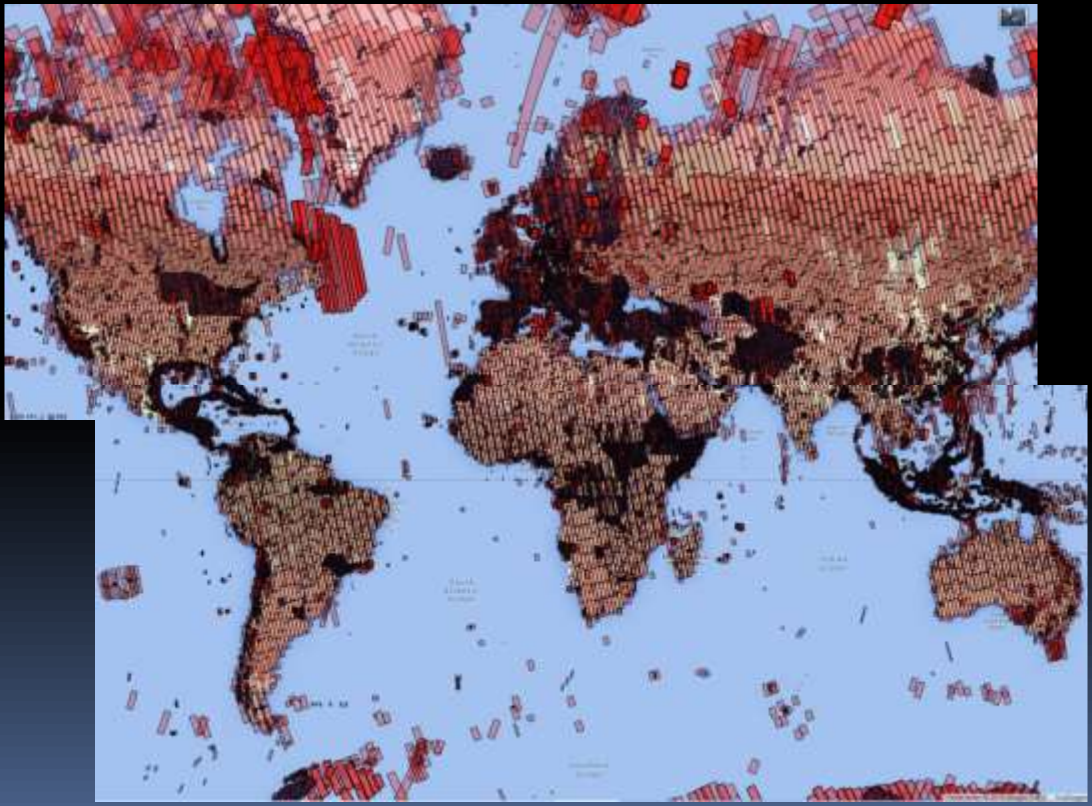
Currently in space, a selection

- Sentinel 1 – acquisition plan (selected modes)



Currently in space, a selection

- TerraSAR-X (since 2007)



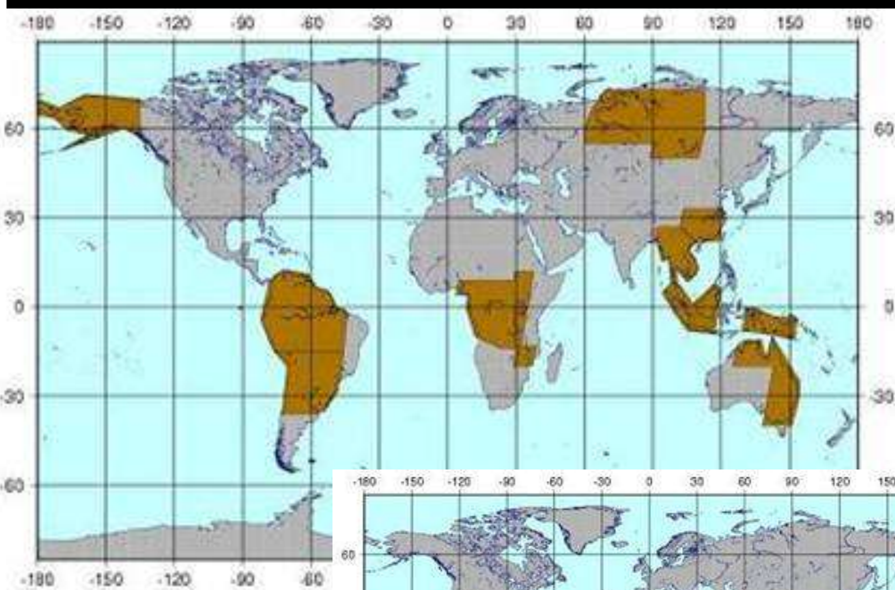
http://terrasar-x-archive.infoterra.de/

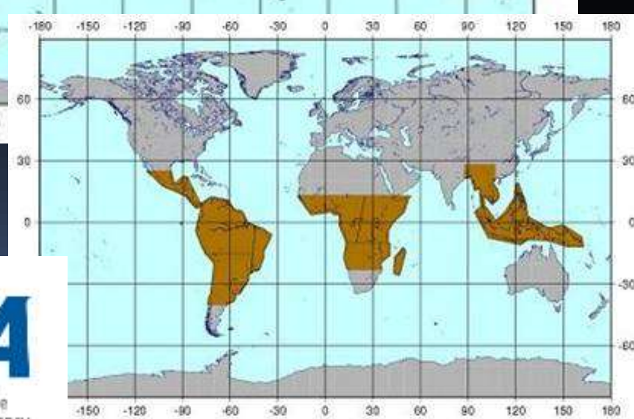
Currently in space, a selection

- ALOS-2 PALSAR (May 2014)

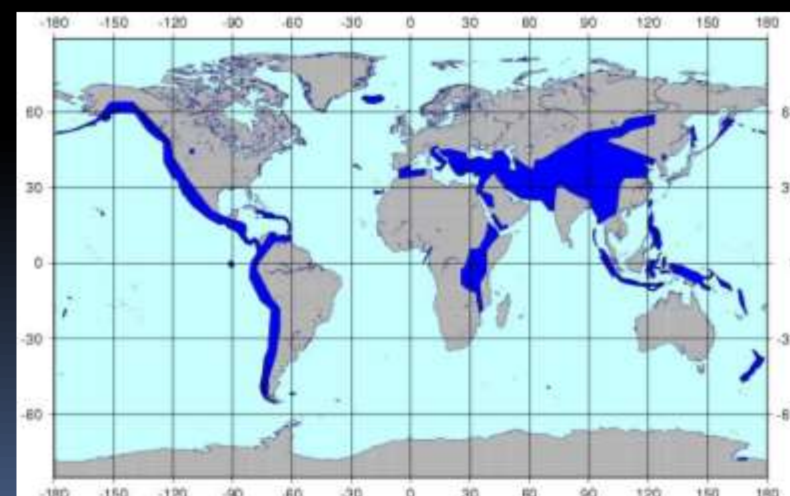
Acquisition plan

Wetlands & deforestation





Crustal deformation



Past sensors - SAR

- Potential service demonstration
- Mid-term changes

- ENVISAT ASAR 2002-2012
  - C-Band

Currently in space, a selection

- Scatterometer

- ASCAT on Metop A and B
  - For meteorological purposes so continuation ensured
  - Operational products, global
  - C-band

Past sensor - scatterometer

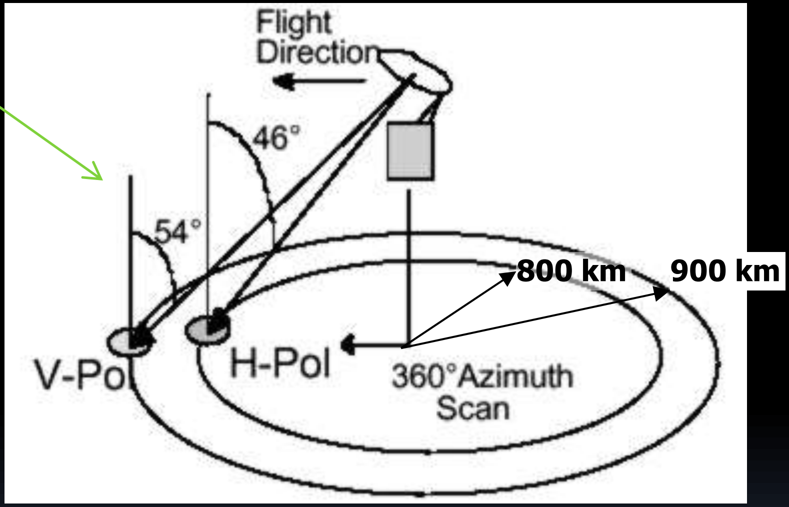
- ERS1, ERS2 (1991-2011)
  - C-band
- Seawind on QuikScat (1999-2009)
  - Ku -band

Past sensor - scatterometer

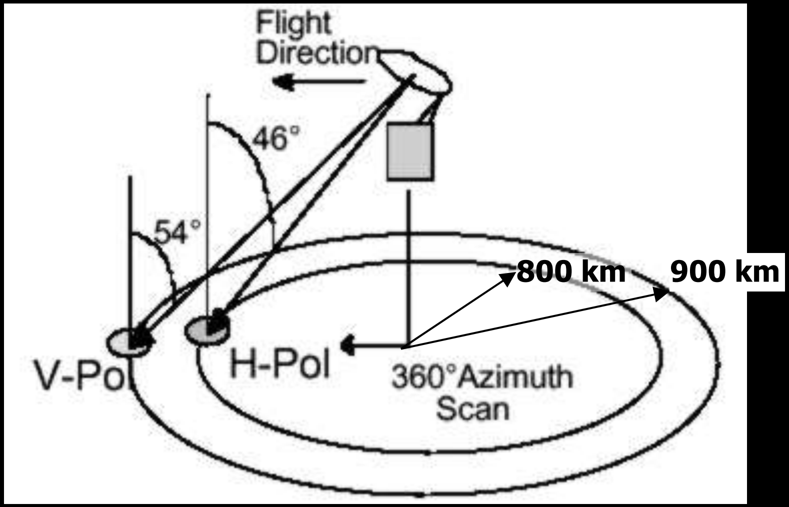
Examples

	ERS-1/2	SeaWinds
FREQUENCY	5.3 GHz	13.6 GHz
AZIMUTHS		
POLAR.	V ONLY	V-OUTER/H-INNER
BEAM RESOLUTION	RANGE GATE	PENCIL-BEAM
SCI. MODES	SAR, WIND	WIND/HI-RES
RESOLUTION	25/50 km	25 km/6x25km
SWATH	500	1400,1800
INCIDENCE ANGS	18° - 59°	45° & 54°
DAILY COVERAGE	< 41 %	92 %
DATES	92–96 & 96–	5/99 & 11/01

Quelle: http://www.scp.byu.edu/



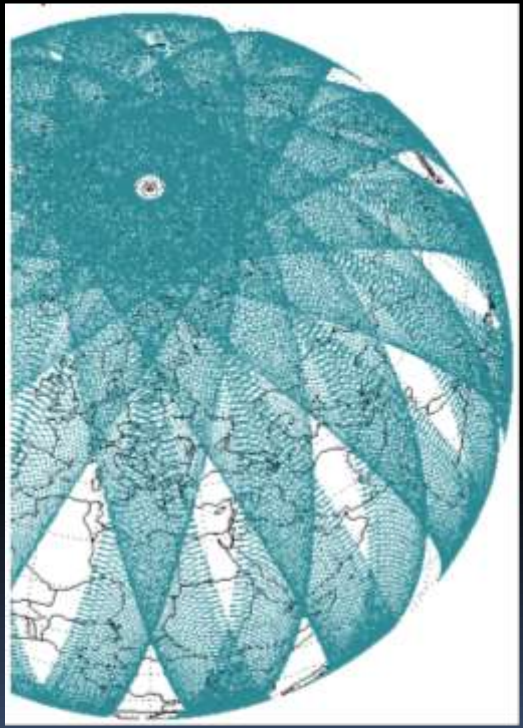
Perry 2000



Perry 2000

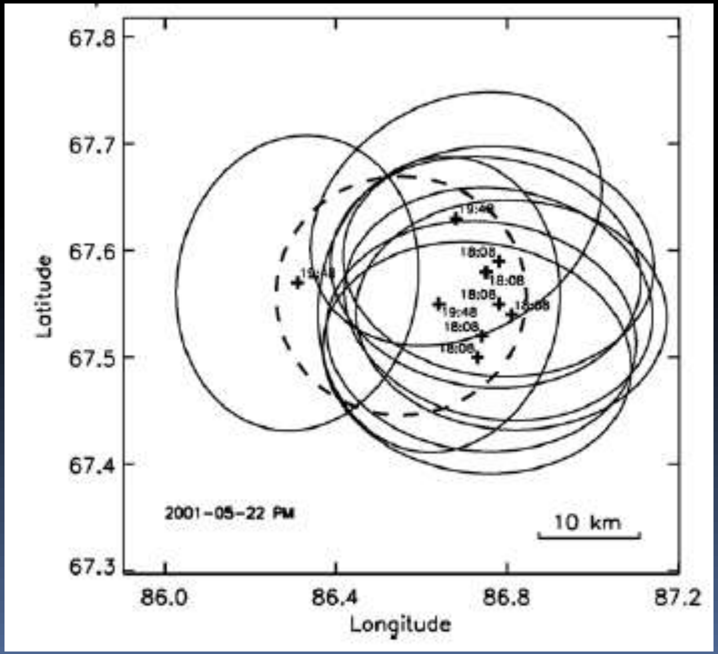
1999 - 2009

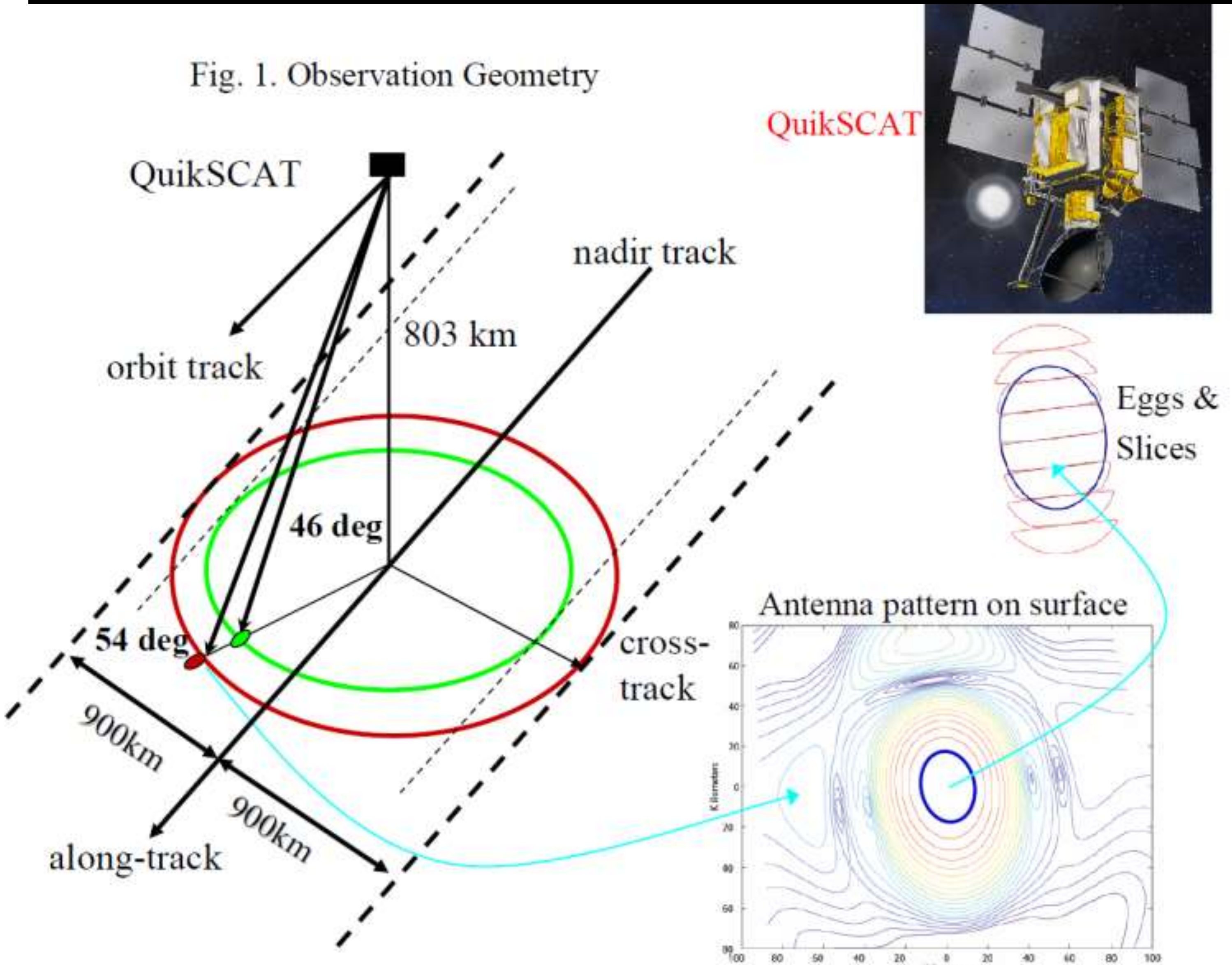
Daily coverage



Naeimi 2010

Distribution of footprints and their time stamp Bartsch et al. 2007





Images based on
‚Eggs':
4.45 km
Effective res.
8.-10. km

(source BYU)

