Operational ET Determinations in the MENA Region for ESI and Water Productivity

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What we propose to do for the MENA Region

- Use the ALEXI energy balance model to obtain daily surface evapotranspiration (ET) in mm/day at 375 m resolution from the NASA Visible Infrared Imaging Radiometer Suite (VIIRS) Satellite Instrument, which provides complete coverage of Earth across the day.

- Use this ET Product for the estimation of the Evaporative Stress Index (ESI), a component of the Composite Drought Index (CDI). The 375 m ET product can also be used for water accounting and availability in watersheds and river basins.

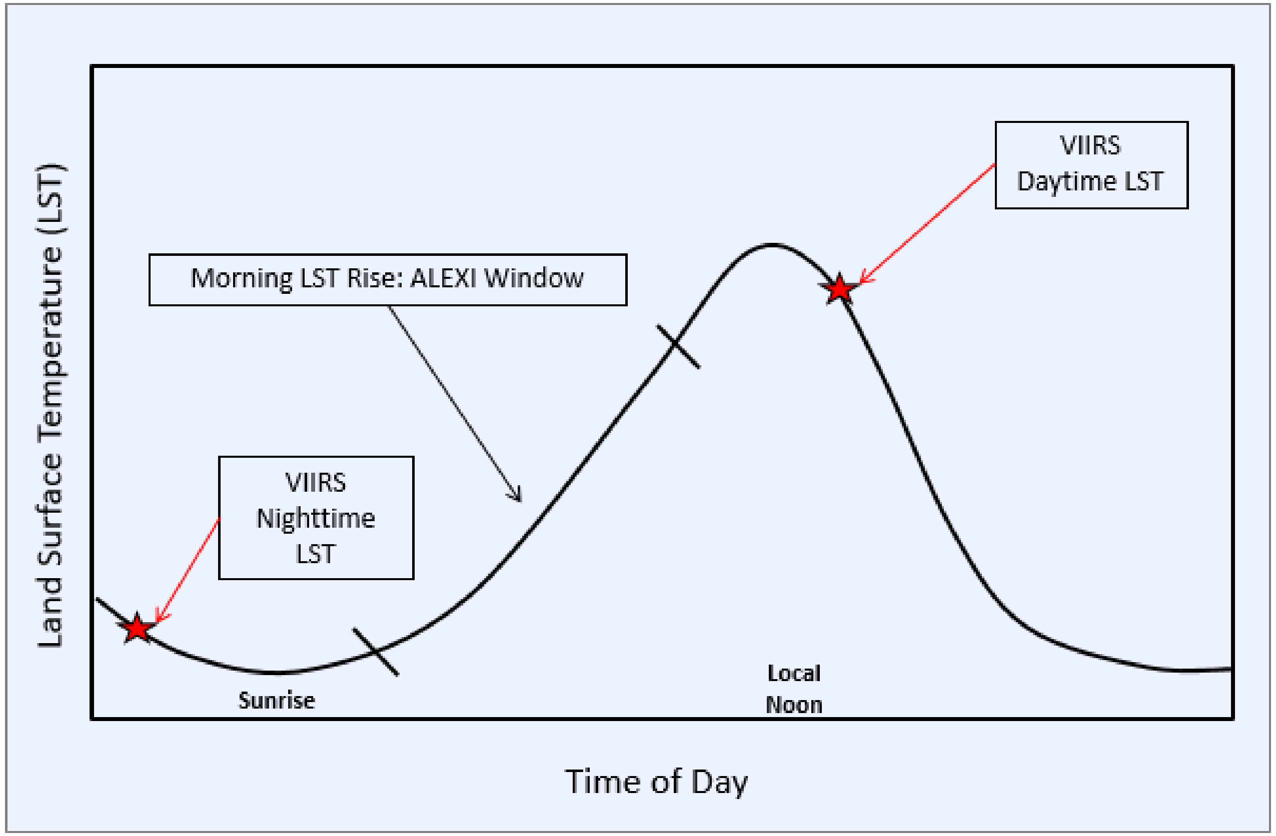
- Disaggregate the ET product using Landsat and PyDisALEXI for field scale water productivity and crop yield estimates at 30 m resolution.

Supplementing ALEXI Capabilities with Polar Orbiting Sensors

- Morning Land Surface Temperature (LST) rise **in the eastern hemisphere** is a needed to run ALEXI in the MENA region.

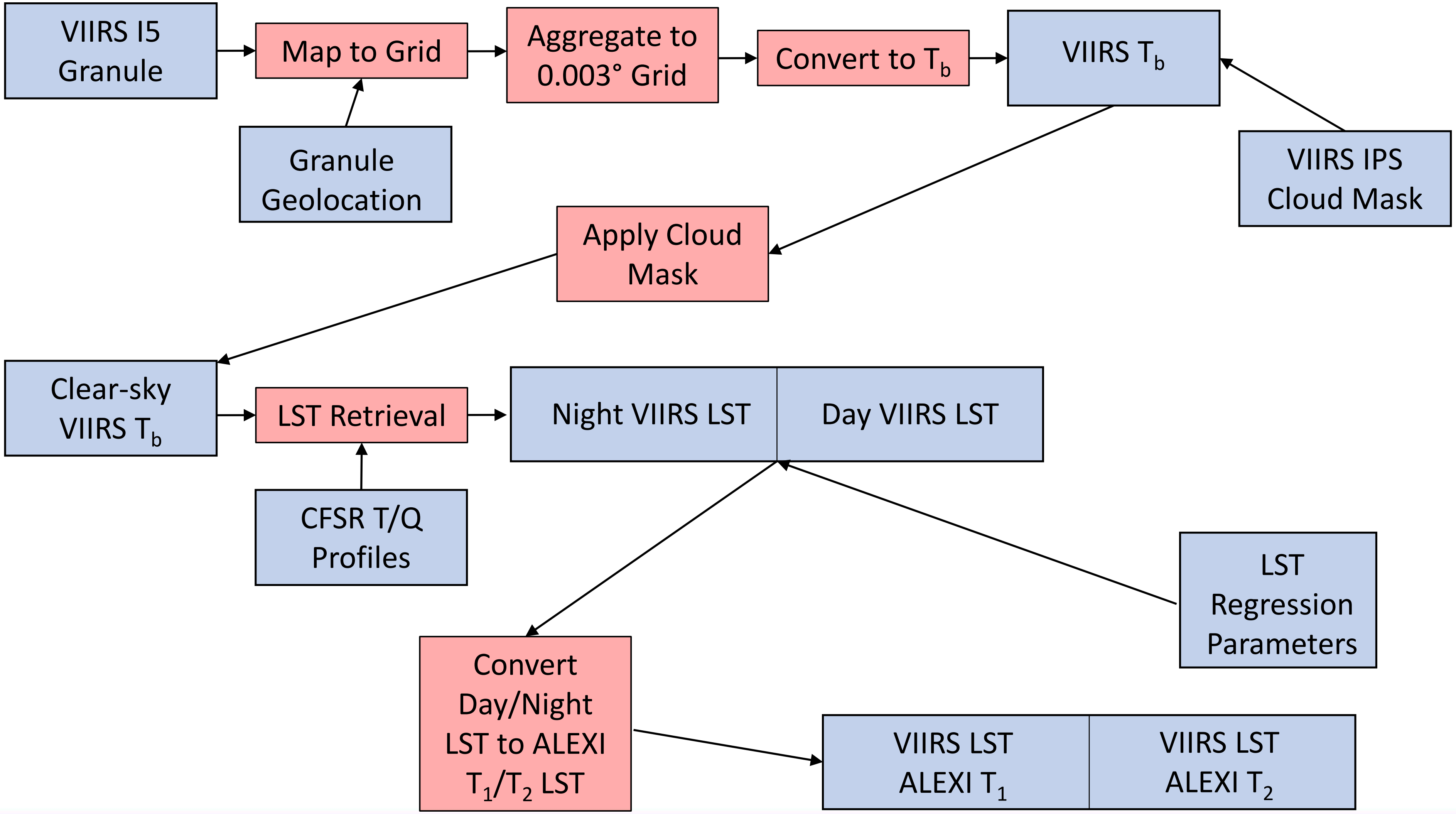
- The NASA Geostationary Operational Environmental Satellite system (GOES) provides coverage of **the western hemispheres** and **continuous** LST data. The polar-orbiting MODIS & VIIRS sensor provides **global coverage** and **twice daily** LST measurements.

- A technique has been developed and evaluated using GOES data to **train a regression model to use day-minus-night LST differences from MODIS/VIIRS to predict the morning LST rise in the MENA region** (root mean squared error ~ 5 to 8%).



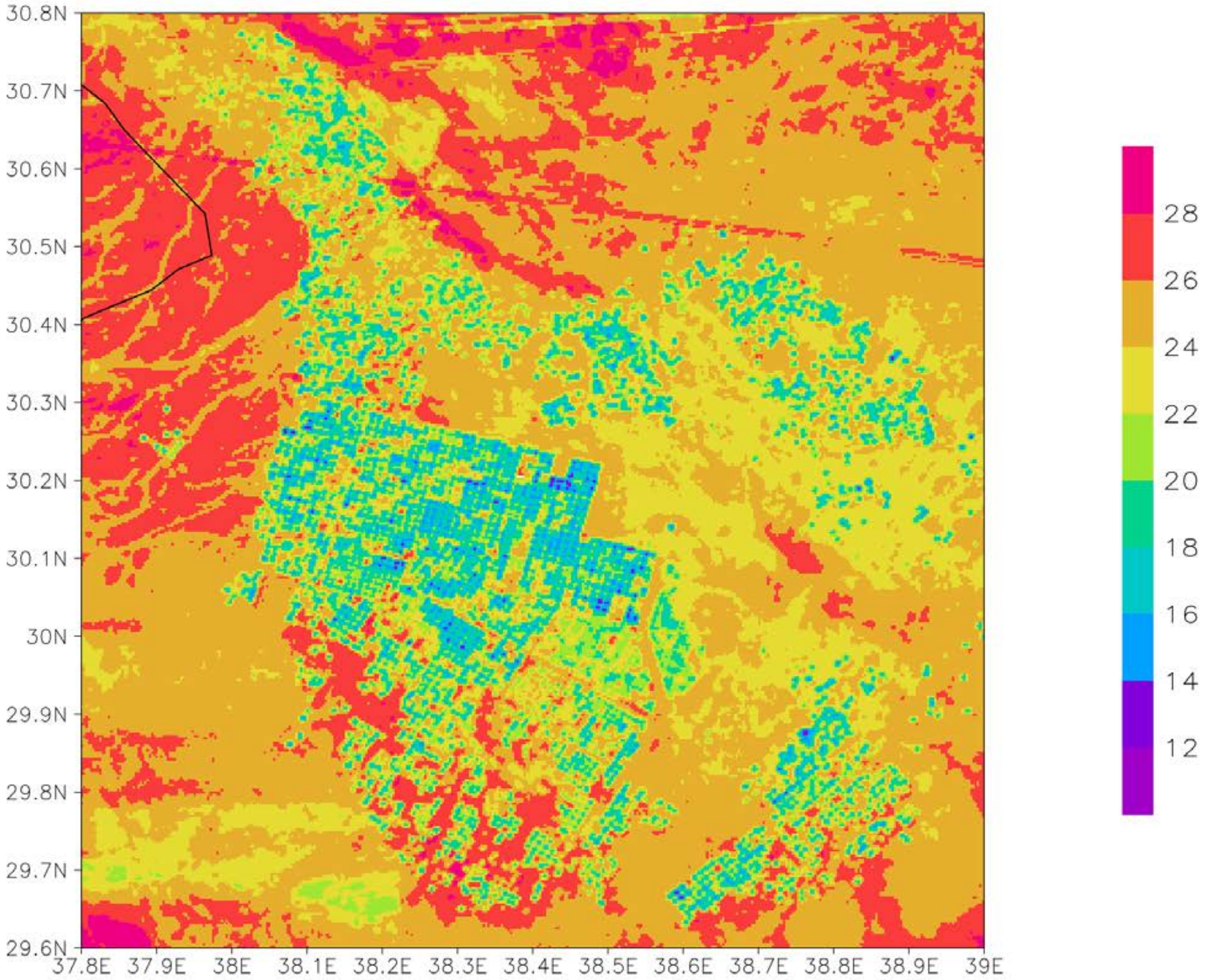
Development of a High-Resolution (375-m) VIIRS ET Product

Input 1: Mid-morning change in Land Surface Temperature



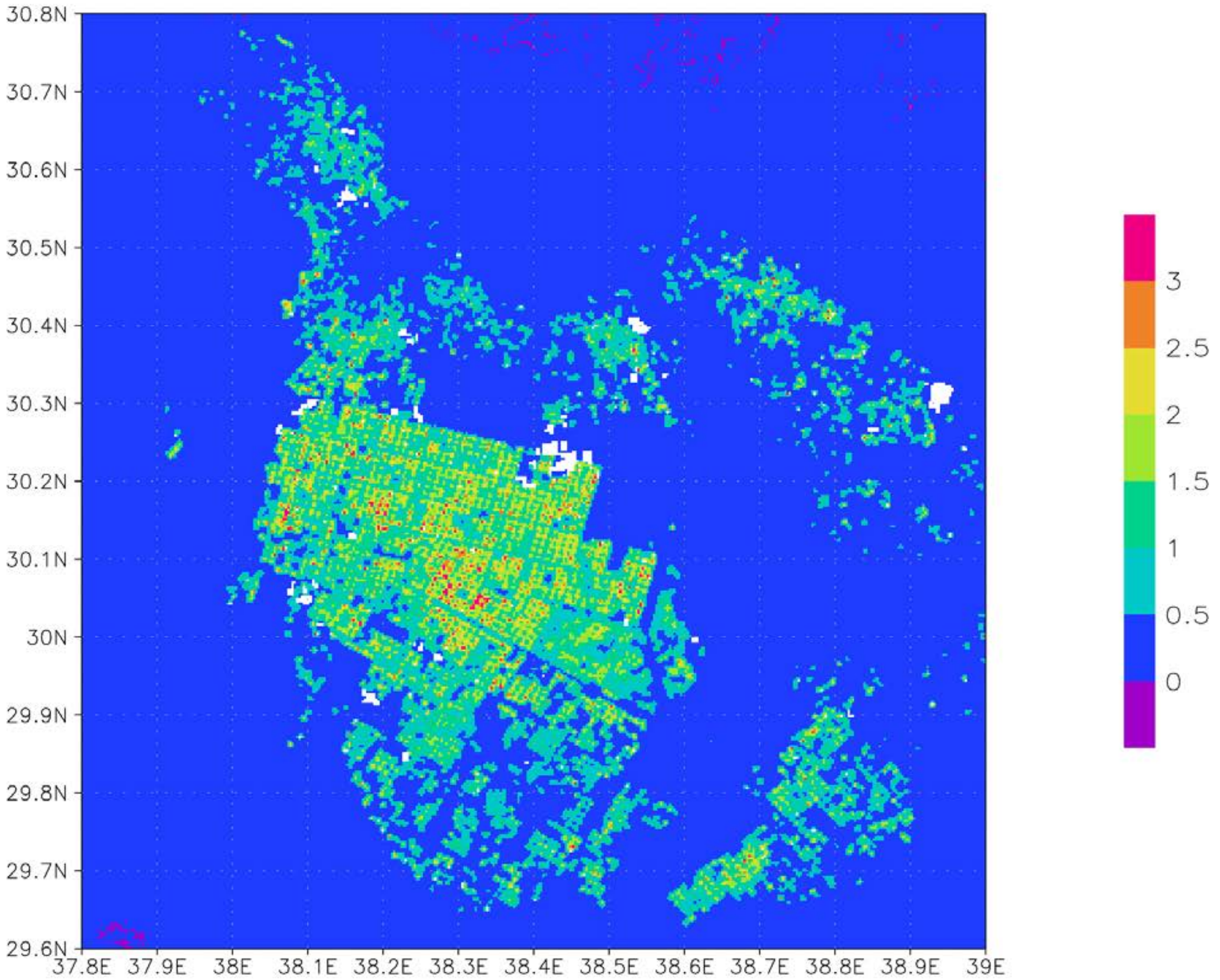
Development of a High-Resolution (375-m) VIIRS ET Product

Input 1: Mid-morning change in Land Surface Temperature



Development of a High-Resolution (375-m) VIIRS ET Product

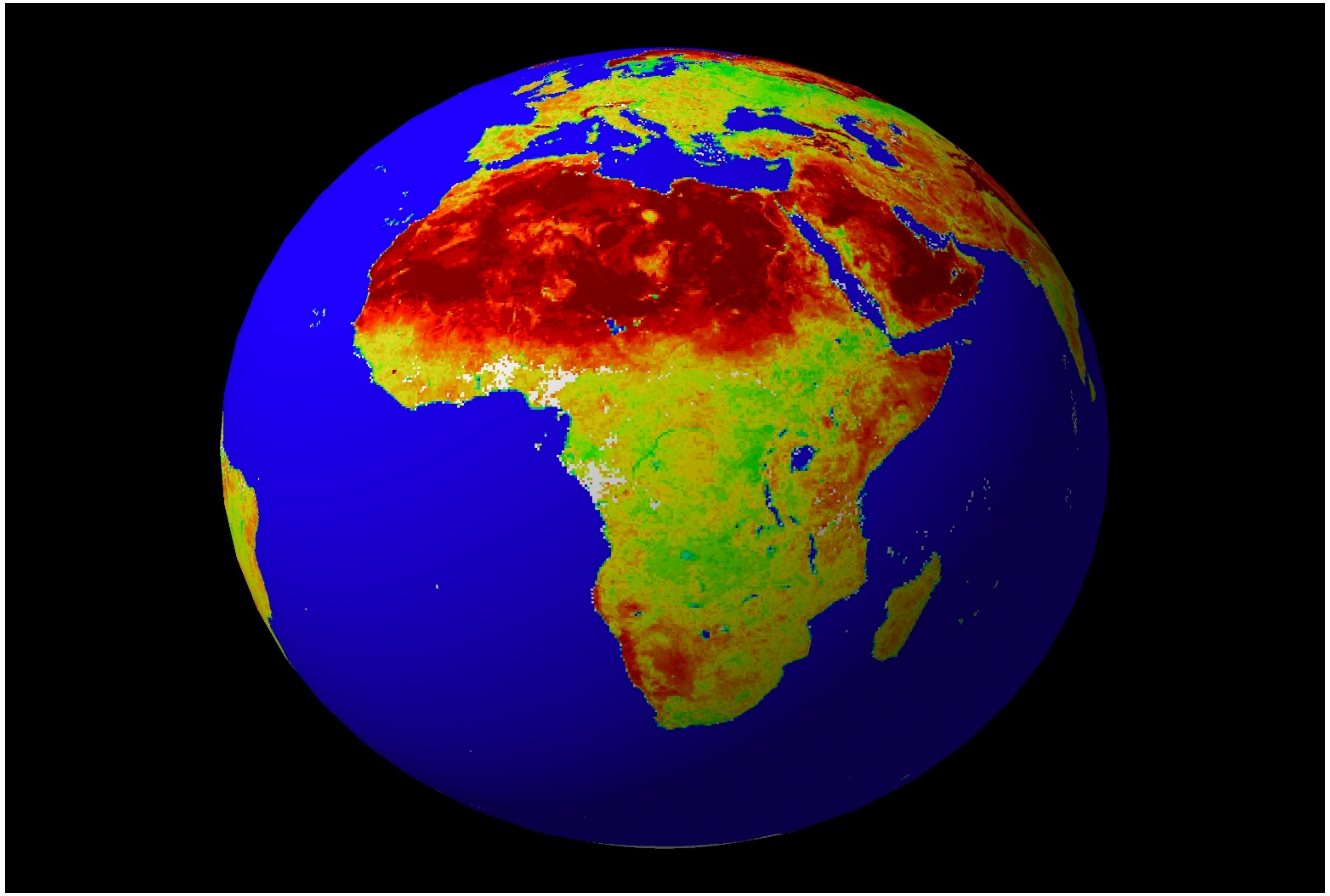
Input 2: Leaf Area Index and Fraction of Green Vegetation Cover (f_c)



