National Aeronautics and Space Administration

ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

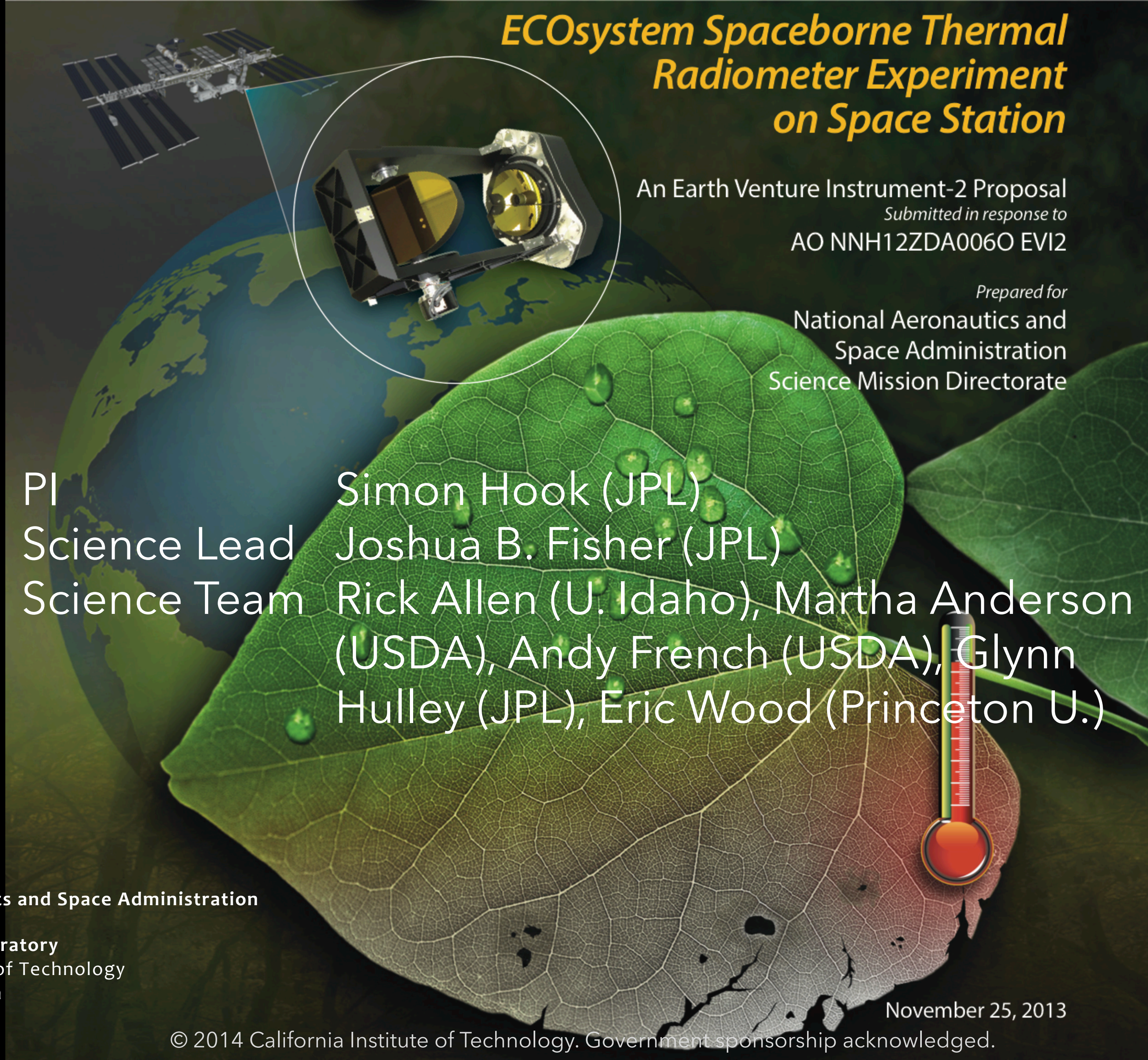
An Earth Venture Instrument-2 Proposal

Submitted in response to

AO NNH12ZDA006O EVI2

Prepared for

National Aeronautics and Space Administration Science Mission Directorate



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National Aeronautics and Space Administration

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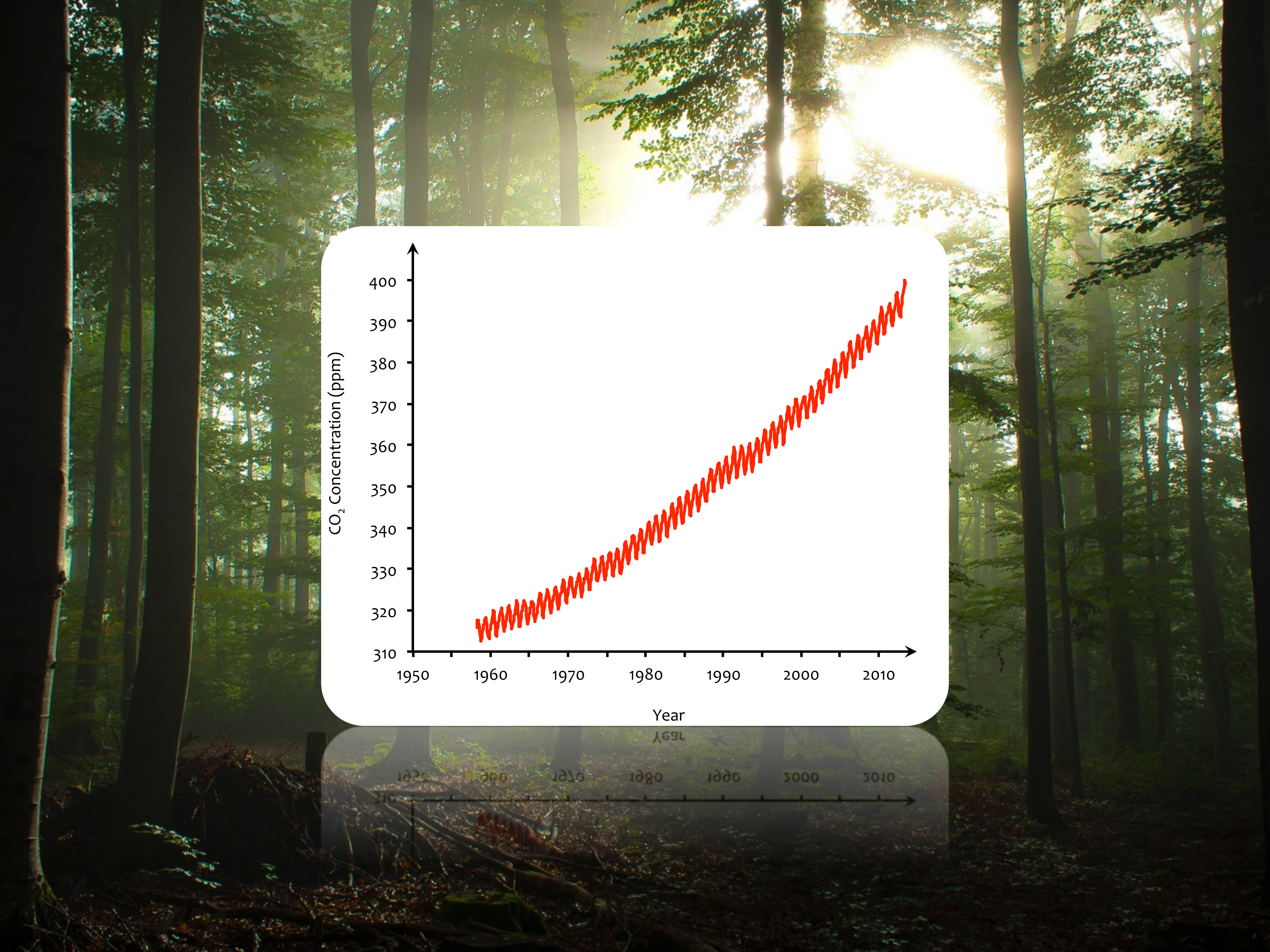
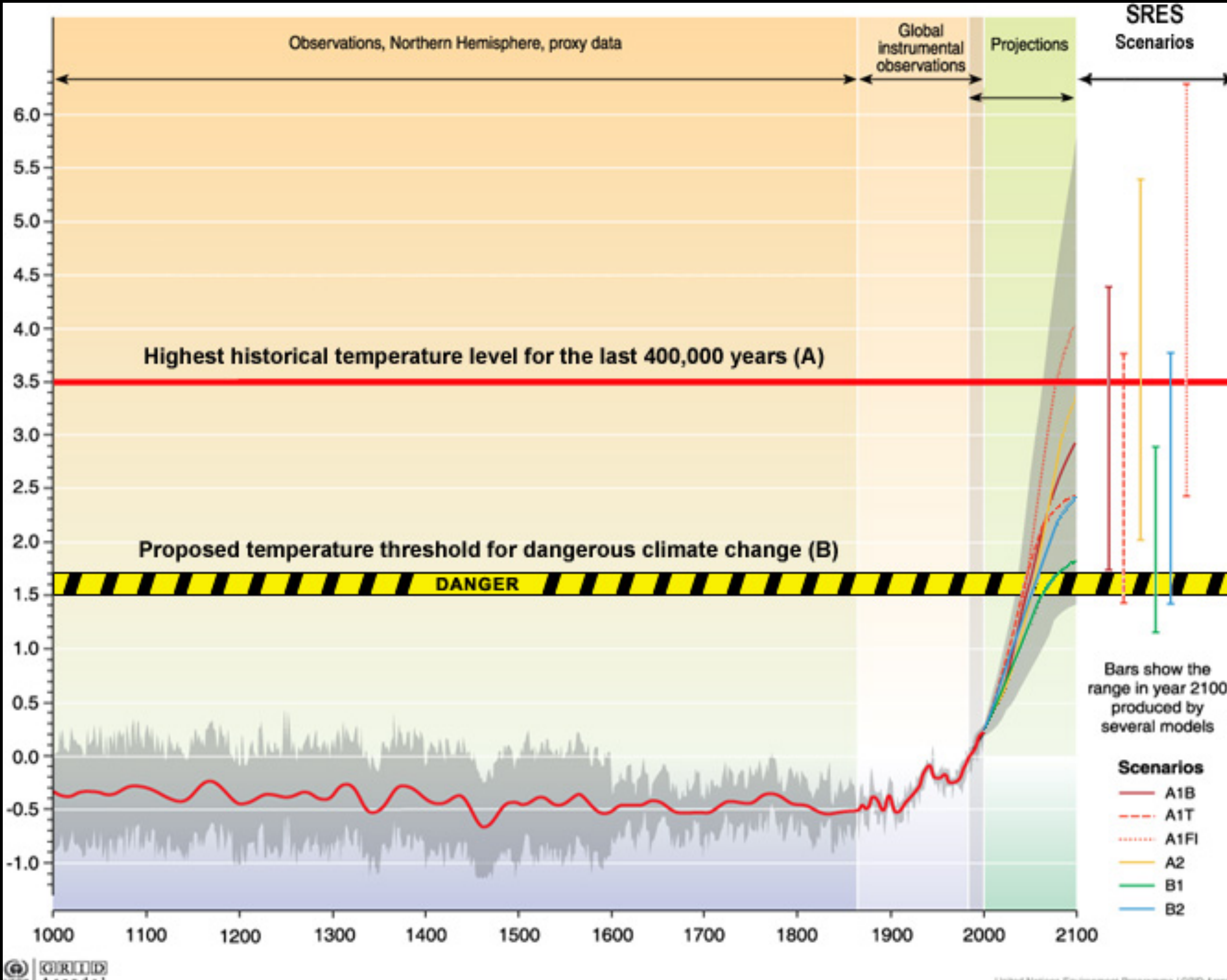
November 25, 2013



CO2 Concentration (ppm)
400
390
380
370
360
350
340
330
320
310
1950
1960
1970
1980
1990
2000
2010
Year


Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
SRES Scenarios
Highest historical temperature level for the last 400,000 years (A)
Proposed temperature threshold for dangerous climate change (B)
DANGER
Bars show the range in year 2100 produced by several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
UNEP
GRID Arendal
United Nations Environment Programme / GRID-Arendal

Uncertainties in CMIP5 Climate Projections due to Carbon Cycle Feedbacks

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ALESSANDRO ANAV,* SPENCER K. LIDDICOAT,@ AND RETO KNUTTI&

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(Manuscript received 31 July 2012, in final form 4 September 2013)

ABSTRACT

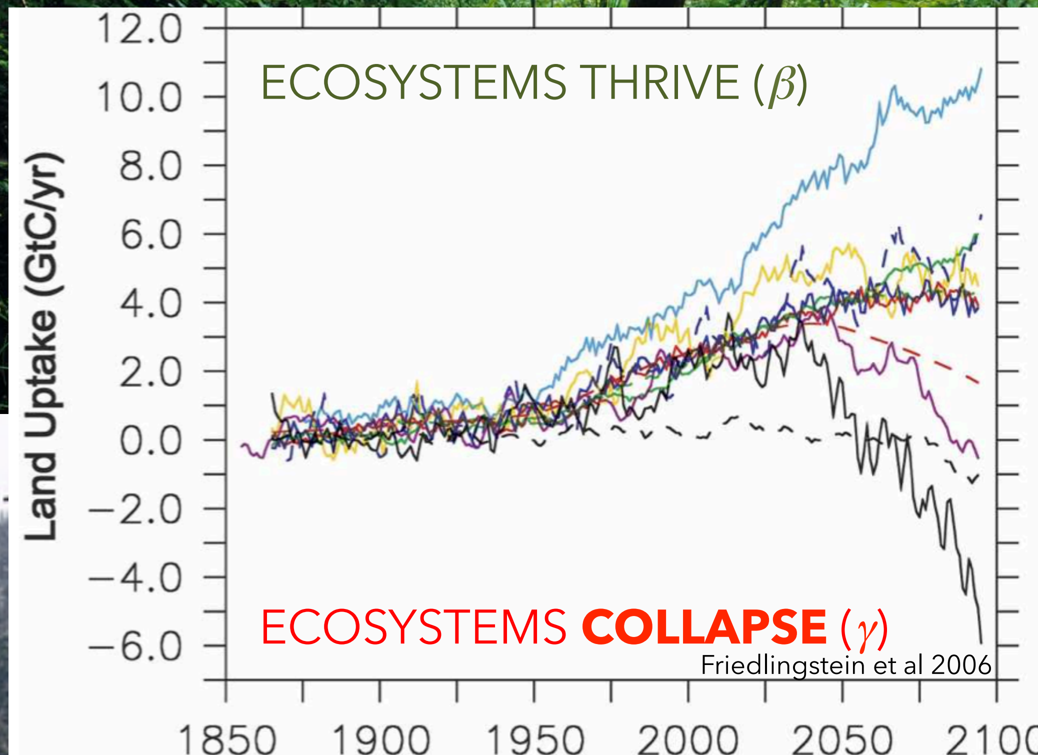
models already overestimate the present-day CO_2, with the present-day biases reasonably well correlated with future atmospheric concentrations' departure from the prescribed concentration. The uncertainty in CO_2 projections is mainly attributable to uncertainties in the response of the land carbon cycle. As a result of simulated higher CO_2 concentrations than in the concentration-driven simulations, temperature projections

driven by CO_2 emissions than for the concentration-driven scenarios (941 ppm). However, most of these models already overestimate the present-day CO_2, with the present-day biases reasonably well correlated with future atmospheric concentrations' departure from the prescribed concentration. The uncertainty in CO_2 projections is mainly attributable to uncertainties in the response of the land carbon cycle. As a result of simulated higher CO_2 concentrations than in the concentration-driven simulations, temperature projections are generally higher when ESMs are driven with CO_2 emissions. Global surface temperature change by 2100 (relative to present day) increased by 3.9° ± 0.9°C for the emission-driven simulations compared to 3.7° ± 0.7°C in the concentration-driven simulations. Although the lower ends are comparable in both sets of simulations, the highest climate projections are significantly warmer in the emission-driven simulations because of stronger carbon cycle feedbacks.

