United Nations/Latvia Workshop on the Applications of Global Navigation Satellite Systems, Riga, Latvia (May 14-19, 2012)

GNSS Positioning in Support of Surface Soil Moisture Retrieval and Flood Delineation in Near Real Time

Michael Hornáček[1,2], Wolfgang Wagner[1], Daniel Sabel[1]

Vienna University of Technology
[1]Institute of Photogrammetry and Remote Sensing
[2]Institute of Software Technology and Interactive Systems

michael.hornacek@tuwien.ac.at
www.ipf.tuwien.ac.at/radar

Outline

- **Context: Climate Change and Water**

- **Gentle Look at Remote Sensing of Water Using Spaceborne Active C-band Radar Instruments**
- **Surface Soil Moisture Retrieval and Flood Delineation at TU Wien**

- **Forthcoming Sentinel-1 Constellation**
- **GNSS and Near Real Time Timeliness, Data Volume Handling**
- **Outlook: GNSS for Crowdsourced Flood Map Augmentation**

Climate Change and Water (IPCC Techn. Paper)

- "Changes in [freshwater] quantity and quality due to climate change are expected to affect food availability, stability, access and utilisation"
- "Climate model simulations for the 21st century are consistent in projecting precipitation increases in high latitudes […] and decreases in some sub-tropical and lower mid-latitude regions"

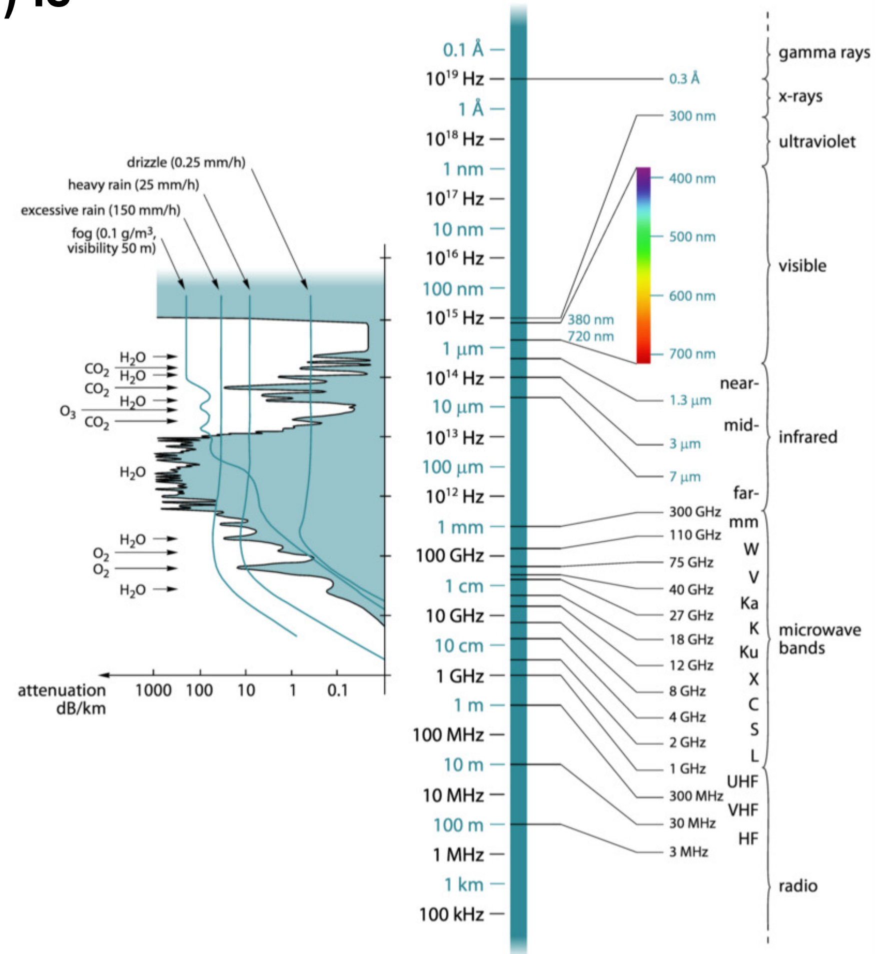
- "Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions"
- "Several gaps in knowledge exist in terms of observations and research needs related to climate change and water"