Development of a High-Resolution (375-m) VIIRS ET Product

Input 3: Land Surface Albedo

Only available VIIRS product is at 750-m, mapped to 375-m grid, used to calculate surface reflectivity in Visible/Near-Infrared spectrum as needed by ALEXI

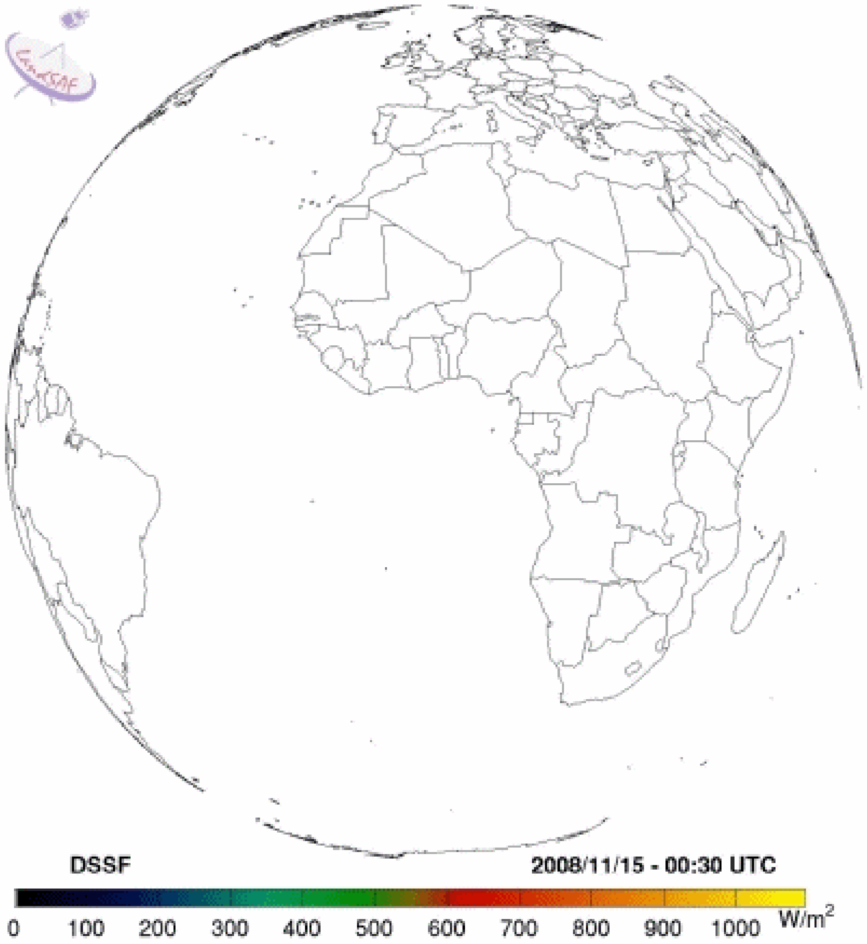


Development of a High-Resolution (375-m) VIIRS ET Product

Input 4: Incoming Solar Radiation

Only available from geostationary platforms – Meteosat (3-km) / will use CFS-4 daily insolation for scaling to daily fluxes as back-up data source

[currently used for other ALEXI applications; not ideal due to model-based estimate but model/RS-based insolation tend to converge when considering monthly-annual time scales]



Development of a High-Resolution (375-m) VIIRS ET Product

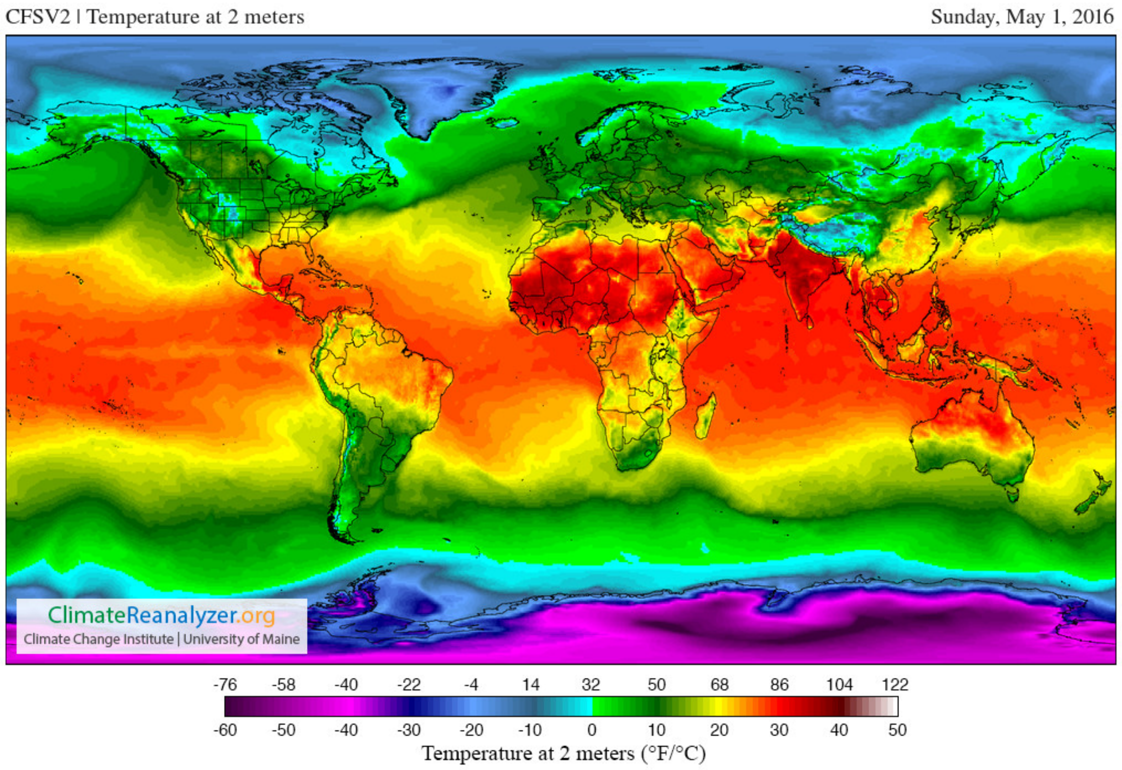
Input 5: Meteorological Surface Fields (air temperature; wind speed; surface pressure; incoming LW)

Available hourly at 0.50º scale from Climate Forecast System Reanalysis (climatereanalyzer.org), developed by Climate Change Institute, University of Maine, and the National Science Foundation.

Input 6: Morning Profile of Potential Temperature

Climate Forecast System Reanalysis (hourly; 0.50º)

CFS-R fields are currently used for all data fusion results (30-m ET) so no issues are expected with this dataset.



Development of a High-Resolution (375-m) VIIRS ET Product

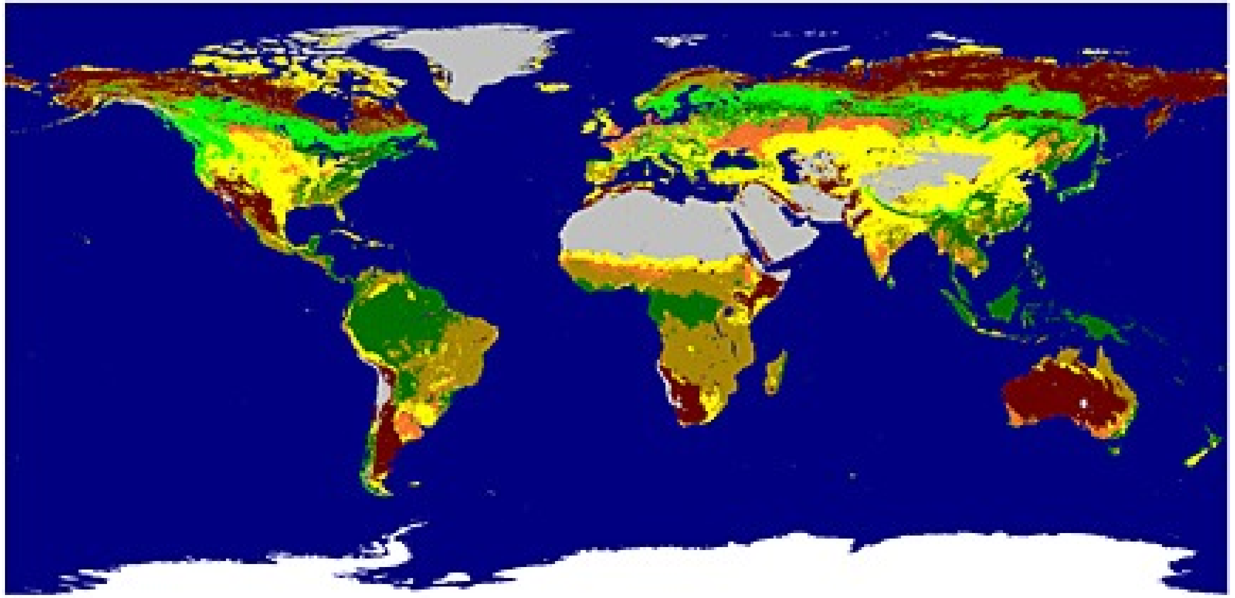
Input 7: Land cover / Vegetation Type

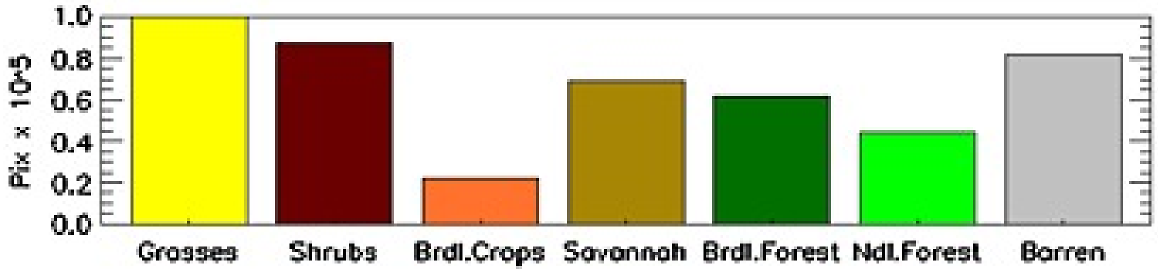
Only available VIIRS product is at 1-km, which is insufficient for 375-m product.

We will use 30-m Landsat-based classification (Chinese dataset) – all tiles over MENA region have been downloaded, gridded to 375-m domain, and the % of each land class in each VIIRS pixel has been calculated.

What happens when Landsat-based classification is not representative of VIIRS EVI/NDVI information?

- We're developing a processing check to ensure changes to agricultural practices which can be determined by VIIRS vegetation time series to ensure we're processing pixels which may be classified as "barren" but now include agricultural pixels.



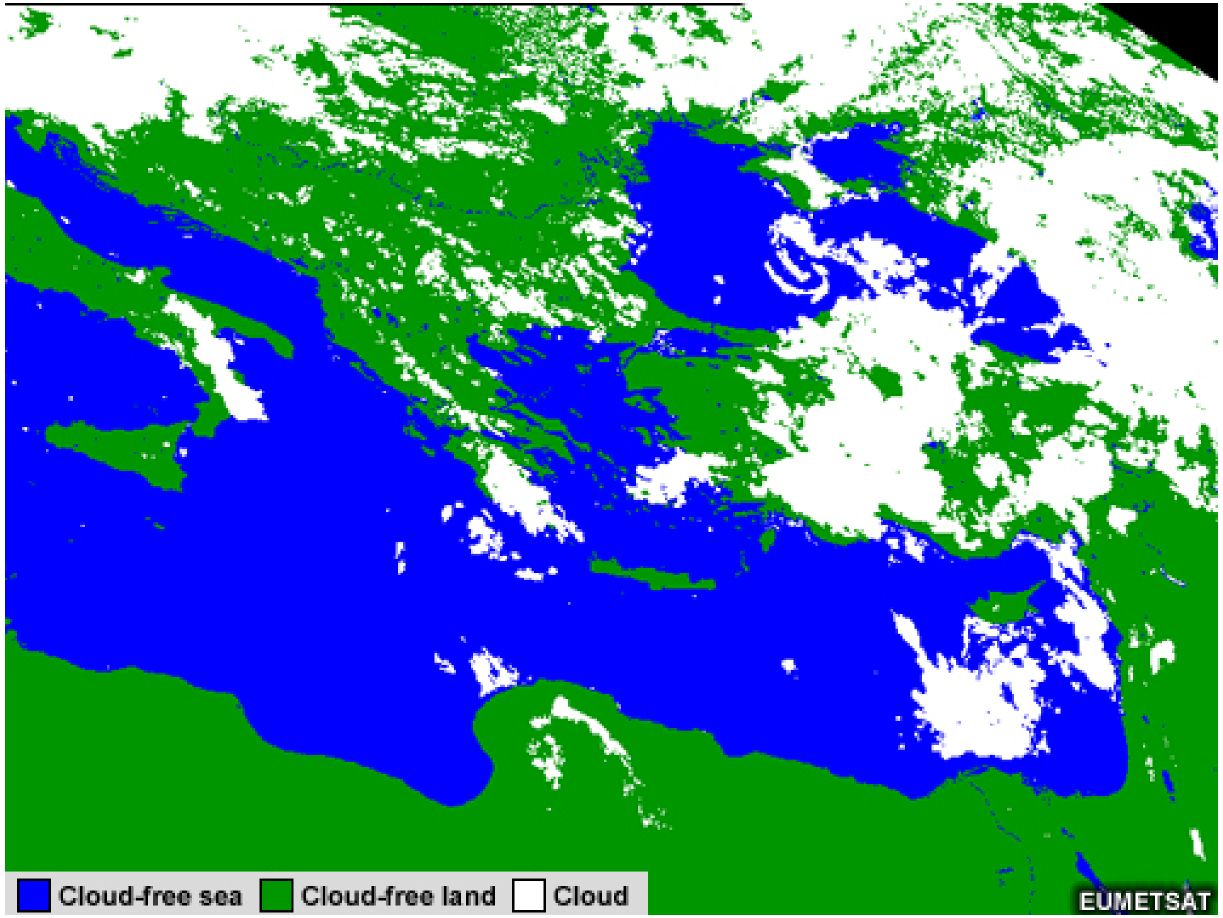


Development of a High-Resolution (375-m) VIIRS ET Product

Input 8: Cloud Mask

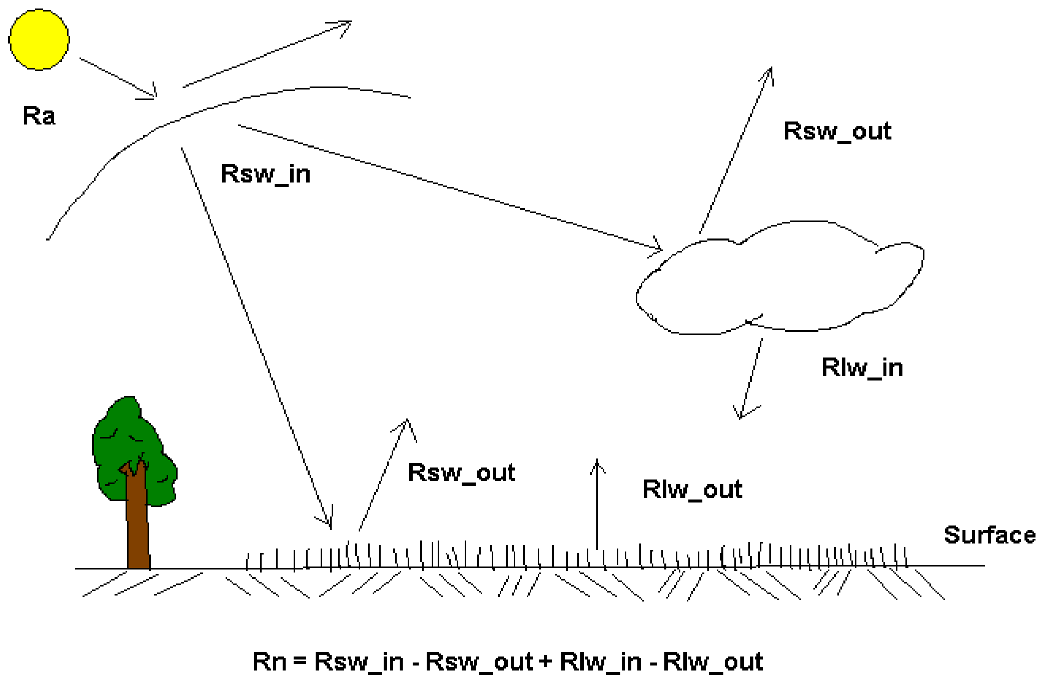
Only available VIIRS product is at 750-m – mapped to 375-m grid.

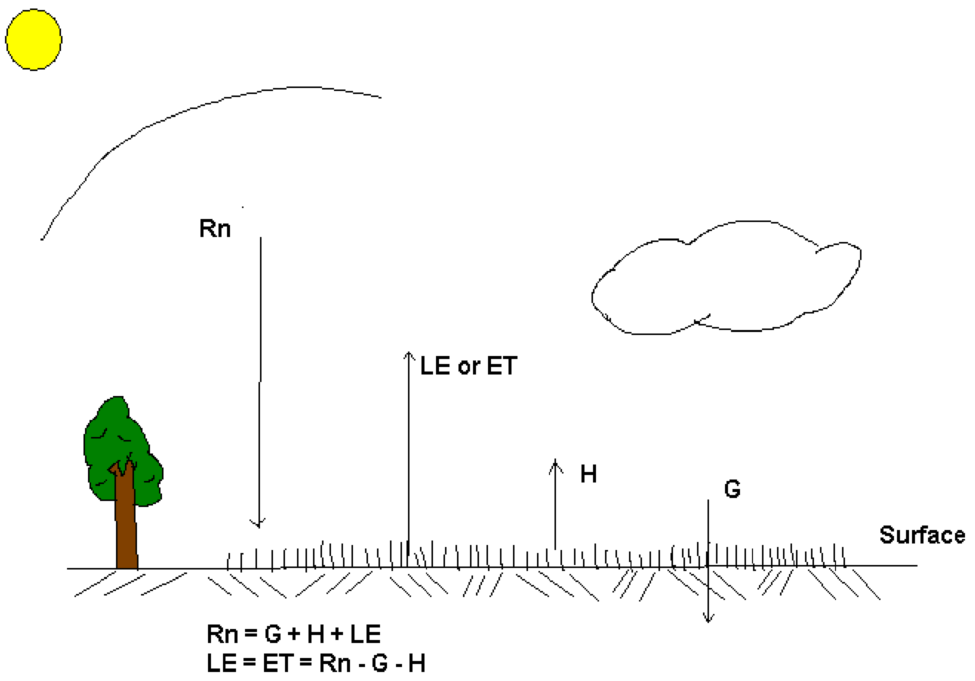
Once we acquire more years of VIIRS data we'll develop additional climatological-based QC metrics to remove cloud contamination that is "missed" in VIIRS cloud mask.



