CEOS SAR Calibration and Validation Workshop
17–19 November 2009, Pasadena, California, USA

SAR Calibration Requirements for Soil Moisture Estimation

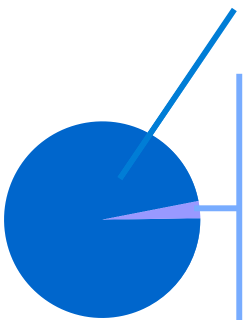
Zoltan Bartalis, Wolfgang Wagner
Vahid Naeimi, Daniel Sabel, Carsten Pathe

Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

zb@ipf.tuwien.ac.at
www.ipf.tuwien.ac.at/zb
www.ipf.tuwien.ac.at/radar

Introduction

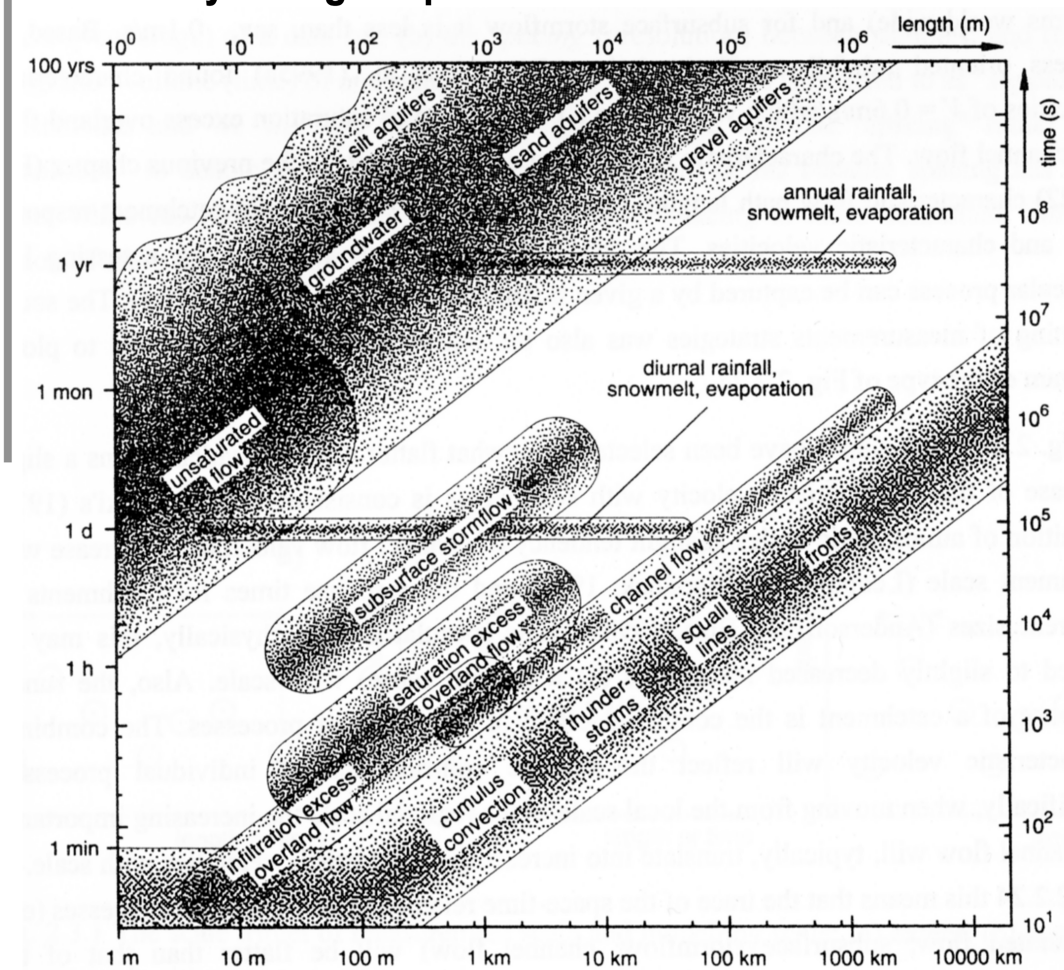
Global water distribution



oceans	97.24%
glaciers & icecaps	2.14%
groundwater 0.61%	
fresh-water lakes	0.009%
inland seas	0.008%
soil moisture 0.005%	
atmosphere	0.001%
rivers	0.0001%

- **Soil moisture:**
  - Key parameter in global cycles of water, energy and carbon
  - Controls separation of precipitation into runoff and infiltration
  - Controls separation of incoming solar radiation into sensible and latent heat fluxes
  - Soil moisture is highly variable in space and time

Hydrological processes and their scales



Soil Moisture Microwave Remote Sensing

- **Radar backscatter σ^0 as a function of surface roughness *R* and soil moisture m_s :**

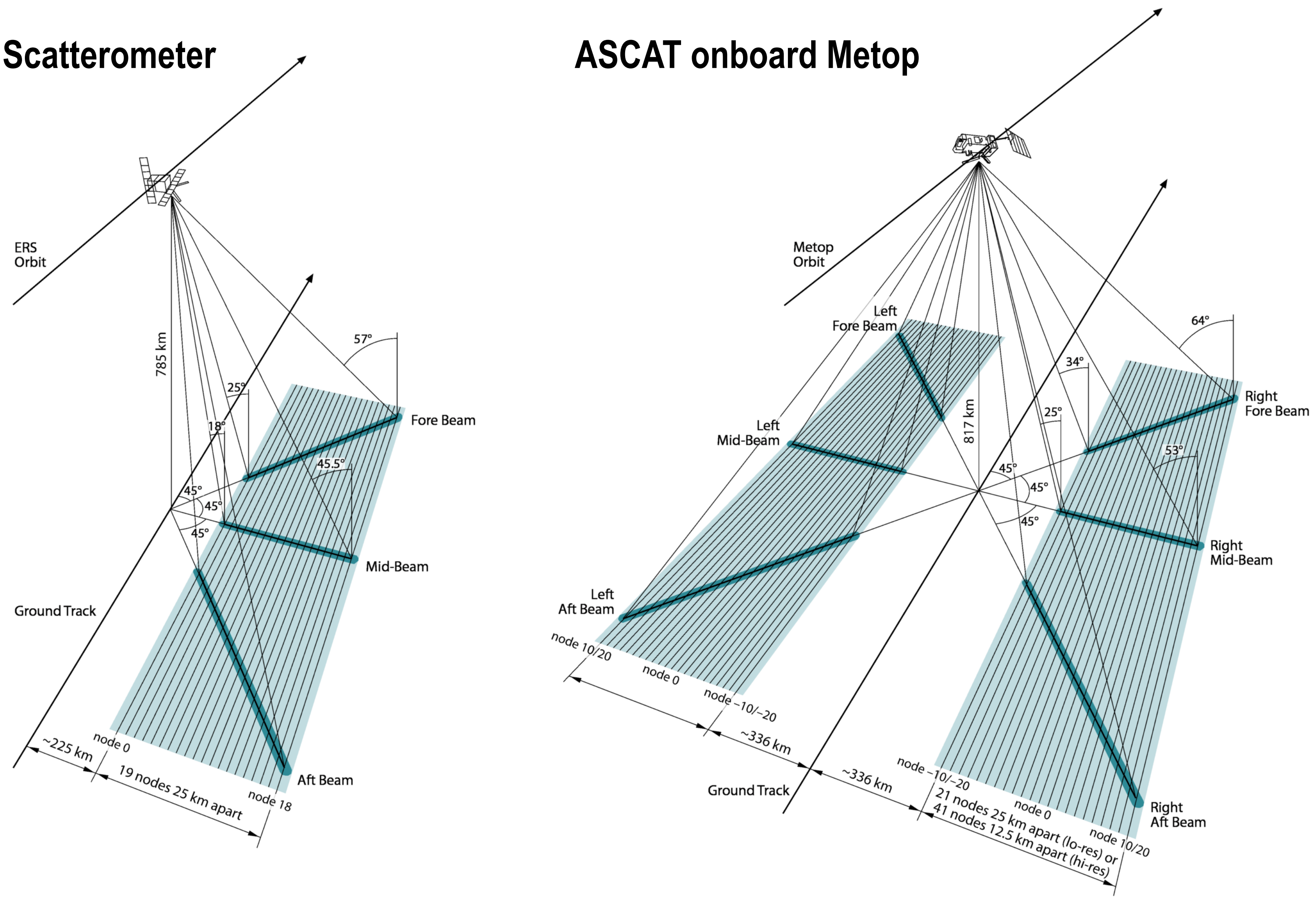
$$\sigma^0 = f\left(m_s, R\right)$$

- **Soil moisture retrieved from σ^0 using empirical, semi-empirical or theoretical models**
- **Change detection very useful. Basic concept: parameters controlling backscatter act on different time scales**
  - **long term changes: vegetation phenology**
  - **short term changes: surface soil moisture m_s**
  - **multi-incidence angle capabilities of scatterometers used to describe vegetation cover effects**
  - **surface roughness influence at coarse spatial resolution can be considered constant in time**

