Using Surface Energy Balance Model (ReSET) to Estimate Seasonal Crop Water Use for Large Agricultural Areas Case Study for KSA

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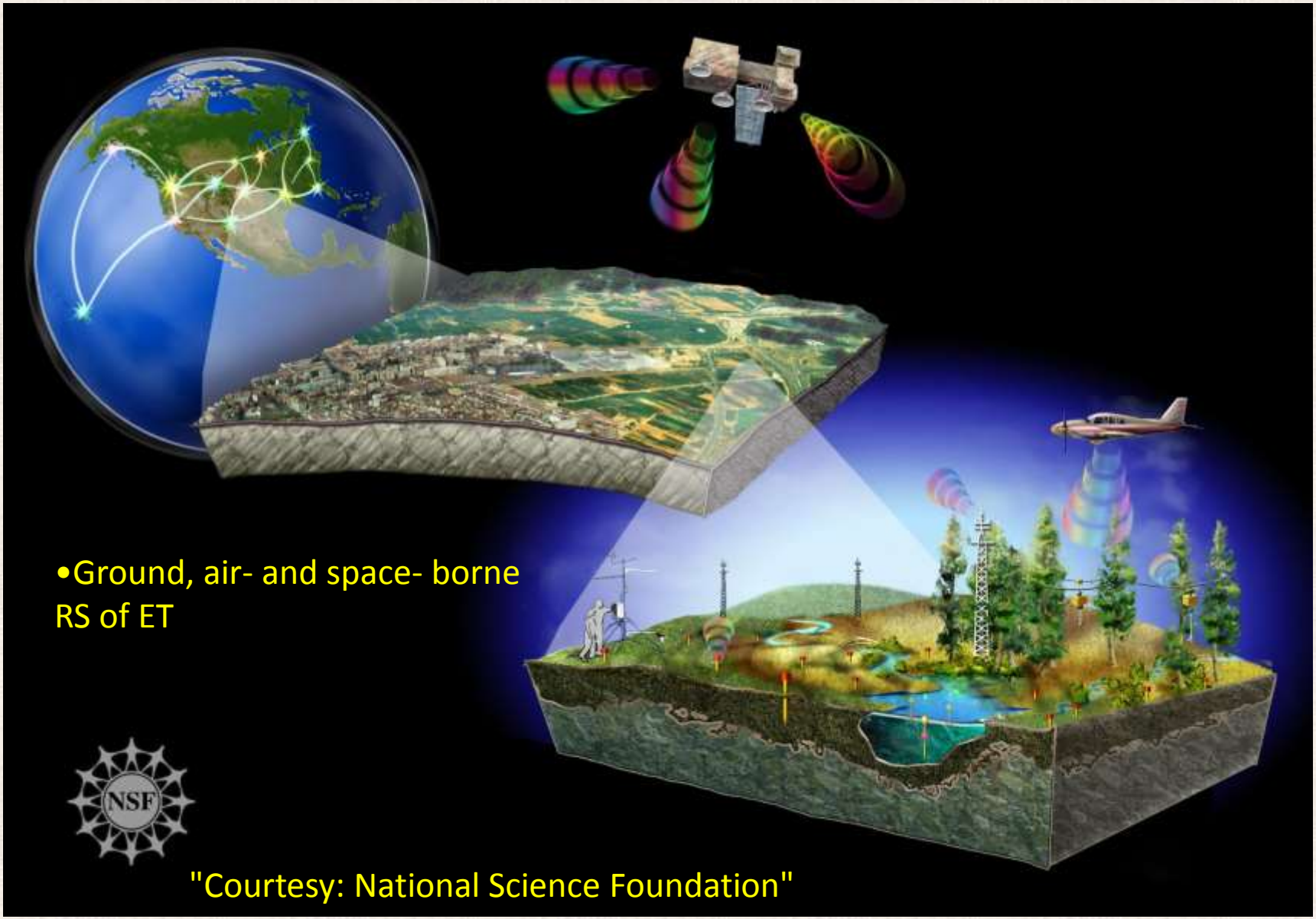
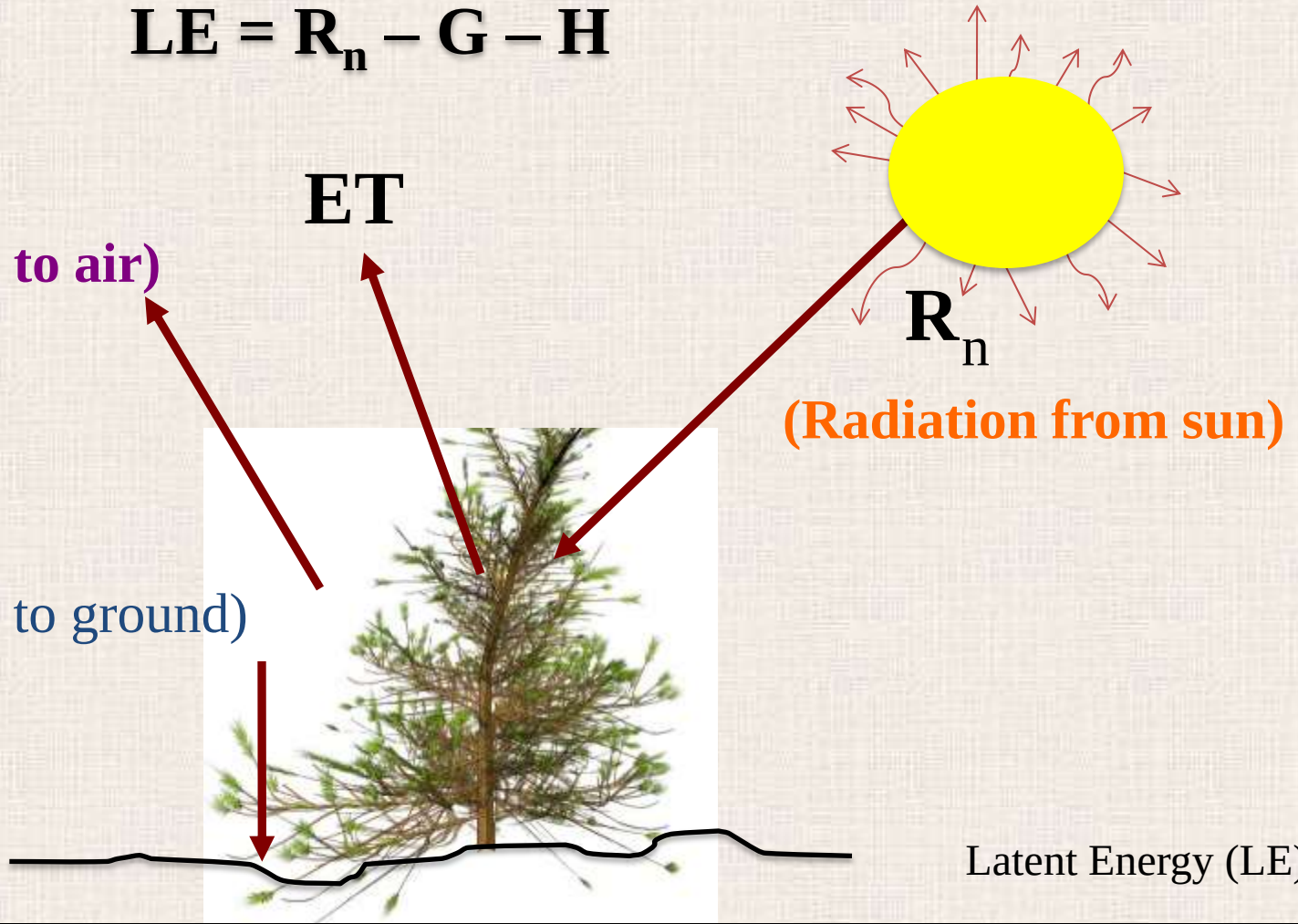
Crop Water Use (ET) Monitoring System



Remote Sensing of Evapotranspiration

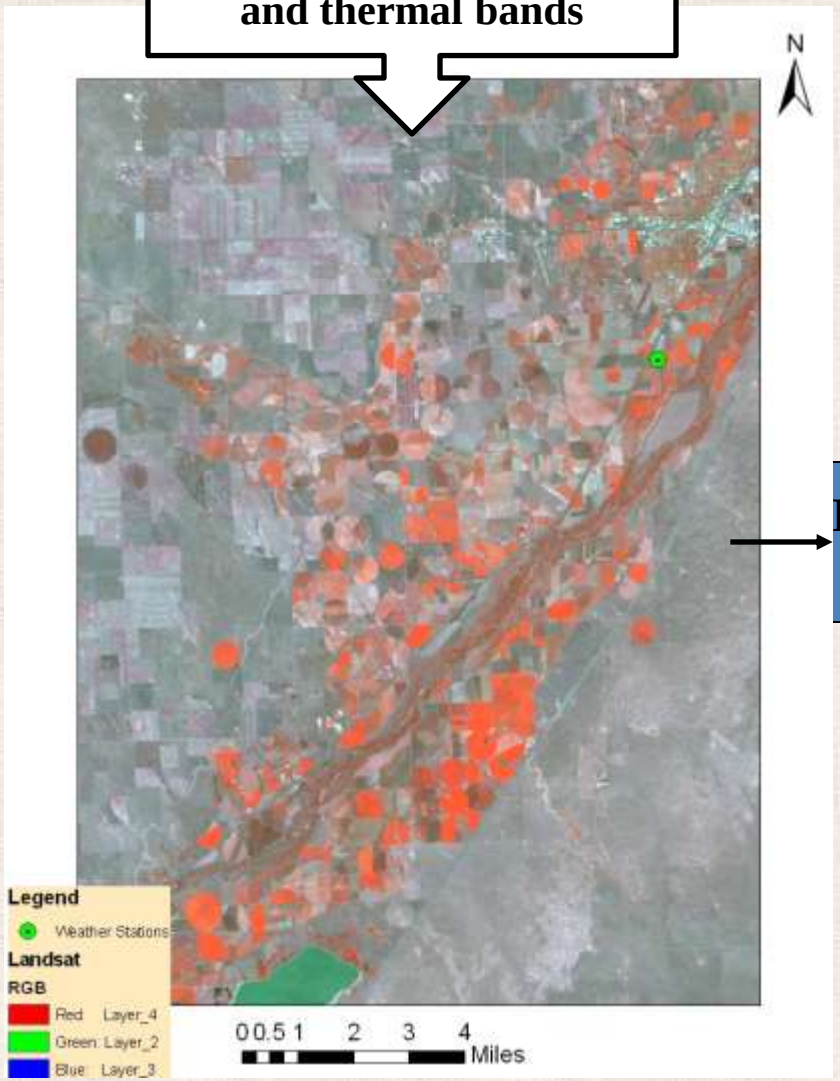
Using Surface Energy Balance ET is calculated as a "residual" of the energy balance

