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

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Motivation

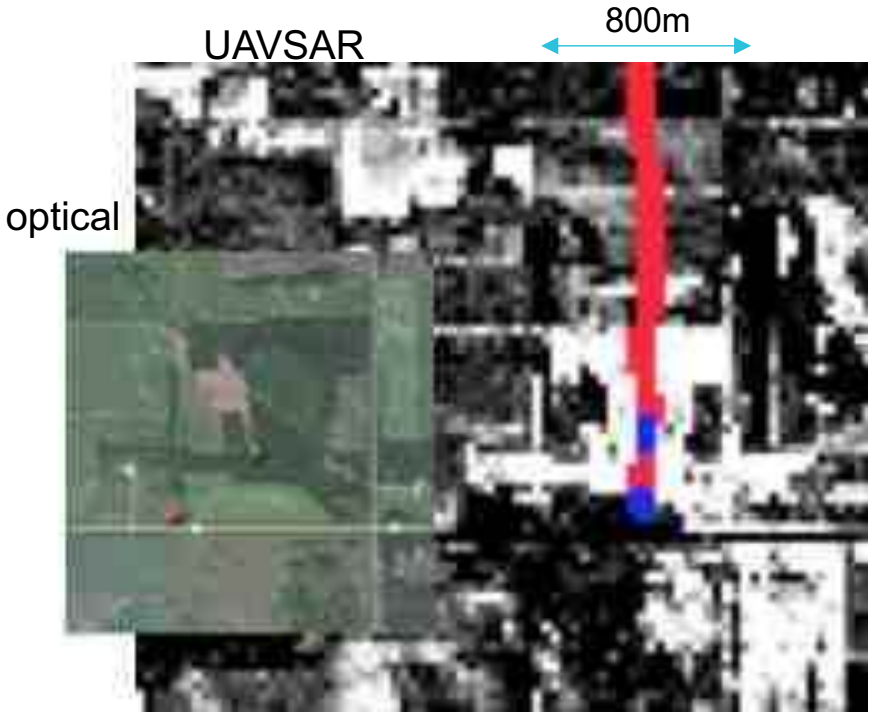
- L-& S-band SAR interferometric multi-polarimetric. Launch in 2022.
- 12 day revisit. ~10m resolution.
- Solid earth, cryosphere, ecosystem (biomass, inundation, crop classification)

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

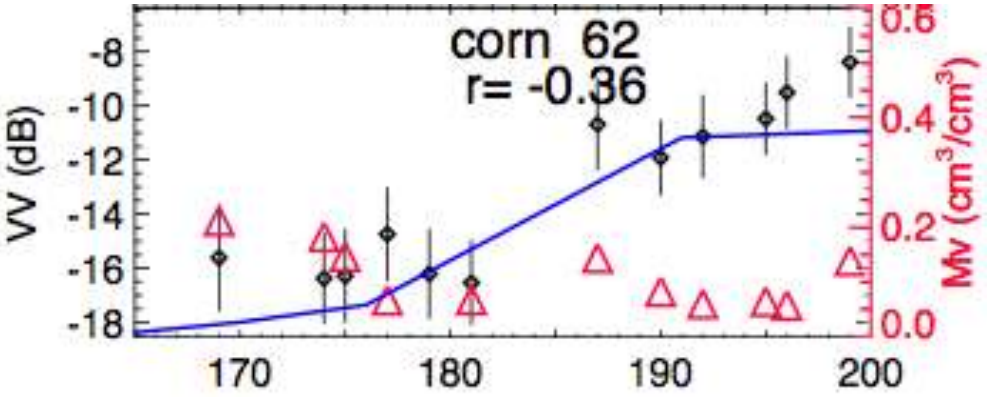
Aiming at field-scale soil moisture

Algorithm : soil moisture

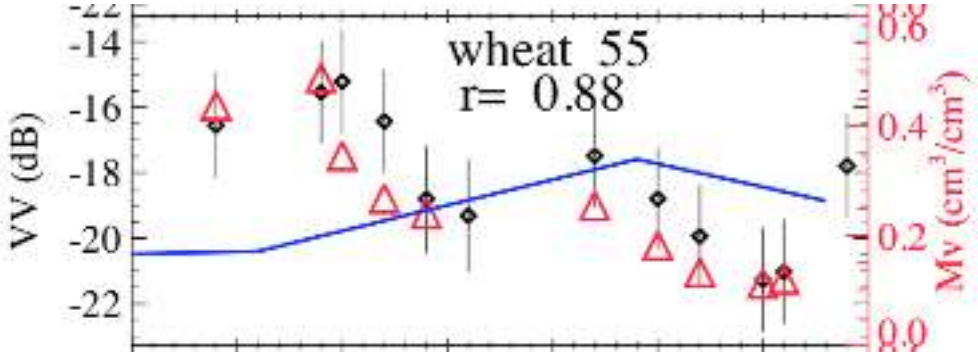
- 200m or better resolution is needed
- Need to rigorously correct for vegetation effect (6 dB change in 8 days)
- Algorithm has to be vegetation specific