Scatterometer-Based Soil Moisture

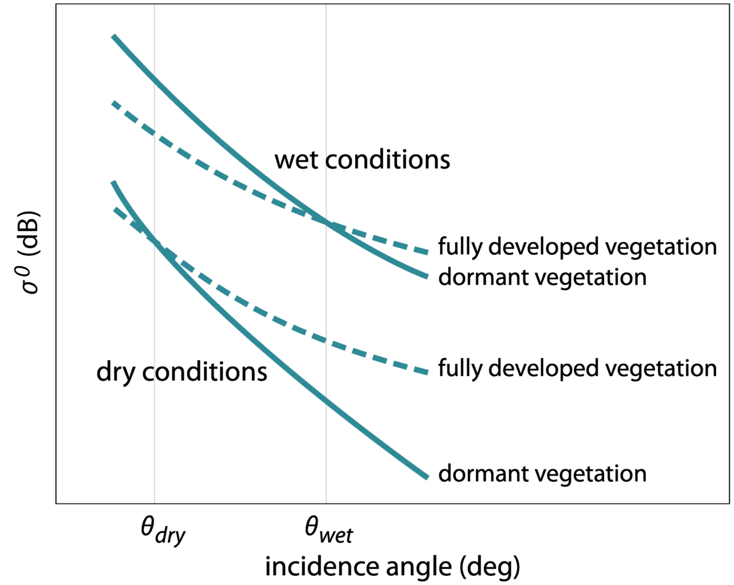
ERS Scatterometer

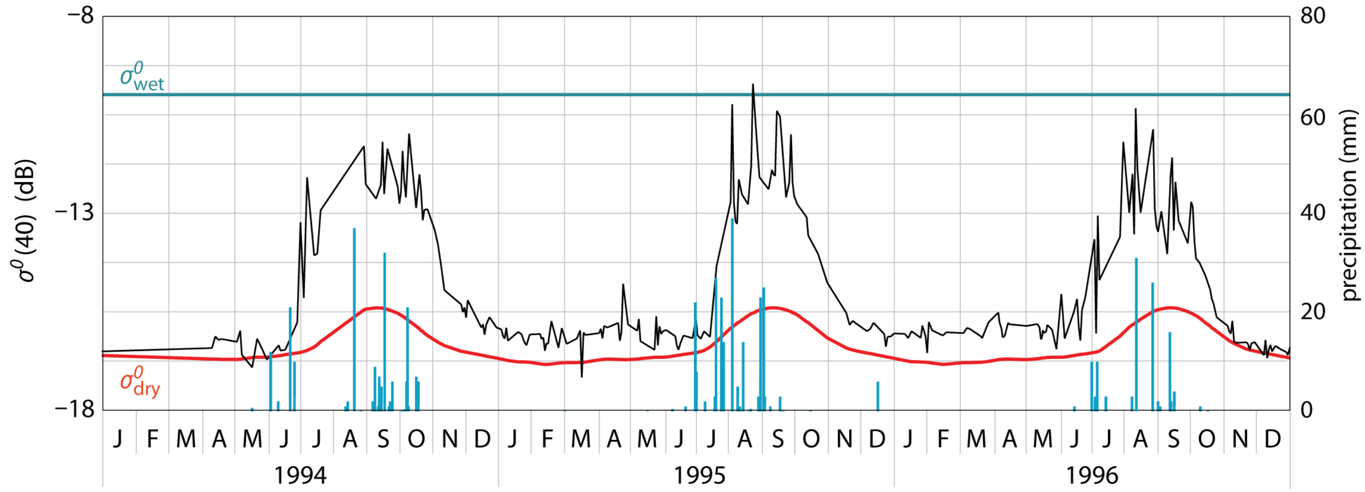
ASCAT onboard Metop



Scatterometer-Based Soil Moisture

- "TU Wien method"
  - First developed for use with scatterometers
- Our philosophy
  - Radar is not a tool for mapping static land cover, but for **monitoring dynamic land-surface processes**
  - Temporal aspect is extremely important, therefore we work mostly with **time series analysis**