$$LE = R_n - G - H$$



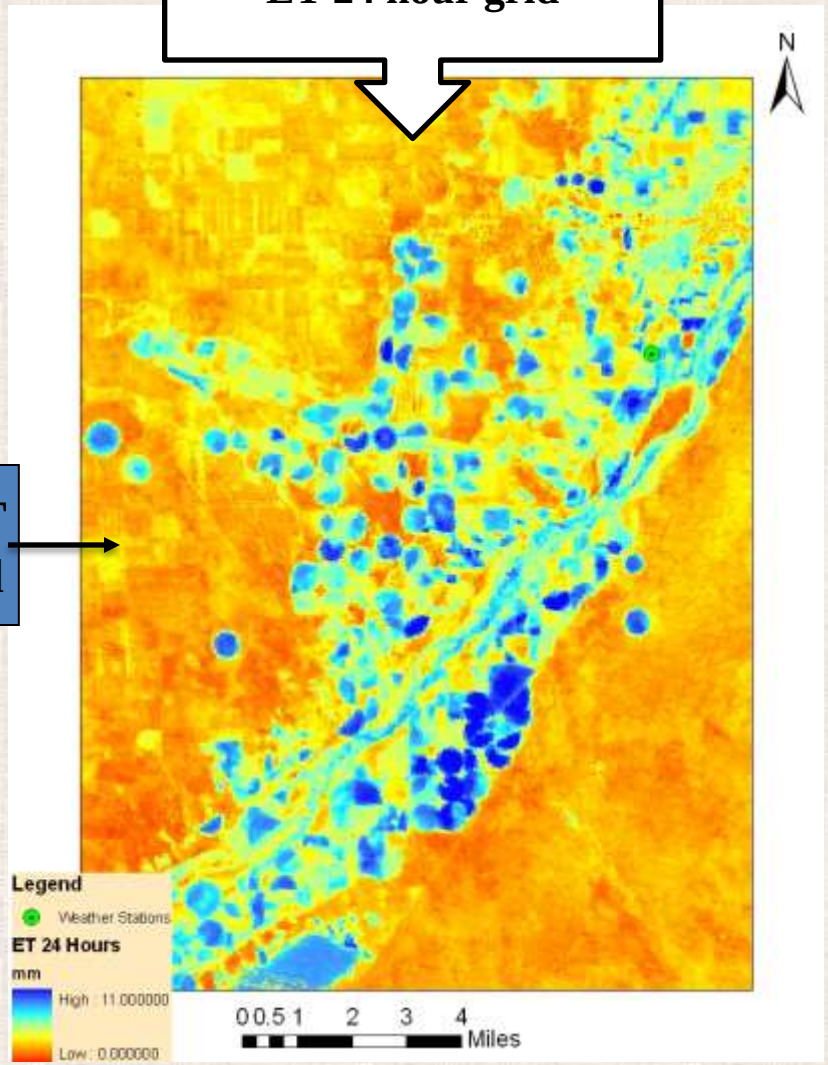
ET Modeling

Aerial images with visible and thermal bands

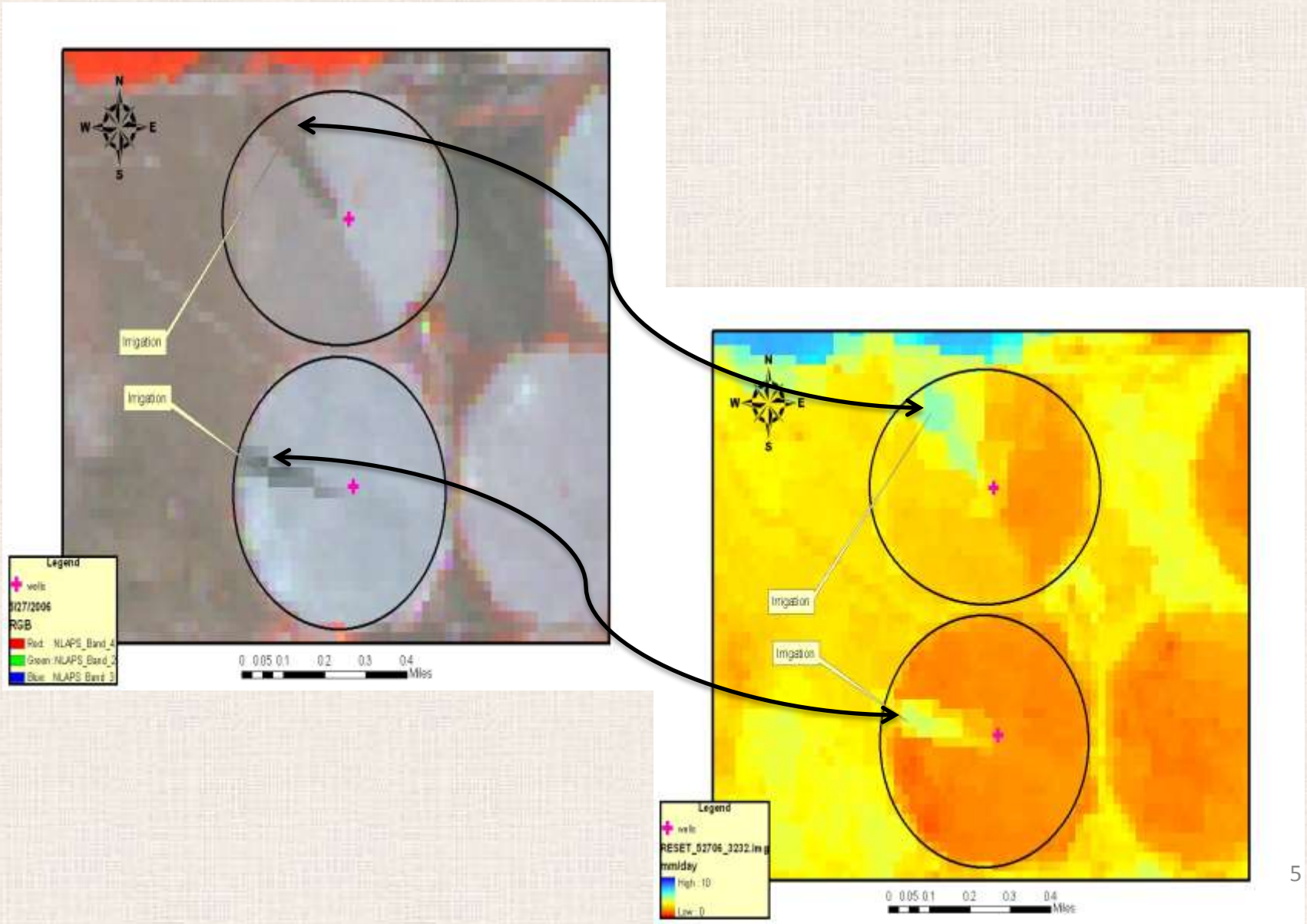


ReSET Model

ET 24 hour grid



Irrigation event detected by the ReSET model on 5/27/2006 using Landsat 5 imagery



Surface Energy Balance Modeling Using a Raster Concept (ReSET-Raster)

Surface Energy Balance Model (ReSET-Raster)