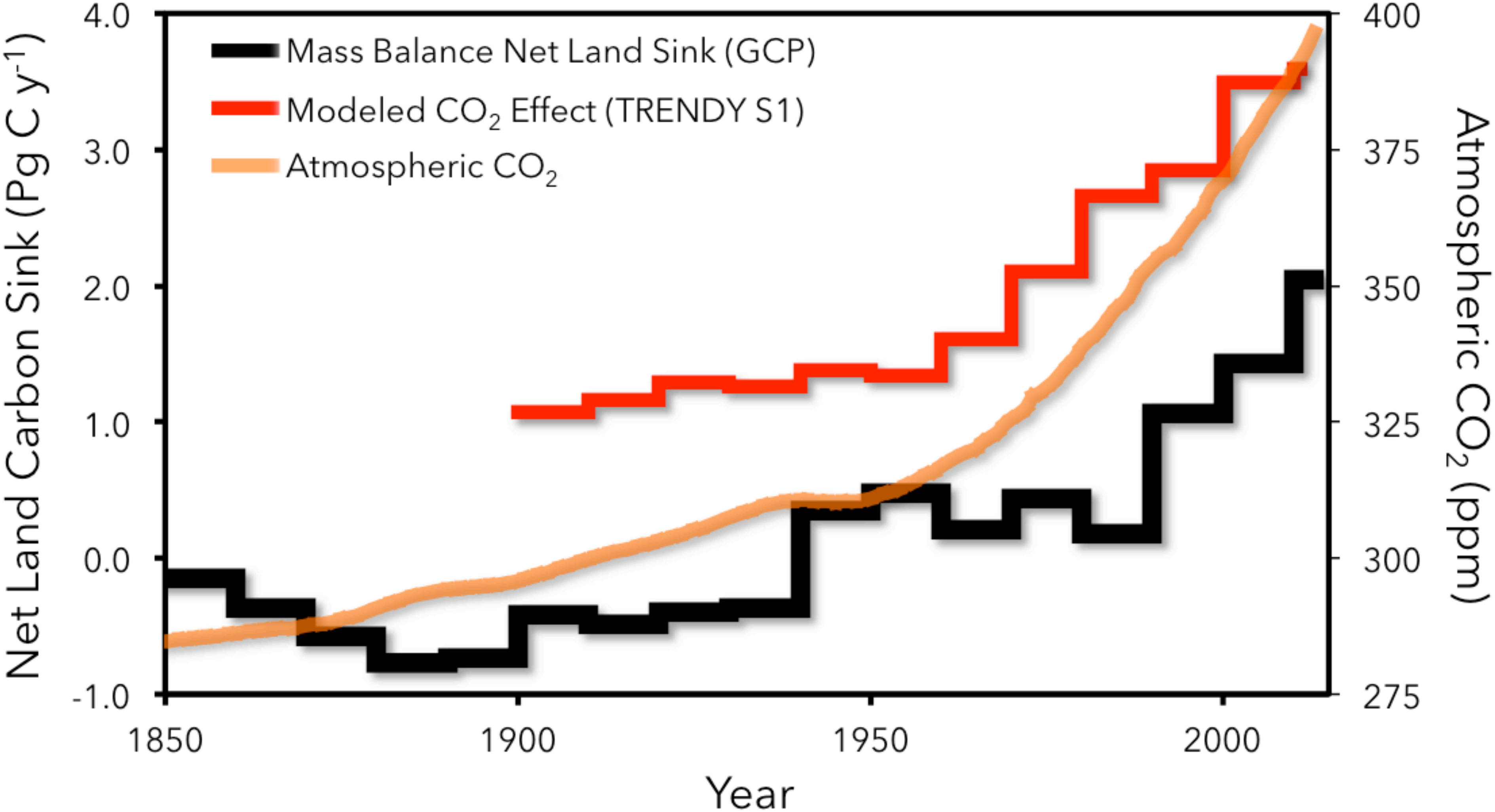
1. Introduction

In the Fourth Assessment Report of the Intergov-

best guess is not centered in the likely range interval; the distribution is asymmetrical with a −40/+60% distribution around the best estimate (i.e., the average of the

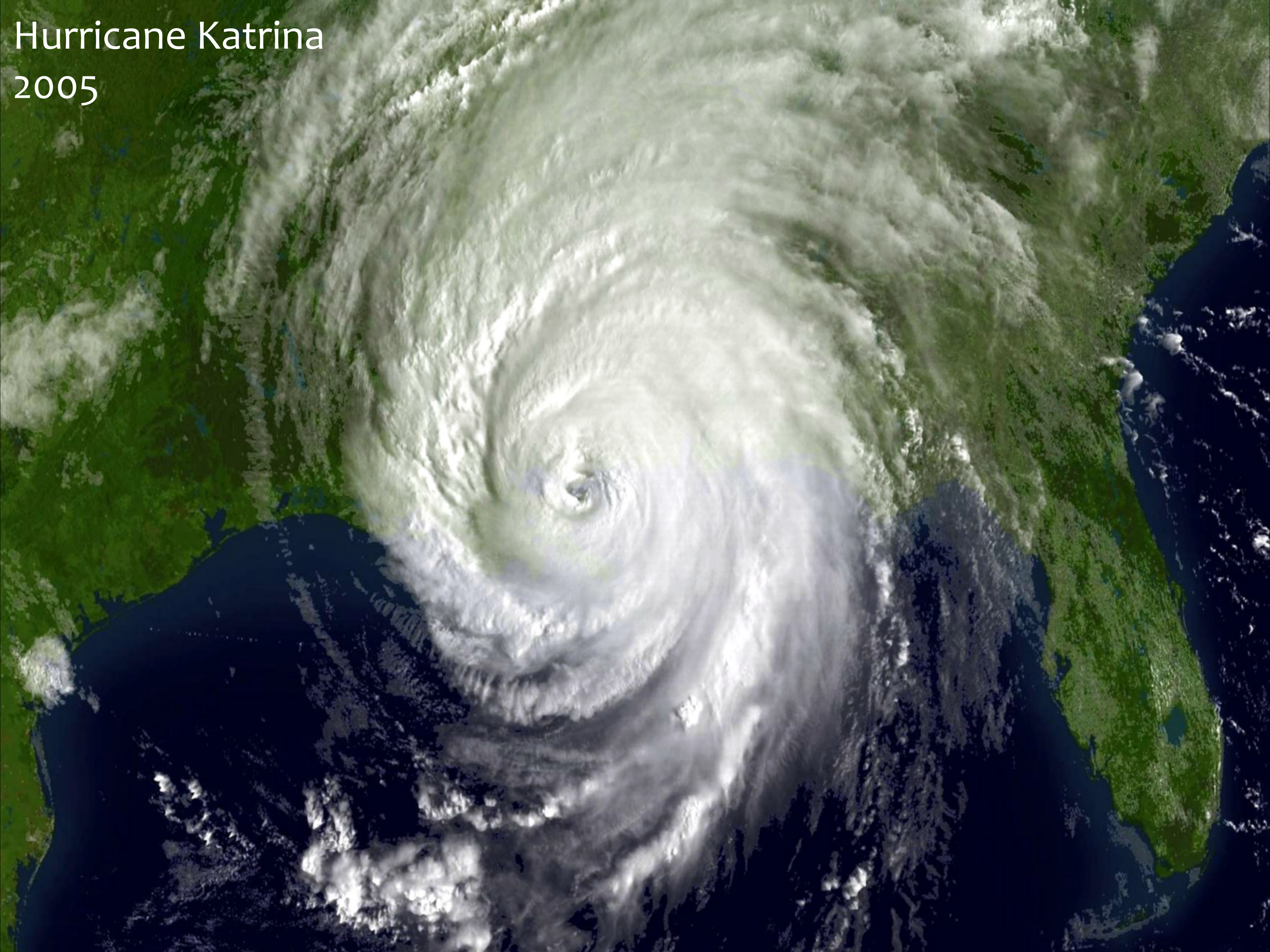


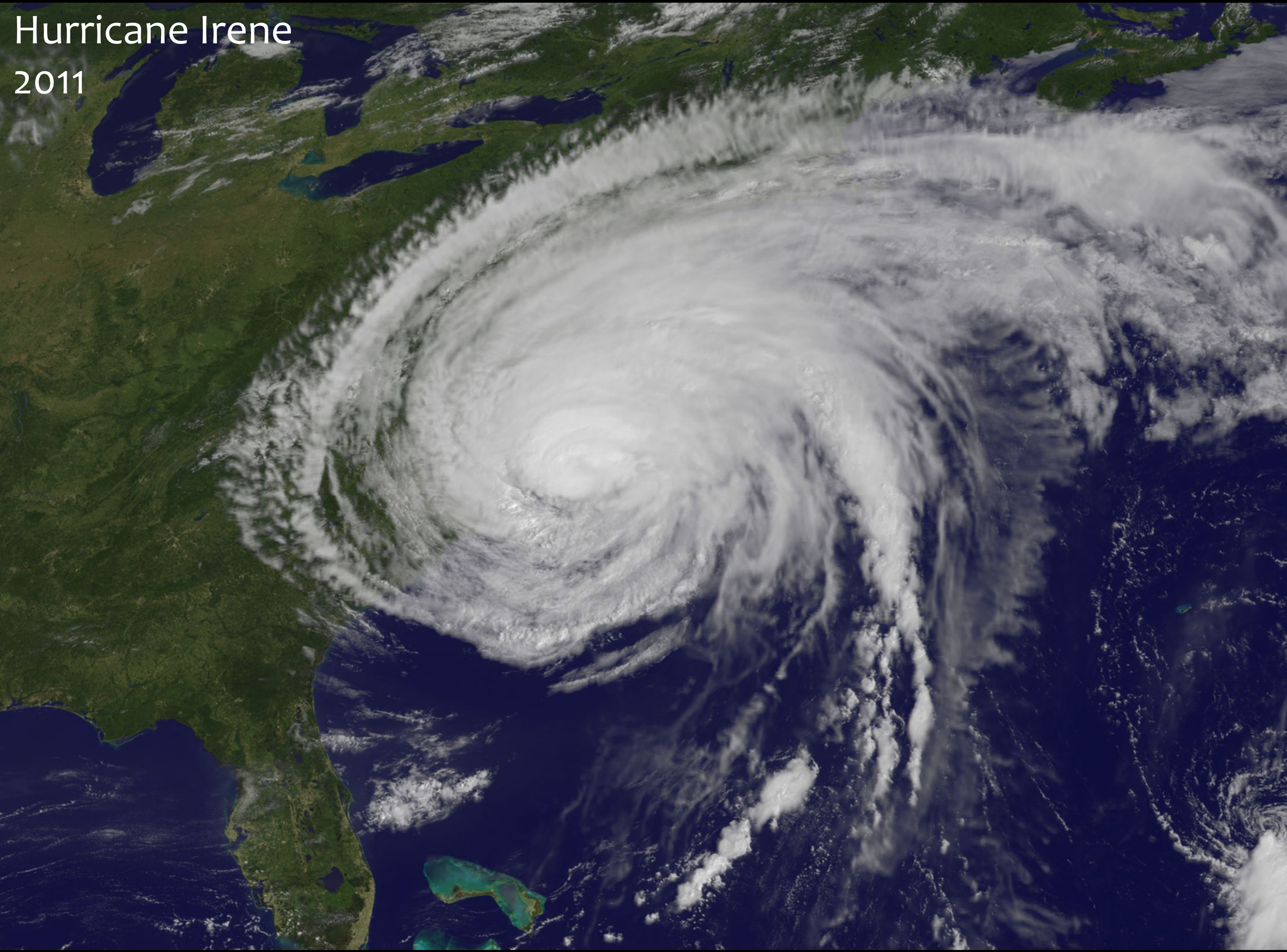
The response of the terrestrial biosphere to changing climate is one of the largest uncertainties in future climate projections.



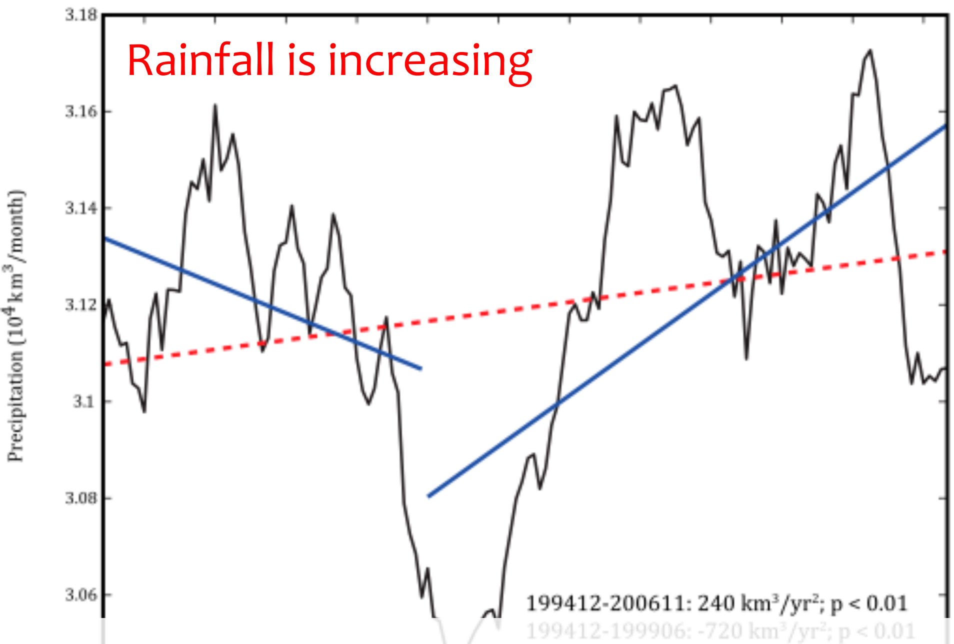
CO_2 FERTILIZATION (β)

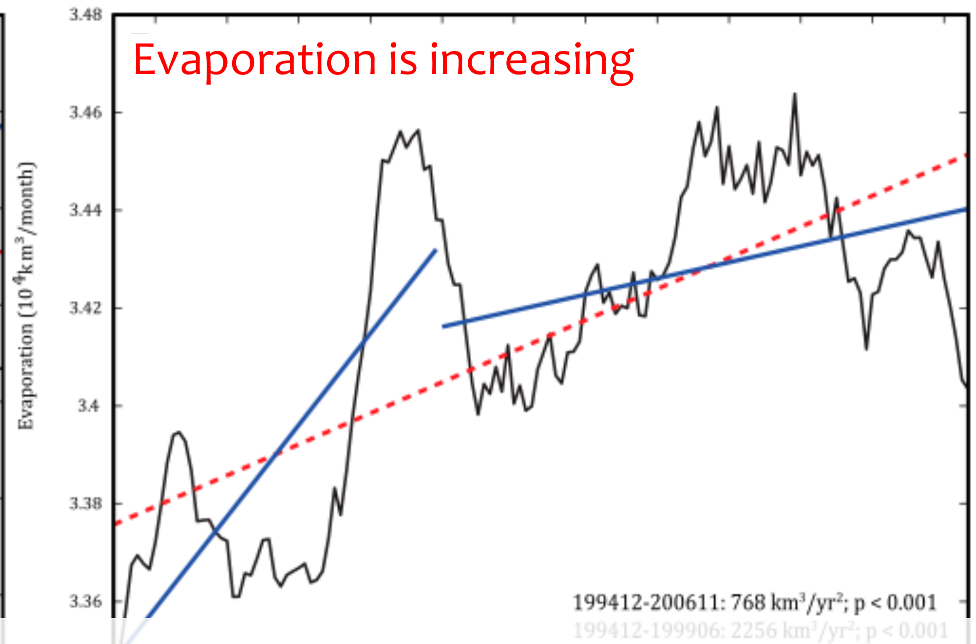
Schimel, D., Stephens, B.B., **Fisher, J.B.**, in press. The effect of increasing CO_2 on the terrestrial carbon cycle. *Proceedings of the National Academy of Sciences, USA*.


