Intelligent Irrigation by fusion of spectral and synthetic aperture radar (SAR) imagery

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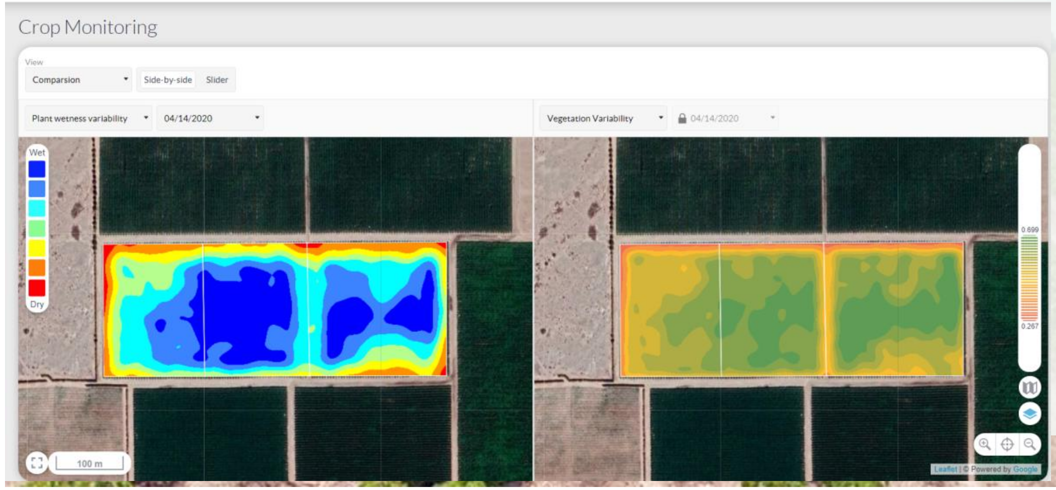
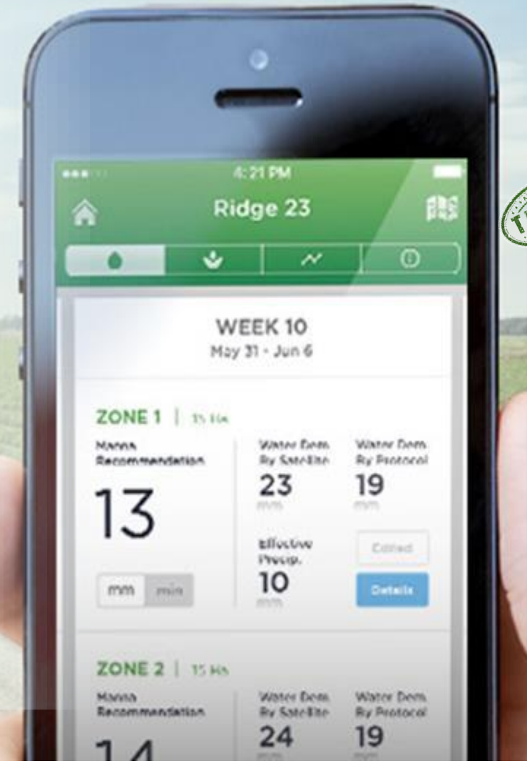
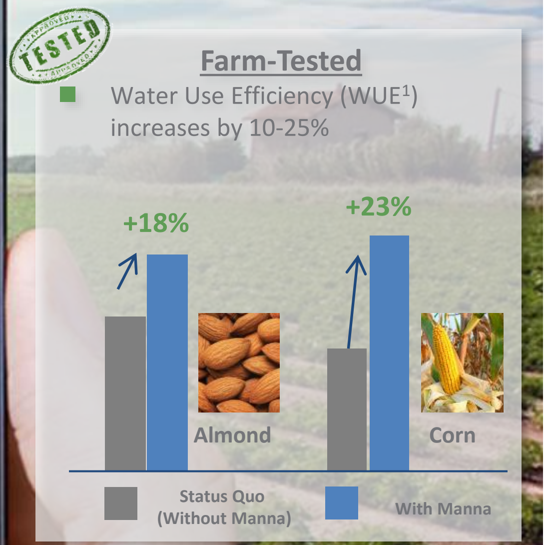
Manna Irrigation at a Glance

Provide a sensor-free, site specific, dynamic irrigation recommendations and crop monitoring for better Water Use Efficiency

- No hardware needed
- Software subscription model
- Field-tested
- 150,000 hectares in 11 countries, 50 crops







