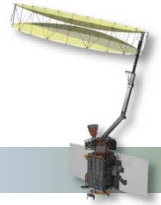

# PALS (Passive Active L-band System) Radiometer-Based Soil Moisture Retrieval for the SMAP Validation Experiment 2012 (SMAPVEX12)

Andreas Colliander[1], Thomas J. Jackson[2], Steven Chan[1], Rajat Bindlish[2], Peggy O'Neill[3], Seth Chazanoff[1], Heather McNairn[4], Paul Bullock[5], Jarrett Powers[4], Grant Wiseman[6], Aaron Berg[7], Ramata Magagi[8], and Eni Njoku[1]

1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
2) USDA ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD 20705, USA
3) Goddard Space Flight Center, MD, USA
4) Agriculture and Agri-Food Canada, Canada
5) University of Manitoba, Winnipeg, Canada
6) Stantec, Winnipeg, MB, Canada
7) University of Guelph, Guelph, Canada
8) University of Sherbrooke, Quebec, Canada

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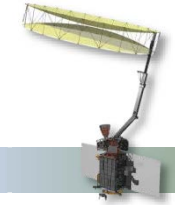
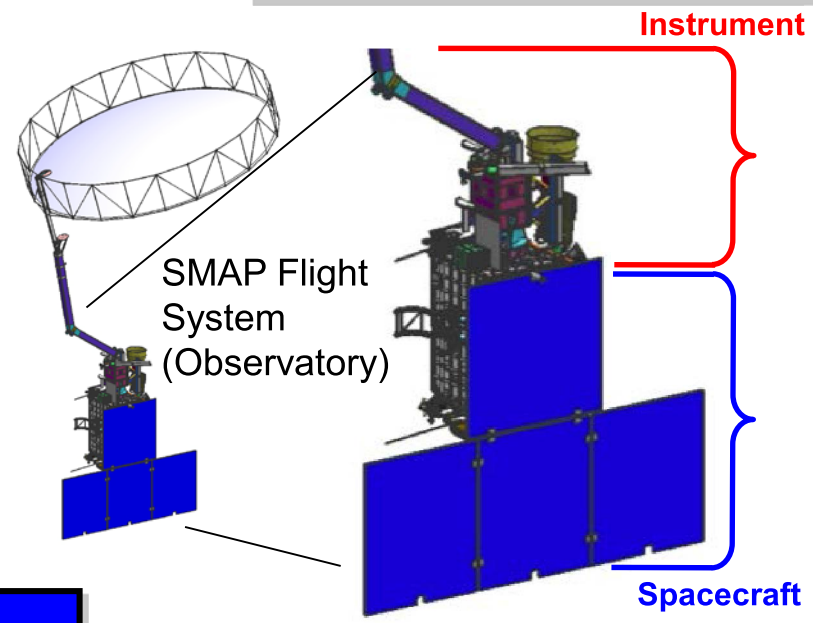
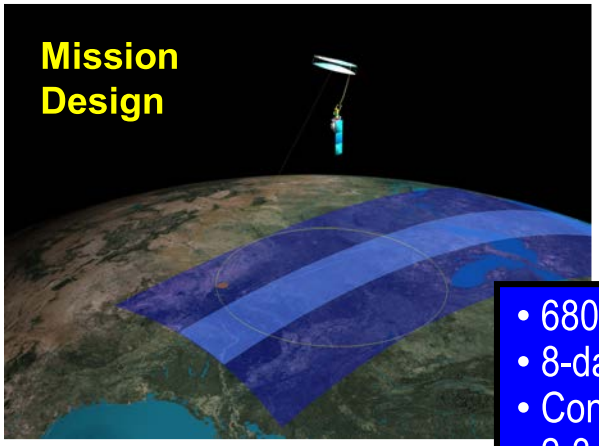
# SMAP



- NASA mission for global retrieval of soil moisture and freeze/thaw state
  - Weather and climate modeling, flood/drought monitoring and prediction, food security etc…
- NASA Earth Science decadal survey first tier mission
- L-band conically scanning radar and radiometer
- Launch in January 2015

- L-band (1.26 GHz) Radar (JPL)
- L-band (1.41 GHz) Radiometer (GSFC)
- Shared Antenna (6m diameter)
  - Conical scan: 14.6 rpm; 40° look
  - Contiguous 1,000 km swath width



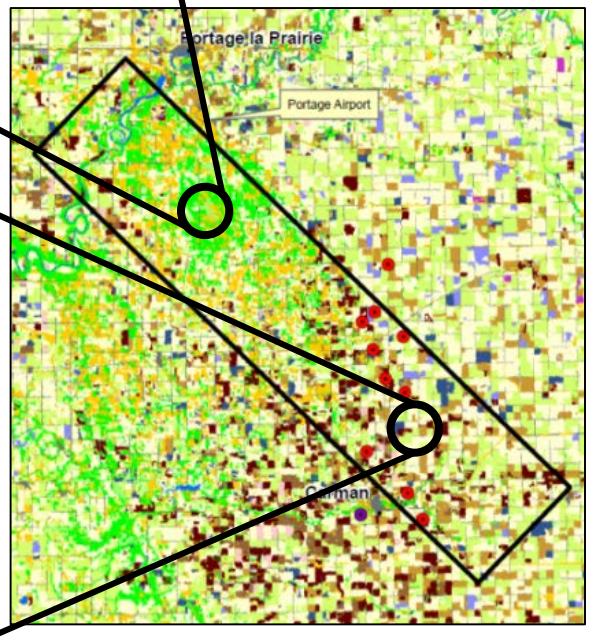




- 680 km polar orbit (sun-sync)
- 8-day repeat ground-track
- Continuous instrument operation
- 2-3 day global coverage
- 3-year mission duration

- JPL-Developed & Built
- JPL's Multi-System Architecture Platform (MSAP) Avionics
- Commercial Space Components

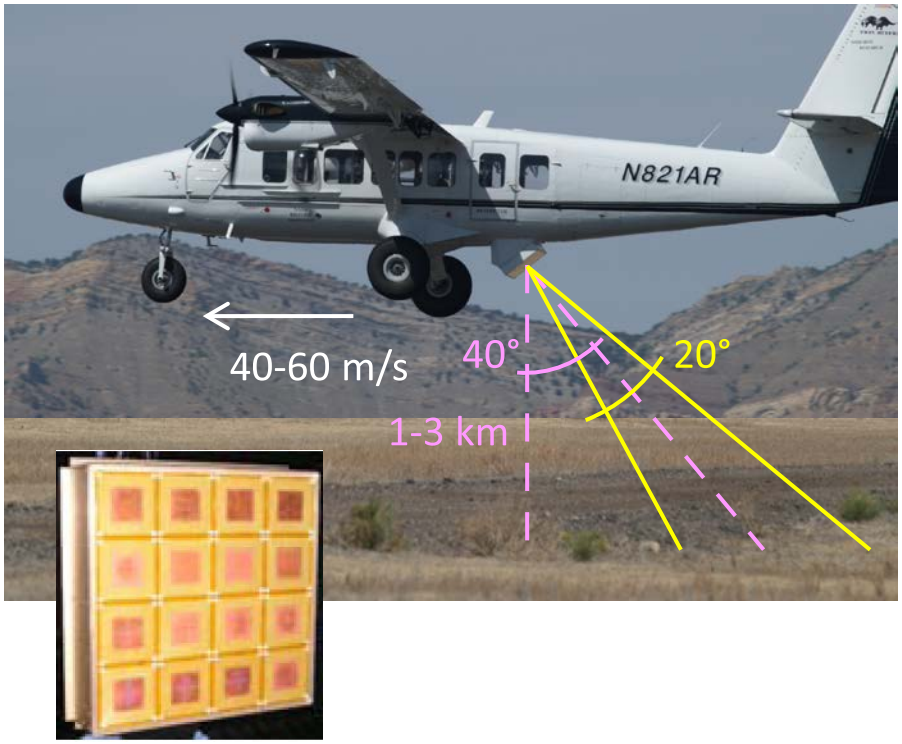
# SMAPVEX12 Campaign Overview

- Winnipeg, Canada
  - La Salle and Morris River watersheds
- June 7 – July 19, 2012
- Cooperation between NASA, AAFC, EC, and U.S. and Canadian universities
- Two aircrafts by NASA for making L-band active and passive measurements
- Data available at NSIDC



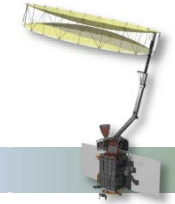
# PALS Instrument in SMAPVEX12

- Passive Active L-band System (PALS) functions as SMAP simulator
- L-band frequency
  - Radiometer: 1.41 GHz
  - Radar: 1.26 GHz
- View angle: 40°
- Operating altitude: 1-3 km
  - With 20° beamwidth 600-1500 m footprint
- Measurement resolution
  - Radiometer < 0.2 K
  - Radar < 0.2 dB
- Installation included a fast sampling digital backend for RFI studies
- Thermal infrared sensor
  - Nadir pointing, 2° beamwidth