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



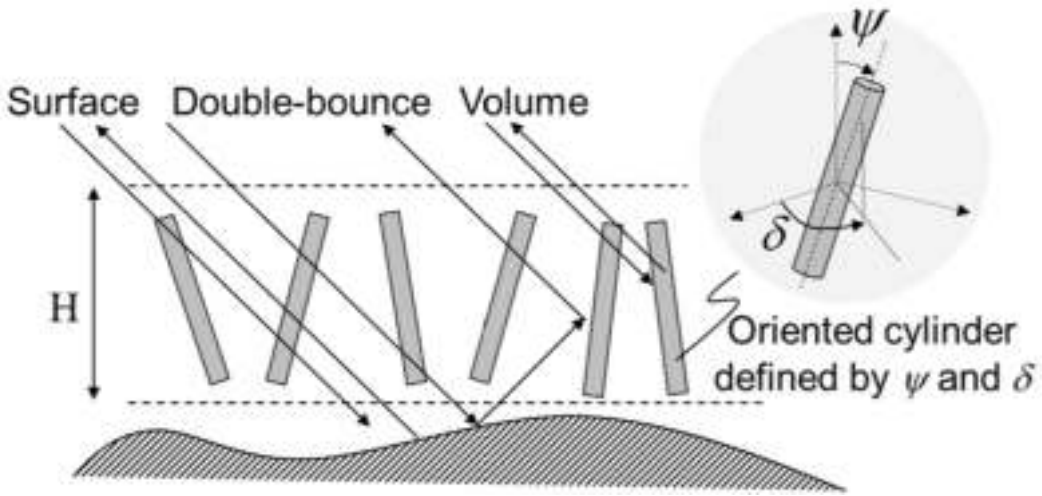
Blue is vegetation water content
(50 t/ha for corn; 30 t/ha for wheat)



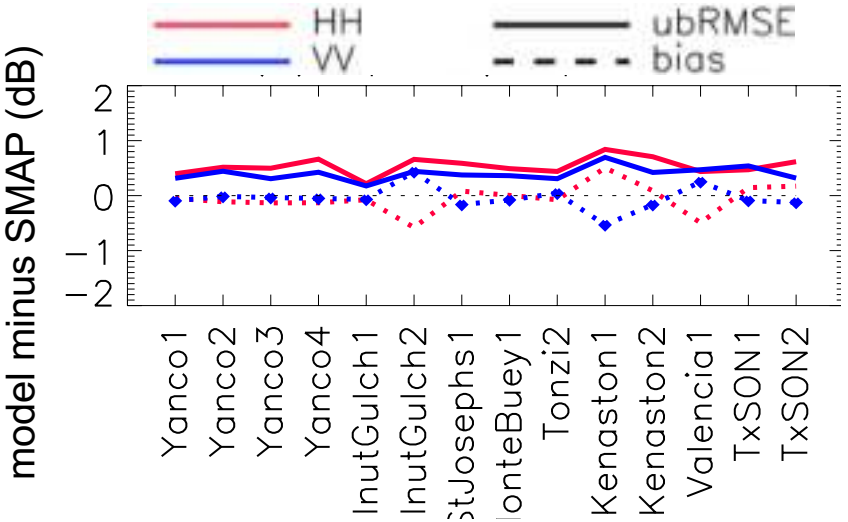
Algorithm : forward model

- 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)

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



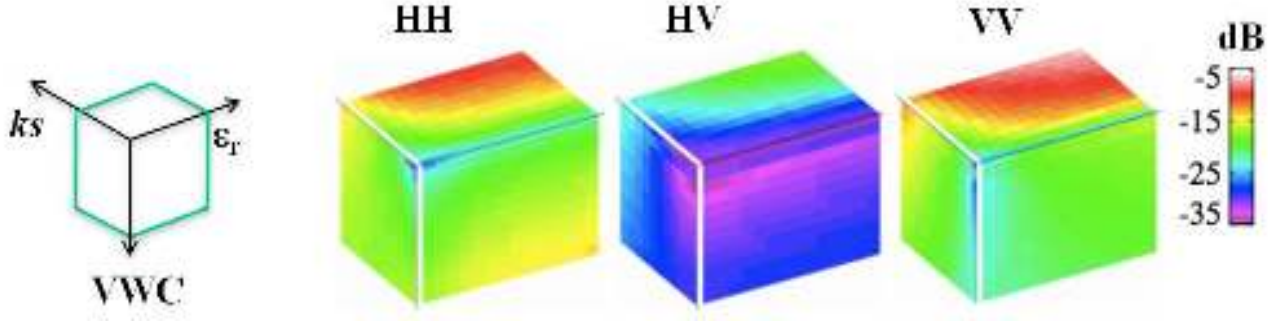
σ^0: input
ε: soil dielectric constant
VWC: vegetation water content
s: soil surface roughness
l: correlation length of s



[Kim et al. TGRS 2017]

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

$$C(\overline{s},\overline{\varepsilon}_{r1},\overline{\varepsilon}_{r2},\ldots,\overline{\varepsilon}_{rN}) =$$

$$w_{1,HH}(\sigma^0_{HH,1}-\sigma^0_{HH,fwd}(\overline{s},\overline{\varepsilon}_{r1},\overline{f}VWC_1)+\overline{c})^2+w_{1,VV}(\sigma^0_{VV,1}-\sigma^0_{VV,fwd}(\overline{s},\overline{\varepsilon}_{r1},\overline{f}VWC_1)+\overline{c})^2+$$

$$w_{2,HH}(\sigma^0_{HH,2}-\sigma^0_{HH,fwd}(\overline{s},\overline{\varepsilon}_{r2},\overline{f}VWC_2)+\overline{c})^2+w_{2,VV}(\sigma^0_{VV,2}-\sigma^0_{VV,fwd}(\overline{s},\overline{\varepsilon}_{r2},\overline{f}VWC_2)+\overline{c})^2+\ldots.+$$

