Vegetation ET Surface Energy Balance Model {ReSET} automation

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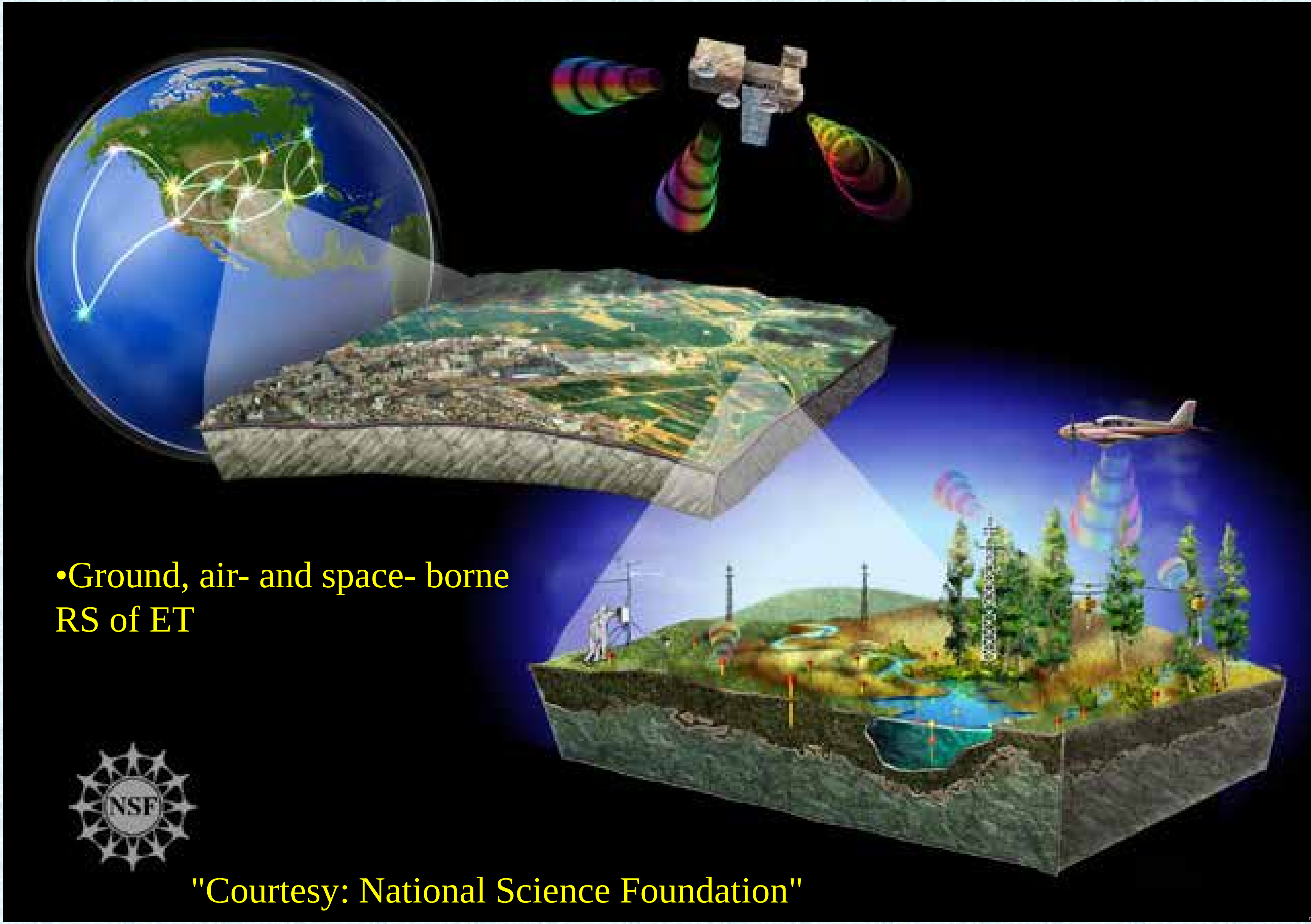
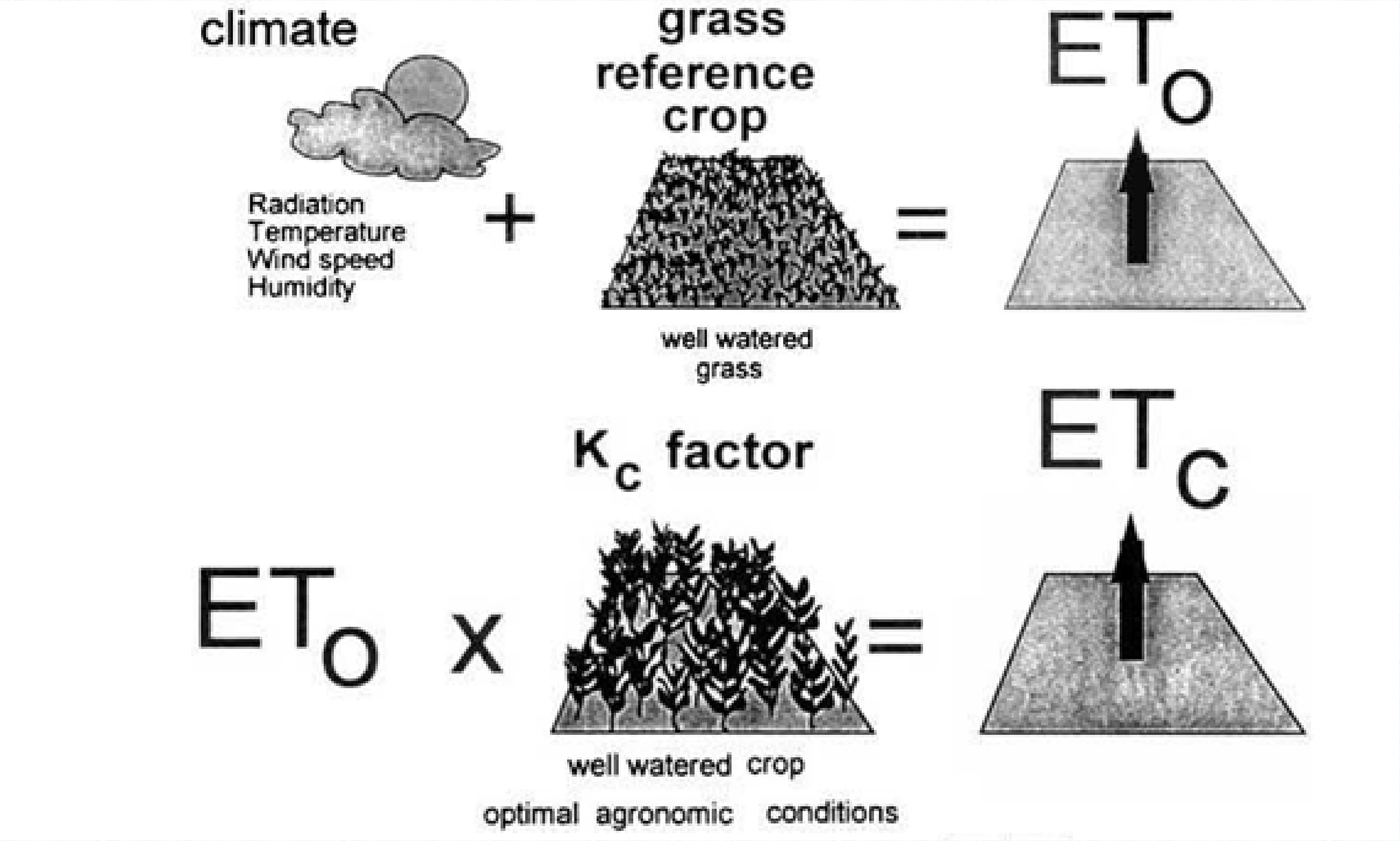
Crop Water Use (ET) Monitoring System



- Ground, air- and space- borne RS of ET

"Courtesy: National Science Foundation"

Traditional ETc Calculation



Advantages of Surface Energy Balance Models Over Other Methods

Classic calculation of crop ET relies on using reference ET and a crop coefficient. Unfortunately, this methodology does not take into account the local conductions such as:

- Water shortage
- Crop Type
- Planting dates
- Salinity

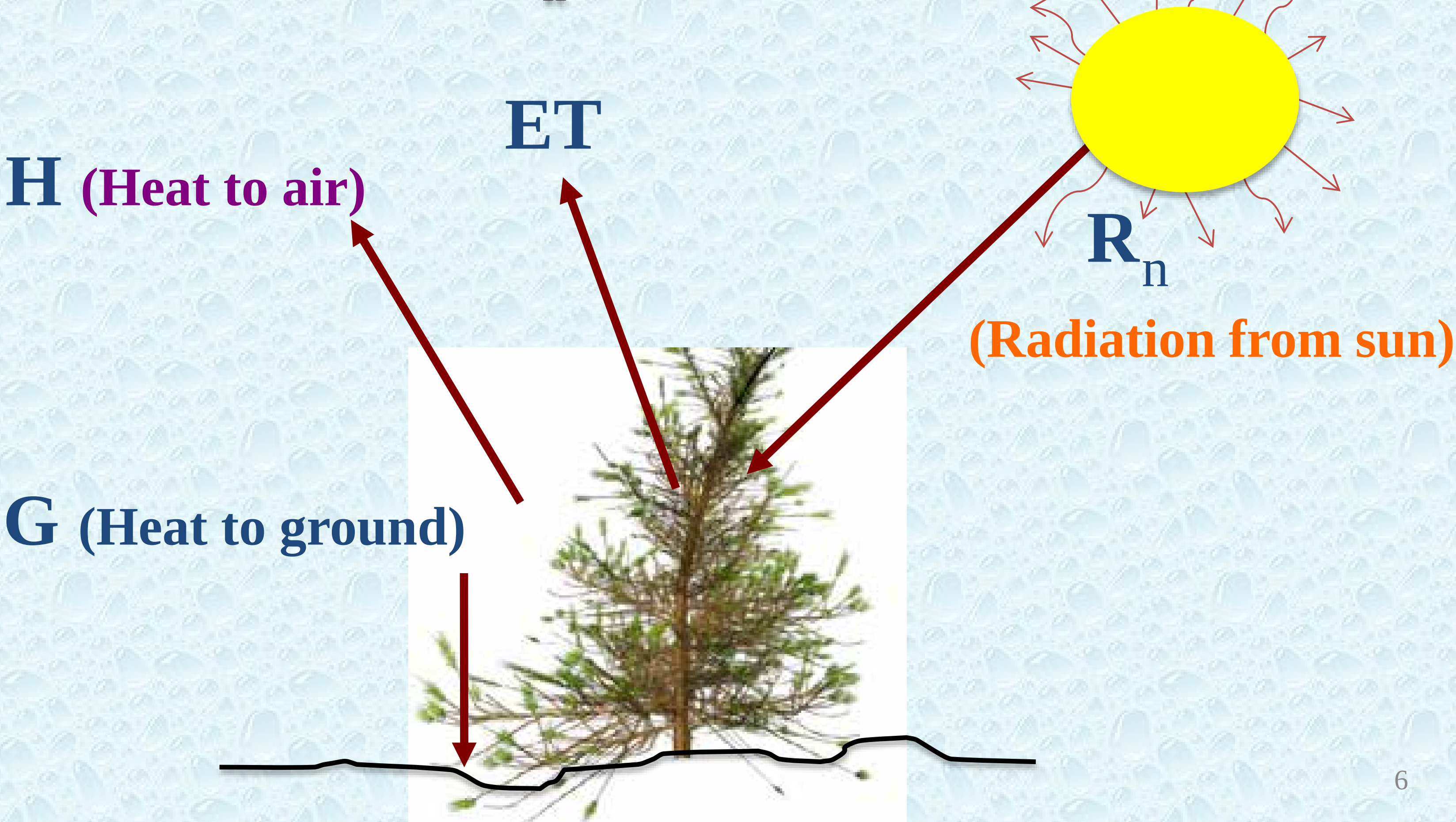
Remote Sensing of ET Models

- Most common ones use the energy balance equation.
- Have large footprint (regional coverage).
- Measure actual, not potential ET.
- Several models have been developed: SEBAL, METRIC, ReSET, SAT, ALARM, etc.

Remote Sensing of Evapotranspiration

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

$$LE = R_n - G - H$$



Description of Energy Balance Models

The use of the energy balance equation:

$$R_n = LE + G + H$$

Net Radiation (R_n), Soil Heat Flux (G), Sensible Heat Flux (H), and Latent Energy consumed by ET (LE).

Model R_n, G and H, then determining LE as a residual.

$$LE = R_n – G – H$$

SEB Models Limitations

Imagery availability

If no images are available for a region SEB models can not 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.

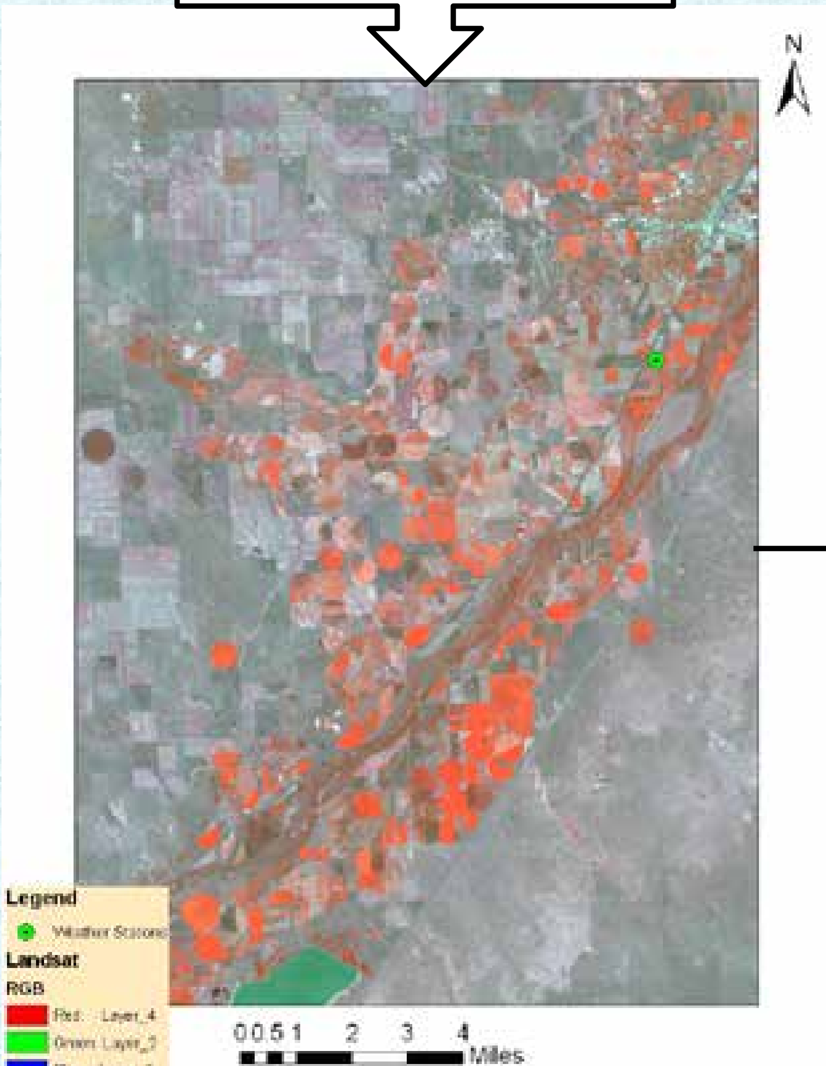
In the calibrated mode high quality weather data is required.

Surface Energy Balance Using A Raster Concept (ReSET-Raster)

- The ReSET-Raster model is a surface energy balance model that uses Surface Energy Balance to calculate actual ET for every pixel.
- Unlike METRIC or SEBAL, ReSET generates surfaces of every variable (wind, hot, cold, ET_r)
- Model main inputs
  1. Aerial imagery with visible and thermal bands.
  2. Ground weather data from available weather stations.