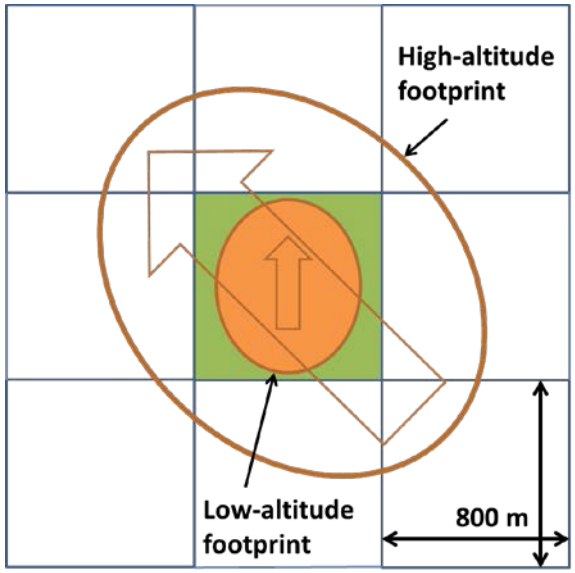


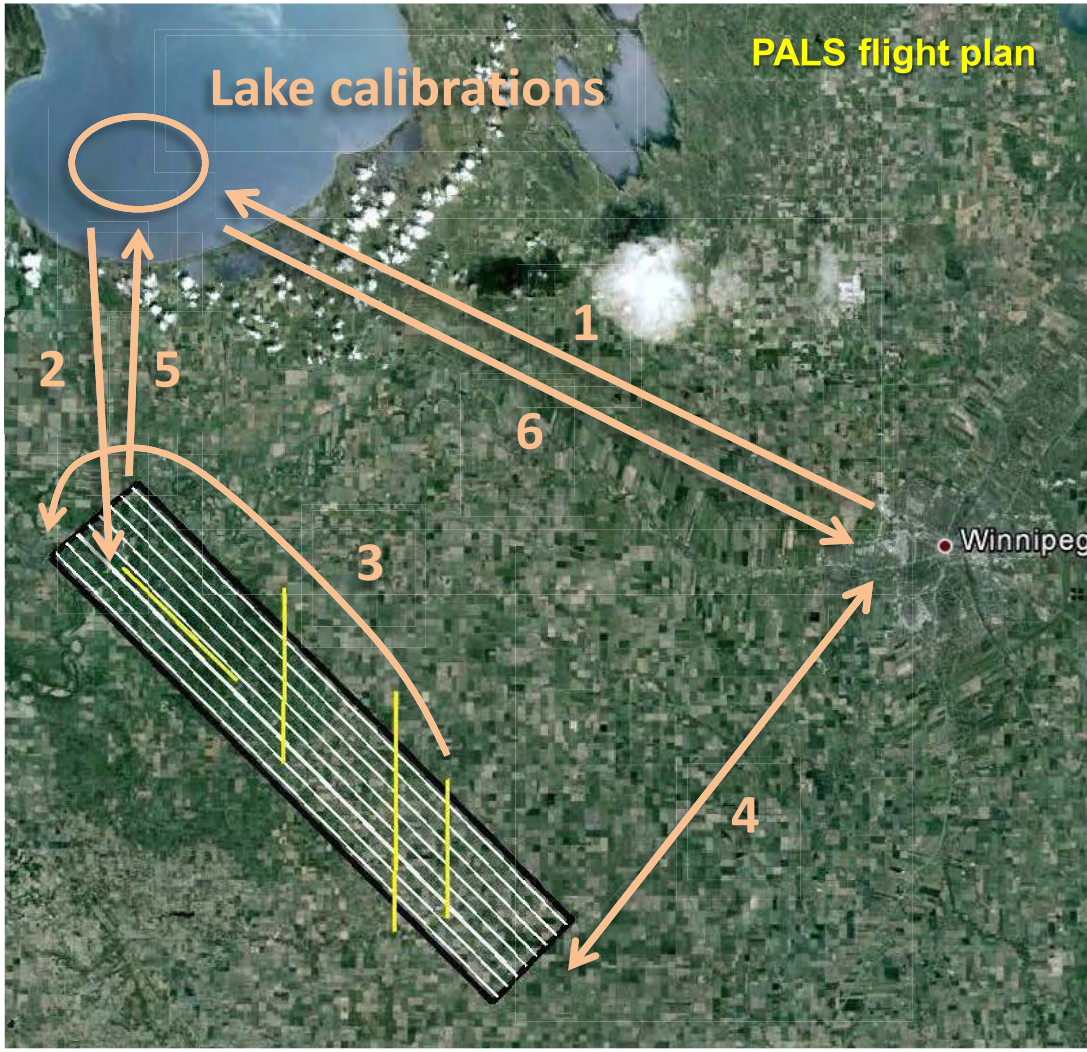

**PALS antenna**

# SMAPVEX12 PALS Observations

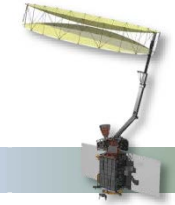


- PALS: 17 flight days/~100 hours
  - Low (~1 km) altitude flights for field-scale studies
  - High (~3 km) altitude flights for mapping (spatial disaggregation studies)



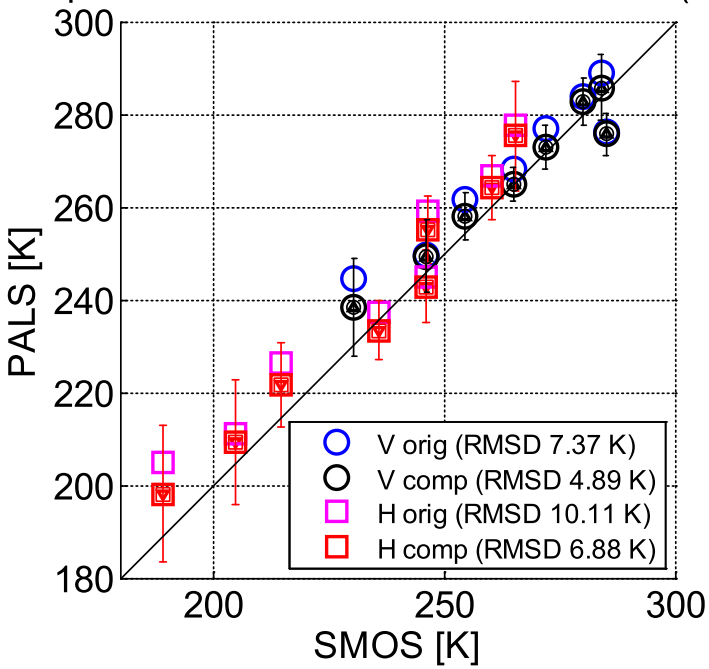



# PALS Comparison to SMOS during SMAPVEX12

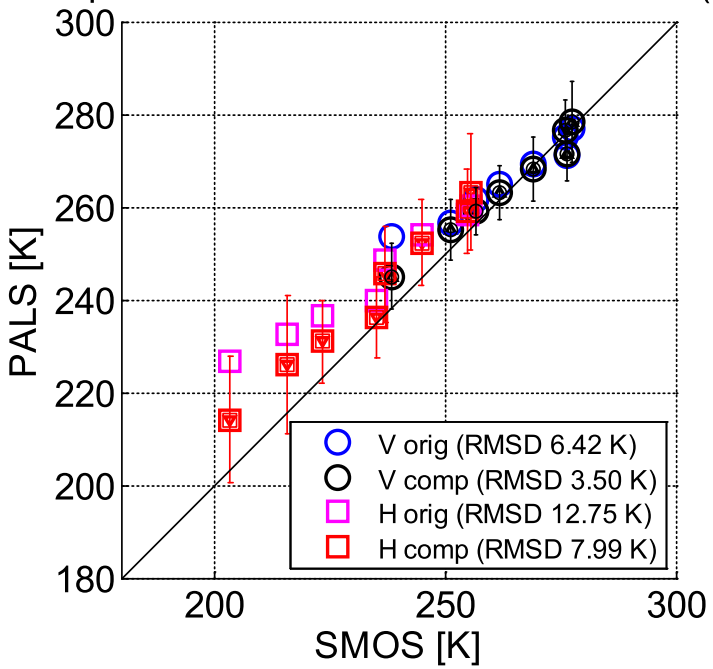


- Overall correspondence between PALS and SMOS within footprint variability*
  - SMOS footprint about 40 km in diameter; the experiment domain does not cover the full footprint
  - Shows that the PALS measurements correspond to spaceborne observations when up-scaled

Correspondence between SMOS and PALS (ag-fields)




Correspondence between SMOS and PALS (mixed)




*) A. Colliander et al., "Comparison of Airborne Passive and Active L-band System (PALS) Brightness Temperature Measurements to SMOS Observations during the SMAP Validation Experiment 2012 (SMAPVEX12)", GRSL, 2014

# Soil Moisture Retrieval: Brightness Temperature Modeling Approach

- Starting point the standard tau-omega model

$$T_B^{TOV} = \left(1 - r_{soil,p}\right)T_{soil}e^{-\tau_p} + T_{veg}\left(1 - \omega_p\right)\left(1 - e^{-\tau_p}\right)\left(1 + r_{soil,p}e^{-\tau_p}\right)$$

  - Mironov model is used to relate soil dielectric constant to soil moisture
  - Physical temperature of soils and vegetation estimated from in situ and airborne measurements
  - Roughness (no polarization mixing) parameter estimated from the field measurements ($h_{0,p} = (2\sigma k)^2$)
  - Vegetation opacity using Vegetation Water Content $\tau_p = \frac{b_p W}{cos(\theta)}$
  - Scattering ($\omega_p$) assumed small
  - Reflectivity correction ($C_p$) based on soil moisture and proximity of the last rain event

$$r_{soil,p} = r_{0,p}e^{-h_p C_p cos^2(\theta)}$$

- Retrieval of soil moisture by minimizing the difference between modeled and measured brightness temperature
  - In aerial retrieval sub-grid forward modeling applied
- Focus here on agriculture and grassland areas
  - Forest parameterized by fitting the modeled TB range to the observed TB range

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# Low Altitude Flights

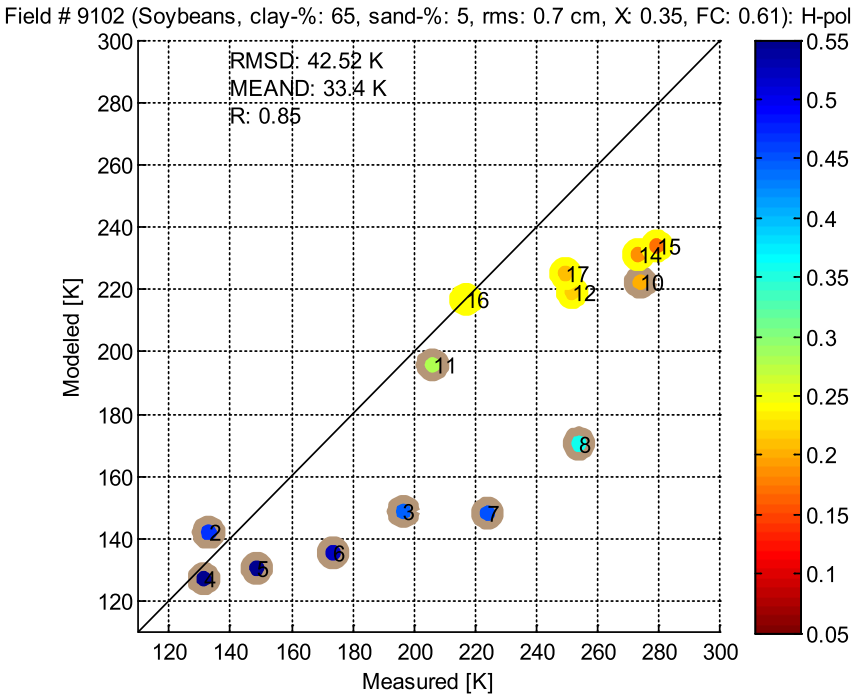
- Low altitude measurements were used for field by field parameterization of the model for different land cover and soil type conditions
  - About 500 m resolution
  - Extreme soil texture variation from field to field
- Best fit search for h and b
  - Adding reflectivity correction using soil moisture and rain event proximity required to achieve satisfactory results

| Land Cover | $b_H$ |
|---|---|
| **Canola** | 0.12 |
| **Wheat and Winter Wheat** | 0.08 |
| **Corn** | 0.15 |
| **Soybeans** | 0.10 |
| **Pasture** | 0.10 |