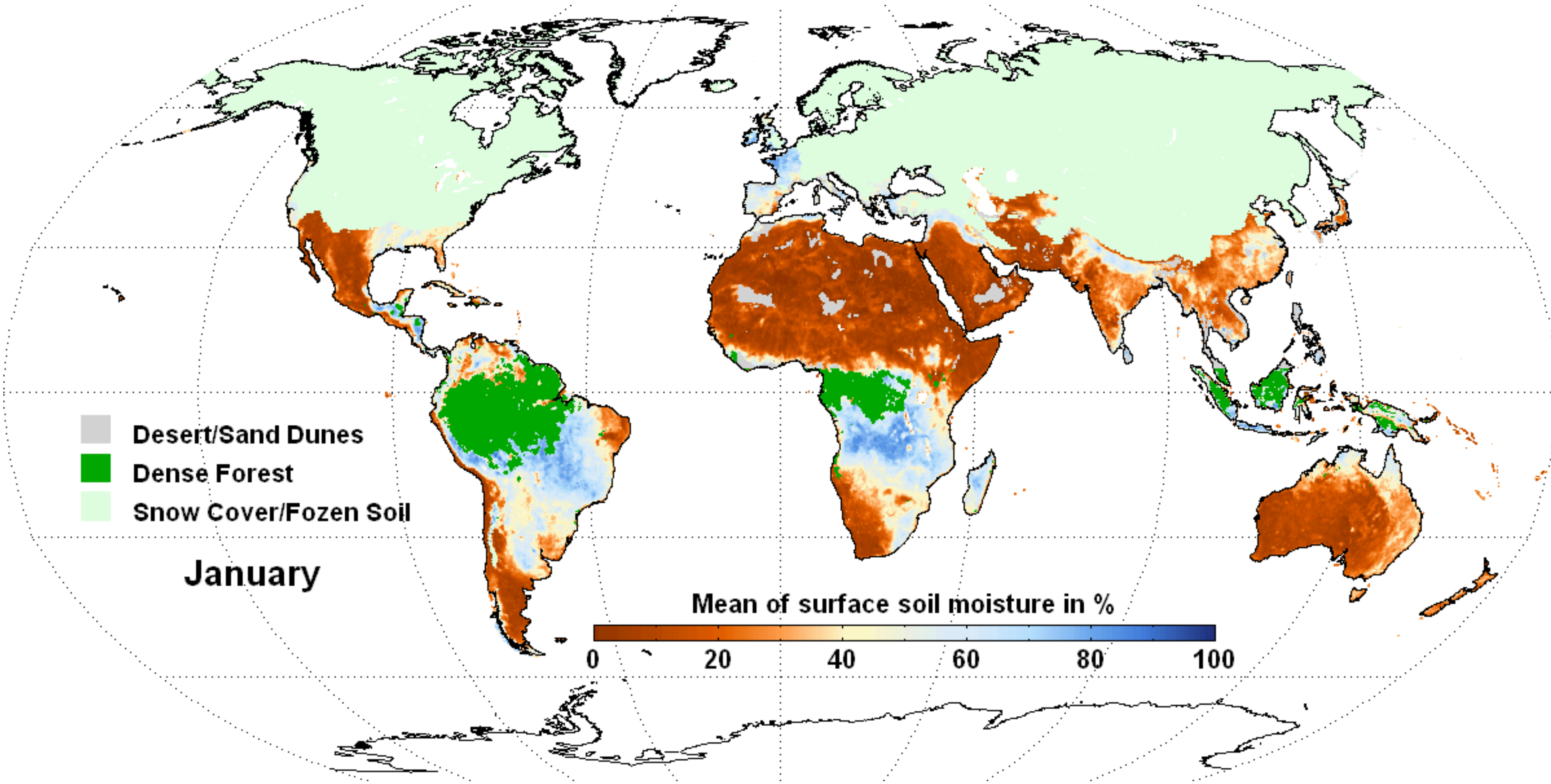




Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

Scatterometer-Based Soil Moisture

- **Mean surface soil moisture seasonal cycle, from ERS-1/2 Scatterometer data**

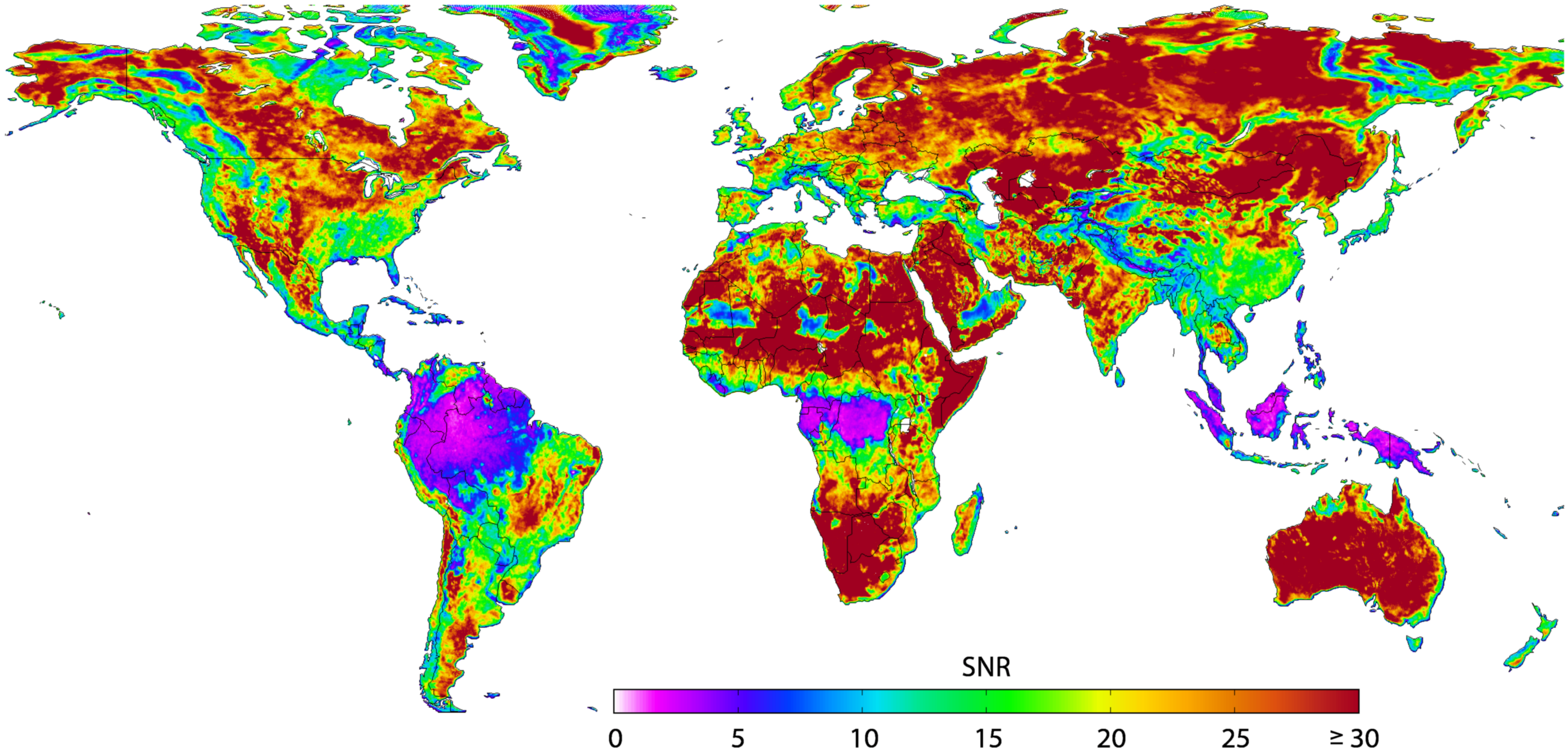


Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

Scatterometer Soil Moisture Performance

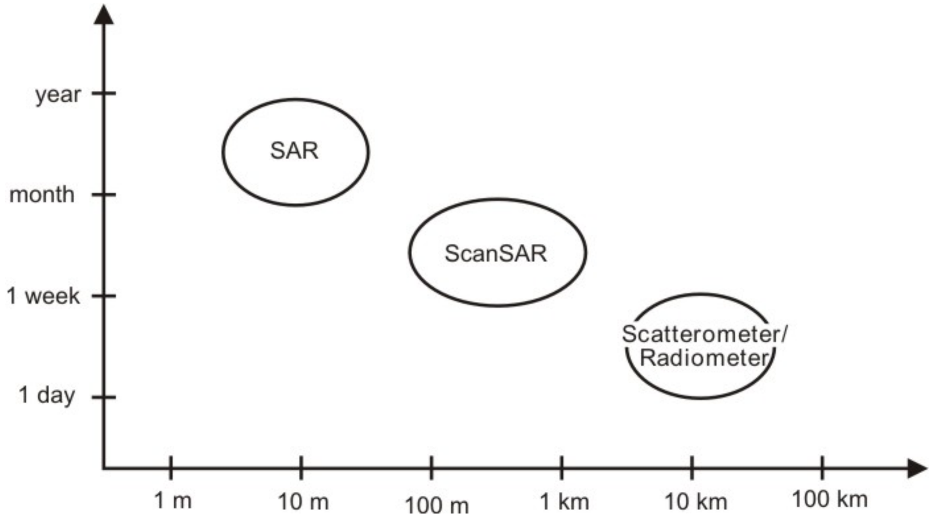
Mean Signal-to-Noise Ratio of the *scatterometer* soil moisture data:

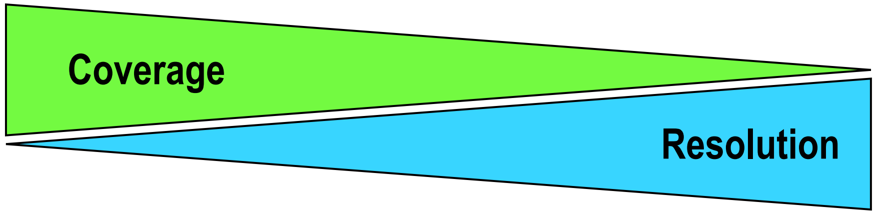
- **signal = sensitivity to soil moisture (difference between wet and dry references)**
- **noise = estimated noise of the sigma-0 at 40º incidence angle**



From Scatterometers to SARs

From Scatterometers to SARs

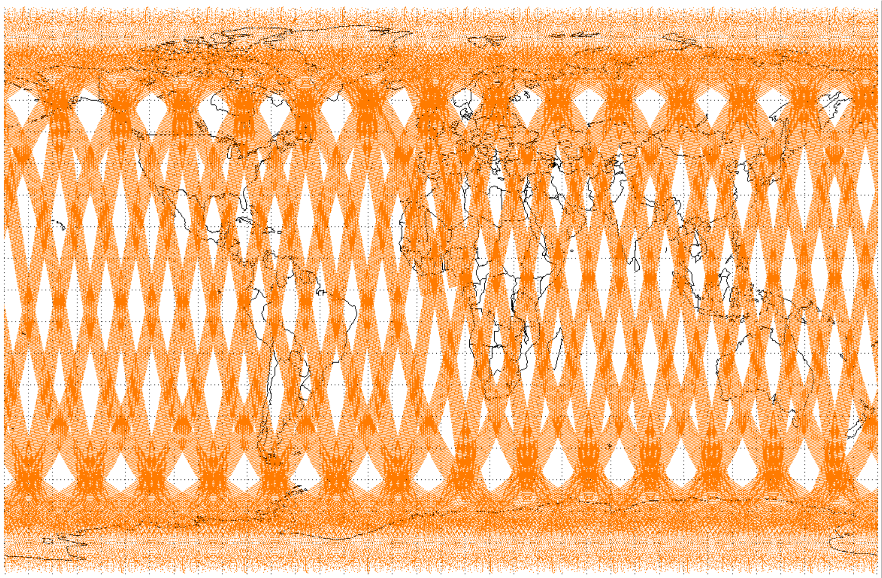


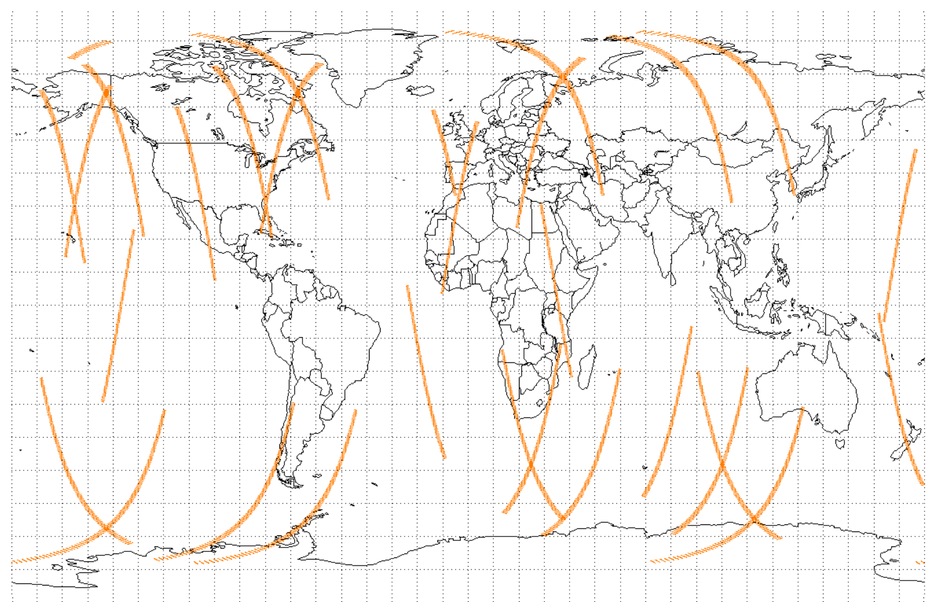


Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

From Scatterometers to SARs

- Daily data coverage

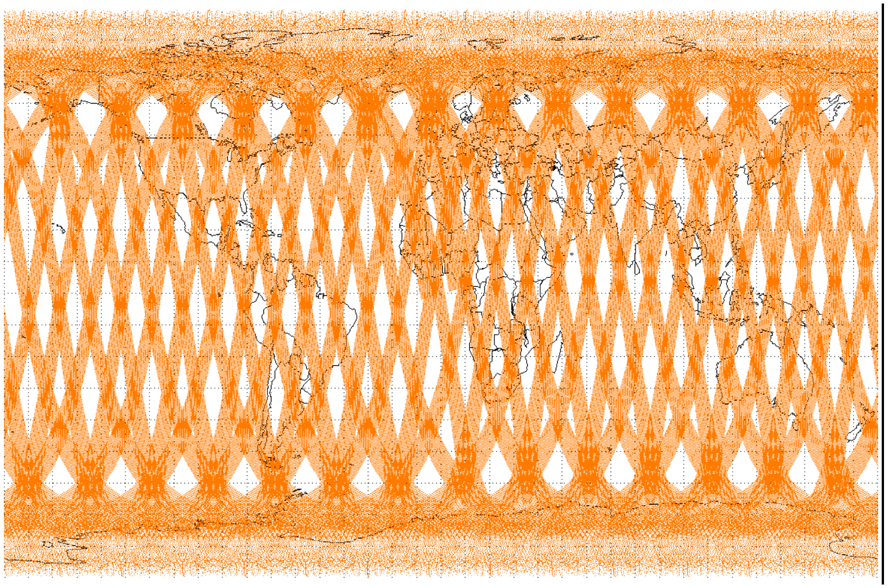


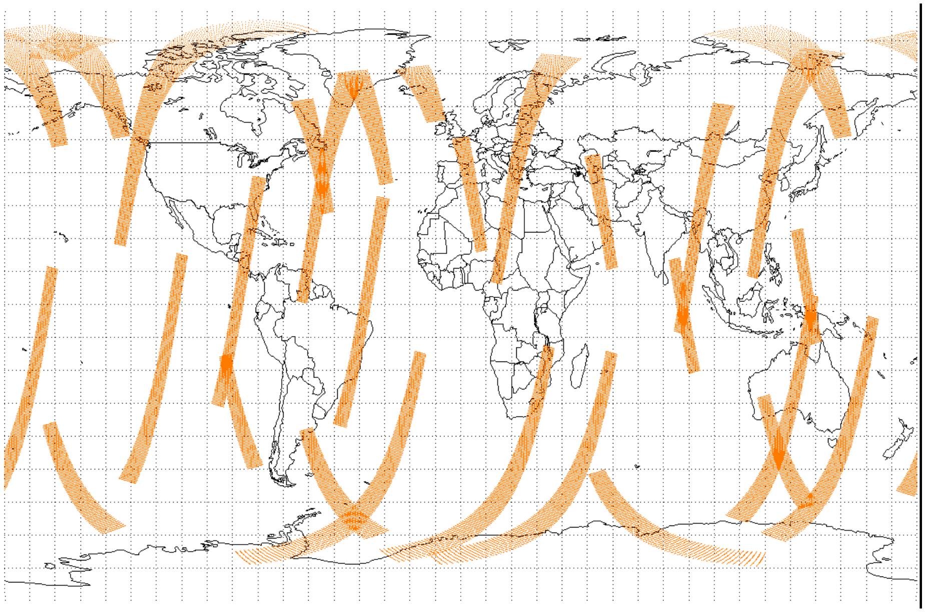


- Metop ASCAT
  - 2 swaths of 550 km each
  - 25 km resolution
  - 100% duty cycle
  - 82% daily global coverage
- ENVISAT ASAR Image Mode
  - 100 km swath
  - 30 m resolution
  - Max. 30% duty cycle

