Global Science Requirements for Space-based Retrievals of Evapotranspiration

Joshua B. Fisher[1], Forrest Melton[2], Elizabeth Middleton[3], Christopher Hain[4,5], Martha Anderson[6], Richard Allen[7], Matthew McCabe[8], Simon Hook[1], Dennis Baldocchi[9], Philip A. Townsend[10], Ayse Kilic[11], Kevin Tu[12], Diego Miralles[13], Johan Perret[14], Jean-Pierre Lagouarde[15], Duane Waliser[1], Adam J. Purdy[1], Andrew French[16], David Schimel[1], James S. Famiglietti[1], Graeme Stephens[1], Eric F. Wood[17]

[1] *Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA*
[2] *NASA Ames Research Center, Moffett Field, CA, USA*
[3] *NASA Goddard Space Flight Center, Greenbelt, MD, USA*
[4] *NASA Marshall Space Flight Center, Huntsville, AL, USA*
[5] *NOAA National Environmental Satellite, Data, and Information Service, College Park, MD, USA*
[6] *US Department of Agriculture, Beltsville, MD, USA*
[7] *University of Idaho, Kimberly, ID, USA*
[8] *King Abdullah University of Science and Technology, Thuwal, Saudi Arabia*
[9] *University of California, Berkeley, CA, USA*
[10] *University of Wisconsin, Madison, WI, USA*
[11] *University of Nebraska-Lincoln, NE, USA*
[12] *DuPont Pioneer, Johnston, IA, USA*
[13] *VU University Amsterdam, The Netherlands*
[14] *EARTH University, San José, Costa Rica*
[15] *INRA – Bordeaux Sciences Agro, Villenave D'Ornon, France*
[16] *US Department of Agriculture, Maricopa, AZ, USA*
[17] *Princeton University, Princeton, NJ, USA*

National Aeronautics and Space Administration

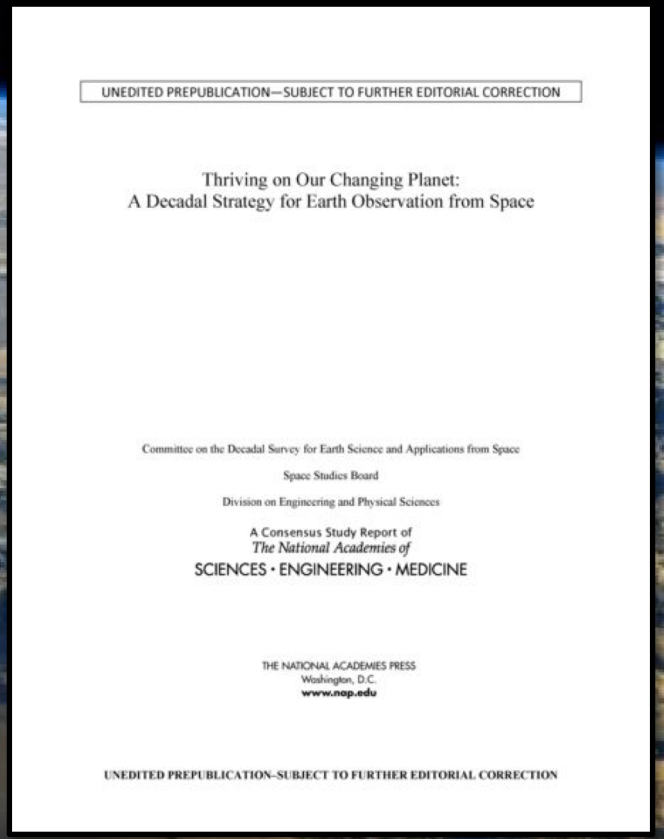
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

© 2018 California Institute of Technology. Government sponsorship acknowledged.

Thriving on Our Changing Planet

A Decadal Strategy for Earth Observation from Space



#EarthDecadal

The National Academies of | SCIENCES ENGINEERING MEDICINE

National Academies of Science 2018 - Thriving on Our Changing Planet A Decadal Strategy for Earth Observation from Space.pdf (page 28 of 701) — Edited
103%
Sort by: Search Rank Page Order
Found on 63 pages Done
National Academies of Science 2...
Page 28 3 matches
Are changes in evapotranspiration and precipitation accelerati...
Page 103 5 matches
Are changes in evapotranspiration an...
Page 110 4 matches
Are changes in evapotranspiration and precipitation accelerati...
Page 131 2 matches
A second high-priority ... emerged is the surface flux of evapotranspira...
Page 134 1 match
water fluxes via evapotranspiration by land plants is also calle...
Page 161 1 match
Snowmelt plays a major role in ..., affecting soil...
Page 162 2 matches
In addition to the obvious ... and energy cycle, through evapotr...
Page 172 3 matches
Atmospheric Winds: Role of winds in energy transport and evapotr...
Page 232 1 match
(2017), The future of evapotranspiration: Global requirements fo...
Page 242 2 matches
Are changes in evapotranspiration and precipitation accelerati...
Page 243 3 matches
of rainfall, snowfall, evapotranspiration, and the frequency and...
Page 244 6 matches
And it stretches from ... precipitation, to measuring evapotrans...
Page 245 4 matches
Improved monitoring of precipitation and evapotranspiration, w...
Page 249 1 match
Such integrated observations ... as atmospheric compositi...
Page 250 4 matches
Are changes in evapotranspiration and precipitation accelerati...

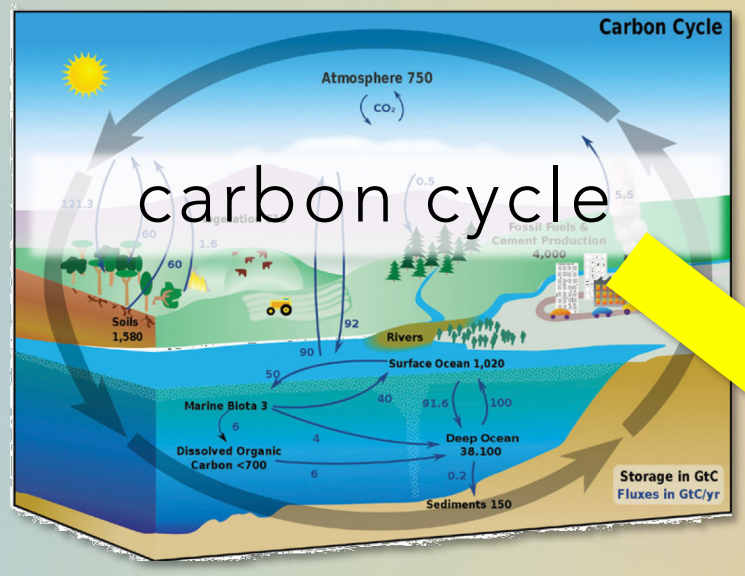
TABLE S.1 Science and Applications Priorities for the Decade 2017-2027

Science and Applications Area	Science and Applications Questions Addressed by **MOST IMPORTANT** Objectives
Coupling of the Water and Energy Cycles	**(H-1)** How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods? **(H-2)** How do anthropogenic changes in climate, land use, water use, and water storage interact and modify the water and energy cycles locally, regionally and globally and what are the short- and long-term consequences?
Ecosystem Change	**(E-1)** What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space? **(E-2)** What are the fluxes (of carbon, water, nutrients, and energy) *between* ecosystems and the atmosphere, the ocean and the solid Earth, and how and why are they changing? **(E-3)** What are the fluxes (of carbon, water, nutrients, and energy) *within* ecosystems, and how and why are they changing?
Extending and Improving Weather and Air Quality Forecasts	**(W-1)** What planetary boundary layer (PBL) processes are integral to the air-surface (land, ocean and sea ice) exchanges of energy, momentum and mass, and how do these impact weather forecasts and air quality simulations? **(W-2)** How can environmental predictions of weather and air quality be extended to forecast Earth System conditions at lead times of 1 week to 2 months? **(W-4)** Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do? **(W-5)** What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems?
Reducing Climate Uncertainty and Informing Societal Response	**(C-2)** How can we reduce the uncertainty in the amount of future warming of the Earth as a function of fossil fuel emissions, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity that drives uncertainty in future economic impacts and mitigation/adaptation strategies?
Sea Level Rise	**(C-1)** How much will sea level rise, globally and regionally, over the next decade and beyond, and what will be the role of ice sheets and ocean heat storage? **(S-3)** How will local sea level change along coastlines around the world in the next decade to century?
Surface Dynamics, Geological Hazards and Disasters	**(S-1)** How can large-scale geological hazards be accurately forecasted and eventually predicted in a socially relevant timeframe? **(S-2)** How do geological disasters directly impact the Earth system and society following an event? **(S-4)** What processes and interactions determine the rates of landscape change?

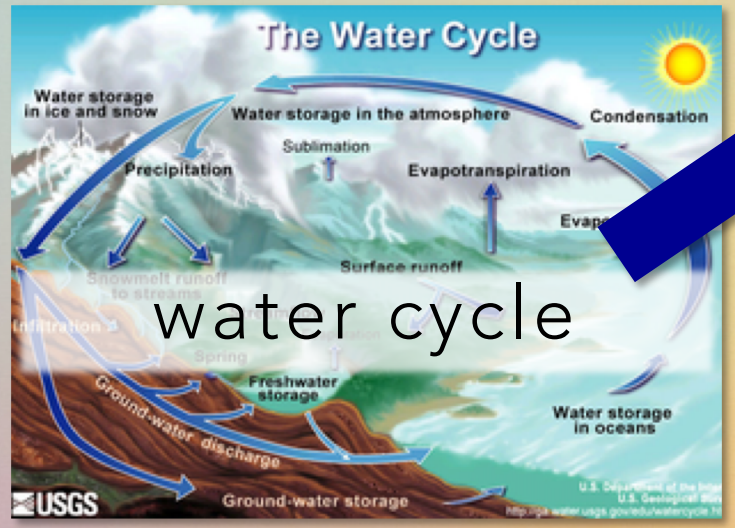
VERY IMPORTANT (summarized)	IMPORTANT (summarized)
(H-4) Influence of water cycle on natural hazards and preparedness **(W-3)** Influence of Earth surface variations on weather and air quality **(C-3)** Impacts of carbon cycle variations on climate and ecosystems **(C-4)** Earth system response to air-sea interactions	**(H-3)** Fresh water availability and impacts on ecosystems/society **(W-6)** Long-term air pollution trends and impacts **(W-7)** Processes influencing tropospheric ozone and its atmospheric impacts **(W-8)** Methane variations and impacts on tropospheric composition and chemistry **(W-9)** Cloud microphysical property dependence on aerosols and precipitation

Copyright © National Academy of Sciences. All rights reserved.

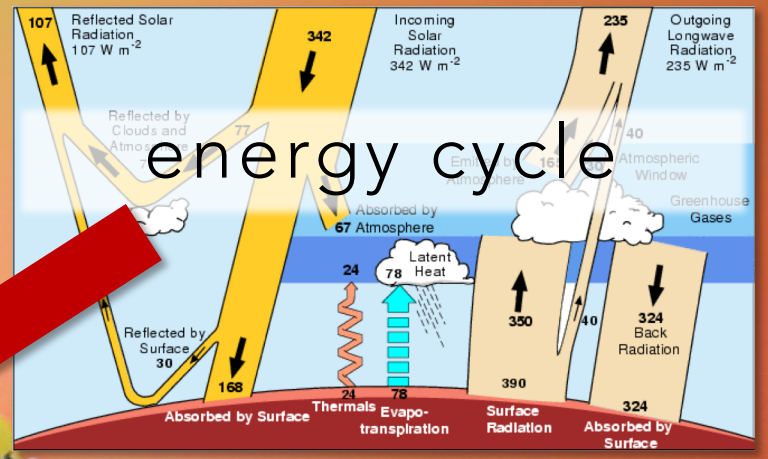
EVAPOTRANSPIRATION
©Florent Courty



carbon cycle



water cycle



energy cycle

ET describes the net exchange of water vapor between the land surface and the atmosphere, and is comprised of water evaporated directly from the soil or other surfaces and water transpired (i.e., used; consumptive use) by plants.

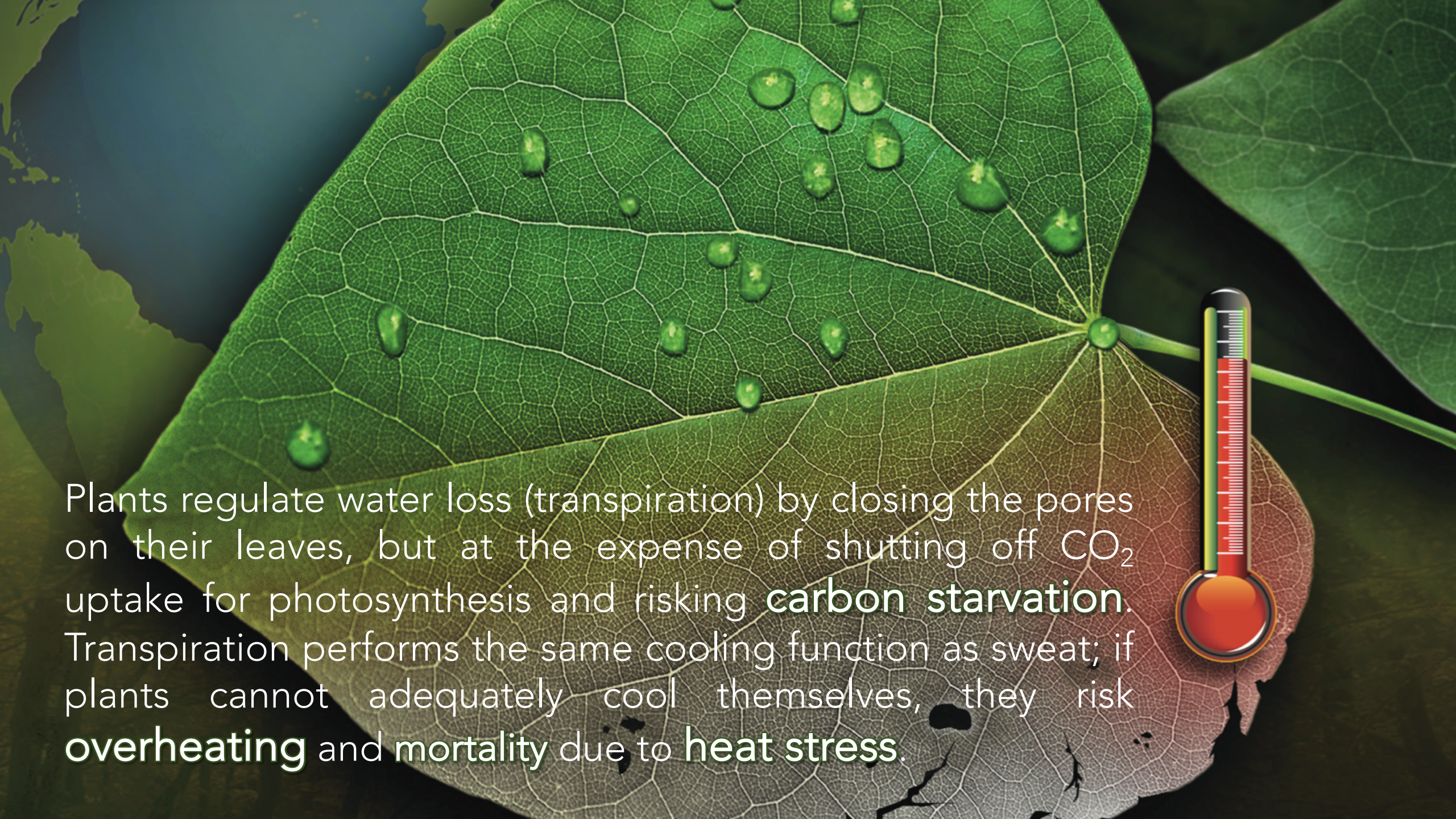
what is evapotranspiration (ET)?