Example Metop ASCAT

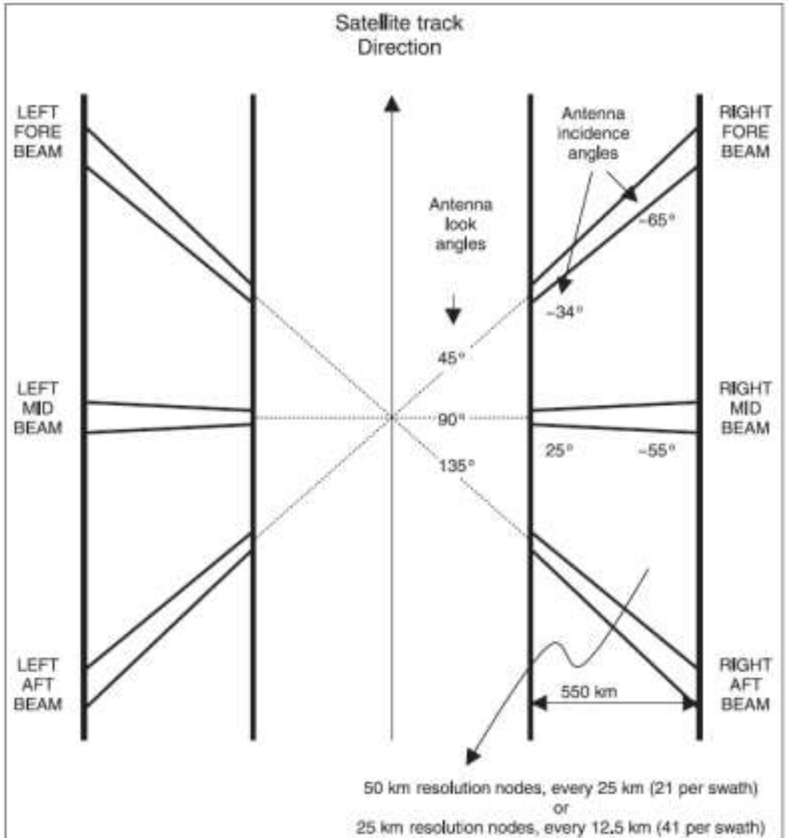
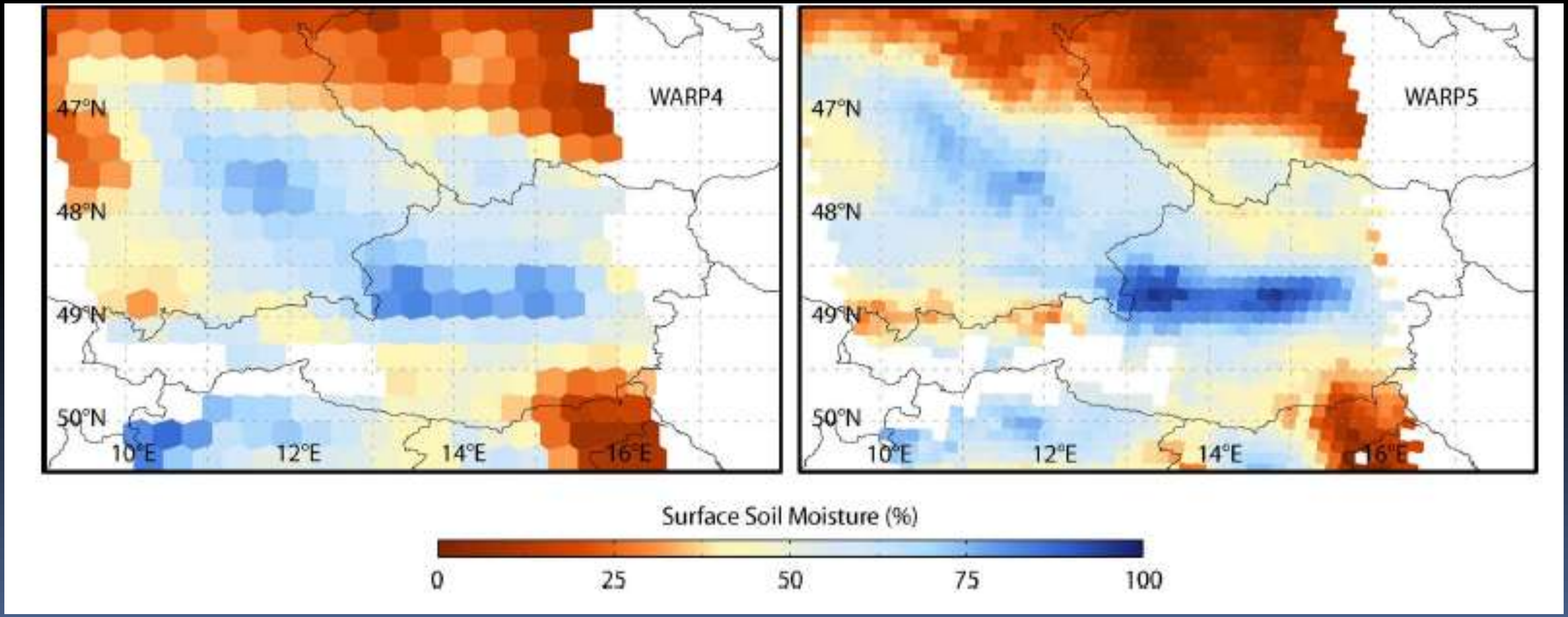


Figure 2. ASCAT swath geometry. Dimensions are given for the right swath, and the left swath is symmetric with respect to the satellite ground track.

Figa et al. 2002

Example Metop ASCAT

- ASCAT soil moisture product gridding

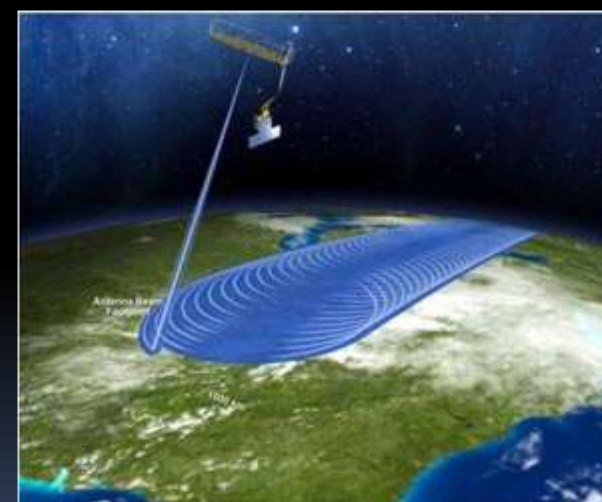


Naeimi et al. 2009

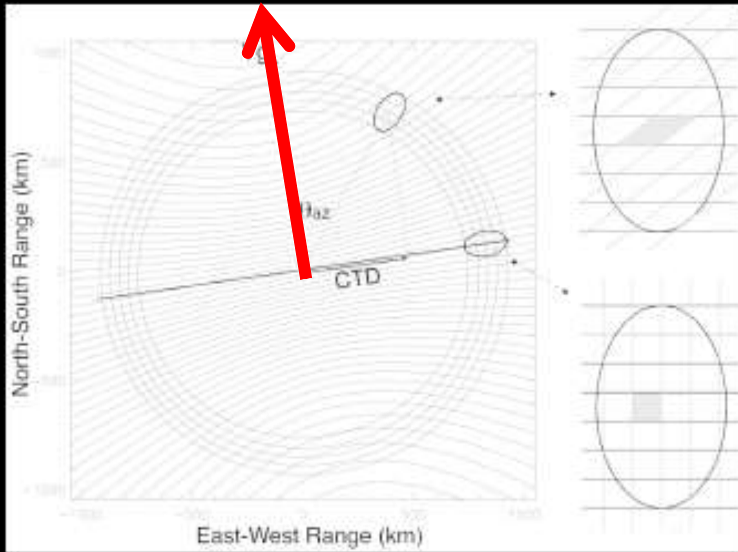
Whats in space - soon

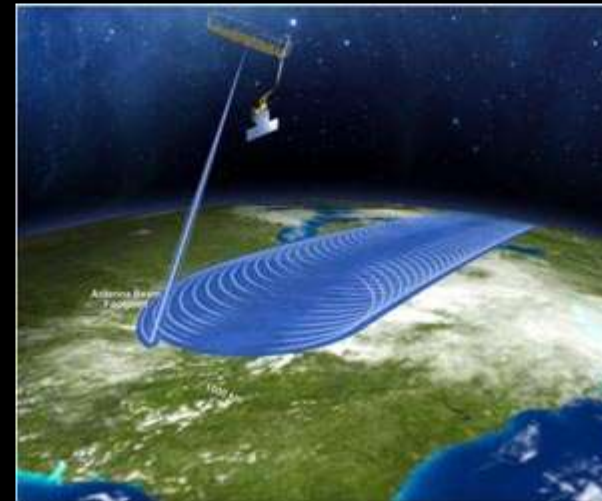
- SMAP – soil moisture active passive
- currently planned for October, 2014

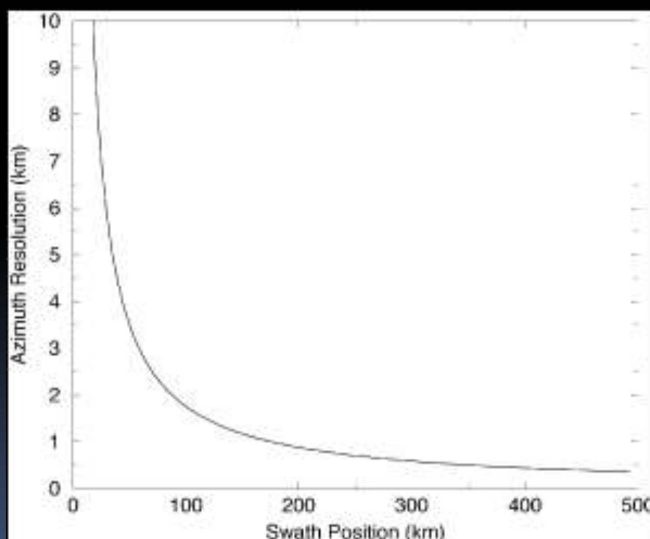
Frequency: 1.26 GHz
Polarizations: VV, HH, HV (not fully polarimetric)
Relative accuracy (3 km grid): 1 dB (HH and VV), 1.5 dB (HV)
Data acquisition:
    High-resolution (SAR) data acquired over land
    Low-resolution data acquired globally

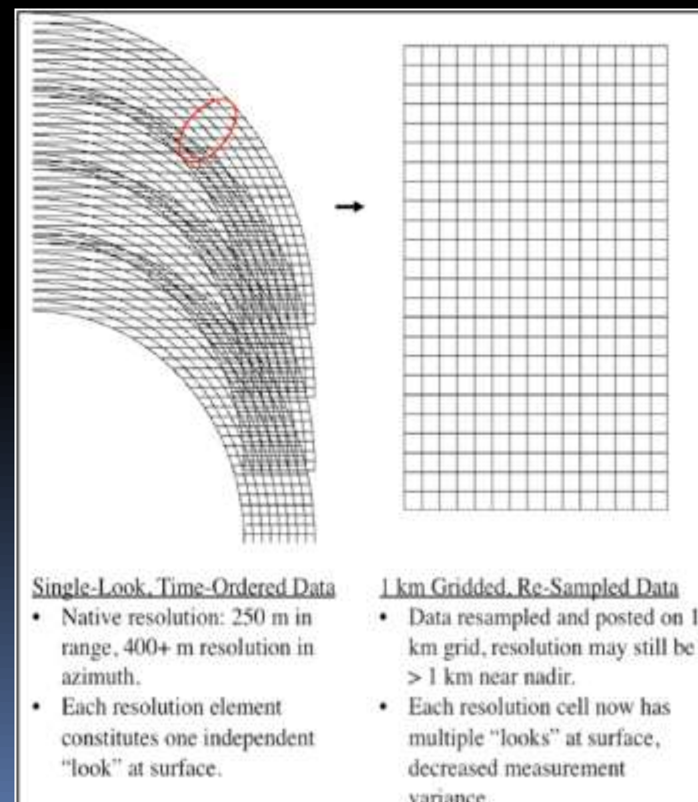


NASA SMAP









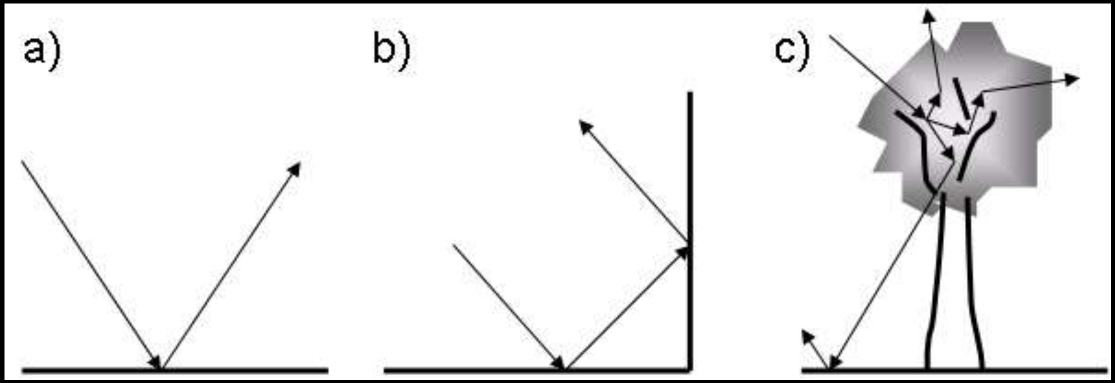
NASA SMAP

EO Summer School 2014

Signal interaction

- Wavelength is very important
  - Penetration depth into soil, snow, vegetation
  - Change of direction
- Polarization is very important
  - Penetration depth into especially vegetation (has a regular structure)

