National Aeronautics and Space Administration

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

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

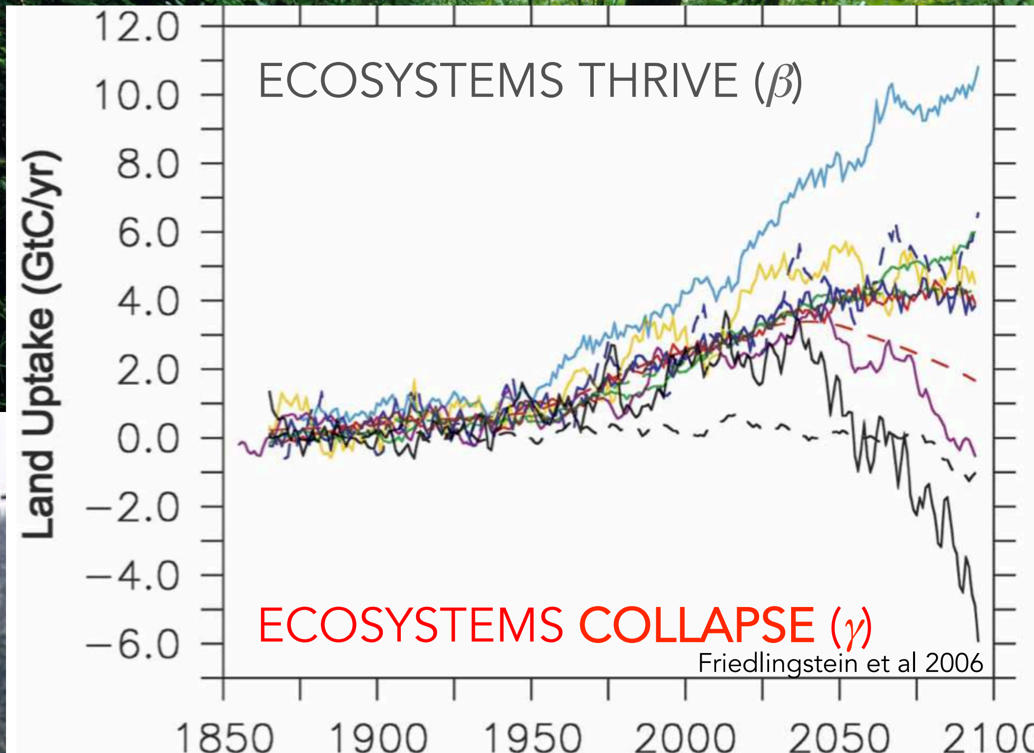
Joshua B. Fisher[1], Forrest Melton[2], Elizabeth Middleton[3], Christopher Hain[4,5], Martha Anderson[6], Richard Allen[7], Matthew F. McCabe[8], Simon Hook[1], Dennis Baldocchi[9], Philip A. Townsend[10], Ayse Kilic[11], Kevin Tu[12], Diego D. Miralles[13], Johan Perret[14], Jean-Pierre Lagouarde[15], 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

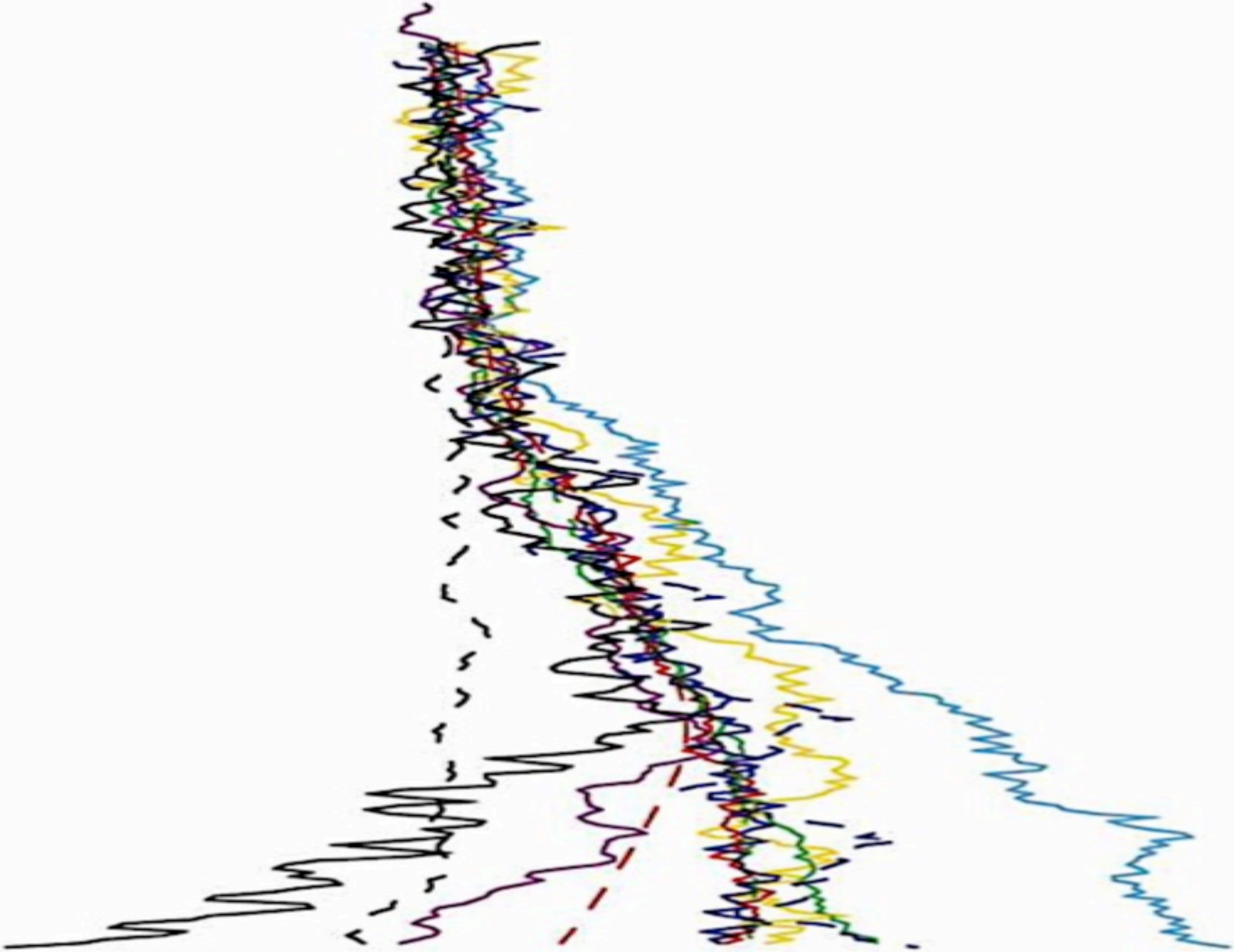
THE FUTURE OF

EVAPOTRANSPIRATION

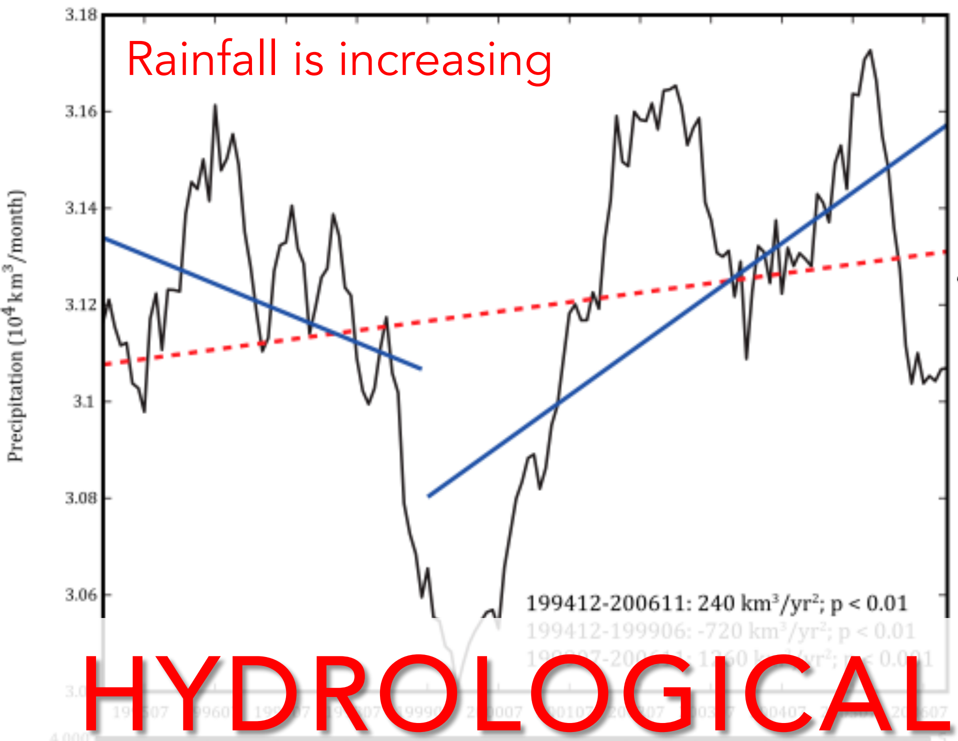
Global requirements for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources.

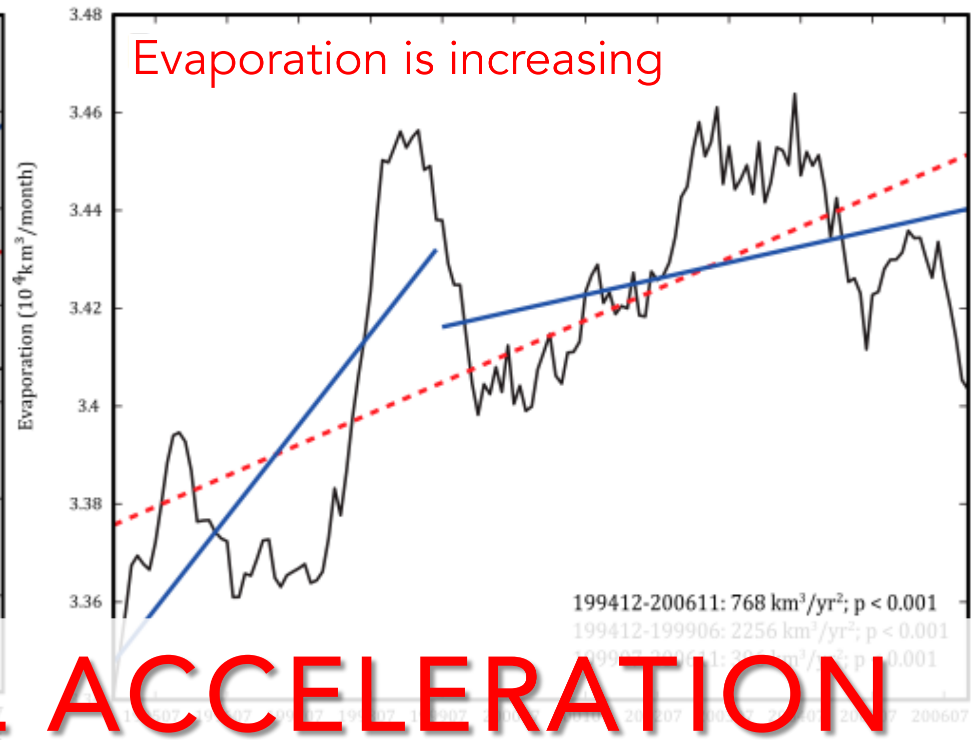


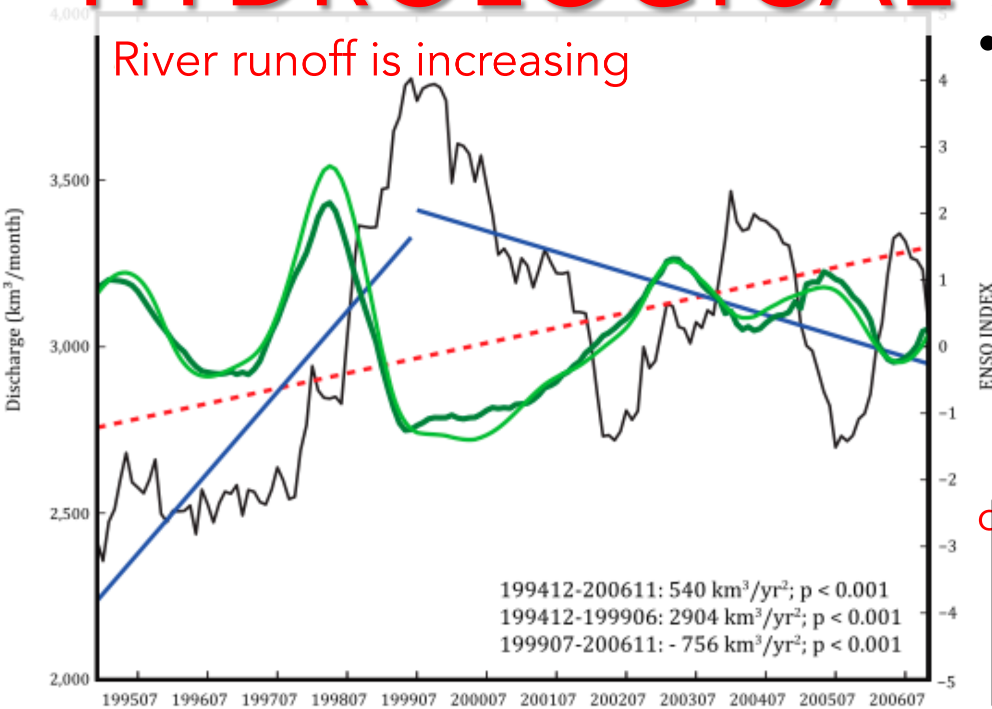
CO_2 fertilization (β) versus drought-induced ecosystem collapse (γ)



