Retrieving soil moisture information from satellite radar altimetry backscatter

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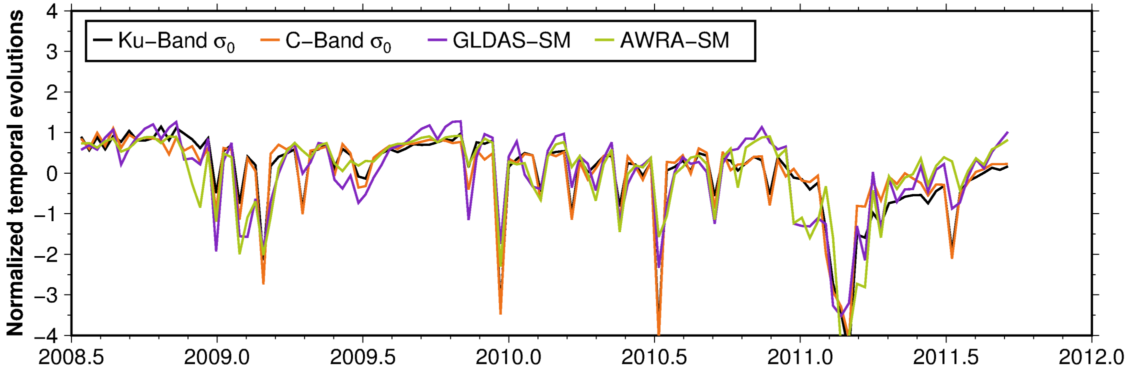
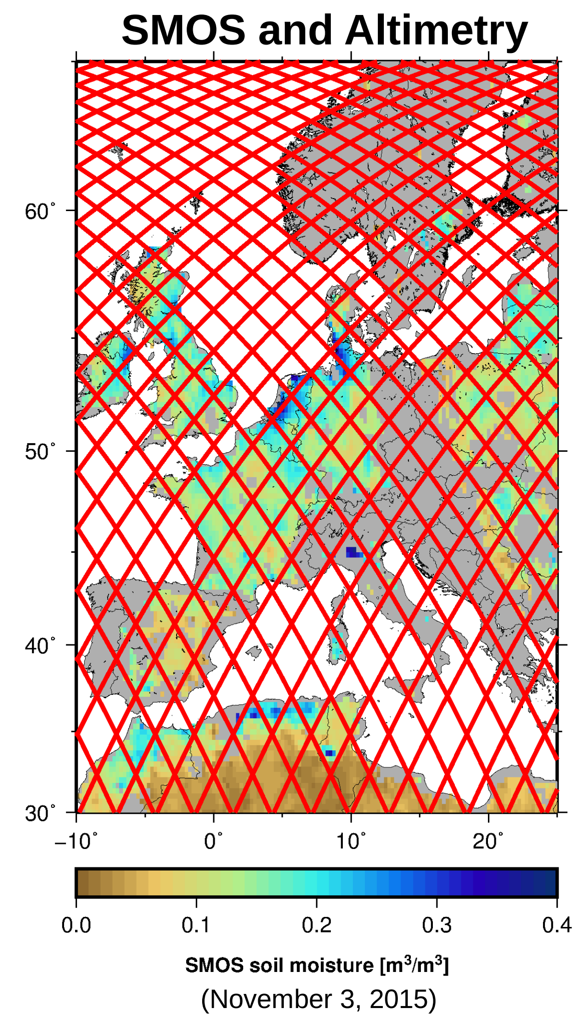
Motivation

