Monitoring Evapotranspiration Over Arid Lands of the U.S. Southwest

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Need for Arid Land Evapotranspiration Remote Sensing Research

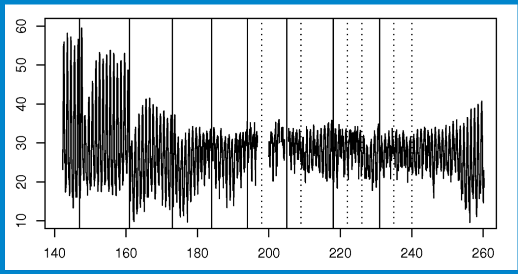
- Increasing population in water scarce regions
- Drought & climate change exacerbating water supplies
- Irrigated agriculture in arid lands are highly productive but will be the first to sacrifice water use.
- Ag. Use 40% of freshwater withdrawals (Hutson et al. 2004)
- Irrigated crops 53% of market value on 17% of crop land (Clemmens et al., 2008)
- Trend: In Arizona annual water supply 2.4 M ac-ft; enough to support 8 M people with no agriculture (Watering the Sun Corridor, Morrison Inst. Public Policy 2011)
- Remote sensing is only way to synoptically observe & estimate land cover and water use changes.

Need for High Spatial & Temporal Resolution

- Arid Lands are highly heterogeneous in space and time
- For water use studies mixed-pixels poorly represent actual conditions
- Better than 100 m needed for VNIR and TIR
- Remote sensing cannot be part of a decision support system if land and water use changes are not up-to-date
- Daily to weekly estimates for croplands, weekly to monthly for rangelands.

Managed Cropland & Urban Interface

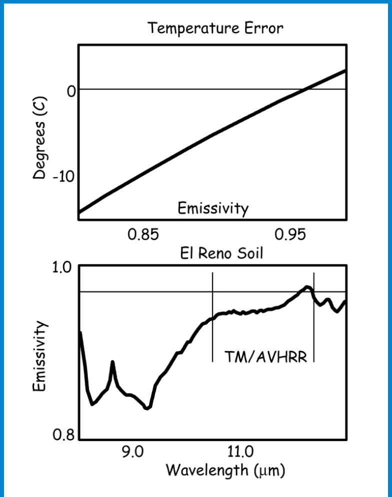
Managed (& Un-managed) Rangeland



Cropland LST

Need for Multispectral/Hyperspectral Remote Sensing

- More accurate energy balance estimates
- Better land cover discrimination
- Observe land surface changes and states unobservable with single or several broadband channels



Energy Balance Modeling for Water Use Estimation

$$R_n - G = H + LE$$

Available **Turbulent Flux**

- Physically based
  - Generality
  - Estimates closely linked to vegetation/soil/atmospheric processes & detects water stress vegetation
  - Complex & computationally demanding
- Empirical & Parameterized
  - Locally calibrated
  - Applies to standardized conditions

$$\mathrm{LE} = \frac{\Delta}{\Delta + \gamma}\left[\mathrm{R_n} - \mathrm{G}\right] + \frac{\gamma}{\Delta + \gamma}\rho c_p \left[e^{\star} - e_a\right]/r_a$$

Penman-Monteith ET (N.B.- no surface temperature)

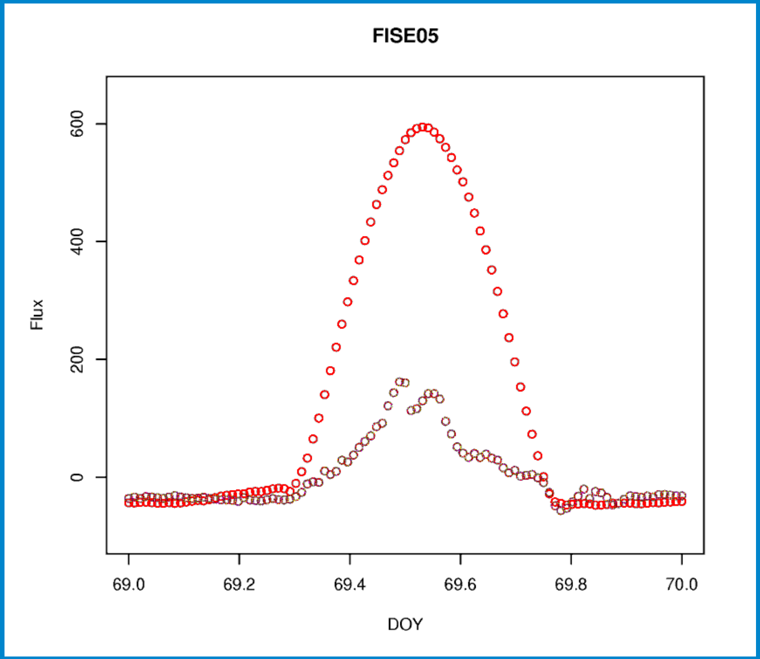
Available Energy: Net Radiation

$$R_n = (1\text{-albedo})R_{solar} + \varepsilon_{air}\, R_{L\downarrow} - \varepsilon_{surface}\, L_{BB,\uparrow}$$

- Single most important component of surface energy balance
- HyspIRI design can improve estimation of R_n beyond broadband sensors
- Error/uncertainty needs to be less the 10%
- Shortwave component dominant term & can be improved with hyperspectral VNIR
- Surface longwave component also important and dependent upon accurate land surface emissivities

Available Energy: Soil Heat Flux

Remote sensing can't directly retrieve G
Typically estimated with Rn and vegetation index
Diurnally variable with time lag
Small : < 50 W m-2
G = c * Rn_soil



Turbulent Energy Flux: Sensible Heat

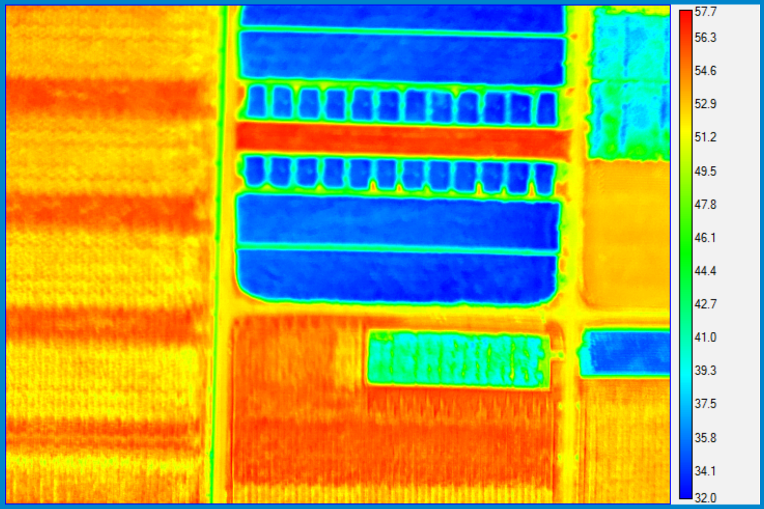
Energy flux due to surface temperature gradients

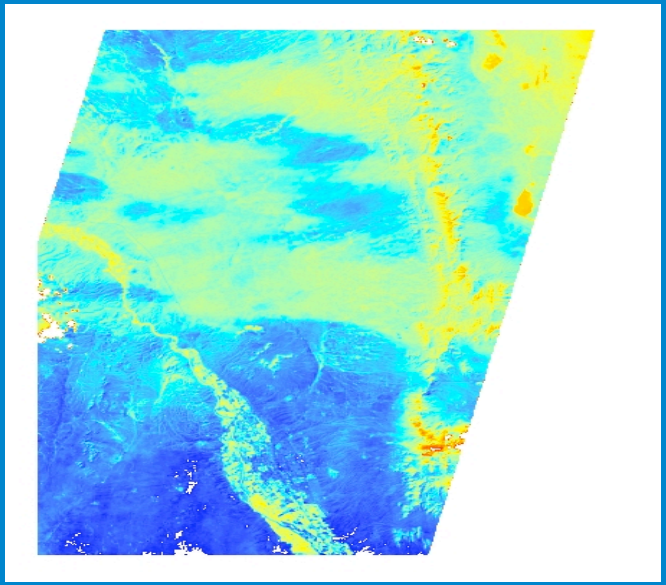
Can be estimated using remotely sensed thermal infrared

Sensible heat related to surface and sub-surface water content

Linked in a non-trivial way to radiometric temperature

$$H = \rho\, c_p\, \Delta T/(r_a + r_s)$$





Turbulent Energy Flux: Latent Heat
-> Evapotranspiration <-

- Component of surface energy balance representing conversion of liquid water to vapor from soil and plants
- Indicator of plant water use and plant water stress
- Estimated from energy balance residual
- Current ET model examples: SEBAL/METRIC, SEBS, TSEB

$$\mathrm{LE_C} = \mathrm{f_g}\alpha \left[\frac{\Delta}{\Delta + \gamma}\right] \mathrm{R_{n,C}}$$

