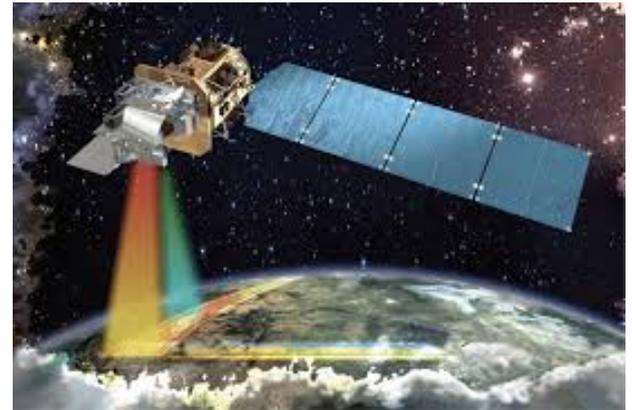


Google Earth Engine Evapotranspiration Flux --- EEFlux



Ayse Kilic, University of Nebraska-Lincoln
Rick Allen, University of Idaho
Members of the Landsat Science Team

Collaborators: **Justin Huntington**, Desert Research Institute / **Wim Bastiaanssen**, UNESCO / **Google**



INOVAGRI, Fortaleza, Brasil, Sept. 1, 2015

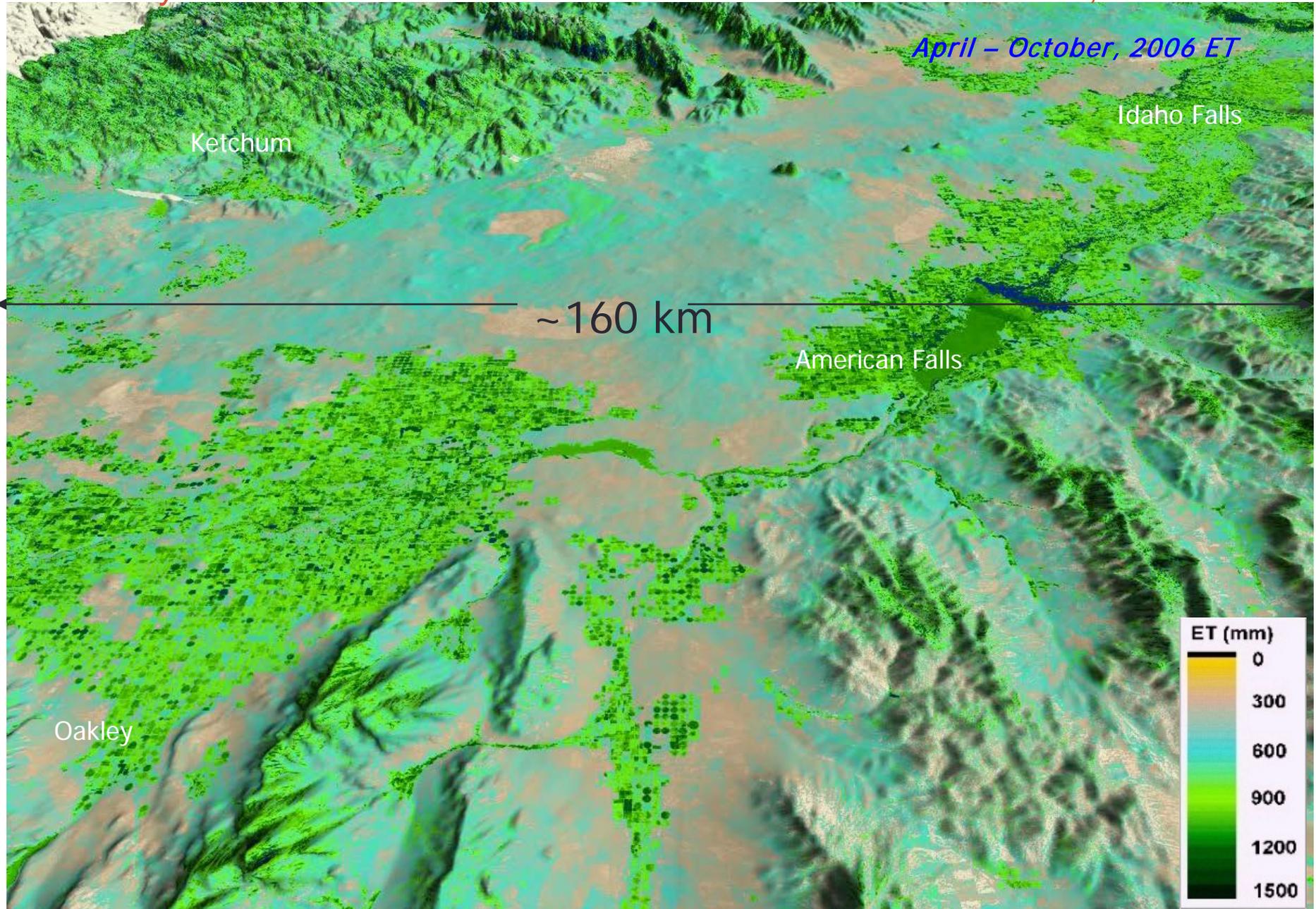
Who Cares about Evapotranspiration?

- State Departments of Water Resources
- Federal Water Management
- Hydrologists
- Environment
- Irrigation Designers
- Irrigators
- Water Rights



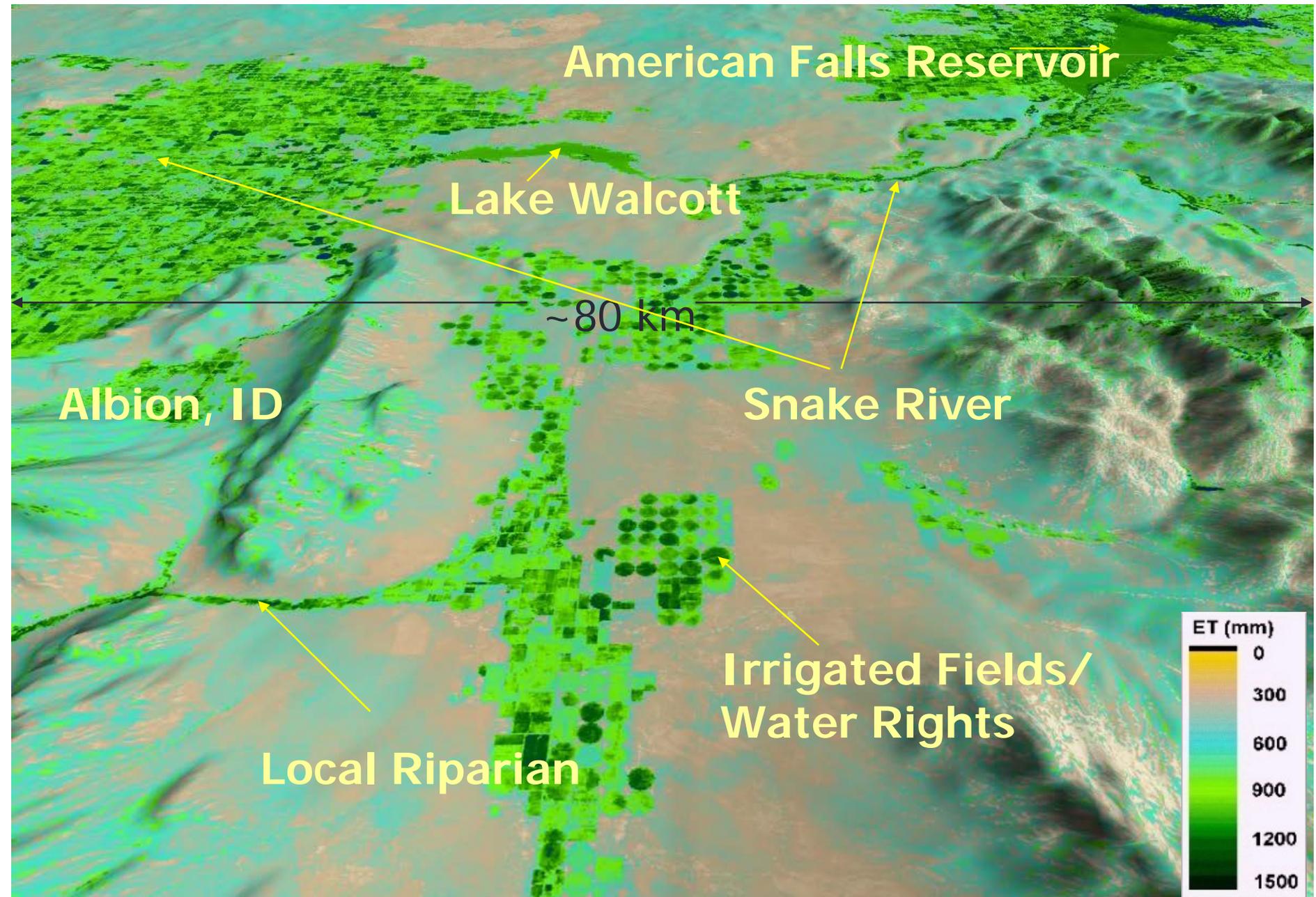
Does ET vary in Space? (Yes!)