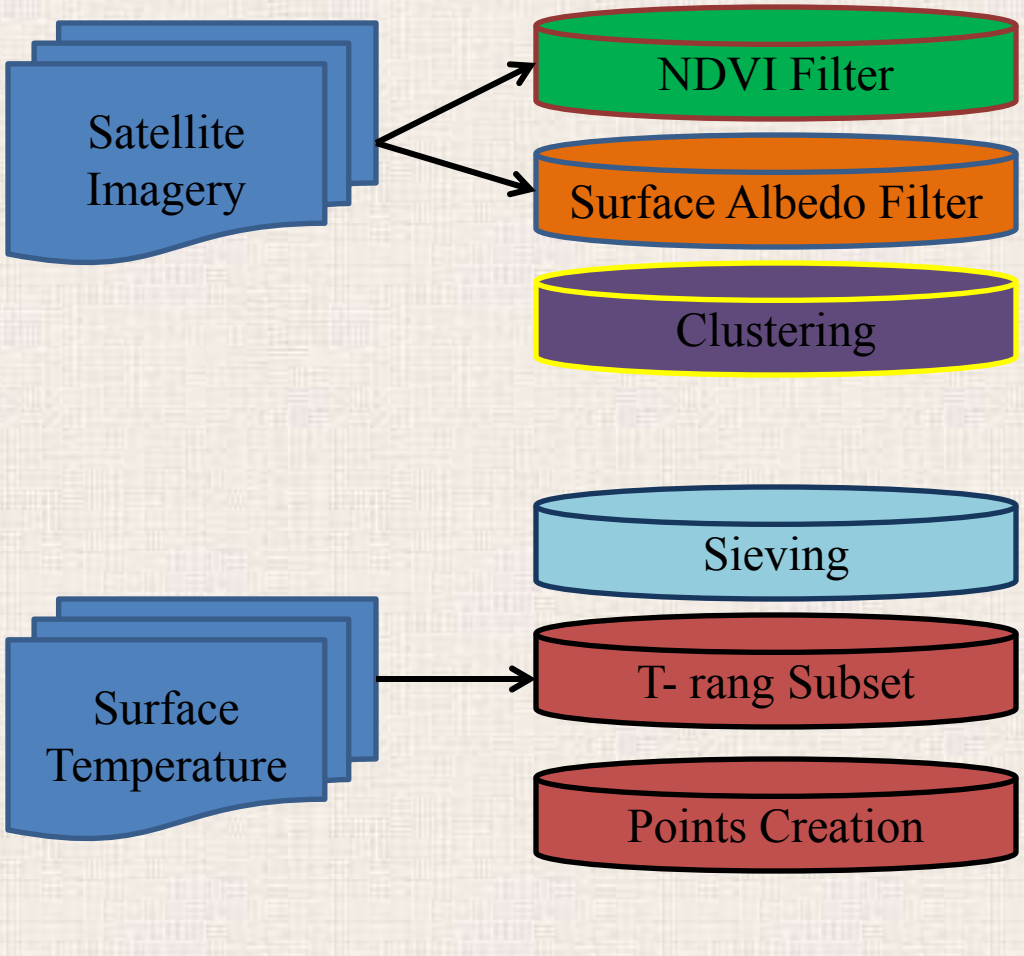
- The ReSET-Raster model uses Surface Energy Balance to estimate the actual ET for every pixel.
- ReSET uses a full raster approach so, a unique spatially based calibration is applied to each cell grid cell.
- The model is fully automated with a smart anchor point selection technique that reduces the need for manual interactions for cloud free images.

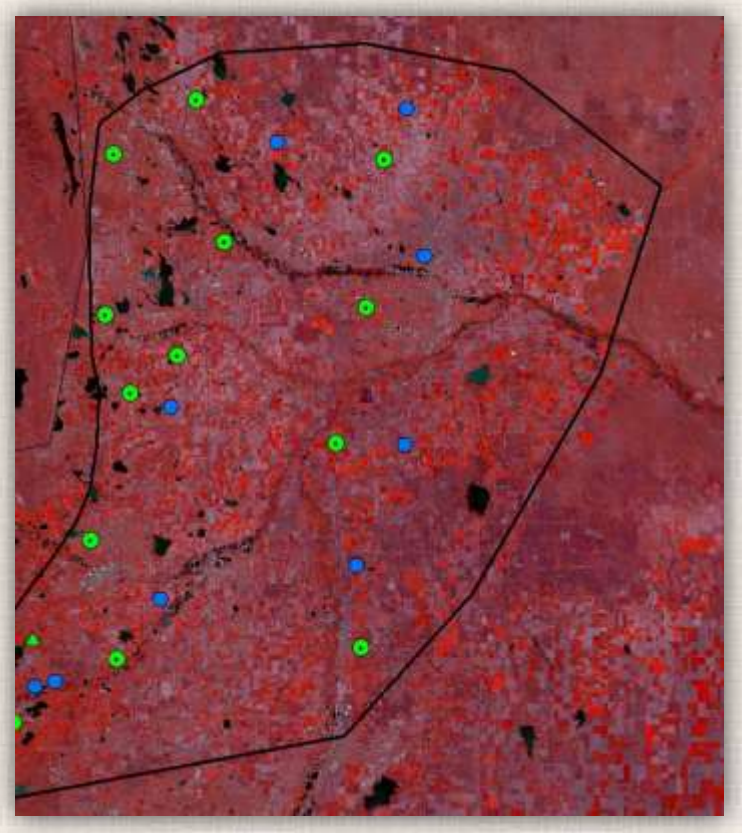
ReSET Model Applications

The ReSET model was applied in:

- Colorado.
- California.
- Spain.
- Egypt.
- Saudi Arabia.

Selection of Hot and Cold Anchor Points

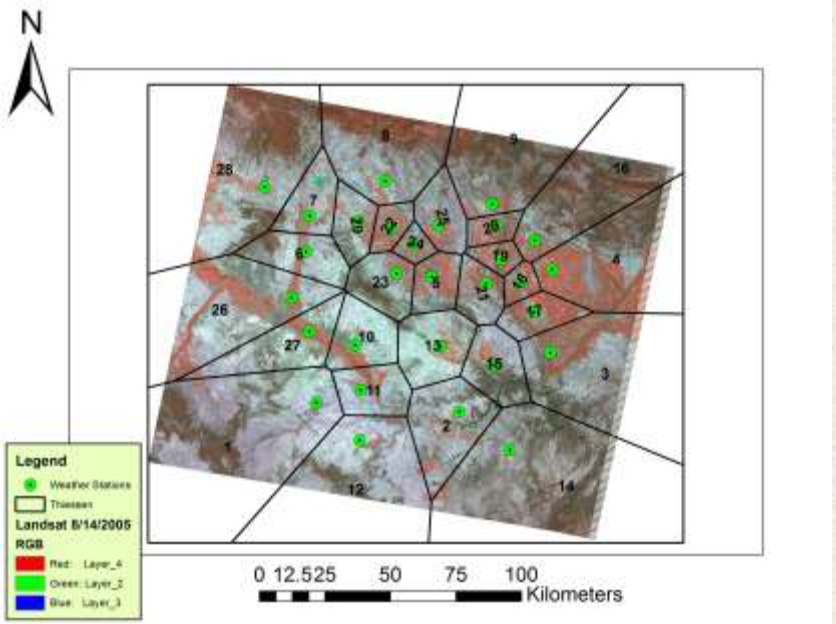




Advantages of ReSET Raster over similar SEB models.

ReSET is developed on the same theoretical basis of several other SEB models except that its native environment is raster which makes it stand out compared to similar models.

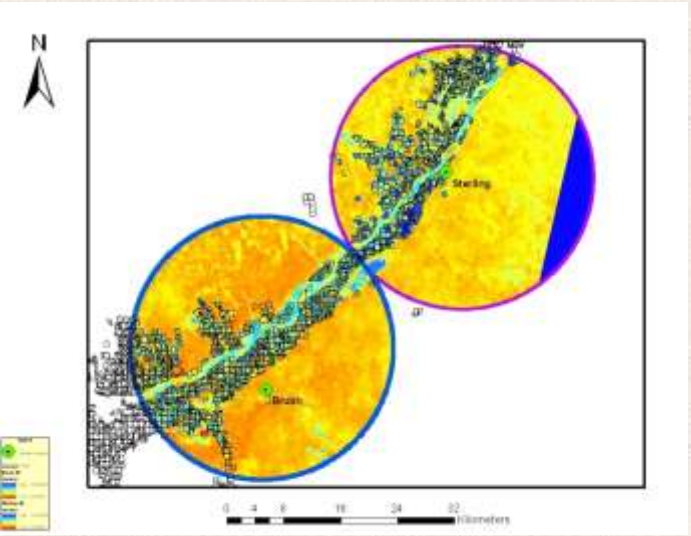
One of the main advantages of the SEB models is estimating ET for large areas that will usually contain several weather stations that should be used to accurately calibrate the model.