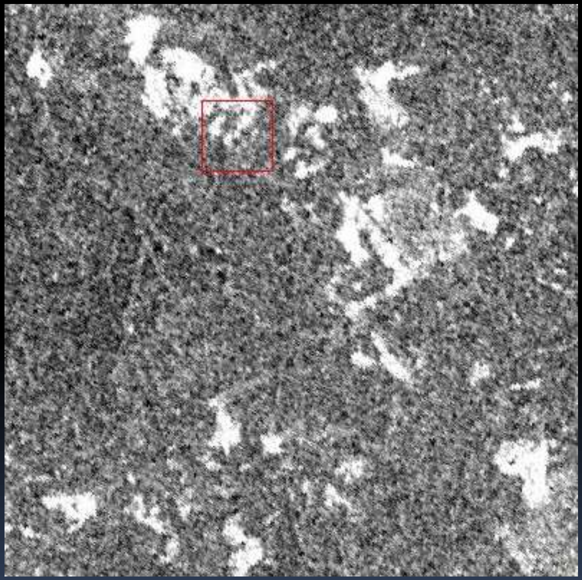
Signal interaction



- + Reflection enhanced when rel. permittivity (dielectric constant) and/or roughness is high

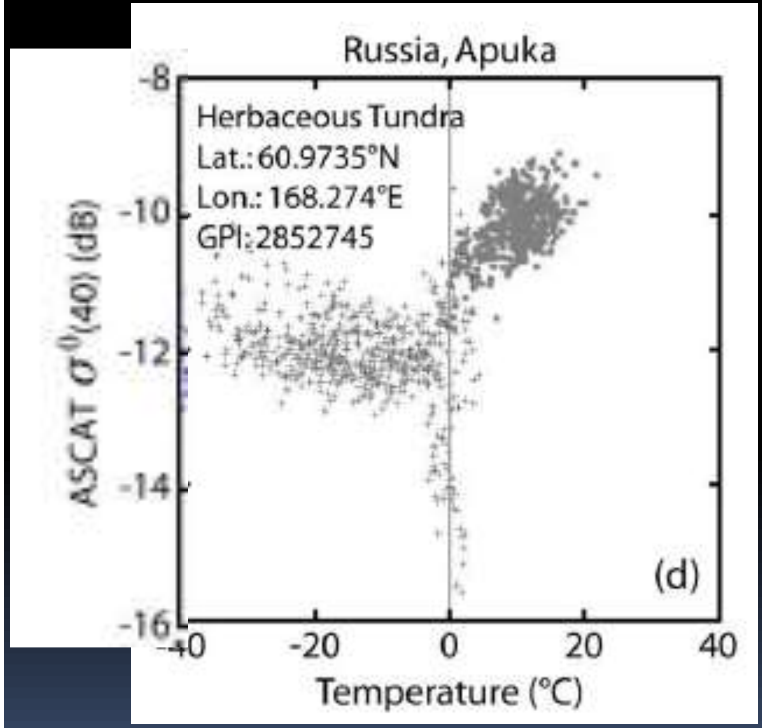
Signal interaction

- Examples C-Band (ASAR WS)

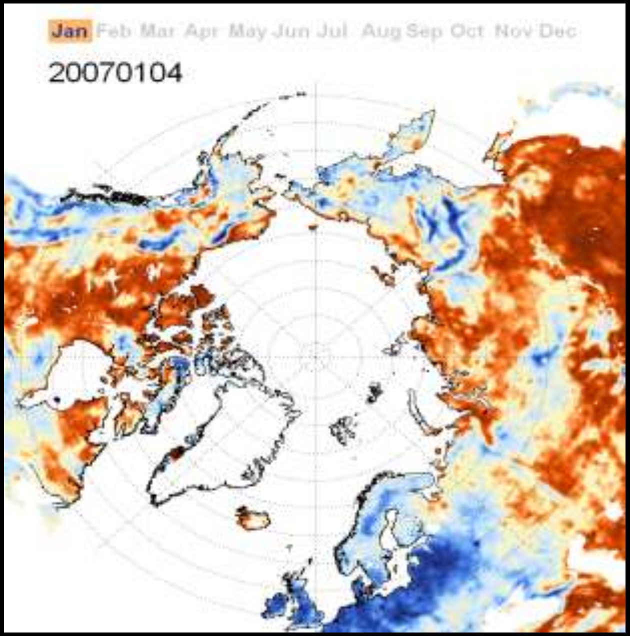


Signal interaction

- Examples C-Band

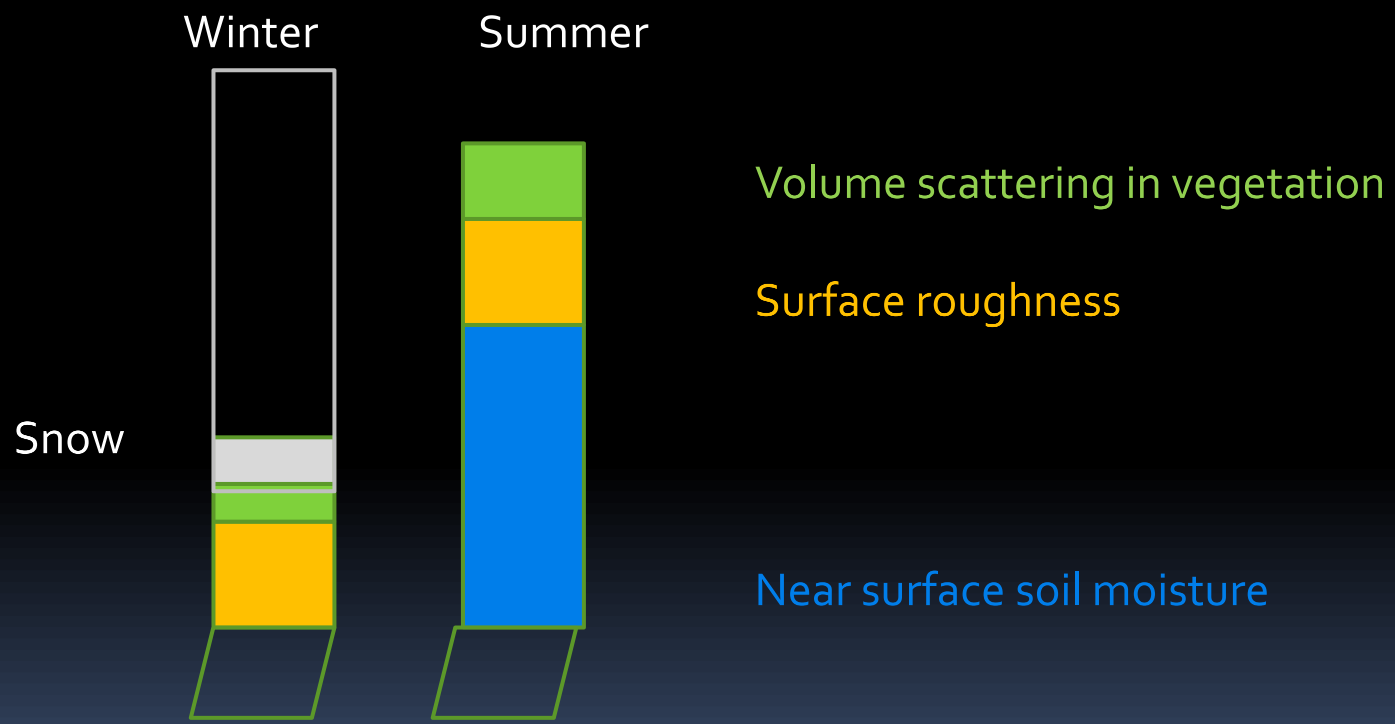


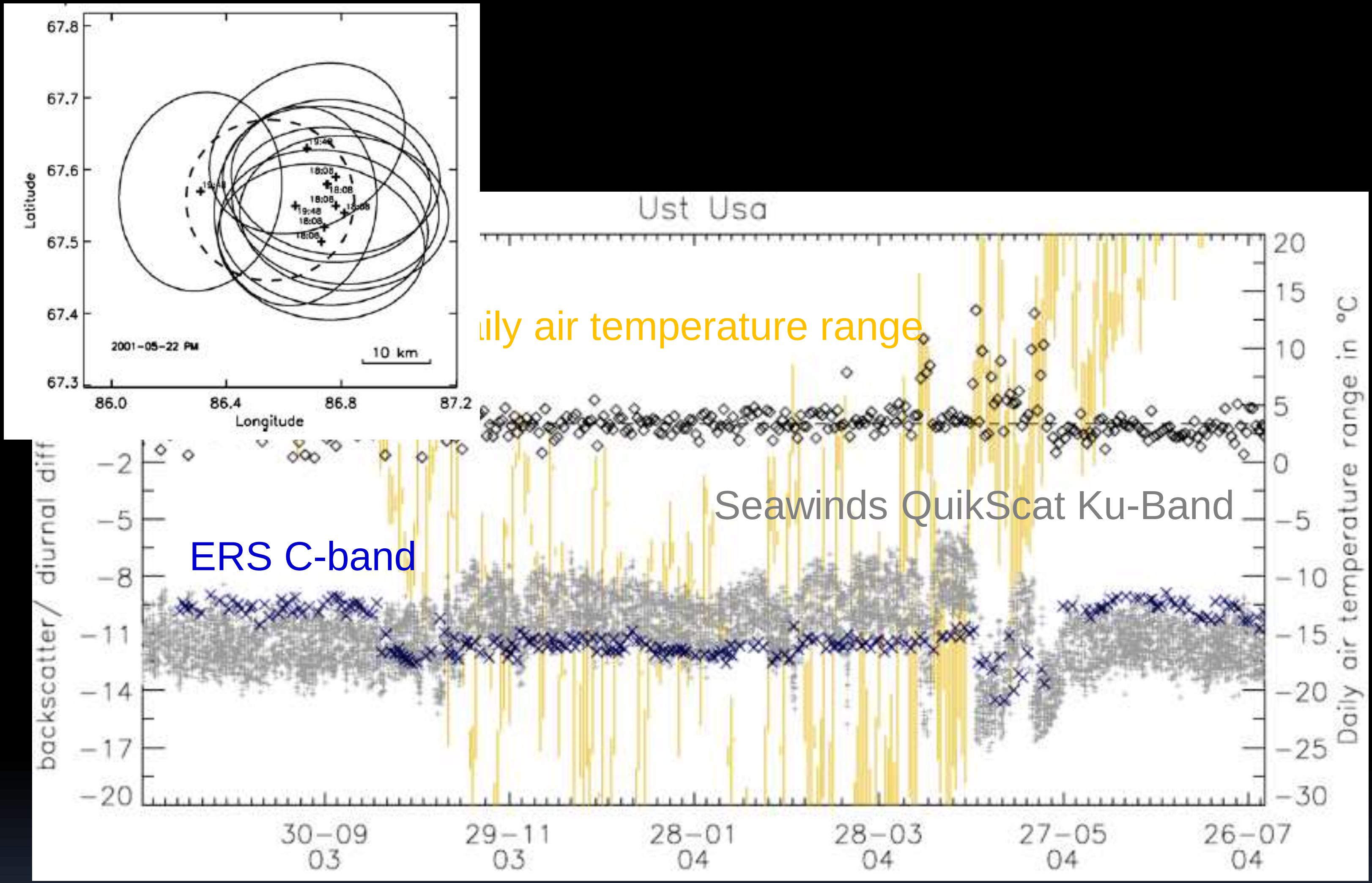
Naeimi et al. 2012



ASCAT

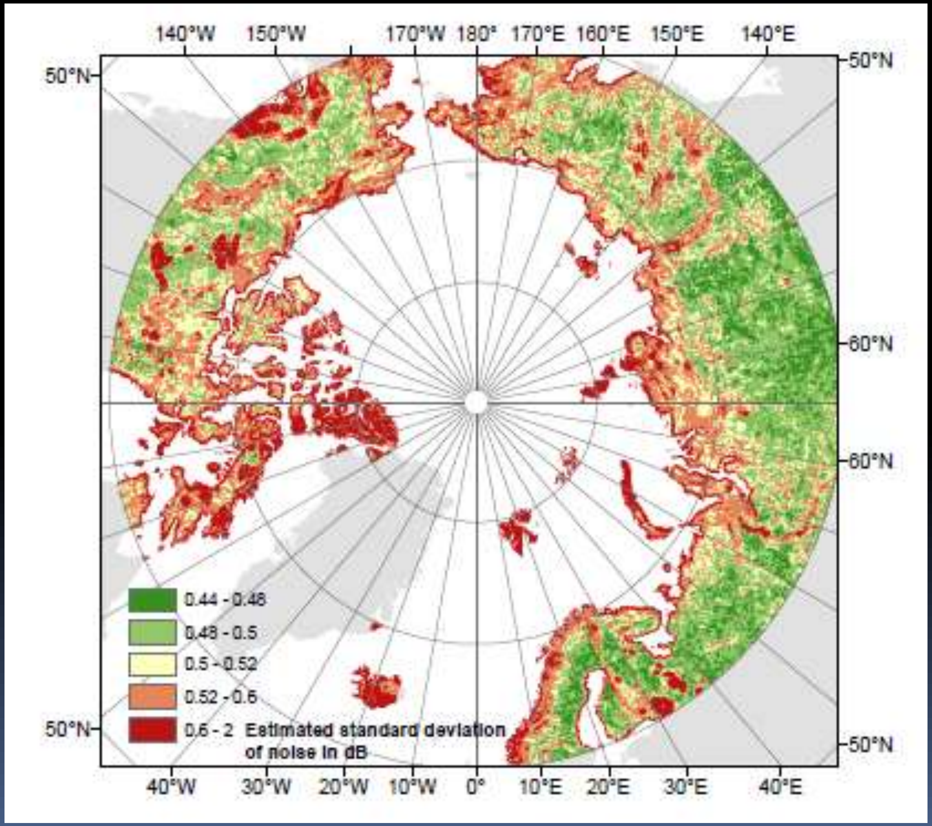
Signal interaction



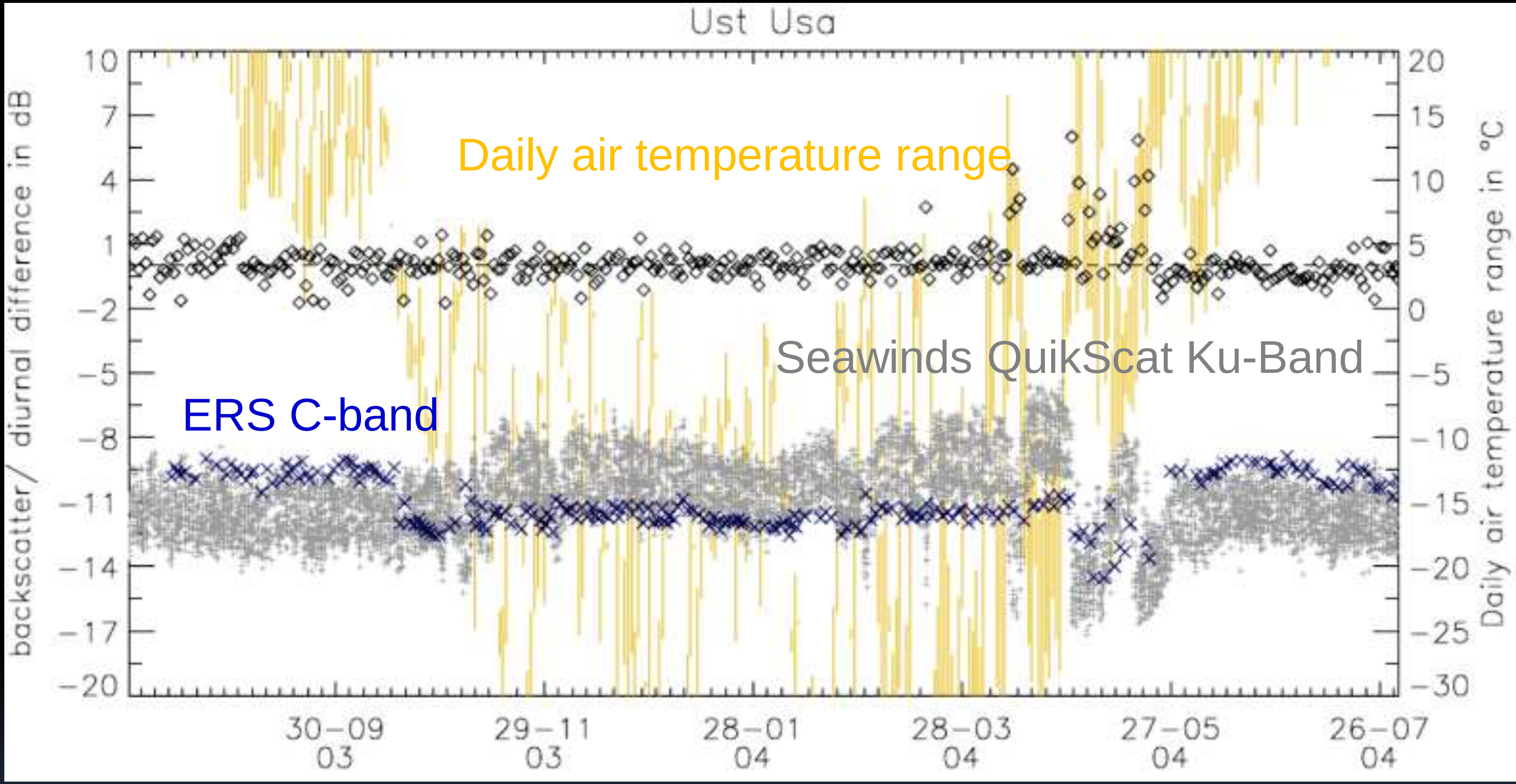


Bartsch, (2010)

