Mapping Water Use and Drought with Satellite Remote Sensing

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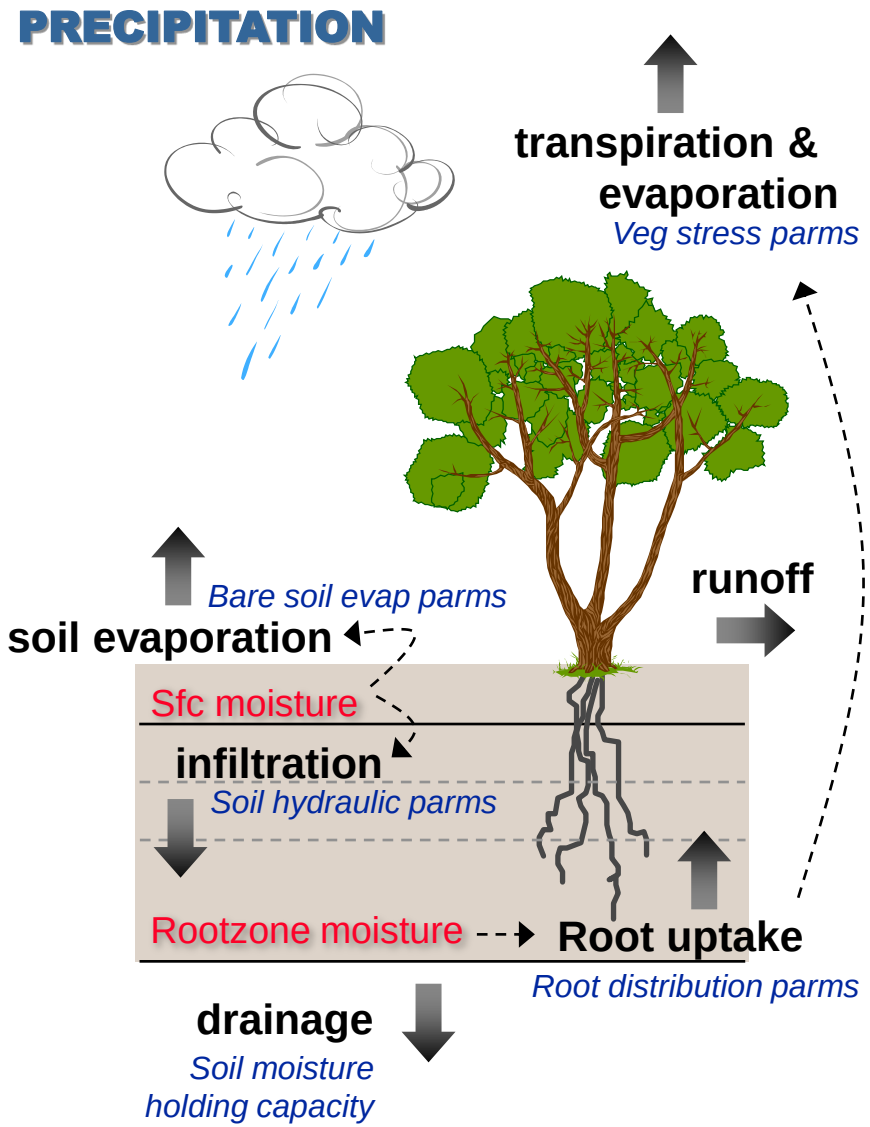
USDA-Agricultural Research Service
Hydrology and Remote Sensing Laboratory
Beltsville, MD

WATER ACCOUNTING AND FOOD SECURITY

- Improved accounting of current water use and crop water productivity
- Monitoring changes in water use with changing climate, land-use and population
- Improved hydrologic monitoring (flood, drought, runoff) to better cope with extremes
- Facilitate design of climate adaptation strategies

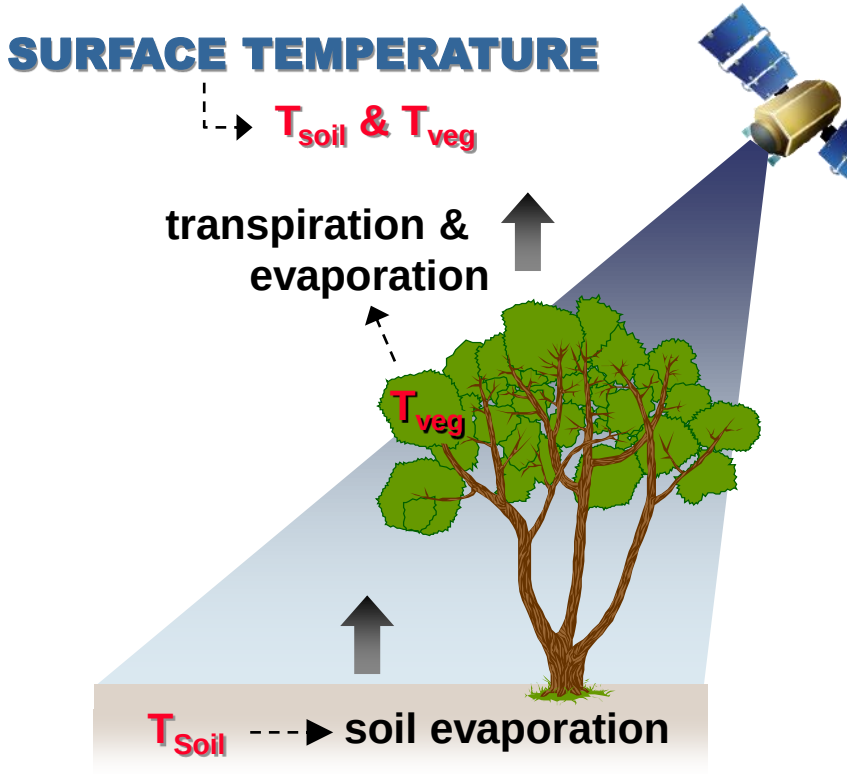
We can't manage what we can't measure …

Approaches to mapping ET



WATER BALANCE APPROACH

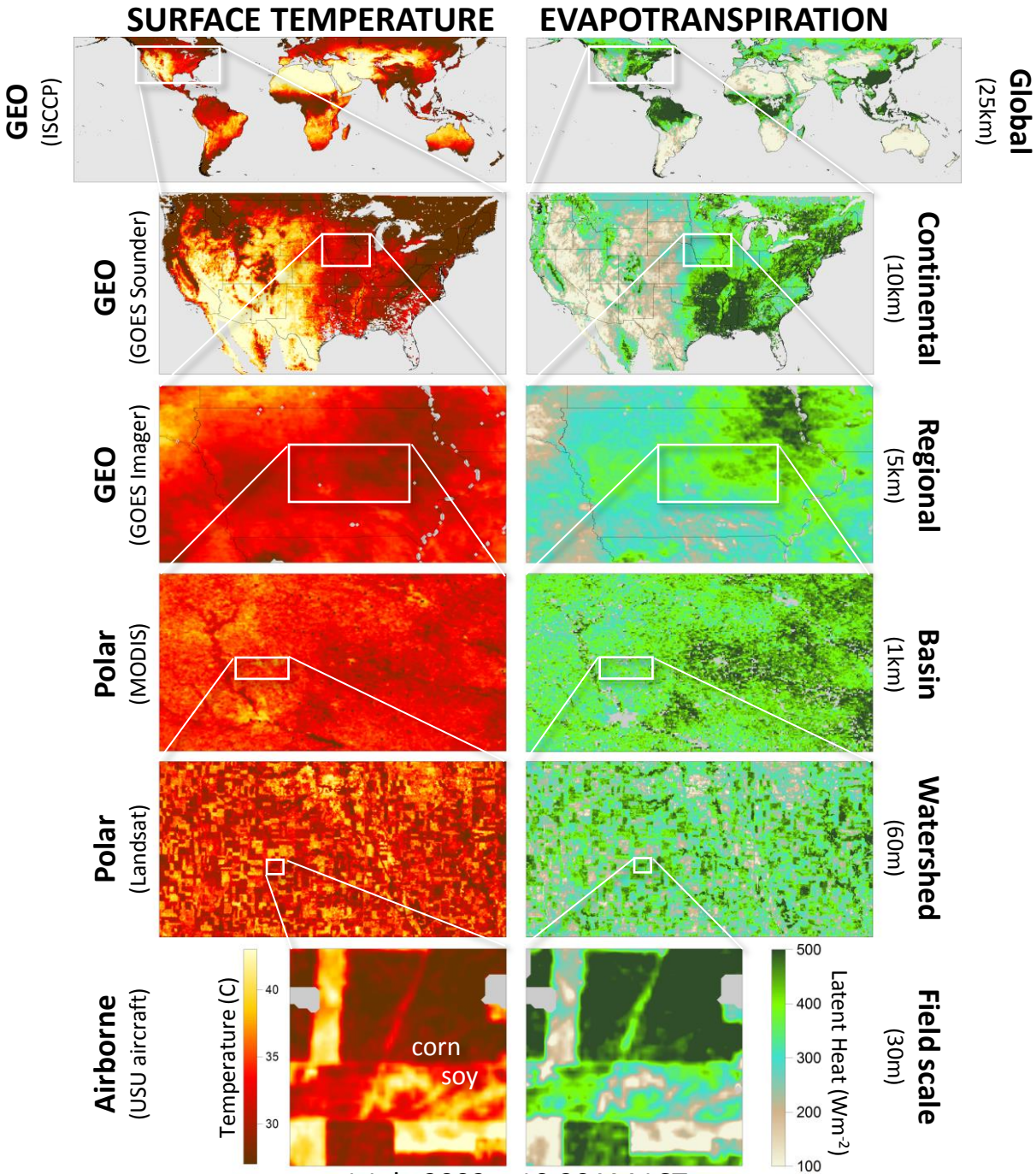
(prognostic modeling)



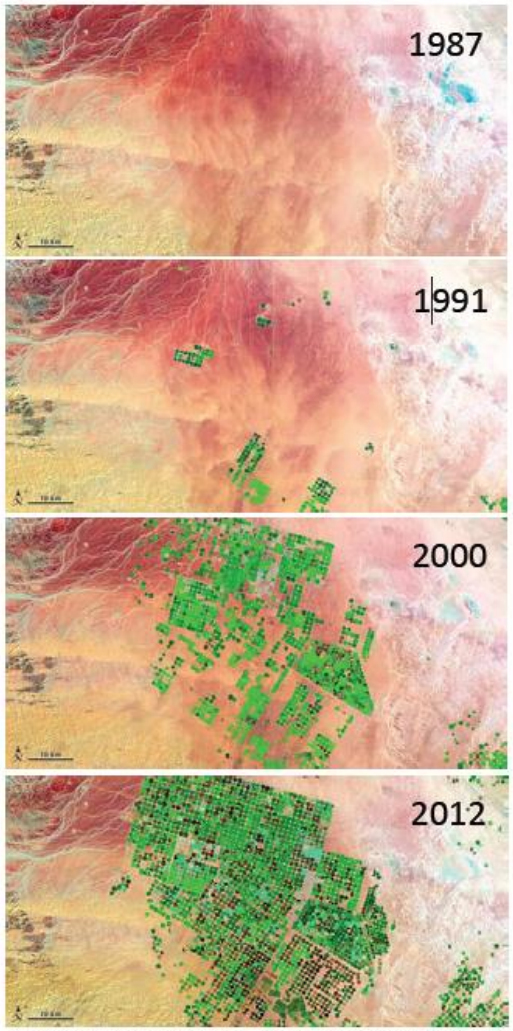
Given known radiative energy inputs, how much water loss is required to keep the soil and vegetation at the observed temperatures?

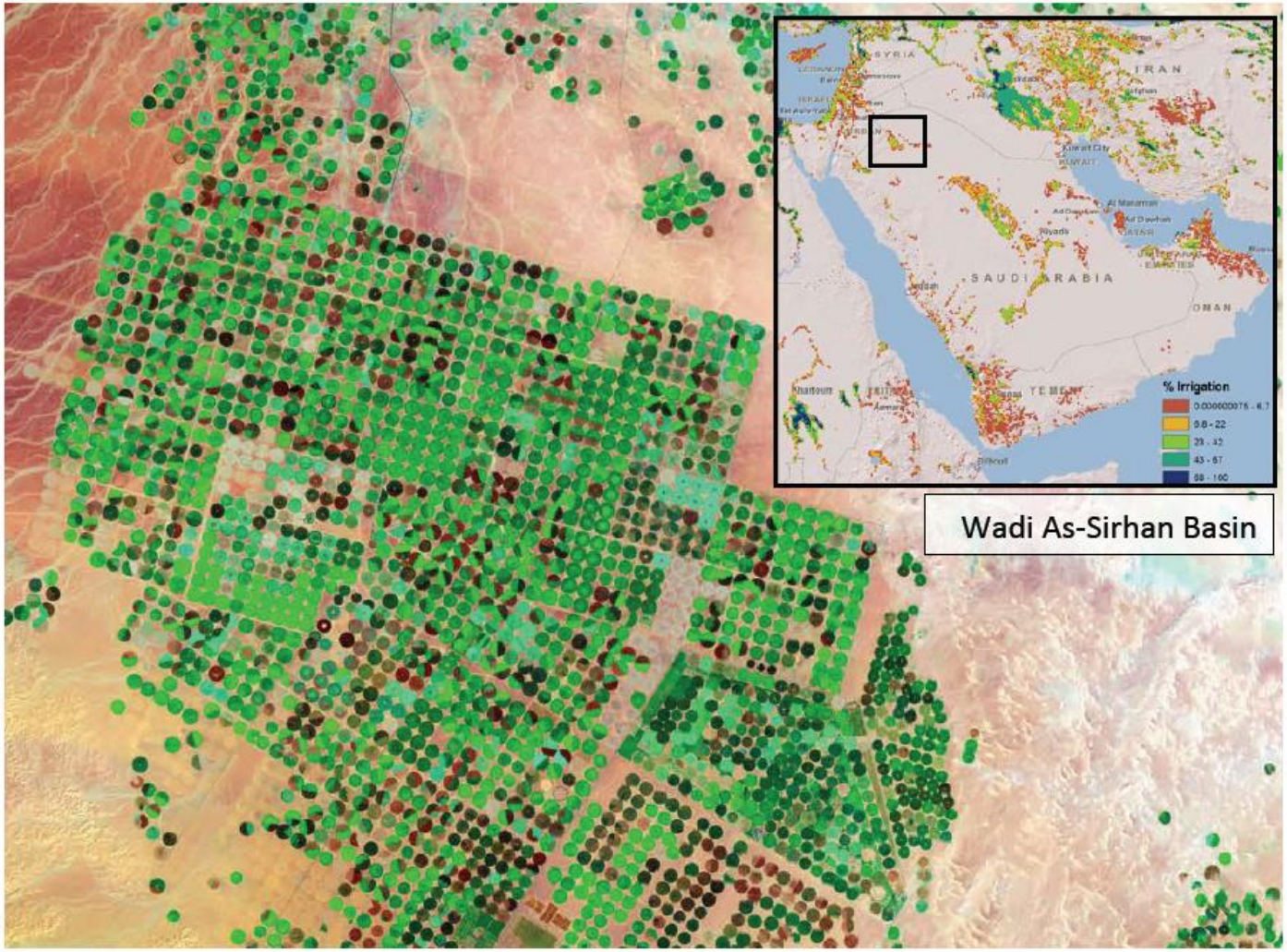
ENERGY BALANCE APPROACH

(diagnostic modeling)


SURFACE TEMPERATURE
EVAPOTRANSPIRATION
GEO (ISCCP)
Global (25km)
GEO (GOES Sounder)
Continental (10km)
GEO (GOES Imager)
Regional (5km)
Polar (MODIS)
Basin (1km)
Polar (Landsat)
Watershed (60m)
Airborne (USU aircraft)
Field scale (30m)
Temperature (C)
40
35
30
corn
soy
Latent Heat (Wm-2)
500
400
300
200
100
1 July 2002 – 10:30AM LST

EXPANSION of IRRIGATION



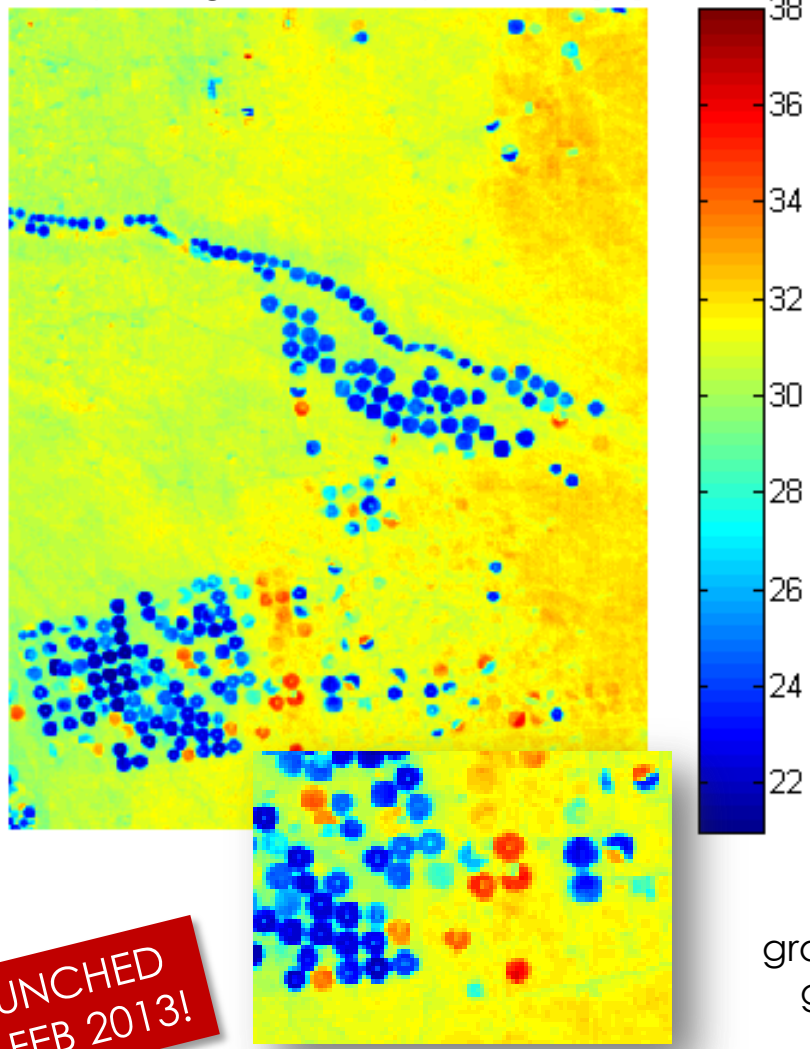


http://earthobservatory.nasa.gov/IOTD/view.php?id=77900

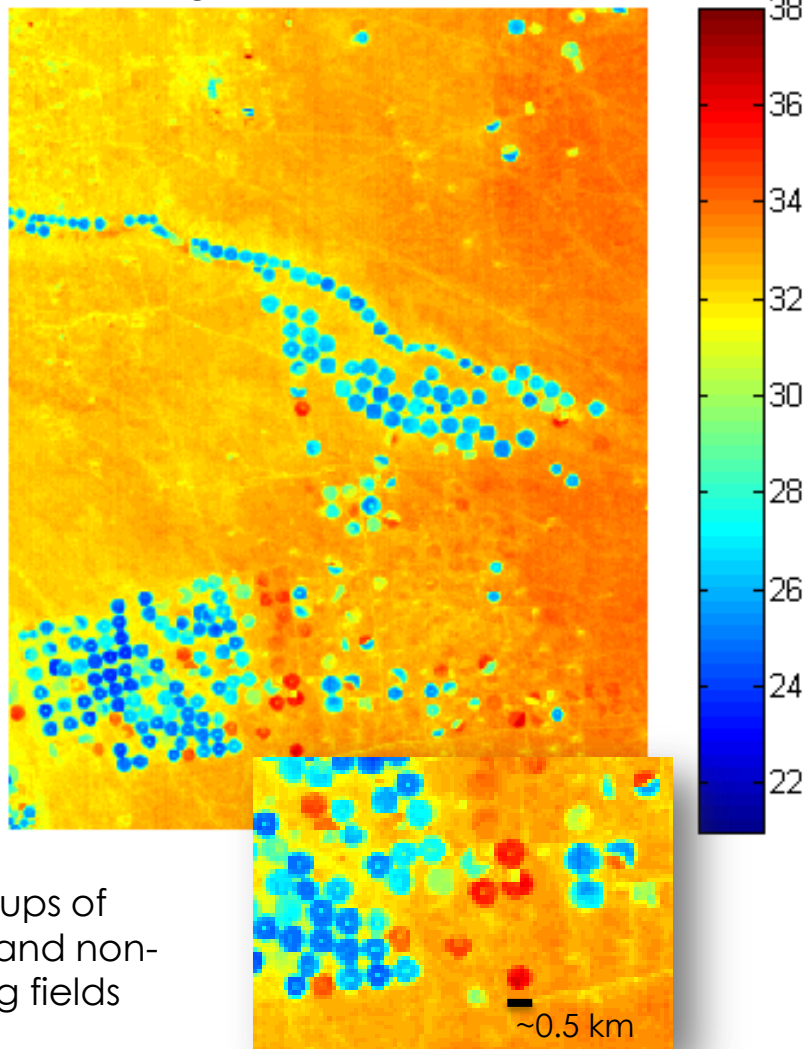
Landsats 4,5,7 – visible, near infrared bands: vegetation amount

CONSUMPTIVE WATER USE

10.8 µm Brightness Temperature [C]



12.0 µm Brightness Temperature [C]

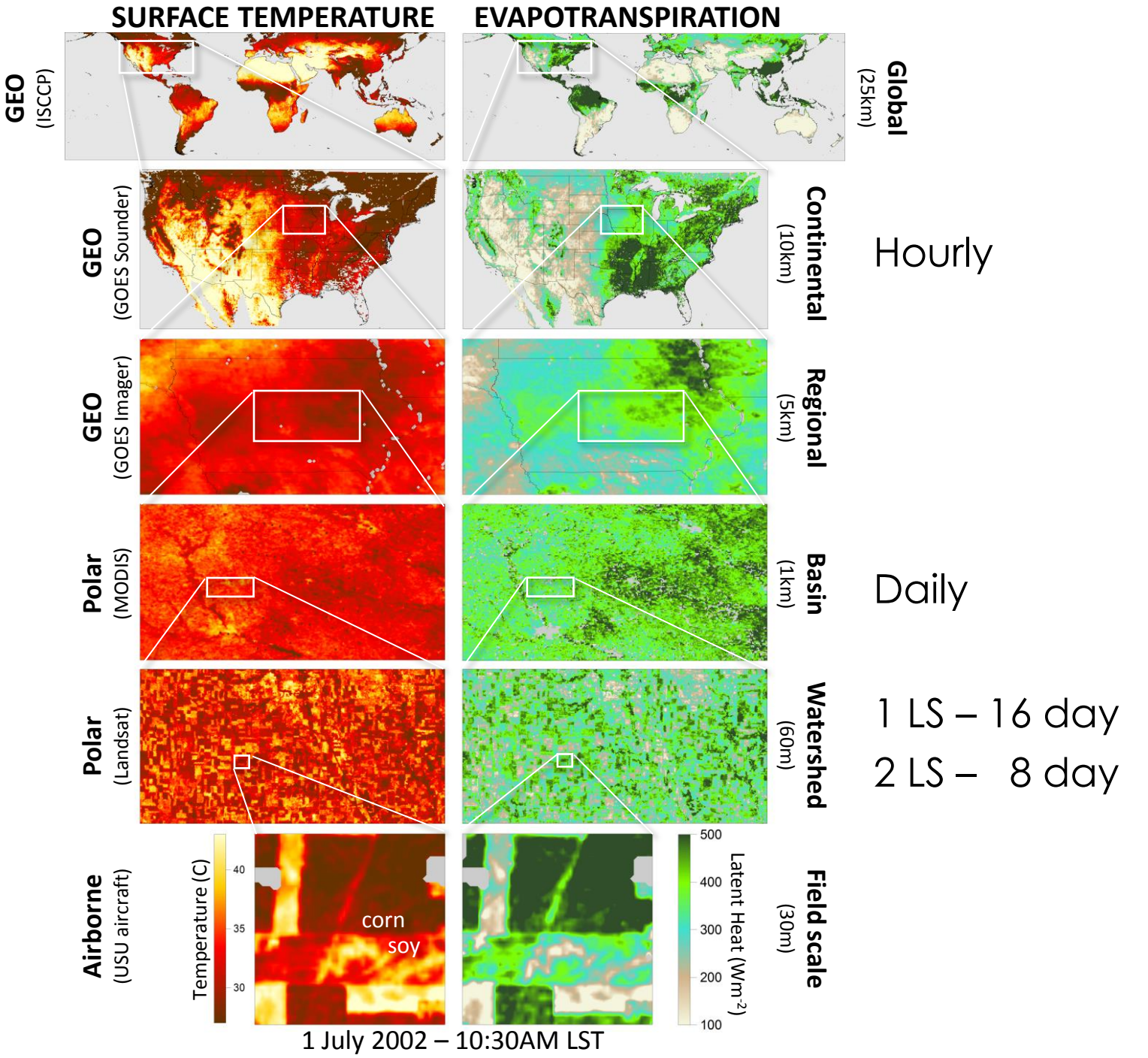


Close-ups of growing and non-growing fields

~0.5 km

LAUNCHED 11 FEB 2013!