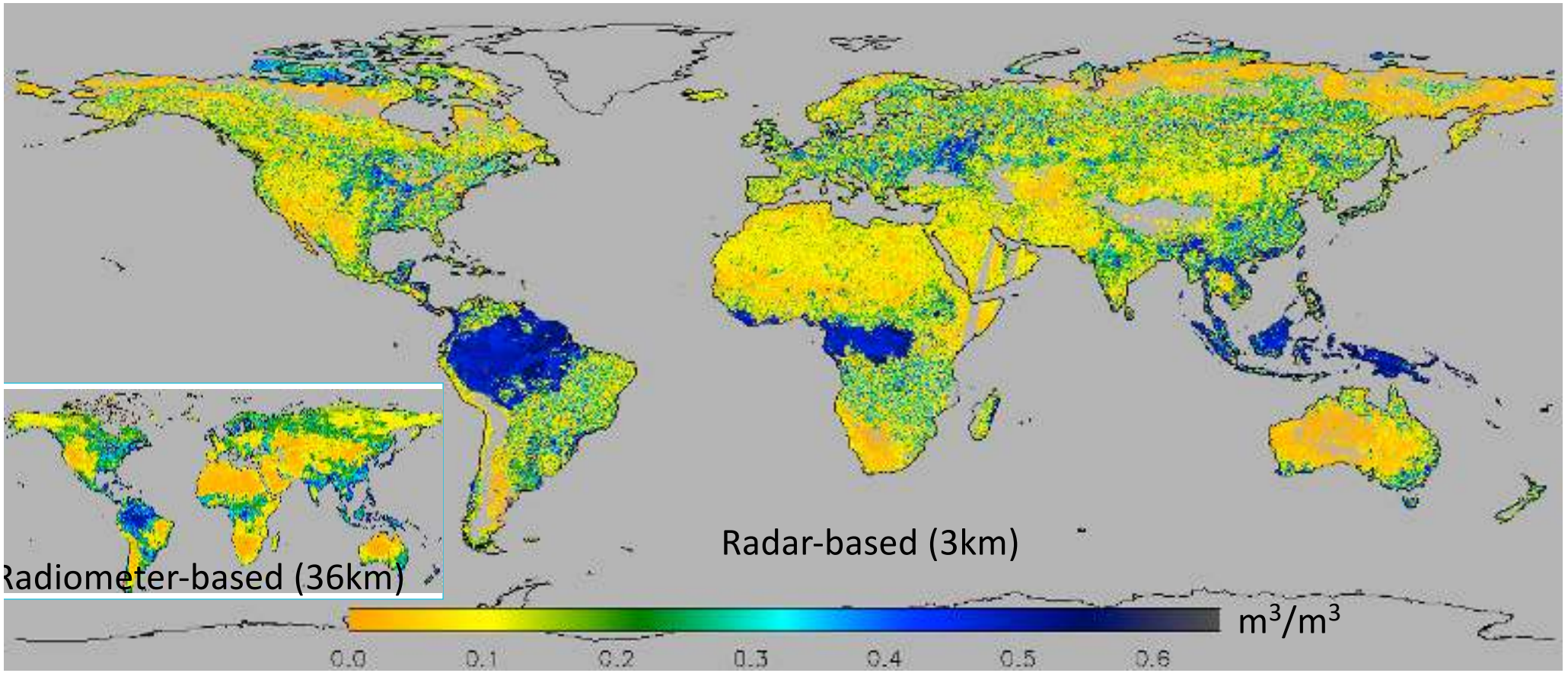
$$w_{N,HH}(\sigma^0_{HH,N}-\sigma^0_{HH,fwd}(\overline{s},\overline{\varepsilon}_{rN},\overline{f}VWC_N)+\overline{c})^2+w_{N,VV}(\sigma^0_{VV,N}-\sigma^0_{VV,fwd}(\overline{s},\overline{\varepsilon}_{rN},\overline{f}VWC_N)+\overline{c})^2$$

2N independent σ^0 input
N+2 unknown (*N* ε, *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)