How do we use Remote Sensing for Estimating Evapotranspiration?

By solving for components of the Energy Balance Equation



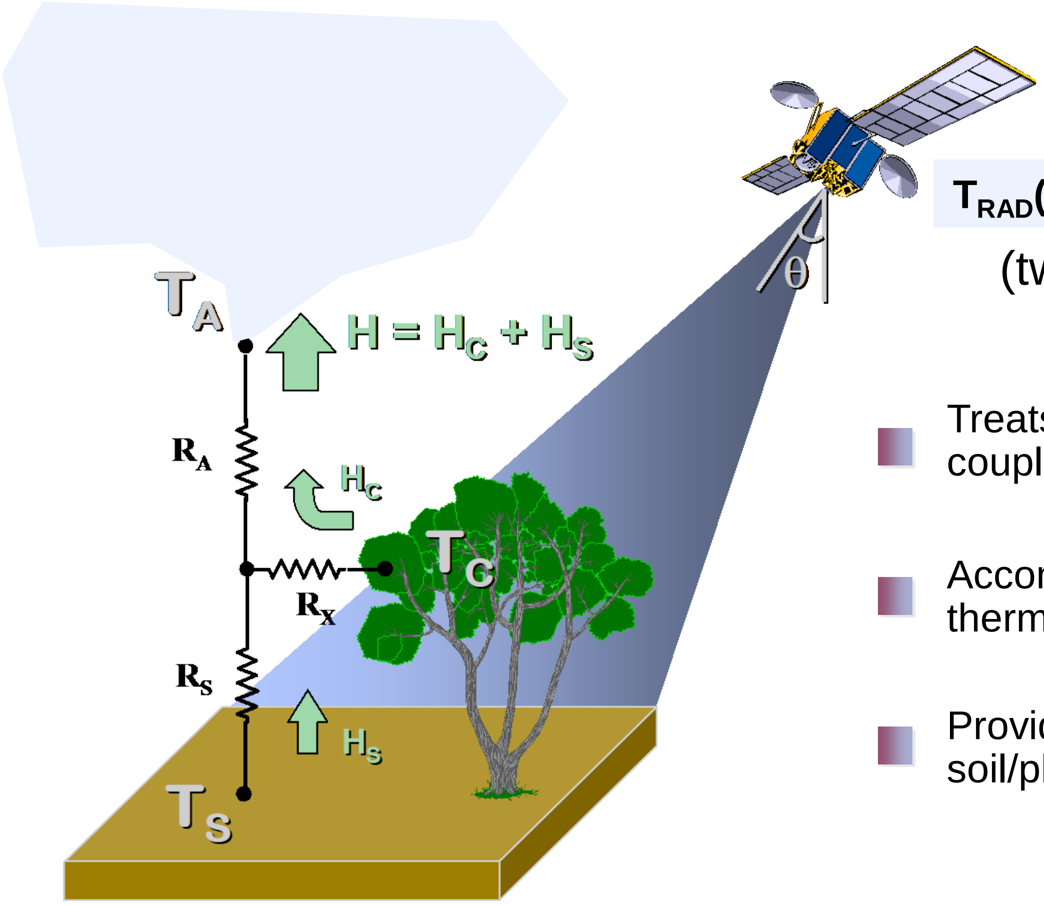


Net Radiation Rn is the balance of incoming shortwave and longwave radiation

Net Radiation is energy available to do work: heat the air (H), the soil (G) and evaporate water (ET)

The ALEXI model runs the TSEB

Two-Source Energy Balance Model (TSEB)



$$T_{RAD}(\theta) \sim f_c(\theta)T_c + [1\text{-}f_c(\theta)]T_s$$

(two-source approximation)

Norman, Kustas et al. (1995)

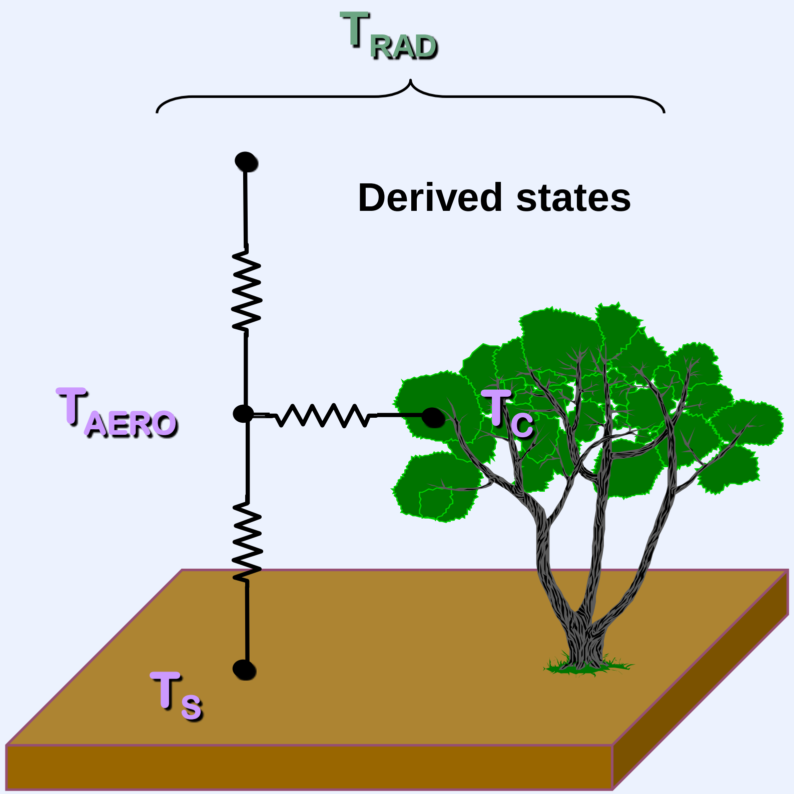
- Treats soil/plant-atmosphere coupling differences explicitly
- Accommodates off-nadir thermal sensor view angles
- Provides information on soil/plant fluxes and stress

The ALEXI model runs the TSEB

System and Component Energy Balance

SYSTEM	RN	=	H	+	λE	+	G
	=		=		=		
CANOPY	RN_C	=	H_C	+	λE_C		
	+		+		+		
SOIL	RN_S	=	H_S	+	λE_S	+	G

Derived fluxes



Latent Heat Flux (TSEB)

$$LE = Rn - G - H$$

Instantaneous R.S. LE to daily ET

$$ETd = [EF\ (Rn - G)d] \times [cf / \lambda v\ \rho w]$$

$$EF = LEi / (Rn - G)i$$

Or:

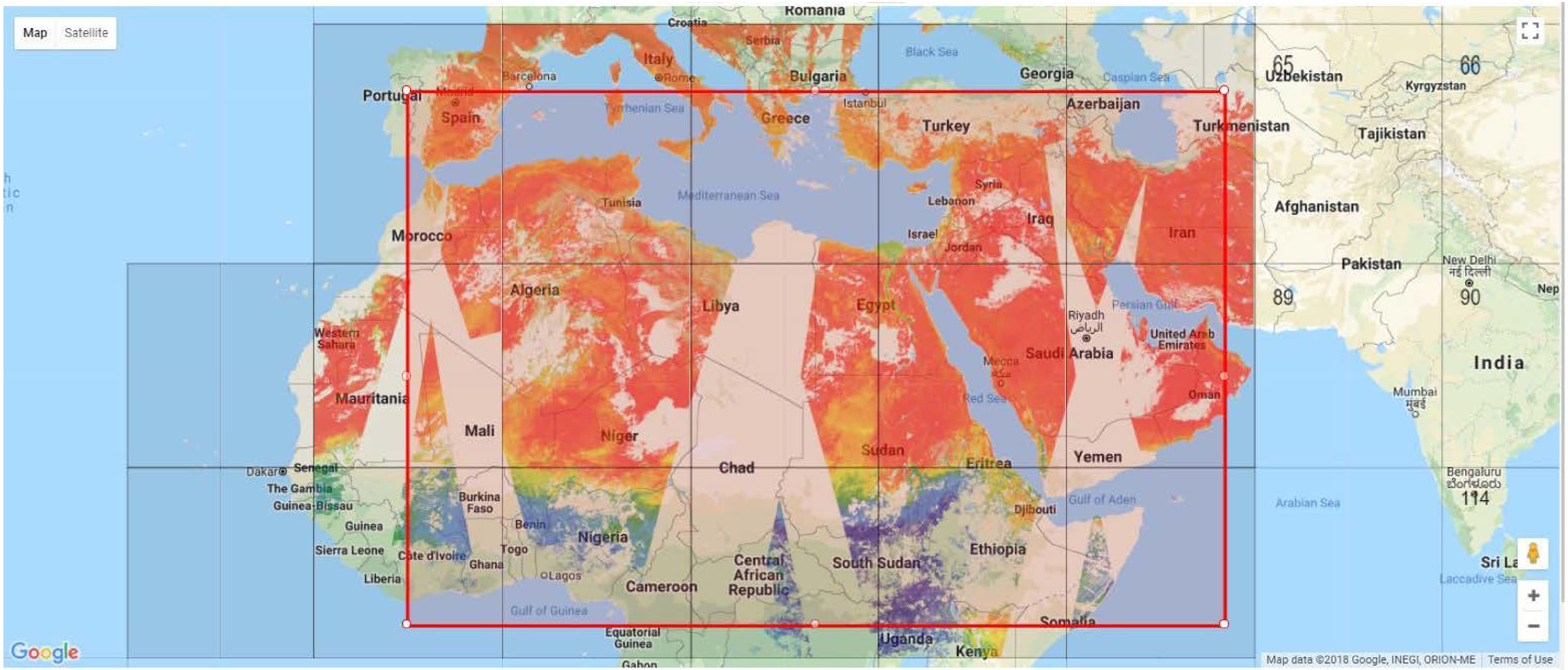
$$ETrf = LEi / (ETr)i$$

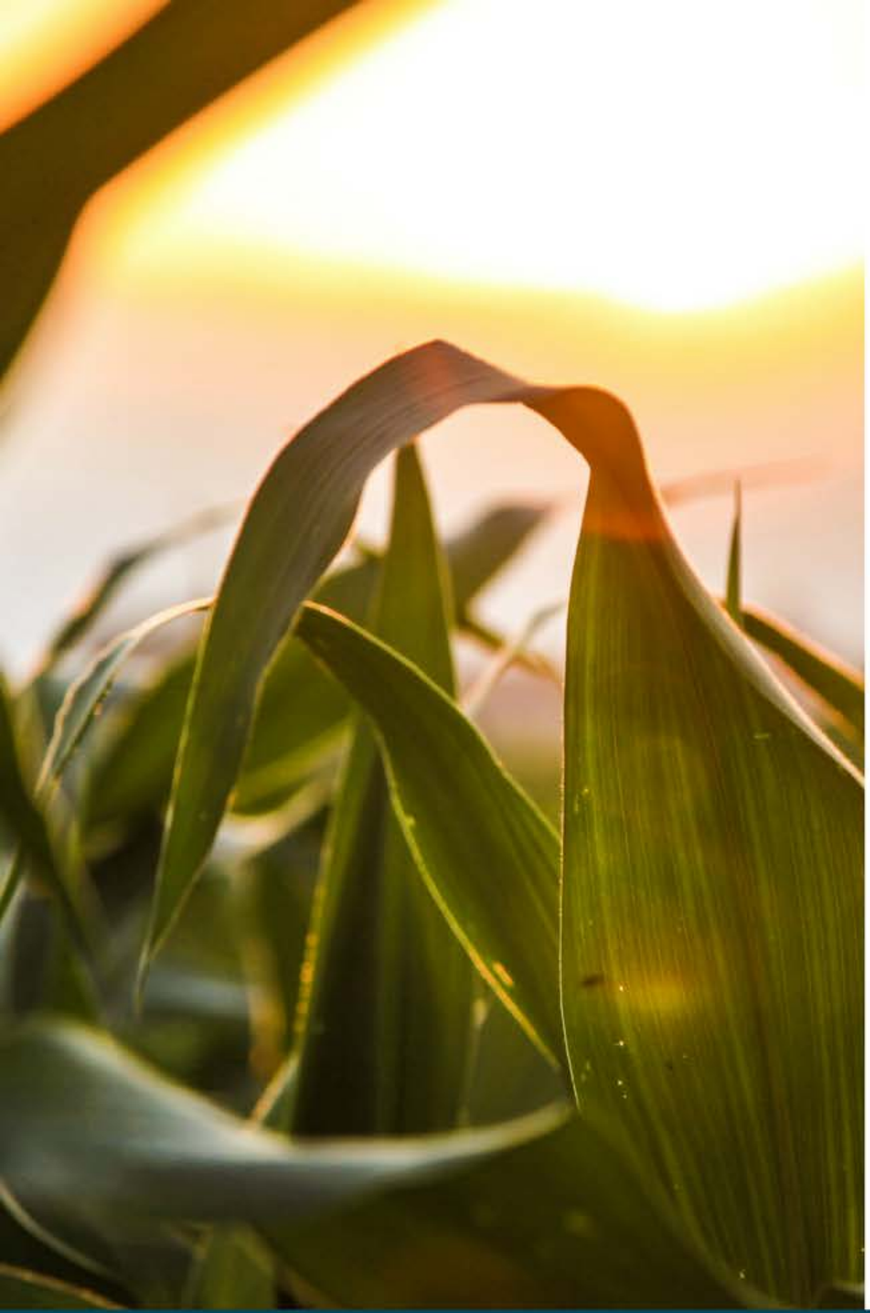
ETd = Daily or 24 hours evapotranspiration rate, mm d-1
(Rn – G)d = Measured mean 24 hr available energy, W m-2
cf = Time (unit) conversion factor equal to 86400 s d-1,
λv = Latent heat of vaporization, W s kg-1
ρw = Density of Water, kg m-3
ETrf = Reference ET fraction
Etr = Reference ET

Development of a High-Resolution (375-m) VIIRS ET Product

MENA region processing nodes are 15 x 15 degree boxes, with a domain of -30W to 60E and 0S to 45N.

Shaded gray boxes denote active processing nodes.

