Towards the development of a complete Landsat ET and energy balance archive to support agricultural consumptive use reporting and prediction in the Central Valley

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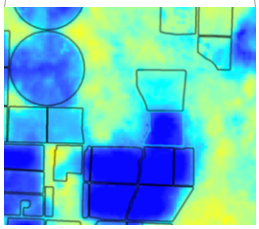
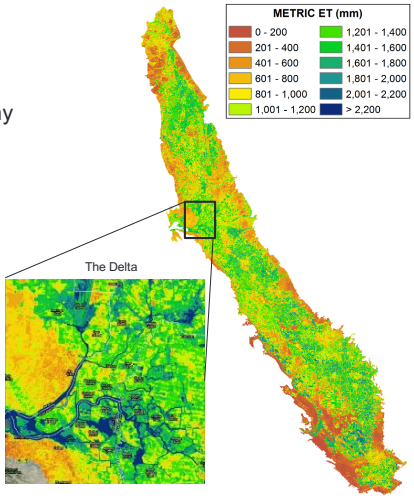
Introduction

- Field scale ET is important for understanding agricultural consumptive use
- Historical ET maps are needed to manage surface and groundwater resources
  - Support predictive studies of surface and groundwater consumptive use
  - Knowing the past will help us better predict the future
- Remote sensing is the only way to estimate actual consumptive use over large areas and long time histories
- "You can't manage what you don't measure"



Goal

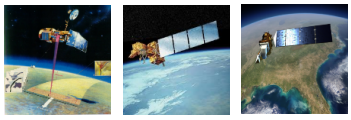
- Develop timely maps of monthly & annual ET for any area and time period
  - Central Valley (1985-Pres.)
  - Landsat Archive
- Why Landsat? Field scale resolution - 30~120m
- Why energy balance? To account for stress and evaporation not directly considered by optical methods



Approach

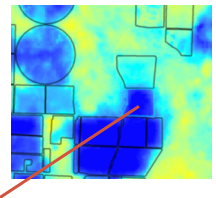
- Use Landsat thermal and optical data to estimate ET with automated METRIC energy balance approach
- Use gridded weather data to estimate ET_r and PPT
- Automation needed – lots and lots of data and processing..
  - ~10 scenes for Central Valley
  - ~22 images / year
  - ~30 years of L5,L7,L8 combined
  - ~6,000 available images to process..

Landsat 5 Landsat 7 Landsat 8



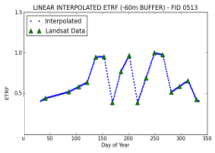
Monthly & Annual ET – Interpolation and Time Integration

- Water managers need monthly & annual ET, not just snapshots of ET
- Estimate the fraction of reference ET (ETrF) at the satellite overpass time using METRIC
- Time interpolate instantaneous ETrF per pixel in between image dates
- Multiply interpolated instantaneous ETrF by daily ETr, and sum to estimate the monthly and annual ET



Time Series of Reference ET (ETr) | Kc = fraction of reference ET (ETrF) estimated by METRIC | Total Daily ET (mm)

x



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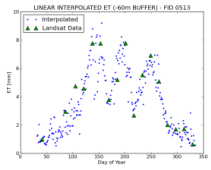


- By using reference ET in the time integration process, we account for impacts of daily variations in solar radiation, temperature, humidity, wind speed on ET

Automated Approach

- Automated METRIC approach developed with Python and GDAL
  - Outlined in Allen et al. (2013) and Morton et al. (2013)
- Originally developed and applied in western Nevada & eastern California
  - Irrigated alfalfa and pasture grass as a test case
- Goal to apply and validate in the CV for all Landsat scenes, and with decent accuracy (+/- 10-20%)