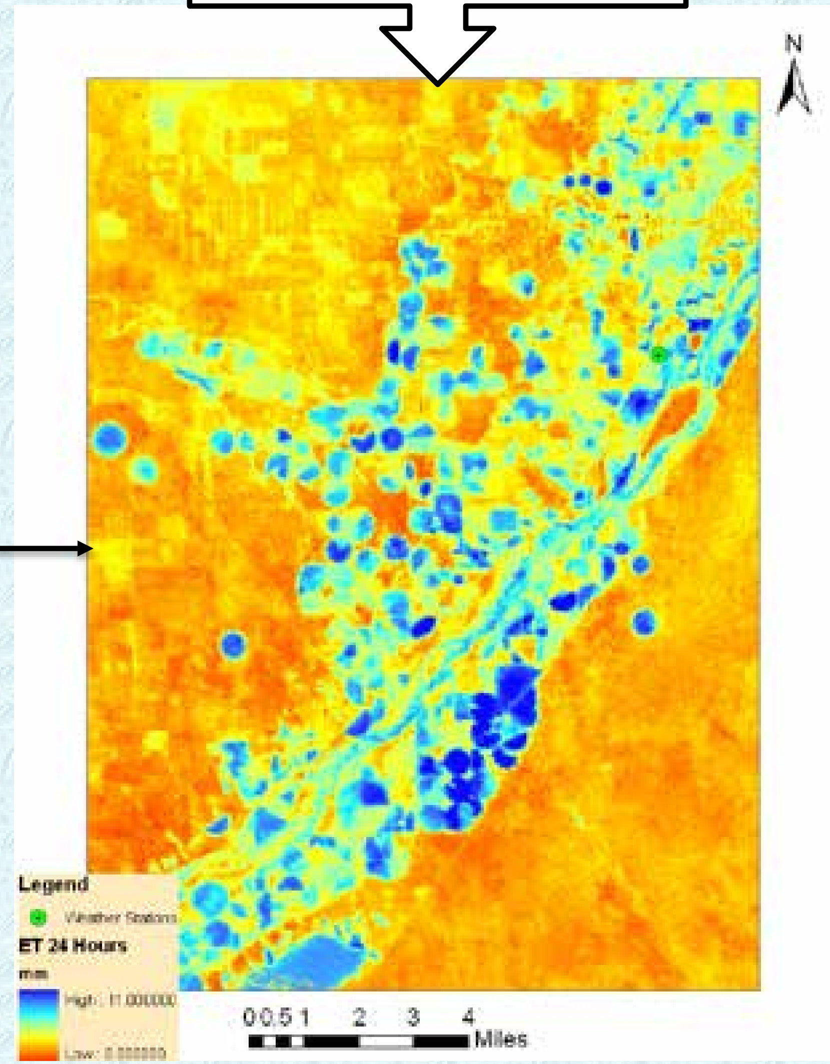
ET Modeling

Aerial images with visible and thermal bands

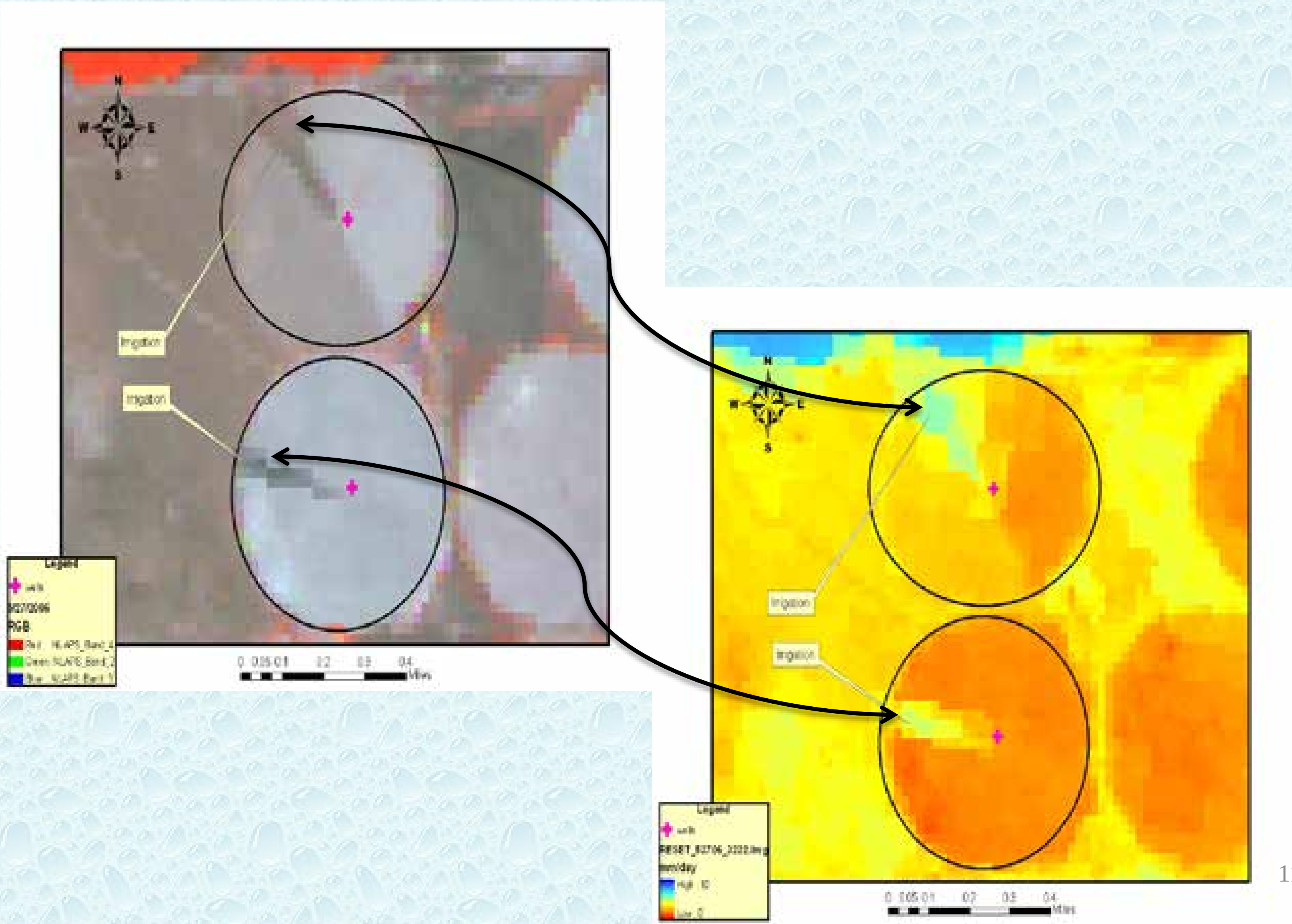


ReSET Model

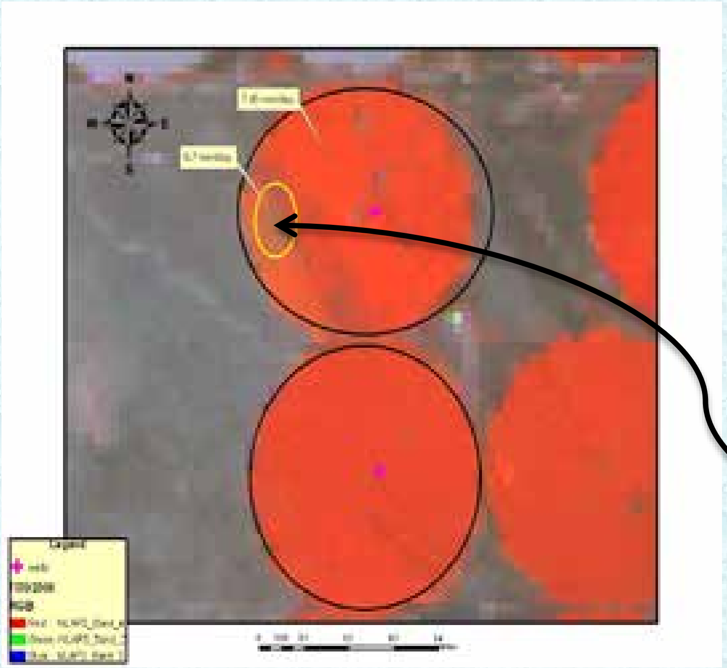
ET 24 hour grid



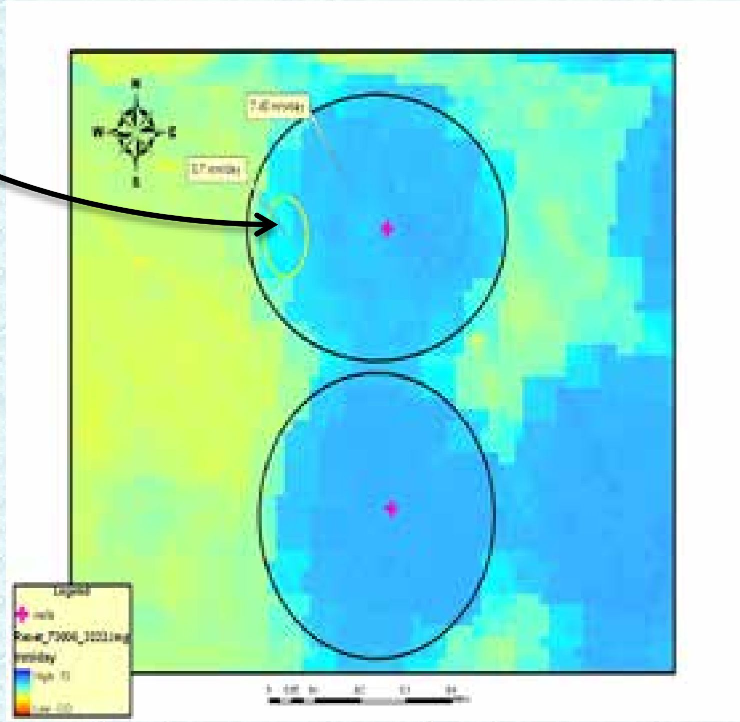
Irrigation event captured by ReSET model5/27/2006



ET variability within fields detected by ReSET model 7/30/2006



Landsat image



ReSET ET grid

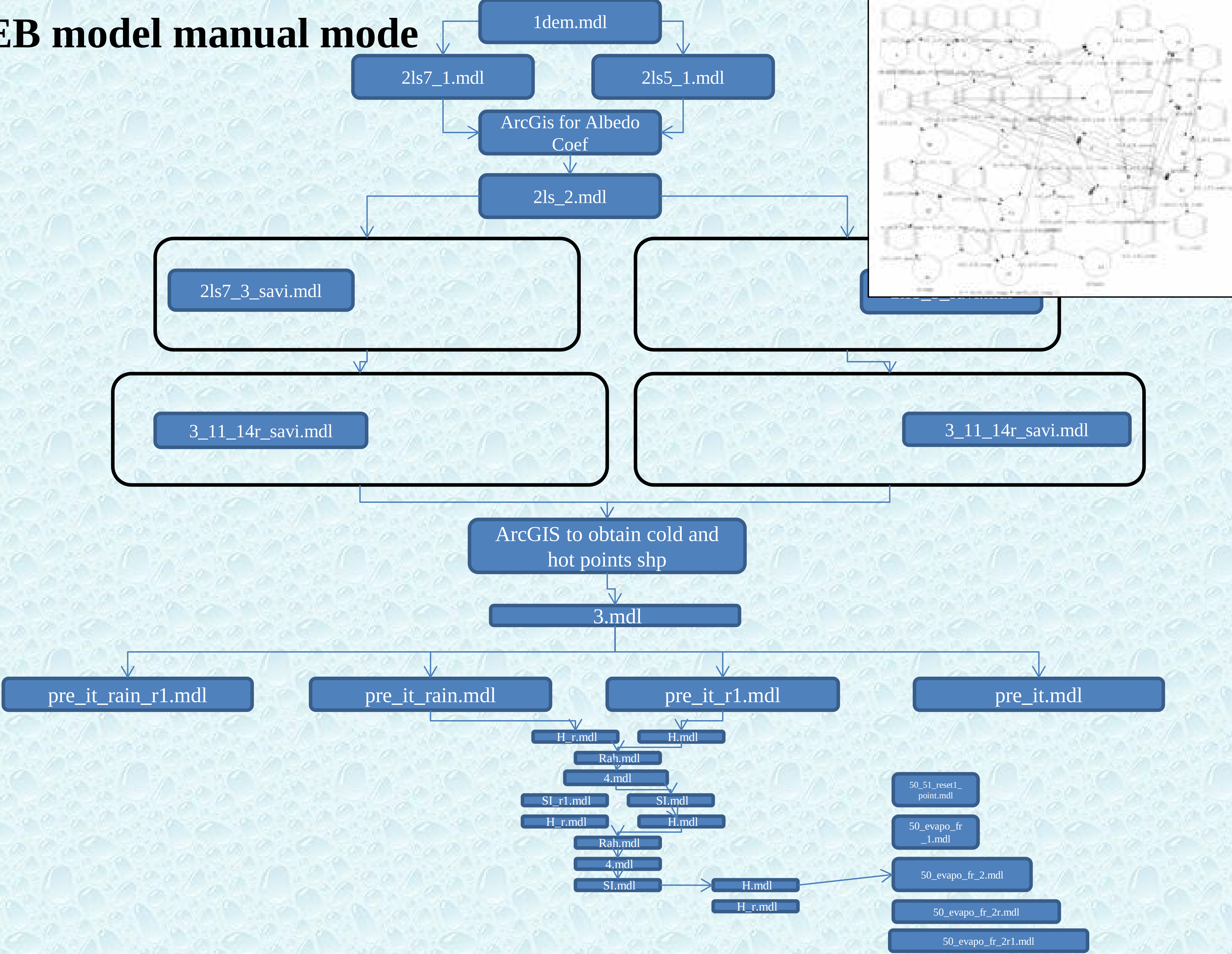
Running surface energy balance based model manually

To manually run SEB models users need to have a background in:

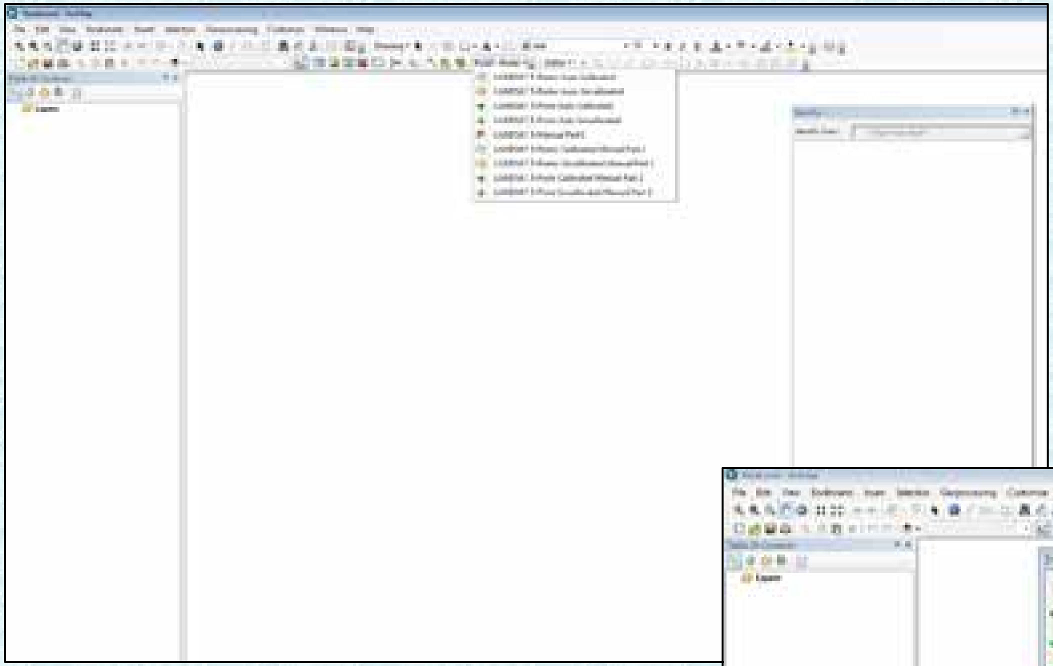
- Hydrologic science.
- Behavior of soil, vegetation and water systems.
- Environmental physics.
- Radiative.
- Aerodynamic.
- Heat transfer.
- Vegetation systems.
- Image Processing.

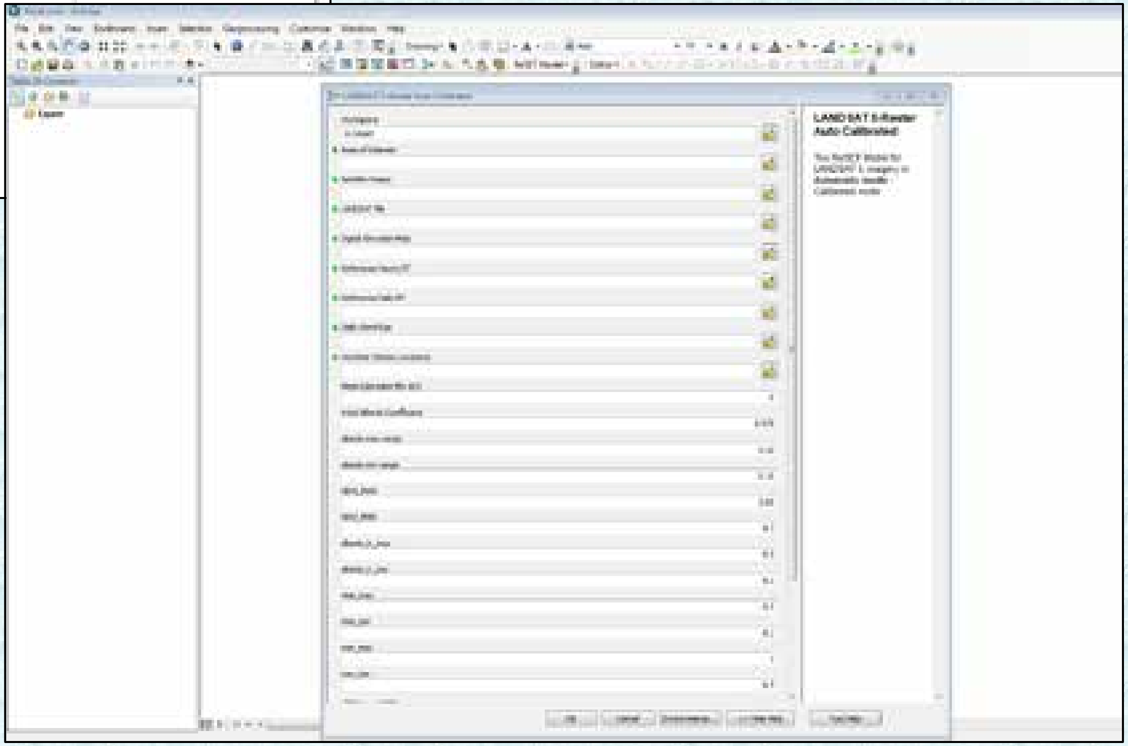
The need for these expertise limits the number of models users and eventually hinders the expansion of surface energy balance models usage and applications.

