NASA Products for Improving the US Bureau of Reclamation AWARDS ET Toolbox in the Middle Rio Grande

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Interim Project Meeting

Towards Verification and Validation Reporting

Updated July 27, 2007

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16 Sept. 2006

Extending the societal and economic benefits of Earth science research, information, and technology …

Objectives

- Apply, evaluate and benchmark the use of NASA satellite and modeling products to improve USBR AWARDS ET Toolbox DST
  - Use NASA satellite data (e.g., MODIS products) in a METRIC/SEBAL approach to either 1) update outdated ET Toolbox Crop Coefficients and/or 2) replace the ET Toolbox costly approach based on land cover
  - Use NASA Land Information System (LIS) modeling products for ET estimation and short-term predictions (1-7 days)
  - Use and evaluate NASA Products the Upper/Middle Rio Grande River Basin Test Site
  - Design and Implement NASA products for improving AWARDS ET Toolbox DST

Water Management

Science to Decision Support

Science Models

- **LSMs:** *Mosaic, Noah, VIC, Catchment, CLM2*
- **Atmospheric Models/Forecasts:** *NCEP Eta, FSL RUC, MM5, CSU RAMS, NASA GEOS (FVDAS)*
- **River Routing/Streamflow Modeling:** *MMS, CASC2D, DHVSM, TOPMODEL, Vflo™*

Data

Monitoring and Measurements

- **Snow cover and water equivalent:** *MODIS, AMSR-e, SSMI, SMMR*
- **Soil Moisture/Water Storage:** *AMSR-e, TRMM TMI, GRACE, SMOS*
- **Radiation/Energy Budget:** *GOES, MODIS, CERES, ERBE*
- **Land Use/Cover:** *MODIS, ASTER, Landsat*
- **River discharge height (large basins):** *TOPEX/POSEIDON, ERS-1 & 2, ENVISAT*
- **Land Surface/Elevation:** *SRTM*

Inputs

Information Products, Predictions, Visualizations, and Computing

- *Runoff/streamflow*
- *ET Estimates*
- *Soil Moisture*
- *Energy Fluxes*
- *Meteorological Data*
- *Assimilation Techniques for use with remote sensing data in LSMs*
- *Research and operations involve multi-spatio-temporal scales*

Outputs

AWARDS (Agricultural WAter Resources Decision Support system)

- **ET Toolbox** – Estimate high resolution daily rainfall and water depletion through evapotranspiration (crop, riparian, open water)
- Used as input into RiverWare

RiverWare

General river basin modeling environment for operations and planning

- Allow users to model any river basin, manage data input and output efficiently enough for near real-time operations
- Integrates reservoir systems, including flood control, water supply and quality, and hydro-electric power-dam operations

Outcomes

Value and Benefits

- Improved water supply estimates and predictions
- Improve ET estimates for riparian and agricultural areas for irrigators
- Help water resource managers make more informed decisions to help meet hydrologic and ESA needs
- Use of soil moisture estimates can improve monitoring effects of drought conditions

Impacts

Description of the DST

- **Agricultural WAter Resources Decision Support (AWARDS)::**
  - The Bureau of Reclamation operates AWARDS ET Toolbox primarily to assess the amount of water available for agriculture.
  - These assessments are used to portion out limited water resources for various agricultural interests while retaining a portion for other uses (ecosystems, recreation, commerce, etc.).

Contributions to the NASA ASP

- Collaboration with USBR to enable and enhance the application of NASA's Earth System science research results for use in partner's DSTs.
- Focusing on:
  - Estimating water storage – reservoir, snowpack, soil moisture
  - Modeling and predicting water fluxes – evapotranspiration, precipitation, river runoff.
- Identify and assess USBR water management responsibilities, plans and DSTs
- Evaluate capacity of NASA Earth system science results to support the DSTs
- Validate and verify application of NASA Earth system science results with DSTs
- In collaboration with USBR, document value of Earth system science results relative to its obligations and support adoption into operational use

Reclamation DSTs

- Describe Reclamation Metrics

AWARDS ET Toolbox ~

● Eddy Covariance Flux Towers ➔ Validation; establish metrics based on validation at select sites

- Middle Rio Grande HRAP Integrated Streamflow for Intercomparison of ET Toolbox estimates to NASA ET products from 1) METRIC using MODIS and Landsat data and 2) LIS Modeling of ET

RiverWare

● AWARDS ET Tool-box input to RiverWare

● Reservoir Management: releases to meet downstream demands; treaty/compact water needs; operational requirements for flood control and management

