# This presentation premiered at WaterSmart Innovations

watersmartinnovations.com

watersmart
INNOVATIONS

# High Resolution Geospatial Mapping of Actual Evapotranspiration Using Small UAS Based Imagery for Site Specific Irrigation Management


## Abhilash Kumar Chandel*

**B. Molaei, L.R. Khot, T.R. Peters and C.O. Stöckle**

*Ph.D. Student

Center for Precision and Automated Agricultural Systems

Department of Biological Systems Engineering

Washington State University


**WaterSmart Innovations**
Conference and Exposition, 2019
Las Vegas, Nevada

Washington State University

World Class. Face to Face.

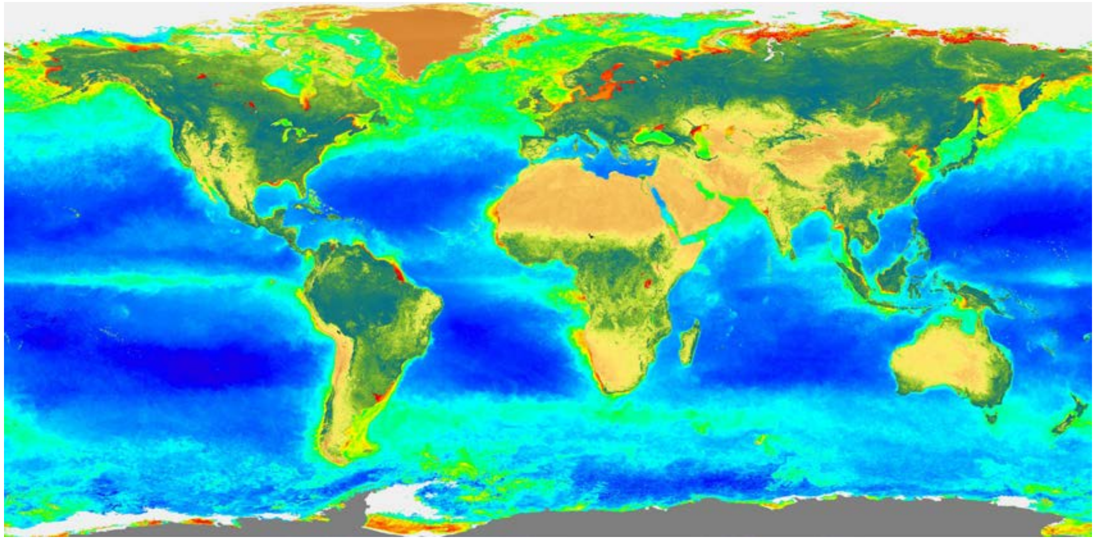
WaterSmart Innovations Conference & Exposition

# Outline

- ❑ **Background**
- ❑ **Hypothesis and objectives**
- ❑ **Methods**
- ❑ **Results**
- ❑ **Conclusions**
- ❑ **Future plan and scope**

# Background

## Water: the most critical resource



Source: NASA

- Covers 71 % of earth
- 96.5 % in oceans/ seas
- Only 0.77 % of fresh water

**Agriculture**

- Accounts over 80% of the US consumptive use
- Biggest consumer of fresh water about 70% (globally)

Washington State University
World Class. Face to Face.

Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources (Oxford University Press, New York).

# Background

## Current challenges

- Population
- Food demand
- Climate change impacts
- Arid and semi arid areas
- Area under irrigation

- Fresh water availability
- Net cultivation area
- Rainfed agriculture
- Ground water

Source: Spiegel online

Conventional irrigation practices

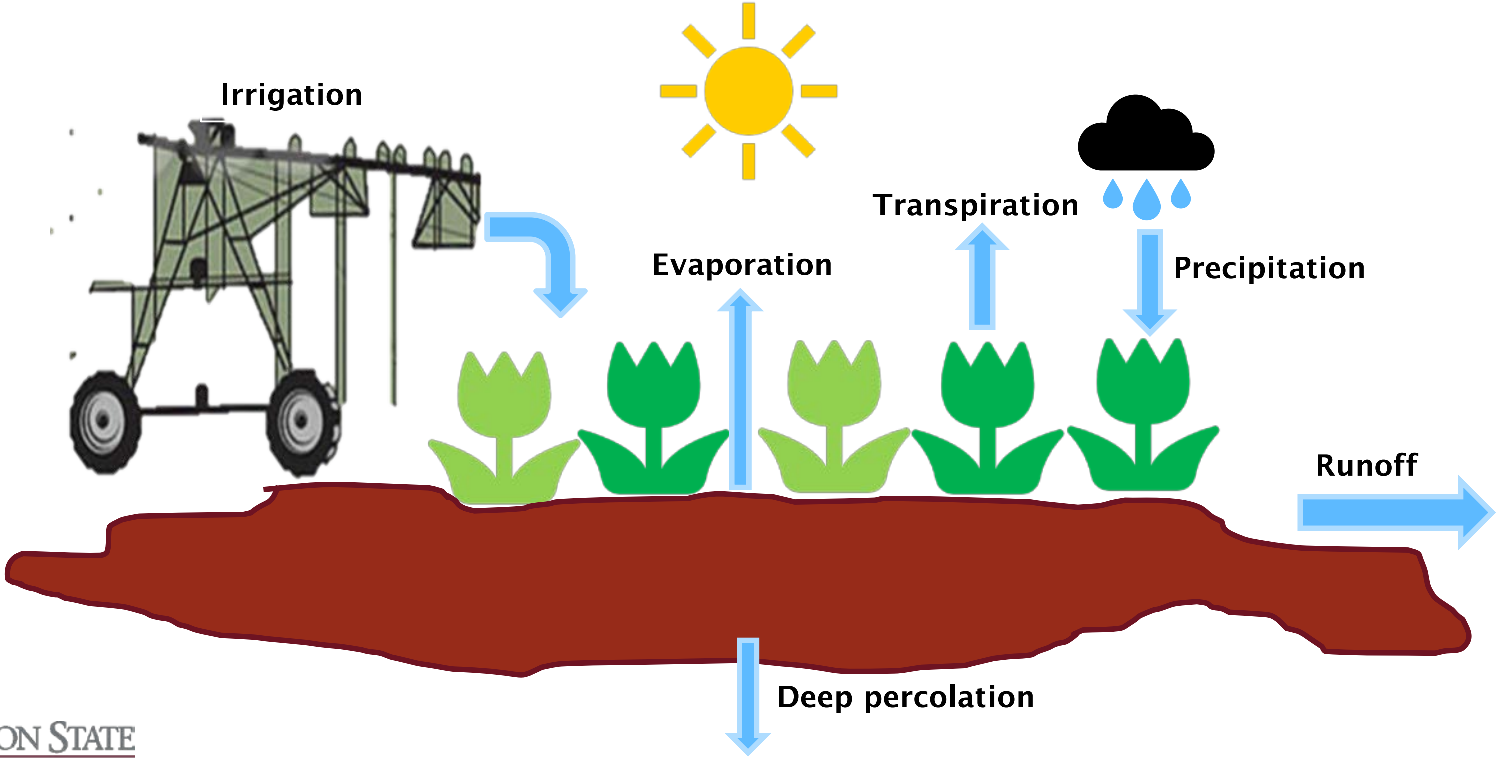
- Constant or over irrigation

*"This calls for specific/ precision irrigation management tools at local/grower level"*

# Background

- Irrigation management requires accurate estimates of actual crop water demands at field level.