Landsat 8 – thermal infrared bands: vegetation status and water use


SURFACE TEMPERATURE
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GEO (ISCCP)
Global (25km)
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Continental (10km)
Hourly
GEO (GOES Imager)
Regional (5km)
Polar (MODIS)
Basin (1km)
Daily
Polar (Landsat)
Watershed (60m)
1 LS – 16 day
2 LS – 8 day
Airborne (USU aircraft)
Field scale (30m)
Temperature (C)
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35
30
corn
soy
Latent Heat (Wm-2)
500
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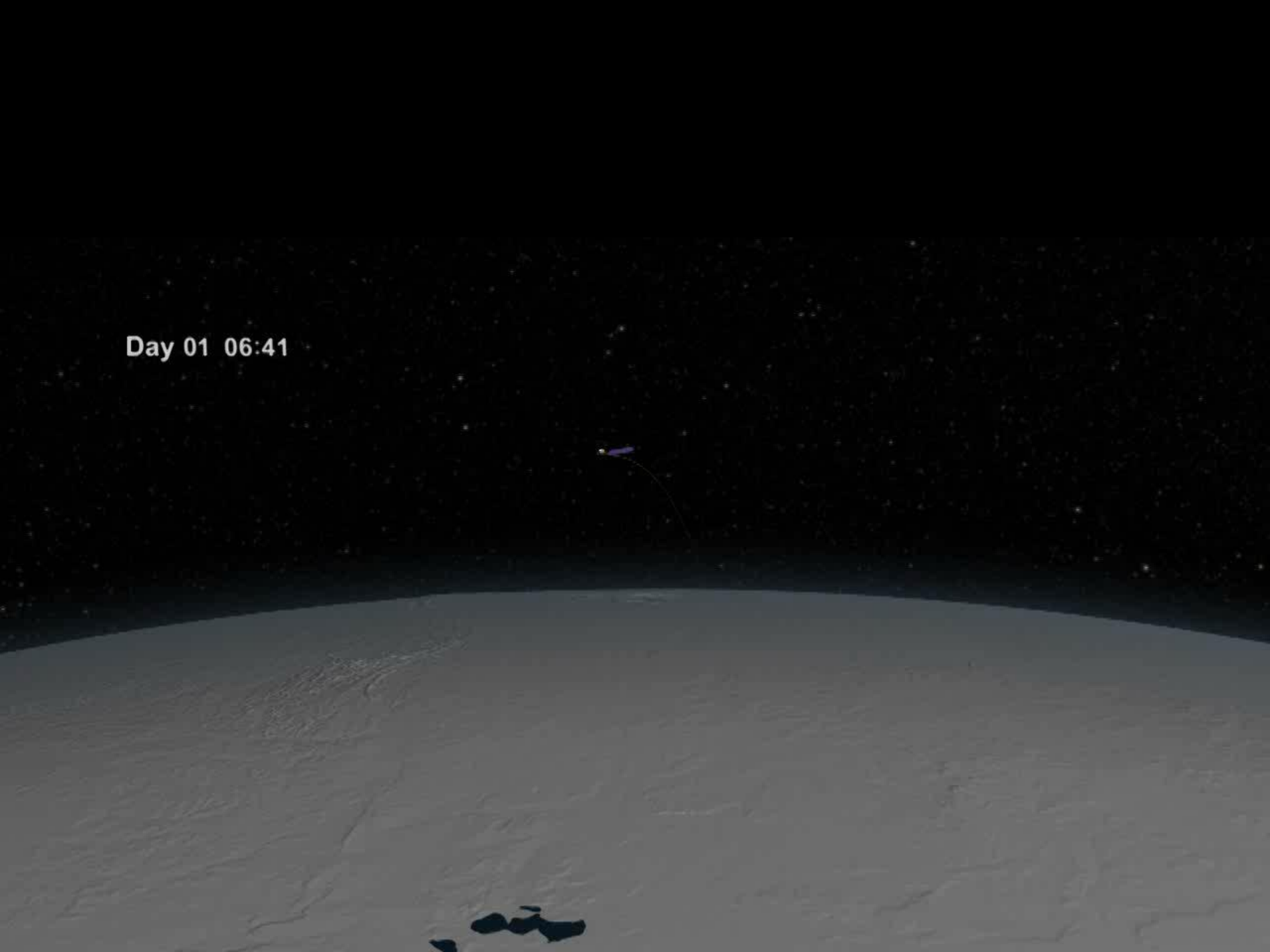
300
200
100
1 July 2002 – 10:30AM LST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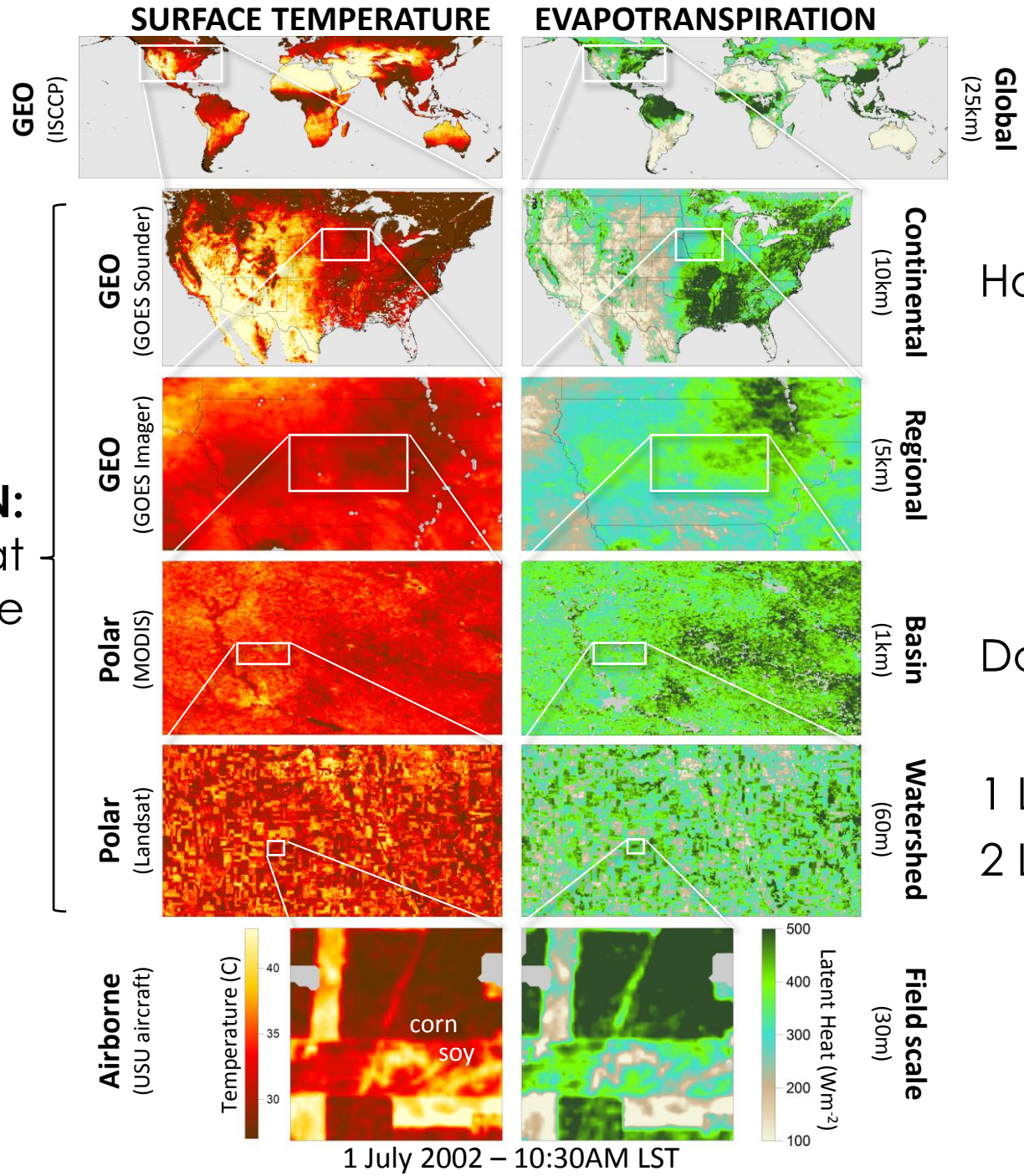
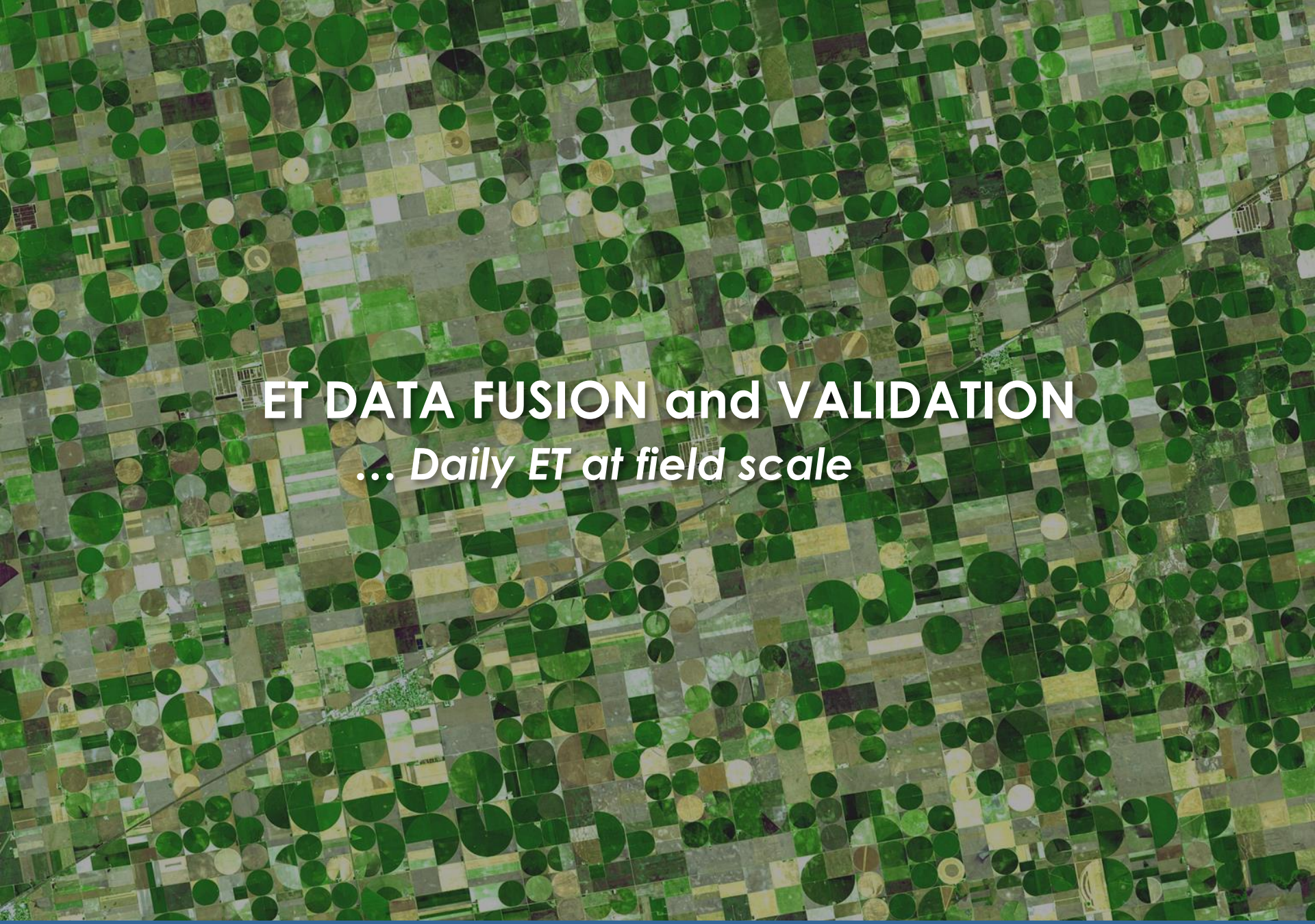


DATA FUSION:
daily ET at field scale

Hourly

Daily

1 LS – 16 day
2 LS – 8 day

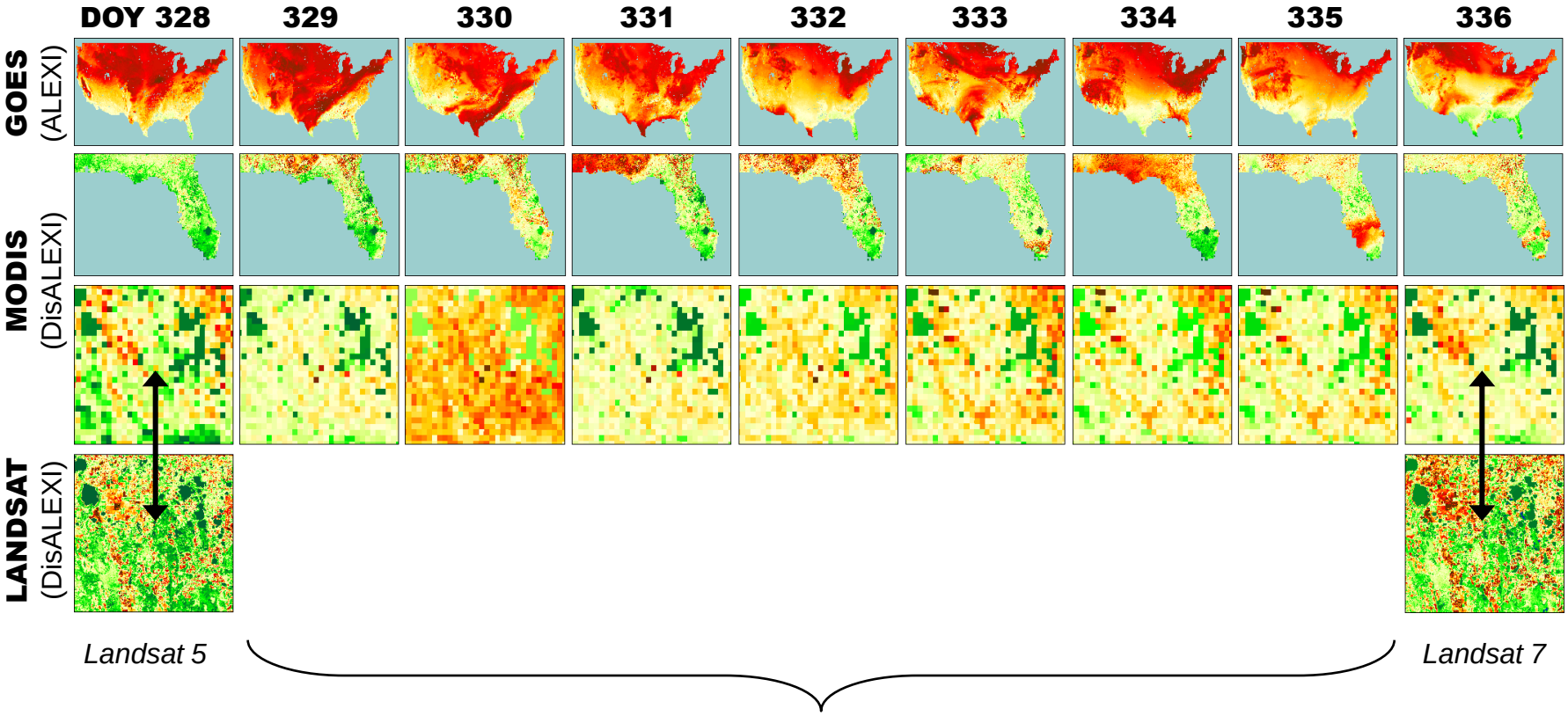


ET DATA FUSION and VALIDATION

… Daily ET at field scale

GOES/MODIS/Landsat FUSION

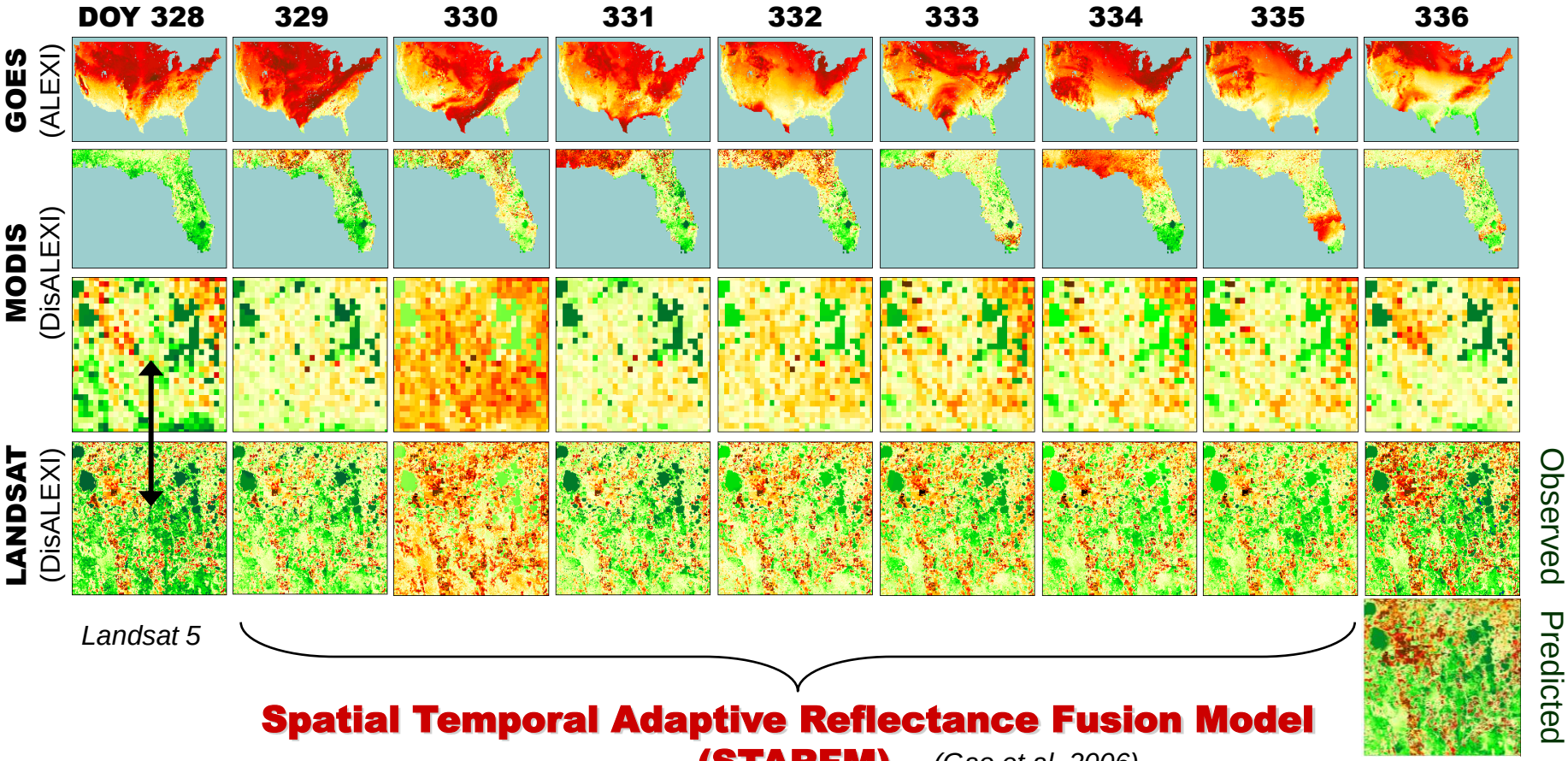
Daily Evapotranspiration – Orlando, FL, 2002



Spatial Temporal Adaptive Reflectance Fusion Model (STARFM) *(Gao et al, 2006)*

GOES/MODIS/Landsat FUSION

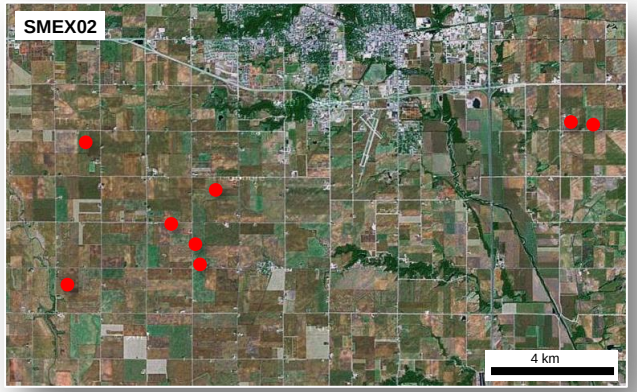
Daily Evapotranspiration – Orlando, FL, 2002



Spatial Temporal Adaptive Reflectance Fusion Model (STARFM) *(Gao et al, 2006)*

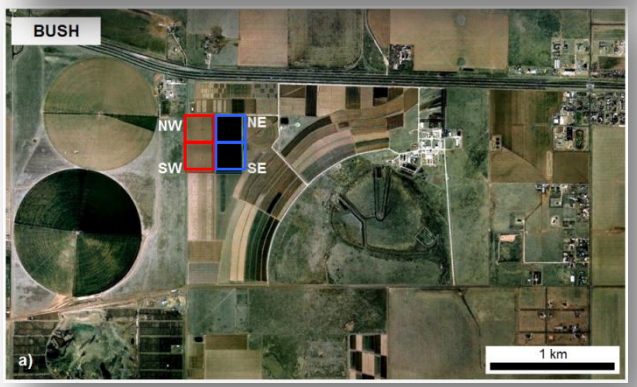
R^2: 0.83
(9% error)

Evaluation of fused ET fluxes



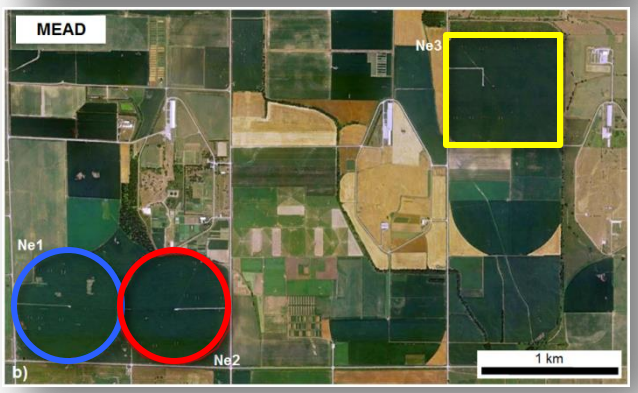
SMEX02

Soil Moisture Experiment 2002
Ames, Iowa
Rainfed corn and soybean



BEAREX08

Bushland ET and Remote sensing Experiment 2008
Bushland, Texas
Rainfed and irrigated cotton



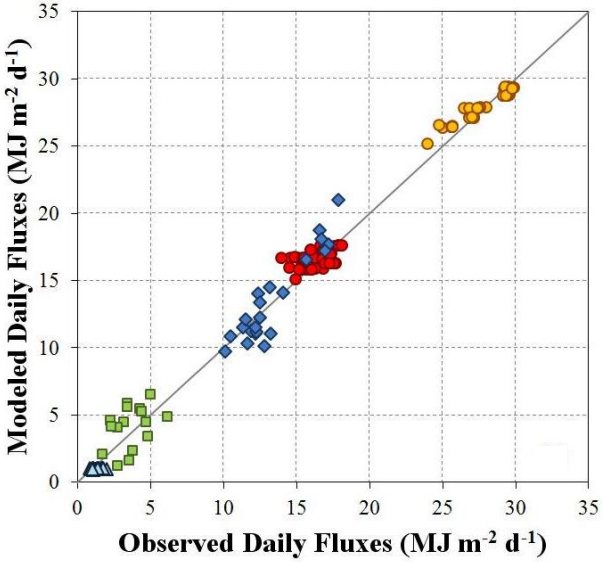
MEAD

Ameriflux site (S. Verma)
Mead, NE
Rainfed and irrigated corn and soybean

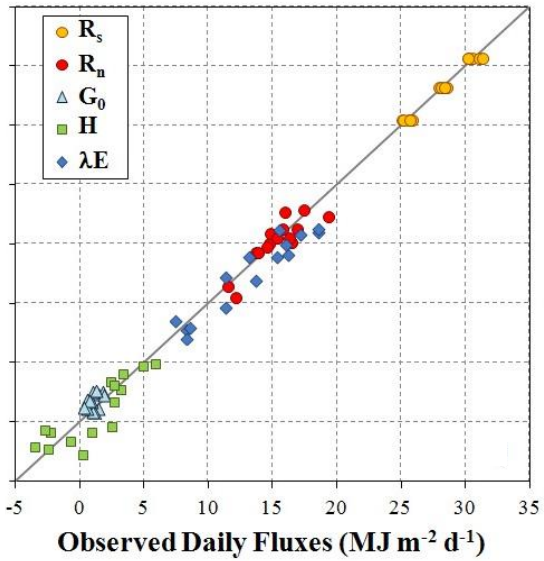
BEAREX08 (Texas Panhandle)

