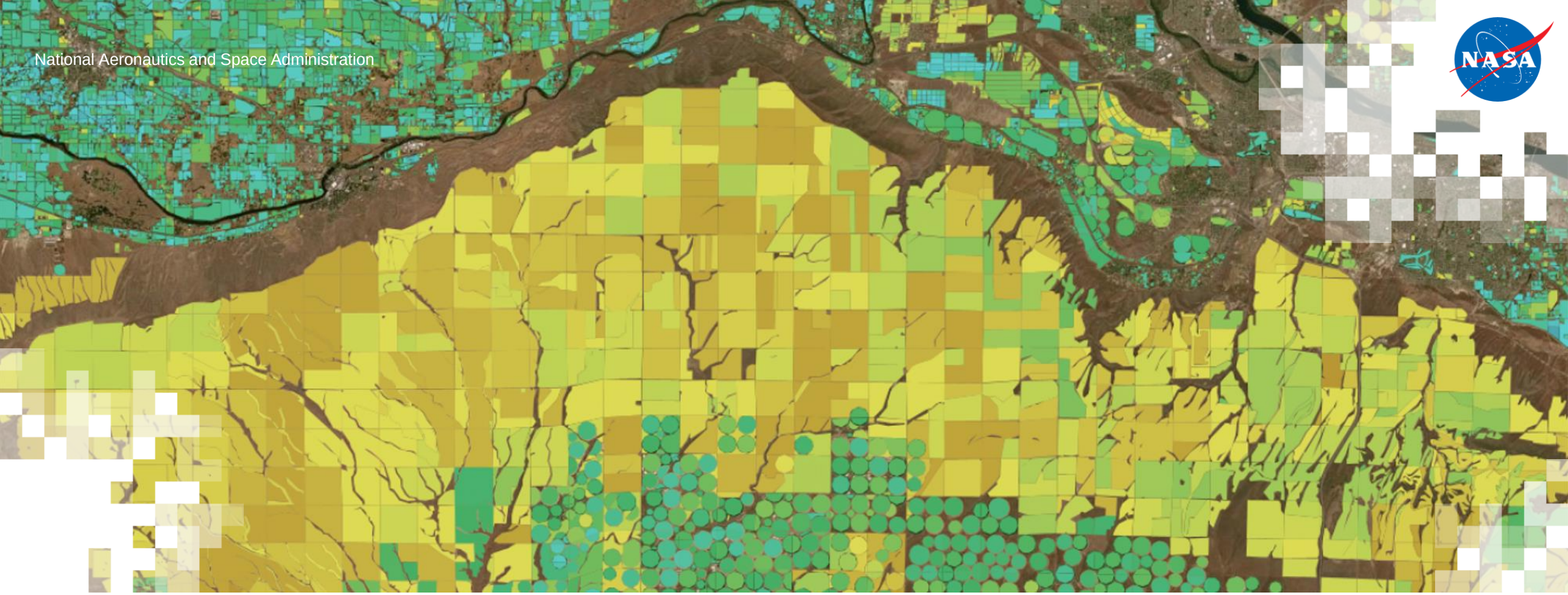


Applications of Remote Sensing-Based Evapotranspiration Data Products for Agricultural and Water Resources Management

Amita Mehta, Forrest Melton

June 1, 2022

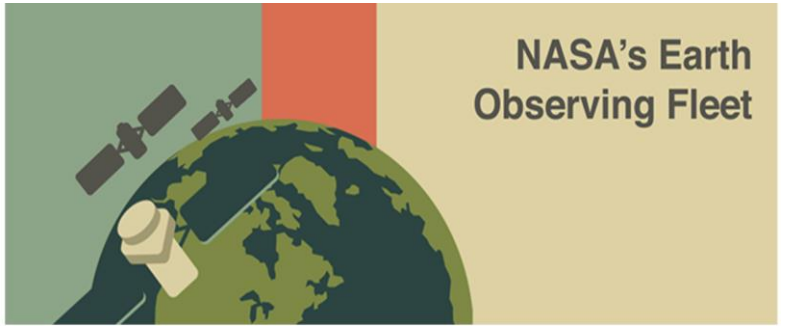
Training Objectives

By the end of this training attendees will be able to:

- Identify state-of-the-art techniques to derive evapotranspiration (ET) using remote sensing
- Recognize how ET data can be used in water resources and agricultural management
- Access OpenET and ECOSTRESS ET data products for their own applications

Prerequisites

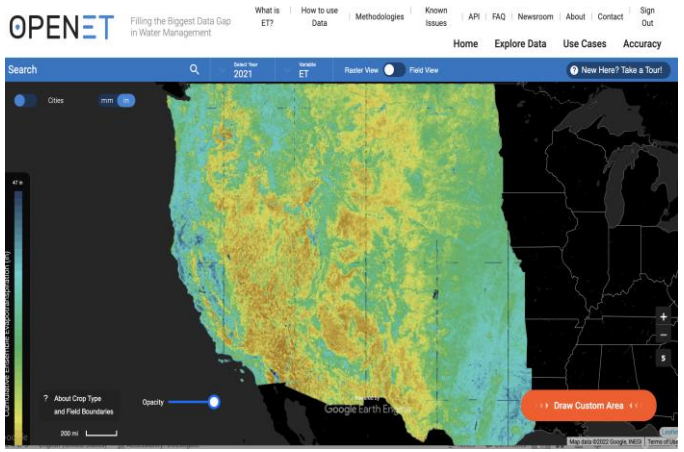
- Fundamentals of Remote Sensing, Sessions 1, 1A and 2B:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-fundamentals-remote-sensing



Training Outline

Three 1.5-hour sessions offered in English with materials available in Spanish

Part 1: June 1, 2022



https://explore.etdata.org/#5/39.665/-110.396

OpenET

Speaker: Forrest Melton
NASA Ames Research Center

Part 2: June 8, 2022

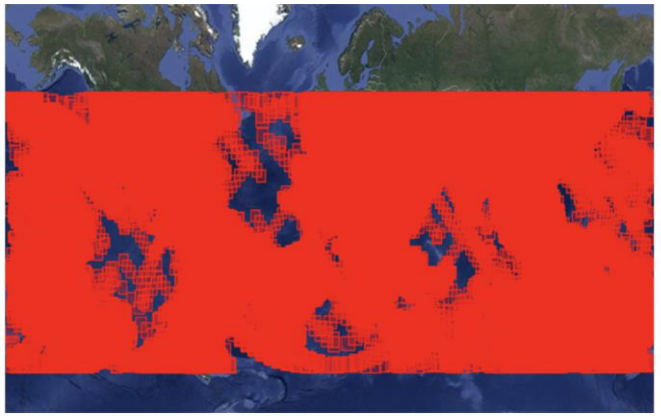


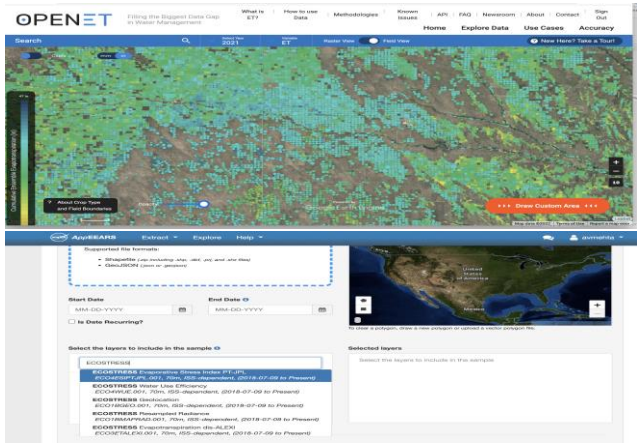
Figure 2 . Represent the actual coverage area acquisition as of 19 March 2020.

https://ecostress.jpl.nasa.gov/science

ECOSTRESS ET

Speaker: Gregory Halverson
NASA JPL

Part 3: June 15, 2022



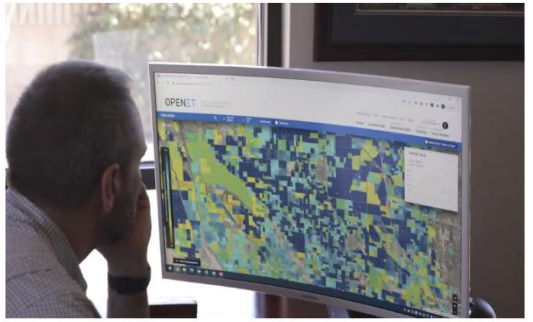
Exercises: Access and Analysis of OpenET and ECOSTRESS ET Data

Outline for Session 1

- About ARSET
- OpenET:
  - Data products, data portal, and applications

OpenET for Water Conservation Programs

OpenET for Rangeland, Forest, and Watershed Management



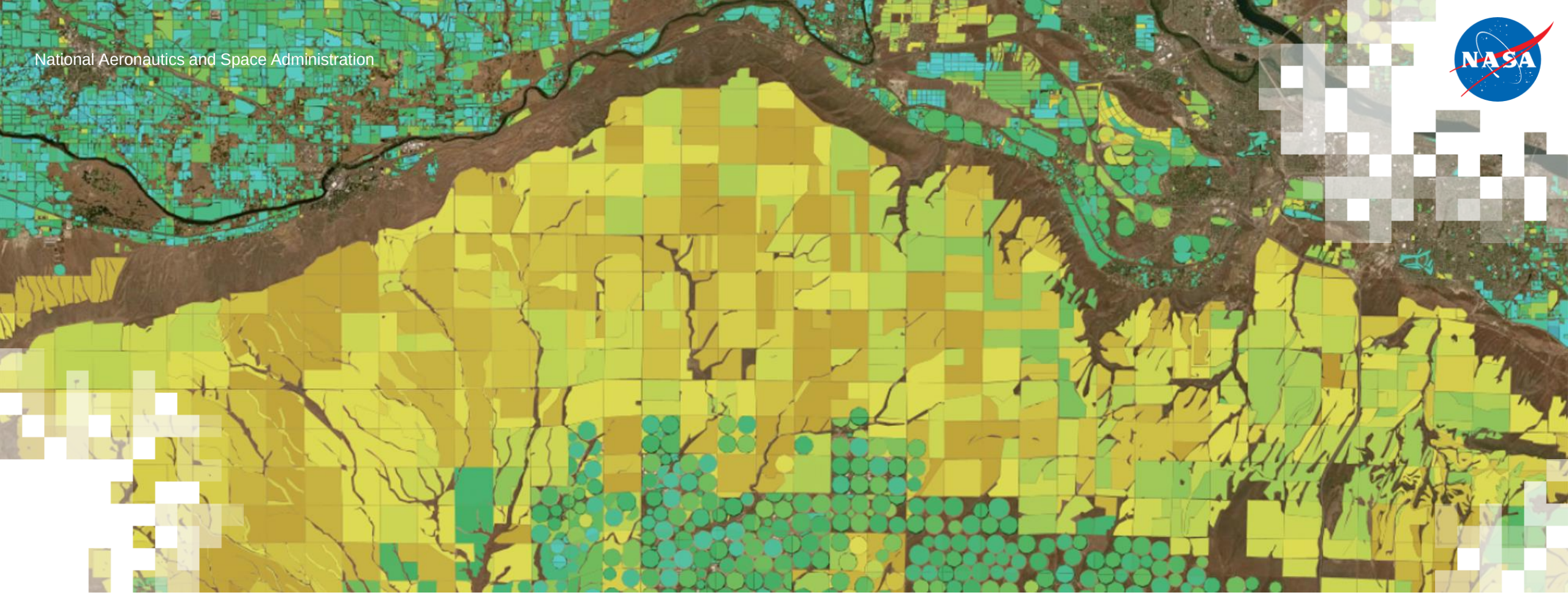
OpenET for Water Accounting

OpenET as a Common Foundation for Decision-Making

Homework and Certificate

- One homework assignment:
  - Answers must be submitted via Google Form accessed from the ARSET website
  - Homework will be made available on June 15, 2022.
  - Due date for homework: July 29, 2022.

- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

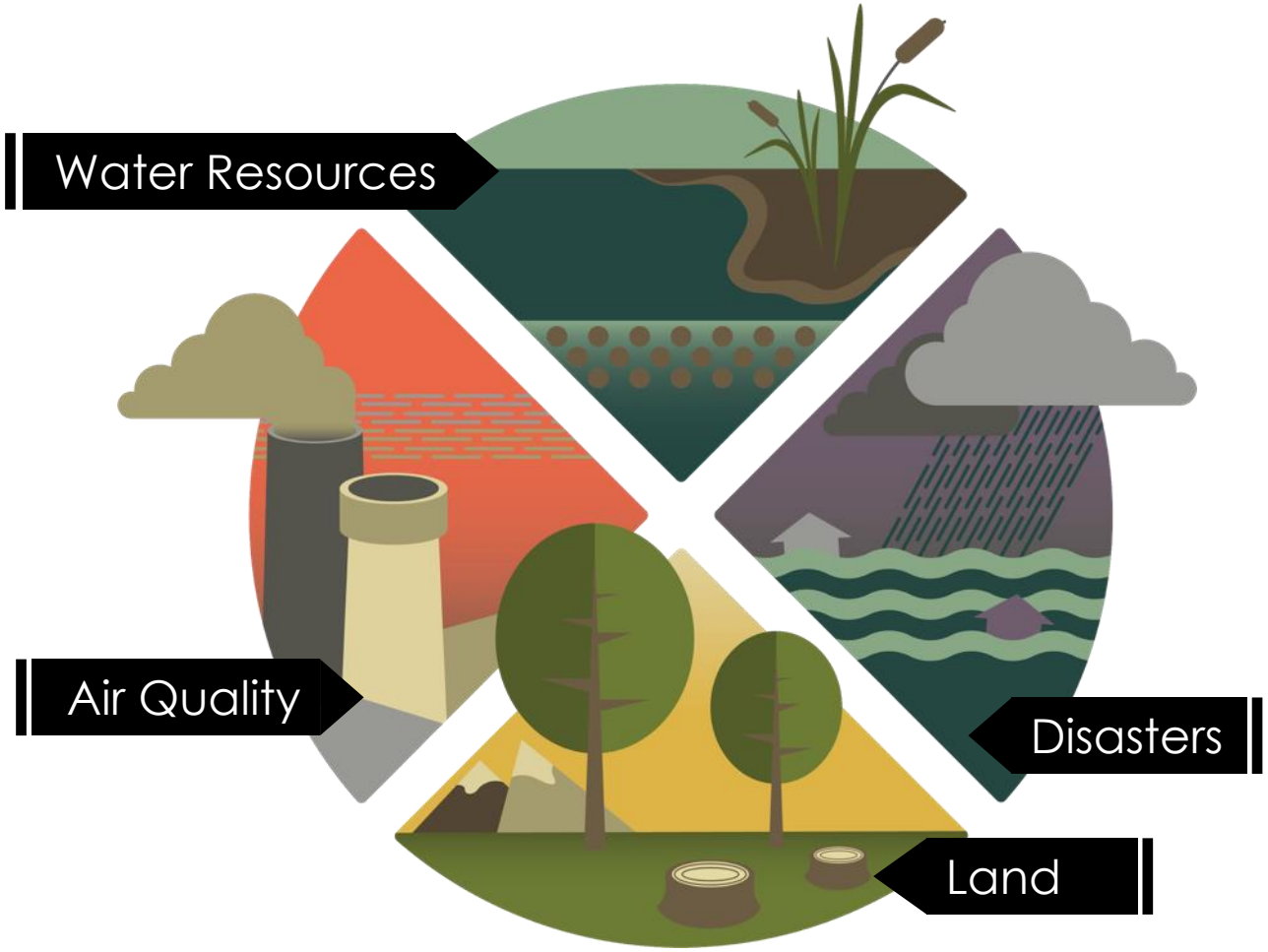


About ARSET

NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- Part of NASA's Applied Sciences Capacity Building Program
- Empowering the global community through online and in-person remote sensing training
- Topics for trainings include:
  - Water Resources
  - Air Quality
  - Disasters
  - Land
  - Climate (recently added)

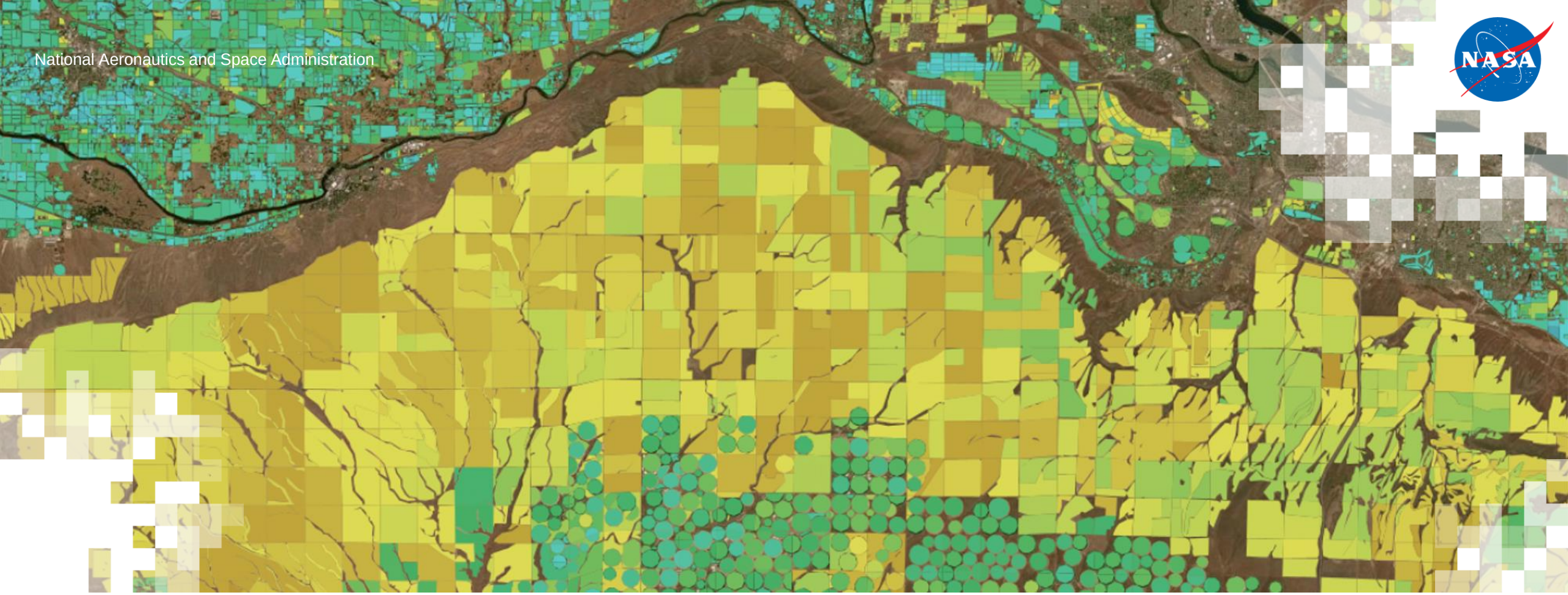


NASA's Applied Remote Sensing Training Program (ARSET)

https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

- ARSET's goal is to increase the use of Earth science remote sensing and model data in decision-making through training for:
  - Professionals in the public and private sector
  - Environmental managers
  - Policy makers

All ARSET materials are freely available to use and adapt for your curriculum. If you use the methods and data presented in ARSET trainings, please acknowledge the NASA Applied Remote Sensing Training (ARSET) program.

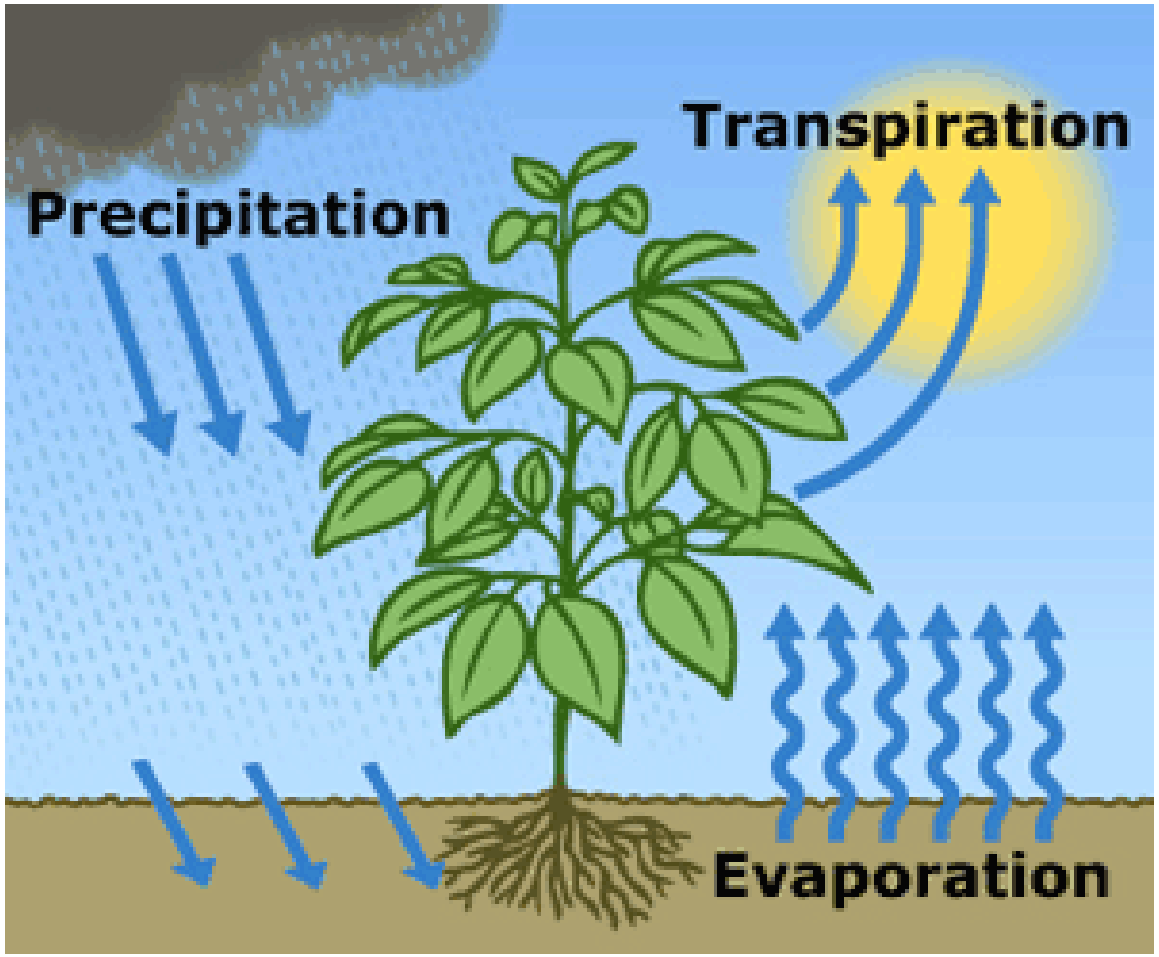


Overview of Evapotranspiration

https://appliedsciences.nasa.gov/join-mission/training/english/arset-applications-remote-sensing-soil-moisture-and

What is evapotranspiration (ET)?