- Evapotranspiration (ET)
  - Amount of water lost by plants and soil to the atmosphere
  - Indicator of actual plant water requirements



# Background

## ❑ Current methods of ET estimation

- **Small/ point scale:**
  - **Lysimeters, neutron probes, soil moisture measurements, point measurement tools etc.**
  - **Limited sampling accuracy and laborious**


**Leaf Porometer**
Source: Meter group


**Neutron probe**
Source: Good fruit grower, WSU


**Crop gas exchange measurement**


**Lysimeter**
Source: environmentalbiophysics.org


**Sap flow meter**
Source: Davis et al., 2012

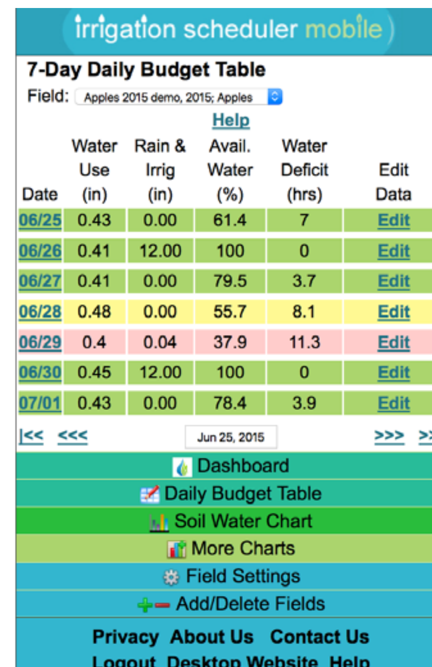
Washington State University
World Class. Face to Face.

# Background

## ❑ Weather based estimations of ET:

- **Penman Monteith method and typical crop coefficients**
- **Irrigation scheduling tools examples**
  - **WSU irrigation scheduler and AgWeather network (Washington State University),**
  - **Irrigation management online (Oregon State University)**
  - **CropManage (University of California)**
- **Limitations: standard crop coefficients may not be the same within field and globally**

Courtesy: http://www.weather.wsu.edu/



irrigation scheduler mobile

**7-Day Daily Budget Table**

Field: Apples 2015 demo, 2015; Apples

Help

| Date | Water Use (in) | Rain & Irrig (in) | Avail. Water (%) | Water Deficit (hrs) | Edit Data |
|---|---|---|---|---|---|
| 06/25 | 0.43 | 0.00 | 61.4 | 7 | Edit |
| 06/26 | 0.41 | 12.00 | 100 | 0 | Edit |
| 06/27 | 0.41 | 0.00 | 79.5 | 3.7 | Edit |
| 06/28 | 0.48 | 0.00 | 55.7 | 8.1 | Edit |
| 06/29 | 0.4 | 0.04 | 37.9 | 11.3 | Edit |
| 06/30 | 0.45 | 12.00 | 100 | 0 | Edit |
| 07/01 | 0.43 | 0.00 | 78.4 | 3.9 | Edit |

|<< <<< Jun 25, 2015 >>> >>|

Dashboard
Daily Budget Table
Soil Water Chart
More Charts
Field Settings
Add/Delete Fields

Privacy About Us Contact Us
Logout Desktop Website Help

http://weather.wsu.edu/is/

# Background

## ❑ Large scale: Remote sensing and energy balance

- **Remote sensing: satellites**
  - **Low spatial resolution ex: Landsat 7/8 (~30 m) and MODIS (1 km)**
  - **Large recurrence period (~16 days) and cloud cover limitations**
  - **Unsuitable for high resolution spatiotemporal mapping**

- **Small unmanned aerial systems (UAS)**
  - **High spatial and temporal resolution**
  - **On-demand data**

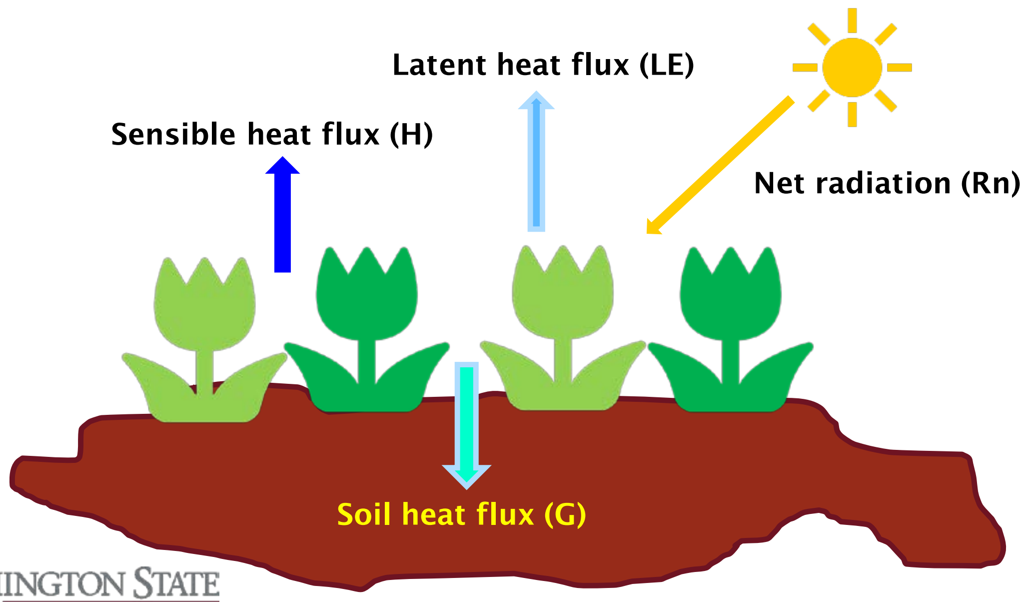
Source: earth magazine

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

## ❑ Energy balance models

- Single source (crop transpiration and soil evaporation combined)
- Dual source (separate crop transpiration and soil evaporation)
  - Complex measurements
  - Limited adaptability

- **METRIC** (Allen et al., 2007)
  - Developed for satellite-based imagery data (multispectral and thermal)
  - Widely adopted, robust and independent of crop specifications
  - Internal calibration using stressed and unstressed conditions




Energy balance concept:

$$LE = Rn - G - H\ ,$$
$$\mathrm{LE} = \lambda * ET$$

$$\lambda = latent\ heat\ of\ water\ vaporization$$

Washington State University
World Class. Face to Face.

# Hypothesis and Objectives

## ❑ Problem statement and hypothesis

- **Site specific irrigation management at field level**
- **Integration of high-resolution imagery data to energy balance model**

High Resolution Imagery + METRIC = High Resolution crop ET → Site-specific Irrigation Management