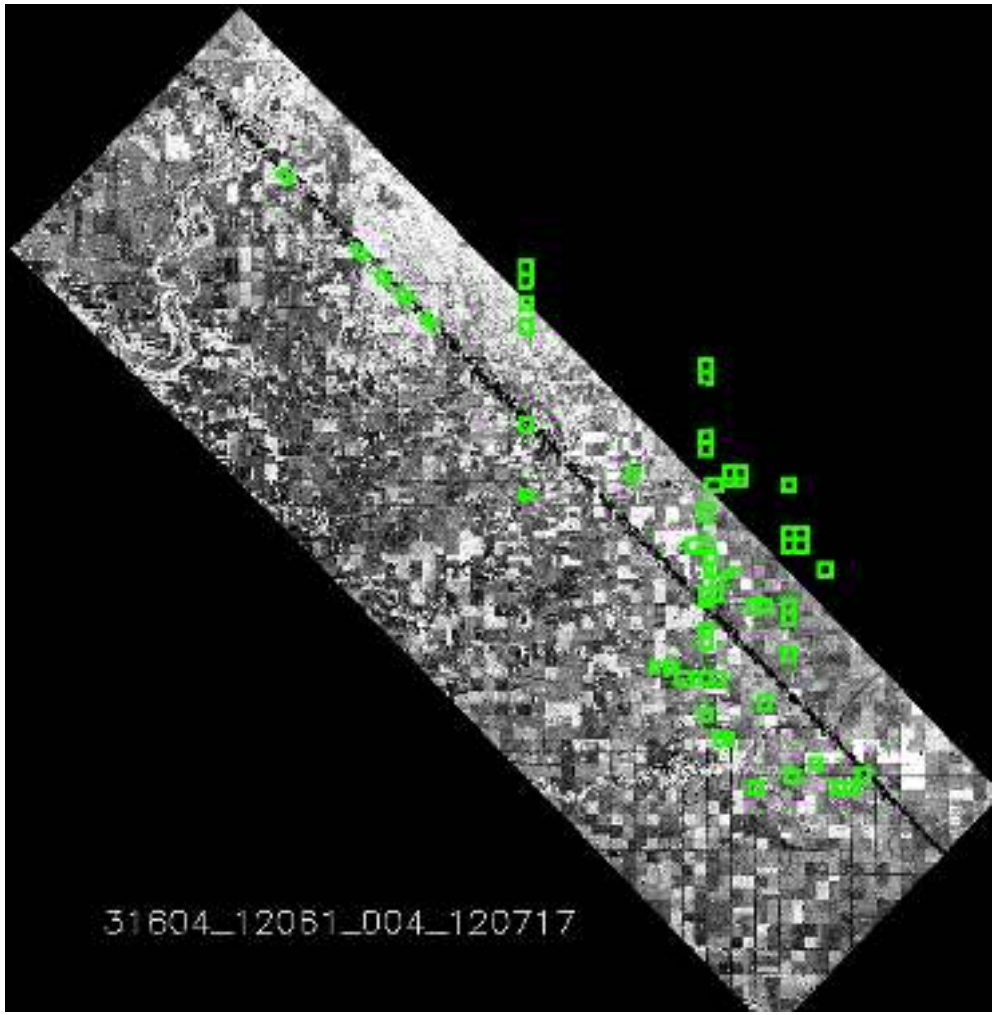
Accuracy goal (0.06 m3/m3) is achievable

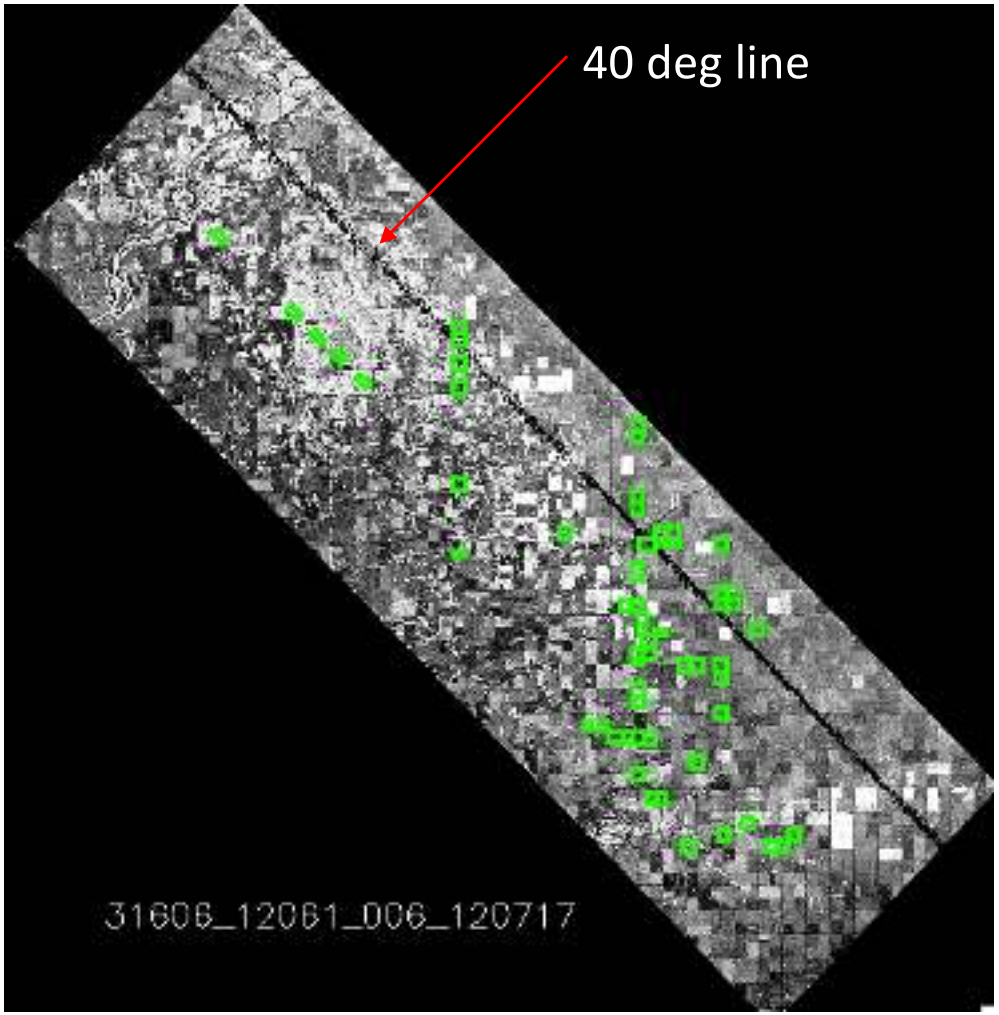
	UAVSAR (~400m)								SMAP (3km)	
	bare soil[0]	wheat	bean[1]	corn[2]	canola	pasture[3]	shrub[4]	forest[5]	crop[6]	non[6]
vegetation kg/m2		<4	<2	<5	<8	<1	<1	<20		
ubRMSE m3/m3	0.044	0.050	0.070	0.071	0.08	0.054	0.055	0.03	0.067	0.040
correlation	0.89	0.92	0.56	0.50	0.73	0.60	0.95	-	0.50	0.51
model error dB	~1	~1	~1	~1.7	~2	~1.8	~1.5	-	<1	<1