HYDROLOGICAL ACCELERATION

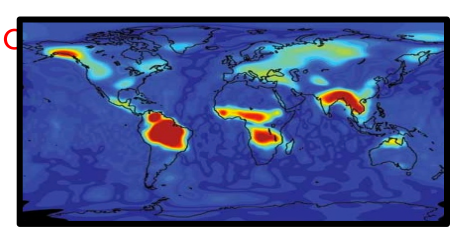






- More energy
  - → More evaporation
  - Atmosphere can't hold all that evaporation
    - → More precipitation
    - BUT, in places where there's already precipitation
    - Atmospheric moisture rains out before it reaches semi-arid places
    - More intense storms; more intense droughts

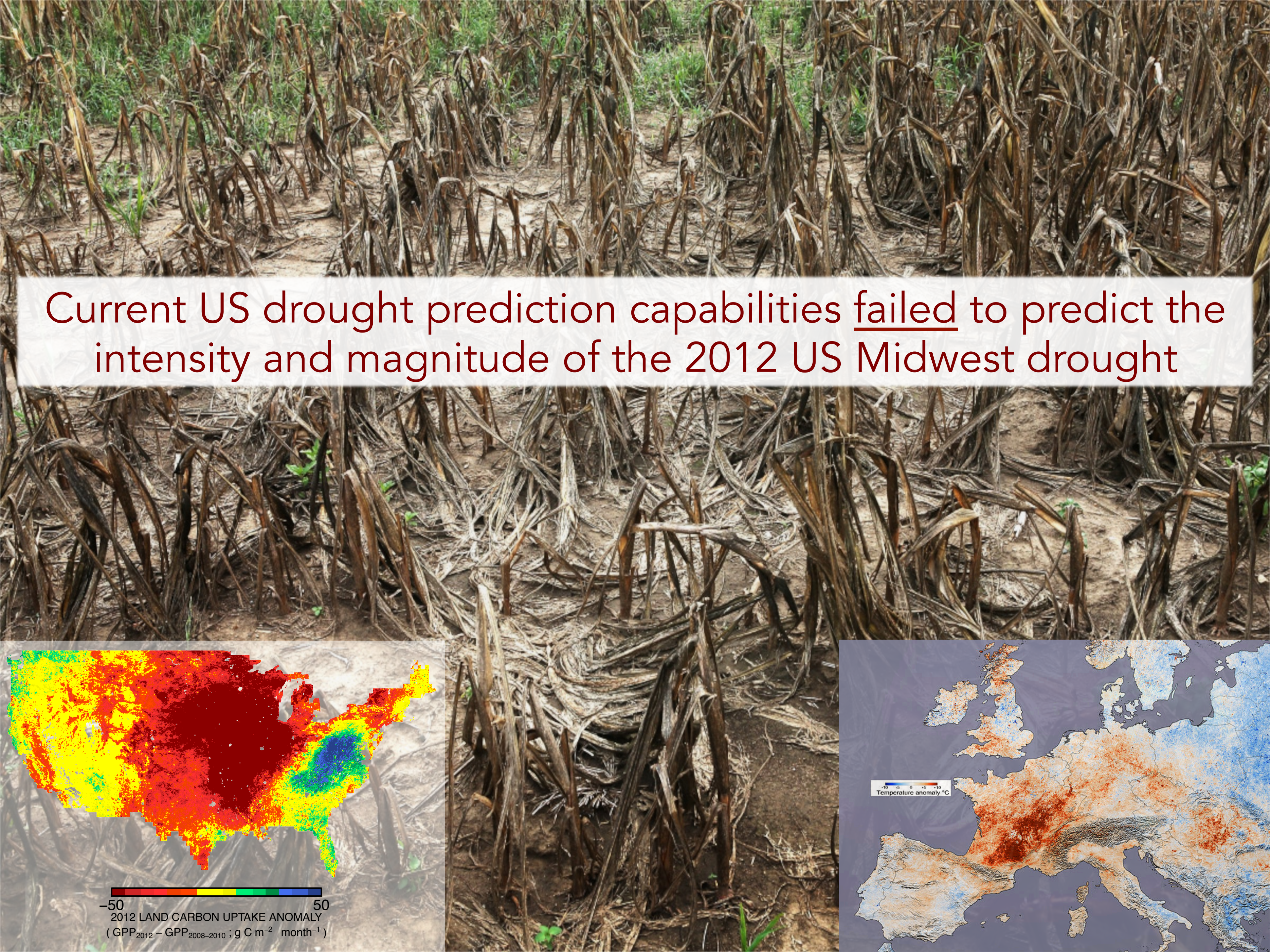
→ Wet get wetter,

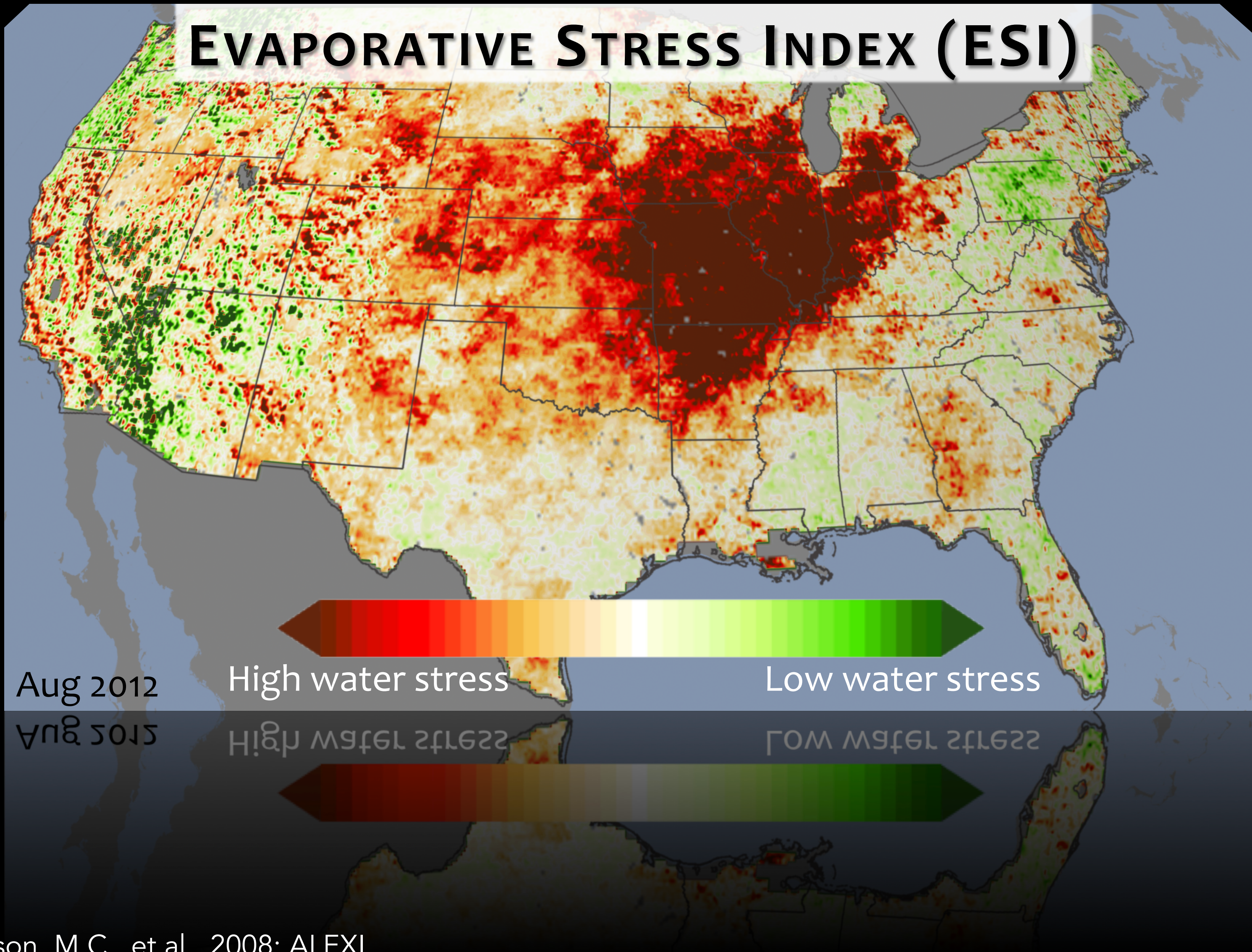


Syed et al 2010

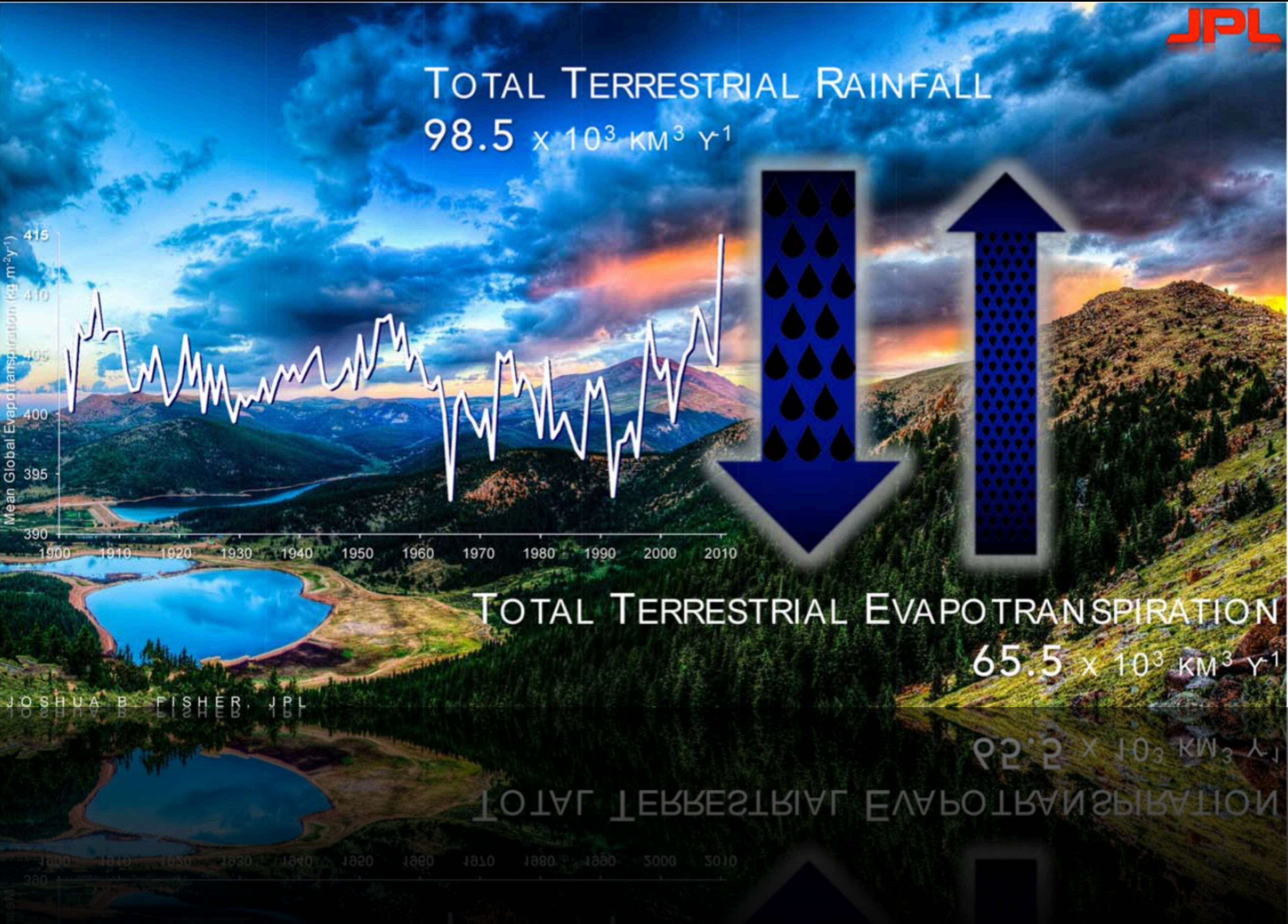
Available online at www.sciencedirect.com
ScienceDirect
Global and Planetary Change 56 (2007) 274–296
GLOBAL AND PLANETARY CHANGE
www.elsevier.com/locate/gloplacha
Climate-induced boreal forest change: Predictions versus current observations
Atmos. Chem. Phys., 11, 7925–7942, 2011
www.atmos-chem-phys.net/11/7925/2011/
doi:10.5194/acp-11-7925-2011
© Author(s) 2011. CC Attribution 3.0 License.
Atmospheric Chemistry and Physics
Satellite- and ground-based CO total column observations over 2010 Russian fires: accuracy of top-down estimates based on thermal IR satellite data
Vol 452 | 24 April 2008 | doi:10.1038/nature06777
nature
LETTERS
Mountain pine beetle and forest carbon feedback to climate change
W. A. Kurz, C. C. Dymond, G. Stinson, G. J. Rampley, E. T. Neilson, A. L. Carroll, T. Ebata & L. Safranyik
REPORTS
Drought Sensitivity of the Amazon Rainforest
1344 6 MARCH 2009 VOL 323 SCIENCE
BREVIA
The 2010 Amazon Drought
Simon L. Lewis, Paulo M. Brando, Oliver L. Phillips, Geertje M. F. van der Heijden, Daniel Nepstad
554 4 FEBRUARY 2011 VOL 331 SCIENCE www.sciencemag.org
www.nature.com/scientificreports
SCIENTIFIC REPORTS
OPEN
Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016
Received: 10 May 2016
Accepted: 23 August 2016
Published: 08 September 2016
SCIENTIFIC REPORTS | 6:33130 | DOI: 10.1038/srep33130