Adapting ET Toolbox for NASA Data Products

- AWARDS ET Toolbox
  - Potential NASA data products that could be used as inputs by AWARDS, include
    - LIS modeled data:
      - Evapotranspiration (Emphasis of Study)
      - Soil moisture
      - Predictive forecasts
      - Uses MODIS land cover, surface temperature, LAI, albedo, etc.
    - METRIC ET
      - MODIS/Landsat/ASTER data
      - Uses nearby weather station data for reference ET extrapolations
- Modifications needed
  - Update Crop Coefficients; Replace land cover approach; Modeling for predictions

Use of LIS in USBR Projects

- At NASA, the land surface models and datasets used in the LIS modeling environment are being customized to fit to each DST's specifics and datasets for evaluation and benchmarking purposes.
- Key fields of interest:
  - River runoff and streamflow (hydrographs)
  - Total evapotranspiration (ET) and ET components
  - Short-term (1-7 days) predictions of streamflow
- USBR Researchers and Water Managers testing the output retrospectively and hopefully eventually operationally

V & V Components

Verification and Validation

The V&V component to this systems engineering approach is closely connected to the evaluation and benchmarking phases:

a) During the V&V phase, NASA data and data products are integrated into the DST to generate model outputs.

b) To insure the quality of the output, the results are VERIFIED by comparison with model runs using in situ data as inputs - these are the default runs shown in the following tables.

c) The next step is the VALIDATION phase in which NASA interacts with the end users (USBR) to insure that the outcome from the enhanced DST (using NASA inputs) meets the functional needs of the Bureau of Reclamation. In other words the DST is operating correctly with the NASA inputs.

Project Products

Benchmark/Final Report

Benchmark report to address the following:

a) Performance of the decision support system (DSS) with the Earth science results compared to DSS beforehand (Metrics are the statistics produced by ET Toolbox)

b) Results of requirements analysis and issues resolved during verification and validation

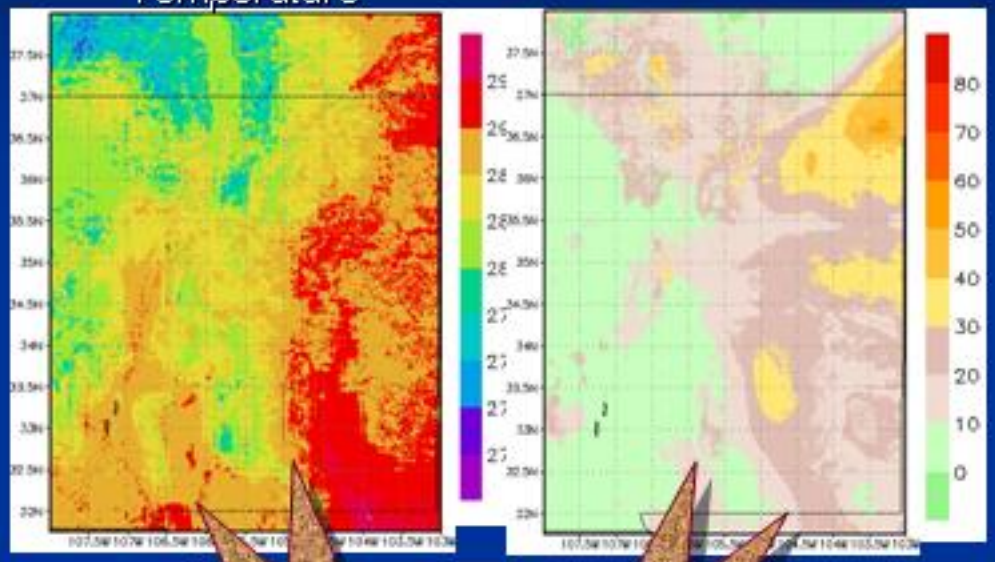
c) Issues related to transfer and adoption by the Bureau of Reclamation

d) Robust documentation of procedures and guidelines to describe the steps to access and utilize the Earth science research results