Active Microwave Remote Sensing at C-band

Backscatter from active microwave instruments operating at C-band (e.g., ENVISAT ASAR, MetOp ASCAT, Sentinel-1) is

- **effectively invariant to weather conditions or the presence of incident sunlight**
- **to some extent able to penetrate vegetation; penetrates soil to ca. 2 cm**

- **sensitive to the dielectric contrast between wet and dry soil**
- **subject to specular effects over smooth water**



Surface Soil Moisture

- Key parameter in global water, energy and carbon cycles
- Ranges from so-called wilting point to saturation of the soil's pores

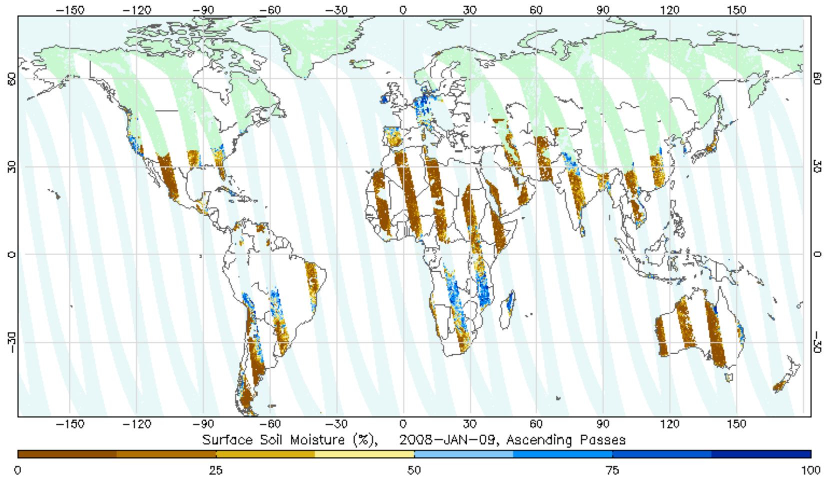
- Can be measured accurately at point scale using *in situ* techniques; however, few *in situ* networks exist worldwide, cross-calibration issues between networks, etc.
- Alternatively, can be measured at a variety of spatial and temporal scales using remote sensing techniques

- Applications include numerical weather prediction, climate monitoring and flood forecasting

Surface Soil Moisture via TU Wien Method

- **Technique originally developed for ERS scatterometer (50 km res.)**
- **Later adapted to MetOp ASCAT (25 km res.); distributed operationally in near real time (NRT) within 130 minutes of acquisition**
- **Third adaptation to ENVISAT ASAR (1 km res.)**

- **For ERS and ASCAT, precise geocoding non-issue; with ASAR, geocoding via computationally expensive Range-Doppler with support of DORIS orbit files**



ASCAT surface soil moisture NRT daily composite (showing ascending passes only)