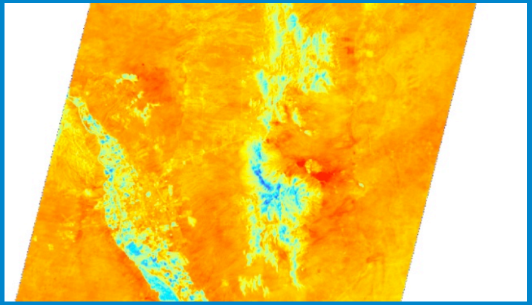
$$H \cong H_{soil}(\Delta T) + H_{canopy}(PT)$$

$$\mathrm{LE_S} = \mathrm{R_{n,S}} - \mathrm{G} - \rho \mathrm{c_p} \frac{\mathrm{T_s} - \mathrm{T_a}}{\mathrm{r_a} + \mathrm{r_s}}$$

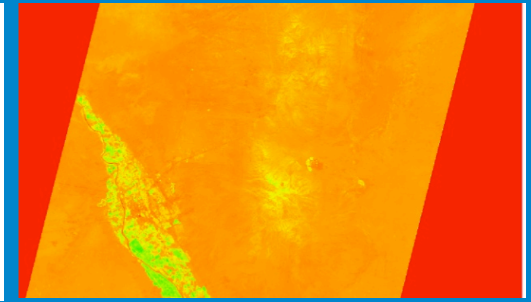
$$\mathrm{LE} = \mathrm{R_n} - \mathrm{G} - \rho \mathrm{c_p} \left[\frac{\Delta \mathrm{T}}{\mathrm{r_a}}\right]$$