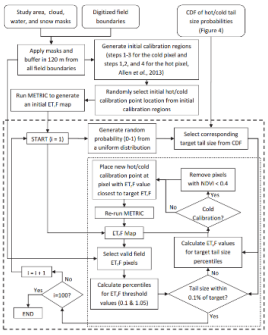
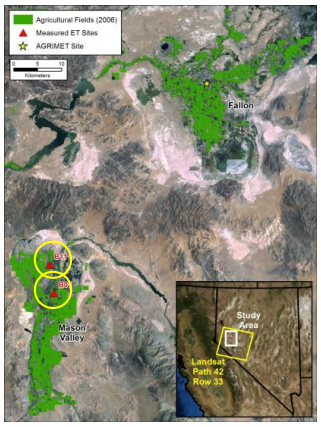


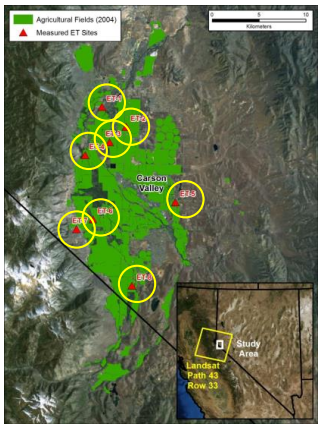
FIGURE 5. Schematic of the Automated Calibration Algorithm. The dashed box is the Monte Carlo process that was repeated 100 times for each Landsat scene. The dotted box is the iterative process to find the hot and cold calibration points that generate an ET_rF distribution with the target tail sizes.

Allen, R.G., et al. (2013). Automated Calibration of the METRIC-Landsat Evapotranspiration Process. Journal of the American Water Resources Association (JAWRA) 49(3): 563-576. DOI: 10.1111/jawr.12056

Morton, C.G., et al. (2013). Assessing Calibration Uncertainty and Automation for Estimating Evapotranspiration from Agricultural Areas Using METRIC. Journal of the American Water Resources Association (JAWRA) 49(3): 549-562.DOI: 10.1111/jawr.12054

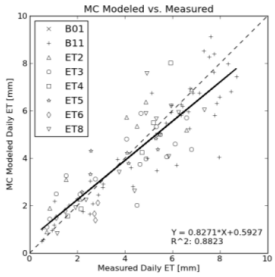
Blind Comparison of Automated Daily Energy Balance ET to Measured Daily ET in Carson and Mason Valley, NV / CA

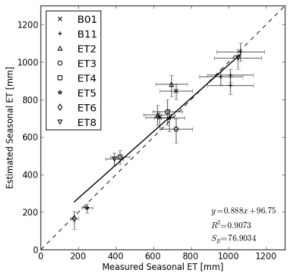




Blind Comparison of Users and Automated ET to Measured ET

- Daily error not bad considering the error in measured daily ET is ~ +/- 20%
- Whiskers on X = +/- 12% USGS estimated uncertainty in measured ET, Y = +/- 95% confidence interval of 100 automated estimates of ET using different input parameters (e.g. hot and cold calibration pixels)
- Over the season error in daily estimates largely cancels out (Ratio of Est/Meas = 1.04; Stdev = 0.13)
- Goal is to upscale and validate in the CV for many different crop types





Morton, C.G., J.L. Huntington, G.M. Pohll, R.G. Allen, K.C. McGwire, and S.D. Bassett. (2013). Assessing Calibration Uncertainty and Automation for Estimating Evapotranspiration from Agricultural Areas Using METRIC. Journal of the American Water Resources Association (JAWRA) 49(3): 549-562.DOI: 10.1111/jawr.12054

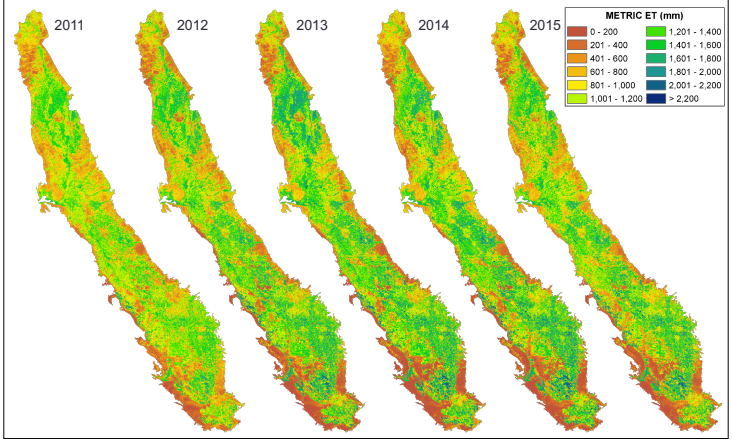
Upscaling Approach – NASA Earth Exchange