Application of NASA Land Information System Products for ET Toolbox

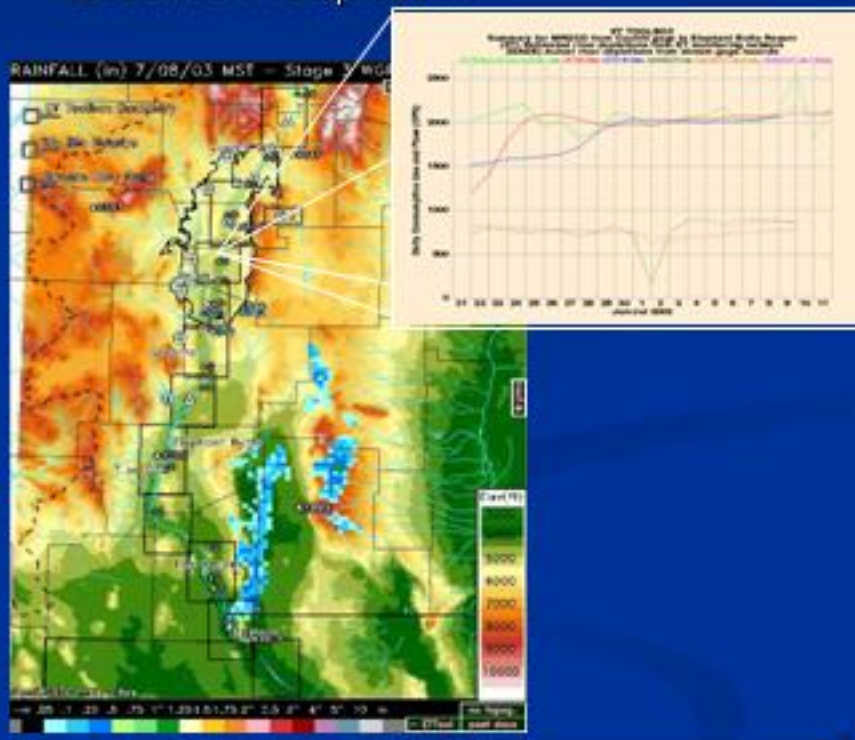
Using LIS Modeled Output for Enhanced Evapotranspiration Estimates – Reclamation Project

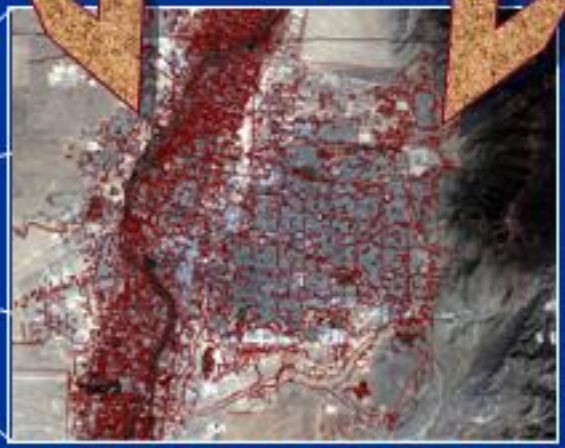
- *LIS Land Surface Temperature*
- *LIS Latent Heat Flux*



Reclamation's AWARDS ET-Toolbox –

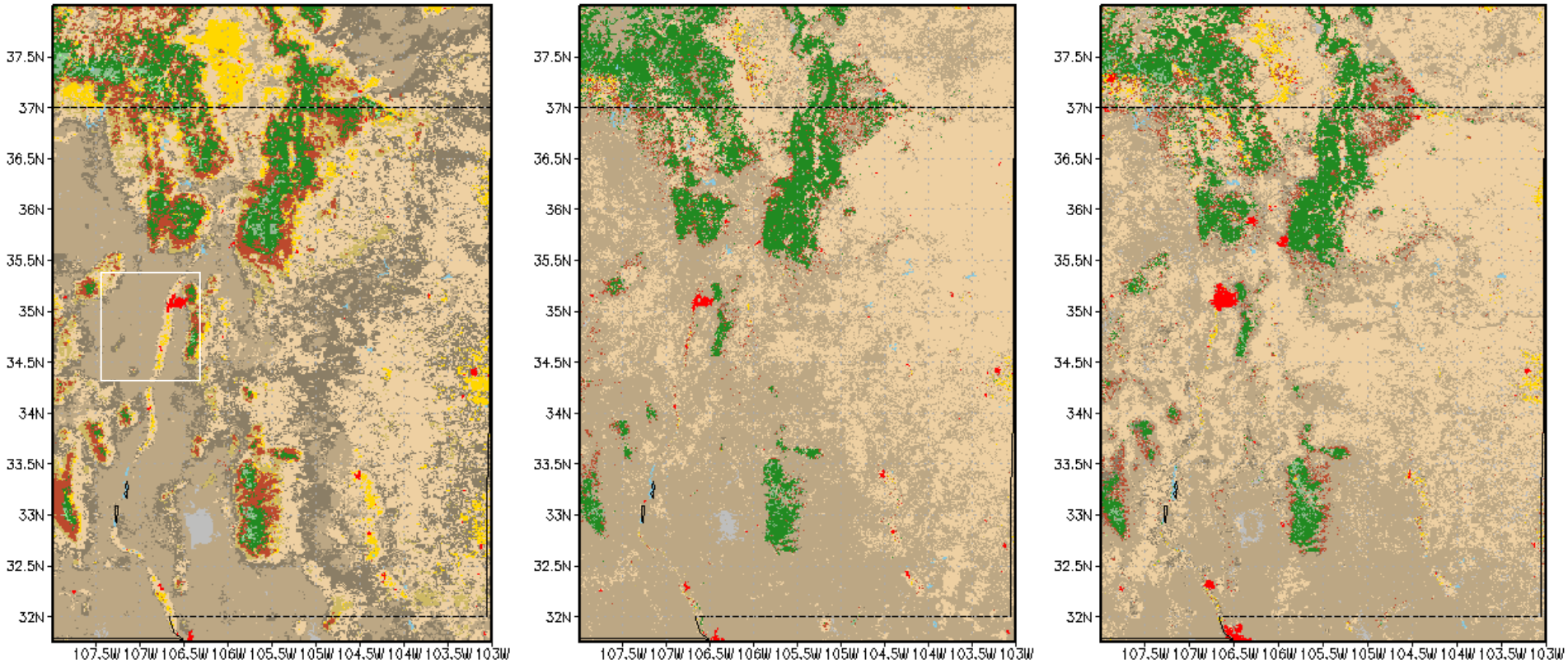
- *Evapotranspiration*
- *Effective Precipitation*