Evapotranspiration is the key climate variable linking the water, energy, and carbon cycles

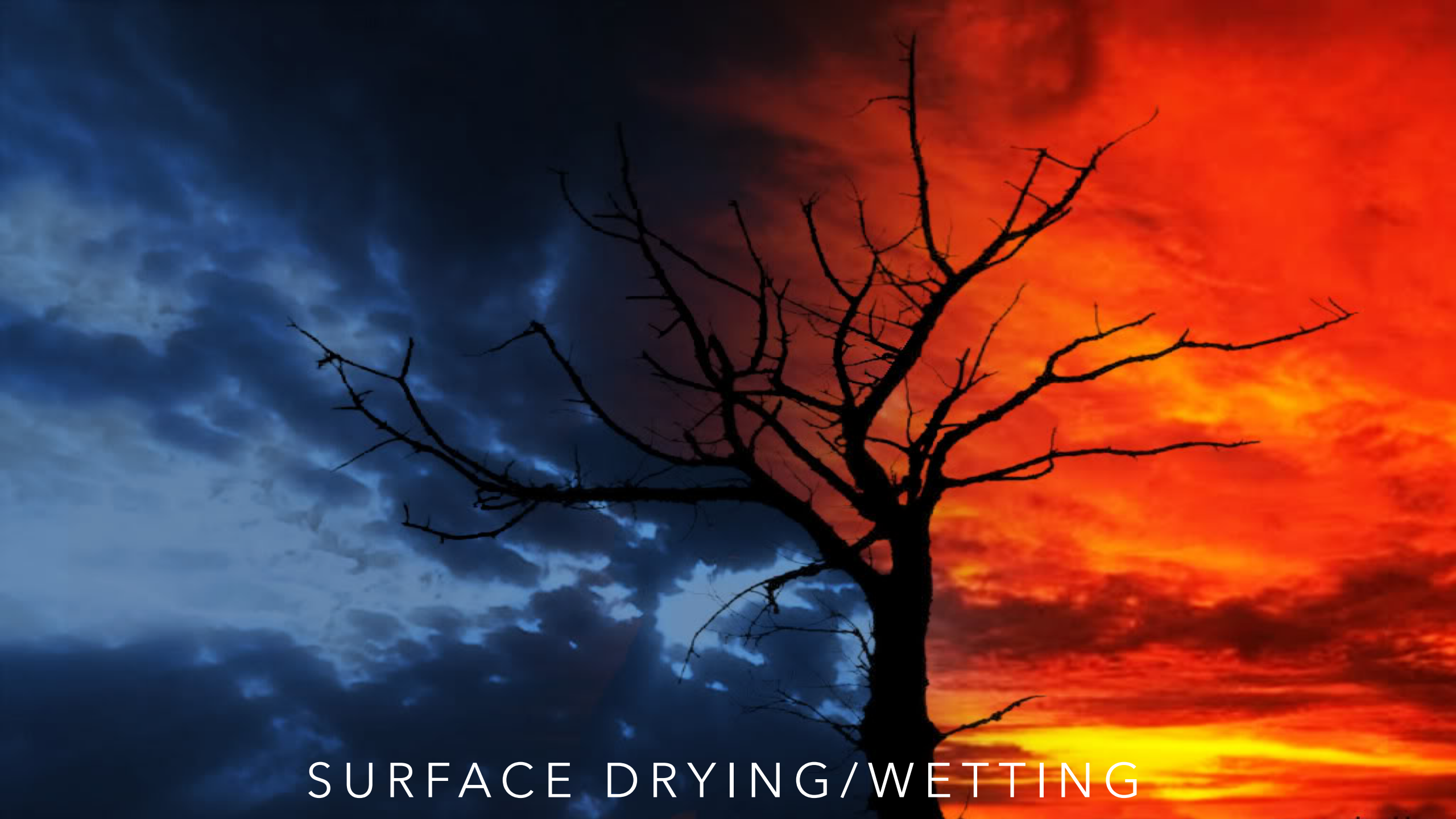
ET describes the net exchange of water vapor between the land surface and the atmosphere, and is comprised of water evaporated directly from the soil or other surfaces and water transpired (i.e., used; consumptive use) by plants.

what is evapotranspiration (ET)?

Evapotranspiration is the key climate variable linking the water, energy, and carbon cycles


Plants regulate water loss (transpiration) by closing the pores on their leaves, but at the expense of shutting off CO_2 uptake for photosynthesis and risking **carbon starvation**. Transpiration performs the same cooling function as sweat; if plants cannot adequately cool themselves, they risk **overheating** and **mortality** due to **heat stress**.

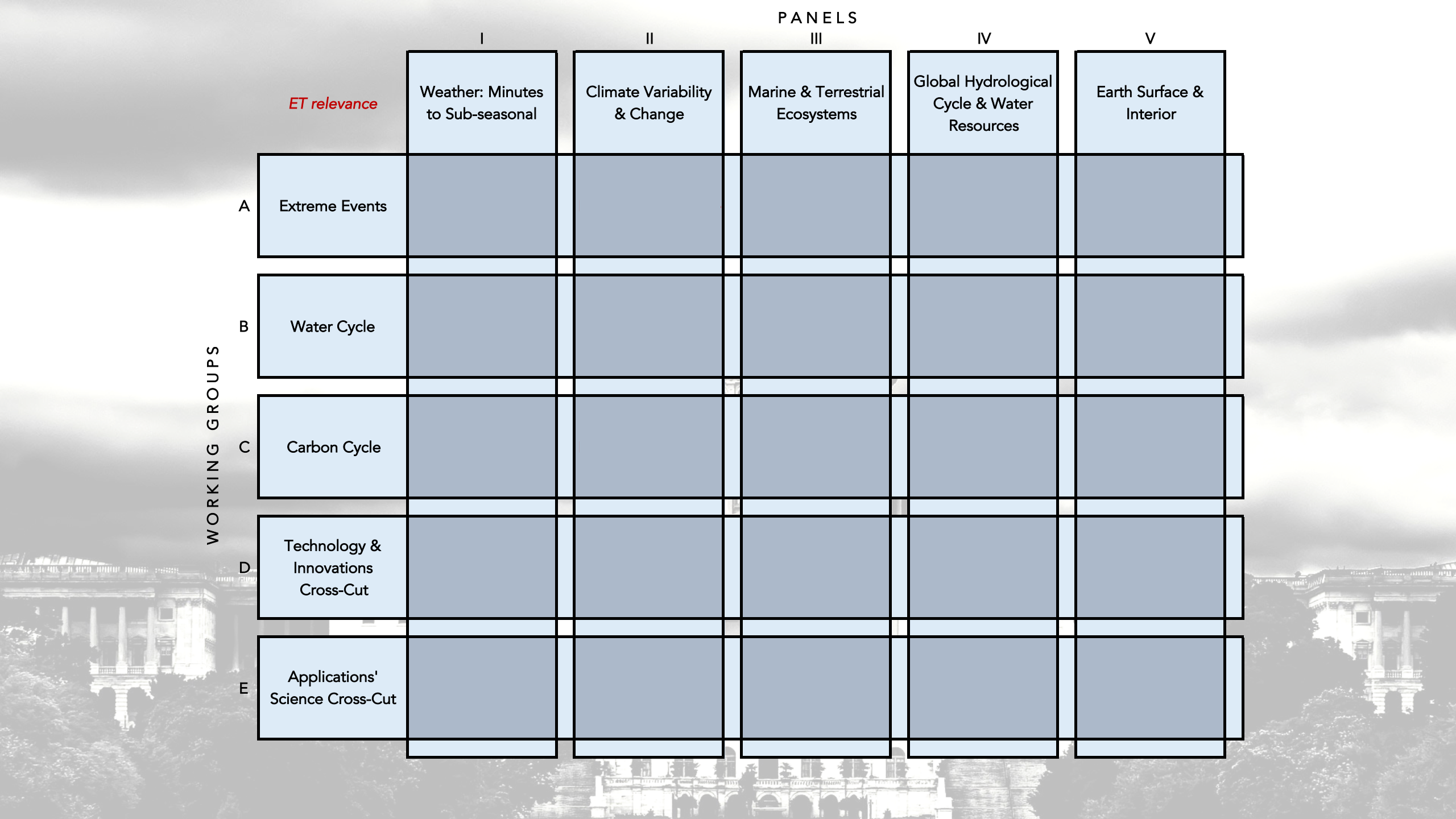
BIODIVERSITY


SURFACE DRYING/WETTING

WEATHER

FLASH DROUGHTS

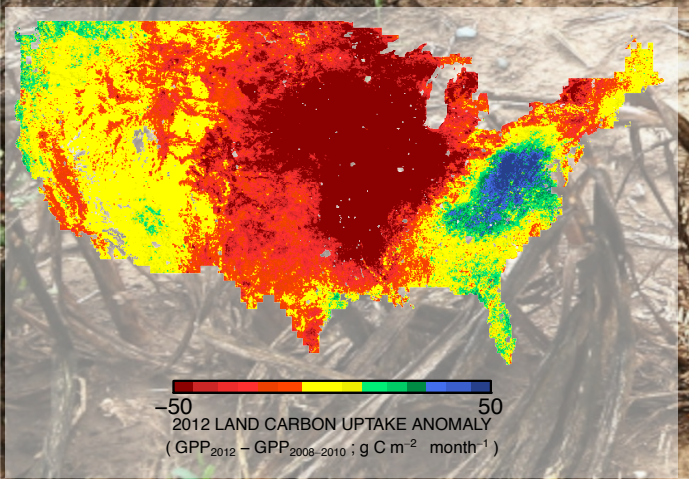
IRRIGATION

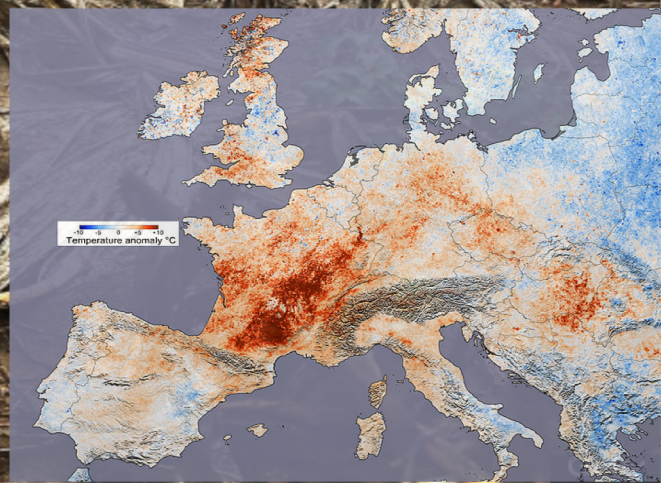

PANELS
I
II
III
IV
V
ET relevance
Weather: Minutes to Sub-seasonal
Climate Variability & Change
Marine & Terrestrial Ecosystems
Global Hydrological Cycle & Water Resources
Earth Surface & Interior
WORKING GROUPS
A
Extreme Events
B
Water Cycle
C
Carbon Cycle
D
Technology & Innovations Cross-Cut
E
Applications' Science Cross-Cut

HOW DO DIFFERENT PLANTS RESPOND TO CHANGES IN WATER AVAILABILITY?

WHICH PLANTS DIE FIRST?

Current US drought prediction capabilities failed to predict the intensity and magnitude of the 2012 US Midwest drought





Principal outstanding ET knowledge gaps; Top-10 ET research and applied science questions

1. How are natural and managed ecosystems **responding to changes in climate** and water availability?
2. How much water do different plant assemblages in ecosystems **use** and how much do they **need**?
3. What is the **timing** of water use among ecosystems, and how does that vary diurnally, seasonally, and annually?
4. How do changes in plant water availability, access, use, and stress **regulate photosynthesis** and productivity?
5. How is ET **partitioned** into transpiration, soil evaporation, and interception evaporation, and how are these components differentially impacted by a changing temperature, CO_2, and hydrologic regime?
6. How does ET redistribute water in a strengthening or weakening **global hydrological cycle**, and what are the underlying causes and consequences?
7. How do changes in ET amplify or dampen climate **feedbacks**, land-atmosphere coupling, and hydrometeorological **extremes** at local to regional scales?
8. Can ET observations help constrain and improve short-term **weather** prediction and future **climate** projections at seasonal to interannual timescales?
9. Can we **unify** the water, carbon, and energy cycles globally from space-borne observations, with ET as the linking variable?
10. How can information on ET be applied to optimize sustainable water allocations, agricultural water use, food production, ecosystem management, and hence **water and food security** in a changing climate to meet the demands of a growing population?