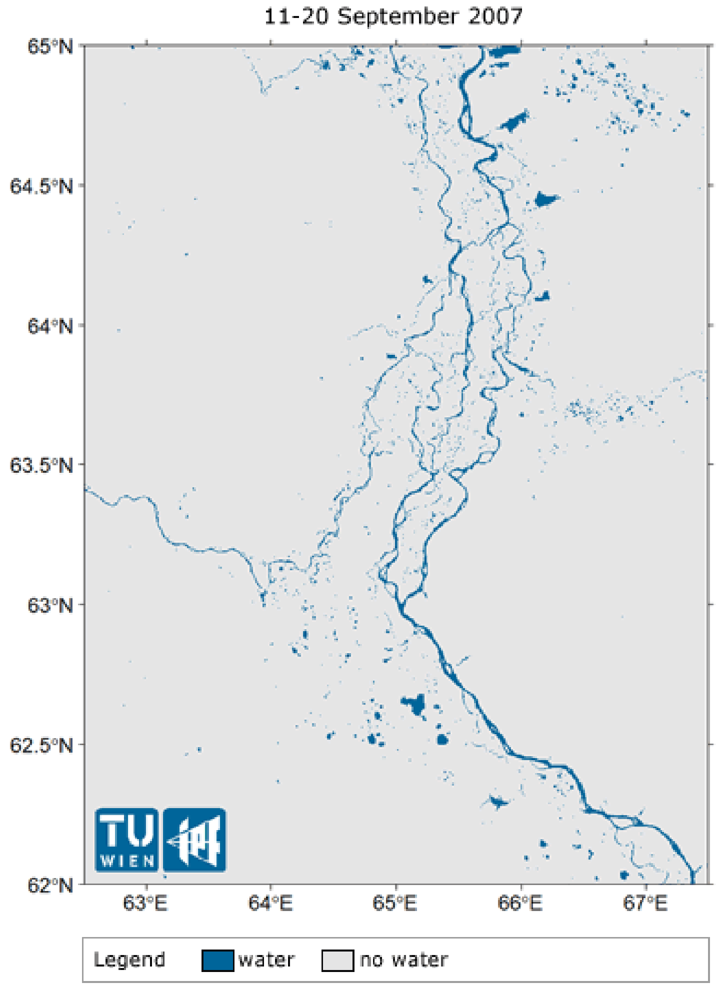
Flood Delineation

- **Variety of (semi-)automatic techniques, including thresholding, change detection, probabilistic approaches, etc.**

- **Useful in support of damage mitigation and assessment**
- **In conjunction with adequate terrain model, can be used for derivation of water level**
- **More recently, has been used for calibration of hydraulic models in support of flood hazard estimation**

Flood Delineation on the Ob River

- **ESA-funded ALANIS project: monitoring of floodplains and wetlands in northern Eurasia**
- **Extent of open water surfaces is critical for modeling methane emissions from high latitude**
- **ENVISAT ASAR Wide Swath (WS) mode data used for 10-day composites of flood extent**



Ob river inundation
(cf. http://www.esa.int/esaEO/SEM1MGRRJHG_index_0.html)

User Wish List (Non-Exhaustive)

SSM

- **High spatial (1 km and finer) and temporal resolution**
- **Ground penetration to at least 1 meter**
- **Product available as soon as possible from acquisition**

Flood Delineation

- **High spatial resolution (50 m and finer)**
- **Flood maps for floods as they occur**

Sentinel-1 Constellation

Forthcoming Sentinel-1 constellation expected to come closest so far to satisfying wishes of user community for large-scale operational applications

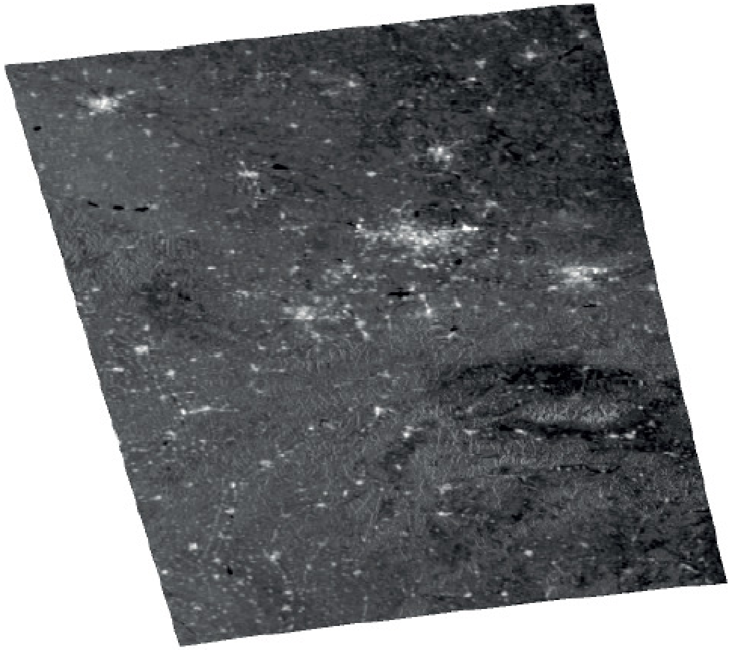
- **C-band SAR (center frequency of 5.405 GHz)**
- **Coverage over land global ca. every 6 days, nearly daily over Europe and Canada**
- **Operational concept supports possibility of NRT (up to 3 hours from acquisition)**
- **Exclusive (non-conflicting) acquisition mode over land in the baseline**

Near Real Time (NRT) Processing for Sentinel-1

- **NRT in direct downlink: within 15 min (in support of emergency services)**
- **NRT in general: within 3 hrs**