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

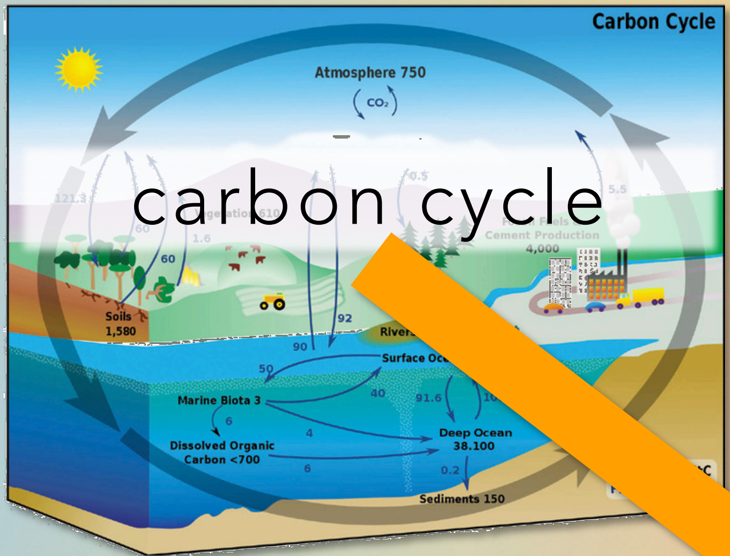


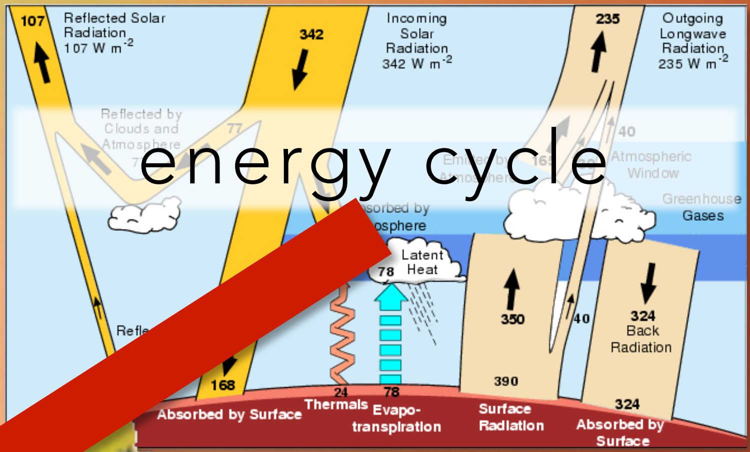


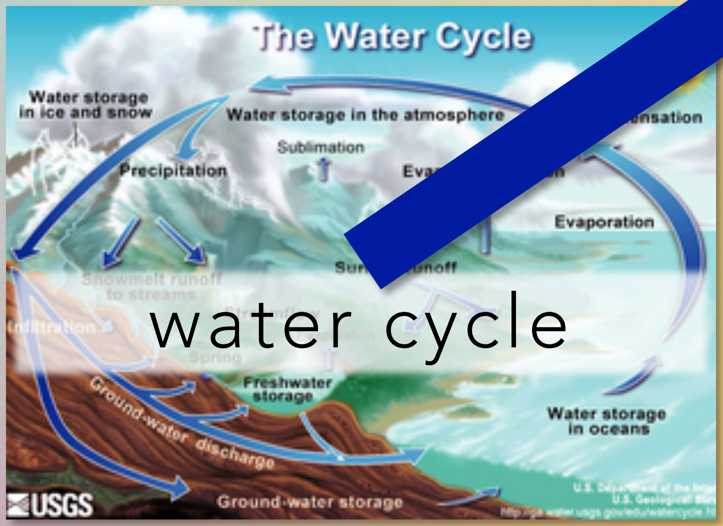
Anderson, M.C., et al., 2008: ALEXI.
Remote Sensing of Environment.



JPL
TOTAL TERRESTRIAL RAINFALL
98.5 x 10³ km³ y⁻¹
Mean Global Evapotranspiration (kg m⁻² y⁻¹)
415
410
405
400
395
390
1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
TOTAL TERRESTRIAL EVAPOTRANSPIRATION
65.5 x 10³ km³ y⁻¹
JOSHUA B. FISHER, JPL



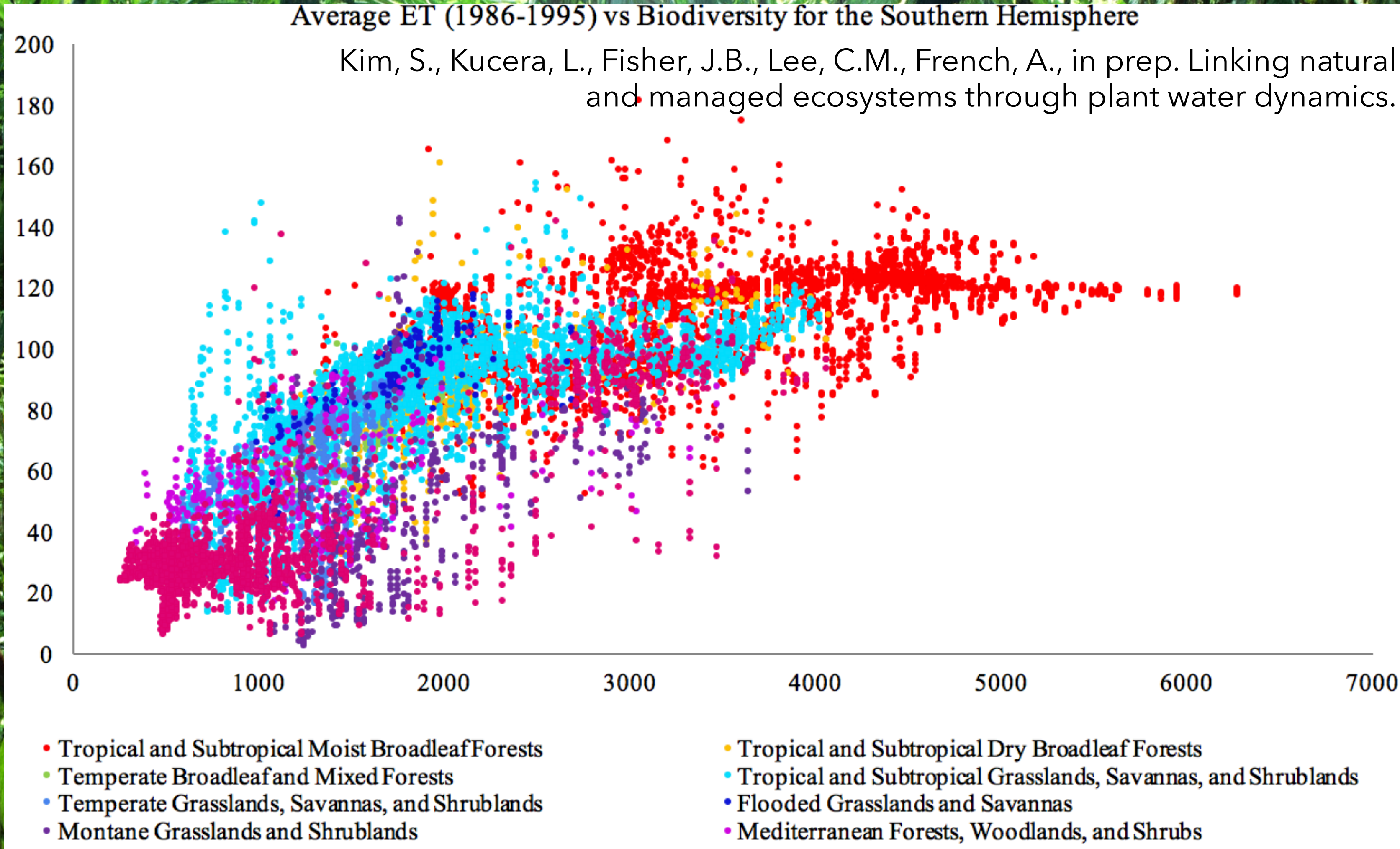




ET describes the net exchange of water vapor between the land surface and the atmosphere, and is comprised of water evaporated directly from the soil or other surfaces and water transpired (i.e., used; consumptive use) by plants.

what is evapotranspiration (ET)?