AGU PUBLICATIONS

Water Resources Research

COMMENTARY
10.1002/2016WR020175

Key Points:
- ET science and applications have significantly advanced across a wide array of fields over the past several decades
- Critical outstanding ET-based research and applied science questions from local to global scales remain due to deficiencies in our observational capabilities
- National and international research priorities should include ET-focused satellite observational investments and programs

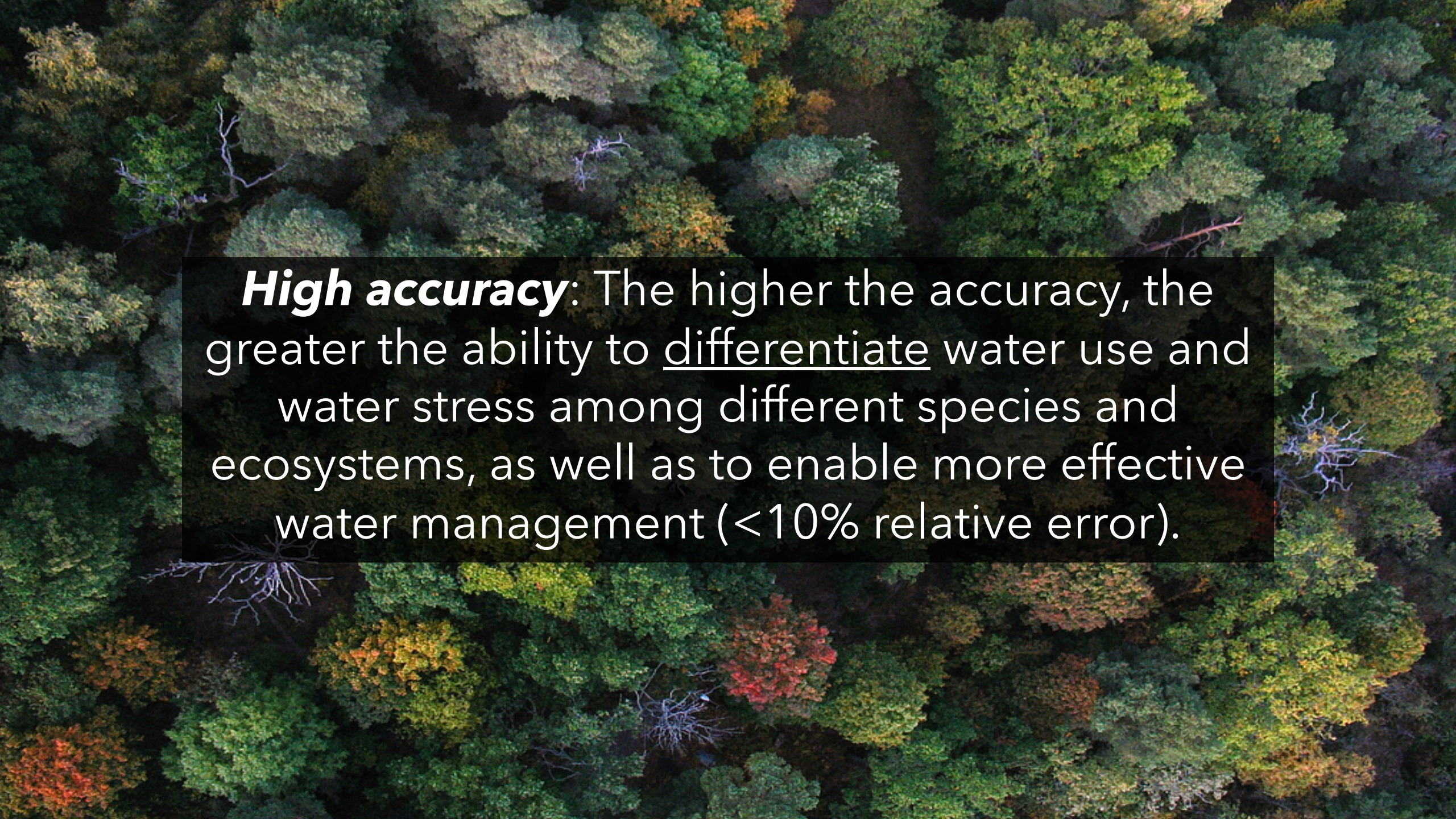
Correspondence to:
J. B. Fisher,
jbfisher@jpl.nasa.gov

The future of evapotranspiration: Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources

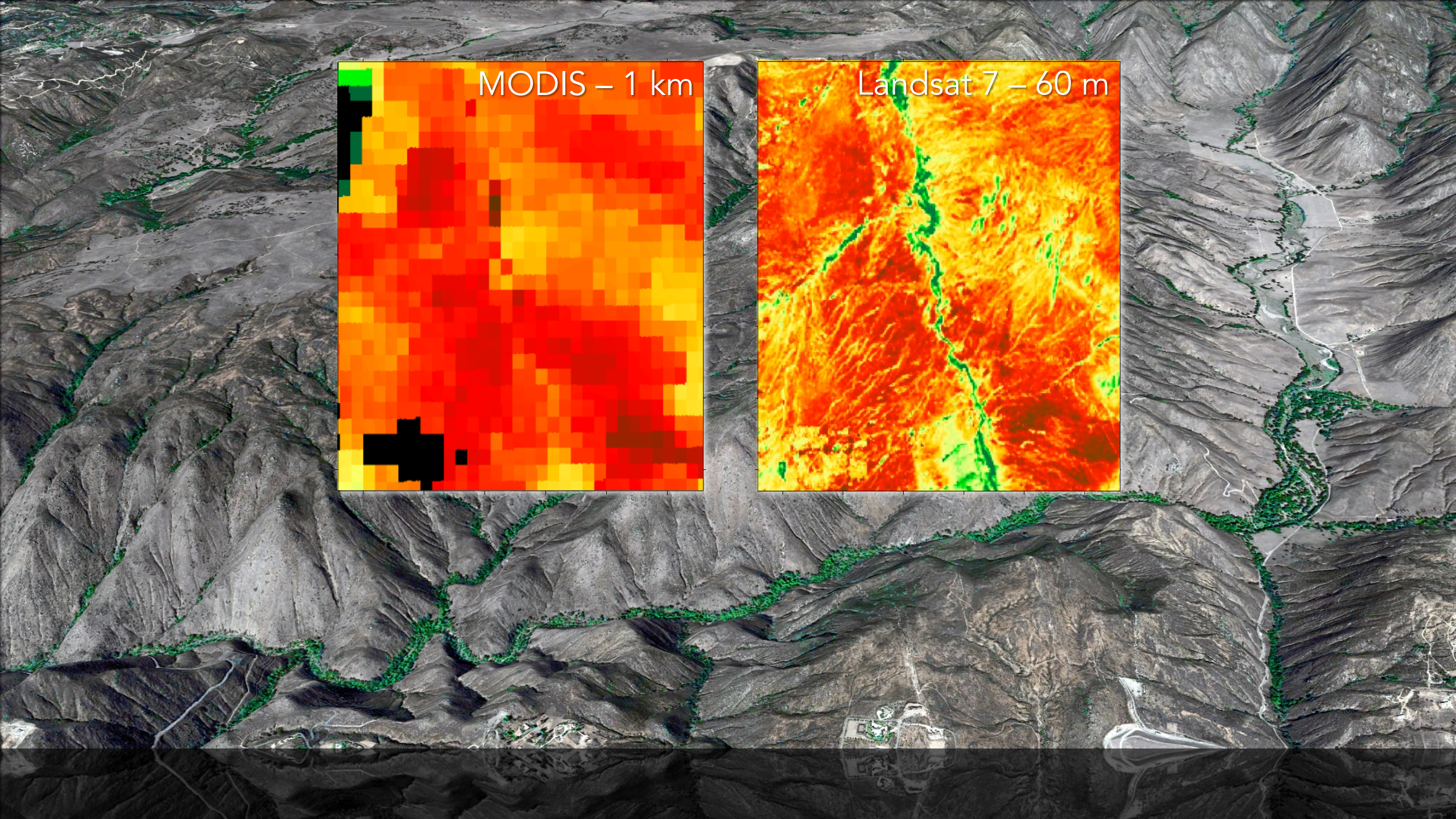
Joshua B. Fisher[1], Forrest Melton[2], Elizabeth Middleton[3], Christopher Hain[4,5], Martha Anderson[6], Richard Allen[7], Matthew F. McCabe[8], Simon Hook[1], Dennis Baldocchi[9], Philip A. Townsend[10], Ayse Kilic[11], Kevin Tu[12], Diego D. Miralles[13], Johan Perret[14], Jean-Pierre Lagouarde[15], Duane Waliser[1], Adam J. Purdy[1], Andrew French[16], David Schimel[1], James S. Famiglietti[1], Graeme Stephens[1], and Eric F. Wood[17]

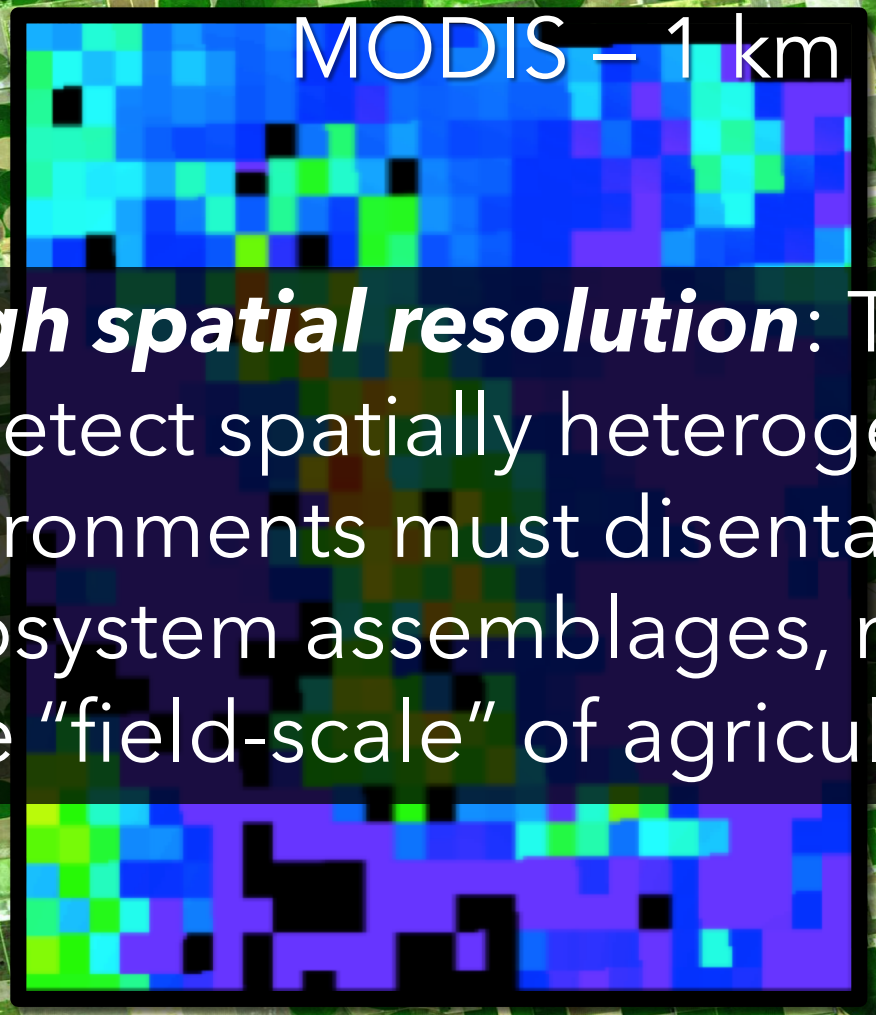
[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [2]NASA Ames Research Center Cooperative for Research in Earth Science in Technology, Moffett Field, California, USA, [3]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [4]NASA Marshall Space Flight Center, Huntsville, Alabama, USA, [5]NOAA National Environmental Satellite, Data, and Information Service, College Park, Maryland, USA, [6]U.S. Department of Agriculture, Beltsville, Maryland, USA, [7]University of Idaho, Kimberly, Idaho, USA, [8]King Abdullah University of Science and Technology, Thuwal, Saudi Arabia, [9]University of California, Berkeley, California, USA, [10]University of Wisconsin, Madison, Wisconsin, USA, [11]University of Nebraska-Lincoln, Lincoln, Nebraska, USA, [12]DuPont Pioneer, Johnston, Iowa, USA, [13]Ghent University, Ghent, Belgium, [14]EARTH University, San, José, Costa Rica, [15]INRA, ISPA UMR 1391, Villenage D'Ornon, France, [16]U.S. Department of Agriculture, Maricopa, Arizona, USA, [17]Princeton University, Princeton, New Jersey, USA

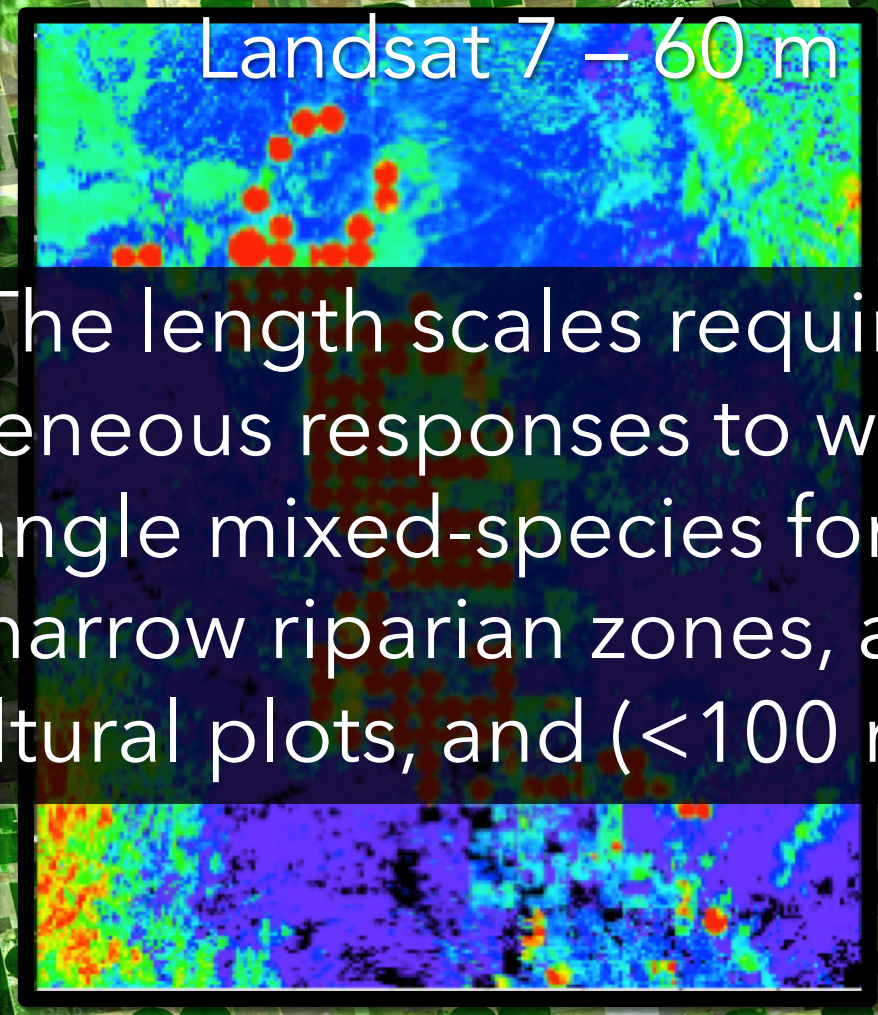
What we need: accurate, high spatial, high temporal, global, ET.