- Seawinds QuikScat - noise



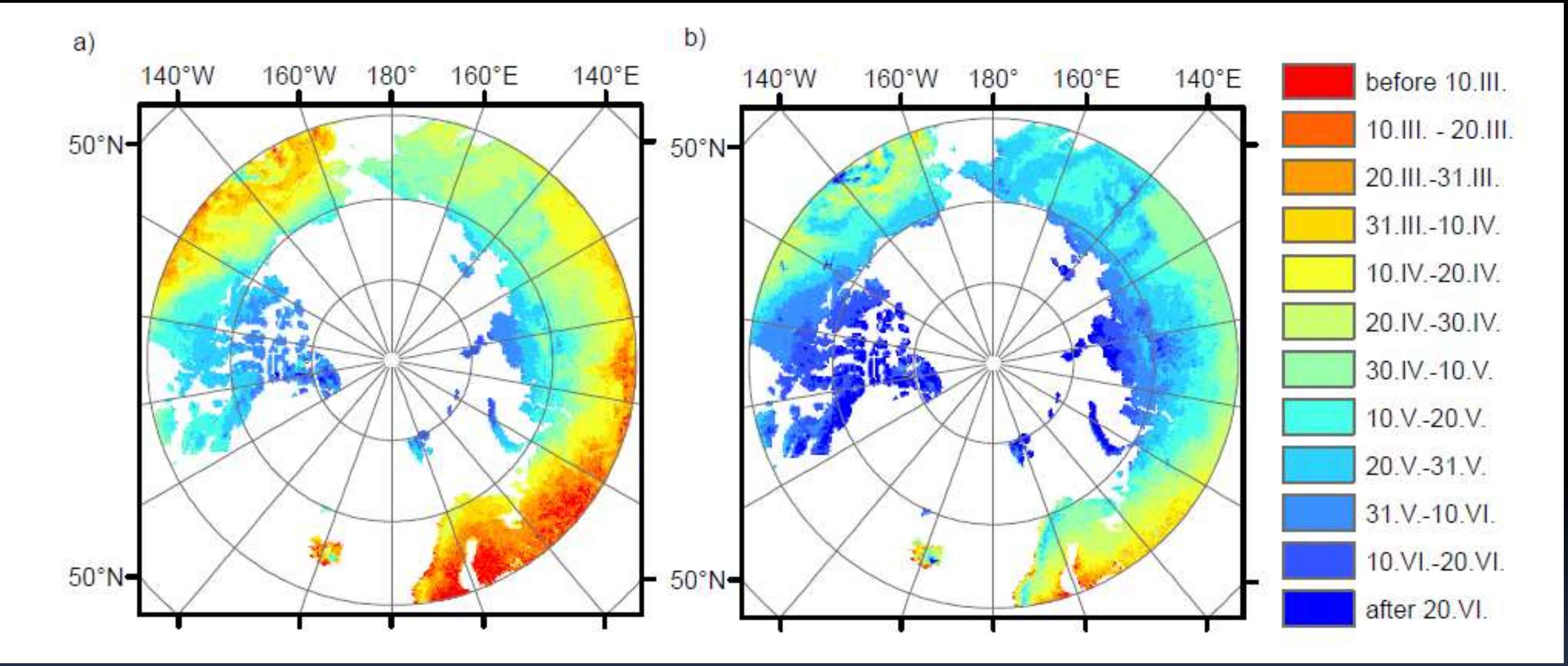
Bartsch 2010



Bartsch, (2010)

Snowmelt

- QuikScat: Precise timing from diurnal difference

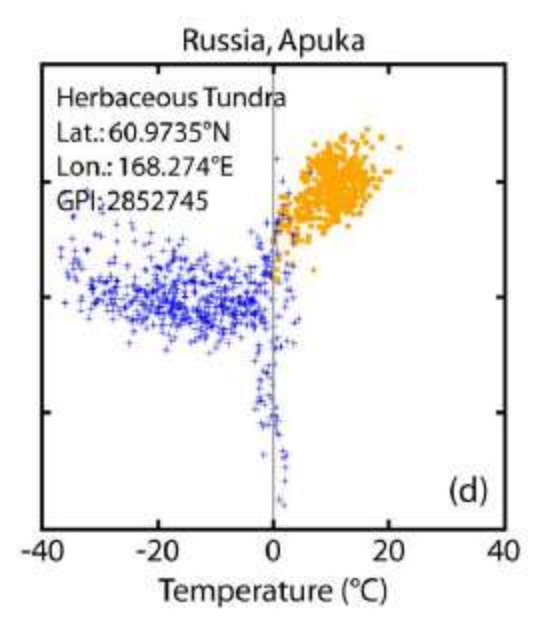


http://doi.pangaea.de/10.1594/PANGAEA.834198

Supplement to: **Bartsch (2010):** Ten Years of SeaWinds on QuikSCAT for Snow Applications. *Remote Sensing*, **2(4)**, 1142-1156, doi:10.3390/rs2041142

Freeze/thaw

- Metop ASCAT



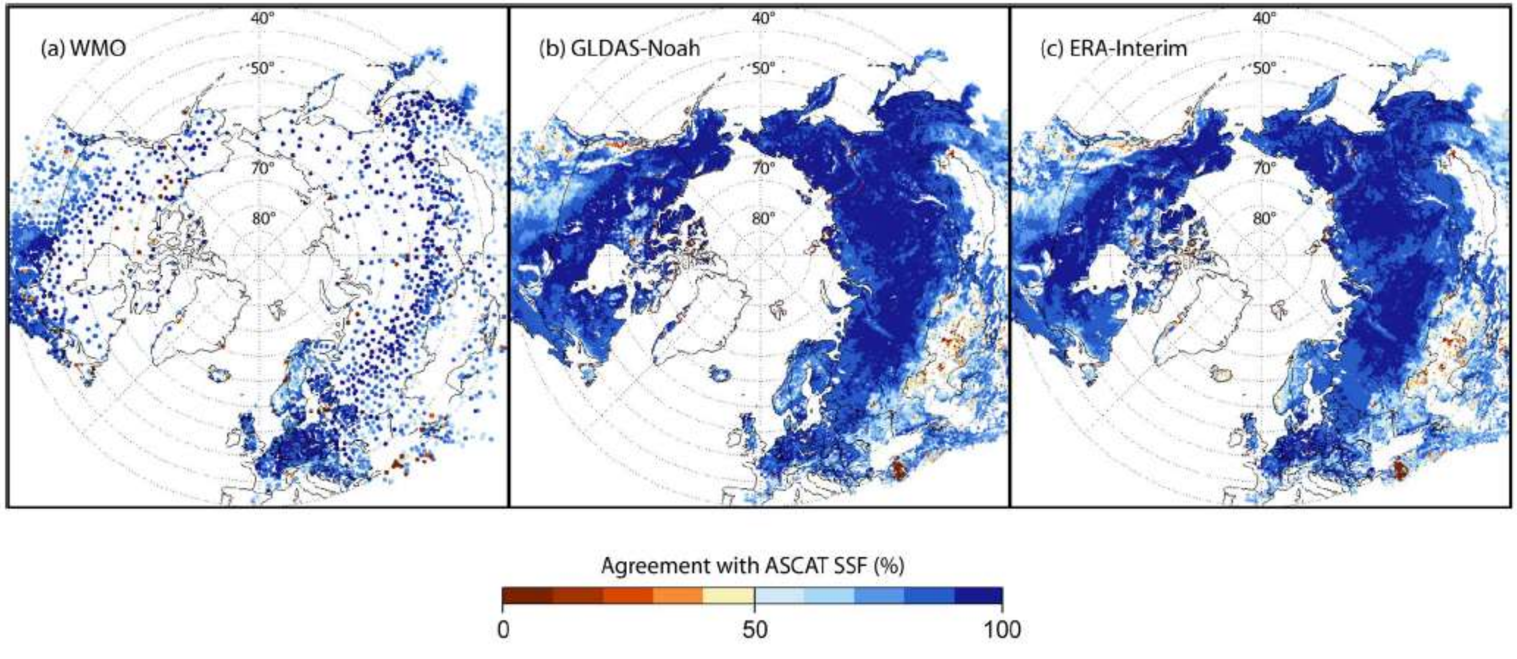
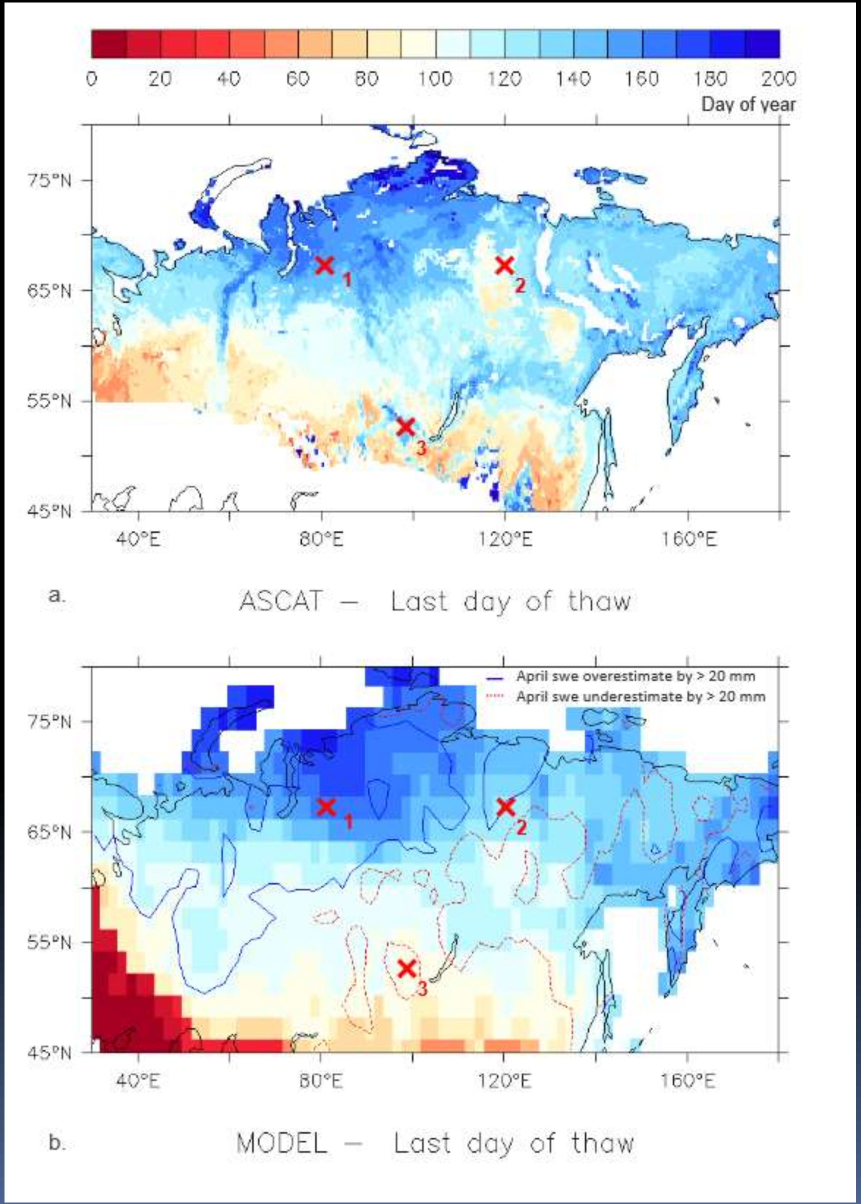


Fig. 18. Comparison of the SSF with (a) the air temperature measured at the nearest WMO meteorological stations, the surface temperature from (b) GLDAS-Noah and (c) ERA-Interim reanalysis data sets.

- **Paulik et al. (2014)** doi:10.1594/PANGAEA.832153
- (2007-01 to 2013-12)
- ORCHIDEE-Land surface model

Gouttevin et al. 2013



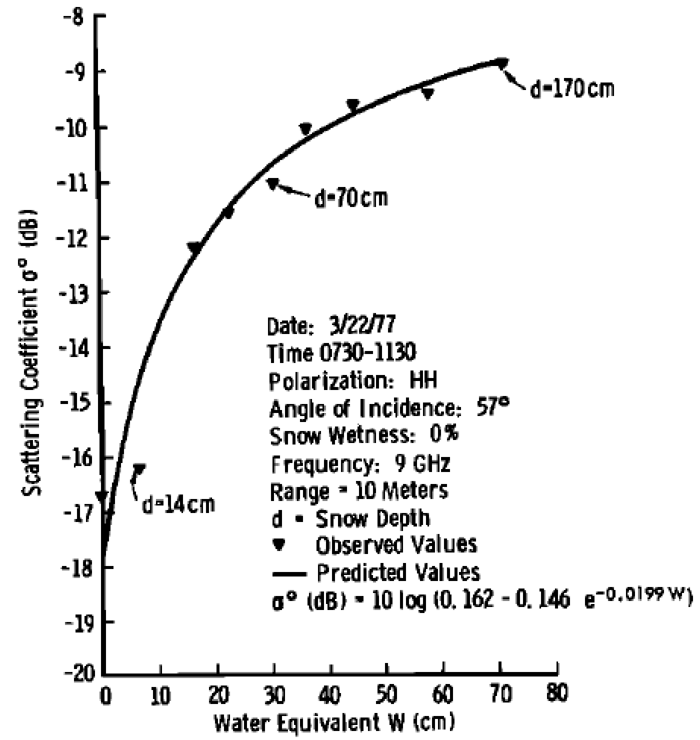
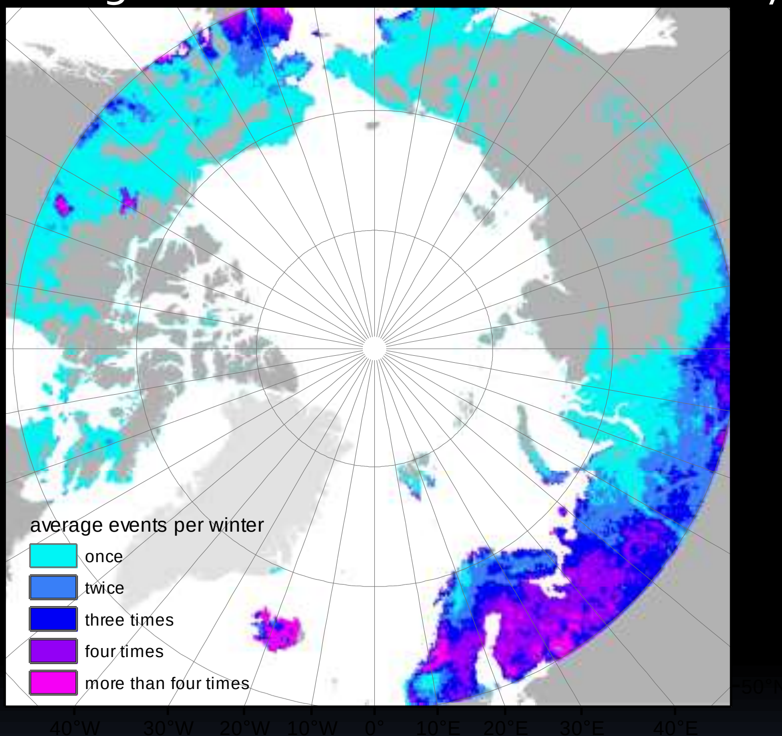


Fig. 4. Scattering coefficient response to snow wetness at 9 GHz.