➡ **Middle Rio Grande River, New Mexico**

➢ Parameterizing and assimilating MODIS, Landsat and ASTER data into LIS models to be tested in the AWARDS ET-Toolbox



AVHRR
UMD land cover

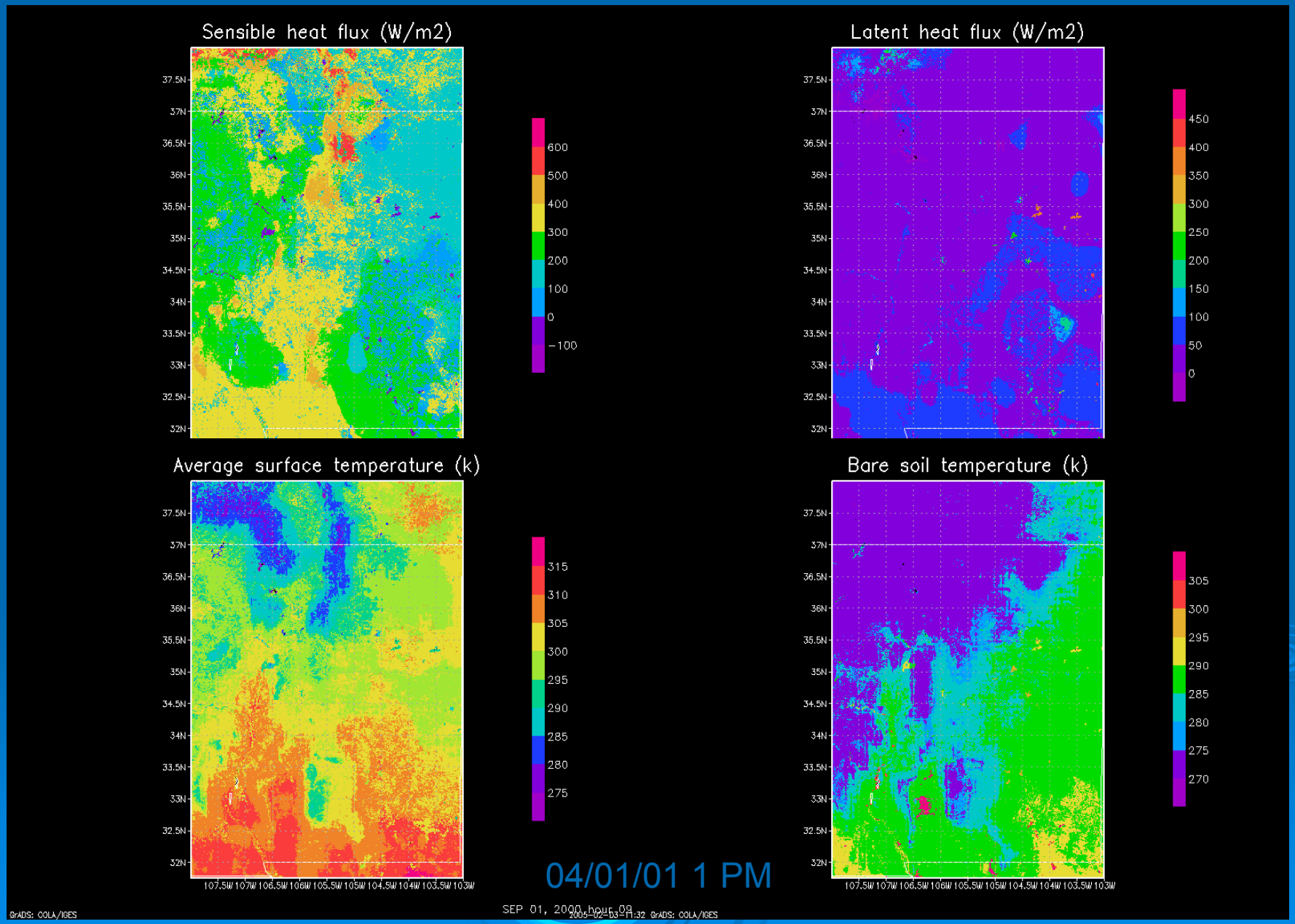
MODIS V3
UMD land cover

MODIS V4