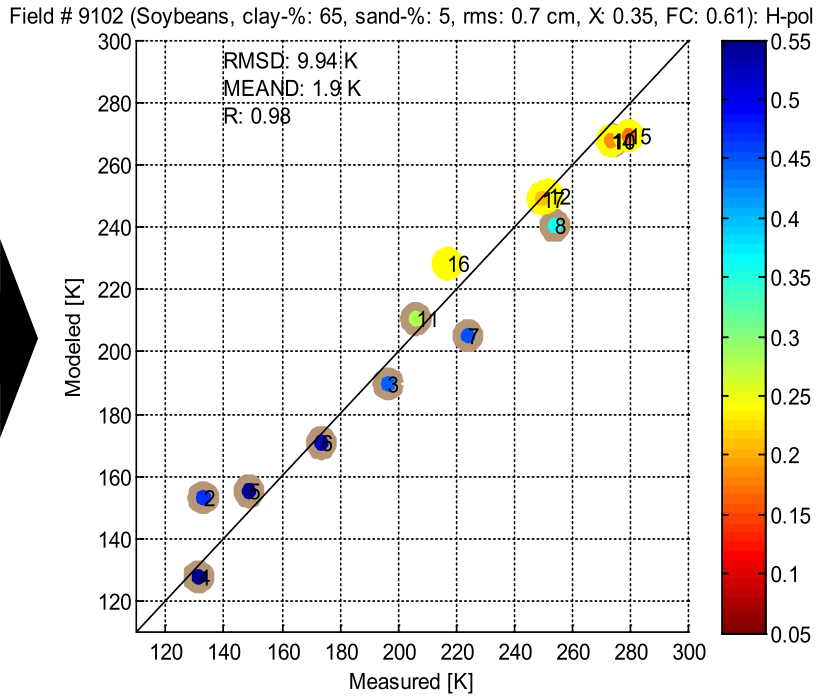
# Low Altitude Flights

- Dynamic correction on reflectivity based on surface conditions (soil moisture and proximity of the last rain event)

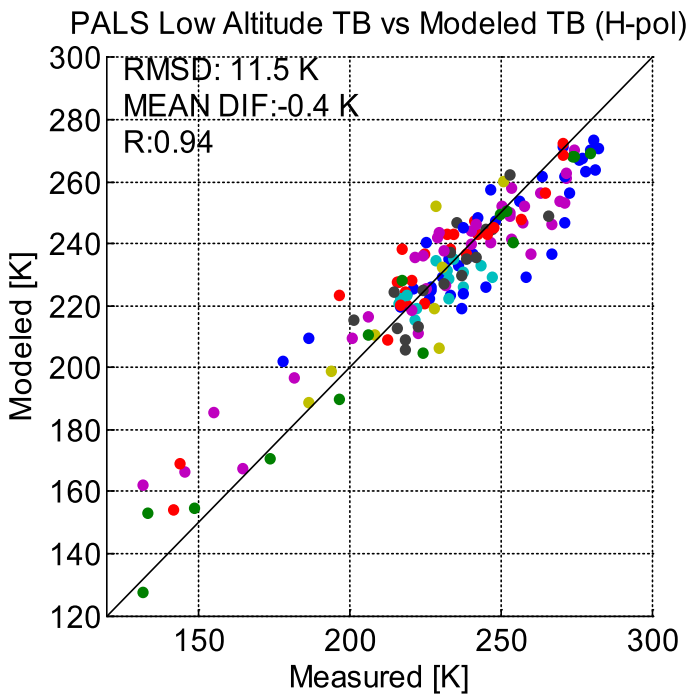
**Static parameters (h ~ 0.1)**

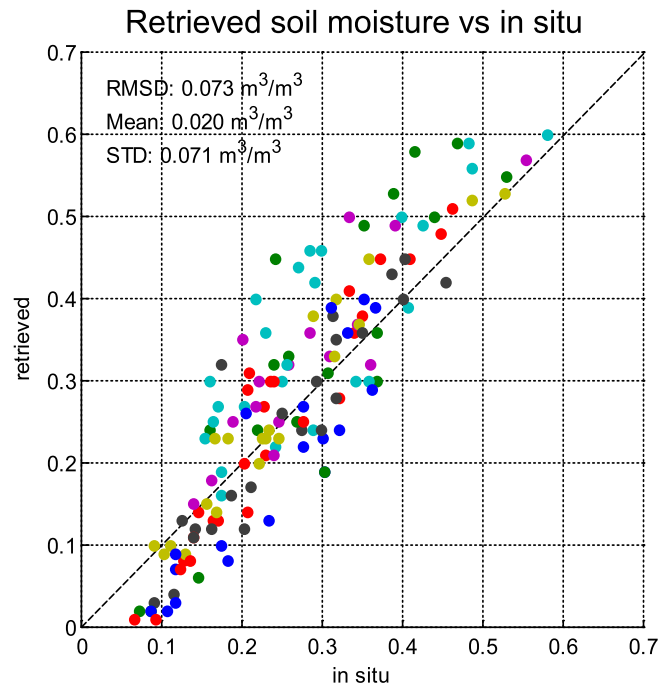



**Soil moisture and rain event based correction on reflectivity**



# Low Altitude Flights

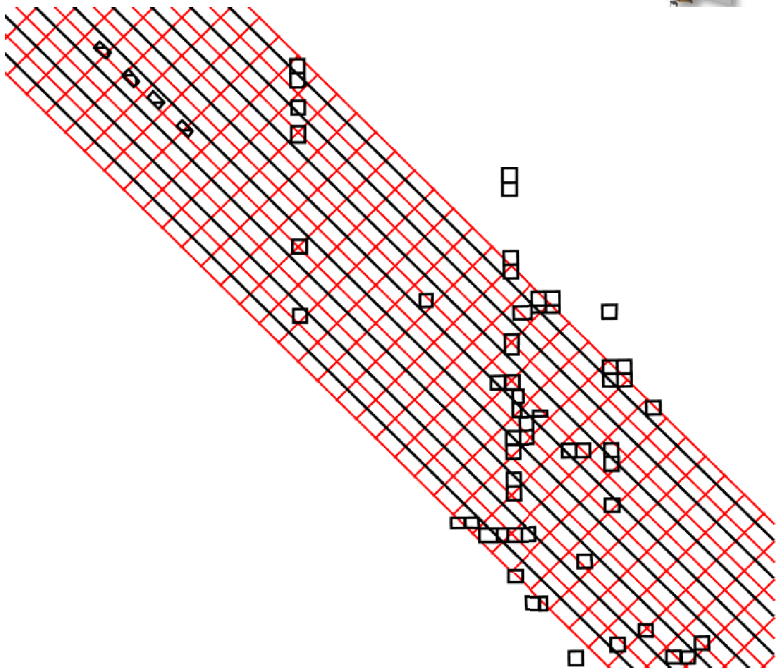


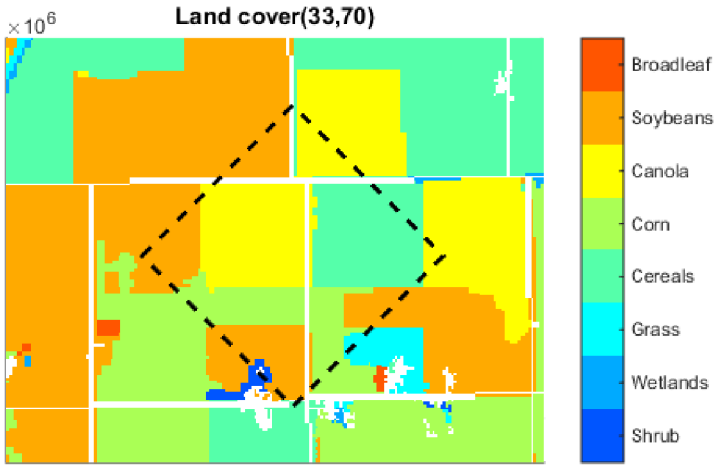




- Reasonable result from the homogeneous footprints
  - Forward modeled brightness temperature has some issues at cold end which translates to some overestimation in soil moisture retrieval
    - Soil texture range extreme

# Soil Moisture Mapping of Experiment Domain

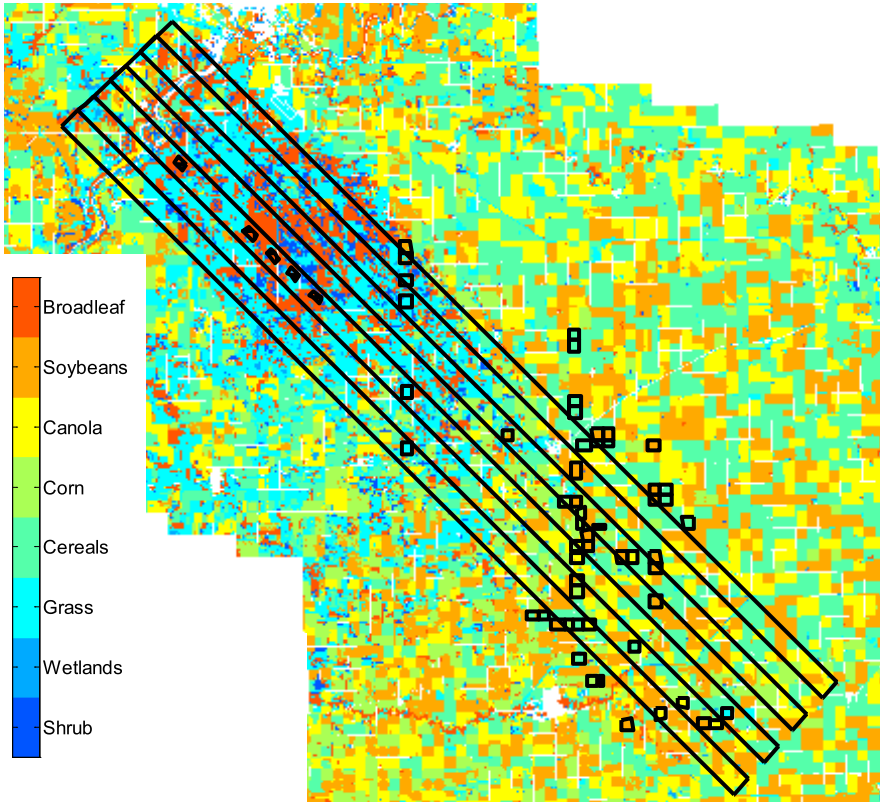
- Grid
  - 1.6 km grid spacing aligned with high altitude flight lines to fit pixels well with the instrument footprint
- Static ancillary data
  - Land cover
  - Soil texture (clay and sand fraction)
- Dynamic ancillary data
  - Estimates of physical temperature of soil and vegetation
  - Vegetation water content
- Model parameters
  - Derived based on the low-altitude flights for specific land classes
- Retrieval based on sub-grid resolution land cover and soil texture classes
  - Figure out fractions of each land cover-soil texture combination (with certain vegetation water content) within a pixel
  - Assume uniform soil moisture
  - Minimize cost function between modeled and measured TB