Ulaby & Stiles 1980

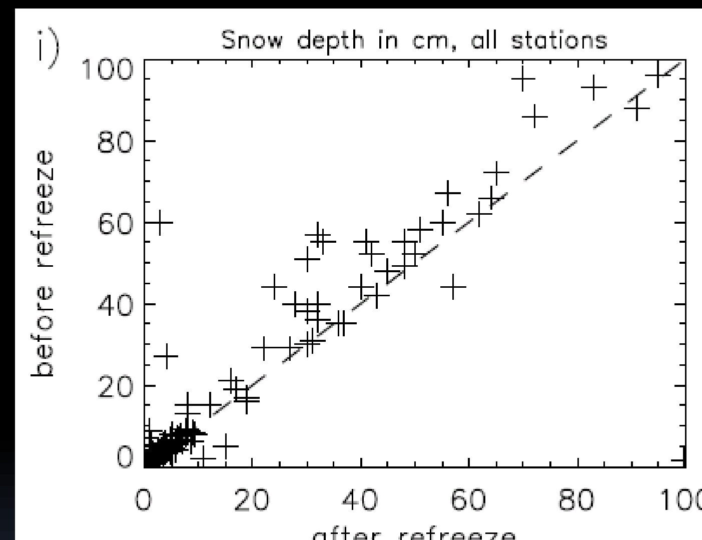
Increase of snow depth in a very short time?

Strong backscatter increase in a few days



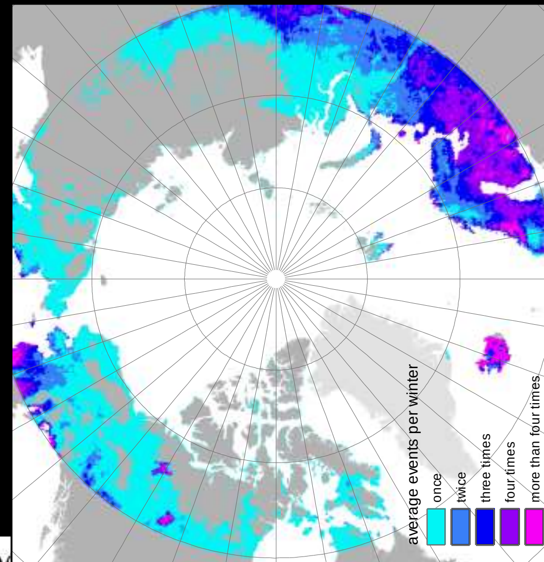
Bartsch (2010)

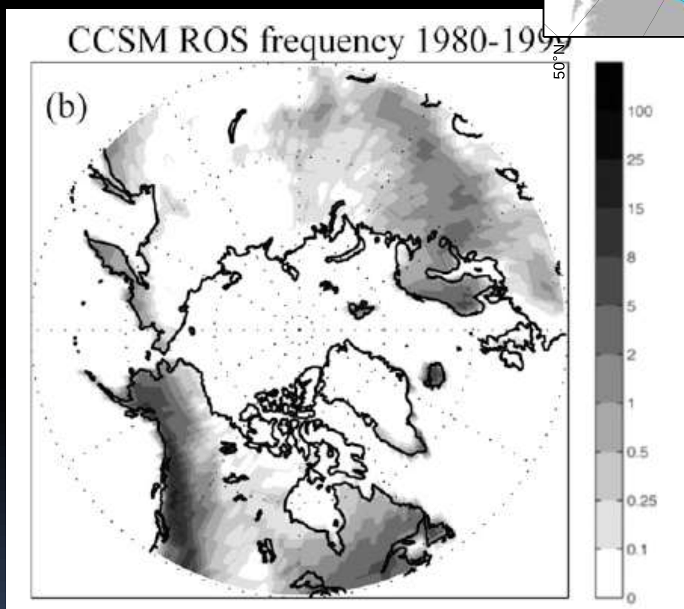
(WMO512)

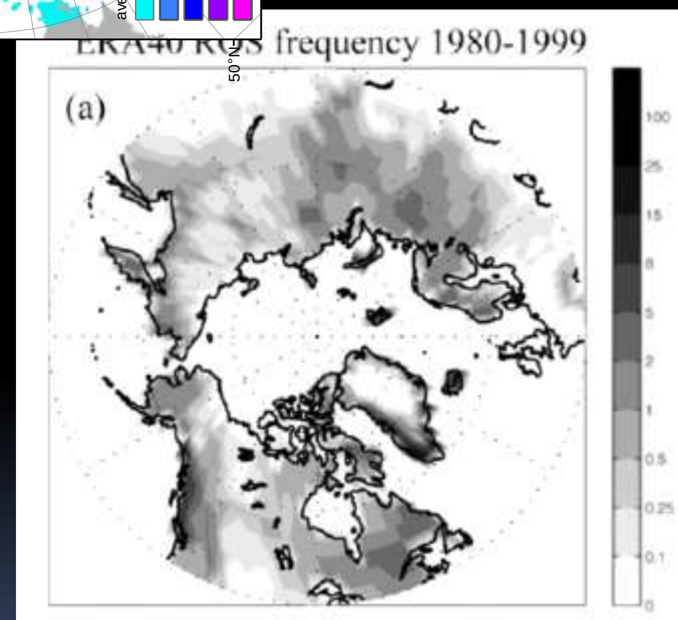


Bartsch et al. 2010

Snow profile taken on the 19th of November 2006. (Photo: Florian Stammler)

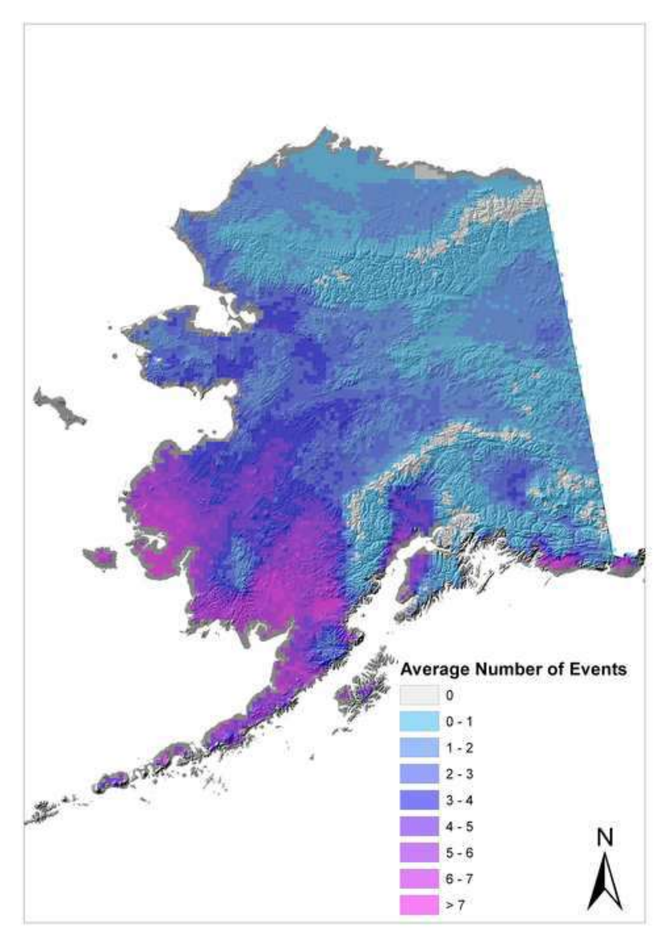






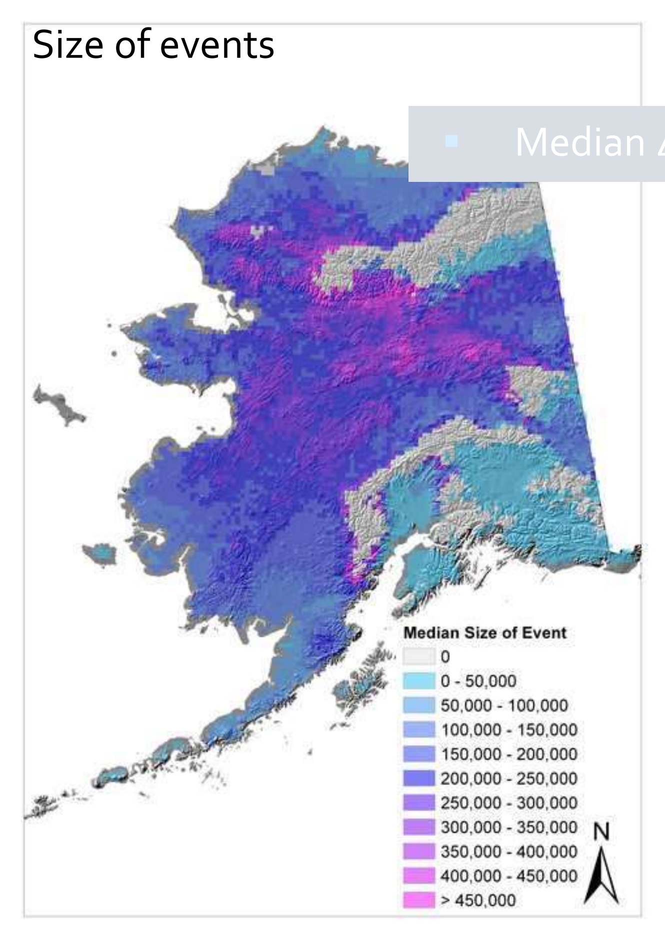
Rennert et al. 2009

number

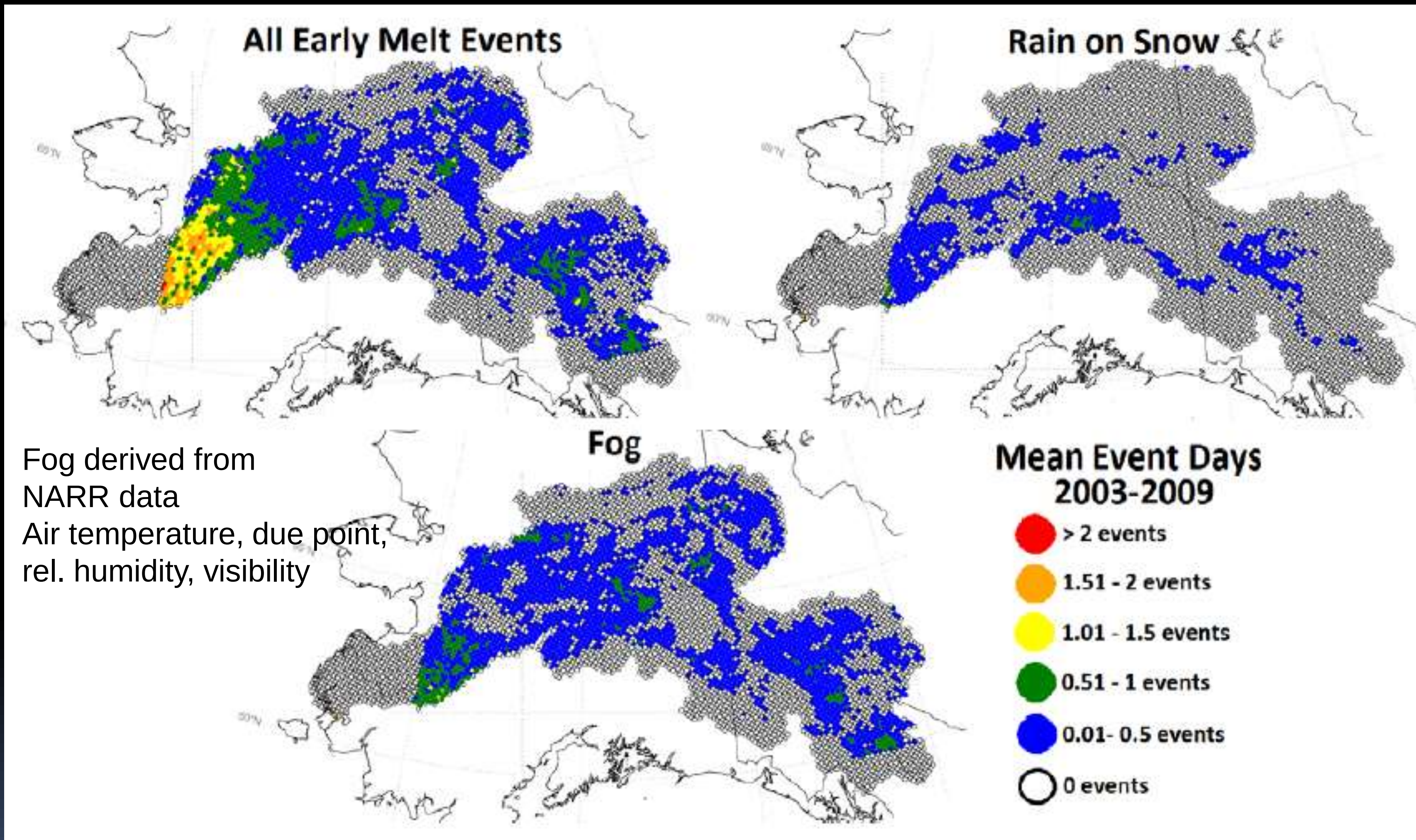


Size of events

- Median 470 km²



Wilson, R.R., et al. 2013

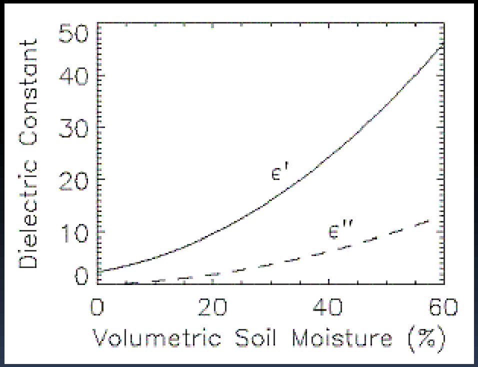


Fog derived from
NARR data
Air temperature, due point,
rel. humidity, visibility

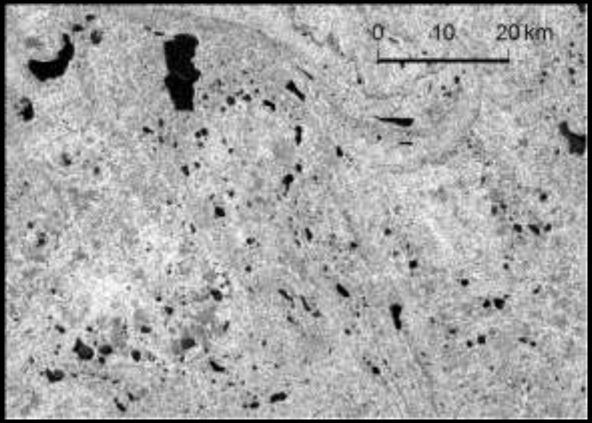
Semmens et al. (2013).