From Scatterometers to SARs

- **Daily data coverage**

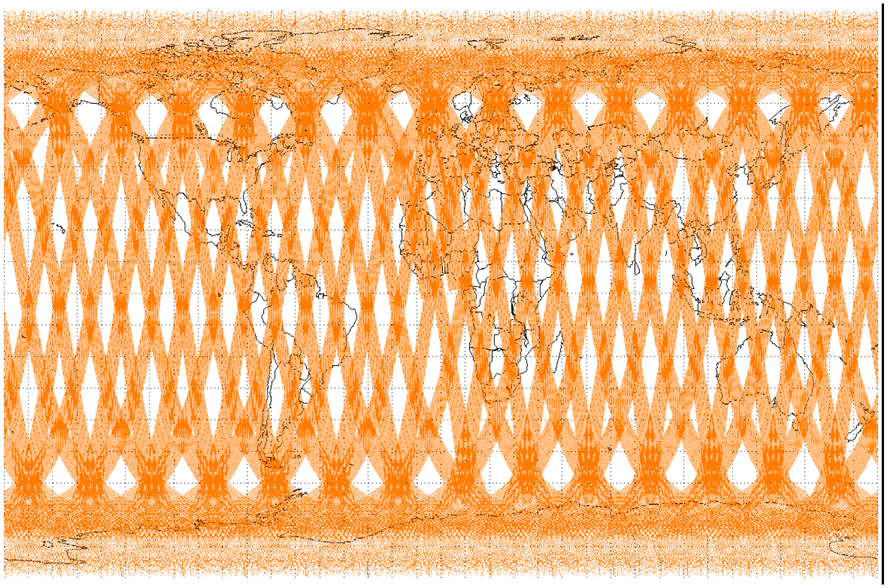


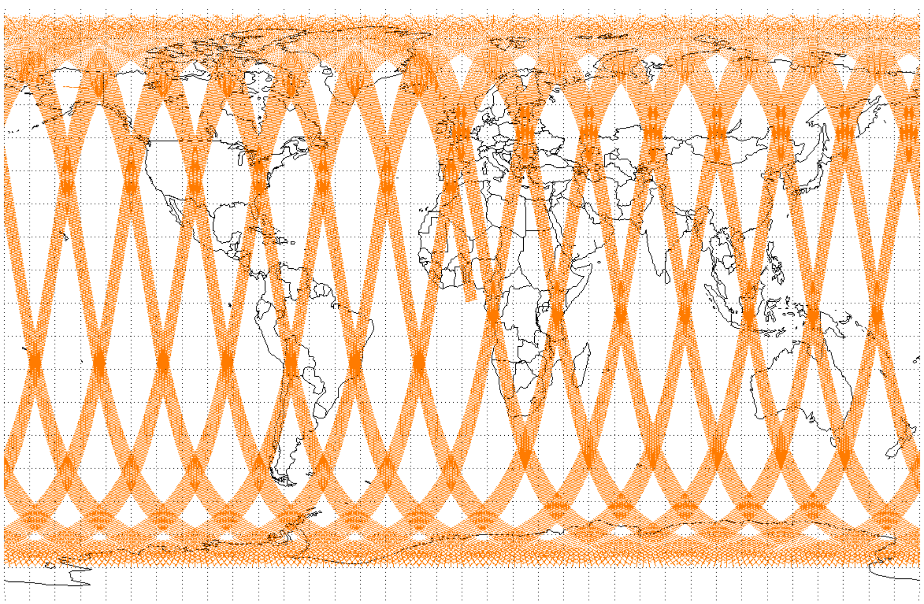


- **Metop ASCAT**
  - **2 swaths of 550 km each**
  - **25 km resolution**
  - **100% duty cycle**
  - **82% daily global coverage**
- **ENVISAT ASAR Wide Swath Mode**
  - **405 km swath (ScanSAR)**
  - **150 m resolution**
  - **Max. 30% duty cycle**

From Scatterometers to SARs

- **Daily data coverage**





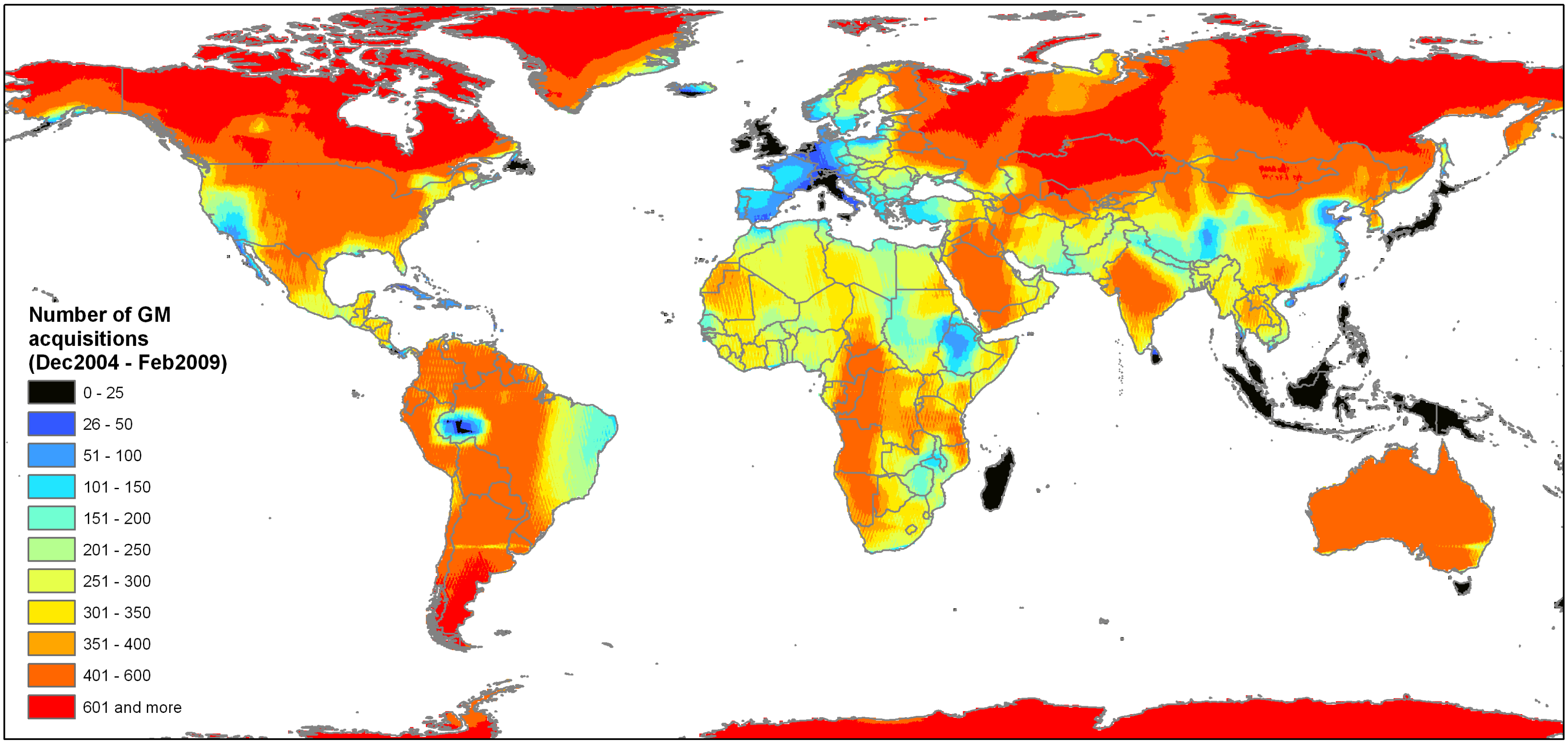
- **Metop ASCAT**
  - 2 swaths of 550 km each
  - 25 km resolution
  - 100% duty cycle
  - 82% daily global coverage

- **ENVISAT ASAR Global Monitoring Mode (GM)**
  - 405 km swath (ScanSAR)
  - 1 km resolution
  - Potentially 100% duty cycle
  - Up to 2 acquisitions per week at Equator

From Scatterometers to SARs

- **ASAR GM chosen because of best data coverage**

ASAR GM data availability Dec 2004 – Feb 2009 (HH polarisation only)



Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

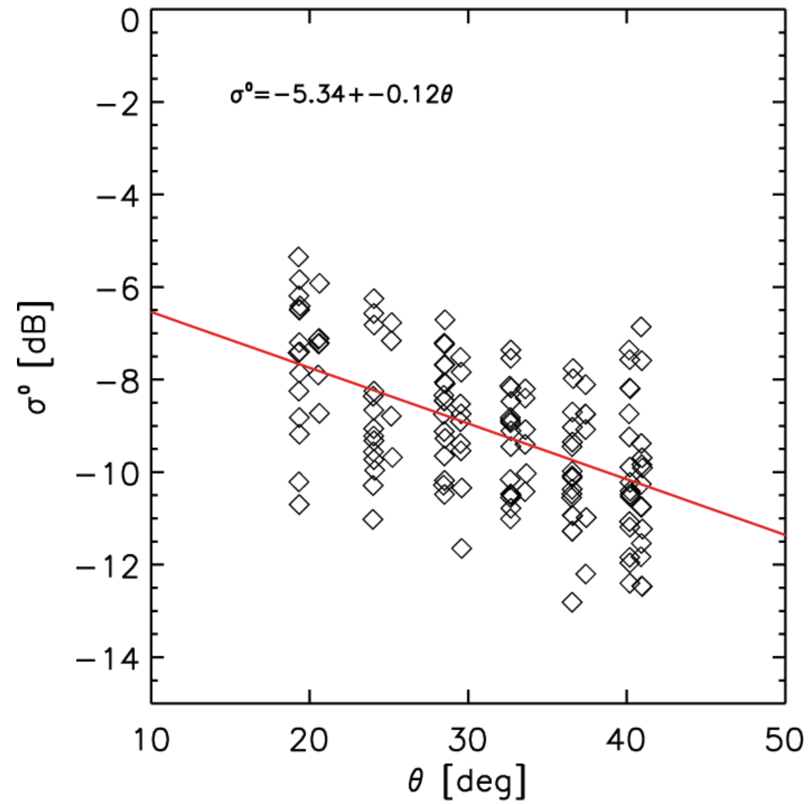
Envisat ASAR Surface Soil Moisture

- **Time-invariant parameters**
  - Uses dry/wet references from scatterometer data
- **No explicit correction for vegetation cycle, however,**
  - ASAR GM in HH polarisation less sensitive to vegetation
  - ASAR GM incidence angle range lower than scatterometers', i.e. less sensitive to vegetation
- **Normalisation of incidence angle (20°–40°) based on all available backscatter data at each location**
- **Simple linear model used**

$$\sigma^0(\theta,t)=\sigma^0_{dry}(30)+\beta(\theta-30)+Sm_s(t)$$

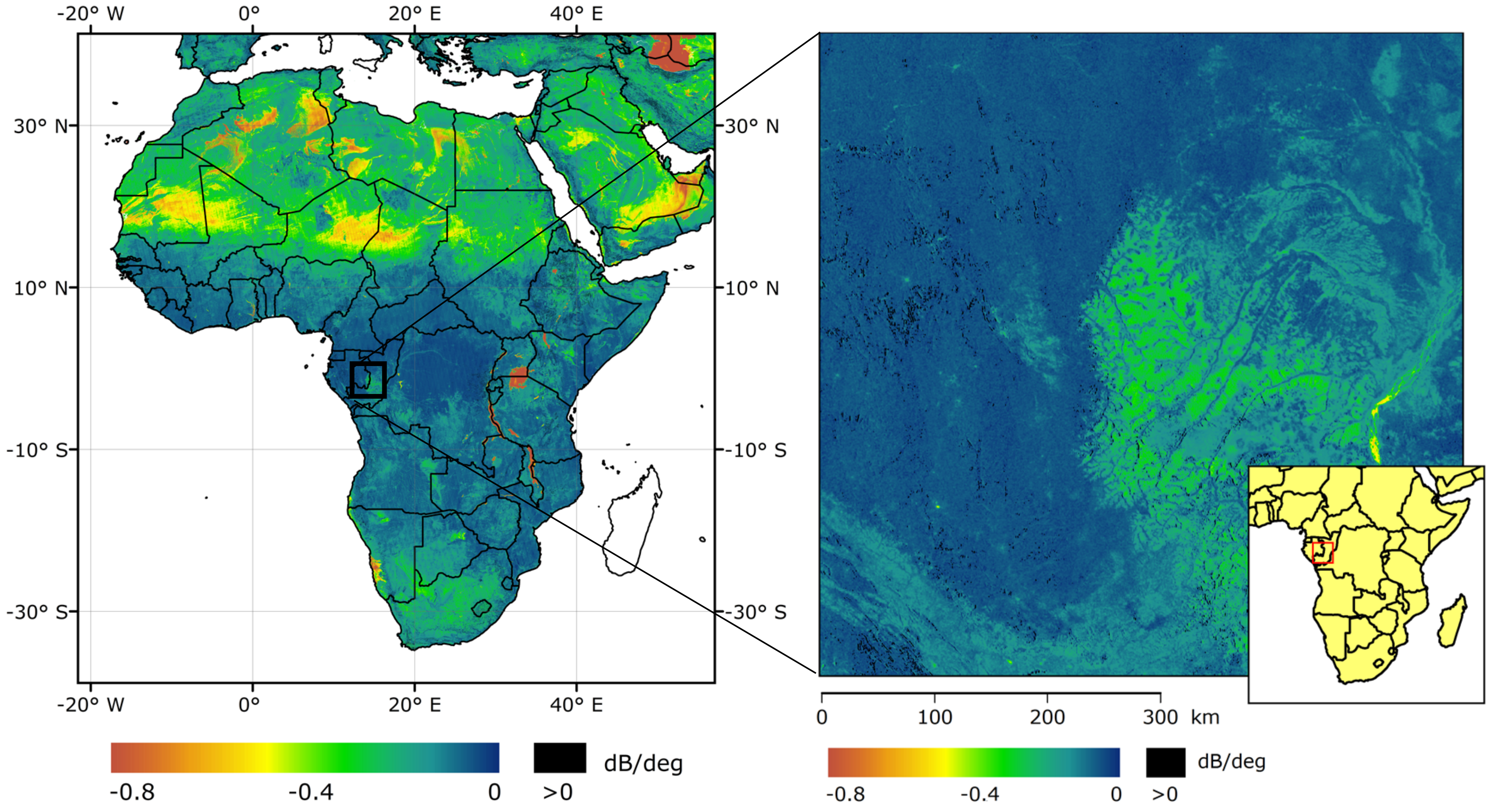
$$S=\sigma^0_{wet}(30)-\sigma^0_{dry}(30)$$

  - σ^0_{dry}, β and S constant in time



Envisat ASAR Surface Soil Moisture

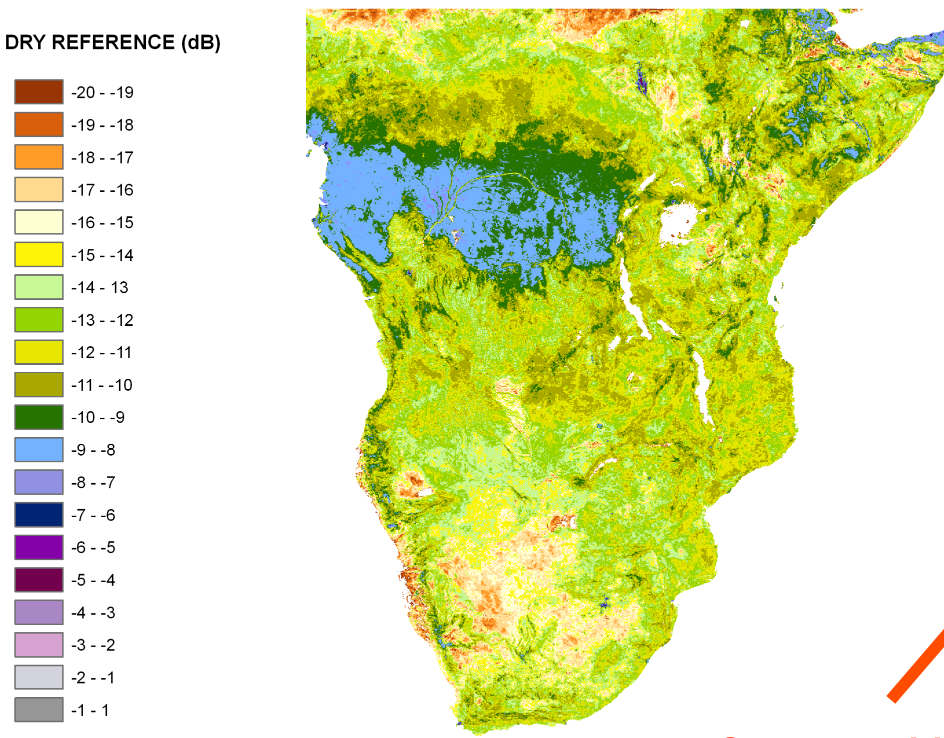
Slope parameter β (dB/deg)



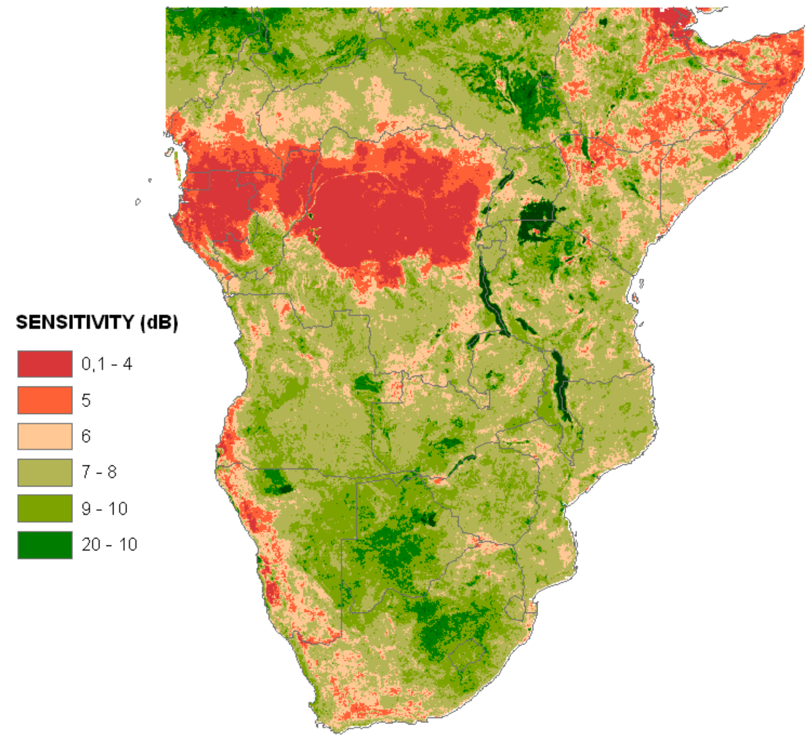
Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