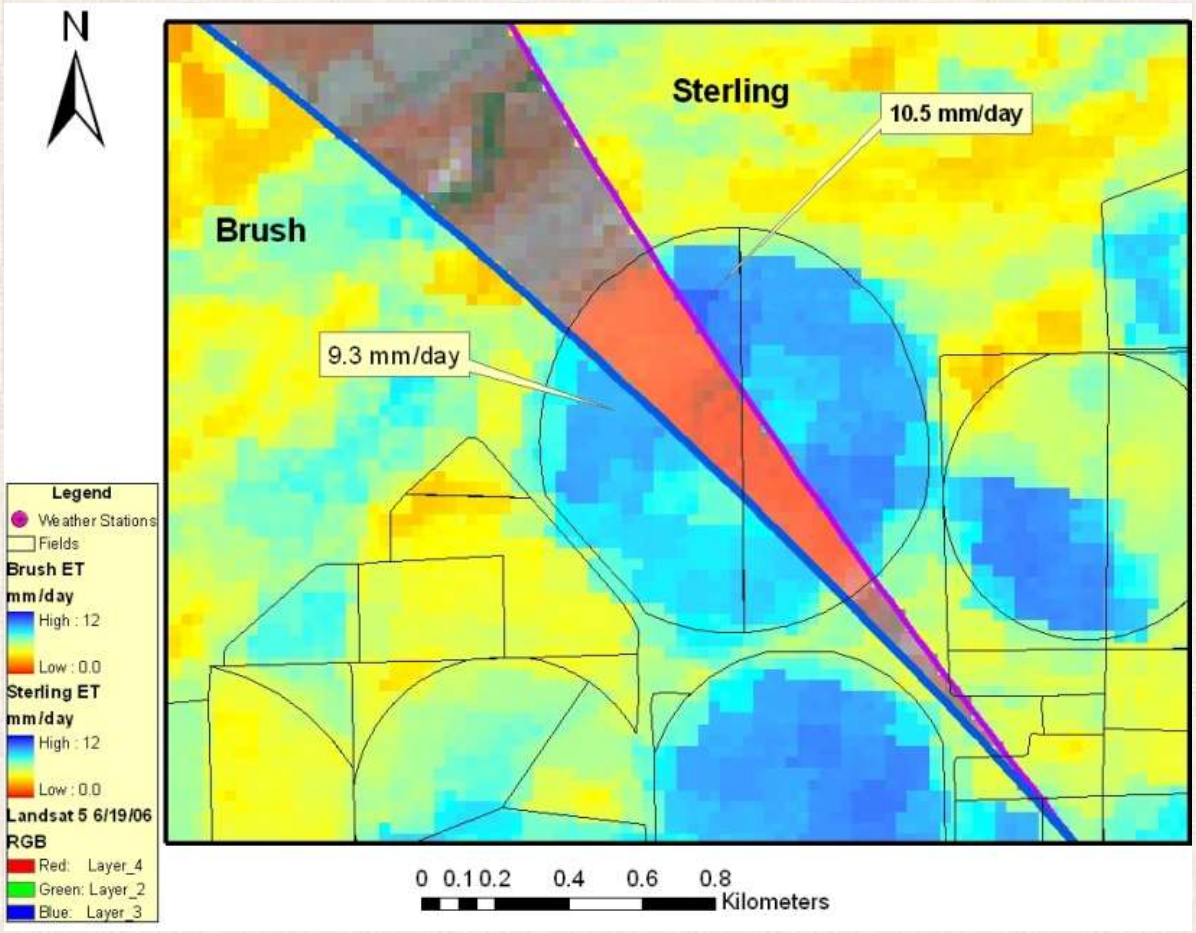


Point based (non raster) SEB models will use either one weather station or an average point value from several weather stations for calibration. The second option for point based models is dividing the area to several sub areas (thiessen polygons) and assign each area to a close by weather station then run the model for each area independently. Even with thiessen polygon solution there will be an abnormal discontinuity in the developed ET grid at the borders of the polygons due to the change of the reference points.

ET Calculation When Using Point Approach

The Sterling referenced part of the center pivot field had a daily ET value of 10.5 mm/day, while the Brush part of the field had a daily ET value of 9.24 mm/day, a gap of 1.2 mm/day (13%).

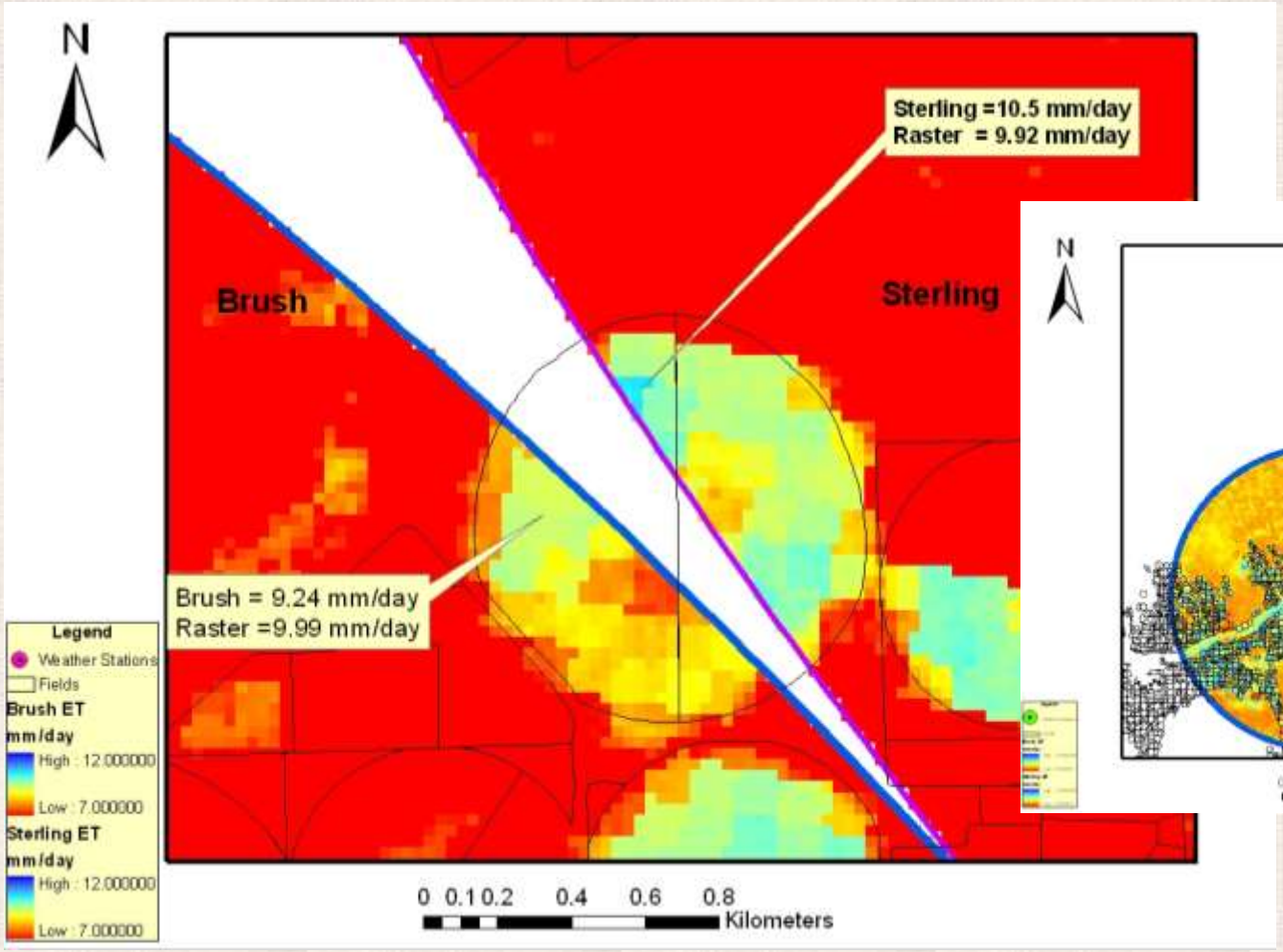


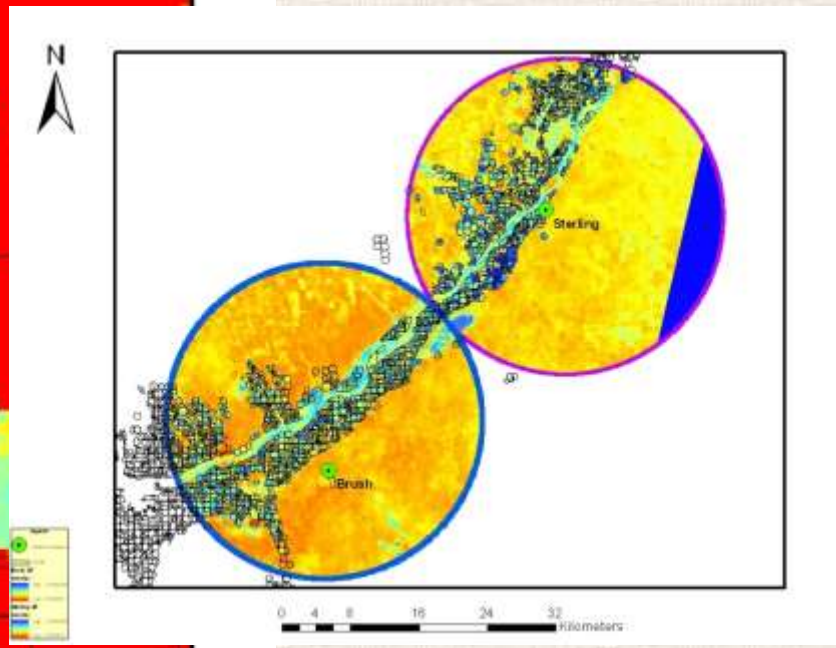


Source : Elhaddad, A., and Garcia, L.A. (2011), "ReSET-Raster a surface energy balance model for calculating evapotranspiration using a raster approach". ASCE Journal of Irrigation and Drainage – 137(4) 203-210.

Point vs. Raster

Using the raster approach, the Sterling part of the field had an ET of 9.92 mm/day and the part towards Brush had an ET of 9.99 mm/day, a - 0.7% difference.





ReSET Model Validation

Comparison with :

1-Arkansas Lysimeter, Rocky Ford, CO.

2-USDA-ARS Lysimeters in Bushland, Texas .

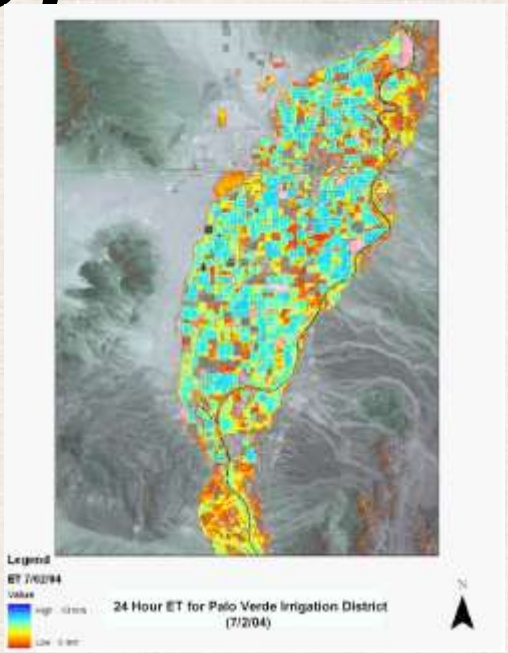
3-ARS-Bushland weather station reference ET.

ReSET (un-calibrated) Validation with the ArkBasin Lysimeter on 2008

Hourly ET

Date	ReSET mm/h	Lysimeter mm/h	ReSET vs. Lysimeter
4/30/2008	0.87	0.82	6.10%
7/3/2008	0.87	0.8	8.75%
7/19/2008	0.89	0.88	1.14%
8/4/2008	0.866	0.8	8.25%

Estimating Annual Crops ET for Palo Verde Irrigation District (PVID)



Elhaddad, A. and Garcia, L.A. (2014) "Using surface energy balance model (ReSET)for estimating seasonal Crop water use for canal service area A Case study for the PVID (Palo Verde Irrigation District" .**2016 Best Paper Award for the Journal of Irrigation and Drainage, ASCE**.