EB model manual mode

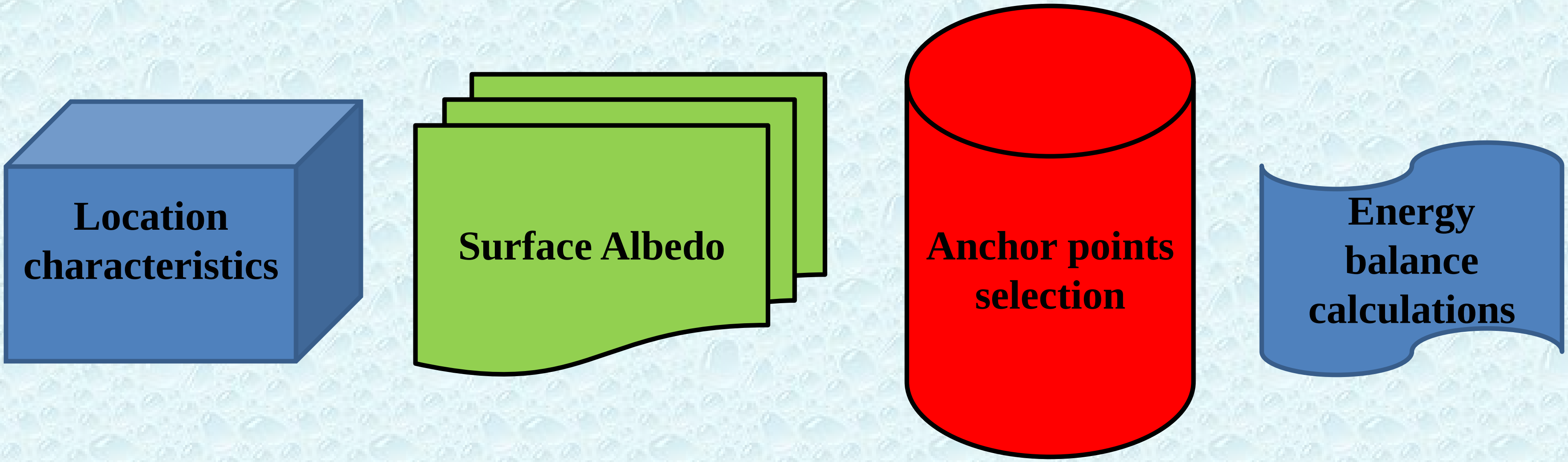


Automated ReSET model under ArcGIS 10.1

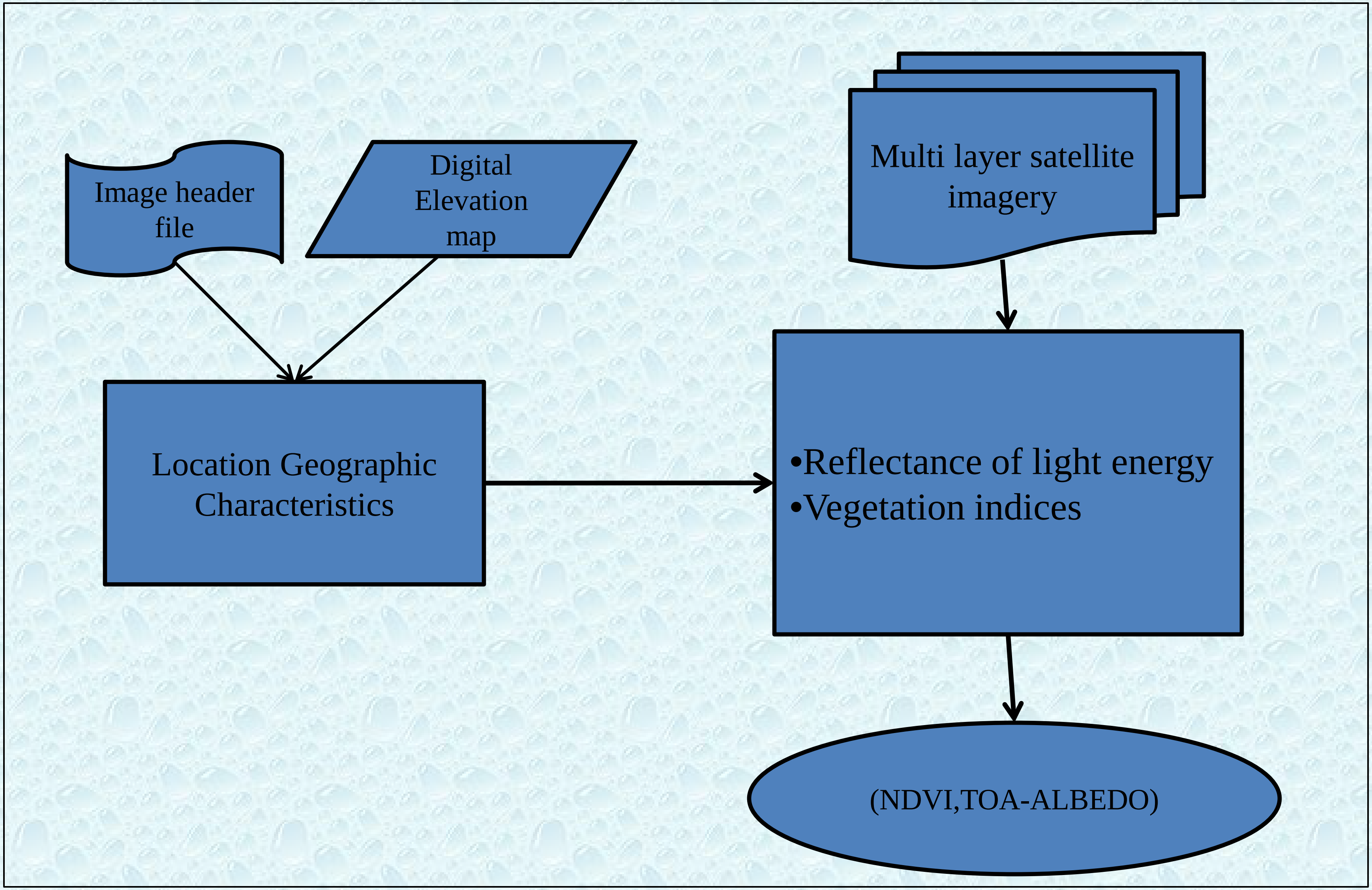




Surface energy balance model components



Model first two components



Surface Albedo calculation

$$a = \frac{a_{toa} - a_{path\_radiance}}{t_{sw}^{2}}$$

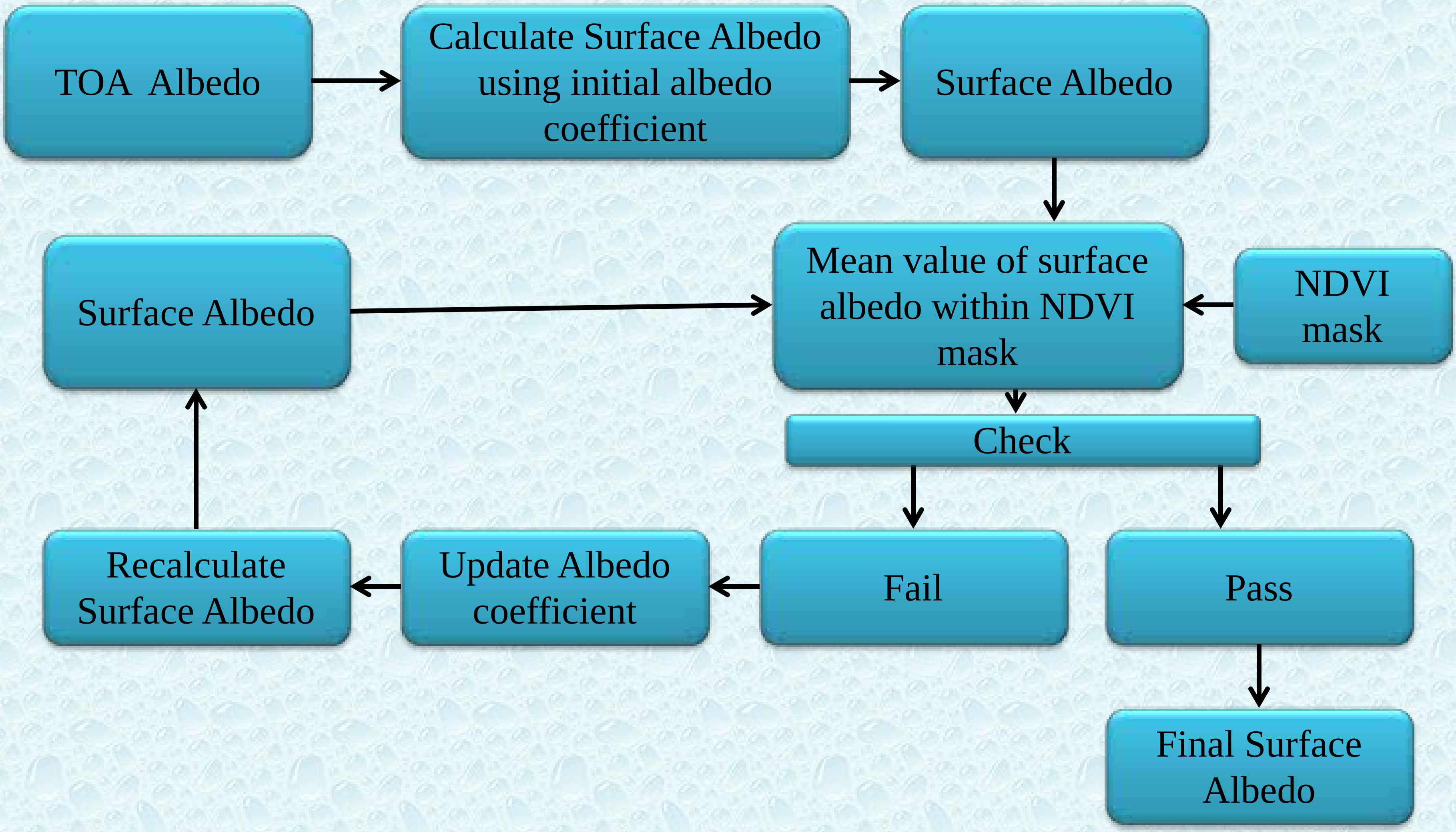
(Chen and Ohring, 1984; Koepke et al., 1985)

$a_{path\_radiance} \sim 0.03$ Bastiaanssen (2000)

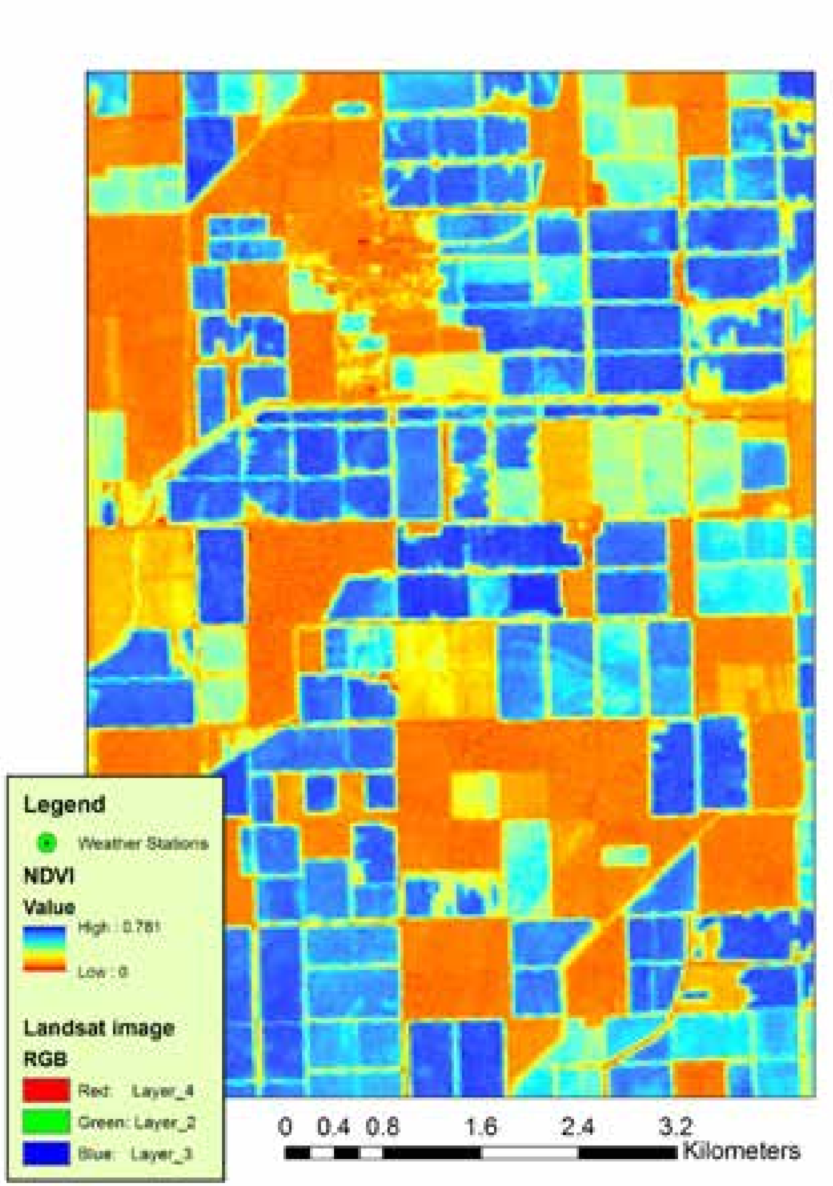
$$t_{sw} = 0.75 + 2 \times 10^{-5} \times z$$