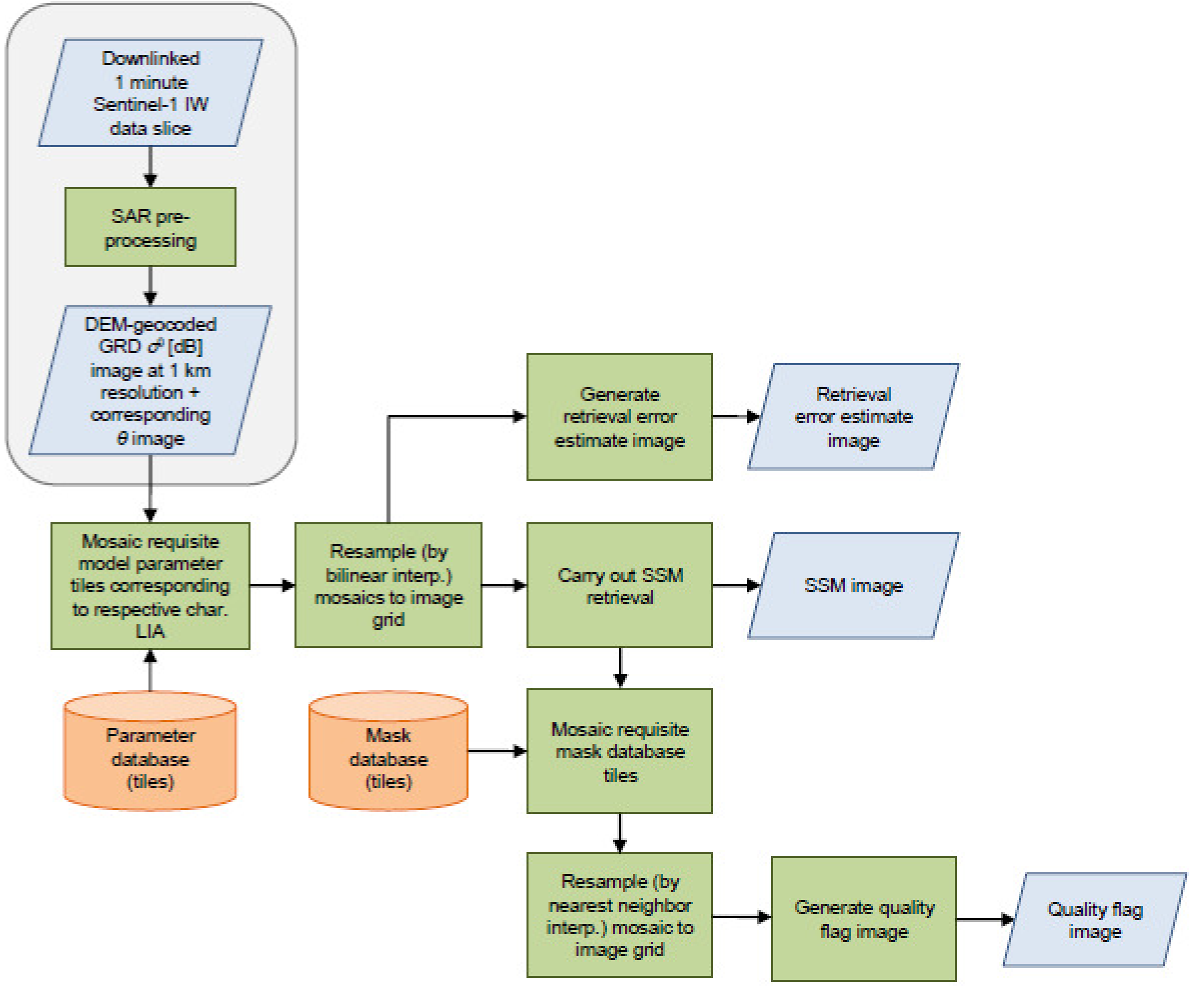
- **Data provided in partially overlapping slices of configurable length; expected to be 1 min → amounts to ca. 408 km in the along track, 250 km in the across track**

- **But: Sentinel-1 Precise Orbit Determination center generates orbit state vectors (10 cm 3D accuracy within 3 hours, 5 cm within 3 weeks) using onboard GPS data downlinked once per orbit**