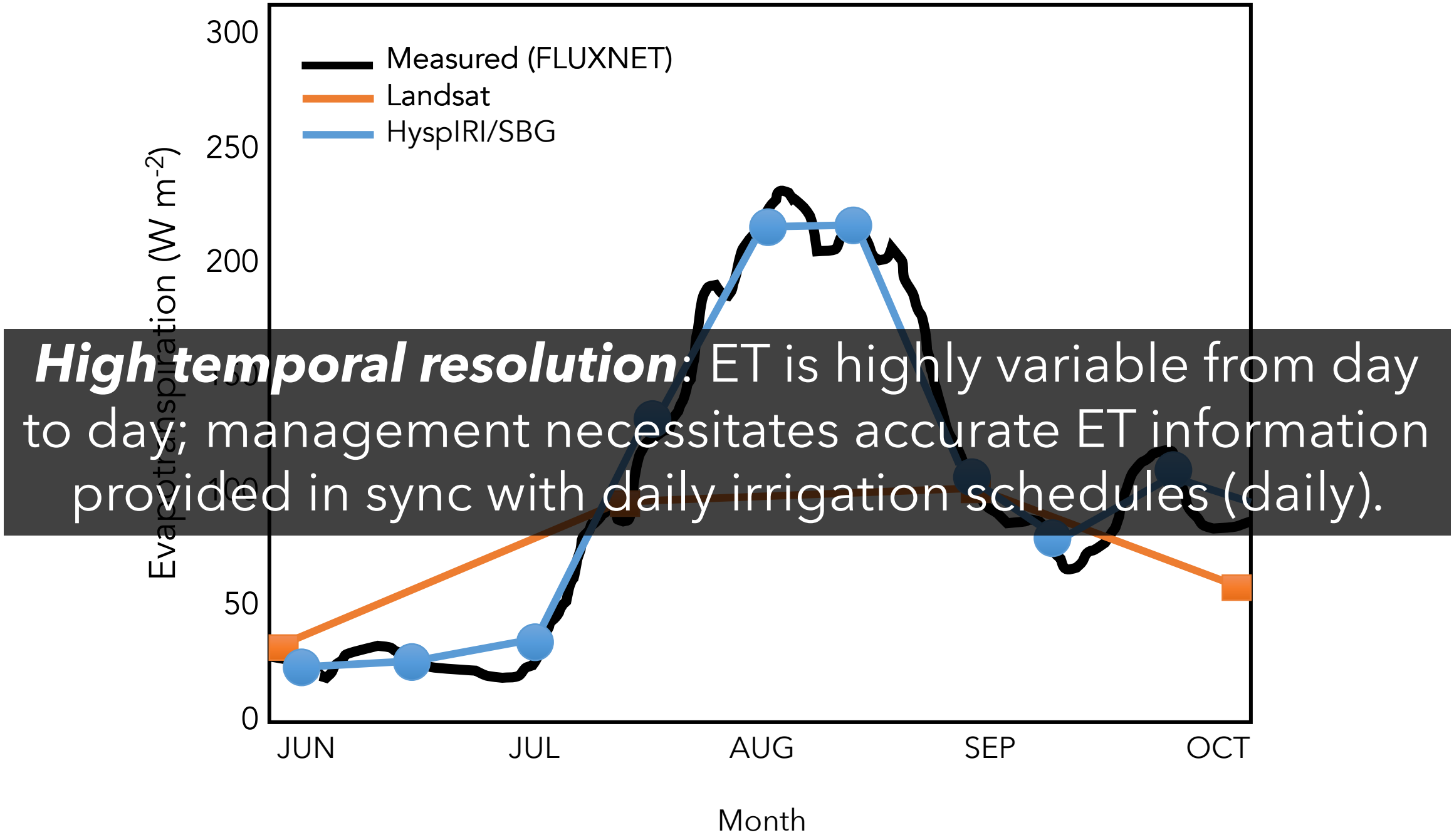
High accuracy: The higher the accuracy, the greater the ability to differentiate water use and water stress among different species and ecosystems, as well as to enable more effective water management (<10% relative error).


MODIS – 1 km
Landsat 7 – 60 m

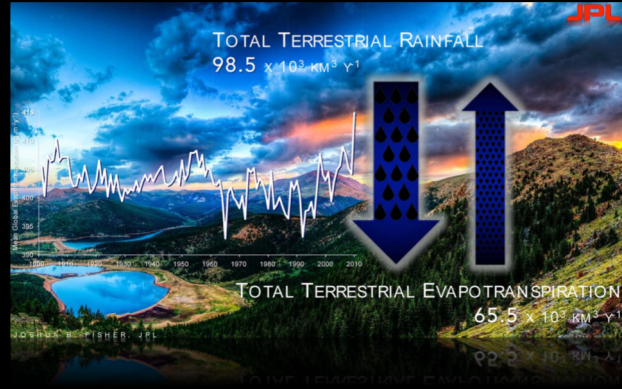




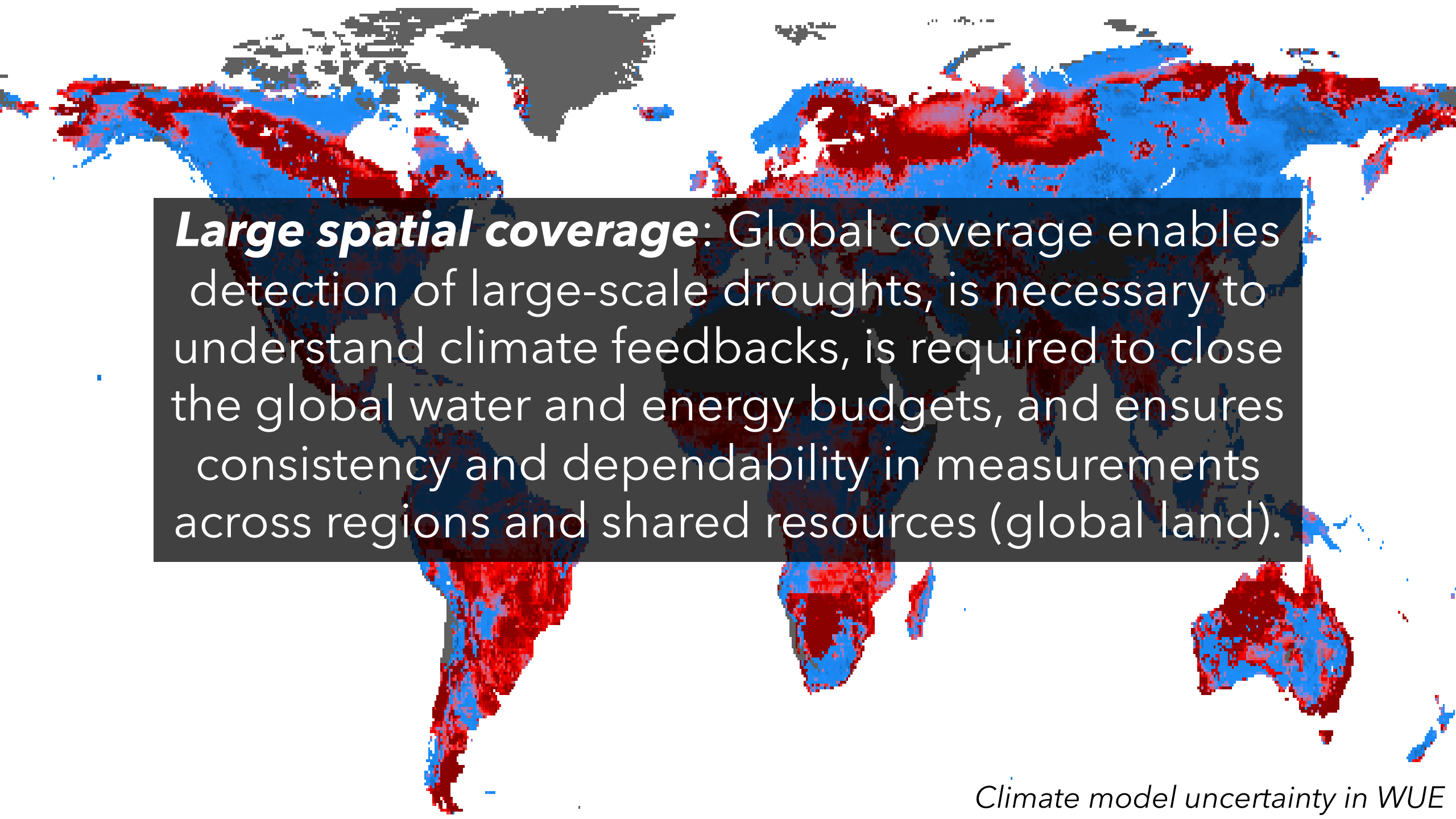
High spatial resolution: The length scales required to detect spatially heterogeneous responses to water environments must disentangle mixed-species forest/ ecosystem assemblages, narrow riparian zones, and the "field-scale" of agricultural plots, and (<100 m).



High temporal resolution: ET is highly variable from day to day; management necessitates accurate ET information provided in sync with daily irrigation schedules (daily).



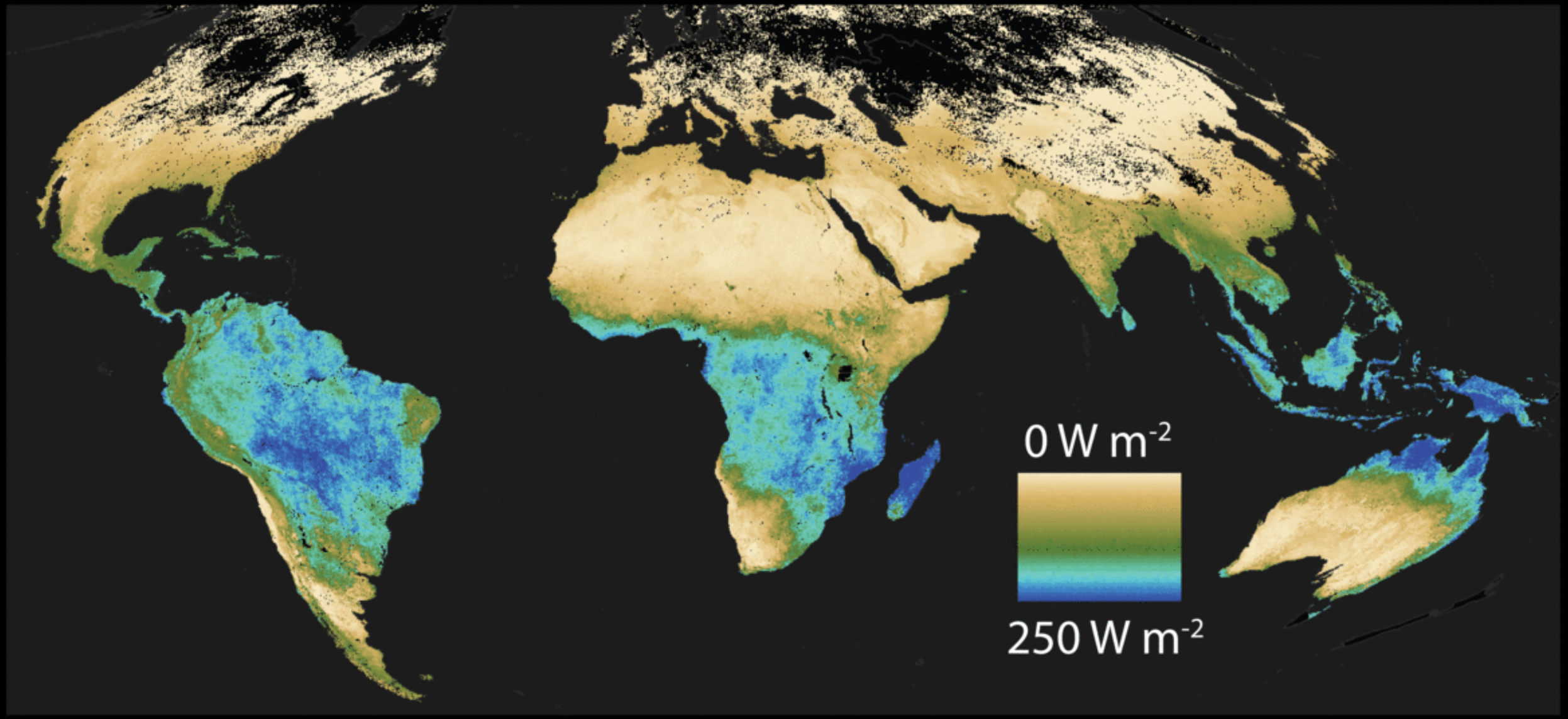
Long-term monitoring: Because heatwaves, droughts and drought responses evolve over the course of multiple years, and as climate becomes increasingly variable, the need for long-term observations will likewise be increasingly critical (decadal scale).



Large spatial coverage: Global coverage enables detection of large-scale droughts, is necessary to understand climate feedbacks, is required to close the global water and energy budgets, and ensures consistency and dependability in measurements across regions and shared resources (global land).

Climate model uncertainty in WUE

Monthly Average of PT-JPL Daily Integrated Latent Heat Flux



1 2 3 4 5 6 7 8 9 10 12 13

J F M A M J J A S O N D

Cal/Val

Geosci. Model Dev. Discuss., 8, 6809–6866, 2015
www.geosci-model-dev-discuss.net/8/6809/2015/
doi:10.5194/gmdd-8-6809-2015
© Author(s) 2015. CC Attribution 3.0 License.

Geoscientific Model Development
Discussions

This discussion paper is/has been under review for the journal Geoscientific Model Development (GMD). Please refer to the corresponding final paper in GMD if available.