Hurricane Katrina
2005

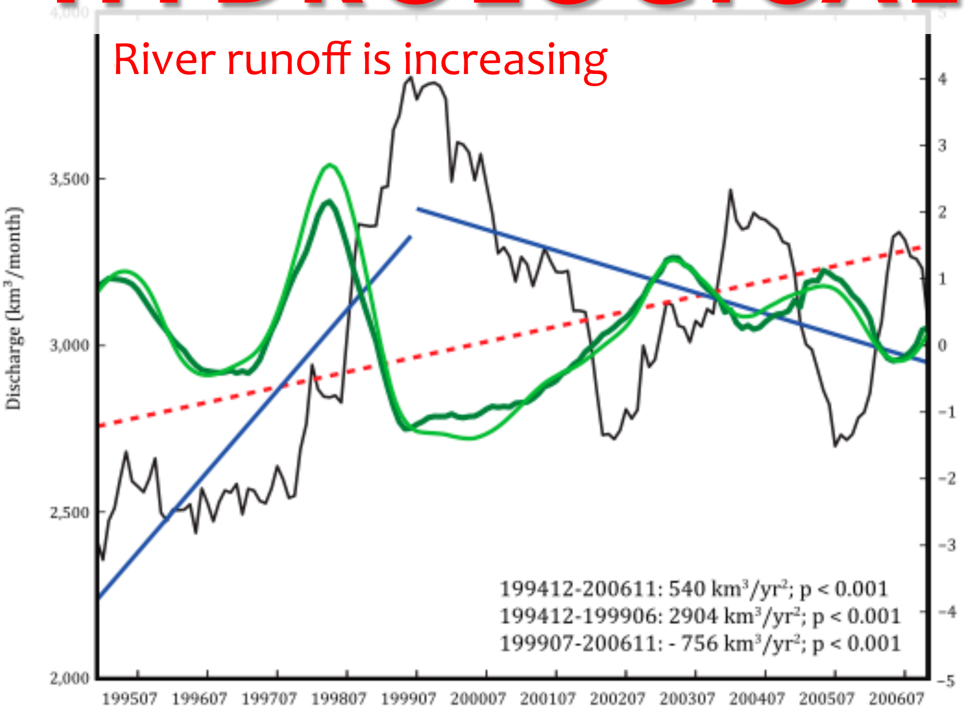

Hurricane Irene
2011


Hurricane Sandy
2012

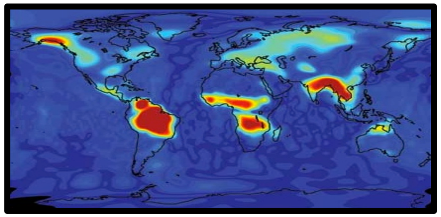




HYDROLOGICAL ACCELERATION

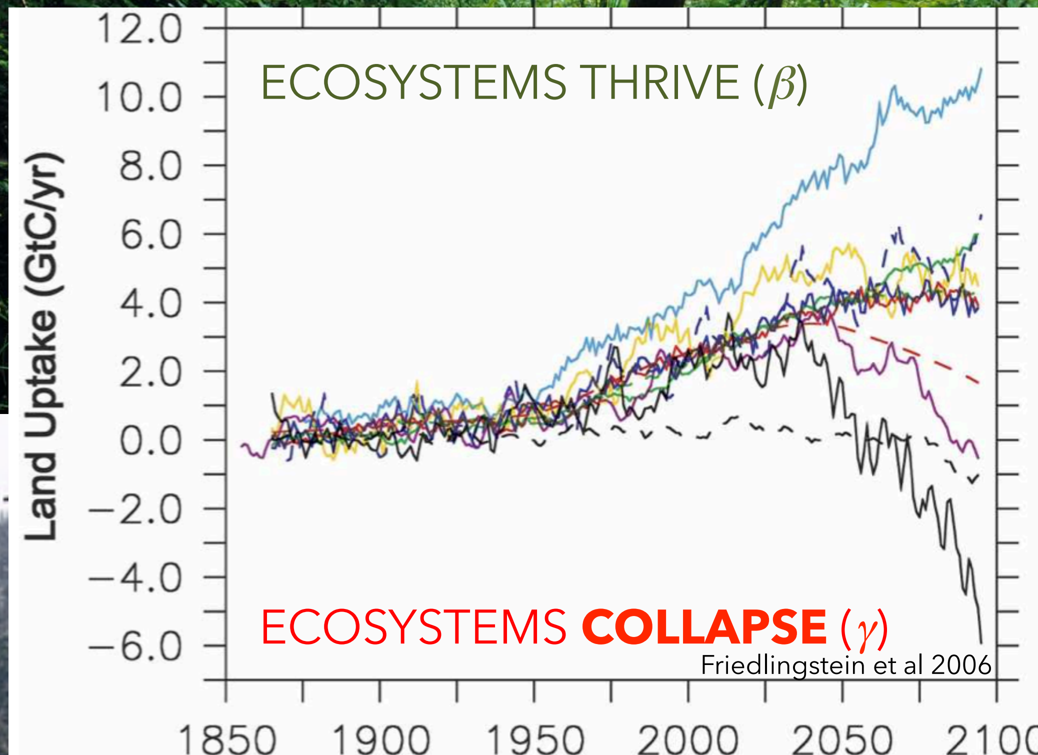


- More energy
  - → More evaporation
    - Atmosphere can't hold all that evaporation
  - → More precipitation
    - BUT, in places where there's already precipitation
    - Atmospheric moisture rains out before it reaches semi-arid places
    - More intense storms; more intense droughts
  - → Wet get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



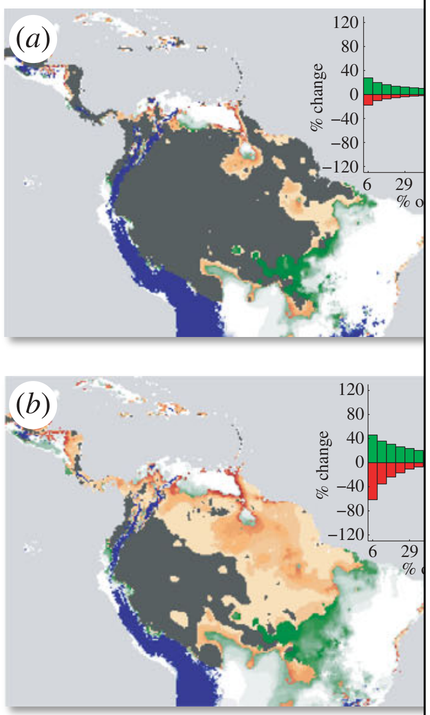
Syed et al 2010

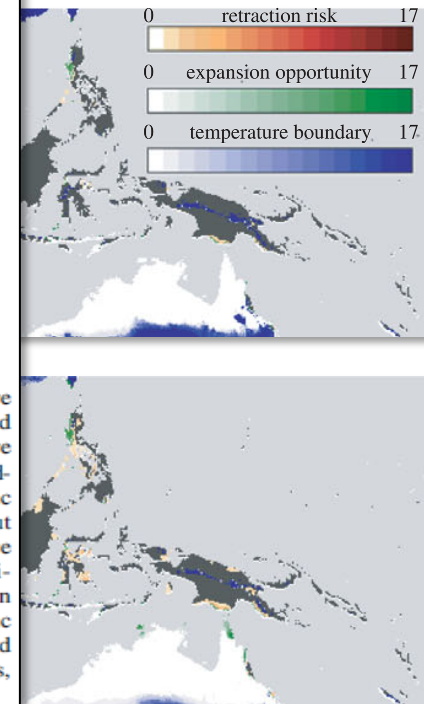

DO NOT
PARK



The response of the terrestrial biosphere to changing climate is one of the largest uncertainties in future climate projections.

CLIMA ACTS





Theor. Appl. Climatol. 78, 137–156 (2004)
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Theoretical and Applied Climatology
Printed in Austria

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Amazonian forest dieback under climate-carbon cycle projections for the 21st century

P. M. Cox[1], R. A. Betts[1], M. Collins[2], P. P. Harris[3], C. Huntingford[3], and C. D. Jones[1]

With 10 Figures

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Summary

The first GCM climate change projections to include dynamic vegetation and an interactive carbon cycle produced a very significant amplification of global warming over the 21st century. Under the IS92a "business as usual" emissions scenario CO_2 concentrations reached about 980 ppmv by 2100, which is about 280 ppmv higher than when these feedbacks were ignored. The major contribution to the increased CO_2 arose from reductions in soil carbon because global warming is assumed to accelerate respiration. However, there was also a lesser contribution from an alarming loss of the Amazonian rainforest. This paper describes the phenomenon of Amazonian forest dieback under elevated CO_2 in the Hadley Centre climate-carbon cycle model.

1. Introduction

About half of the current anthropogenic emissions of carbon dioxide are being absorbed by the ocean and by land ecosystems (Schimel et al., 1996). The processes involved are known to be sensitive to climate. Temperature affects the solubility of carbon dioxide in sea-water and the rate of terrestrial and oceanic biological processes. Vegetation also responds directly to elevated CO_2 through increased photosynthesis and reduced transpiration (Sellers et al., 1996; Field et al., 1995), and may also change its structure and distribution in response to any associated climate change (Betts et al., 1997). The biosphere therefore has great potential to produce a feed-back on the climate change due to anthropogenic CO_2 emissions. However, simulations carried out with General Circulation Models (GCMs) have generally neglected the coupling between the climate and the biosphere. Instead, vegetation distributions have been static and atmospheric concentrations of CO_2 have been prescribed based on results from simple carbon cycle models, which neglect the effects of climate change.

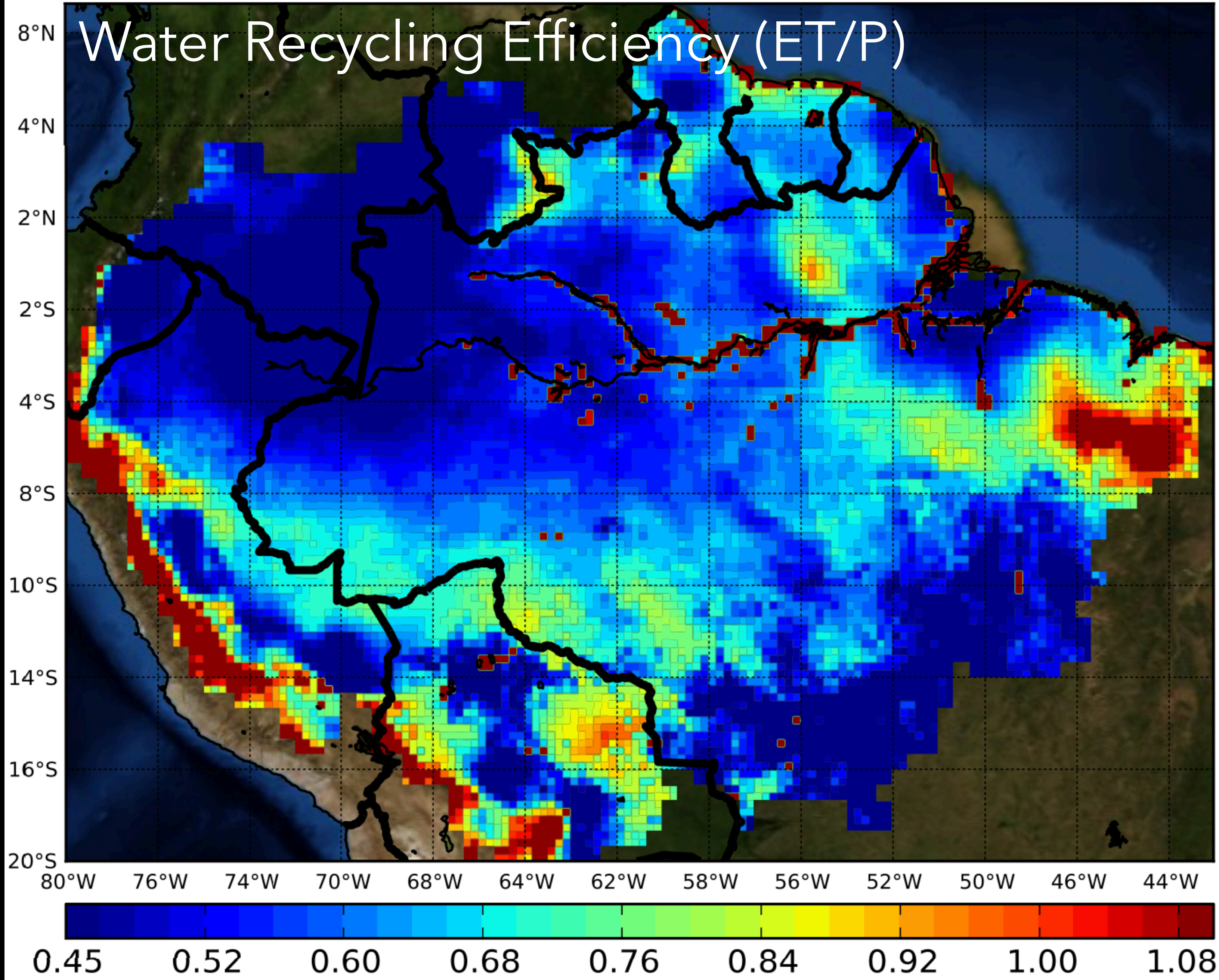
Recently some groups have begun to include representations of the carbon cycle within GCMs (Friedlingstein et al., 2001; Cox et al., 2001). The first climate change projection to include both an interactive carbon cycle and dynamic vegetation was carried out at the Hadley Centre, and this showed a significant acceleration of CO_2 increase and climate change arising from the additional feedback loops (Cox et al., 2000). Under the IS92a "business as usual" emission scenario the Hadley Centre coupled-climate carbon cycle model produced a CO_2 concentration of about 980 ppmv by 2100, compared to about

Figure 5. Change in the potentia … °C and (b) 4°C global warming.
This scenario accounts for the de … urface scheme (see also figure 4).
Dark grey areas mark the niche … all AOGCMs. Shades of red and
green mark the potential HTF … d in blue. In mountainous areas
adjacent to HTFs, they define th … percentage of models that agree
on a change up to the plotted lev

Zelazowski, P., Malhi, Y., Huntingford, C., Sitch, S., **Fisher, J.B.**, 2011. Changes in the potential distribution of humid tropical forests on a warmer planet. *Philosophical Transactions of the Royal Society A – Mathematical, Physical & Engineering Sciences*.

As drought increases, live trees decrease.