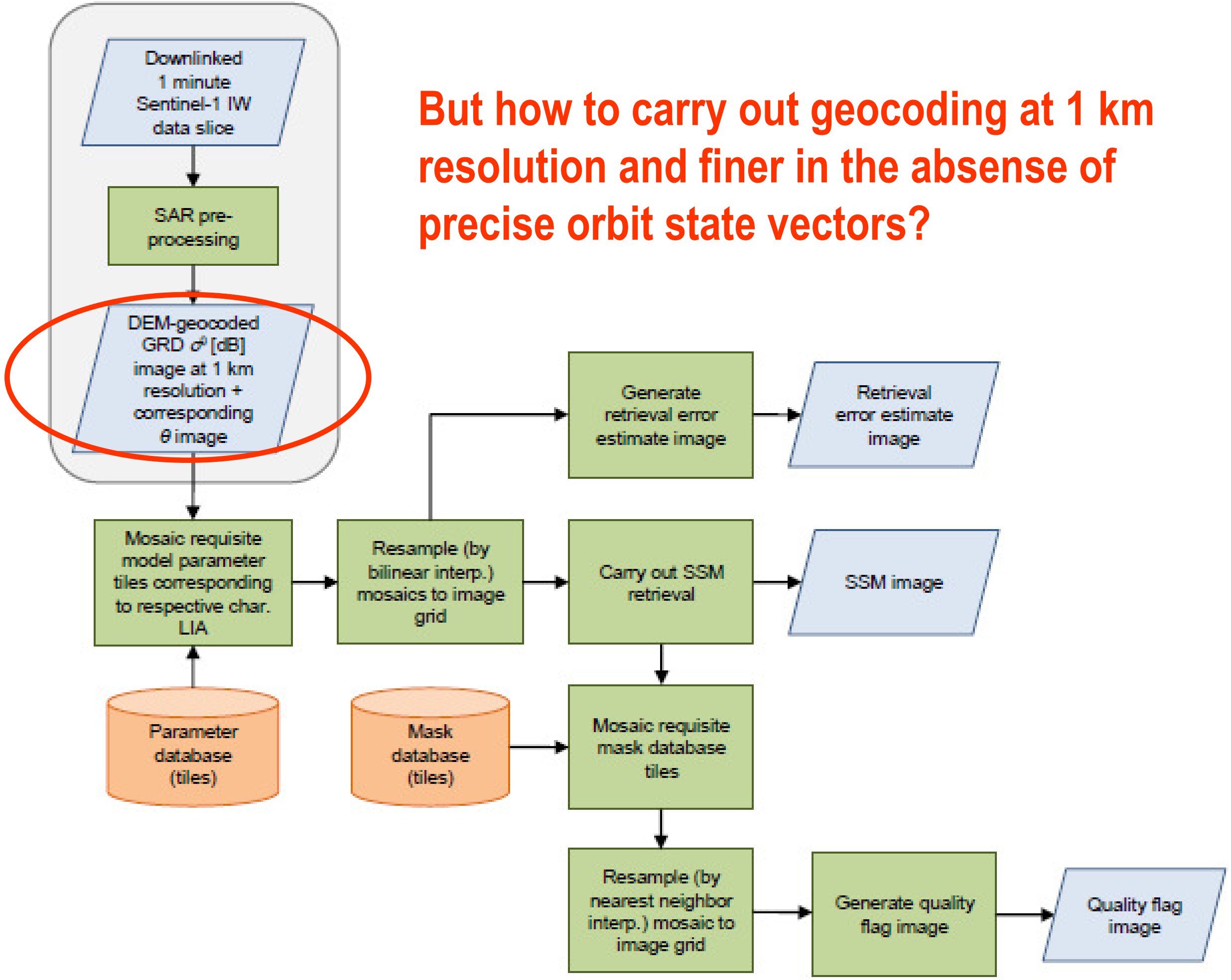


Simulated 1 minute DEM-geocoded Sentinel-1 IW mode GRD slice at 1 km resolution over central Europe, provided in plate carrée projection