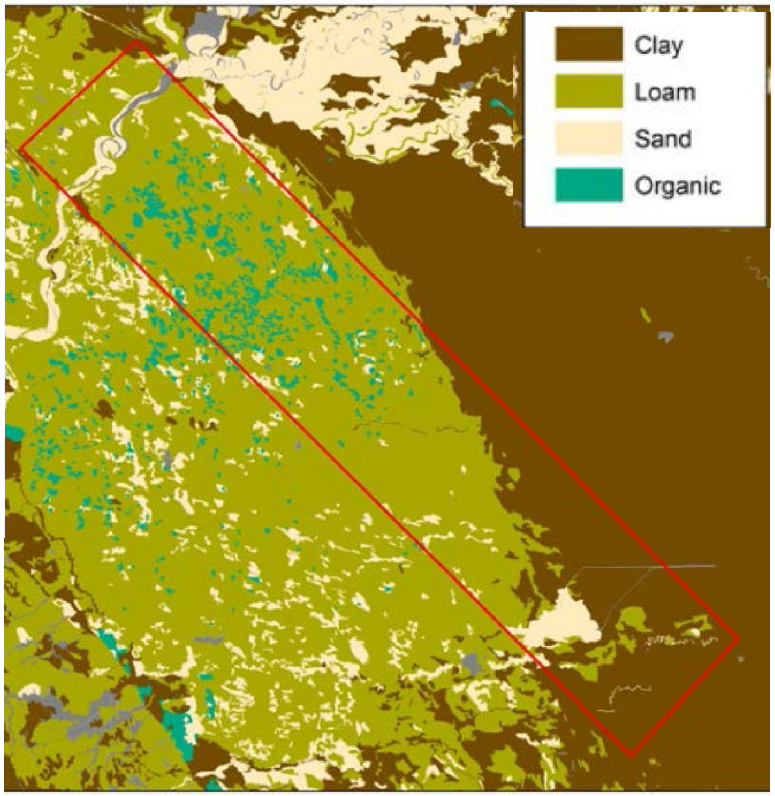


# Land Cover and Soils

Land Cover

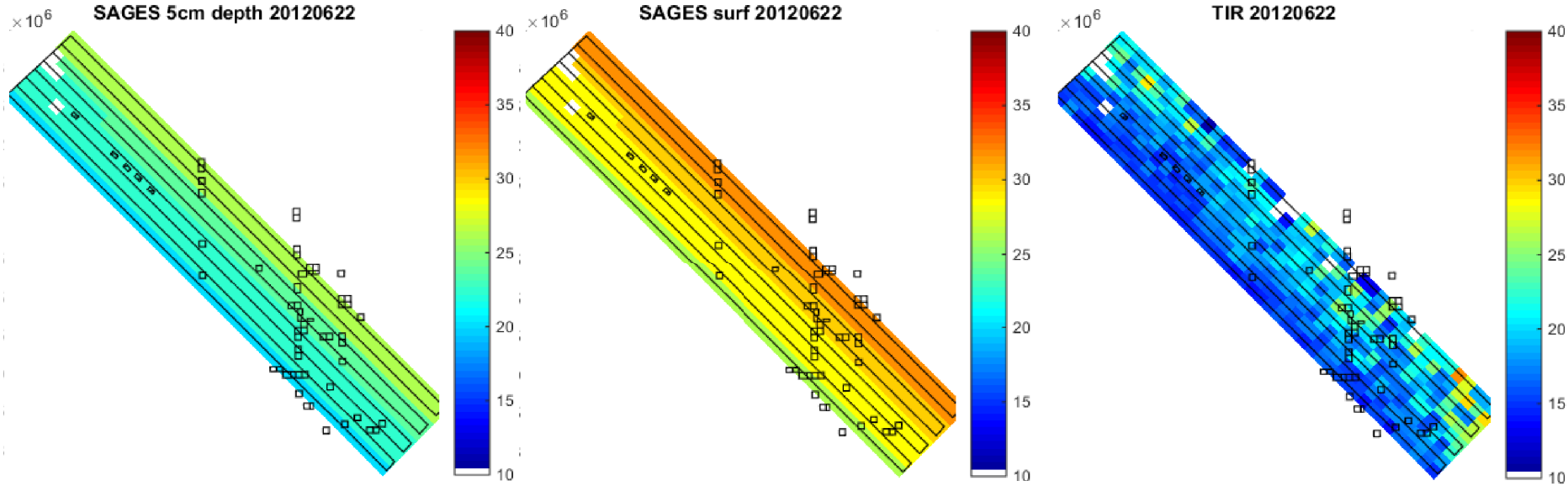



Soil Texture



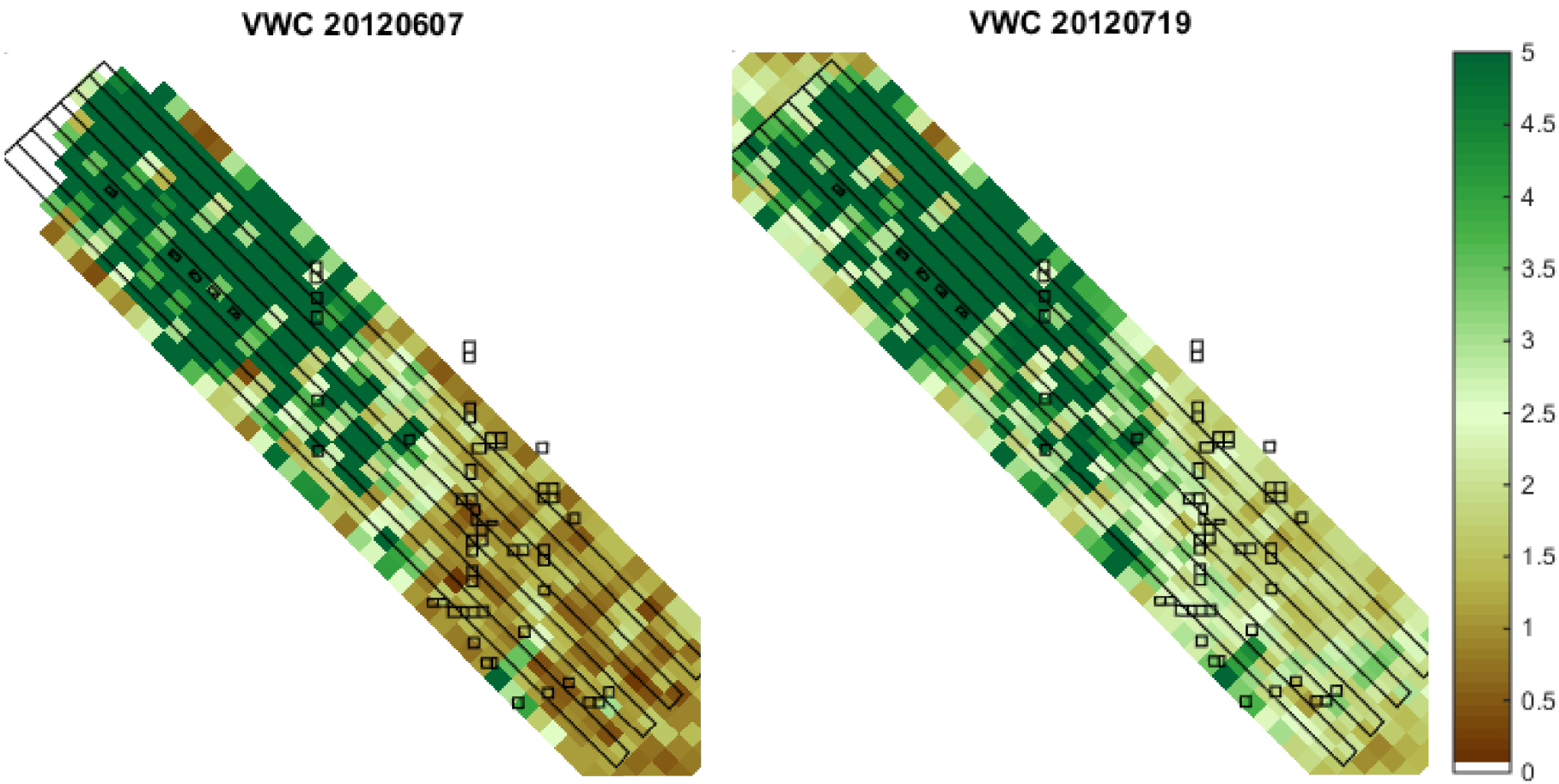

- The crop and land cover map was produced from a supervised classification of optical (SPOT and DMCii) and RADARSAT-2 imagery
  - Land cover map simplified to 8 main classes
- AAFC high resolution soil texture map over Canada

# Physical Temperatures




- Permanent monitoring stations (temperature measurement for skin and 5 cm depth) were used to estimate soil temperature at the time of the flights
- Airborne TIR measurements were used in vegetation temperature estimation
- For the algorithm:
  - Tsoil = (T5cm+Tskin)/2
  - Tveg = (TIR+Tskin)/2
- The evolution of the temperatures during the day are clearly visible in the images

# Vegetation Water Content

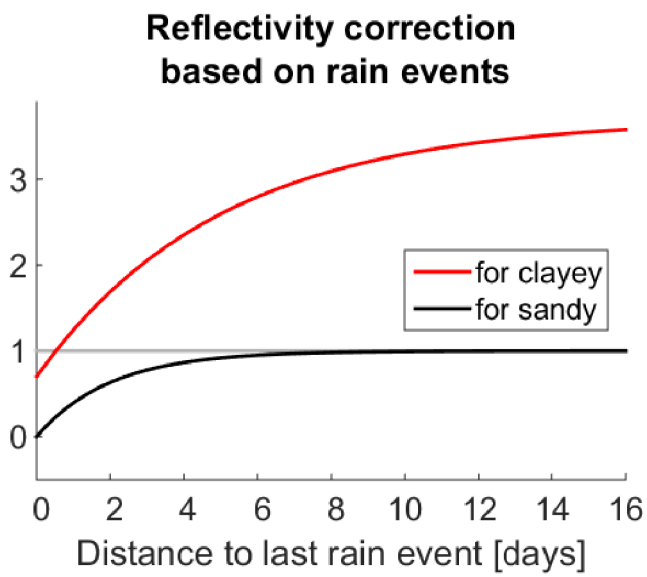



- Based on Rapid Eye and SPOT vegetation indices (by Mike Cosh, USDA)