The GEWEX LandFlux project: evaluation of model evaporation using tower-based and globally-gridded forcing data

M. F. McCabe[1], A. Ershadi[1], C. Jimenez[2], D. G. Miralles[3], D. Michel[4], and E. F. Wood[5]

Agricultural and Forest Meteorology 187 (2014) 46–61
Contents lists available at ScienceDirect
Agricultural and Forest Meteorology
journal homepage: www.elsevier.com/locate/agrformet

Multi-site evaluation of terrestrial evaporation models using FLUXNET data

A. Ershadi[a,*], M.F. McCabe[b], J.P. Evans[c,d], N.W. Chaney[e], E.F. Wood[e]

Remote Sensing of Environment 115 (2011) 801–823
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

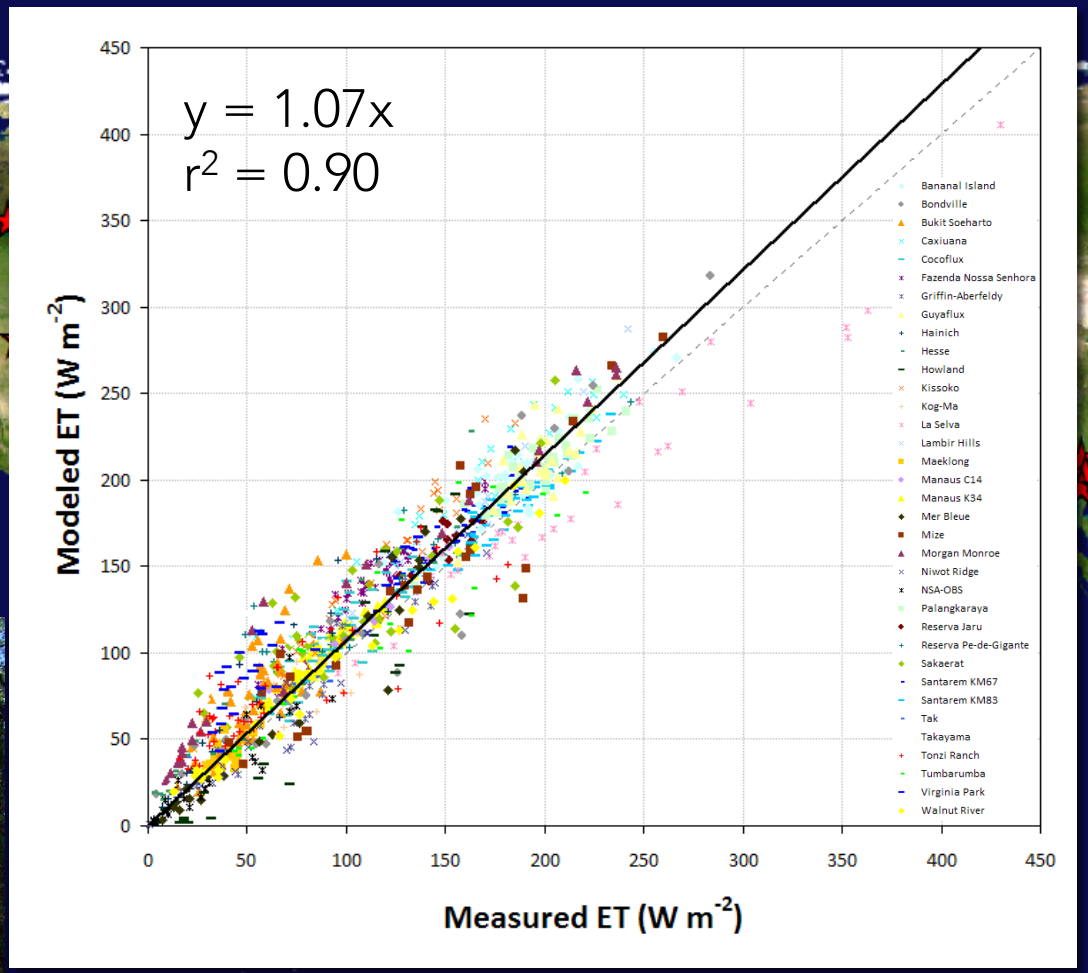
Global estimates of evapotranspiration for climate studies using multi-sensor remote sensing data: Evaluation of three process-based approaches

Raghuveer K. Vinukollu[a,*], Eric F. Wood[a], Craig R. Ferguson[a], Joshua B. Fisher[b]

Manuscript prepared for Hydrol. Earth Syst. Sci.
with version 2015/04/24 7.83 Copernicus papers of the LaTeX class copernicus.cls.
Date: 4 September 2015

The WACMOS-ET project - Part 1: Tower-scale evaluation of four observation-based evapotranspiration algorithms

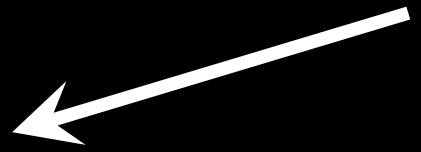
D. Michel[1], C. Jiménez[2,3], D.M. Miralles[4,5], M. Jung[6], M. Hirschi[1], A. Ershadi[7], B. Martens[5], M.F. McCabe[7], J.B. Fisher[8], Q. Mu[9], Z. Su[10], S.I. Seneviratne[1], E.F. Wood[11], and D. Fernández-Prieto[12]



stations as independent metrics of performance, the tower-based analysis indicated that PT-JPL provided the highest overally statistical performance (0.72; 61 W m^{-2}; 0.65), followed closely by GLEAM (0.68; 64 W m^{-2}; 0.62), with values in parenthe-

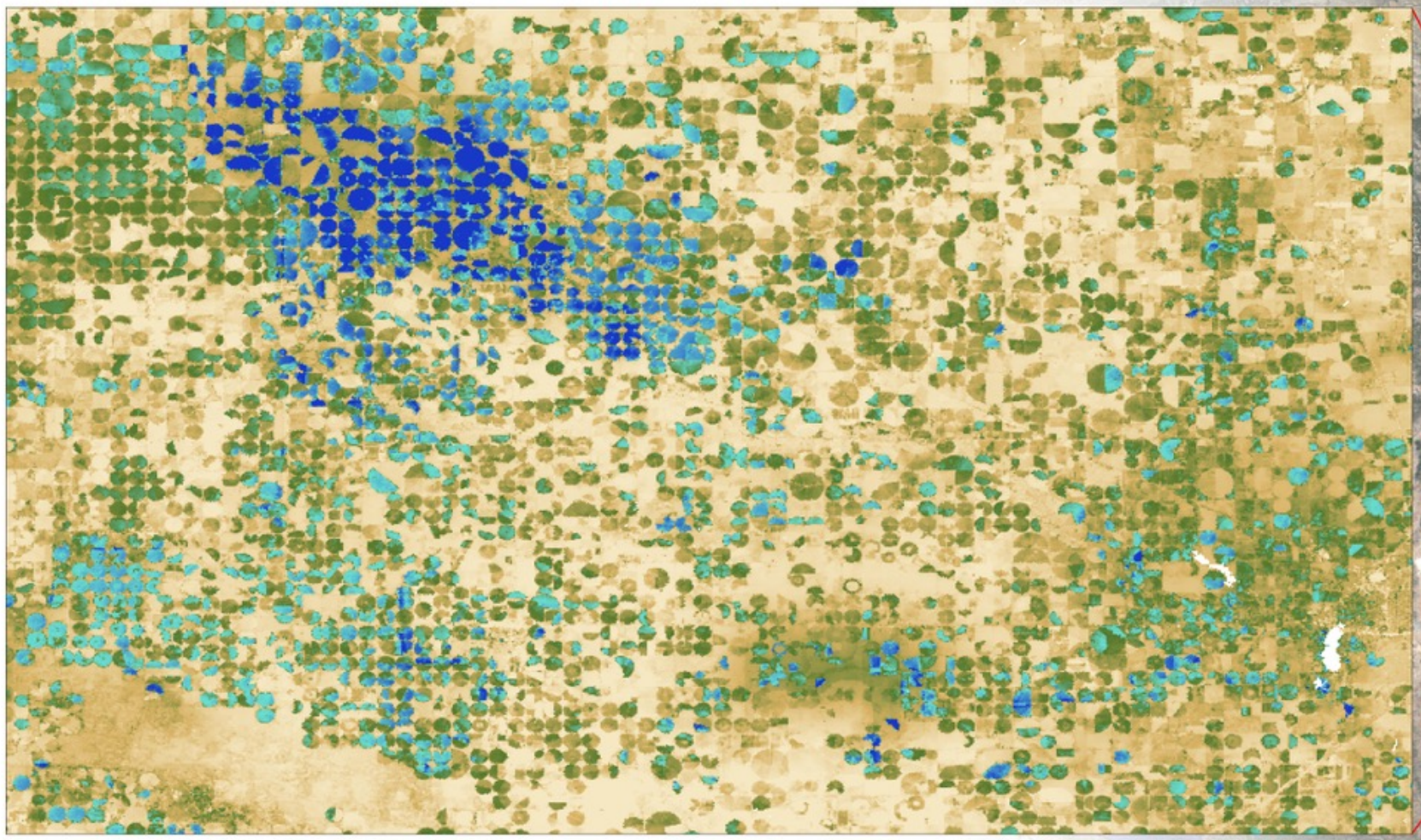
Fisher, J.B., Tu, K.P., Baldocchi, D.D., 2008. *Remote Sensing of Environment.*

ECOSTRESS!



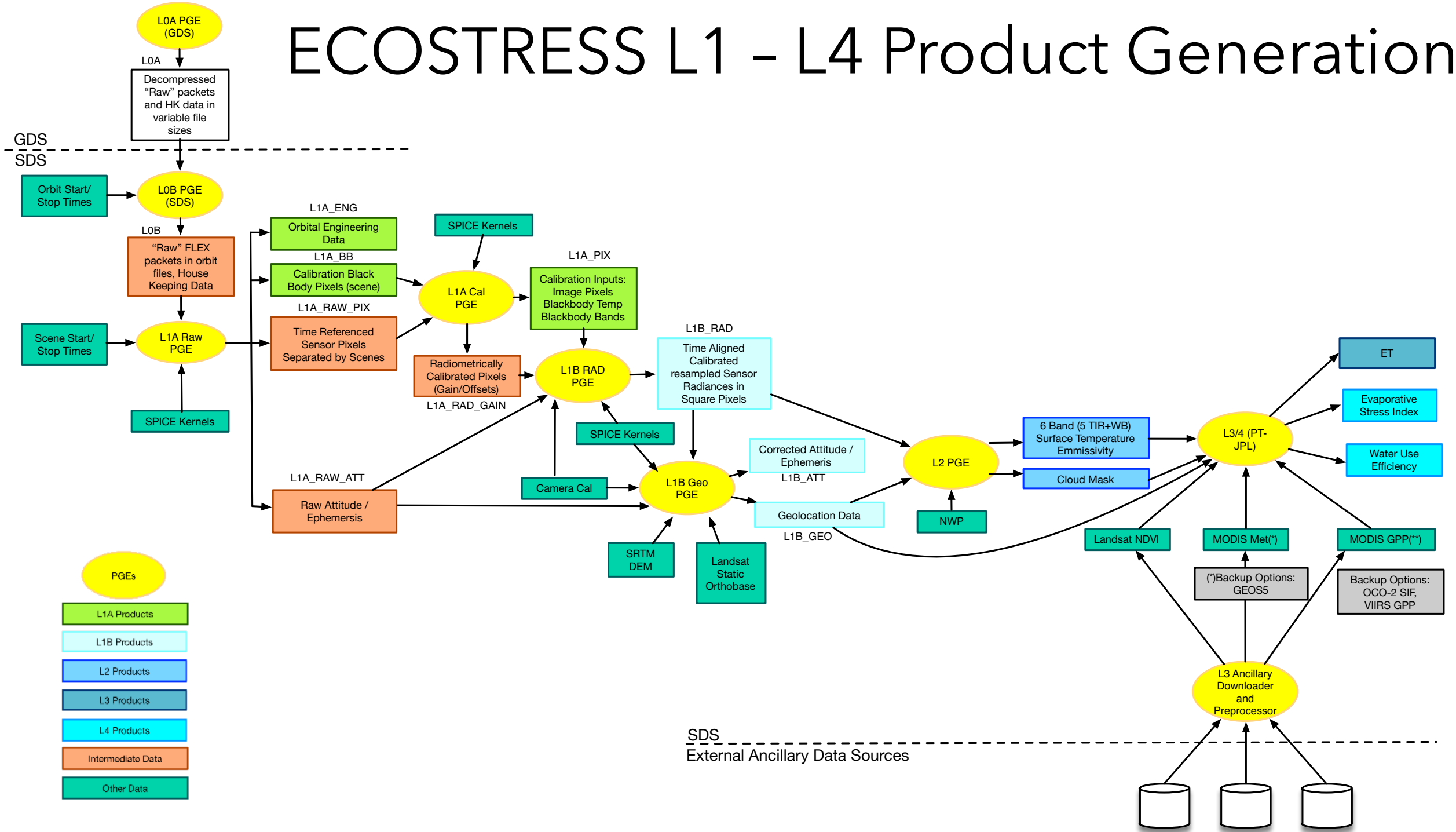
29 JUN 2018

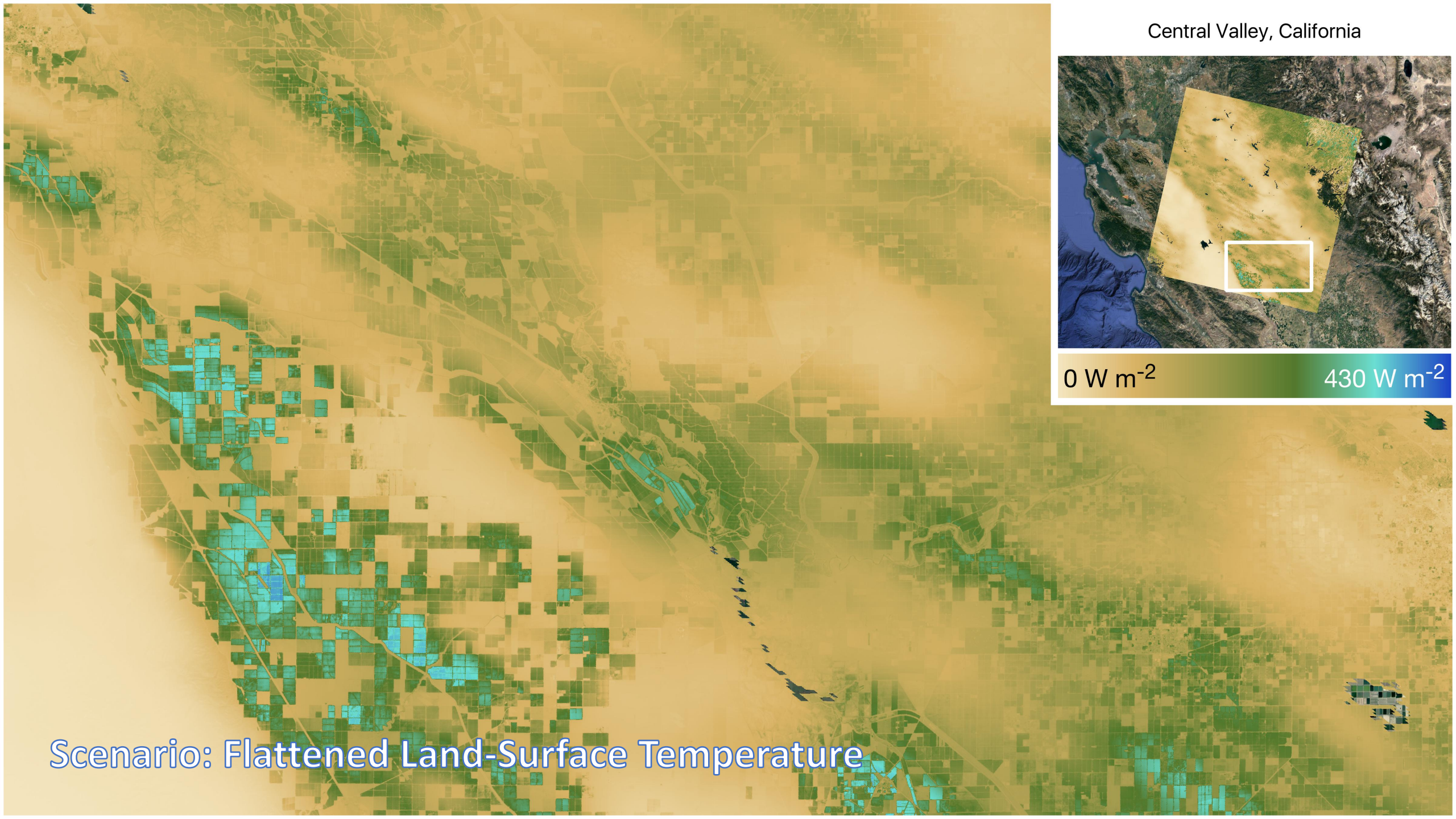
ECOSTRESS L3 (ET PT-JPL) 2018-07-29 18:19 CDT