-- Monthly and Seasonal ET at 30 m resolution for Eastern Idaho, USA



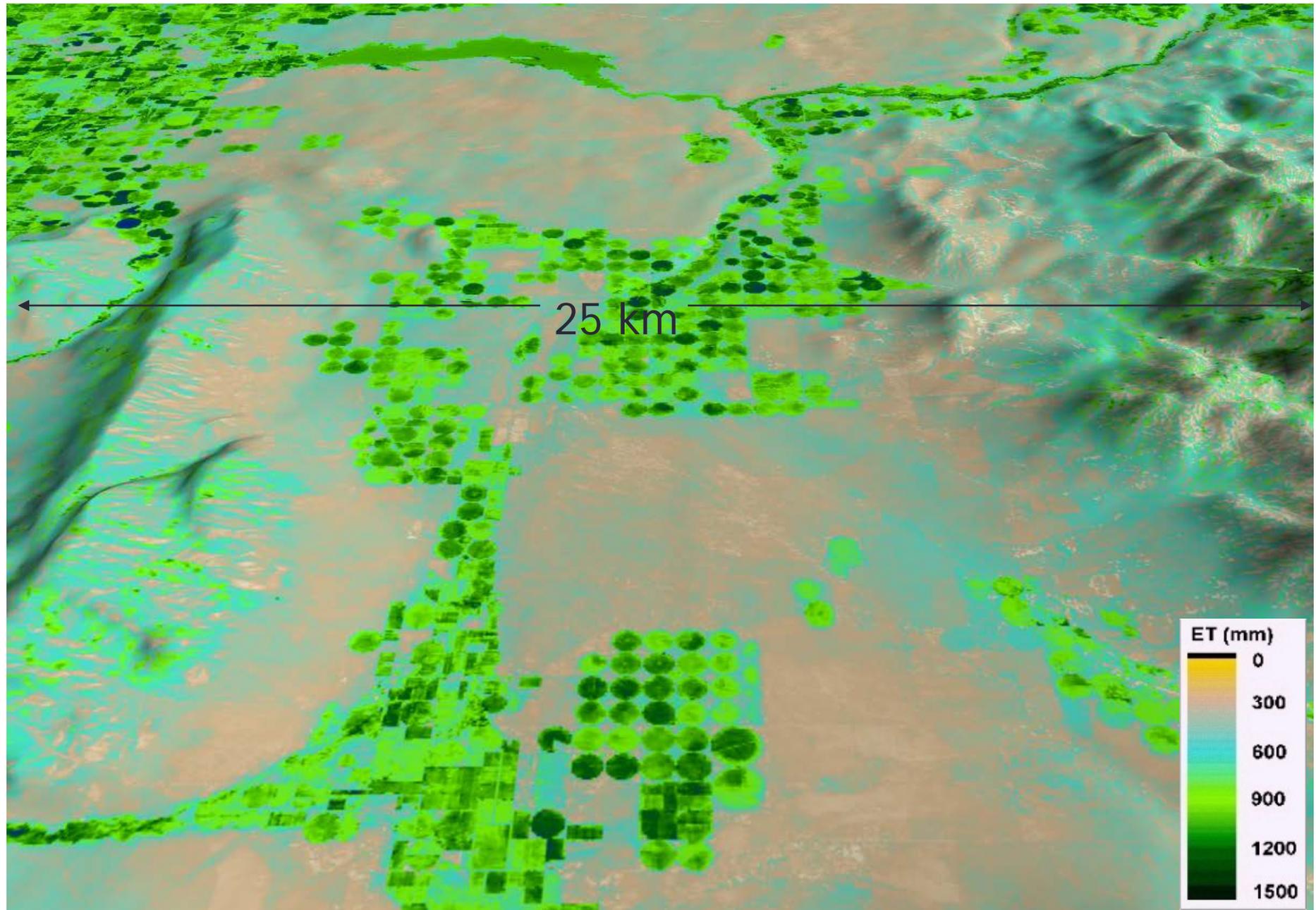
ET features at 30 m resolution

April – October, 2006 ET from METRIC-Landsat



ET features at 30 m resolution

April – October, 2006 ET from
METRIC-Landsat

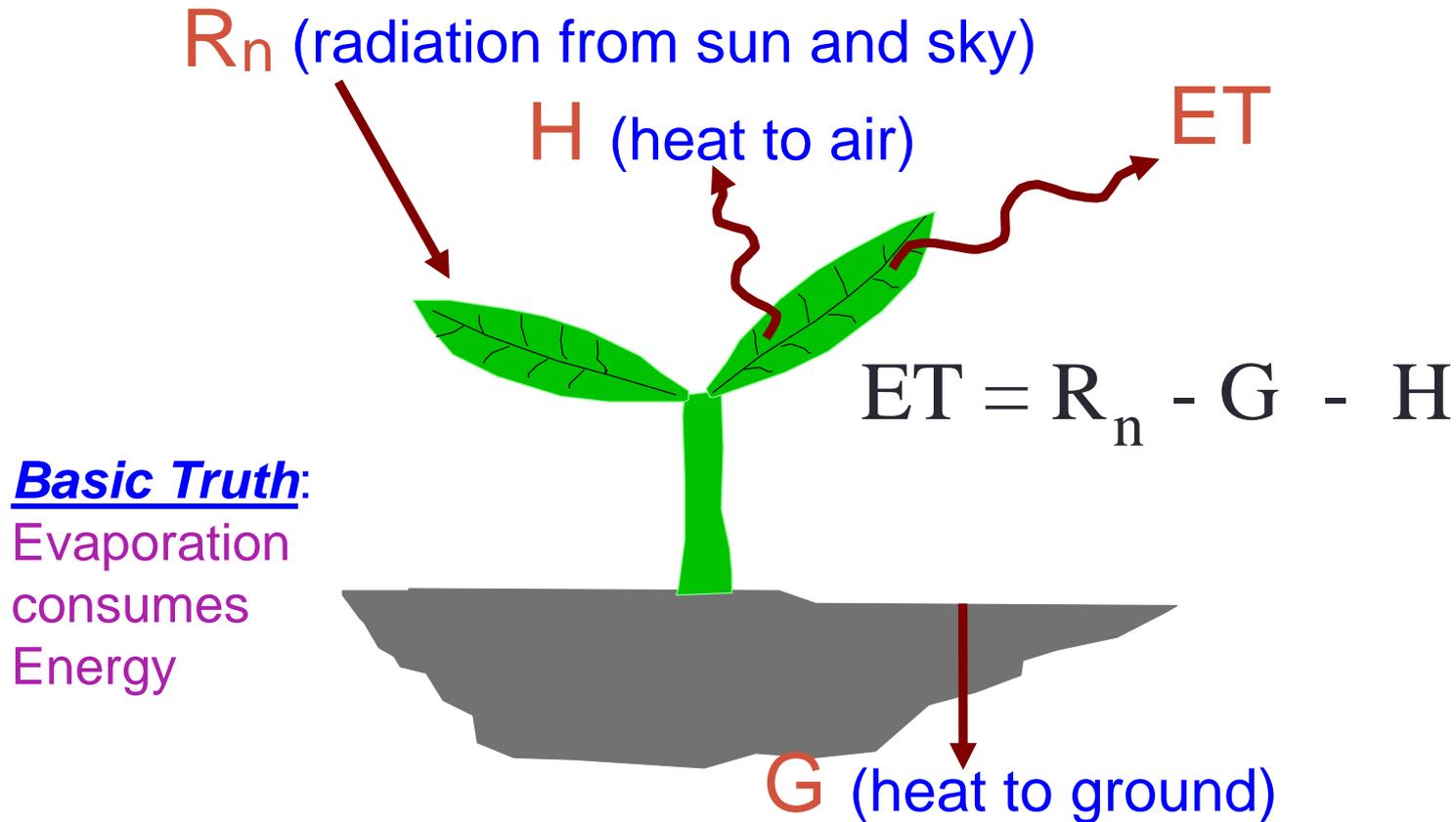


Acronyms

- METRIC – Mapping Evapotranspiration at high Resolution using Internalized Calibration
- EEFlux -- Earth Engine Evapotranspiration Flux