Soil Moisture (SM) from Satellite Altimetry

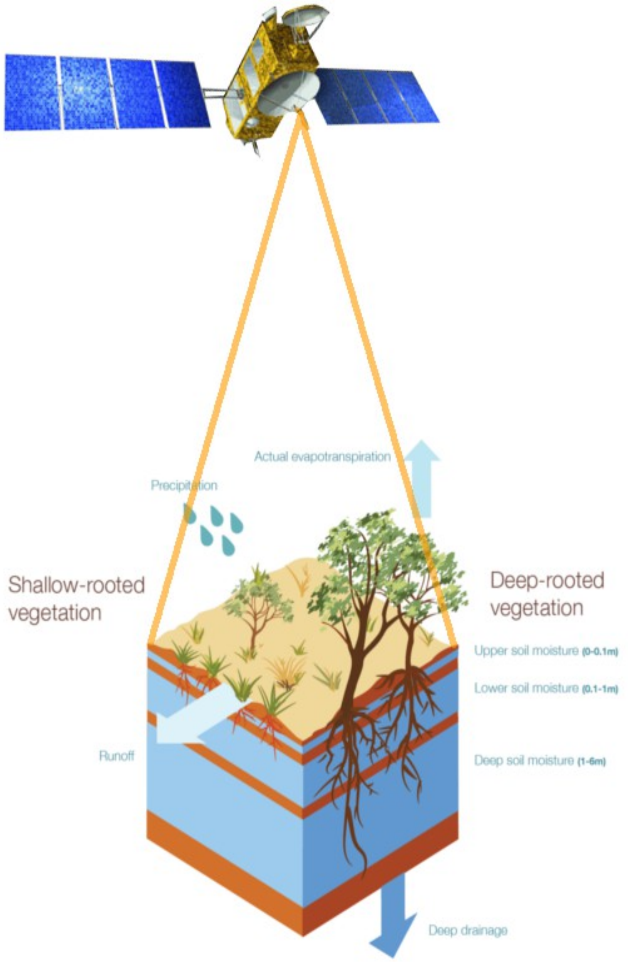
- Independent dataset
  - Extend already available data basis
- High along-track resolution
- Nadir-looking instrument
  - Less influence from canopy
- Idea: Prior information from models can be used to constrain backscatter and convert it to surface soil moisture





Overview

- Data
- Backscatter σ_0
- Inversion Framework
- Results
  - Western Australia, Australia
  - Ruhr-Erft Region, Germany
- Summary and Conclusion



Modified from http://www.bom.gov.au

Data

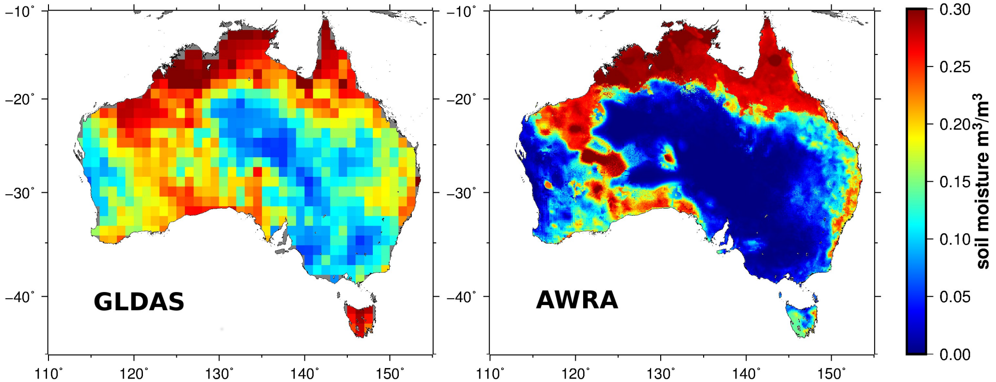
Altimetry, SMOS and Model Data

- Jason-2 and Envisat altimetry backscatter σ_0
  - 10 day Jason-2 and 35 day Envisat repeat orbit (~300m along track)
- Australian Water Resource Assessment (AWRA)
  - Daily 5km resolution fields
- Global Land Data Assimilation System (GLDAS-Noah)
  - 3 hourly 100km resolution fields
- Daily Soil Moisture and Ocean Salinity (SMOS) L3 products
  - 3 day repeat orbit, 25km

Luigi Renzullo (CSIRO)
Albert I.J.M. van Dijk (ANU)

Goddard Earth Sciences Data and Information Services Center

www.smos-bec.icm.csic.es



Backscatter

Land-surface Features

- Backscatter: $$\sigma_0 = s + q + \Delta_{atm}$$

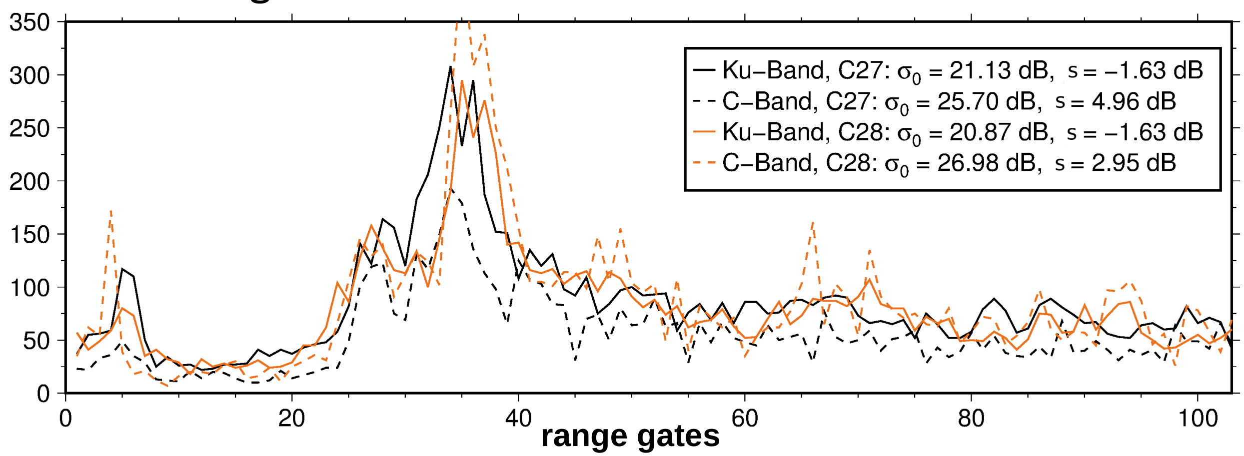
  with scaling factor s, retracking correction q, atmospheric correction Δ_{atm}