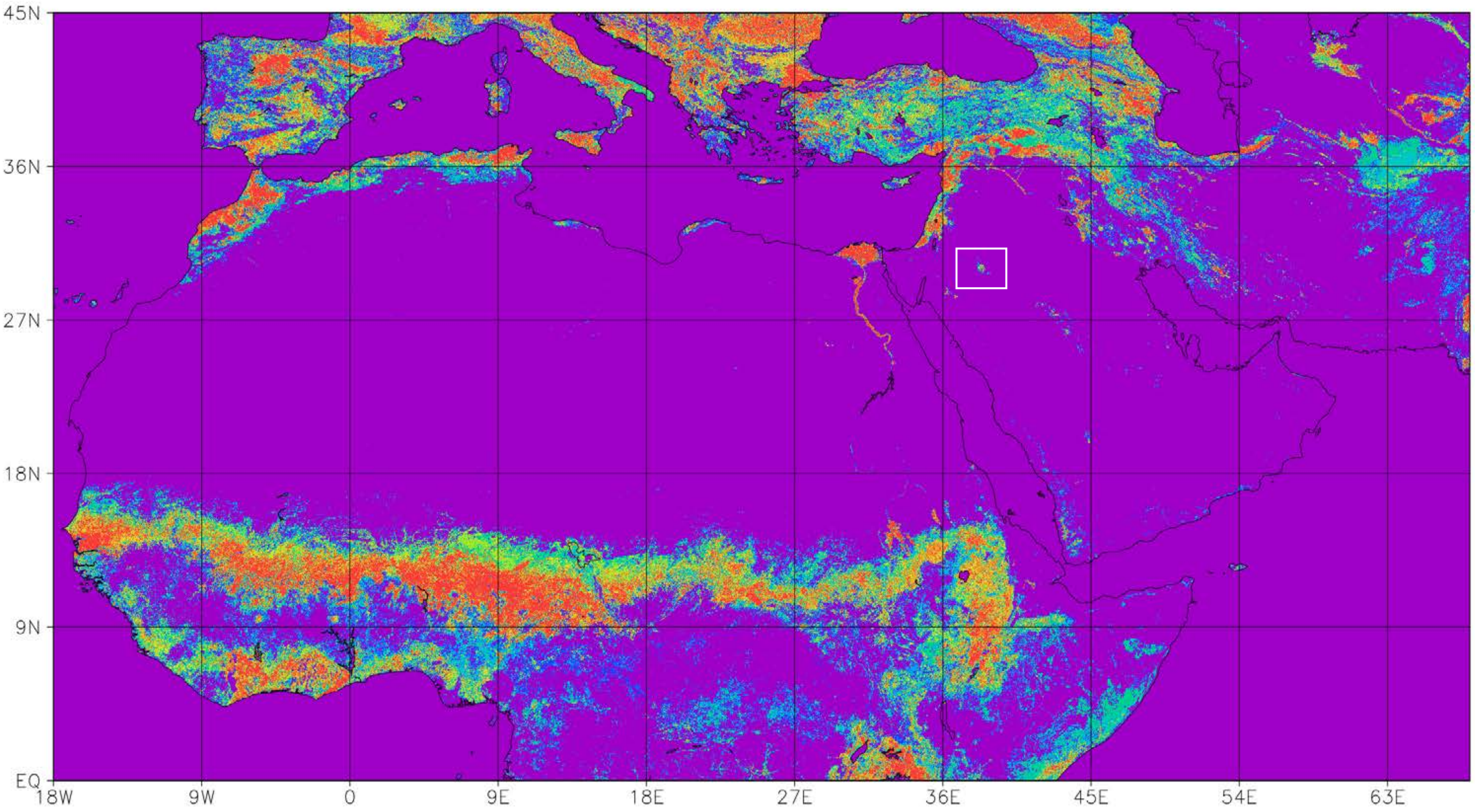




Initial 375-m VIIRS ET Results

Development of a High-Resolution (375-m) VIIRS ET Product

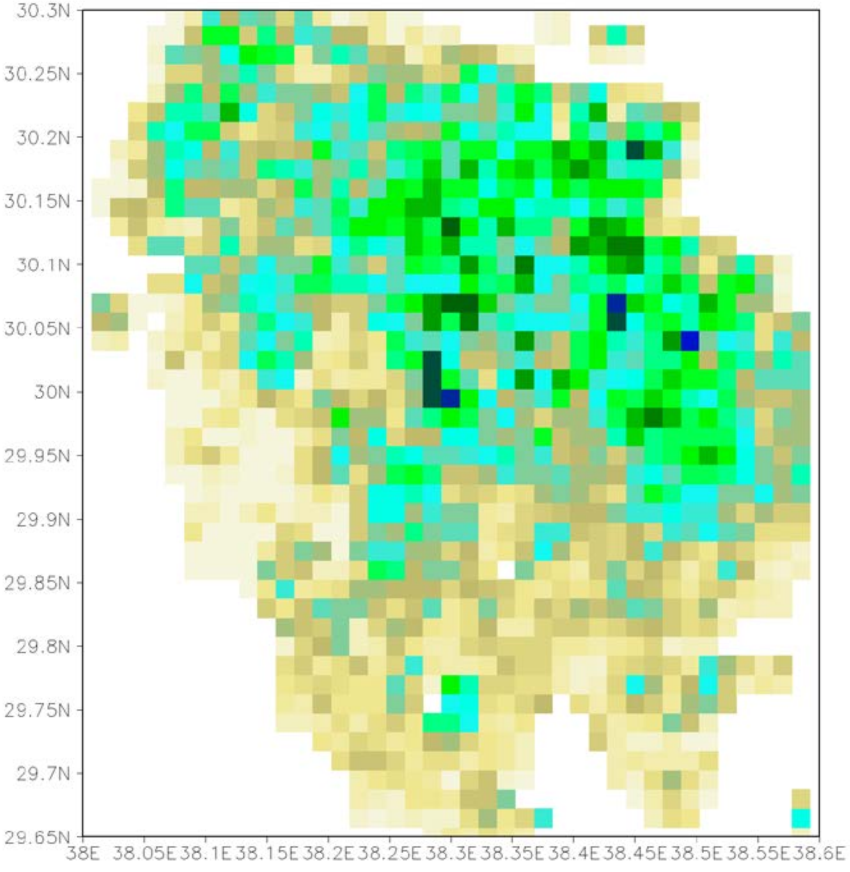
Example location



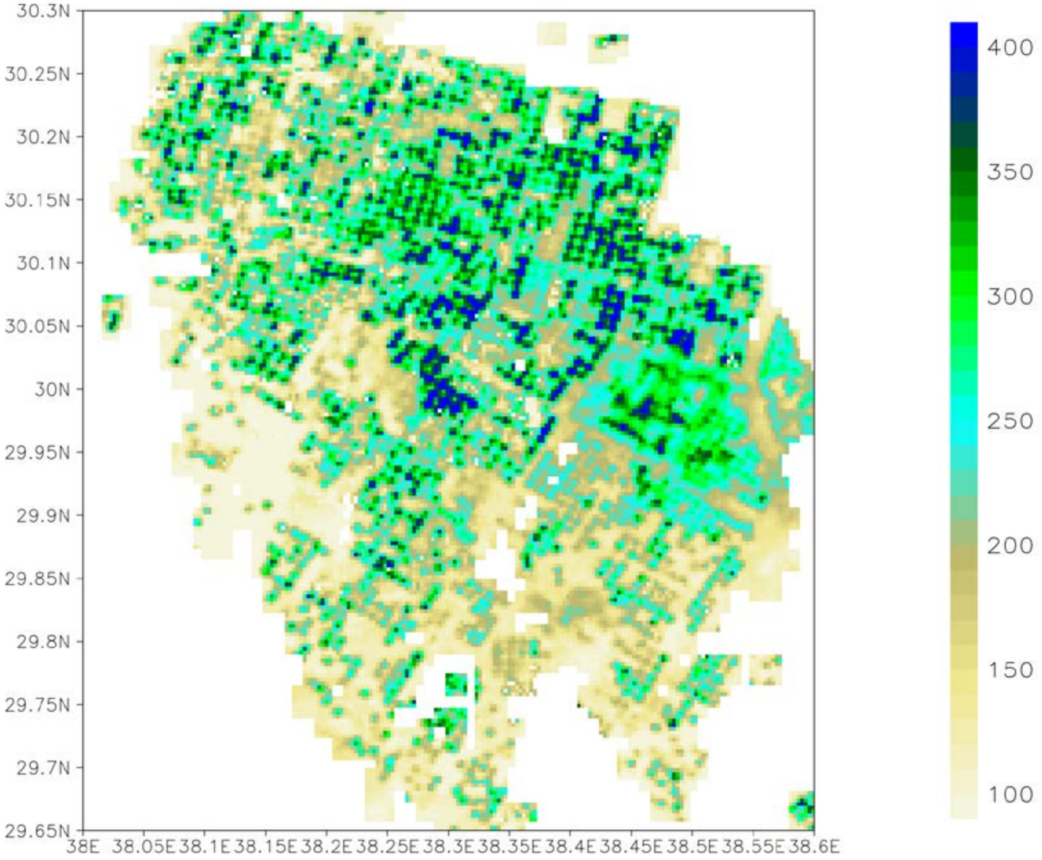
*Shading indicates 1-km percentage of cropland from global synthesis of several RS-based land use maps

Development of a High-Resolution (375-m) VIIRS ET Product

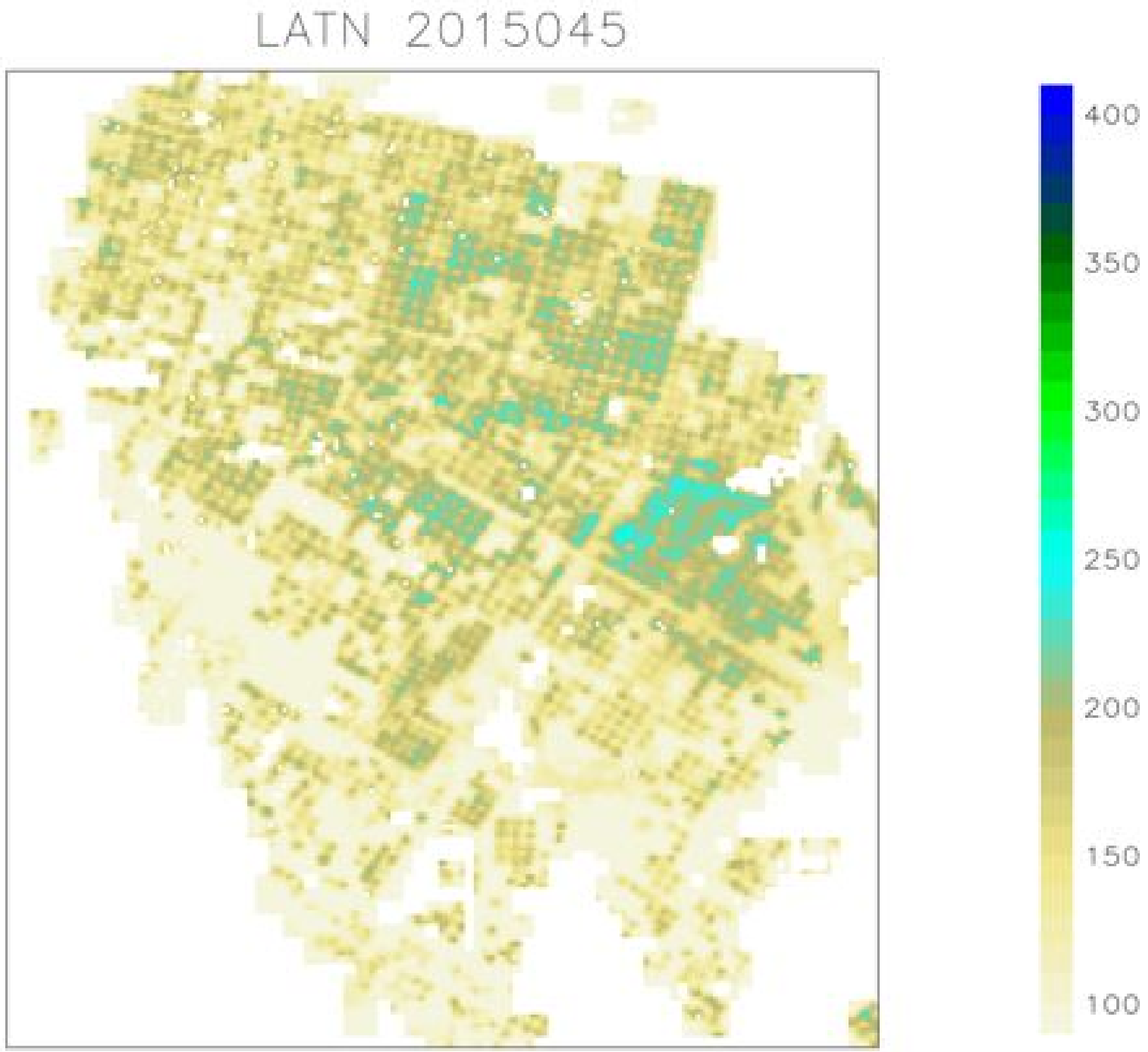
Current MODIS Capability (1000-m)



VIIRS Capability (375-m)

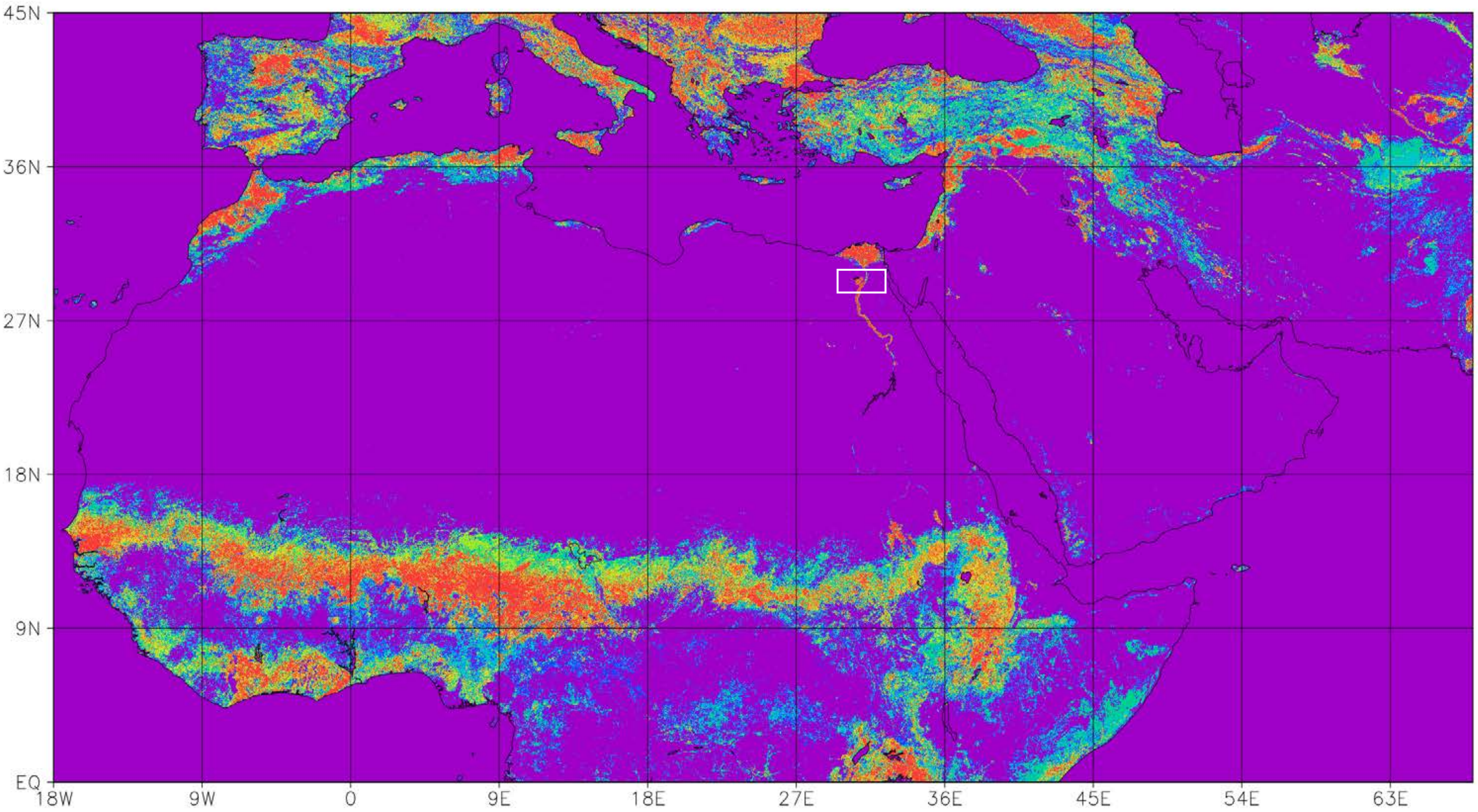


Current VIIRS Latent Heat Flux (W m^{-2}) Capability (375-m)



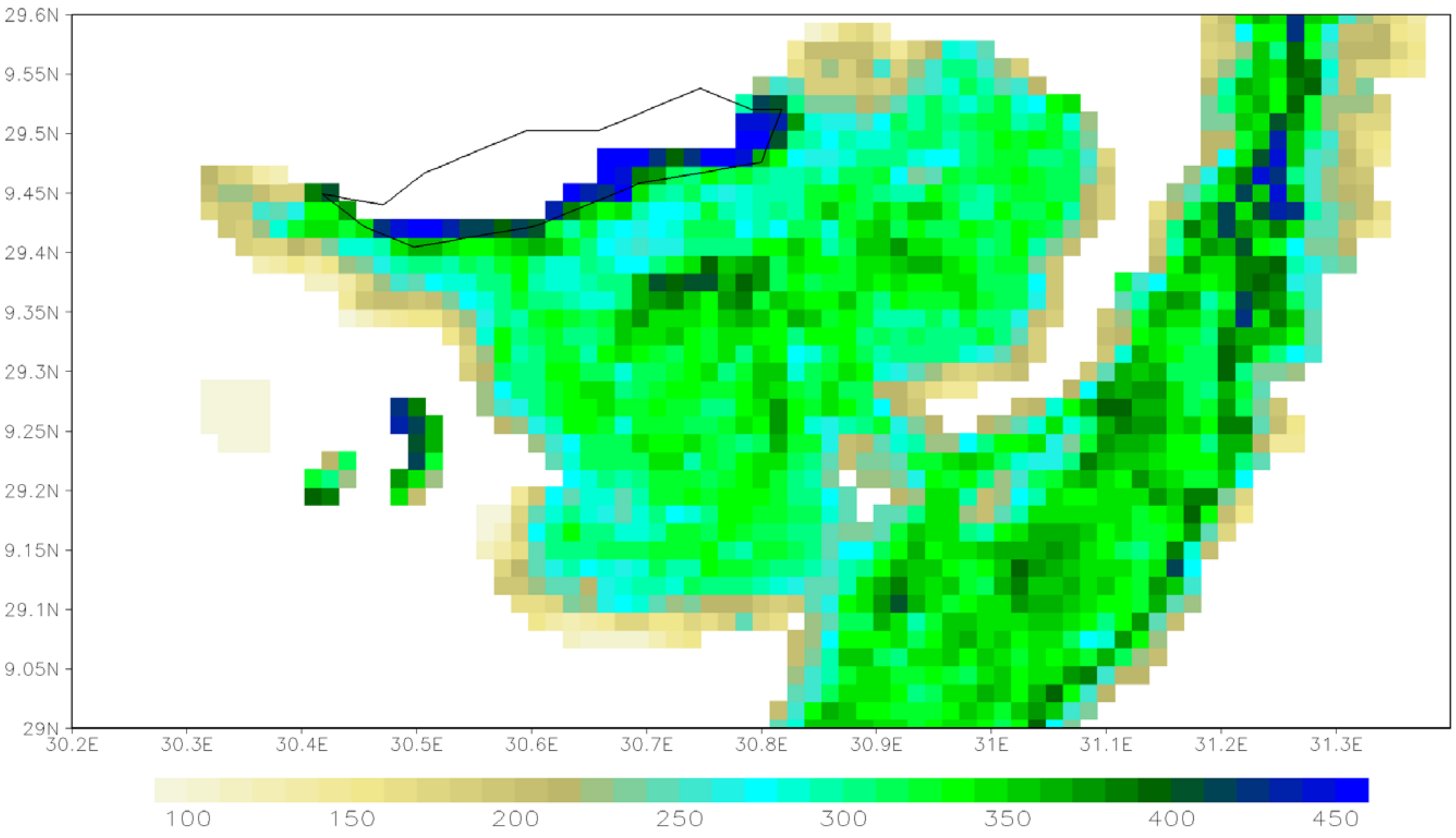
Development of a High-Resolution (375-m) VIIRS ET Product