Landsat 5,7,8
FMASK – cloud mask algorithm
ATM Correction – Tasumi et al.(2008)
NLDAS – hourly vapor pressure for ATM correction and ETr
Spatial CIMIS – daily ETr for time integration
SSURGO soils data – soil water balance model
Crop boundaries to limit automated calibration

- Want to provide ET maps in a timely and costly manner for the entire Landsat archive (1985-pres)
  - ~6,000 available images to process..
- Migrated automated METRIC to NASA's Earth Exchange (NEX) Super Computer and tested
- We can now run METRIC for entire states / years and with Monte Carlo type uncertainty analysis (i.e. ~100 different runs per scene to make 100 different annual totals)

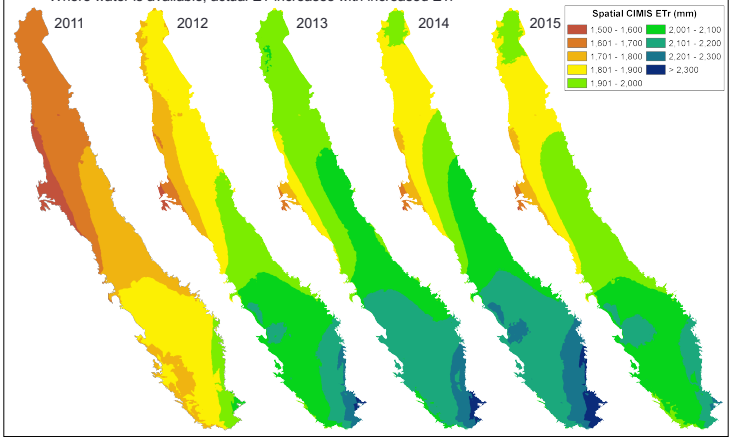
Initial Results – ET for the last 5 years

- Lower ET during drought in water limited areas
- Higher ET during drought in well-watered areas



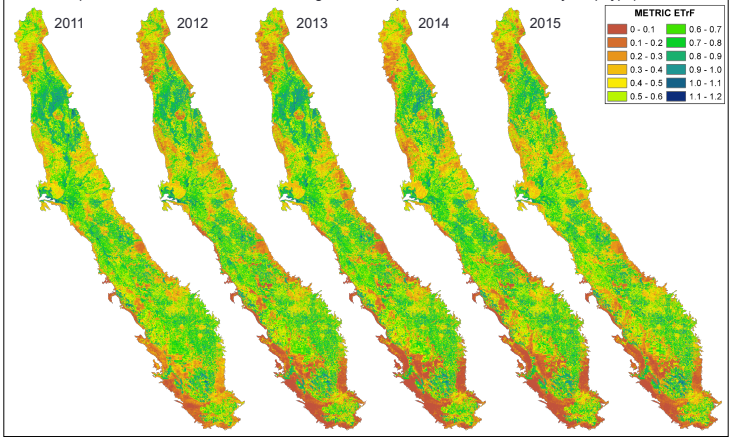
Spatial CIMIS Reference ET (ETr)

- Reference ET exceptionally high in 2013 - 2015 (complementary theory: decreased PPT = increased ETr)
- Where water is available, actual ET increases with increased ETr