METRIC and EEFlux use an “Energy balance”

- ET is calculated as a “residual” of the energy balance



Energy balance gives us “actual” ET

Energy Balance can ‘see’ impacts on ET caused by:

- **water shortage**
- disease
- crop variety
- planting density
- cropping dates
- salinity
- management

• *(these effects can cause the ratio widely, thus the need to compute ET as a residual of the energy balance)*



EEFlux runs on the Google Earth Engine “Cloud”

Earth Engine JavaScript Language and Development “Playground”

Google Earth Engine

Help eefluxgeneral2014

Scripts Docs A_Pecora_Modesto Get Link Save Run Reset Inspector Console

```
return elev.subtract(datum).multiply(lapse_rate * 0.001).add(ts);  
659  
660 // Net Radiation (Rn)  
661 function rn_func (doy, cos_theta, tau, albedo, em_wb, ts, ts_dem_cold) {  
662 // Net Incident & Reflected Longwave Radiation  
663 var rl_in = tau.log().multiply(-1).pow(0.09).multiply(0.85 * 5.67E-8)  
664 // Use NLDAS air temperature  
665 // .multiply(ta.add(273.15).pow(4));  
666 // Use delapsd Ts_dem at the cold calibration point  
667 .multiply(ts_dem_cold.pow(4));  
668 // Emitted Longwave Radiation  
669 var rl_out = ts.pow(4).multiply(em_wb).multiply(5.67E-8).add(rl_in)  
670 .subtract(rl_in.multiply(em_wb));  
671 // Shortwave Radiation  
672
```

Inspector Console

Use print(...) to write to this console.

Ts Cold: 2... JSON

Ts Hot: 31... JSON

A: 0.80738... JSON

B: -229.52... JSON

Cold: 0.91... JSON

Layers Map Satellite

- Layer 8
- Layer 7
- ETrF
- Ts
- NDVI
- Albedo
- False_Color
- True_Color

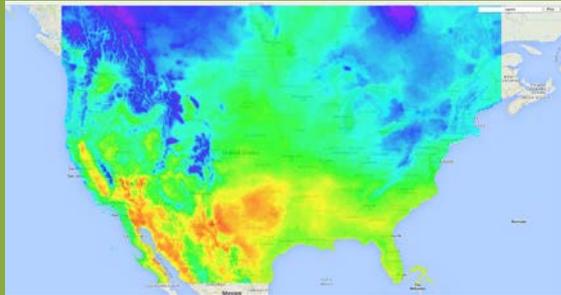
Map data ©2014 Google 5 km Terms of Use Report a map error

9:09 AM 11/20/2014

Modesto, California (Central Valley) area
--- monitoring impacts of drought

Data Resources Used by EFlux

NLDAS-Jan 1, 1979 - Current



GRIDMET-Jan 1, 1979 - Current



NLCD Landuse



DEM



Soil Data Layers

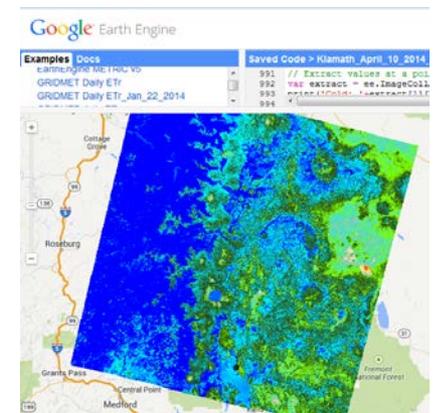


- Landsat 5/7/8 and MODIS
- Weather Data
 - Hourly Weather Data (NLDAS)--CONUS
 - Daily Weather Data (GRIDMET)--CONUS
 - Climate Forecast System Version 2, 6-hourly Products (CSFV2)--nonCONUS
- Landuse and Digital Elevation Maps
- Soil Data Layers (STATSGO--CONUS and FAO)

EEFlux (ET) on Google Earth Engine

Data:

- Gridded Weather data – used to calibrate EEFlux energy balance and to calculate Reference ET used for Time Interation of ET:
 - NLDAS – North American Land Data Assimilation System
 - hourly weather data at 12 km available for > 30 year period for CONUS
 - GridMET - daily, bias corrected weather data at 4 km available for > 30 year period for CONUS
 - Climate Forecast System Version 2, 6-hourly Product (CSFV2)—nonCONUS
 - Real Time Mesoscale Analysis (RTMA) – downloaded daily to Earth Engine – used to fill in time gaps between NLDAS and today for processing recent Landsat imagery
- Soils -- Used to produce a daily time series of evaporation from bare soil.
 - Statsgo soils data is available for CONUS for top 0.15 m of soil
 - FAO soils data base used for rest of globe



Klamath, 2014

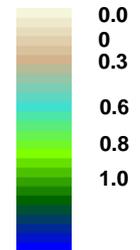
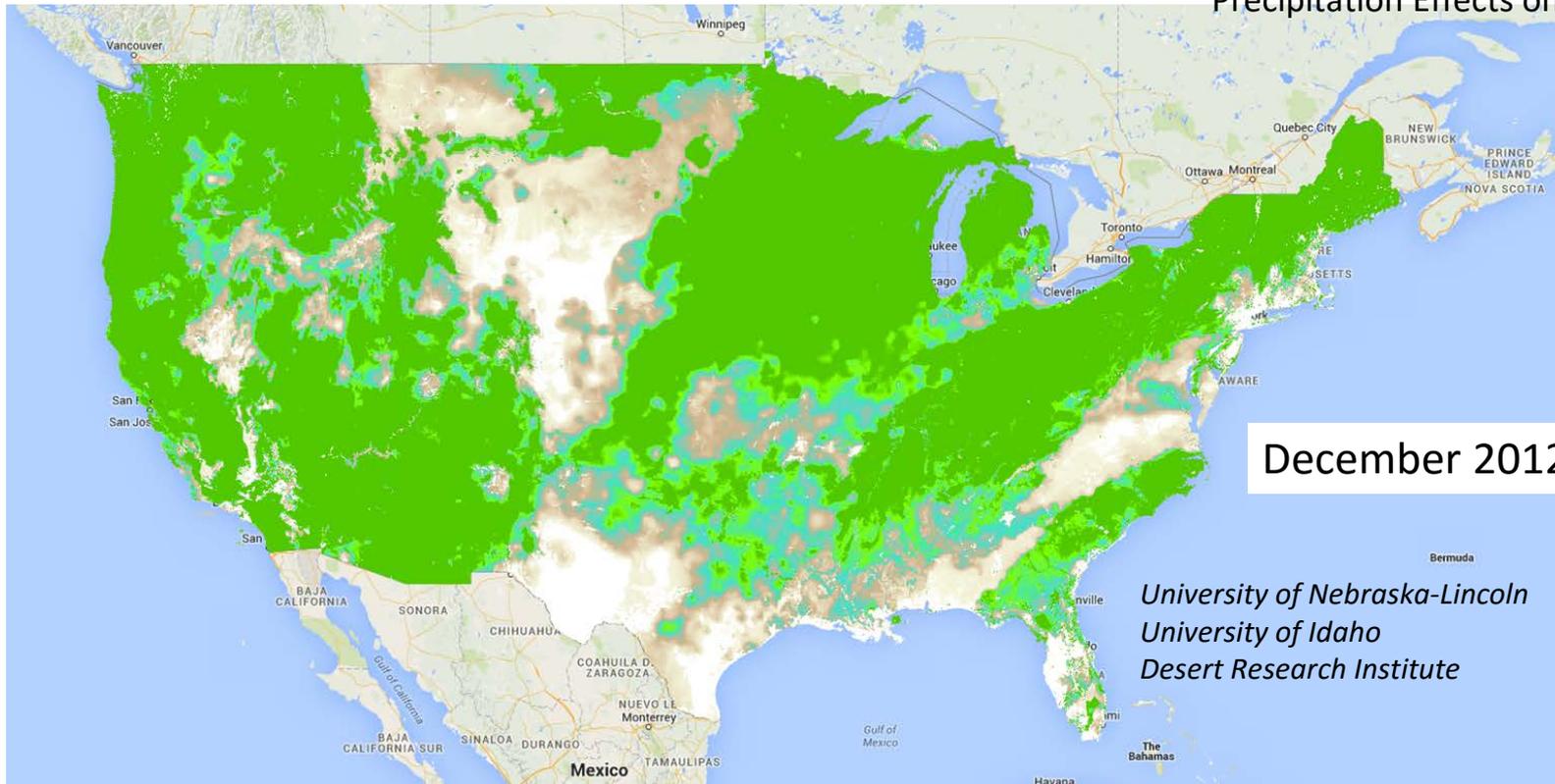
ET between Landsat dates is scaled using Reference ET App of Google EE



Reference ET is calculated using the ASCE Standardized Penman-Monteith Equation for the Tall Reference (Alfalfa) --computed from the daily GridMET data set of Abatzoglou (2012)

The Soil Surface Evaporation Component of the Google Earth Engine EFlux App.