Example location south of Nile Delta

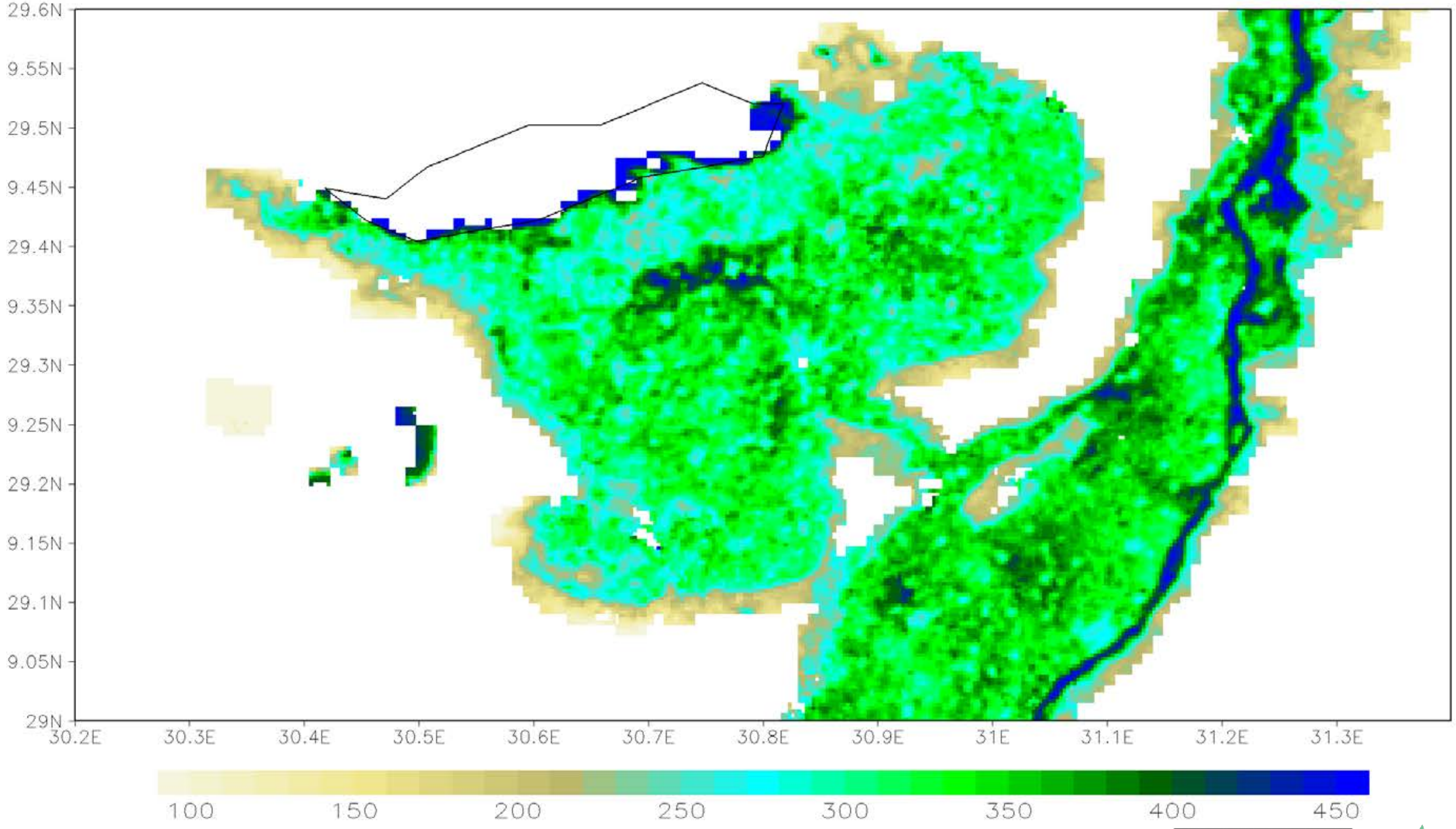


***Shading indicates 1-km percentage of cropland from global synthesis of several RS-based land use maps**

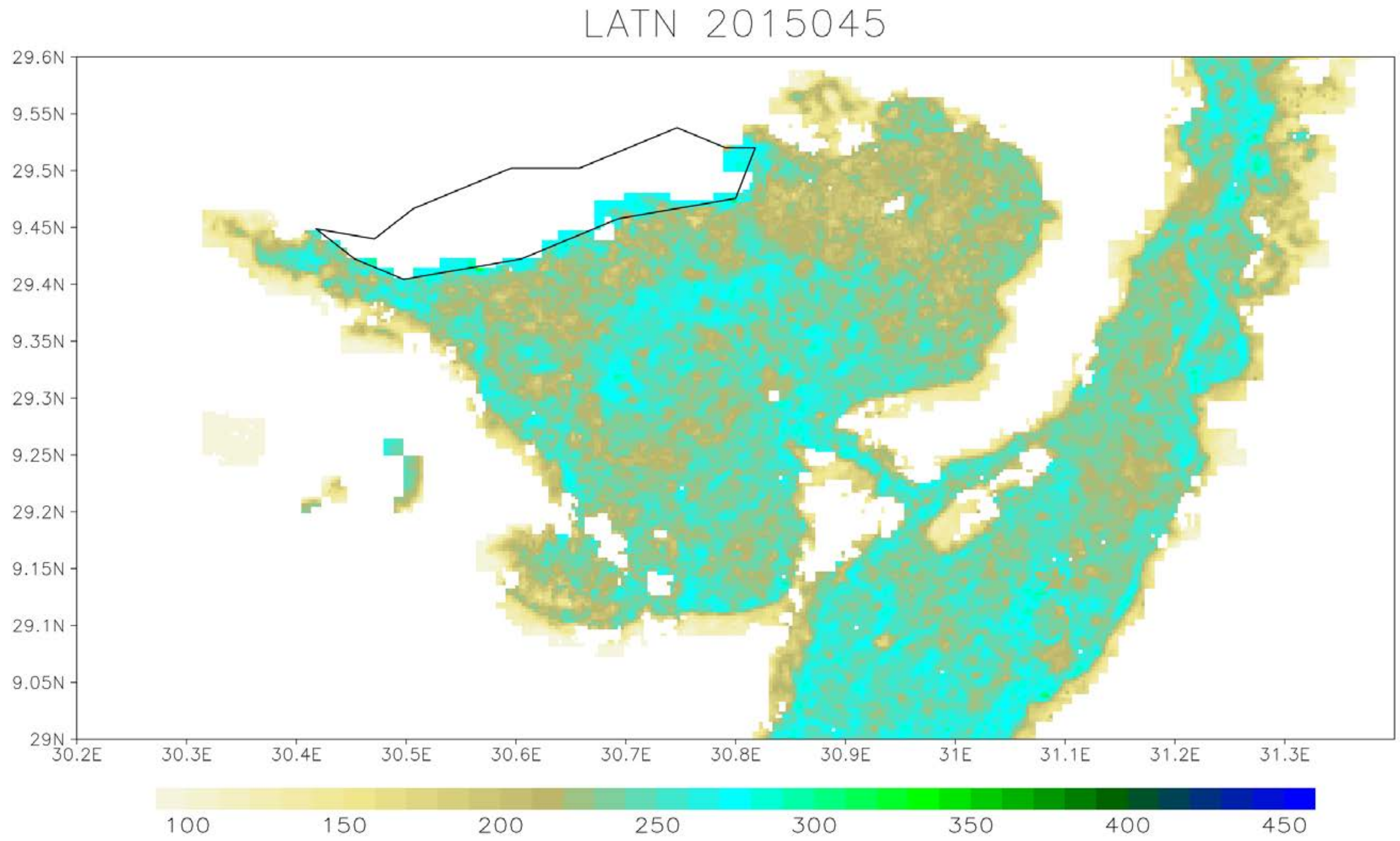
Current MODIS Latent Heat Flux (W m^{-2}) Capability (1-km)



Current VIIRS Latent Heat Flux (W m^{-2}) Capability (375-m)

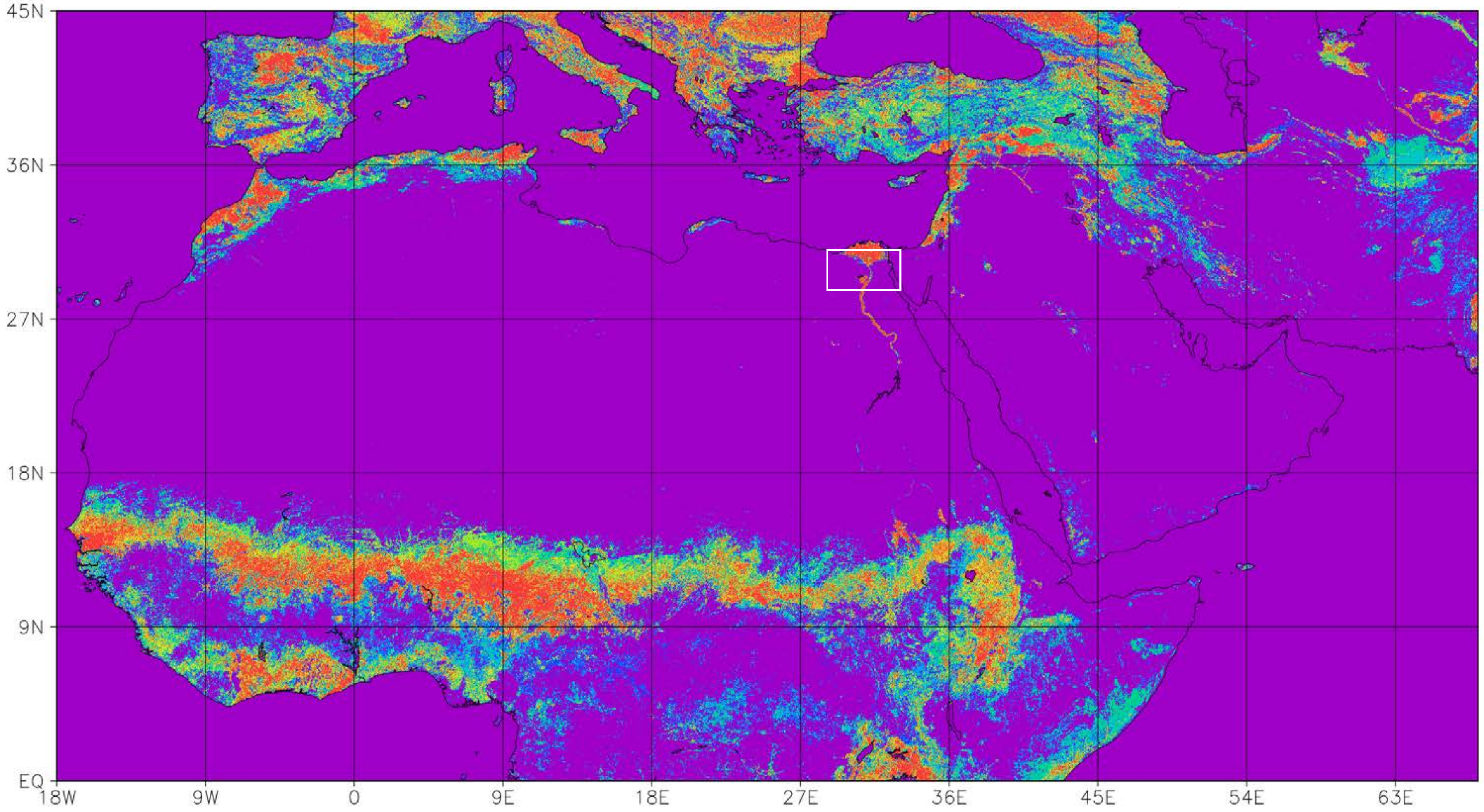


Current VIIRS Latent Heat Flux (W m^{-2}) Capability (375-m)



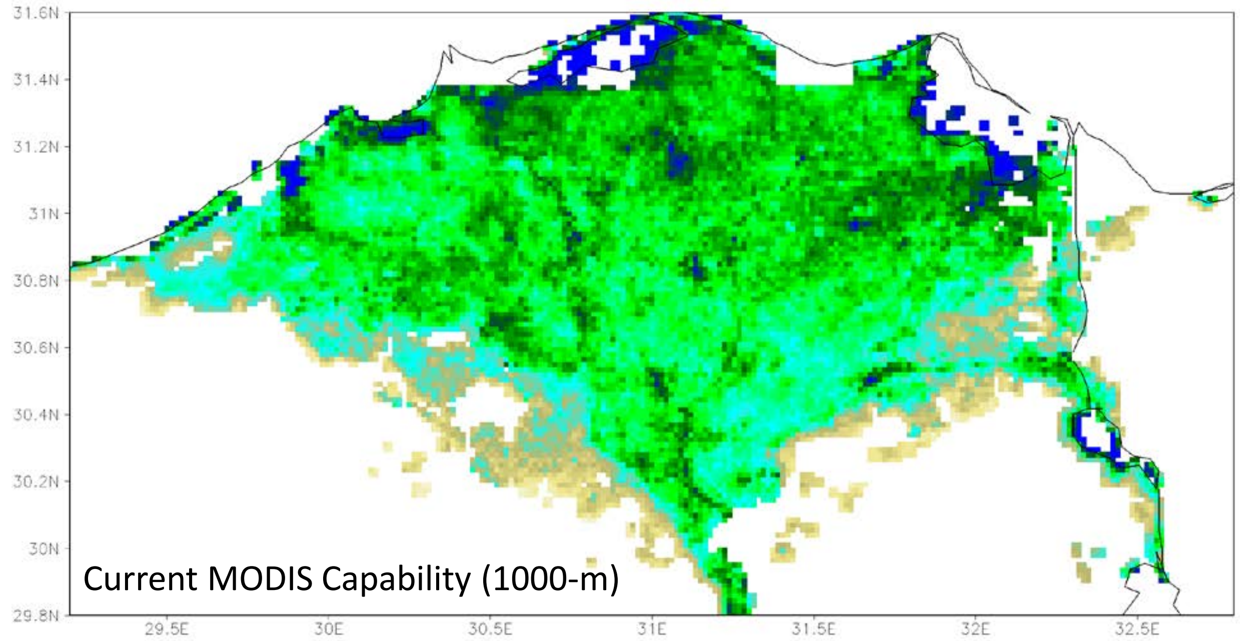
Development of a High-Resolution (375-m) VIIRS ET Product

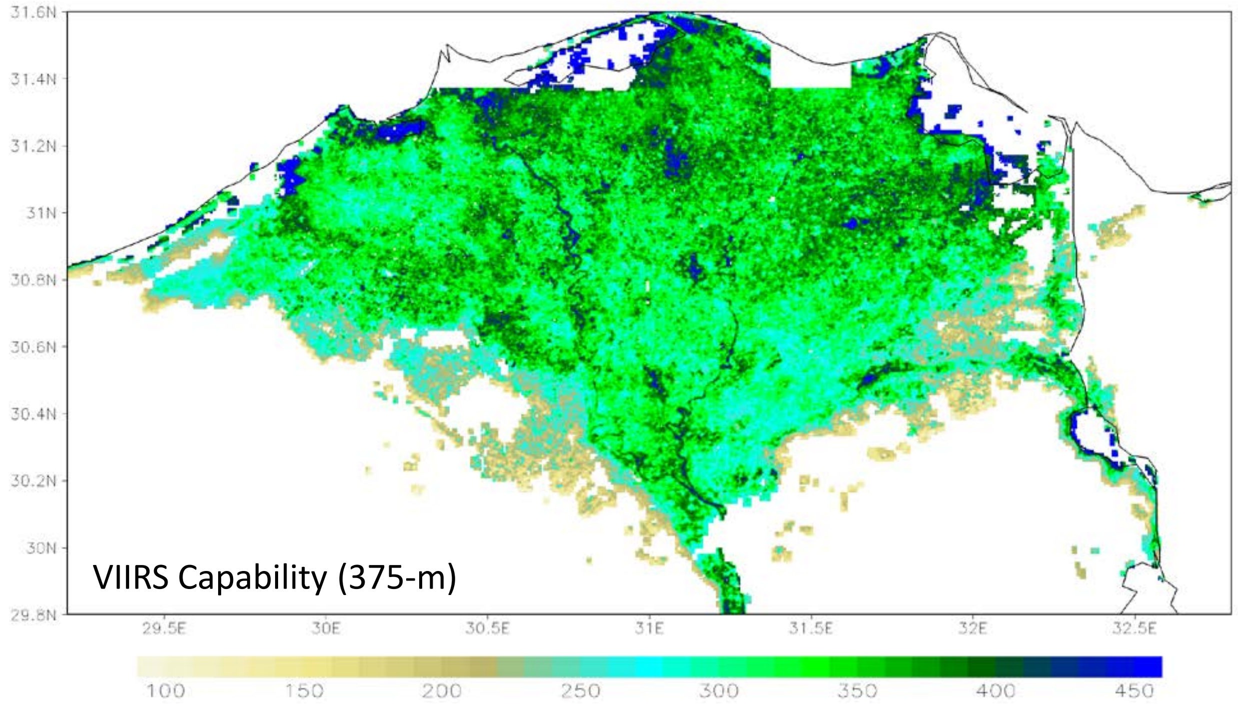
Data coverage for VIIRS ET product. Example location at Nile Delta



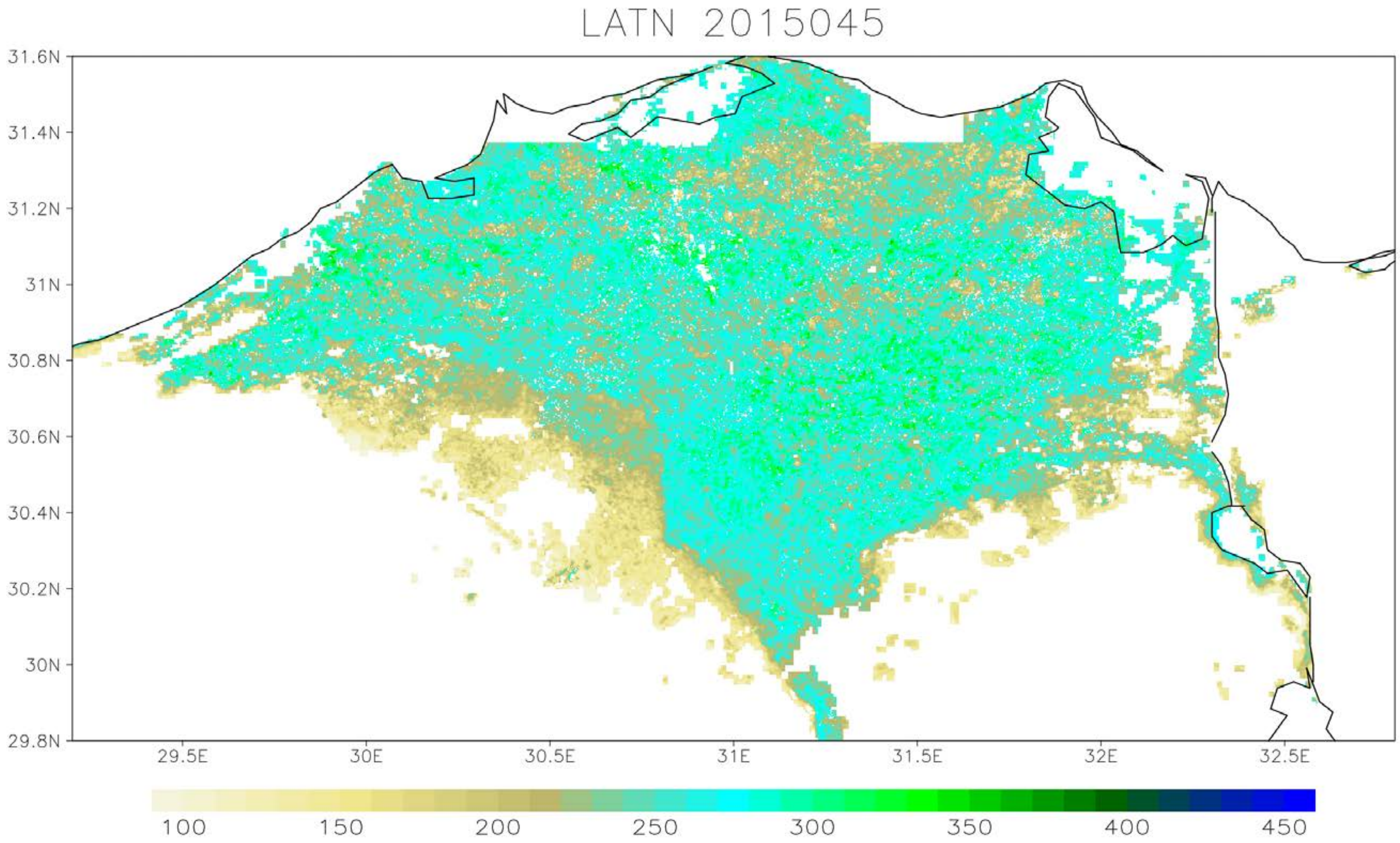
***Shading indicates 1-km percentage of cropland from global synthesis of several RS-based land use maps**

Current MODIS & VIIRS Latent Heat Flux (W m^{-2}) Capability (1-km)