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How to conduct sensor-free irrigation decision making? The importance of the crop coefficient (Kc)

Crop evapotranspiration (ETc) = reference evapotranspiration (ET0) * Kc

Kc - represents the crop's relative water demand based on its characteristics and growth stage

Tw3 site. Biometeorology Lab, Environmental Science, Policy and Management, UC Berkeley (with permission)

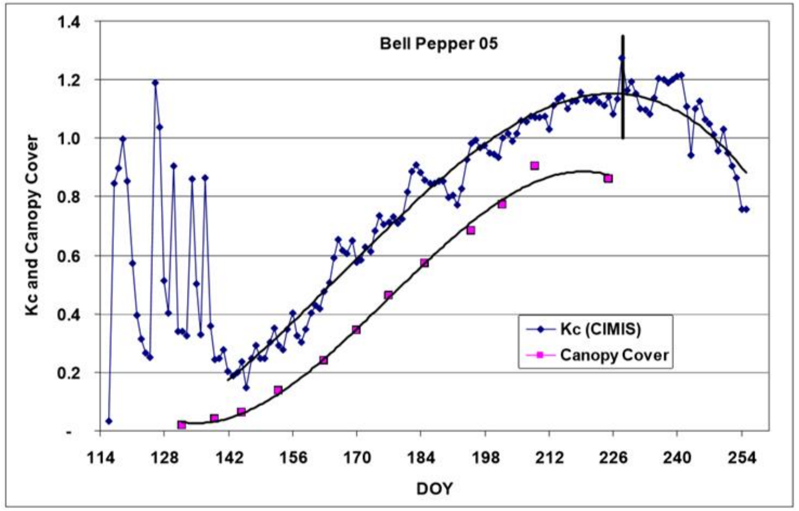
How to monitor and determine Kc :

- Lysimeter or flux tower
- Crop measurements: Kc as function of vegetation fraction (Vf) or leaf-area-index (LAI) (Allen and Pereira, 2009)
- Imagery: globally coverage by Landsat and Sentinel platforms, where the Kc is estimated as function of spectral-vegetation-indices

  Dis-advantages:

  - cloud cover
  - "Seesaw" in time series data

This presentation will outline how to solve these issues with radar data and smooth operation



Johnson, L.F., Trout, T.J., 2012. Remote Sens. 4, 439–455.

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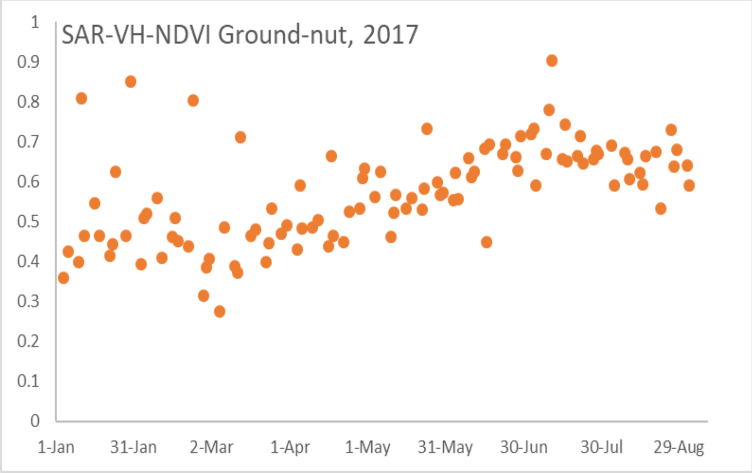
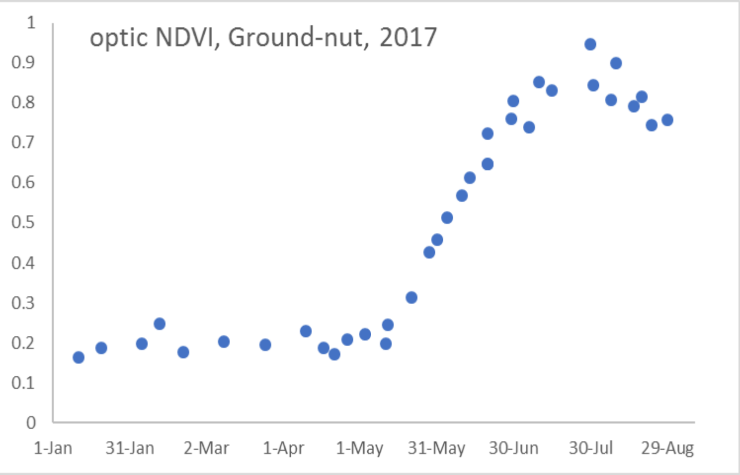
Fused SAR and optic to estimate Kc : Knowledge gaps and objectives

Smooth by local weighted regression :
What is the best weighted parameter?





