The NASA Satellite Irrigation Management Support (SIMS) System:
Applications of satellite data to support improvements in irrigation management in California

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UC Cooperative Extension

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Overview

Why is NASA involved in ET mapping?

What is the Satellite Irrigation Management Support (SIMS) system?

How does SIMS work?

How accurate is SIMS?

Accessing Data from SIMS

SIMS 2.0

OpenET
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF

NASA Earth Science Missions and Instruments
Earth Science Instruments on ISS:
RapidScat, CATS,
LIS, SAGE III (on ISS), TSIS-1, OCO-3,
ECOSTRESS, GEDI,
CLARREO-PF

Altimetry-FO (Formulation in FY16; Sentinel-6/Jason-CS)

NASA Earth Science Missions and Instruments

Contributing to Water Cycle Studies
Threats to Water Supplies and Water Quality in California

Source: UC Davis

Source: CDWR

Snowpack since 1950

Community Public and State Small Water Systems, Raw Water Nitrate Levels, 2006-2010 (mg/L)
- up to 1.0
- 1.1 - 15
- 15.1 - 22.6
- 22.6 - 45
- 45.1 - 90
- over 90

Source: UC Davis

Source: CDWR
Objective: *Increase the utility of satellite data for irrigation scheduling and evaluation of on-farm water use efficiency by growers/irrigators.*

Requirements:
- Field scale
- Cost effective
- 10+ year baseline
- Known accuracy
- Timely
- Open data
- Data continuity is critical

Melton et al., 2012, IEEE JSTARS
**Objective:** Increase the utility of satellite data for irrigation scheduling and evaluation of on-farm water use efficiency by growers/irrigators.

**Applications:**
- Irrigation scheduling and management
- Calculation of water use efficiency metrics
- Compliance monitoring for water transfer agreements
- ET mapping

**Processing Steps**
- Surface reflect.
- Cloud masking
- Gap-filling
- NDVI
- Fractional cover
- Kcb * ETo
- ETcb

**NASA Earth Exchange**

**Satellite Data**

**CIMIS**

**Site info.**

**Web browser**

**Mobile**

Melton et al., 2012, IEEE JSTARS
California Irrigation Management Information System

Landsat 5/7/8

MODIS, Terra & Aqua

ESA Sentinel-2A/2B

Spatial CIMIS ET₀ (mm)

SIMS ET₀ (mm)

CIMIS Station
Satellite Data

Landsat 5/7/8 (TM / ETM+ / OLI)
30m / 0.25 acres
Overpass every 8-16 days

Sentinel-2A and 2B
20m / 0.1 acres
Overpass every 5-10 days
Approach: Combining CIMIS and Satellite Data

\[
ET_{cb} = ET_0 \times K_{cb}
\]

(CoAgMet, AgriMet, AZMET)

**Standard \( K_c \) Profile (manual)**

**SIMS \( K_{cb} \) Profile (Automated, Satellite-derived)**

Crop coefficient (\( K_{cb} \)) - 36.397N, 120.062W

\( K_c \) profiles via reflectance based algorithms (\( K_{cb} \))

Figure credit: 2005 California Water Plan Update
Step 1:
NDVI $\rightarrow$ Fractional Cover ($F_c$)
- Based on studies by Trout et al., 2008; Johnson et al., 2012

Step 2:
$F_c \rightarrow K_d \rightarrow K_{cb}$
- Allen and Pereira, 2009 / ASCE Manual 70; (also Bryla et al., 2010; Grattan et al., 1998; Hanson & May, 2006; Lopez-Urrea et al., 2009 . . .)