Phillips, O.L., Aragão, L., Lewis, S.L., **Fisher, J.B.**, et al., 2009. Drought sensitivity of the Amazon rainforest. *Science*.



Vergopolan, N. and **Fisher, J.B.**, in review. The impact of deforestation on the hydrological cycle in Amazonia as observed from remote sensing. *Geophysical Research Letters*.

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Climate-induced boreal forest change: Predictions versus current observations

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Keywords: climate change evidence; fire; infestation disturbance; treeline progression; boreal; montane

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E-mail address: a.j.soja@larc.nasa.gov (A.J. Soja).

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doi:10.5194/acp-11-7925-2011

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

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Revised: 22 July 2011 – Accepted: 1 August 2011 – Published: 4 August 2011

Abstract. CO total column data are presented from three space sounders and two ground-based spectrometers in Moscow and its suburbs during the forest and peat fires that occurred in Central Russia in July–August 2010. Also presented are ground-based in situ CO measurements. The Moscow area was strongly impacted by the CO plume from these fires. Concurrent satellite- and ground-based observations were used to quantify the errors of CO top-down emission estimates. On certain days, CO total columns retrieved from the data of the space-based sounders were 2–3 times less than those obtained from the ground-based sun-tracking spectrometers. The depth of the polluted layer over Moscow was estimated using total column measurements compared with CO volume mixing ratios in the surface layer and on the TV tower and found to be around 360 m. The missing CO that is the average difference between the CO total column accurately determined by the ground spectrometers and that retrieved by AIRS, MOPITT, and IASI was determined for the Moscow area between 1.6 and 3.3×10^{18} molec cm^{-2}. These values were extrapolated onto the entire plume; subsequently, the CO burden (total mass) over Russia during the fire event was corrected. A top-down estimate of the total emitted CO, obtained by a simple mass balance model increased by 40–100 % for different sensors due to this correction. Final assessments of total CO emitted by Russian wildfires obtained from different sounders are between 34 and 40 Tg CO during July–August 2010.

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nature

LETTERS

Mountain pine beetle and forest carbon feedback to climate change

W. A. Kurz[1], C. C. Dymond[1], G. Stinson[1], G. J. Rampley[1], E. T. Neilson[1], A. L. Carroll[1], T. Ebata[2] & L. Safranyik[1]

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Curculionidae, Scolytinae) is a native insect of the pine forests of western North America, and its populations periodically erupt into large-scale outbreaks[1–3]. During outbreaks, the resulting widespread tree mortality reduces forest carbon uptake and increases future emissions from the decay of killed trees. The impacts of insects on forest carbon dynamics, however, are generally ignored in large-scale modelling analyses. The current outbreak in British Columbia, Canada, is an order of magnitude larger in area and severity than all previous recorded outbreaks[4]. Here we estimate that the cumulative impact of the beetle outbreak in the affected region during 2000–2020 will be 270 megatonnes (Mt) carbon (or 36 g carbon m^{-2} yr^{-1} on average over 374,000 km^2 of forest). This impact converted the forest from a small net carbon sink to a large net carbon source both during and immediately after the outbreak. In the worst year, the impacts resulting from the beetle outbreak in British Columbia were equivalent to ~75% of the average annual direct forest fire emissions from all of Canada during 1959–1999. The resulting reduction in net primary production was of similar magnitude to increases observed during the 1980s and 1990s as a result of global change[5]. Climate change has contributed to the unprecedented extent and severity of this outbreak[6]. Insect outbreaks such as this represent an important mechanism by which climate change may undermine the ability of northern forests to take up and store atmospheric carbon, and such impacts should be accounted for in large-scale modelling analyses.

Forest insect epidemics can have severe impacts on ecosystem dynamics by causing mortality and reducing the growth of millions of trees over extensive areas[7]. Native insects and alien invasive species affect both managed and natural forests. Beyond the ecological impacts are the associated economic (for example, disrupted timber supply to mills) and social (for example, unemployment, crime rates) effects[8]. The impact of insects on carbon (C) dynamics and global climate are not well documented[9].

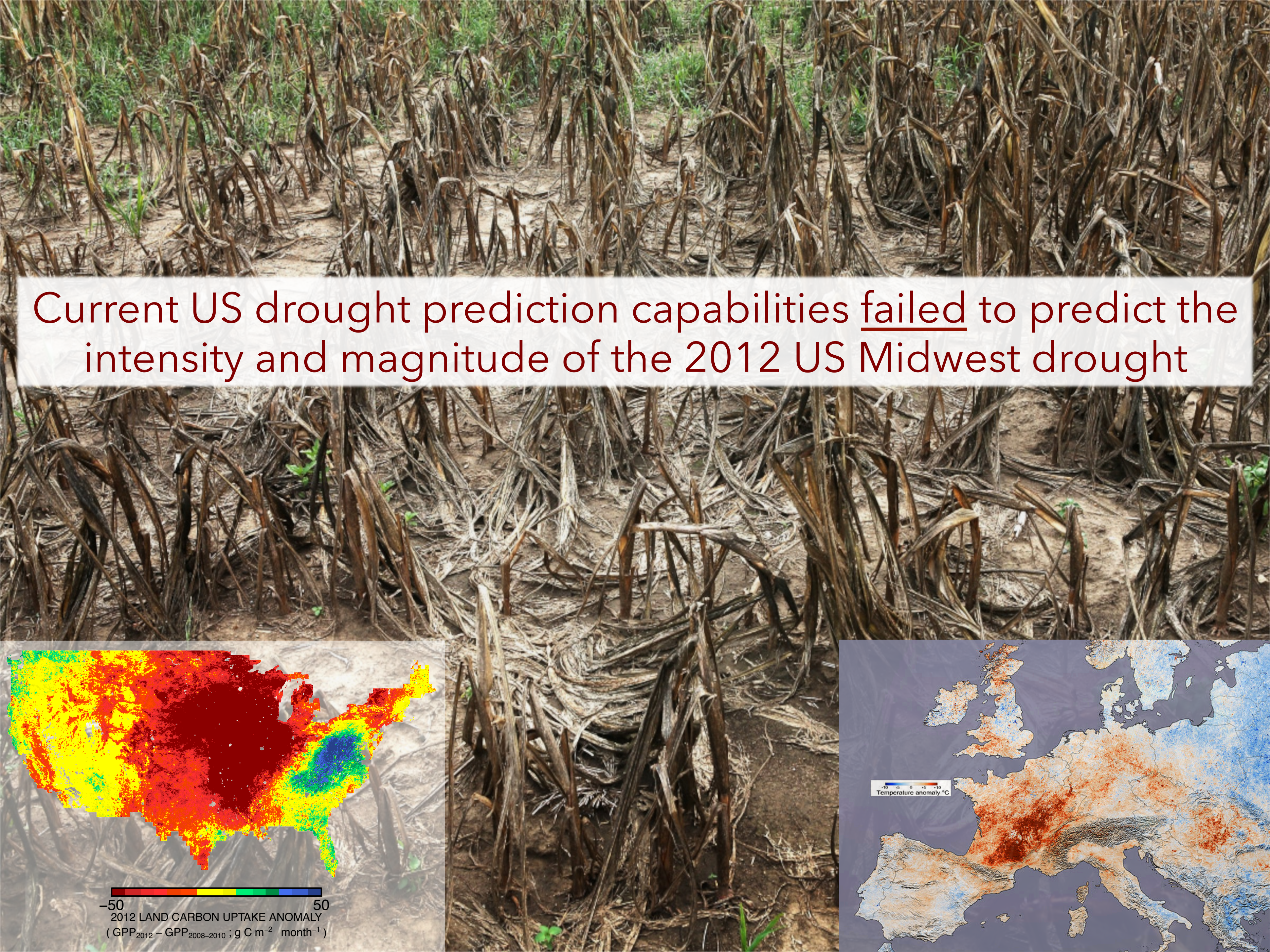
The current outbreak of mountain pine beetle in western Canada is an order of magnitude greater in area than previous outbreaks owing to the increased area of susceptible host (mature pine stands) and favourable climate[4] (see also Supplementary Fig. 3). An expansion in climatically suitable habitat for the mountain pine beetle, including reduced minimum winter temperature, increased summer temperatures and reduced summer precipitation, during recent decades has facilitated expansion of the outbreak northward and into higher elevation forests[4,10]. This range expansion, combined with an increase in the extent of the host, has resulted in an outbreak of unprecedented scale and severity. By the end of 2006, the cumulative outbreak area was 130,000 km^2 (many stands being attacked in multiple years), with tree mortality ranging from single trees to most of a stand in a single year[11]. Timber losses are estimated to be more than 435 million m^3, with additional losses outside the commercial forest[12]. The forest sector has responded by increasing harvest rates and reallocating some harvest, increasing the pine portion of the provincial total volume harvested from 31% to 45% over four years (2001–2004).

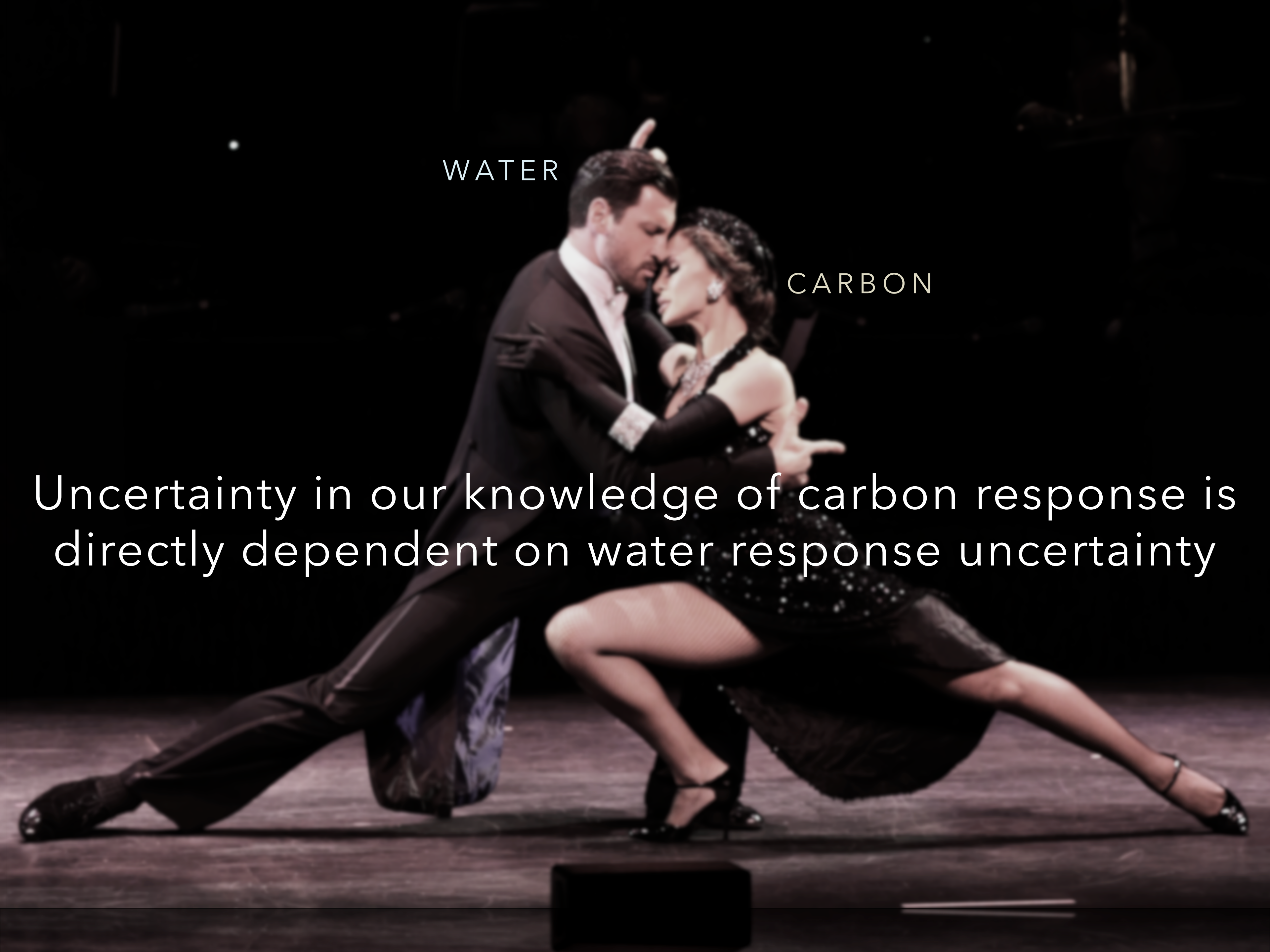
We estimated the combined impact of the beetle, forest fires and harvesting on forest productivity and carbon balance from 2000 until 2020 for the south-central region of British Columbia (Fig. 1). This area includes 374,000 km^2 of productive forest, largely dominated by pine (*Pinus*) and spruce (*Picea*) species. We used a Monte Carlo design for simulating future net biome production (NBP) using a forest ecosystem model (the Carbon Budget Model of the Canadian Forest Sector, CBM-CFS3). This model accounts for annual tree growth, litterfall, turnover and decay, and it explicitly simulates harvest, beetle-caused mortality, and fire-caused mortality and fuel consumption. We developed regional probability distribution functions of the annual area burned and projected future beetle dynamics on the basis of the characteristics of the remaining host (that is, pine stands of suitable age) and the judgement of regional entomologists. We conducted 100 Monte Carlo simulations with different random draws from the probability distributions for the annual area of beetle outbreak and the annual area burned.

For the period 2000–2020, the average annual NBP was -15.8 ± 7.9 Mt C yr^{-1} (or -42.4 ± 21 g C m^{-2} yr^{-1}; Fig. 2). Carbon losses result from emissions from decomposition and fires and from the transfer of timber to the forest product sector. In a separate analysis[13], we estimated that the study area was a net sink from 1990 to 2002. The first two years of this study also reported a net sink (0.59 Mt C yr^{-1}), but with increasing beetle impact (Fig. 3), the forest converted to a source of 17.6 Mt C yr^{-1} from 2003 to 2020. With decreasing beetle impact (Fig. 3), NBP began to recover, but by 2020, the estimated NBP had not yet returned to pre-outbreak levels. Although we can expect that forests will eventually recover from the beetle outbreak, we are reluctant to extend projections beyond 2020 or to speculate on the rate of recovery beyond 2020 given uncertainties about non-host responses, rates of regeneration, and future fires in a region in which major climate change impacts are forecast[14].

One component of the uncertainty in future NBP is that we do not know the future area that will be infested by the beetle. We projected the area infested during 2007–2020 using random draws from regionally calibrated probability distributions of outbreak area and duration that were based on: the 2000–2006 area; mortality and host statistics; historical, spatial and temporal dynamics; remaining host population; and judgment from entomologists. The outbreak was projected to peak between 2006 and 2008, with the maximum area infested ranging from 74,000 km^2 to 94,000 km^2 (Fig. 3).