- Retracking correction: $$q = 10\log_{10}(Pu) \quad Pu = \sqrt{\frac{\sum_{i=1}^{N} P_i^4(t)}{\sum_{i=1}^{N} P_i^2(t)}}$$

  → Peaks resulting from off-nadir surface waters disturb the land-surface backscatter signal

- Assumption: Between two cycles, changes in backscatter at a certain location are mainly driven by soil moisture changes

  → use differences between successive cycles instead of absolute values (same for model data)

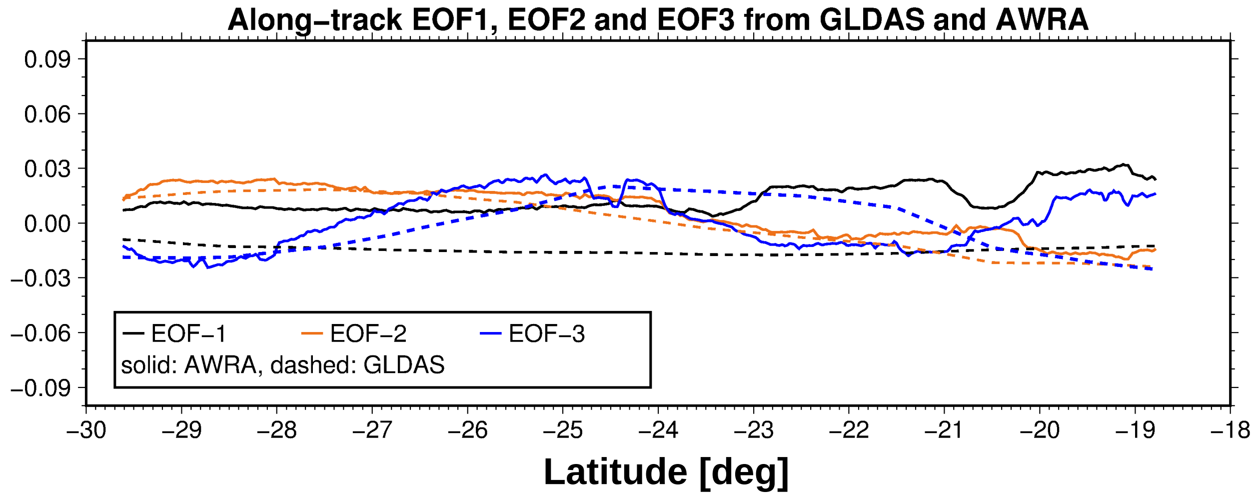


Inversion Framework

Principal Component Analysis (PCA)

- Spatial and temporal interpolation of model data onto the altimeter ground track and to the epochs of the satellite crossing the study areas
- The spatio-temporal variability of a data matrix $\mathbf{X}(t, s)$ can be decomposed into normalized principal components $\bar{\mathbf{P}}(t)$ and empirical orthogonal functions $\bar{\mathbf{E}}^T(s)$ using PCA

$$\mathbf{X}(t, s) = \bar{\mathbf{P}}(t)\, \mathbf{\Lambda}\, \bar{\mathbf{E}}^T(s)$$