UMD land cover

Satellite-derived land cover classifications for the state of New Mexico.

Arsenault et al. 2005

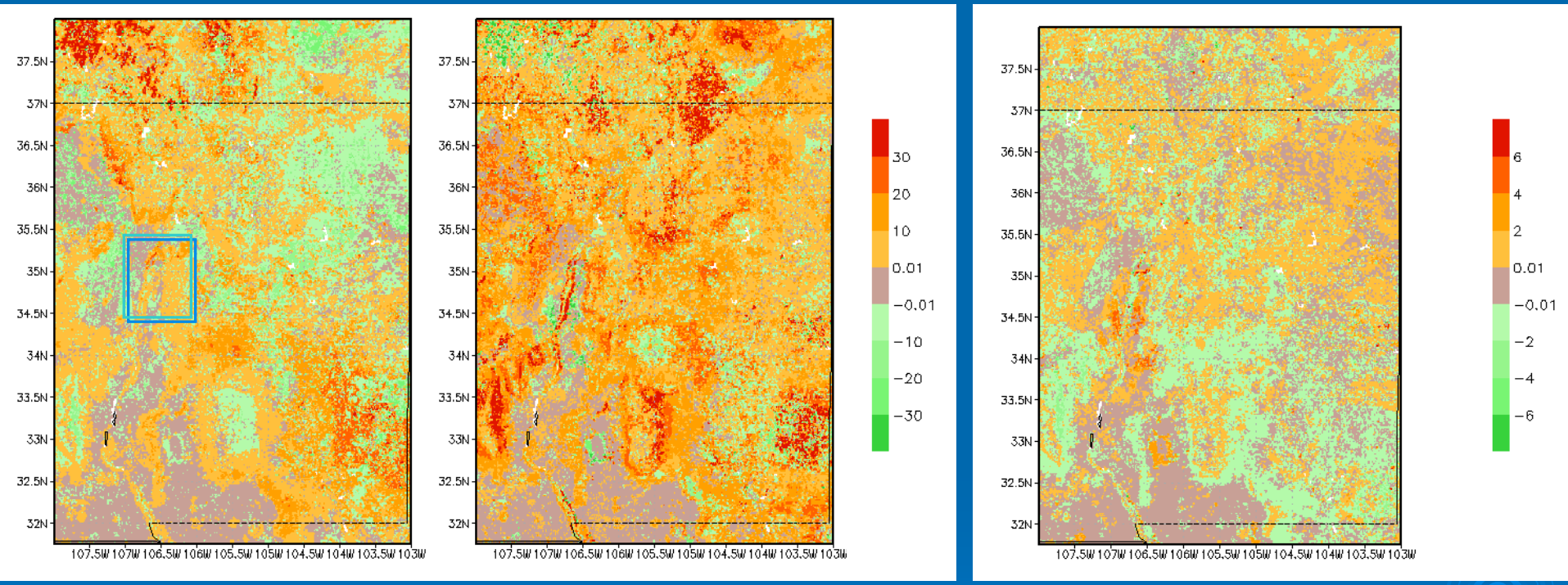
LIS Land Surface Model Runs Over New Mexico



Differences between (1) AVHRR run and (2) MODIS-V3

May 30, 2002 (18 Z)