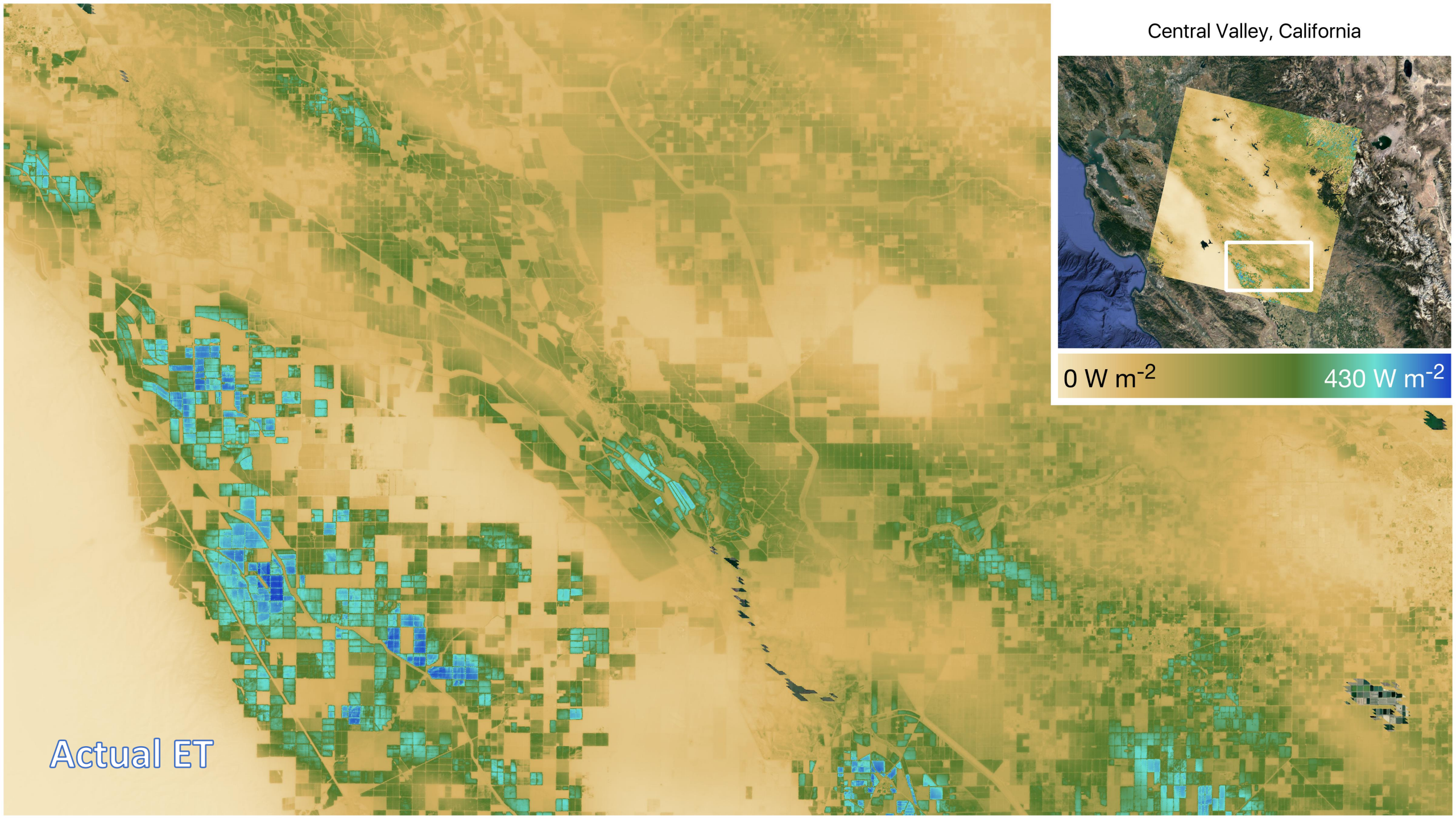


27 mg H_2O s^{-1} m^{-2} — 155 mg H_2O s^{-1} m^{-2}

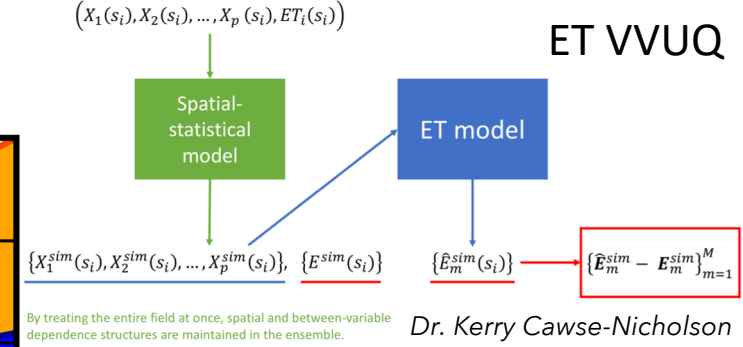
ECOSTRESS L1 – L4 Product Generation



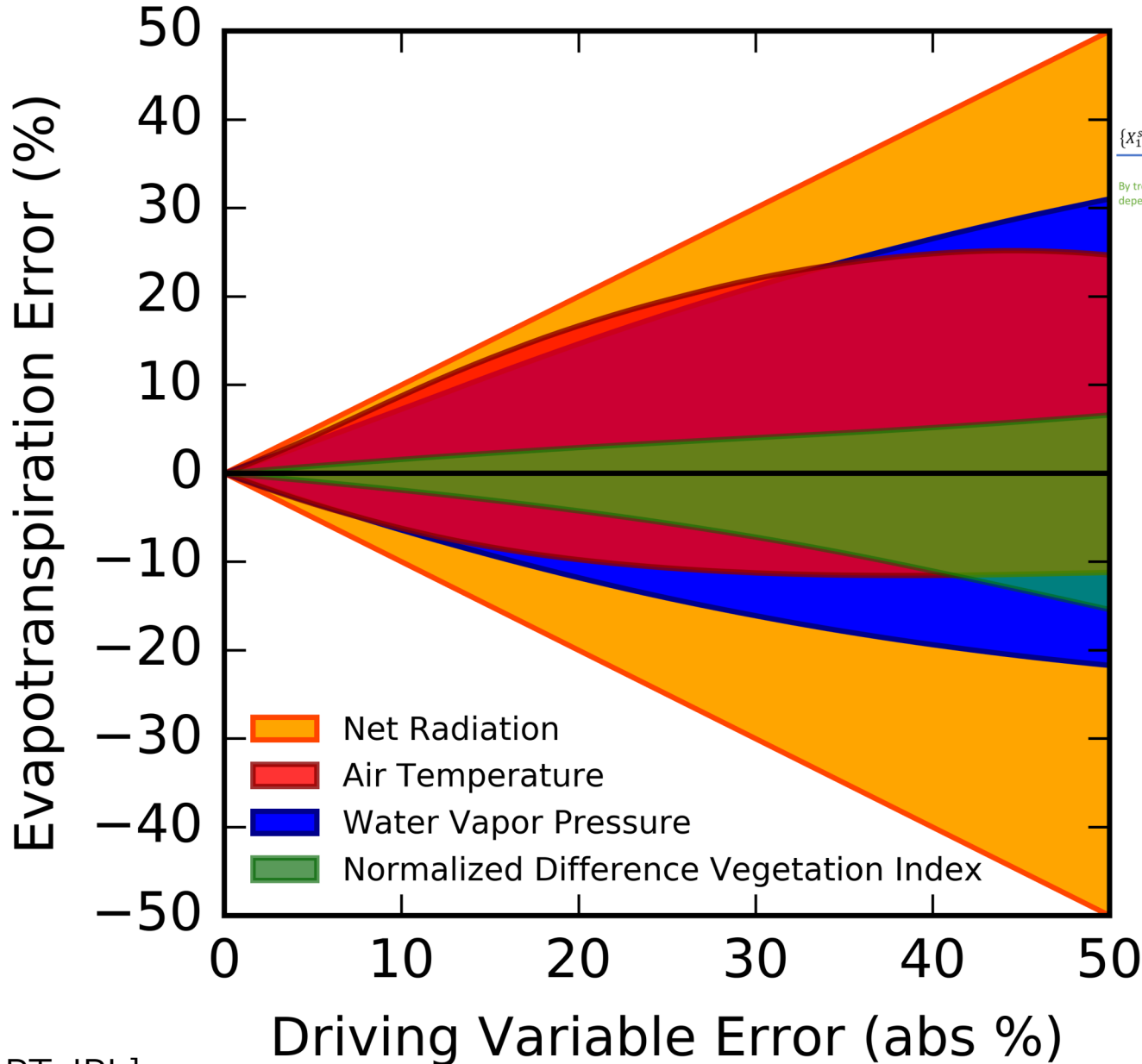

Central Valley, California
0 W m-2
430 W m-2
Scenario: Flattened Land-Surface Temperature


Central Valley, California
0 W m-2
430 W m-2
Actual ET

ET VVUQ



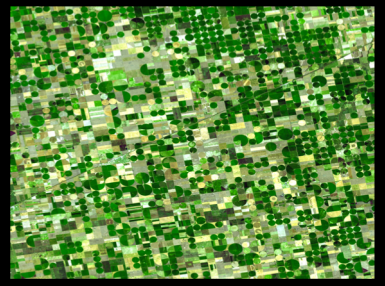
Dr. Kerry Cawse-Nicholson



[global: PT-JPL]

ET Spaceborne Measurement Requirements

Parameters	Minimal	Optimum	Landsat 8	MODIS	ECOSTRESS
Spatial resolution (m) – TIR	120	≤30	100	1000	69x57
Spatial resolution (m) – VSWIR	120	≤30			
Return Cycle (days) – TIR	8	≤4	16	1	3-5
Return Cycle (days) – VSWIR	16	≤4			
Number of bands – TIR	1	>2	2	3	5
Number of bands – VSWIR	10	>15			
Coverage	US	Global land	Global	Global	ISS coverage



Science / Applied Science Question	Science / Applied Science Objective(s)	Partners	Partner Data Baseline	Physical Parameters	Observables	Requirements	Anticipated / Desired Capability	Mission Functional Requirements	DS Reference
How do different plants respond to changes in water availability?	AS-I. Determine water use in natural ecosystems.	FLUXNET	100s of flux sites and intensive measurement sites	LST with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage, natural vegetation; temporal continuity 3 years NDVI, albedo, ea, Ta with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years	TIR with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage, natural vegetation; temporal continuity 3 years VSWIR with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years		2020		
	AS-II Determine water stress under water limitation.	Ecological community		LST with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years NDVI, albedo, ea, Ta with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years	TIR with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years VSWIR with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years		2020		
	AS-III. Determine water requirements in managed ecosystems.	Agricultural community (e.g., USDA)		LST with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage, managed vegetation; temporal continuity indefinitely NDVI, albedo, ea, Ta with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years	TIR with uncertainty better than 1 K; spatial resolution < 100 m; temporal resolution < 1 week; global coverage, managed vegetation; temporal continuity 3 years VSWIR with uncertainty better than 10%; spatial resolution < 100 m; temporal resolution < 1 week; global coverage; temporal continuity 3 years		2020		