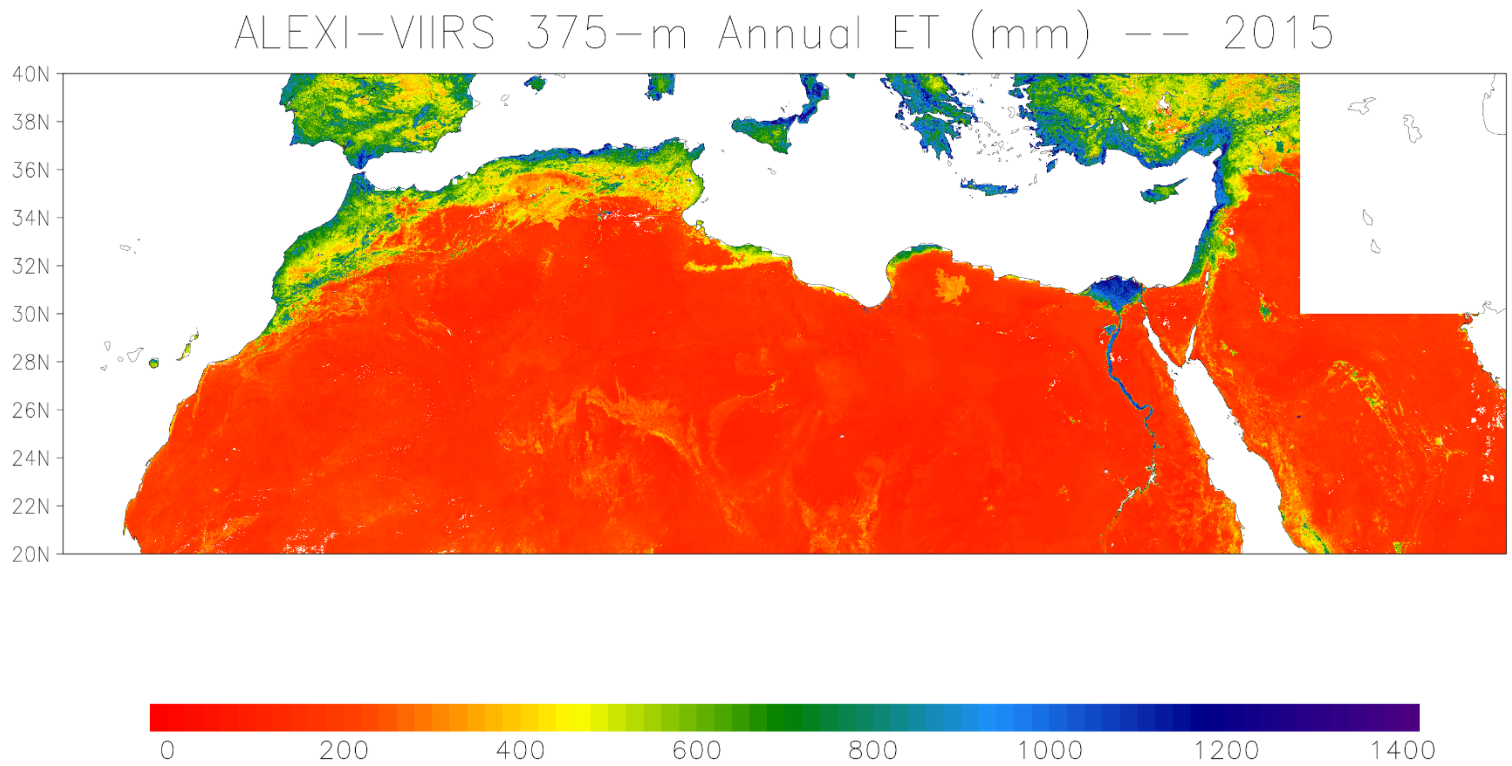


Current VIIRS Latent Heat Flux (W m^{-2}) Capability (375-m)



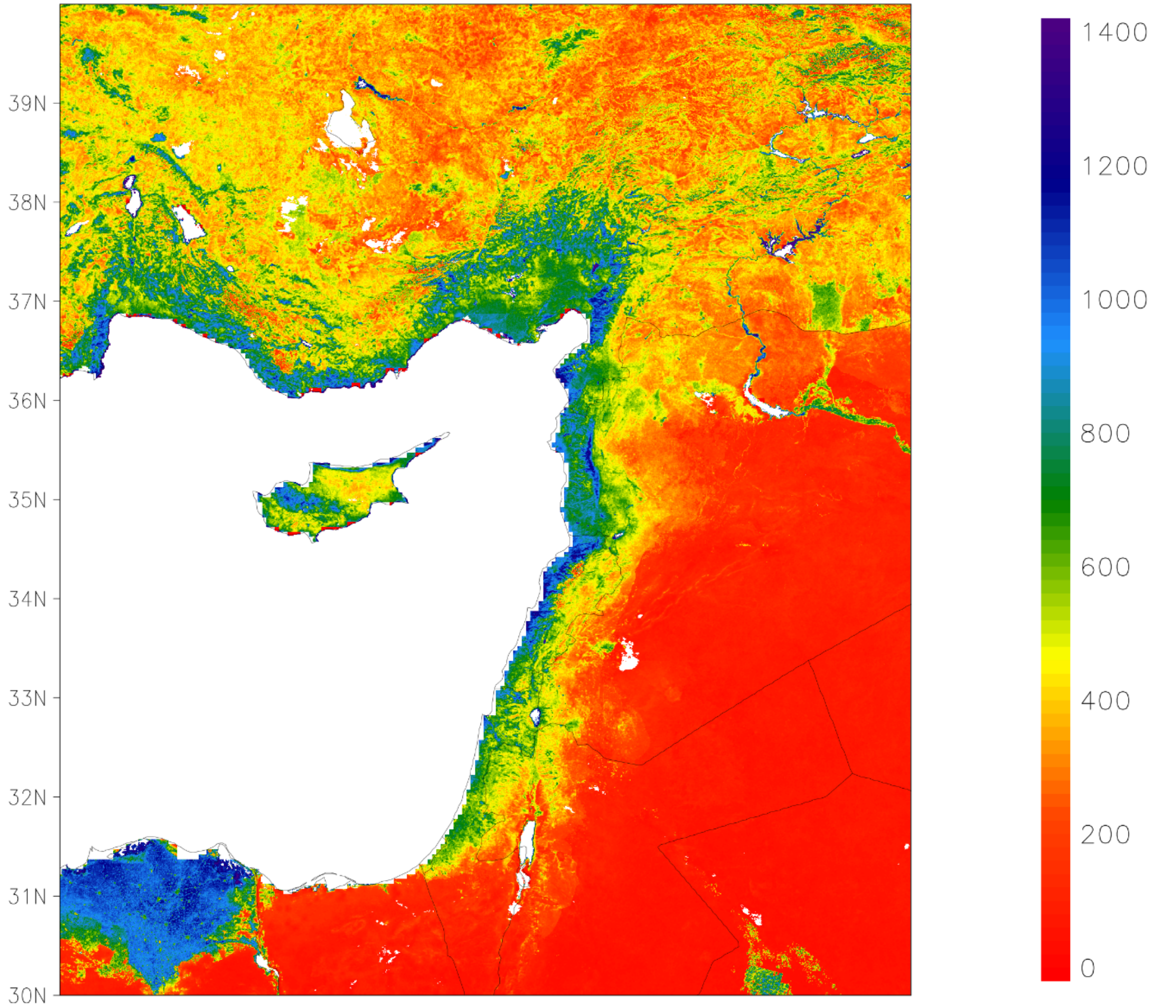
Development of a High-Resolution (375-m) VIIRS ET Product

Annual ET estimated from integrating daily values for 2015



Development of a High-Resolution (375-m) VIIRS ET Product

VIIRS 375 m Annual ET (mm)



Evaporative Stress Index (ESI) Methodology

ALEXI ESI represents temporal anomalies in the ratio of actual ET to potential ET.

- ESI does not require precipitation data, ***the current surface moisture state is deduced directly from the remotely sensed LST*** , therefore it may be more robust in regions with minimal in-situ precipitation monitoring.
- Signatures of vegetation stress are manifested in the LST signal before any deterioration of vegetation cover occurs, for as example as indicated in NDVI, so TIR-based indices such as ESI can provide an effective early warning signal of impending agricultural drought.
- ALEXI ESI inherently includes non-precipitation related moisture signals (such as irrigation; vegetation rooted to groundwater; lateral flows) that need to be modeled a priori in prognostic LSM schemes.
- ALEXI ESI provides an independent assessment of current drought conditions, supplementing precipitation and modeling-based indices – an invaluable resource to decision-makers who usually depend on a convergence of information in the decision making process.

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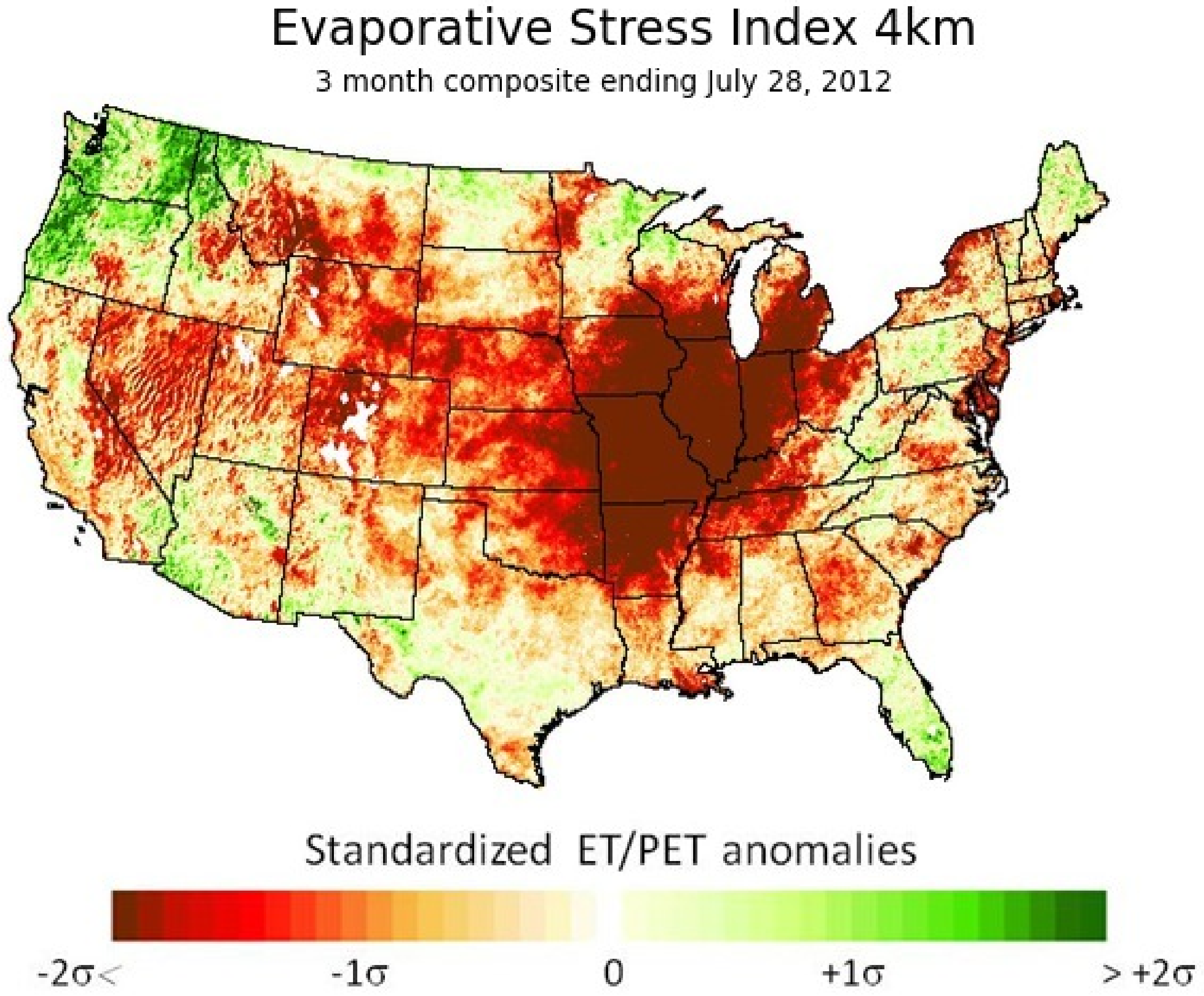
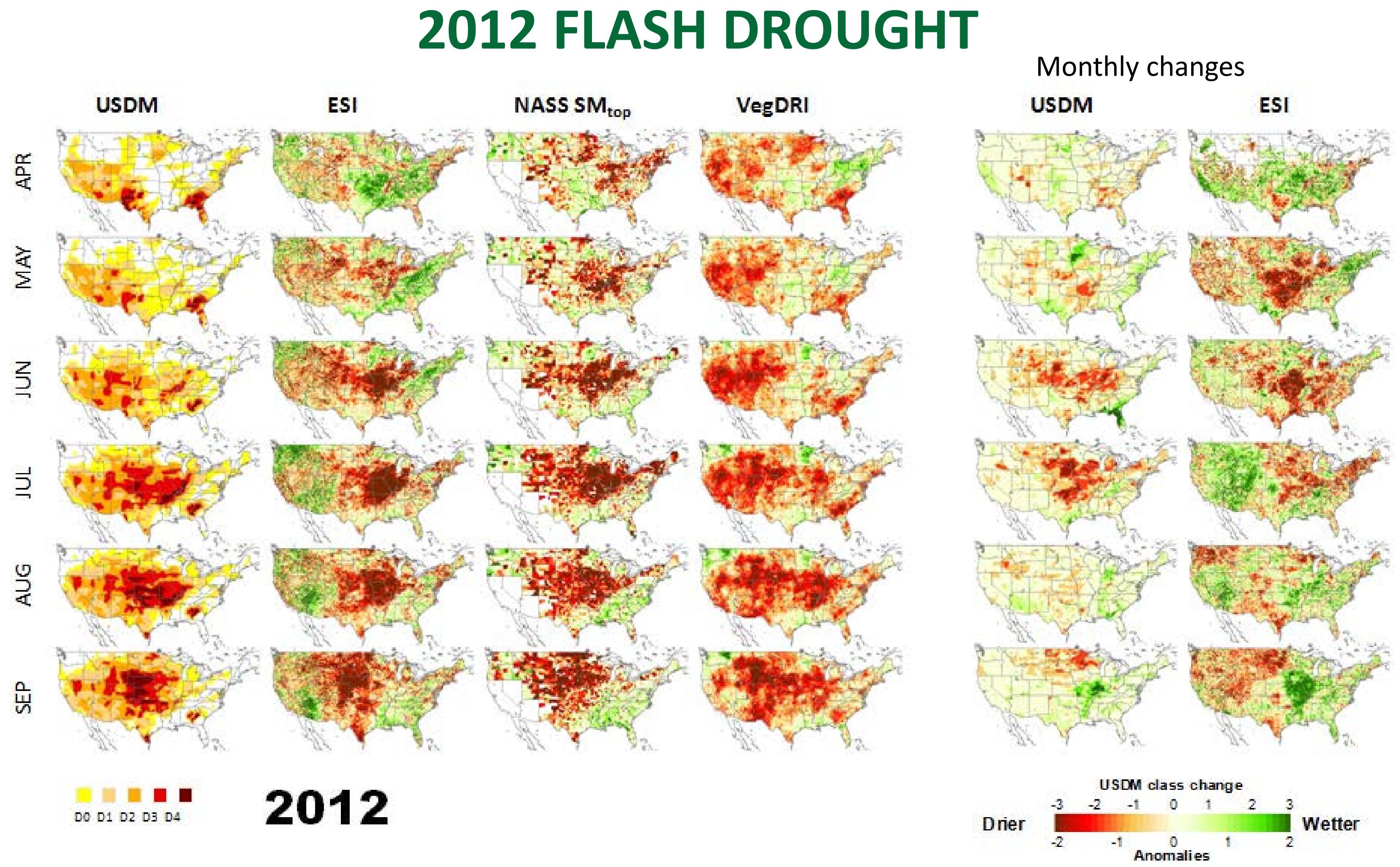
Satellite ET Drought Indicator



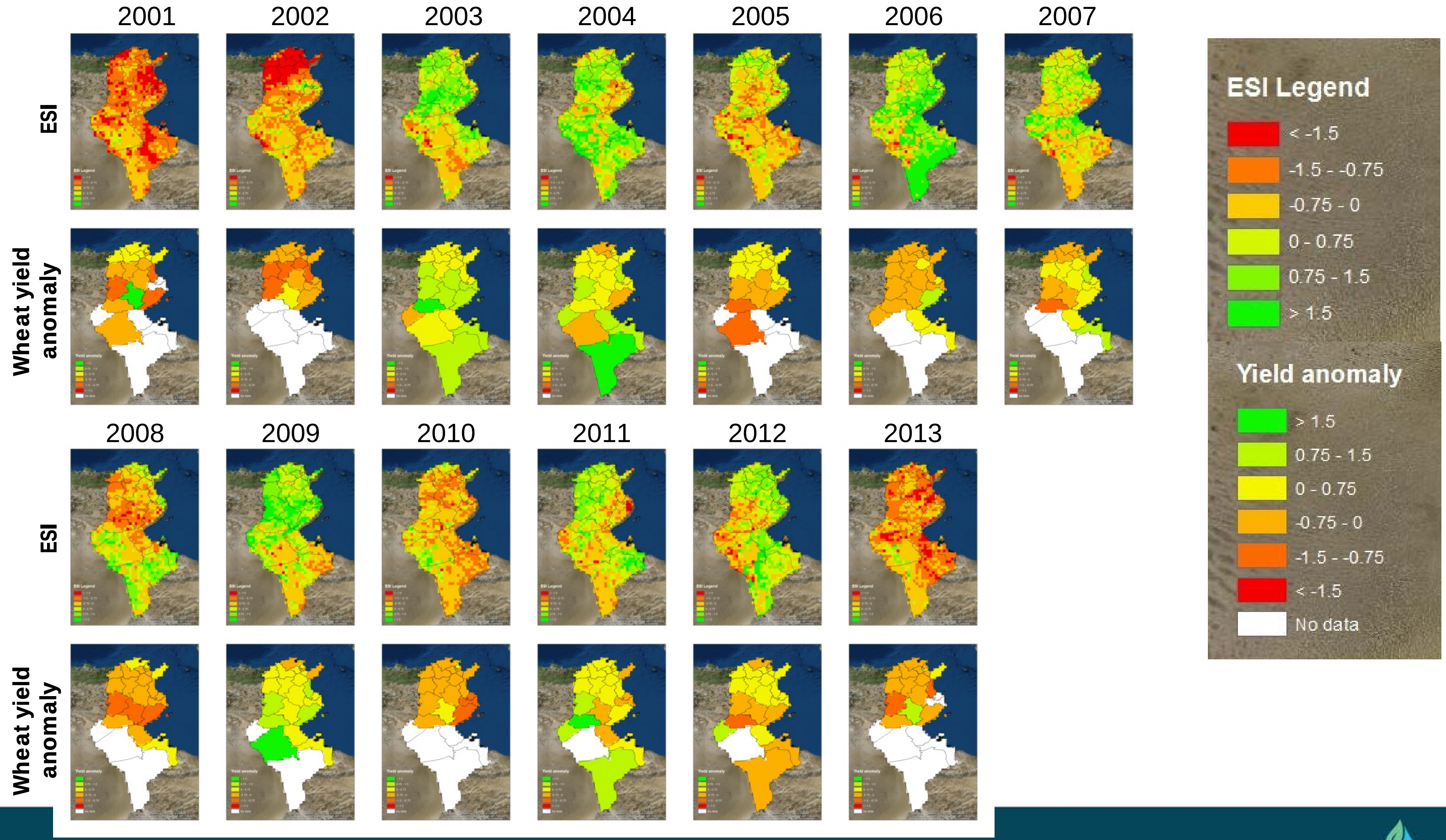
Atmosphere-Land Exchange Inverse Model (ALEXI)

(Anderson et al., 1997, 2007)