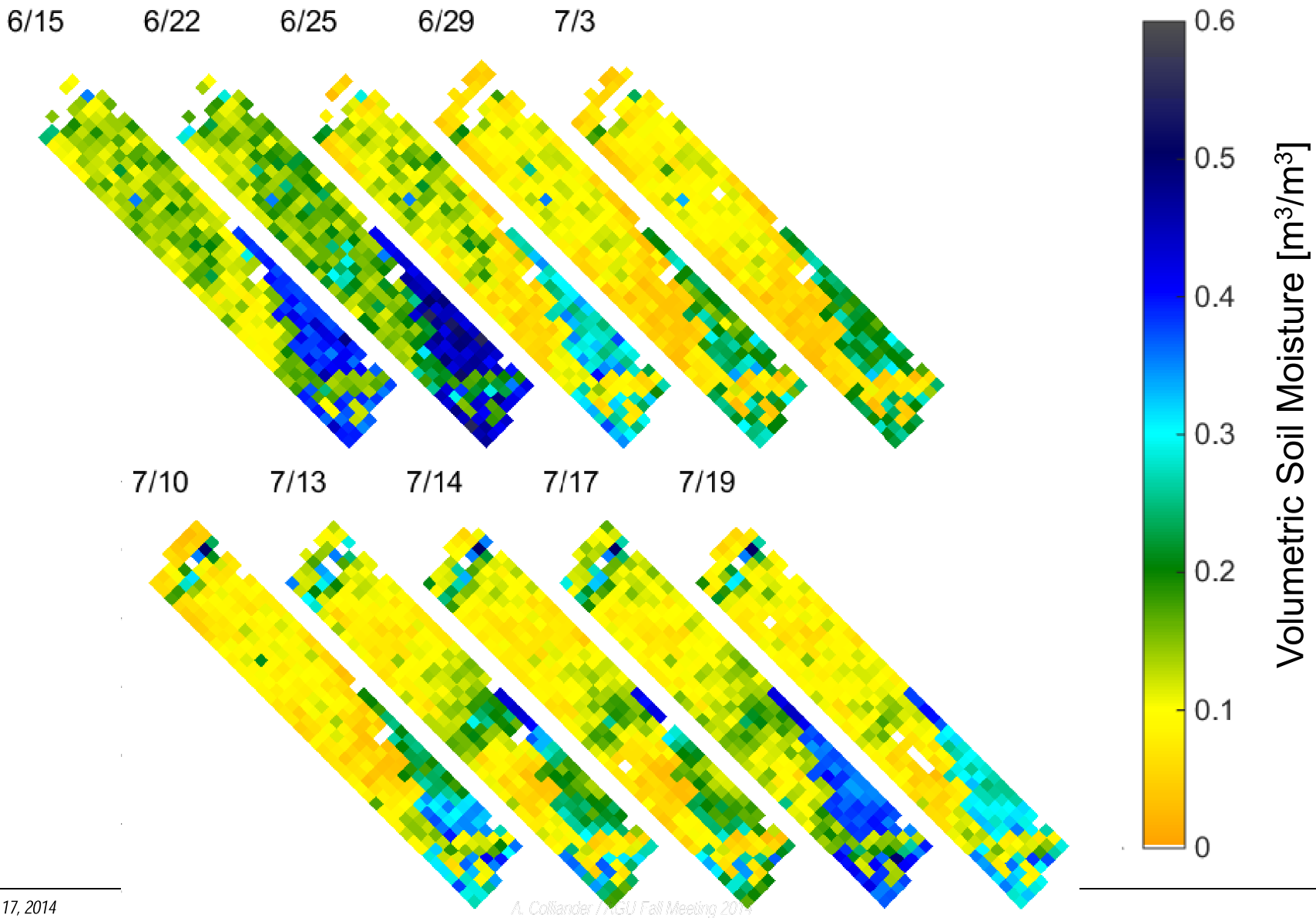
# Model Parameters

## Parameters

| | Land Cover | $b_H$ | $\omega_H$ | RMS [cm] |
|---|---|---|---|---|
| 1 | Unclassified | 0.10 | 0.05 | 0.5 |
| 2 | Water | - | - | - |
| 3 | Urban | - | - | - |
| 4 | Shrub | 0.10 | 0.05 | 0.5 |
| 5 | Wetlands | 0.10 | 0.05 | 0.5 |
| 6 | Pasture | 0.10 | 0.05 | 0.5 |
| 7 | Cereals | 0.08 | 0.05 | 0.5 |
| 8 | Corn | 0.15 | 0.05 | 0.5 |
| 9 | Canola | 0.12 | 0.05 | 0.5 |
| 10 | Soybean | 0.10 | 0.05 | 0.5 |
| 11 | Broadleaf | 0.03 | 0.11 | 0.5 |

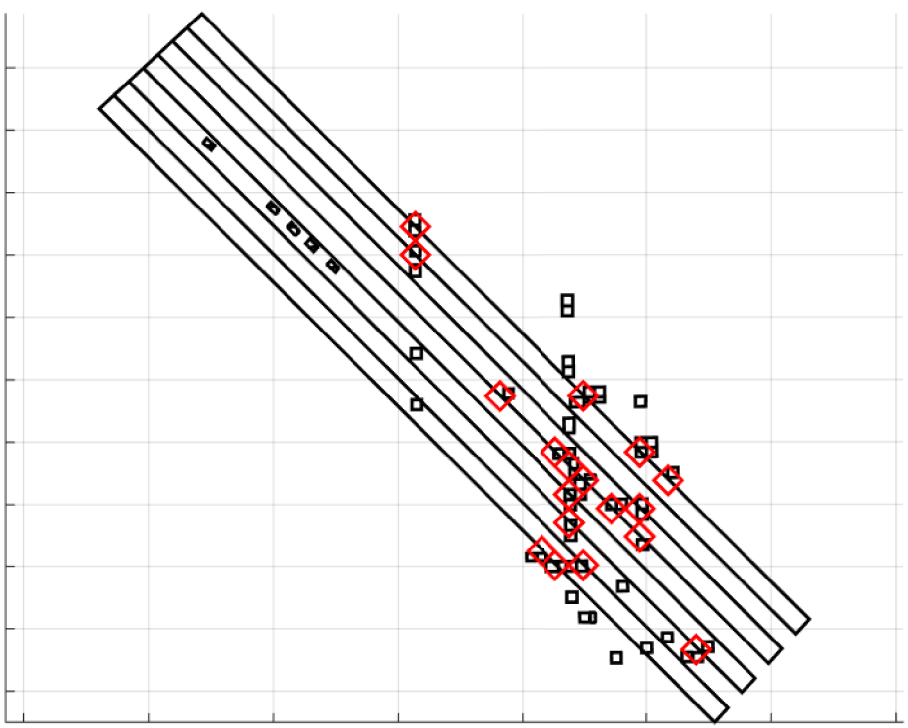


# Soil Moisture Maps



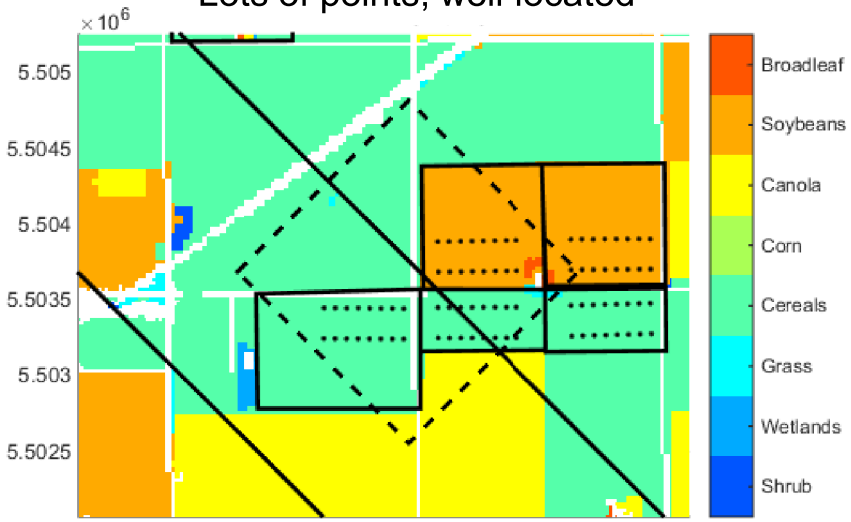
# Validation

- Define test pixels
  - At least 10 in situ measurements within a pixel
  - The nearest measurement cannot be farther away than 500 meters from the pixel center