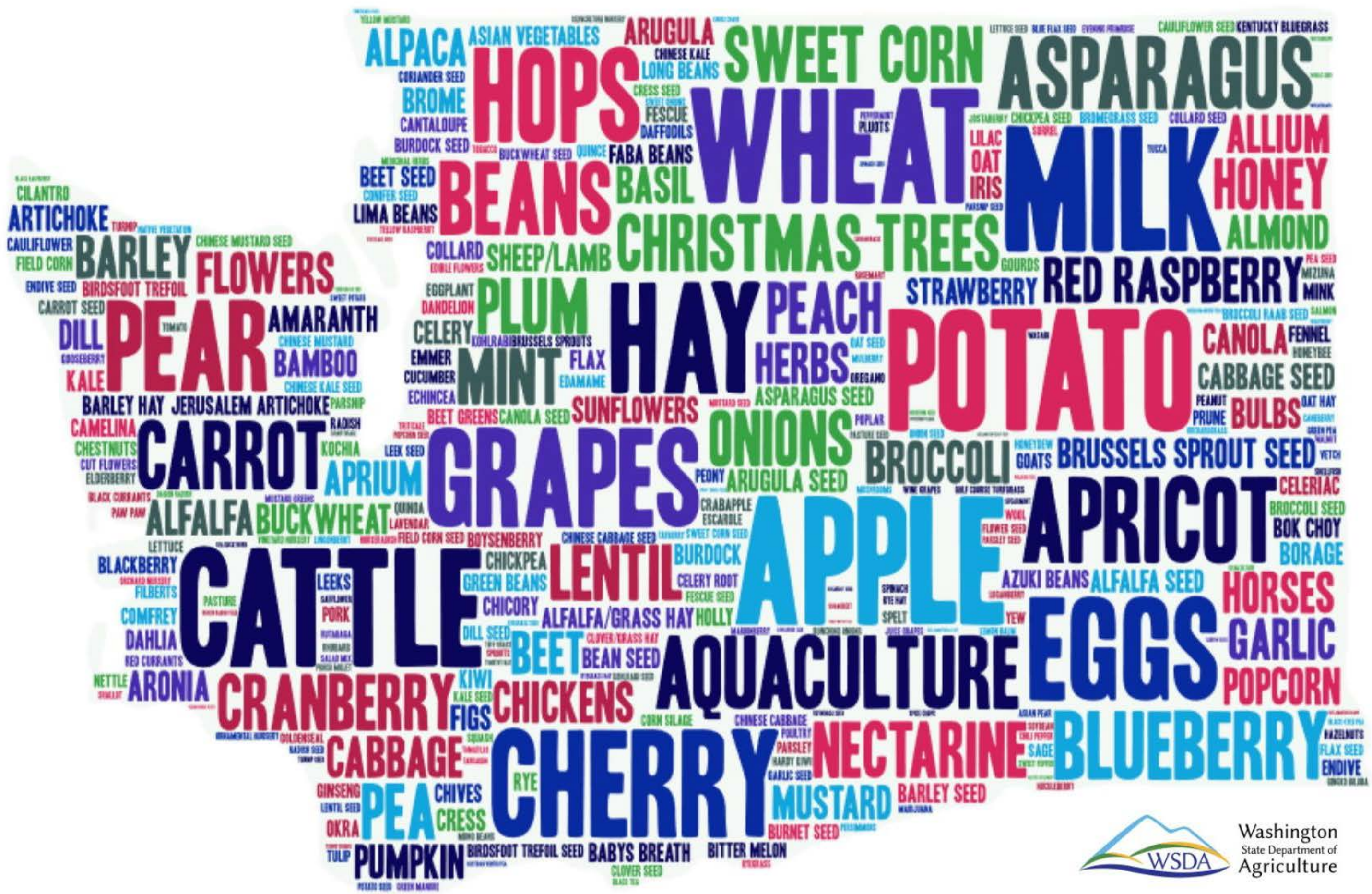
## ❑ Objectives

- **METRIC energy balance model for high spatiotemporal mapping of actual evapotranspiration using small UAS based multispectral and thermal infrared imagery**
- **Comparison and validation of the modified METRIC with the conventional approaches**

# Methods

## ❑ Data collection

- **Season: 2018**
- **Selected crops**
  - **Potato**
  - **Grapevine**
  - **Alfalfa**
  - **Spearmint**




WASHINGTON STATE UNIVERSITY
*World Class. Face to Face.*

# Methods

## ❑ Irrigation methods

**Potato:** center pivot

**Grapevines:** surface and sub-surface drip

**Alfalfa:** wheel line

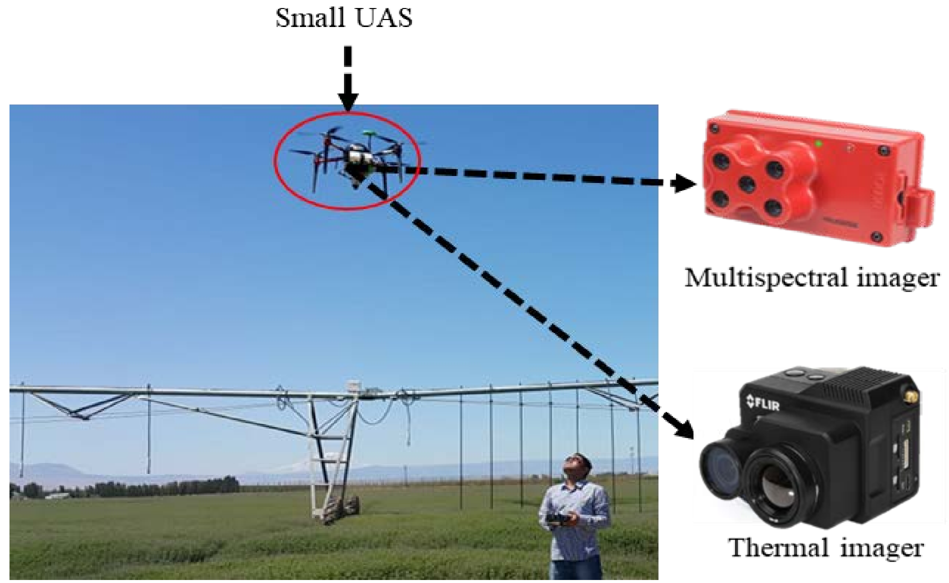
**Spearmint:** center pivot

WASHINGTON STATE UNIVERSITY

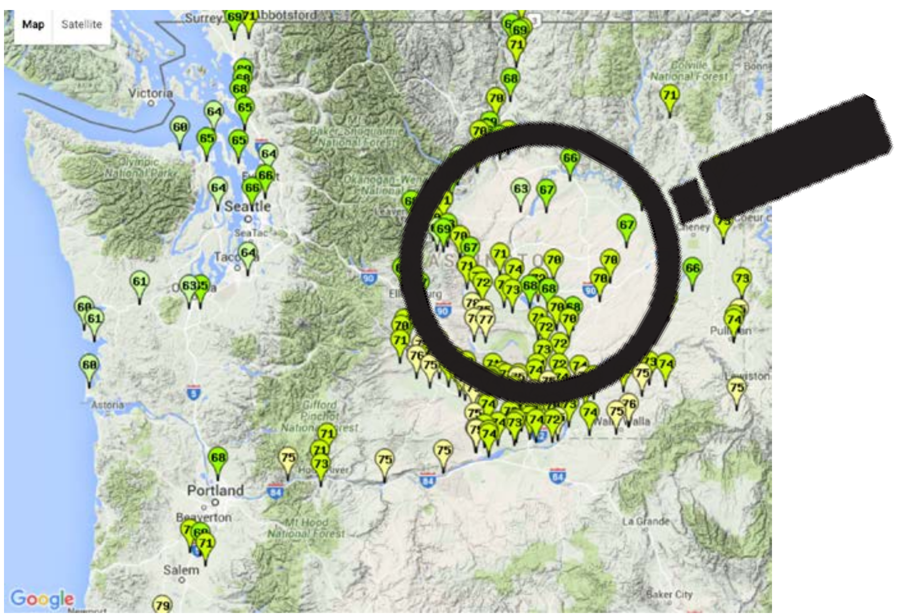
*World Class. Face to Face.*

## ❑ Data collection (cont.)

- **Imagery data**
  - **Visible, near-infrared and thermal infrared**
- **Imaging platforms (overlapped missions)**
  - **Small UAS**
  - **Landsat 7/8 satellites**




- **Weather data: (WSU AgWeathernet network)**




Source: WSU AgWeathernet

# Methods

Table 1. Imaging sensor specifications

| Platform | Imaging sensor | Spectral Bands | Ground sampling distance |
|---|---|---|---|
| **Small UAS** | Five band multispectral | Red, Green, Blue, NIR and Red Edge | 6.9 cm/pixel @ 100m |
| | Thermal | Long wave infrared | 13.20 cm/pixel @ 100m |
| **Satellite (Landsat 7/8)** | Multispectral | Red, Green, Blue, NIR, SWIR | 30 m/pixel |
| | Thermal | Long wave infrared | 30 m/pixel |