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



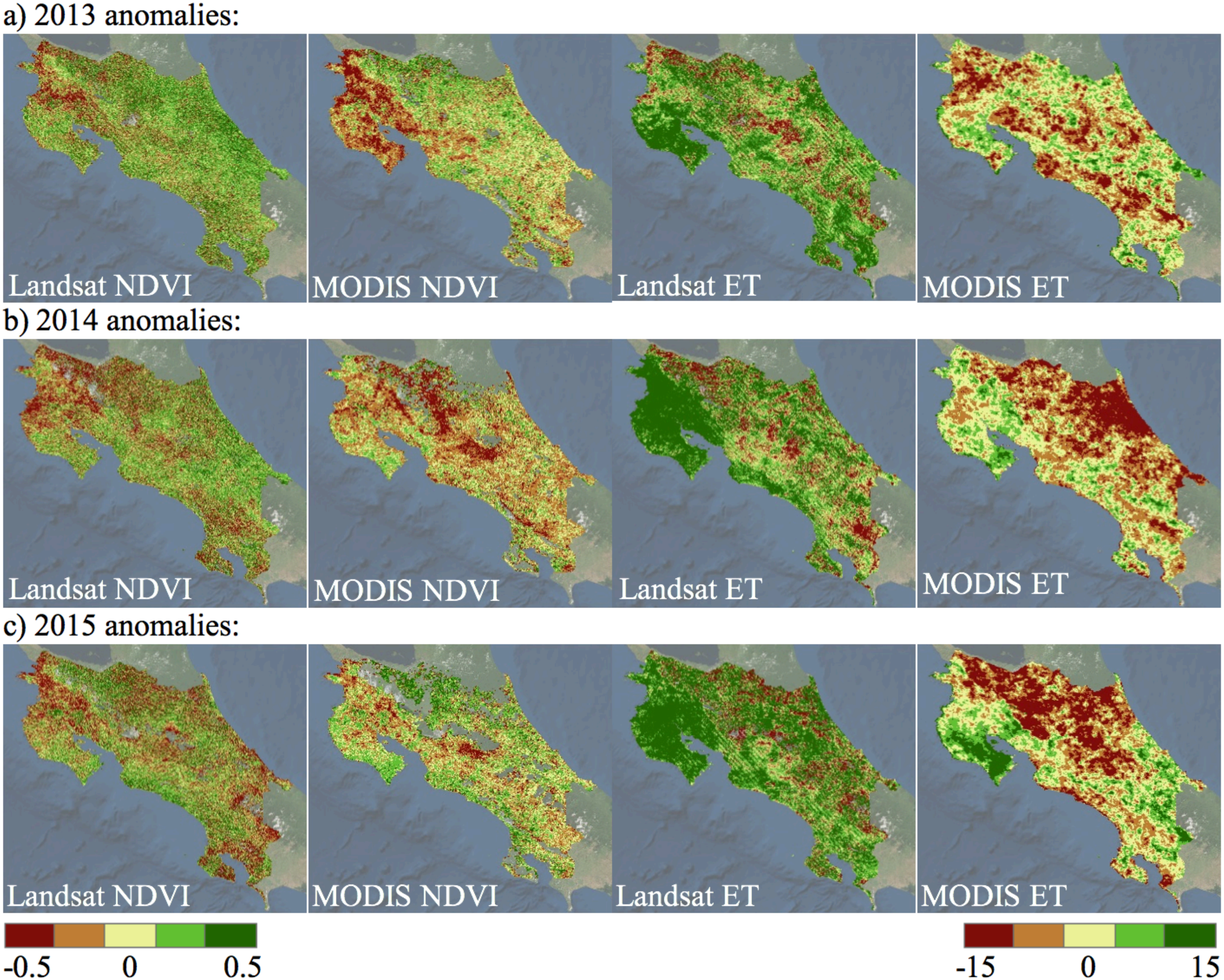
BIODIVERSITY


IRRIGATION

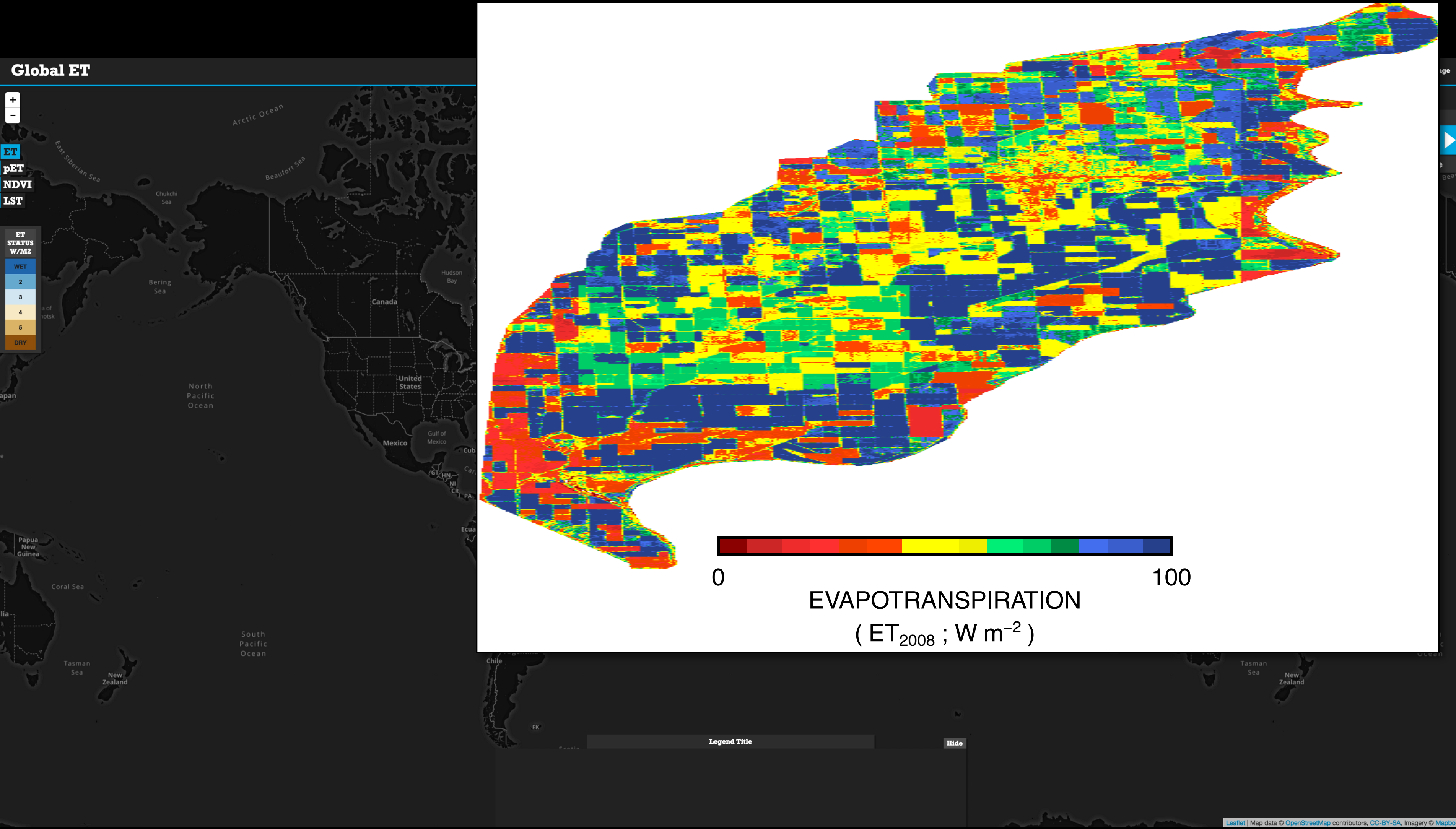

FLASH DROUGHTS


WEATHER


SURFACE DRYING/WETTING



Cavanaugh, K., Fisher, J.B., Lee, C., Perret, J., Kim, S., Comer, D., in prep. Analyzing Advantages of ECOSTRESS as a Tool for Drought Detection and Water Management Practices.



PT-JPL EVAPOTRANSPIRATION

Geosci. Model Dev. Discuss., 8, 6809–6866, 2015
www.geosci-model-dev-discuss.net/8/6809/2015/
doi:10.5194/gmdd-8-6809-2015

Geoscientific Model Development Discussions

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-

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.elsevie

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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]

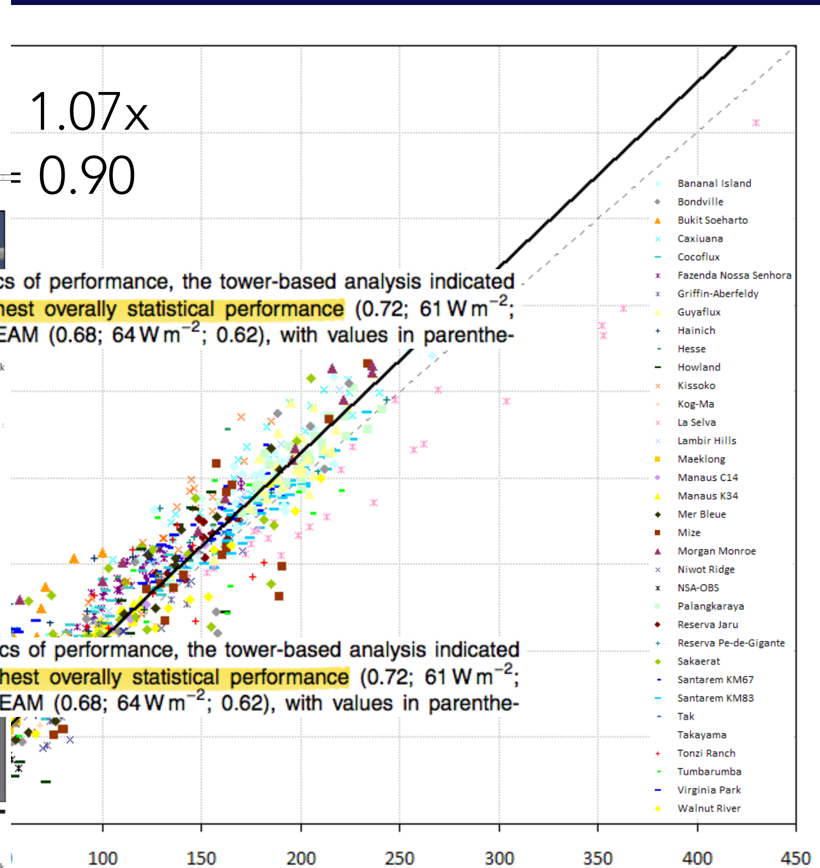
Remote Sensing of Environment 115 (2011) 801–823
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

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. Ferguso

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-

Remote Sensing of Environment 14
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse



Comparison of satellite-based evapotranspiration models over terrestrial ecosystems in China

Yang Chen[a,b], Jiangzhou Xia[a,b], Shunlin Liang[b,c], Jinming Fe
Shuguang Liu[g], Zhuguo Ma[d], Akira Miyata[h], Qiaozhen Mu[i]
Jun Wen[l], Yueju Xue[l], Guirui Yu[m], Tonggang Zha[n], Li Zhan
Liang Zhao[p], Wenping Yuan[a,q,*]

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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],
B. Martens[5], M.F. McCabe[7], J.B. Fisher[8], C
E.F. Wood[11], and D. Fernández-Prieto[12]

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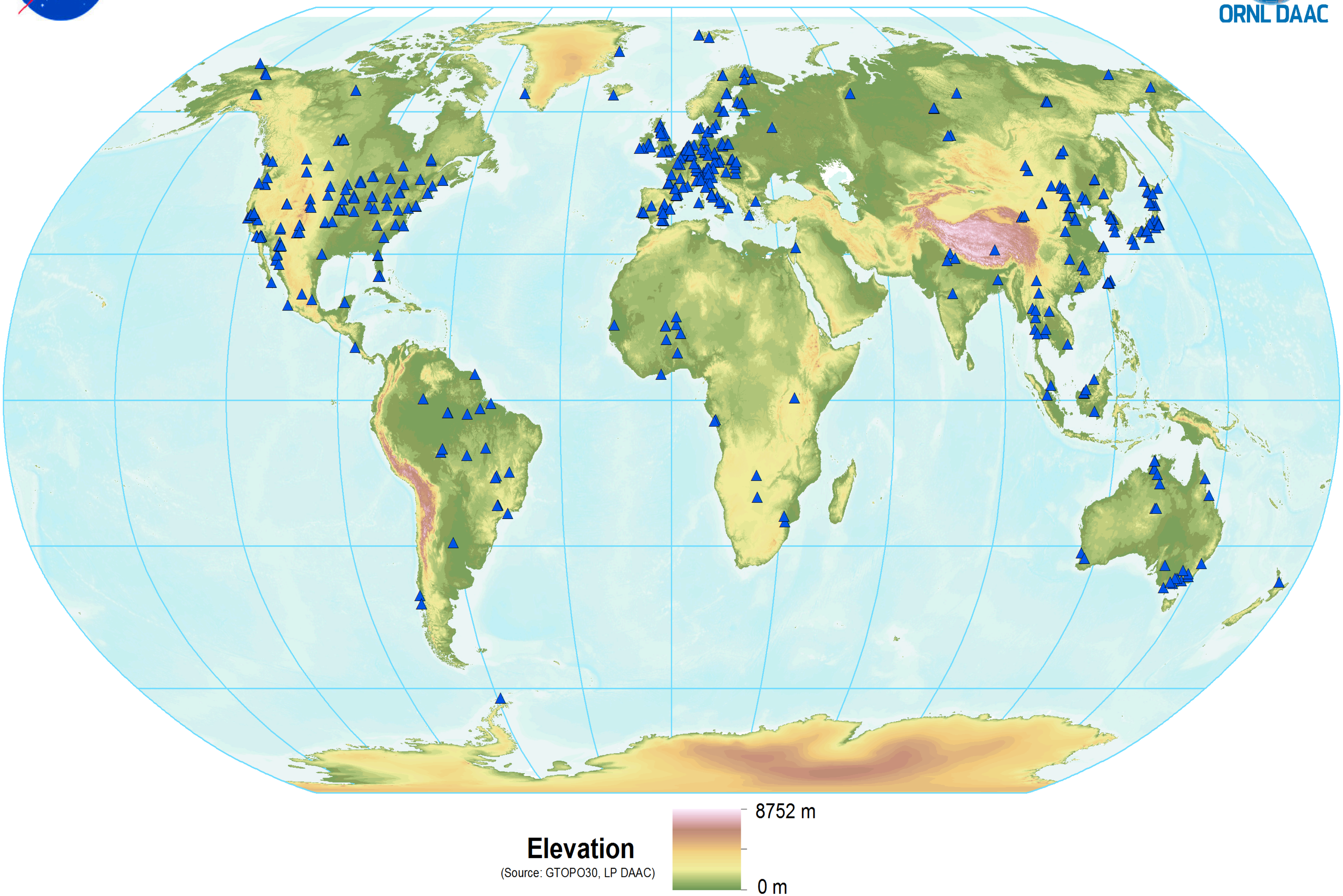
ET VALIDATION