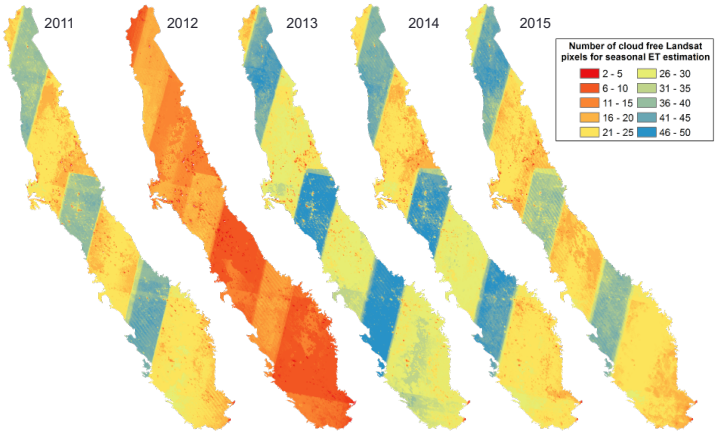
Fraction of Reference ET (ETrF)

- Fraction of reference ET (ET/ETr) high in rice and tree crop areas - lower in 2015
- Multiple factors to consider when evaluating ET results (ETr, ETrF, water availability, crop type)



Annual per pixel Landsat scene counts

- Important to show scene counts for estimating seasonal and annual ET! Scene counts for estimating annual ET vary greatly - path overlaps from use of Landsat 5,7, and 8. Only Landsat 7 available in 2012.

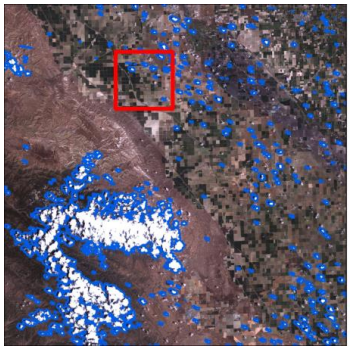


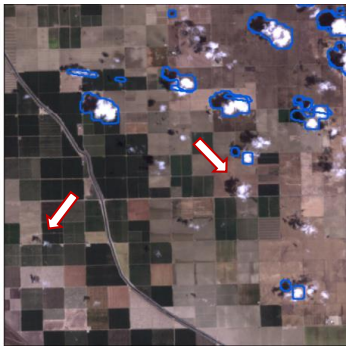
From Pretty Pictures to Accuracy

- Regional field scale ET maps are nice for evaluating patterns and trends, but *field scale accuracy* is important for water and agricultural management
- Working with NASA ARC / CSUMB collaborators to validate and improve automated METRIC ET maps using eddy covariance, surface renewal, and soil water balance estimates of ET for multiple crop types in the CV
- There are limitations with the current automated approach and initial results
  - Automated calibration parameterization for California crops is more complex than for typical alfalfa and hay grass (much more complexity in CV, >400 crop types)
  - Not accounting for precipitation and subsequent evaporation in between satellite snap shots
  - Not properly estimating ETrF in the winter time and beginning of the growing season (i.e. no crops are at a full cover alfalfa ET rate that is typically assigned to the cold pixel during winter and green-up)
  - Not accounting for albedo impacts for tree crops and vineyards
  - Not including enhanced aerodynamic roughness functions for trees / orchards (i.e. Perrier (1982) function)
  - No cloud gap filling other than temporal linear interpolation between cloud free scenes
  - We are adding all this functionality and testing workflow over the next 6 months..

Challenges - Cloud Masking

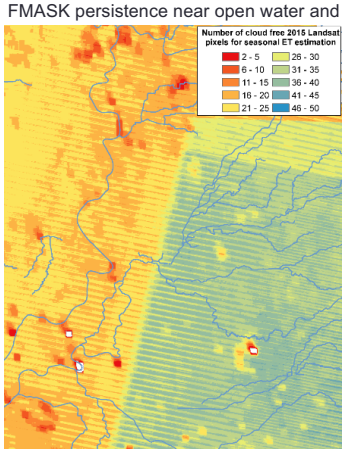
- FMASK sees majority of clouds and shadows, but some slip through
- Combining different masks (LEDAPS/FMASK), buffering, and manual masking by digitizing.. manual digitizing is best.. but time intensive.