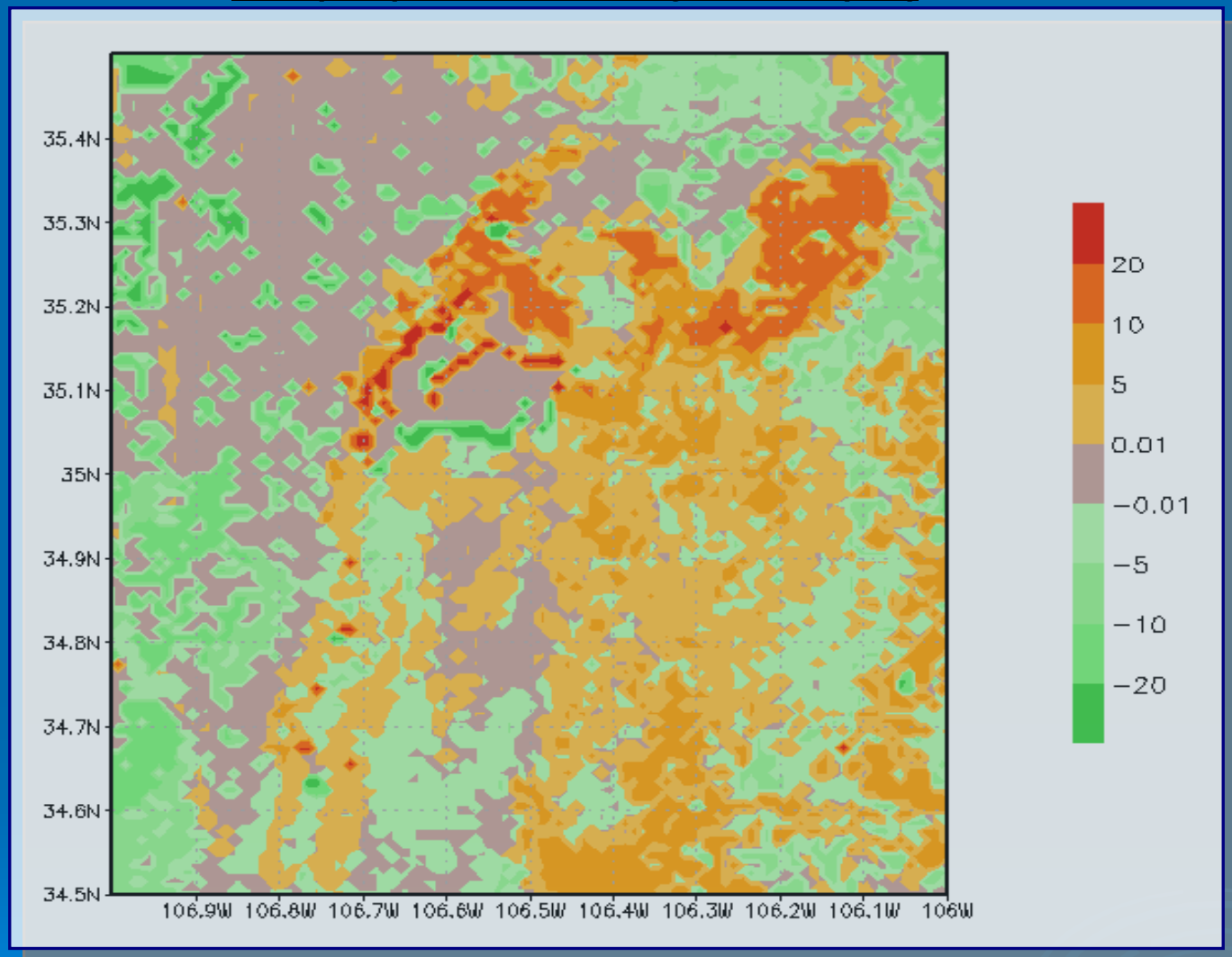
Latent Heat Flux (W m^{-2}) | Sensible Heat Flux (W m^{-2}) | Top 10 cm Soil Temperature (Celsius)



"The figures above show the differences in latent heat flux, sensible heat flux and the top layer soil temperature for the Noah LSM with regard to two different satellite-derived land class maps. The boxed area in the LH Flux plot (left-most figure above) is highlighted further on the next slide.

Latent Heat Flux (W m-2): AVHRR run – MODIS3 run

Albuquerque, NM area – May 30, 2002 (18Z)



The figure above is the Albuquerque area and shows the difference between the latent heat flux fields of the AVHRR run and the MODIS-V3 run.