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

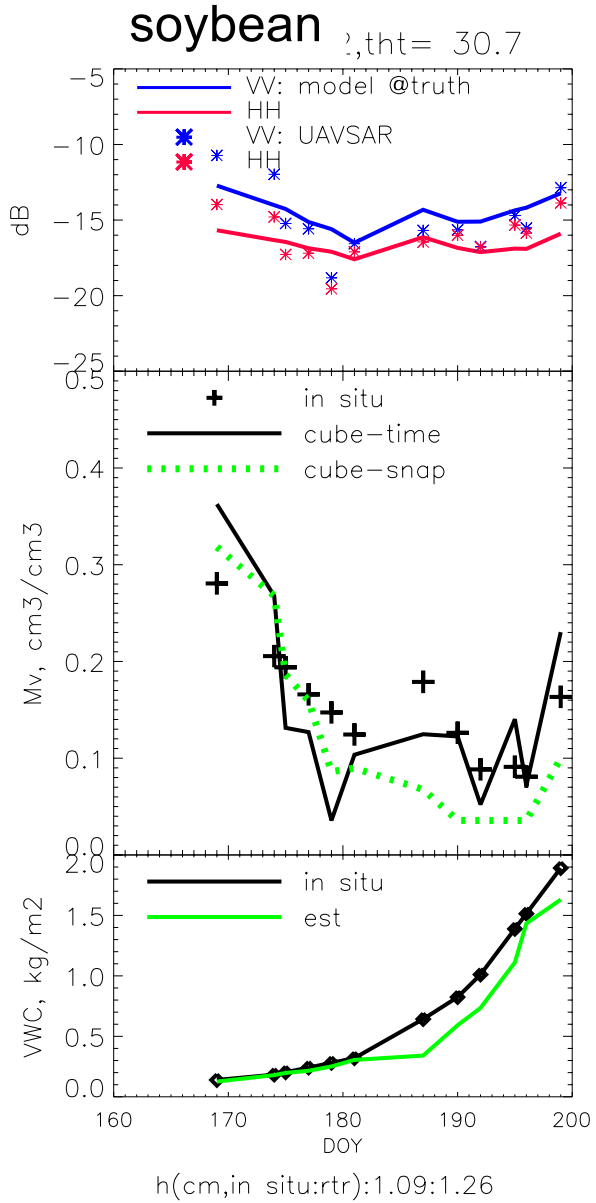
Multi-angular algorithm test : UAVSAR

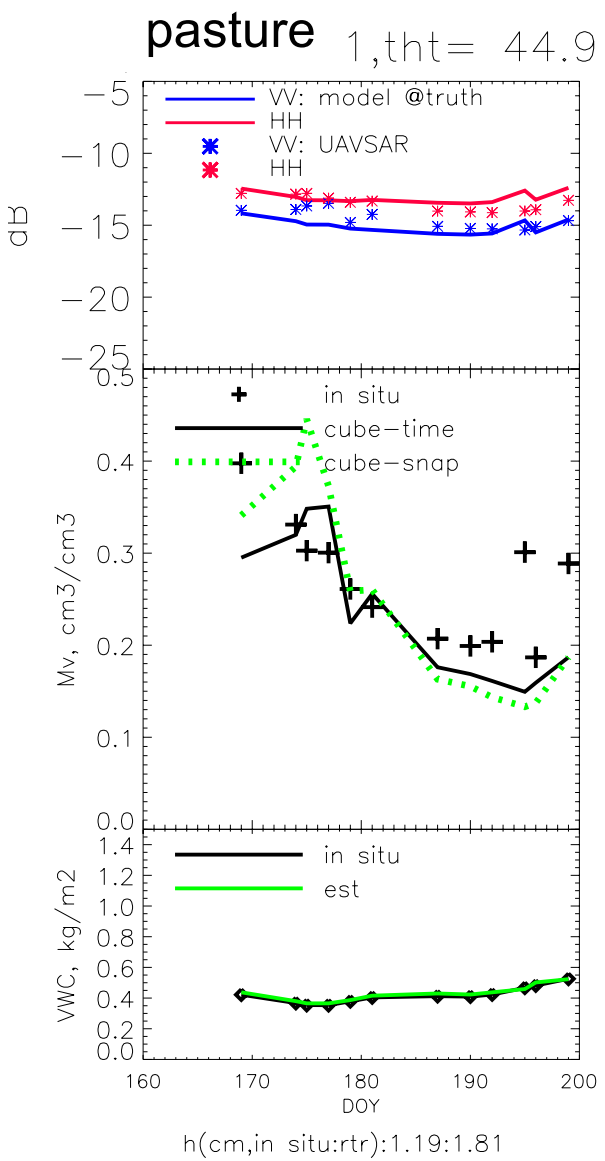




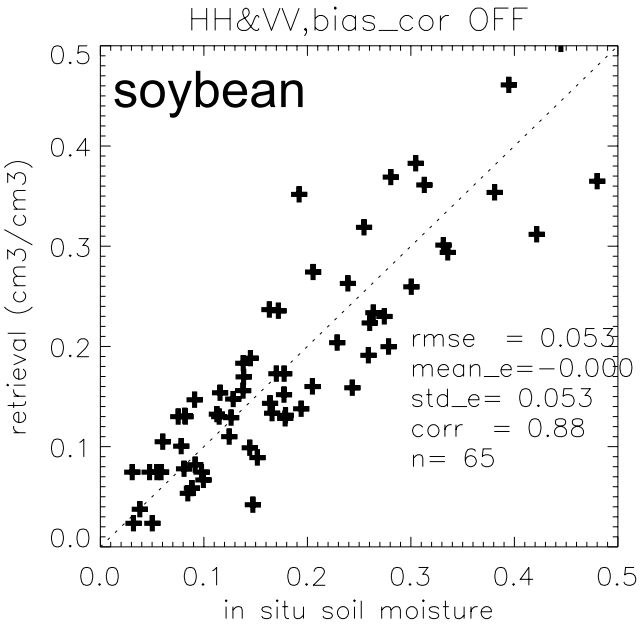
- 60 fields of crops and forest. Crops grew from seeds to harvest height