Envisat ASAR Surface Soil Moisture

Dry reference parameter σ^0_{dry} (dB)



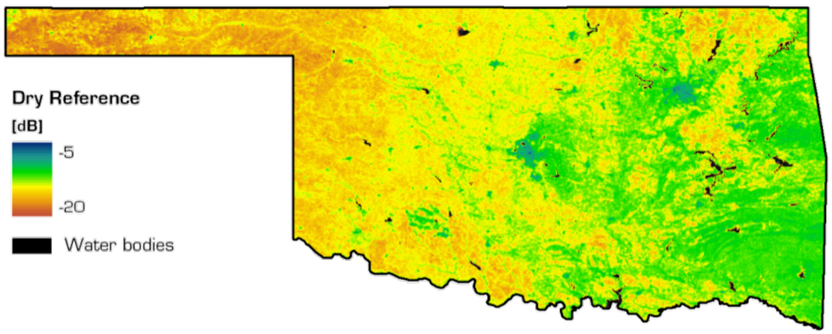
Sensitivity parameter *S* (dB)



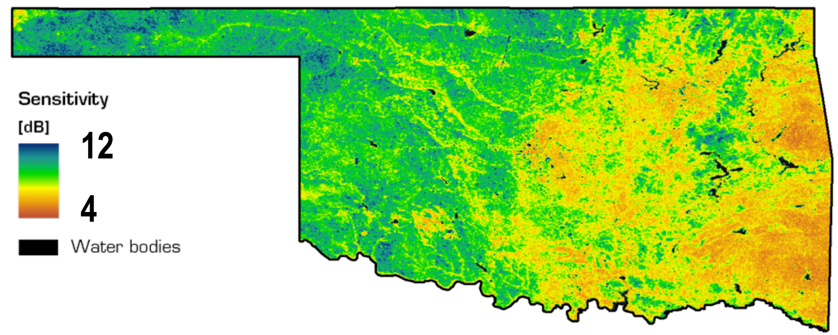
Compare this with
SAR radiometric resolution

Envisat ASAR Surface Soil Moisture

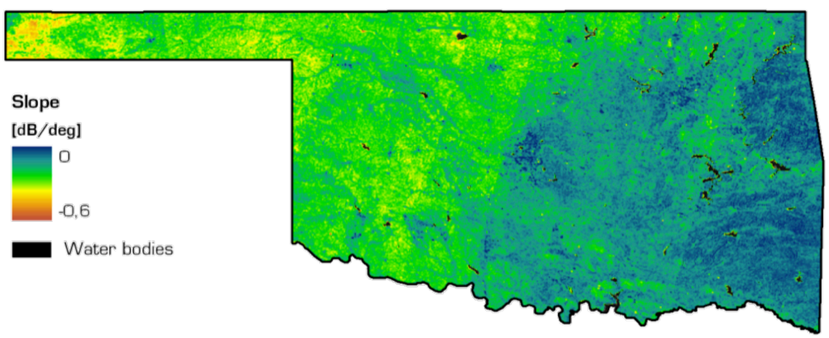
Dry reference parameter σ^0_{dry} (dB)



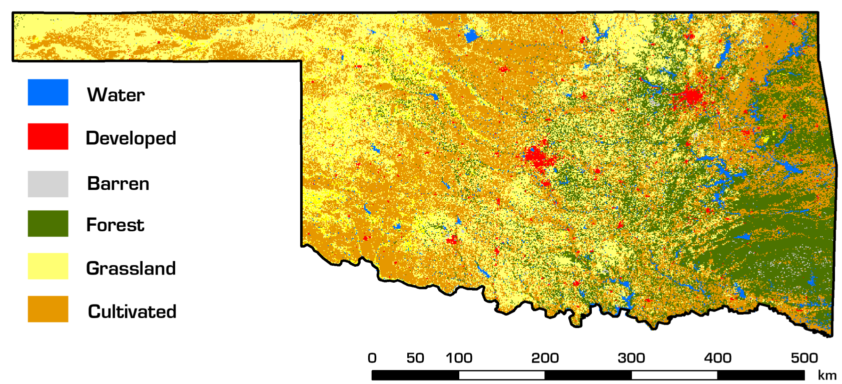
Sensitivity parameter *S* (dB)



Slope parameter β (dB/deg)