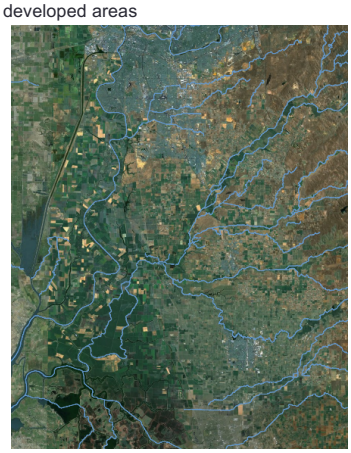


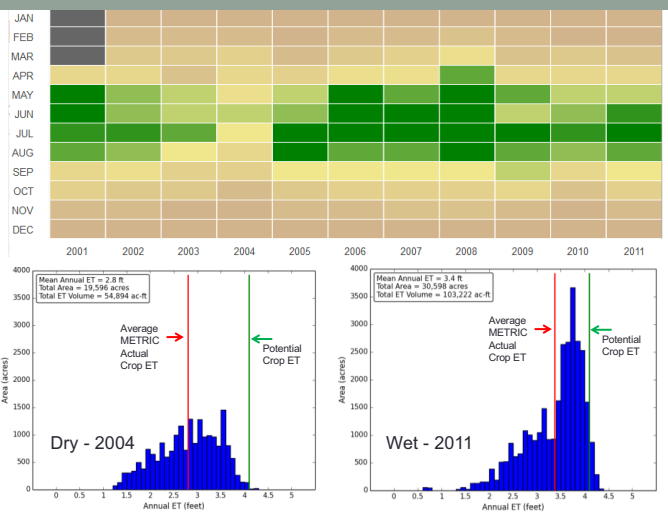


Challenges - Cloud Masking

- FMASK persistence near open water and developed areas





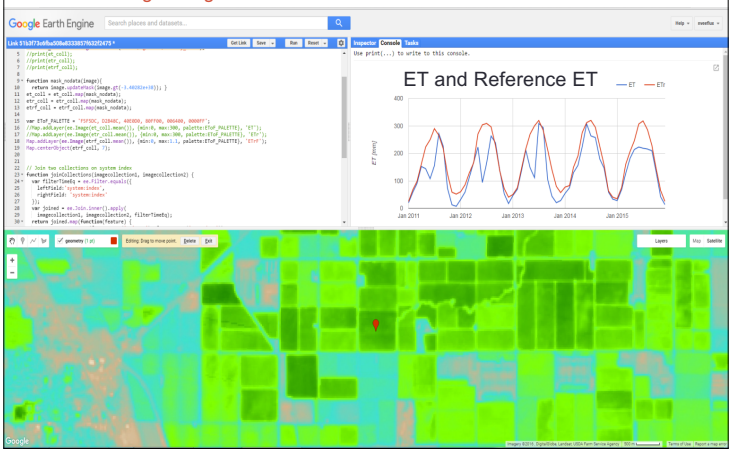


Future Directions for Operational & Automated ET

- Use of cloud and super computing and create, store, post-processes, and deciminate data
- Datasets can then be accessed through the cloud via a web application like *ClimateEngine.org*, others
  - New ability to programmatically and operationally compute, store, post-process and access data in the cloud is really powerful and exciting..game changer!

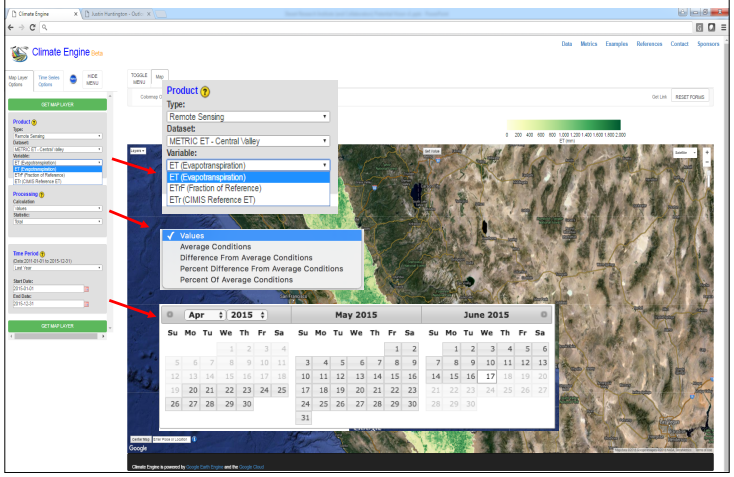
Our First Test – Loading ET maps to Earth Engine