Energy balance modeling to get daily ET

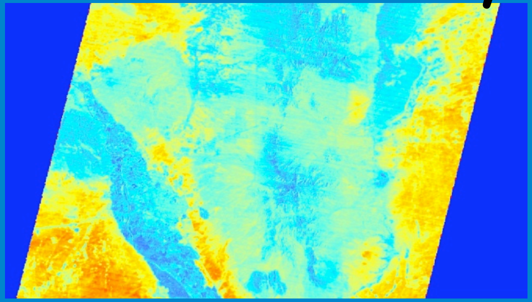
LST



NDVI



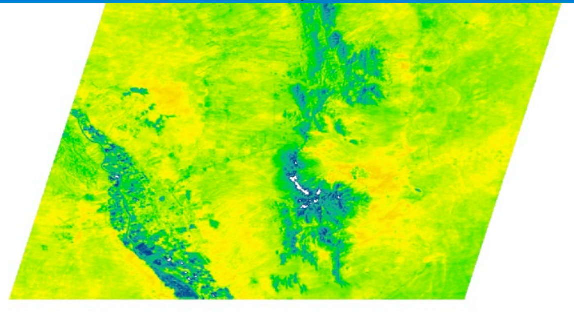
Emissivity



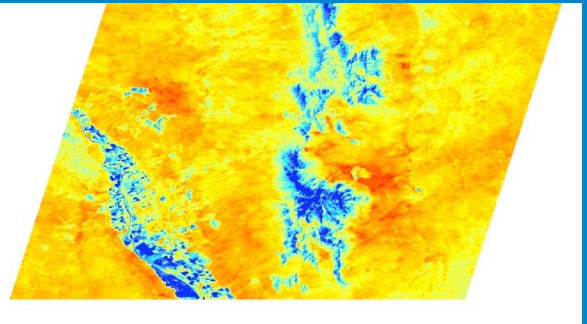
+Land Use
+Meteorology+…

ASTER
6 Oct 2002

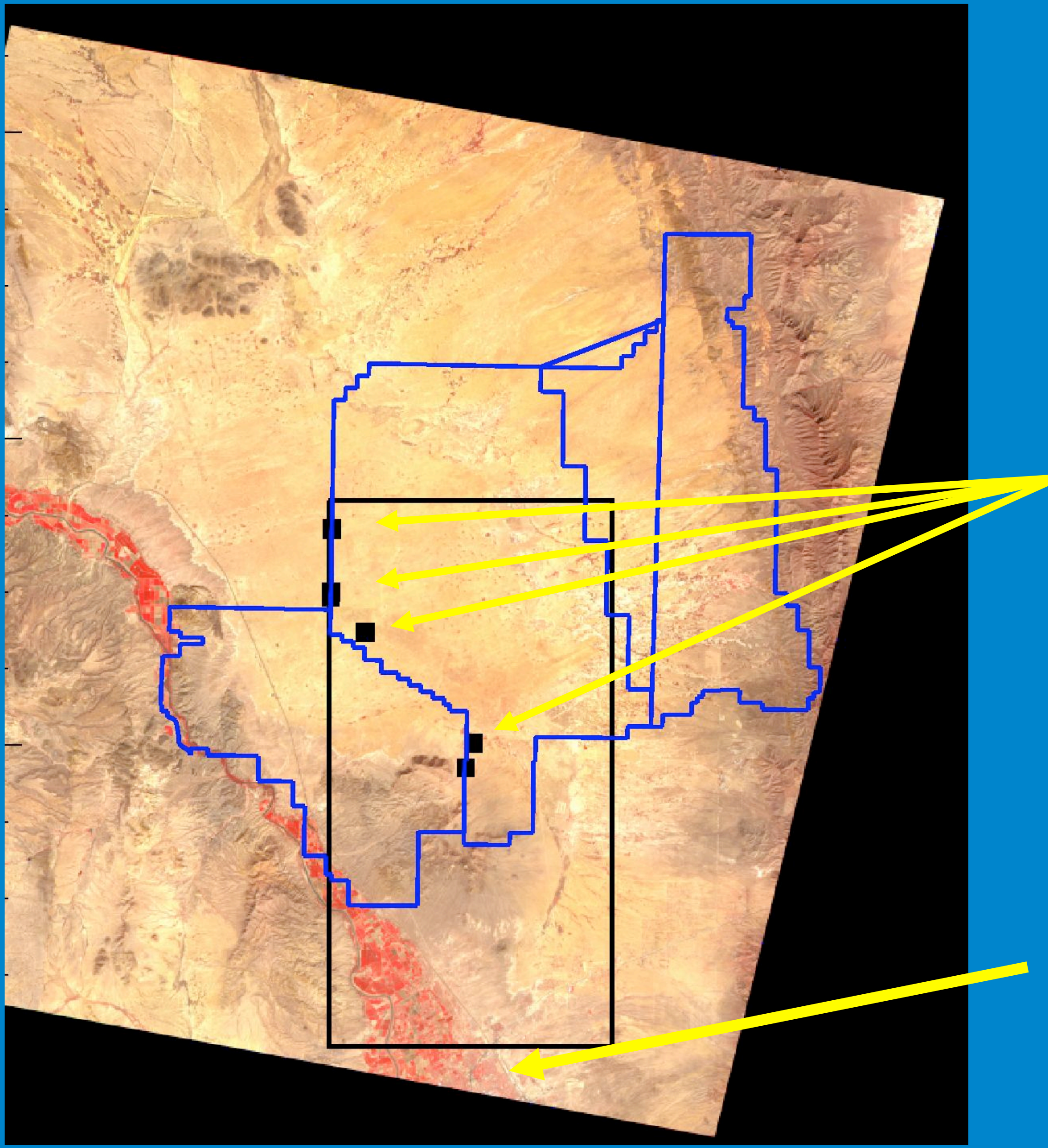
H



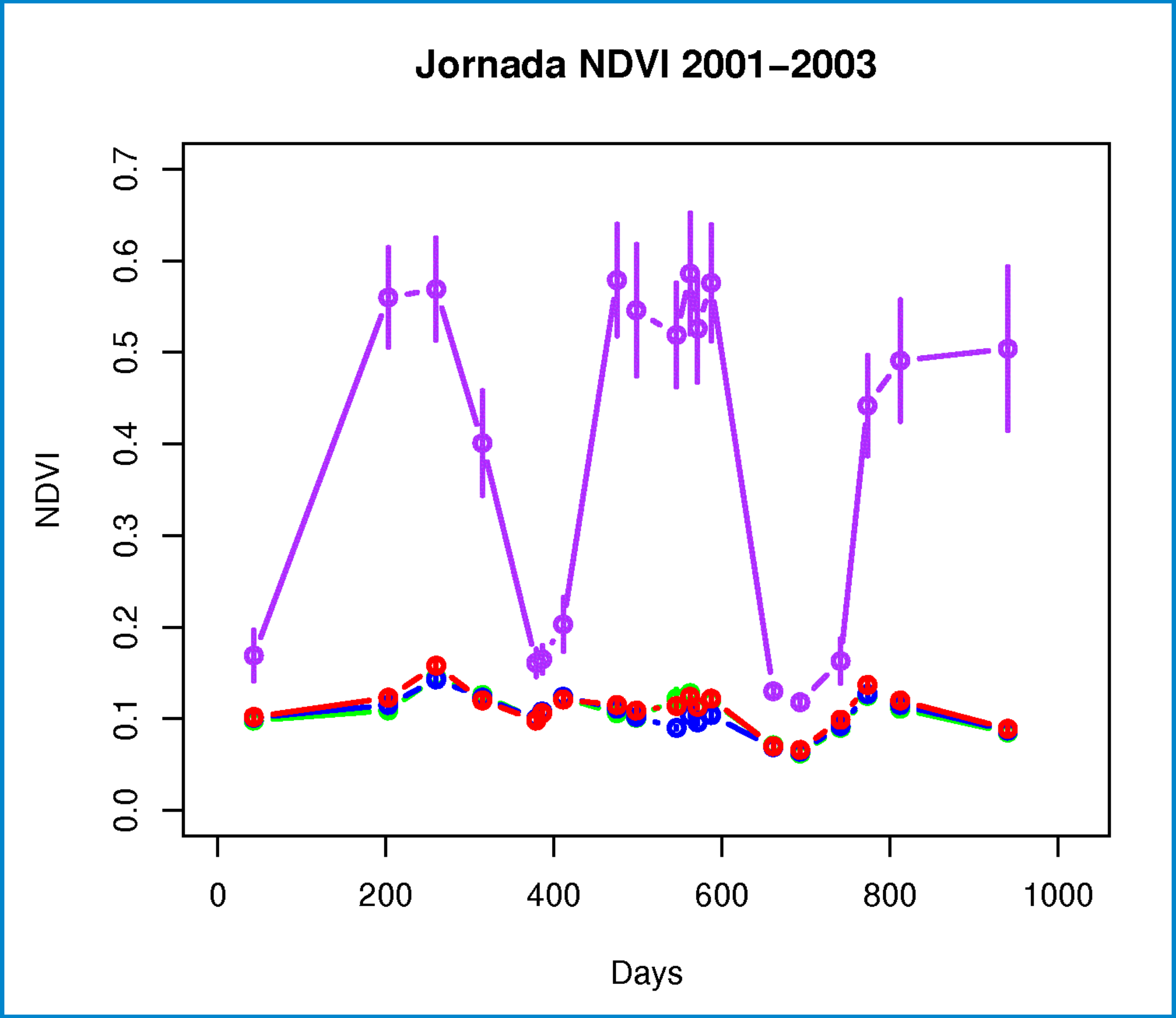
LE

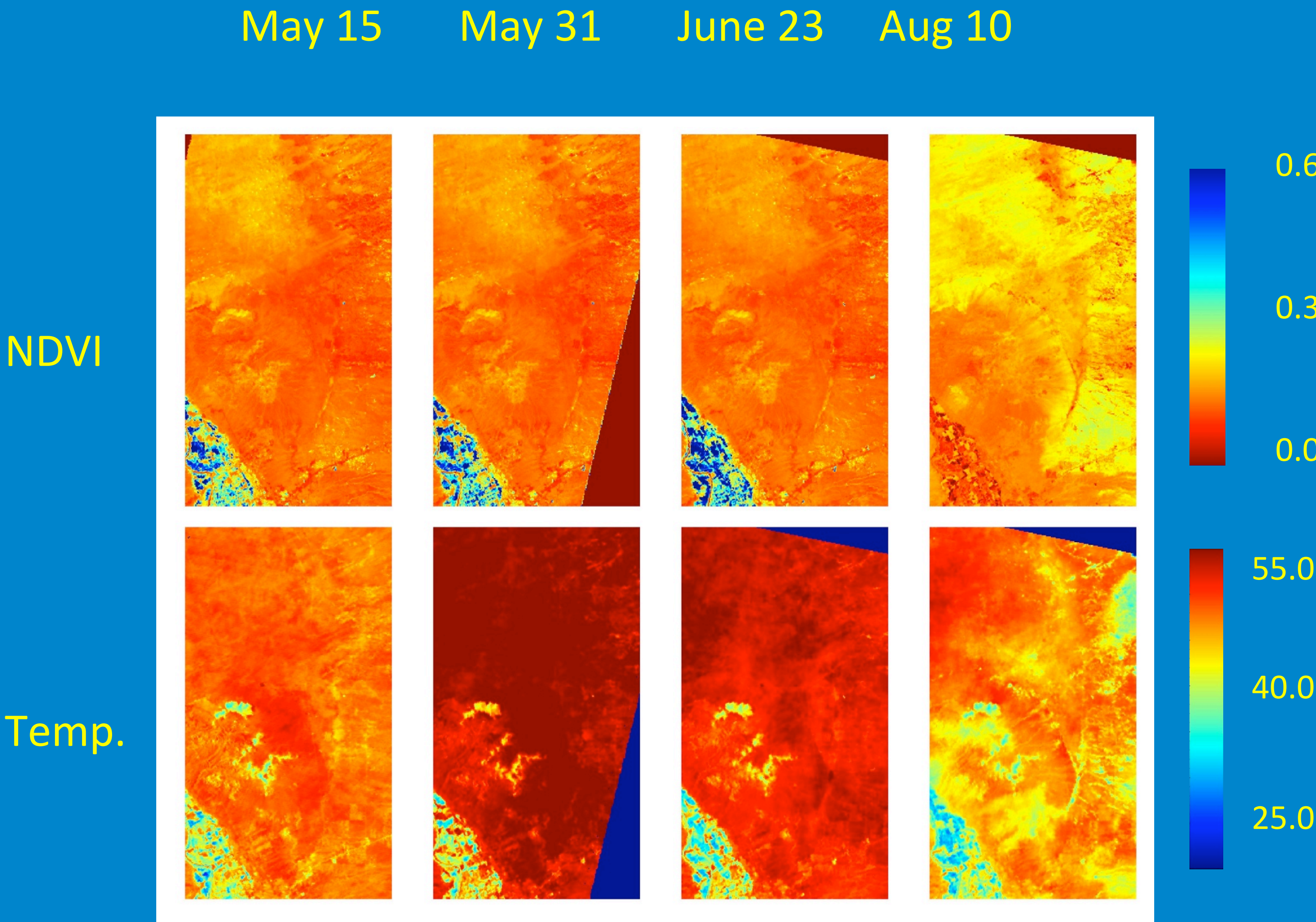


Jornada Region
6 October 2002
ASTER VNIR



NDVI for Jornada & Rio Grande 2001-2003




May 15
May 31
June 23
Aug 10
NDVI
Temp.
0.6
0.3
0.0
55.0
40.0
25.0

ET estimates at 90 m Resolution

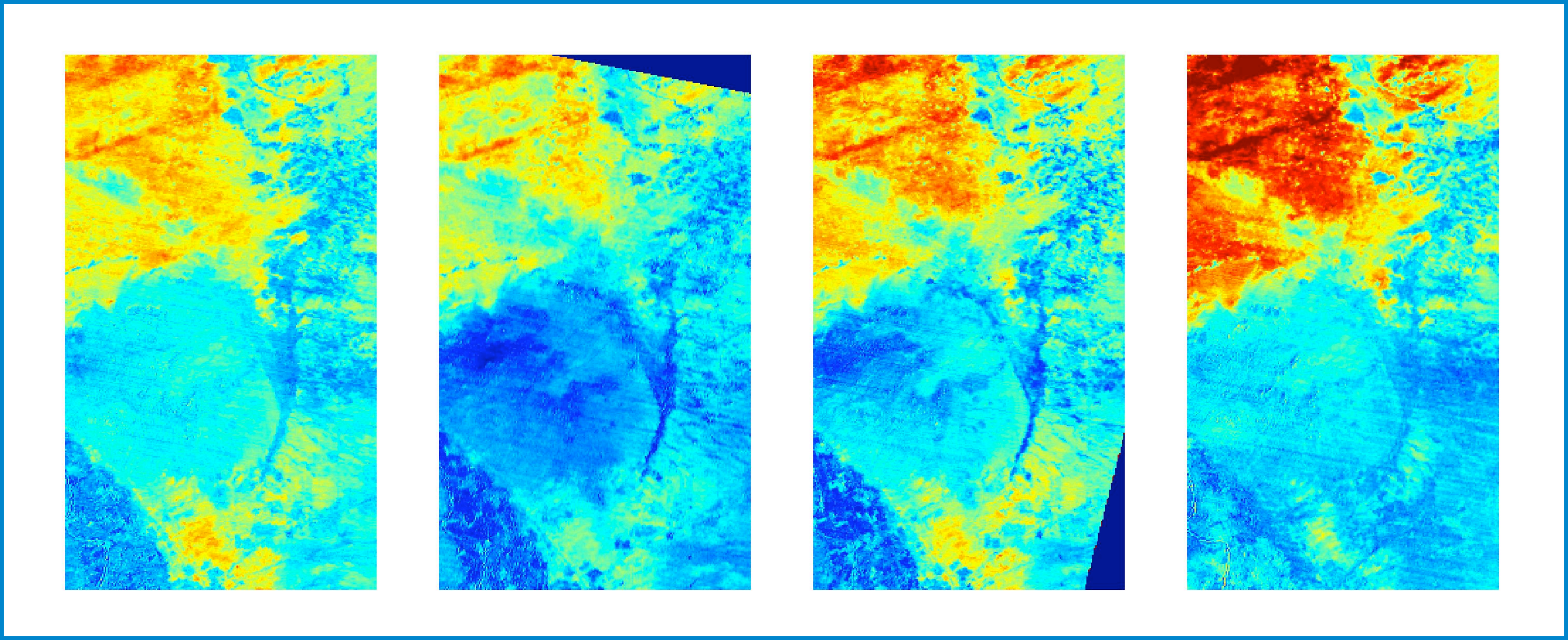
Site	H	LE	G	R_n
Grass	411 (7) 377	0 8	92 (2) N/A	505 (1) N/A
Transition (Bowen)	419 (7) 326	0 91	88 (2) 121	509 (1) 538
Mesquite	418 (35) 364	0 22	89 (8) N/A	508 (7) N/A