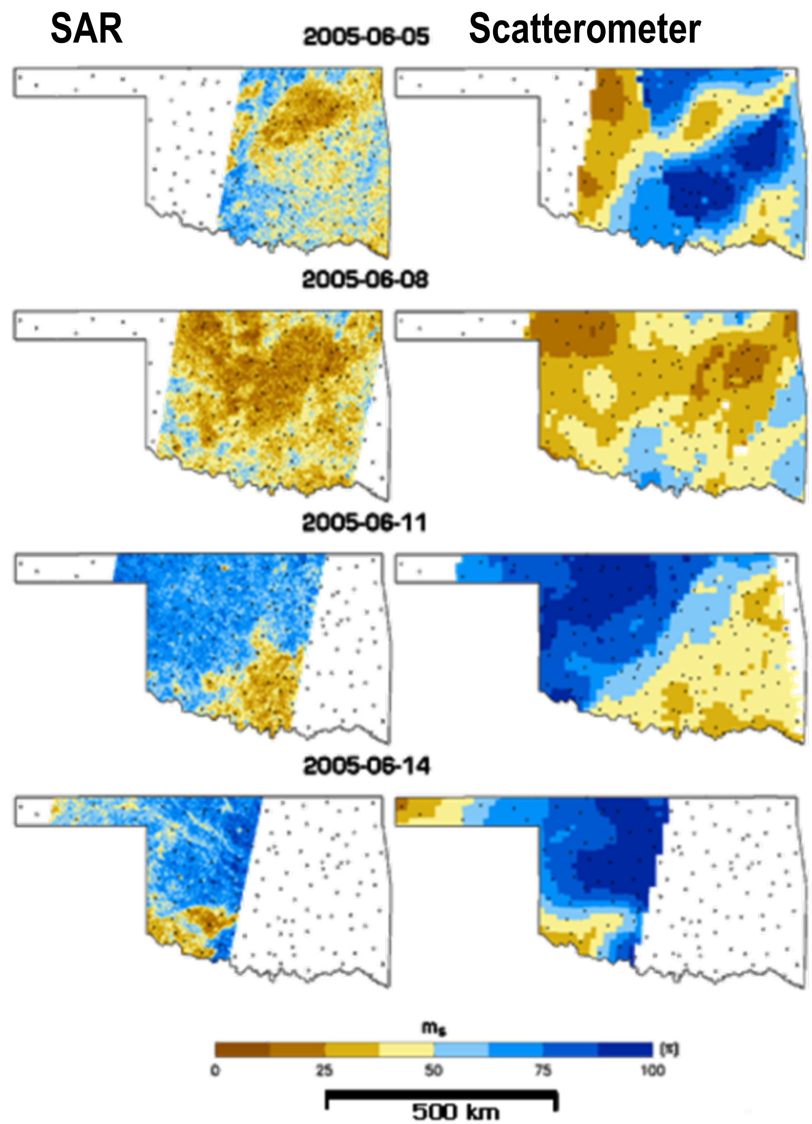


Land cover

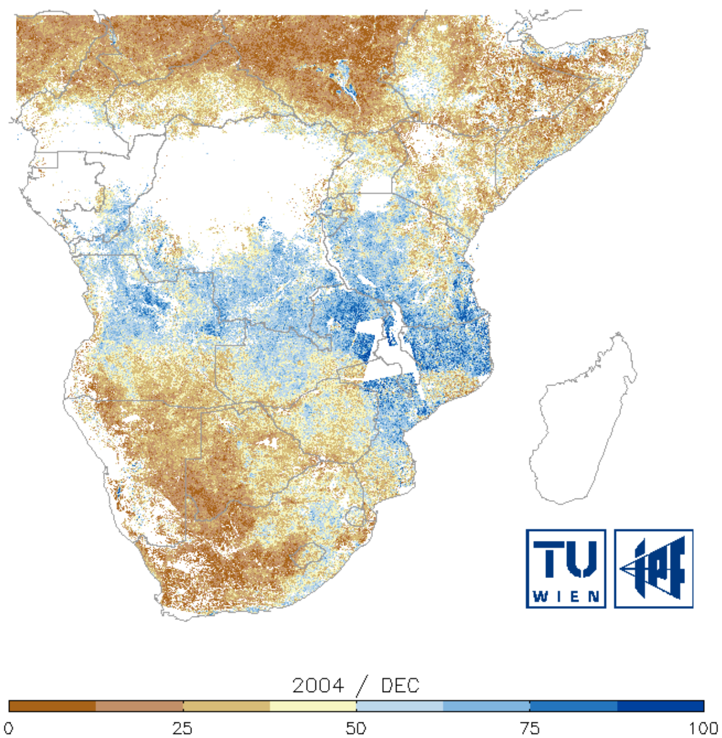


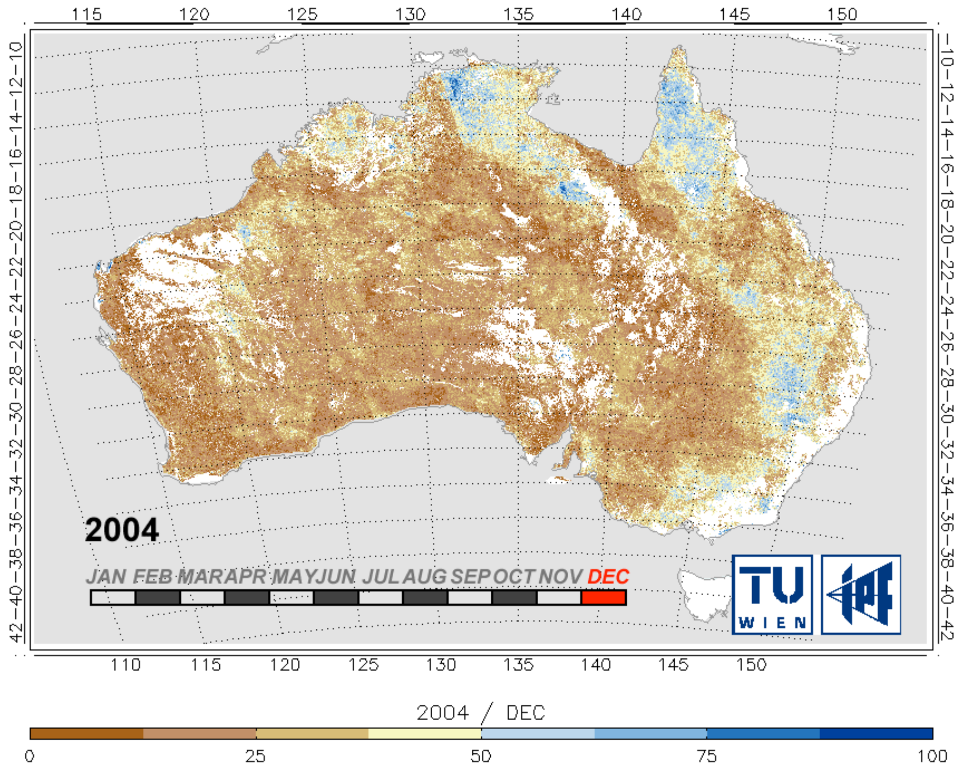
Envisat ASAR Surface Soil Moisture

- **Potential for operational applications**
- **Updated monthly**
- **Data available by user request**
- **Time range: Dec. 2004 – present**
- **Spatial resolution: 1 km**
- **Radiometric quality: 3-5 classes of soil moisture**
- **Temporal resolution:**
  - **Australia: ~8 samples/month**
  - **Africa: 3-7 samples/month**



Envisat ASAR Surface Soil Moisture





Calibration Issues

Influence of ASAR Data Quality on Soil Moisture

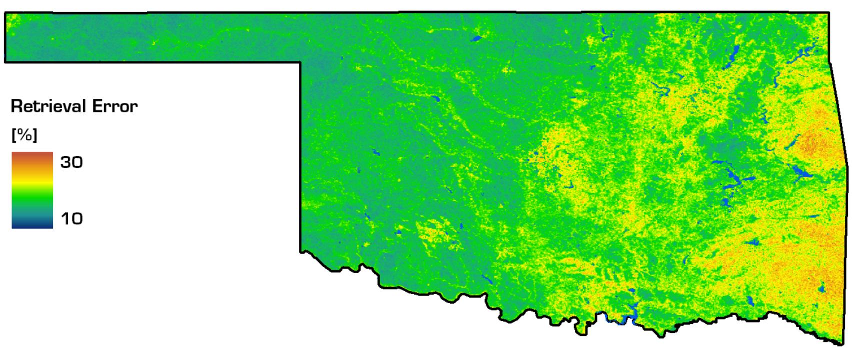
- Since some of the ASAR soil moisture parameters are scatterometer-based, the quality of ASAR soil moisture depends on both scatterometer and SAR calibration
- Absolute calibration not the biggest concern, since change detection is used
- Relative calibration on the other hand is of crucial importance. We need:
  - Good stability of σ^0 from each individual instrument
  - Accurate calibration between SARs / scatterometers / scatterometer generations: ERS-1/2 → ASCAT A/B/C

Influence of ASAR Data Quality on Soil Moisture

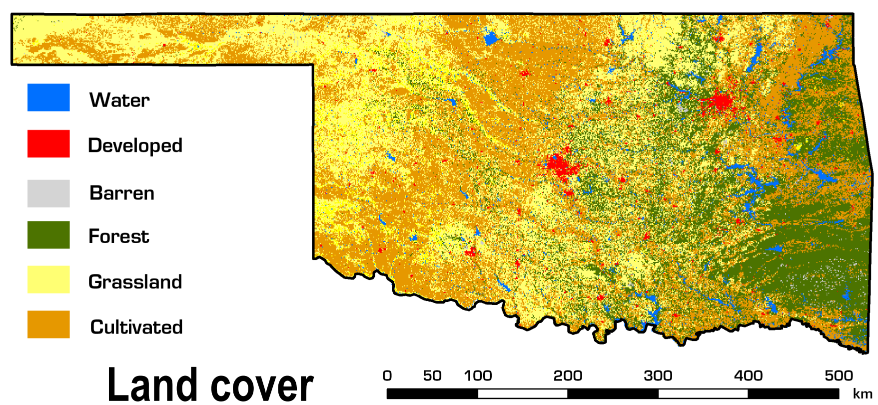
- **ASAR Soil Moisture error budget: which of the parameters has the largest influence on soil moisture?**
  - **Gaussian error propagation**

$$\Delta m_s = \sqrt{\left(\frac{\partial f}{\partial \sigma^0}\Delta\sigma^0\right)^2 + \left(\frac{\partial f}{\partial \beta}\Delta\beta\right)^2 + \left(\frac{\partial f}{\partial \sigma^0_{dry}}\Delta\sigma^0_{dry}\right)^2 + \left(\frac{\partial f}{\partial \sigma^0_{wet}}\Delta\sigma^0_{wet}\right)^2}$$

  - **The radiometric accuracy of ASAR GM data is identified as the main error source in the retrieval (~1.2 dB for ASAR vs. ~0.3 dB for the ERS Scatterometer)**



Retrieval error (%)



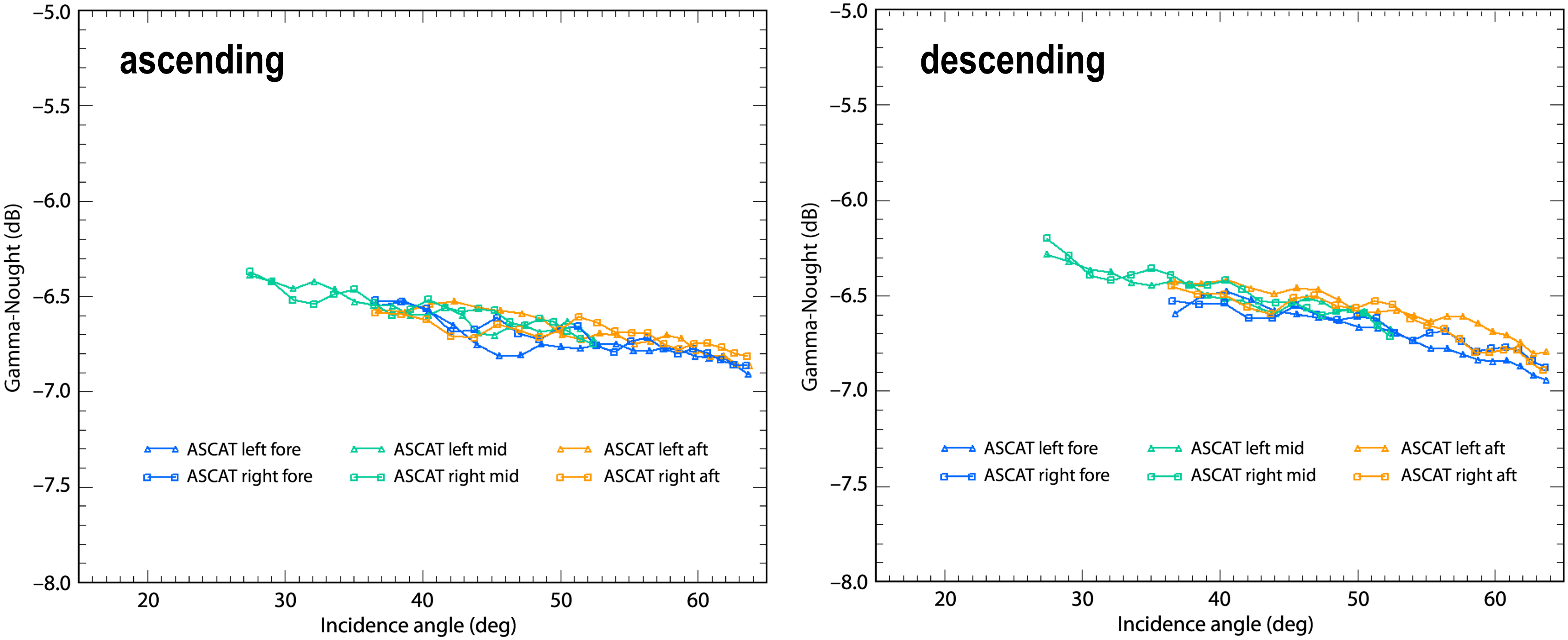
Land cover

Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

Absolute Calibration — Tropical Forests

- **ASCAT backscatter behaviour over the Amazon tropical forests satisfactorily consistent, but g^0 not as constant as expected**