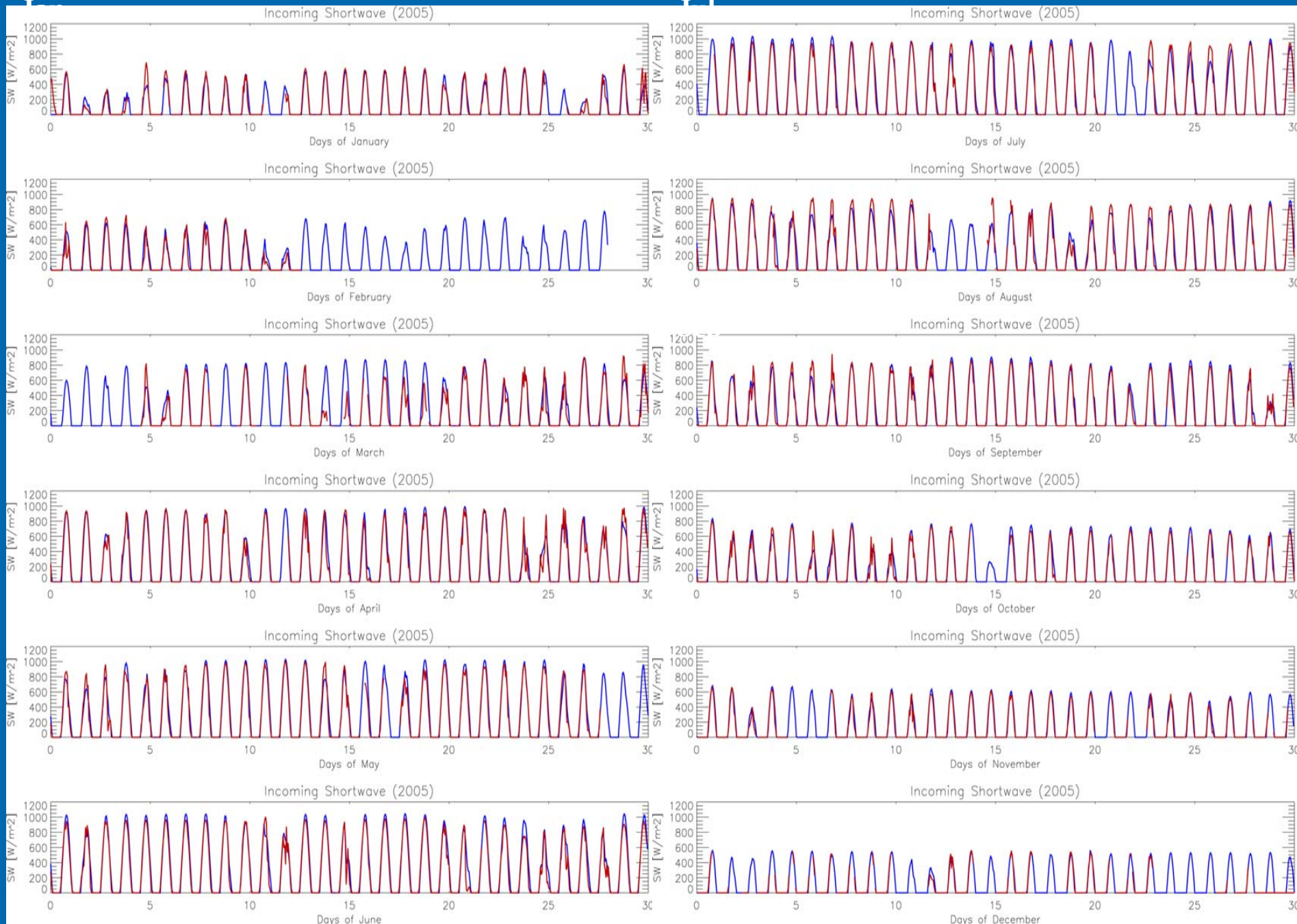
Comparison of LIS Derived Water and Energy Flux for Two Reference Sites in Middle Rio Grande site

Sevilleta (SEV)	Latitude	Longitude
	34.265ºN	106.865ºW
Soil	Loamy sand	
	Sand fraction	0.82
	Clay fraction	0.06
	Silt fraction	0.12
In Noah	Porosity	0.421
	SMCREF	0.248458
	SMCWLT	0.0285
Vegetation	Salt cedar	
	NROOT	4
	LAI	5.0
	Greenness fraction	Seasonal
	RSMIN	150

SHK	Latitude	Longitude
	34.955ºN	106.685ºW
Soil	Silty clay loam	
	Sand fraction	0.1
	Clay fraction	0.34
	Silt fraction	0.56
In Noah	Porosity	0.421
	SMCREF	0.248458
	SMCWLT	0.0285
Vegetation	Cottonwood	
	NROOT	4
	LAI	5.0
	Greenness fraction	Seasonal
	RSMIN	150