- The sum of evaporation from the land surface plus transpiration from plants
- ET transfers water from land surface to the atmosphere in vapor form
- Energy is required for ET to take place (for changing liquid water into vapor)



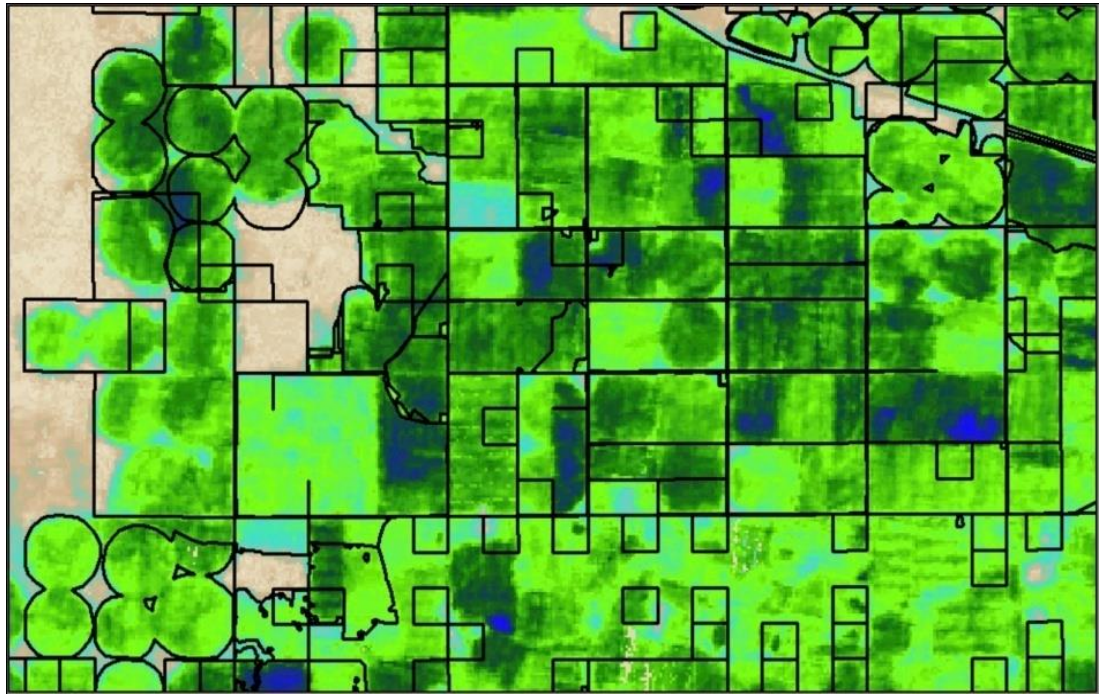
Source: USGS

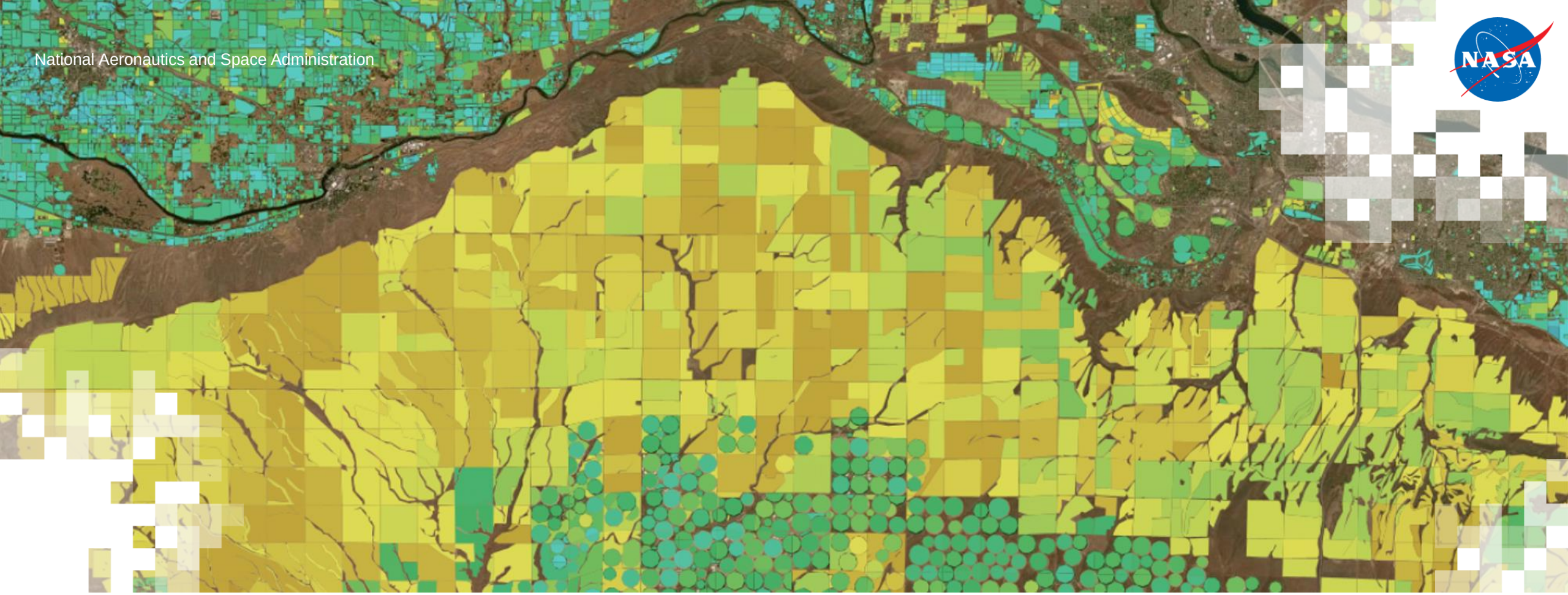
Importance of ET

- Critical component of the water and energy balance of climate-soil-vegetation interactions.
- Useful for:
  - determining agricultural water consumption
  - assessing drought conditions
  - developing water budgets
  - monitoring aquifer depletion
  - monitoring crops and carbon budgets

Challenges in Measuring ET

- ET depends on many variables:
  - solar radiation at the surface
  - land and air temperatures
  - Humidity
  - surface winds
  - soil conditions
  - vegetation cover and types
  - Highly variable in space and time





OpenET

Speaker: Forrest Melton (NASA Ames Research Center)

OPENET

Evapotranspiration Data for Water Management and Precision Agriculture

NASA
Google Earth Engine
EDF ENVIRONMENTAL DEFENSE FUND
DRI
USGS science for a changing world
USDA ars
University of Idaho
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON
UNIVERSITY OF MARYLAND
University of Nebraska Lincoln
California State University MONTEREY BAY
HabitatSeven
UFRGS UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

OPENET Filling the Biggest Data Gap in Water Management

What is ET? | How to use Data | Methodologies | Known Issues | API | FAQ | Newsroom | About | Contact | Sign Out

Home Explore Data Use Cases Accuracy

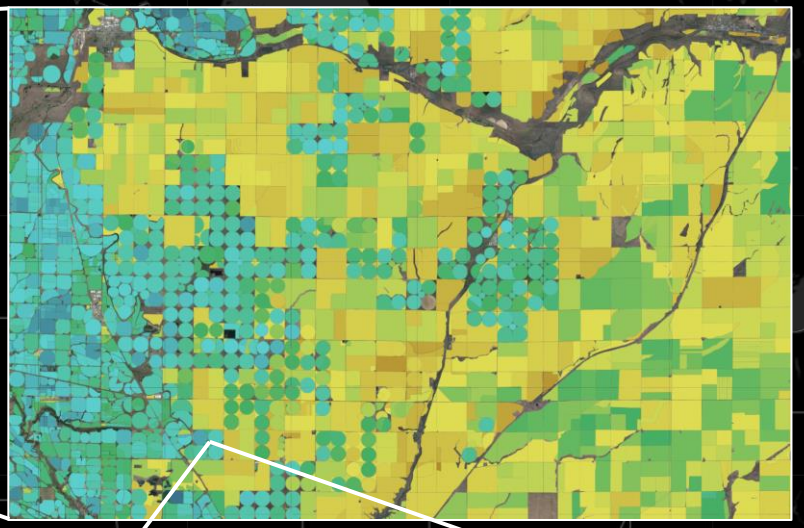
Search | Select Year 2021 | Variable ET | Raster View | Field View | New Here? Take a Tour!

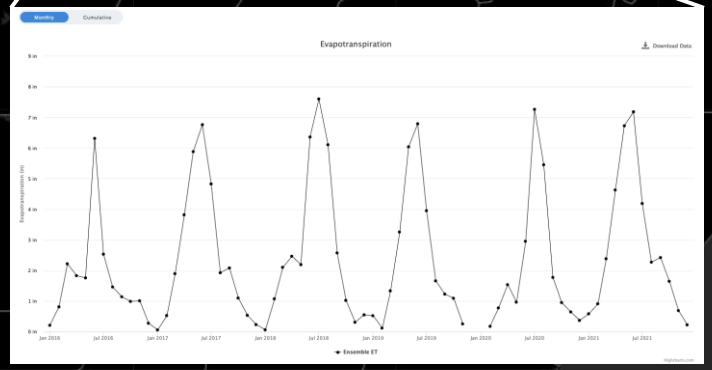
Cities | mm | in

27 in

Cumulative Ensemble Evapotranspiration (in)

0 in





https://openetdata.org

? About Crop Type and Field Boundaries

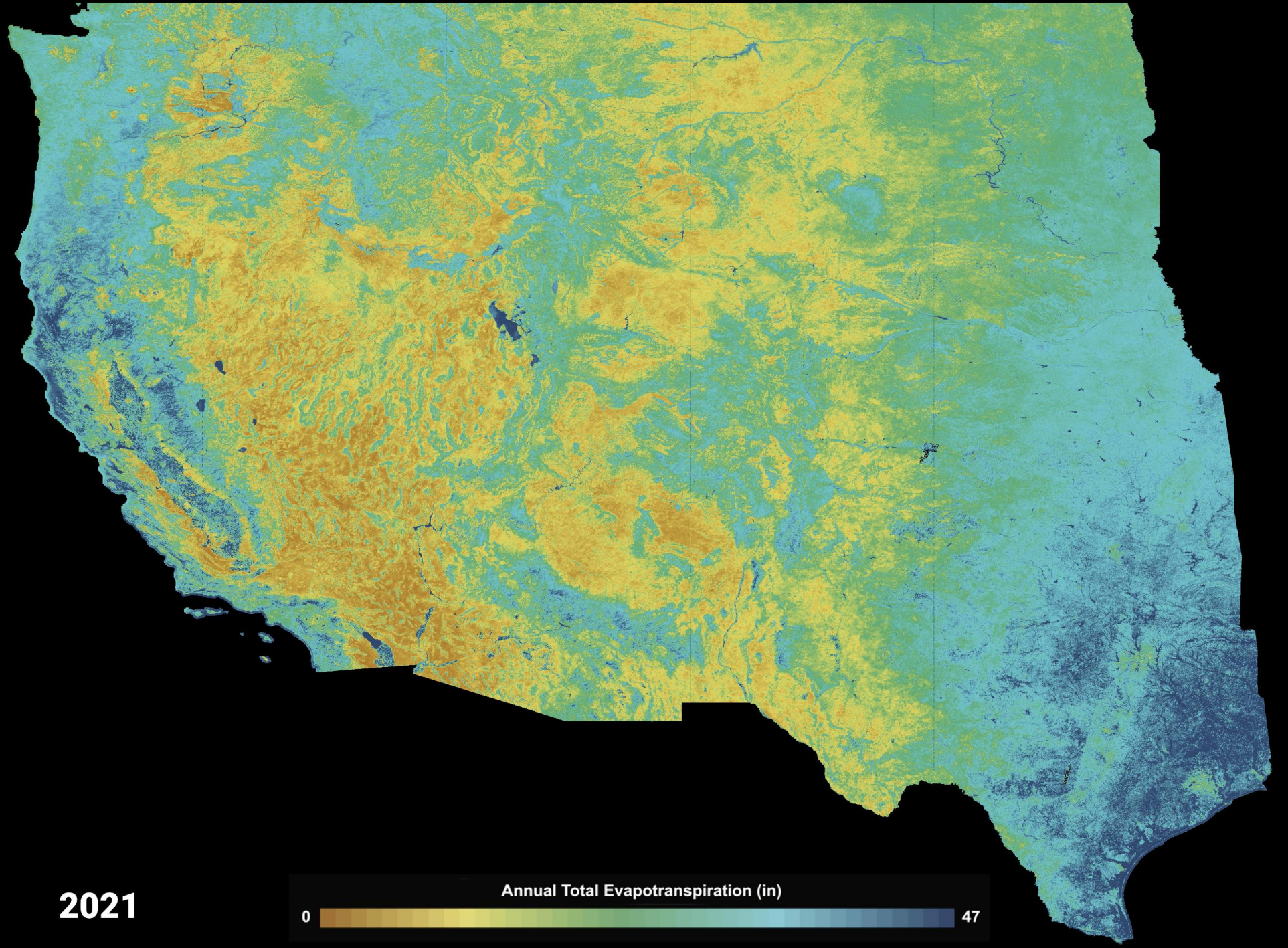
Opacity

Powered by Google Earth Engine

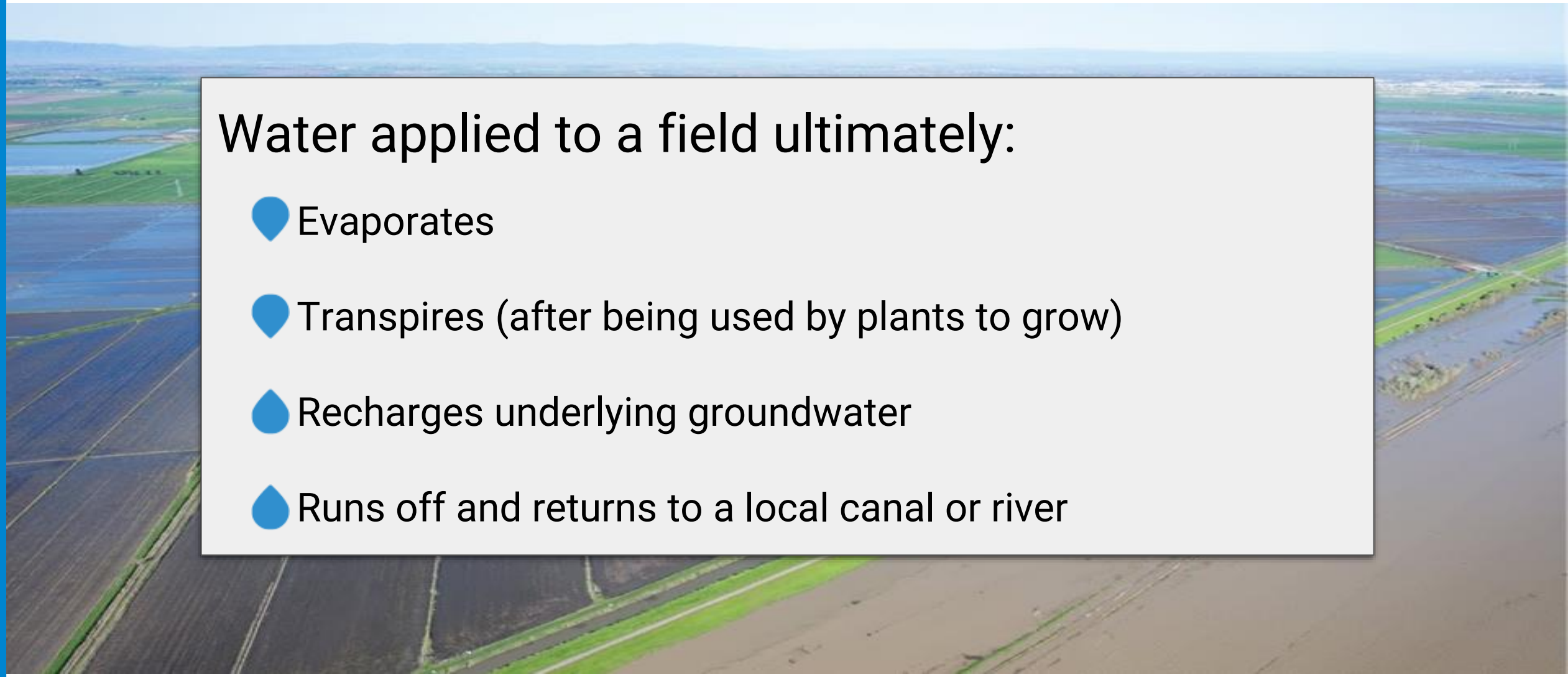
Draw Custom Area

Google 100 mi

Leaflet | Map data ©2022 Google, INEGI | Terms of Use


2021
Annual Total Evapotranspiration (in)
0
47

Evapotranspiration (ET)



Water applied to a field ultimately:

- Evaporates
- Transpires (after being used by plants to grow)
- Recharges underlying groundwater
- Runs off and returns to a local canal or river

Overview

1. OpenET and the Value of Open Data
2. How OpenET Works
3. OpenET Accuracy Assessment
4. Use Cases and Pilot Projects
5. Next steps for OpenET
6. Lessons Learned
7. NASA and the Western Water Applications Office

OpenET and the Value of Open Data

Founded on Open Science

DRI, NASA Ames, Habitat Seven (Multimodel Development, Integration, API, UI) Forrest Melton, Jamie Herring, Charles Morton, Britta Daudert, Alberto Guzman, Jody Hansen, Jordan Harding, Matt Bromley, Justin Huntington

USDA, NASA Marshall Space Flight Center, U. Maryland, U. Wisconsin (ALEXI/DisALEXI) Martha Anderson, Yun Yang, Christopher Hain

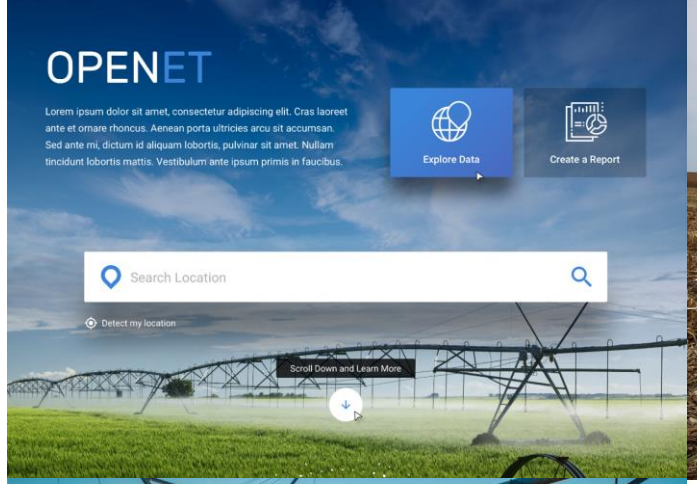
U. of Nebraska, U. of Idaho, DRI (EE METRIC) Ayse Kilic, Rick Allen, Peter Revelle, Samuel Ortega

NASA JPL (PT JPL) Josh Fisher, Gregory Halverson

NASA Ames, CSUMB, Stanford University (SIMS) Forrest Melton, Alberto Guzman, Lee Johnson, Will Carrara, Tianxin Wang, Conor Doherty

USGS (SSEBop) Gabriel Senay, MacKenzie Friedrichs, Gabe Parrish

Google Earth Engine Tyler Erickson



OpenET Goals:

Reliable and transparent ET data are produced and **easily accessible for all farmers, communities, and water managers in the west via openetdata.org**

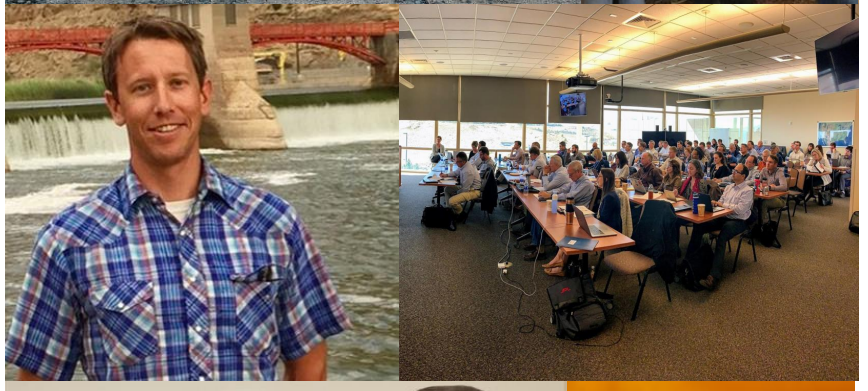
There is trust in the validity of the data and information provided by the platform, and it is utilized by farmers, and private and public resource managers at the local, state and federal levels.