Results

- The alfalfa fields in the area had a maximum **ET_a value of 1,748 mm/yr**.
- The alfalfa ET for the Blythe weather station from the California Irrigation Management Information System (CIMIS) is **1,774 mm/yr** which is only **1.5%** more than the annual ET estimated by the calibrated ReSET model.

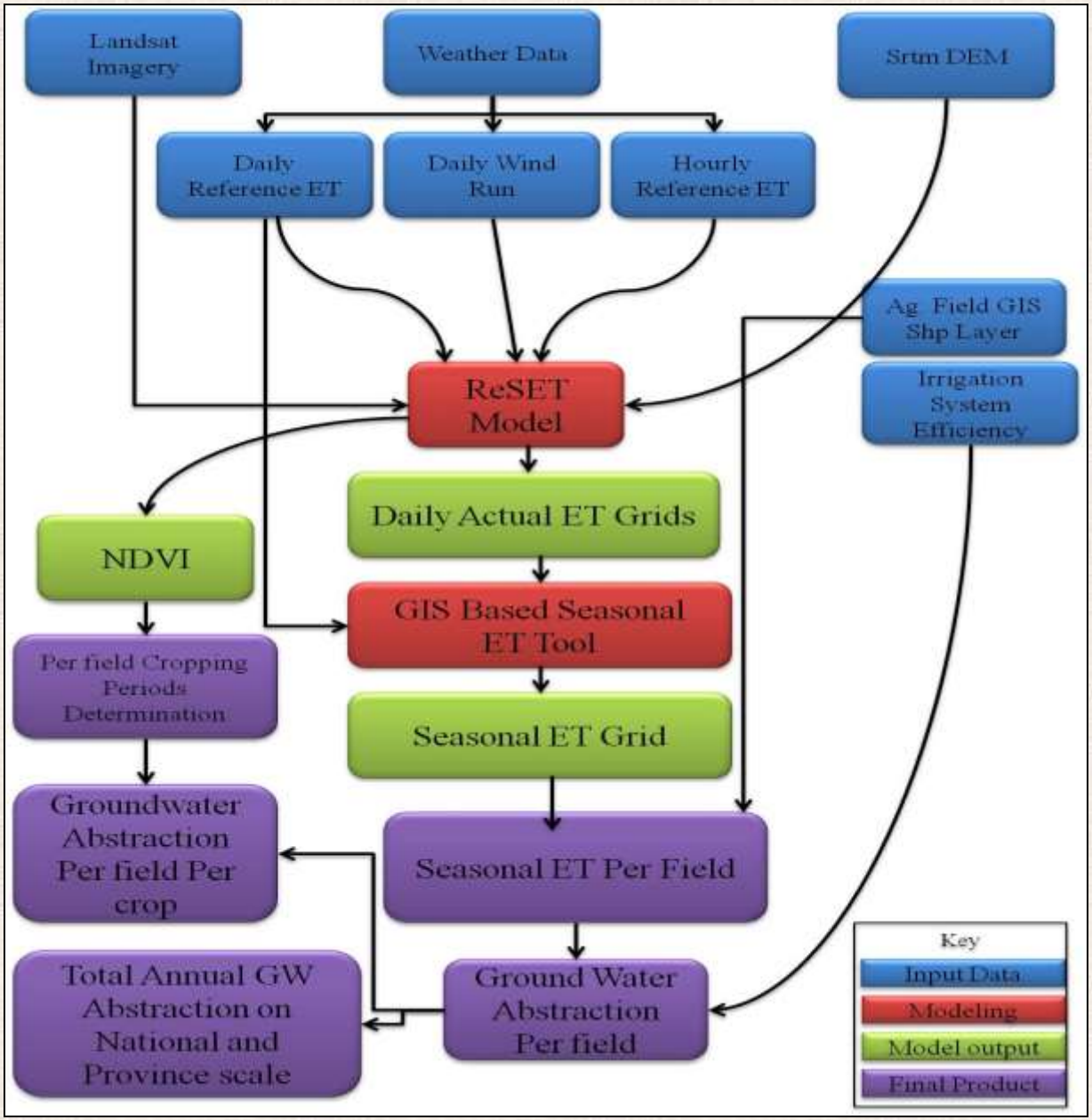
Table 1. Comparison between the maximum annual alfalfa ET estimated by ReSET and the LCRAS Report

Run Type	Annual ET from ReSET Model (mm/yr)	Annual ET from LCRAS Report in (mm/yr)	Difference (%)
Un-calibrated	1,612	1,774	-9.1%
Calibrated	1,748	1,774	-1.5%

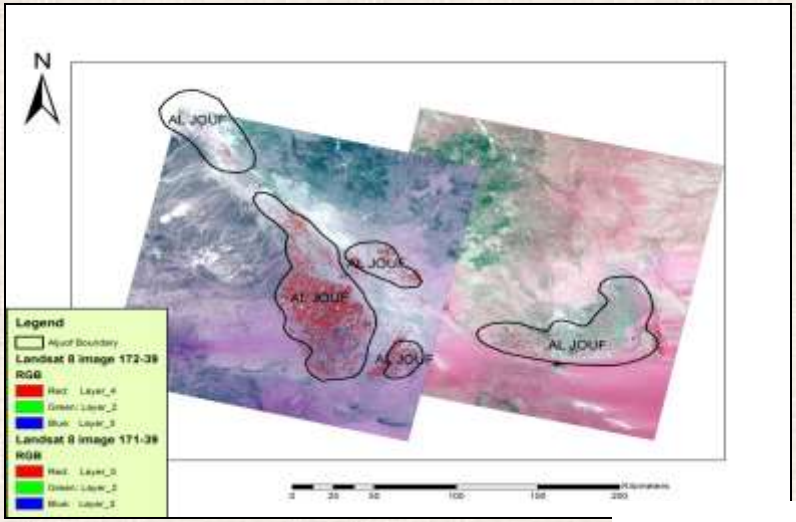
- For all crops in the study area (92,492 acres) the currently used approach overestimated the annual crop water use by **16%** (70,925,206 m3 or **57,500** acre-feet) compared to the ReSET-Raster estimates.

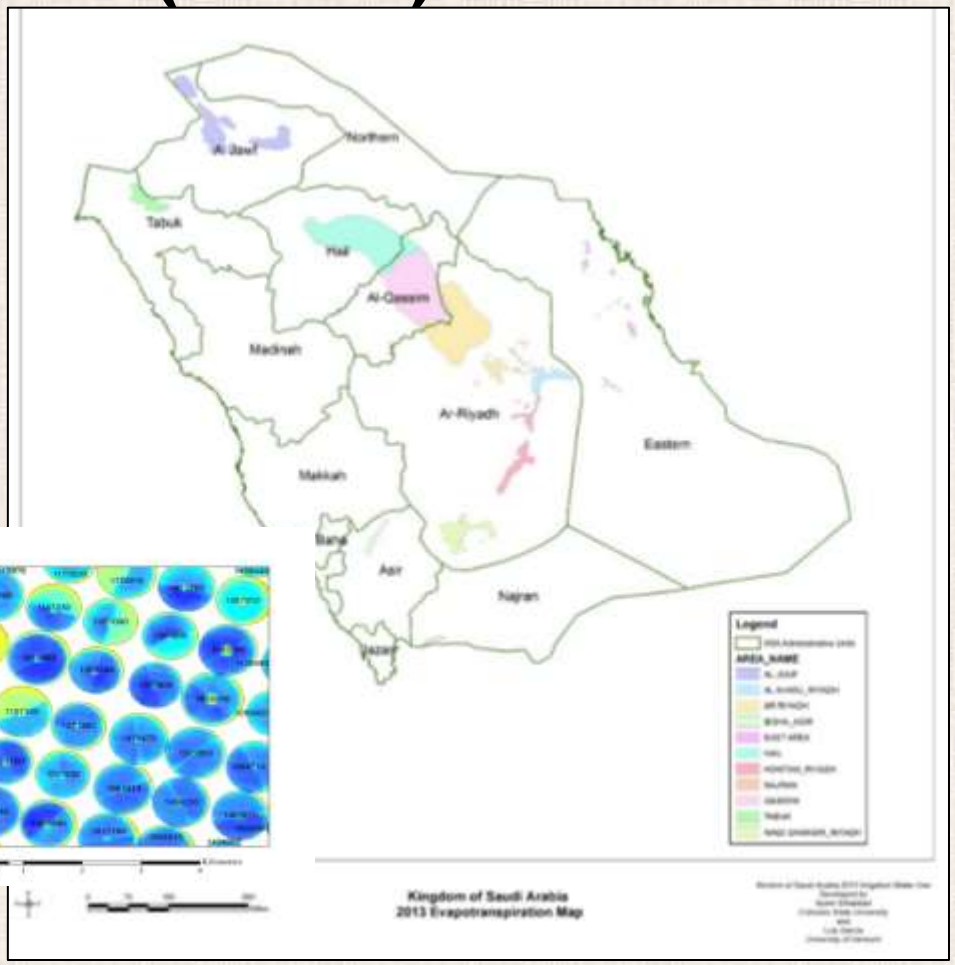
Saudi Arabia

ReSET Model


Landsat Imagery
Weather Data
Srtm DEM
Daily Reference ET
Daily Wind Run
Hourly Reference ET
Ag Field GIS Shp Layer
ReSET Model
Irrigation System Efficiency
Daily Actual ET Grids
NDVI
GIS Based Seasonal ET Tool
Per field Cropping Periods Determination
Seasonal ET Grid
Groundwater Abstraction Per field Per crop
Seasonal ET Per Field
Total Annual GW Abstraction on National and Province scale
Ground Water Abstraction Per field
Key
Input Data
Modeling
Model output
Final Product