Inversion Framework

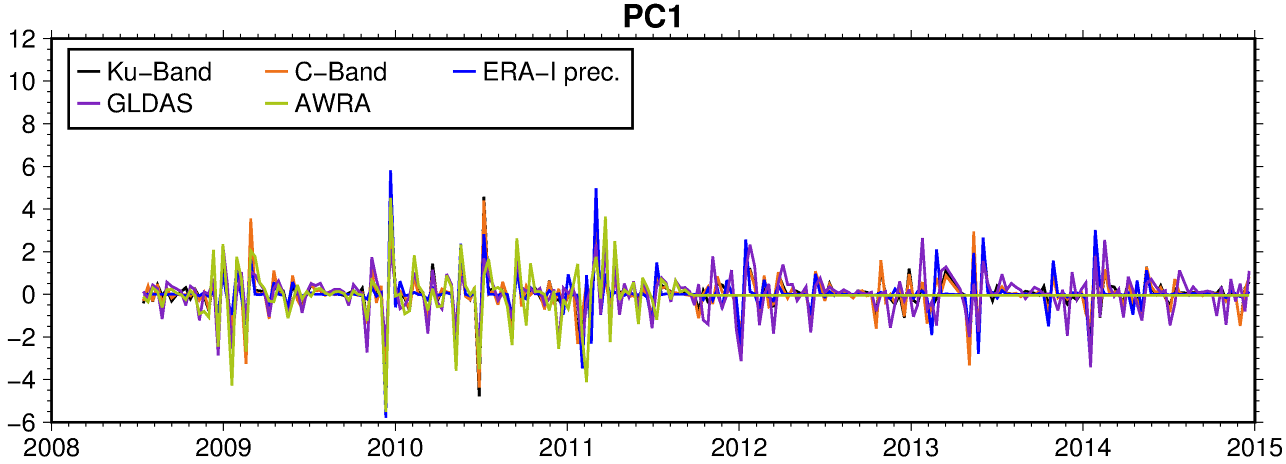
Estimation of Soil Moisture

- Modes from model data $\bar{\mathbf{E}}_{\mathrm{sm}}^{T}(s)$ are used as base functions to estimate the temporal variability $\hat{\bar{\mathrm{P}}}(t)$ by fitting to backscatter σ_0

$$\hat{\bar{\mathbf{P}}}(t) = \boldsymbol{\Lambda}_{\sigma_0}^{-1} \left[\bar{\mathbf{E}}_{\mathrm{sm}}^{T}(s)\ \bar{\mathbf{E}}_{\mathrm{sm}}(s)\right]^{-1}\ \bar{\mathbf{E}}_{\mathrm{sm}}^{T}(s)\ \sigma_0(t,s)$$

- Utilize estimated principal components to compute Altimetry Reconstructed Soil Moisture (ARSM, $\mathbf{X}(t,s)$)

$$\hat{\mathbf{X}}_{sm}(t,s) = \hat{\bar{\mathbf{P}}}(t)\ \boldsymbol{\Lambda}_{\mathrm{sm}}\ \bar{\mathbf{E}}_{\mathrm{sm}}^{T}(s)$$



Jason-2 Ku- and C-Band perform similar

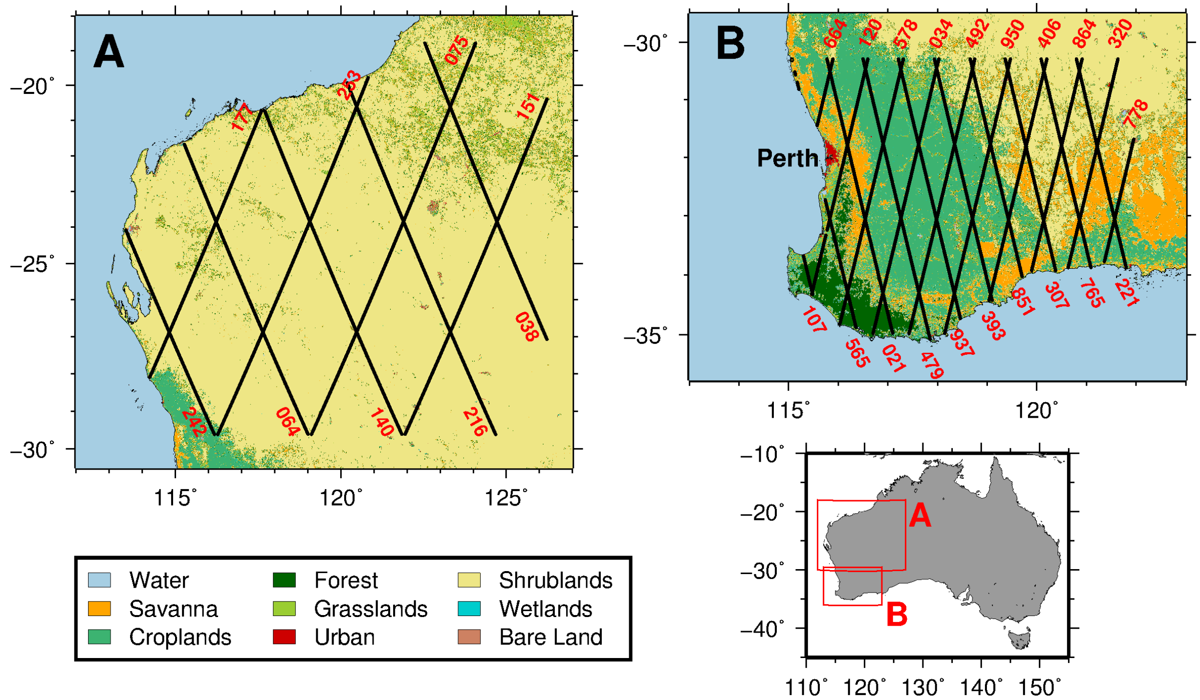
→ only consider Jason-2 C-Band in the following