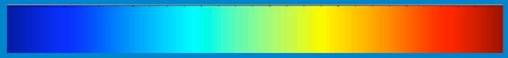
ASTER TSEB   Ground Observation

Emissivity Contrast at Jornada

Emissivity data are dynamic
Provide additional information about the land surface
Obtainable only from multispectral TIR

May 15 Aug 10 Sep 20 Oct 6

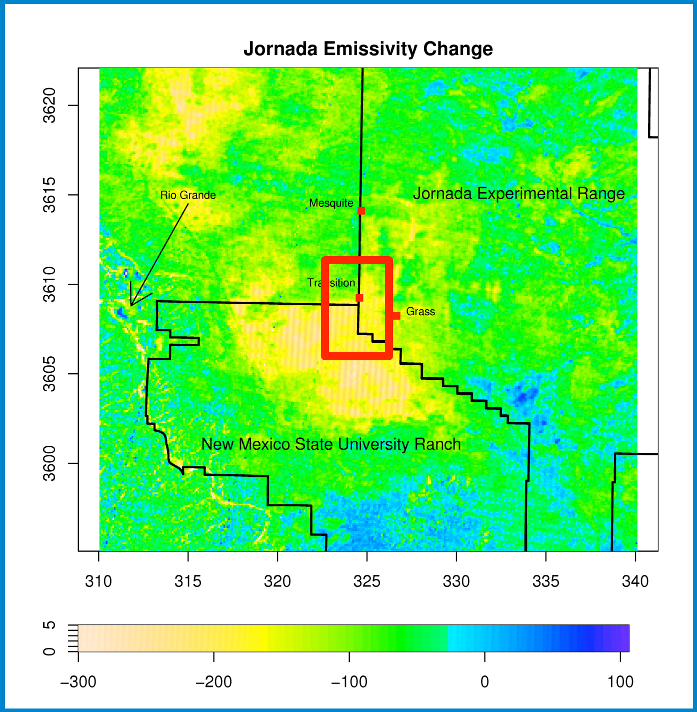




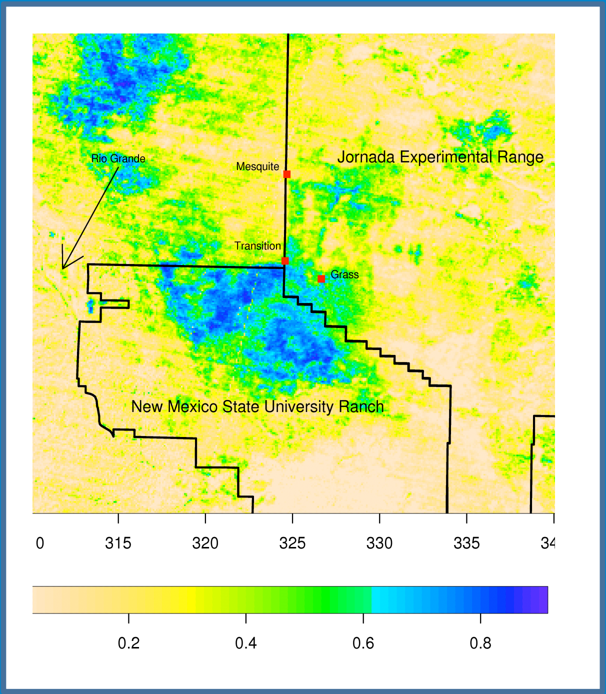
-Soil moisture effects
-Atmospheric correction errors

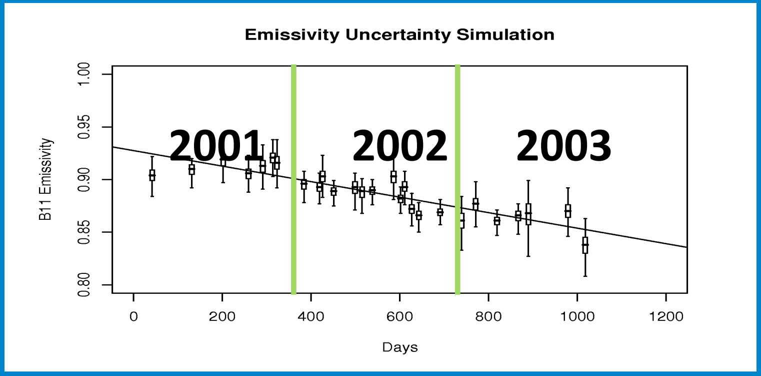
Remote Sensing of ET with Multispectral TIR