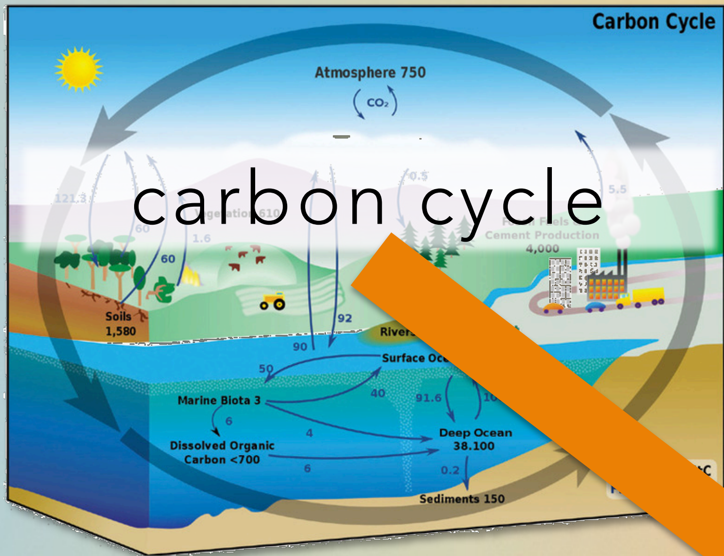
[1] Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, V8Z 1M5, Canada. [2] British Columbia Ministry of Forests and Range, Victoria, British Columbia, V8W 9C2, Canada.

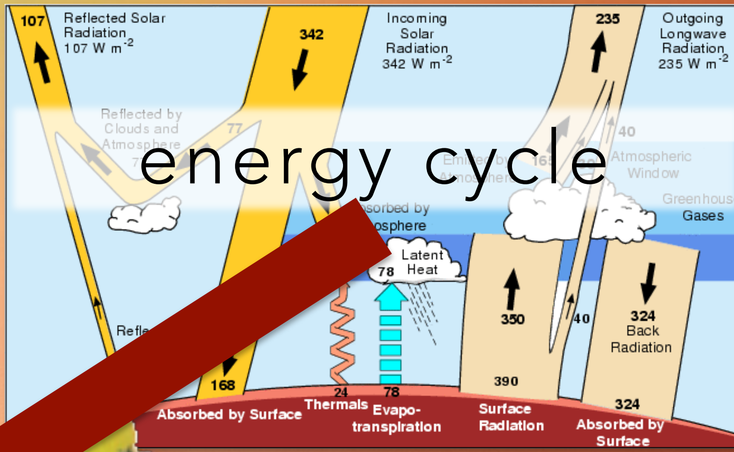

Current US drought prediction capabilities failed to predict the intensity and magnitude of the 2012 US Midwest drought
−50
50
2012 LAND CARBON UPTAKE ANOMALY
(GPP2012 – GPP2008–2010 ; g C m-2 month-1)
Temperature anomaly °C

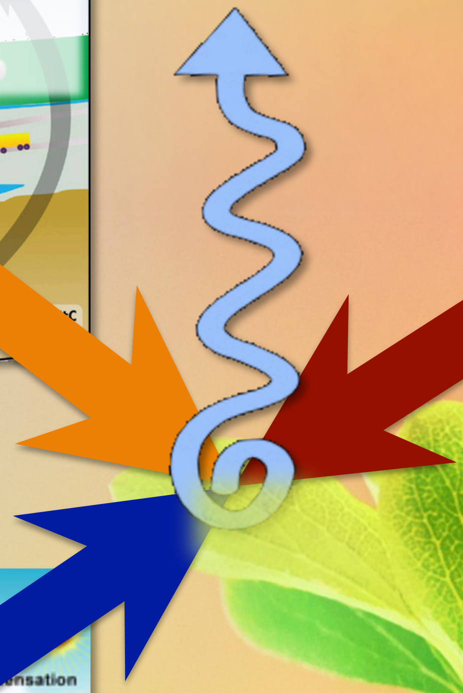


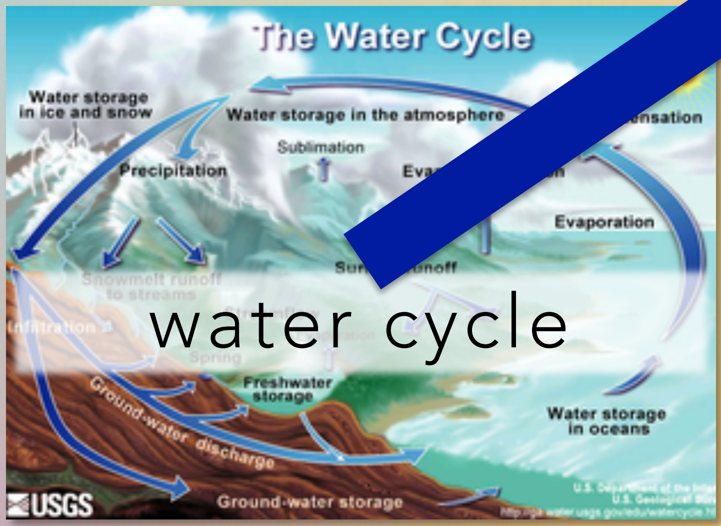
Uncertainty in our knowledge of carbon response is directly dependent on water response uncertainty


EVAPOTRANSPIRATION
©FLORENT COURTY









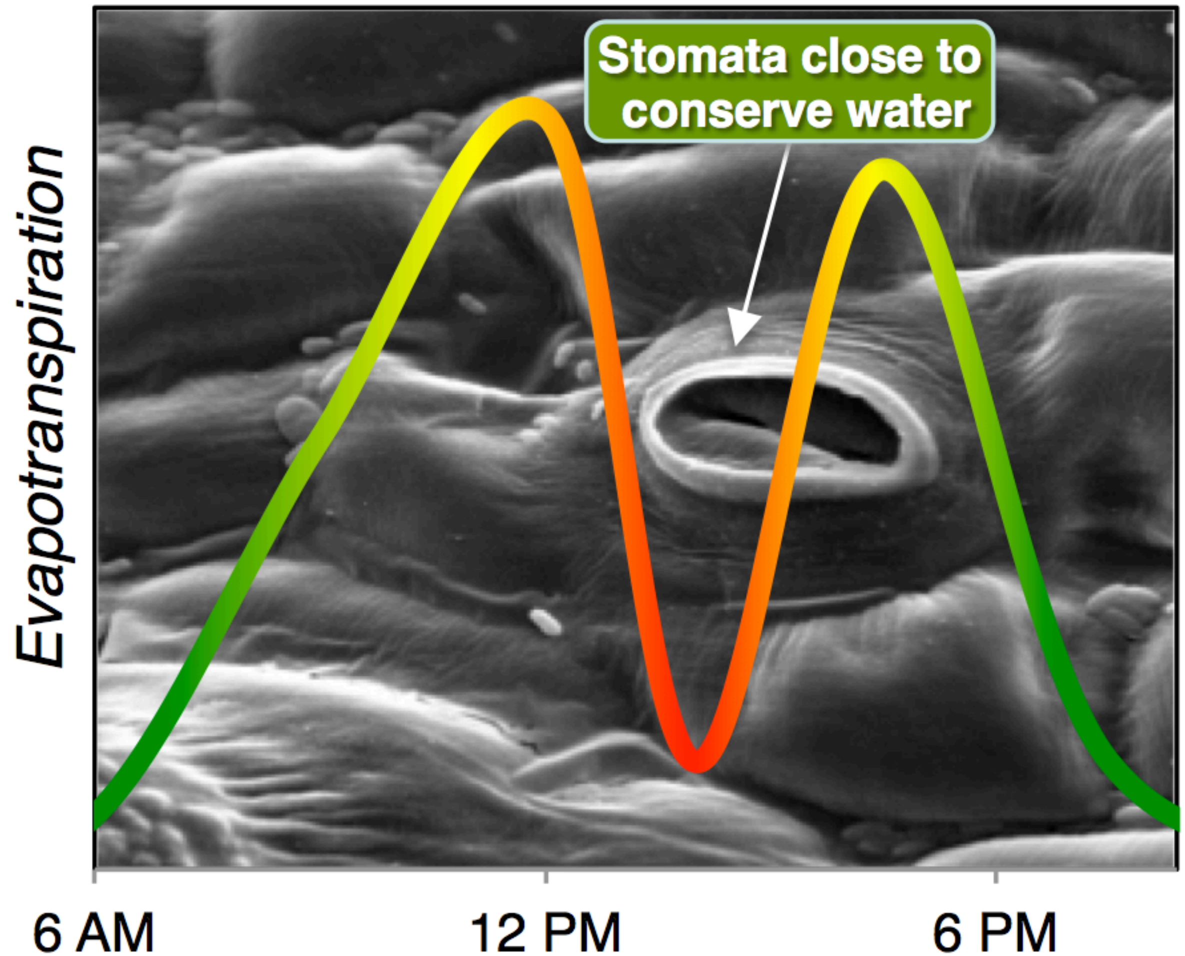
ET describes the net exchange of water vapor between the land surface and the atmosphere, and is comprised of water evaporated directly from the soil or other surfaces and water transpired (i.e., used; consumptive use) by plants.

what is evapotranspiration (ET)?

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

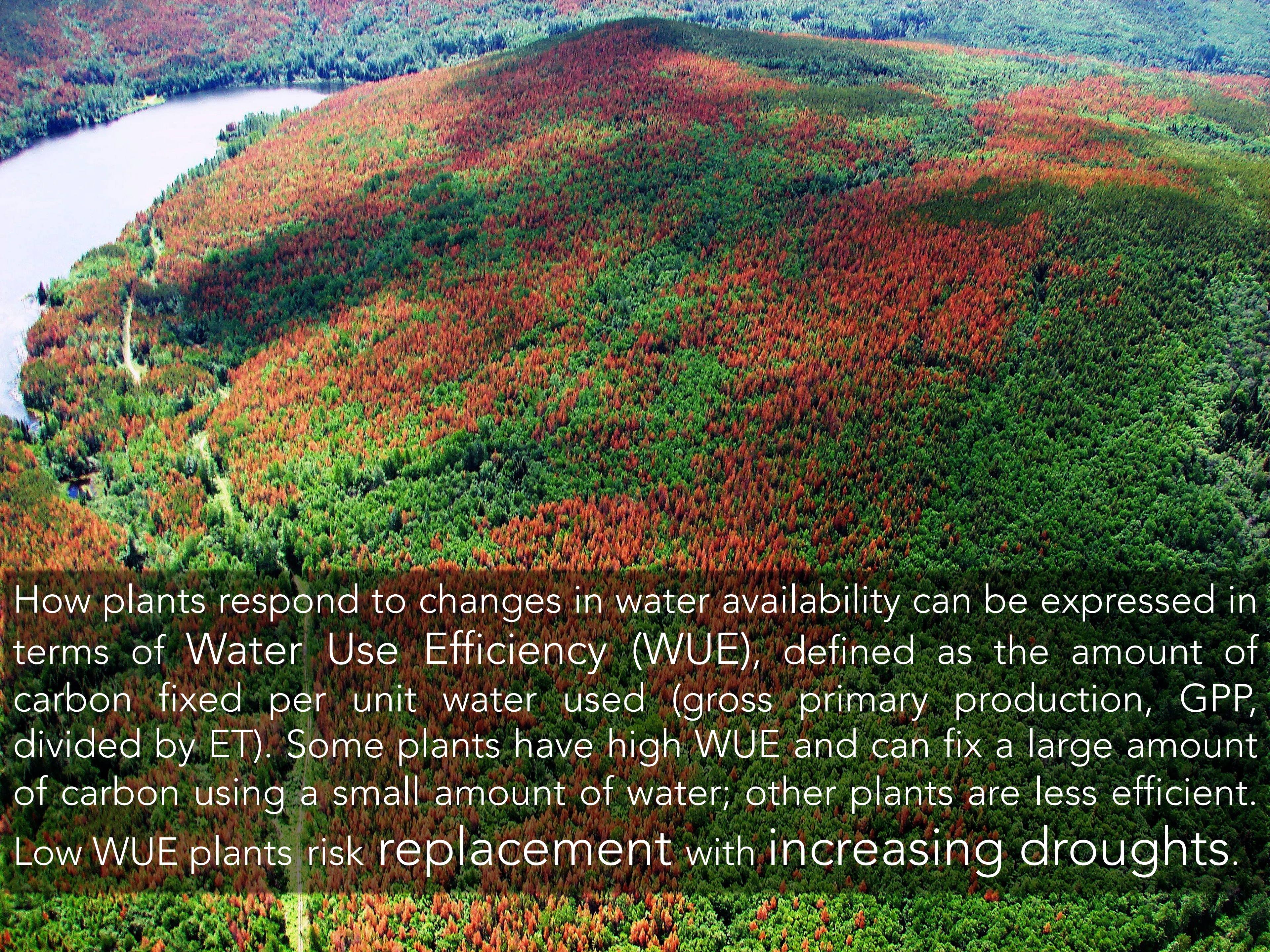
Plants regulate water loss (transpiration) by closing the pores on their leaves, but at the expense of shutting off CO_2 uptake for photosynthesis and risking **carbon starvation**. Transpiration also performs the same cooling function as sweat; if plants cannot adequately cool themselves, they risk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

Water Stress Drives Plant Behavior



HOW DO DIFFERENT PLANTS RESPOND TO CHANGES IN WATER AVAILABILITY?


WHICH PLANTS DIE FIRST?


How plants respond to changes in water availability can be expressed in terms of Water Use Efficiency (WUE), defined as the amount of carbon fixed per unit water used (gross primary production, GPP, divided by ET). Some plants have high WUE and can fix a large amount of carbon using a small amount of water; other plants are less efficient. Low WUE plants risk replacement with increasing droughts.

ECOSTRESS KEY SCIENCE QUESTIONS

1. HOW IS THE TERRESTRIAL BIOSPHERE RESPONDING TO CHANGES IN WATER AVAILABILITY?

2. HOW DO CHANGES IN DIURNAL VEGETATION WATER STRESS IMPACT THE GLOBAL CARBON CYCLE?

3. CAN AGRICULTURAL VULNERABILITY BE REDUCED THROUGH ADVANCED MONITORING OF AGRICULTURAL CONSUMPTIVE USE AND IMPROVED DROUGHT DETECTION?