Results

Study Site: Western Australia

- Arid, semi-arid climate
  - North: mostly shrublands and graslands, little human influence
  - South: lots of agricultural land use, human influence (irrigation)

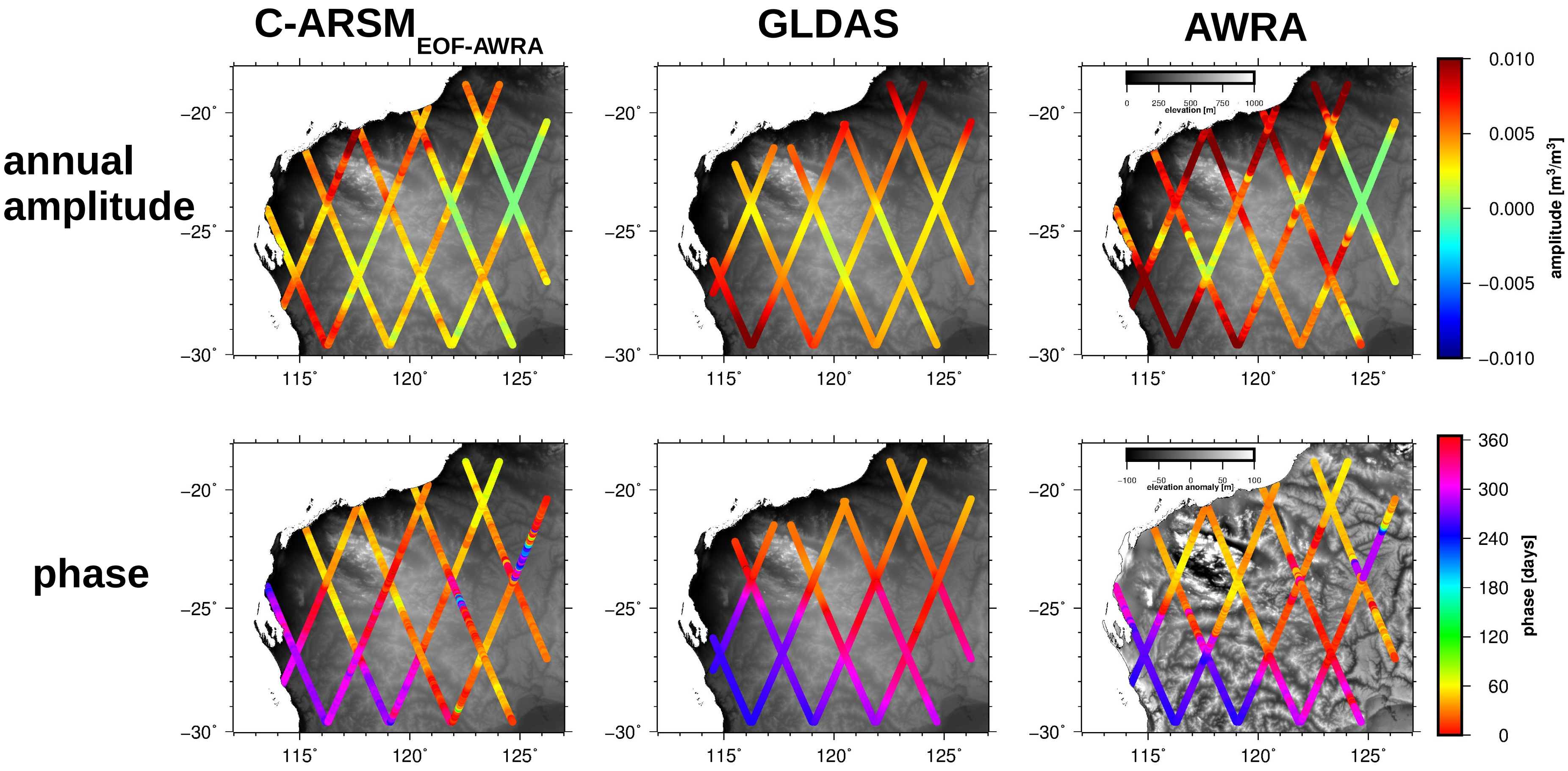
Jason-2



Envisat

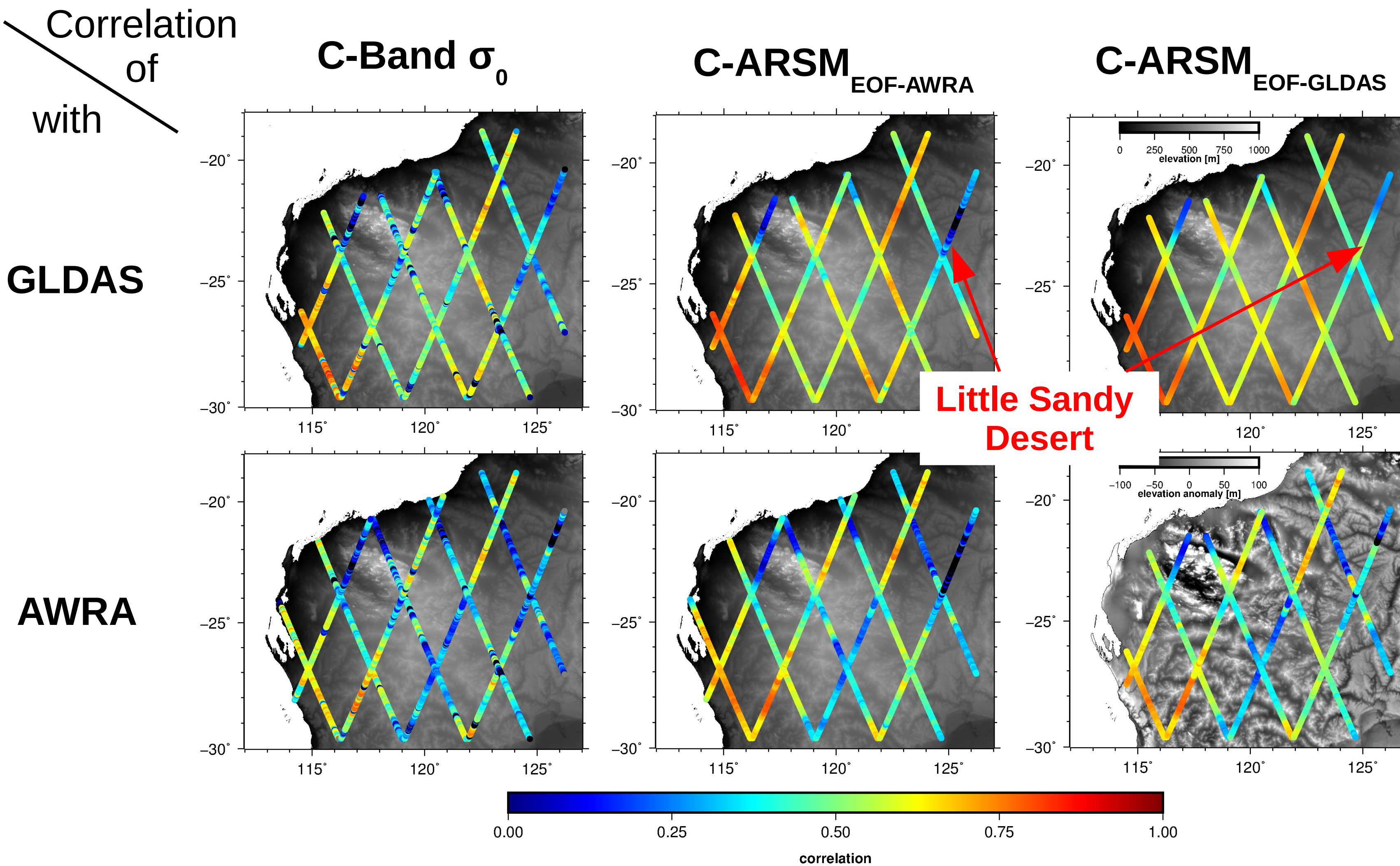
Results

Consistency with Model Data



Results

Soil Moisture from Jason-2 (C-Band)