FLUXNET
October 2015
517 Active Sites



PANELS

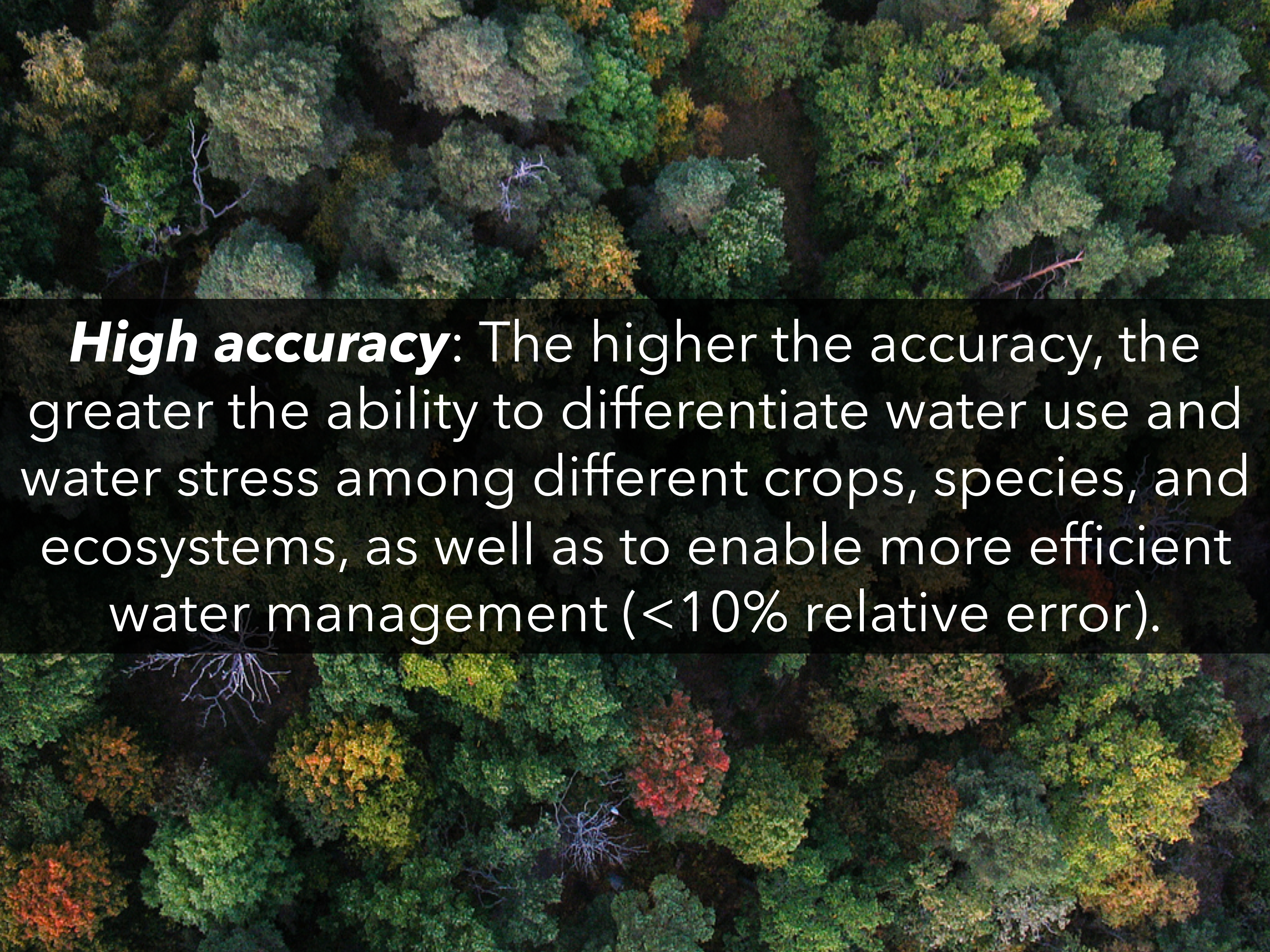
GROUPS

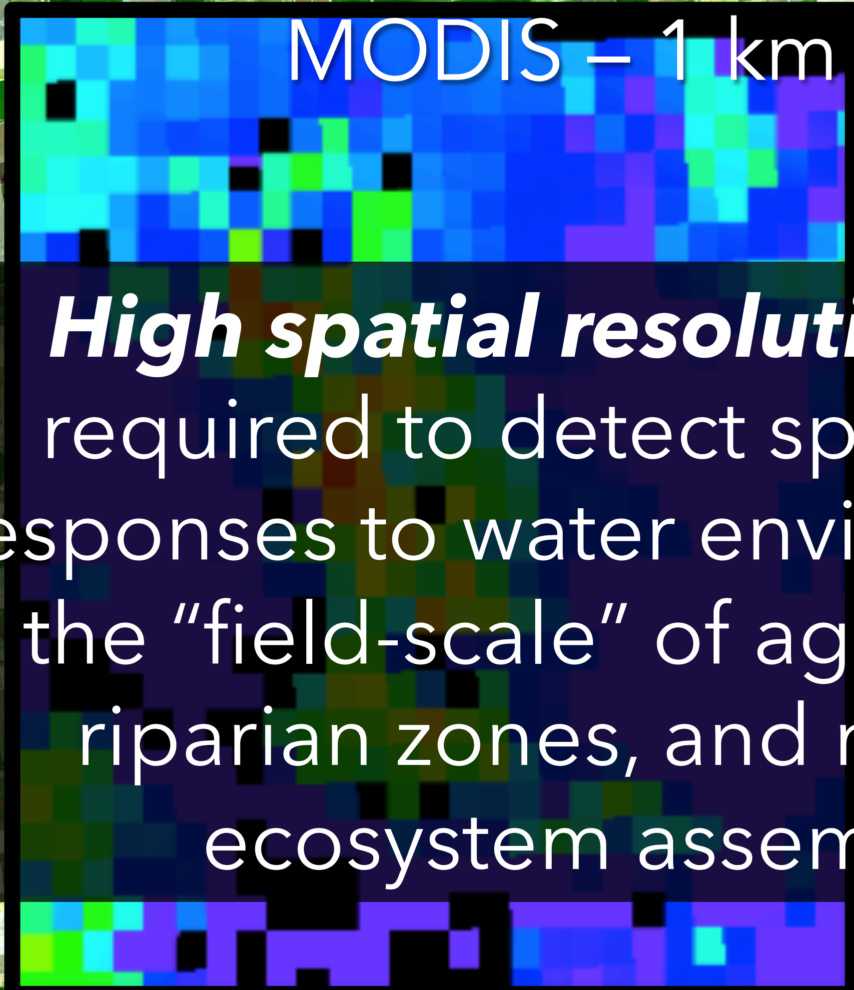
	ET relevance	I Weather: Minutes to Sub-seasonal	II Climate Variability & Change	III Marine & Terrestrial Ecosystems	IV Global Hydrological Cycle & Water Resources	V Earth Surface & Interior
A	Extreme Events					
B	Water Cycle					
C	Carbon Cycle					
	Technology & Innovations Cross-Cut					
	Applications'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

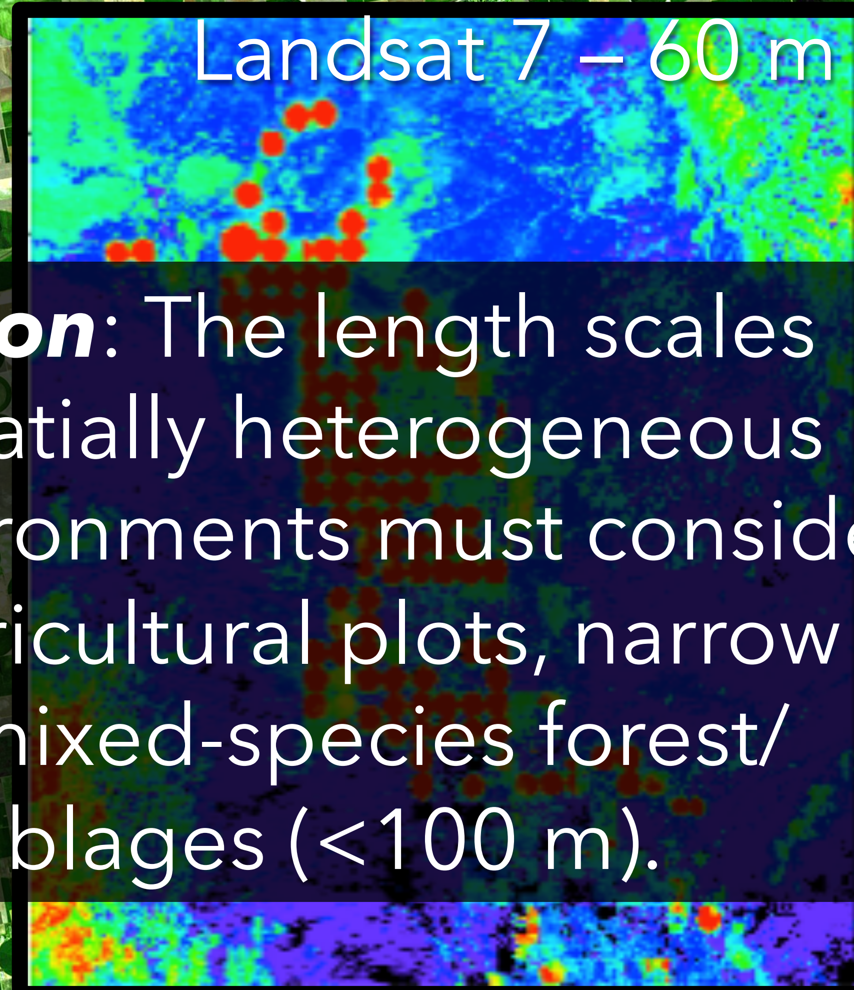
ence fostered by increased spatial and temporal resolution, as well as accuracy. As a product of the NRC Decadal Survey process, we identified and synthesized the principal outstanding knowledge gaps into ten research and applied science questions:

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?

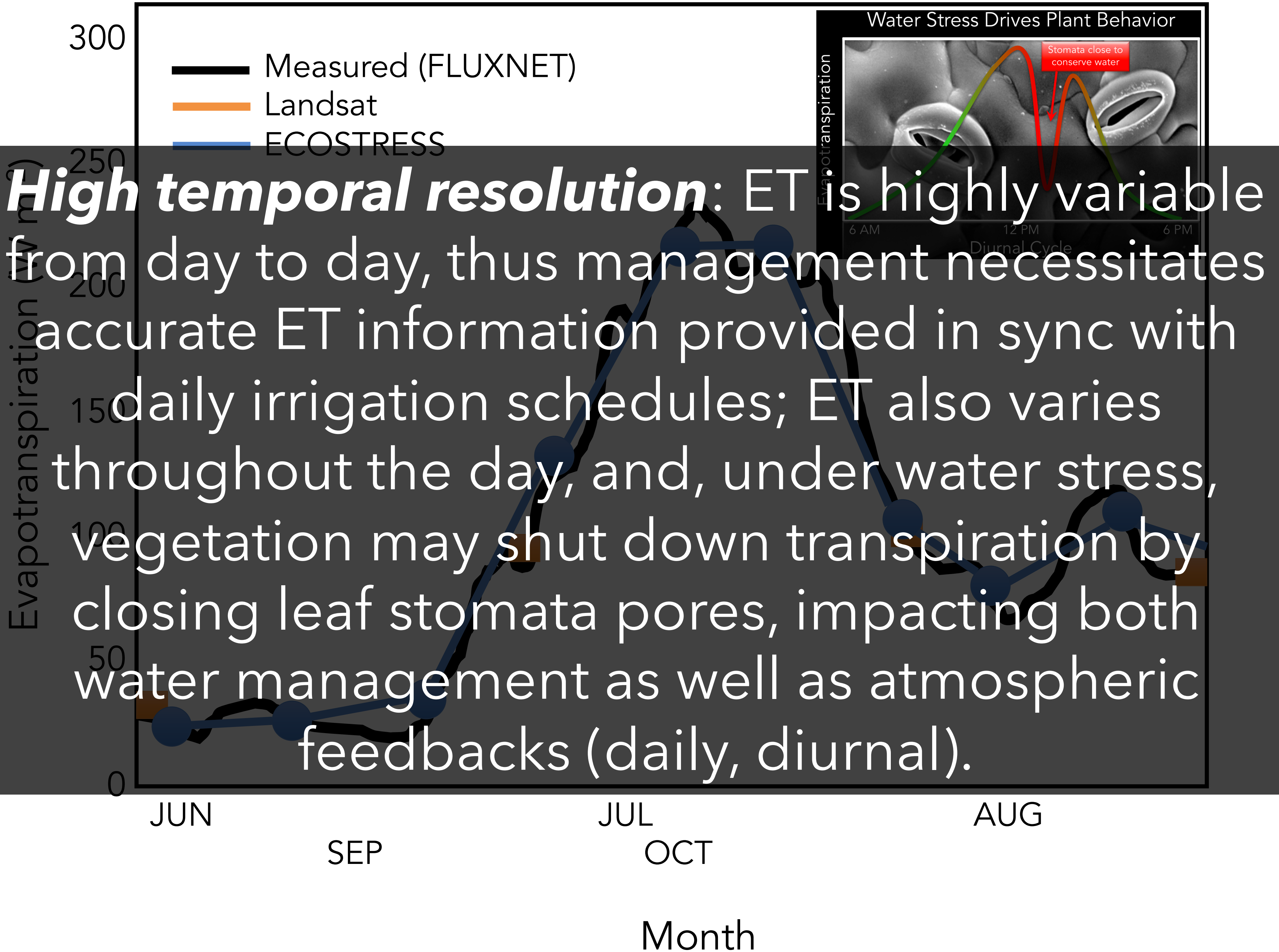

PATH FORWARD


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



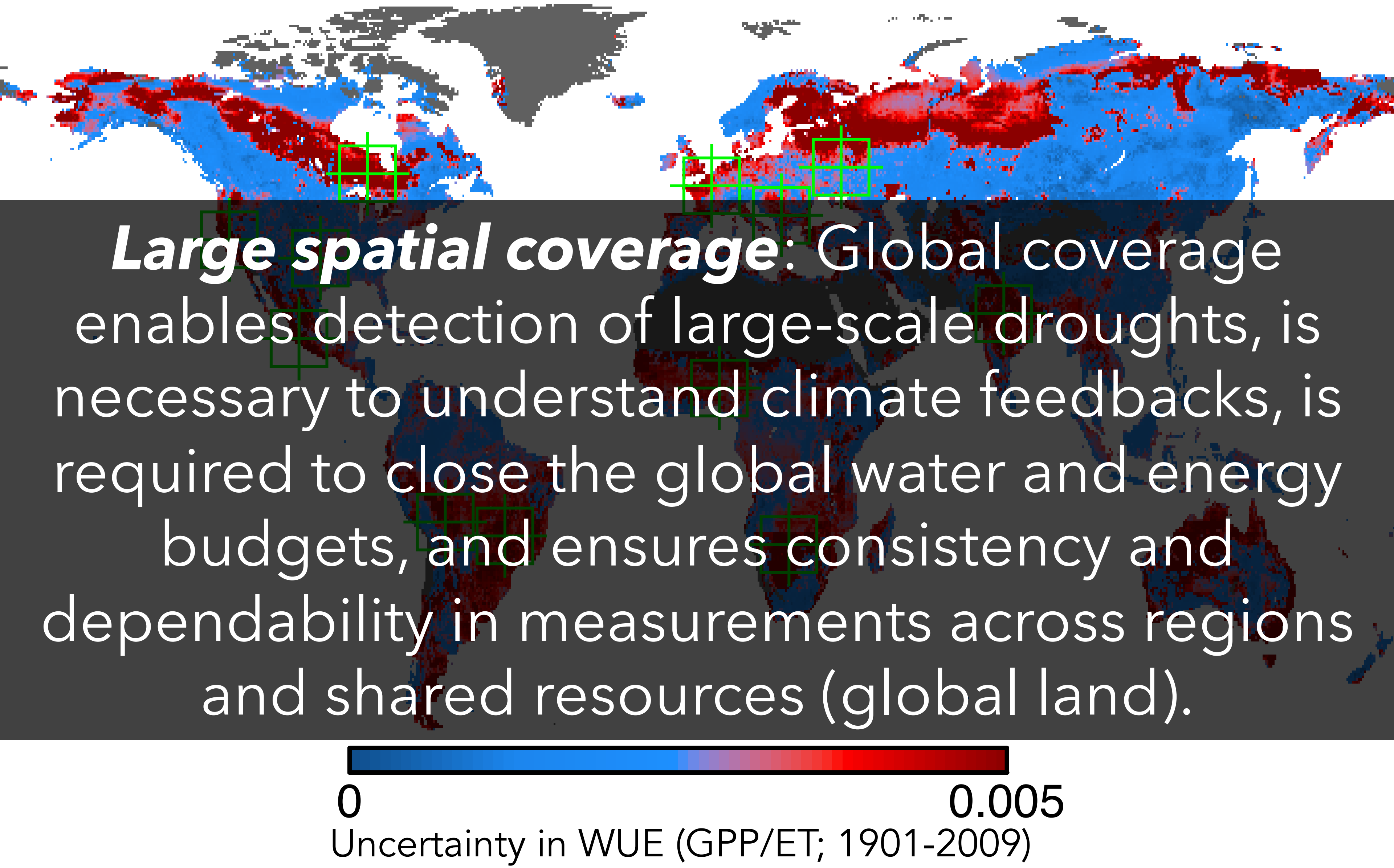


High spatial resolution: The length scales required to detect spatially heterogeneous responses to water environments must consider the “field-scale” of agricultural plots, narrow riparian zones, and mixed-species forest/ ecosystem assemblages (<100 m).