Model performance on Landsat dates

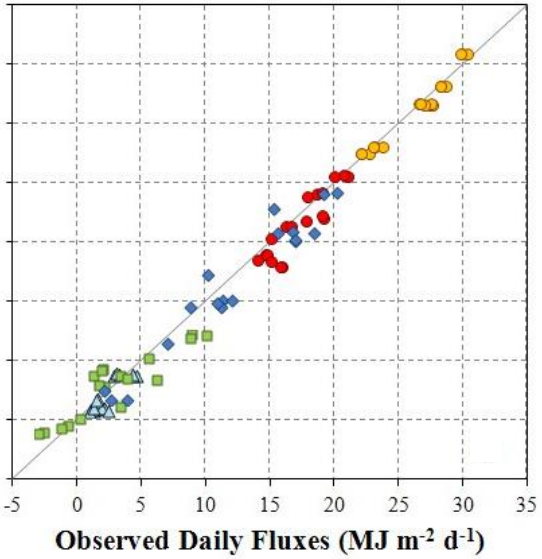
SMEX02



BEAREX08

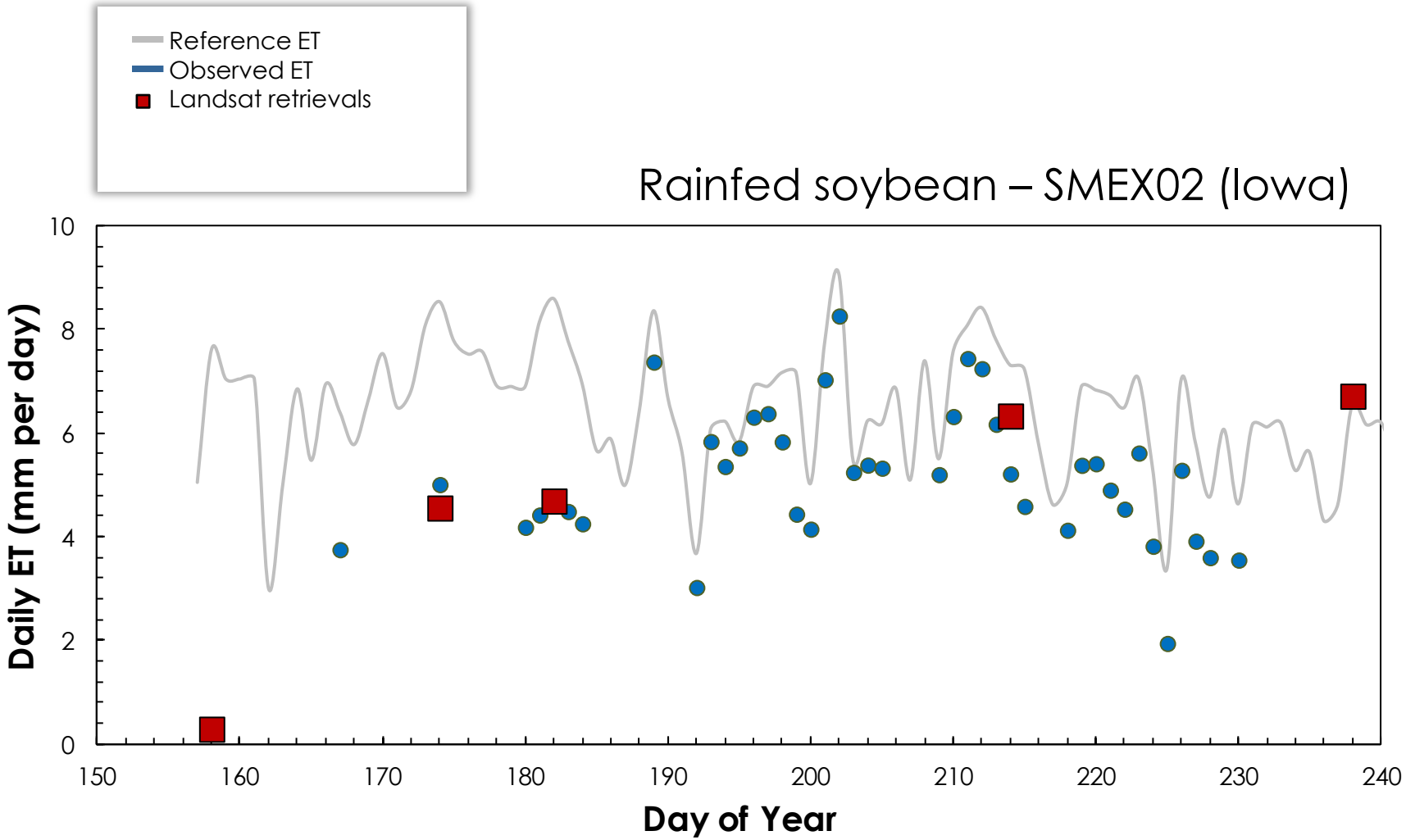


MEAD

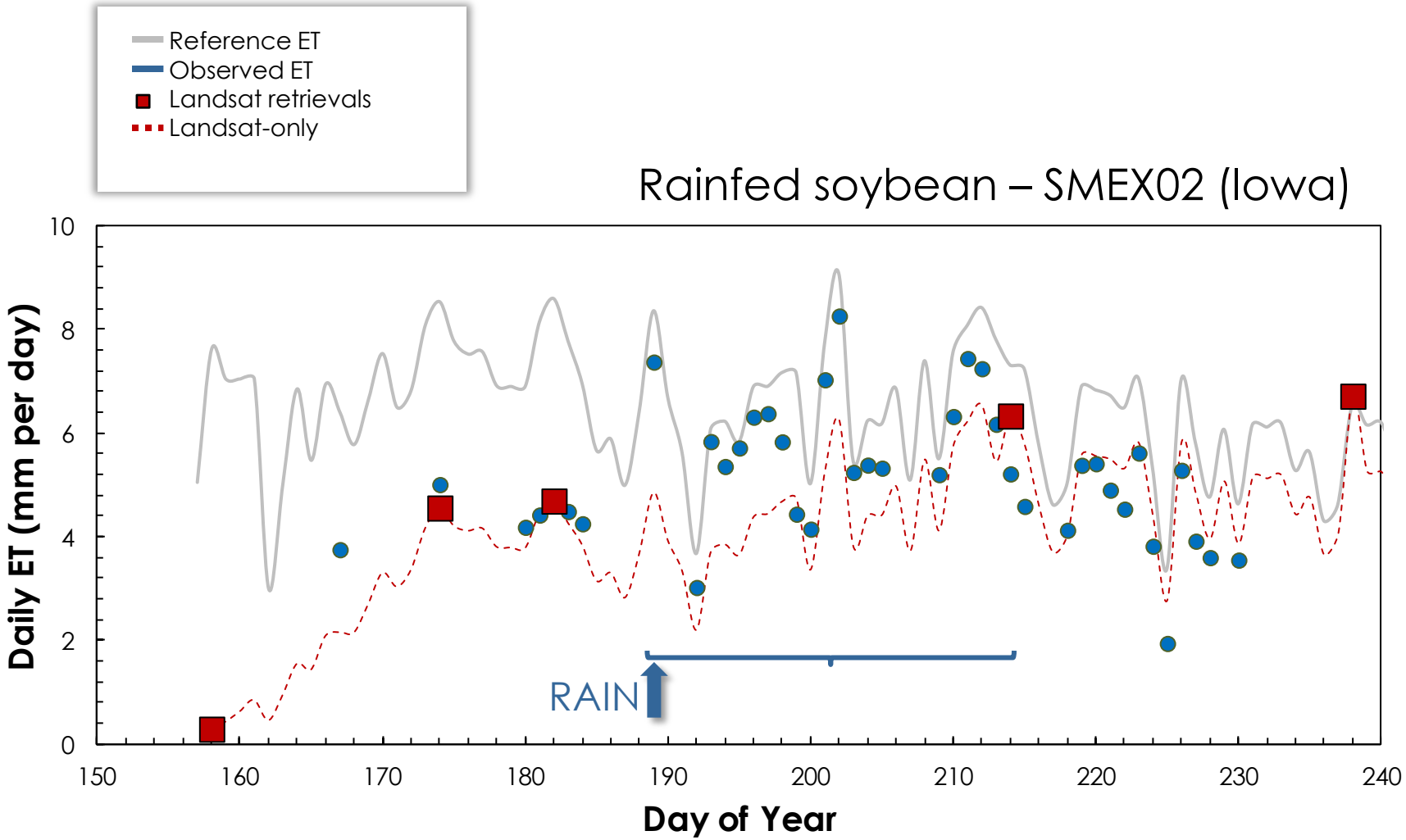


	SMEX02	BEAREX08	MEAD
MAE:	1.08 MJ m^{-2} d^{-1}	1.3 MJ m^{-2} d^{-1}	1.3 MJ m^{-2} d^{-1}
RE:	8%	10%	11%

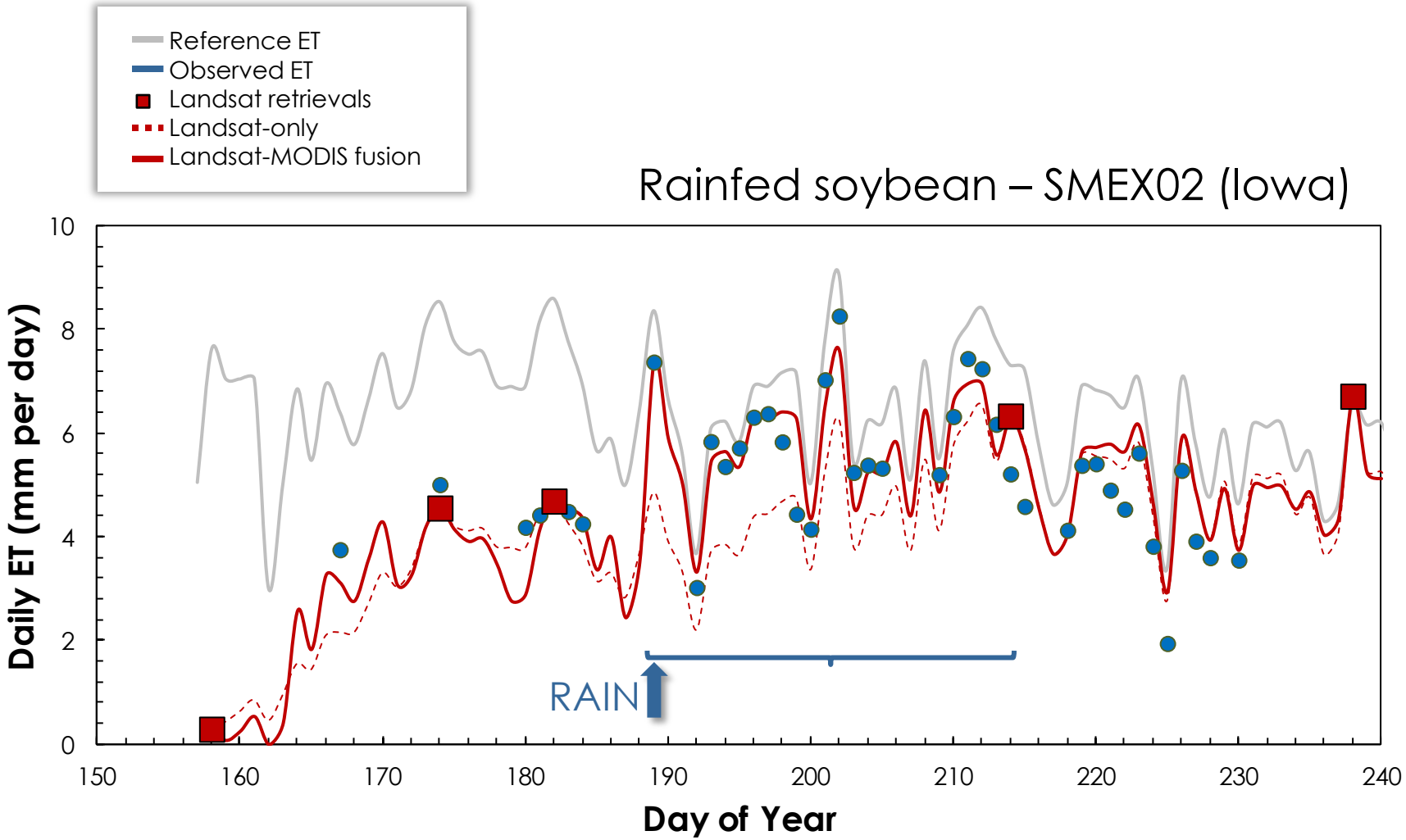
Validation using flux tower data



Validation using flux tower data

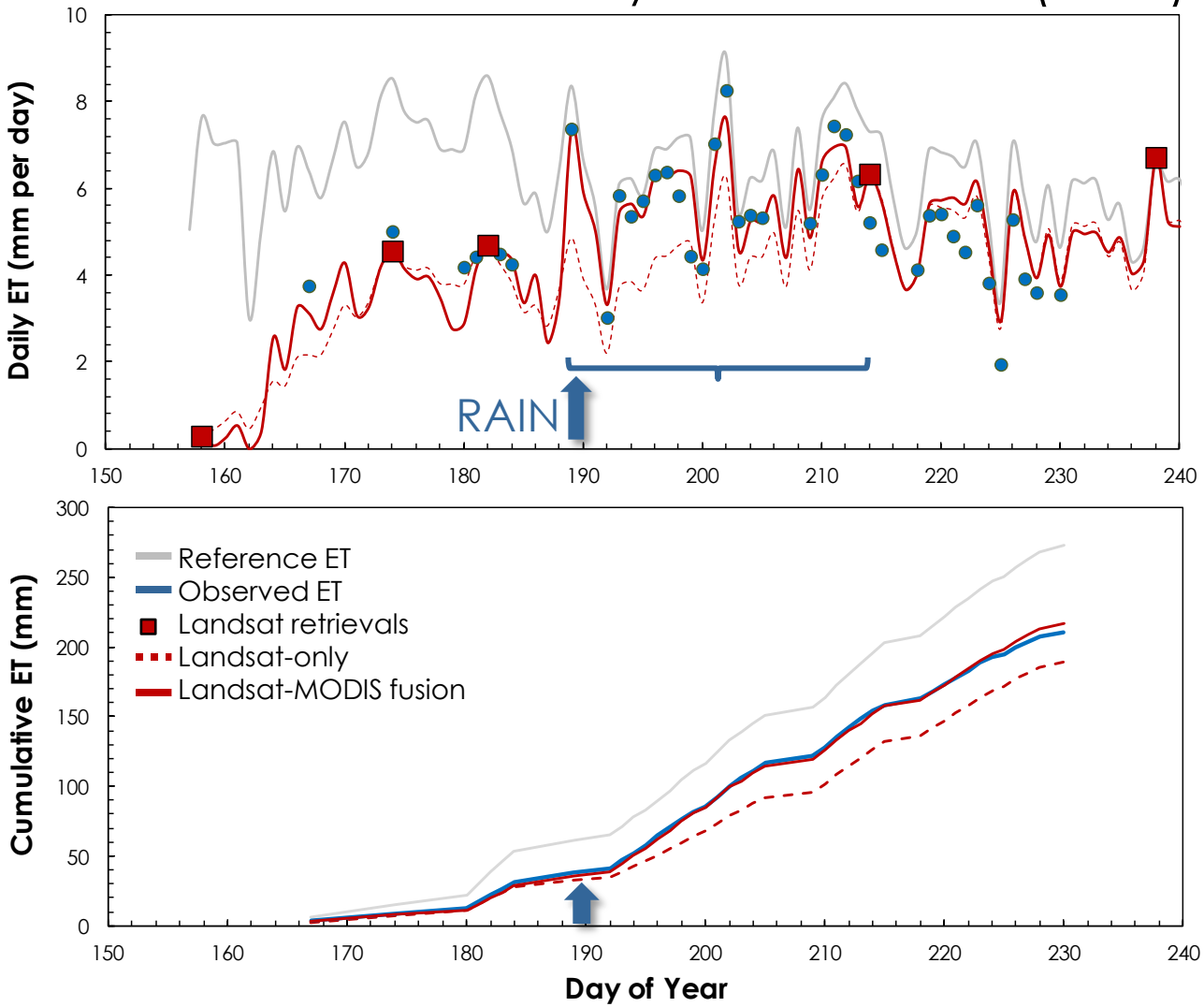


Validation using flux tower data

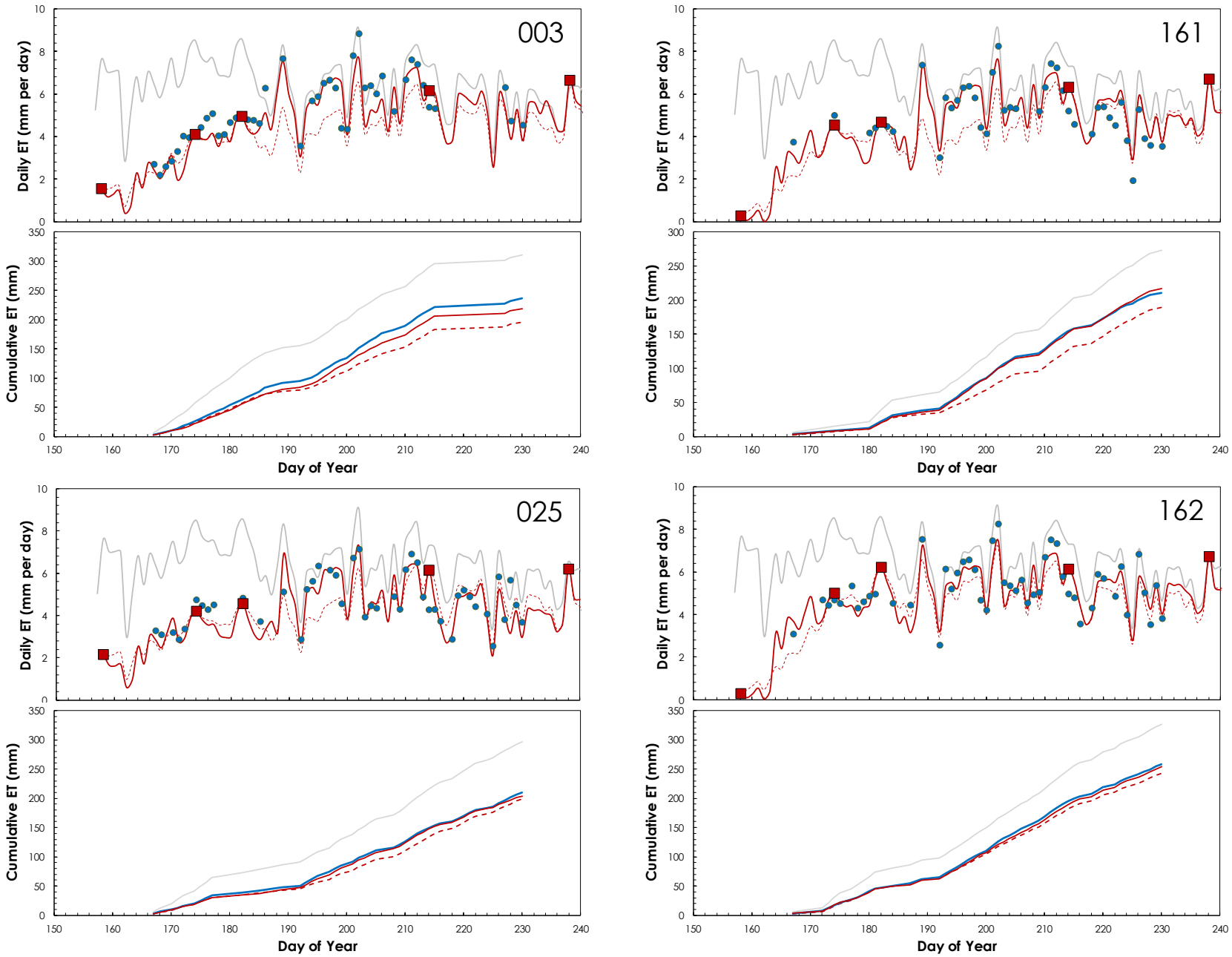


Validation using flux tower data

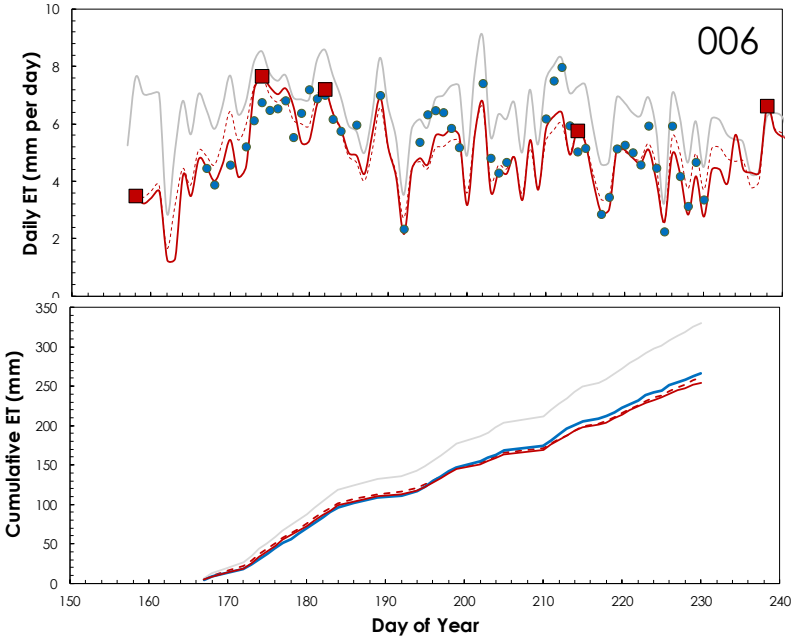
Rainfed soybean – SMEX02 (Iowa)