Step 3:
$ET_{cb} = ET_0 * K_{cb}$
- Follows FAO-56 approach
- $ET_0$ from CIMIS
- Calculation of soil evaporation and crop stress via soil water balance

\[ K_d = \min(1, M_L * F_{c\_eff}, F_{c\_eff}^{1/(1+h)}) \]

- $M_L$ : effect of canopy density on shading / max relative $ET$
- $K_d$ : density coefficient
- $F_{c\_eff}$ : effective fractional cover
- $h$ : crop height

Allen and Pereira, 2009
Remote Sensing of Evapotranspiration: Reflectance-based Approach
**SIMS Approach: Strengths and Limitations**

**Limitations of the SIMS Approach**
- Additional corrections needed for soil evaporation and crop stress (e.g., via METRIC or soil water balance)
- At present, only applicable for ag land cover types, but could be extended

**Strengths of the SIMS Approach**
- Extensible framework for satellite data processing
- $ET_{cb}$ represents biological demand for water by the plant
- Fully automated estimates at field scale
- NDVI data freely available from multiple satellites (e.g., Landsat 7, Landsat 8 and Sentinel-2A)
- Field scale estimates that account for weather conditions and observed crop canopy conditions
- Increasingly well-known uncertainty; small bias error
SIMS Web Interface
http://ecocast.arc.nasa.gov/dgw/sims/
SIMS Basal Crop Evapotranspiration ($ET_{cb}$)
Accuracy Assessment Field Campaign

1) Surface Energy Balance
   - Eddy covariance / surface energy balance residual flux towers

2) Soil Water Balance
   - Volumetric water content / capacitance probes
   - Flow meters
   - Capillary lysimeters
<table>
<thead>
<tr>
<th>Crop Type</th>
<th>Crop</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain</td>
<td>Corn*</td>
<td>CSU Fresno</td>
</tr>
<tr>
<td>Grain</td>
<td>Wheat</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Garlic</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Lettuce*</td>
<td>SJ &amp; Salinas Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Broccoli*</td>
<td>Salinas Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Cauliflower</td>
<td>San Joaquin Valley</td>
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<tr>
<td>Row</td>
<td>Tomato(2)*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Row</td>
<td>Cotton (drip)*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Melon</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Wine grapes*</td>
<td>Salinas Valley</td>
</tr>
<tr>
<td>Vine</td>
<td>Raisins*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Tree</td>
<td>Peach*</td>
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<tr>
<td>Tree</td>
<td>Almond*</td>
<td>San Joaquin Valley</td>
</tr>
<tr>
<td>Tree</td>
<td>Orange*</td>
<td>San Joaquin Valley</td>
</tr>
</tbody>
</table>

*Eddy covariance / SEBR instrumentation.*
Accuracy Assessment Summary

Seasonal Accuracies

- SIMS ET<sub>cb</sub> MAE is +/- 15% with ~12% positive bias error across all crops studied
- For well irrigated crops, SIMS ET<sub>cb</sub> MAE is less than 9% with 6% positive bias error
- For individual fields, SIMS ET<sub>cb</sub> + IrriQuest soil water balance model reduces MAE to less than 8% across with less than 2% bias error for all crop types studied → highly accurate for field-scale evaluation of on-farm water use efficiency
- Accuracies relative to ground measurements; approaching accuracy of ground measurements (weighing lysimeter 5%, eddy covariance ~10%)

Daily Accuracies

- MAE of 0.4 to 0.75 mm for well watered crops for SIMS ET<sub>cb</sub>
- MAE of 0.5 to 1.25 mm for deficit irrigated crops for SIMS ET<sub>cb</sub>
- Bias errors are positive for almost all sites
Benefits of ET-based Irrigation Scheduling

Results to date for reductions in applied water from field trials:

- Lettuce (Iceberg & Romaine): 21-29%
- Broccoli: 30-40%
- Cabbage: 21-22%
- Strawberries: 28%

No statistically significant differences in yield/quality

Johnson et al., 2016, Hort Sci 51.7
Zaragoza et al., in prep.
SIMS Web Data Services for Integration with Irrigation & Nutrient Management Software