Objective 1: define (1) best weighted factor for SAR and (2) best for optic

Satellite index: What is the best index to estimate Kc?

- Optic – NDVI as proposed by Tasumi et al, 2006 and evaluated by Beeri et al 2019
- SAR – 4 indices were evaluated, each was transformed to be like-NDVI:
    1. VH = (VH-40)/(-3 - -40)
    2. VH-VV = ((VH-VV) - 15)/(0 - -15)
    3. VH+VV = ((VH-VV) - 50)/(-15 - -50)
    4. SNI =2.5*(VH-VV)/(VH+VV). SNI = Sentinel-Normalized-Index

Objective 2: report accuracy of each SAR index, accuracy of NDVI and the integration accuracy

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Integration workflow

1. Image calculation

- Sentinel-1: VH and VV
- QA
- Calculate 4 SAR indices

- Optic: Red, NIR & QA
- QA
- Calculate NDVI

2. Smooth time series until current image

Smooth: Local weighted regression
Weighted = 10 to 50

Smooth: local weighted regression
Weighted = 4 to 20

Merge and Smooth

3. Output fused data

Transformed output Fused value to Kc, regardless of sensor type

4. Evaluate outputs to ensure system independency

Transformed output SAR value to Kc

Transformed output optic value to Kc

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Evaluation Methods: Orchards

Kc calculation in this study:

Orchards LAI

- 2-3 sites in commercial orchards: Almonds, Olives, Apples and Pomegranate.
- Each site was an area of around 30x30 m
- leaf-area-index (LAI) for each site, each sampling date: 200 readings (above weeds)
- LAI measurements every 1-2 weeks in spring and every 4-6 weeks after
- Crop Kc was calculated from the LAI as proposed by Allen and Pereira, 2009

Total Kc - 62: Almonds 18, Apples 8, Olives 18 and Pomegranate 18

Flux tower Kc

- Datasets from 4 flux towers of Almonds (ASM, ASH) and Pistachio (PSL, PSH), from USA (https://ameriflux.lbl.gov/)
- Timeframe: February-March 2017
- Calculation of daily Kc as in Beeri et al, 2019

Total flux tower Kc - 44: Almonds 20, Pistachio 24

Imagery Kc

- SAR and optic data was collected from Google Earth Engine
- Imagery data was collected at the day of crop measurement or until ± 2 days
- Imagery Kc was calculated as proposed by Tasumi et al, 2006

Total imagery Kc - 106: SAR 85, NDVI 54

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Evaluation Methods: Orchards

Model evaluation

Objective 1: weighted factor for SAR (10, … 50) and for optic (4, 8, … 20)

Objective 2: accuracy of each of the four SAR indices, accuracy of NDVI and the integration accuracy

Imagery index	Weighted factor for optic	Weighted factor for SAR	Fused
NDVI	No-smooth, 4, 8, 12, 16, 20		
VH		No-smooth, 10, 20, 30, 40, 50	NDVI & VH
VH-VV		No-smooth, 10, 20, 30, 40, 50	NDVI & VH-VV
VH+VV		No-smooth, 10, 20, 30, 40, 50	NDVI & VH+VV
SNI		No-smooth, 10, 20, 30, 40, 50	NDVI & SNI