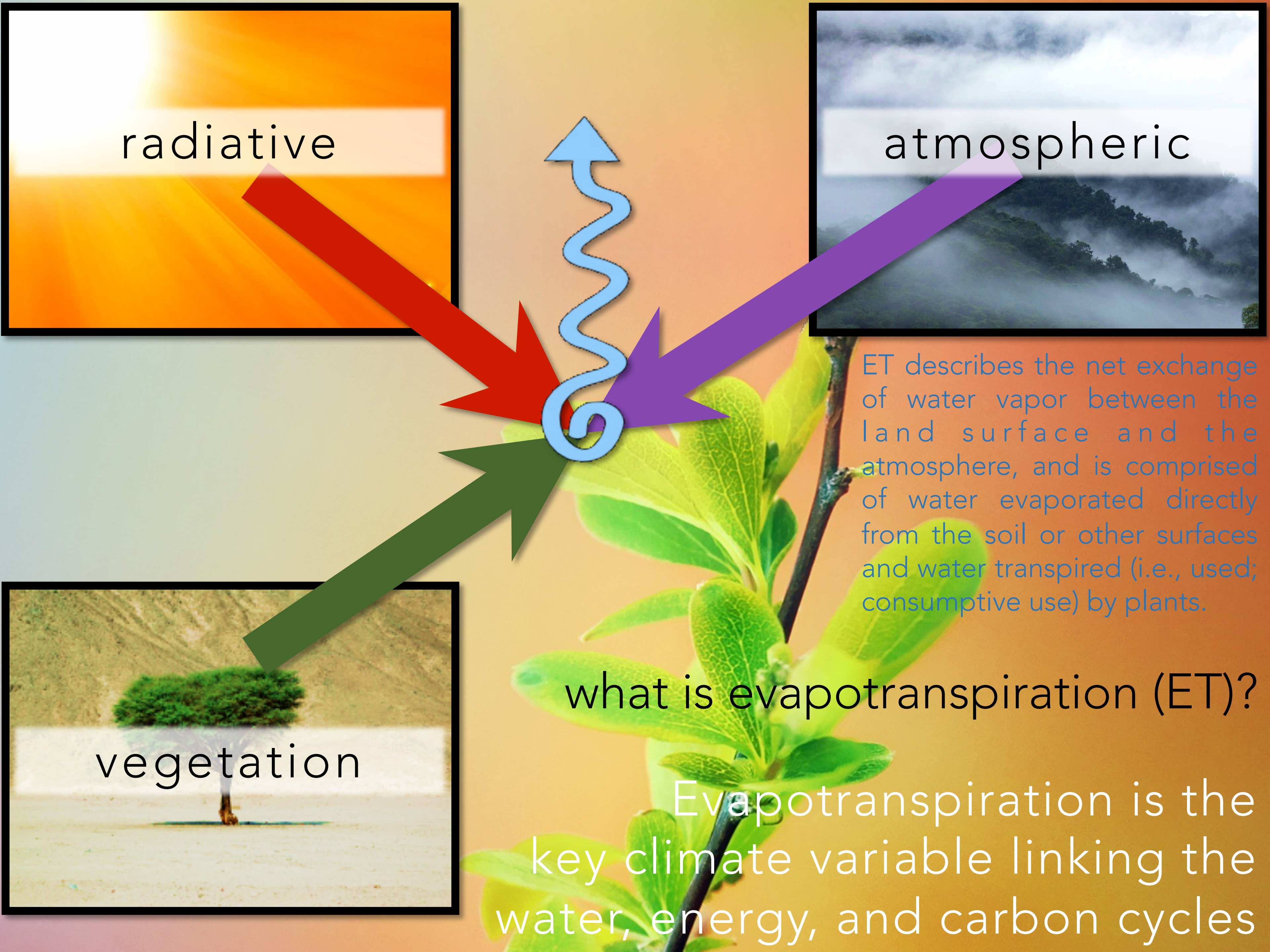


High temporal resolution: ET is highly variable from day to day, thus management necessitates accurate ET information provided in sync with daily irrigation schedules; ET also varies throughout the day, and, under water stress, vegetation may shut down transpiration by closing leaf stomata pores, impacting both water management as well as atmospheric feedbacks (daily, diurnal).

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).



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).


radiative
atmospheric
vegetation
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.
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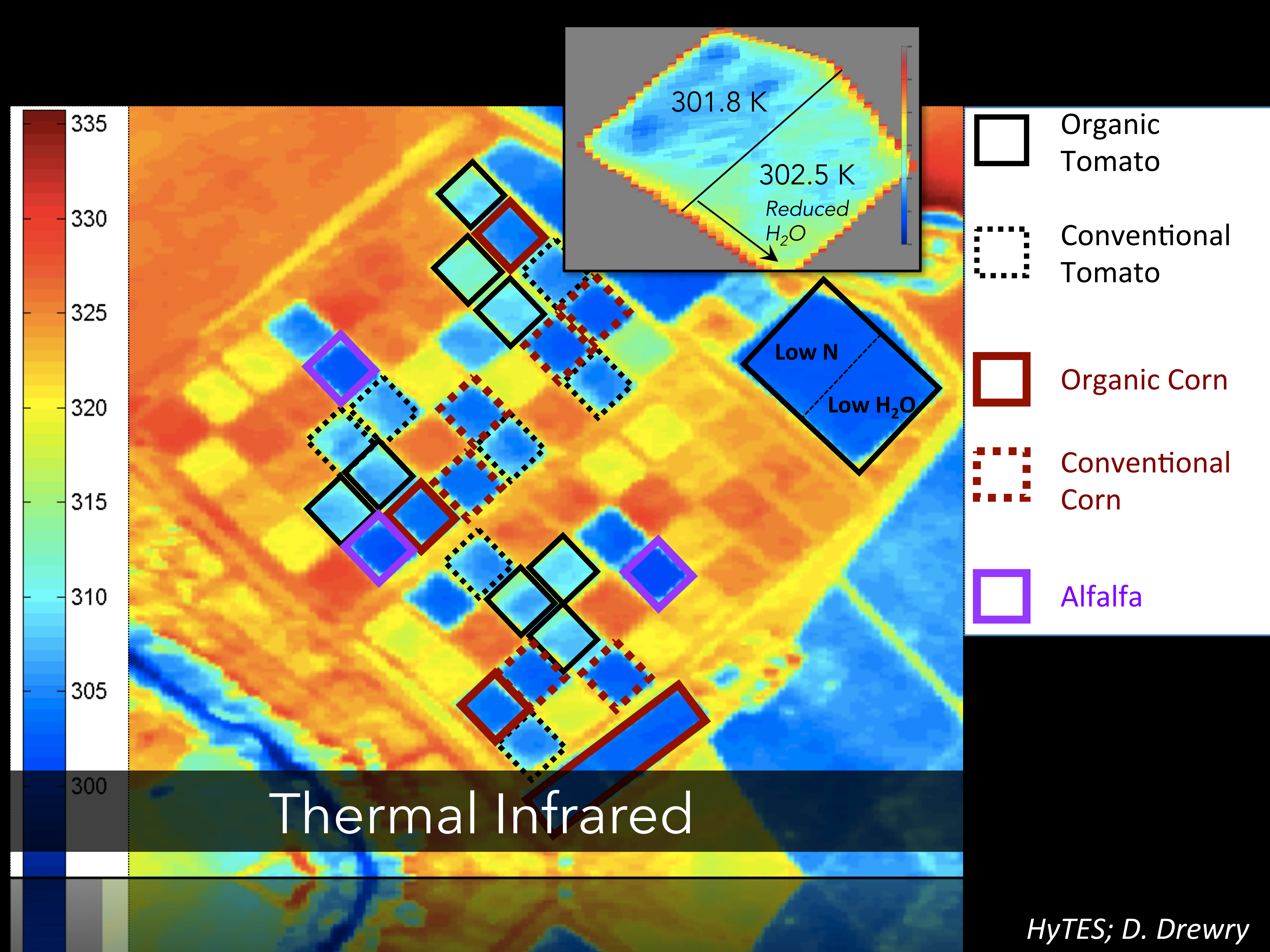
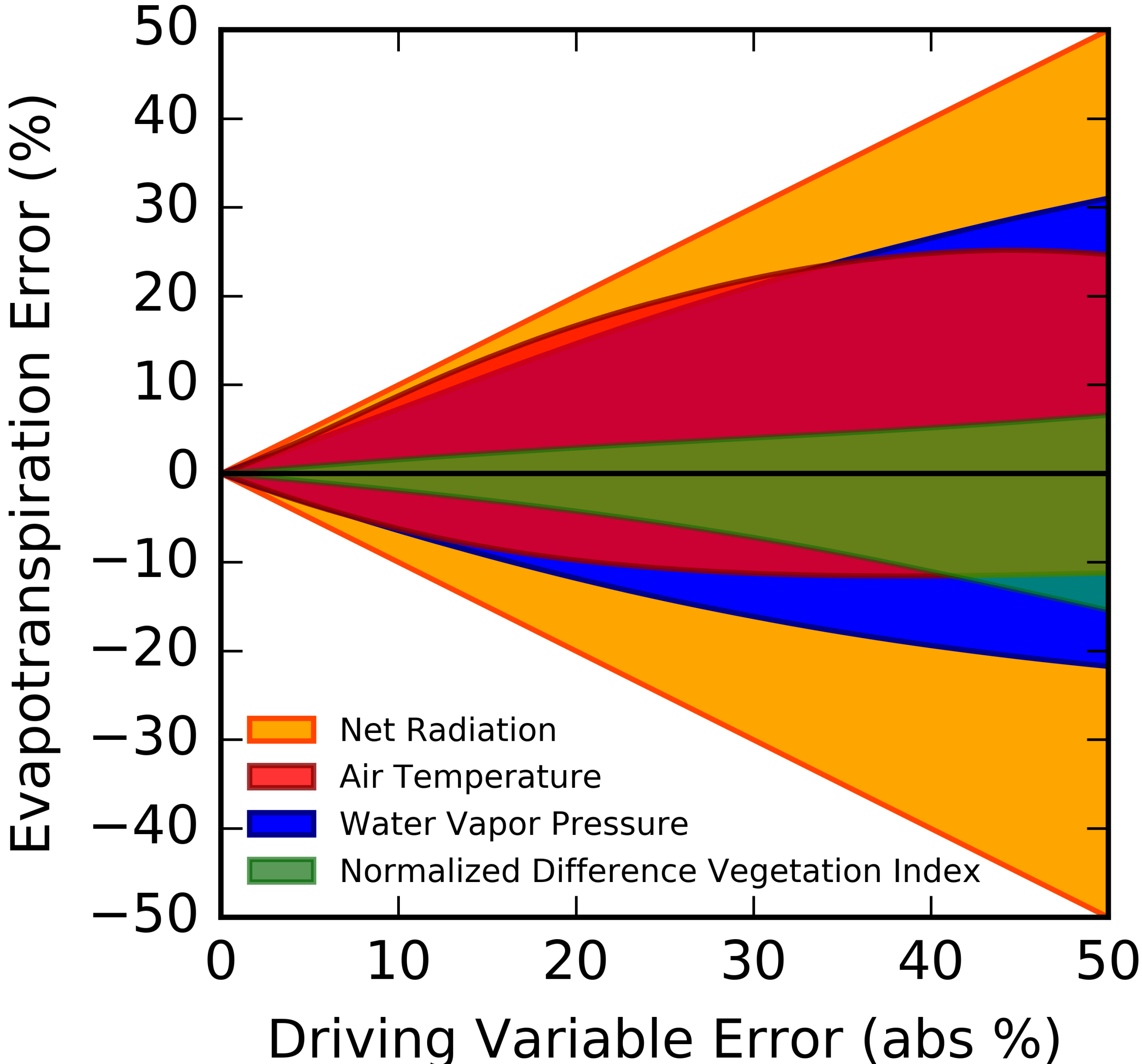


335
330
325
320
315
310
305
300
301.8 K
302.5 K
Reduced H_2O
Low N
Low H_2O
Organic Tomato
Conventional Tomato
Organic Corn
Conventional Corn
Alfalfa
Thermal Infrared
HyTES; D. Drewry



[global: PT-JPL]