Real-time Drought Monitoring



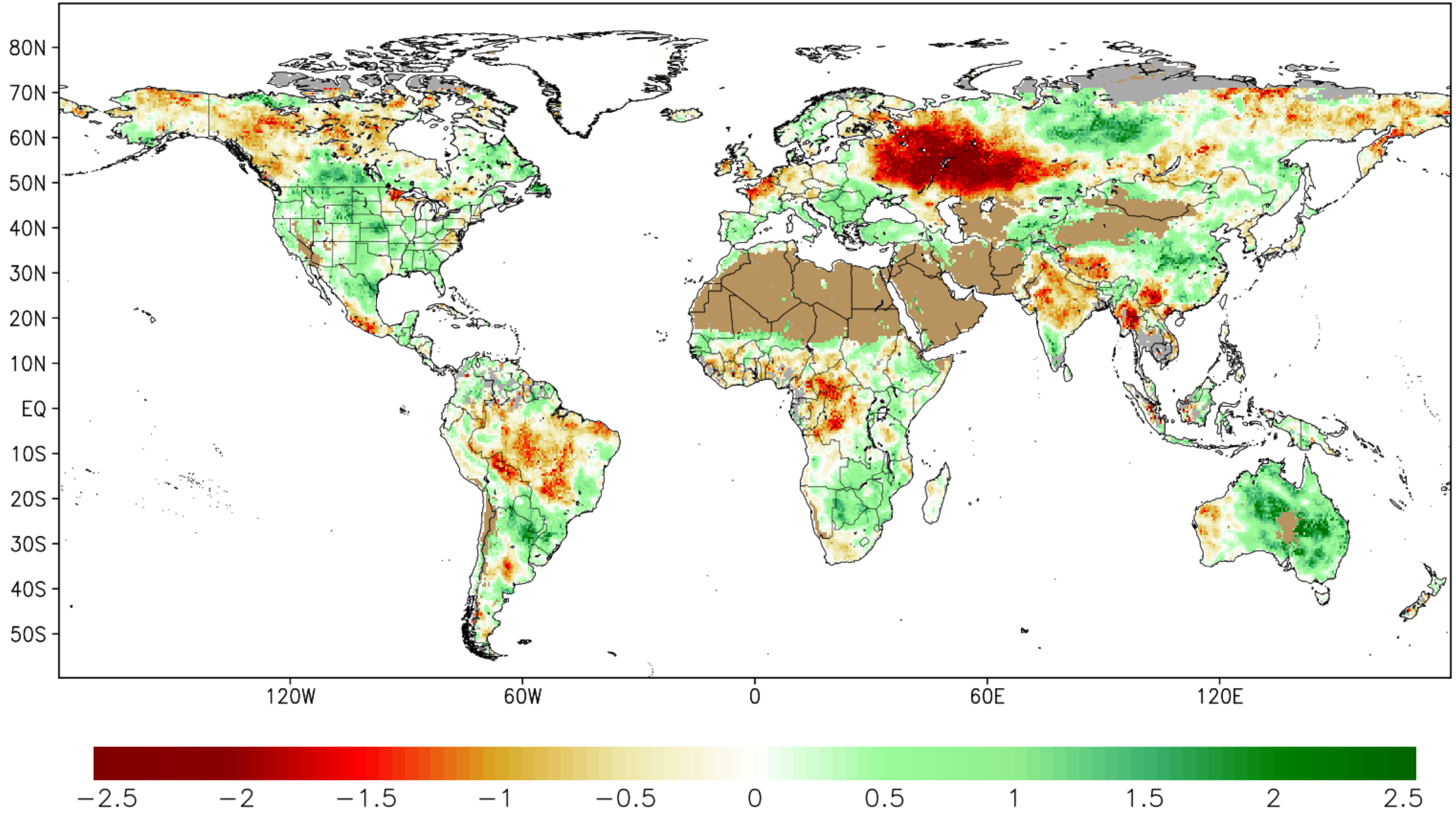
Yield Estimation in Tunisia



ET/PET standardized anomaly (2000-2011 baseline)

JULY 2010

12-week composite

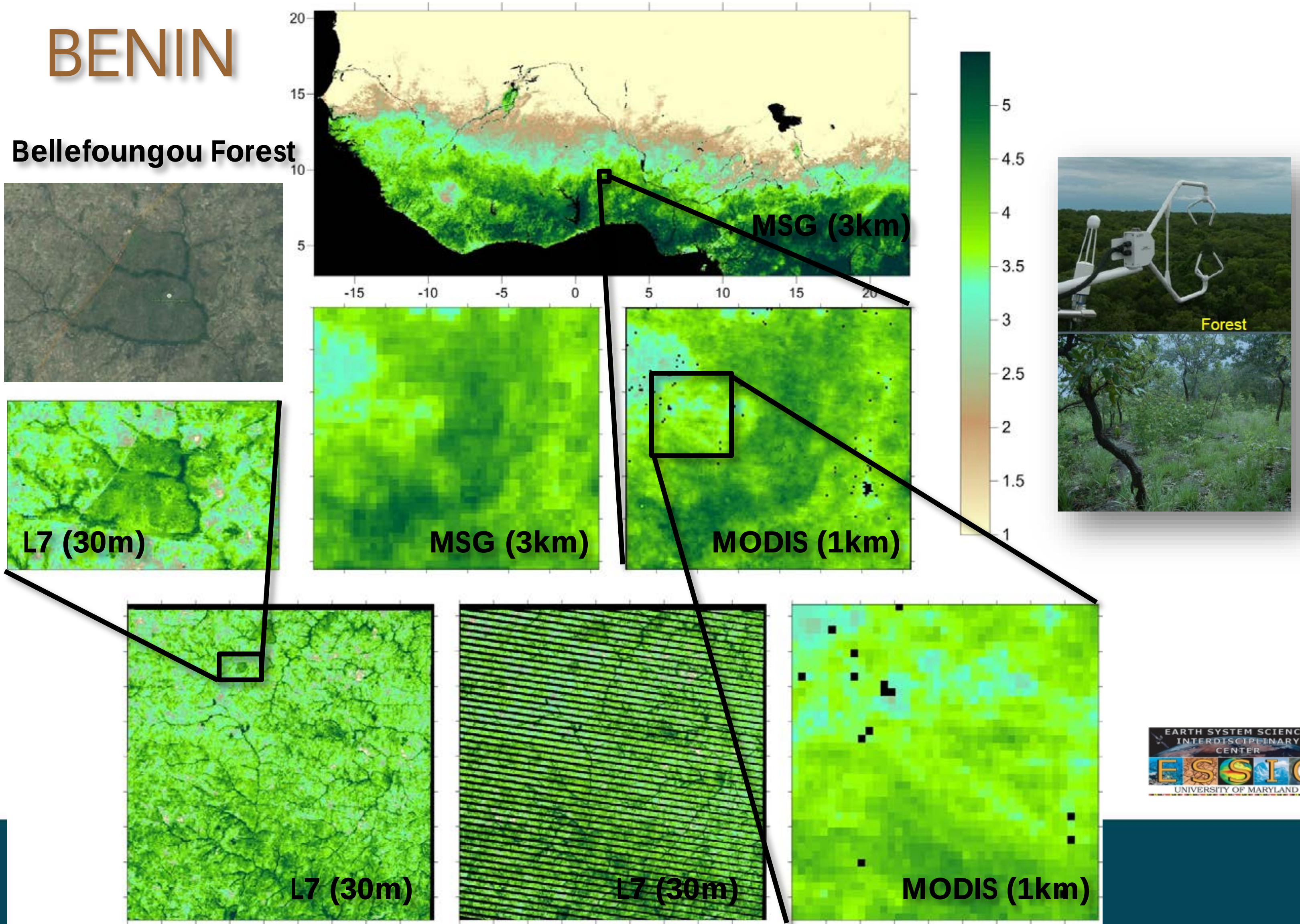


Disaggregation of VIIRS 375 m product to Higher Resolutions

- Disaggregation and data fusion downscaling to higher resolutions will be done using the DisALEXI model
- The 375 m product is the upper boundary condition
- An open source version of DisALEXI is being developed for this purpose called PyDisALEXI
- PyDisALEXI is programmed in Python in an open source mode, so it can be distributed
- We will train the cooperating agencies in the different MENA countries to use this software and downscale ET to agricultural and irrigated areas

High-resolution Disaggregation and Data Fusion

Downscaling to 30 m using the DisALEXI model



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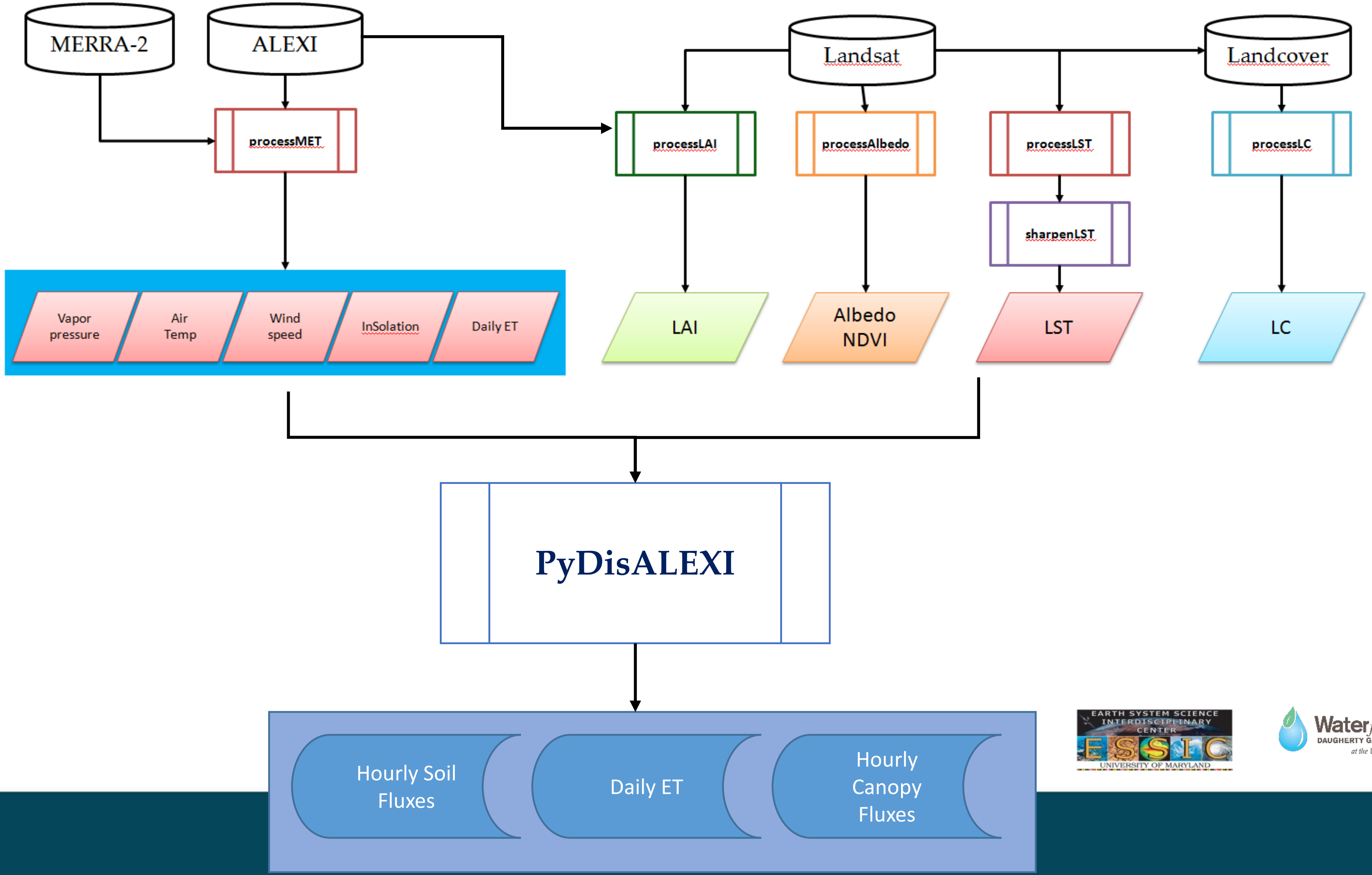
PyDisALEXI Overview

PyDisALEXI is an open source implementation of the DisALEXI fusion suite. It is primarily composed of the following freely available python modules.

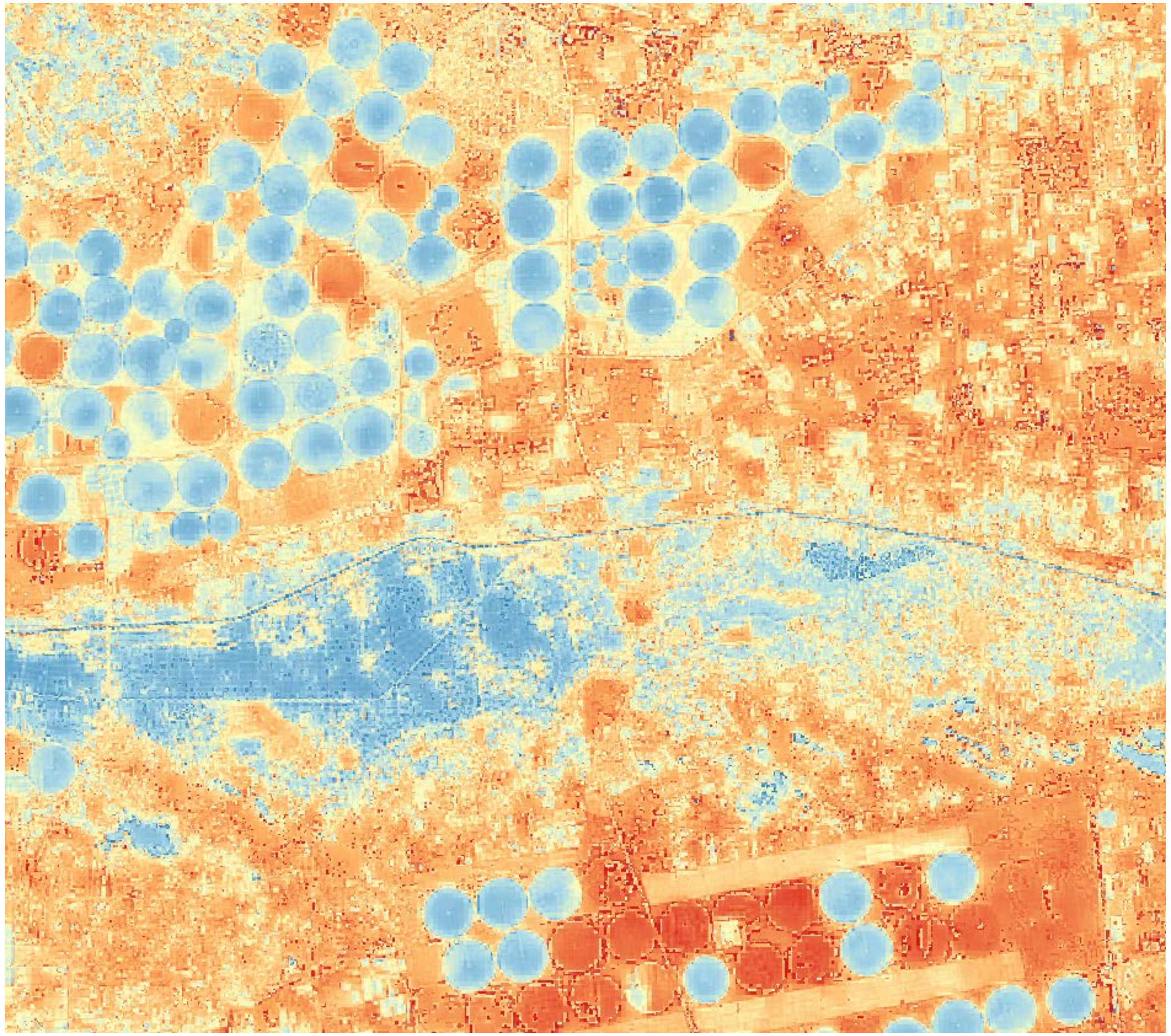
- Continuuim's Anaconda python distribution is used:
  - NumPy
  - SciPy
  - Pandas
- Other important modules:
  - Geospatial Data Abstraction Library (GDAL)
  - Pythonic implementation of RTTOV, pyrttov
  - Landsat-util
  - Pygaarst
  - PyDAP
  - H5py
  - PyCurl

PyDisALEXI Flowchart



Input data: Land Surface Temperature (LST)

Nile Delta Irrigation



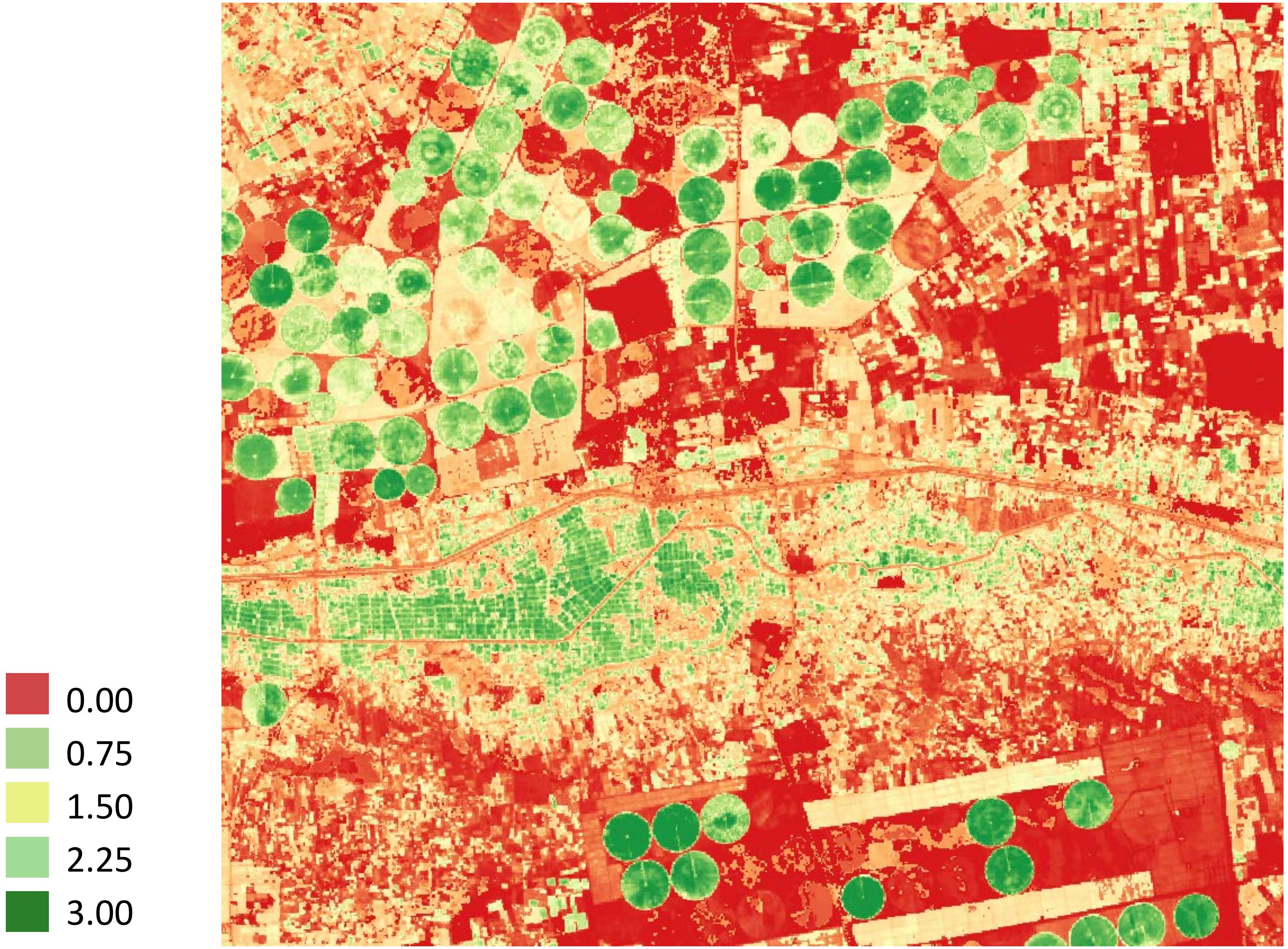
300
310
320
330
340

Sharpened LST (K)

- Thermal data Provided by USGS at 90 m.
- LST calculated using the RTTOV atmospheric radiative transfer model
- Sharpened to 30 m by the Data Mining Sharpening (DMS) tool using visible (30 m) and LST (90 m) data.