Foreseen NRT SSM Processing Chain



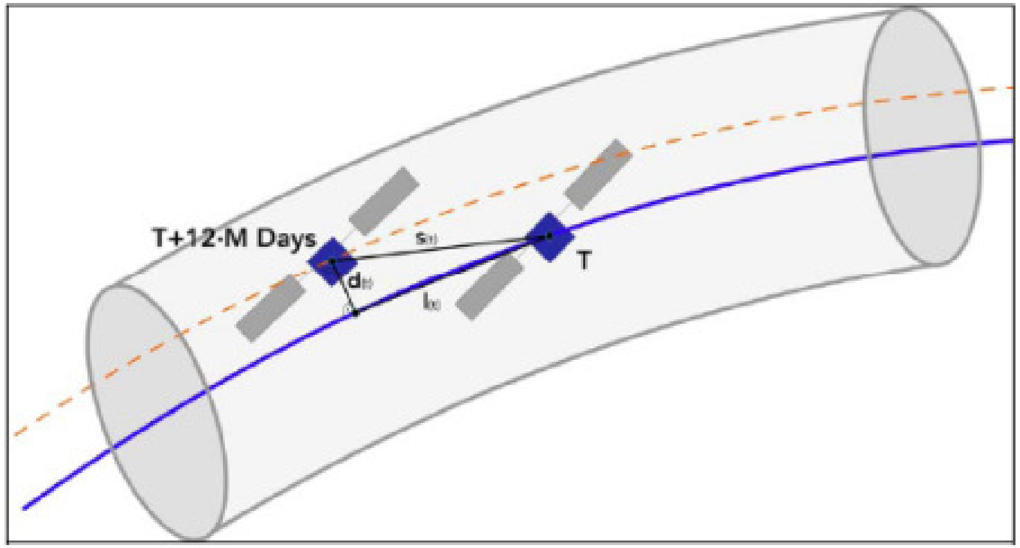
Foreseen NRT SSM Processing Chain



But how to carry out geocoding at 1 km resolution and finer in the absense of precise orbit state vectors?

GPS-driven Reference Orbit Stability

Reference orbit of both satellites to be maintained within the same Earth-fixed orbital tube radius of 50 meter-rms along grid of predefined orbit tie points, achieved with support of GPS positioning



LUT Geocoding for NRT Processing

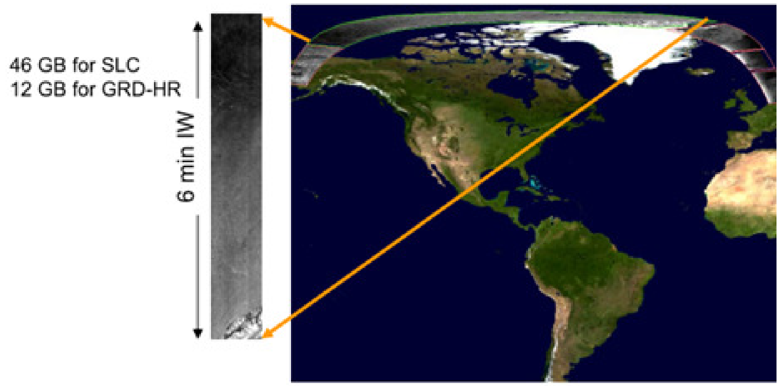
- Approximate orbit state vectors can be predicted owing to the stability of the acquisition geometry
- Renders fast lookup table (LUT) geocoding possible in support of NRT applications

- In non-NRT, latest available revised orbit state vectors can be used for refined Level 2 product generation

Data Volumes

- **Data volumes for only Level 0 data across all acquisition regions for a single Sentinel-1 satellite expected to reach ca. 320 TB per annum, amounting to ca. 2.3 PB in the course of the mission's nominal lifetime**
- **Total Level 1 data volumes for baseline products expected to be 4-5 times larger than for Level 0**

- **Data volumes such that only Level 0 raw data is to be stored**
- **LUT geocoding concept renders fast on-the-fly processing of Level-0 raw data up to Level 1/2 possible—in case of need—for supporting datasets in NRT, using latest available orbit state vectors**