A variety of **innovative and locally driven water management practices are enabled** at a much larger scale than currently possible.

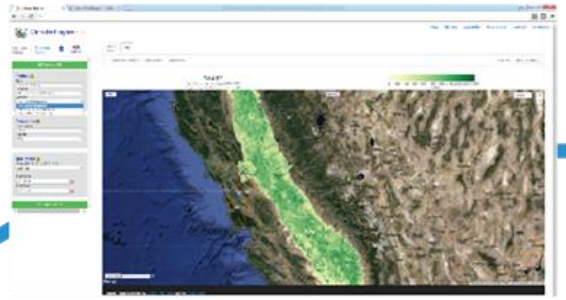
Dedicated to Transparency and Equal Data Access

Available on www.openetdata.org:

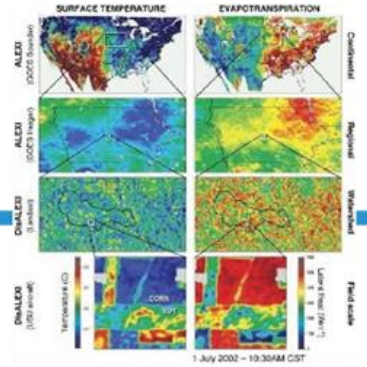
(and more)



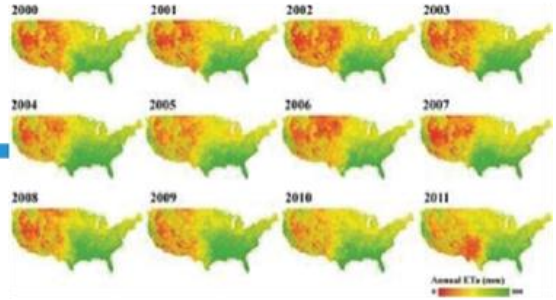
OpenET Uses Well-Established Methods



EE METRIC
University of Nebraska,
University of Idaho

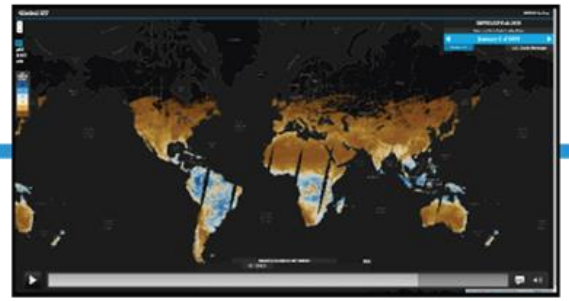


ALEXI/DisALEXI
USDA, NASA, University of Maryland,
University of Wisconsin

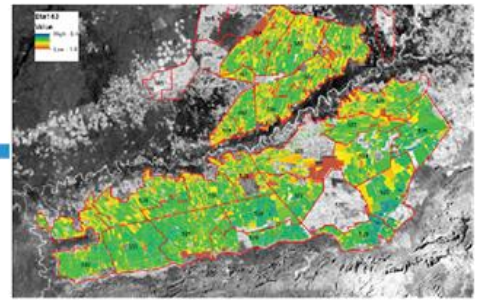


SSEBop
USGS

SIMS
NASA, CSUMB, Stanford University

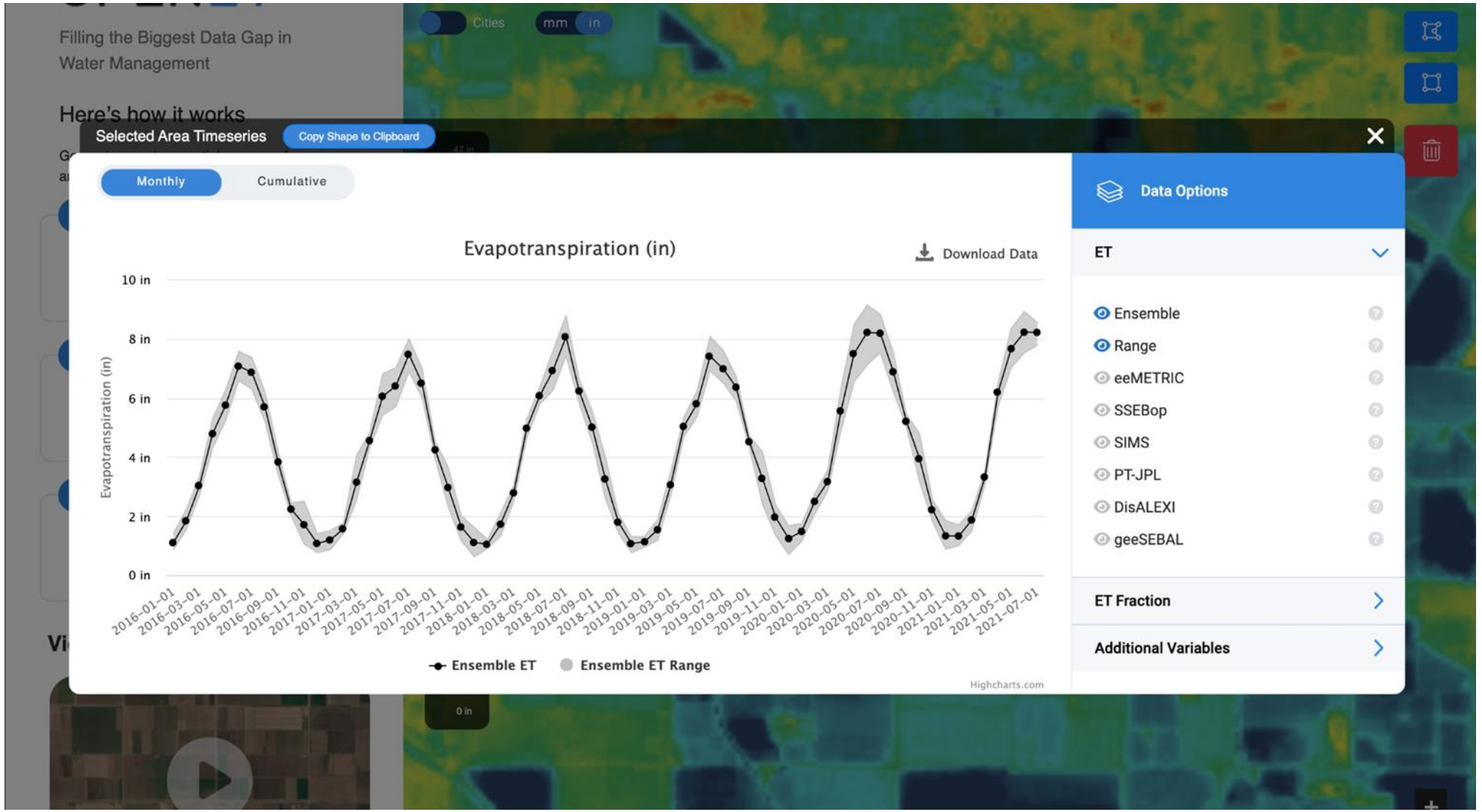


PT-JPL
NASA

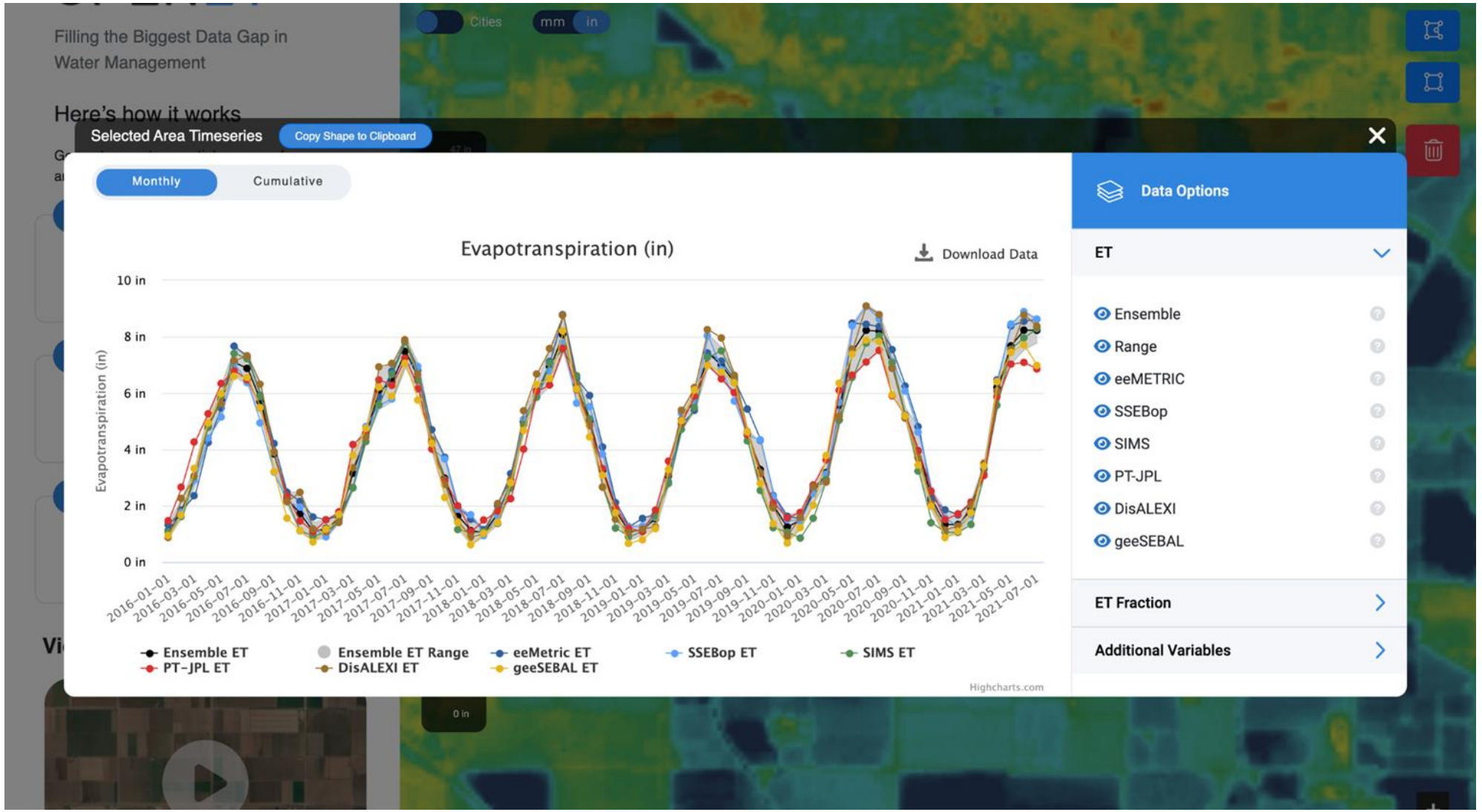


SEBAL
Universidade Federal
do Rio Grande do Sul

OpenET Ensemble Approach



OpenET Ensemble Approach



How OpenET Works

https://openetdata.org

OPENET

Filling the Biggest Data Gap in Water Management

What is ET? | How to use Data | Methodologies | Known Issues | API | FAQ | Newsroom | About | Contact | Sign Out

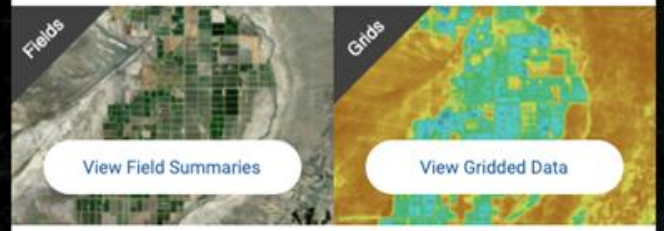
Home Explore Data Use Cases Accuracy

Search 2020 ET Raster View Field View New Here? Take a Tour!

Cities mm in

Cumulative Ensemble Evapotranspiration (in)

Choose to view data by **fields** or by **grids**.



OpenET provides data at different scales. You can view the data summarized for millions of individual fields or in the original raster format, or you can create a custom report to define your own boundaries, time frames, and data summaries.

Terms of Service I How to Use OpenET Data

About Crop Type and Field Boundaries

Opacity

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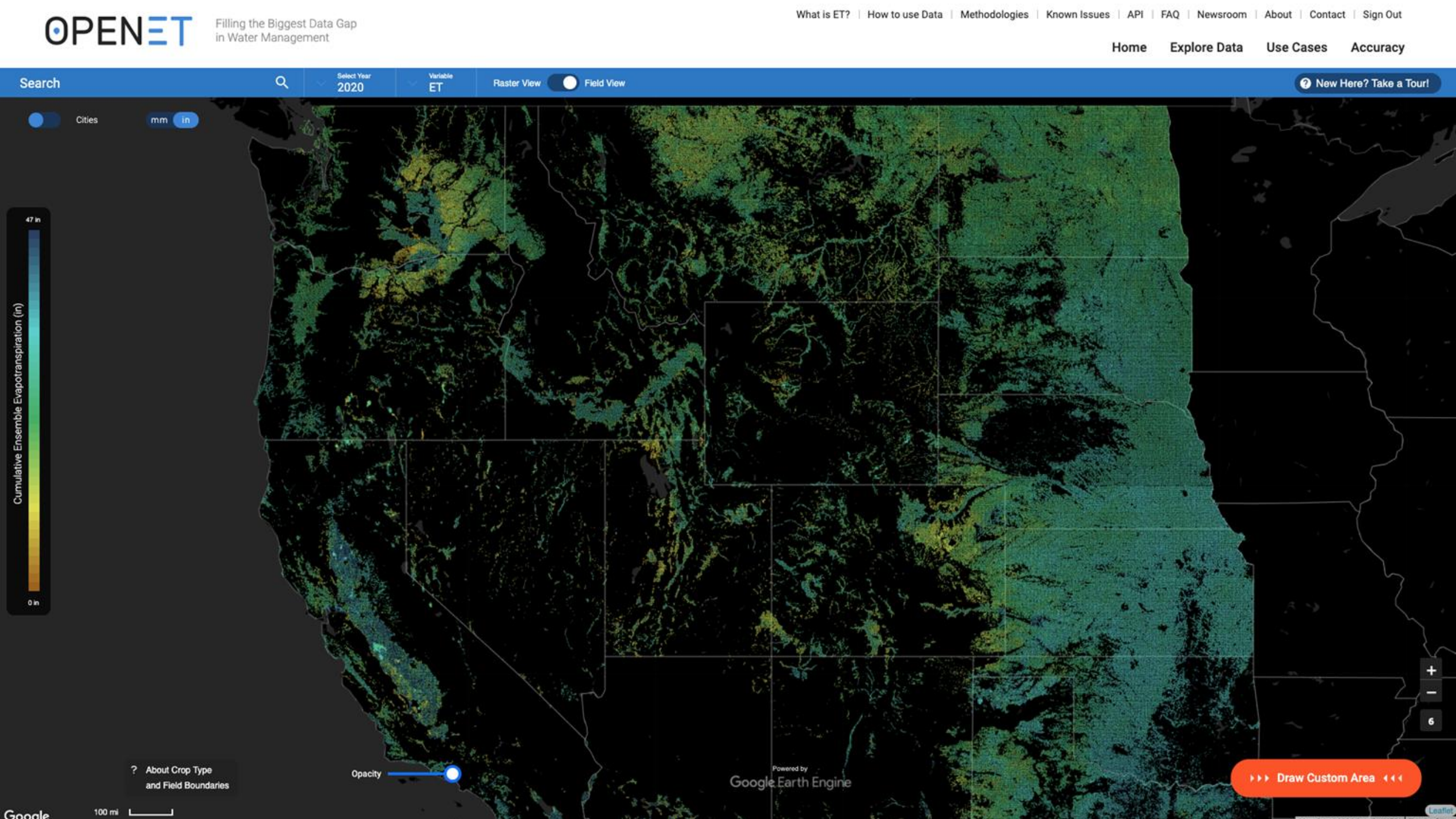
Draw Custom Area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Home
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Use Cases
Accuracy
Search
Select Year
2020
Variable
ET
Raster View
Field View
New Here? Take a Tour!
Cities
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47 in
Cumulative Ensemble Evapotranspiration (in)
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? About Crop Type and Field Boundaries
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Google Earth Engine
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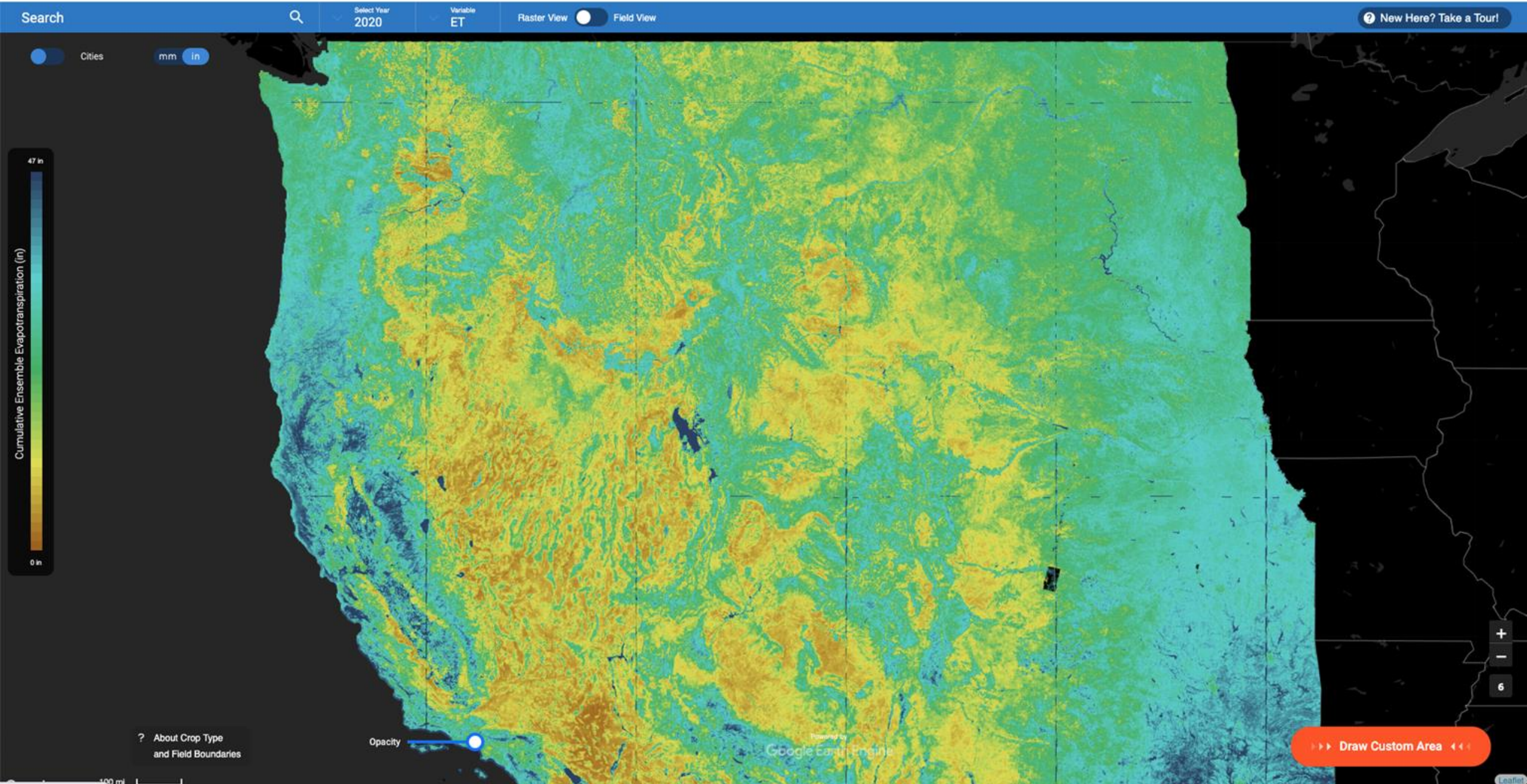
Search
Select Year
2020
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Cities
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Cumulative Ensemble Evapotranspiration (in)
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? About Crop Type and Field Boundaries
Opacity
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Draw Custom Area
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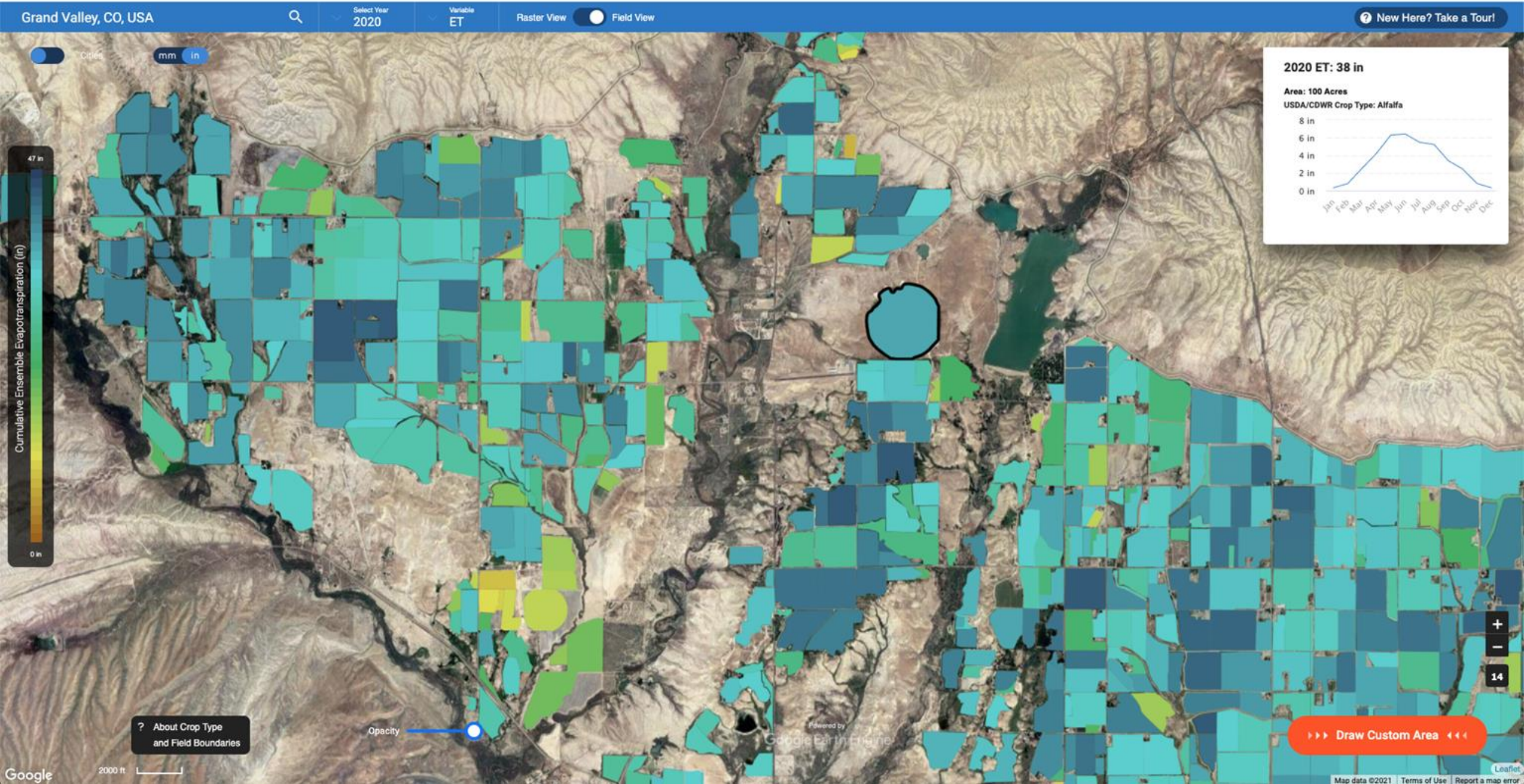
Leaflet