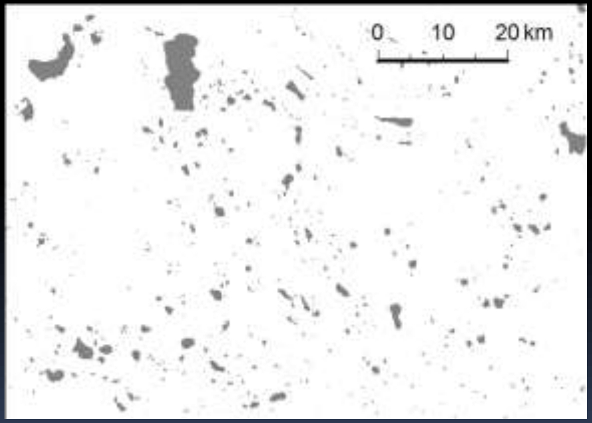
Wetland mapping

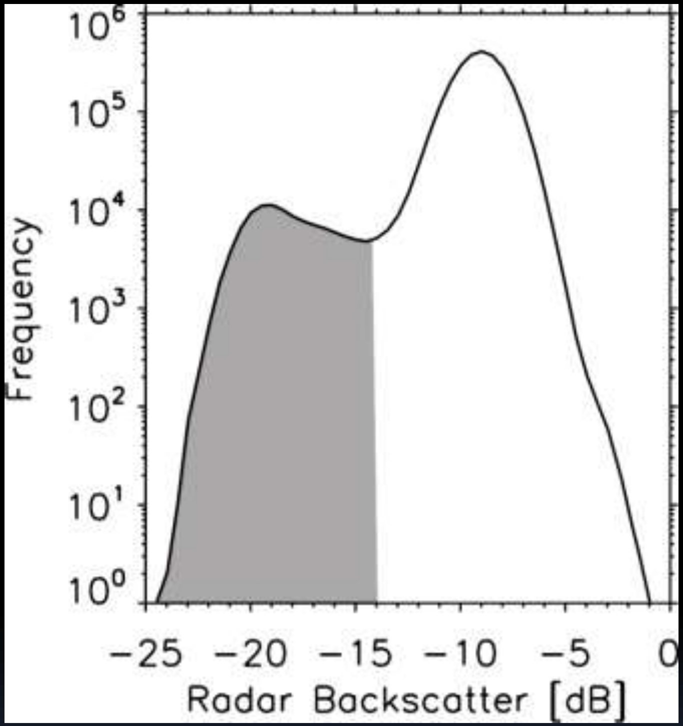
- Inundation – permanent, seasonal
- Wet soils

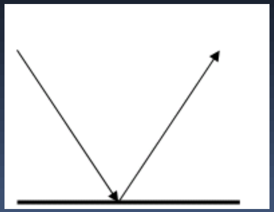


Inundation mapping with SAR





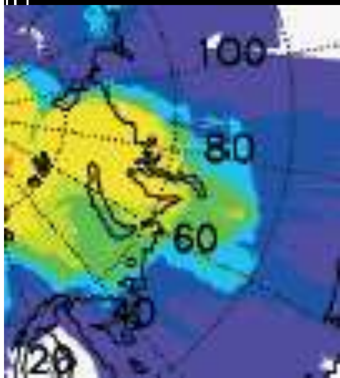


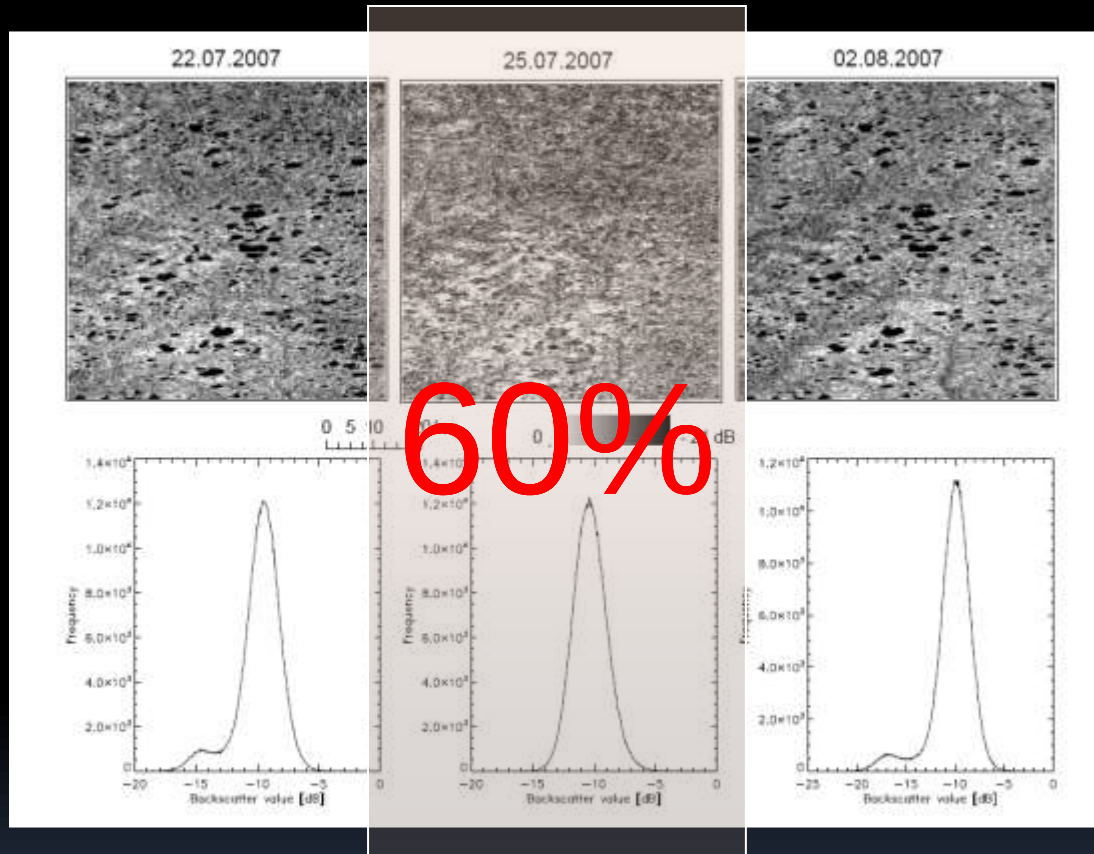


Specular Reflection over water

Bartsch et al. (2008)

West Siberien Lowlands Test with more than 4000 subsets of 0.25°





Bartsch, A., Trofaier, A., Hayman, G., Sabel, D., Schlaffer, S., Clark D. & E. Blyth (2012): Detection of open water dynamics with ENVISAT ASAR in support of land surface modelling at high latitudes; Biogeosciences, 9, 703-714.

Wetland areas

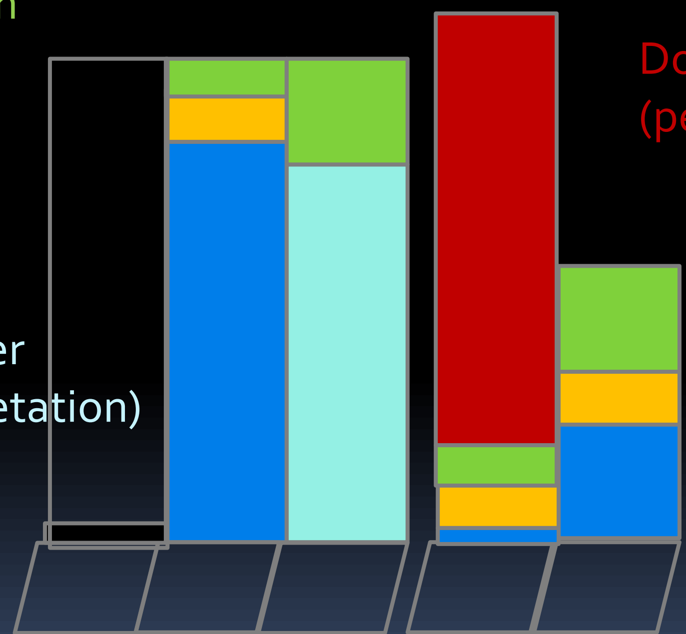
Volume scattering in vegetation

Surface roughness

Near surface soil moisture

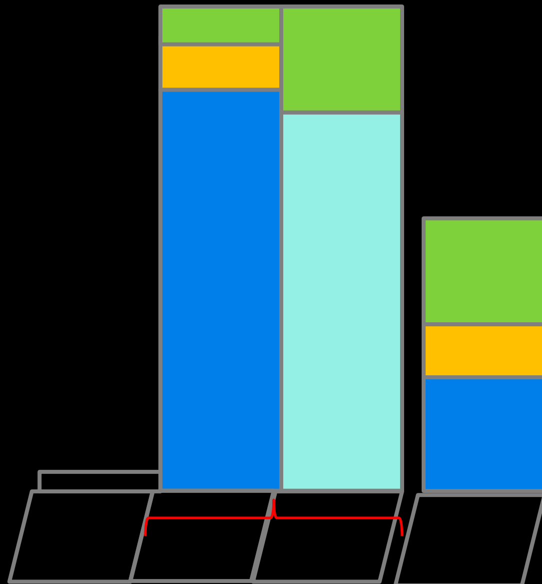
Double bounce – standing water (permanent and emerging vegetation)

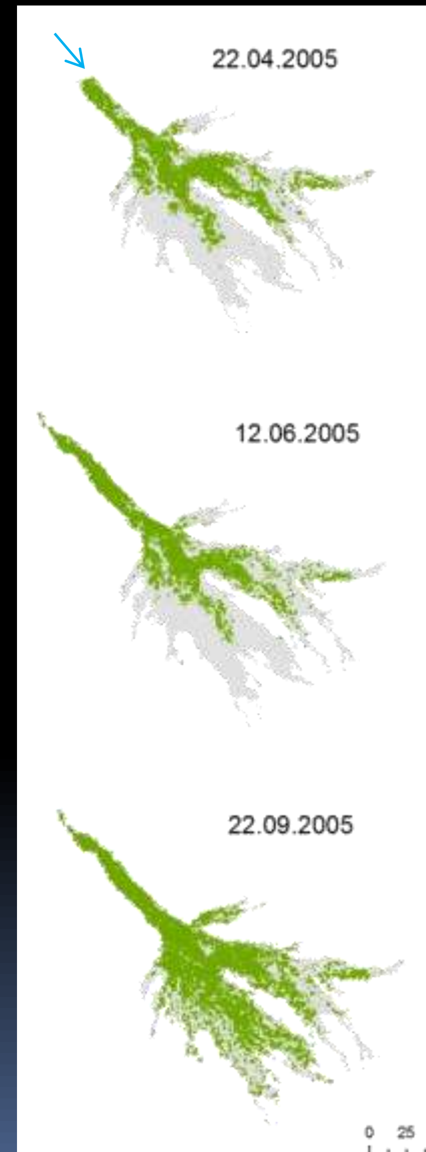
Mostly smooth water



Double bounce – urban (permanent phenomen)