Forrest Melton Ranch User

CropManage

Selva

Plantings

<table>
<thead>
<tr>
<th>Lot</th>
<th>Planting</th>
<th>Crop</th>
<th>Start Date</th>
<th>End Date</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Soil Sample ppm Nitrate-N</th>
<th>Fertilizer - Fertilizer Units</th>
<th>Water - in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/22/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
<td></td>
</tr>
<tr>
<td>7/28/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
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<tr>
<td>7/29/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
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<tr>
<td>7/31/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
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</tr>
<tr>
<td>8/2/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
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</tr>
<tr>
<td>8/4/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
<td></td>
</tr>
<tr>
<td>8/6/2015</td>
<td>27-0-0-4.8</td>
<td>30.0 gal/acre</td>
<td></td>
</tr>
<tr>
<td>8/17/2015</td>
<td>1 ft depth: 39.5 ppm Nitrate-N</td>
<td>2 ft depth: 37.5 ppm Nitrate-N</td>
<td></td>
</tr>
</tbody>
</table>

https://cropmanage.ucanr.edu/  Michael Cahn, UCCE
Crop Manage – SIMS API

https://cropmanage.ucanr.edu/  
Michael Cahn, UCCE
IrriQuest
On-farm Water Use Efficiency Calculator

Example for almond in San Joaquin Valley, 2013

FAO-56 Soil water balance model:

- Derives stress & evaporation coefficients: K_s, K_e
- Calculates adjusted ET as: \( ET_c = (K_s * K_{cb} + K_e) * ET_o \)

Outputs:
- Crop ET (daily, seasonal)
- Crop Consumptive Use Fraction
- Agronomic Water Use Fraction

Lee Johnson, NASA Ames / CSUMB
https://ecocast.arc.nasa.gov/simsi/irriquest/
SGMA Applications
SIMS Annual $ET_{cb}$, 2010-2017

2016

$ET_{cb}$ (mm)

0 250 500 750 1000 1250 1500 1750 2000

ET$_{cb}$ (mm)
ET Intercomparison Study for the SF Bay Delta

Methods compared:

- CalSIMETAW (DWR)
- DETAW (DWR)
- DisALEXI (USDA-ARS)
- ITRC-METRIC (ITRC Cal Poly SLO)
- UCD-METRIC (UC Davis)
- UCD-PT (UC Davis)
- SIMS (NASA-ARC)

Josue Medellin, Yufang Jin, UC Davis
Medellin et al., 2016
Total Annual ET by CA Delta Subregion

Preliminary results from 1st year of 2-year study
Medellin et al., 2016
Average Observed ET$_{rf}$ (K$_c$) by Crop Type for CA Delta

- SIMS close to median of ET model ensemble for most crop types

Preliminary results from first year of two-year study

Medillin et al., 2016; https://watershed.ucdavis.edu/project/delta-et
SIMS 2.0: Moving SIMS to the Cloud

- Currently porting SIMS from the NASA Earth Exchange to Google Earth Engine
  - Reduced costs for satellite data management / sustained operations
  - Easier to scale to other regions
  - Ability to create automated reports
- With support from CA DWR, work beginning to implement IrriQuest prototype as a desktop application
SIMS Application Programming Interface

- Designed for machine to machine queries
- Contact forrest.s.melton@nasa.gov for a user API key and API documentation

Data Service:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1

Query example for a single day:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
apikey=userkey&date=2016-04-14&lon=-120.46428&lat=36.69523&croptype=75

Query example for a timeseries for full year or current year-to-date:
http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
apikey=userkey&year=2016&lon=-120.46428&lat=36.69523&croptype=75

http://ec2-54-196-147-232.compute-1.amazonaws.com/cgi-bin/simsAPI_v.1?
varname=Fc&apikey=userkey&year=2016&croptype=75&geom=POLYGON+((-120.9710708296299941+37.4955228156940024,
-120.9765639936899930+37.4573781184929970,
-120.9133926069799969+37.4475663354349990,
-120.9216323530699952+37.4955228156940024,
-120.9710708296299941+37.4955228156940024))
OpenET
A Water Community Focused Open Source ET Project

Towards Filling the Biggest Gap in Water Information

Justin Huntington, Charles Morton – Desert Research Institute
Forrest Melton, Lee Johnson, Alberto Guzman, NASA Ames / CSUMB
Robyn Grimm & Maurice Hall, EDF, Josh Fisher, JPL, Martha Anderson, USDA ARS,
Chris Hain, NASA MSFC, Wim Bastiaanssen, IHE-DELFT . . . and many others . . .
One Platform, Multiple Operational Models

OpenET: Shared Architecture for ET Mapping

- User interface: query, data access, data summary and reporting tools, account and permission management
- Common API for Data Queries

Models / Applications (implemented on Earth Engine)
- METRIC
- DiSALXI
- SEBAL
- SSEBop
- SIMS
- Other models/applications

Satellite & Weather Data
- Landsat, MODIS, VIIRS, GOES, Sentinel-2A/2B, Spatial CIMIS, FRET, GFS...
- ALEXI, JPL-PT, METRIC (manual/expert)...