Grand Valley, CO, USA
Select Year
2020
Variable
ET
Raster View
Field View
New Here? Take a Tour!
Cities
mm
in
2020 ET: 38 in
Area: 100 Acres
USDA/CDWR Crop Type: Alfalfa
8 in
6 in
4 in
2 in
0 in
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
47 in
Cumulative Ensemble Evapotranspiration (in)
0 in
? About Crop Type and Field Boundaries
Opacity
Draw Custom Area
14
Google
2000 ft
Leaflet
Map data ©2021
Terms of Use
Report a map error

Grand Valley, CO, USA | Select Year 2020 | Variable ET | Raster View | Field View | New Here? Take a Tour!

mm | in

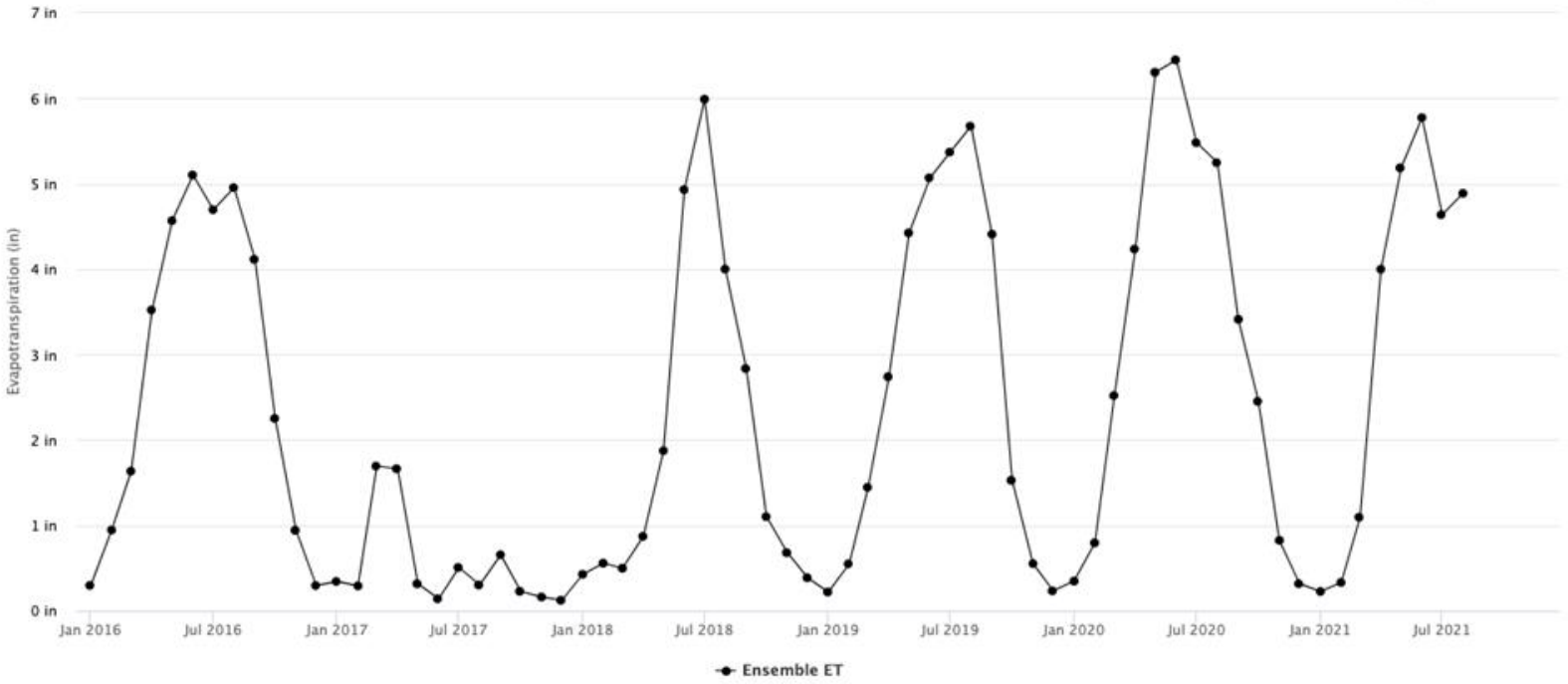
Cumulative Ensemble Evapotranspiration (in)

USDA/CDWR Crop Type: Alfalfa | Area: 100 Acres | Field ID: 084171

Monthly | Cumulative

Evapotranspiration

Download Data



Data Options

ET

- Ensemble
- Range
- eeMETRIC
- SSEBop
- SIMS
- PT-JPL
- DisALEXI
- geeSEBAL

ET Fraction

Additional Variables

About Crop Type and Field Boundaries

Opacity

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OPENET

Filling the Biggest Data Gap in Water Management

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Home | Explore Data | Use Cases | Accuracy

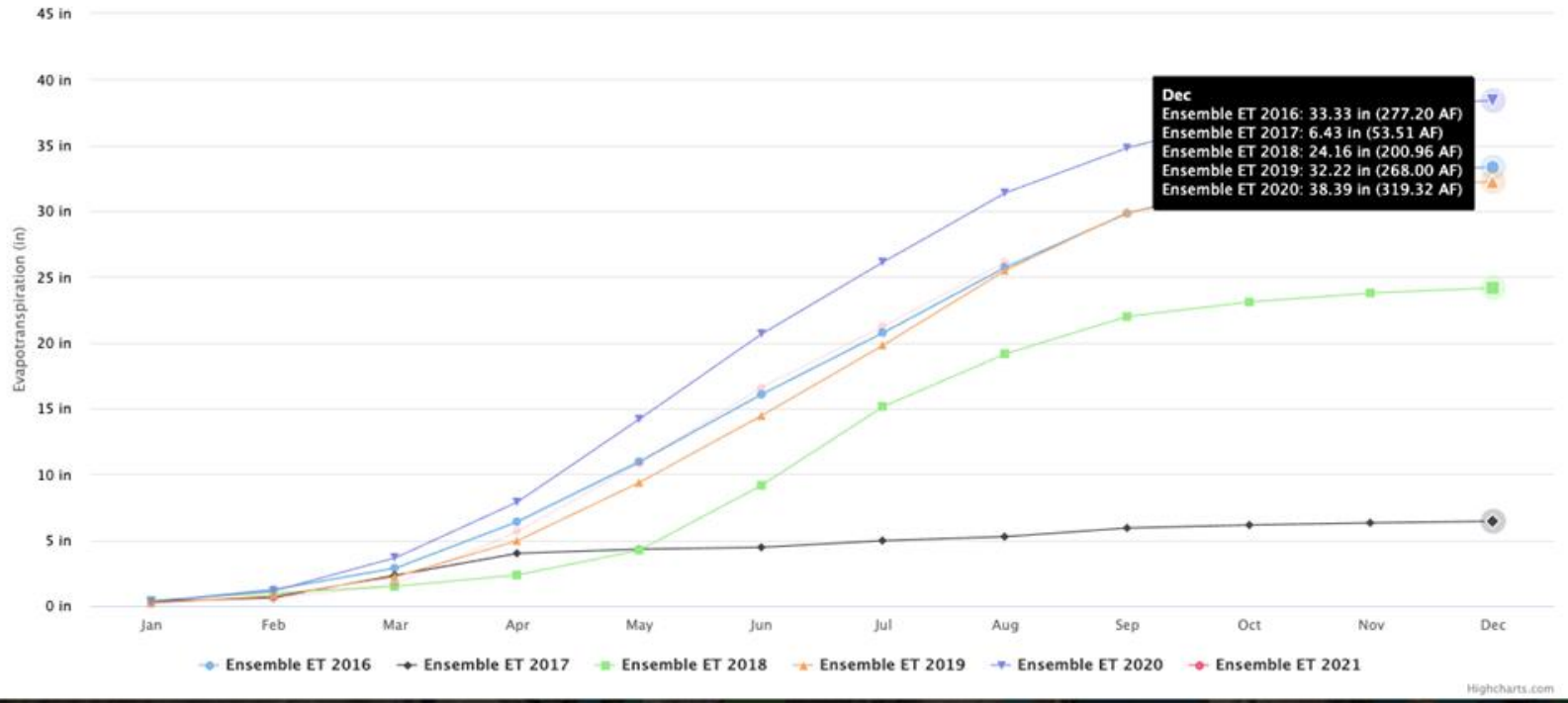
Grand Valley, CO, USA | Select Year 2020 | Variable ET | Raster View | Field View | New Here? Take a Tour!

USDA/CDWR Crop Type: Alfalfa | Area: 100 Acres | Field ID: 084171

Monthly | Cumulative

Cumulative Ensemble Evapotranspiration

Download Data



Data Options

ET

- (•) Ensemble
- ( ) eeMETRIC
- ( ) SSEBop
- ( ) SIMS
- ( ) PT-JPL
- ( ) DisALEXI
- ( ) geeSEBAL

Additional Variables

Cumulative Ensemble Evapotranspiration (in)

About Crop Type and Field Boundaries

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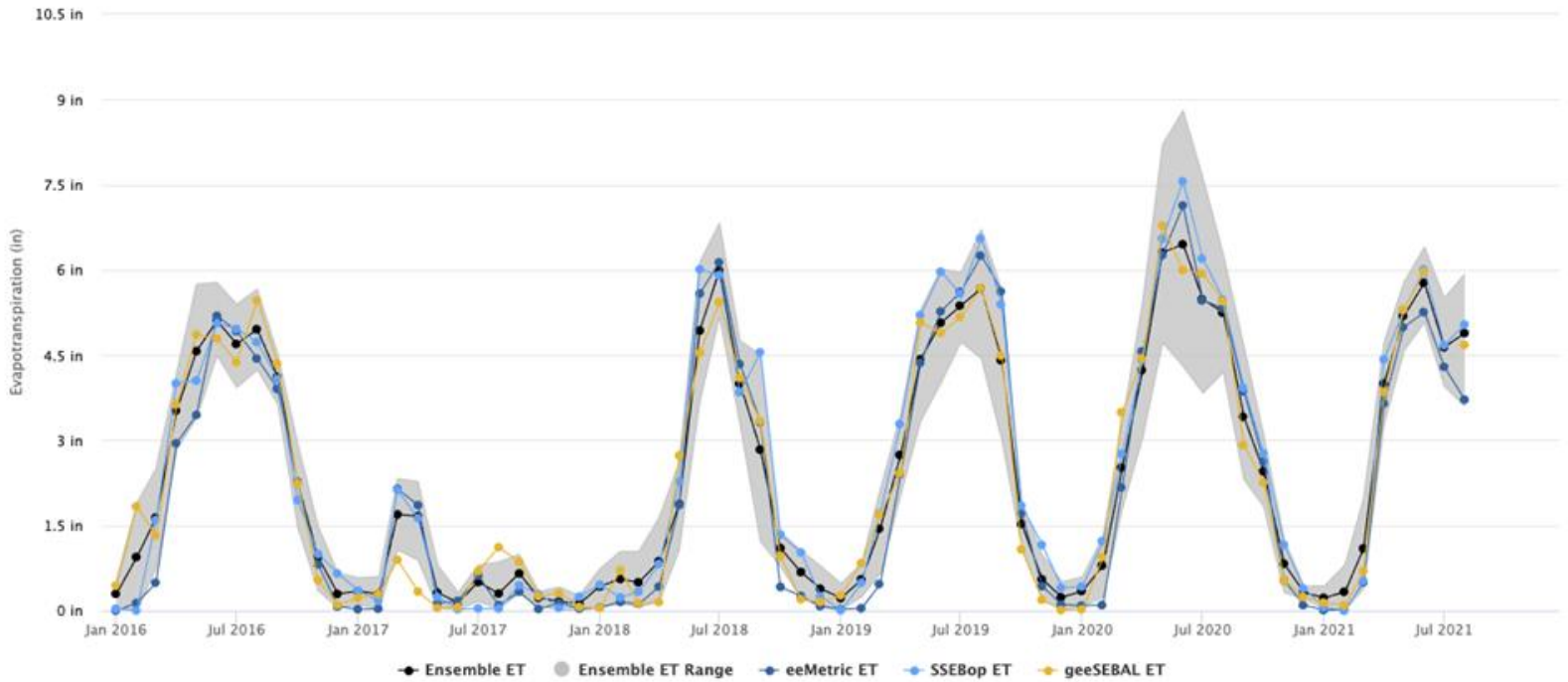
USDA/CDWR Crop Type: Alfalfa | Area: 100 Acres | Field ID: 084171

Monthly | Cumulative

Evapotranspiration

Download Data



Data Options

ET

- Ensemble
- Range
- eeMETRIC
- SSEBop
- SIMS
- PT-JPL
- DisALEXI
- geeSEBAL

ET Fraction

Additional Variables

Cumulative Ensemble Evapotranspiration (in)

About Crop Type and Field Boundaries

Opacity

Draw Custom Area

Google

OPENET

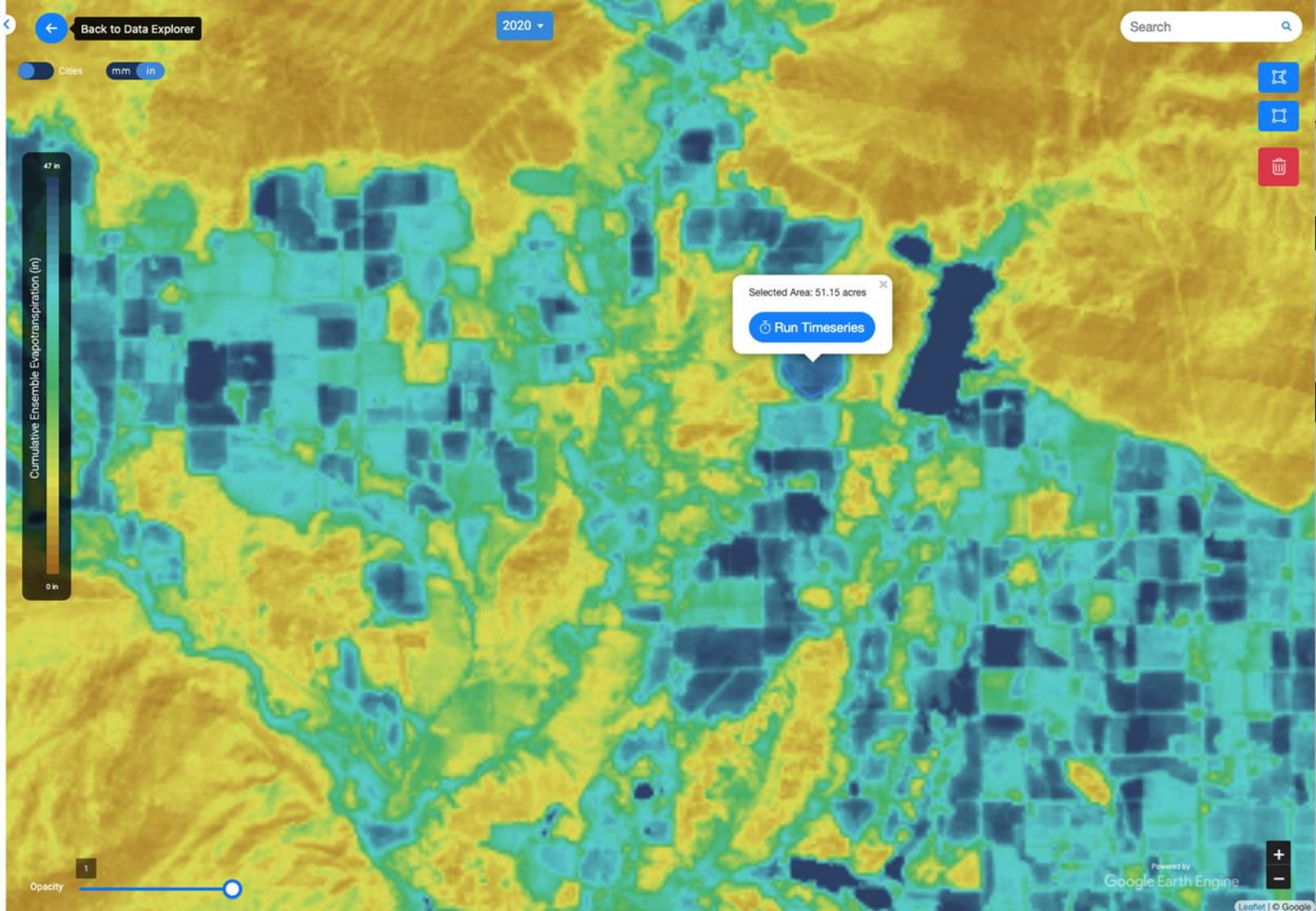
Filling the Biggest Data Gap in Water Management

Here's how it works

Generate a custom spatial summary for area up to 1000 ha.

1. Zoom and drag or use the search tool to find your location of interest on the map.
2. Use the polygon drawing tools to draw your area of interest.
3. Once done, click "run time series" to get data specific to the area drawn on the map.