- Incidence angle ranges from 25 deg to 65 degs

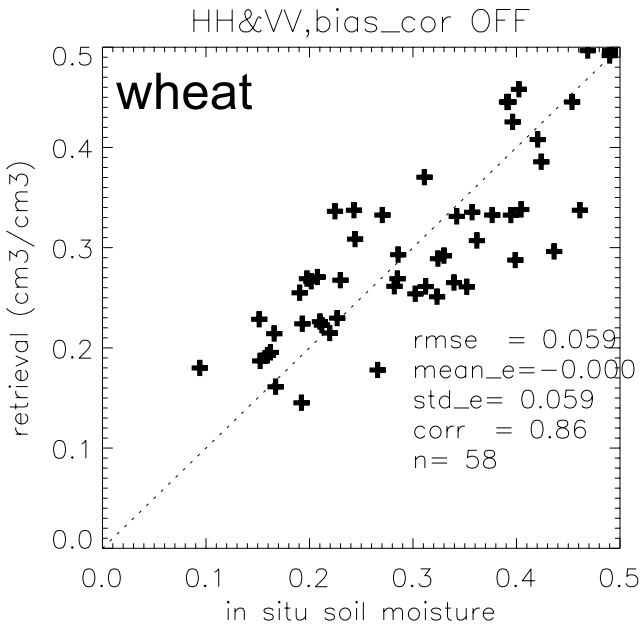
Retrieving soil moisture and VWC

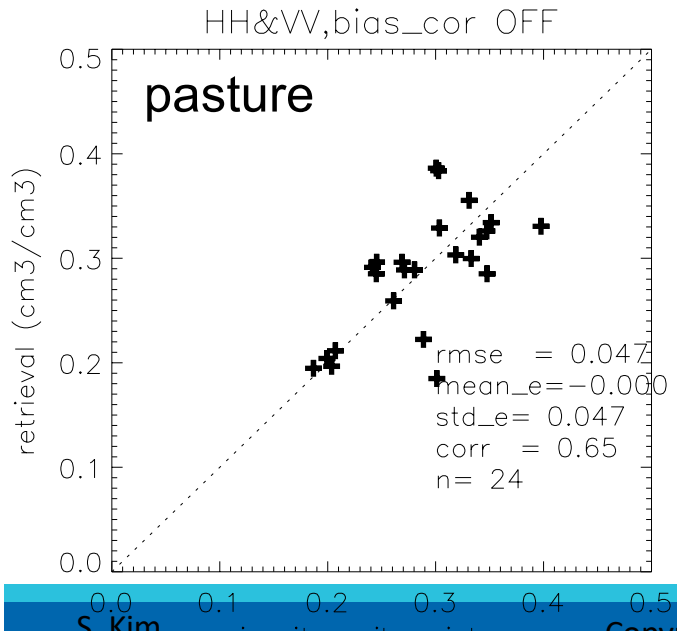




Multi-angular algorithm test
UAVSAR (30 to 50deg NISAR angles)