Uploaded NASA NEX pre-computed Landsat monthly ET (2011-2015) for the CV to asset manager, and accessed in the Google Earth Engine Playground and *ClimateEngine.org*



Our First Test – Hosting ET data in the cloud

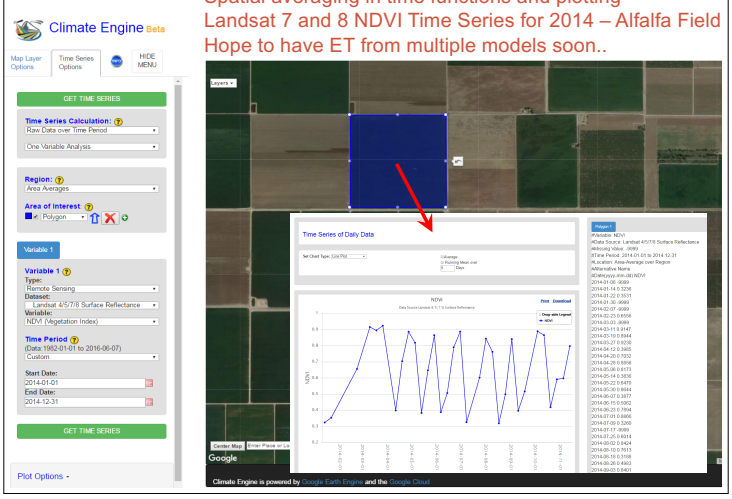
Hosting ET on App / Earth Engine based web application, *ClimateEngine.org*



Our First Test – Linking to App / Earth Engine based web application

Spatial averaging in time functions and plotting Landsat 7 and 8 NDVI Time Series for 2014 – Alfalfa Field

Hope to have ET from multiple models soon..

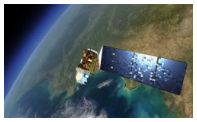


Summary

- We developed and implemented an automated workflow for METRIC to be run on NASA's Earth Exchange (NEX)
- Allows for timely field scale historical ET estimates over large areas using the entire Landsat archive
- Once additional workflow is implemented and results are validated, an energy balance ET collection for the Central Valley will be extremely useful for water use reporting, ecological stress and drought impact assessments, and developing supply / consumptive use relationships for predictive analyses
- Additional measurements across multiple sites and crops are critical for validation and continued model improvements – robust benchmark datasets are needed
- Cloud storage and super computing is necessary for efficient data creation and data discovery, model comparison, post-processing, and data dissemination
- Where to next? Quick and accurate field scale ET analysis with a simple web connection

Landsat 8, Launched Feb 11, 2013

Many thanks to:
Collaborators
NASA
USGS
Landsat Science Team
ClimateEngine.org Team
NV Division of Water Resources



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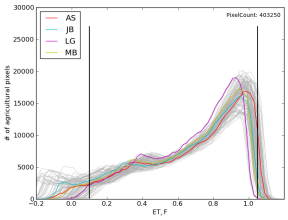
Add. Material



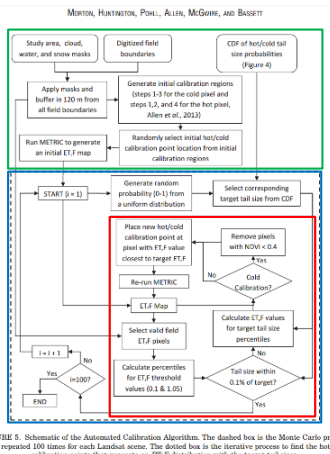


FIGURE 5. Schematic of the Automated Calibration Algorithm. The dashed box is the Monte Carlo process that was repeated 100 times for each Landsat scene. The dotted box is the iterative process to find the hot and cold calibration points that generate an ET,F distribution with the target tail sizes.

Initial Pixel Rating and Selection

Iteration based on ETrF tail size distributions

Monte Carlo Resampling