Video demo



OPENET

Filling the Biggest Data Gap in Water Management

Here's how it works

Generate a custom spatial summary for area up to 1000 ha

1. Zoom a search t of intere
2. Use the to draw
3. Once d series" t the area

Video demo

Back to Data Explorer

2020

Search

Cities

mm in

47 in

Selected Area Timeseries

Copy Shape to Clipboard

Monthly Cumulative

Evapotranspiration (in)

Download Data

Jun 2016
Ensemble ET: 5.84 in (24.91 AF)

Evapotranspiration (in)

8 in
7 in
6 in
5 in
4 in
3 in
2 in
1 in
0 in

2016-01-01 2016-03-01 2016-05-01 2016-07-01 2016-09-01 2016-11-01 2017-01-01 2017-03-01 2017-05-01 2017-07-01 2017-09-01 2017-11-01 2018-01-01 2018-03-01 2018-05-01 2018-07-01 2018-09-01 2018-11-01 2019-01-01 2019-03-01 2019-05-01 2019-07-01 2019-09-01 2019-11-01 2020-01-01 2020-03-01 2020-05-01 2020-07-01 2020-09-01 2020-11-01 2021-01-01 2021-03-01 2021-05-01 2021-07-01

Ensemble ET

Highcharts.com

Data Options

ET

- Ensemble
- Range
- eeMETRIC
- SSEBop
- SIMS
- PT-JPL
- DisALEXI
- geeSEBAL

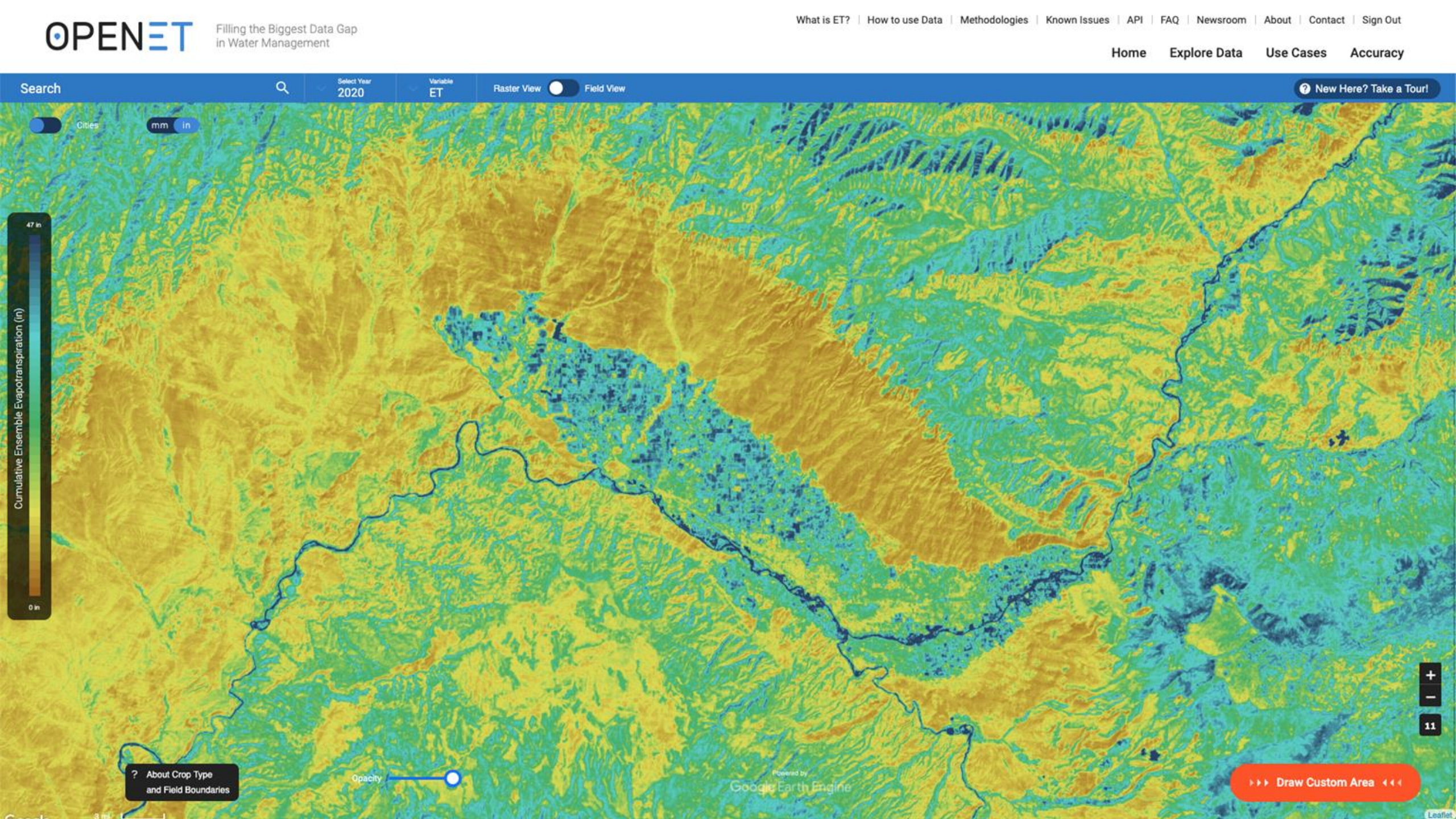
ET Fraction

Additional Variables

Opacity 1

Powered by Google Earth Engine

Leaflet | © Google


OPENET
Filling the Biggest Data Gap in Water Management
What is ET? | How to use Data | Methodologies | Known Issues | API | FAQ | Newsroom | About | Contact | Sign Out
Home
Explore Data
Use Cases
Accuracy
Search
Select Year
2020
Variable
ET
Raster View
Field View
New Here? Take a Tour!
Cities
mm
in
47 in
Cumulative Ensemble Evapotranspiration (in)
0 in
? About Crop Type and Field Boundaries
Opacity
Powered by Google Earth Engine
Draw Custom Area
11
Leaflet

Important Considerations

1. OpenET provides information on the total amount of water consumed through ET
    - Includes ET from irrigation, precipitation, and access to shallow groundwater
    - When comparing to meters, important to subtract effective precipitation

2. The crop type information available on OpenET is from publicly available datasets, and does not affect the accuracy of the ensemble ET value.

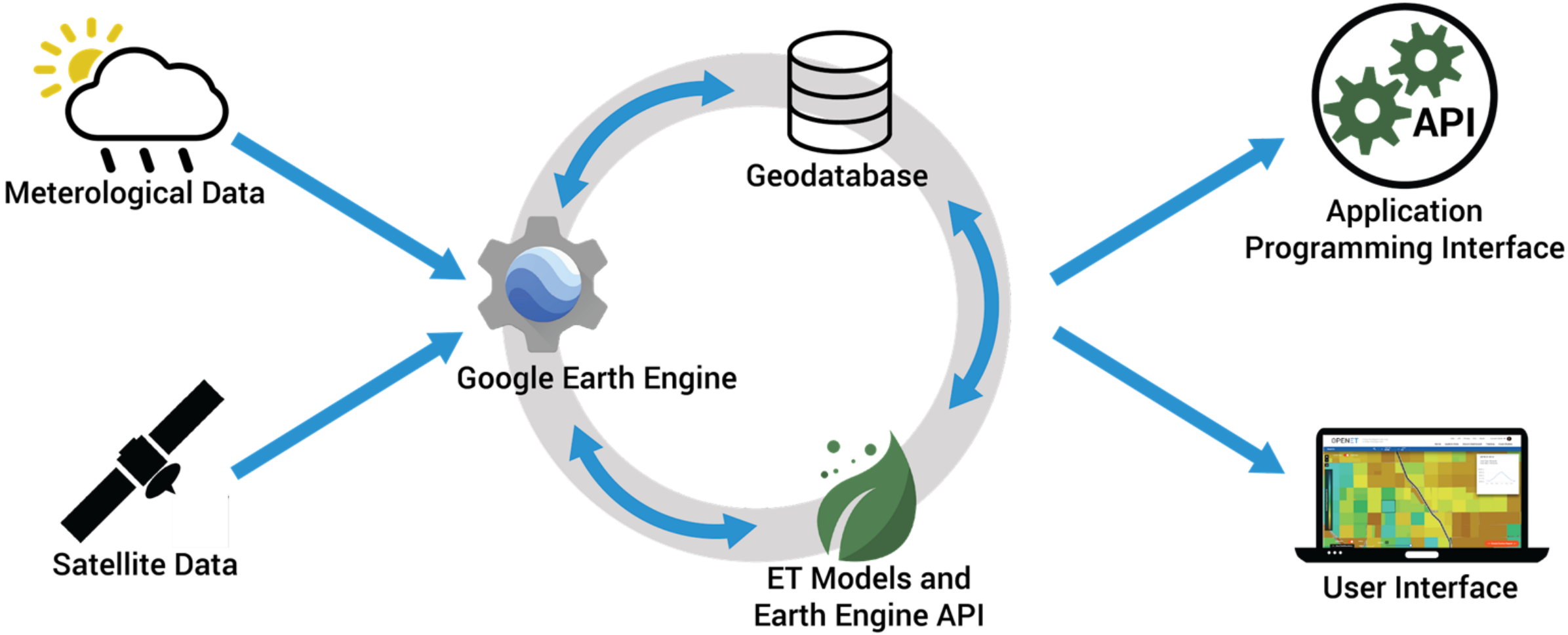
3. The relationship between ET and crop water requirements can be complex.

Important Considerations

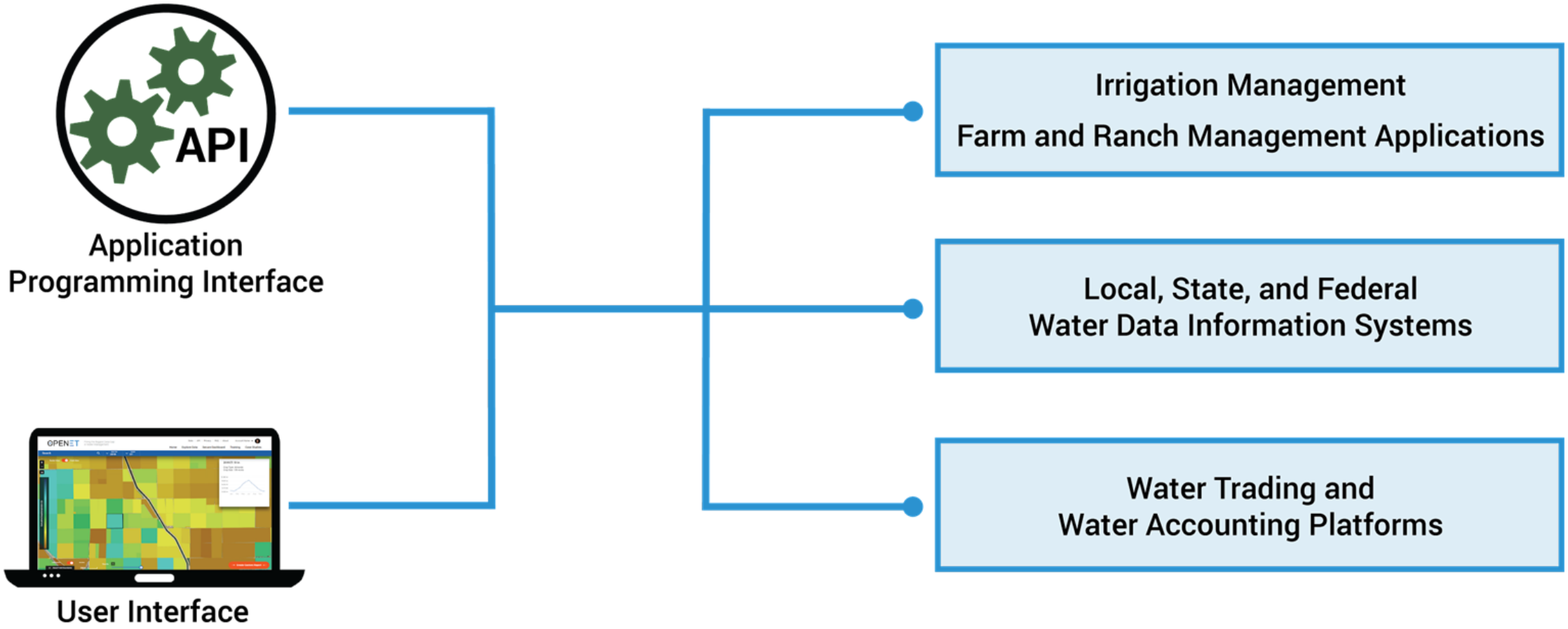
4. OpenET data do not represent direct measurements of ET; rather they are calculations based on satellite, meteorological, soil, and vegetation datasets that are used within state-of-the-art ET models.

    - While they are generally accurate and consistent, these data and models have limitations, particularly during times of consistent and dense cloud cover and within complex topography.

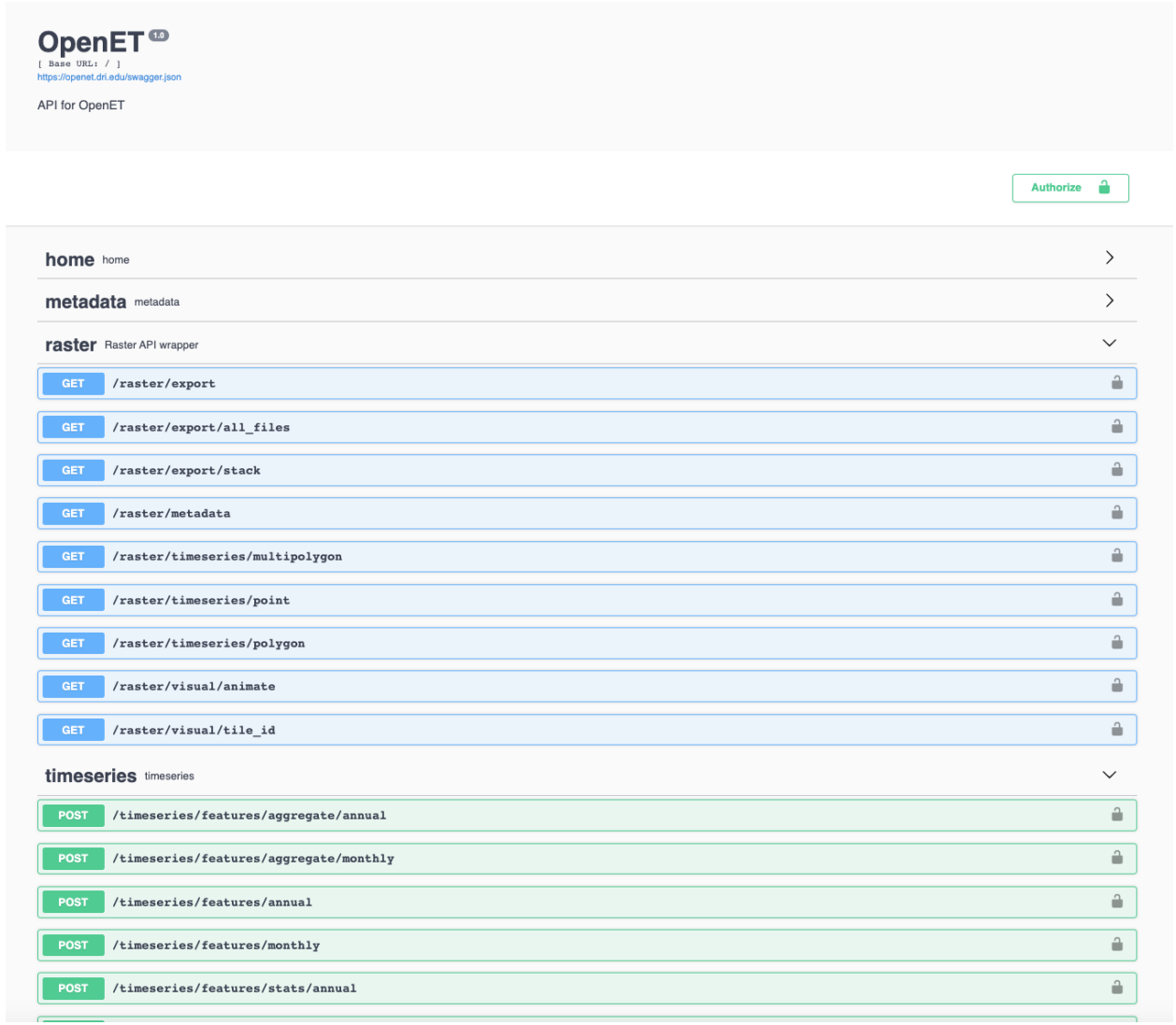
OpenET Architecture Overview

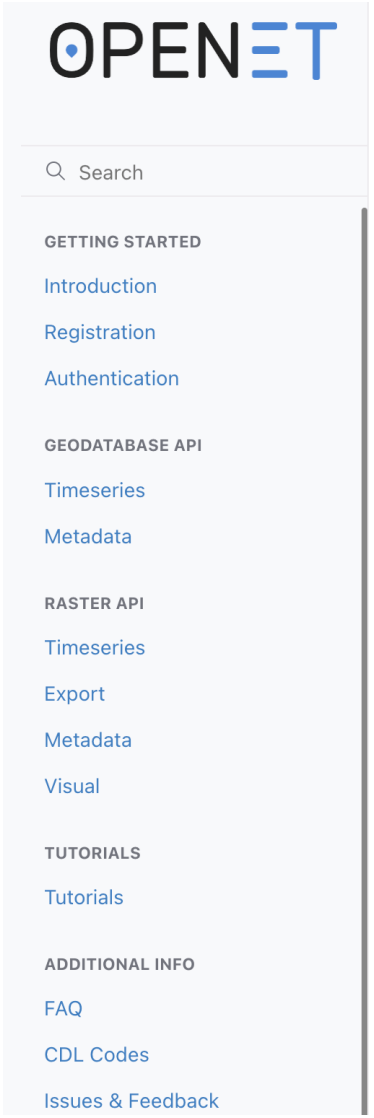


OpenET API for Integration with Other Software



OpenET Application Programming Interface





API Documentation

Last updated

May 09, 2022

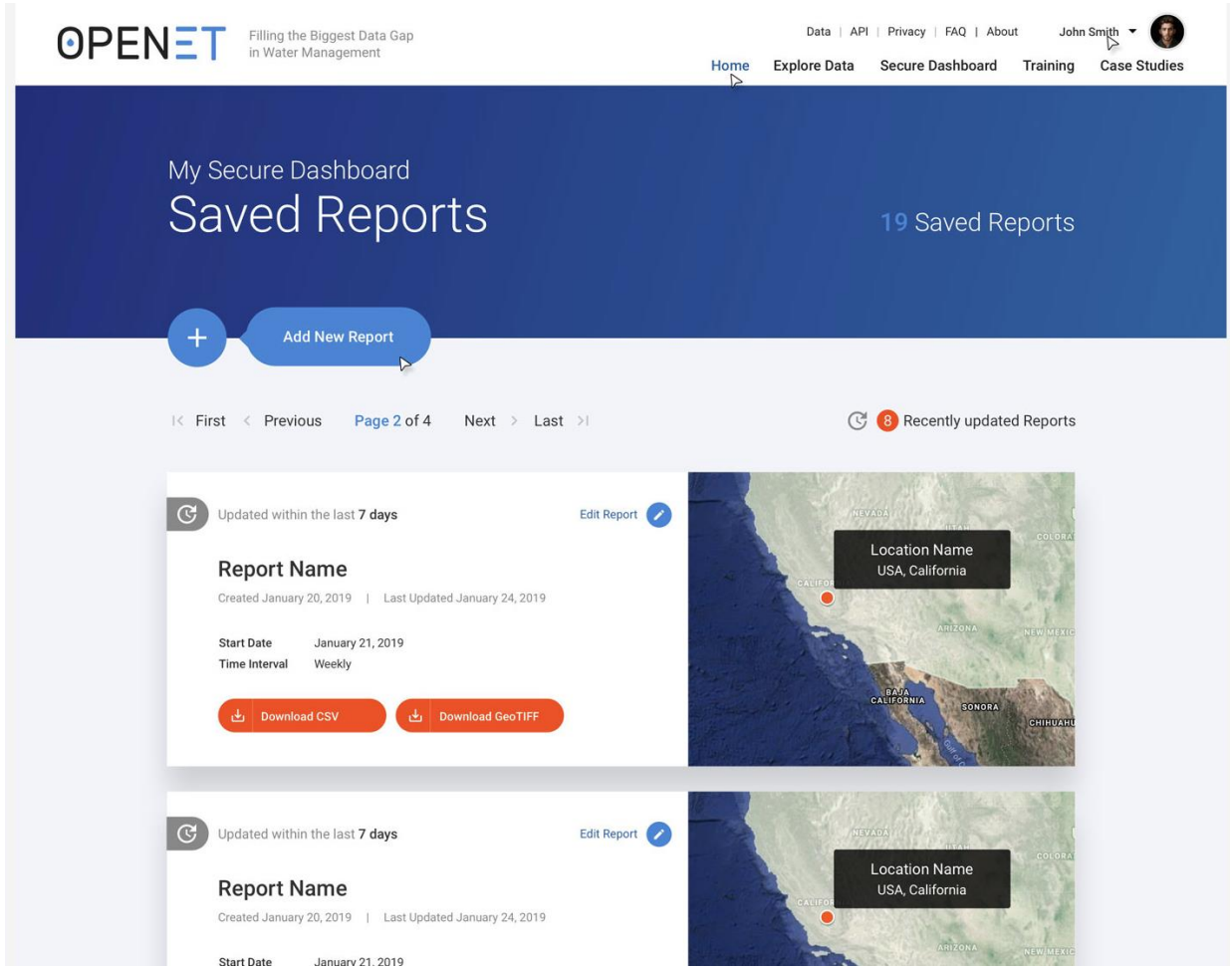
GETTING STARTED

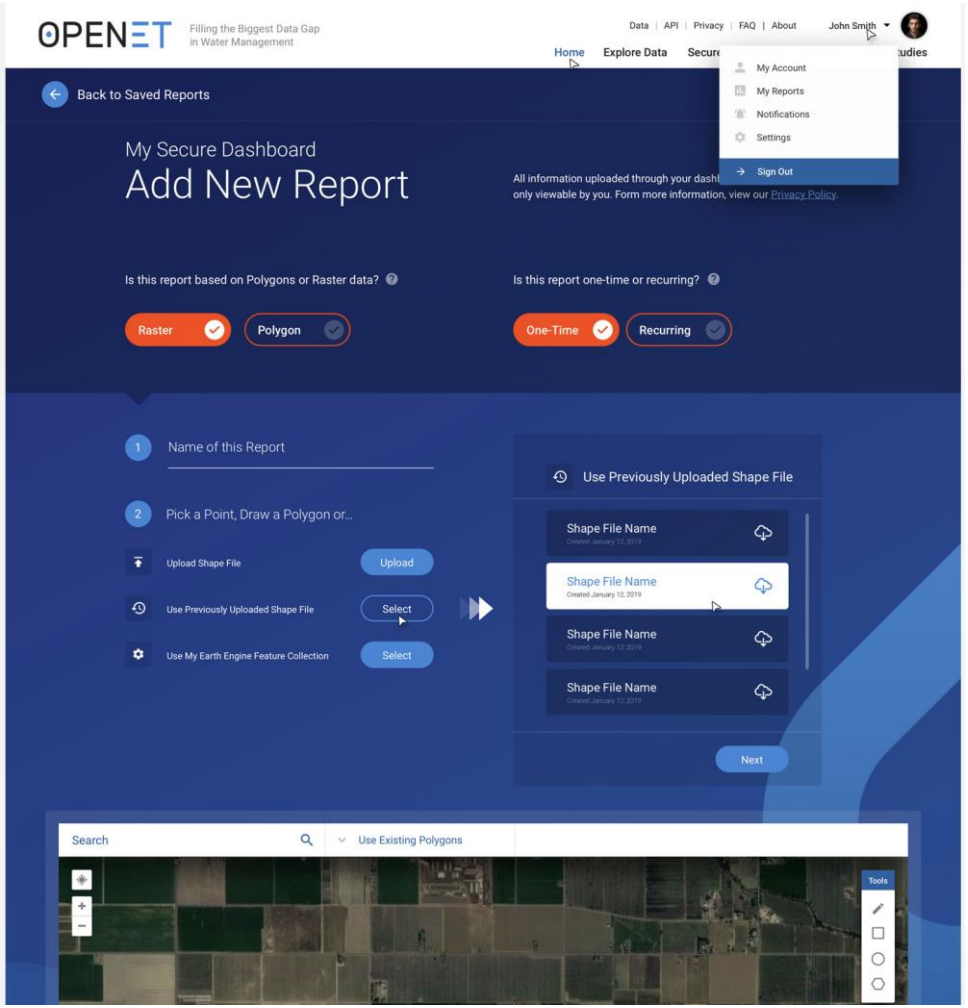
- Introduction
  - Geodatabase API
  - Raster API
  - OpenAPI UI
- Registration
  - Creating an Account
- Authentication
  - Tokens
  - Security