Table 2. Data collection dates

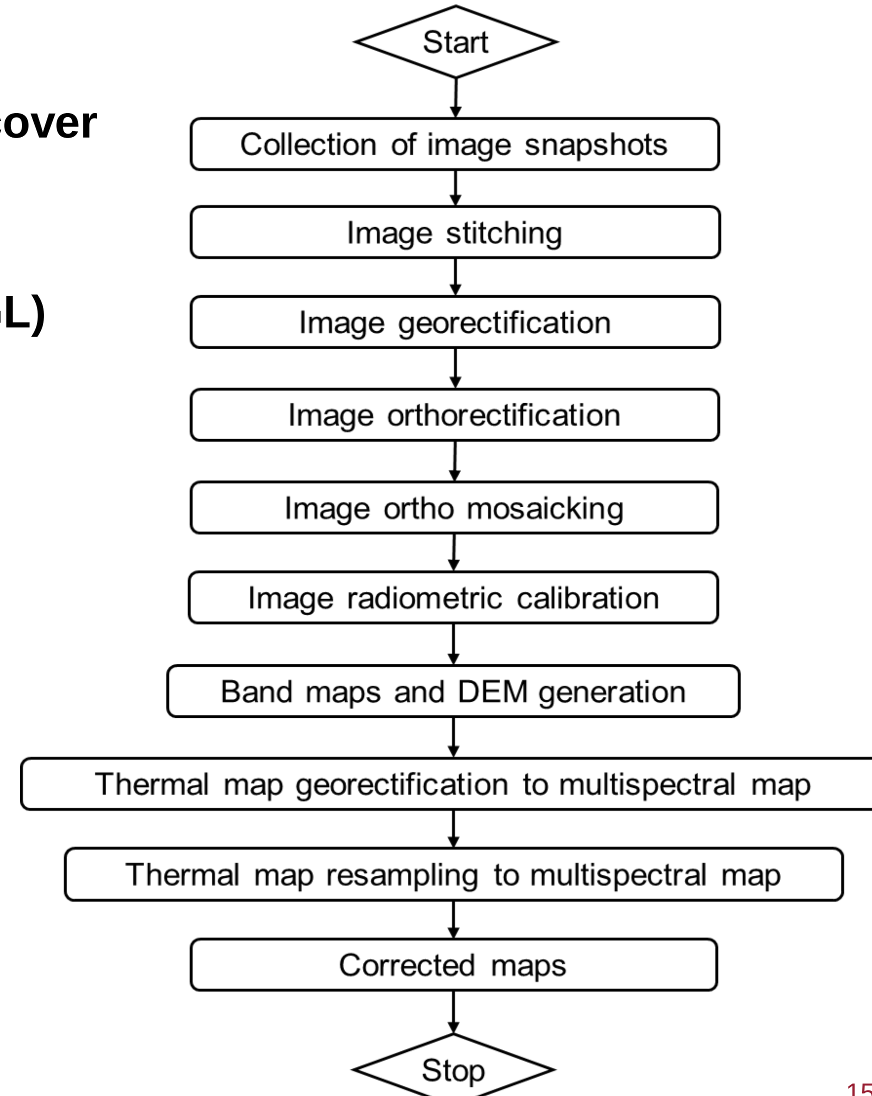
| Day of year (DOY) | Date | Crop | Nearest AgWeathernet station |
|---|---|---|---|
| 175 | 06/24/2018 | Mint | Toppenish |
| 184 | 07/03/2018 | Potato | Wheelhouse |
| 191 | 07/10/2018 | Alfalfa | Roza |
| 192 | 07/11/2018 | Grapevine | Benton City |
| 207 | 07/26/2018 | Grapevine | Benton City |
| 207* | 07/26/2018 | Potato | Wheelhouse |
| 208 | 07/27/2018 | Potato | Wheelhouse |
| 208* | 07/27/2018 | Grapevine | Benton City |
| 223 | 08/11/2018 | Alfalfa | Roza |

*Additional imagery data from Landsat 7/8 for same area of study

# Methods

- **Adapting METRIC energy balance**
  - **Surface albedo**
  - **Leaf area index: using fraction canopy cover**
  - **Digital land surface elevation model**
  - **Incoming short-wave radiation (~2 m AGL)**
  - **Surface temperature map**

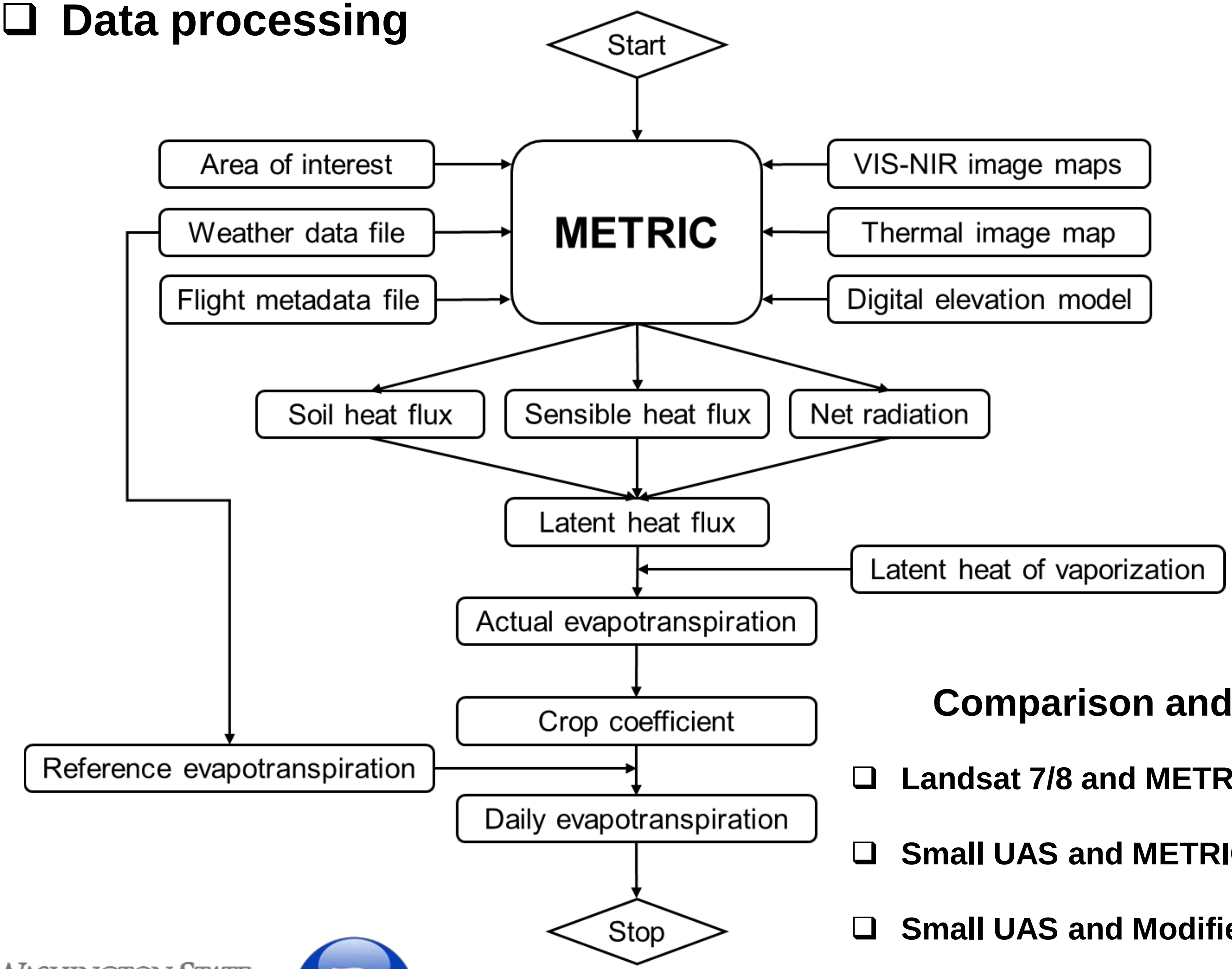
**Data preprocessing**




Washington State University
World Class. Face to Face.