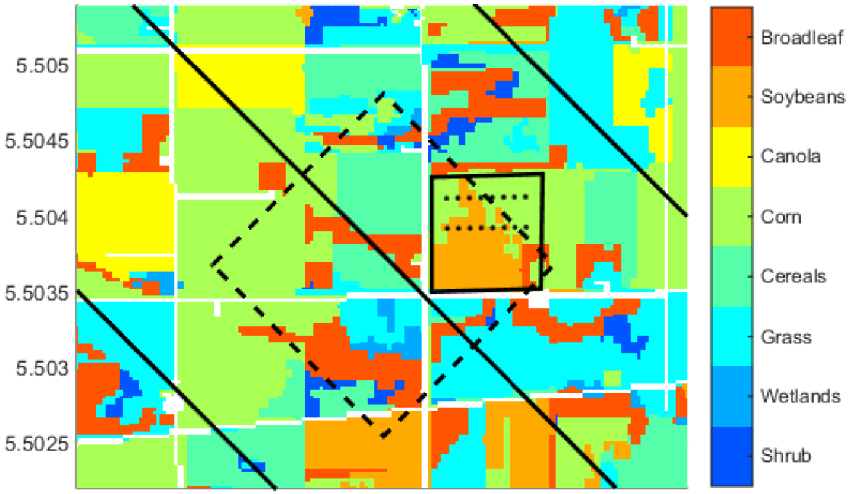


# Validation

Lots of points, well located

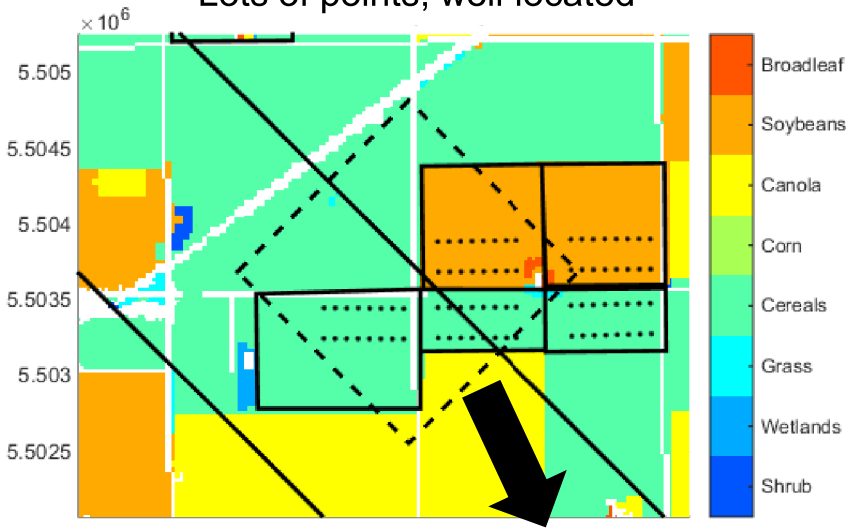


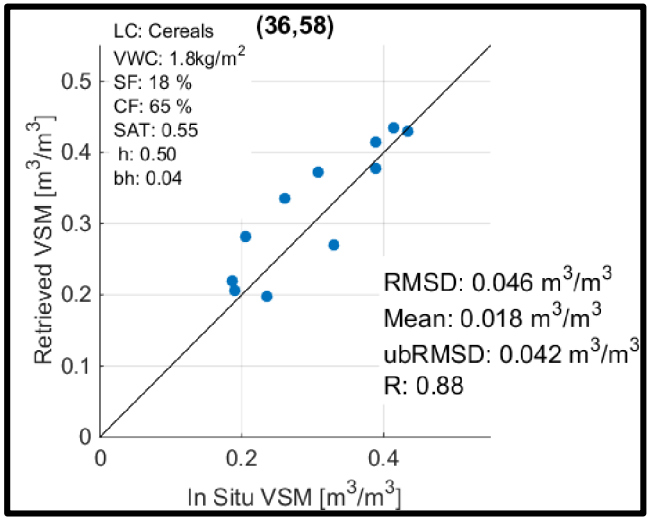

Minimum number of points, poorly located



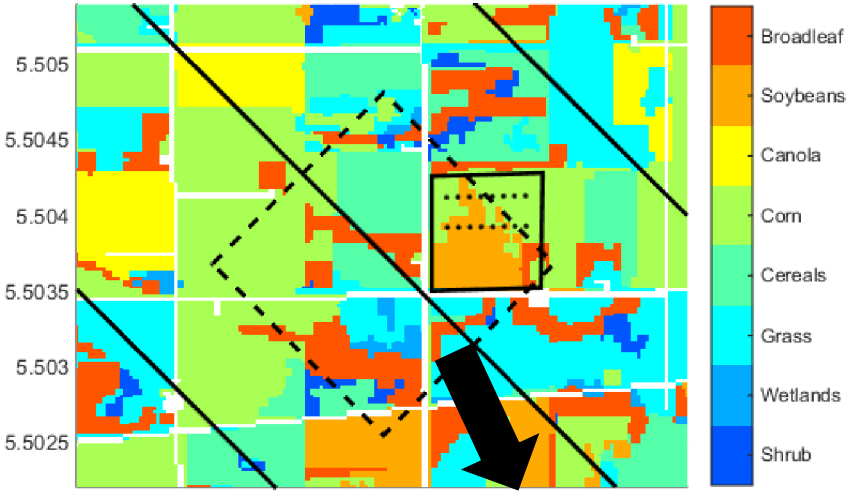
# Validation

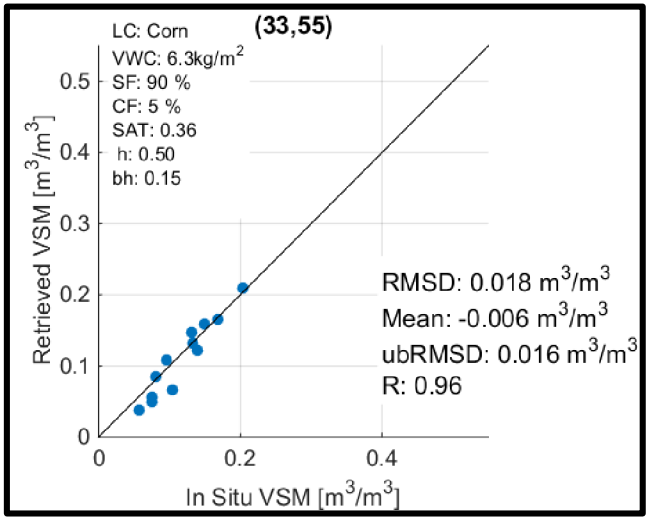
## Lots of points, well located



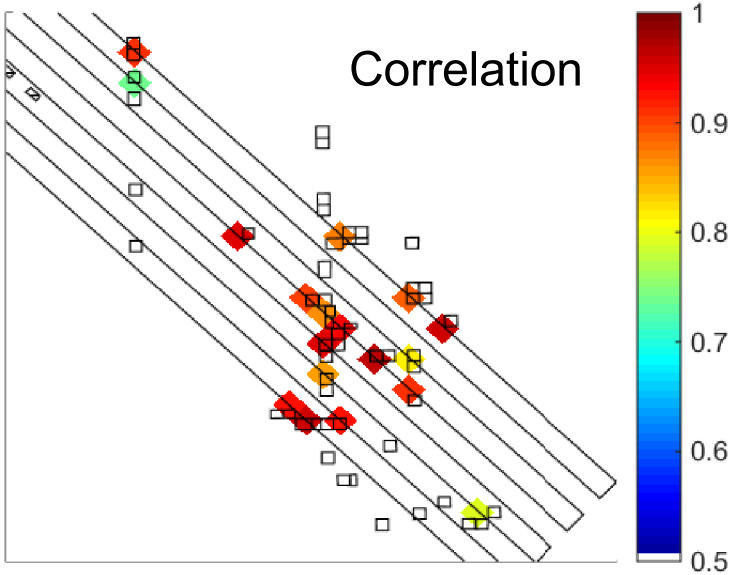




## Minimum number of points, poorly located

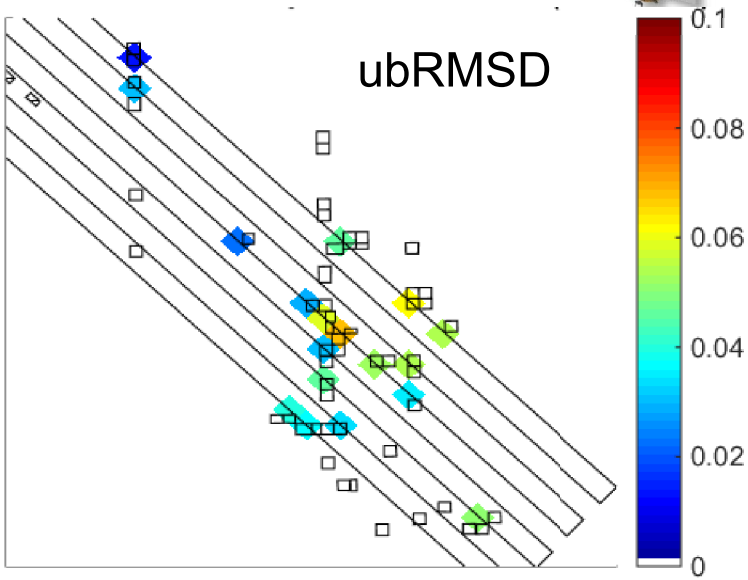