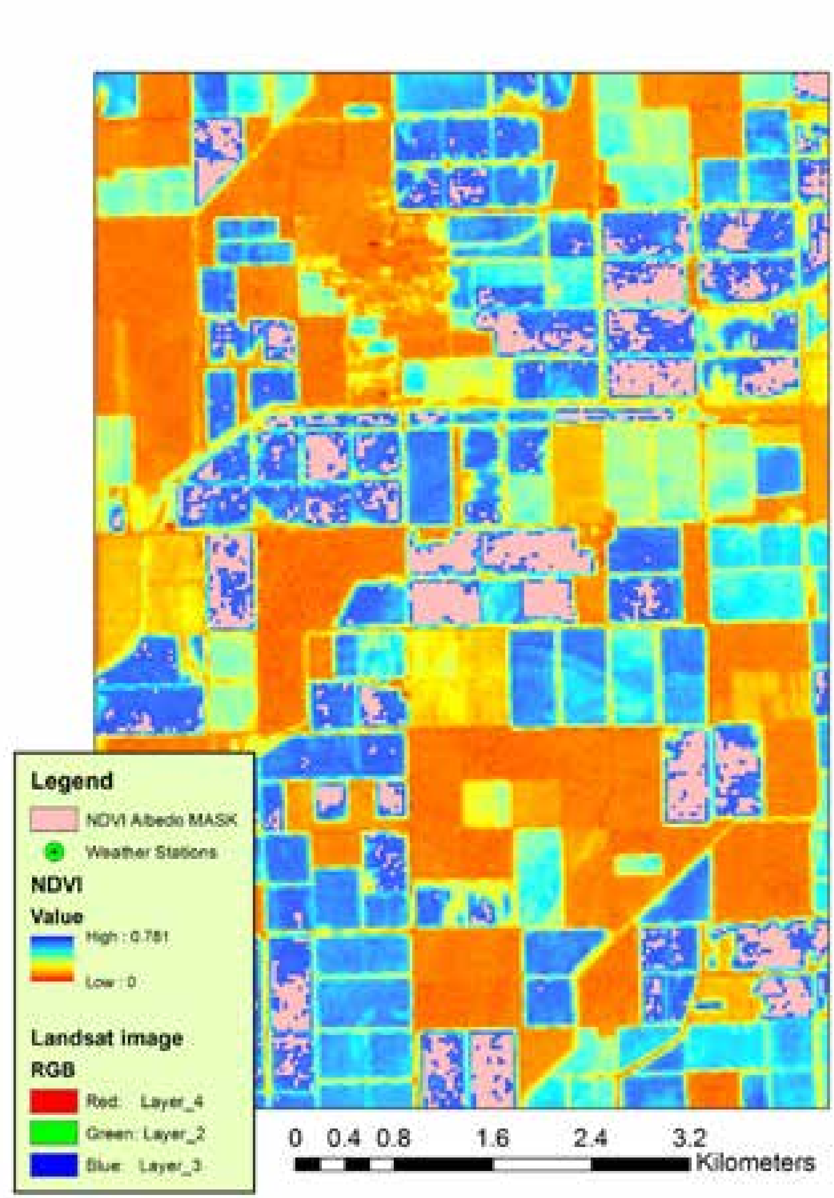
FAO 56

Iterative process for calculating surface Albedo

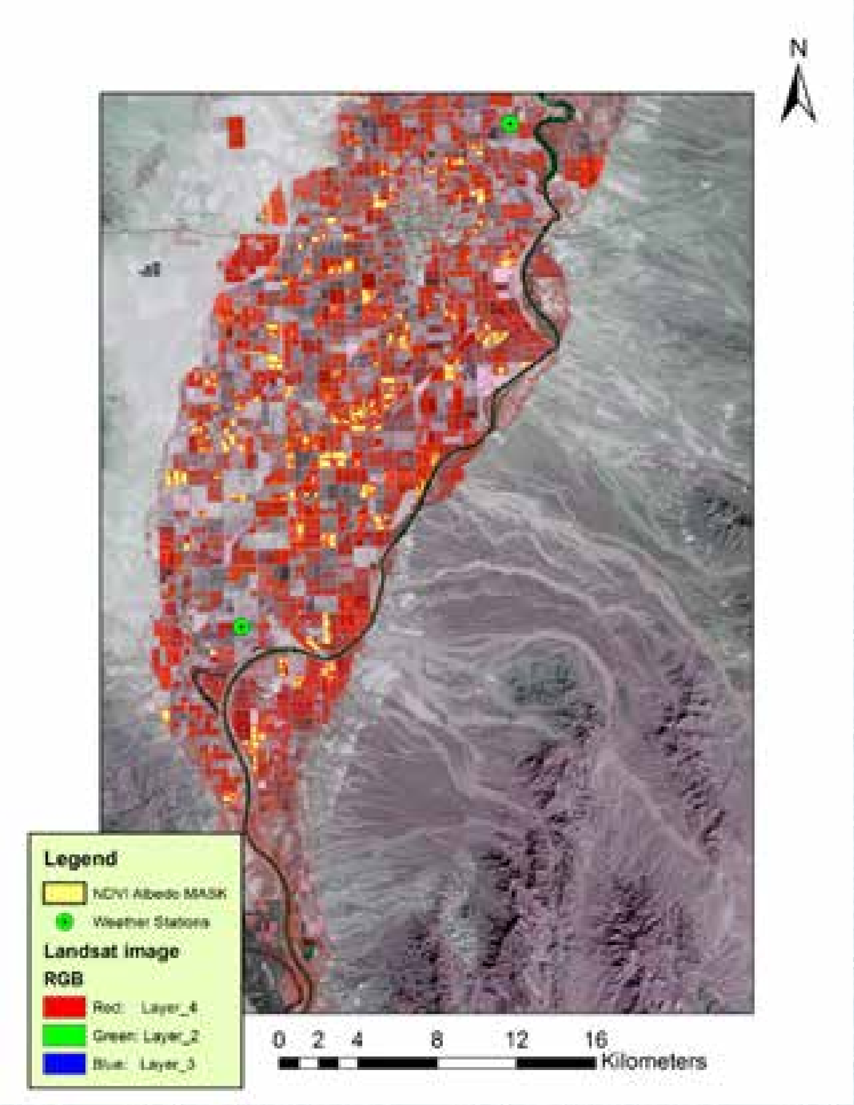


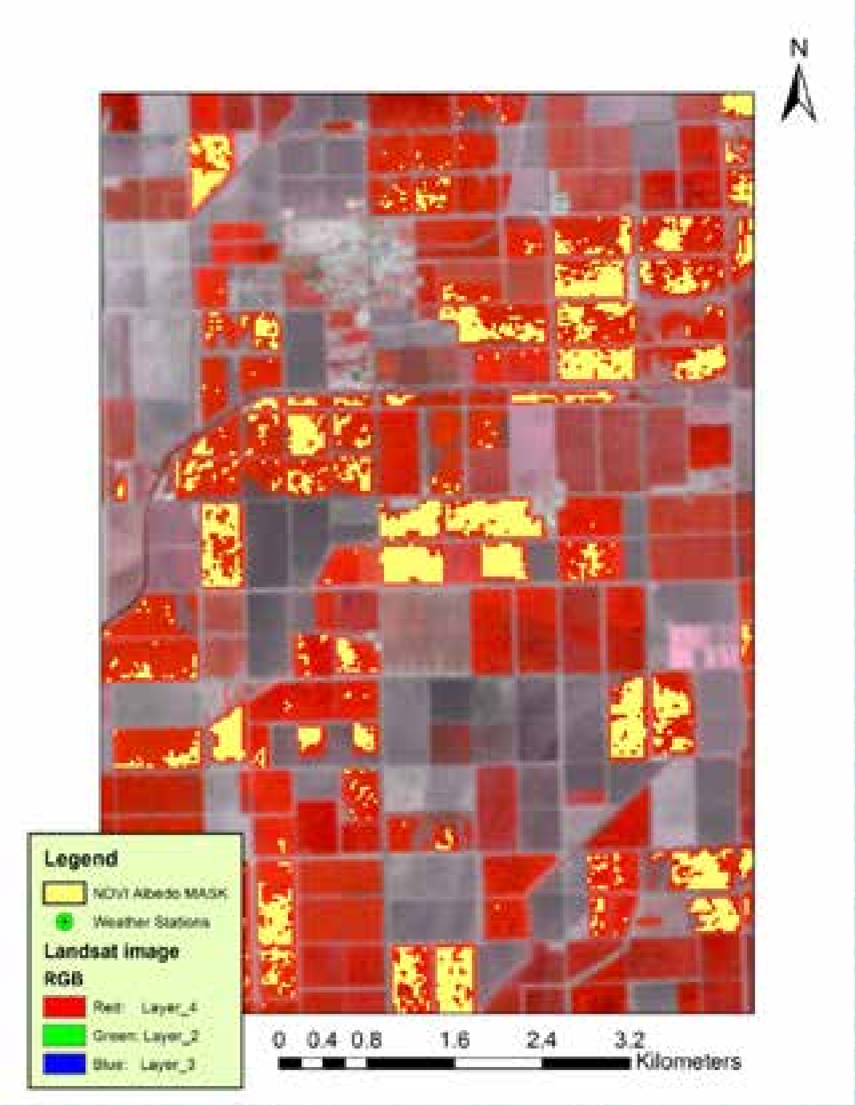
NDVI image(left) and NDVI mask (right) for Albedo





NDVI mask for Surface Albedo





Modeling of Fluxes

$(R_n = LE + G + H)$

- In the energy balance equation various fluxes are modeled as follows:
- **Net Radiation (R_n) = Gain – Losses**

Broad band emissivity

$$R_n = (1 - \alpha)\, R_s + R_L\downarrow - R_L\uparrow - (1-\varepsilon_o)\, R_L\downarrow$$

- **Soil Heat Flux (G) – Empirical equation**

$$G = (T_s/\alpha\, (0.0038\alpha + 0.0074\alpha^2)\, (1 - 0.98 NDVI^4))\, R_n$$

- **Sensible Heat Flux (H)**

$$H = \rho_a C_p\, (T_1 - T_2)/r_{ah}$$

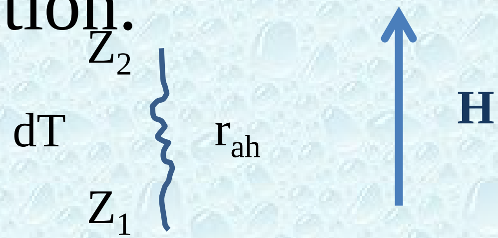
C_p = air specific heat
ρ_a = air density

r_{ah} = aerodynamic resistance to heat transport
$(T_1 - T_2)$ = dT = near surface temperature diff.