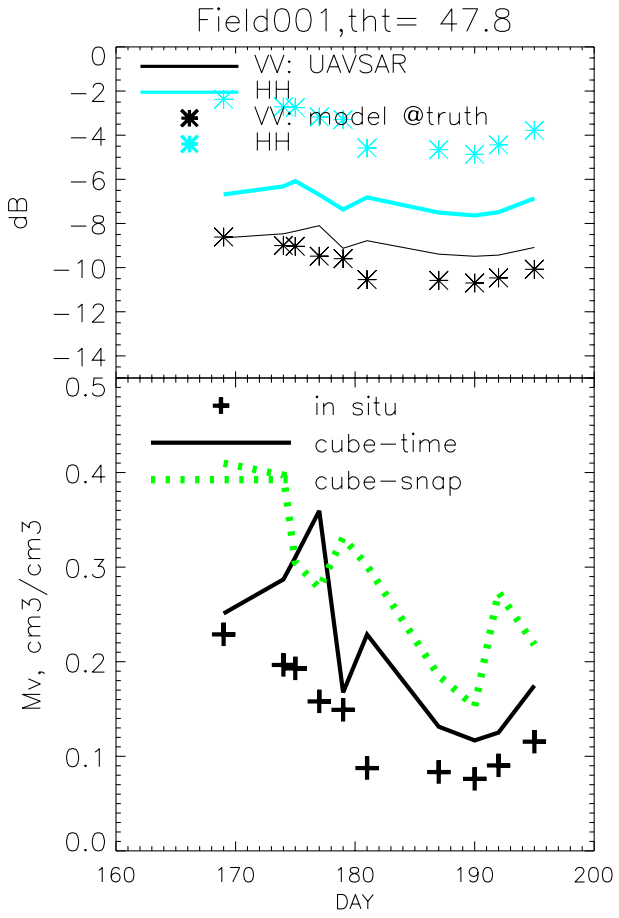
- Successful performance, meeting accuracy goal

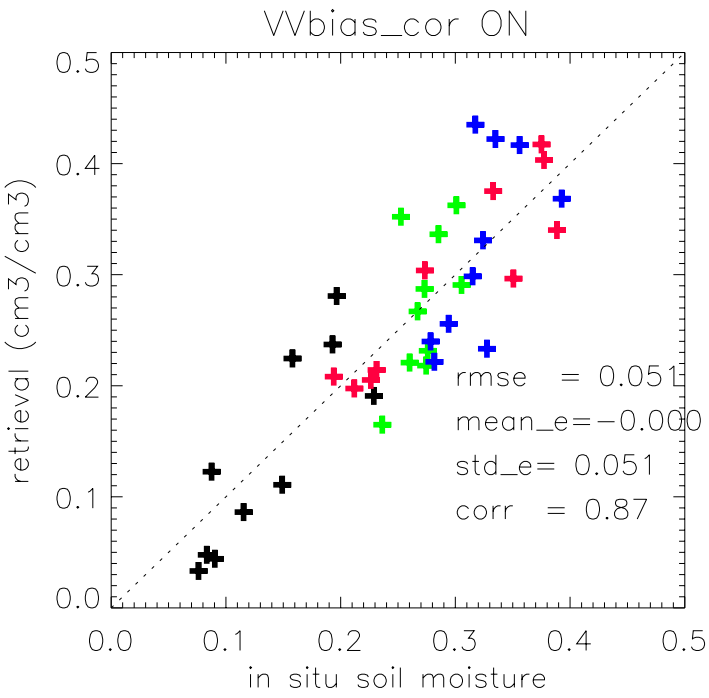
(error in standard deviation is 0.035 to 0.053 m3/m3. goal is 0.06 m3/m3)

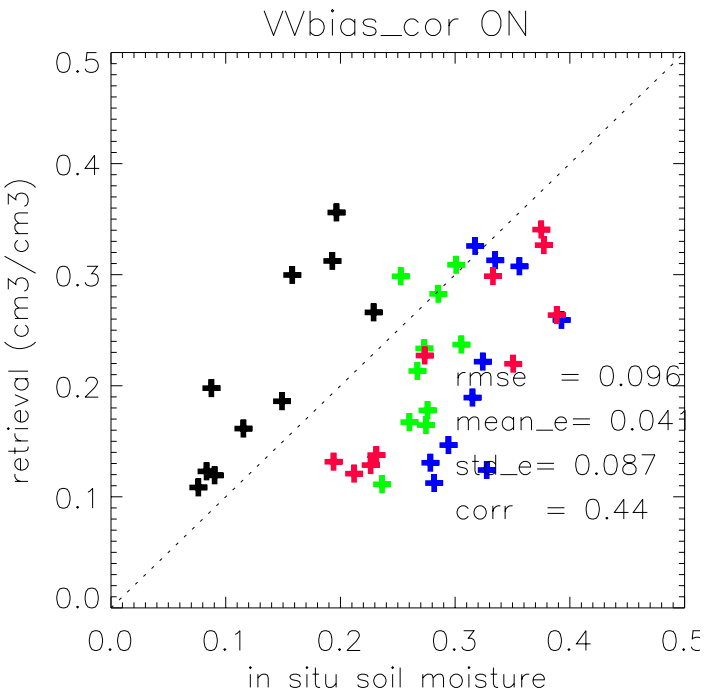
(correlation of 0.65-0.91)