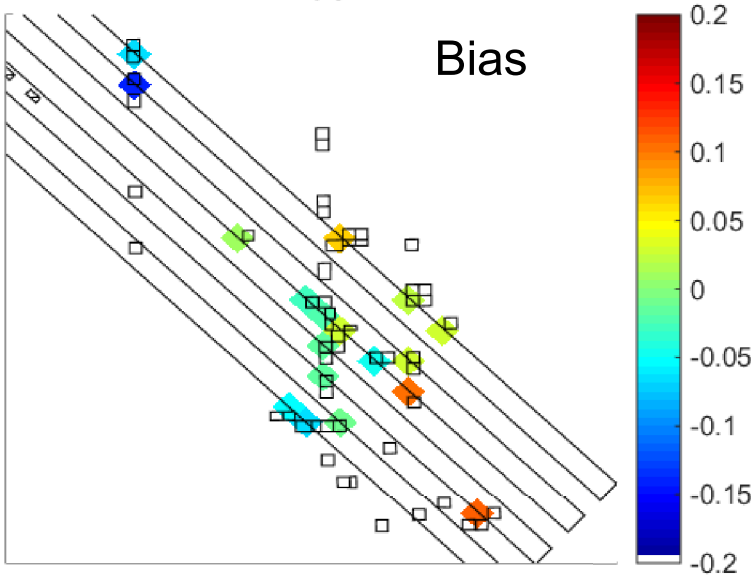



# Validation: Summary

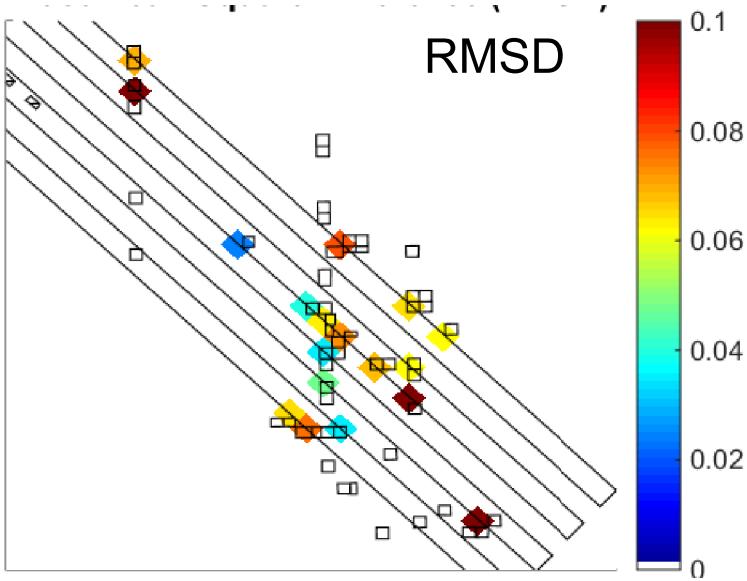



Relative metrics
very good
for ALL test pixels




Bias issues
for a few of
the test pixels



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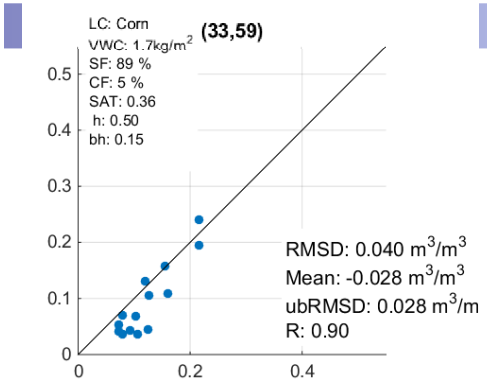
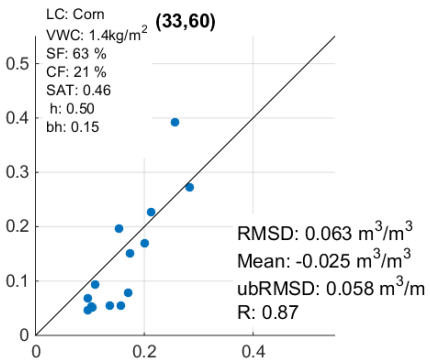
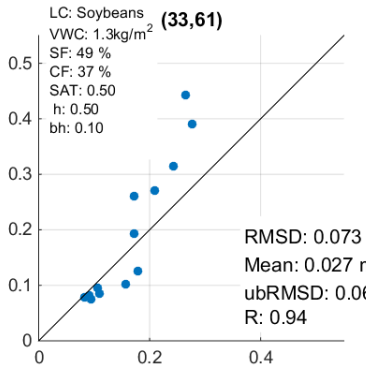
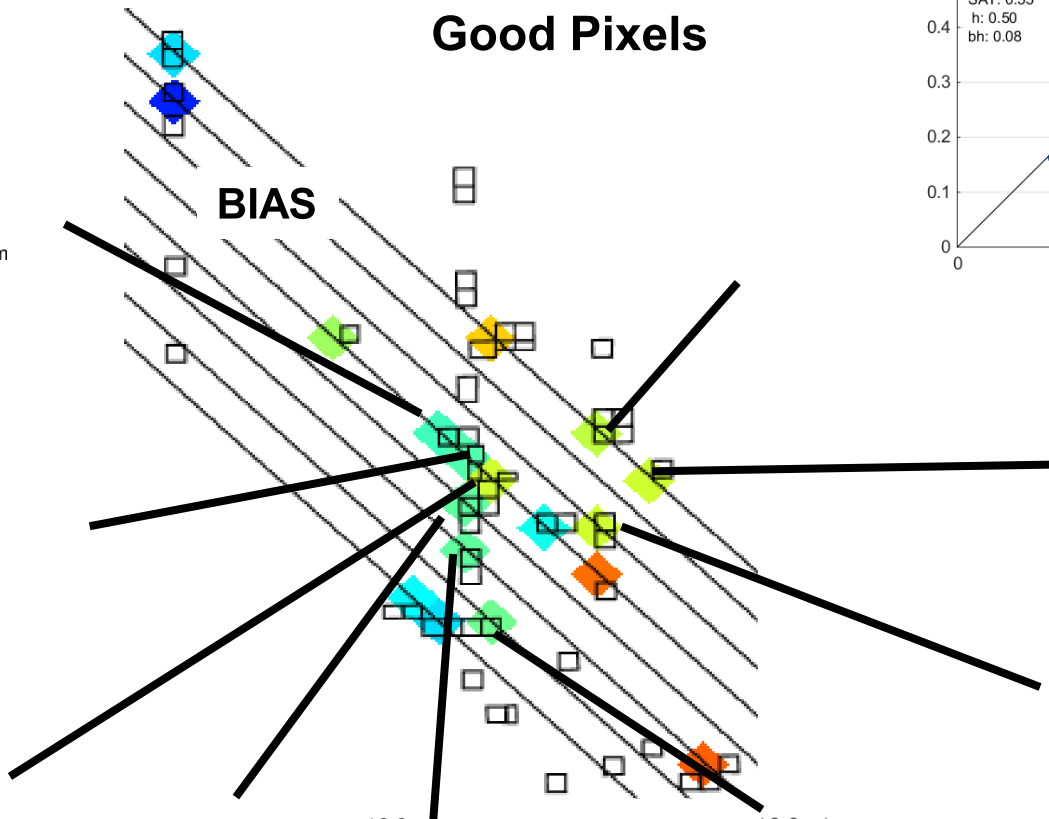
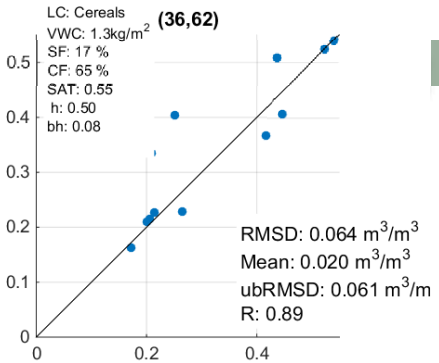
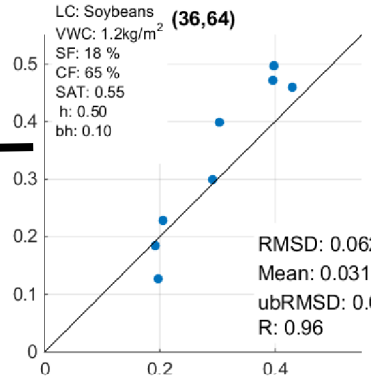