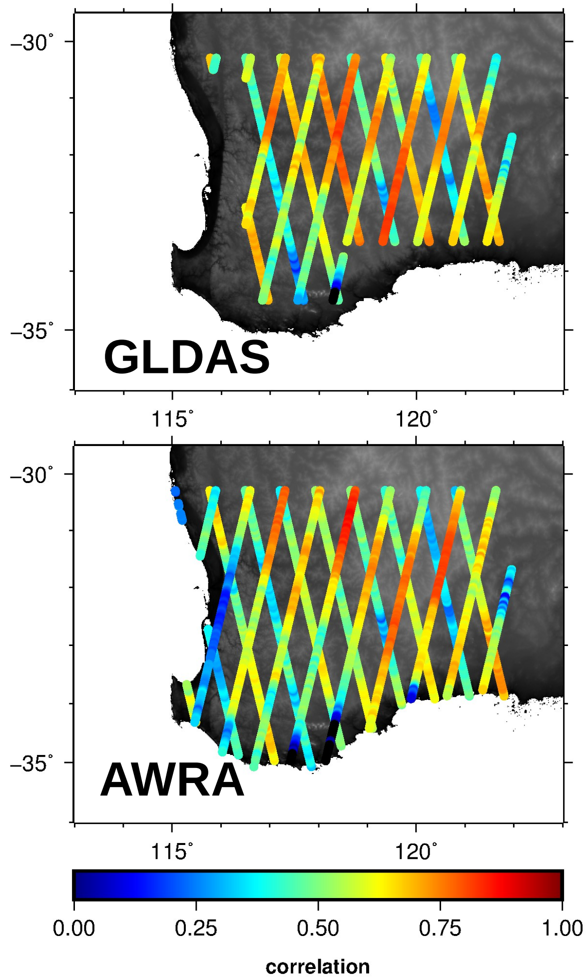
Results

Soil Moisture from Envisat (Ku-Band)

- Weak dependence of ARSM on the utilized model EOFs
  - Results using $ARSM_{EOF\text{-}AWRA}$ tend to agree better with GLDAS model data
- For Envisat, the correlation of descending tracks ( ) show better agreement compared to ascending tracks ( )
  - Near perfect 35-day repeat orbit leads to approximately the same local time for each latitude
    - 1am – 2am descending
    - 2pm – 3pm ascending

  → more stable conditions during the night

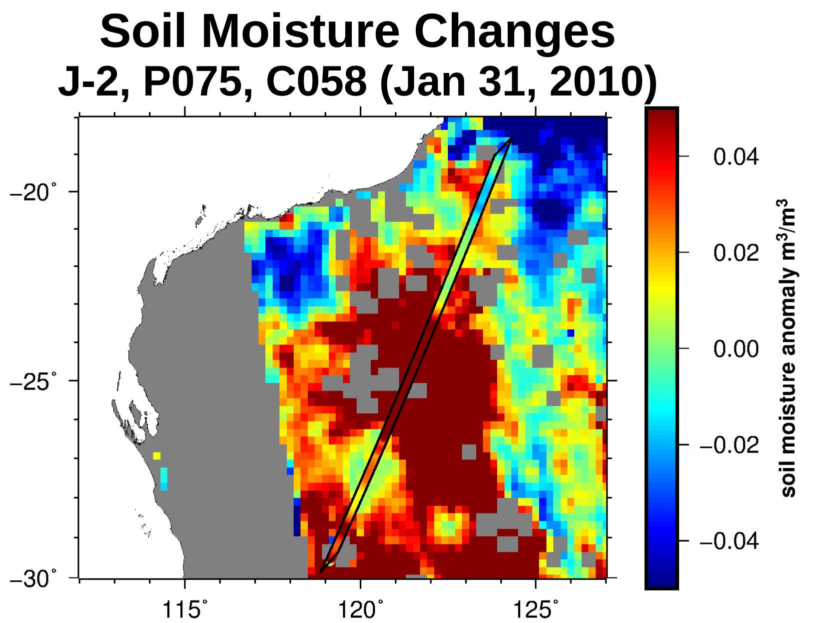
Correlation of
$Ku\text{-}ARSM_{EOF\text{-}AWRA}$