GEODATABASE API

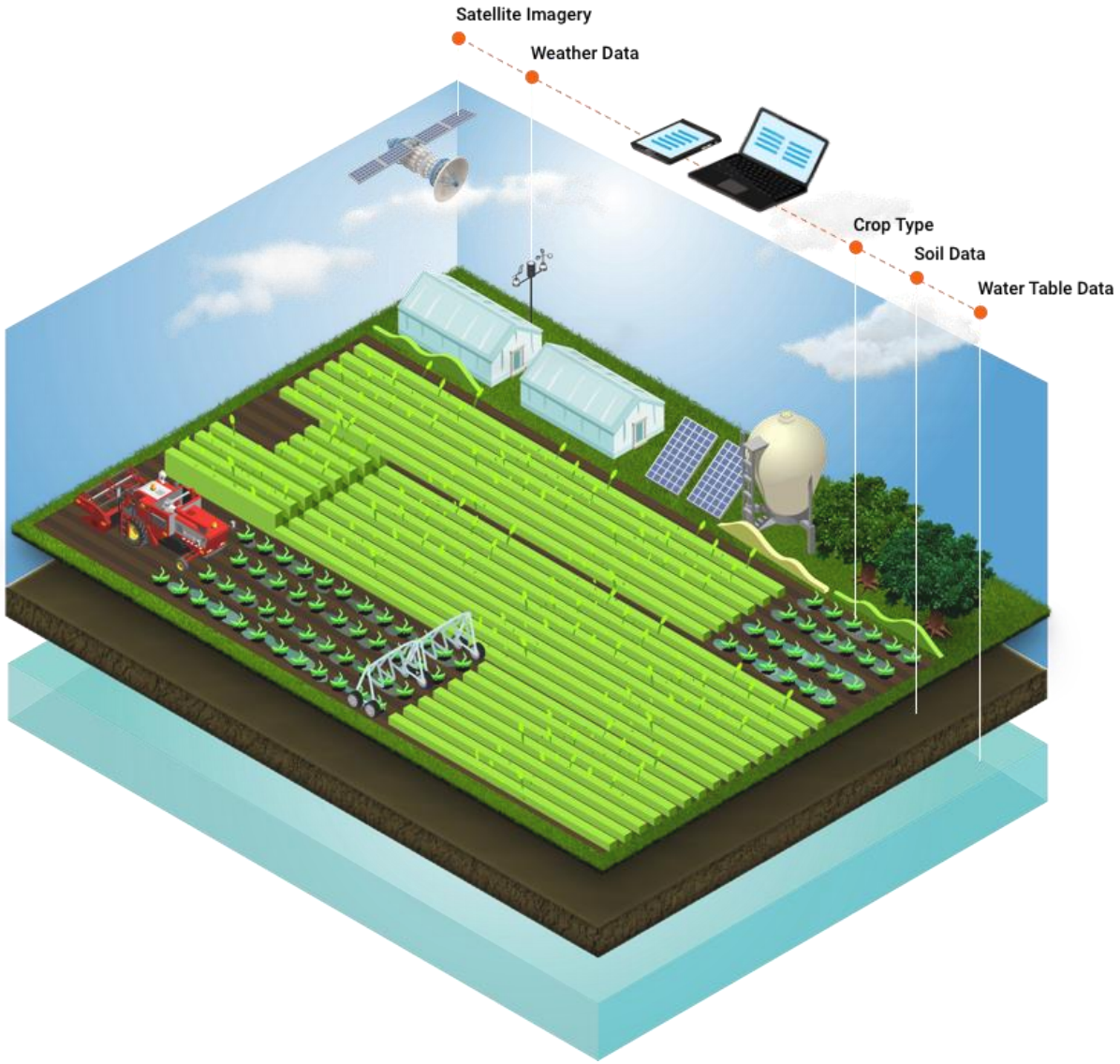
- Timeseries
  - timeseries/{field_id}
  - timeseries/features/annual
  - timeseries/features/monthly
  - timeseries/features/stats/annual
  - timeseries/features/stats/monthly
  - timeseries/features/aggregate/annual
  - timeseries/features/aggregate/monthly
- Metadata
  - metadata/openet/features
  - metadata/openet/feature_collection_names
  - metadata/openet/metadata/feature_ids_list
  - metadata/openet/feature_collection/feature_ids_list
  - metadata/openet/region_of_interest/feature_ids_list

OpenET Custom Reporting Tools

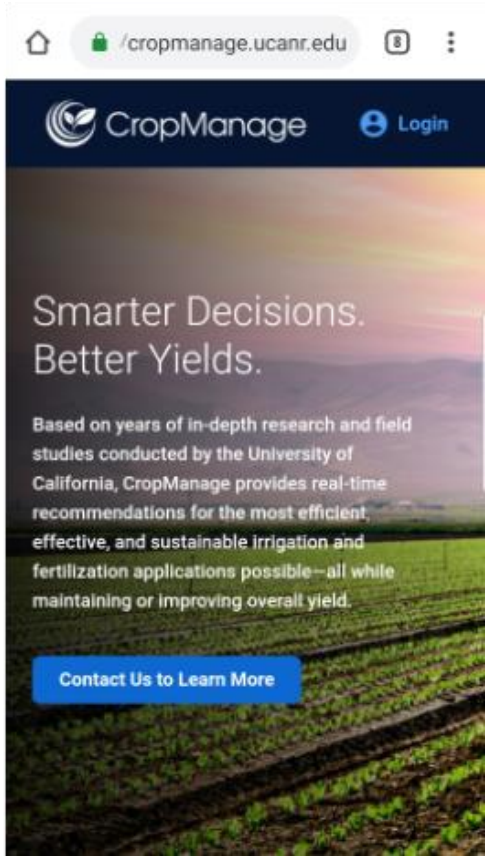


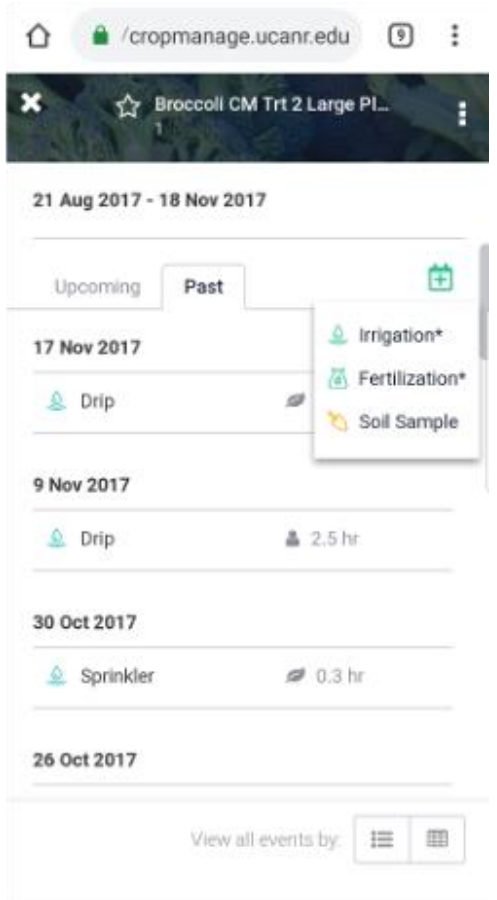


Linking Satellite Data with Irrigation Mgmt Software



UCANR CropManage





https://cropmanage.ucanr.edu/
Dr. Michael Cahn

OpenET Uses Data from a Constellation of Satellites

Image credit: NASA/Goddard Space Flight Center Conceptual Image Lab

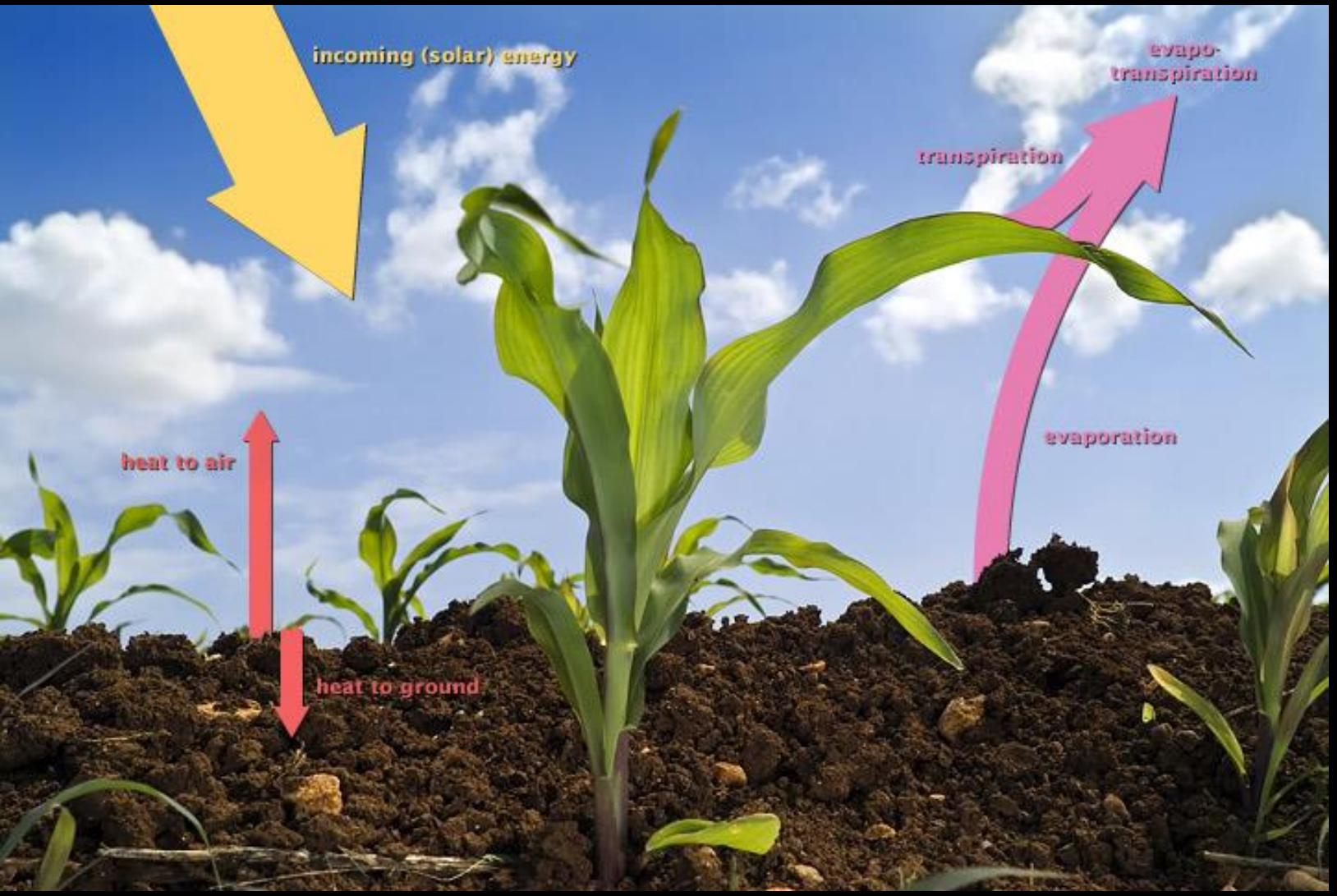
USGS-NASA Landsat 5/7/8 (TM / ETM+ / OLI)
30m/0.22 acres | overpass every 8-16 days

NASA Terra / Aqua
1 km | daily overpass

NASA-NOAA Suomi NPP
~300-375m | daily overpass

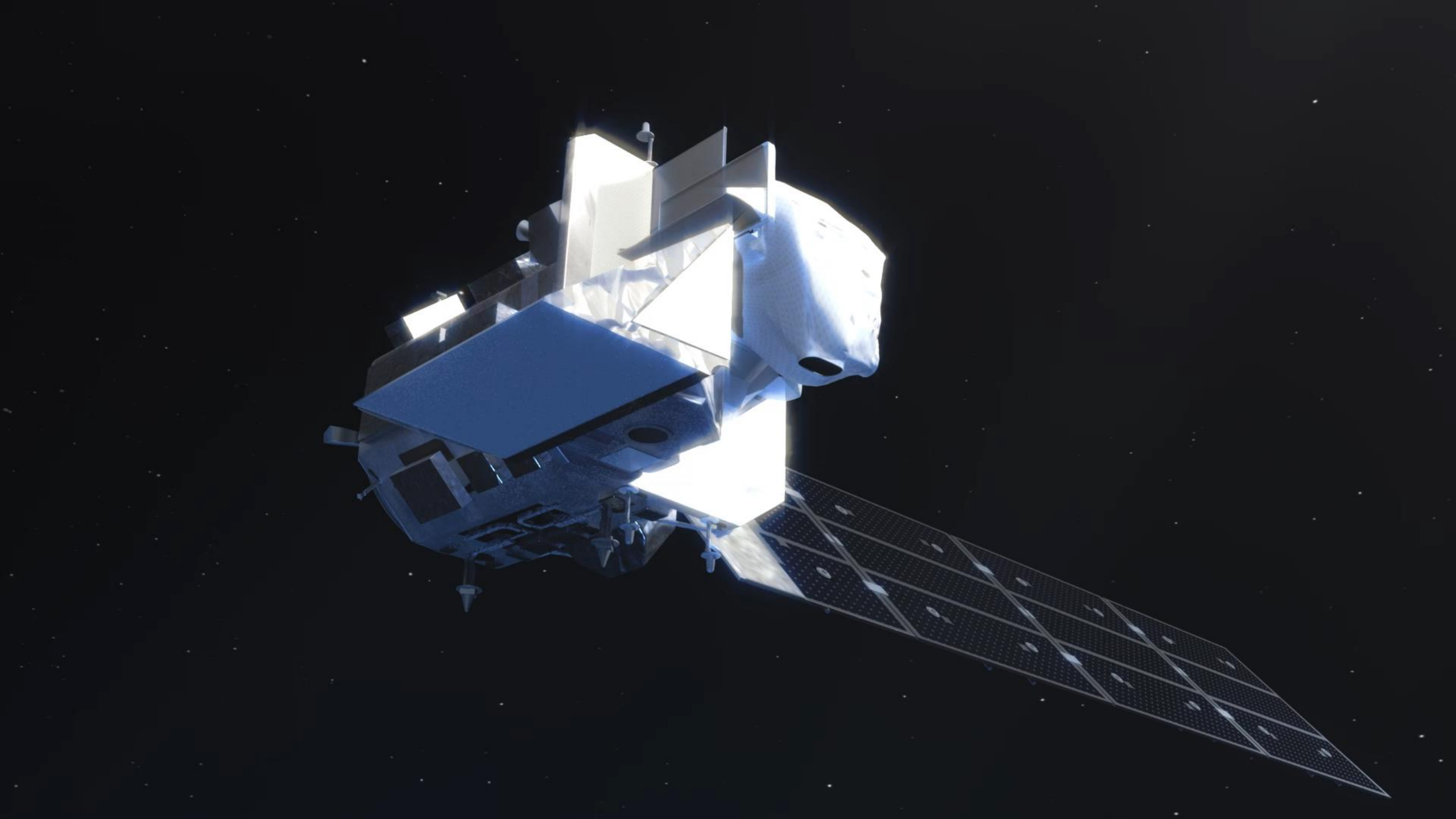
NOAA GOES-15/16/17
0.5-4 km | < hourly

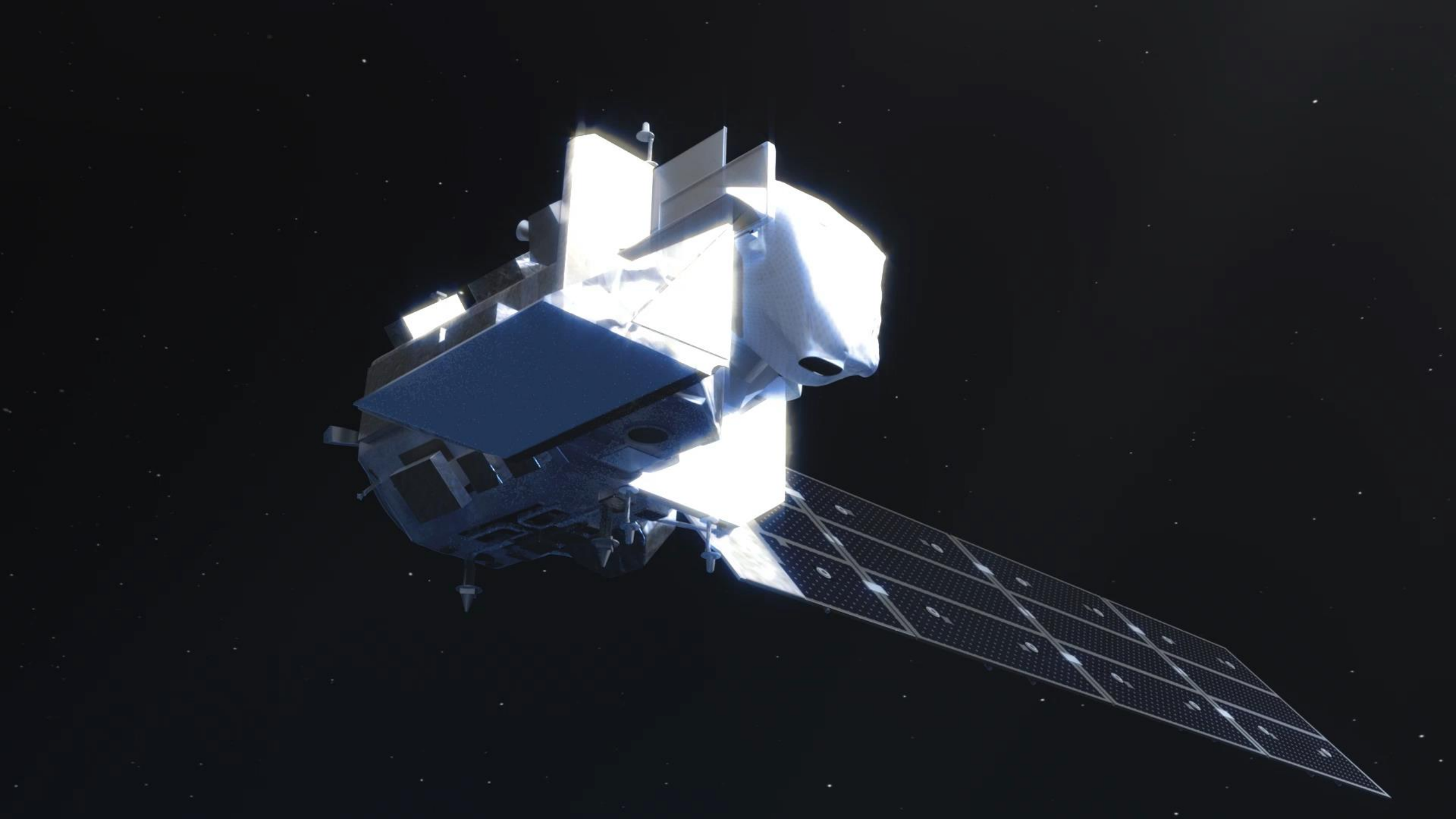
ESA Sentinel-2A, 2B
20m/0.1 acres | overpass every 5-10 days



Key principle:

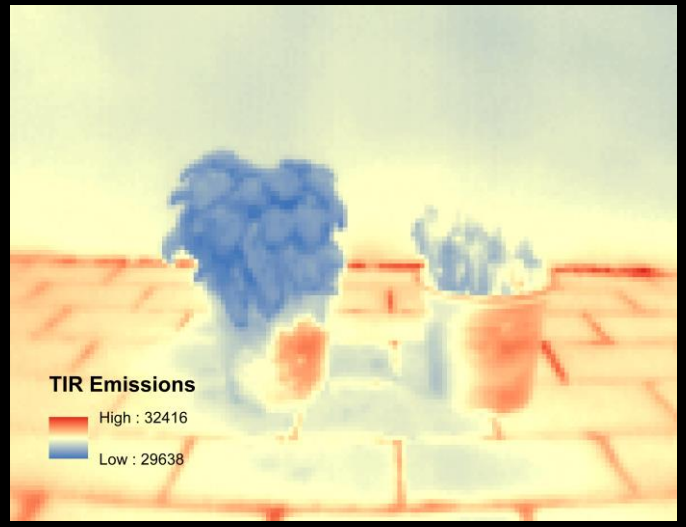
Evapotranspiration consumes energy!