Outlook to Crowdsourcing for Flood Mapping

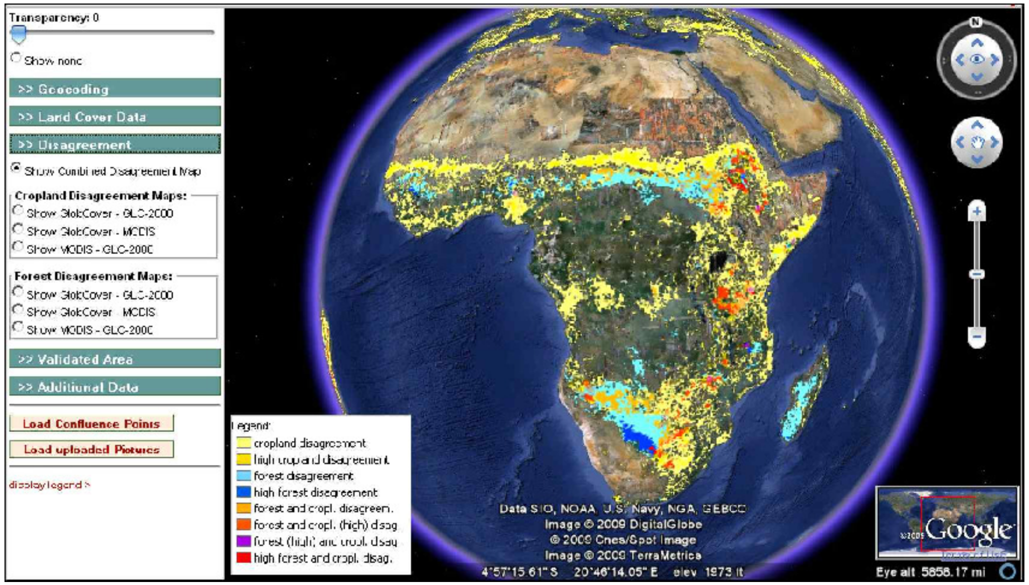
- Automatic flood maps not perfect in general
- Crowdsourcing provides outlook to correction/augmentation of NRT flood maps via user interaction on, e.g., tablet computers
- User can modify flood map (e.g., as cubic spline curve) to take into account what is seen on the ground

- Corrected NRT flood maps can be made available online, following a collaborative wiki-like philosophy

Calls for adequately accurate positioning of the user!

Geospatial Crowdsourcing Today: Geo-Wiki.org

- **Voluntary global land cover validation tool, built on top of Google Earth**
- **Inputs: land cover data sets (GLC-2000, MODIS and GlobCover) and supporting photographic data sets (Degrees of Confluence project, user uploaded photographs with geolocation annotations)**
- **Notion of disagreement analysis**



Conclusion

- **Sentinel-1 reference orbit stability rendered possible using regular GPS positioning, which in turn renders possible predictable LUT geocoding in support of NRT applications**
- **LUT geocoding used in support of handling data volumes in the Sentinel-1 baseline; makes supporting data sets available in support of NRT applications**
- **Crowdsourcing for correction/augmentation of flood maps a potential collaborative GNSS application**

Further Reading

- **M. Hornáček *et al.*, "Potential for High Resolution Systematic Global Surface Soil Moisture Retrieval via Change Detection Using Sentinel-1," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 2012.**
- **Y. H. Kerr *et al.*, "Soil Moisture Retrieval from Space: the Soil Moisture and Ocean Salinity (SMOS) Mission," *IEEE Transactions on Geoscience and Remote Sensing*, 2001.**

- **A. Bartsch *et al.*, "Detection of Open Water Dynamics with ENVISAT ASAR in Support of Land Surface Modelling at High Latitudes," *Biogeosciences*, 2012.**
- **G. Schumann and G. Di Baldassarre, "The Direct use of Radar Satellites for Event-Specific Flood Risk Mapping," *Remote Sensing Letters,* 2010.**

- **R. Torres *et al.*, "GMES Sentinel-1 Mission," *Remote Sensing of Environment*, 2012.**
- **"GMES Space Component Sentinel-1 Payload Data Ground Segment Operations Concept Document," European Space Agency, Tech. Rep. GMES-GSEG-EOPG-TN-08-0012, 2009.**

- **S. Fritz *et al.*, "Geo-Wiki.org: The Use of Crowdsourcing to Improve Global Land Cover," *Remote Sensing*, 2009**

Thank you for your attention