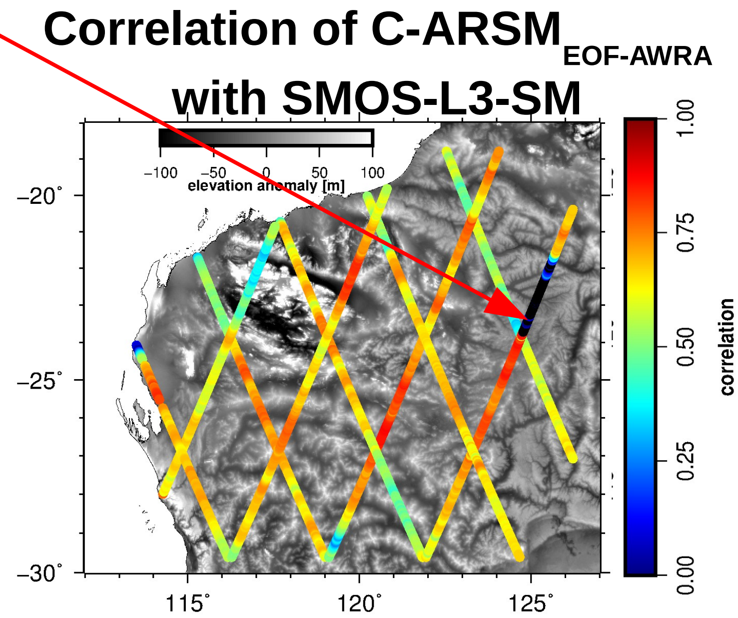


Results

Comparison to SMOS L3 SM Products

- Jason-2 ARSM and SMOS-L3-SM agree well for individual dates, as well as in overall correlation
  - Less agreement over regions with rapidly changing topography
  - Disagreement over Little Sandy Desert likely due to the limitation of AWRA

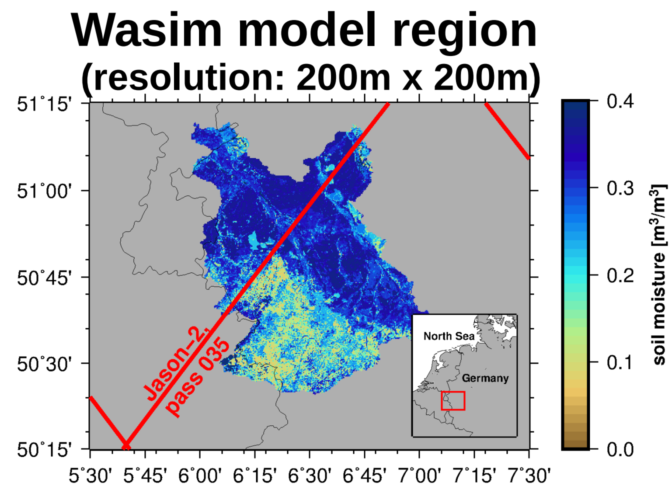


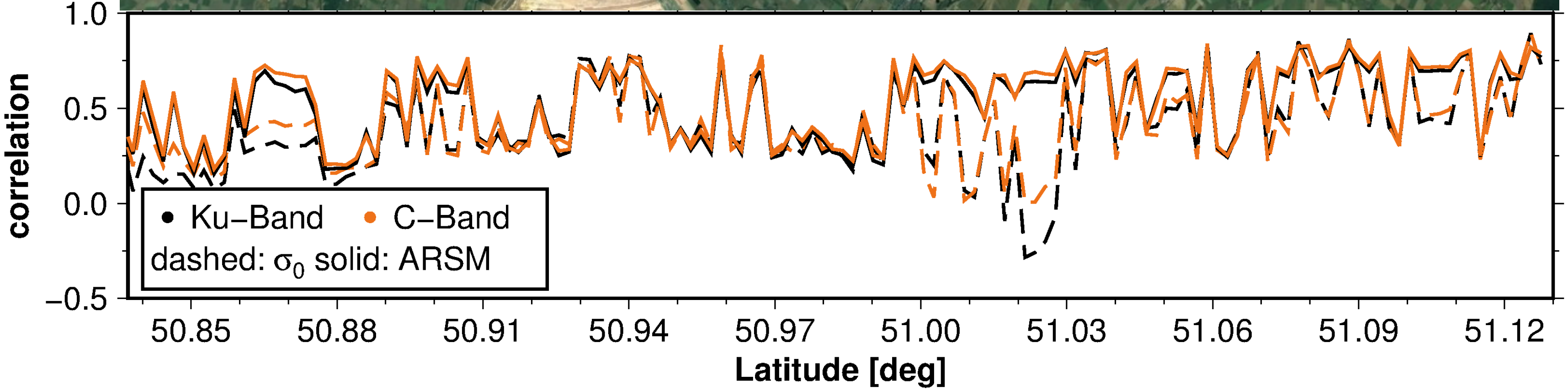


Results

Transfer to Western Germany

- Correlations of 0.7 – 0.8 with high resolution model data (Wasim) (Carsten Montzka, FZ-Jülich)
  - Influence from seasonal effects (snow) ?
  - Human influence (cities, mining)





Summary and Conclusion

- Satellite altimetry backscatter can provide high resolution along-track information on surface features, especially soil moisture
- The presented inversion scheme utilizes prior information on the spatial variability derived from model data to estimate the temporal variability from the altimetry backscatter
  - Relatively weak dependence on chosen model data
  - Possibility to combine with global low resolution model data (GLDAS), as well as regional high resolution data
  - Results agree well with independently measured SM from SMOS L3 data
- Outlook:
  - Include prior information on canopy variability to improve the separation of the soil moisture signal from the total backscatter
  - Investigate spatial bounds of the along-track PCA