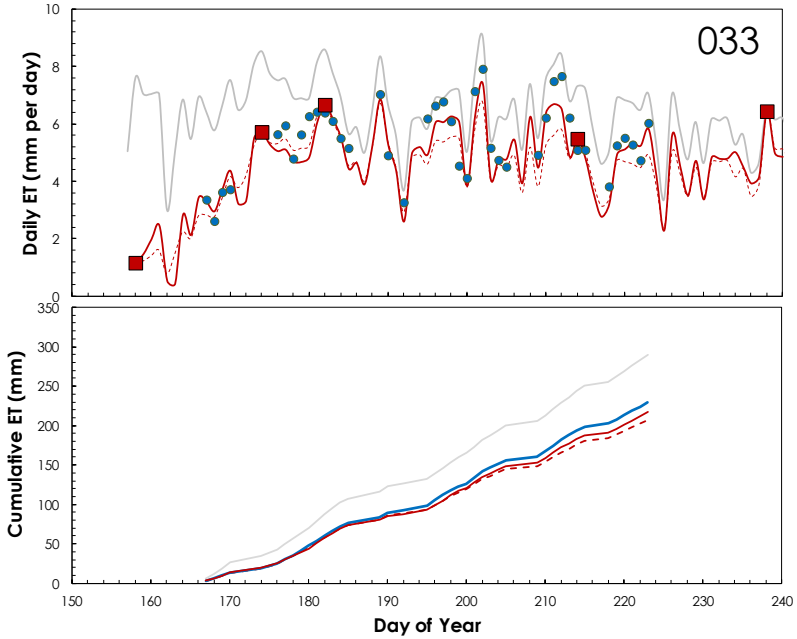


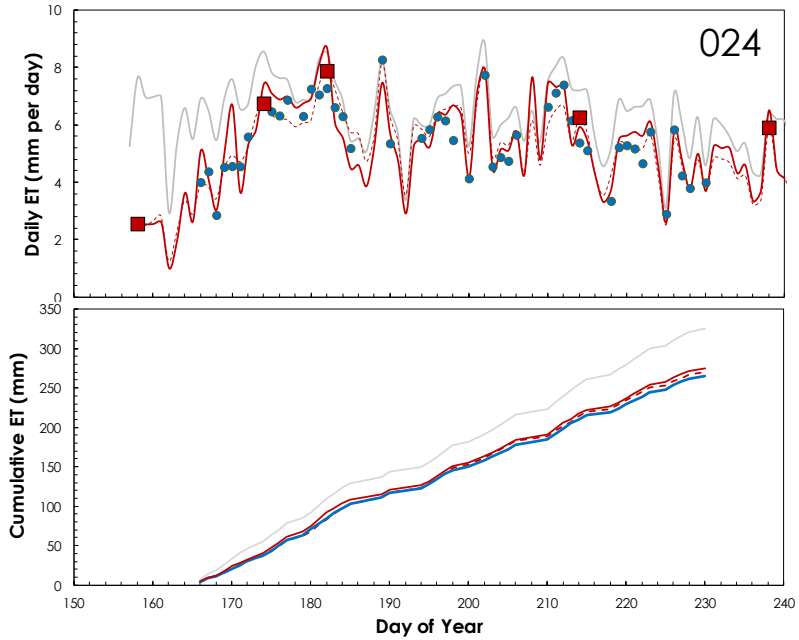
SMEX02: soybean and stunted corn

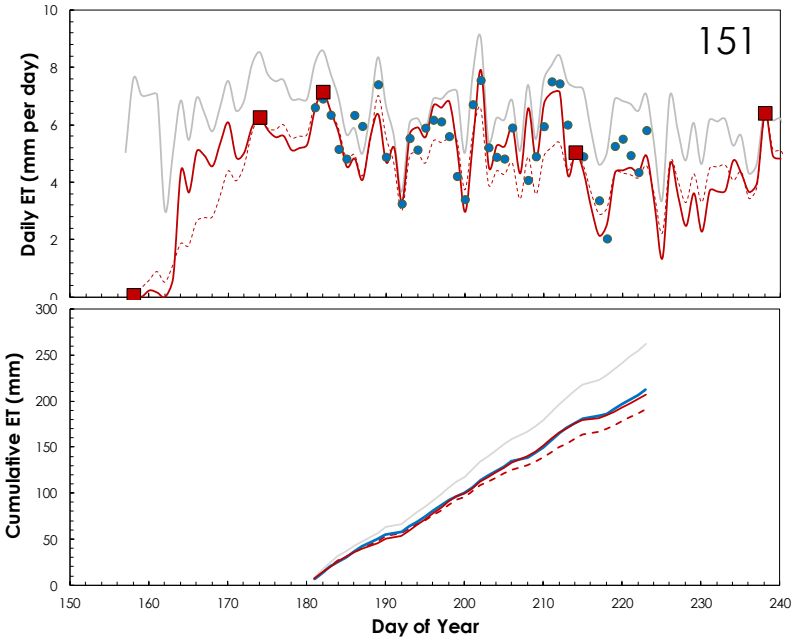


SMEX02: healthy corn

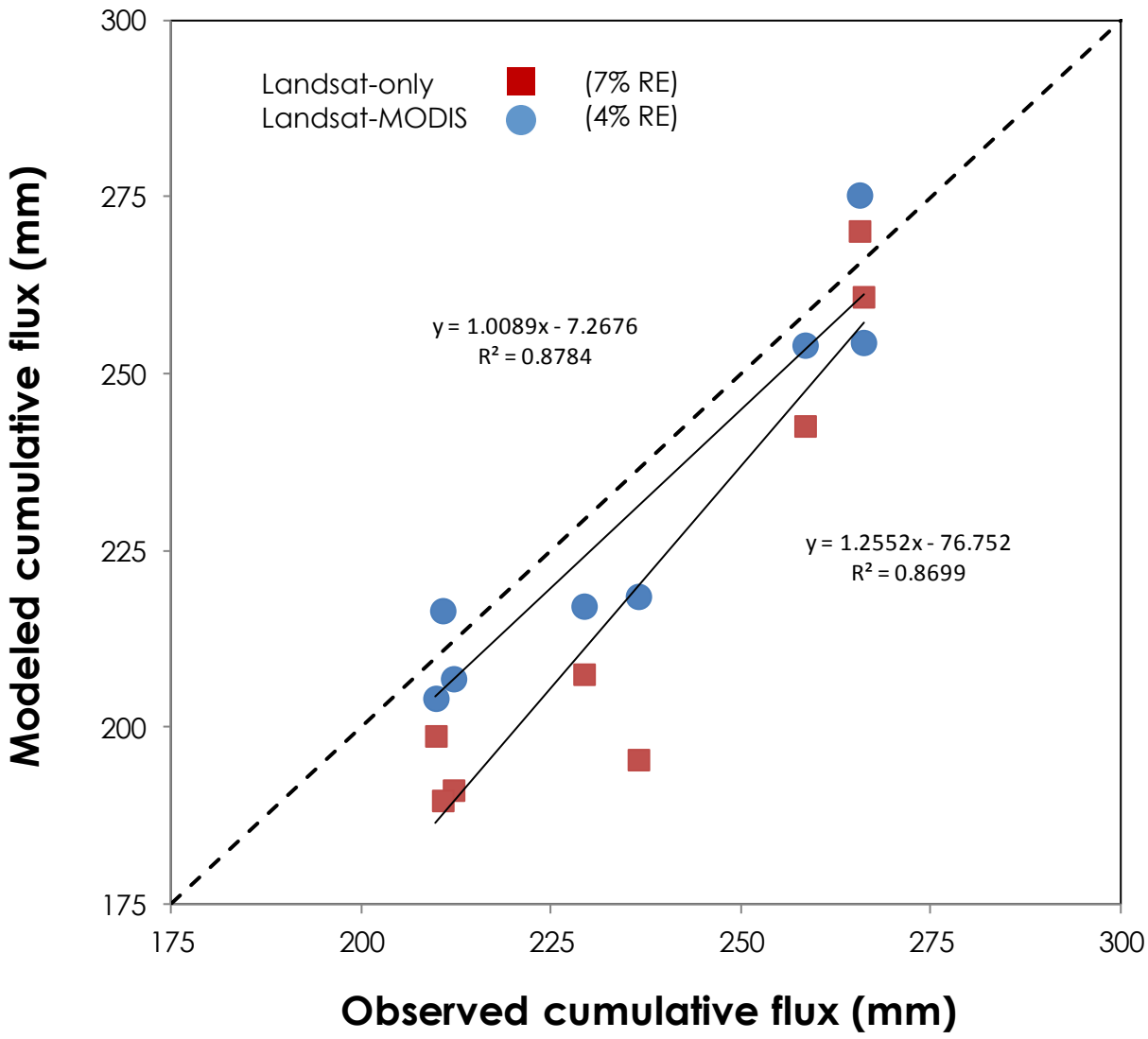






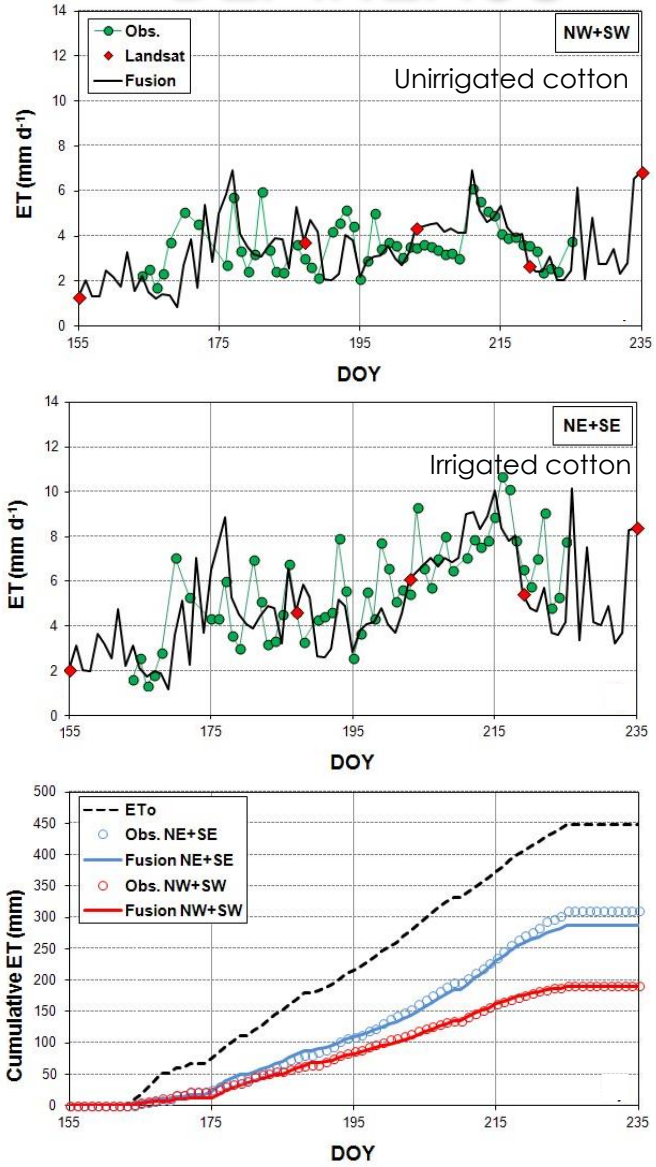


SMEX02 cumulative fluxes

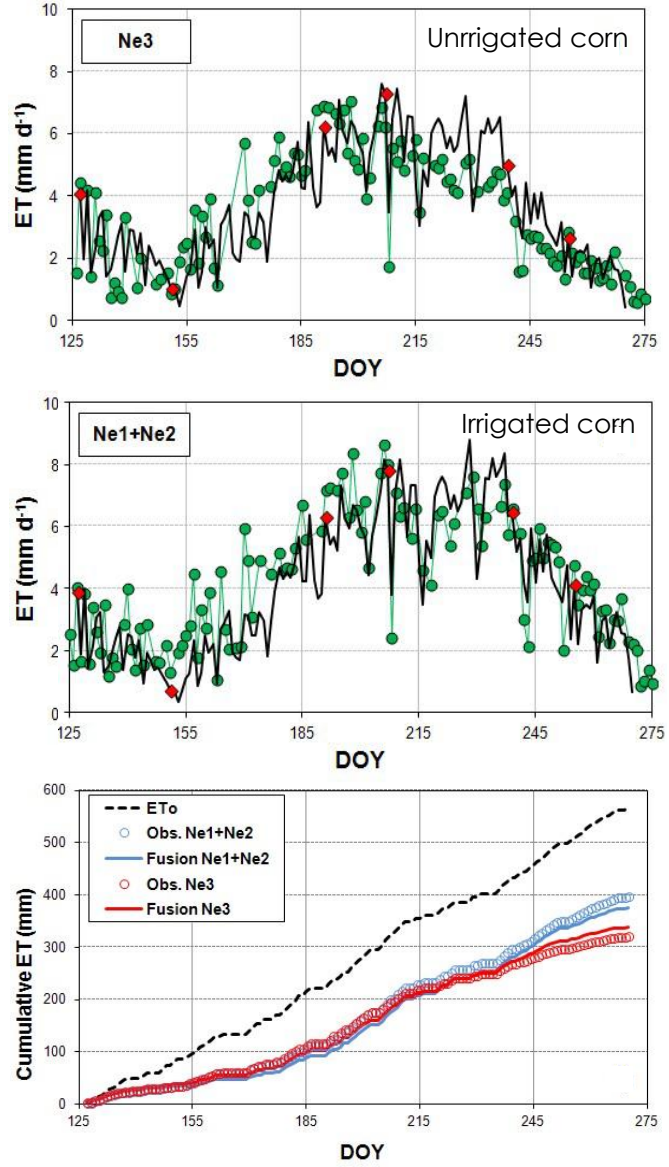


BEAREX08 and MEAD

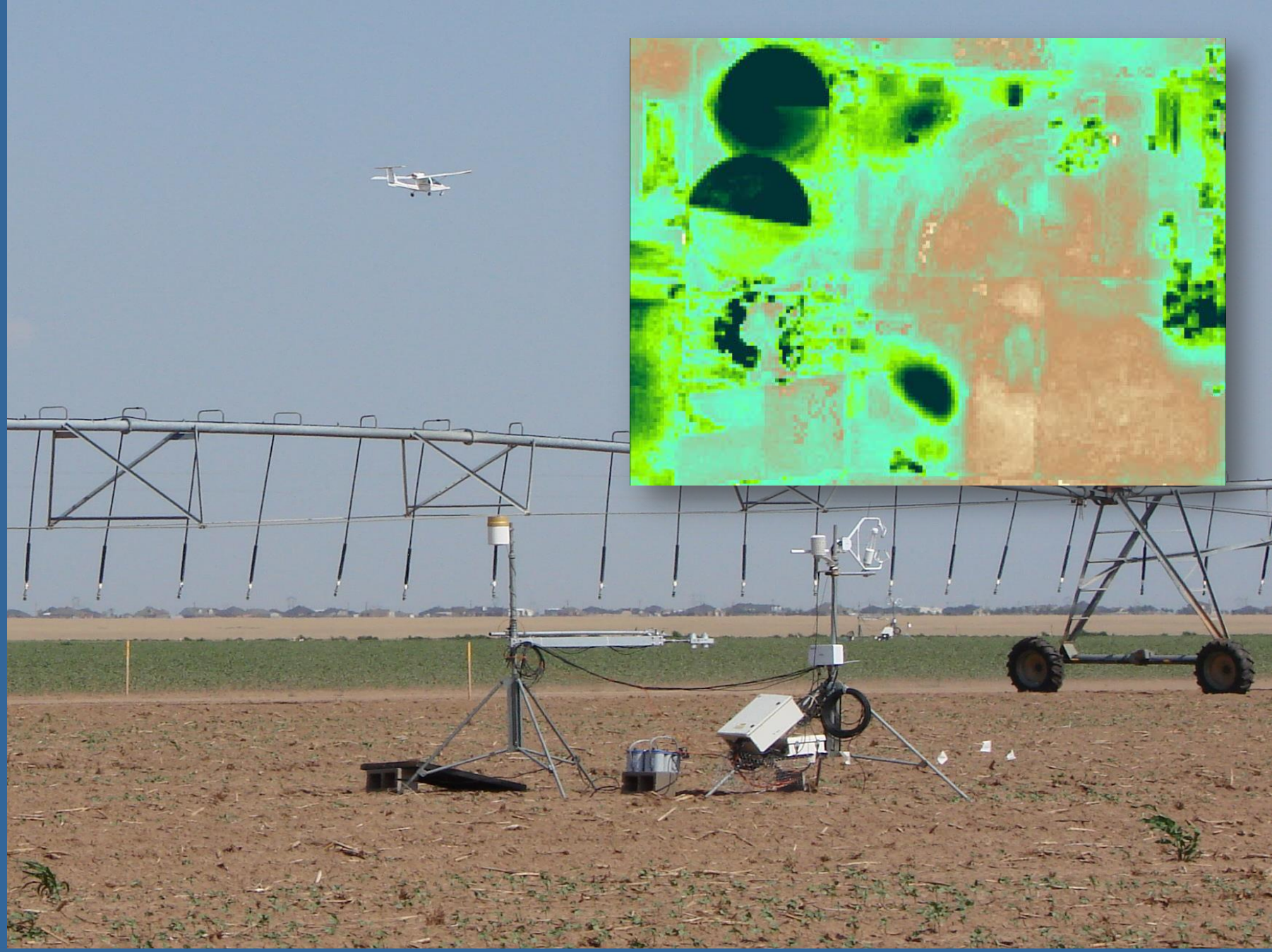
BEAREX08



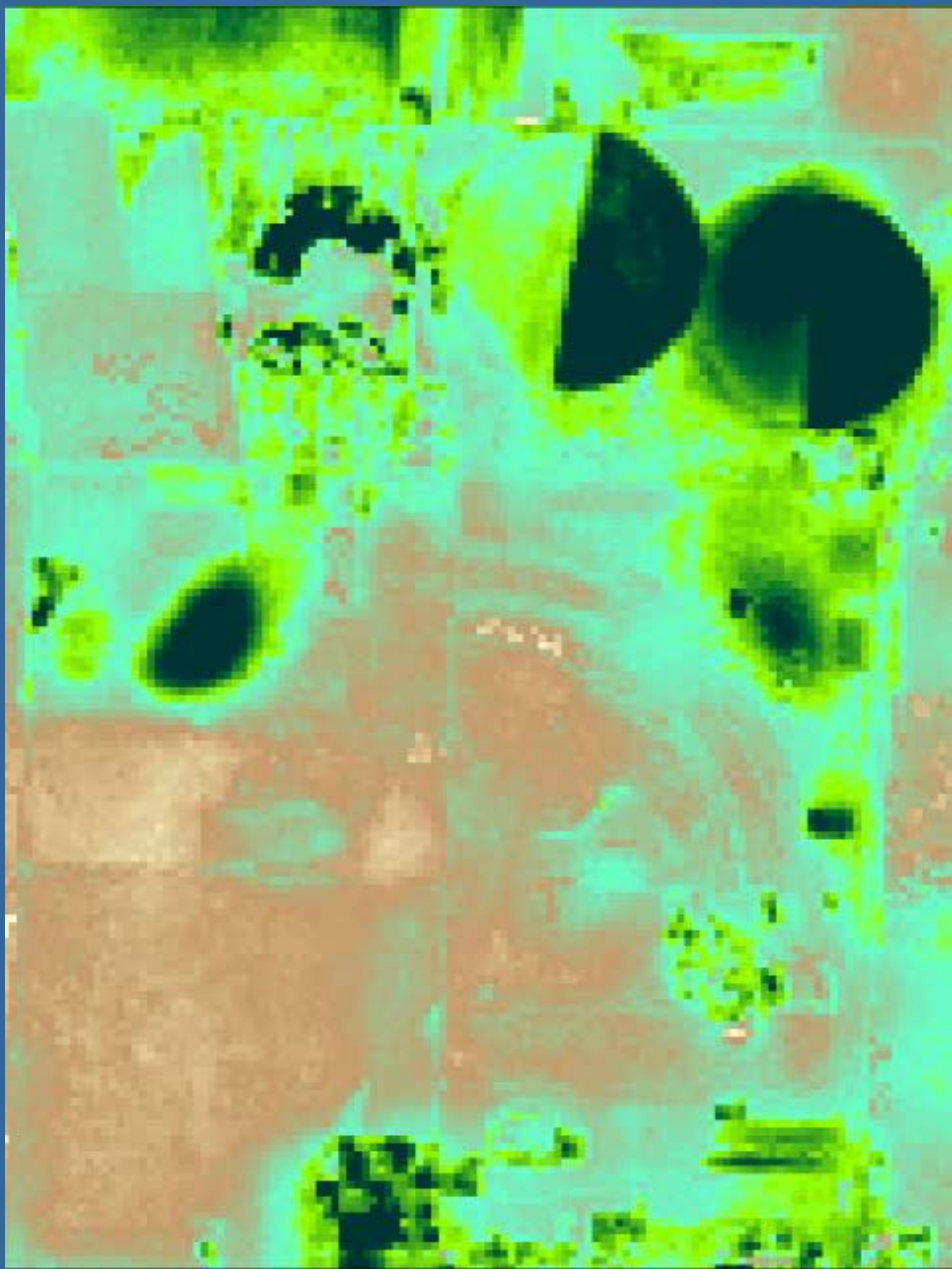
MEAD



BEAREX08 (Texas Panhandle)



Daily ET at field scale (Landsat+MODIS)

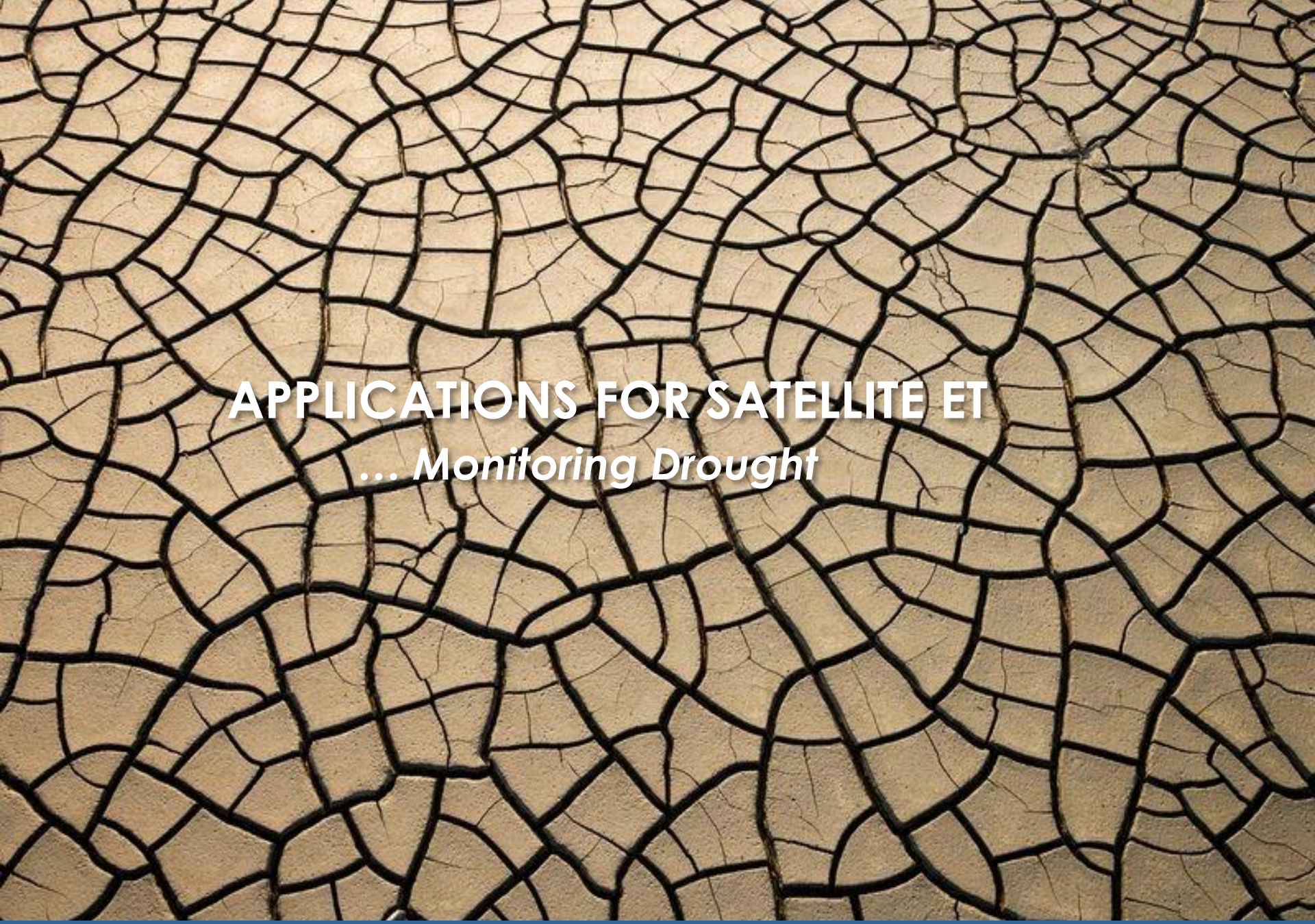


Applications for Remotely Sensed ET

WATER MANAGEMENT

DROUGHT MONITORING

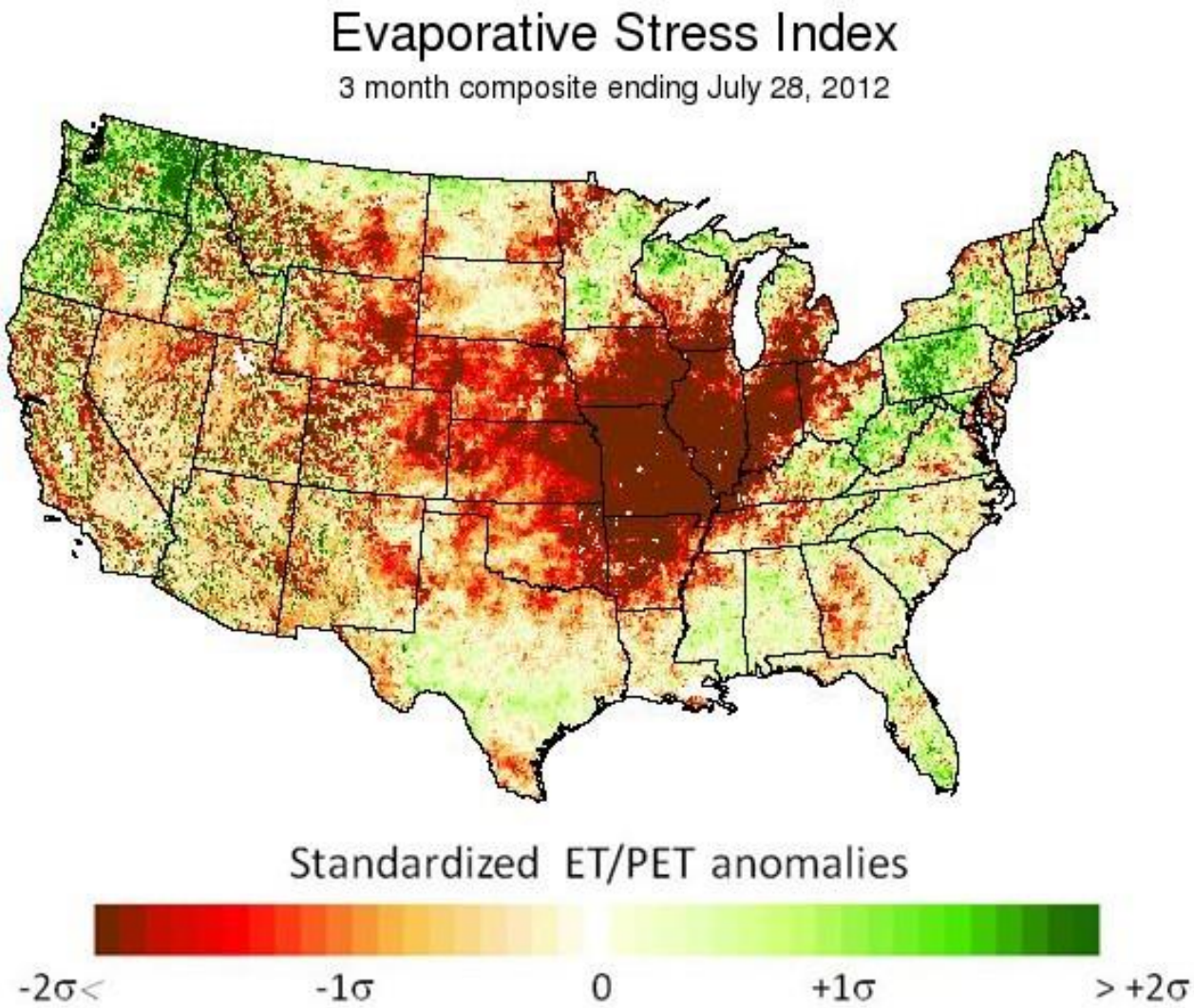
FOOD AND WATER SECURITY



APPLICATIONS FOR SATELLITE ET

… Monitoring Drought

Satellite ET Drought Indicator

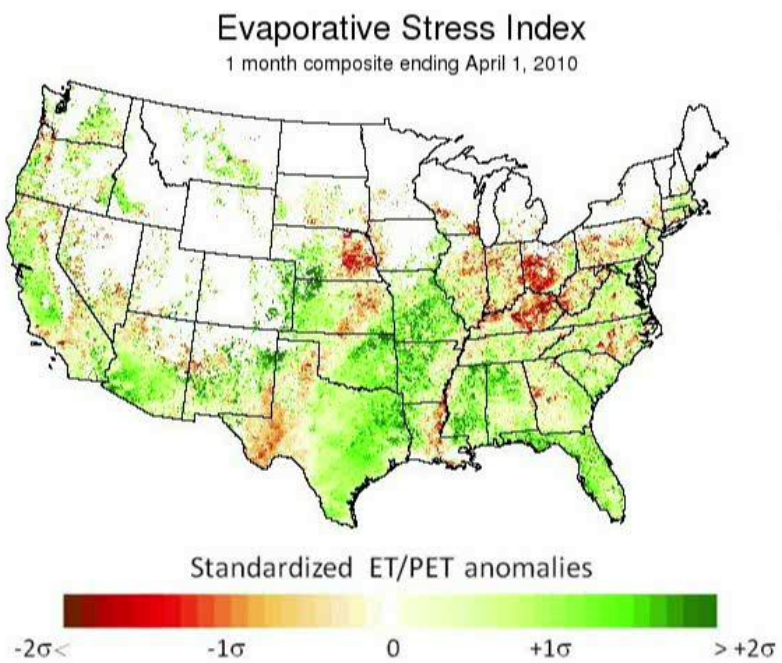


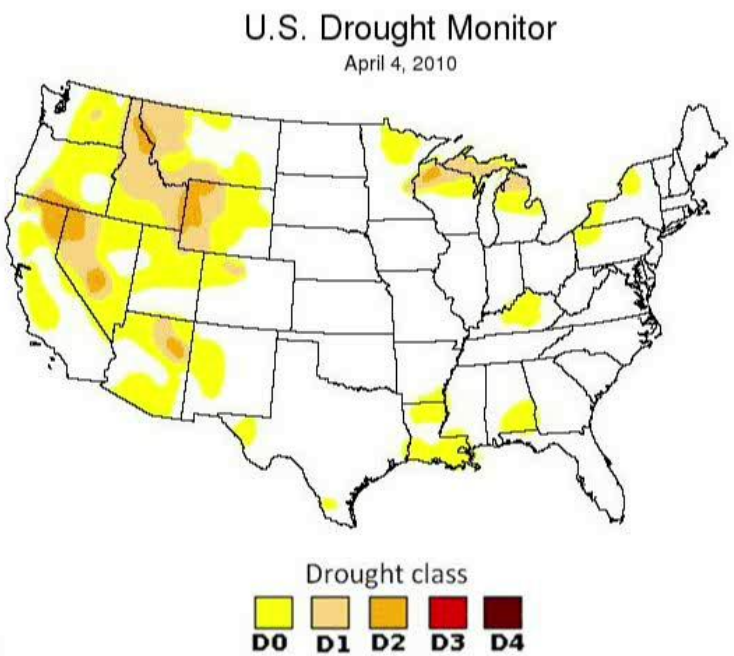
Atmosphere-Land Exchange Inverse Model (ALEXI)

(Anderson et al., 1997, 2007)

Realtime Drought Monitoring

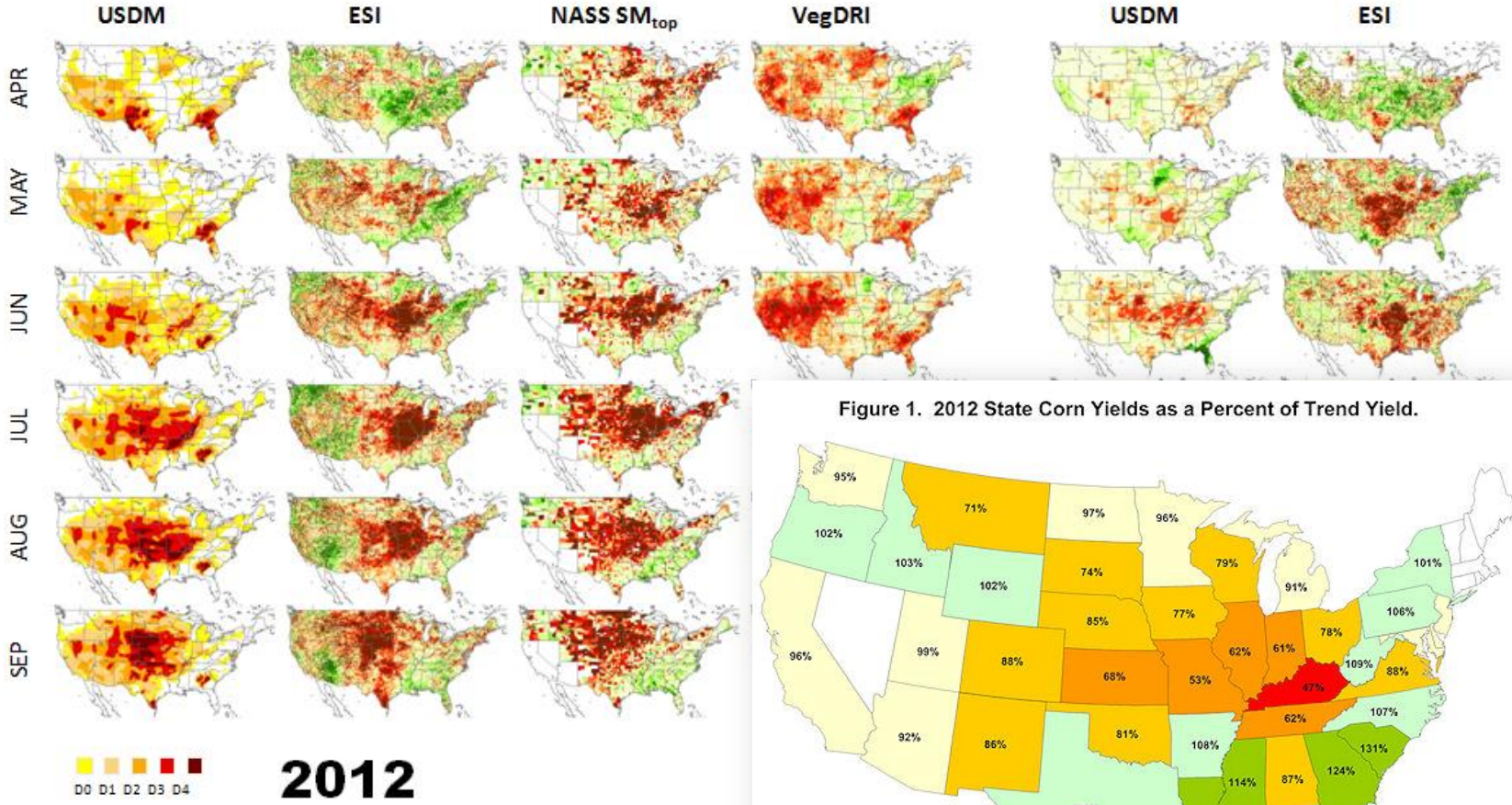
DROUGHT: 2010-2012





Realtime Drought Monitoring

2012 FLASH DROUGHT



Realtime Drought Monitoring

Firefox

(109 unread) - ec... | Topics in Science... | Evaporative Stres... | Downloads | University Resear... | LTAR Network In... | Problem loading ... | Typhoon Bolave... | 2012 AMS Inform...

hrsl.arsusda.gov/drought

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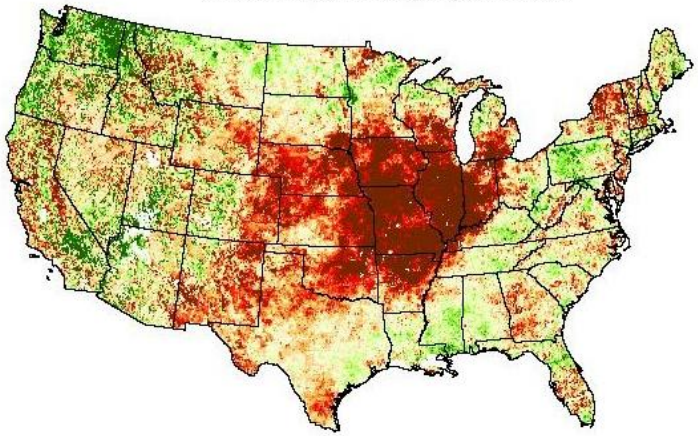
USDA

Evaporative Stress Index

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

Evaporative Stress Index

1 month composite ending August 27, 2012



Standardized ET/PET anomalies

-2σ< | -1σ | 0 | +1σ | > +2σ

Download

Description

The Evaporative Stress Index (ESI) describes temporal anomalies in evapotranspiration (ET), highlighting areas with anomalously high or low rates of water use across the land surface. Here, ET is retrieved via energy balance using remotely sensed land-surface temperature (LST) time-change signals. LST is a fast-response variable, providing proxy information regarding rapidly evolving surface soil moisture and crop stress conditions at relatively high spatial resolution. The ESI also demonstrates capability for capturing early signals of "flash drought", brought on by extended periods of hot, dry and windy conditions leading to rapid soil moisture depletion.