Estimating Annual Actual Agriculture ET for SA (2013)





FID_	COUNT	AREA_1	MIN	MAX	RANGE	MEAN	STD	SUM	ET_vol_m3
0	518	466200	824.382	2110.93	1186.55	1640.38	238.964	849718	764744
1	675	607500	913.086	2843.18	1131.17	1714.9	212.954	1157550	1041800
2	530	477000	972.282	2134.09	1161.8	1790.52	258.417	948974	854077
3	896	806400	659.348	2164.46	1514.11	1786.89	332.535	1600705	1440950
4	560	522000	822.068	2196.5	1374.41	1776.01	263.664	1033008	929672
5	756	682200	765.563	2059.01	1293.43	1429.02	361.443	1085328	974880
6	754	678600	1158.21	3254.26	1996.05	1930.22	201.982	1455638	1309840
7	838	754200	485.3	1175.15	789.846	846.042	126.163	708983	638885
8	755	679500	1067.87	2169.74	1102.67	1810.64	222.333	1367031	1230330

Case Study Overview

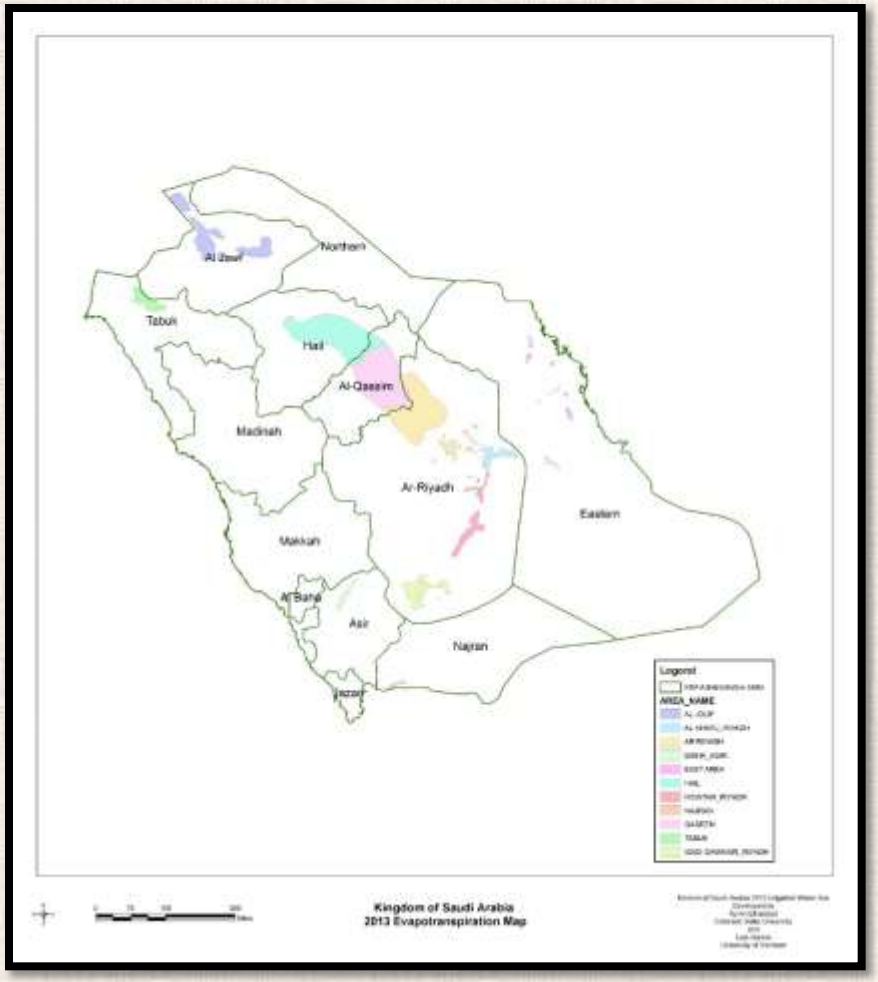
- The main goal of this study is to develop annual ET maps for 11 agriculture areas in Saudi Arabia (SA) for the calendar year 2013 using a remote sensing based model (Remote Sensing of ET ReSET).
- Landsat 7 and 8 imagery and ground metrological data were processed using the ReSET model to produce daily evapotranspiration maps with a resolution of 30 meters.

Case Study Overview

- A seasonal tool that uses a liner interpolation technique was used to estimate annual evapotranspiration on a farm level over the kingdom using actual daily evapotranspiration developed using the ReSET model.
- The case study final product was the amount of water consumed by agriculture crops. The ReSET model estimated **10.88 km^3** of water used by **1,246** thousand hectares of irrigated land in the **year 2013**.

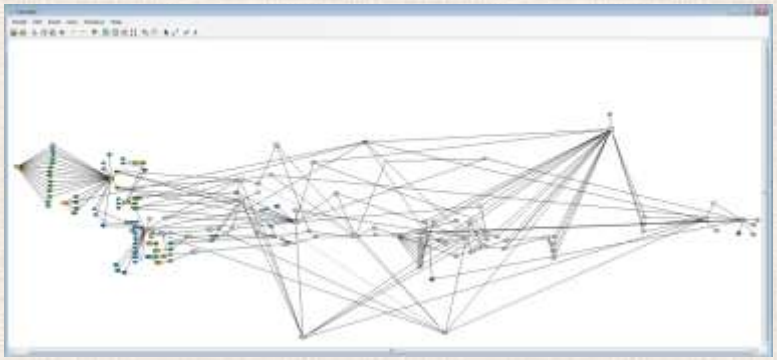
Irrigated Regions

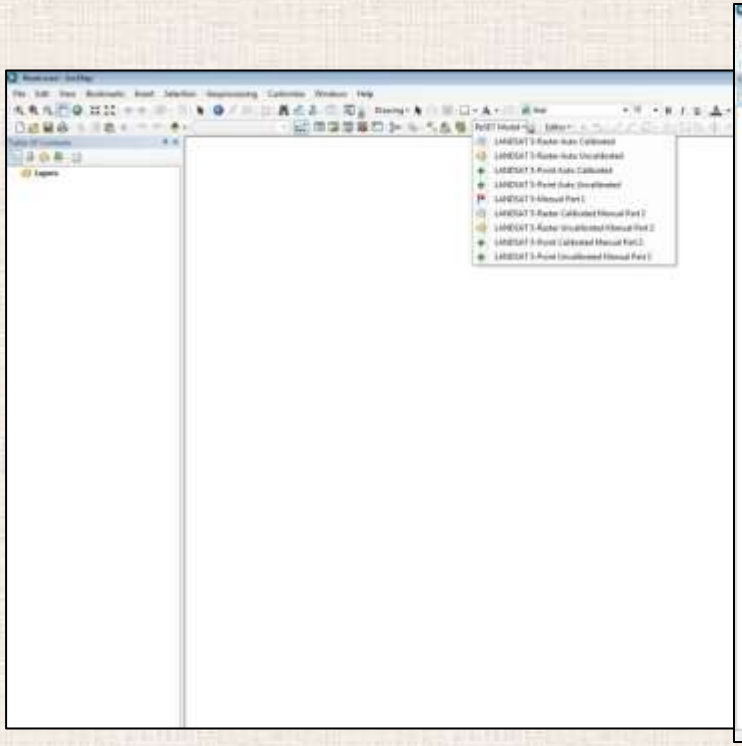
The 11 regions that cover the majority of the irrigated agricultural areas in SA consists of multiple Landsat scenes (around 30). All available imagery were checked and 374 images were selected to provide the best temporal coverage.