--- Evaporation from Bare Soil --- used to calibrate the EFlux Evapotranspiration Surface Energy Balance to account for background Precipitation Effects on ET Evap. Coef. (K_e)



$$(K_e = E_{act} / ET_{ref})$$

December 2012

University of Nebraska-Lincoln
University of Idaho
Desert Research Institute

--computed from the GridMET weather data set of Abatzoglou (2012)
-- GridMET is traceable to NLDAS and PRISM data sets

EEFlux Applications

Imperial Valley
and Palo Verde,
CA



Jordan

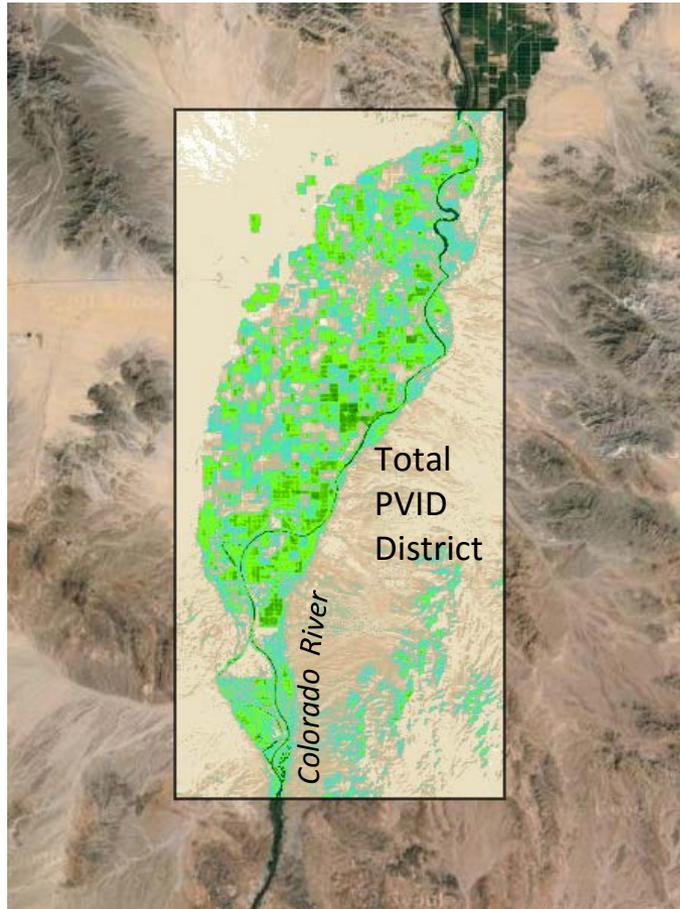


Chile



We are testing EEFlux over the globe in a number of Countries and Conditions

Google Earth Engine Flux --- EEFlux



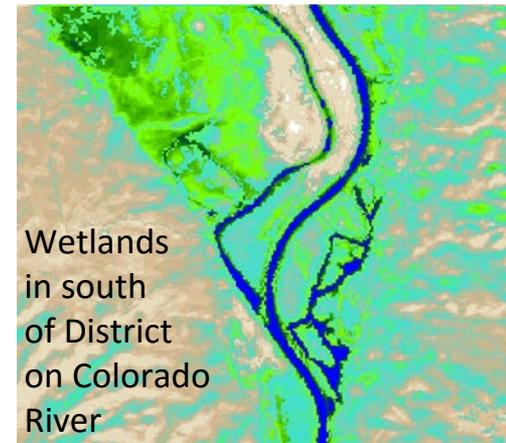
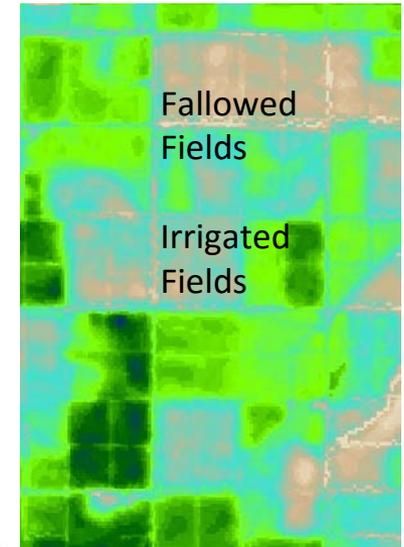
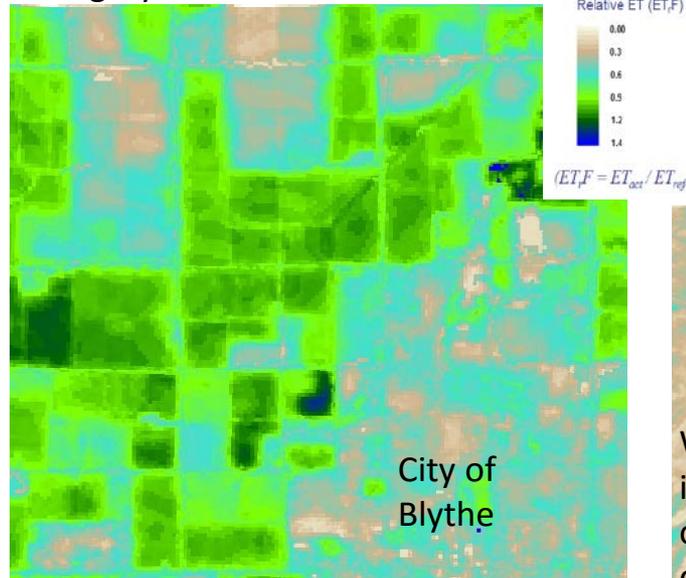
Earth Engine Evapotranspiration Flux

Palo Verde Irrigation District

Blythe, California – Jan. – Dec. 2008

-- Landsat 5
imagery

Dec.



Univ. Nebraska-Lincoln, Univ. Idaho, Desert Research Institute

Computations are based on a complete surface energy balance (METRIC)

EEFlux API's

- ee.Algorithms.EEFlux(Landsat)
 - ee.Algorithm.EEFlux.HourlyETr
 - ee.Algorithm.EEFlux.DailyETr
 - ee.Algorithm.EEFlux.SoilWaterBalance
 - ee.Algorithm.EEFlux.LandsatPreprocessing
 - ee.Algorithm.EEFlux.surfaceReflectance
 - ee.Algorithm.EEFlux.surfaceAlbedo
 - ee.Algorithm.EEFlux.surfaceTemperature
 - ee.Algorithm.EEFlux.AutoHC
 - ee.Algorithm.EEFlux.NetRadiation
 - ee.Algorithm.EEFlux.dT
 - ee.Algorithm.EEFlux.SensibleHeatFlux
 - ee.Algorithm.EEFlux.SoilHeatFlux
 - ee.Algorithm.EEFlux.EnergyBalance

API = Application Programming Interface

Each API will be callable by any user's Earth Engine Script

Soon to be available in earth engine playground

ee.Algorithm.EEFlux.HourlyETr

sample
ee call

```
ee.Algorithms.EEFlux.HourlyETr(Tair, SPH, Rs, WindSpeed, Elevation, Zw, doy, hour, ReferenceSurface )
```

- Reference evapotranspiration (ETr) is the rate at which readily available soil water is vaporized from specified vegetated surfaces (Grass or Alfalfa).
- This algorithm is based on the 'Standardized Reference Evapotranspiration Equation' recommended by American Society of Civil Engineers (ASCE-ET).
- Outputs a single band containing the computed hourly reference ET.