- HH & VV input

Success and challenges in forest







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

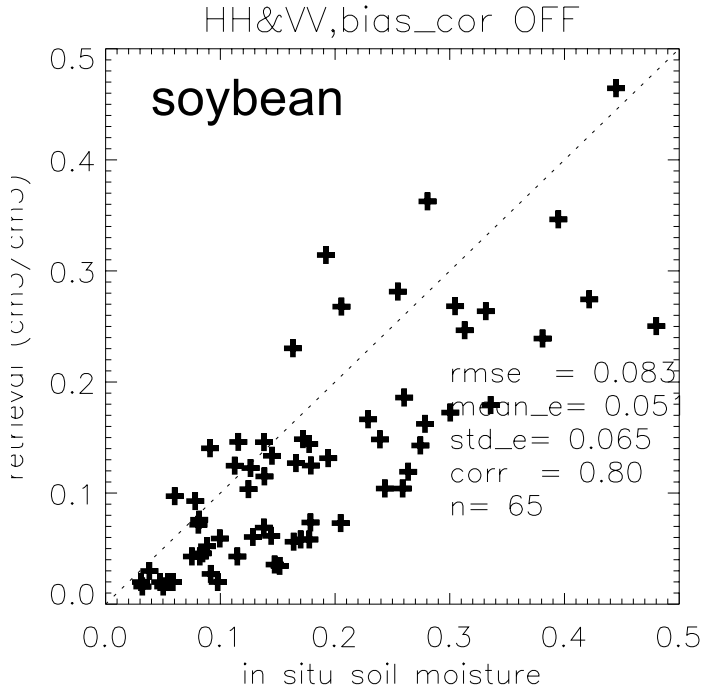
- Each color: four individual fields
- (left) bias removed using in situ reference
- (right) texture-based bias removal

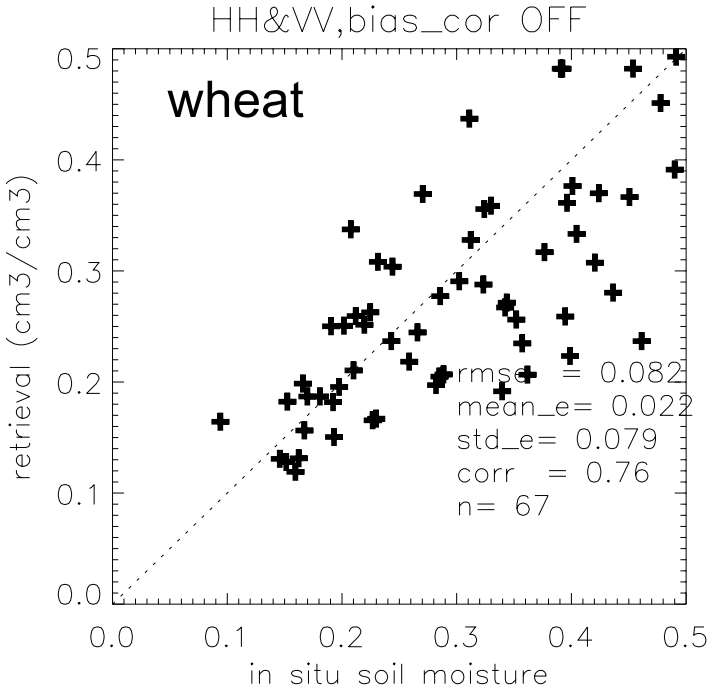
Summary

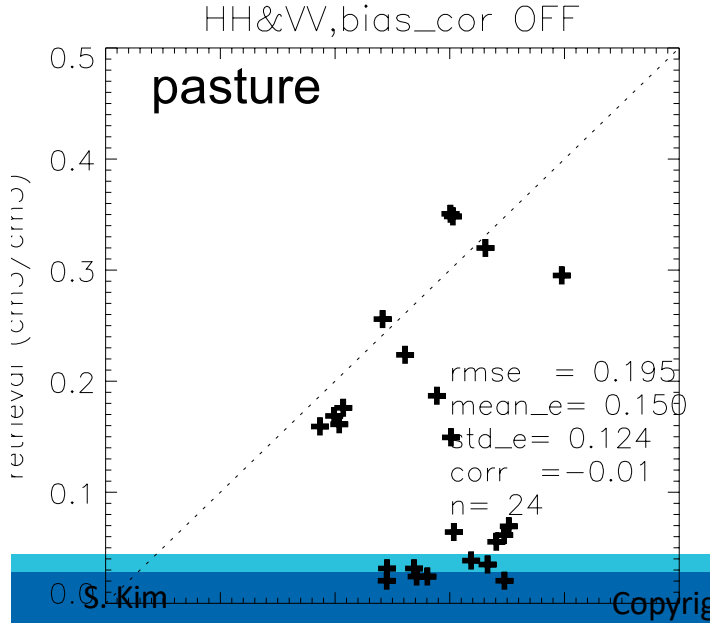
- Soil moisture retrieval at field scale
  - Using airborne SAR data over 30-50deg incidence angle range and soybean, pasture, wheat, forest: the unbiased rmse is 0.25 to 0.07 m3/m3

- 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