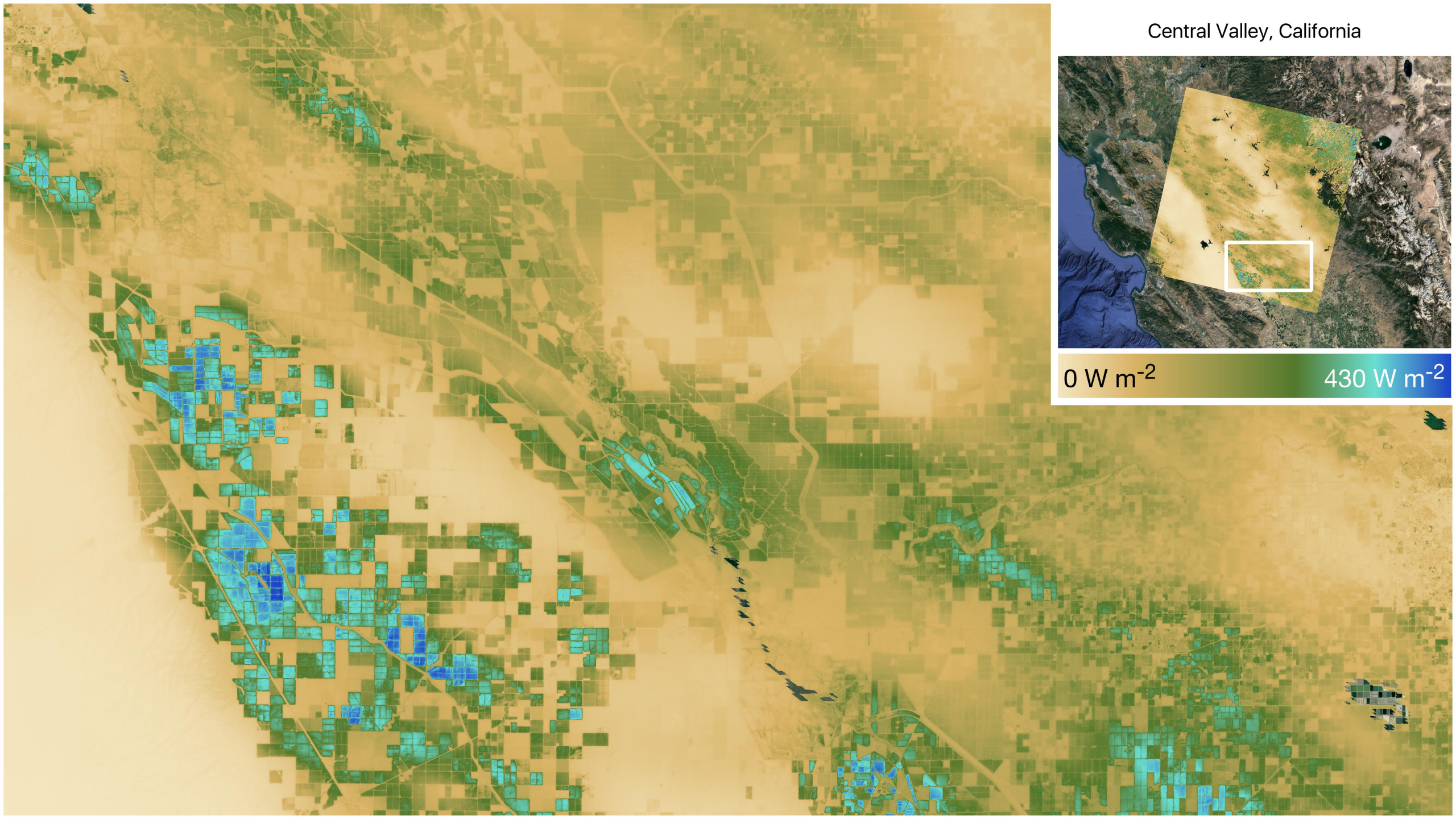
Conclusions

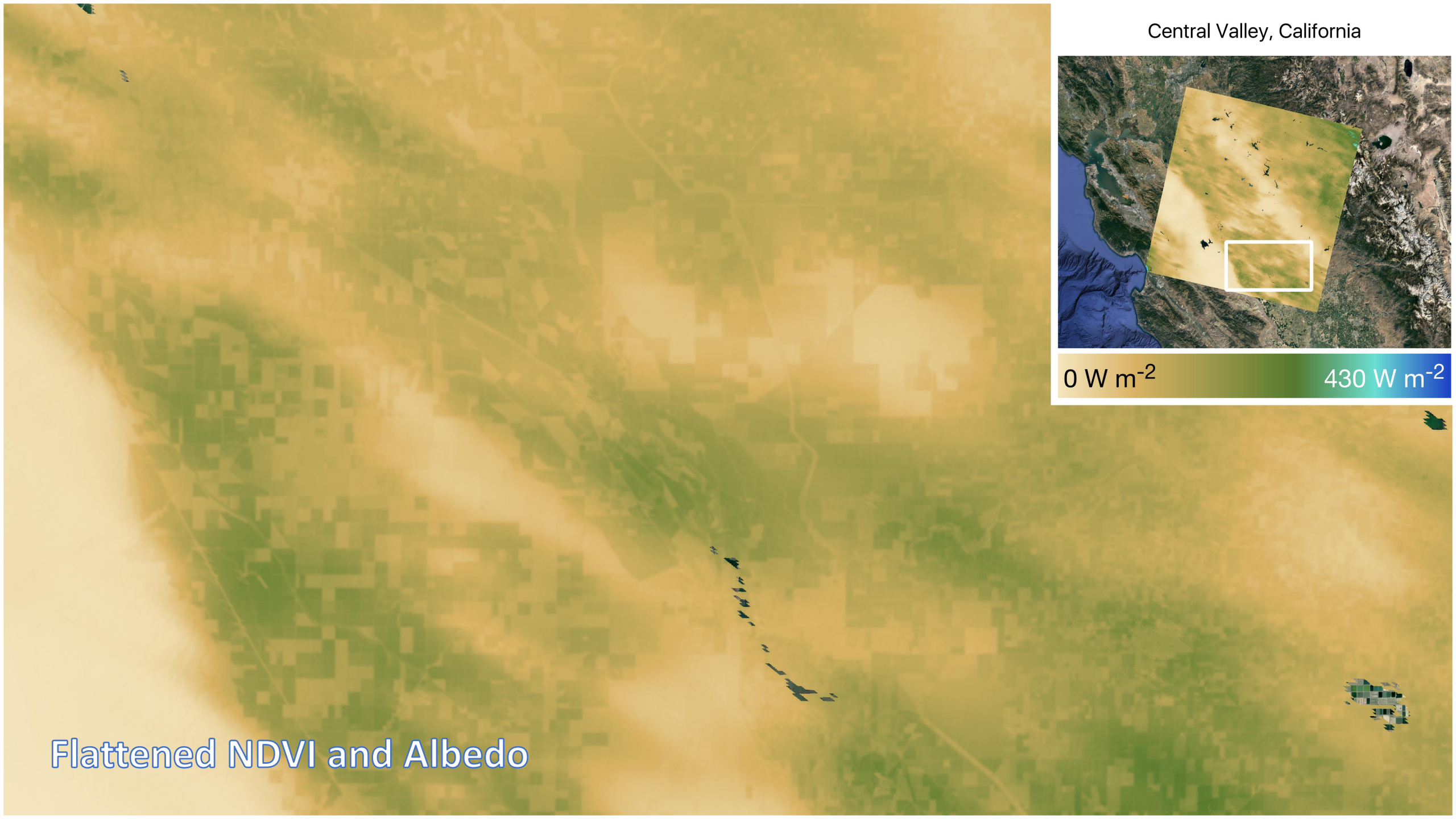
- **Decadal Survey**: ET a top science and applications priority throughout
  - Ecosystems: key biodiversity functional trait
  - Water & Energy Cycle: central coupling variable
  - Weather: cloud formation
  - Climate: drying, water-carbon cycle feedbacks
- **Urgency**: droughts, food & water security
- **Challenge/Uniqueness**: no current mission captures all ET requirements
- **TIR+VSWIR**: need together for ET
  - Function of TIR (radiation), VNIR (vegetation), and VSWIR (atmosphere)
  - Need tight geolocation for spatial requirements
  - Need consistency and reliability between measurements

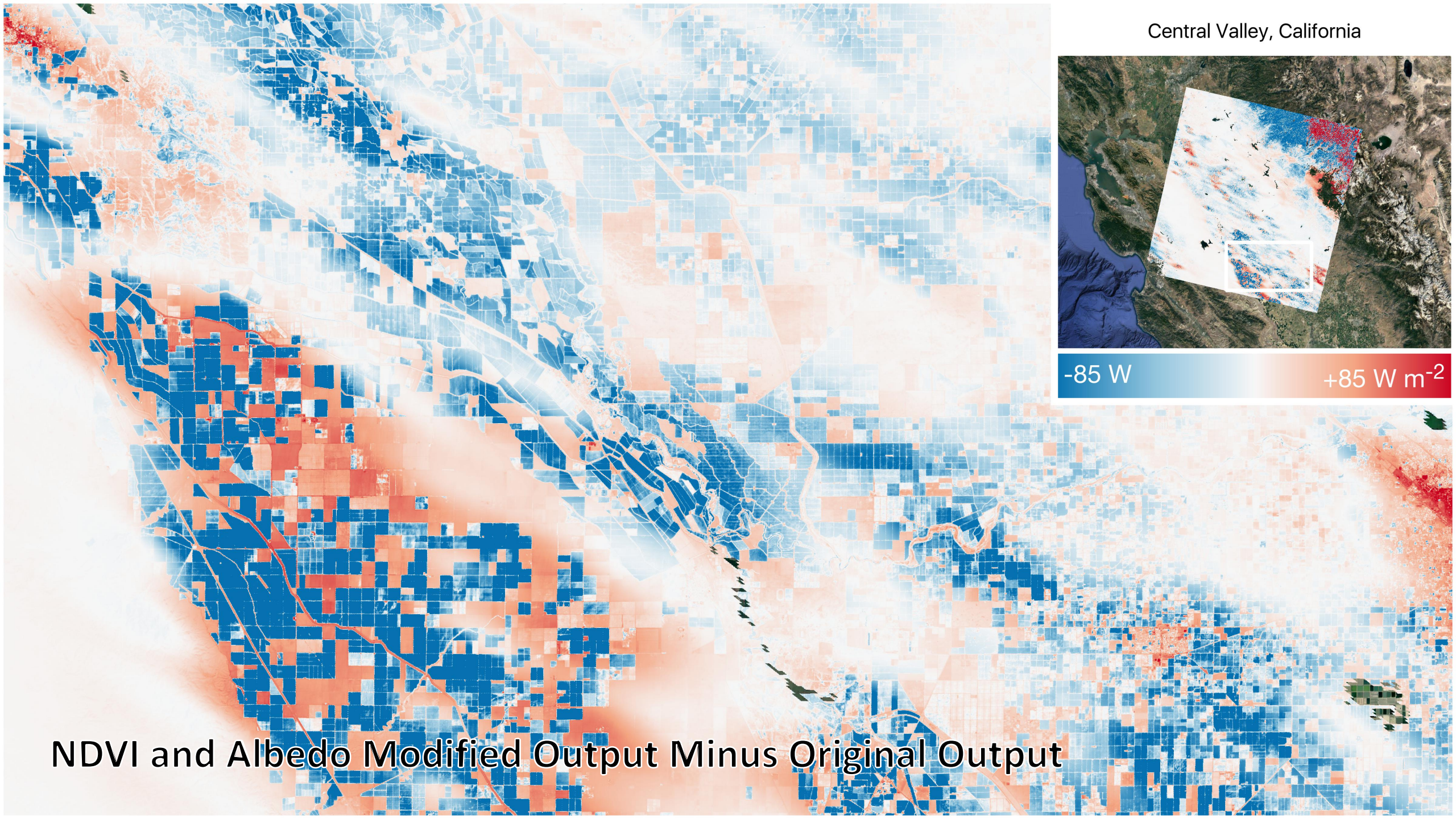
B A C K U P

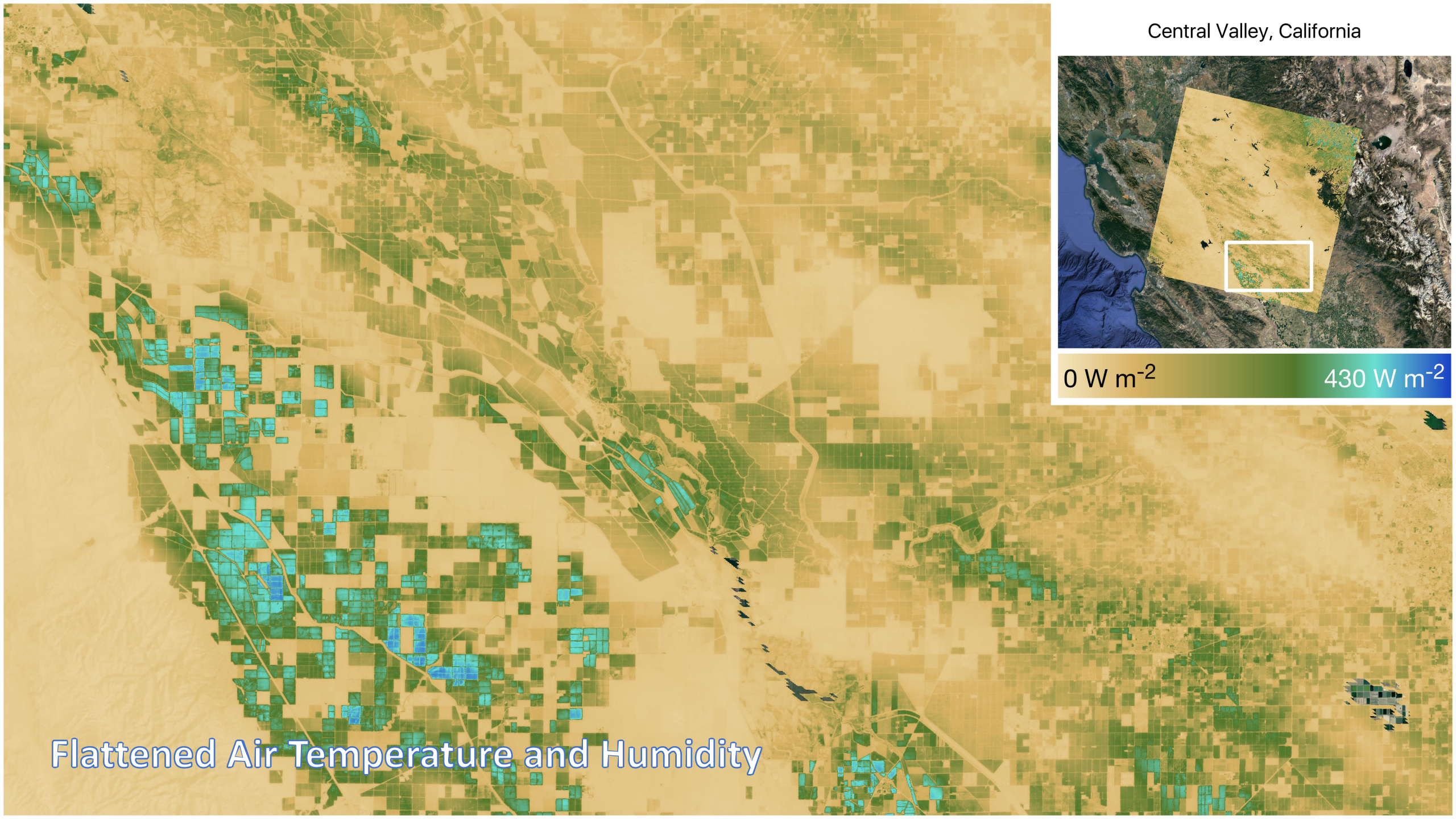
MODIS Bands Necessary for Evapotranspiration and their Correspondence to HyspIRI Prototypes