Dynamic Emissivity & Land Cover Change



R^2

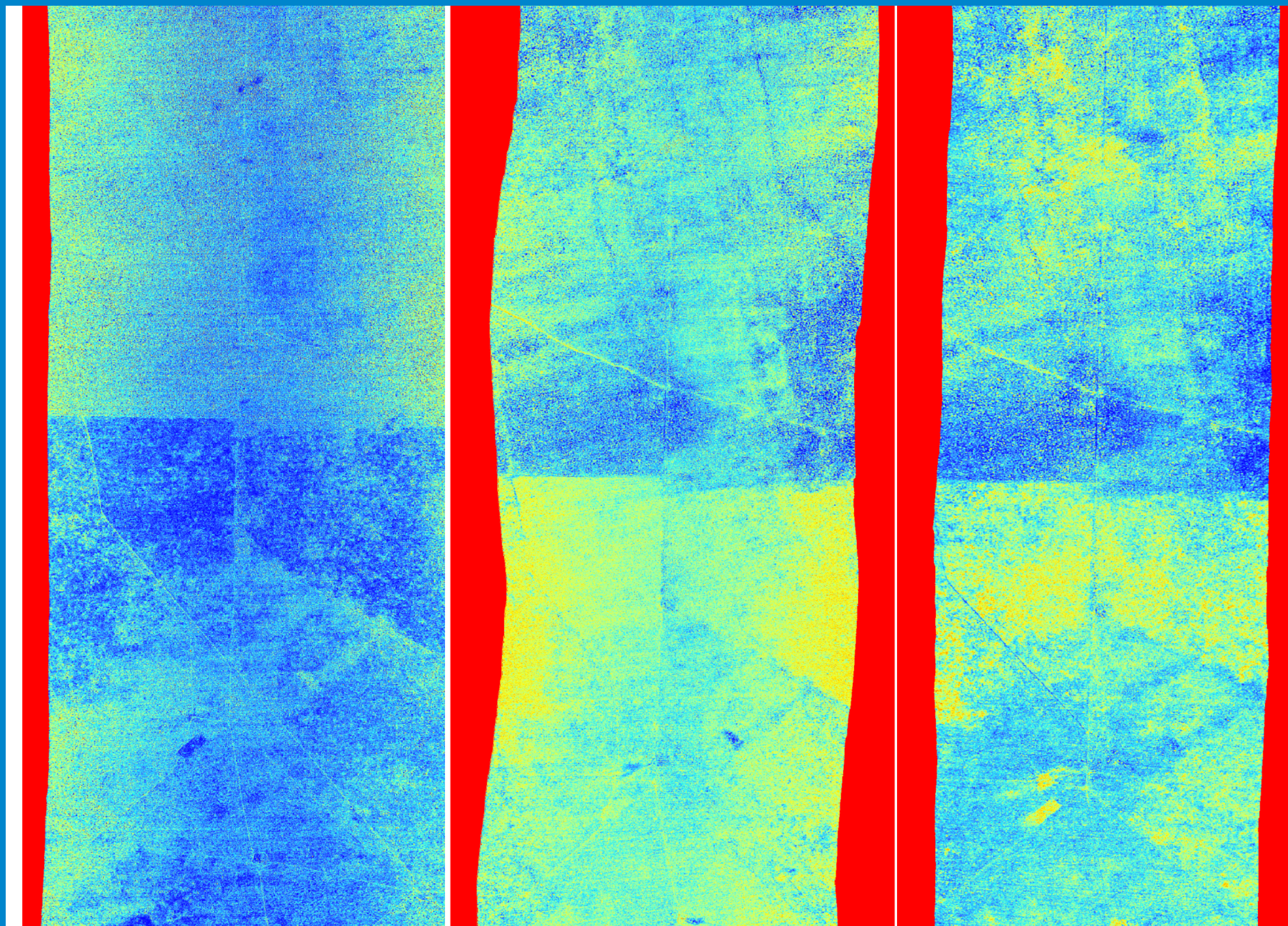




200 m extract

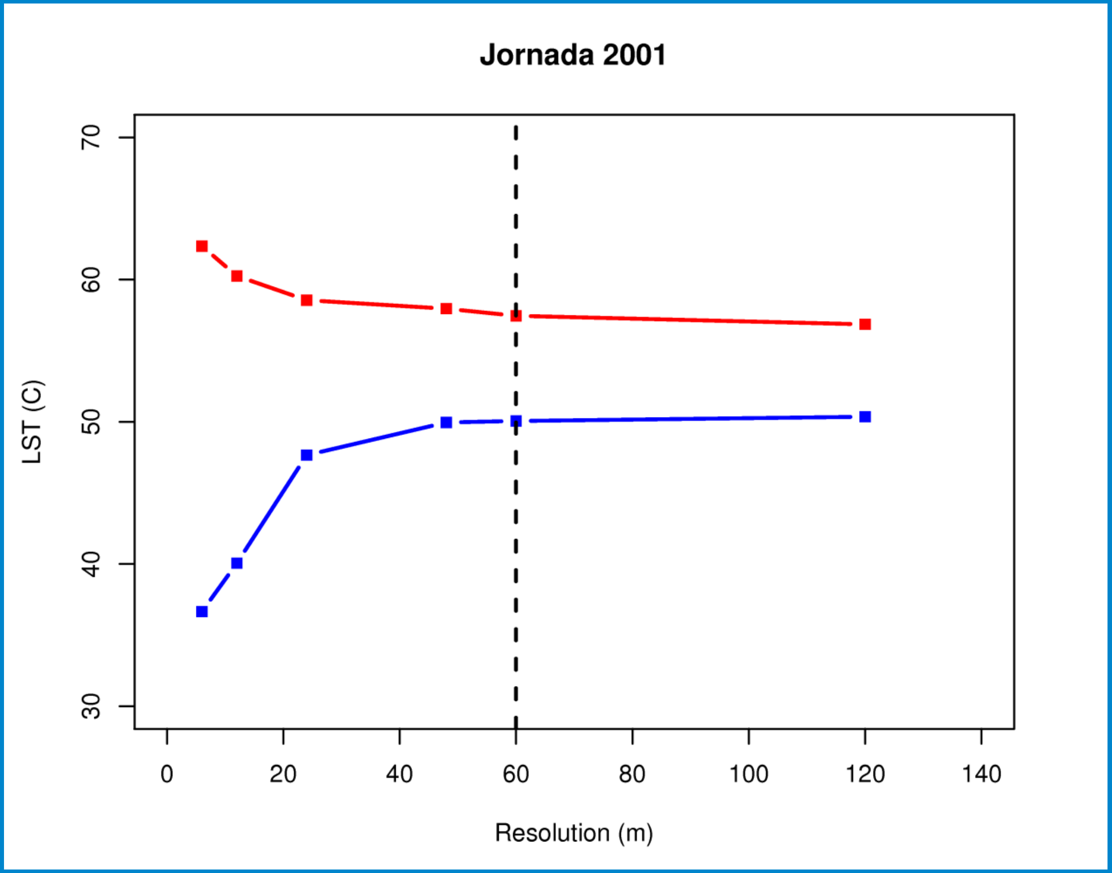
MASTER Confirms Emissivity Changes

6-12 m resolution



May 2001 May 2002 May 2003

Importance of Spatial Resolution: Scaling of Land Surface Temperatures



- Most of LST dynamic range lost ~50m
- LST contrast loss mainly over cooler surfaces
- HyspIRI resolution will discriminate land used changes, but not individual shrubs
- Loss of range needs to be considered when modeling surface energy fluxes