Arguments:

Input layers:

- Tair: Air Temperature (C)
- SPH: Specific Humidity (kg/kg)
- Rs: Solar Radiation (W/m2)
- WindSpeed: Wind speed (m/s)
- Elevation : Elevation (meters)
- DoY: Julian Date / Day of Year (Integer (0-365/366))
- Hour: Hour in GMT (Integer 00-23)
- Zw : Anemometer Height (meter)
- Reference surface (0/1):
 - Grass (0) or Alfalfa (1)

Image layers



Returns: Image of ETr/ETo (mm)

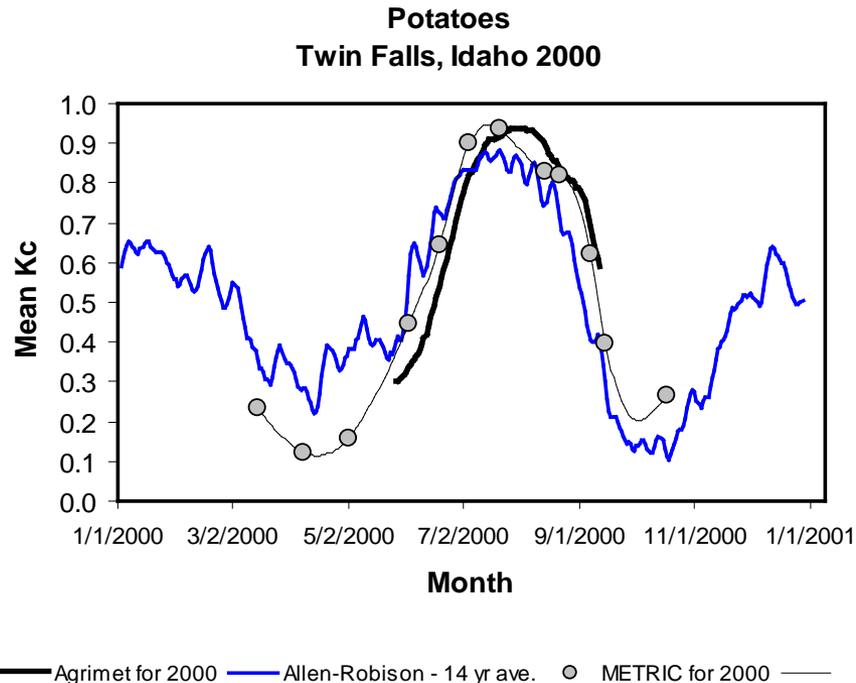
- Reference: Allen, R. G. et al. The ASCE Standardized Reference Evapotranspiration Equation. Reston, VA: American Society of Civil Engineers, 2005.

We Need a 30 meter SELFIE of Planet Earth DAILY



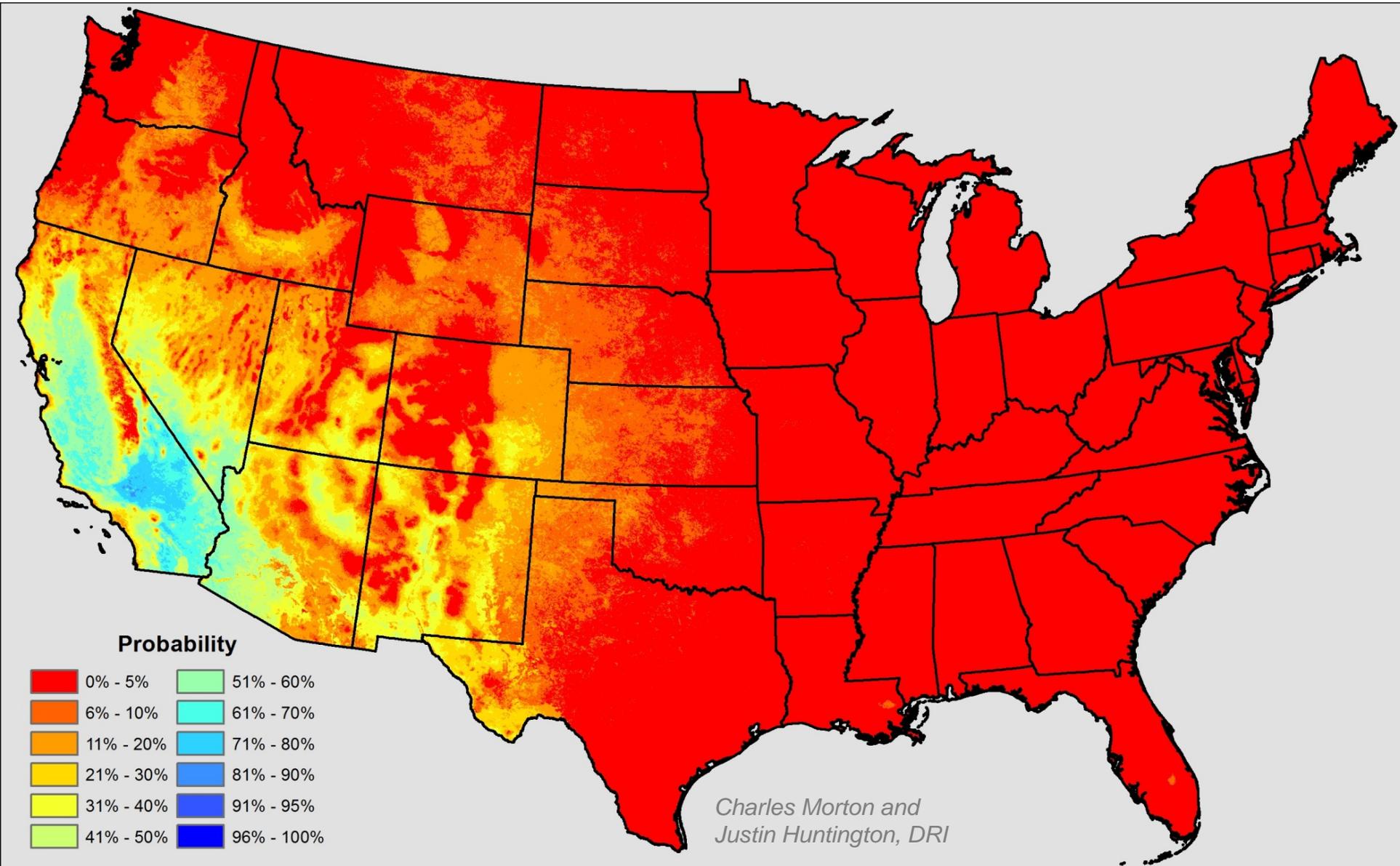
The impact of Number of Satellites (Revisit time) on estimating Water Consumption

- For estimating ET over extended time periods, we would 'like' information for any one 'point' each 32 days (at a minimum) to follow evolution of vegetation and water availability
- For parcel scale ET mapping, this requires multiple Landsat-type satellites



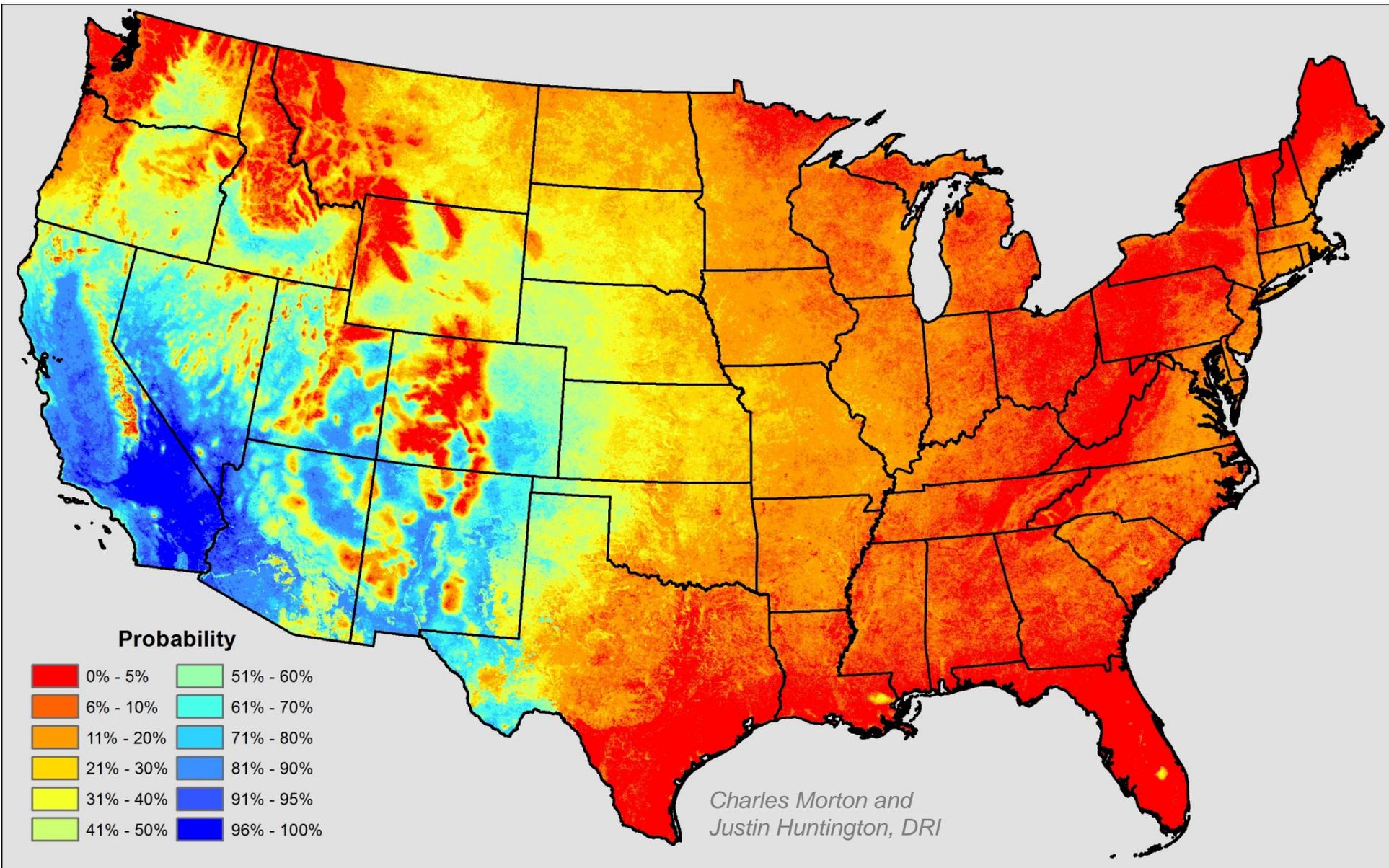
1 (180 km path) Landsat Satellite (each 16 days)

