Robust retrieval of soil moisture across wide-ranging incidence angles over short crops: for application to NASA-ISRO SAR

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Motivation

- 12 day revisit. ~10m resolution.
- Solid earth, cryosphere, ecosystem (biomass, inundation, crop classification)

- Global L-band surface soil moisture @ ~200m resolution, ~6 day repeat, ~ 0.06 m³/m³ unbiased rmse

  Aiming at field-scale soil moisture

https://nisar.jpl.nasa.gov/
Algorithm: soil moisture

- 200m or better resolution is needed
- Need to rigorously correct for vegetation effect (6 dB change in 8 days)
- Algorithm has to be vegetation specific

[McNairn et al. TGRS 2014; Kim et al. JSTAR 2015]

Blue is vegetation water content (50 t/ha for corn; 30 t/ha for wheat)
Inversion of physical scattering models [Kim et al. TGRS 2014]

- Full range of vegetation growth; generalized model
- NI-SAR biomass model: not physical but parameterized semi-empirical (Water Cloud Model)

\[
\sigma^{total} = \sigma^{surface}(\varepsilon, s, l)\exp\left(-2\tau_{pq}(VWC)\right) + \sigma^{volume}(VWC) + \sigma^{double}(VWC, \varepsilon, s, l)
\]

- \(\sigma^0\): input
- \(\varepsilon\): soil dielectric constant
- VWC: vegetation water content
- s: soil surface roughness
- l: correlation length of s

[S. Kim]
Algorithm: retrieval

- lookup table of the forward model to speed up retrieval at 3 deg incidence angle interval from 30 to 50 degs

- Least squares estimator of \( N \) time-series
  - Overbar denotes parameters to retrieve
  - Assume time-scale (roughness) >> time-scale (soil moisture)
  - Vegetation water content: first guess from climatology

\[
C(\bar{s}, \bar{\varepsilon}_r, \bar{\varepsilon}_{r1}, \bar{\varepsilon}_{r2}, ..., \bar{\varepsilon}_{rN}) = \\
w_{1,HH}(\sigma_{HH,1}^0 - \sigma_{HH,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_1) + \bar{c})^2 + w_{1,VV}(\sigma_{VV,1}^0 - \sigma_{VV,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_1) + \bar{c})^2 + \\
w_{2,HH}(\sigma_{HH,2}^0 - \sigma_{HH,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_2) + \bar{c})^2 + w_{2,VV}(\sigma_{VV,2}^0 - \sigma_{VV,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_2) + \bar{c})^2 + .... + \\
w_{N,HH}(\sigma_{HH,N}^0 - \sigma_{HH,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_N) + \bar{c})^2 + w_{N,VV}(\sigma_{VV,N}^0 - \sigma_{VV,fwd}^0(\bar{s}, \bar{\varepsilon}_r, \bar{fVWC}_N) + \bar{c})^2
\]

2\( N \) independent \( \sigma^0 \) input

N+2 unknown (\( N \varepsilon, s, f \))

[Kim et al. TGRS 2014]
Past performance: soil moisture
SMAP SAR (3km @ 40 deg)

- 8-day in May 2015
Past performance: soil moisture
SMAP & UAVSAR (40 deg)

Accuracy goal (0.06 m³/m³) is achievable

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>UAVSAR (~400m)</th>
<th>SMAP (3km)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bare soil⁰</td>
<td>wheat</td>
</tr>
<tr>
<td>vegetation kg/m²</td>
<td>&lt;4</td>
<td>&lt;2</td>
</tr>
<tr>
<td>ubRMSE m³/m³</td>
<td>0.044</td>
<td>0.050</td>
</tr>
<tr>
<td>correlation</td>
<td>0.89</td>
<td>0.92</td>
</tr>
<tr>
<td>model error dB</td>
<td>~1</td>
<td>~1</td>
</tr>
</tbody>
</table>

0) Kim, Tsang, Johnson, Huang, van Zyl, Njoku TGRS 2012
1) Huang, Kim, Tsang, Xu, Liao, Jackson, Yueh, JSTAR, 2016
2) Liao, Kim, Tan, Tsang, Su, Jackson, JSTAR, 2016
3) Kim, Moghaddam, Tsang, Burgin, Xu, Njoku TGRS 2014
4) Kim, Arii, Jackson, JSTAR 2017
5) Tabatabaeenejad and Moghaddam, TGRS 2011
6) Kim et al. TGRS 2017

1 kg/m² = 10 t/ha
Multi-angular algorithm test: UAVSAR

- 60 fields of crops and forest. Crops grew from seeds to harvest height
- Incidence angle ranges from 25 deg to 65 degs
Retrieving soil moisture and VWC

soybean

\[ \text{VWC, kg/m}^2 \]

\[ \text{W, cm}^3/\text{cm}^3 \]

\[ \text{in situ, cube-time, cube-snap} \]

\[ \text{W: model @truth} \]

\[ \text{HH} \]

\[ \text{W: UAVSAR} \]

\[ \text{HH} \]

pasture

\[ \text{VWC, kg/m}^2 \]

\[ \text{W, cm}^3/\text{cm}^3 \]

\[ \text{in situ, cube-time, cube-snap} \]

\[ \text{W: model @truth} \]

\[ \text{HH} \]

\[ \text{W: UAVSAR} \]

\[ \text{HH} \]
Multi-angular algorithm test

UAVSAR (30 to 50deg NISAR angles)

- Successful performance, meeting accuracy goal
  (error in standard deviation is 0.035 to 0.053 m3/m3. goal is 0.06 m3/m3)
  (correlation of 0.65-0.91)

- HH & VV input
Success and challenges in forest

- HH forward models have large bias
- VV is used for retrieval

• Each color: four individual fields
• (left) bias removed using in situ reference
• (right) texture-based bias removal
Summary

• Soil moisture retrieval at field scale
  • Using airborne SAR data over 30-50deg incidence angle range and soybean, pasture, wheat, forest: the unbiased rmse is 0.25 to 0.07 m³/m³

• Challenges and plans
  • Tall crops (corn and canola) have less accurate retrievals
  • Topography
  • Organic soils
  • Heterogeneity
  • Forests
Multi-angular algorithm test

UAVSAR (30 to 50deg NISAR angles)

- Without bias removal using in situ