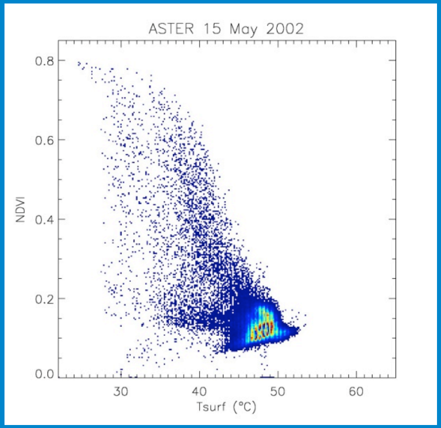
NDVI an Unsatisfactory LST Estimator

Rangeland has limited NDVI range

Cropland has broad variance of LST

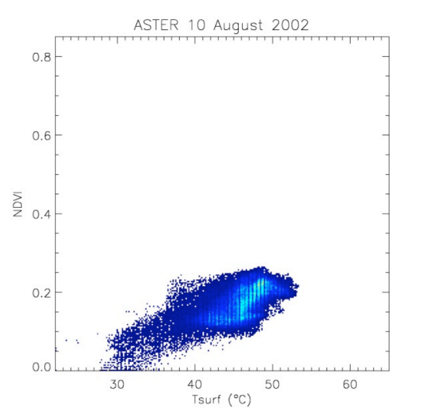
Cannot discriminate plant stress

NDVI



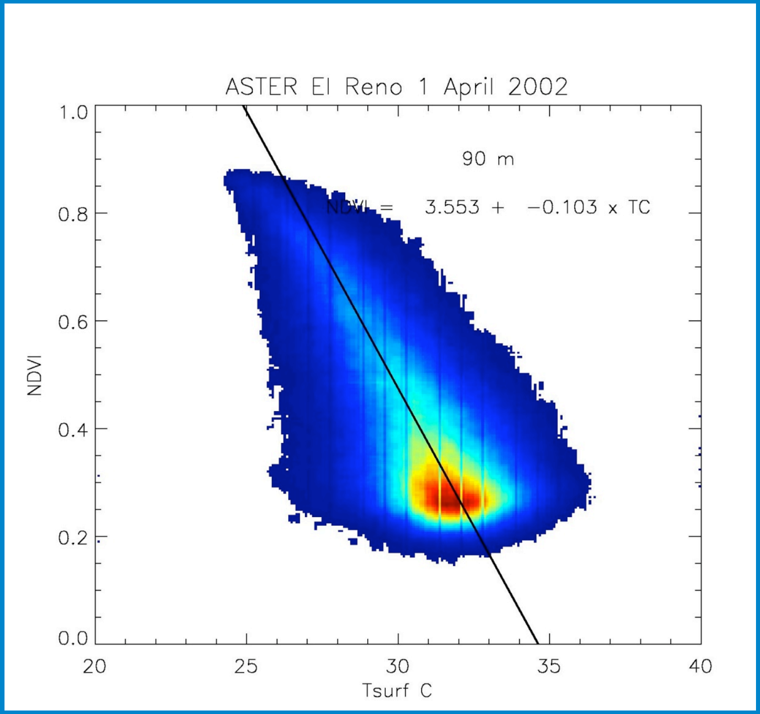
15 May

NDVI



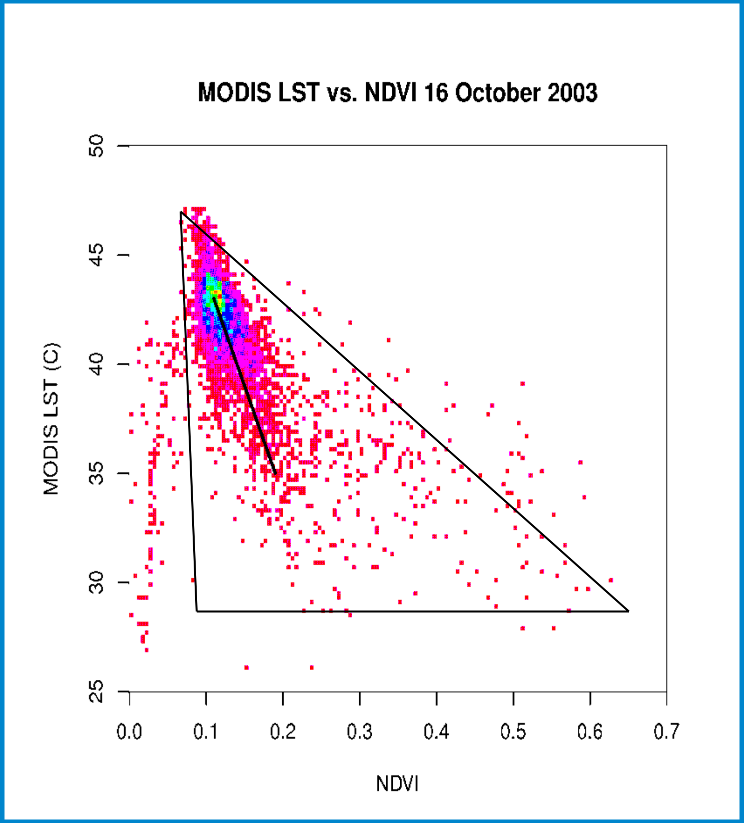
10 August

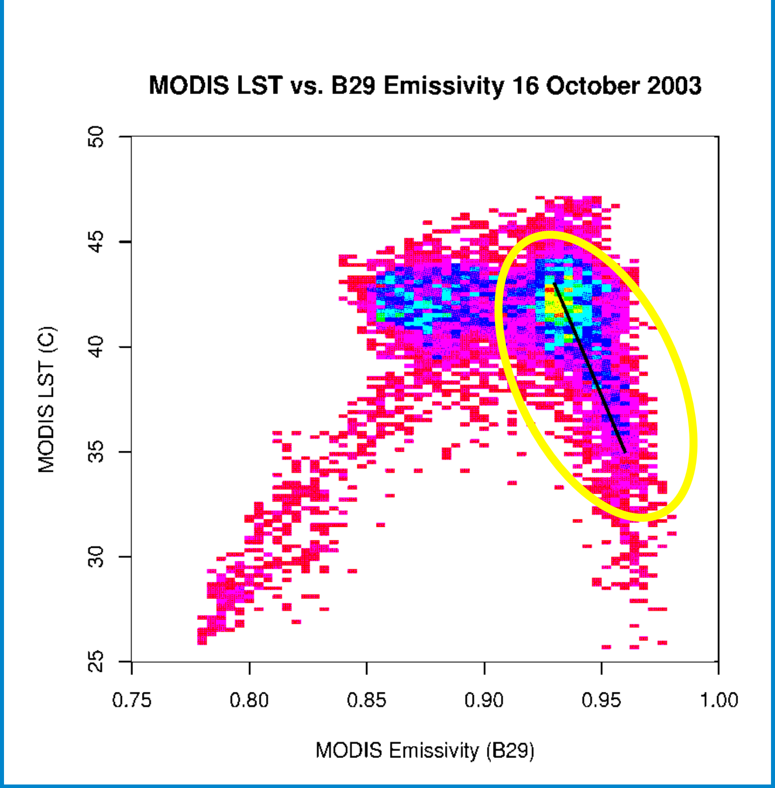
Tsurf



Slope is time of day dependent

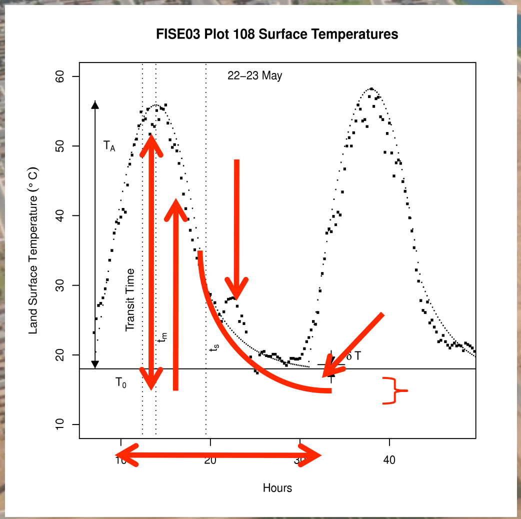
Emissivities May Help Disaggregation

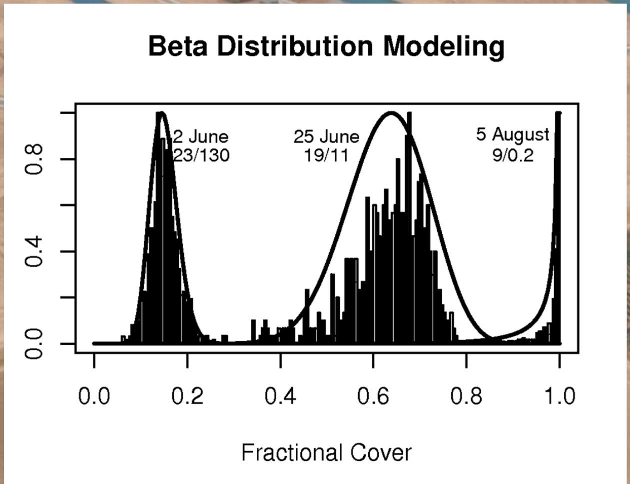


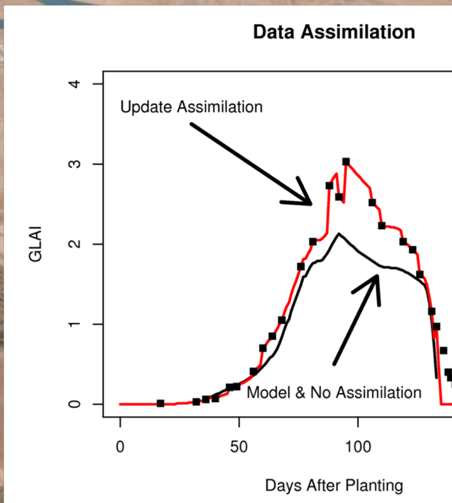


$$LST = k\left[b_0 + b_1 NDVI\right] + (1-k)\left[c_0 + c_1 Emiss.\right]$$

ET Estimation for Croplands







Diurnal LST modeling

Weekly vegetation Cover modeling

Daily biophysical mo

- Integration of multiple sensors, ground-based information & models re
- Decision support tools require <weekly estimates & spatial resolution <

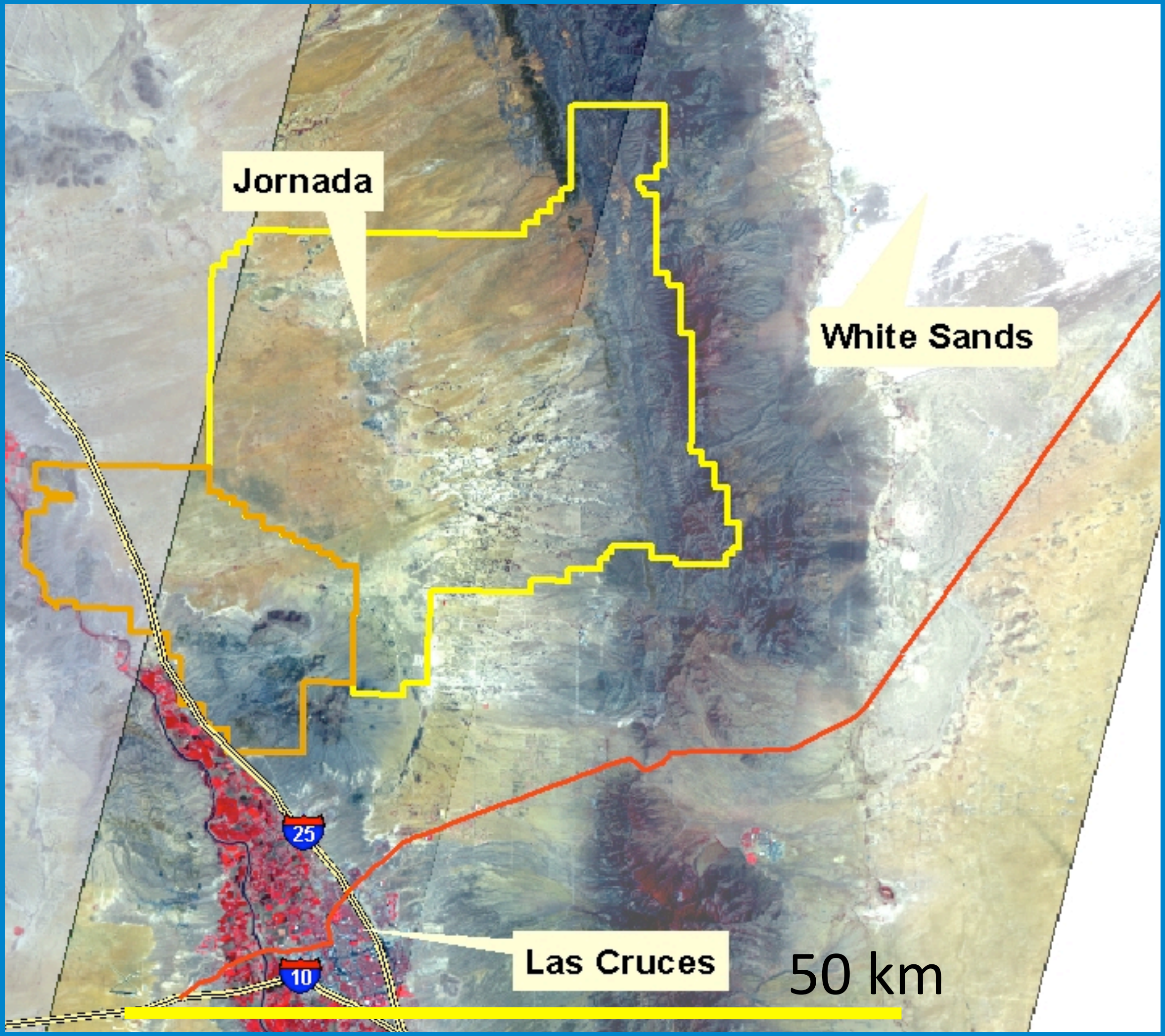
Remote Sensing of ET with Simulated HyspIRI