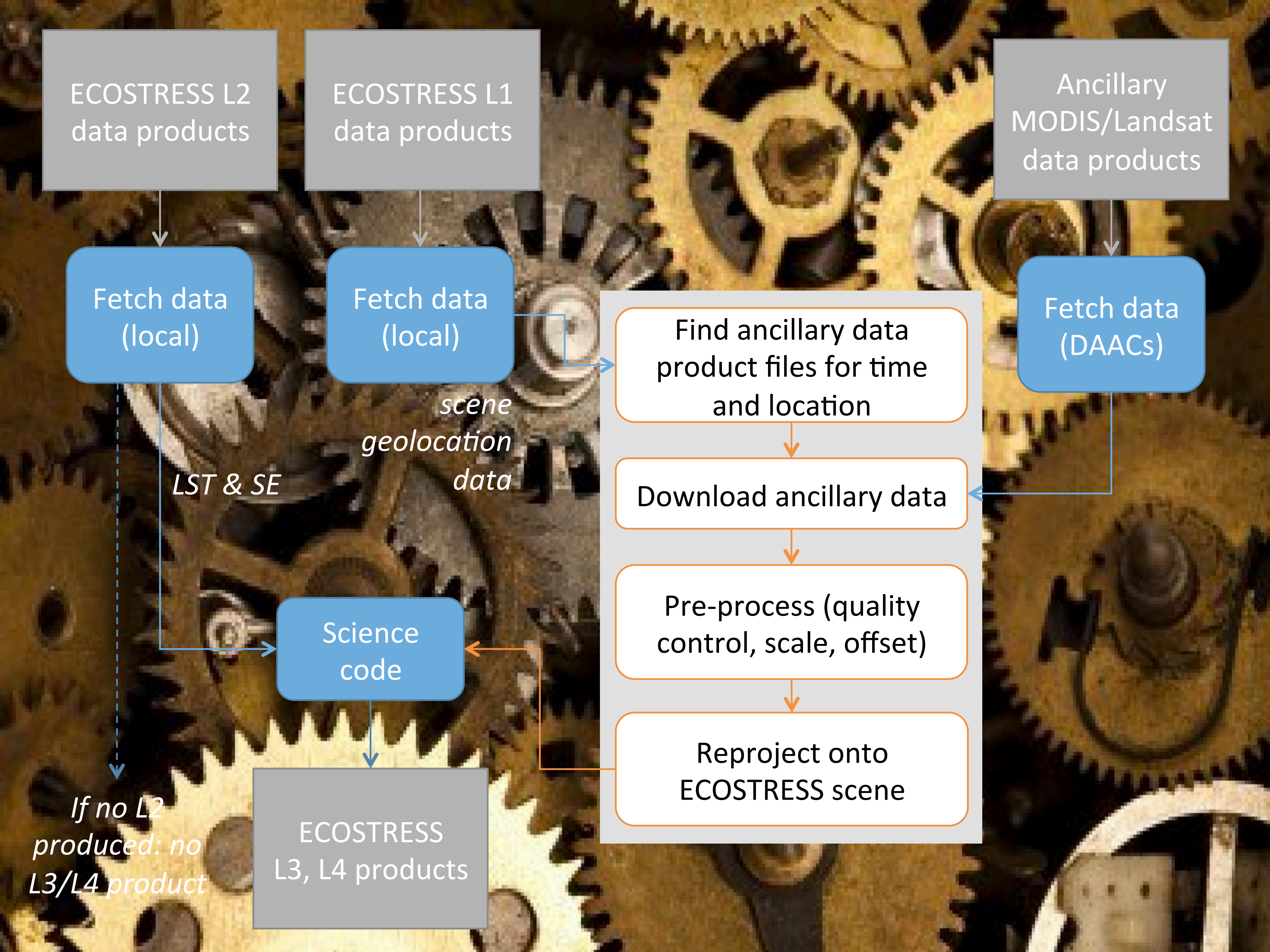
National Aeronautics and Space Administration

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov


SPACEX


ECOSTRESS L2 data products
ECOSTRESS L1 data products
Ancillary MODIS/Landsat data products
Fetch data (local)
Fetch data (local)
Fetch data (DAACs)
Find ancillary data product files for time and location
Download ancillary data
Pre-process (quality control, scale, offset)
Reproject onto ECOSTRESS scene
scene geolocation data
LST & SE
Science code
If no L2 produced: no L3/L4 product
ECOSTRESS L3, L4 products

ECOSTRESS cal/val

Joshua B. Fisher (Science Lead), Simon Hook (PI), Glynn Hulley

JPL D-XXXX 9 June 2016
Initial

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS)

Level 2-4 Calibration and Validation Plan

Part of the Project Implementation Plan (PIP)
Section 02.08 - Project Verification and Validation Plan

9 June 2016
Initial

Prepared by:

E. Natasha Stavros — Date: 15 June 2016
Jet Propulsion Laboratory, California Institute of Technology

Co-authors:
Joshua B. Fisher (Jet Propulsion Laboratory, California Institute of Technology)
Glynn Hulley (Jet Propulsion Laboratory, California Institute of Technology)
Roel Rodriguez (California Institute of Technology)
Audrey Wang (California Institute of Technology)
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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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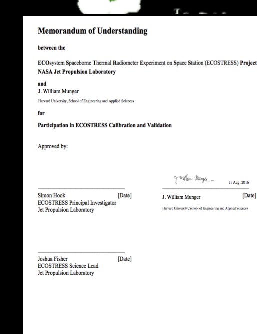
Page 1 of 33

L2(LSTE)	**LAND SURFACE TEMPERATURE**	*LW*$_U$
L3(ET_PT-JPL) L3(ET_ALEXI)	**EVAPOTRANSPIRATION**	*LE*
L4(WUE)	**WATER USE EFFICIENCY**	*LE/GPP*

n=~90



Memorandum of Understanding

between the

ECOsystem **S**paceborne **T**hermal **R**adiometer **E**xperiment on **S**pace **S**tation (ECOSTRESS) **Project**
NASA Jet Propulsion Laboratory

and
J. William Munger
Harvard University, School of Engineering and Applied Sciences

for

Participation in ECOSTRESS Calibration and Validation

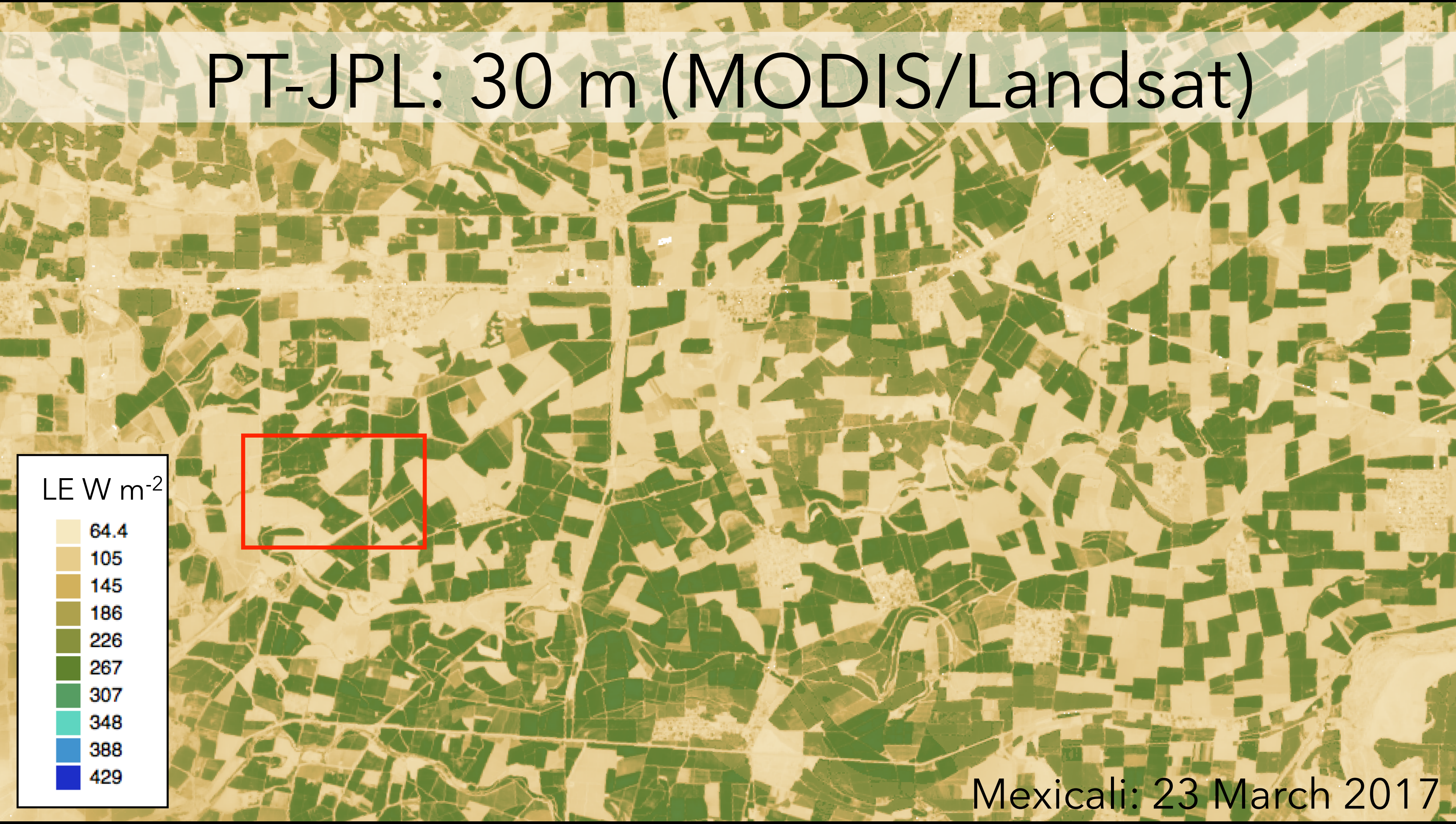
Approved by:

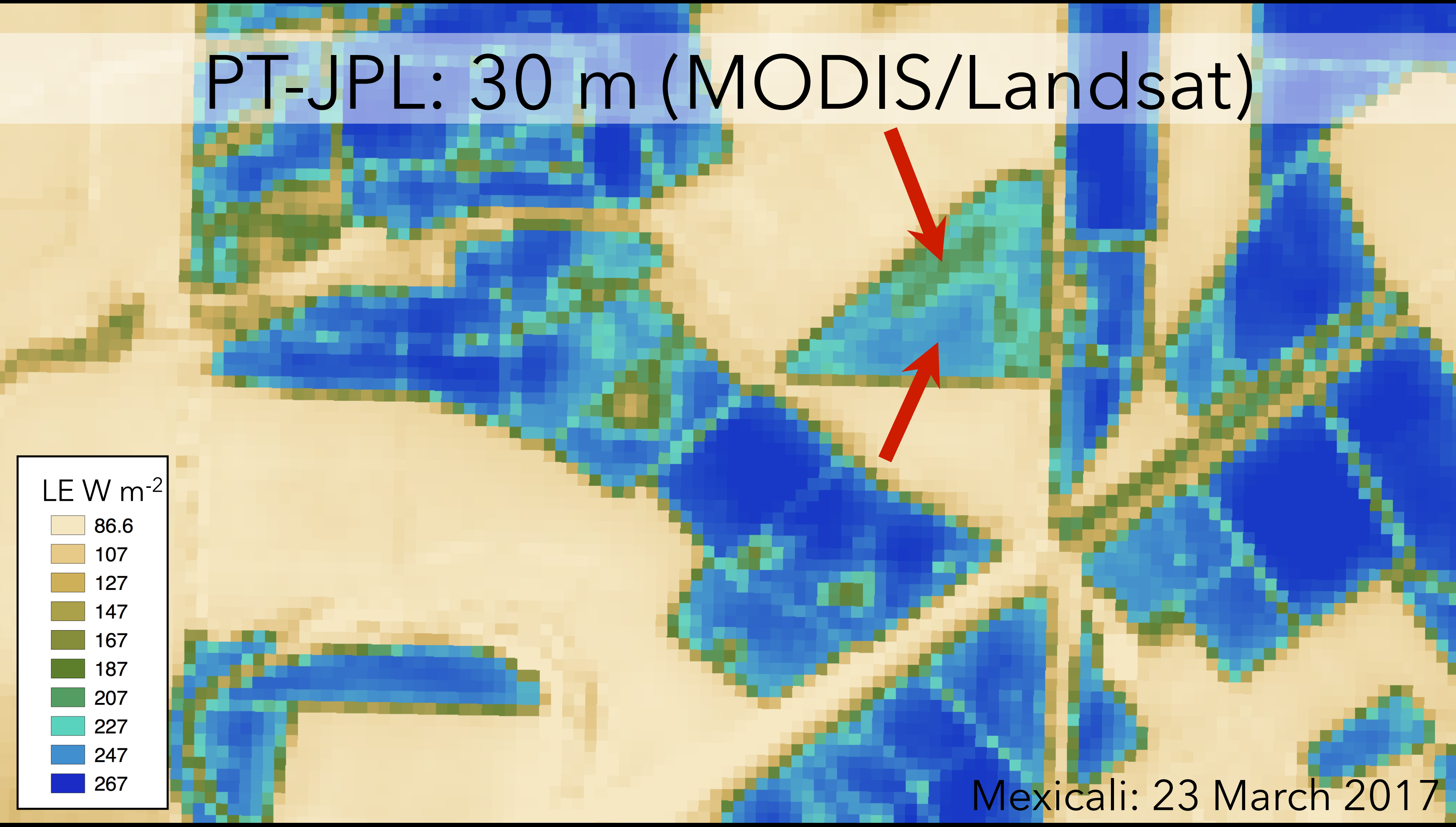
Simon Hook [Date]
ECOSTRESS Principal Investigator
Jet Propulsion Laboratory

J. William Munger [Date] 11 Aug. 2016
Harvard University, School of Engineering and Applied Sciences

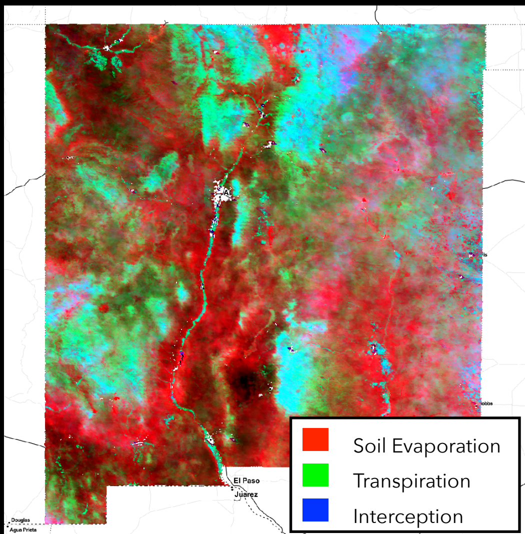
Joshua Fisher [Date]
ECOSTRESS Science Lead
Jet Propulsion Laboratory