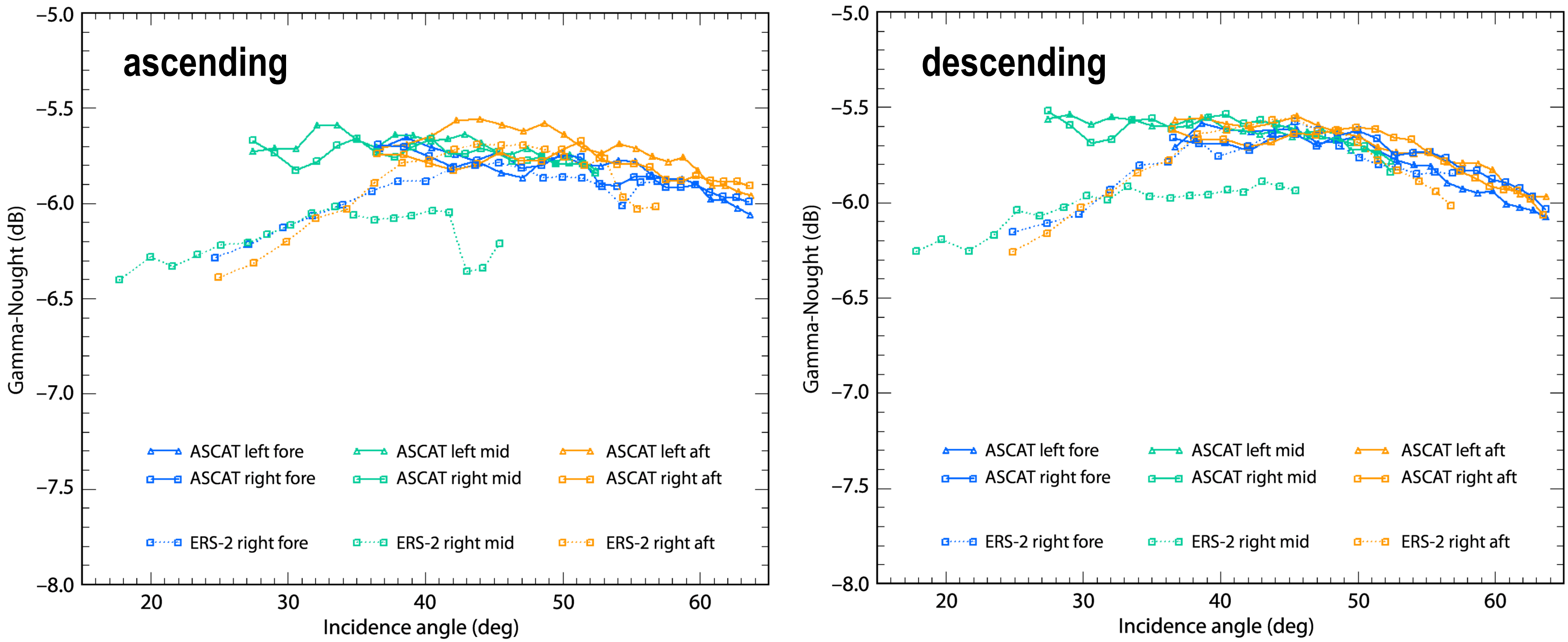
Node-wise average g^0 values for 2007–2008



Absolute Calibration — Tropical Forests

- **Borneo site: higher ASCAT g^0 values than for Amazon**
- **ERS-2 g^0 lower than ASCAT g^0**

Node-wise average g^0 values for 2007–2008

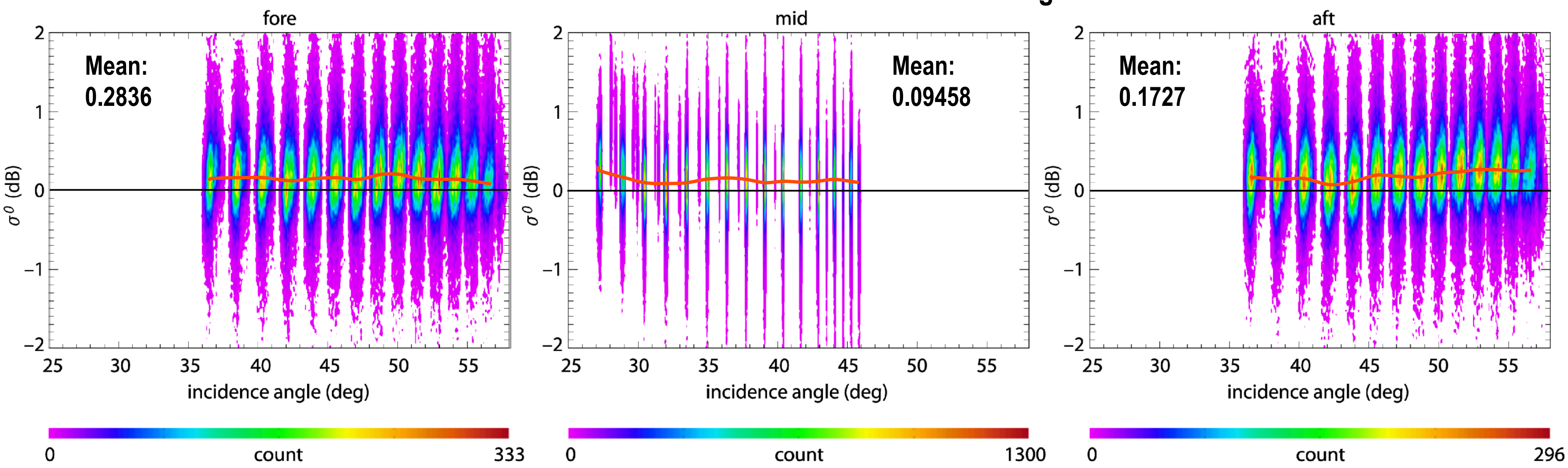


Relative Calibration — Scatterometer s⁰ collocation

- **ASCAT – ERS-2 s⁰ collocation study for 2007–2008**
- **Strict collocation conditions**
  - distance between pairs: max 12.5 km
  - difference in incidence angle: max 1°
  - difference in azimuth angle: max 5°
  - difference in time: max 6 hours (in practice, ASCAT approx. 1 hour earlier than ERS-2 for all collocated pairs)

3-beam mean: 0.18363

Collocated s⁰ differences vs. incidence angle



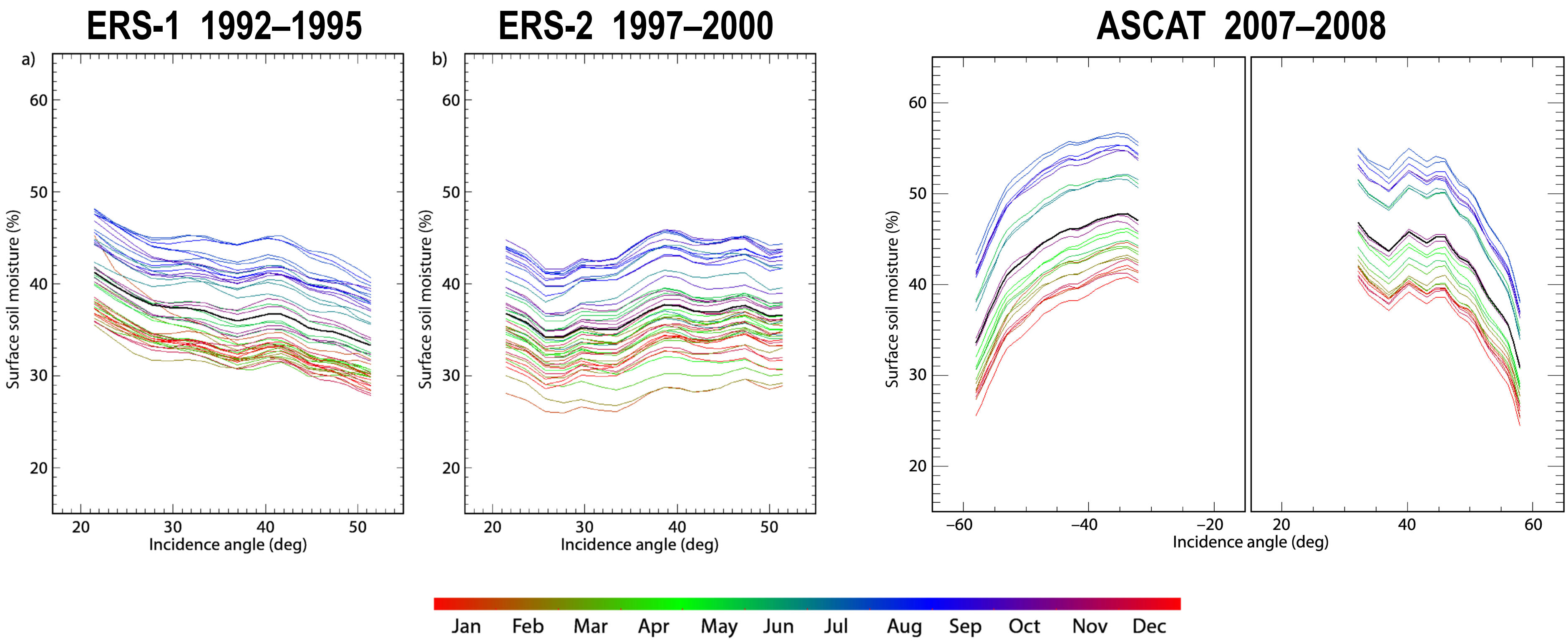
Institute of Photogrammetry and Remote Sensing
Vienna University of Technology

Relative Calibration — Soil Moisture vs. Incidence Angle

- **To account for the ASCAT–ERS s^{0} cross-calibration, we can also investigate the soil moisture vs. incidence angle behaviour for both ERS- and ASCAT-based soil moisture**
- **If computed for both instruments using the long-term scattering parameters from ERS only, it will reveal differences in calibration between the instruments**
- **Irrespective of instrument, the scattering parameters database indicates that a bias of 0.2 dB in s^{0} for each scatterometer beam results in a global soil moisture change of 5-6% (percentage points)**

Relative Calibration — Soil Moisture vs. Incidence Angle

- **Long-term soil moisture vs. incidence angle for all three scatterometers**



Conclusions & Outlook

Conclusions and Outlook

- SAR systems have traditionally focused on
  - high spatial resolution
  - multiple polarisation and mode capabilities
- At the same time, SAR systems have relatively long revisit times
- Many studies focus on image analysis using multiple polarisations and/or frequencies with only a few SAR scenes
- There is a need for operational high-resolution soil moisture products, but:
- to do retrieval with SAR instruments based on time-series analysis knowledge acquired through work with scatterometers, there is a need to:
  - improve the temporal resolution
  - decrease radiometric noise
- Relative calibration is also very important:
  - Continuity between Envisat ASAR and Sentinel-1 SAR instruments
  - Continuity between ERS Scatterometers and Metop ASCAT

Thank you for your attention!

Microwave Remote Sensing Team
Institute of Photogrammetry and Remote Sensing
Vienna University of Technology