Coverage

Current Conditions

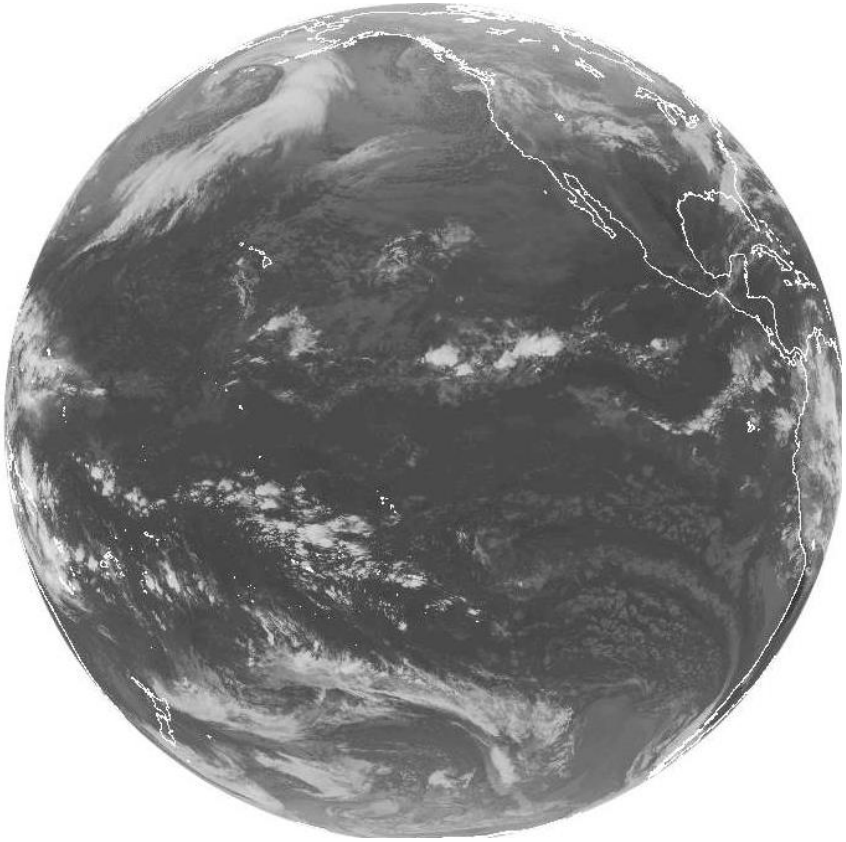
Hydrology and Remote Sensing Laboratory | 10300 Baltimore Avenue | Beltsville, MD 20705 | Contact Us
Version 2.1.2

hrsl.arsusda.gov/drought/index.php

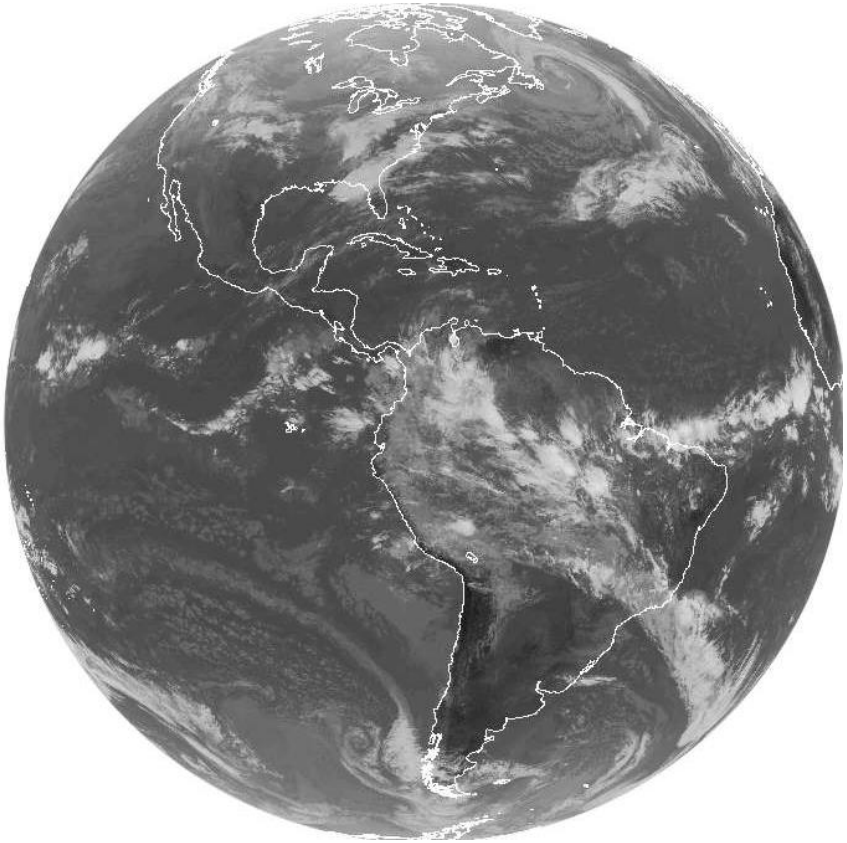
Geostationary Operational Environmental Satellites

NOAA NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNITED STATES DEPARTMENT OF COMMERCE

GOES coverage

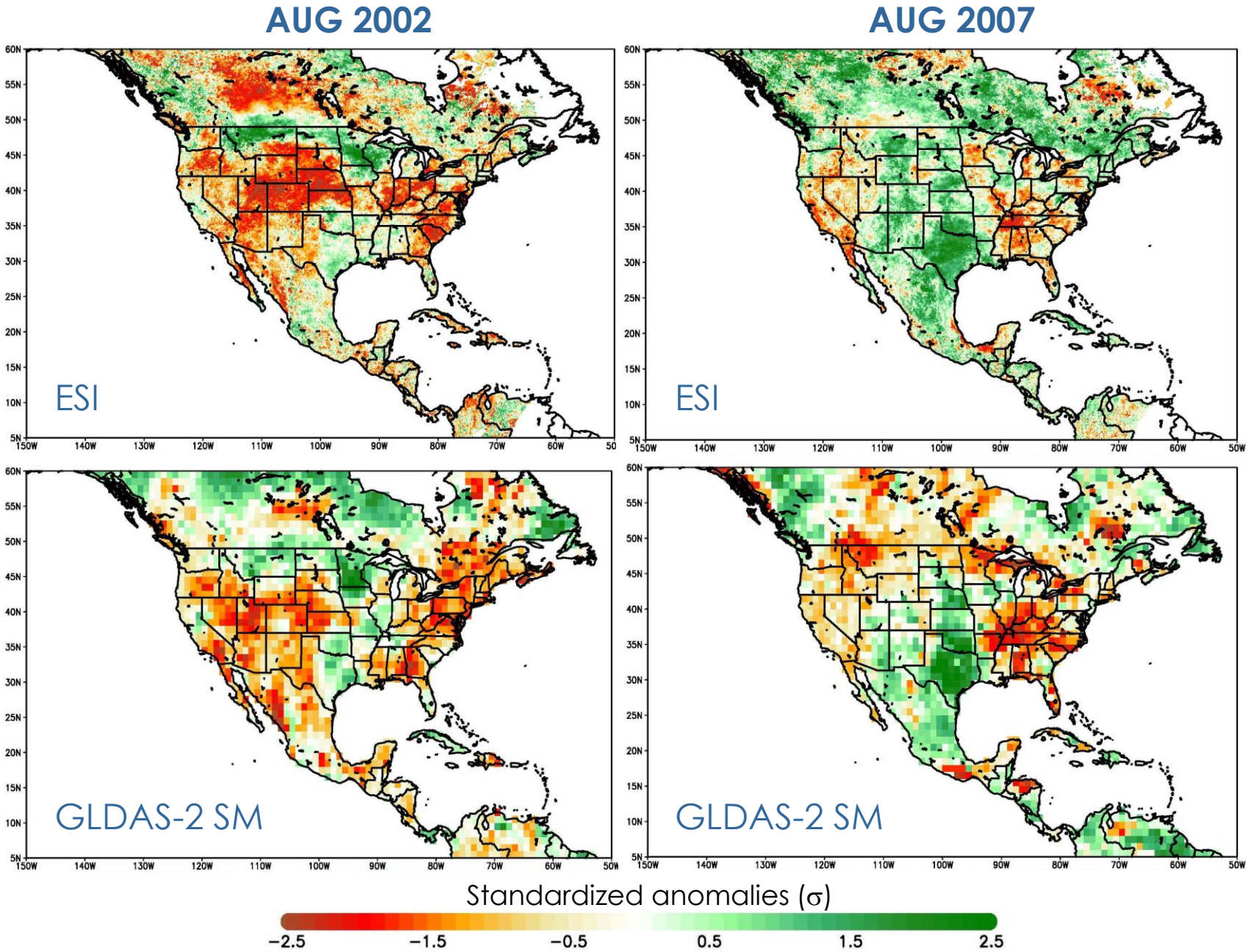


GOES – West
(Pacific)

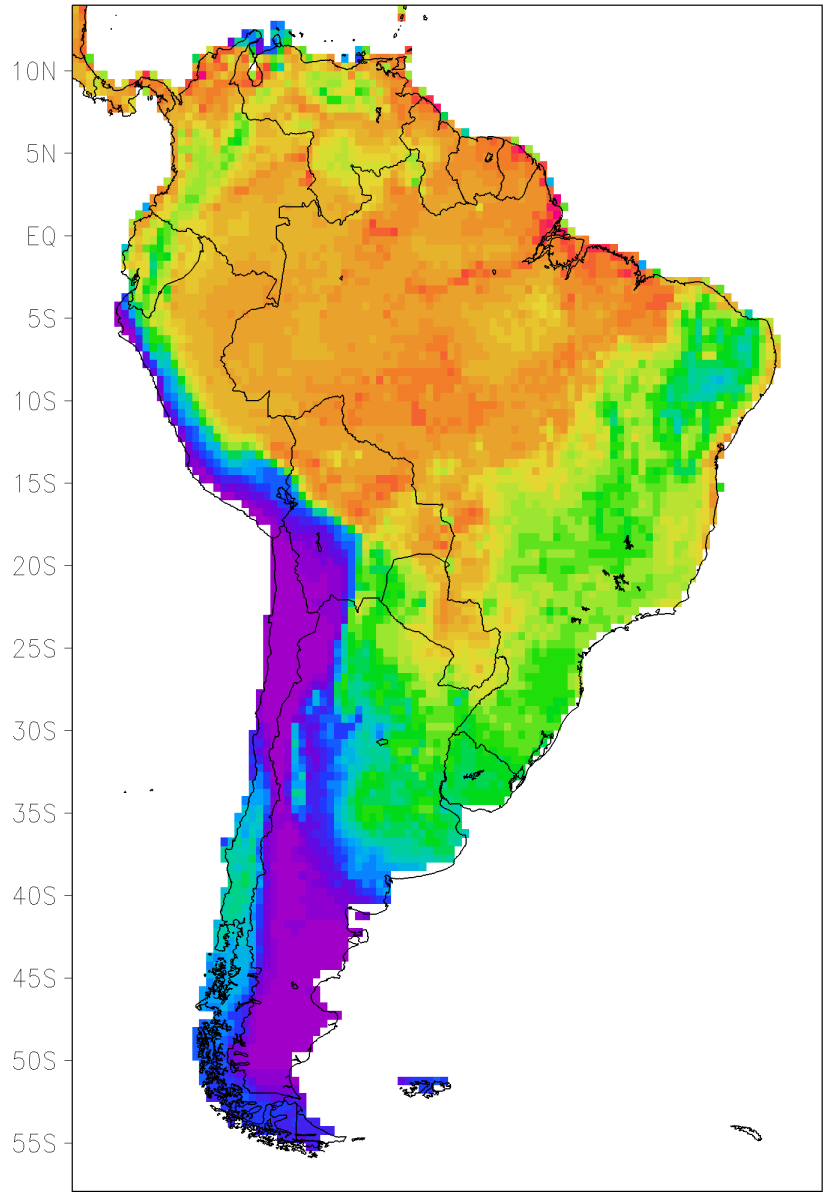


GOES – East
(Atlantic)

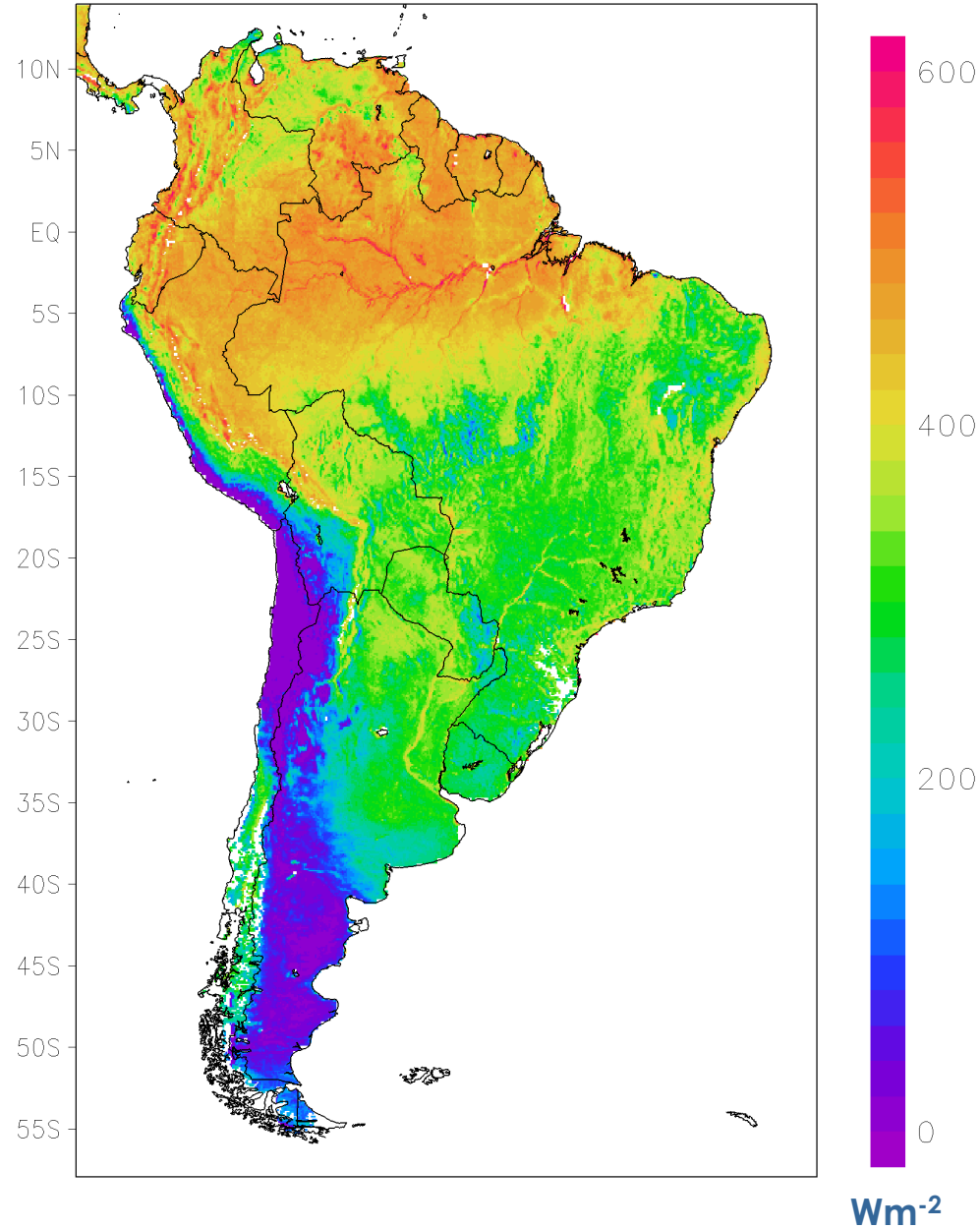
North American ESI

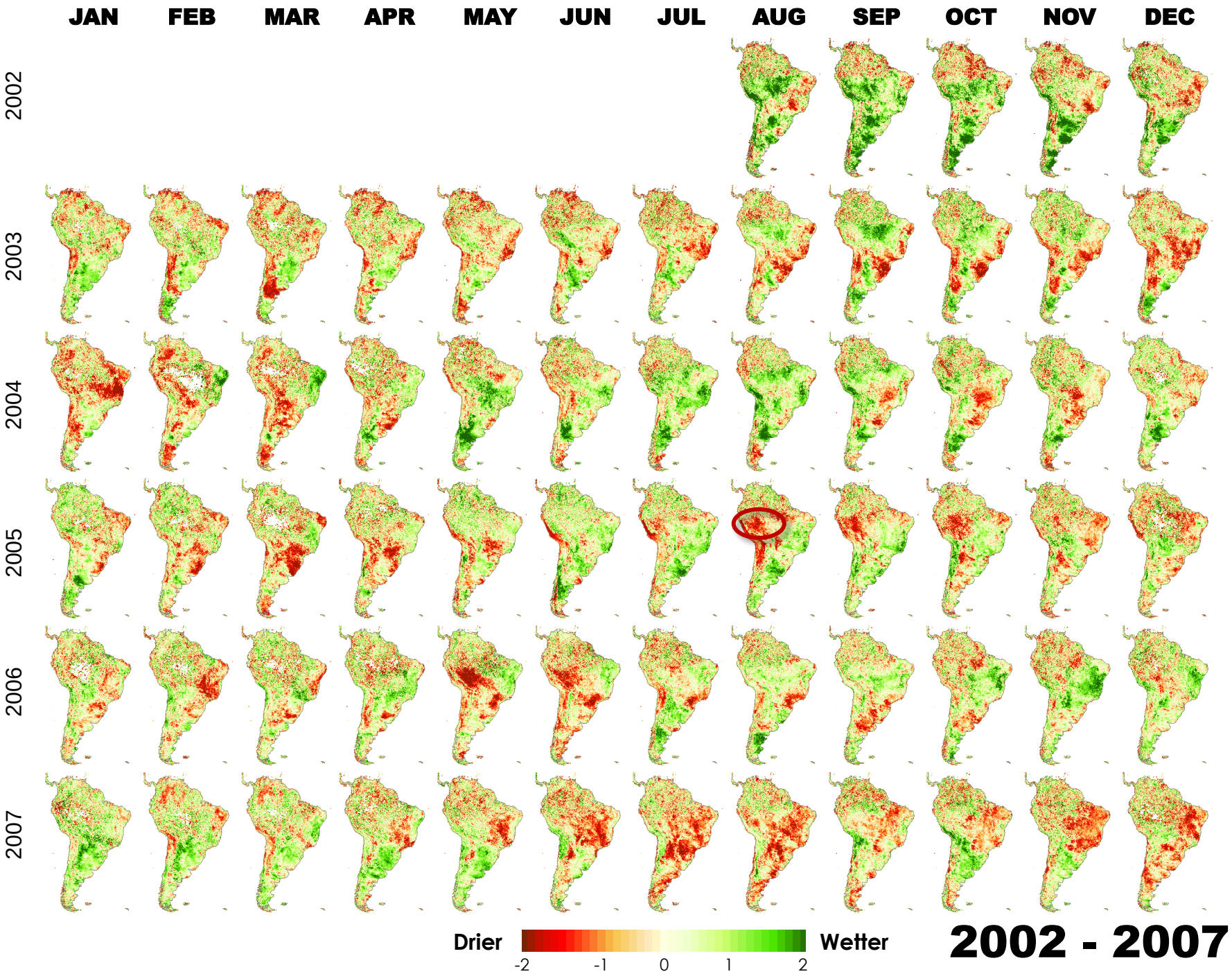


FLUXNET (Daily ET)



ALEXI (Clear-sky midday ET)




JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2002
2003
2004
2005
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2007
Drier
Wetter
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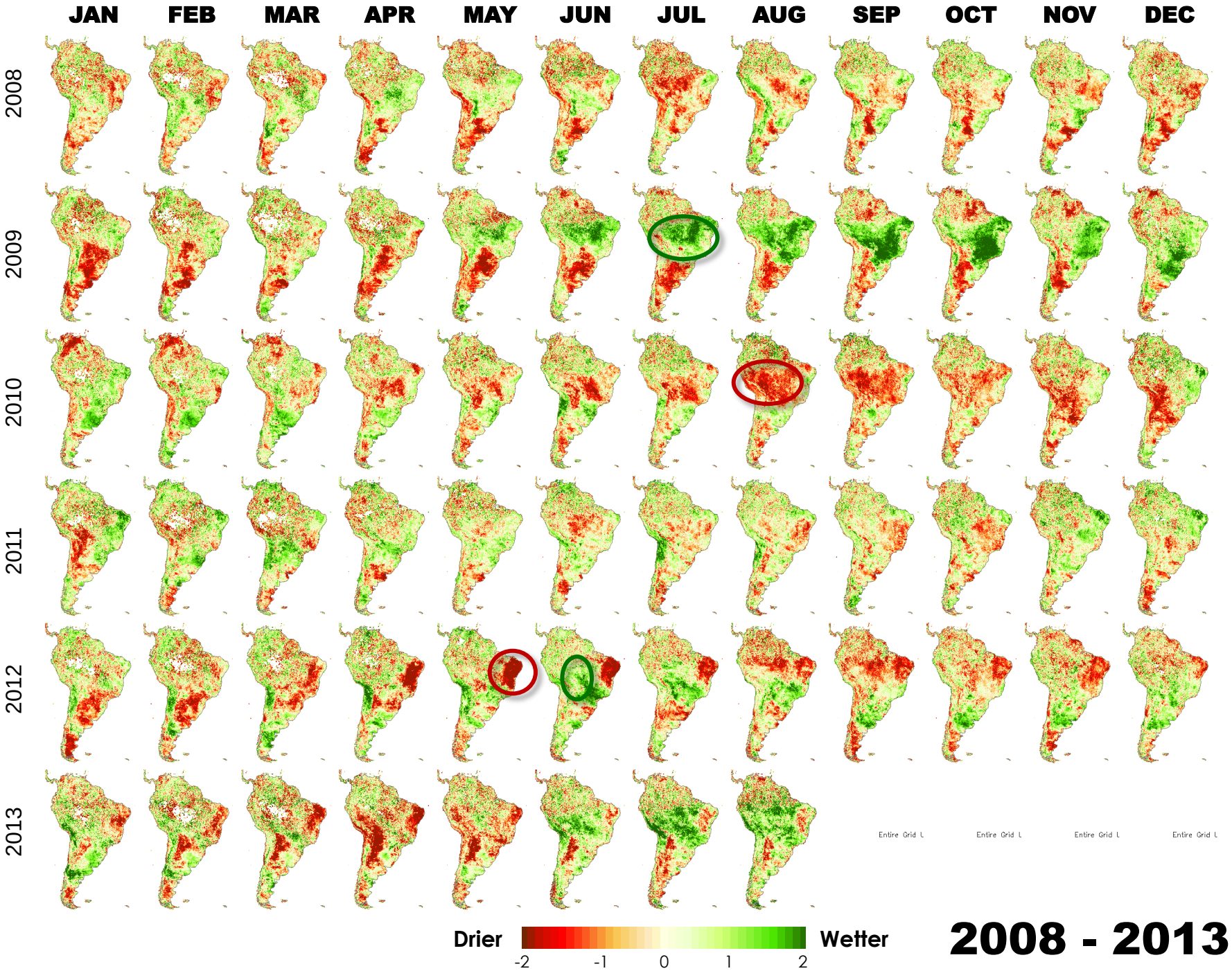
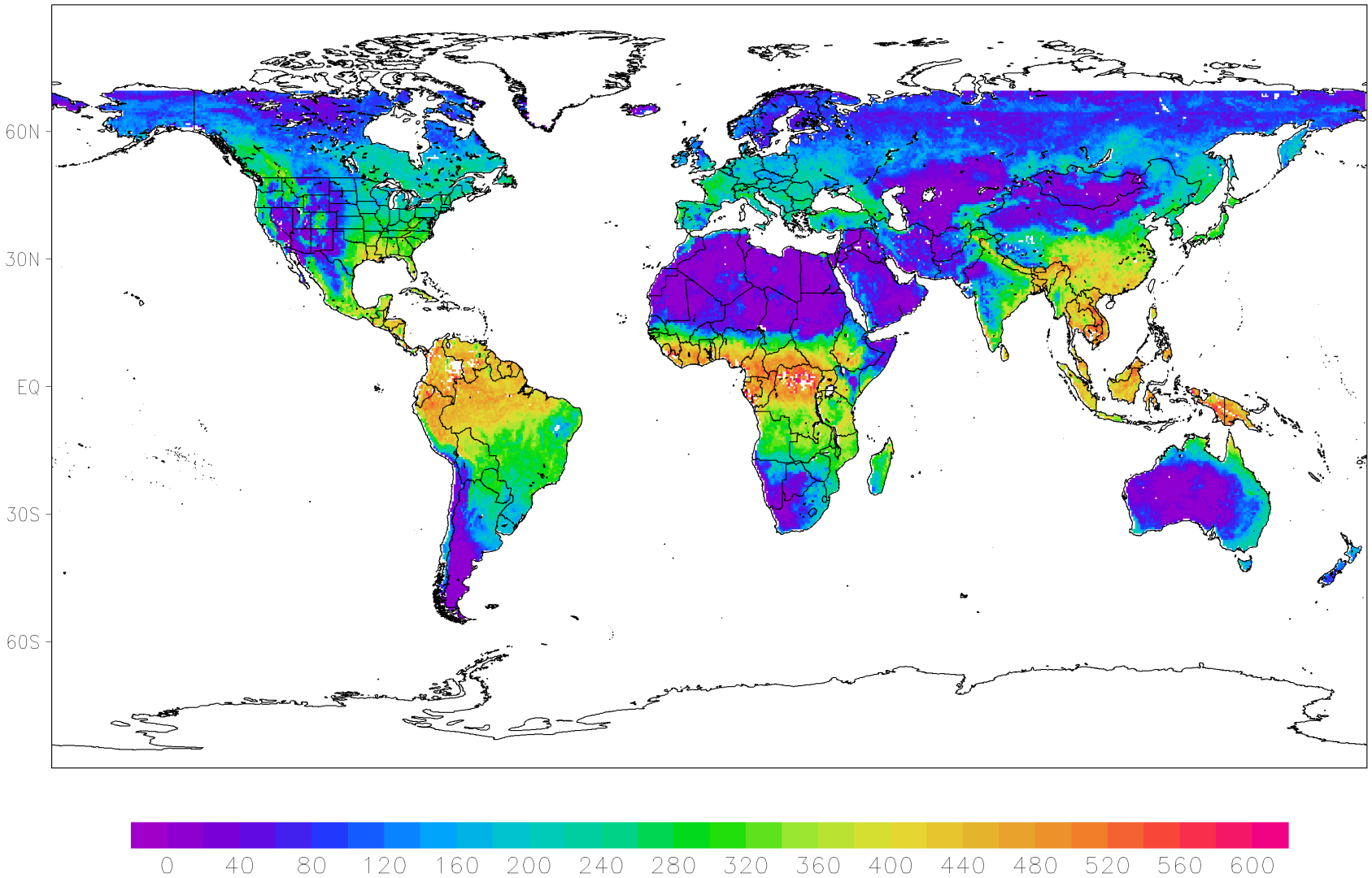
-1
0
1
2
2002 - 2007


JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
2008
2009
2010
2011
2012
2013
Entire Grid L
Entire Grid L
Entire Grid L
Entire Grid L
Drier
Wetter
-2
-1
0
1
2
2008 - 2013

Global monitoring (coming soon)



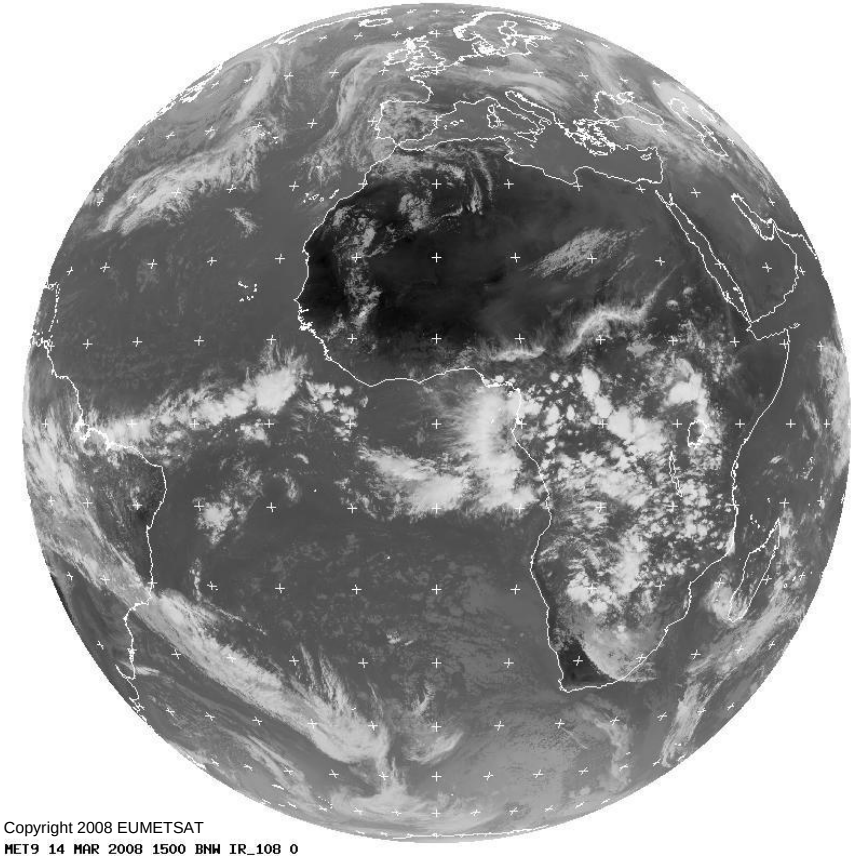
APPLICATIONS FOR SATELLITE ET

… Monitoring in MENA region

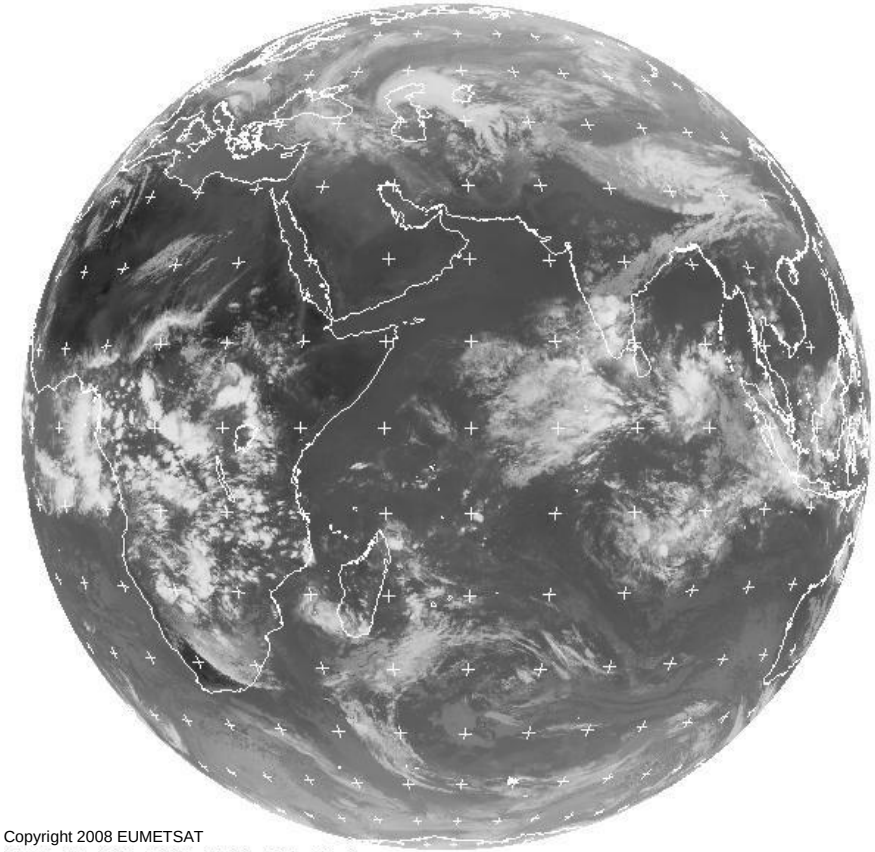
Meteosat Coverage

EUMETSAT

Monitoring weather and climate from space
Surveiller le temps et le climat depuis l'espace