What does the satellite ‘see’?

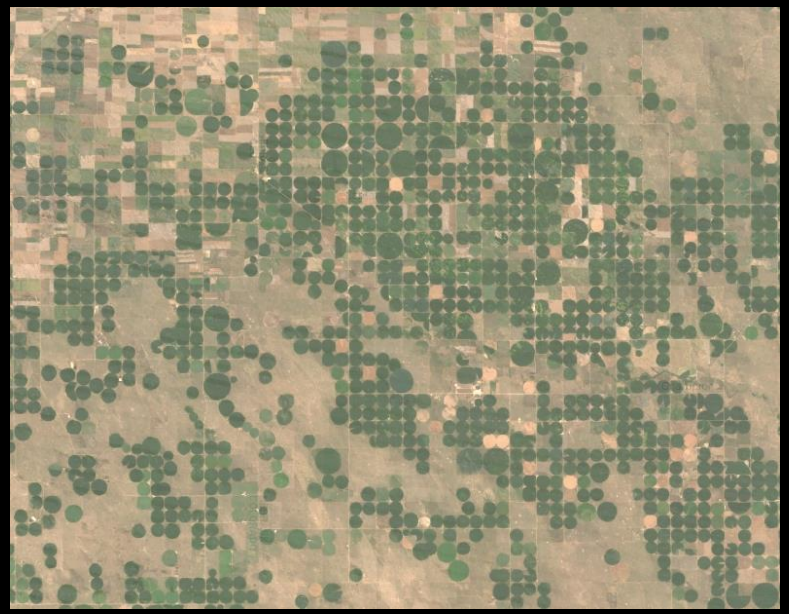
“True color”
(red, green, blue)



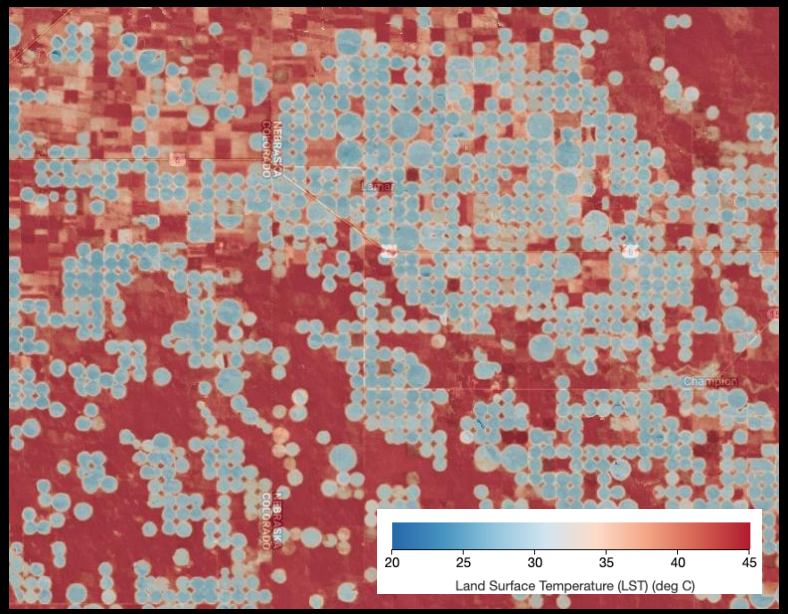
Thermal infrared
emissions

NDVI
(Normalized Difference
Vegetation Index)

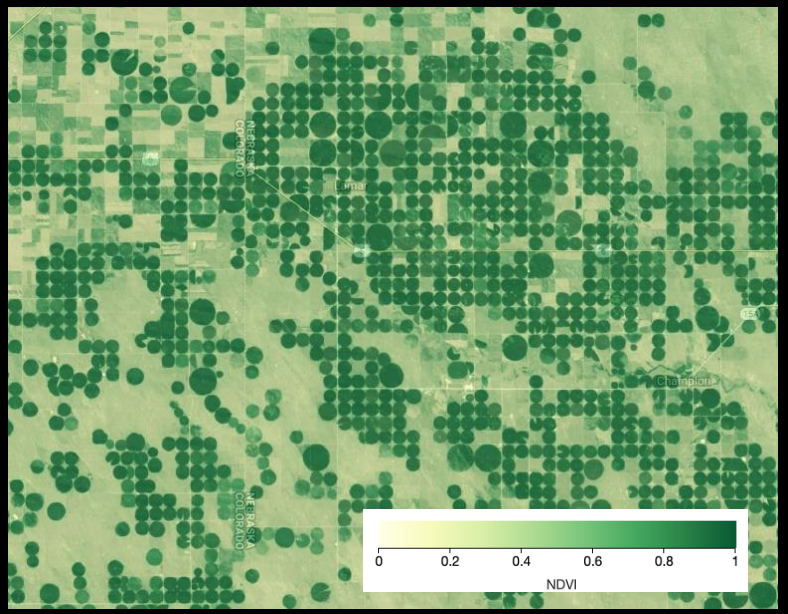
What does the satellite ‘see’?



“True color”
(red, green, blue)



Thermal infrared
emissions

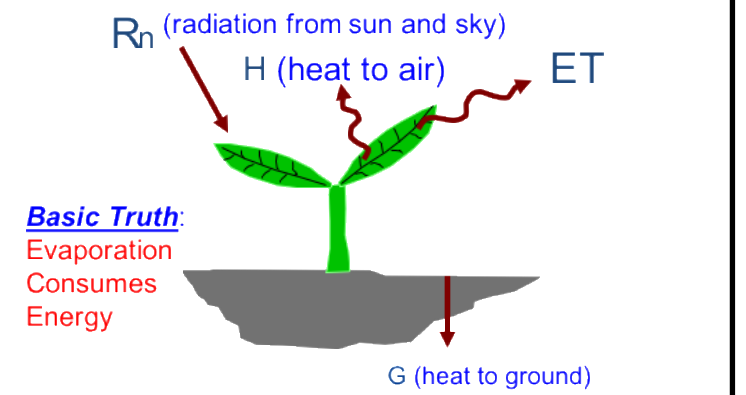


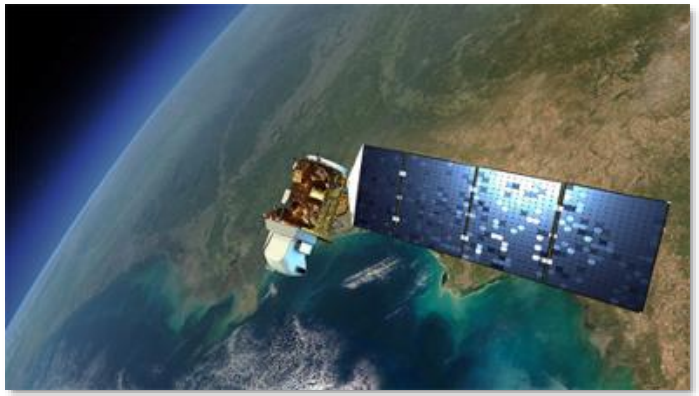
NDVI
(Normalized Difference
Vegetation Index)

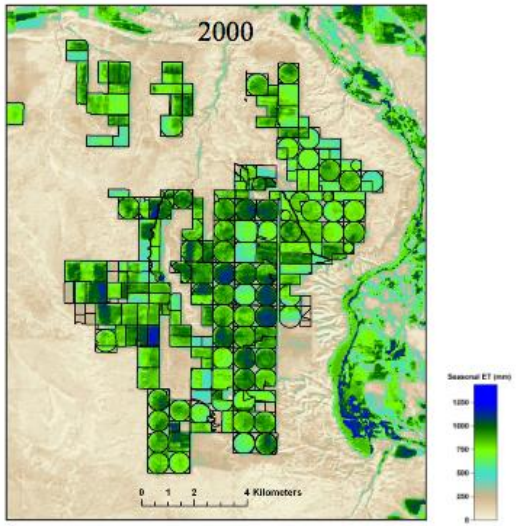
Remote Sensing of Evapotranspiration:

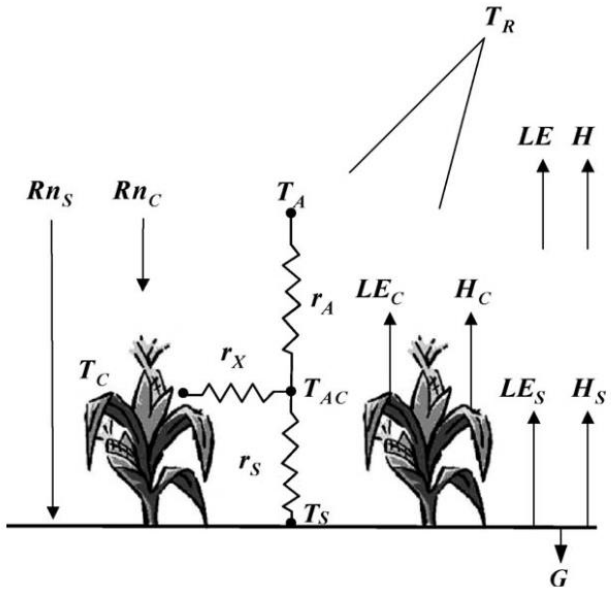
Energy Balance Approach

$$ET = R_n - G - H$$









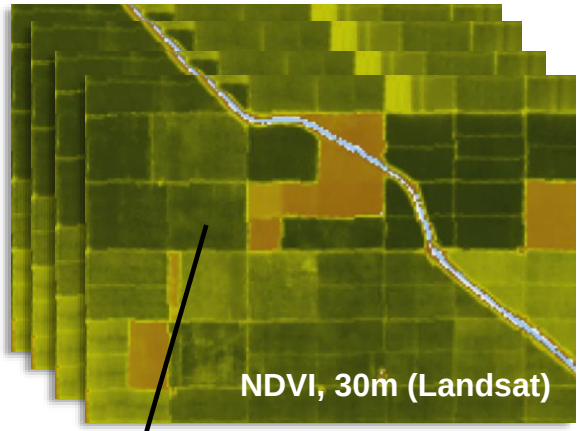
Norman et al., 1995; Bastiaanssen et al., 1998; Allen et al., 2007

Remote Sensing of Evapotranspiration: Reflectance-based Approach

$$ET_c = ET_o * K_c$$

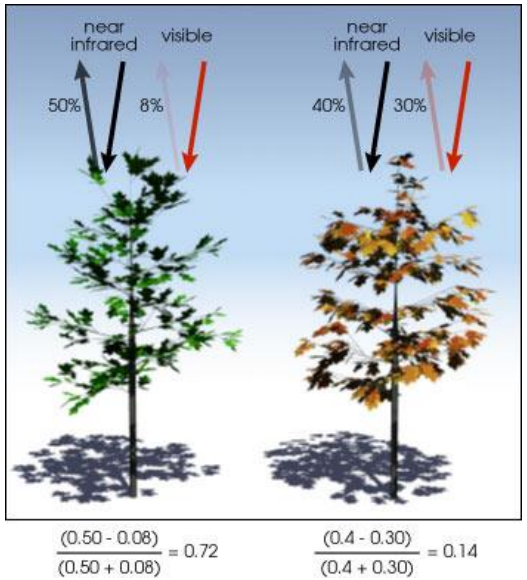
ASCE-PM Ref ET
Allen et al., 1998; ASCE 2000

Satellite data



Normalized Difference Vegetation Index (NDVI)

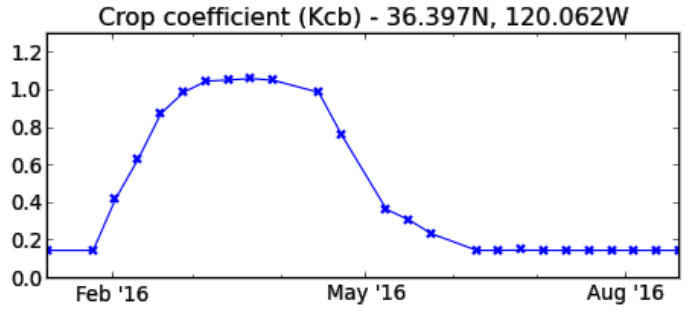
$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$



$K_d = \min(1, M_L * Fc\_eff, Fc\_eff^{1/(1+h)})$

M_L : effect of canopy density on shading / max relative evapotranspiration
K_d : density coefficient
F_{c_eff} : effective fractional cover
h : crop height

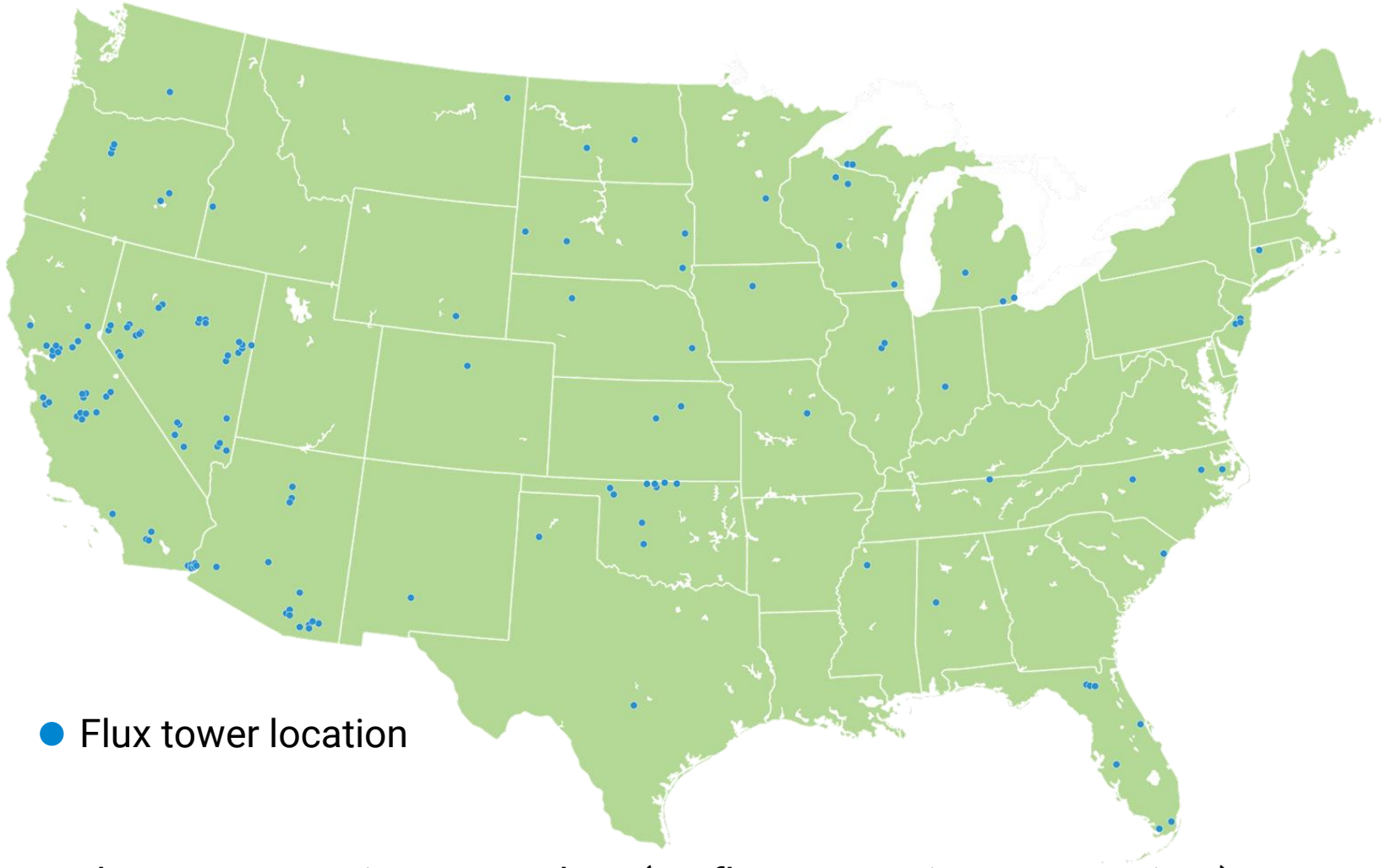
Allen & Pereira, 2009; Pereira et al., 2020



Trout et al., 2008
Johnson and Trout, 2012

Accuracy of the OpenET Approach

Intercomparison and Accuracy Assessment



- Phase I comparison complete (70 flux tower sites; 24 ag sites)
- Phase II comparison for 142 flux tower sites; 70 ag sites

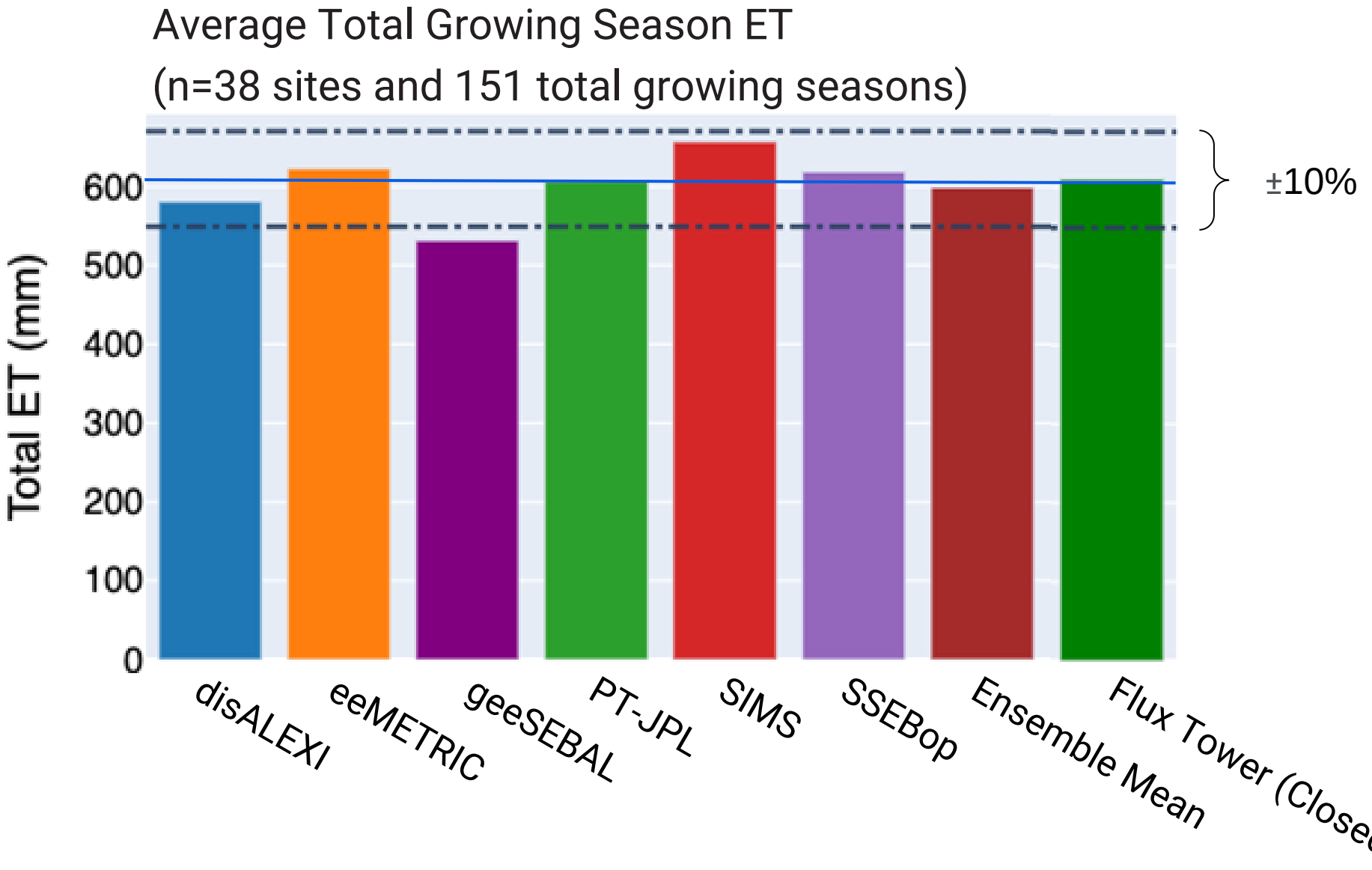
OpenET Ensemble Value: Croplands

Accuracy Summary for Croplands for the OpenET Ensemble ET Value						
Time Period	**Slope**	**Mean Bias Error)**	**Mean Absolute Error**	**Root Mean Squared Error**	**r-squared**	**Mean flux tower ET**
Water Year: 14 sites / 48 total water years	0.93	-71.6 mm (-7.0%)	91.3 mm (8.9%)	100.5 mm (9.8%)	0.88	1024 mm
Growing Season: 38 sites / 151 growing seasons	1.0	-10.1 mm (-1.7%)	80.3 mm (13.2%)	92.7 mm (15.2%)	0.88	609.5 mm
Monthly: 45 sites / 1,682 months	0.95	-3.6 mm (-3.9%)	15.6 mm (16.6%)	20.0 mm (21.3%)	0.91	93.7 mm
Daily: 49 sites / 4,804 days	0.88	-0.3 mm (-7.4%)	0.8 mm (22.8%)	1. 1 mm (29.7%)	0.82	3.6 mm

Melton et al., JAWRA, 2021

Slope: Measure of overall bias; 1.0 is perfect
Mean Bias Error (MBE): Measure of bias; 0.0 is perfect
Mean Absolute Error (MAE): Measure of expected error; 0.0 is perfect
Root Mean Squared Error (RMSE): Measure of expect error with additional weight for outliers; 0.0 is perfect
r-squared: Measure of the ability of the model to reproduce observed variability; 1.0 is perfect

Ensemble Value: Croplands



Use Cases and Pilot Projects

OpenET can help:

- Rural communities to design locally driven water conservation and trading programs.
- Water managers to develop more accurate water budgets, incentive programs and other innovative strategies.
- Policymakers to more accurately track water supplies, simplify regulatory compliance, and co-develop solutions with local communities.
- Farmers to expand use of data-driven irrigation practices to maximize “crop per drop” and reduce costs for fertilizer, water, and energy.