# Methods

## ❑ Data processing

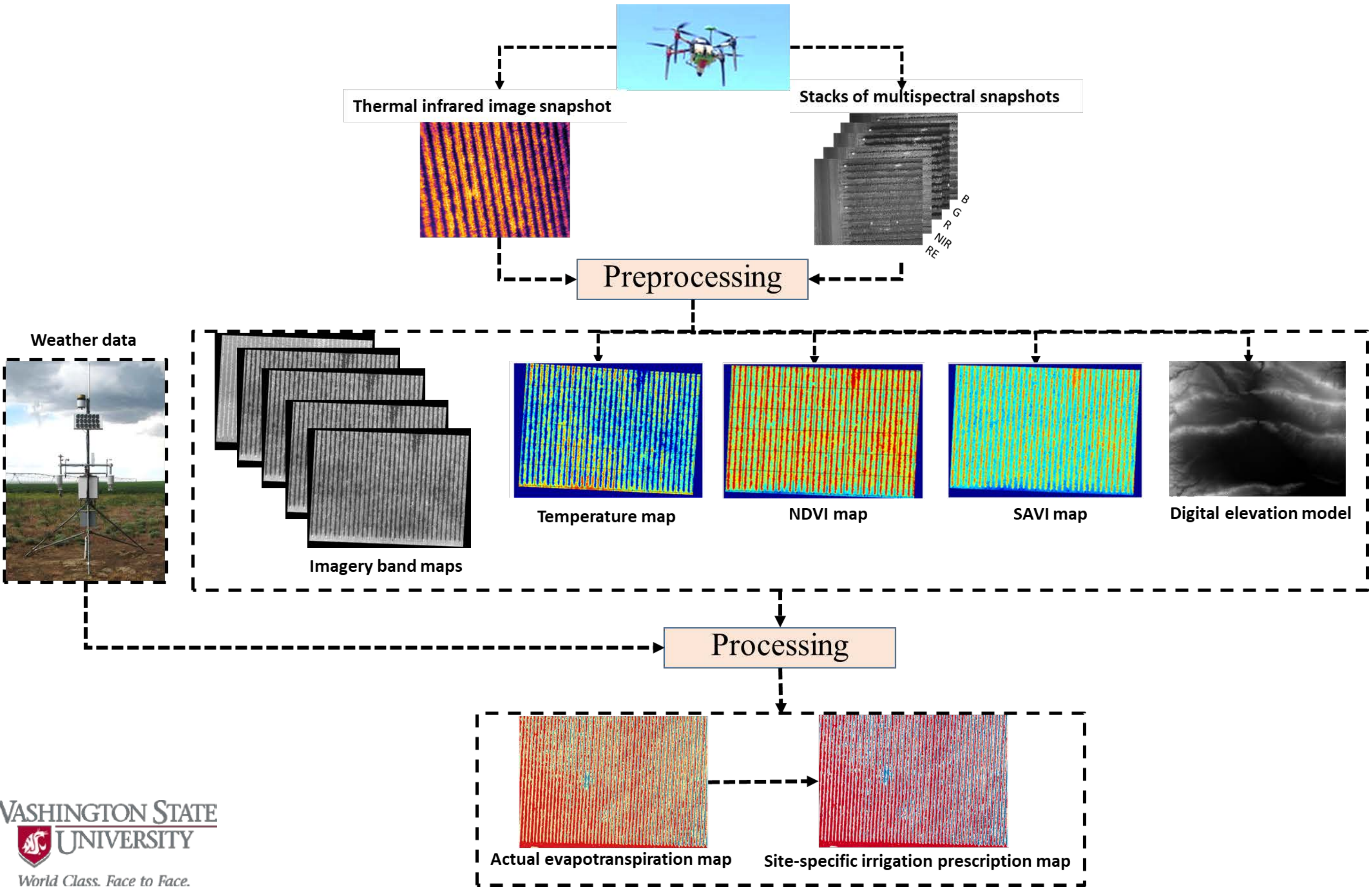



## Comparison and validation

- ❑ **Landsat 7/8 and METRIC (LM)**
- ❑ **Small UAS and METRIC (SUASM)**
- ❑ **Small UAS and Modified METRIC (SUASMM)**
- ❑ **Single crop coefficient approach (FAO-Kc)**

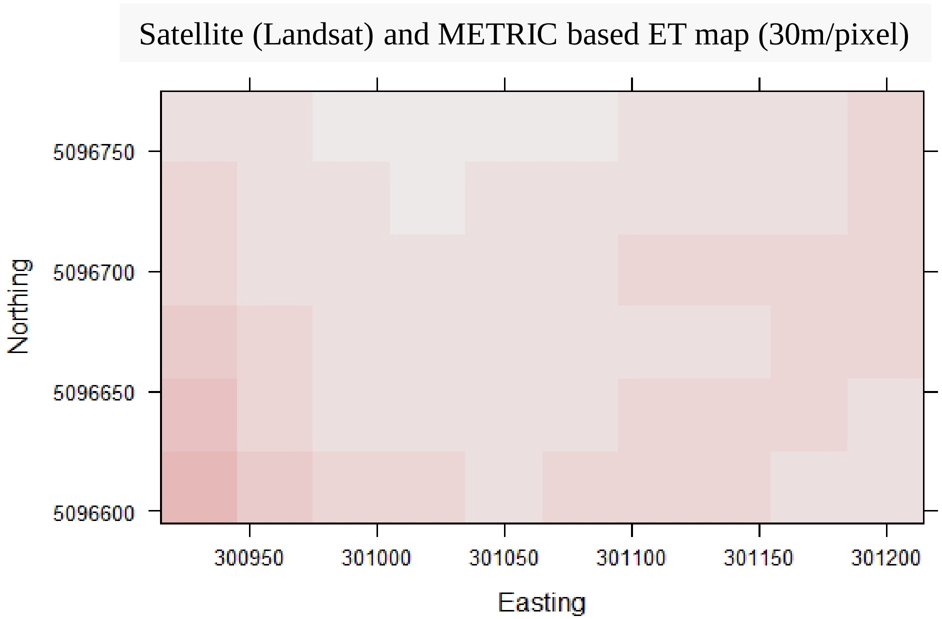
# Methods

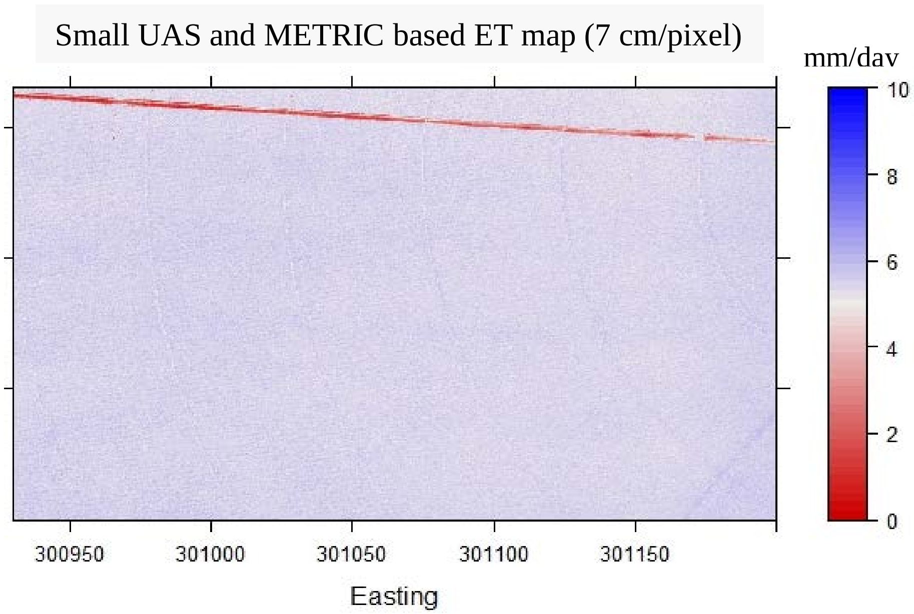
## High resolution imagery data preprocessing and processing illustration