Modeling of Fluxes (cont.)

$$H = \rho_a C_p \, (T_1 - T_2)/r_{ah}$$

- Due to the difficulty of computing $T_1 - T_2$ the model uses a **dT** function.



r_{ah} = aerodynamic resistance to heat transport
$(T_1 - T_2)$ = dT = near surface temperature diff.

$$H = \rho_a C_p \, (dT)/r_{ah}$$

C_p = air specific heat
ρ_a = air density

dT Function

- To determine **dT**, two extreme pixels are selected (cold and hot anchor pixels).
- The **cold pixel** is selected from a well water vegetated area where

$$dT_{cold} = 0$$

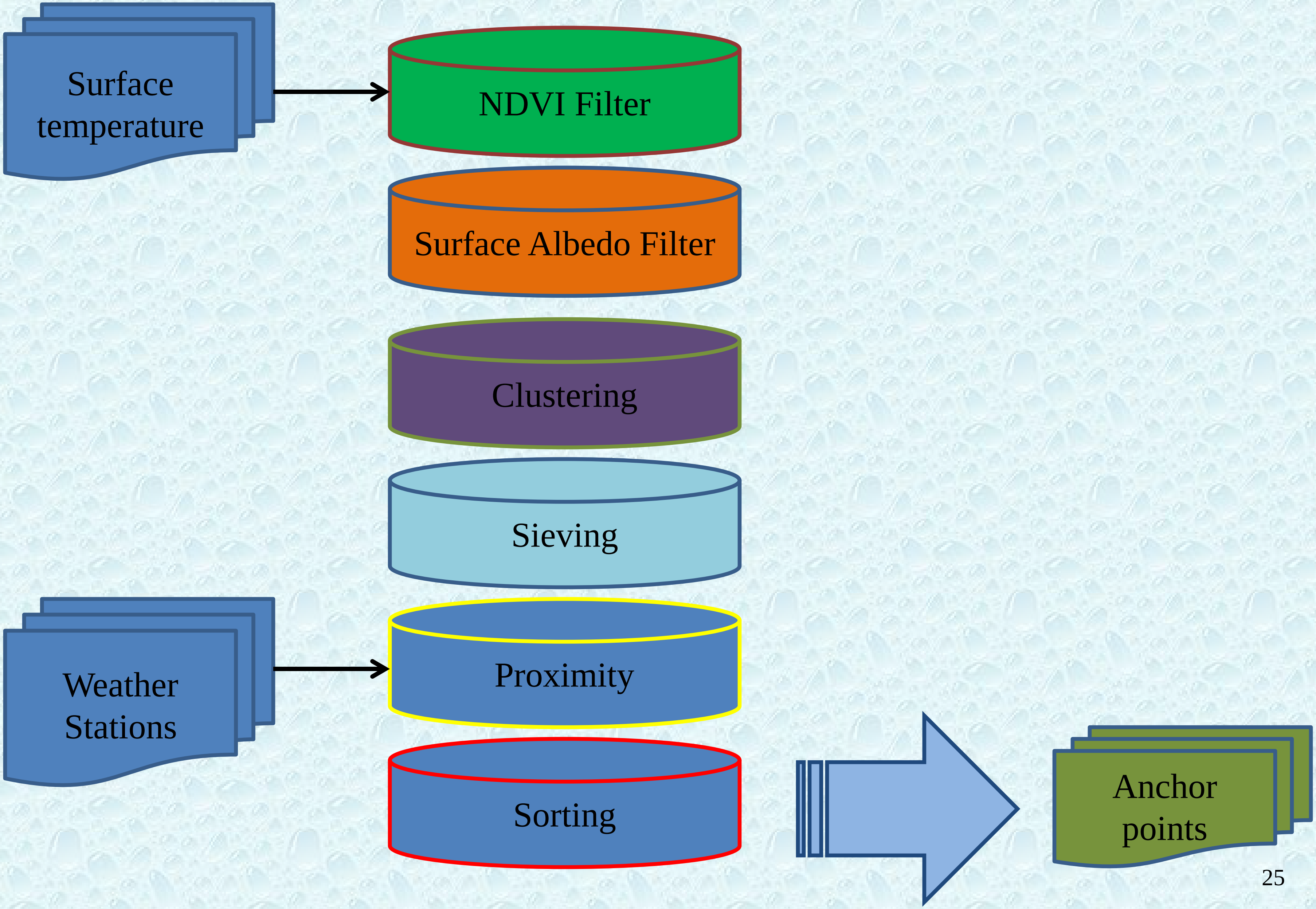
- The **hot pixel** is selected as a very dry land area where it is expected that LE = 0.

$$dT_{hot} = (R_n - G)\, r_{ah} / (\rho_a C_p)$$

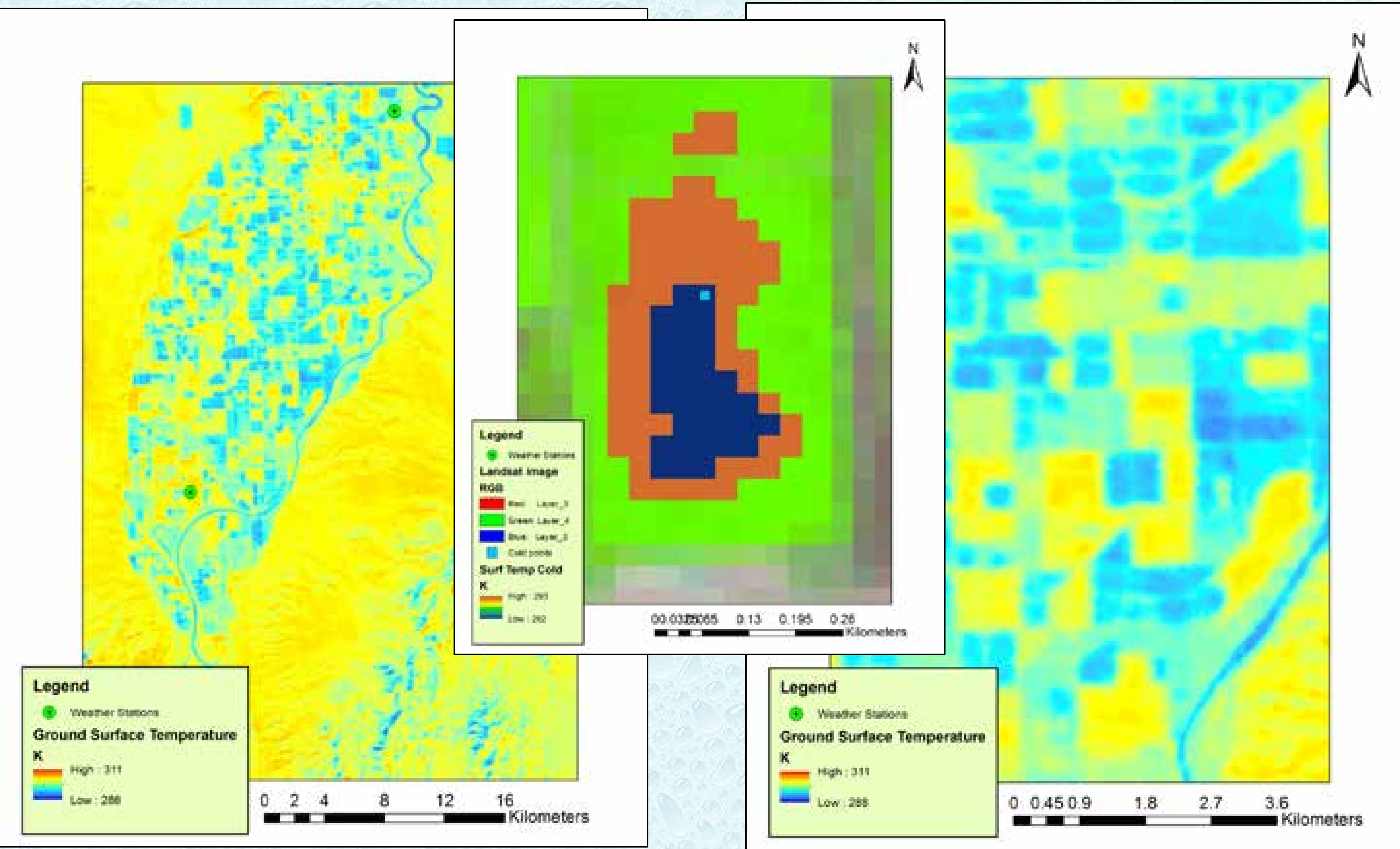
$H = R_n – G – (LE = 0)$

- A linear relationship is assumed to exist between the surface temperature and dT, which then enables the calculation of H for each pixel.