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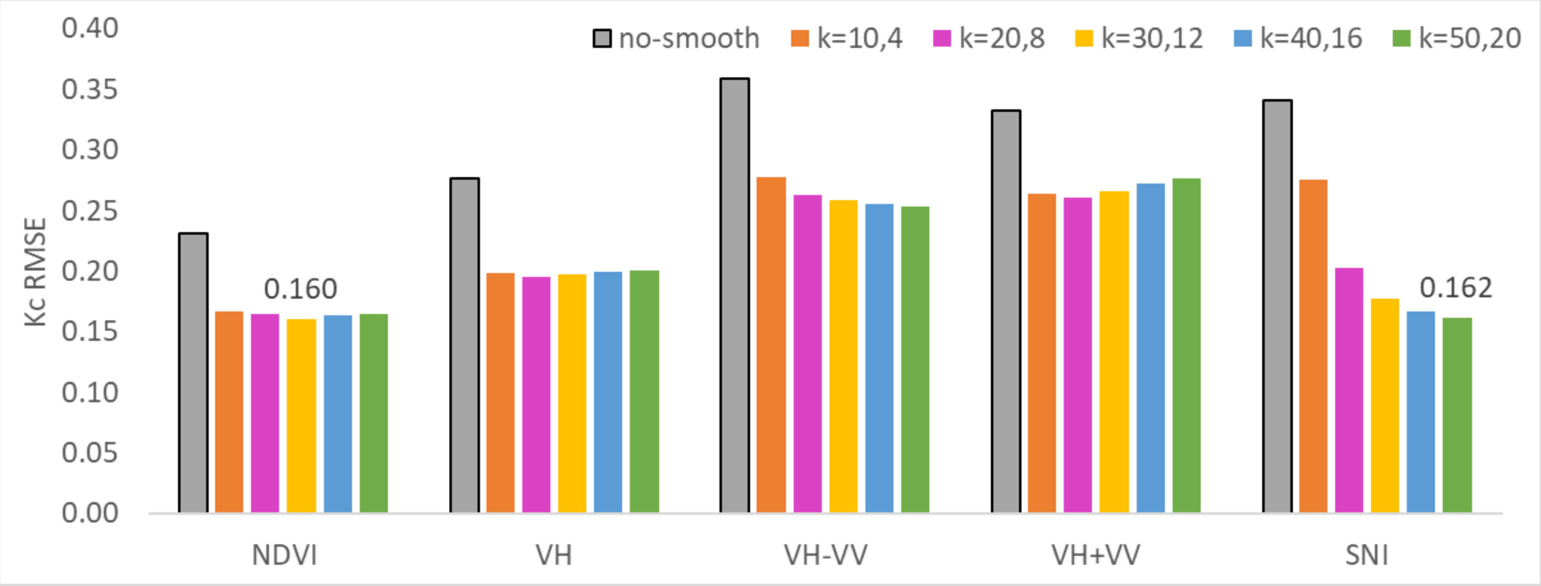
Results: best smooth kernel and best SAR index

Figure conclusions:

1. The smooth method improve accuracy by 20-50%
2. The smooth improve RMSE of SAR to be as the optic-NDVI and as published RMSE
3. Best accuracy of SAR achieved by the SNI



Published Kc RMSE

RMSE:	Crops	Reference
0.16-0.19;	Corn, Alfalfa, Soybean.	Kamble, et al, 2013.
0.04-0.30;	Corn, Barley, Olives	Pacos et al, 2015.
0.14-0.17;	Rice, Forest	Park et al, 2017
0.08-0.09;	Corn, Alfalfa, Soybean.	Beeri et al. 2019.

RMSE – range: 0.04-0.30, mean: 0.15-0.18

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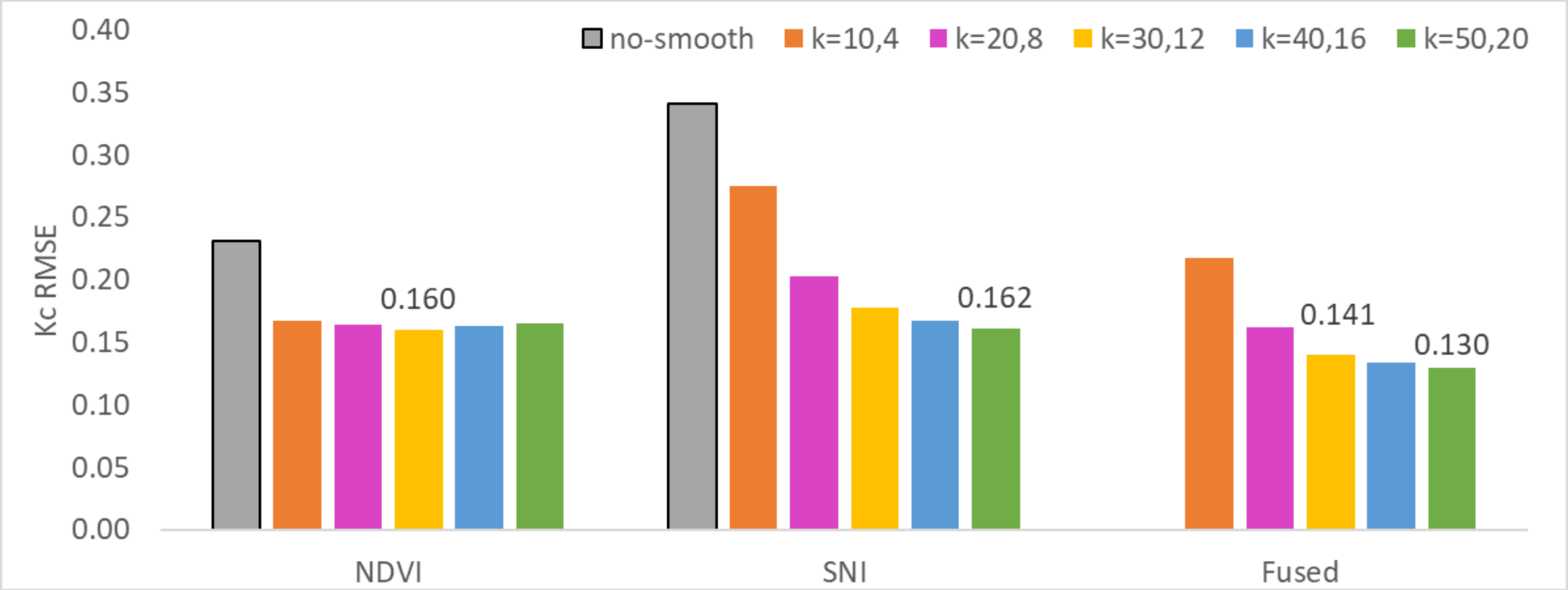
Results: Fused of NDVI and SNI