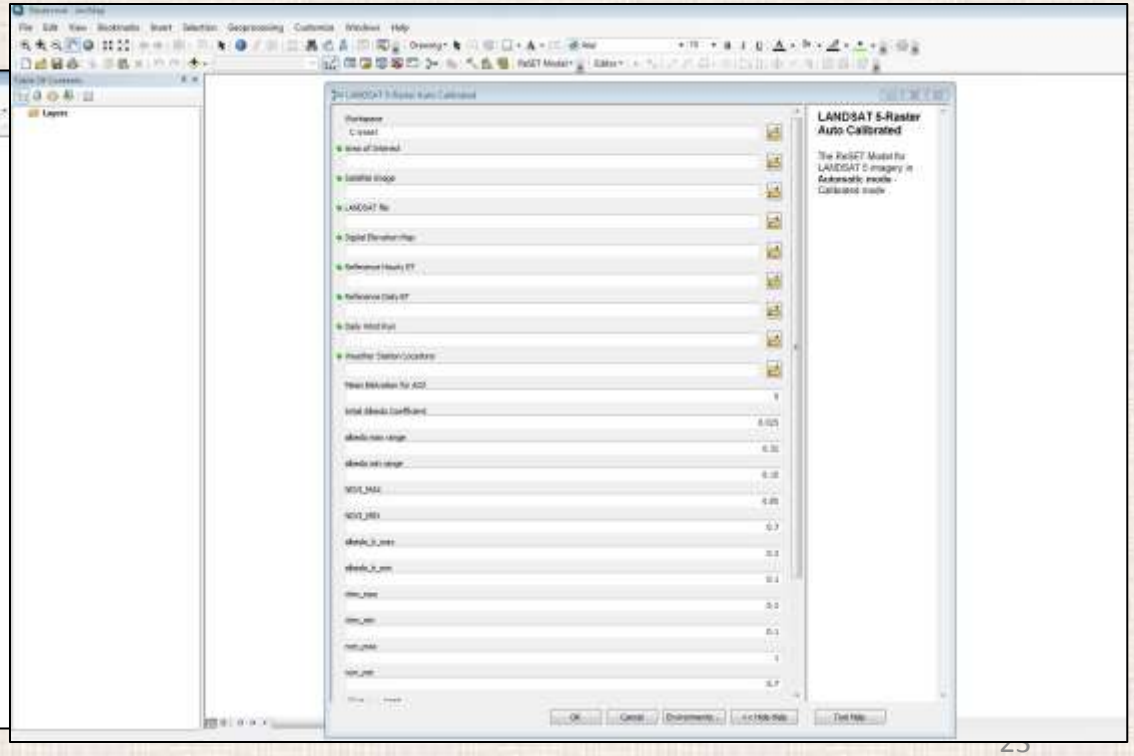


Automated ReSET Model Under ArcGIS 10.1 Model Builder

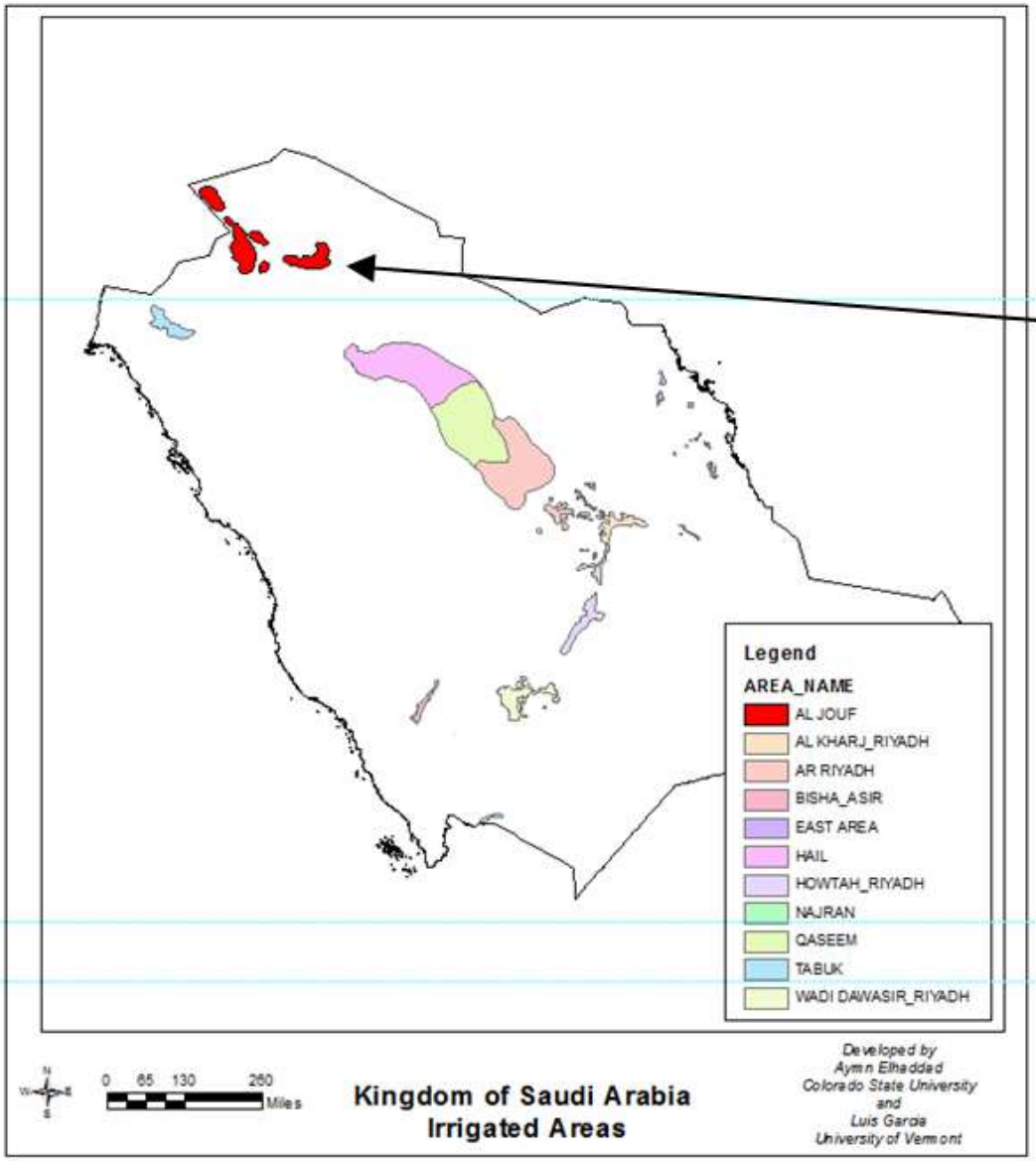
We were able to process 374 Landsat images by using an automated version of the ReSET Raster model.

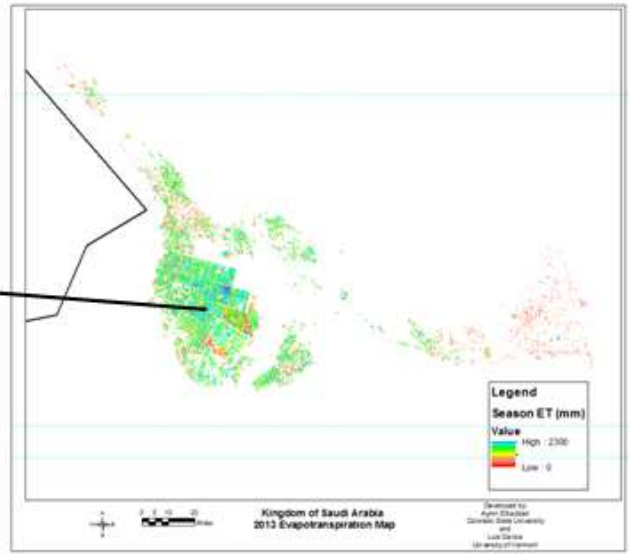


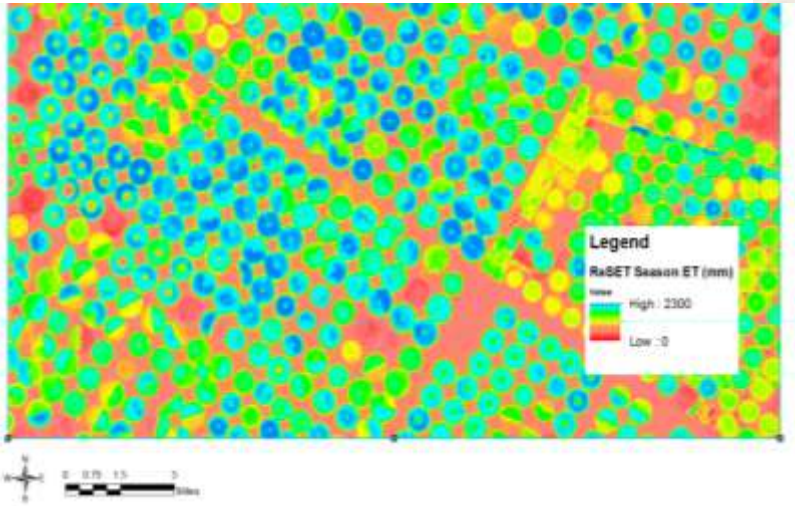




The Al Jouf Areas Shown in Red







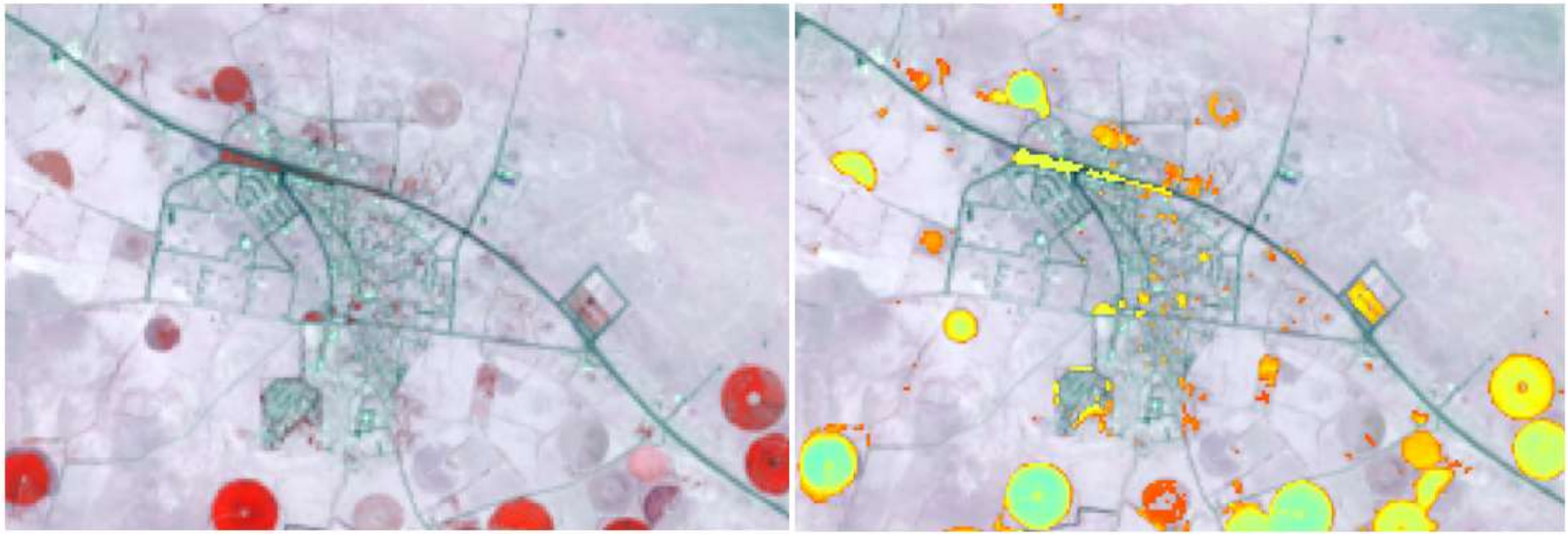
Using NDVI Sum Approach to Detect Irrigated Lands for Annual ET Estimation

- An NDVI threshold approach were used to determine the irrigated lands .
- The sum of the NDVI images varied from zero to 8 non dimensional units; the minimum NDVI threshold for irrigated areas was set at 1.5. All pixels (30m by 30m) that had an annual NDVI value of 1.5 or more was considered to be irrigated land.