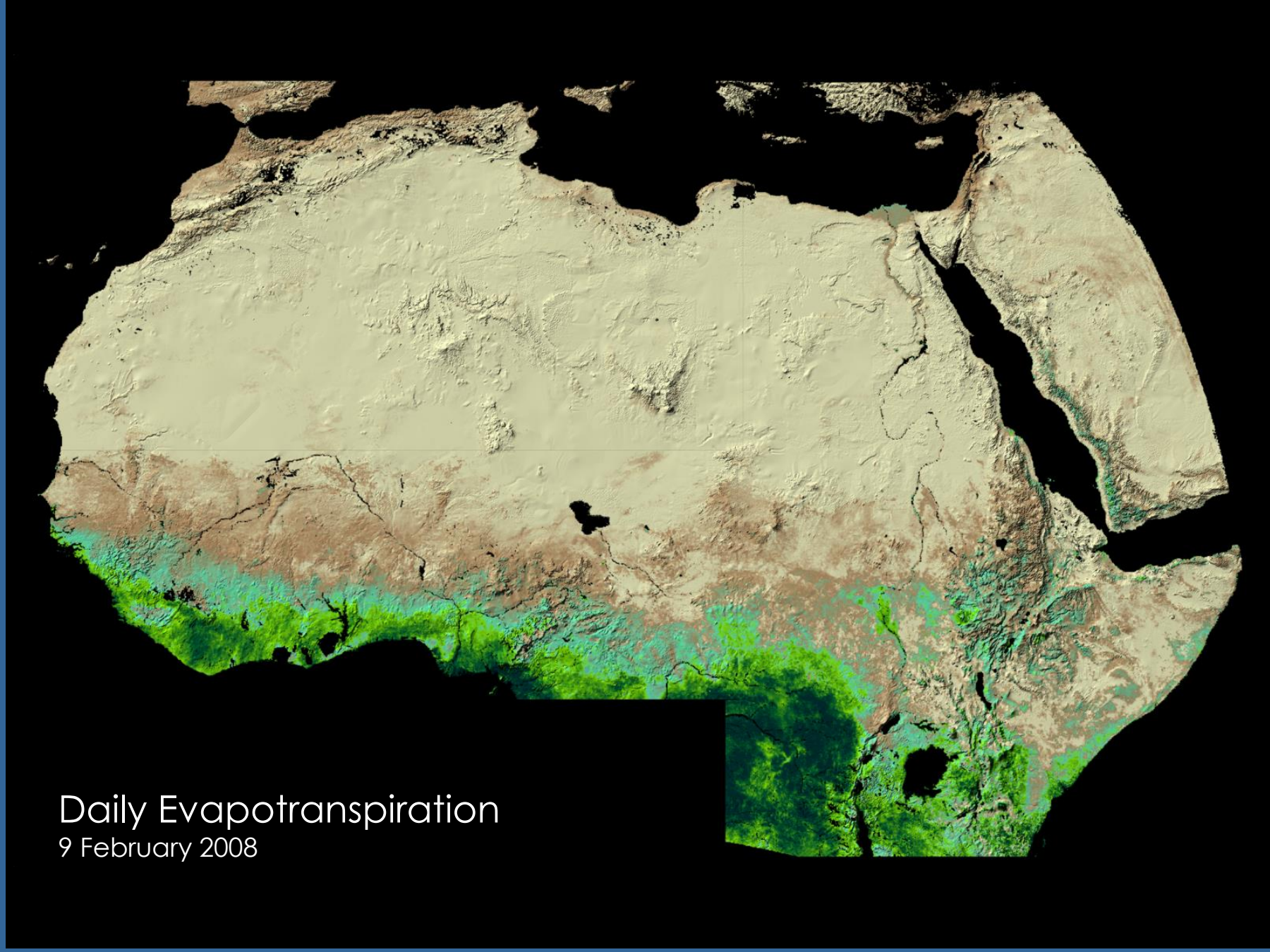


0° Operational

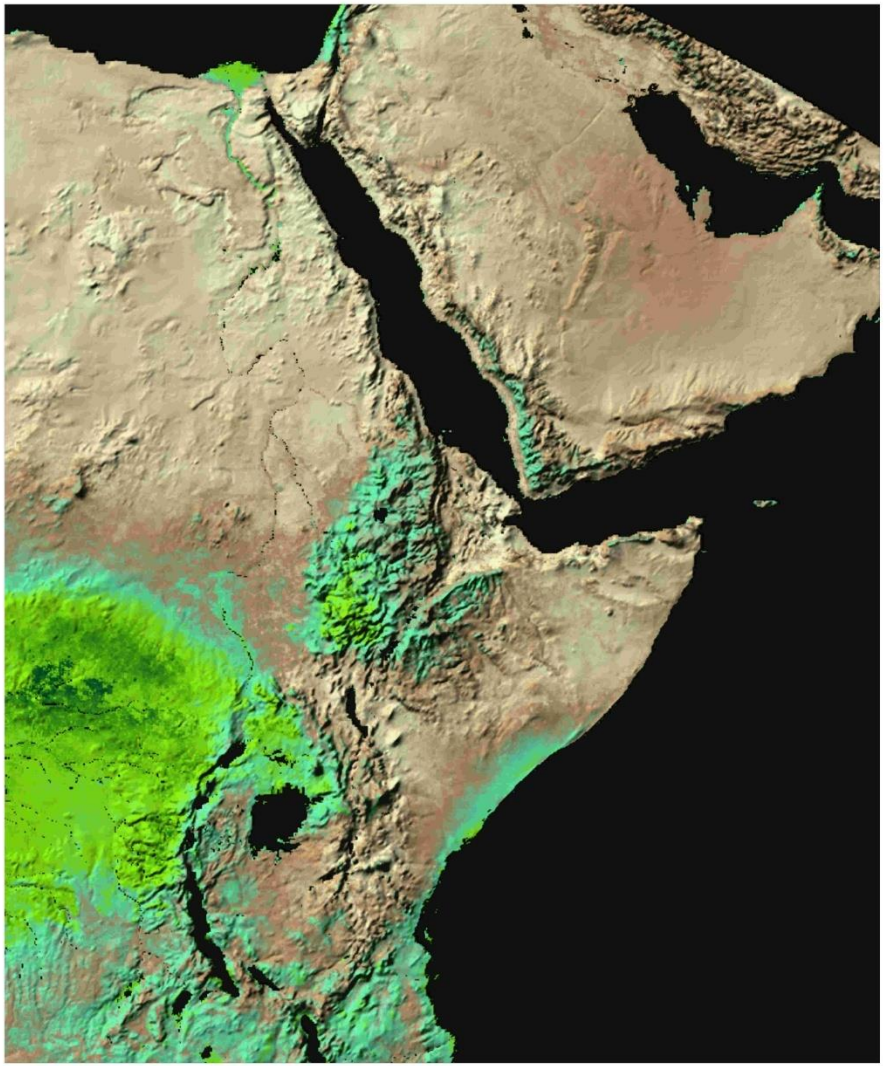


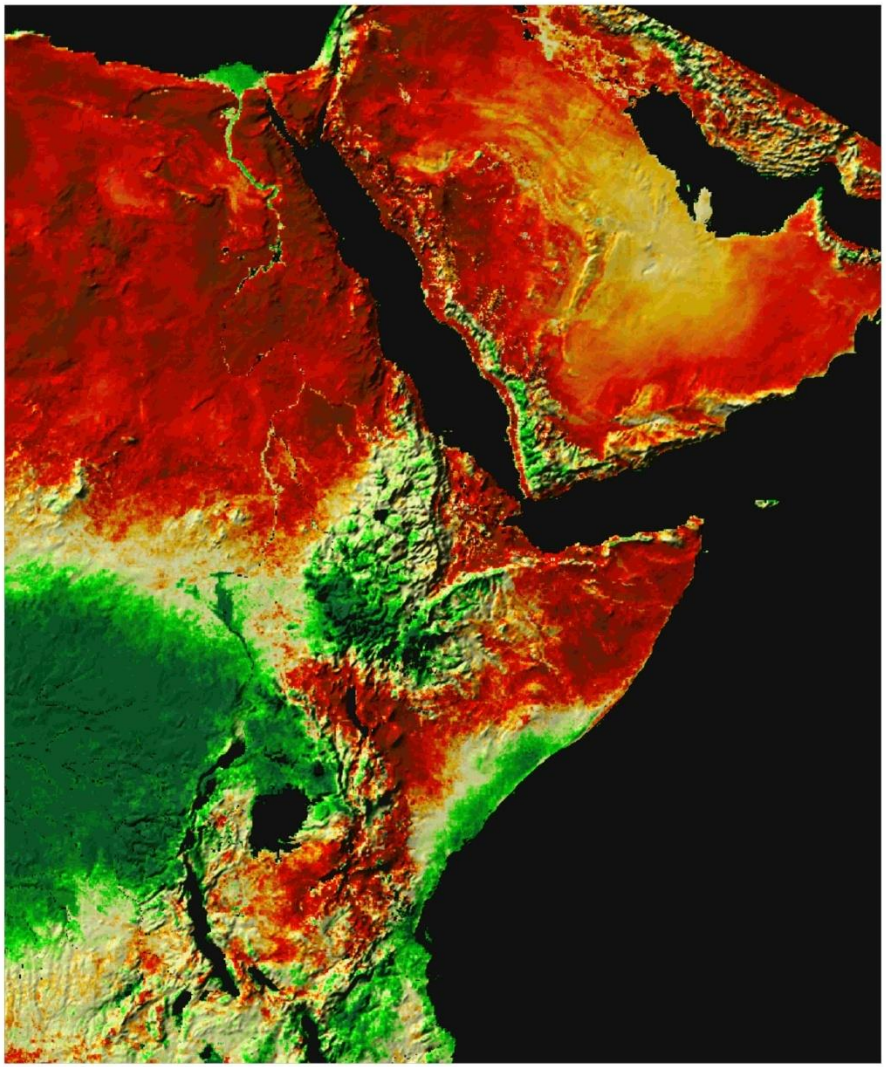
Indian Ocean

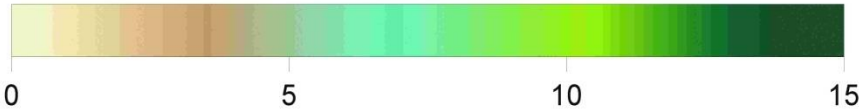
ALEXI ET over MENA Region



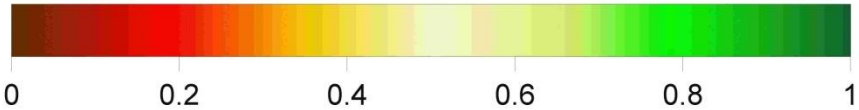
2009 APRIL-SEPTEMBER







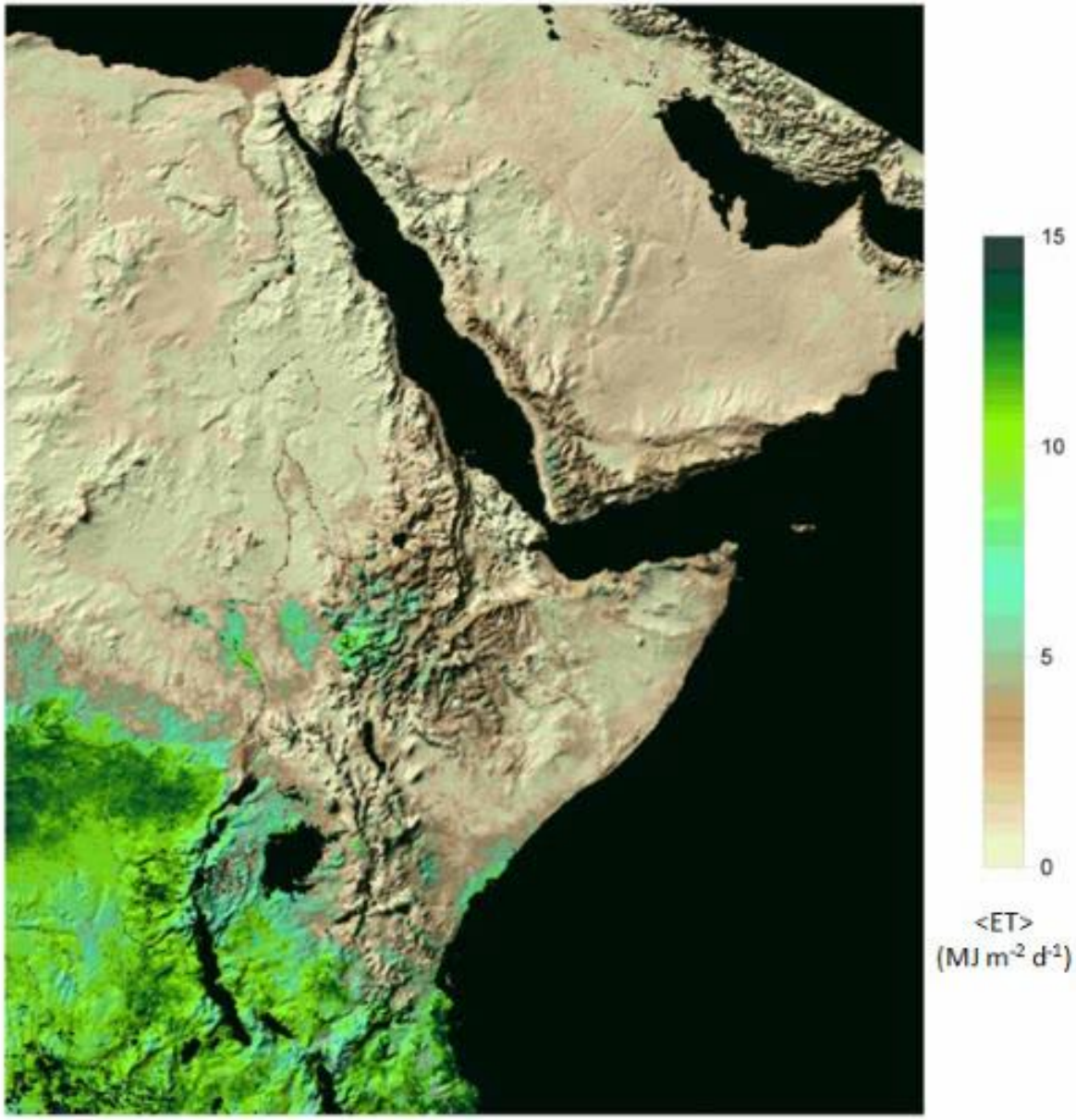
Average ALEXI ET (MJ m^{-2} d^{-1})