- Implement ET methodology at 60m using MASTER data (11 Flights 1999-2010) and AVIRIS (6 flights 1998-2002)
- Investigate ways to improve LST retrieval for low emissivity contrast surfaces
- Incorporate hyperspectral data to improve vegetation detection, classification and albedo

Conclusions

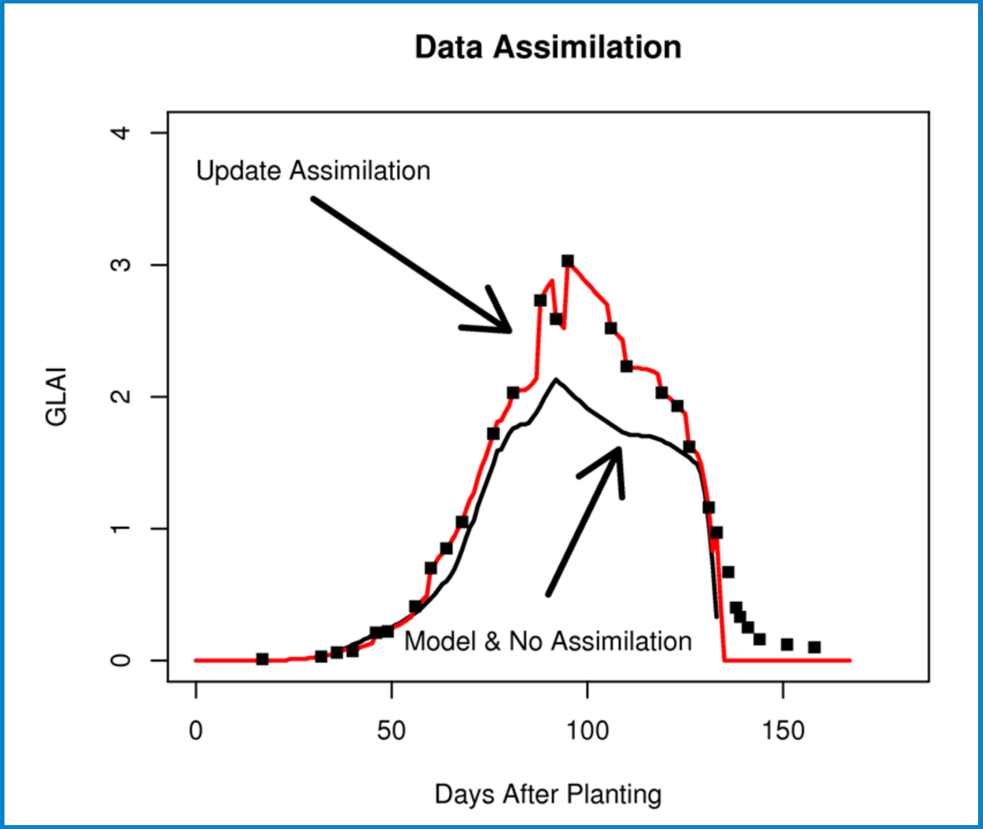
- Finding accurate ways to estimate ET is vital for monitoring water use & building decision support tools to manage freshwater supplies.
- Remote sensing essential for global scale studies
- HyspIRI will advance these goals by providing frequent high spectral & spatial resolution spanning multiple thermal bands & contiguous VSWIR bands needed for resolving the surface energy balance components.

ASTER Composite over Jornada 2001-2003

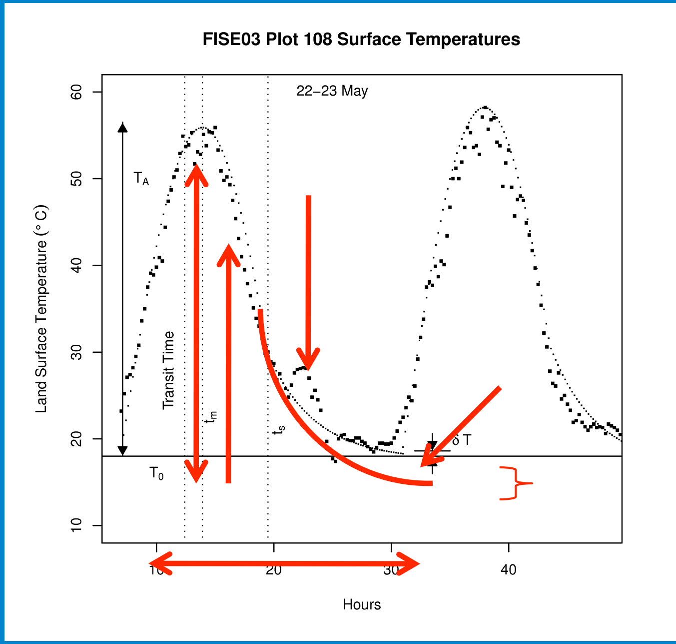


Update ET estimates beyond Remote Sensing Times

- Image data not available frequently enough, nor with sufficient resolution
- Background crop model constrains growth to physiological plausible ranges
- But process model not spatial, so need image data to map ET
- Update with observables such as LAI and LST