OpenET Use Cases

Irrigation Management in the Harney Basin

Mark Owens
Farmer
Harney County, OR

Water Accounting in the CA Central Valley

Eric Averett
Former General Manager
Rosedale-Rio Bravo Water Storage District

Forest Management in Arizona

Elvy Barton
Senior Water Policy Analyst
Salt River Project

Next Steps for OpenET

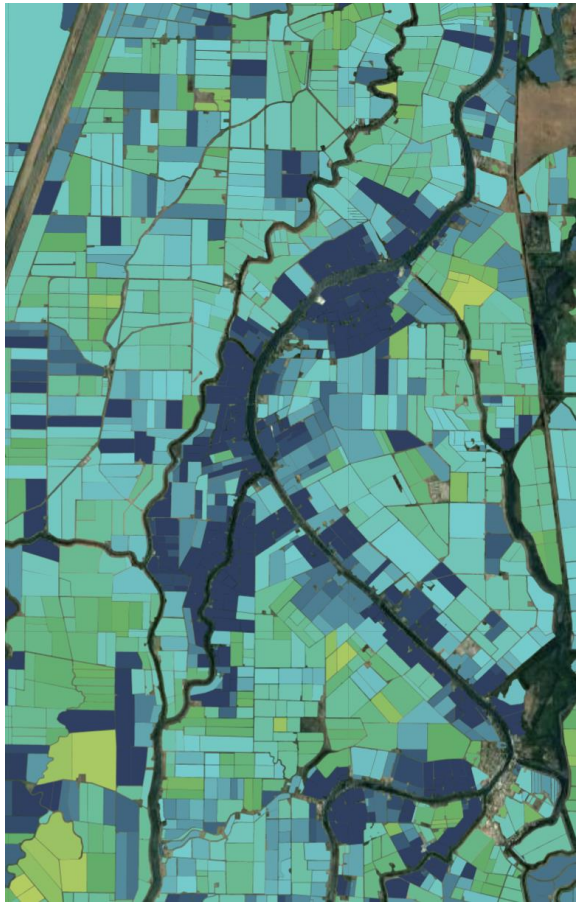
What's next for OpenET?

- Addition of daily data and integration with irrigation scheduling tools
- Public release of the API in second half of 2022
- Completion of the custom reporting tools
- Best Practices Manual and updates to the ensemble ET value (OpenET Collection 2)
- Further development in the underlying science
  - Evaluating the models for mature tree crops, open water evaporation, and for forested and other non-agricultural landscapes
  - Calculation of effective precipitation and ET of applied water

Lessons Learned

Look for win-win solutions

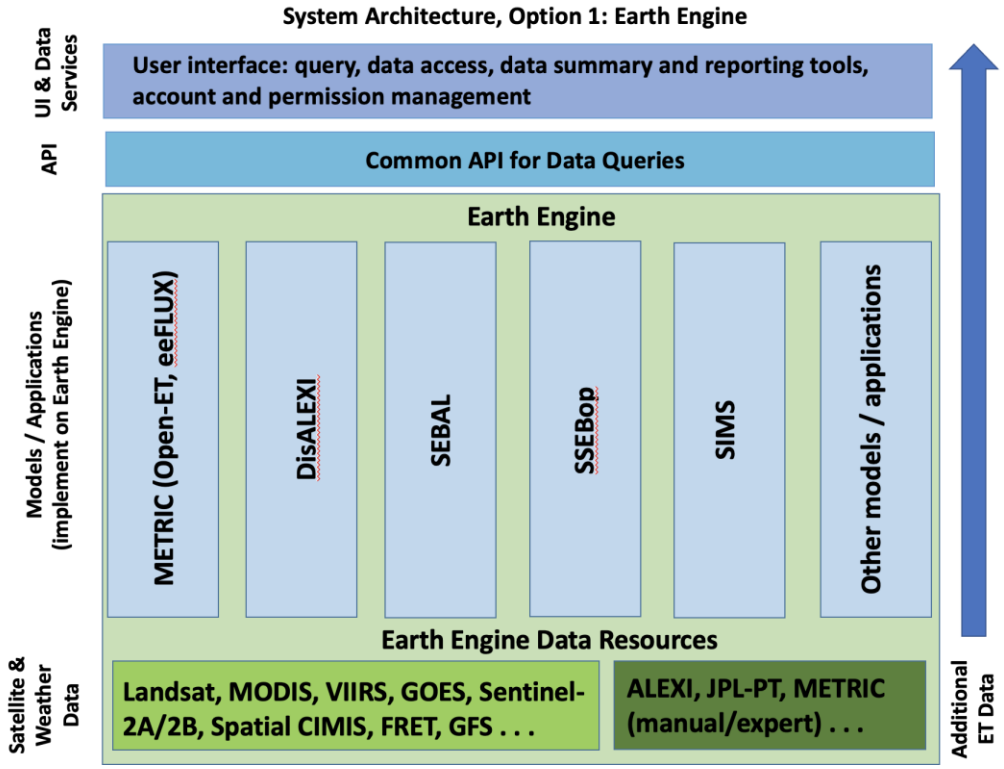
- New water data can be sensitive
- Important to listen to concerns from all stakeholders
- Identify and prioritize “win-win” solutions



Open science and open data are not free

- Free to the user ≠ free to the provider
- Plan far ahead
- Start early
- Of course, nothing will go according to plan

User-driven design works (if time allows!)



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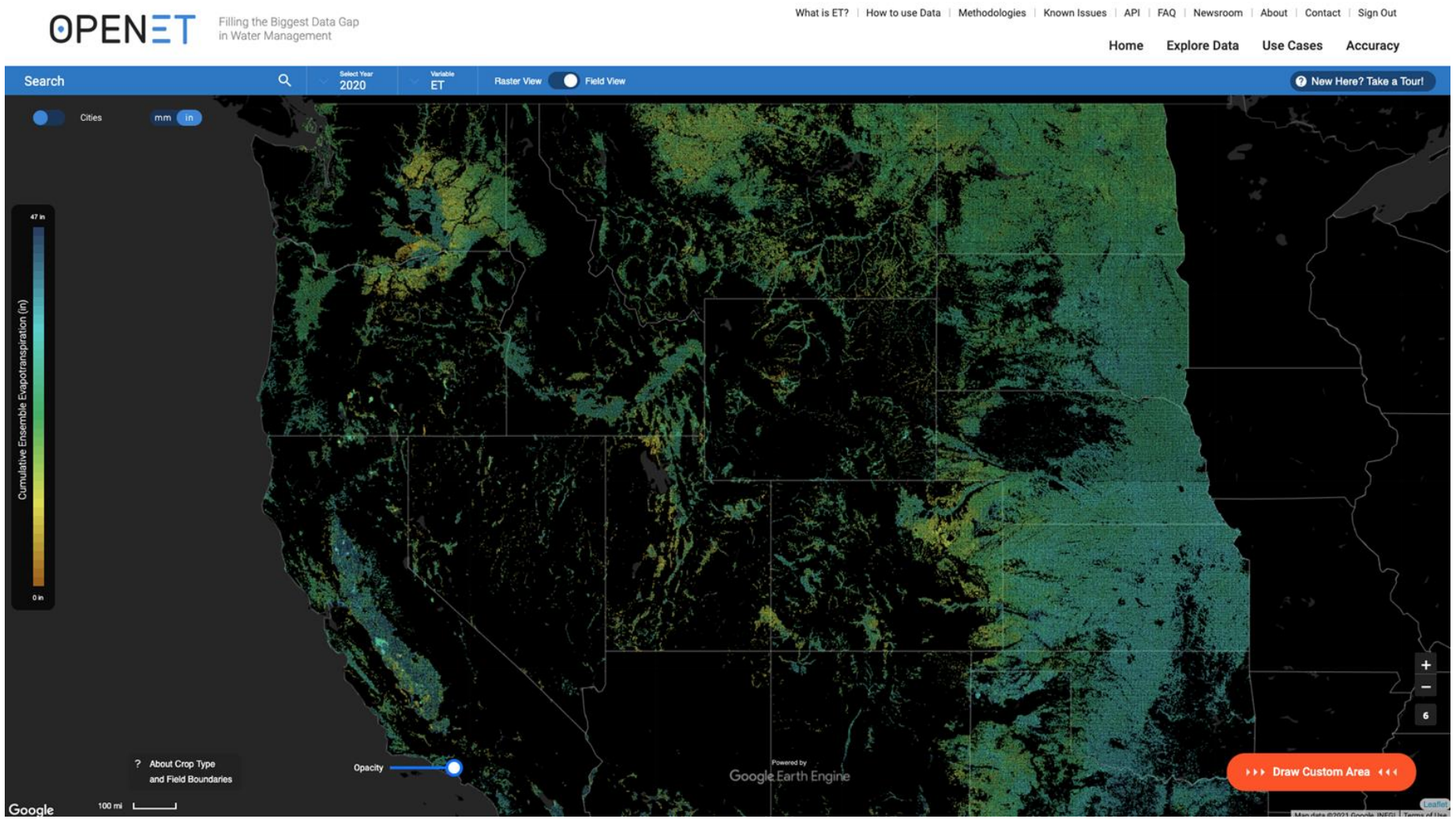
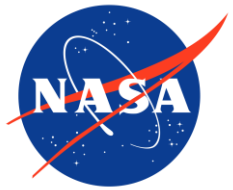


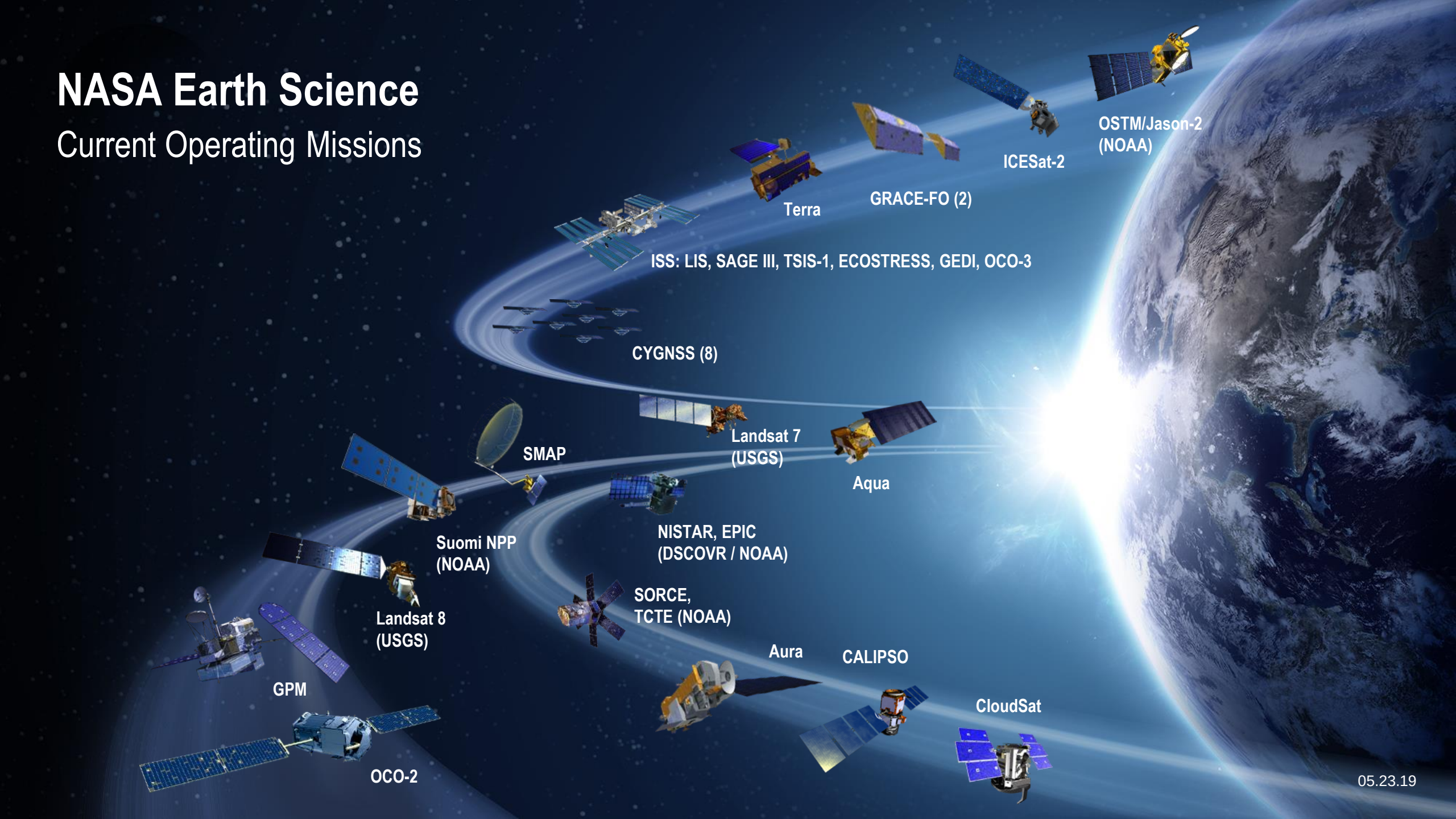
Partnerships matter!



NASA and the Western Water Applications Office

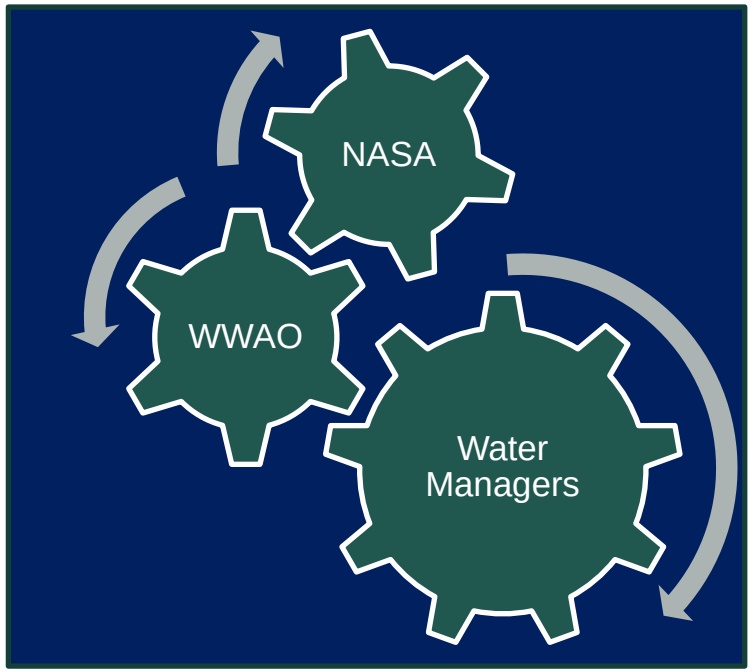
NASA Earth Science

Current Operating Missions



05.23.19

NASA Applied Sciences Program: Western Water Applications Office (WWAO)



WWAO's Mission

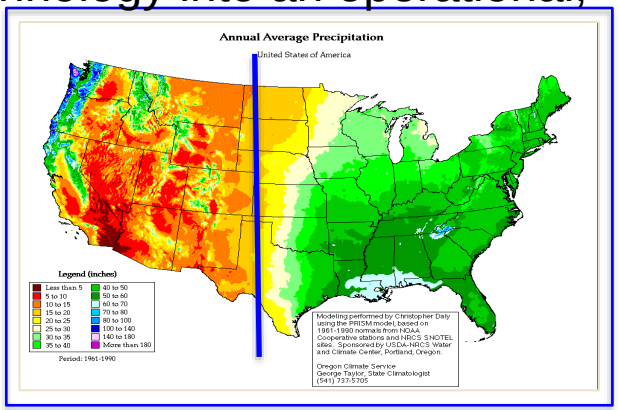
- **Improve how water is managed by applying NASA data, technology, tools in partnership with water managers and decision makers in the western U.S.**

WWAO does this by:

- **Identifying needs in western water management** for information and decision support
- **Making connections between stakeholders and NASA** scientists, technology, tools, and data
- **Supporting projects tailored to meet those needs**, engaging with partners from beginning to end
- **Transition of water applications** and technology into an operational, sustainable state for long-term impact

Why WWAO?

- NASA's science, remote-sensing data and expertise can bring a unique set of capabilities to address water management challenges
- Remote-sensing data can help fill critical data gaps in the West
- WWAO leverages decades of investment in science and technology, as well as deep relationships with partners and stakeholders

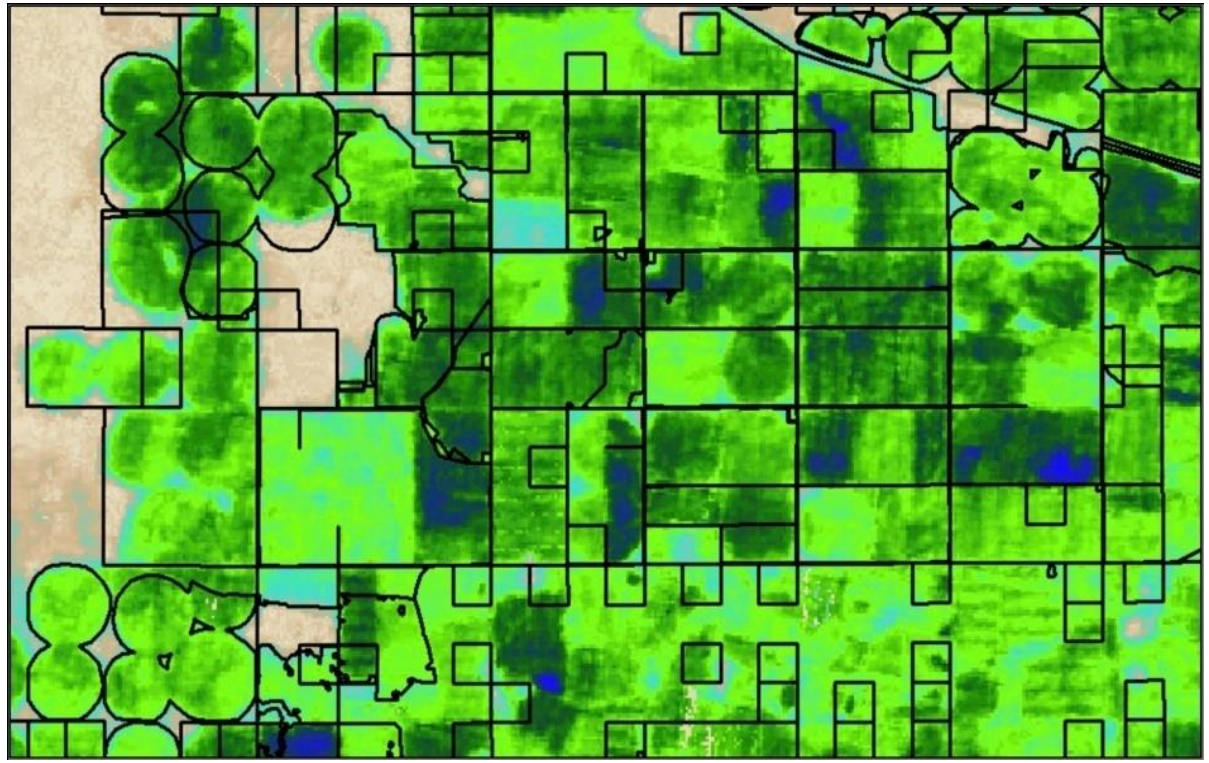


Questions?

forrest.s.melton@nasa.gov
openetdata.org

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



Contacts

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  - Forrest Melton: forrest.s.melton@nasa.gov
  - Amita Mehta: amita.v.mehta@nasa.gov
- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-applications-remote-sensing-based-evapotranspiration-data
- ARSET Website:
  - https://appliedsciences.nasa.gov/arset
- Twitter: @NASAARSET

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TRAIN - EMPOWER - ADVANCE

Thank You!