



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

Joshua B. Fisher¹ , Forrest Melton², Elizabeth Middleton³, Christopher Hain^{4,5}, Martha Anderson⁶, Richard Allen⁷, Matthew F. McCabe⁸, Simon Hook¹, Dennis Baldocchi⁹, Philip A. Townsend¹⁰, Ayse Kilic¹¹, Kevin Tu¹², Diego D. Miralles¹³, Johan Perret¹⁴, Jean-Pierre Lagouarde¹⁵, Duane Waliser¹, Adam J. Purdy¹, Andrew French¹⁶, David Schimel¹, James S. Famiglietti¹, Graeme Stephens¹, and Eric F. Wood¹⁷

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THE FUTURE OF

RANSPIRATIO

National Aeronautics and Space Administration

Jet Propulsion Laboratory

California Institute of Technology

Pasadena, California agricultural management, and water resources.





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







Climate-induced boreal forest change: Predictions versus current observations

Amber J. Soja a,*, Nadezda M. Tchebakova b, Nancy H.F. French c Michael D. Flannigan d, Herman H.



E I Parfenova^b F Sta

* National Institute of Ae 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 Licens



Rec

Abstract

For about three decades, there have been esponse to changes in rights reserved.

Keywords: climate change evidence; fire; infestation

Corresponding author. Tel.: +1 757 864 5603; fax: E-mail address: a.j.soja(jelar: nasa.gov (A.J. Soja). 921-8181/S - see front matter © 2006 Elsevier B.V. foi 10.10365 elsevier 2006.07.078



Correspondence to: L. N. Yurganos



Satellite- and ground-based CO total column observations over 2010 Russian fires: accuracy of top-down estimates based on thermal IR satellite data

L. N. Yurganov¹, V. Rakitin², A. Dzhola², T. August¹, E. Fokceva², M. George⁴, G. Gorchakov², E. Grechko², S. Hannon¹, A. Karpov², L. Ott⁵, E. Sennutnikova⁶, R. Shumsky², and L. Strow¹

¹ Louris, J. C. M. P. J. C. W. F. Somminović, R. Shuma, Joint Center for Earth Systems Technology, University of Me ²Onekokov Institute of Atomospheric Physics, Moscow, Russia ³ELMETSAT, Journada, Germanya ⁴UPMC, Univ. Paris 06, Univ. Versailles St. Quentin, CNRS/I ⁵NASA, Coddaid Space Flight Center, Greenbelt, MD, USA ⁶Moscocomotioning, Moscow, Russia Vol 452/24 April 2003/doi:10.3038 Received: 18 March 2011 - Published in Atmos. Chem. Phr

Revised: 22 July 2011 - Accepted: 1 August 2011 - Public Abstract. CO total column data are presented from the

Abstract. CO total column data are presented from there are consider and tree promb-based spectrometers in Maccours and its solution having the forms and pert three discourses of a constraint having the forms and pert three discourses of a constraint having the discourse of the column based on the second spectra of the column based solution for the free. Concurrent multilities and promoth based observ-tions over used to quantify the errors of CD top doos non-tions that the second spectra of the perturbation of the second spectra of the second spectra of the perturbation of the second spectra of the second spectra of the perturbation of the second spectra of the perturbation of the spectra of the perturbation spectra of the perturbation of the spectra of the perturbation with CD values multility attains in the entire layer and non-tra of the second spectra of the particular layer and the spectra of the sp with CO volume mixing ratio in the surface layer and on the TV stores and found to be around 390 m. The mixing CO that is the average difference between the CO studio clonum accountely detormined by the ground approximation and an interaction of the star of the transmission of the tra

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LETTERS

Mountain pine beetle and forest carbon feedback to climate change

W. A. Kurz¹, C. C. Dymond¹, G. Stinson¹, G. J. Rampley¹, E. T. Neilson¹, A. L. Carroll¹, T. Ebata² & L. Safranyik¹

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Drought Sensitivity

in forests are a key but poorly understood component of the pated, they dry this century, they might acculerate climate du-ped surface energy balances. We used necesds from multiple is main to assess forest responses to the intense 2005 drought a bid forest lost biomasc, revensing a large long-term carbon sits well where the dy sociaon was unsurally intense. Relative to pri-red where the dy sociaon was unsurally intense. Relative to prigrams, Amazon losses to exert feedback on climate chan