Probability of a Cloud-free Pixel at least every 32 days



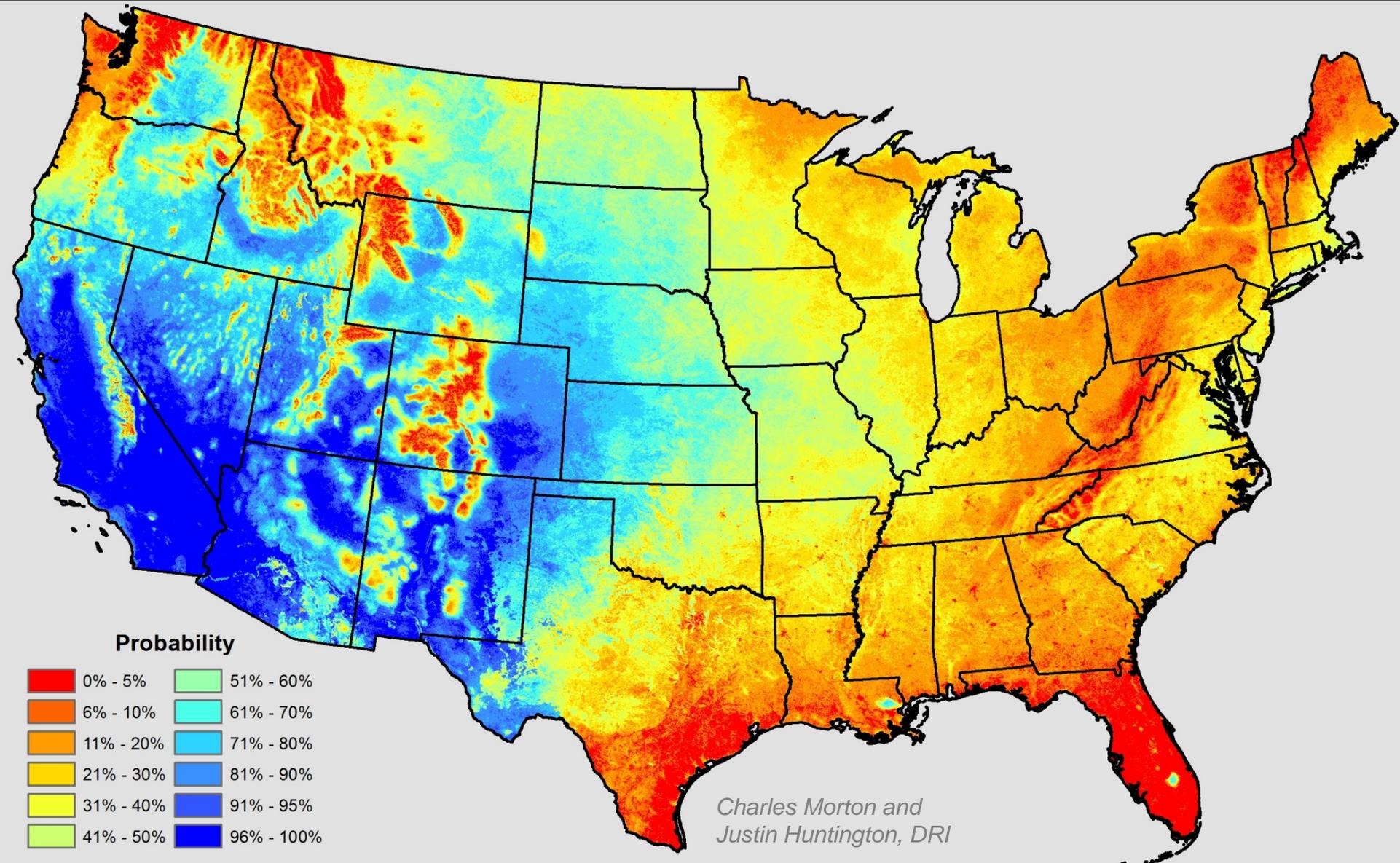
2 Landsat Satellites (image each 8 days)

Probability of a Cloud-free Pixel at least every 32 days



3 Landsat Satellites (image each ~5 days)

Probability of a Cloud-free Pixel at least every 32 days



*Charles Morton and
Justin Huntington, DRI*

Image each 4 days -- Four 180 km Landsat Satellites or Two 360 km Landsat Satellites

Probability of a Cloud-free Pixel at least every 32 days

(This is what the 'water community' should be asking for)