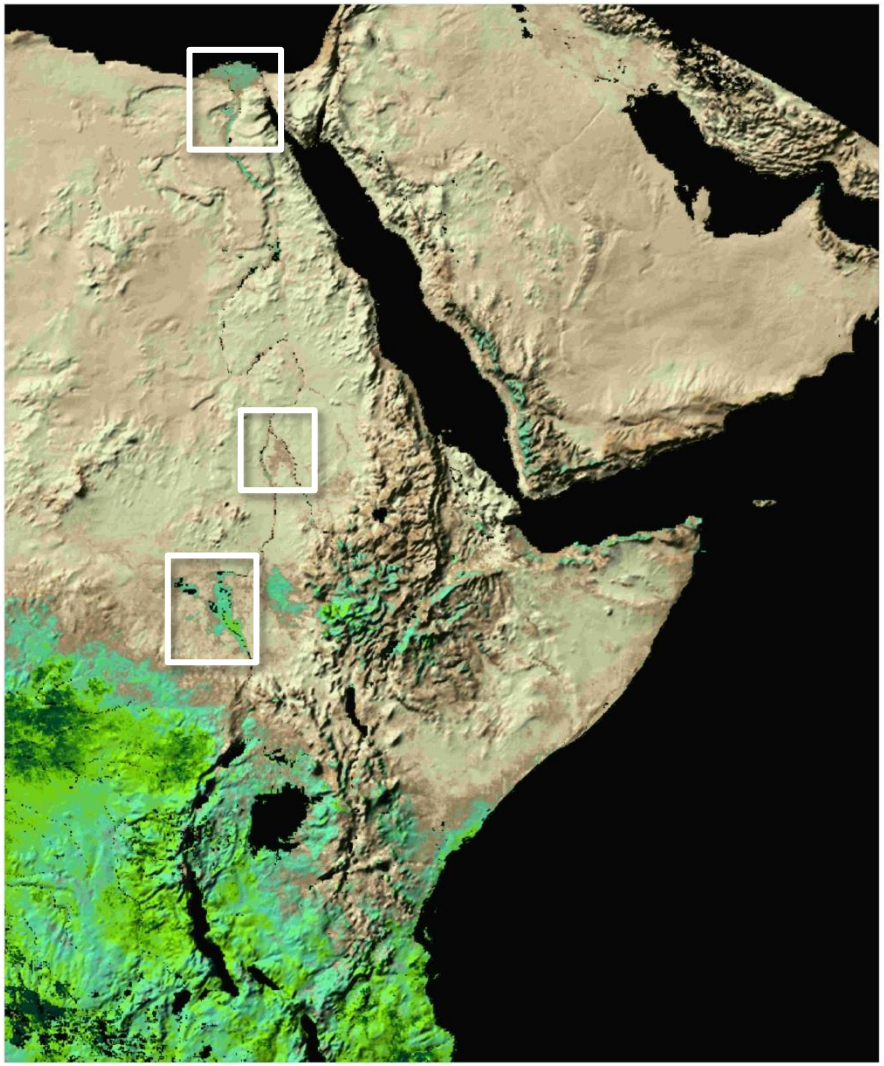
Average ALEXI ET/PET

2009 JANUARY

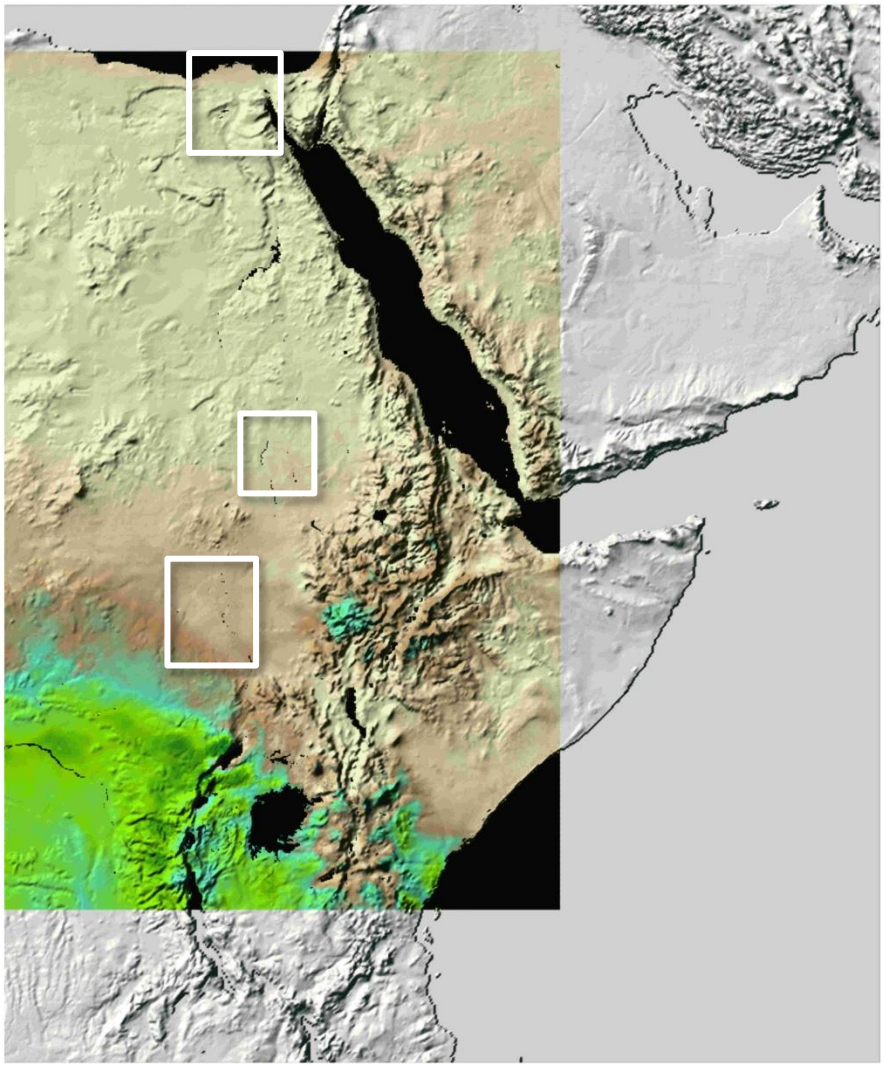
MONTHLY AVERAGE LATENT HEAT



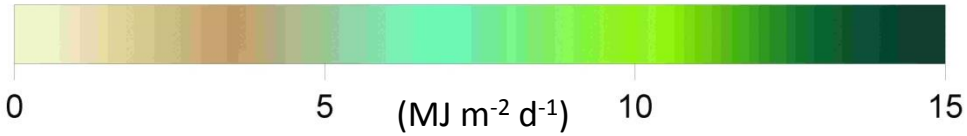
2009 FEBRUARY



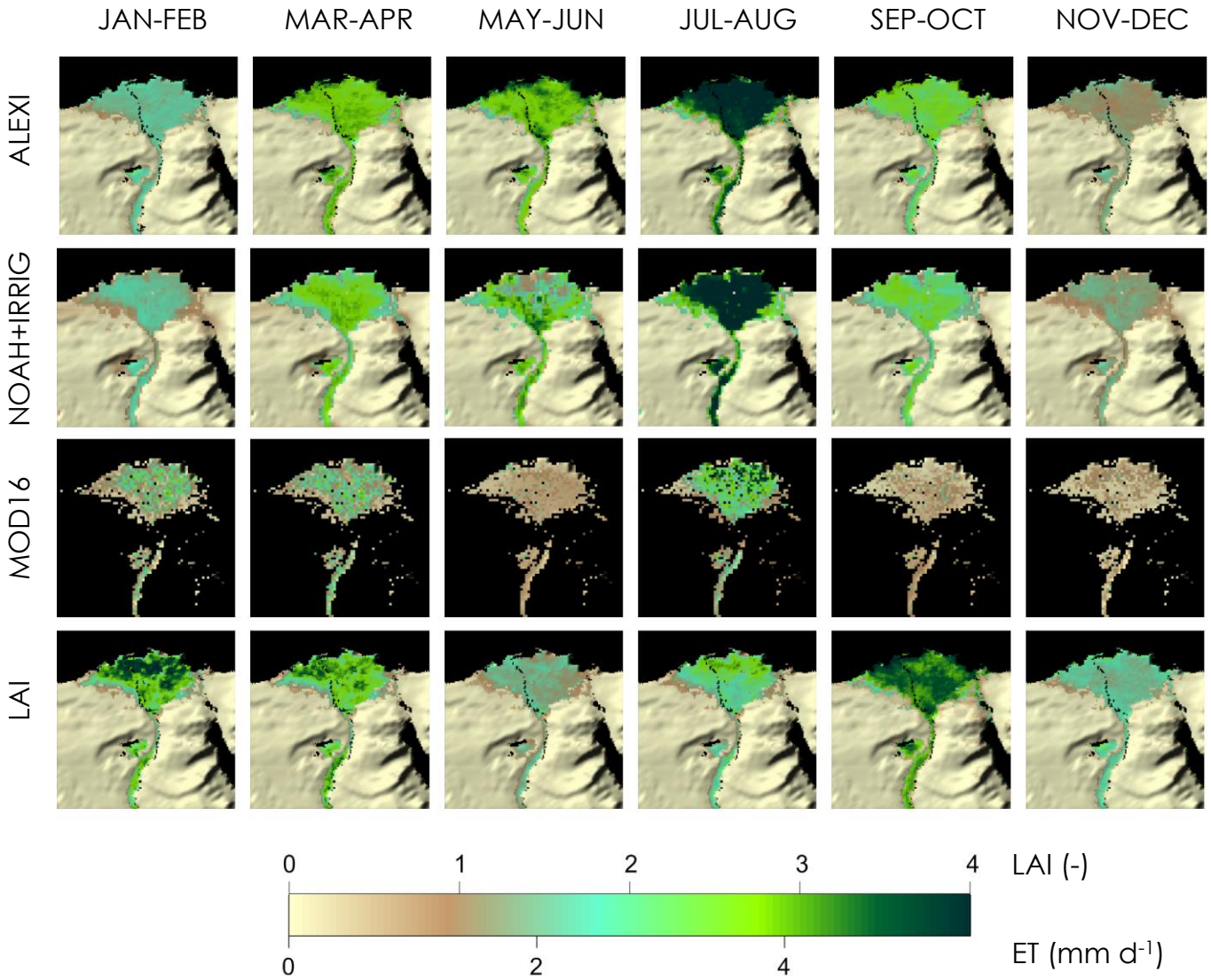
Average ALEXI ET



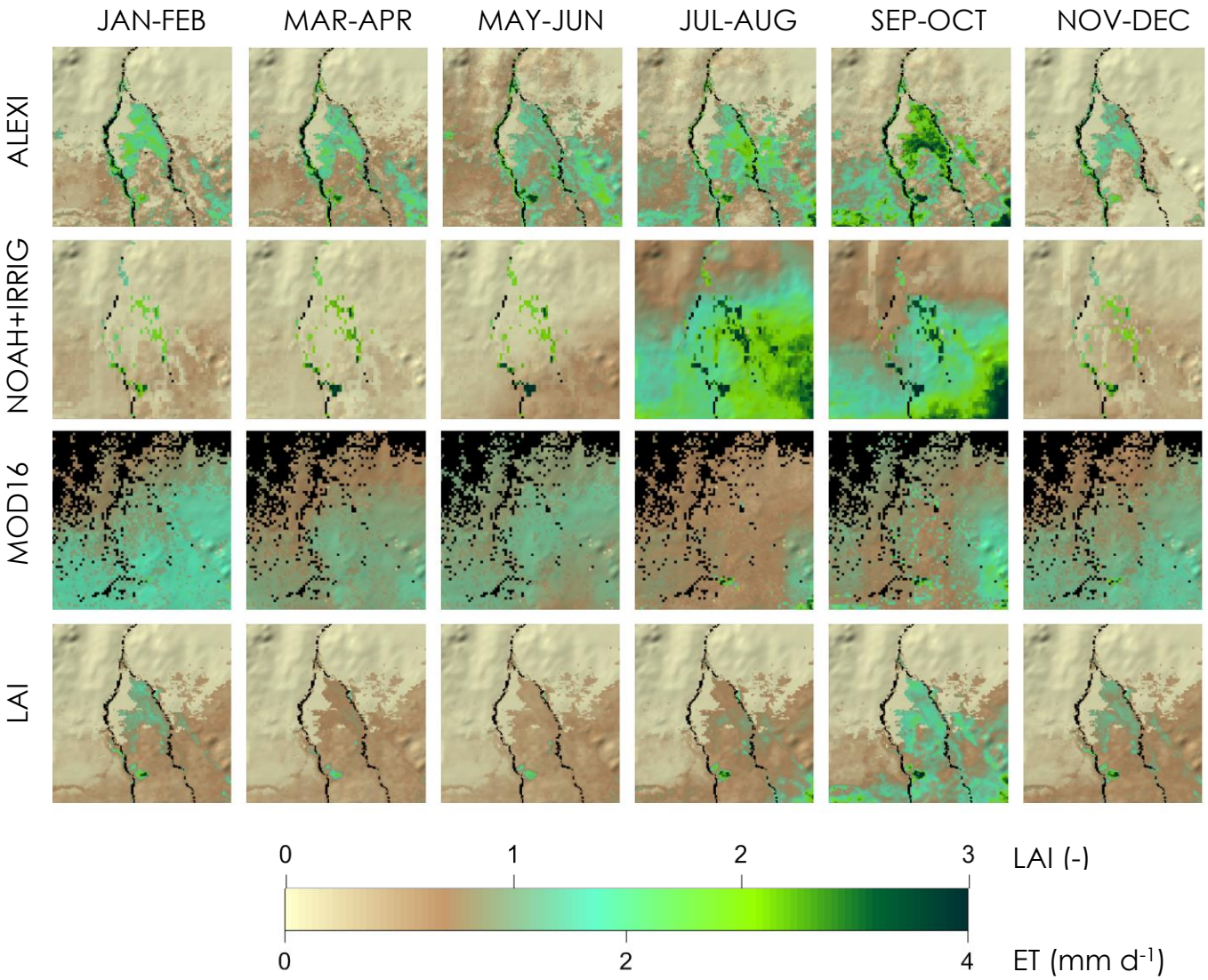
Average Noah ET



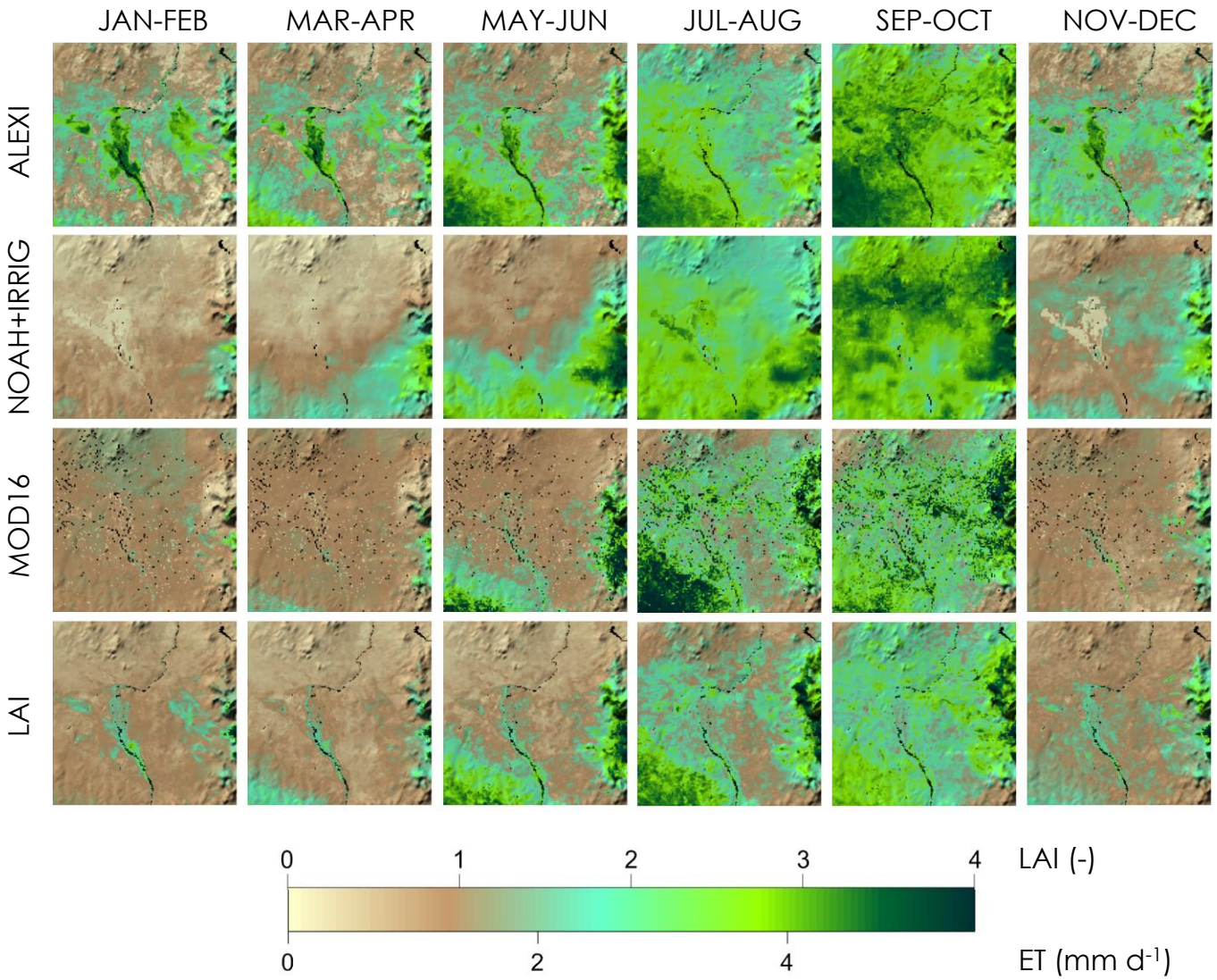
NILE DELTA

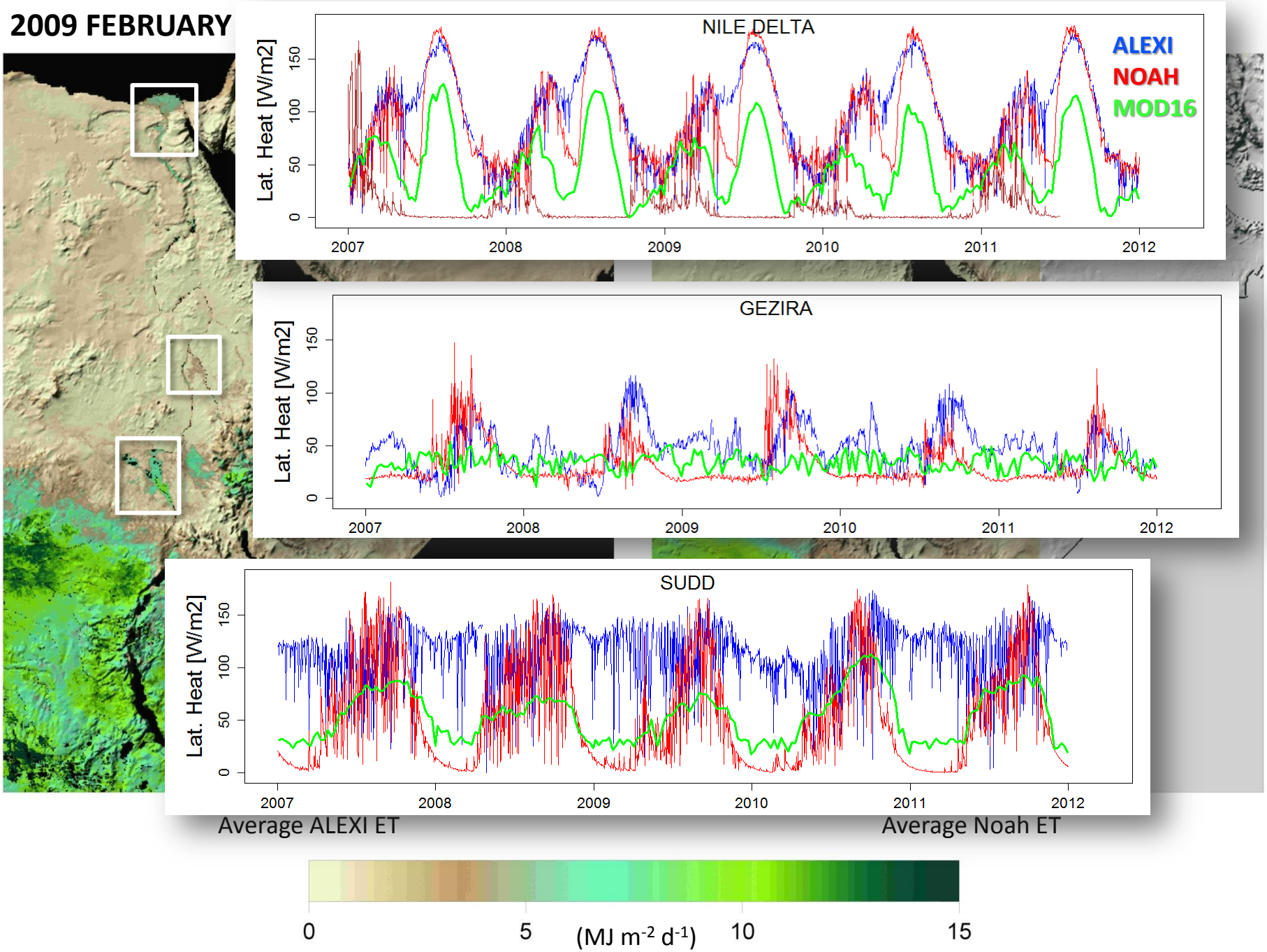

JAN-FEB
MAR-APR
MAY-JUN
JUL-AUG
SEP-OCT
NOV-DEC
ALEXI
NOAH+IRRIG
MOD16
LAI
0
1
2
3
4
LAI (-)
0
2
4
ET (mm d-1)

GEZIRA IRRIGATION SCHEME



SUDD WETLAND




2009 FEBRUARY
NILE DELTA
ALEXI
NOAH
MOD16
Lat. Heat [W/m2]
0
50
100
150
2007
2008
2009
2010
2011
2012
GEZIRA
Lat. Heat [W/m2]
SUDD
Lat. Heat [W/m2]
Average ALEXI ET
Average Noah ET
0
5
10
15
(MJ m-2 d-1)

ALEXI Source/Sink of ET

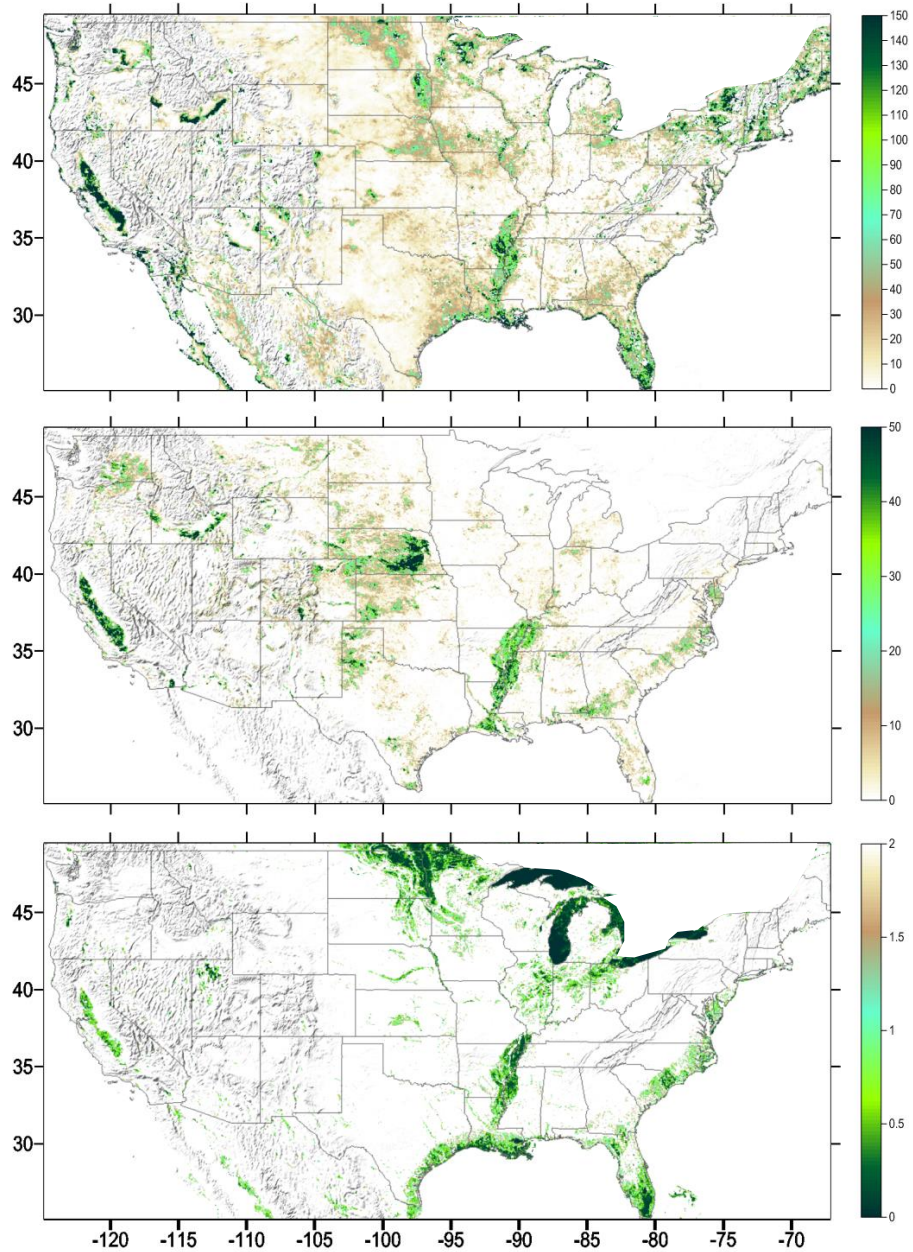
ASSET

$(LE_{ALEXI} - LE_{Noah})$ $\frac{LE_{ALEXI}}{VAR_{ALEXI}}$

(Green indicates persistently wetter than expected based on local water balance)

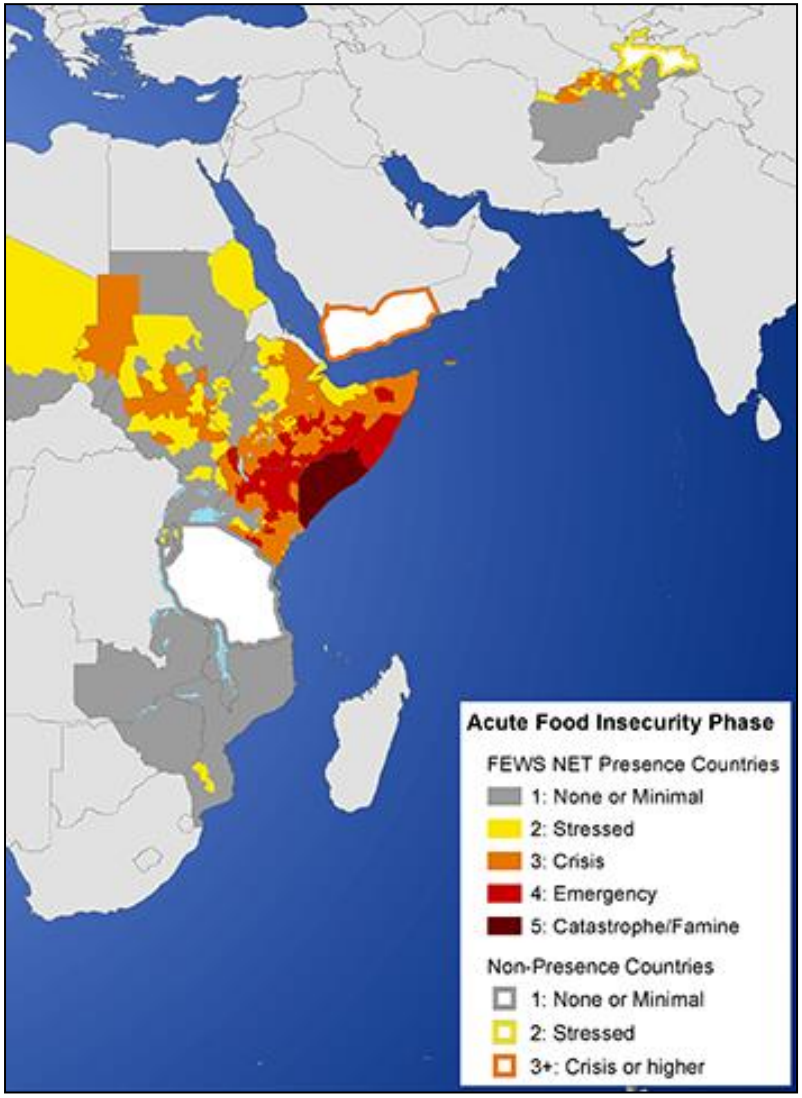
% Irrigation

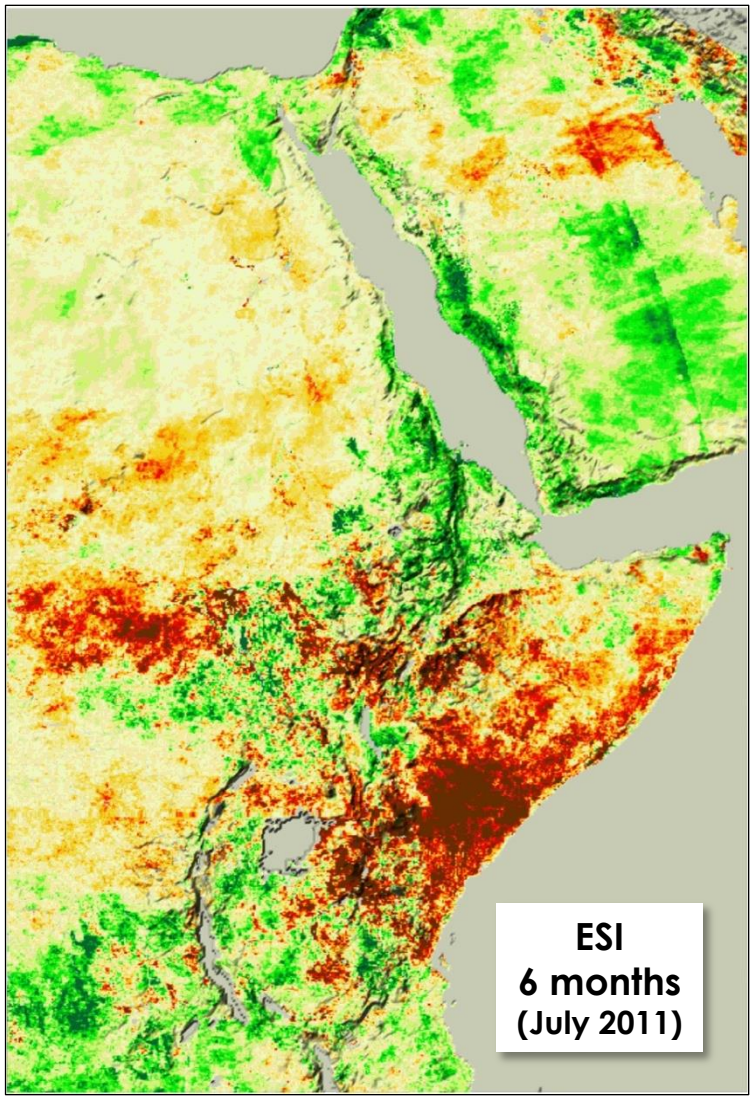
Depth to Water table (WTD) (m)



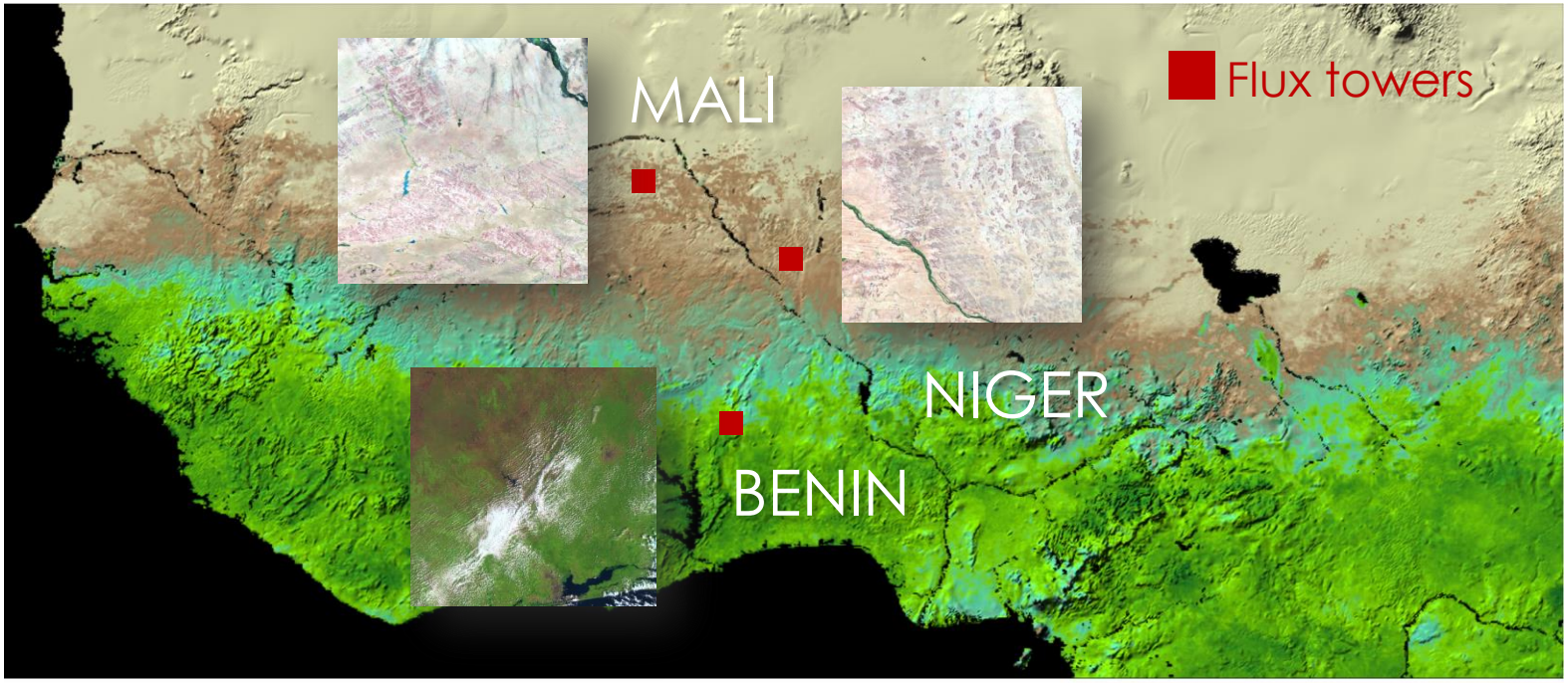
Hain, et al. (2014)

2011 Famine in Somalia

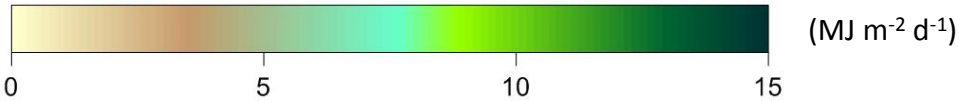




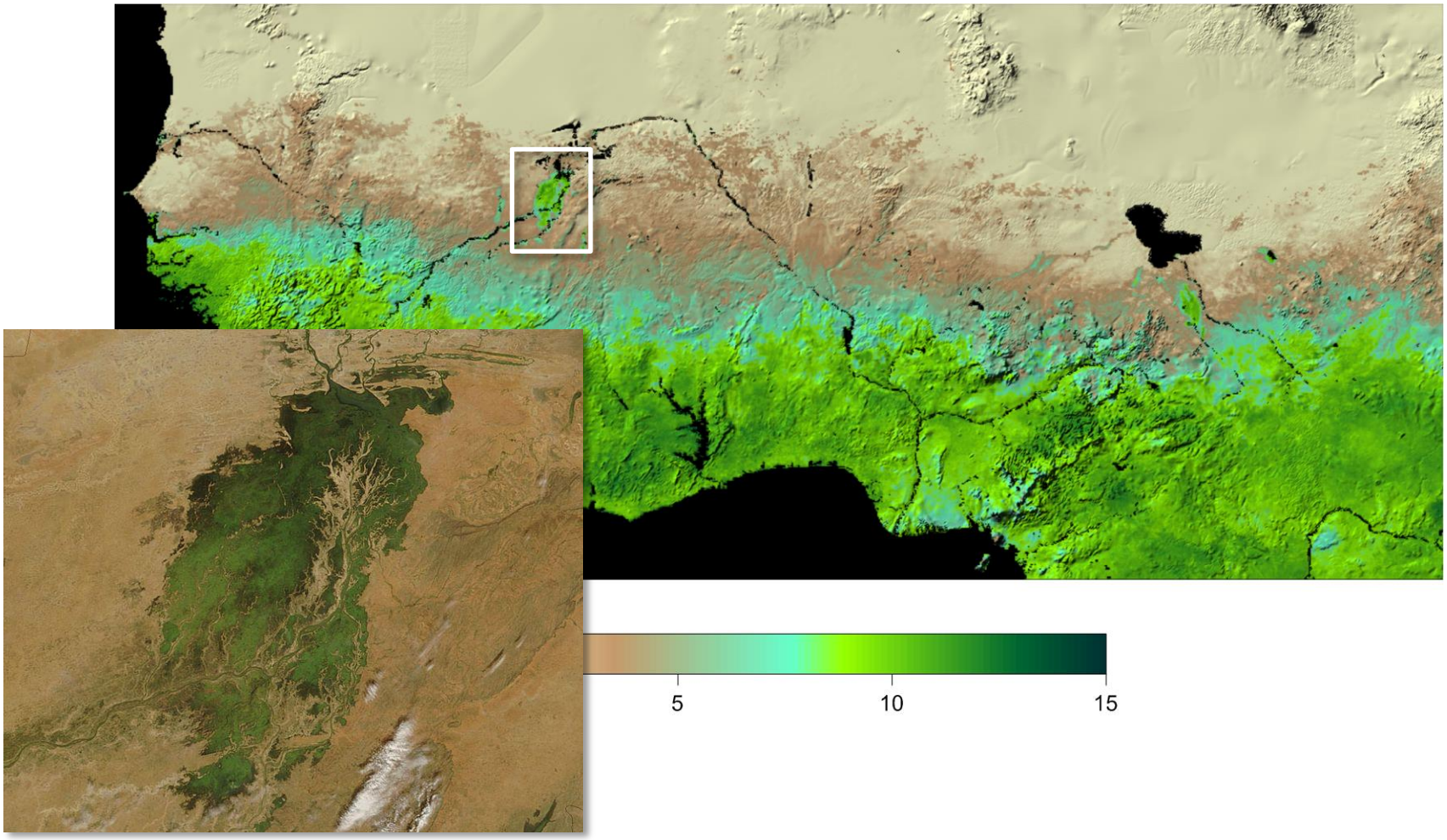
ALMIP AMMA Land Surface Model Intercomparison Project