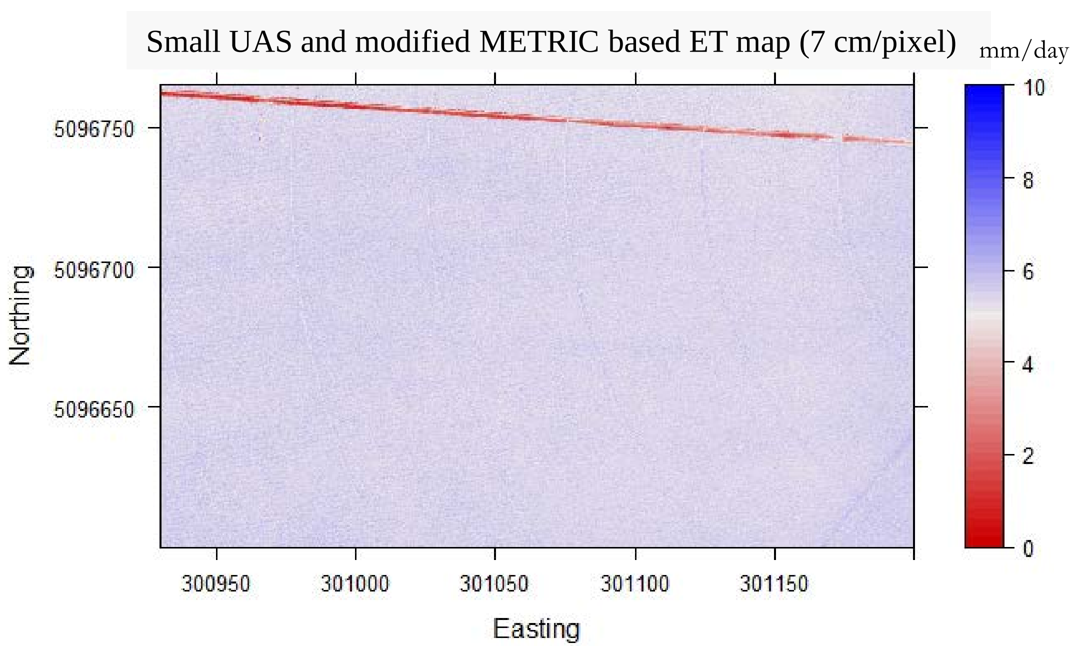



Washington State University
World Class. Face to Face.

# Results: Potato



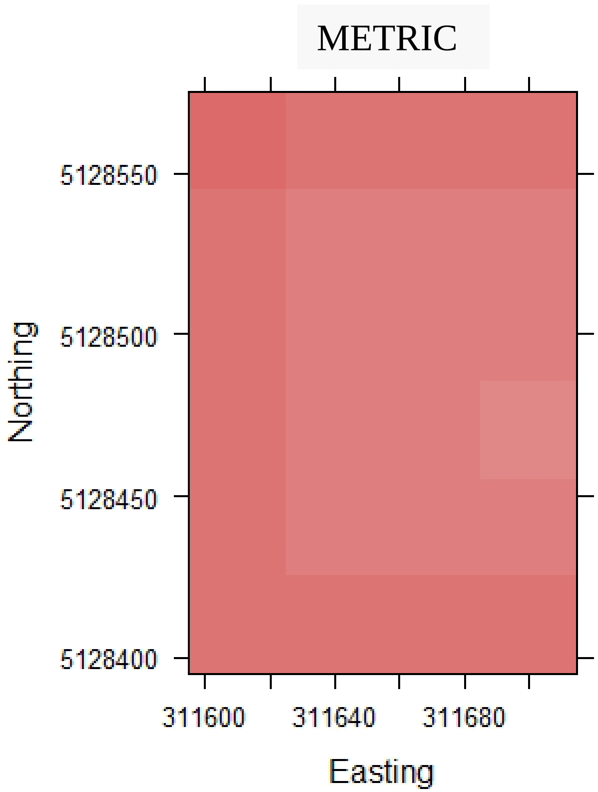



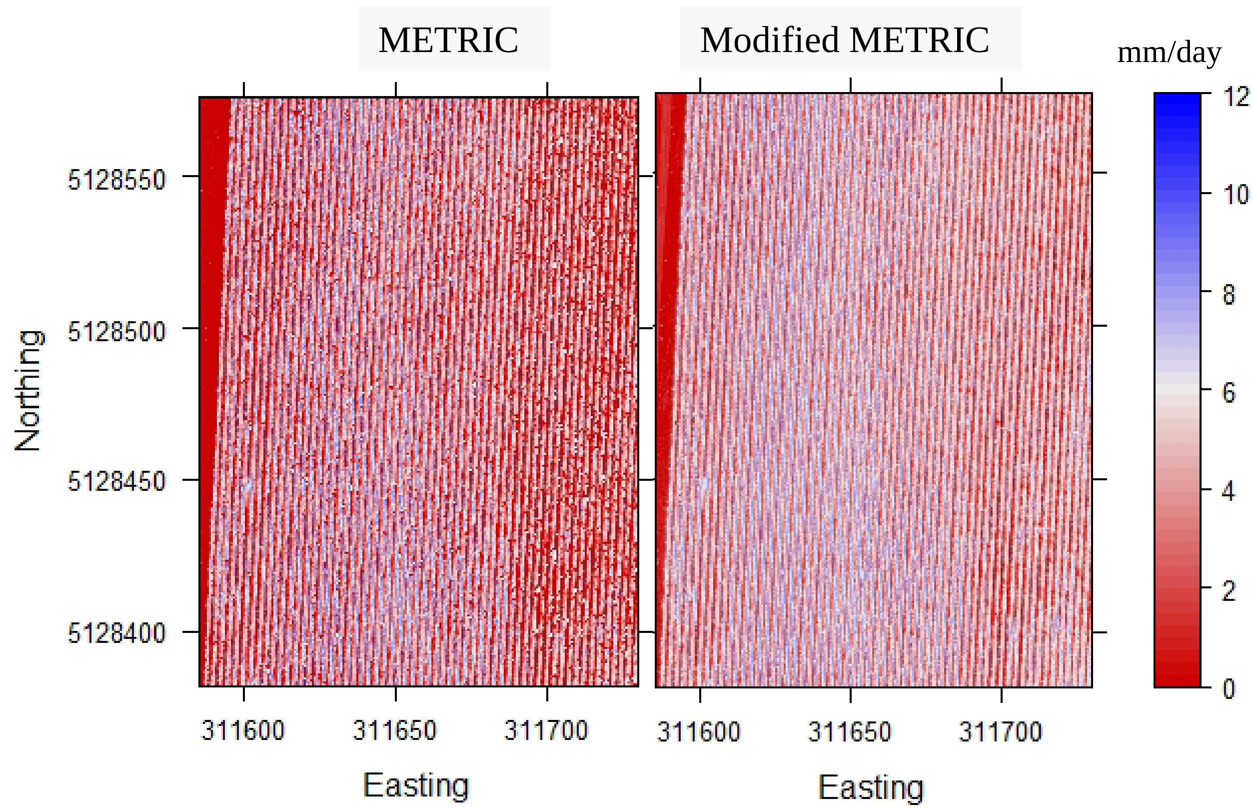

Washington State University
World Class. Face to Face.

# Results: Grapevine

Satellite (Landsat) based actual crop ET map (30 m/pixel)

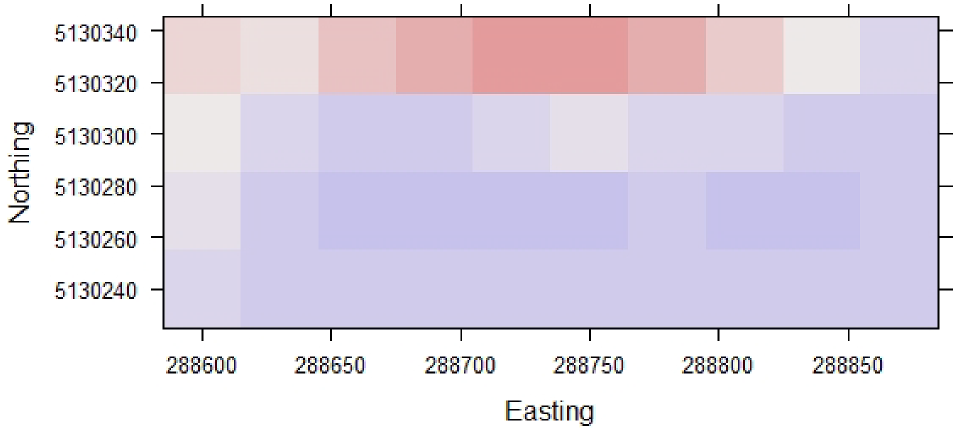
Small UAS based actual crop ET map (6.9 cm/pixel)