Land surface temperature modeling

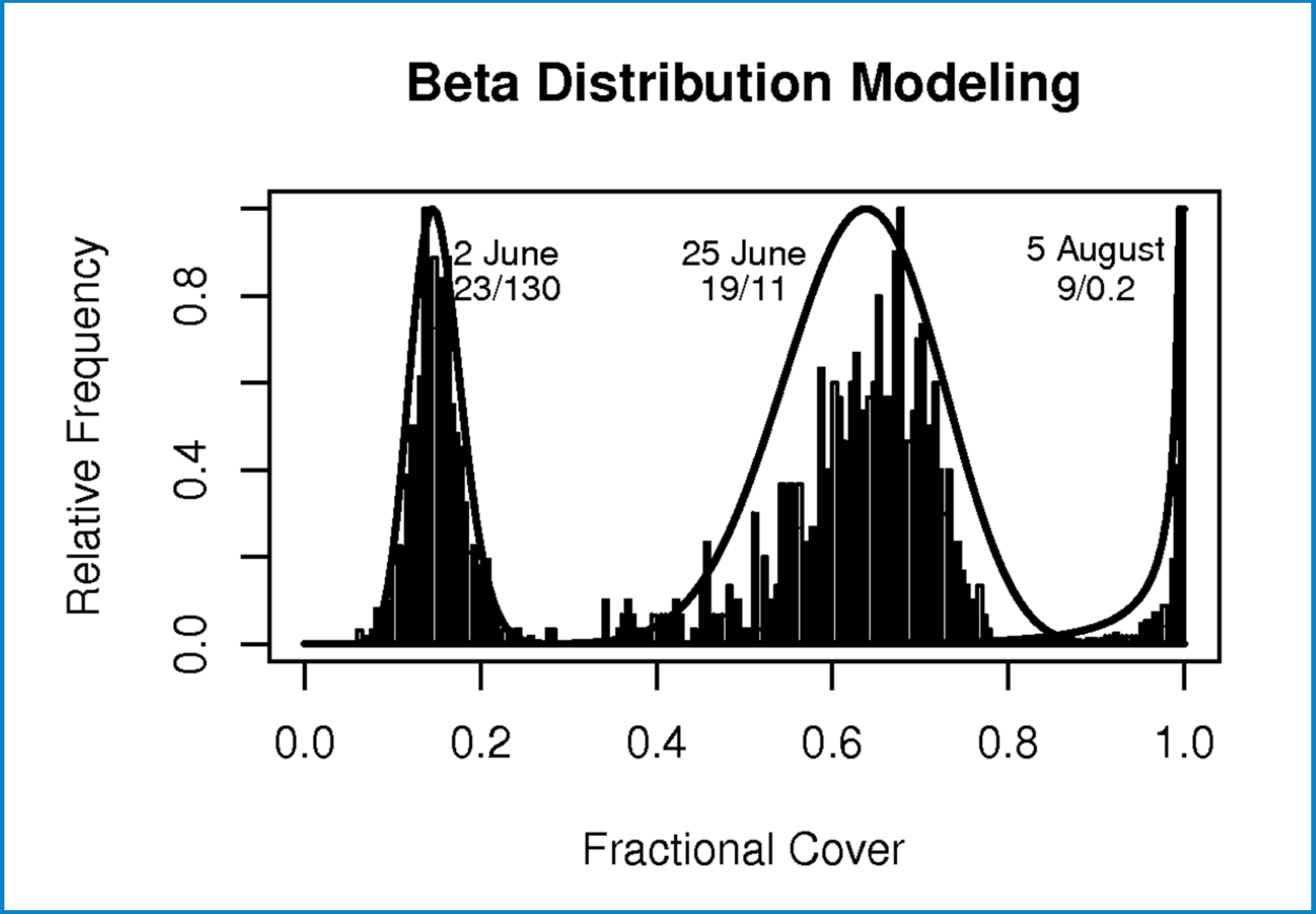


7 Parameter Composite Diurnal Function
- Day length
- Time of maximum temperature
- Time of cosine/exp transition
- Newton cooling decay constant
- Residual temperature difference
- Temperature at sunrise
- Temperature amplitude

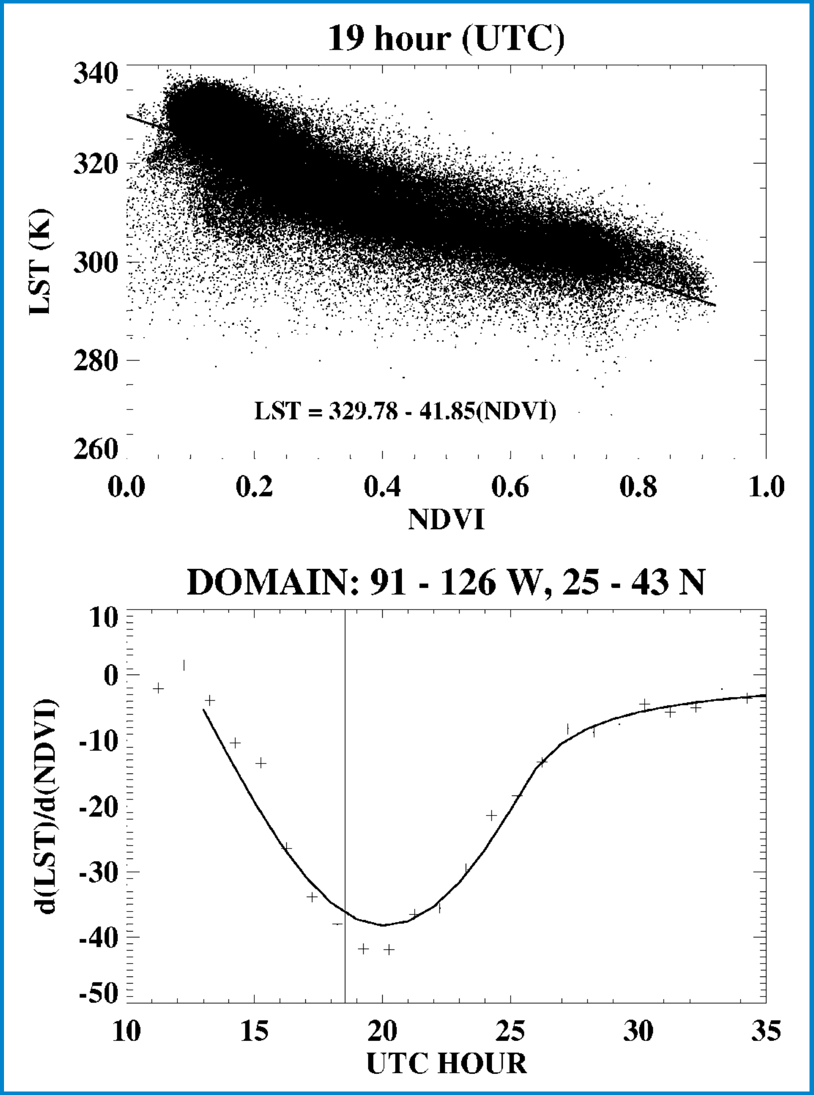
$$T(t) = \begin{cases} T_0 + T_a \cos\left[\frac{\pi}{\omega}(t - t_m)\right] & t < t_s \\ (T_0 + \delta T) + \left[T_a \cos\left[\frac{\pi}{\omega}(t_s - t_m)\right] - \delta T\right] \exp\frac{-(t-t_s)}{k} & t \geq t_s \end{cases}$$

How to extrapolate spatially distributed plant cover?

- Updates needed at least weekly
- Some (most?)process models don't handle spatial effects
- Extrapolation needed for 2-week periods
- Model needs to accommodate plot means and variabilities

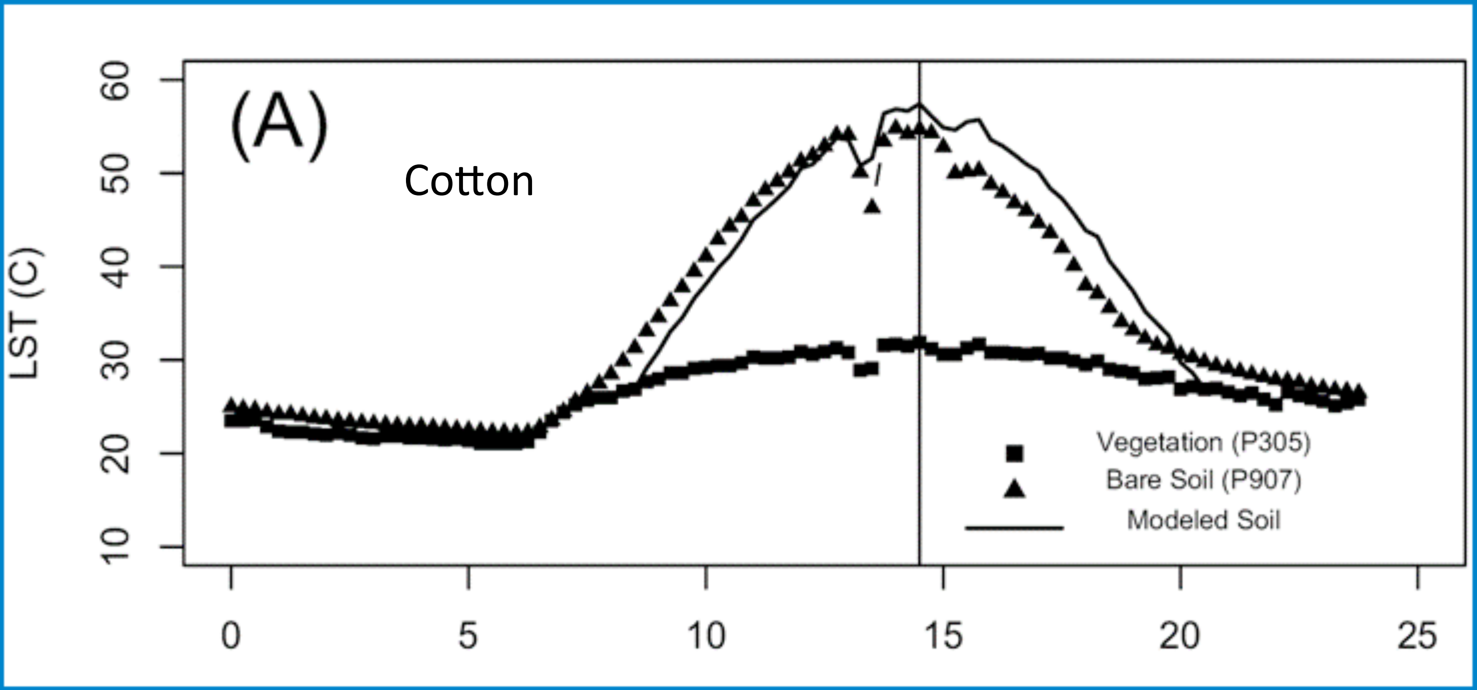


LST Disaggregation & Diurnal LST/NDVI variability



How to Spatially Extrapolate Land Surface Temperatures?

- Empirical approach scales ground observations based on vegetative cover



LST's observations from 2-min radiometric observations of plant/soil

Partitioning of Composite Radiometric Temperature

$T^4 = f*Tveg^4 + (1-f)*Tsoil^4$

- Need additional information to solve
- Sensitive to errors when one fraction is < 0.2
- Some compensation due to corresponding decrease in component Rn