African Monsoon Multidisciplinary Analysis (CNRM, CESBIO)



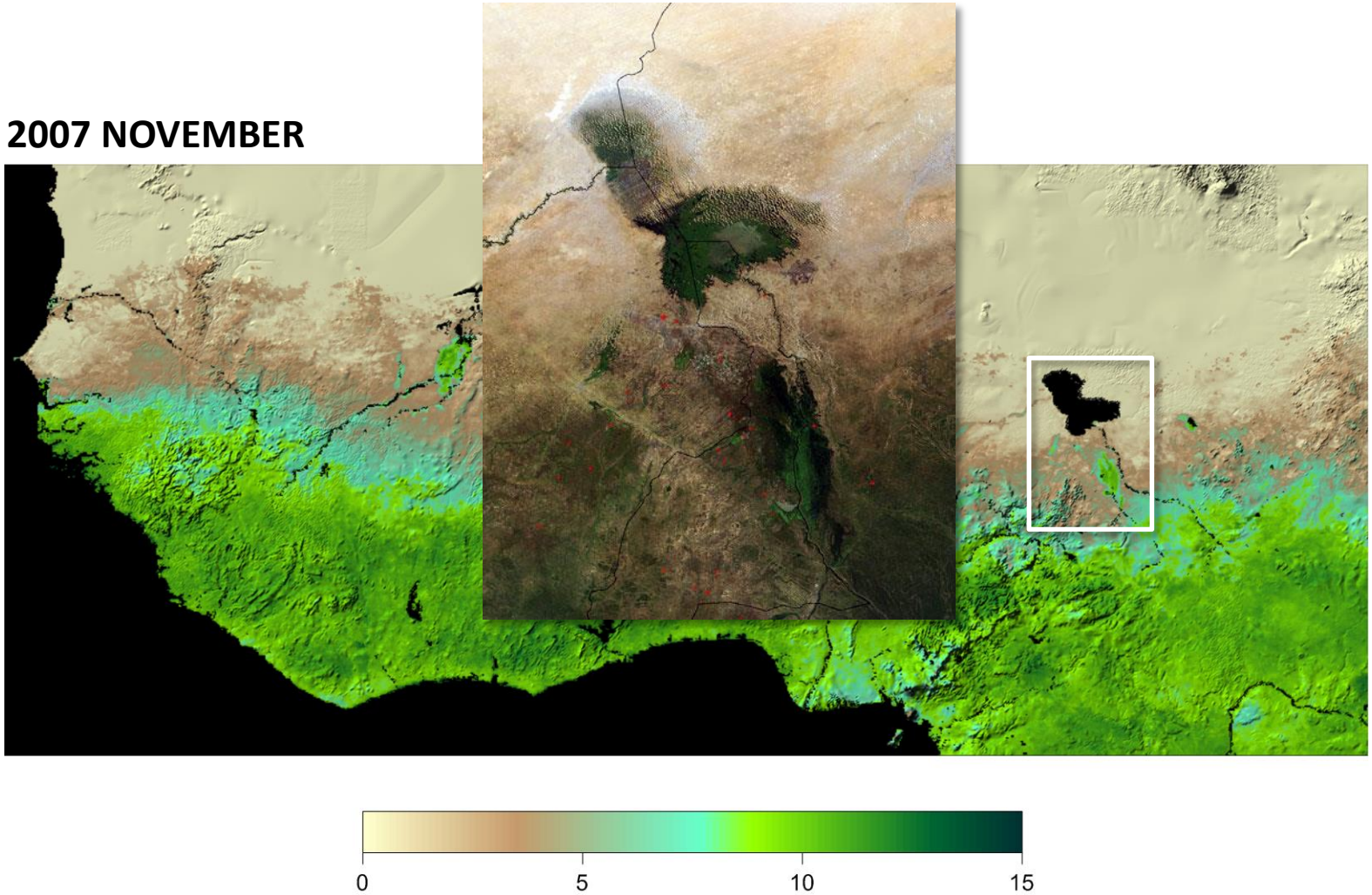
2007 NOVEMBER



Inland Niger Delta, MODIS

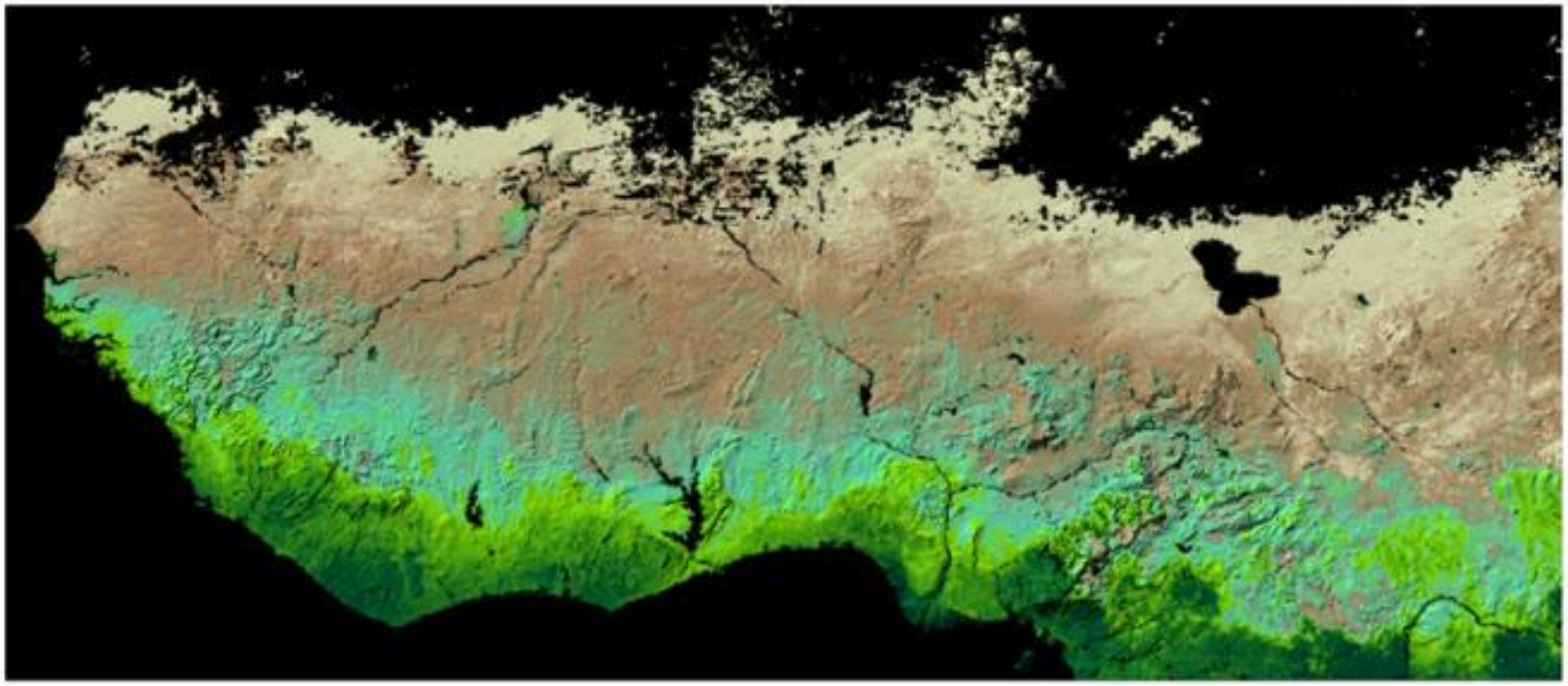
Lake Chad and Logone floodplain, MODIS

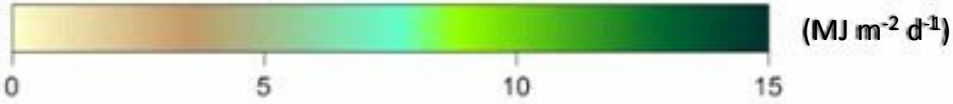
2007 NOVEMBER



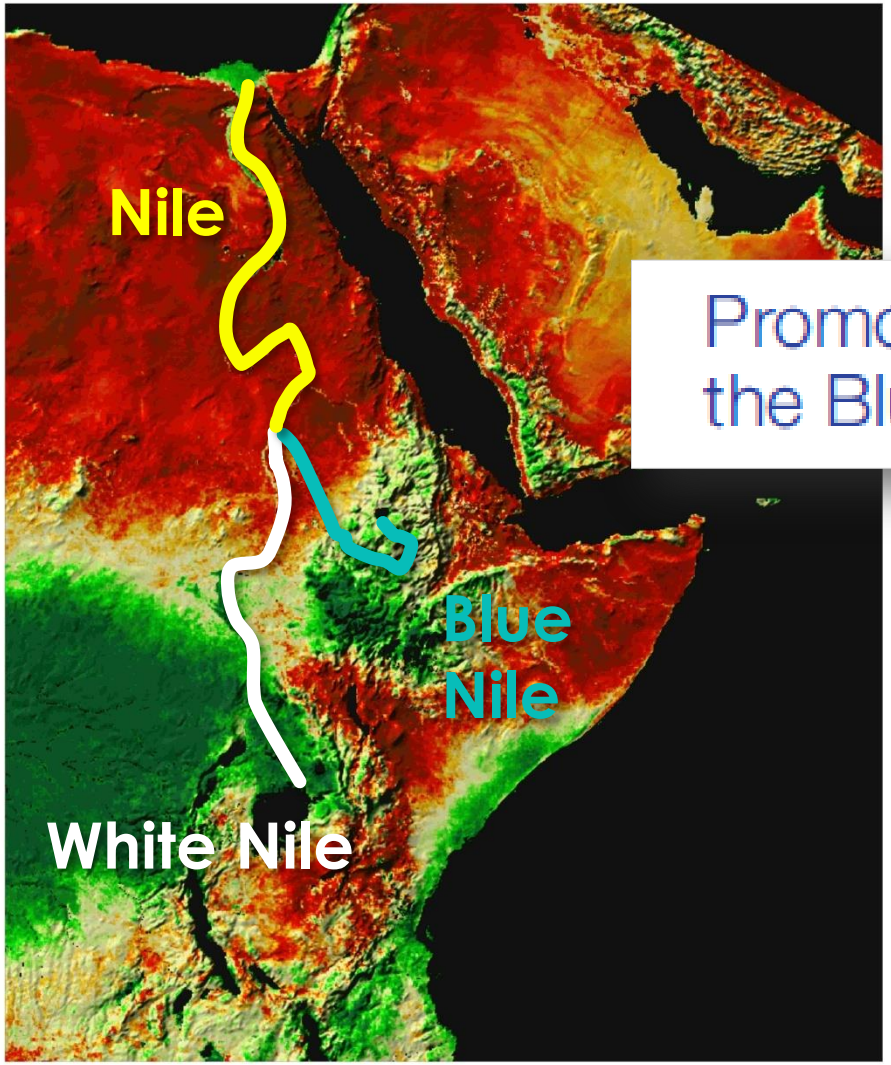
MONTHLY AVERAGE LATENT HEAT

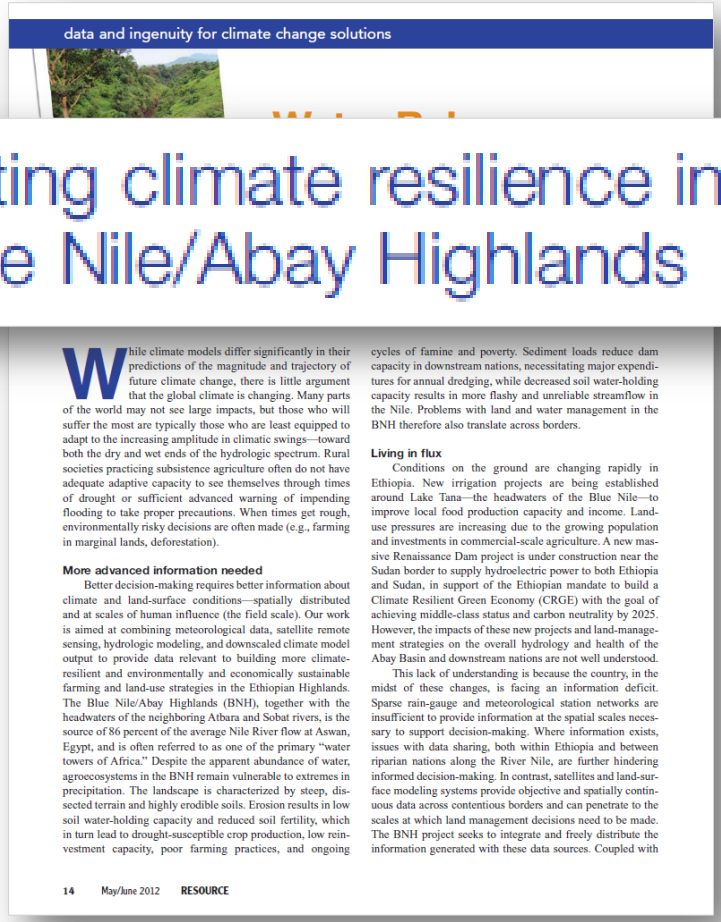
2007 JANUARY





Blue Nile Highlands Project





data and ingenuity for climate change solutions

Promoting climate resilience in the Blue Nile/Abay Highlands

While climate models differ significantly in their predictions of the magnitude and trajectory of future climate change, there is little argument that the global climate is changing. Many parts of the world may not see large impacts, but those who will suffer the most are typically those who are least equipped to adapt to the increasing amplitude in climatic swings—toward both the dry and wet ends of the hydrologic spectrum. Rural societies practicing subsistence agriculture often do not have adequate adaptive capacity to see themselves through times of drought or sufficient advanced warning of impending flooding to take proper precautions. When times get rough, environmentally risky decisions are often made (e.g., farming in marginal lands, deforestation).

More advanced information needed

Better decision-making requires better information about climate and land-surface conditions—spatially distributed and at scales of human influence (the field scale). Our work is aimed at combining meteorological data, satellite remote sensing, hydrologic modeling, and downscaled climate model output to provide data relevant to building more climate-resilient and environmentally and economically sustainable farming and land-use strategies in the Ethiopian Highlands. The Blue Nile/Abay Highlands (BNH), together with the headwaters of the neighboring Atbara and Sobat rivers, is the source of 86 percent of the average Nile River flow at Aswan, Egypt, and is often referred to as one of the primary "water towers of Africa." Despite the apparent abundance of water, agroecosystems in the BNH remain vulnerable to extremes in precipitation. The landscape is characterized by steep, dissected terrain and highly erodible soils. Erosion results in low soil water-holding capacity and reduced soil fertility, which in turn lead to drought-susceptible crop production, low reinvestment capacity, poor farming practices, and ongoing cycles of famine and poverty. Sediment loads reduce dam capacity in downstream nations, necessitating major expenditures for annual dredging, while decreased soil water-holding capacity results in more flashy and unreliable streamflow in the Nile. Problems with land and water management in the BNH therefore also translate across borders.

Living in flux

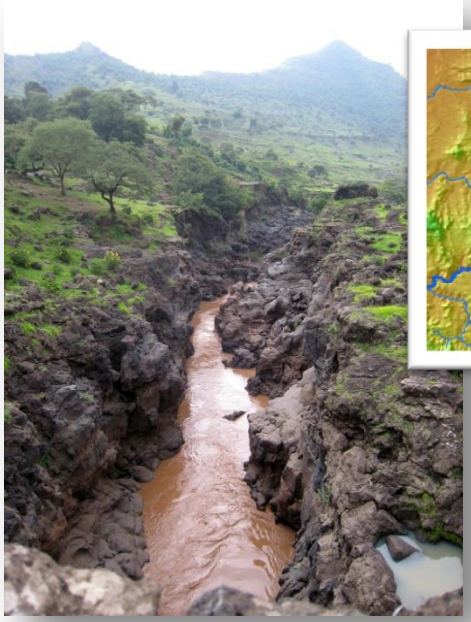
Conditions on the ground are changing rapidly in Ethiopia. New irrigation projects are being established around Lake Tana—the headwaters of the Blue Nile—to improve local food production capacity and income. Land-use pressures are increasing due to the growing population and investments in commercial-scale agriculture. A new massive Renaissance Dam project is under construction near the Sudan border to supply hydroelectric power to both Ethiopia and Sudan, in support of the Ethiopian mandate to build a Climate Resilient Green Economy (CRGE) with the goal of achieving middle-class status and carbon neutrality by 2025. However, the impacts of these new projects and land-management strategies on the overall hydrology and health of the Abay Basin and downstream nations are not well understood.

This lack of understanding is because the country, in the midst of these changes, is facing an information deficit. Sparse rain-gauge and meteorological station networks are insufficient to provide information at the spatial scales necessary to support decision-making. Where information exists, issues with data sharing, both within Ethiopia and between riparian nations along the River Nile, are further hindering informed decision-making. In contrast, satellites and land-surface modeling systems provide objective and spatially continuous data across contentious borders and can penetrate to the scales at which land management decisions need to be made. The BNH project seeks to integrate and freely distribute the information generated with these data sources. Coupled with

14 May/June 2012 RESOURCE

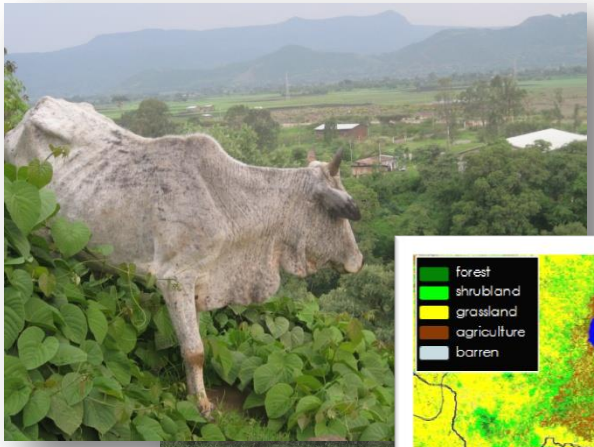
Blue Nile Highlands Project

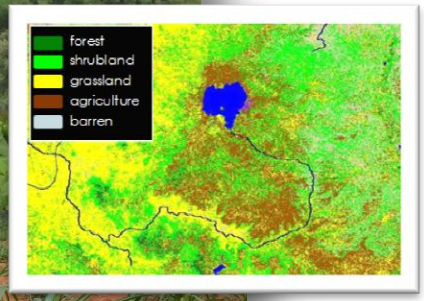
INFORMATION PRODUCTS

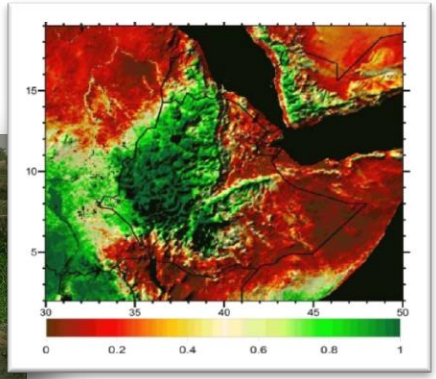


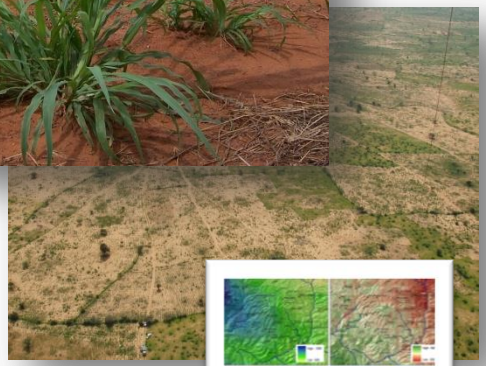
Erosion potential
Sediment loads

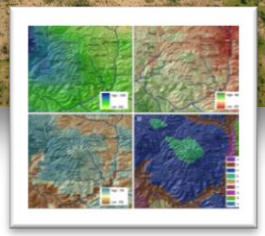
Land-use planning
Resilient cropping systems











Water use/availability
Drought and flood monitoring

Conclusions

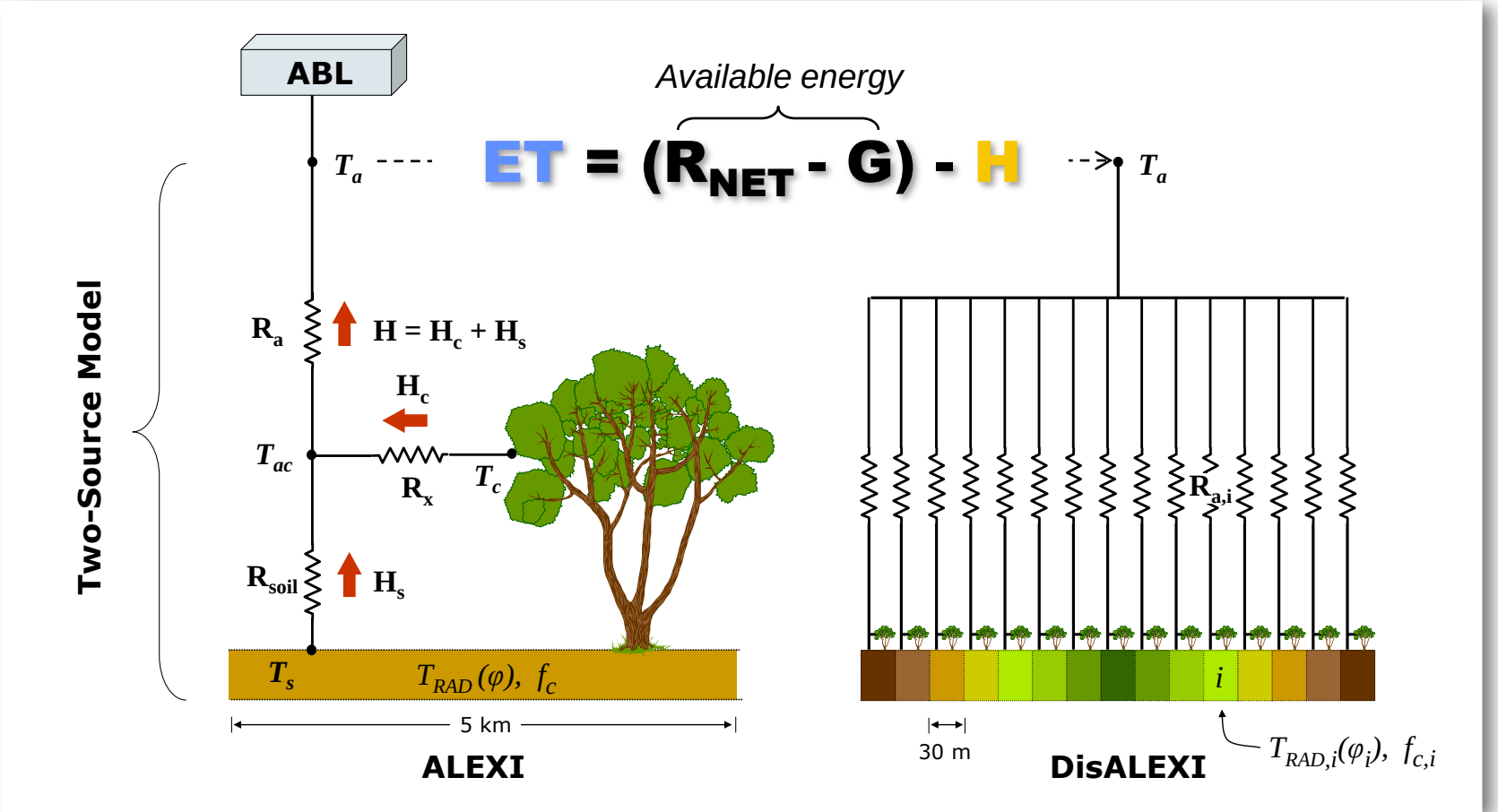
Satellite Evapotranspiration

- Monitoring water use at field to continental scales
- Land-surface temperature conveys early warning of vegetation stress
- Independent check on precipitation-based drought indices
- Applications in global water and food security

hrsl.arsusda.gov/drought

USDA is an equal opportunity provider and employer.

Atmosphere-Land Exchange Inverse



Regional scale

Surface temp: ΔT_{RAD} - GOES

Air temp: T_a - ABL model

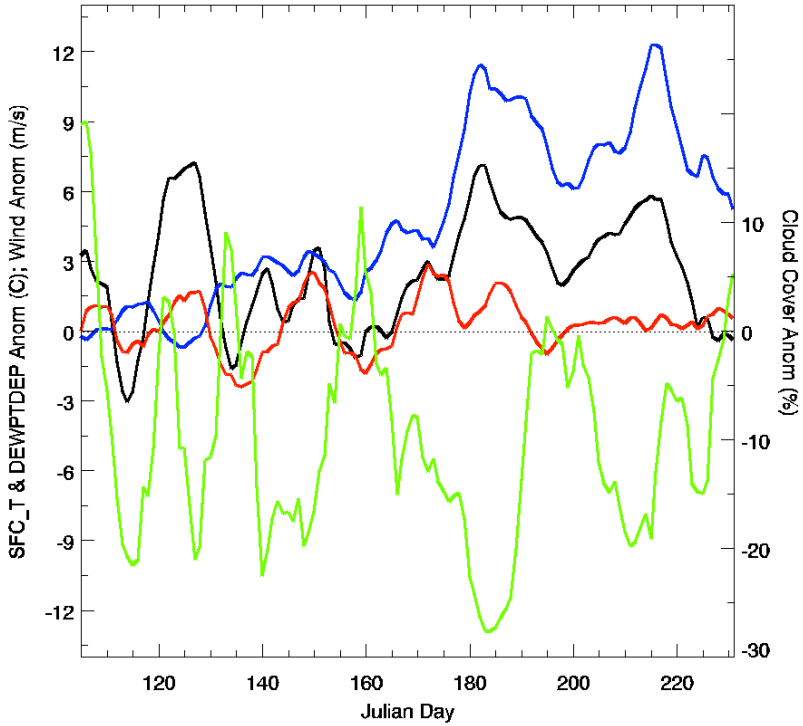
Landscape scale

T_{RAD} - TM, MODIS, HyspIRI

T_a - ALEXI

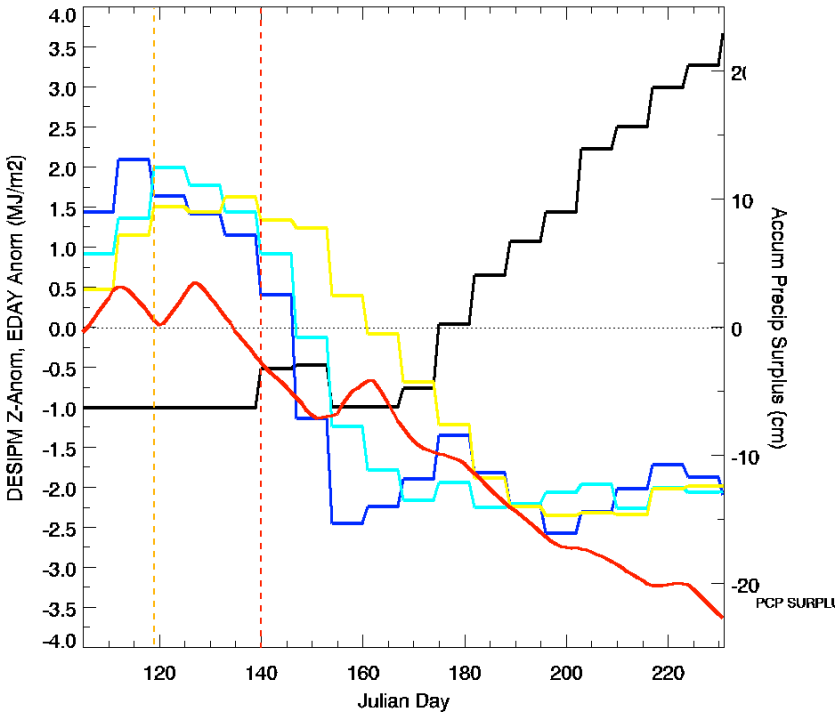
ESI Change over NE Oklahoma

DRIVERS



Air temp
Dewpoint depression
Wind
Cloud cover

RESPONSES



USDM
ESI – 2WK
ESI – 4WK
ESI – 8WK
Accum precip anomaly