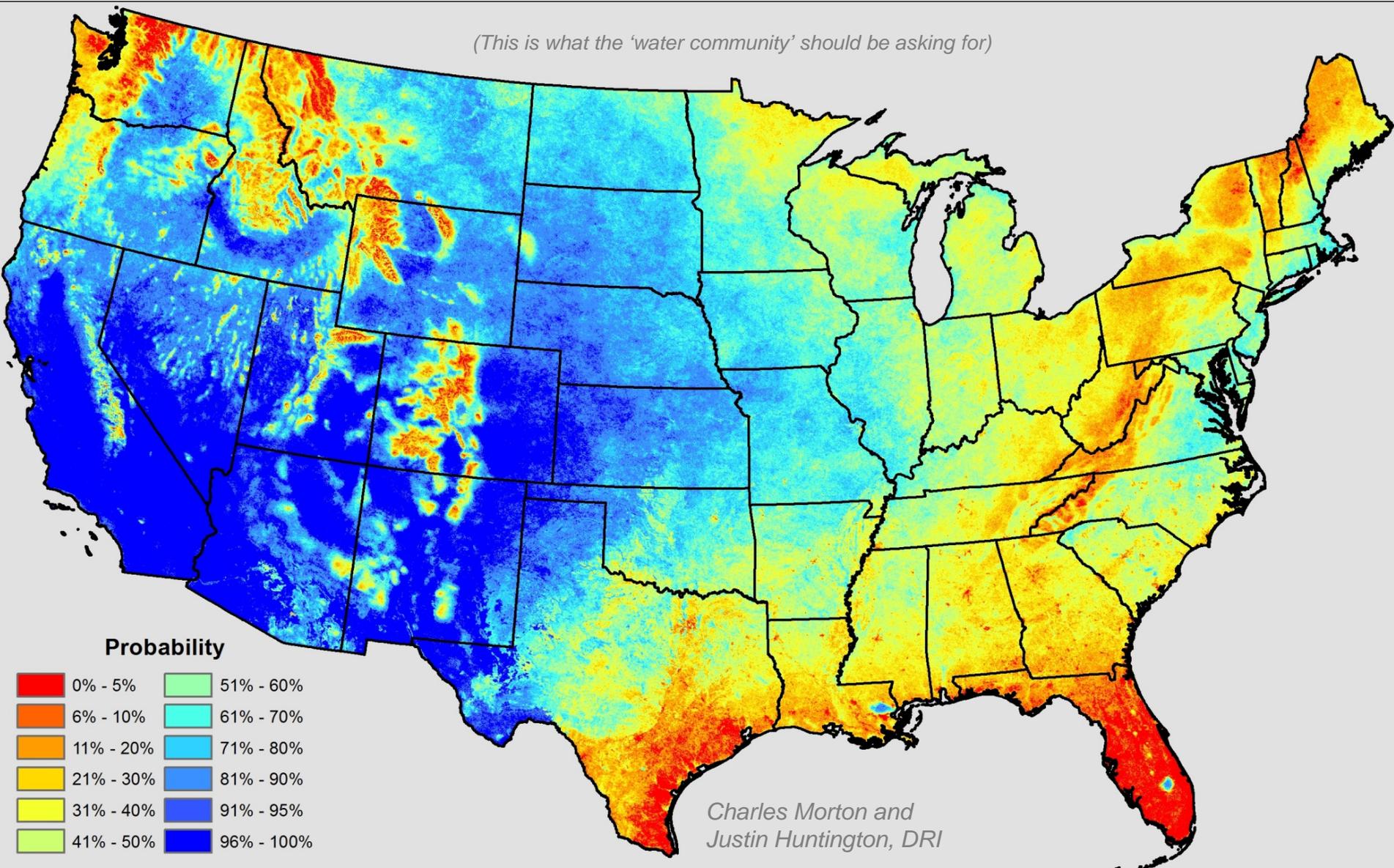
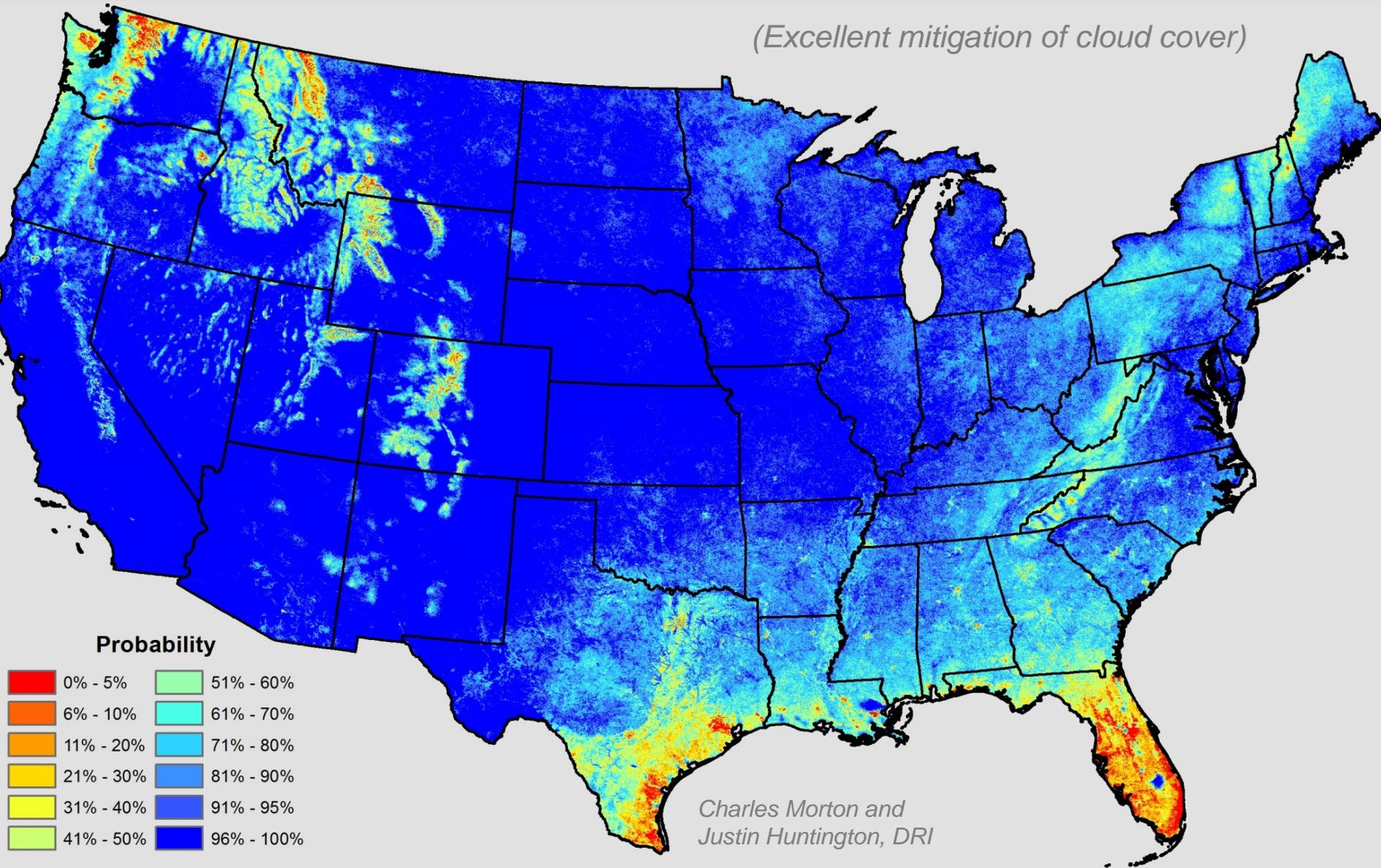


Image each 2 days – Eight 180 km Landsat Satellites or Four 360 km Landsat Satellites

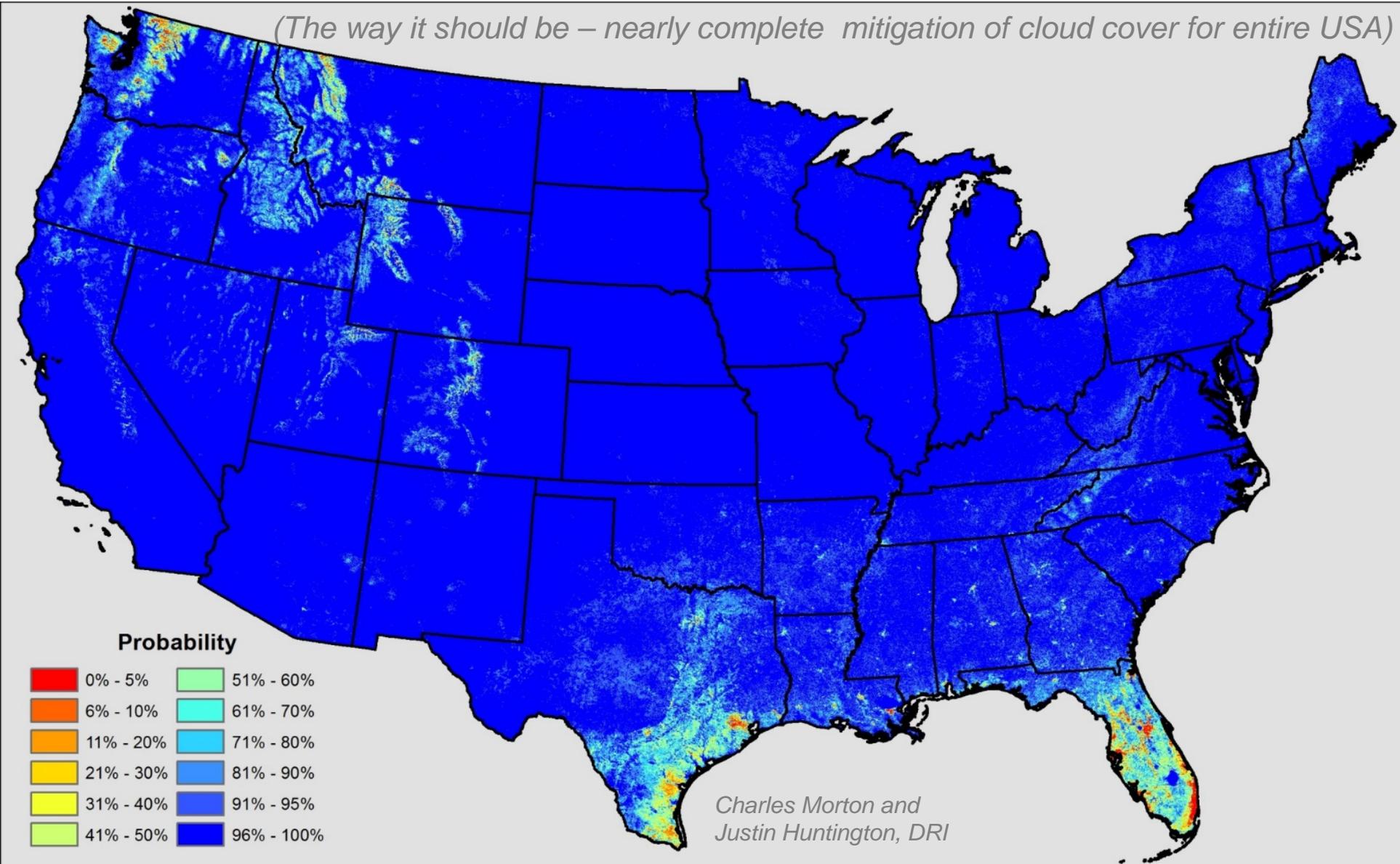
Probability of a Cloud-free Pixel at least every 32 days