Earth Engine Data Resources

Additional ET Data
Our First Test

- Regional scale field level ET mapping on Google Earth Engine
- Justin Huntington & Charles Morton (DRI), Gabriel Senay & MacKenzie Friedrichs (USGS)

2015 annual ET - 16,000 Landsat images processed over a weekend
Questions?

For more information:
forrest.s.melton@nasa.gov

Support from the NASA Applied Sciences Program, CSU Agricultural Research Institute, California Department of Water Resources and CDFA
Lessons Learned

1) Field validation and quantification of accuracy is critical, but also challenging in commercial agriculture settings

2) Partnership with growers / ag community is key, but requires sustained investment of time

3) For agricultural applications, data continuity is essential → Landsat 8 TIRS data interruptions have been challenging

4) Needs for APIs to integrate with other tools → Collaboration creates success; competition creates confusion for stakeholders

5) Transition to operations always takes longer than planned → start planning on Day 1 of a new effort
A Few Definitions

- **Potential ET (PET)**: The evapotranspiration that would occur if a sufficient water source were available.

- **Reference ET (ET<sub>r</sub>):** The PET from a well-watered reference surface (usually a 1 m alfalfa crop or a grass surface).

- **Basal crop evapotranspiration (ET<sub>cb</sub>):** The evapotranspiration from a well-watered crop on a dry soil surface (i.e., transpiration + diffusive soil evaporation).

- **Actual basal crop evapotranspiration (ET<sub>cb-a</sub>):** ET<sub>cb-a</sub> adjusts ET<sub>cb</sub> to account for the observed canopy extent and crop growth stage, incorporating crop-specific corrections for stomatal resistance at different stages (SIMS provides ET<sub>cb-a</sub>).

- **Actual crop evapotranspiration (ET<sub>a</sub>):** Total crop evapotranspiration, including soil evaporation and crop stress.
Results: Ground Measurements

Field Measurements of ET:
Eddy Covariance / SEBR vs Soil Water Balance

Mean Abs. Difference = 11.6% (46 mm)
Results: Eddy Covariance vs SIMS ET$_{cb}$

Eddy Covariance / SEBR vs SIMS ET$_{cb}$

Mean Abs. Error = 11%
Mean Bias Error = 8.5%

$y = 1.1654x$

$R^2 = 0.97638$
Results: Field Soil Water Balance vs SIMS ET<sub>cb</sub>

Soil Water Balance ET vs SIMS ET<sub>cb</sub>

Mean Abs. Error = 14.2%
Mean Bias Error = 12.4%

\[ y = 1.1544x \]
\[ R^2 = 0.8876 \]
Results: Field Soil Water Balance vs SIMS ET<sub>cb</sub>

Soil Water Balance ET vs SIMS ET<sub>cb</sub>
Well Irrigated Only

Mean Abs. Error = 8.7%
Mean Bias Error = 6%

\[ y = 1.0502x \]
\[ R^2 = 0.98441 \]
Results: Eddy Covariance vs SIMS $\text{ET}_{\text{c-adj}}$

**SIMS + IrriQuest**

![Graph showing Eddy Covariance / SEBR vs SIMS+IQ ET$_{c-adj}$](image)

- **Mean Abs. Error** = 8.5%
- **Mean Bias Error** = -1.3%
- $y = 0.9753x$
- $R^2 = 0.97878$
Results: Field Soil Water Balance vs ET\textsubscript{c-adj}

SIMS + IrriQuest

**Soil Water Balance ET vs SIMS+IQ ET\textsubscript{c-adj}**

- Mean Abs. Error = 7%
- Mean Bias Error = 2%

\[ y = 1.0359x \]
\[ R^2 = 0.97449 \]