The fused data set not only increase number of data points (from 57 or 38 to 62) but also **improve accuracy**.



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Results: Does accuracy change among SAR indices for different crops?

1. The VH has the lowest RMSE for Apples and Pomegranate, while the SNI has the lowest for almonds and Olives
2. In three out of four crops (yellow) the SAR is more accurate than the optic
3. The Fused of NDVI & VH have the lowest RMSE for Pomegranate, yet the Fused data of NDVI & SNI has RMSE below <0.15 for any crop

	NDVI	VH	VH-VV	VH+VV	SNI
Almonds	0.121	0.222	0.252	0.349	**0.187**
Apple	0.169	**0.166**	0.201	0.220	0.205
Olives	0.163	0.268	0.341	0.348	**0.152**
Pomegranate	0.204	**0.091**	0.149	0.104	0.124
Overall	0.165	0.201	0.253	0.276	0.162

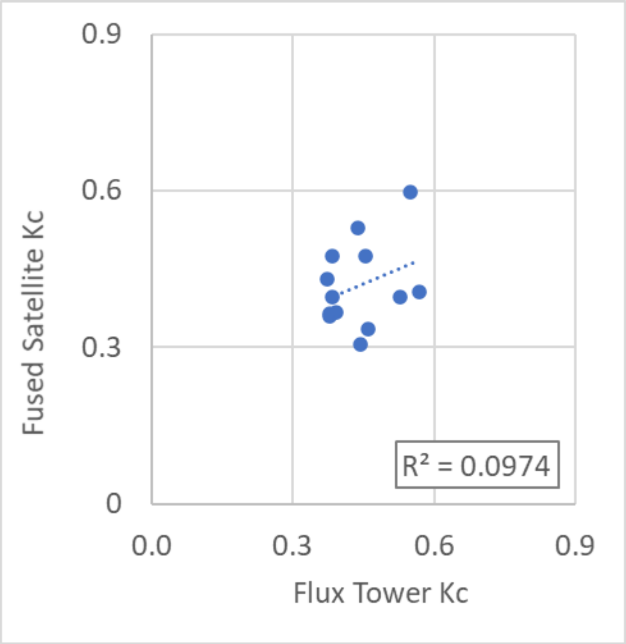
Fused		**NDVI & VH**	**NDVI & VH-VV**	**NDVI & VH+VV**	**NDVI & SNI**
Almonds		0.179	0.215	0.278	0.125
Apple		0.168	0.190	0.223	0.143
Olives		0.265	0.340	0.348	0.142
Pomegranate		0.100	0.142	0.128	0.116
Overall		0.190	0.240	0.262	0.130

Results: How did the fused SNI-NDVI compare to flux tower Kc?