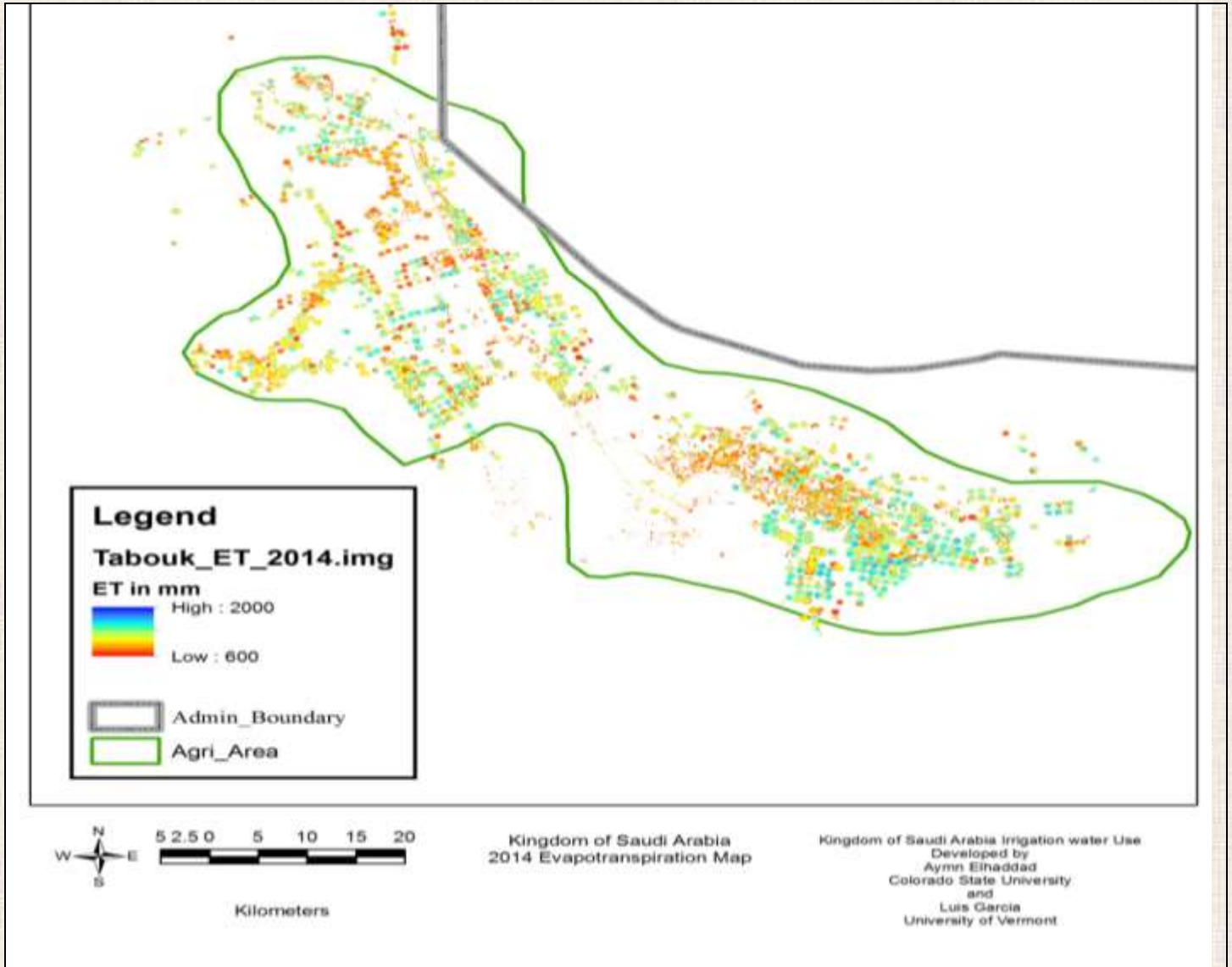
Using NDVI Sum Approach to Detect Irrigated Lands for Annual ET Estimation

- The NDVI based method for identifying irrigated areas was manually verified and proved to be more accurate and efficient than manually digitize polygons of irrigated area since irrigated fields boundaries changes every year and even during the same year.

The figure below shows an example of the areas included with the Landsat false color on the left and an ET grid overlaying the same image on the right.



A Zoomed In Map of the 2013 Annual ET Estimate for the Tabouk Area



Crop Season Based Classification

- In order to determine the period that the crop was grown we needed to conduct an analysis.
- Based on the crop calendar from FAO. 2012. AQUASTAT. http://www.fao.org/nr/aquastat the irrigated area were separated into five categories.

Crop Season Based Classification

- Winter crop areas (January to June).
- Summer crop areas (July to November).
- Areas cultivated with full year crop.
- Area cultivated with two crops that are grown for the full year.
- Mixed areas that did not qualified to be in any of the above classes.

Crop Temporal Classification

- The approach used for determining the crop temporal classification was based on the NDVI values and the sum of these values for different periods during the year.
- The first step was to classify the cultivated areas into two main categories for full year cultivation or partial year cultivation.
- The next step was classifying the two main categories in another four subcategories.

Crop Temporal Classification

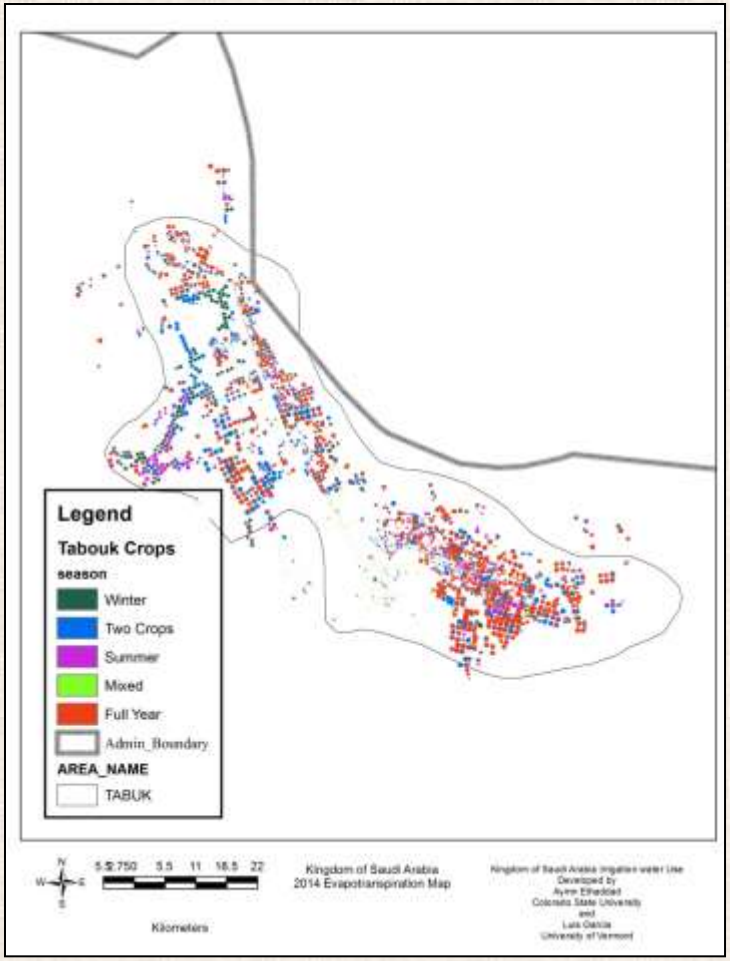
- Starting with the fields cultivated only during winter the sum of the NDVI values for the period from January to June had to exceed a threshold, the same approach was used for the summer crops but for the sum of NDVI values during the period from July to December.
- For the fields that had actively growing crops for the full year they were classified into two categories one represents full year crops and the second category represents fields that had two crops throughout the year.

Tabouk Area Temporal Classified Crops

The table below has five categories of fields and it shows the ET for each category in km^3 per year. The area for each category is also provide in hectars.

Class	Season	ET_km3	Area_Hect
1	Winter	0.0454	5633.64
2	Summer	0.0590	6666.93
3	Full Year	0.3440	27854.40
4	Two Crops	0.1760	16003.90
5	Mixed	0.0253	3288.24

Table showing Detailed ET and area for cropped fields.



Cropped Areas and Annual ReSET ET for the Study Regions

Area	Cropped Areas (1000's Hectares)	Annual ET (Km^3)
Al Jawf	279.9	2.64
Tabuk	77.94	0.769
Addawaser	186.4	1.77
Aseer	6.04	0.06
Nagran	14.8	0.15
Hail	212.0	1.9
Al-Qassim	224.0	1.78
Ar-Riyadh	168	1.24
Al Kharj Riyadh	50	0.37
Howtah Riyadh	27	0.201
Total	1246.08	10.88

SEB Models Limitations

Imagery availability

If no images are available for a region, SEB models cannot be used.

Cloud cover

SEB models are sensitive to clouds since clouds impact the thermal band.

Calibration

In the model without ground calibration, if advection occurs, it will introduce errors in the results. In the calibrated mode, high quality weather data is required.

Questions