tially affect the concen-ic CO2 and thus the rate e change itself. A key parameter in cause Amaze ng the magnitude of this effect is the that increase —or resilience—of tropical forests periods boo ¹Eology and Global Damps, School of Geography, University of Lends, Lends US2 997, UK. ²Environment, Oxford Dimensity, Gr. School of Geography and Environment, Oxford Dimensity, Gr. utol COII 2074, ⁽¹⁾, ²Sandin Belainion de Missouri, Ossapema, at Oxford Oxford Dimension, Companya, at 2012 Tacklass, Fo 147, Song Jaka Sandarada di Yamana (Kabapanja, Yantha Kasada da Pengahan an Amazaha A. Janga 1753 (P 478, 69060-011 Manaus AM, Brasti, Yanama Emilio Goold, Ar. Perinstat, 2001 Teru P. 64077-4010 Belleri PA. Farshall. "Stockal Collago 1990 Statustica Sandara (Kabapan) Sandara (Kabapan) "Dapatamento P. 64077-4010 Belleri PA. Farshall Sandara Sandara (Kabapan) Sandara (Kabapan) "Dapatamento Nacional Sandara "Dapatamento Nacional Sandara "Sandara (Kabapan) "Sandara nd Monitoring Network (TEAM), Conservation 2011 Crystal Drive, Saite 500, Arlington, VA 22222, USA. ¹Museo de Historia Natural Nosi Kiengell Mercado, Castila XMID, A.: Insis 555, Santa Cruz, Boltva. ¹Missouri Bo-tenical Gardier, Box 299, S2.: Louis, MD Galdade, USA. ¹Programa de Ciencias del Agro y del Mar, Werbarlo Universitario (FORT). Brity Moore R: 94129, USA.³ --processingut pair
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6 MARCH 2009 VOL

surge-state on-me-ground assessments of the ecological impacts of topical doughts are com-pletely lacking, precluding tosts of these ideas. In 2005, large areas of the Amaren Basin reperienced one of the most intense droughts of the past 100 years (1/8), providing a unique sportmity to directly evaluate the large-scale matrixing and the state of the sta

The 2010 Amazon Drought Simon L. Lewis,¹⁺† Paulo M. Brando,^{2,1+} Oliver L. Phillips,¹ Geertje M. F. van der Heijden,⁴ Daniel Nepstad²



Fig. 1. (A and B) Satelli

4 FEBRUARY 2011 VOL 331 SCIENCE www.s

mitted carbon flux from

and years (~1.4 Pg C aff

SCIENTIFIC REPORTS

OPEN Record-breaking warming and extreme drought in the Amazon rainforest during the course of El Niño 2015–2016

Juan C. Jiménez-Muñoz¹, Cristian Mattar², Jonathan Barichivich^{1,4,1,4}, Andrés Santamaria Artigas², Ken Takahashi², Yadvinder Malhi², José A. Sobrino¹ & Gerard van der Schrier⁴⁰

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Current US drought prediction capabilities <u>failed</u> to predict the intensity and magnitude of the 2012 US Midwest drought





Remote Sensing of Environment.

TOTAL TERRESTRIAL RAINFALL 98.5 x 10³ κm³ γ¹

1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

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> TOTAL TERRESTRIAL EVAPOTRAN SPIRATION 65.5 x 10³ κm³ γ¹

> **TOTAL TERRESTRIAL EVAPOTRANSPIRATION**

65.5

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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



- Tropical and Subtropical Moist BroadleafForests
- Temperate Broadleaf and Mixed Forests
- Temperate Grasslands, Savannas, and Shrublands
- Montane Grasslands and Shrublands

- Tropical and Subtropical Dry Broadleaf Forests
- Tropical and Subtropical Grasslands, Savannas, and Shrublands
- Flooded Grasslands and Savannas
- Mediterranean Forests, Woodlands, and Shrubs

BIODIVERSITY



FLASH DROUGHTS



SURFACE DRYING/WETTING

a) 2013 anomalies:



b) 2014 anomalies:



c) 2015 anomalies:



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 © Author(s) 2015. CC Attribution 3.0 License.



this discussion paper is/has been under review for Development (GMD). Please refer to the correspond 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 1.07x M. F. McCabe¹, A. Ershadi¹, C. Jimenez², D. G. Miralles³, D. Michel⁴, and E. F. Wood⁴ r = 0.90Bananal Island gricultural and Forest Meteorology 187 (2014) Bondville Contents lists available at ScienceDirect Bukit Soehart Caxiuana Agricultural and Forest Meteorology Cocoflux stations as independent metrics of performance, the tower-based analysis indicated iournal homepage: www.elsevir 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-Hainich 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 Contents lists available at ScienceDirect Remote Sensing of Environment journal homepage: www.elsevier.com/locate/rs/ Morgan Monro Niwot Ridge NSA-OBS Global estimates of evapotranspiration for climate studies using multi-sensor remote Palangkaraya sensing data: Evaluation of three process-based approaches Raghuveer K. Vinukollu **, Eric F. Wood *, Craig R. Ferguso stations as independent metrics of performance, the tower-based analysis indicated Sakaerat that PT-JPL provided the highest overally statistical performance (0.72; 61 W m⁻²; Santarem KM6 0.65), followed closely by GLEAM (0.68; 64 W m⁻²; 0.62), with values in parenthe-Contents lists available at ScienceDirect **Remote Sensing of Environment** Tonzi Ranch Tumbarumb Virginia Park iournal homepage; www.elsevier.com/locate/rse Walnut River 100 150 200 250 300 350 400 450 Comparison of satellite-based evapotranspiration models over terrestrial ecosystems in China stations as independent metrics of performance, the tower-based analysis indicated Yang Chen ^{ab}, Jiangzhou Xia^{ab}, Shunlin Liang ^{bc}, Jinming ^{Fe} that PT-JPL provided the highest overally statistical performance (0.72; 61 W m⁻²; Shuguang Liu^g, Zhuguo Ma^d, Akira Miyata^h, Ojaozhen Mu[†] that PT-JPL provided the highest overally statistical performance (0.72; 61 W m⁻²;