ECOSTRESS SCIENCE OBJECTIVES

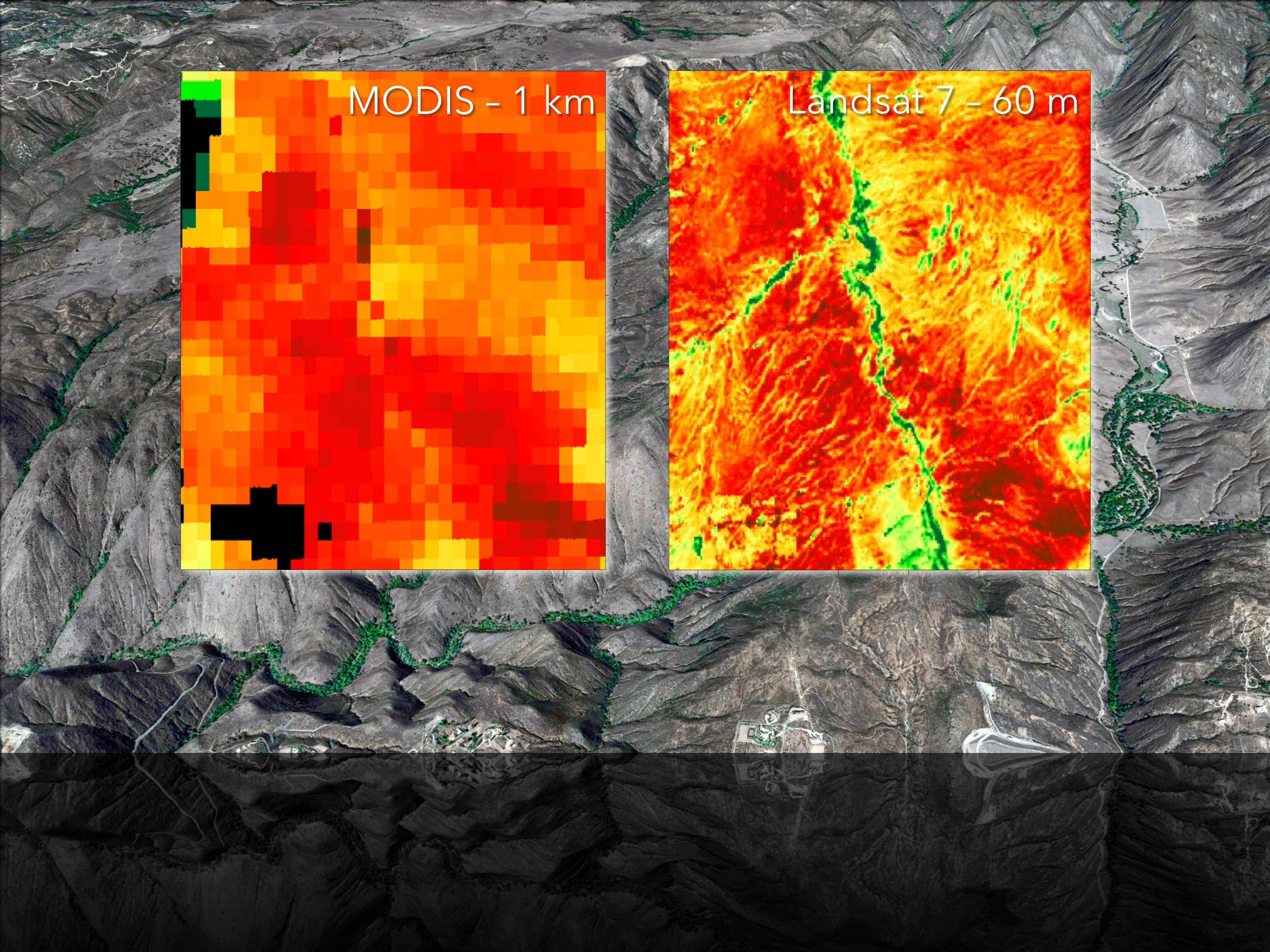
1. IDENTIFY **CRITICAL THRESHOLDS** OF WATER USE AND WATER STRESS IN KEY CLIMATE SENSITIVE BIOMES (E.G., TROPICAL/ DRY TRANSITION FORESTS, BOREAL FORESTS);

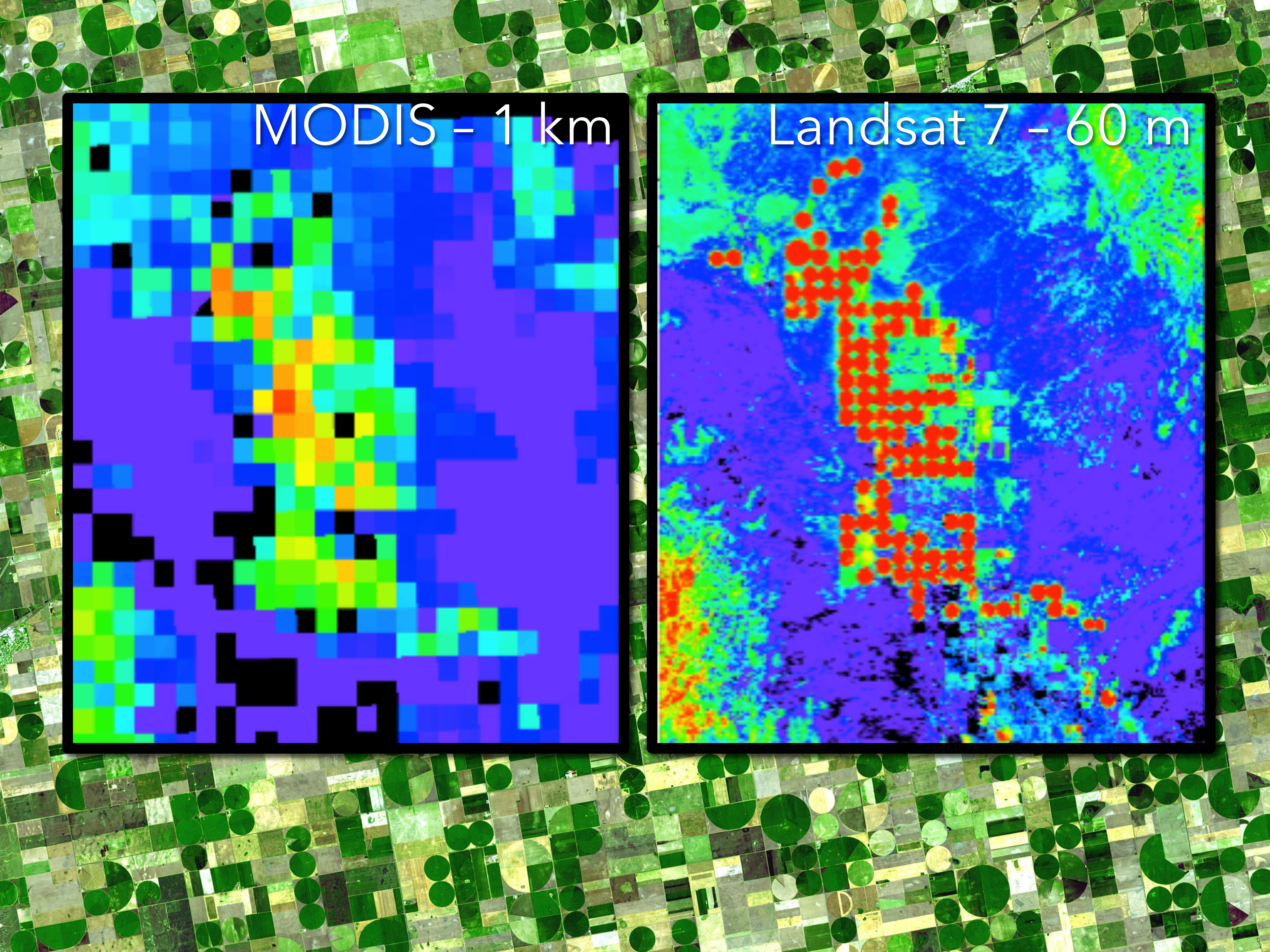
2. DETECT THE TIMING, LOCATION, AND PREDICTIVE FACTORS LEADING TO PLANT WATER UPTAKE DECLINE AND/OR CESSATION OVER THE **DIURNAL CYCLE**;

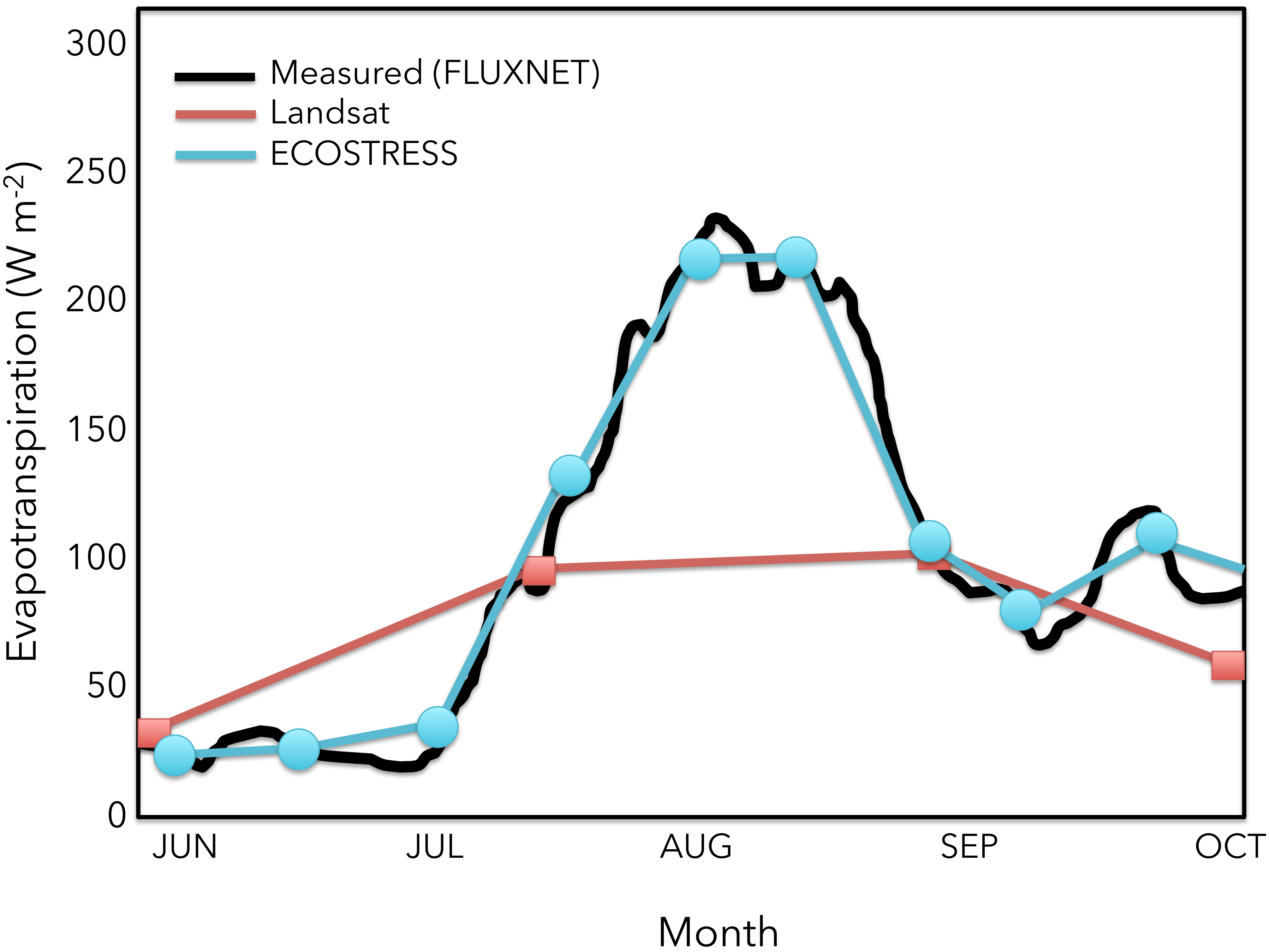
3. MEASURE AGRICULTURAL WATER **CONSUMPTIVE USE** GLOBALLY AT SPATIOTEMPORAL SCALES APPLICABLE TO IMPROVING DROUGHT ESTIMATION ACCURACY.

APPROACH

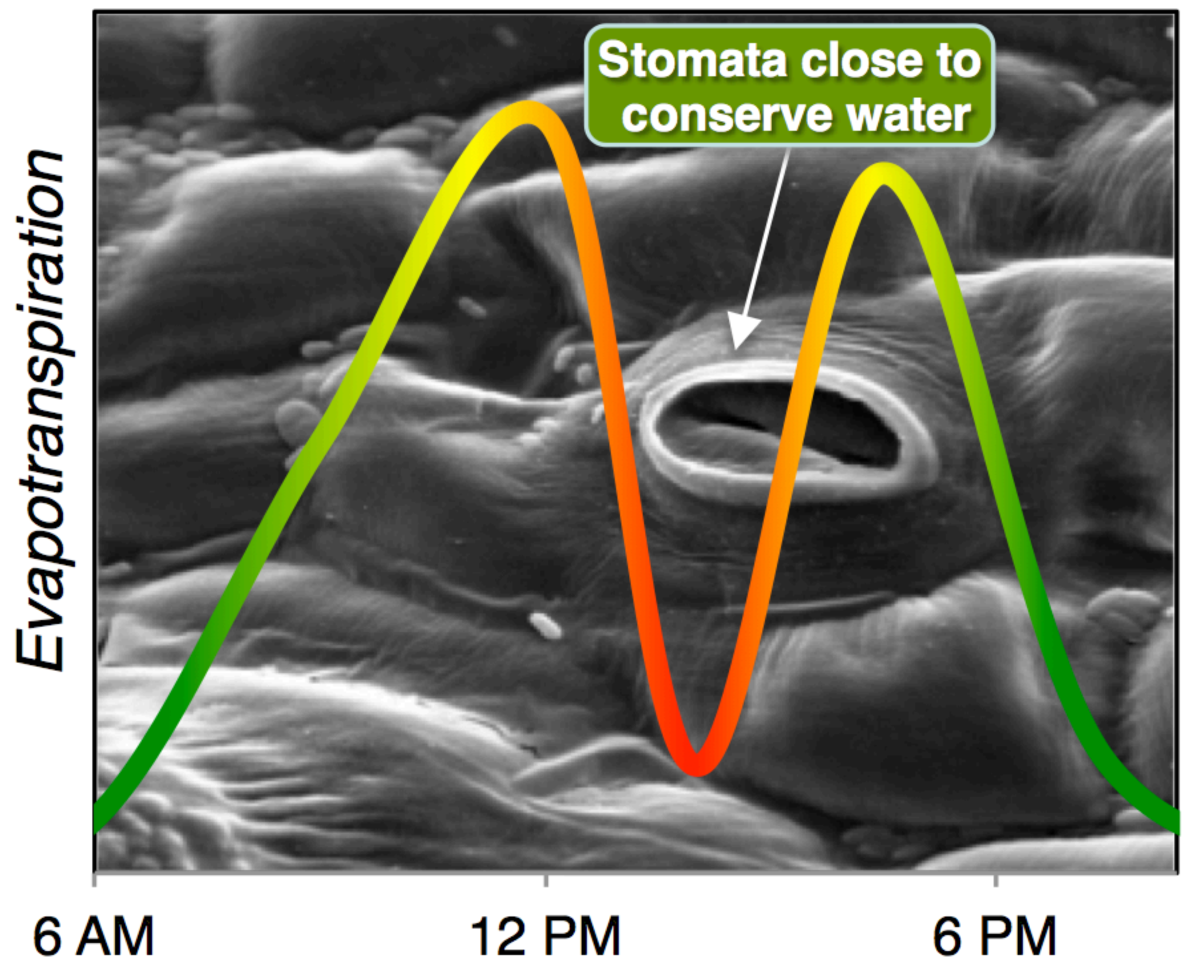
What we need: accurate, high spatial, high temporal, diurnal cycle, global, ET.