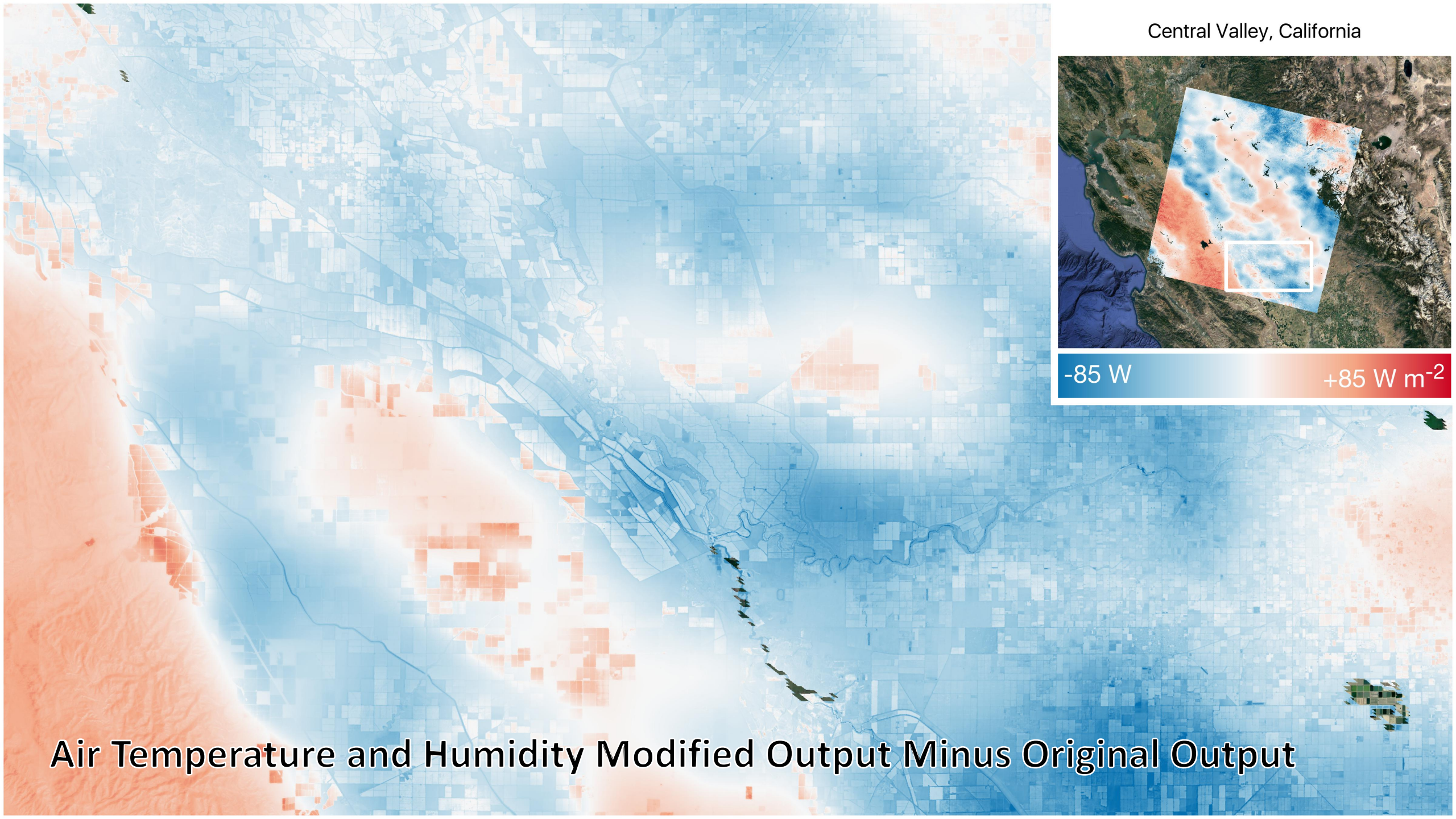
Band #	Wavelength		Products	Variables	HyspIRI Prototypes	MODIS Predecessors
3	0.459 µm	0.479 µm	MOD04, MOD13, MCD43	albedo, AOT, VI	AVIRIS, AVIRIS-NG	Landsat
4	0.545 µm	0.565 µm	MOD04, MOD13, MCD43	albedo, AOT, VI	AVIRIS, AVIRIS-NG	Landsat, AVHRR
1	0.620 µm	0.670 µm	MOD04, MOD06, MOD13, MCD43	albedo, AOT, COT, VI	AVIRIS, AVIRIS-NG	Landsat
2	0.841 µm	0.876 µm	MOD04, MOD06, MOD13, MCD43	albedo, AOT, COT, VI	AVIRIS, AVIRIS-NG	Landsat, AVHRR
5	1.230 µm	1.250 µm	MOD04, MOD06, MOD13, MCD43	albedo, AOT, COT, VI	AVIRIS, AVIRIS-NG	
6	1.628 µm	1.652 µm	MOD04, MOD06, MOD13, MCD43	albedo, AOT, COT, VI	AVIRIS, AVIRIS-NG	Landsat, AVHRR
7	2.105 µm	2.155 µm	MOD04, MOD06, MOD13, MCD43	albedo, AOT, COT, VI	AVIRIS, AVIRIS-NG	Landsat
20	3.660 µm	3.840 µm	MOD06	COT	Not Covered	HIRS, AVHRR
25	4.482 µm	4.549 µm	MOD07	Ta, Td		HIRS
27	6.535 µm	6.895 µm	MOD07	Ta, Td		HIRS
28	7.175 µm	7.475 µm	MOD07	Ta, Td		HIRS
29	8.400 µm	8.700 µm	MOD07, MOD21	Ta, Td, LST	HyTES, ECOSTRESS	HIRS
30	9.580 µm	9.880 µm	MOD07	Ta, Td	HyTES, ECOSTRESS	HIRS
31	10.780 µm	11.280 µm	MOD06, MOD07, MOD11, MOD21	Ta, Td, COT, LST	HyTES, ECOSTRESS	HIRS, AVHRR
32	11.770 µm	12.270 µm	MOD07, MOD11, MOD21	Ta, Td, LST	HyTES, ECOSTRESS	HIRS, AVHRR
33	13.185 µm	13.485 µm	MOD07	Ta, Td	Not Covered	HIRS
34	13.485 µm	13.785 µm	MOD07	Ta, Td		HIRS
35	13.785 µm	14.085 µm	MOD07	Ta, Td		HIRS
36	14.085 µm	14.385 µm	MOD07	Ta, Td		HIRS

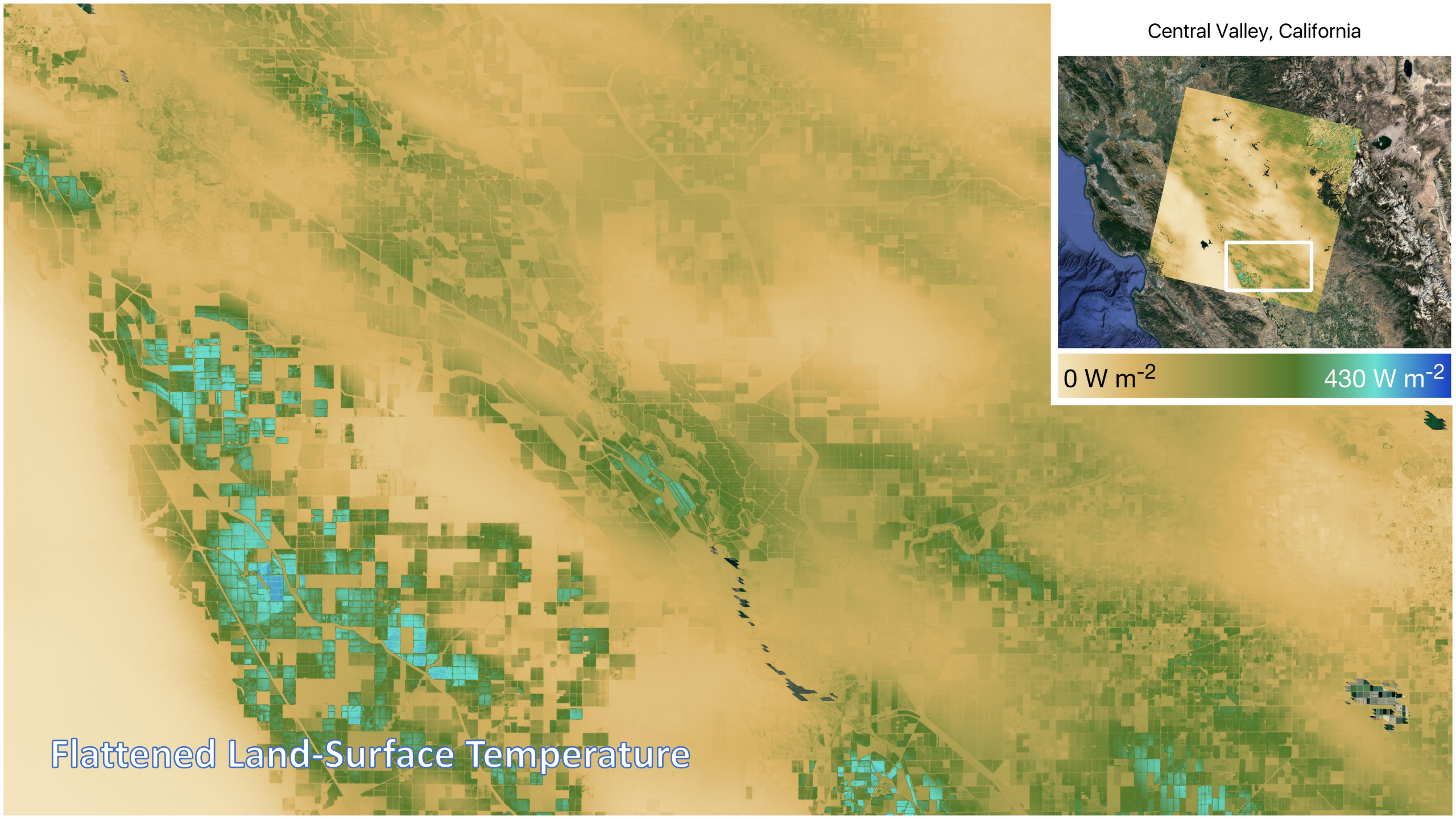

Central Valley, California
0 W m-2
430 W m-2

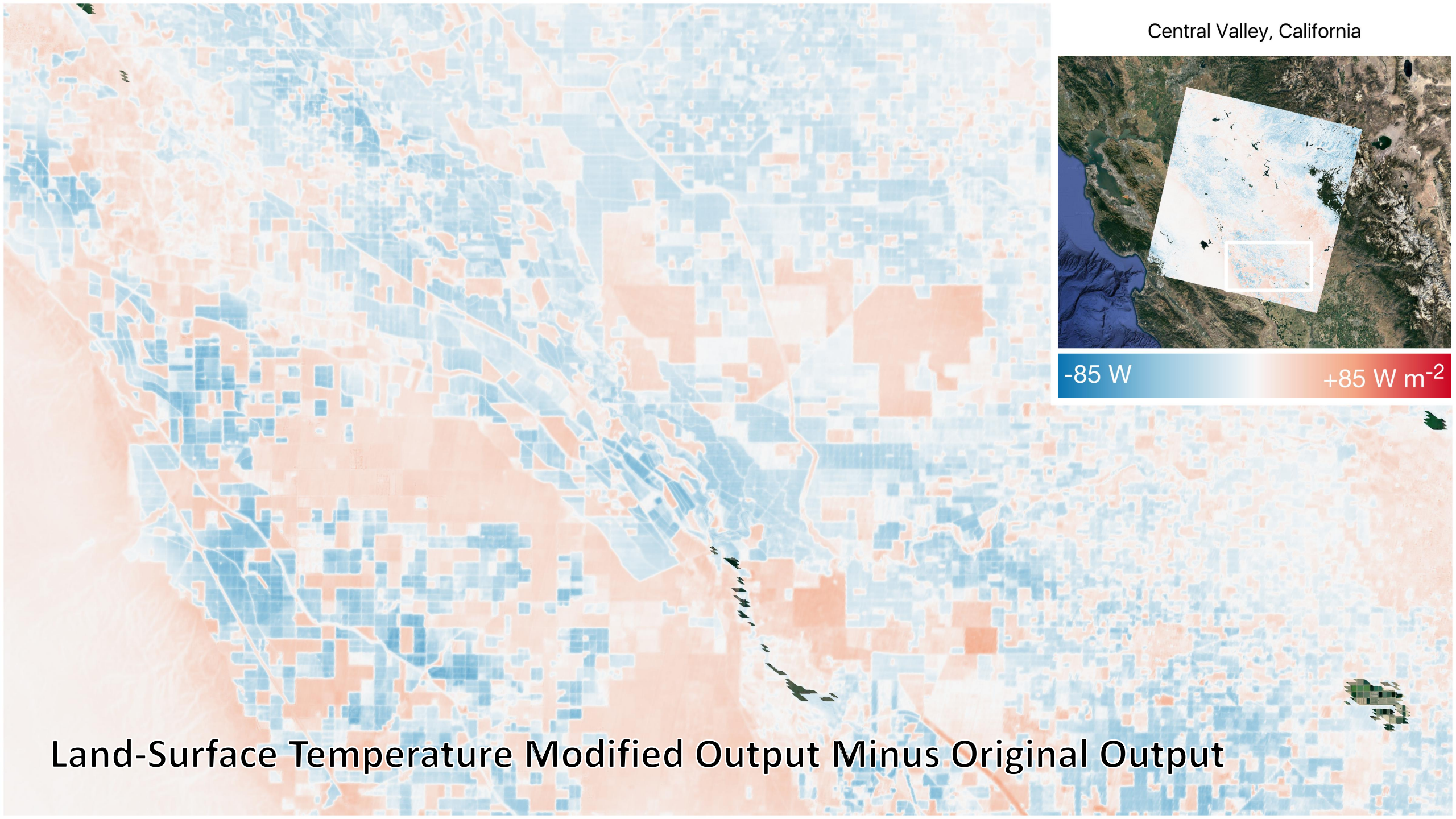

Central Valley, California
0 W m-2
430 W m-2
Flattened NDVI and Albedo


Central Valley, California
-85 W
+85 W m-2
NDVI and Albedo Modified Output Minus Original Output


Central Valley, California
0 W m-2
430 W m-2
Flattened Air Temperature and Humidity


Central Valley, California
-85 W
+85 W m-2
Air Temperature and Humidity Modified Output Minus Original Output


Central Valley, California
0 W m-2
430 W m-2
Flattened Land-Surface Temperature



Land-Surface Temperature Modified Output Minus Original Output