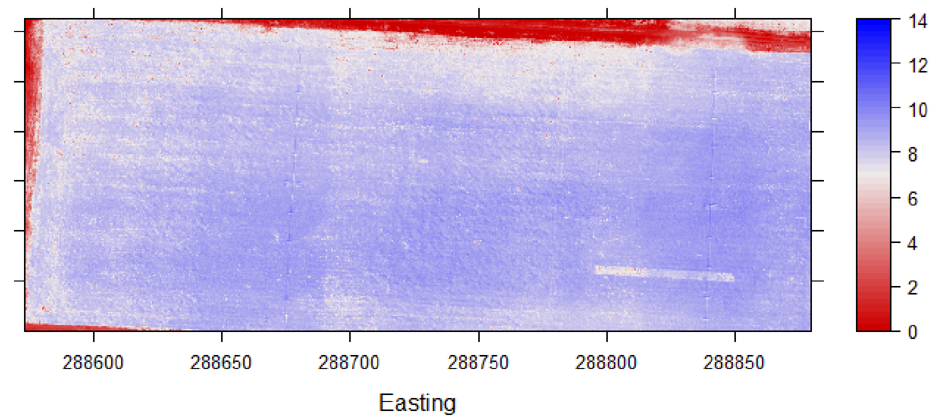



# Results: Alfalfa

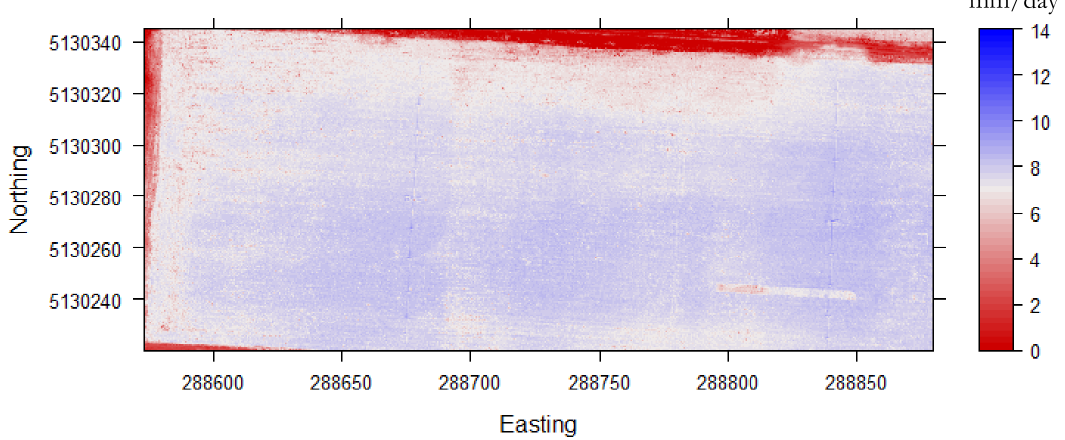
Satellite (Landsat) and METRIC based ET map (30m/pixel)




Small UAS and METRIC based ET map (7 cm/pixel)



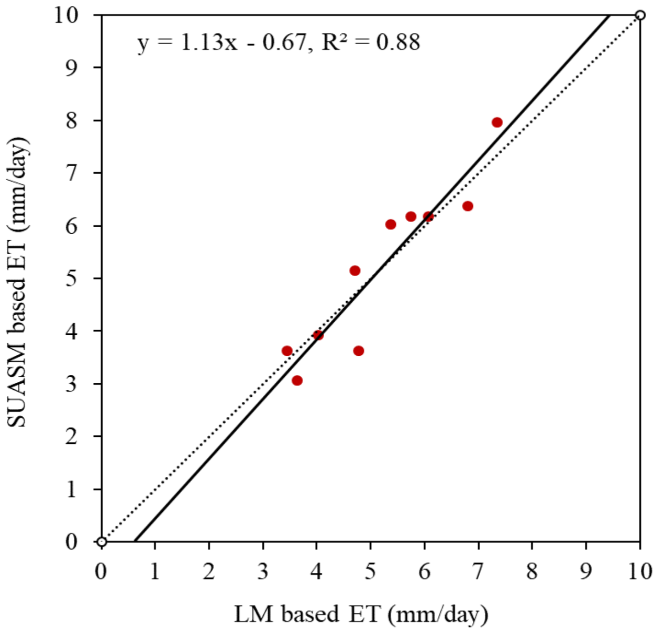

Small UAS and modified METRIC based ET map (7 cm/pixel)