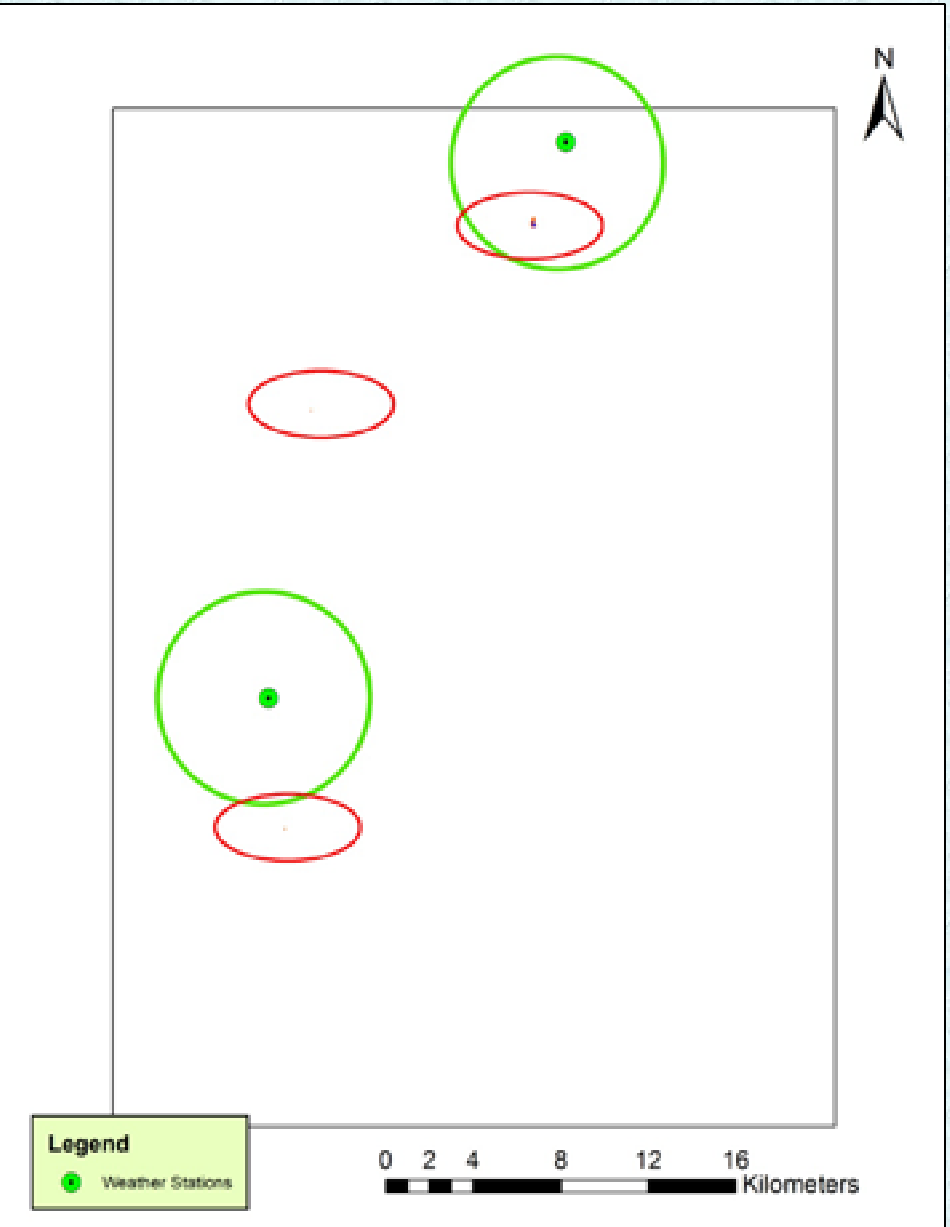
Hot and cold anchor points selection

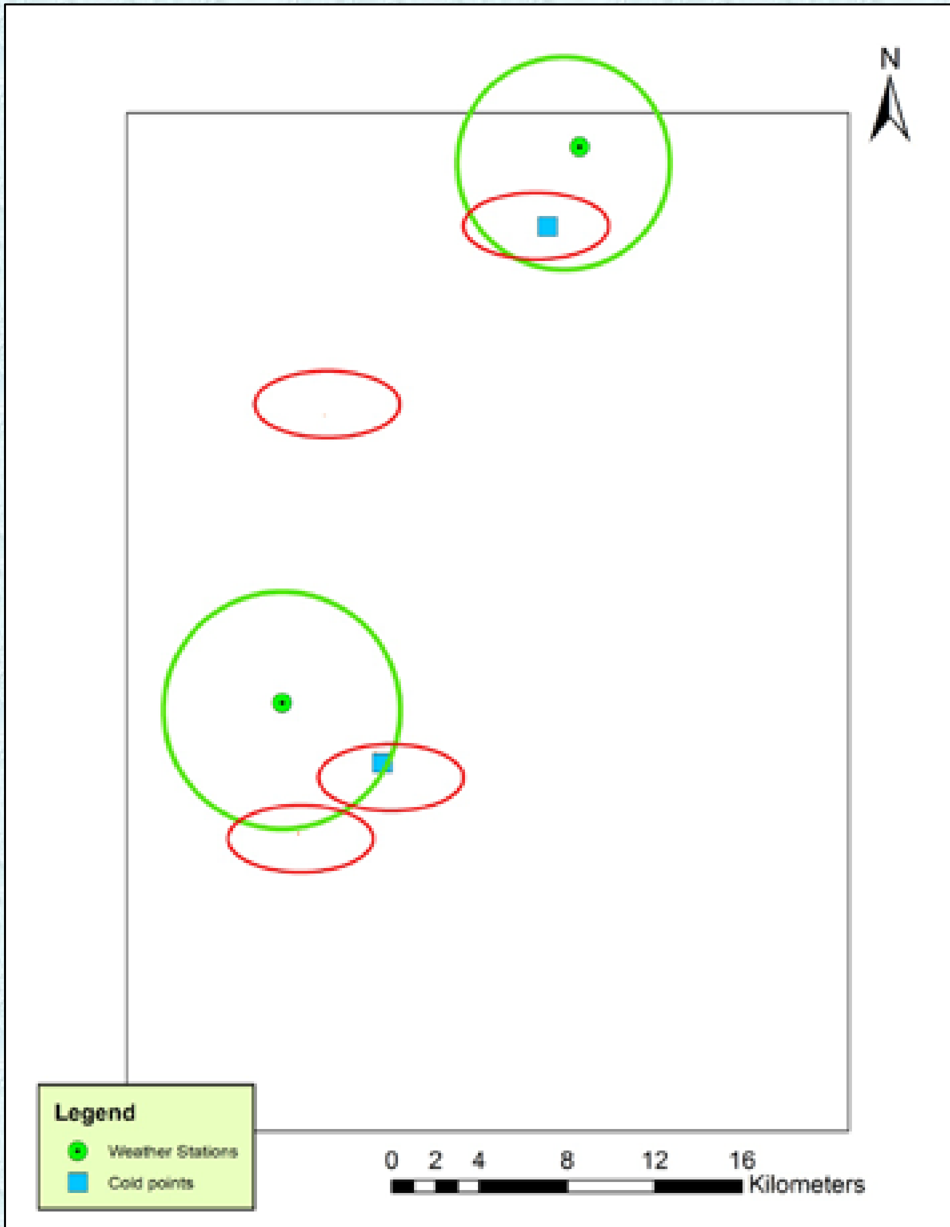


Cold anchor points value check



Cold anchor points proximity check



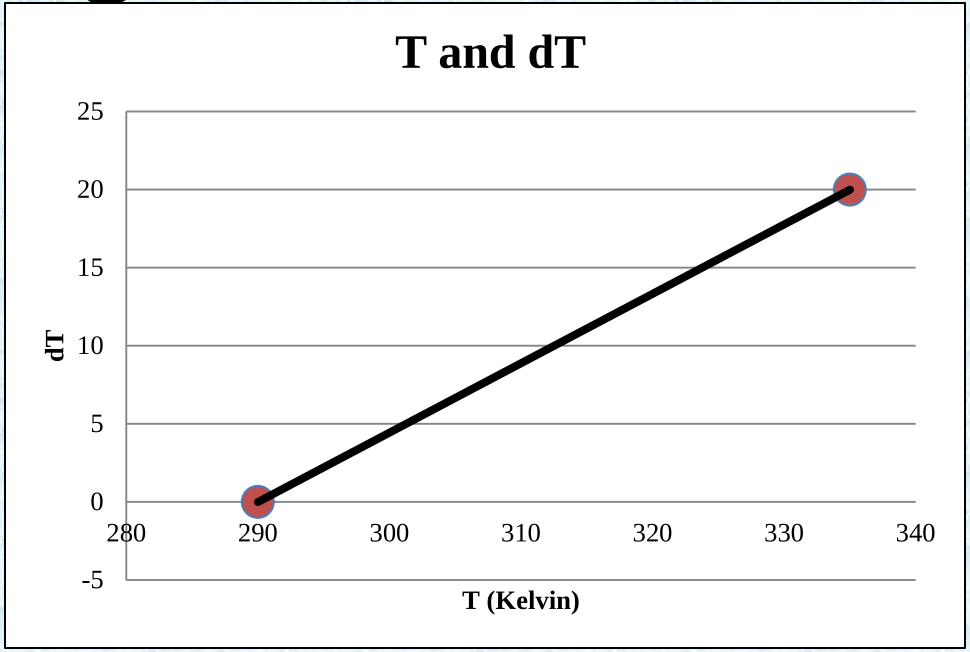


Solving for H

- $H = \rho_a C_{pa}\,(dT)/r_{ah}$

We find H for every pixel

$$LE = R_n - G - H$$



$$ET_{inst} = 3600\,\frac{LE}{\lambda_v}$$

λ_v is latent heat of vaporization (j/kg) representing the energy required to evaporate a unit mass of water

To extrapolate from instantaneous ET to 24-hour ET, $ET_r F$ is multiplied by 24-hour ET_r.

LE and EF Calculation

- Using LE the evaporative fraction (EF) is calculated:

$$\mathbf{EF = LE/(R_n - G)}$$ Evap./Available energy

- It assumes that this fraction remains constant throughout the day, therefore can be used in determining daily ET as shown below:

$$\mathbf{ET_{24} = 86{,}400 * EF * (R_{n24} - G_{24})/ \lambda_v}$$

- Under calm weather conditions or moderate advection for non-irrigated areas, the assumption of EF being constant can be acceptable.

Model inputs 1-Acuired data sets

- Imagery data:

  Satellite imagery and header file.

- Weather data:

  Reference ET daily and hourly as single point values or grids and daily wind run.

- Location data:

  Shp file of weather station locations and shp file for the area of interest.

Model inputs 2- User entered parameter

- **User** enters several values for masks creation and filtering process.
- Those processing parameter are **critical** but does not require **advanced** background.
- The model initial run uses **default** parameter (which is suitable under **normal** crop growing conditions).
- Model running parameters are then fine-tuned in a learning process through a feed back from the area of interest the model being applied on.

Automation advantages

- Help the **expansion** of surface energy balance models applications .

- Facilitate the **mass production** of actual ET maps on several temporal and spatial resolution (current and historical).

- Provide Valuable **inputs** to near real time **irrigation** scheduling models.

Automation limitation

- The automated model was used in different areas in the US (Colorado, California, Texas) and the world (Spain, Egypt, Saudi Arabia) with a **performance** that matched or surpassed the manual mode, however the automation process is **unable** to accommodate these two limitations :
- Pixels affected by Clouds.
- Bad pixel data (Landsat 7),image boundaries.

Overcoming automation limitation

1. Imagery **preprocessing** can be done to overcome the previously mentioned limitations.
   - Clouds:

     Image pixels affected by clouds should be masked and replaced with no data values.
   - Bad pixel data:
     - Satellite images should be clipped at the borders to eliminate pixels with bad data at the edges of the image.
     - Bad stripes in satellite imagery (Landsat 7) should be filled with same image date adjacent data.
2. Running the model in semi automated mode where the user can manually select hot and cold anchor points.

ReSET Raster Applications

- **South Platte Basin** – Estimation of irrigation efficiency and validation of pumping records, development of Kc.
- **Arkansas River Basin** – Estimation of actual crop water use, Aquifer recharge/depletion, impact of salinity on ET, calculation of canal service area water use.
- **Palo Verde Irrigation District** – Estimation of actual crop water use.
- **Aragona Irrigation District in Spain** – Estimation of actual crop water use.
- **Nile Delta in Egypt-** Evaluate irrigation canal system efficiency.

Reset Model Modes

- ReSET model is available in Full automatic and semi automatic mode for all Landsat satellites imagery (LS 5,LS7 ,LS8) and MODIS

- Colorado State University will be offering a three day training on the ReSET model this fall, for more information please email *Aymn.elhaddad@colostate.edu*

Questions