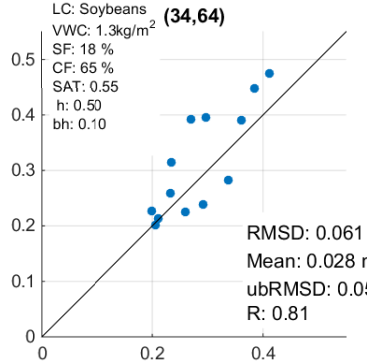



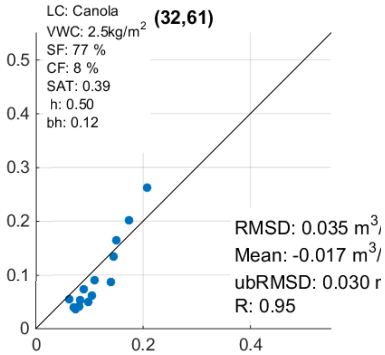



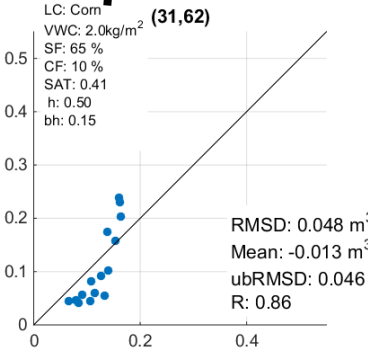



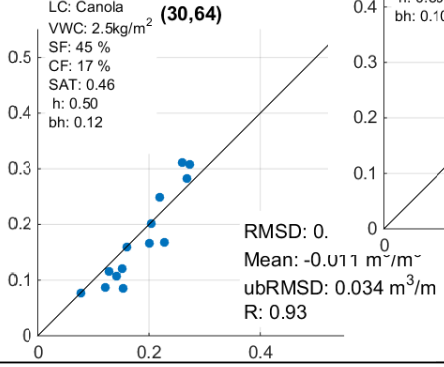



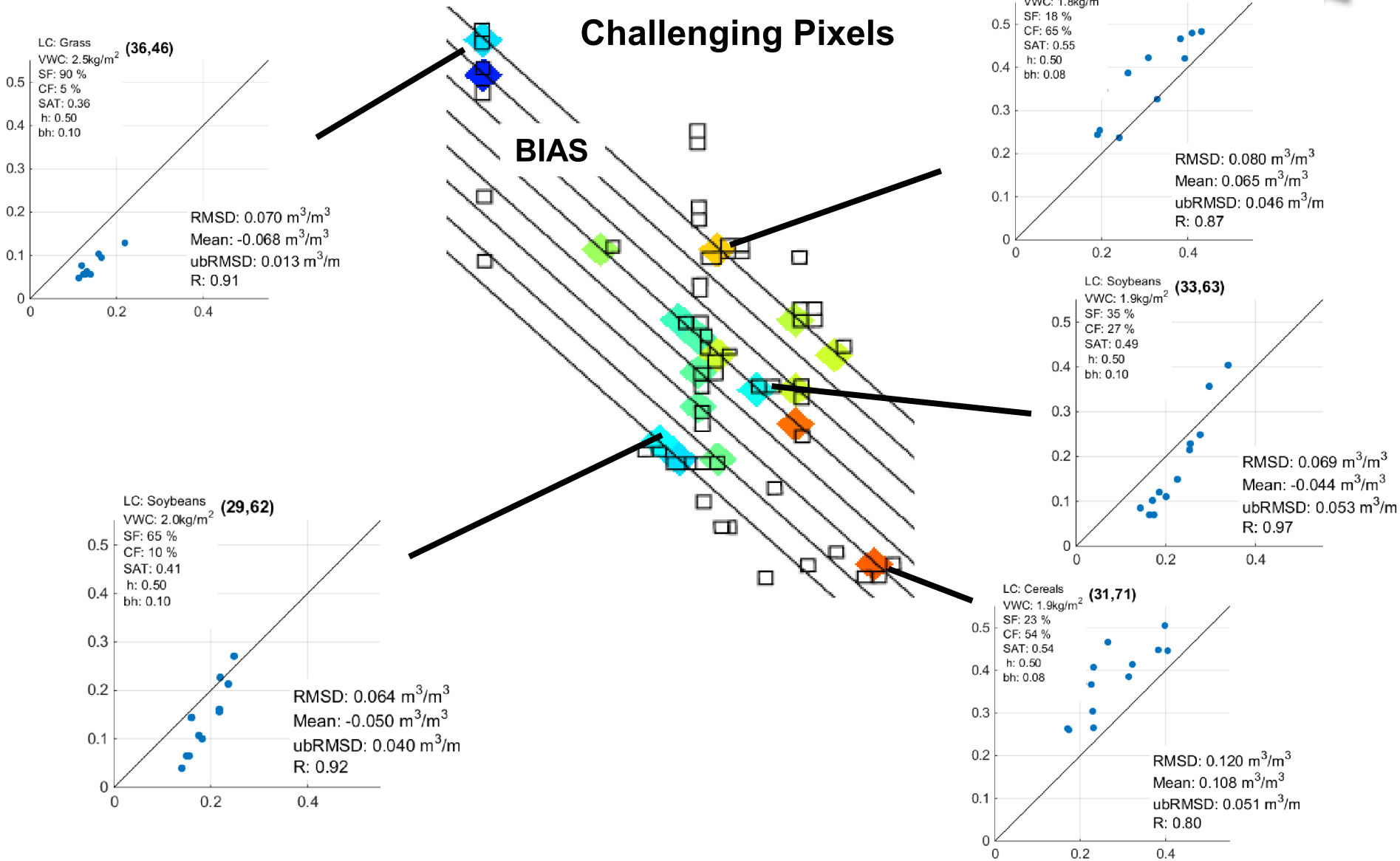



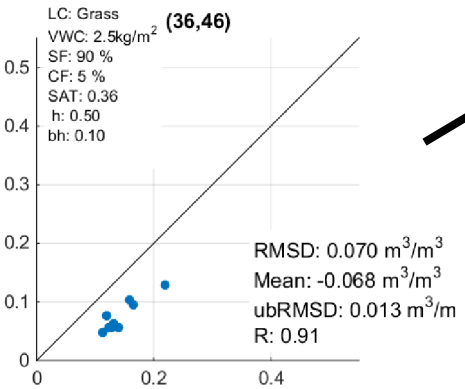



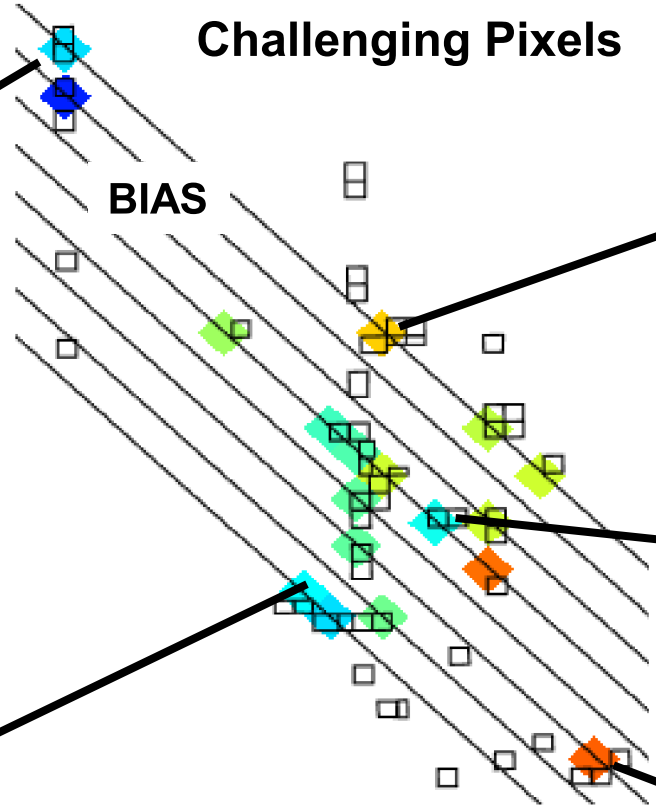



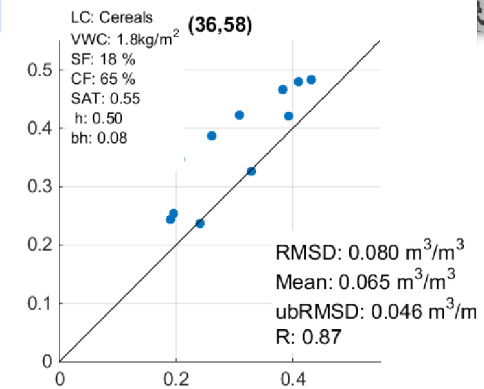
# Validation: Summary

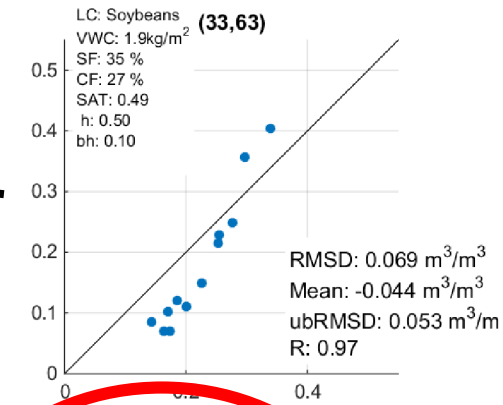


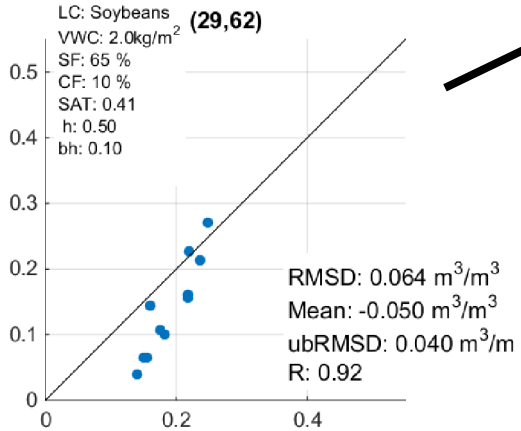
# Validation: Summary

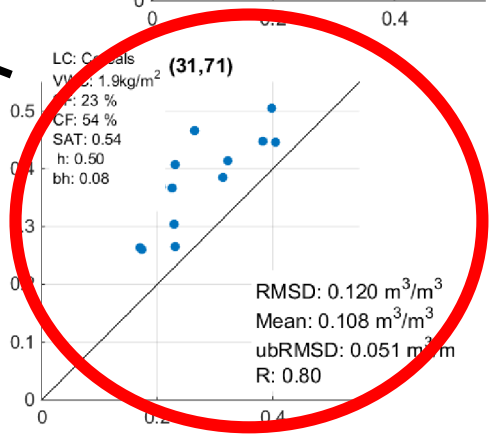


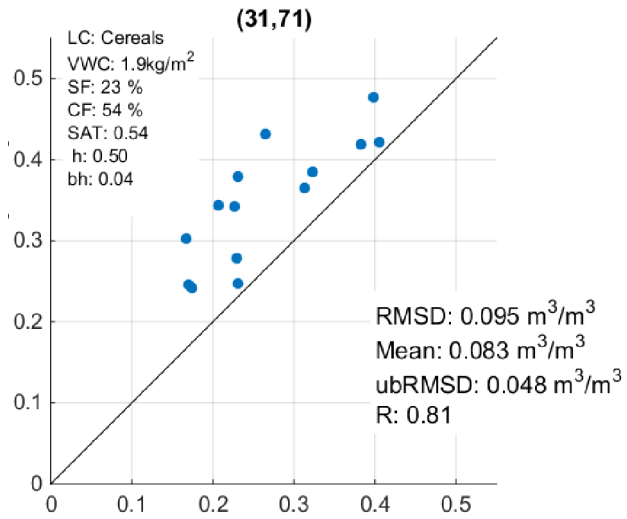



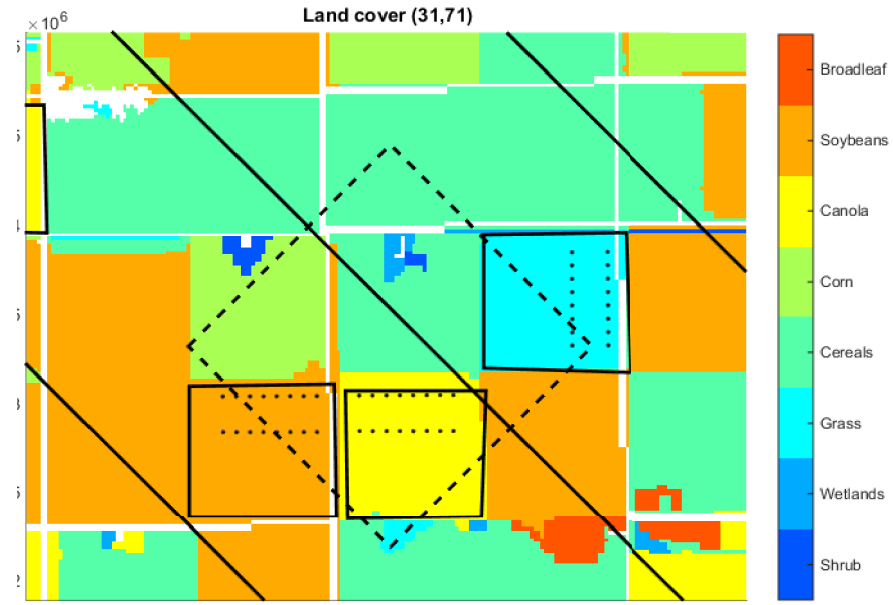



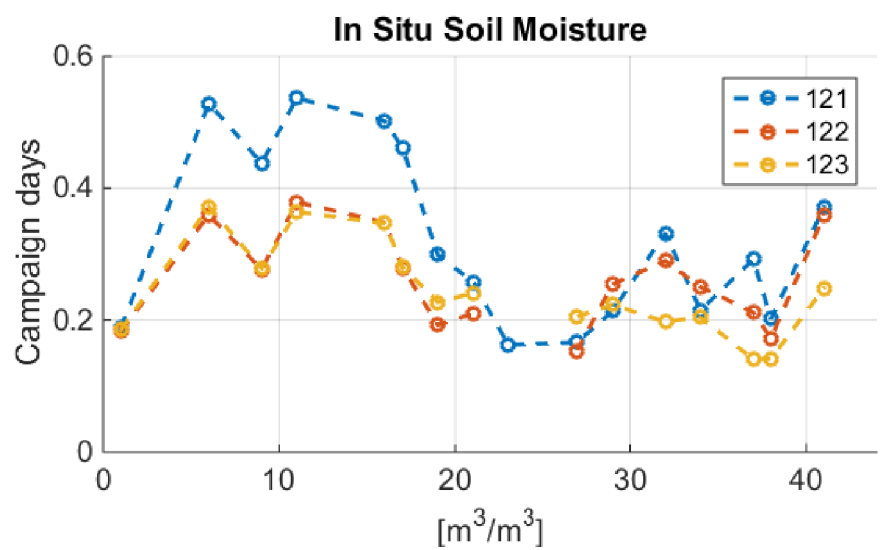



# Example of a problematic case




- Complex land cover in the pixel
- Pasture has very different soil moisture from the other two measured fields



# Conclusions

- Soil moisture retrieved for the SMAPVEX12 domain based on the PALS radiometer measurements
  - Parameterization based on the low-altitude high-resolution flights
- Validation based on the in situ measurements
- Results show good performance over most of the validation pixels

- Next steps:
  - Adjustments for the grassland/forest mixtures and forested areas
  - Once validation complete the retrieved soil moisture will be distributed through the NSIDC site