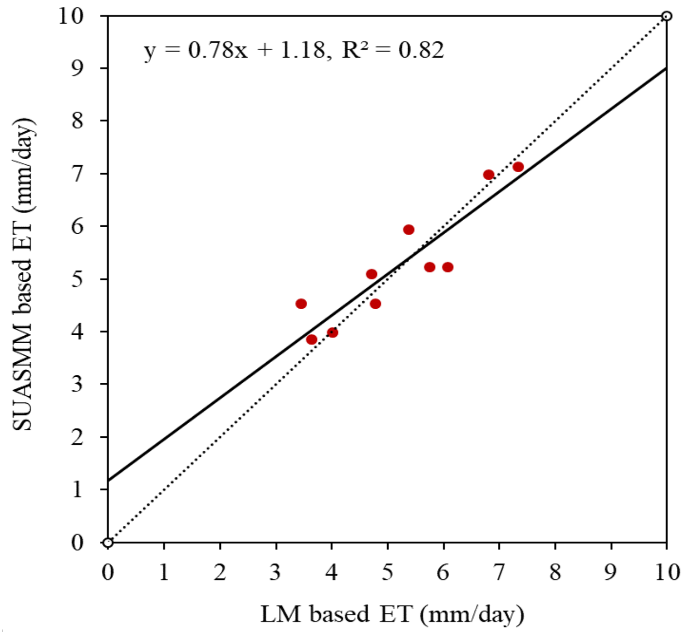


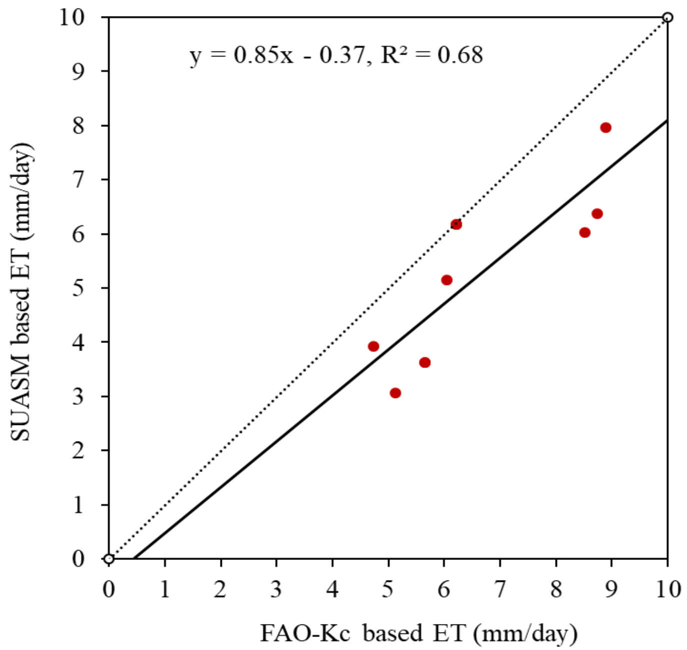

Washington State University

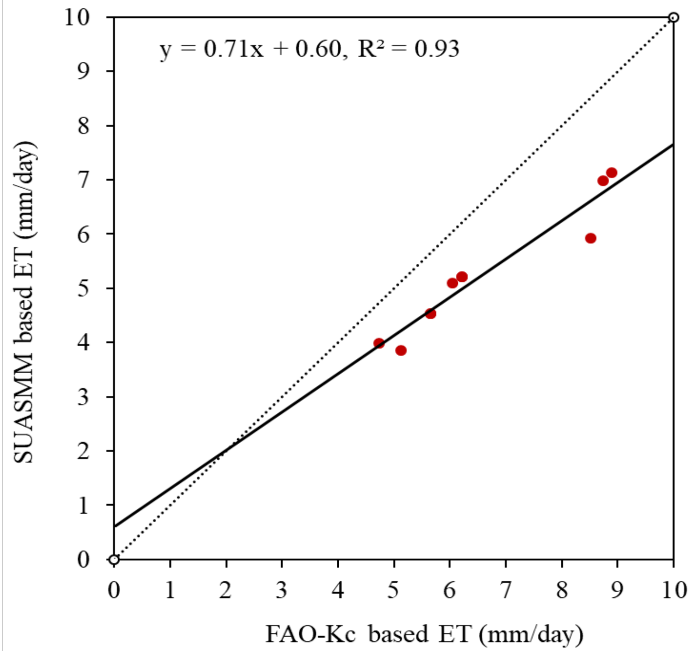
World Class. Face to Face.

# Results




**Approach**

SUASM: small UAS METRIC

SUASMM: small UAS modified METRIC

LM: Landsat METRIC

FAO-Kc: Standard single crop coefficient

# Results (Mean of actual crop ET maps)

Table 3. Mean of actual crop ET maps

| Approach/ Platform | Mean of actual crop ET maps (mm/day) |
|---|---|
| SUASM | 5.21 ± 1.59 |
| SUASMM | 5.25 ± 1.14 |
| LM | 5.20 ± 1.32 |
| FAO-Kc | 6.42 ± 1.29 |

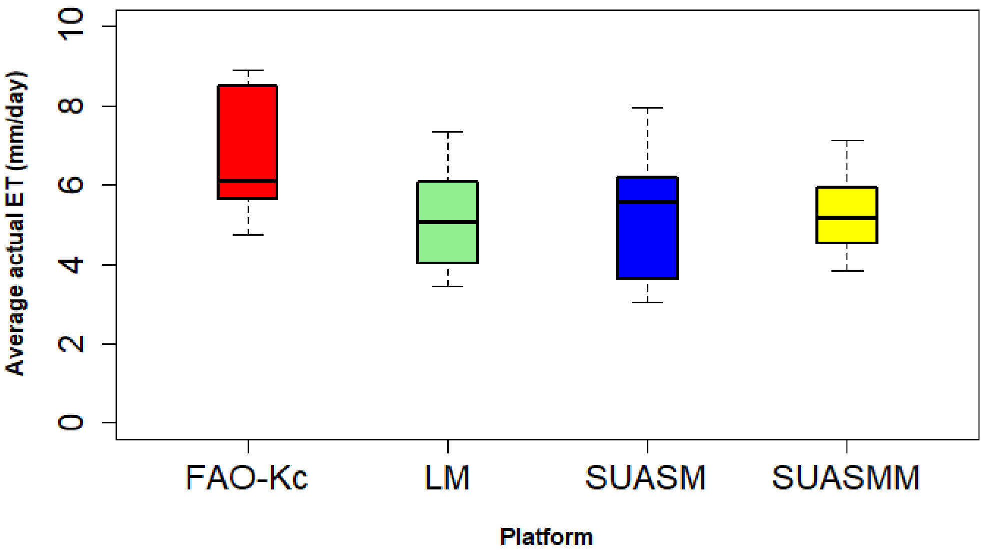



Table 4. Comparison of mean actual crop ET mapped from different approaches

| Approach/ Platform | RMSE (mm/day) | MBE (mm/day) | RMSE (%) | MBE (%) | Difference |
|---|---|---|---|---|---|
| SUASM-LM | 0.56 | 0.02 | 10.72 | 0.29 | NS (P>0.05) |
| SUASMM-LM | 0.53 | 0.05 | 10.20 | 1.04 | |
| SUASM-FAO-Kc | 1.63 | -1.37 | 24.79 | -20.81 | |
| SUASMM-FAO-Kc | 1.43 | -1.33 | 21.72 | -20.22 | |

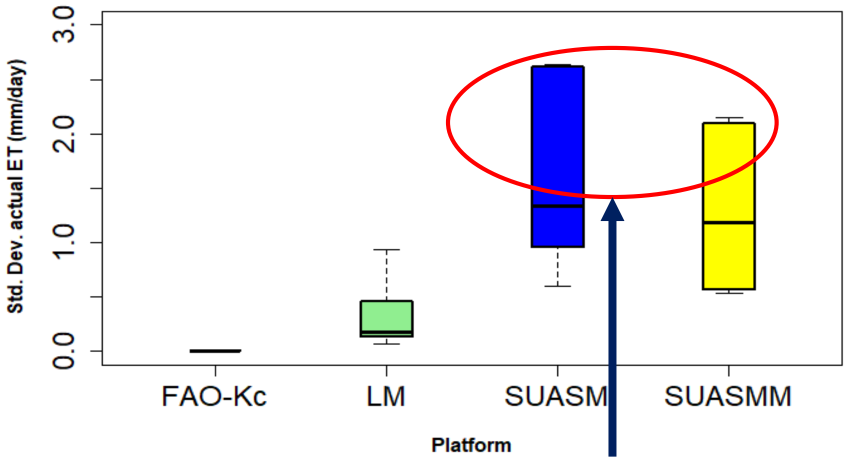
UNIVERSITY

World Class. Face to Face.

# Results (Std. Dev. in actual crop ET maps)

Table 5. Standard deviation in actual crop ET maps

| Approach/ Platform | Mean Std. Dev. in actual crop ET maps (mm/day) |
|---|---|
| SUASM | 1.55 |
| SUASMM | 1.24 |
| LM | 0.31 |
| FAO-Kc | 0 |




Potential for spatial variability assessment

Table 6. Comparison of standard deviation in actual crop ET maps from different approaches

| Approach/ Platform | RMSE (mm/day) | Difference | Groups |
|---|---|---|---|
| LM-SUASM | 1.47 | S (P<0.05) | b, a |
| LM-SUASMM | 1.14 | | b, a |
| FAO-Kc-SUASM | 1.73 | | b, a |
| FAO-Kc-SUASMM | 1.40 | | b, a |

WASHINGTON STATE UNIVERSITY

World Class. Face to Face.

# Conclusions

## ❑ High spatial resolution- METRIC

- **Better handling of heterogeneous pixels (soil and crop)**
- **High resolution mapping of spatial variations in crop water demand**
- **Suitable for tree fruit crops**

## ❑ Future plan and scope

- **Model local calibration using artificial reference materials (Hot and Cold)**
- **Crop ET estimation with reliable soil water balance approach**
- **Validation and improvement of SUASMM with soil water balance approach**
- **Site specific irrigation prescription maps**

# Acknowledgments


- This project was funded by USDA-NIFA and College of Agricultural, Human, and Natural Resource Sciences, Washington State University

- Dr. Pete Jacoby, Dr. Mark Pavek, Dr. Rajeev Sinha, Mr. Paco Gonzalez-Tapia, Mr. Xiaochi Ma and Mr. Austin for their assistance during data collection

- Kiona vineyards, Landon Lommers (Mint grower, Toppenish), Troy Grimes (Potato grower, Paterson) and WSU-Roza farms management team

- Universities Council on Water Resources

- Alaska Airlines


United States Department of Agriculture
National Institute of Food and Agriculture

College of Agricultural, Human, and Natural Resource Sciences
CAHNRS COUGS

UCOWR | UNIVERSITIES COUNCIL ON WATER RESOURCES

WRC STATE OF WASHINGTON WATER RESEARCH CENTER

UCOWR

Alaska AIRLINES

WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

# Thank You

# Questions/ suggestions ?