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

Liang Zhao ^p, Wenping Yuan ^{a,q,a}

tations as independent metrics of performance, the tower-based analysis indicated D. Michel¹, C. Jiménez^{2,3}, D.M. Miralles^{4,5} that **PT-JPL** provided the highest overally statistical performance (0.72; 61 W m⁻²; B. Martens⁵, M.F. McCabe⁷, J.B. Fisher⁸, C 0.65), followed closely by GLEAM (0.68; 64 W m⁻²; 0.62), with values in parenthe-E.F. Wood¹¹, and D. Fernández-Prieto¹²

Jun Wen¹, Yueju Xue¹, Guirui Yu^m, Tonggang Zhaⁿ, Li Zhan 0.65), followed closely by GLEAM (0.68; 64 W m⁻²; 0.62), with values in parenthe-

ET VALIDATION





		I	Ш	PANELS 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	
A	Extreme Events									
B	Water Cycle			74						
	Carbon Cycle									
ана (1974) А. 405 — 1 (1974) С.	Technology & Innovations Cross-Cut									
	Applications' Science Cross-Cut									
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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, CO₂, 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?

food production, ecosystem management, and hence water and food security in a changing climate to meet the demands of a growing population?

10. How can information on ET be applied to optimize sustainable water allocations, agricultural water use,

PATH FORWARD

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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).

Landsat 7 – 60 m

MODIS – 1 km

Water Stress Drives Plant Behavior

300

Measured (FLUXNET)
Landsat
ECOSTRESS



High temporal resolution: ET is highly variable from day to day, thus management necessitates Saccurate ET information provided in sync with 15 daily irrigation schedules; ET also varies throughout the day, and, under water stress, vêgetation may shut down transport closing leaf stomata pores, impacting both feedbacks (daily, diurnal).

JUN JUL AUG SEP OCT Month



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).

> 0 0.005 Uncertainty in WUE (GPP/ET; 1901-2009)

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

vegetation

atmospheric

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





ECOSTRESS



An Earth Venture Instrument-2 Proposal Submitted in response to AO NNH12ZDA006O EVI2

> National Aeronautics and Space Administration Science Mission Directorate

PI SCIENCE LEAD SCIENCE TEAM SCIENCE TEAM

Jet Propulsion Laboratory California Institute of Technology Pasadena, California Simon Hook (JPL) Joshua B. Fisher (JPL) Rick Allen (U. Idaho) Martha Anderson (USDA) Andy French (USDA) Chris Hain (MSFC) Glynn Hulley (JPL) Eric Wood (Princeton U.)

www.nasa.gov

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ECOSTRESS L2 data products

ECOSTRESS L1 data products

Fetch data (local)

LST & SE

Fetch data (local)

scene geolocation data

Science code

If no L2 produced: no L3/L4 product

ECOSTRESS L3, L4 products Find ancillary data product files for time and location

Download ancillary data

Pre-process (quality control, scale, offset)

Reproject onto ECOSTRESS scene Ancillary MODIS/Landsat data products

> Fetch data (DAACs)





PT-JPL: 30 m (MODIS/Landsat) LE W m⁻² 86.6 Mexicali: 23 March 2017





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).

L3 PT-JPL ET,

L4 ESI, L4 WUE

output from Science code



Diurnal Testing 130 MERRA-2 12% 8% $\rho = 0.98$ Dew-Point Air Dew-Point Temperature $R^2 = 0.97$ 21 diurnal $RMSE = 6.65 W/m^{2}$ **PT-JPL** 90 processing Latent Energy w/m² Incoming Incoming Shortwave Longwave Radiation 70 Radiation **150 FLUXNET Sites** 50 30 ^{32%} 35% <u>46% 53</u>% 1074 5 6 11 12 13 14 15 16 17 18 19 20 21 22 23 2 3 4 7 8 9 Hour of Day - PT-JPL ······· FLUXNET PT-JPL ET using MODIS and MERRA2 compared to La Thuile FLUXNET

180" 160"W 140"W 120"W 100"W 80"W 60"W 40"W 20"W 0" 20"E 40"E 80"E 100"E 120"E 140"E 160"E 180

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



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.