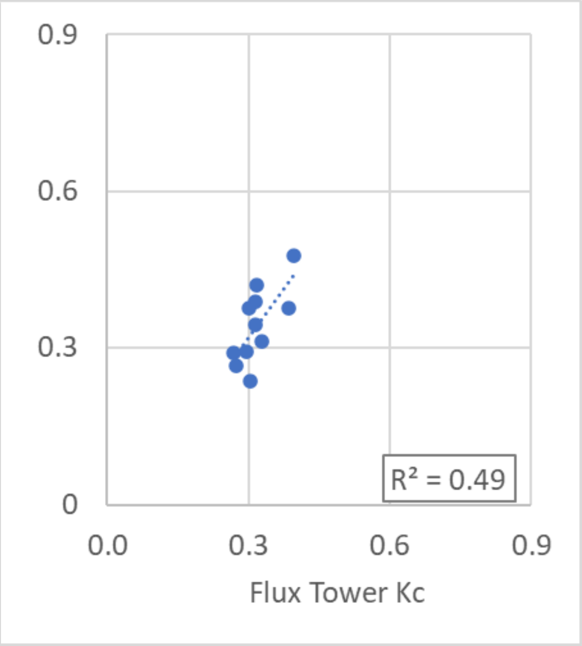
The independent dataset, with different method to calculate Kc.

1. RMSE for each flux tower data is better than published for optic satellites, although include 68% SAR data

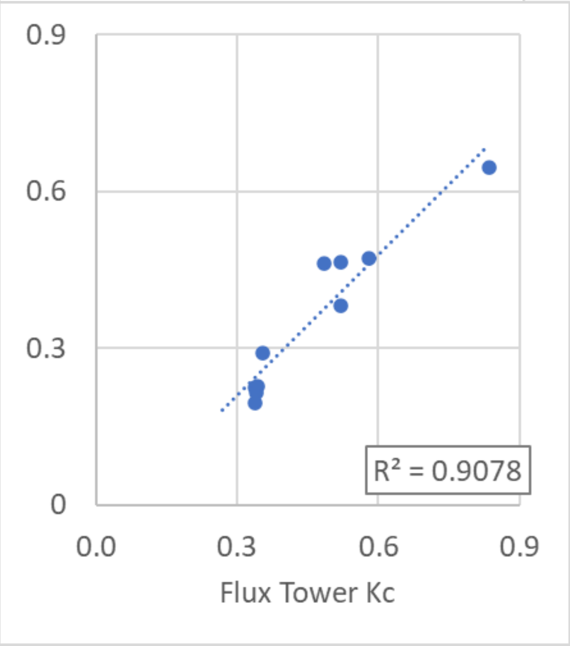
Pistachio (PSH).
RMSE = 0.088



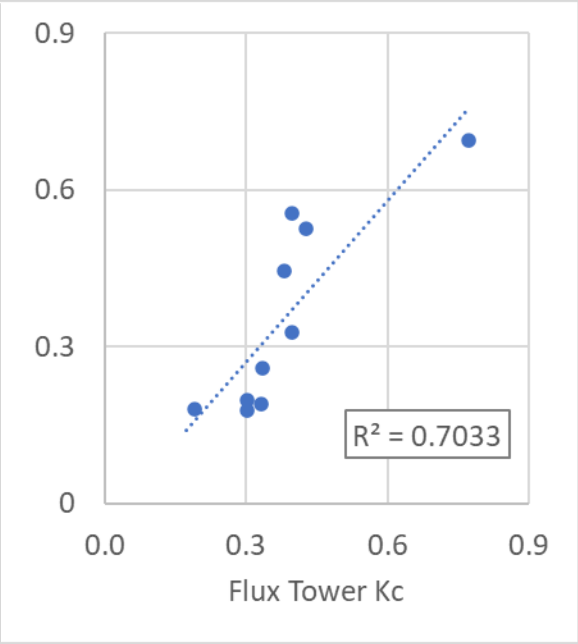
Pistachio (PSL).
RMSE = 0.058



Almonds (ASM).
RMSE = 0.106



Almonds (ASM).
RMSE = 0.103



Summary

The SAR dataset:

- Increase number of datapoints: Israel – SAR = 57 vs. Optic = 38; USA - SAR = 28 vs. Optic = 13
- Ensure at least a data point once a week
- The SNI accuracy is at least as good as the optic estimations

Smooth operation:

- The smoothing method increases accuracy
- The smoothing method is more important to the SAR datasets, as we did not smooth spatially (multi-looking or Lee-filter) in order to preserve pixel size

Overall accuracy - the accuracy of the optic and the SAR, separately and combined, is in the range of published Kc accuracy by optic satellites

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Thank you

Questions?

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