(Excellent mitigation of cloud cover)



A daily **SELFIE** at 30 m requires → 16 – 180 km Landsat Satellites or 8 – 360 km Landsat Satellites
Probability of a Cloud-free Pixel at least every 32 days

(The way it should be – nearly complete mitigation of cloud cover for entire USA)

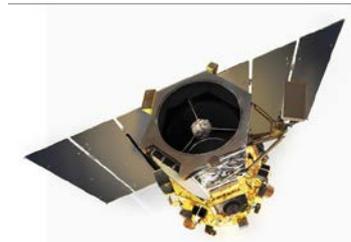


Why 30 m? (or 10 m or 20 m)

- 30 m provides enough detail for parcel – scale observations ---- The level of human impacts
 - agricultural fields
 - riparian systems
 - wetlands
- 30 m ‘blends’ very fine details such as shadows and individual vegetation into 30 m ‘blocks’ of blended impacts having intra-parcel definition
- 30 m pixel size is constrained by size, optics, accuracy and revisit time of satellite

Matching Imaging with Impact Scale

High resolution (< 10 m) imaging is highly valuable, but not necessary for high frequency mapping of evolutionary processes like vegetation growth and water consumption on 1) a parcel scale and 2) nationally or globally



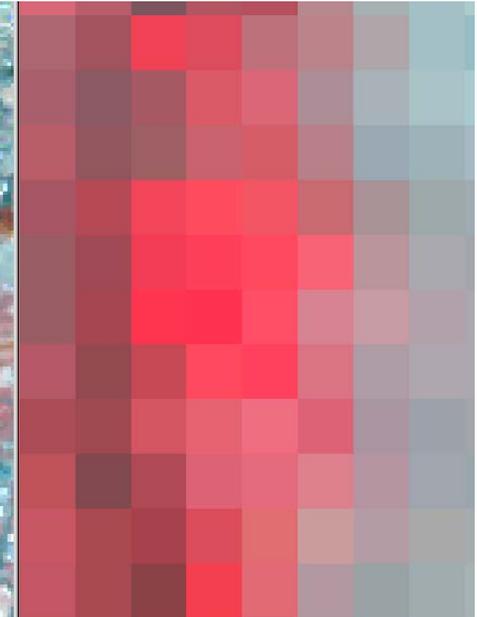
High Resolution intra-human impact scales



Landsat specific human impact scale



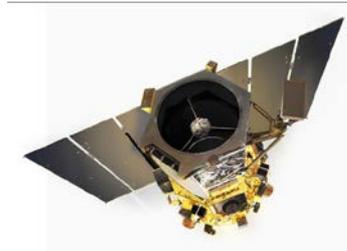
MODIS subregional / local scale



The Challenge for US Congress and others



“No, Take me!”



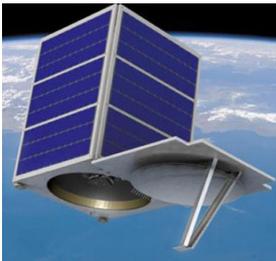
“Take me!”



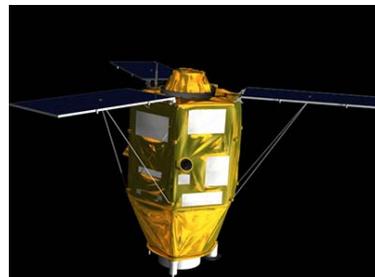
“Take me!”



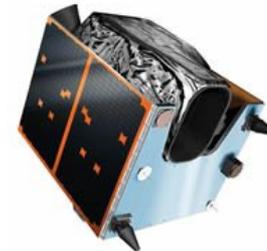
“No, Take me!”



“Take me!”



“No, Take me!”



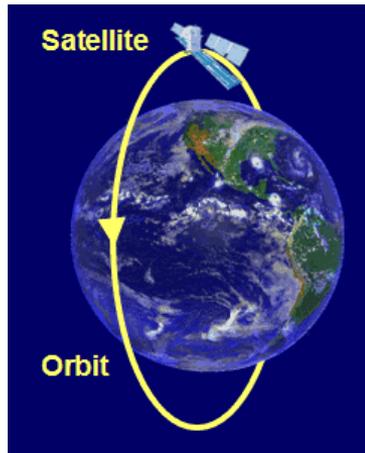
“Take me!”

A formula for calculating revisit time for a satellite (and the number of satellites needed for a daily “Selfie”)

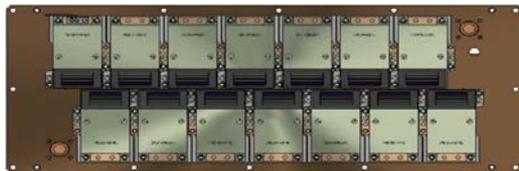
Earth's Circumference = 40,000,000 m Satellite Orbit time = 98.9 minutes for L8



X



= 16 days for 1 sat.
or 16 satellites for daily



X



constrained by telescope
size and signal to noise
ratio req.

Effective Number of Detectors
(no. pixels) = ~5,700 for L8

Pixel size = 30 m for L8

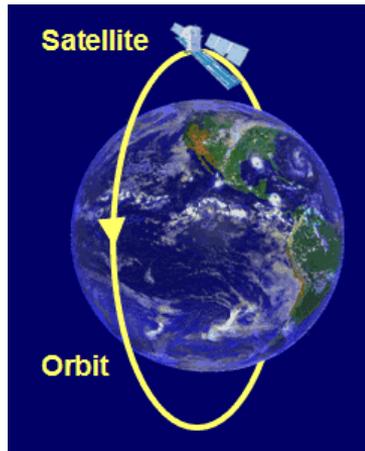
Swath Width of Satellite

A formula for calculating revisit time for a satellite (and the number of satellites needed for a daily “Selfie”)

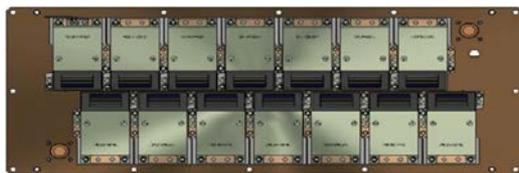
Earth's Circumference = 40,000,000 m Satellite Orbit time = 98.9 minutes for L8



X



= 48 days for 1 sat.
or 48 satellites for daily



X



Effective Number of Detectors
(no. pixels) = ~5,700 for L8

Pixel size = 10 m

constrained by telescope
size and signal to noise
ratio req.

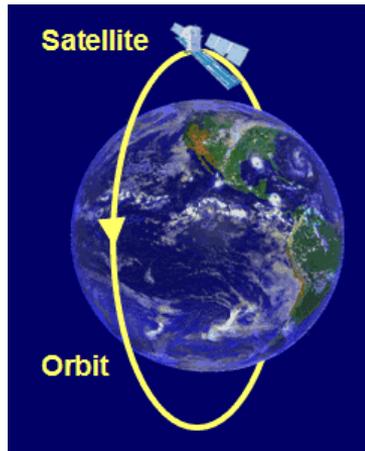
Swath Width of Satellite

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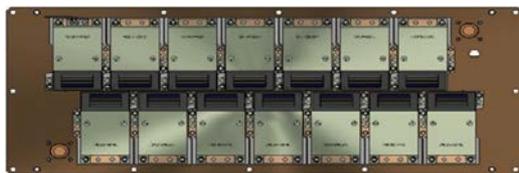
Earth's Circumference = 40,000,000 m Satellite Orbit time = 98.9 minutes for L8



X



= 480 days for 1 sat.
or 480 satellites for daily



X



Effective Number of Detectors
(no. pixels) = ~5,700 for L8

Pixel size = 1 m

constrained by telescope
size and signal to noise
ratio req.

Swath Width of Satellite

How much would a Daily Landsat Cost? i.e., 16 Landsat satellites in orbit

= \$15 billion over 10 years

= 16 Landsats per 10 years

Cost Equivalency - three coffee-lattes per
American per year