Okavango example



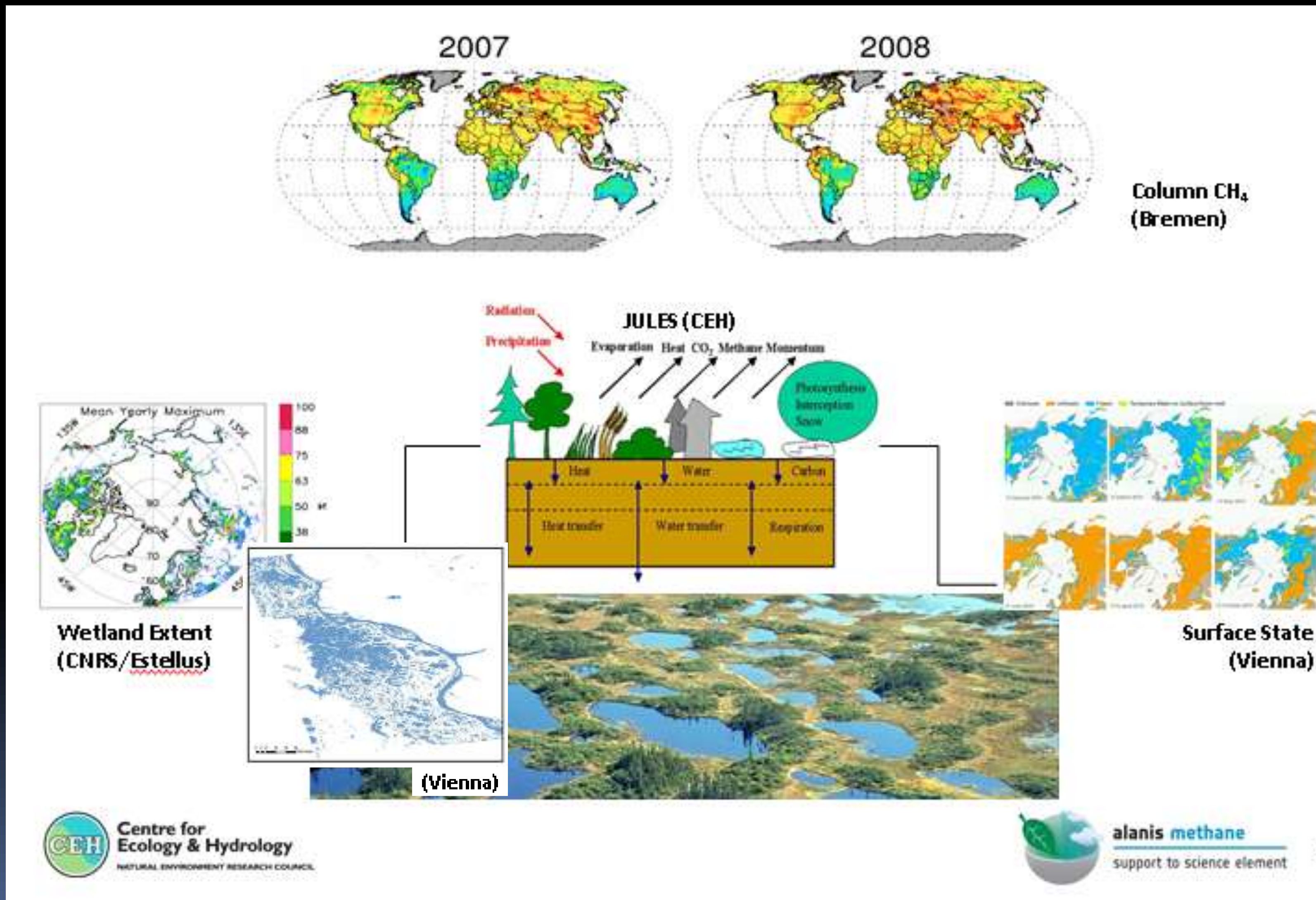


end of rain season

dry season

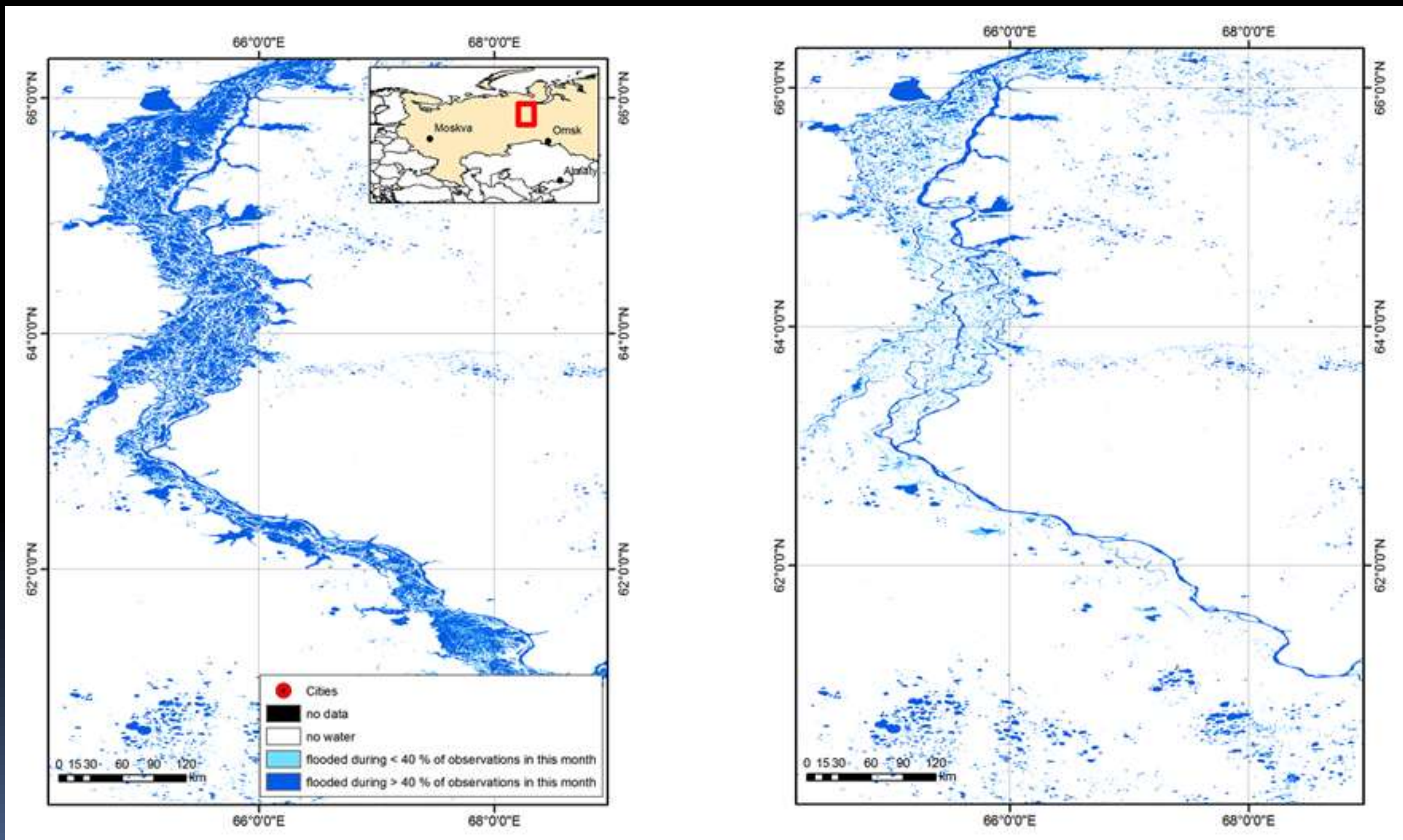
Bartsch 2009

ESA STSE ALANIS Methane



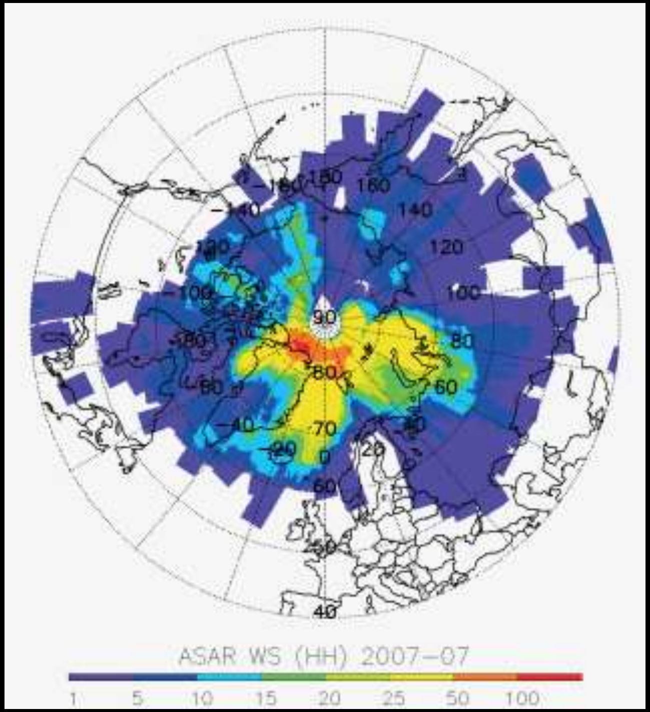
ESA STSE ALANIS Methane –

experimental product from ENVISAT ASAR WS



June 2007 | September 2007

Example

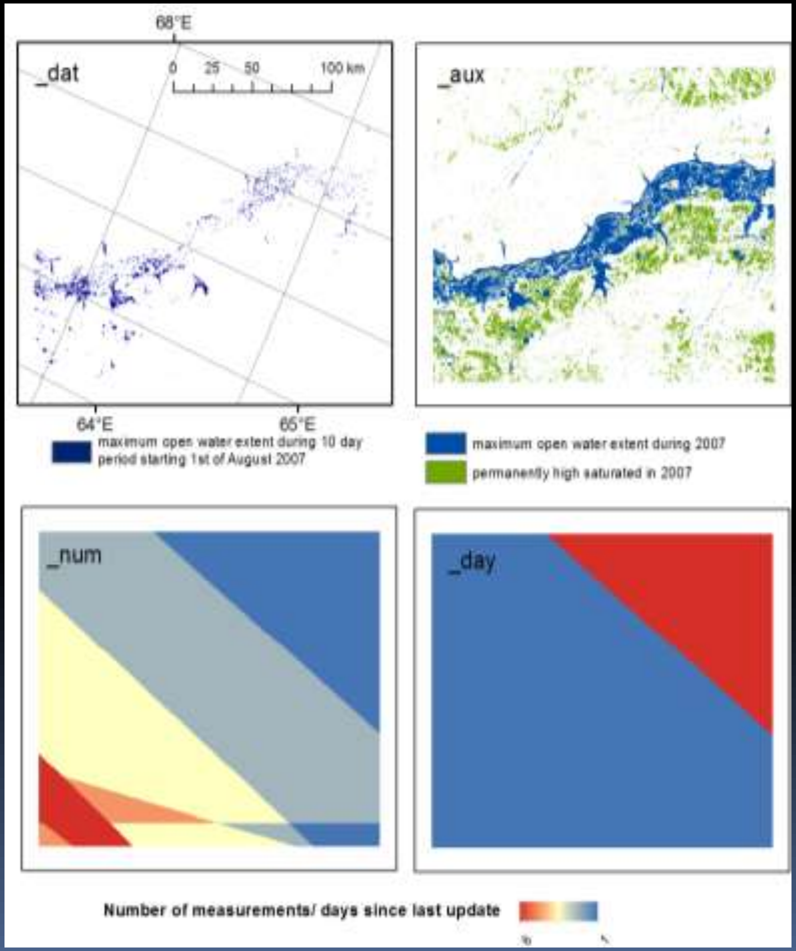


- ENVISAT ASAR Wide swath
  - Best available coverage among SAR sensors
  - Actual coverage does however vary
  - C-Band – sensitivity to weather in case of this specific application
  - Continuity with Sentinel 1

Bartsch et al., 2012

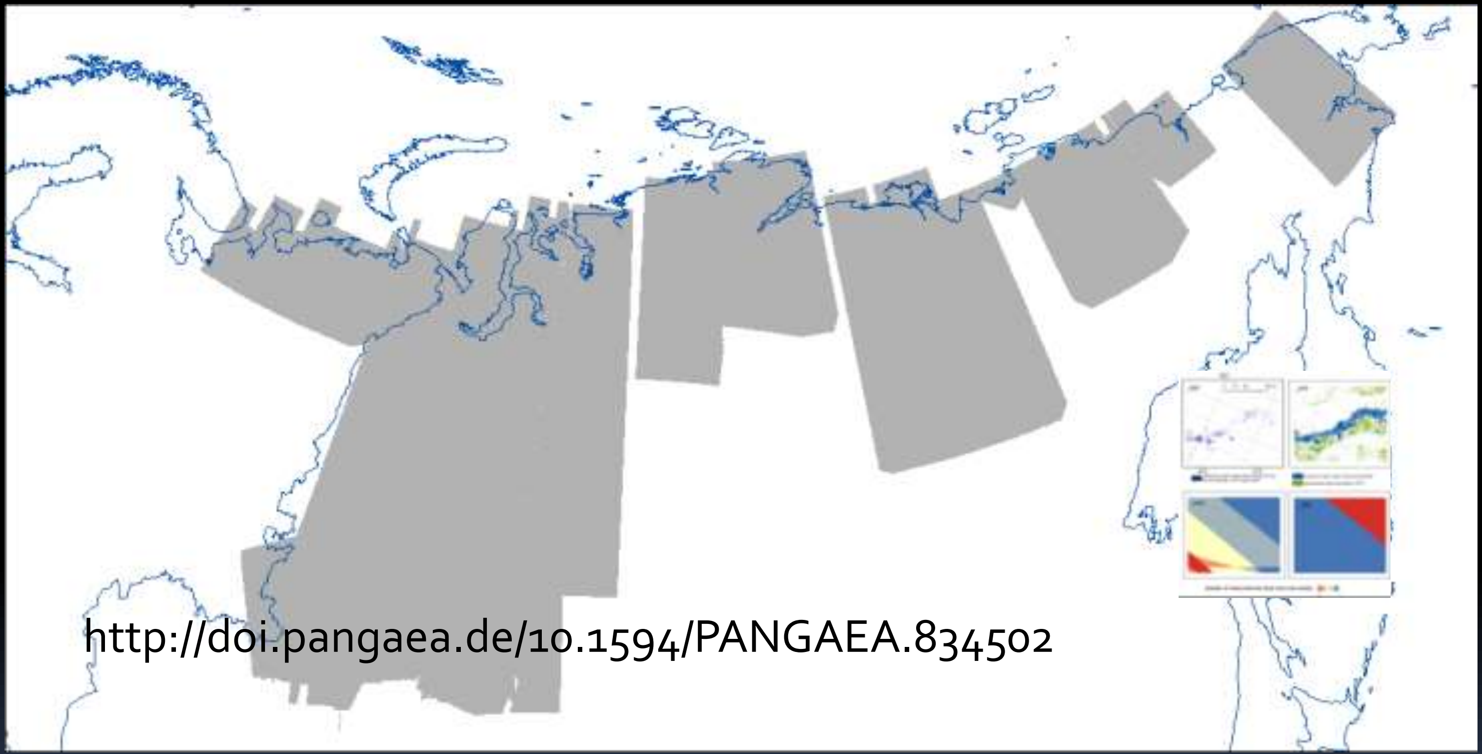
ESA STSE ALANIS Methane – experimental product

10 days



All summer including saturated area

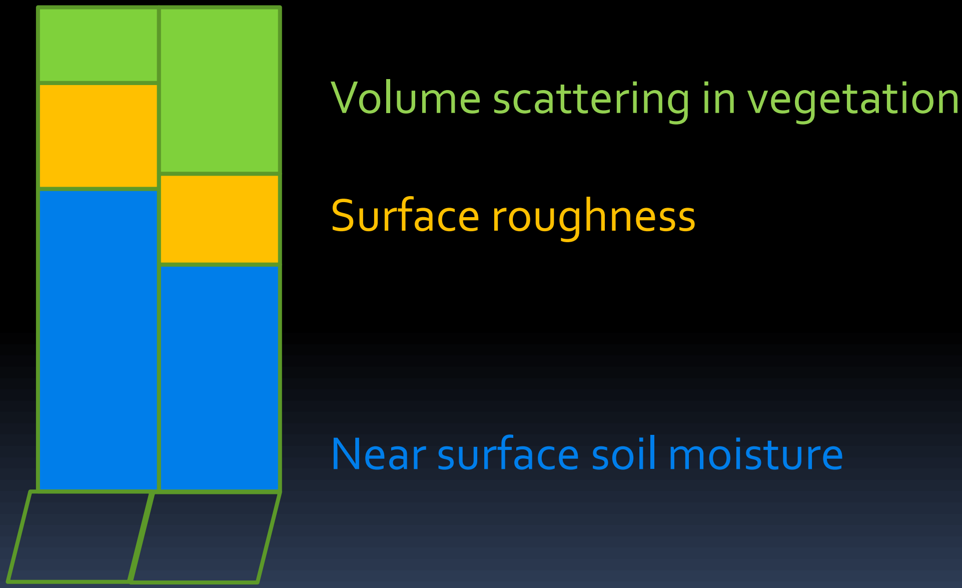
ESA STSE ALANIS Methane – experimental product



http://doi.pangaea.de/10.1594/PANGAEA.834502

Supplement to: **Reschke, Julia; Bartsch, Annett; Schlaffer, Stefan; Schepaschenko, Dmitry (2012):** Capability of C-Band SAR for operational wetland monitoring at high latitudes. *Remote Sensing*, **4(12)**, 2923-2943, doi:10.3390/rs4102923

Signal interaction

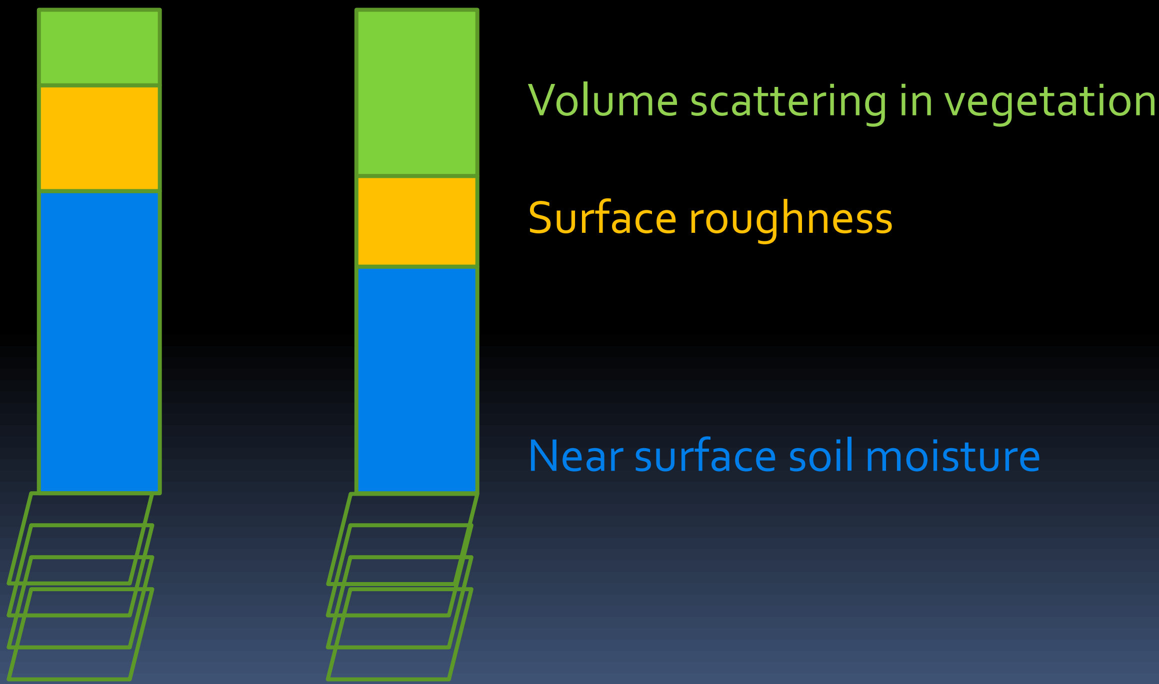


Two adjacent pixels, same total backscatter

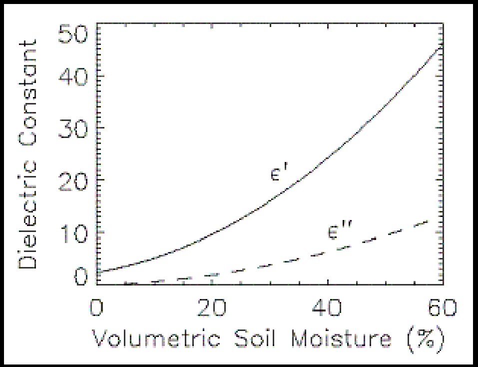
Signal interaction

- How to separate those contributions
  - Use a model
  - Exploit different polarizations
  - Combine with optical
  - Rule out changes of certain mechanisms over time