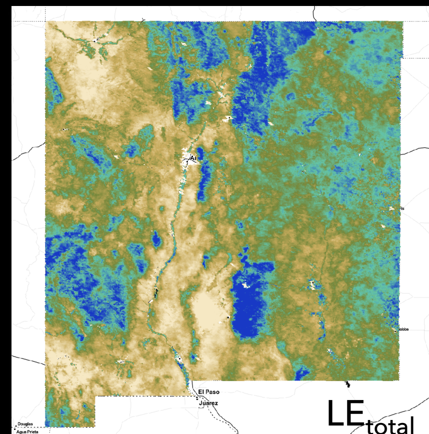
PT-JPL: 30 m (MODIS/Landsat)

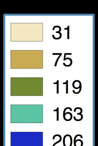


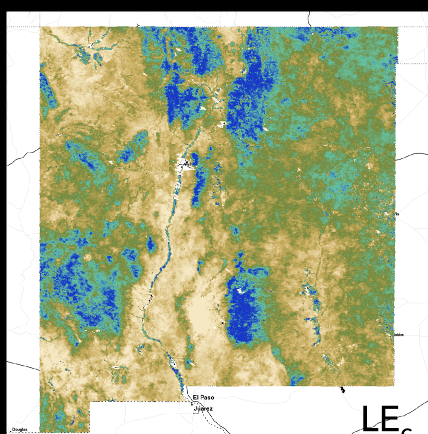

PT-JPL: 30 m (MODIS/Landsat)
LE W m-2
86.6
107
127
147
167
187
207
227
247
267
Mexicali: 23 March 2017

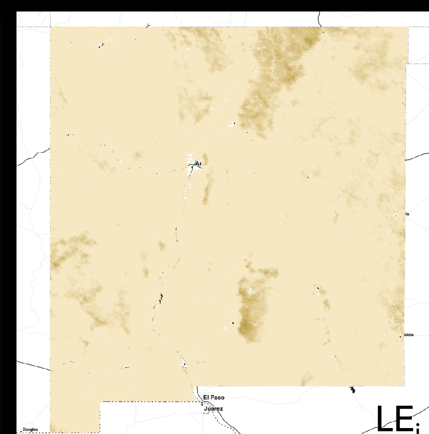
ET Partitioning

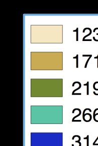




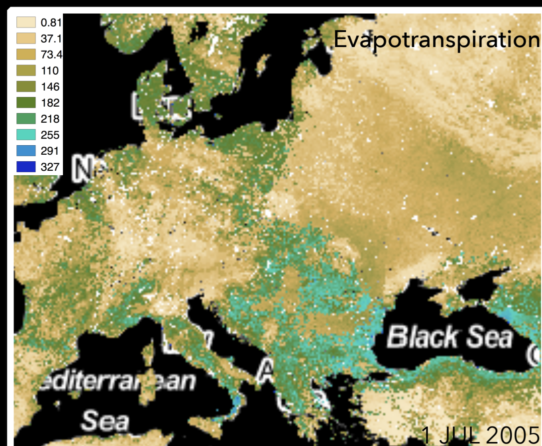


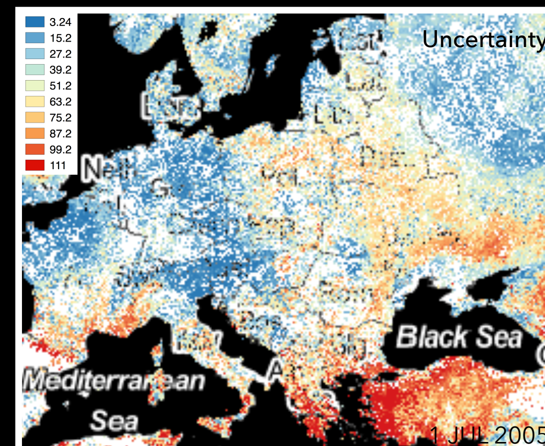


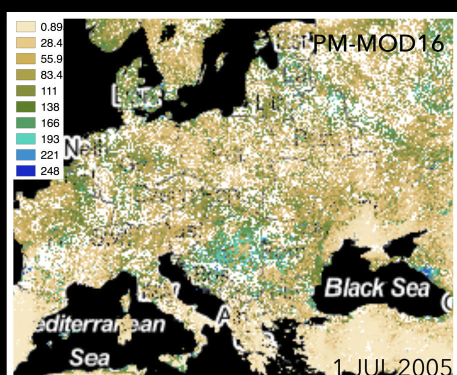


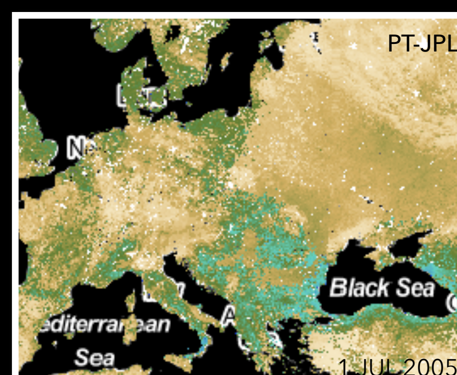


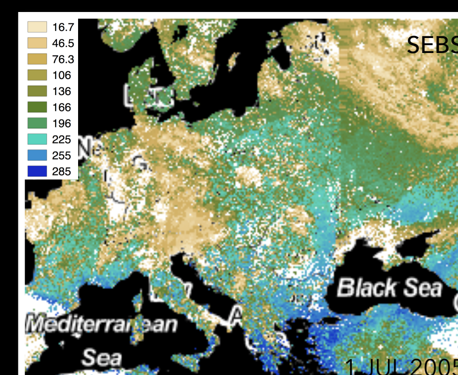
ET Uncertainty





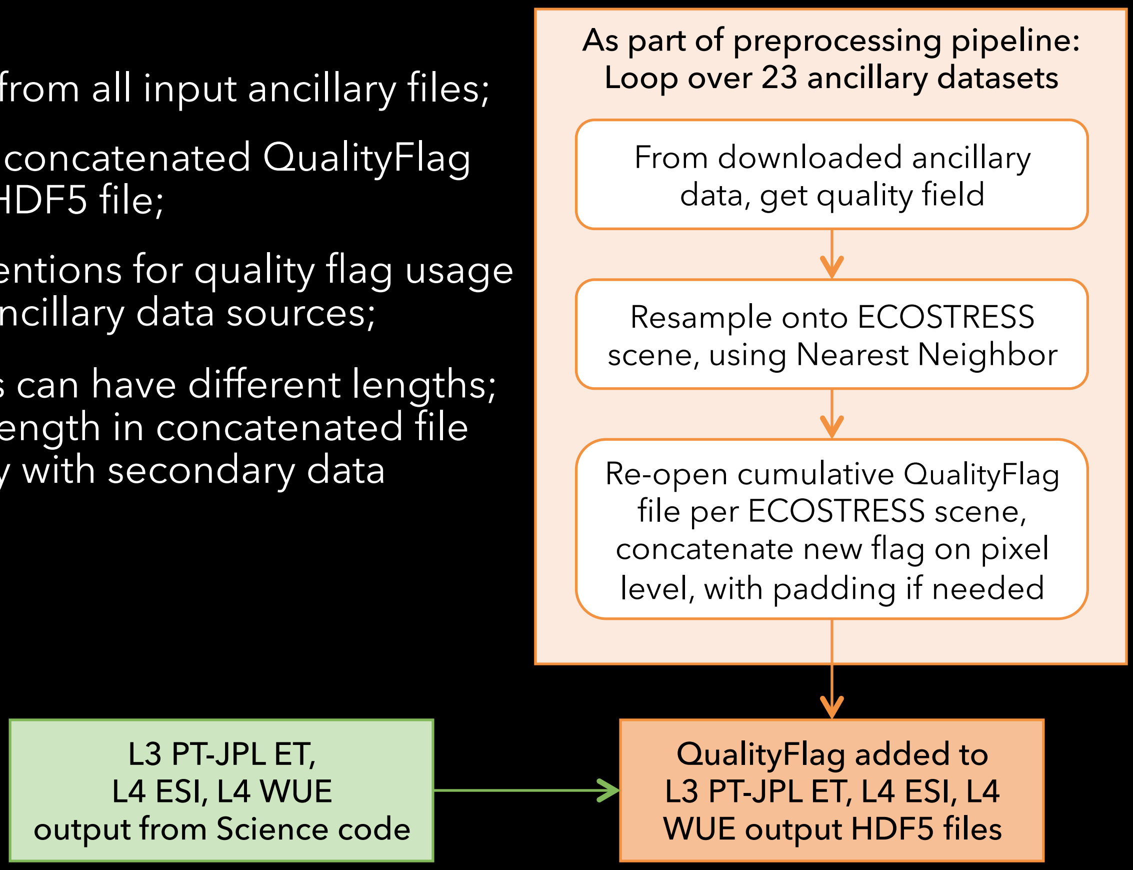




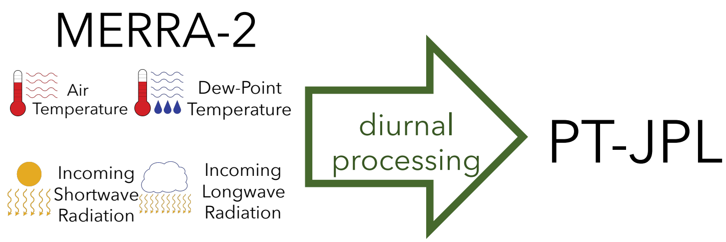


Quality Flags

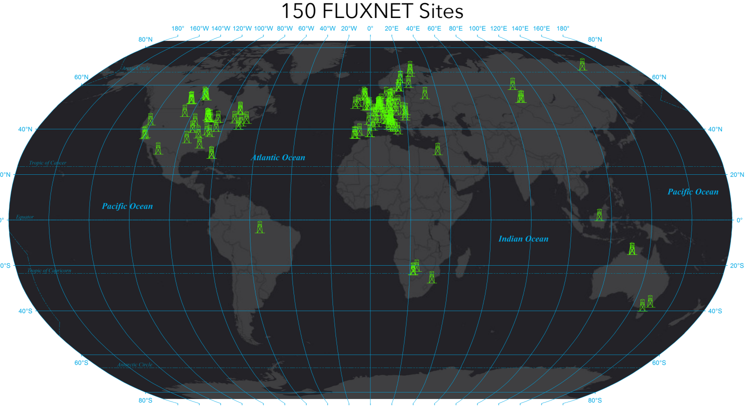
- Collect quality flags from all input ancillary files;
- Place in pixel-based concatenated QualityFlag data field in output HDF5 file;
- Retain original conventions for quality flag usage and meaning from ancillary data sources;
- Original quality flags can have different lengths; padded to uniform length in concatenated file (ensure compatibility with secondary data sources).

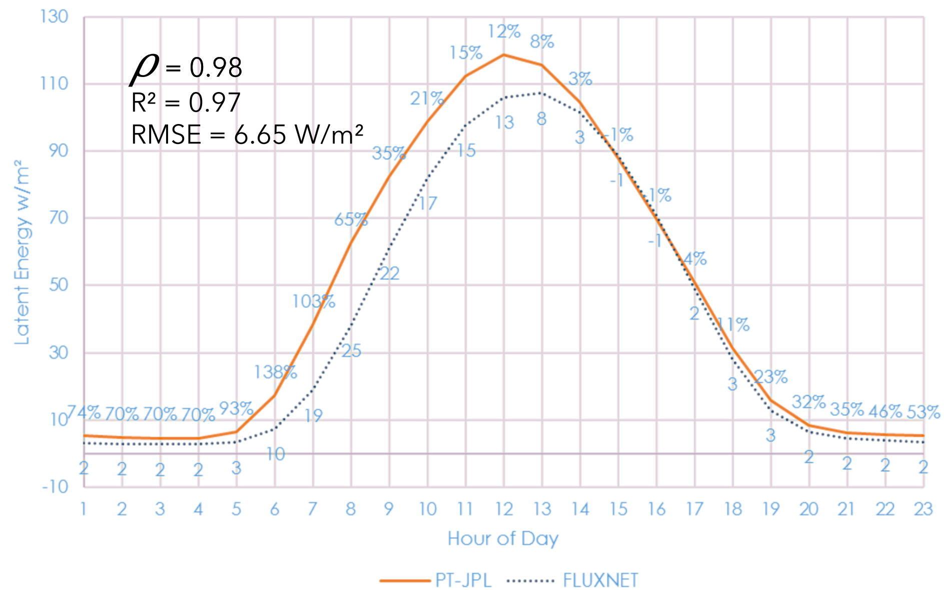


Diurnal Testing



150 FLUXNET Sites





PT-JPL ET using MODIS and MERRA2 compared to La Thuile FLUXNET aggregated by hour at all sites with absolute and percentage bias

ECOSTRESS:

A technology that will help us understand how plants react to our changing planet

BROWN

Olivia Mansion

ET Spaceborne Measurements Requirements

Parameters	Minimal	Optimum	Landsat 8	MODIS	HyspIRI*	ECOSTRESS
Return Cycle (days)	≤8	≤4	16	1	5	3-5
Number of TIR bands	1	>2	2	3	8	5
Spatial resolution (m)	120	30	100	1000	60	38x57
Coverage	US always on	World always on	US always on	World always on	World always on	World always on+

Source: Letter to Anne Castle on "Water Resources Needs" dated November 22, 2011, R. Allen, U. Idaho, referencing Allen 2010, Allen et al 2011.

** Proposed mission >2023.*

The Future of Evapotranspiration

- ET science and applications have significantly advanced across a wide array of fields over the past few decades;
- Critical outstanding ET-based science and application questions remain from local to global scales due to deficiencies in our observational capabilities;
- National and international public policies need to prioritize ET-focused investments and programs.