Input data: Leaf Area Index (LAI)

Nile Delta Irrigation

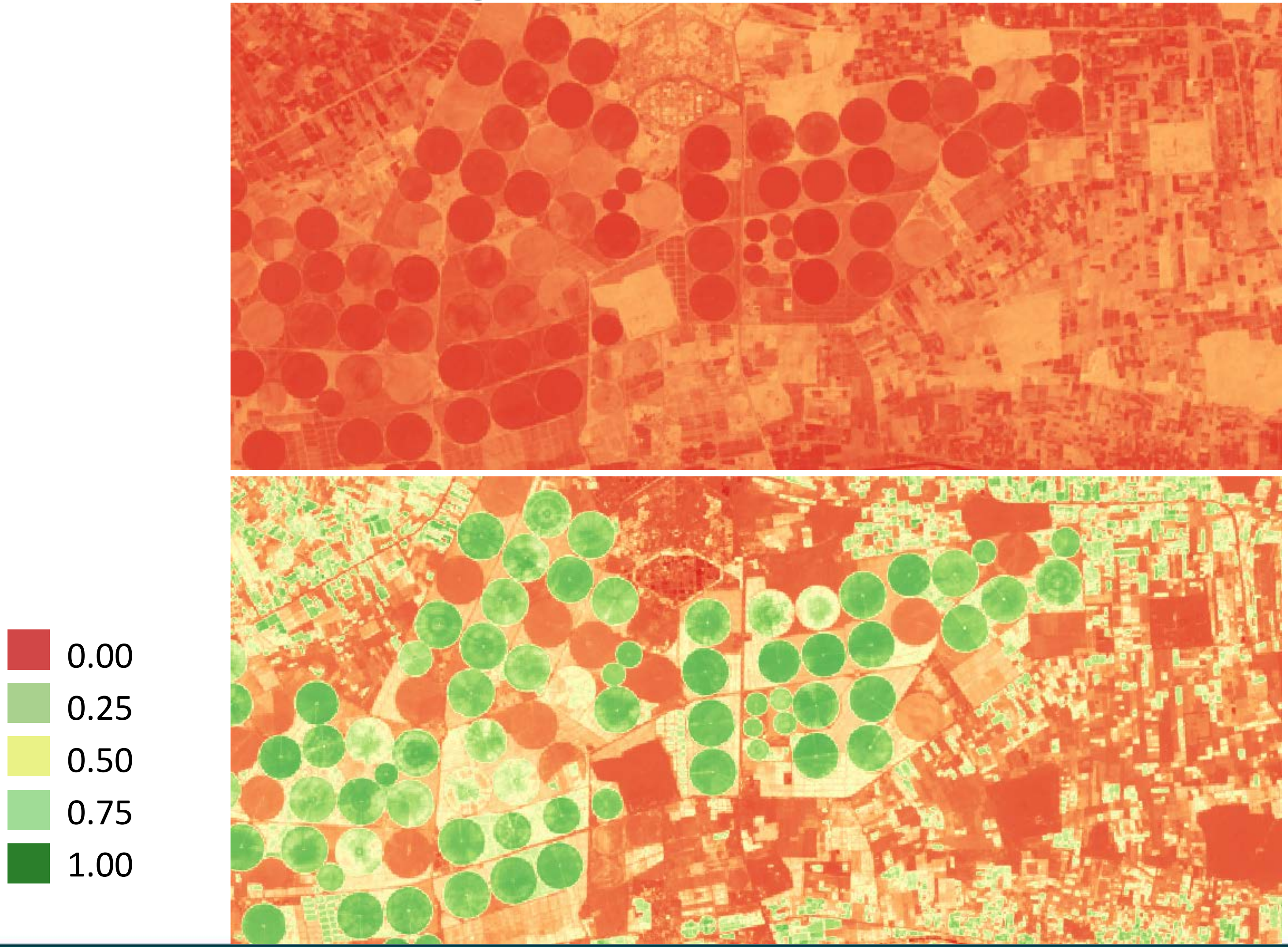


Landsat LAI

- 30 m LAI product downscaled LAI from lower resolution instruments (i.e. MODIS 1 km , VIIRS 375 m)
- LAI is downscaled to 30 m by the Data Mining Sharpening (DMS) tool using visible (30 m) and LAI at coarser scales data.

Input data: NDVI/albedo

Nile Delta Irrigation



Landsat Albedo

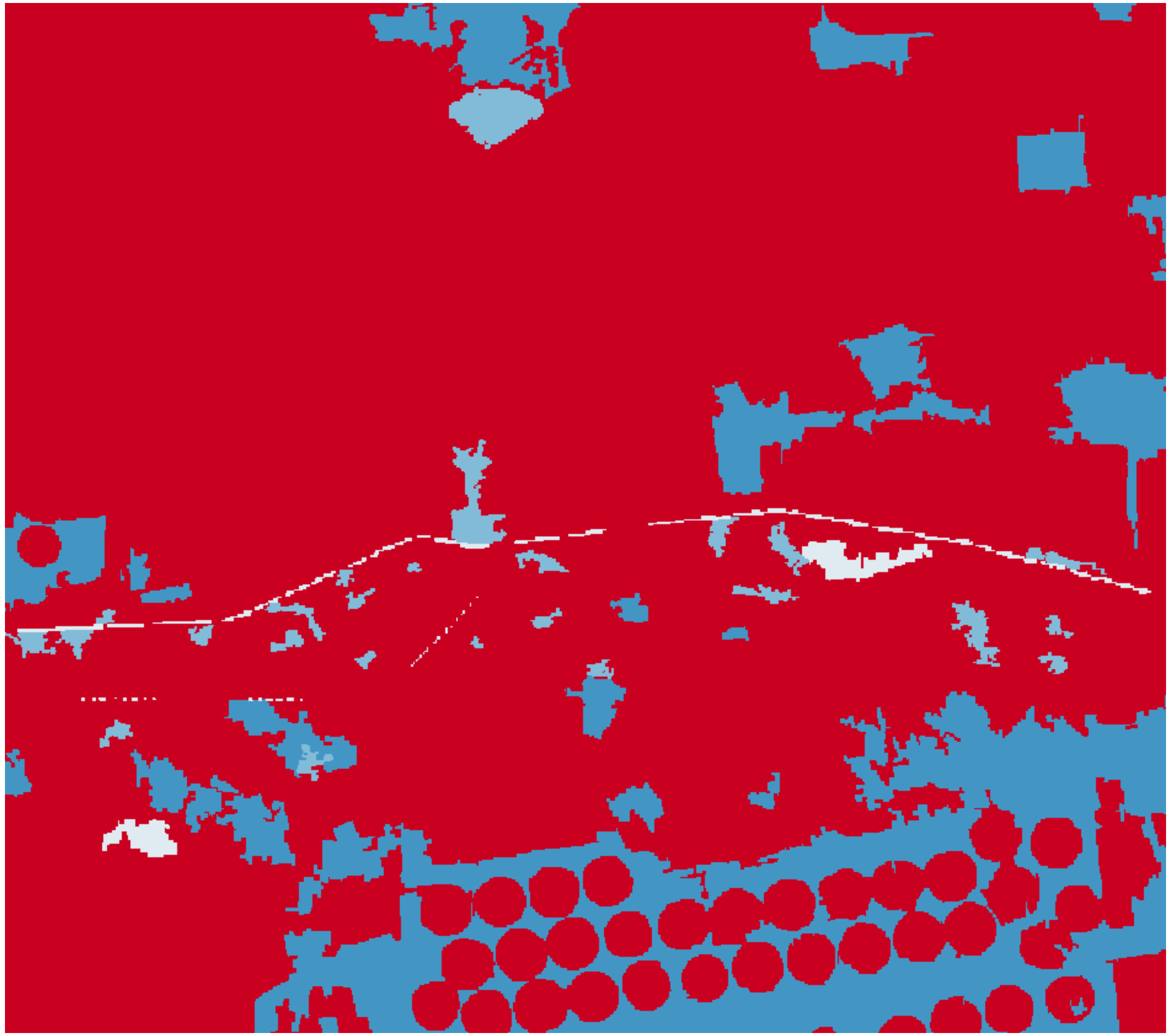
- Visible broadband albedo calculated using USGS Landsat surface reflectance.
- Predetermined band coefficients from Liang 2000 were used.

Landsat NDVI

- NDVI calculated using USGS Landsat surface reflectance.

Input data: Land cover

Nile Delta Irrigation



Landsat Landcover

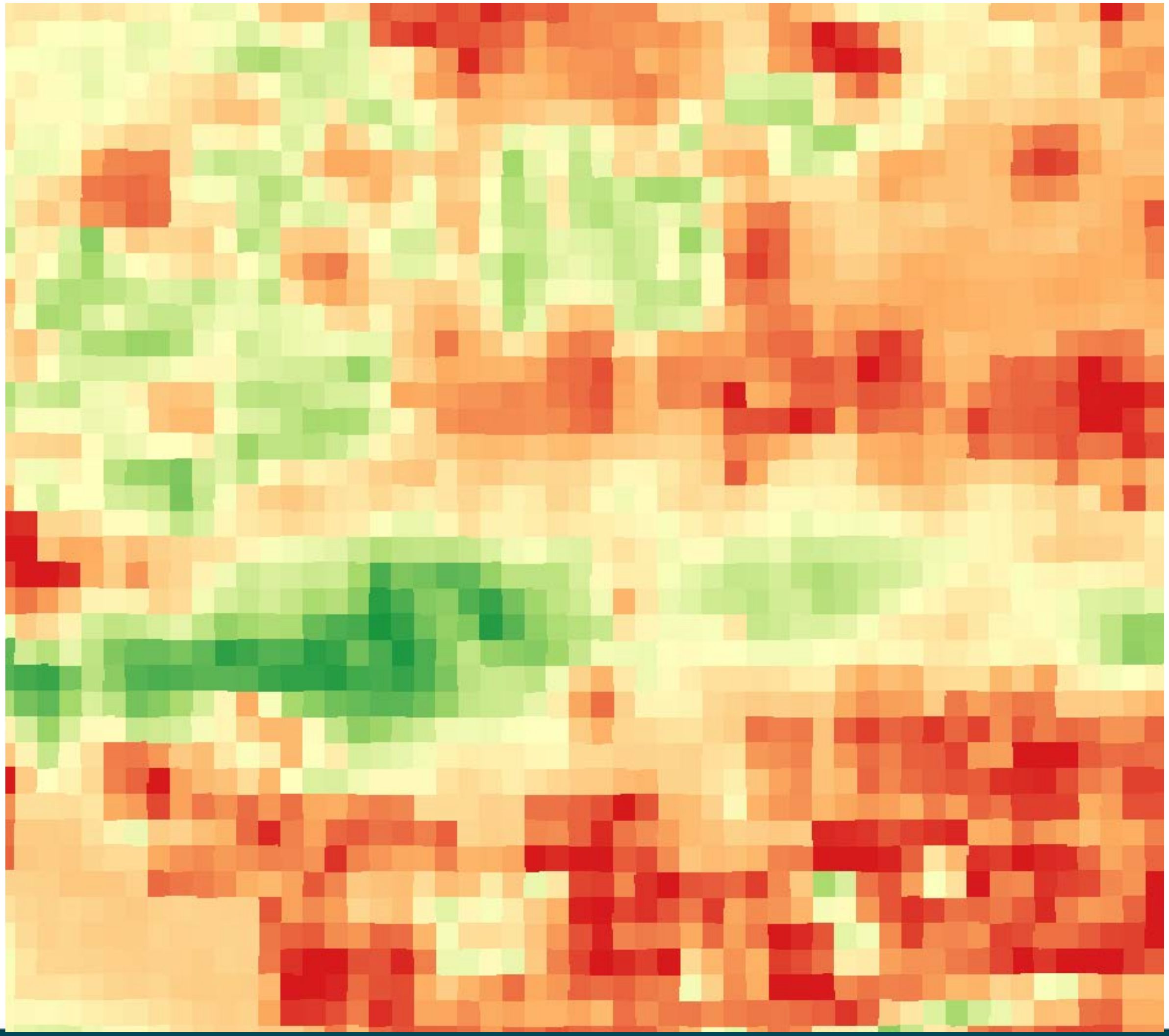
- 30 m Landcover databases are used for landcover based parameters.
- Areas in the US can use the National Land Cover Database (NLCD). Outside the US the GlobaeLand30 (shown at left) is used.

Classes shown

- Cultivated Crops
- Open Water
- Artificial Surface
- Bareland

Initial results: ALEXI daily ET

Nile Delta Irrigation



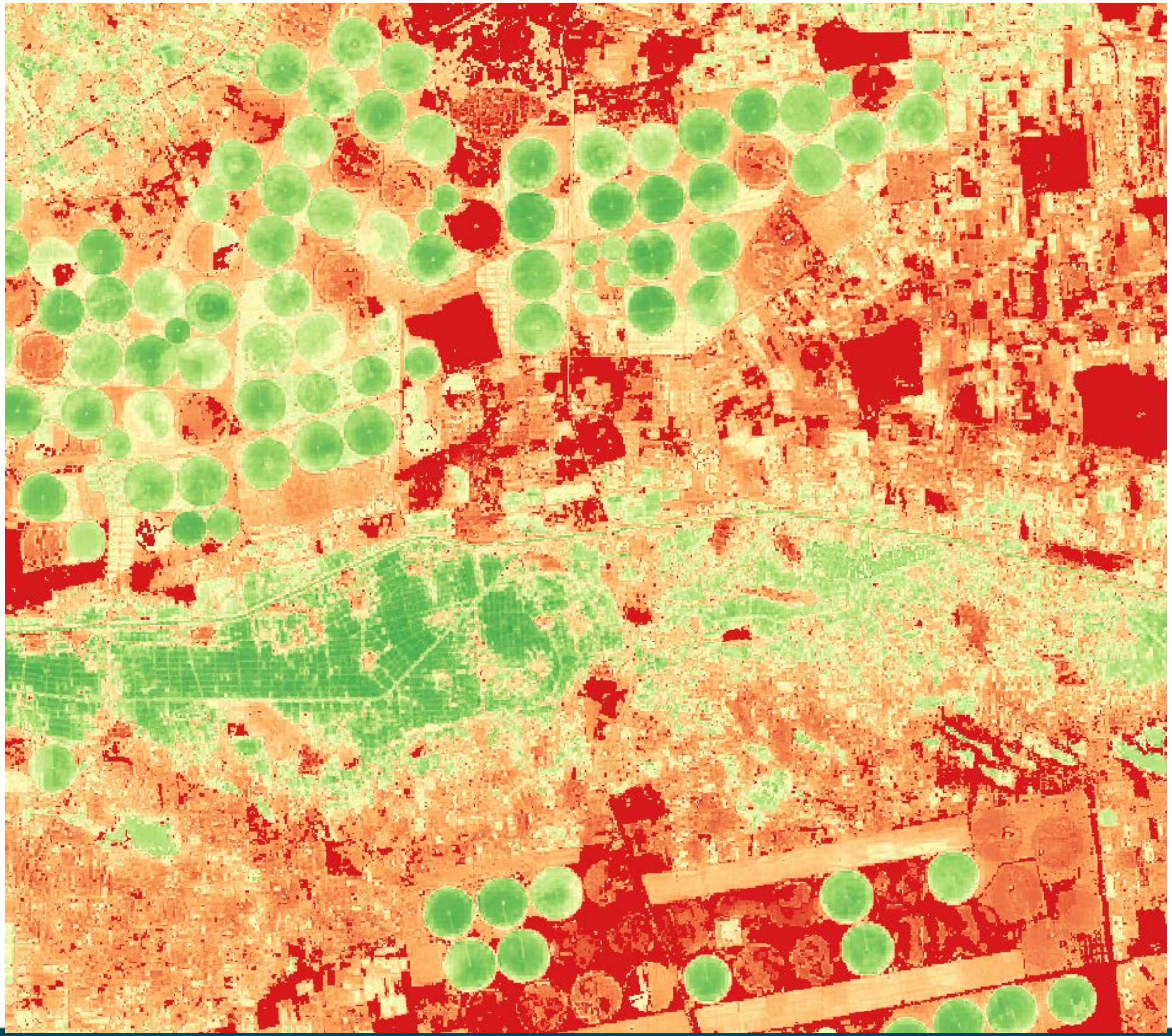
0.00
3.75
7.50
11.25
15.00

VIIRS daily ET mm/d

- Daily ET calculated at VIIRS 375 m data using the ALEXI model.

Initial results: Landsat daily ET

Nile Delta Irrigation



0.00
3.75
7.50
11.25
15.00

Landsat daily ET mm/d

- Landsat Daily ET downscaled from ALEXI using the PyDisALEXI model.

Current and Future Work

- Currently work is being done to optimize PyDisALEXI to run faster.
- Working to run PyDisALEXI over larger areas (Landsat scenes).
- Validate all inputs and results over flux tower locations.
- Current work is being conducted on Landsat but other sensors should be able to use PyDisALEXI.

Last Updated: March 2018

Automated Weather Stations for Reference ET

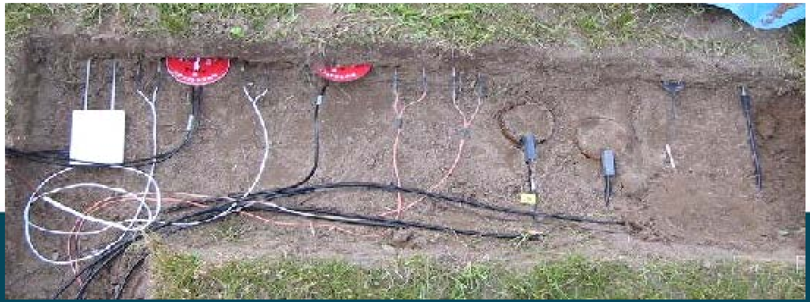
Typically provide hourly averages of weather parameters and ET0

Energy balance fluxes measured with eddy covariance systems (full energy balance: Rn, LE, H, G) placed in corn and soybean fields

Corn

Soybean

4 sets of soil heat flux plates distributed in rows and furrows



Ground Validation of the Daily Evapotranspiration Product

What is needed for validation of daily ET and downscaled values:

- Data from automated weather stations that estimate reference evapotranspiration using Penman-Monteith equation, their location and description of surrounding vegetation
- Historical records from these weather stations
- Evapotranspiration data for different regional crops from lysimeters if available and the systems are well managed
- Energy Balance Fluxes from Eddy Covariance or Bowen Ratio flux towers, their location and vegetated surfaces they represent
- Water flow measurements in irrigation systems (canal inflows, lateral canal flows, drainage and operational spills, groundwater levels etc.) to establish a water balance

Thank you

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