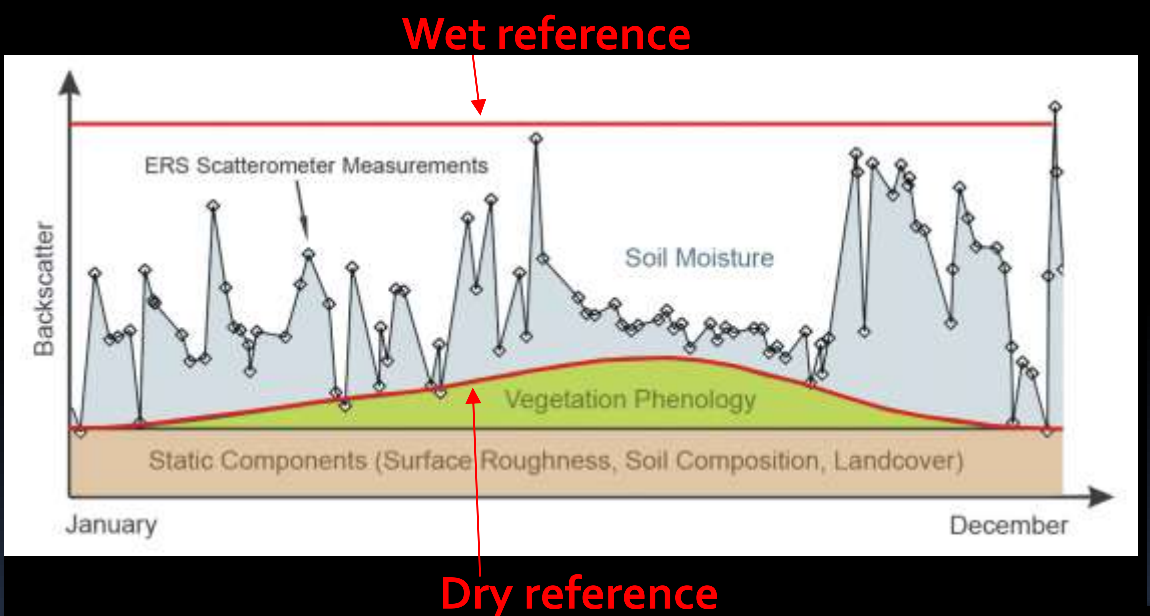
Signal interaction



Soil moisture



Time series for a single location (C-band)



Wagner et al. 1999

Assumptions:
- No rougness change
- Vegetation impact can be modelled from incidence angle variation
- References need to be known

- ASCAT

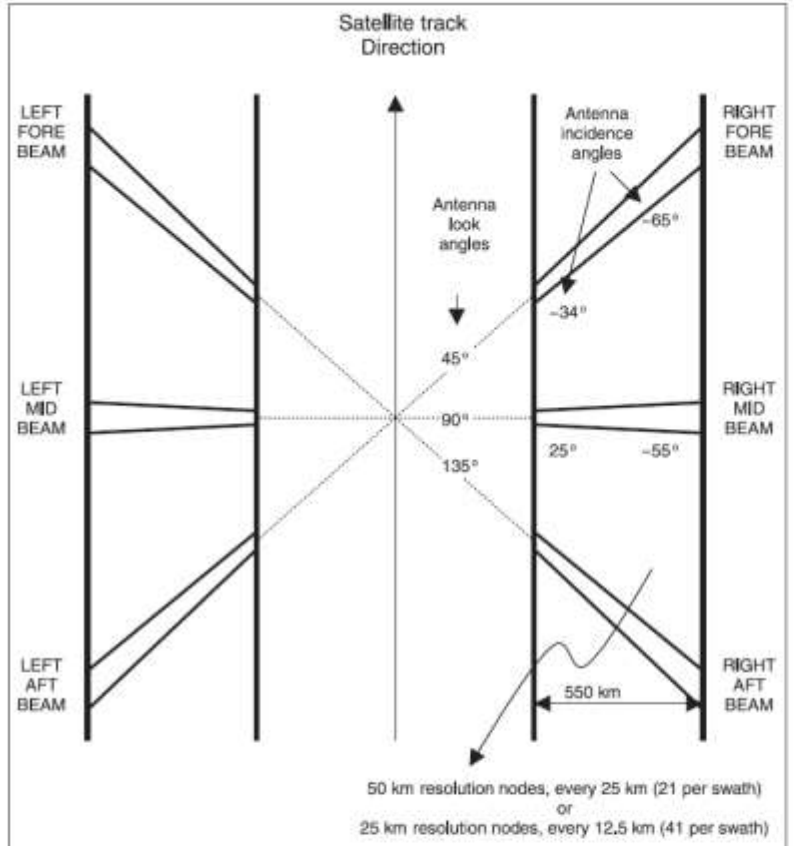
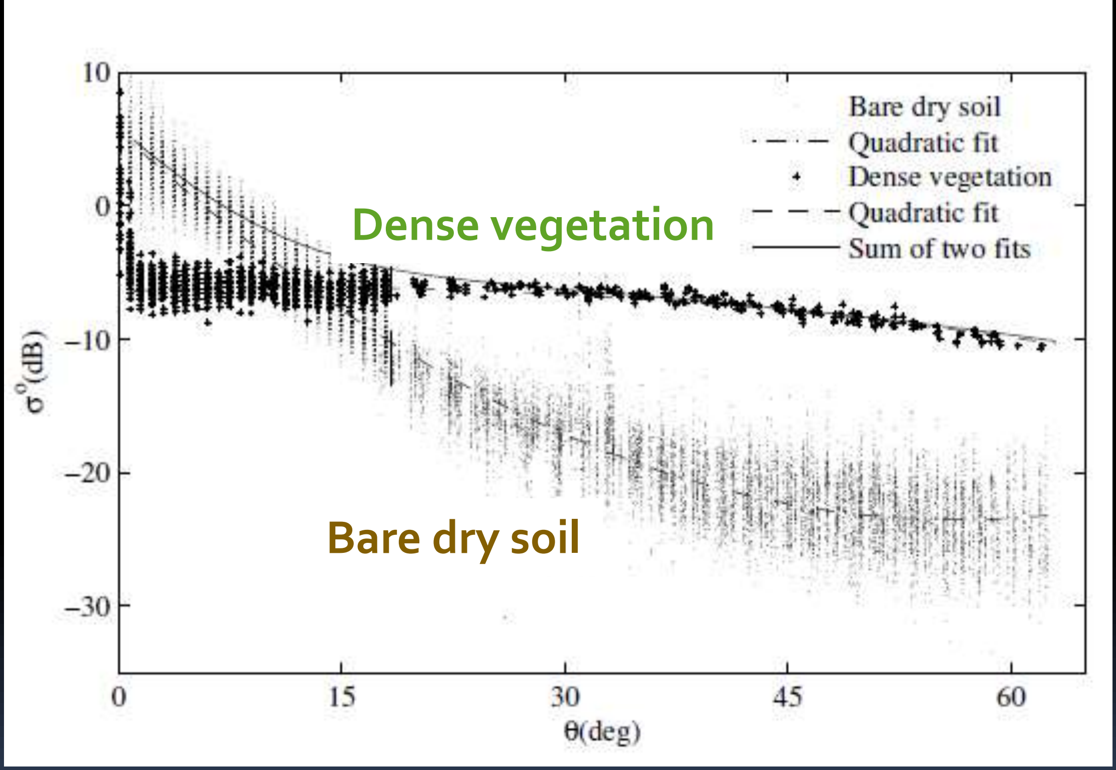


Figure 2. ASCAT swath geometry. Dimensions are given for the right swath, and the left swath is symmetric with respect to the satellite ground track.

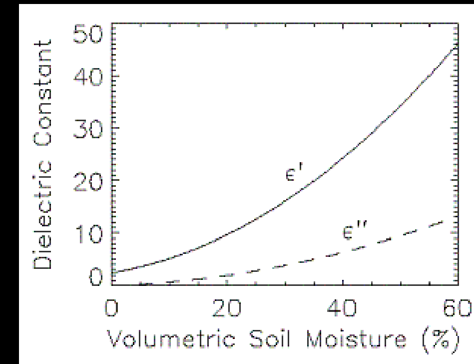
Basics

Backscatter – local incidence angle

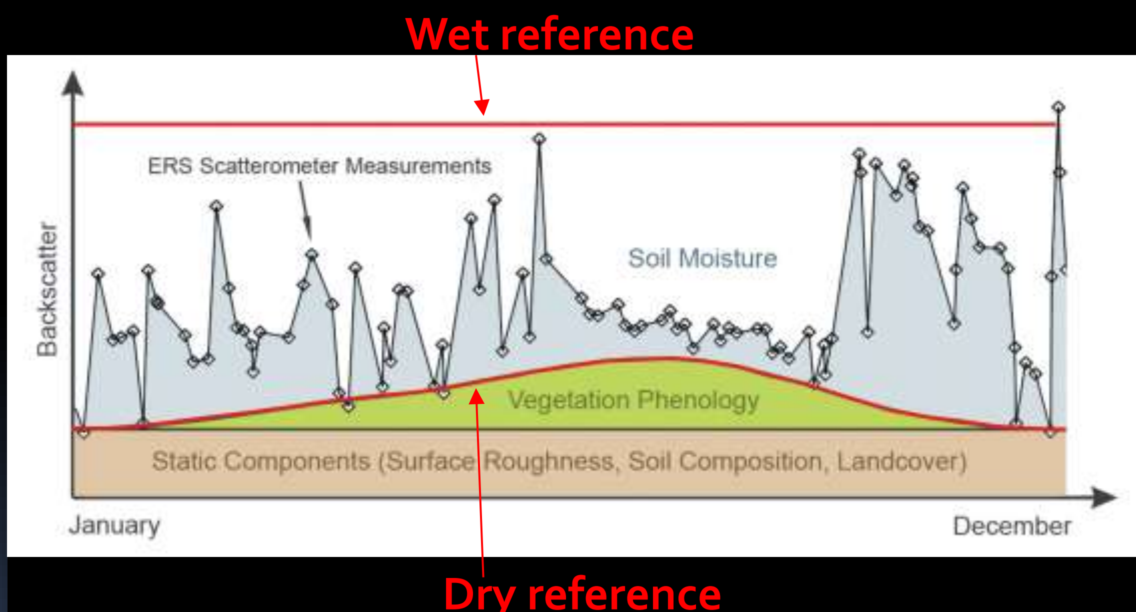


K_U-Band; Stephen 2006

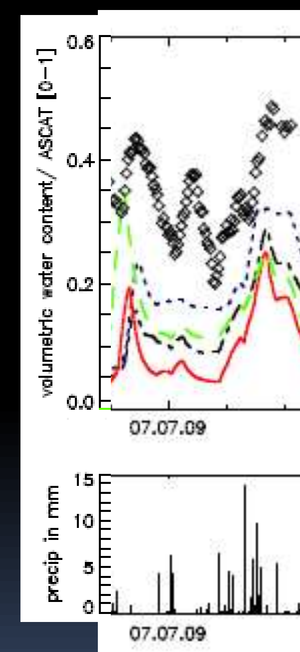
Soil moisture



Time series for a single location (C-band)



Wagner et al. 1999



Bartsch et al. 2012

Soil moisture

- Penetration depth?

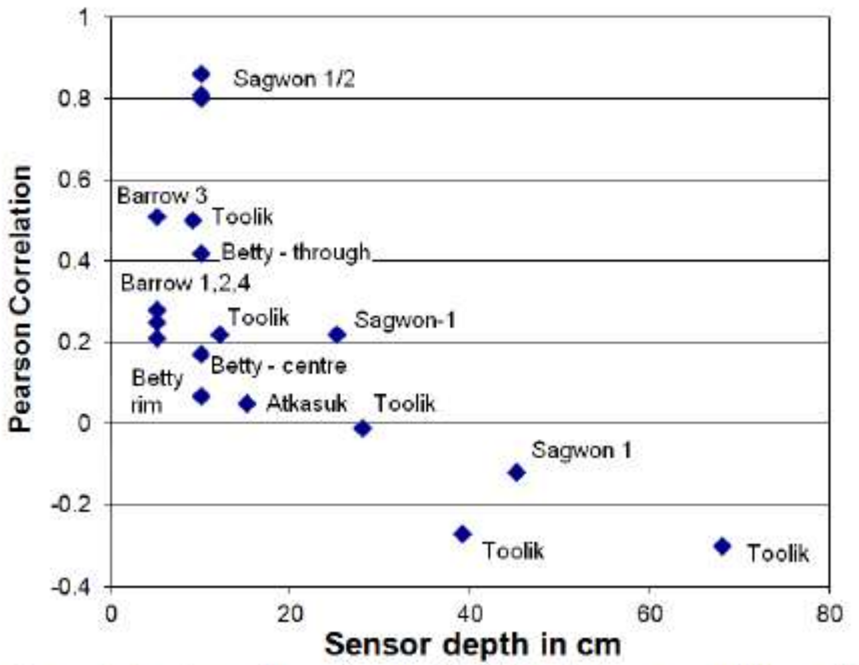
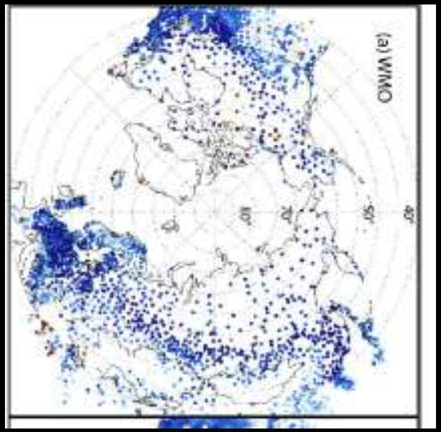


Figure 4. In situ volumetric and ASCAT relative near-surface soil moisture ($p<0.05$ for sites with $R>0.2$).

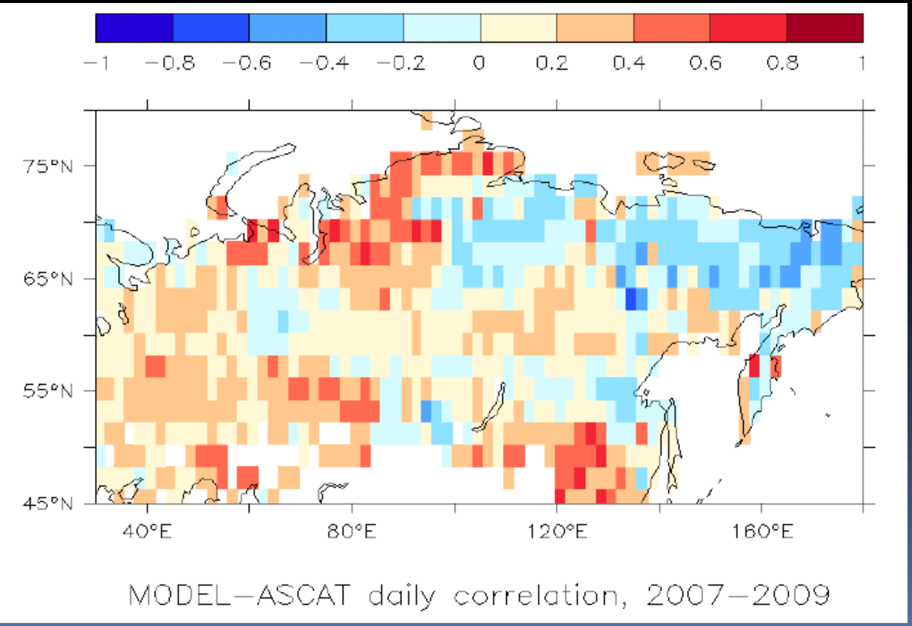
Bartsch et al. 2012

Soil moisture



- But roughness change is possible
  - In areas with high water fraction
  - Change of scattering mechanism in part of the footprint – flooding, freezing, snow

Comparison with landsurface model ORCHIDEE, Gouttevin et al. 2013



Summary

- Soil moisture
  - Footprint heterogeneity
  - Weather impact!
- Snow
  - Derived information: frozen/unfrozen
  - Timing crucial (diurnal changes)
  - Short wavelength required
- Inundantion
  - Weather impact!