MODIS - 1 km
Landsat 7 - 60 m


MODIS – 1 km
Landsat 7 – 60 m

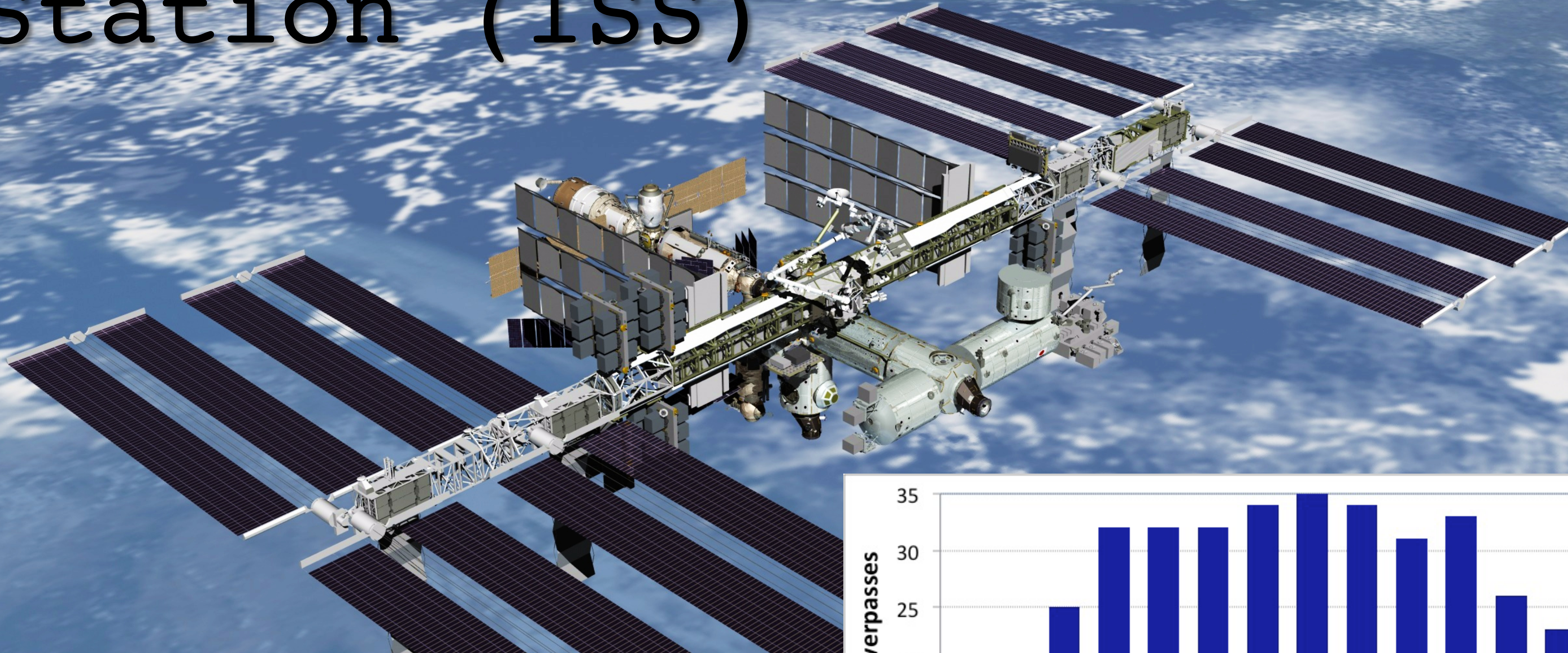

Measured (FLUXNET)
Landsat
ECOSTRESS
Evapotranspiration (W m-2)
300
250
200
150
100
50
0
JUN
JUL
AUG
SEP
OCT
Month

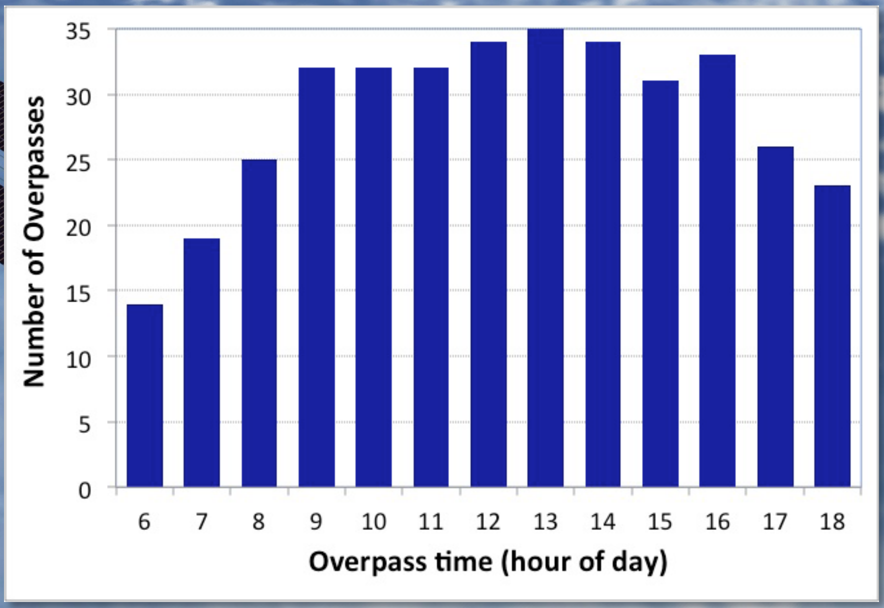
Water Stress Drives Plant Behavior

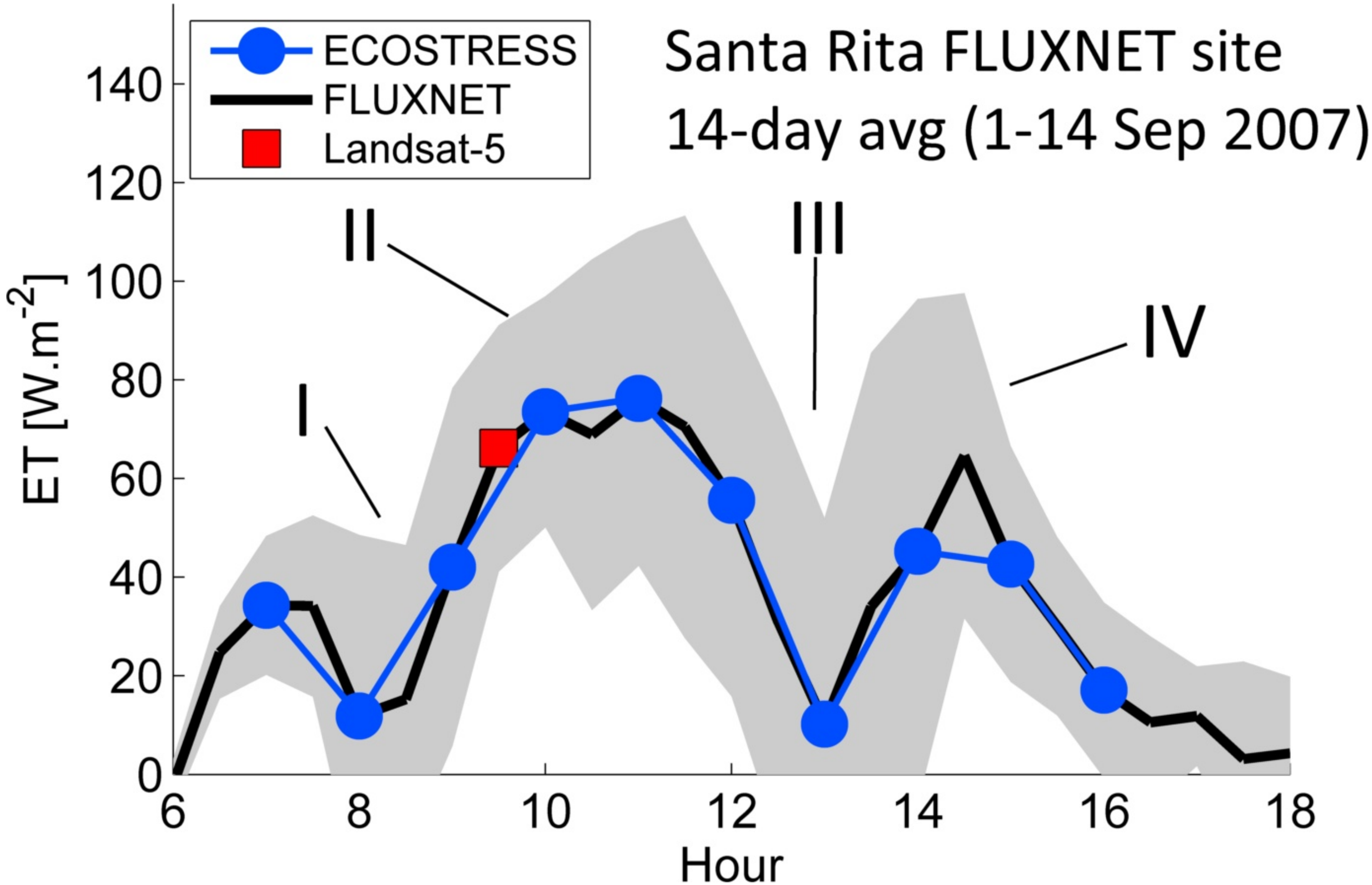



GOES-R
AMERICA'S
NEXT GENERATION
WEATHER SATELLITE

The International Space Station (ISS)







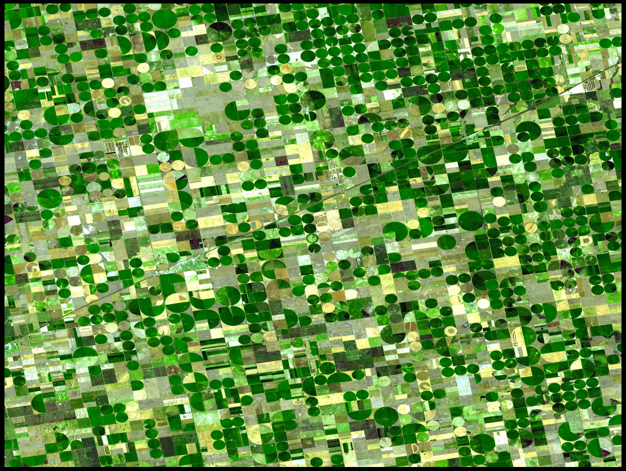
Gray shading represents mean **diurnal variation** in ET over 14-days. The afternoon decline in ET is related to water stress (clear day).

- **I** Xylem refilling after initial water release.
- **II** ET at maximum/potential rate in the morning.
- **III** Stomata shut down water flux in the afternoon.
- **IV** ET resumes at maximum/potential in early evening when demand is reduced.

ET Spaceborne Measurements Requirements

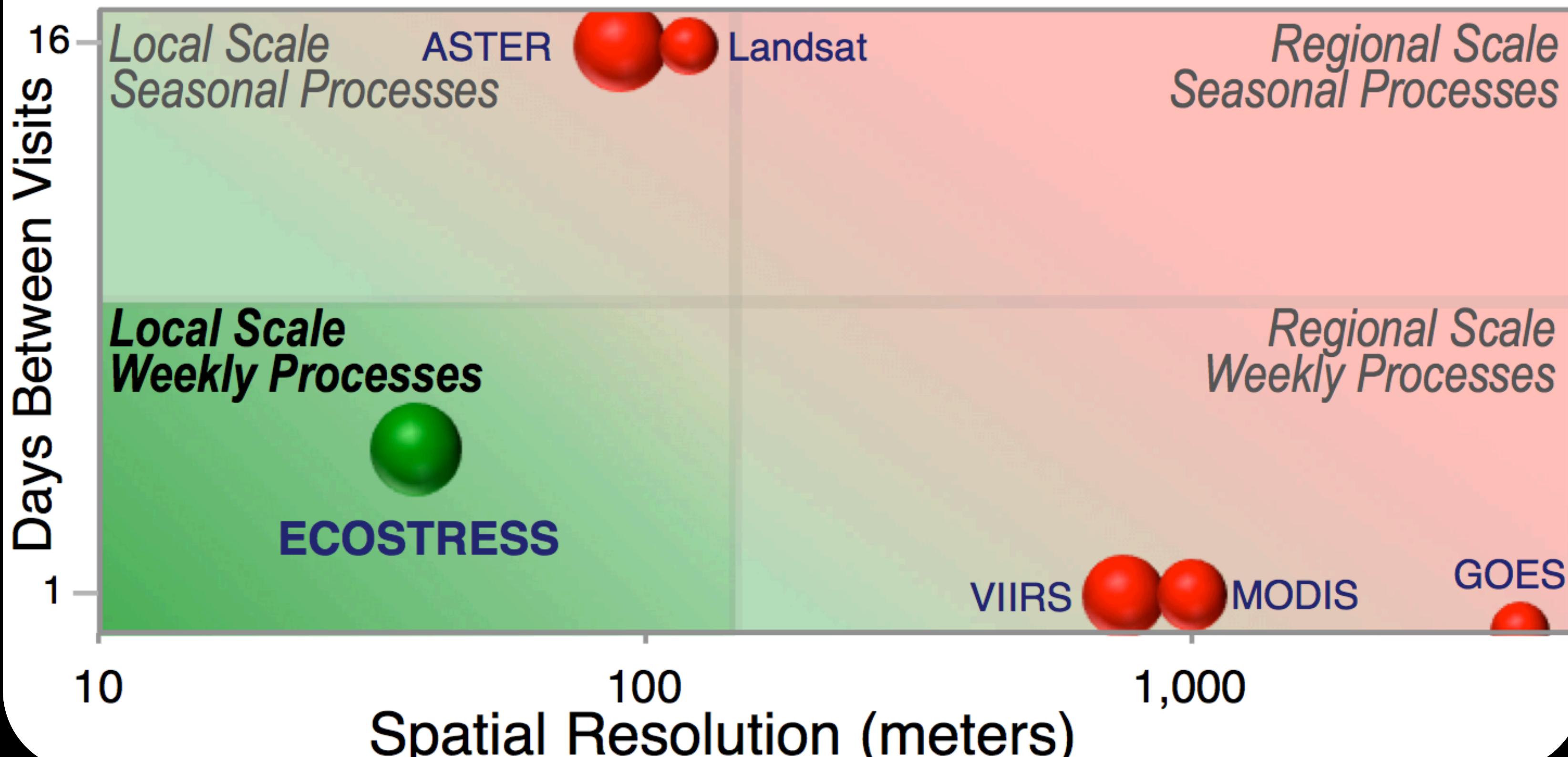
Parameters	Minimal	Optimum	Landsat 8	MODIS	HyspIRI*	ECOSTRESS
Return Cycle (days)	≤8	≤4	16	1	5	3-5
Number of TIR bands	1	>2	2	3	8	5
Spatial resolution (m)	120	30	100	1000	60	38x57
Coverage	US always on	World always on	US always on	World always on	World always on	World always on+

