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

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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.

Abstract

The fate of the terrestrial biosphere is highly uncertain given recent and projected changes in the water cycle, ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources. The development of effective adaptation strategies for ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, and highlight both the outstanding science and applications questions and the actions, especially from a space-based perspective, that should be prioritized. Critical outstanding ET-based research and applied science questions from local to global scales remain due to deficiencies in our observational capabilities.

The future of evapotranspiration (ET) represents the key variable in linking ecosystem functioning, carbon and climate feedbacks, agricultural management, and water resources, and programs. 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.
ECOSYSTEMS THRIVE ($\beta$) versus drought-induced ecosystem collapse ($\gamma$)
Uncertainty in our knowledge of carbon response is directly dependent on water response uncertainty.
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, dry get drier

River runoff is increasing

Rainfall is increasing

Evaporation is increasing

HYDROLOGICAL ACCELERATION

Syed et al. 2010

Rainfall is increasing

Evaporation is increasing

River runoff is increasing

199412-200611: 240 km³/yr²; p < 0.01
199412-199906: -720 km³/yr²; p < 0.001
199907-200611: -756 km³/yr²; p < 0.001

199412-200611: 768 km³/yr²; p < 0.001
199412-199906: 2256 km³/yr²; p < 0.001
199907-200611: -3256 km³/yr²; p < 0.001

Syed et al 2010
anticipated, they dry this century, they might accelerate climate change through carbon losses and

Marcos Silveira,

more than twice the rate of anthropogenic

potential for large carbon losses to exert feedback on climate change.

Eliana Jiménez,

Amazon dieback this century (and some models predict climate-induced Am-

Sandy Andelman,

Southern Oscillation events and associated peri-

Rodolfo Vásquez,

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Current US drought prediction capabilities failed to predict the intensity and magnitude of the 2012 US Midwest drought.
**Total Terrestrial Rainfall**
98.5 x 10^3 km^3 y^-1

**Total Terrestrial Evapotranspiration**
65.5 x 10^3 km^3 y^-1
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.
Average ET (1986-1995) vs Biodiversity for the Southern Hemisphere

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


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

Raghavender K. Vinukollu, Eric F. Wood, Craig R. Ferguson

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

Yang Chen, Zhangzhou Xia, Shuxing Liang, Jiming Ren, Shuangqiang Liu, Zhang Ma, Akira Miyata, Guoqiong Ma, Yan Wei, Yuxue Xue, Guiyi Yu, Tongyang Zha, Lian Zhou, Wenging Yuan

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

<table>
<thead>
<tr>
<th>Panels</th>
<th>I</th>
<th>II</th>
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<td>Weather: Minutes to Sub-seasonal</td>
<td>Climate Variability &amp; Change</td>
<td>Marine &amp; Terrestrial Ecosystems</td>
<td>Global Hydrological Cycle &amp; Water Resources</td>
<td>Earth Surface &amp; Interior</td>
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<td>Extreme Events</td>
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<td>B</td>
<td>Water Cycle</td>
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<td>C</td>
<td>Carbon Cycle</td>
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<td>D</td>
<td>Technology &amp; Innovations Cross-Cut</td>
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<td>E</td>
<td>Applications' Science Cross-Cut</td>
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ET relevance

- **A**: Extreme Events
- **B**: Water Cycle
- **C**: Carbon Cycle
- **D**: Technology & Innovations Cross-Cut
- **E**: 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, 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?
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).
Evapotranspiration is the key climate variable linking the water, energy, and carbon cycles. What is evapotranspiration (ET)?

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.

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

HyTES; D. Drewry
Ancillary MODIS/Landsat data products

ECOSTRESS L2 data products

ECOSTRESS L1 data products

Fetch data (local)

Fetch data (local)

scene geolocation data

Find ancillary data product files for time and location

Download ancillary data

Pre-process (quality control, scale, offset)

Reproject onto ECOSTRESS scene

ECOSTRESS L1 data products

Fetch data (local)

If no L2 produced: no L3/L4 product

LST & SE

Science code

Ancillary MODIS/Landsat data products

Fetch data (DAACs)
ECOSTRESS cal/val

JOSHUA B. FISHER (SCIENCE LEAD), SIMON HOOK (PI), GLYNN HULLEY

LAND SURFACE TEMPERATURE
L2(LSTE)
L3(ET_PT-JPL)
L3(ET_ALEXI)
L4(WUE)

EVAPOTRANSPIRATION
n=\sim 90

WATER USE EFFICIENCY
LE
LE/GPP

LW
PT-JPL: 30 m (MODIS/Landsat)

Mexicali: 23 March 2017
ET Partitioning

Soil Evaporation
Transpiration
Interception
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).

As part of preprocessing pipeline: Loop over 23 ancillary datasets

1. From downloaded ancillary data, get quality field
2. Resample onto ECOSTRESS scene, using Nearest Neighbor
3. Re-open cumulative QualityFlag file per ECOSTRESS scene, concatenate new flag on pixel level, with padding if needed
Diurnal Testing

MERRA-2

PT-JPL

\[ \rho = 0.98 \]

\[ R^2 = 0.97 \]

RMSE = 6.65 W/m²

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

Olivia Mansion
## ET Spaceborne Measurements Requirements

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Minimal</th>
<th>Optimum</th>
<th>Landsat 8</th>
<th>MODIS</th>
<th>HyspIRI*</th>
<th>ECOSTRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return Cycle (days)</td>
<td>≤8</td>
<td>≤4</td>
<td>16</td>
<td>1</td>
<td>5</td>
<td>3-5</td>
</tr>
<tr>
<td>Number of TIR bands</td>
<td>1</td>
<td>&gt;2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Spatial resolution (m)</td>
<td>120</td>
<td>30</td>
<td>100</td>
<td>1000</td>
<td>60</td>
<td>38x57</td>
</tr>
<tr>
<td>Coverage</td>
<td>US always on</td>
<td>World always on</td>
<td>US always on</td>
<td>World always on</td>
<td>World always on</td>
<td>World always on+</td>
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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.