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.*

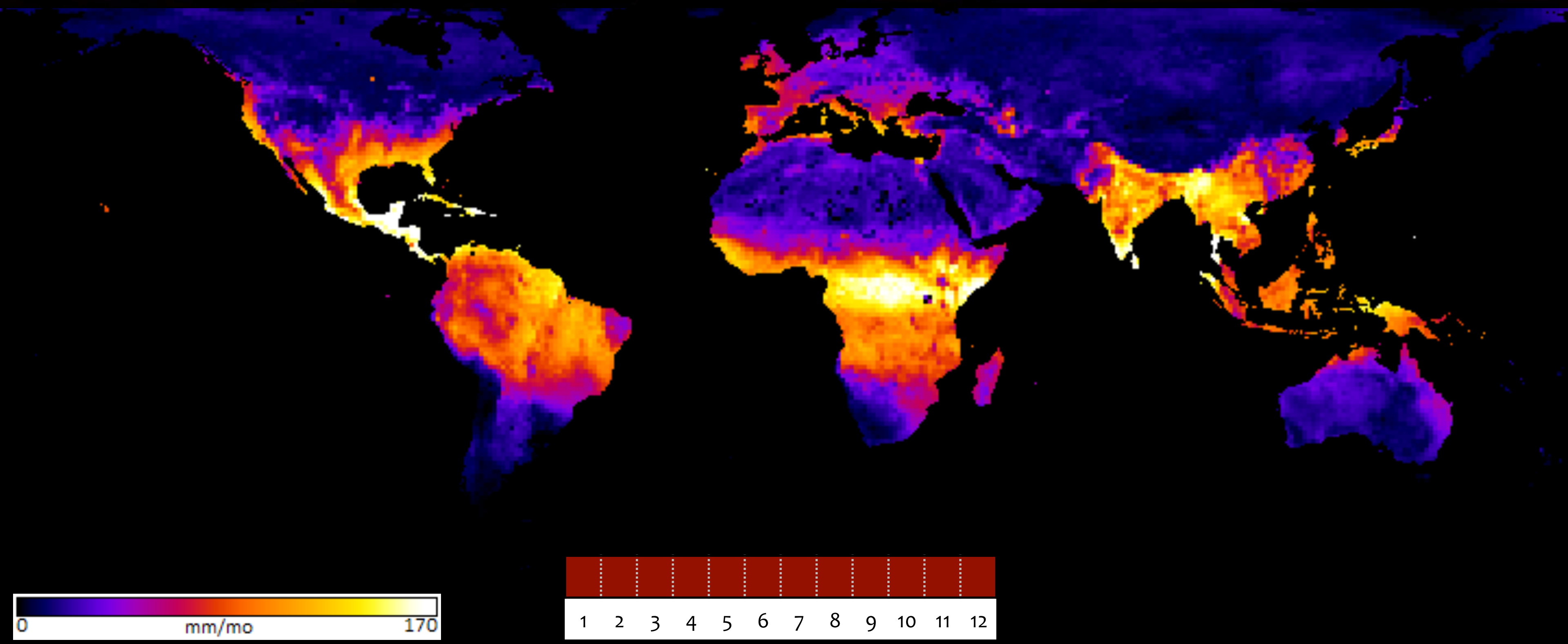


Revisit Time versus Spatial Resolution

With sphere size indicating # of thermal infrared window bands

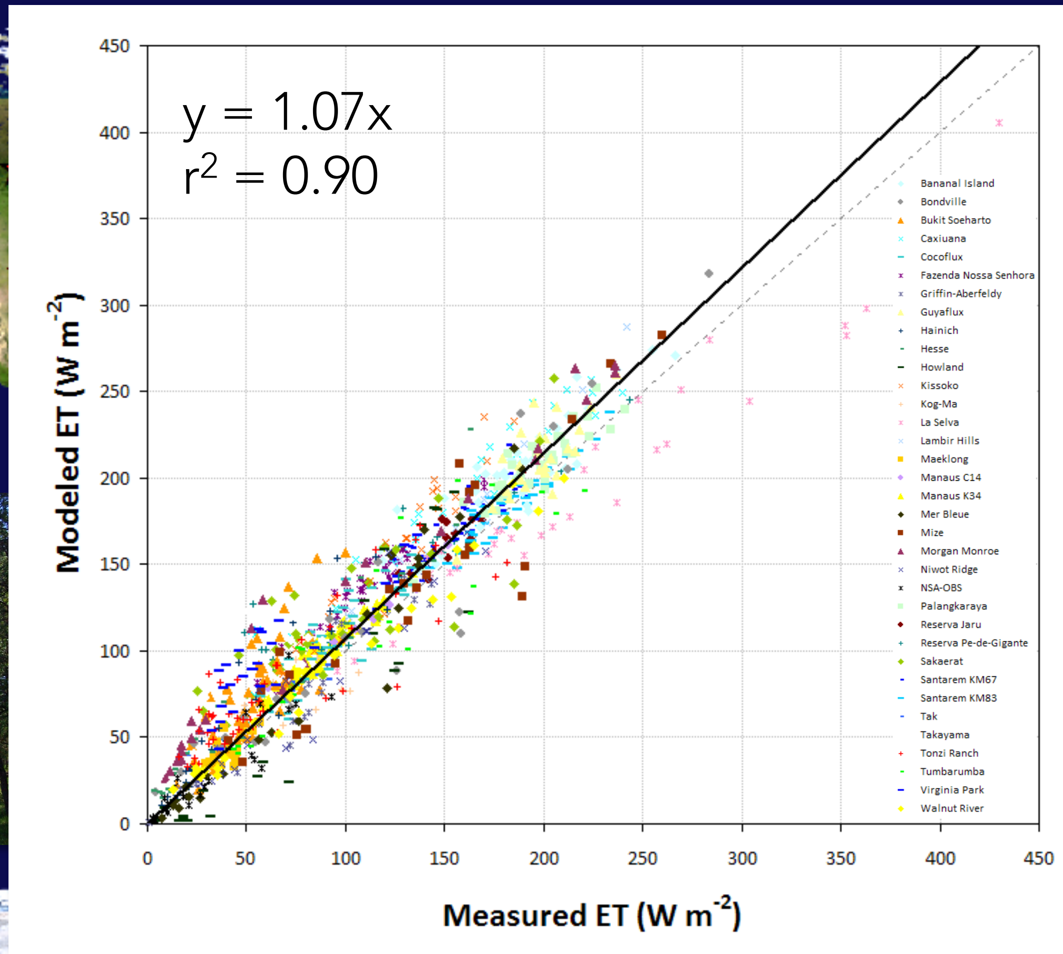


PT-JPL GLOBAL ET



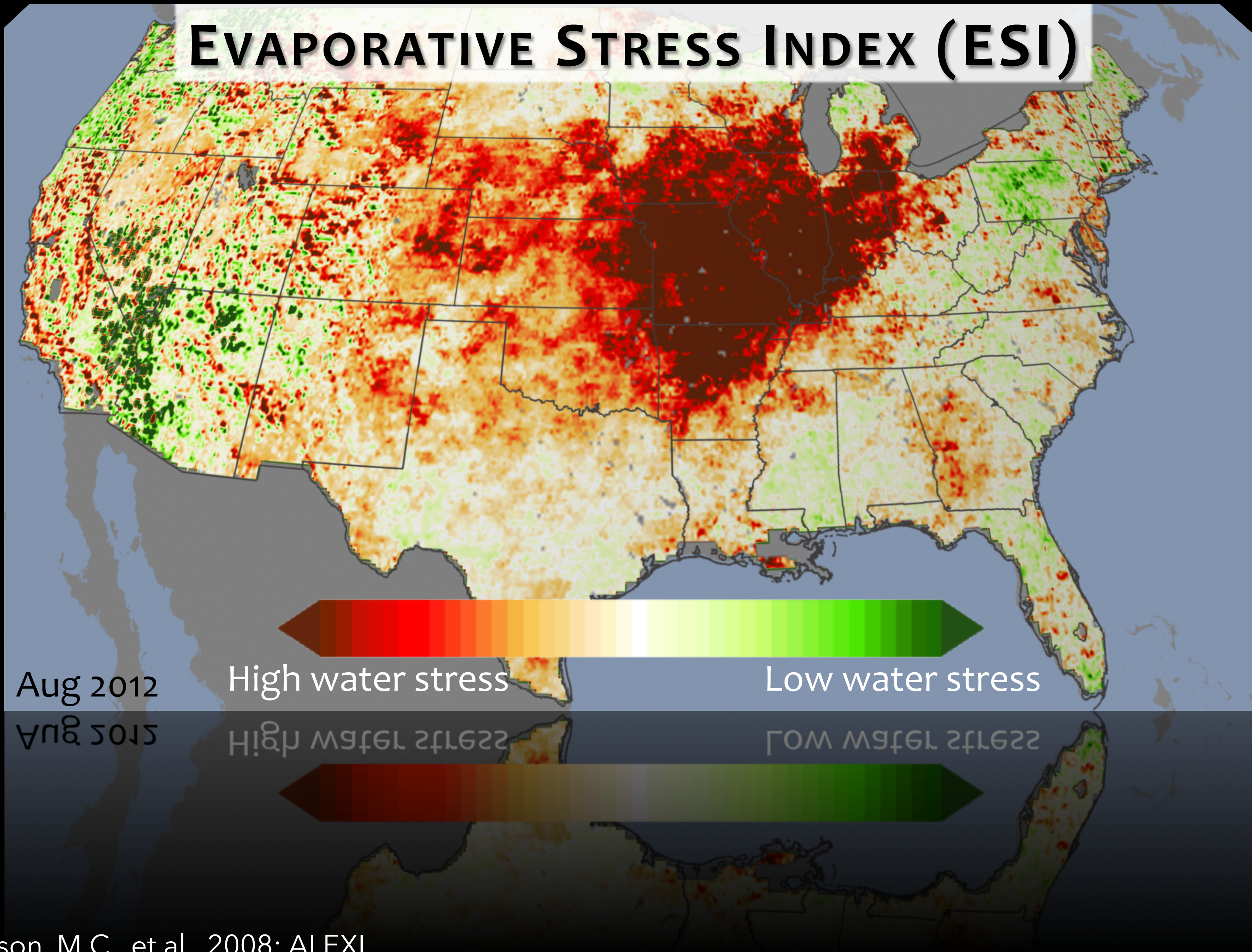
Fisher, J.B., Tu, K.P., Baldocchi, D.D., 2008. *Remote Sensing of Environment*.

MONTHLY, 0.5 DEGREE



PT-JPL ET VALIDATION

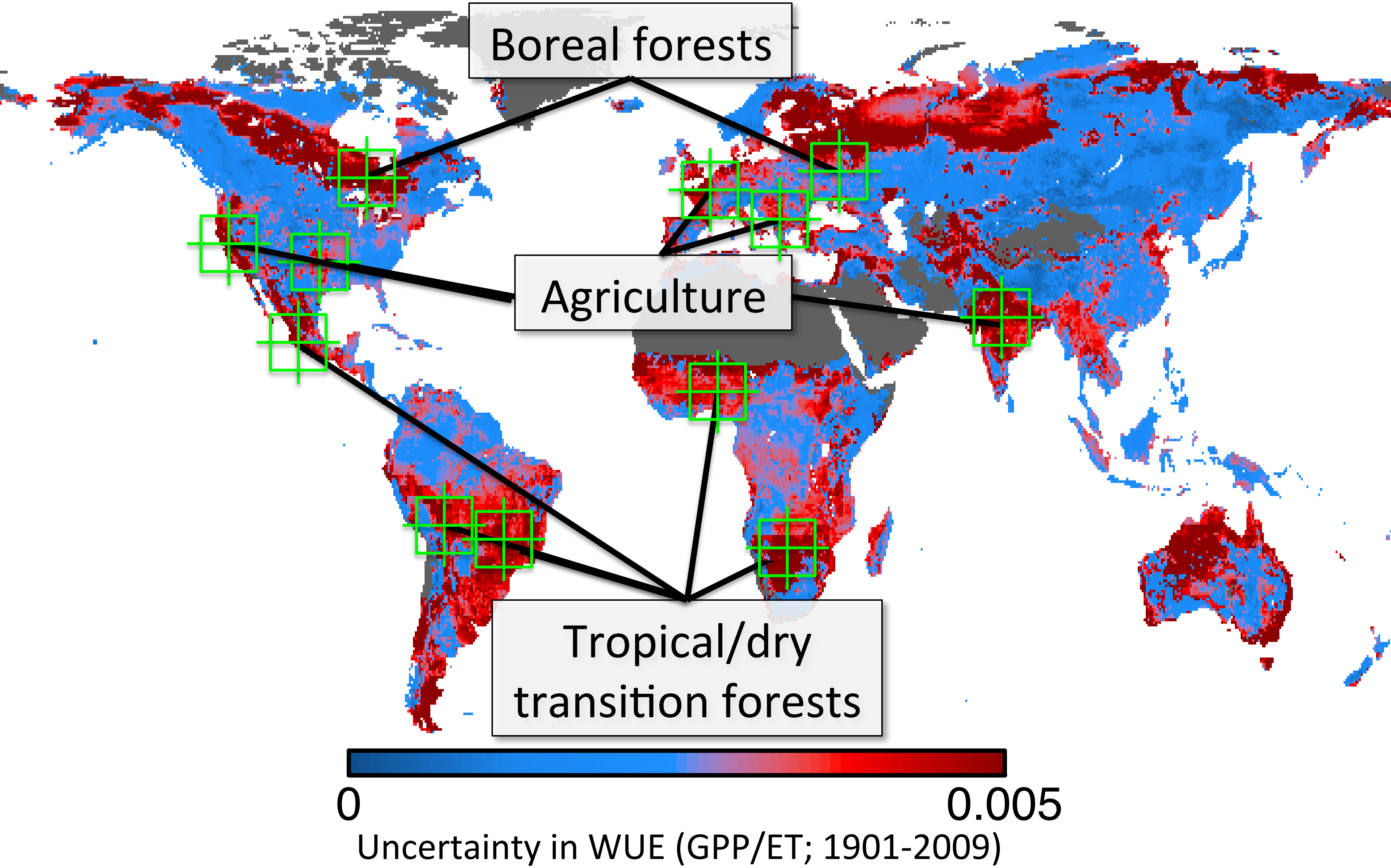
Fisher, J.B., Tu, K.P., Baldocchi, D.D., 2008. *Remote Sensing of Environment.*



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

ECOSTRESS will provide critical insight into ***plant-water dynamics*** *and how* ***ecosystems change with climate*** *via* ***high spatiotemporal*** *resolution thermal infrared radiometer measurements of evapotranspiration from the International Space Station (ISS).*

ECOSTRESS Science Data Products	
L2	Surface Temperature Surface Emissivity
L3	Evapotranspiration
L4	Water Use Efficiency Evaporative Stress Index



Nine land surface models were run with only a perturbed climate (i.e., CO_2, land use constant) over the 20th century, representing the γ-response, or climate sensitivity to identify key *WUE uncertainty hotspots*.


FLUXNET
A Global Network
NASA AirMOSS EV-1
Airborne Microwave Observatory of Subcanopy and Subsurface Project

ECOSTRESS CORE SCIENCE HYPOTHESES

H1: THE WUE OF A CLIMATE SENSITIVE HOTSPOT IS SIGNIFICANTLY LOWER THAN NON-HOTSPOTS OF THE SAME BIOME TYPE;

H_2: DAILY ET IS OVERESTIMATED WHEN EXTRAPOLATING FROM MORNING-ONLY OBSERVATIONS;

H_3: REMOTELY SENSED ET MEASURED AT THE FIELD SCALE WILL IMPROVE DROUGHT PREDICTION OVER MANAGED ECOSYSTEMS.

Our first objective on climate sensitivity and biome response, focused on water limitation and droughts, is specifically called out in:

- **Decadal Survey**: *recommended observations, key questions and science themes* [*US NRC*, 2007; Chapter 2: p27; Chapter 7: p196];
- **WCRP**: *grand science challenges* [*WCRP*, 2012];
- **NASA Earth Science**: *big questions* [*NASA Earth Science*, 2013].

Our second objective on plant-water dynamics and the functioning of terrestrial ecosystems over the diurnal cycle is encompassed within:

- **Decadal Survey**: *role of satellites in understanding ecosystems* [*US NRC*, 2007; Chapter 7: p192; Chapter 9: p257];
- **NASA Terrestrial Hydrology, Ecology, and Carbon Cycle Programs**: *primary scientific objective* and *goals* [*e.g., A.20-1 ROSES2013*].

Our third objective with relevance to agricultural applications and water management is specifically called for in:

- **NRC**: *"Global Change and Extreme Hydrology"* [*US NRC*, 2011], *"Assessment of Intraseasonal and Interannual Climate Prediction and Predictability"* [*US NRC*, 2010], and *"Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program" [US NRC*, 2013*]* ;
- **Decadal Survey**: *key questions and science themes* [*US NRC*, 2007; Chapter 7: p196]; and
- **USGCRP**: *strategic goals* [*USGCRP*, 2012].
- **White House**: *National Drought Resilience Partnership* [*Council on Environmental Quality*, 2013].

ECOSTRESS also addresses many of the science goals of the NRC Decadal Survey HyspIRI mission and Landsat mission [*US NRC*, 2013], providing lower cost, higher spatial, spectral and temporal resolution thermal infrared measurements.

Evolving ECOSTRESS, and Beyond…

- → HyspIRI →
- → Landsat/SLI →