Incoming Shortwave Radiation @ SEV

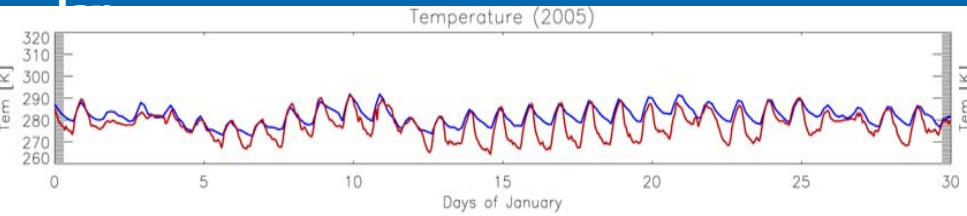
NLDAS: blue OBS: red

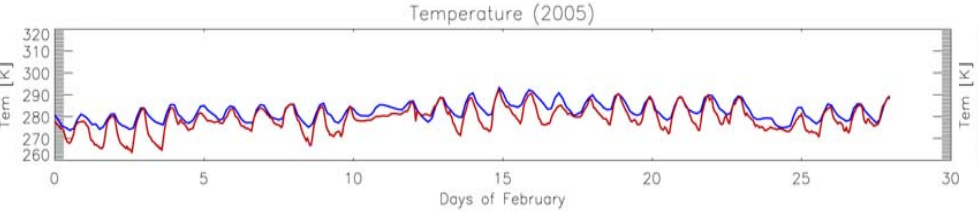


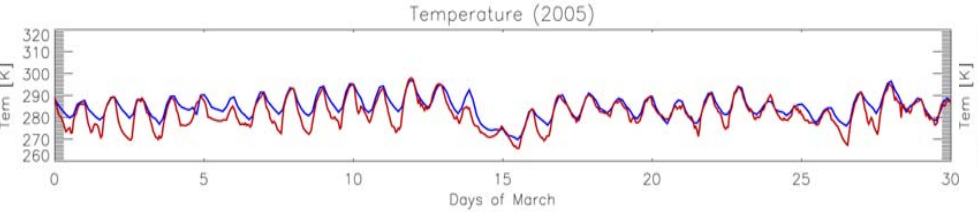
Temperature @ SEV

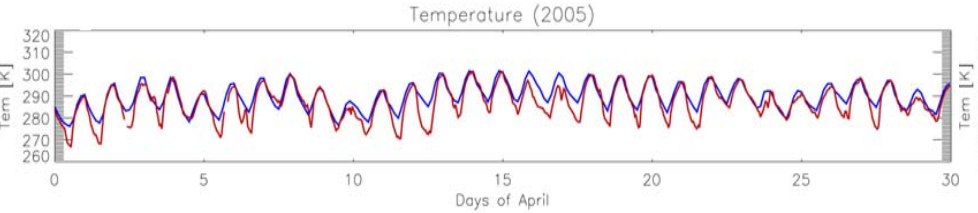
NLDAS: blue OBS: red

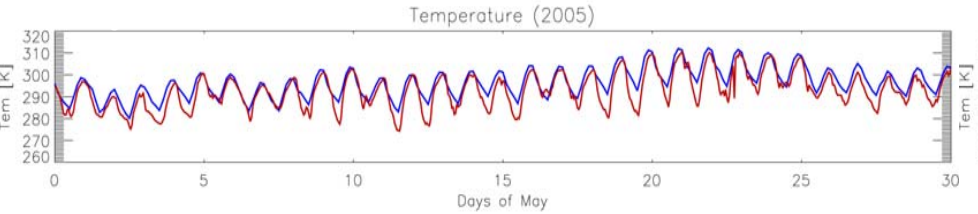
Jan

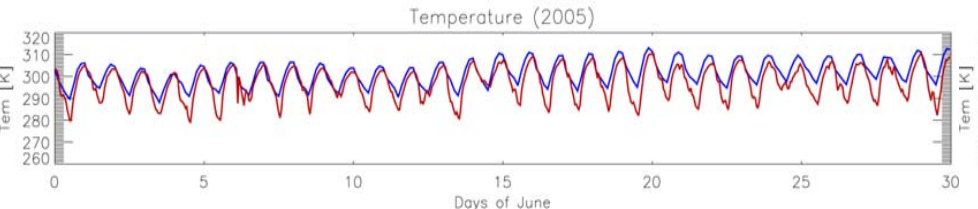












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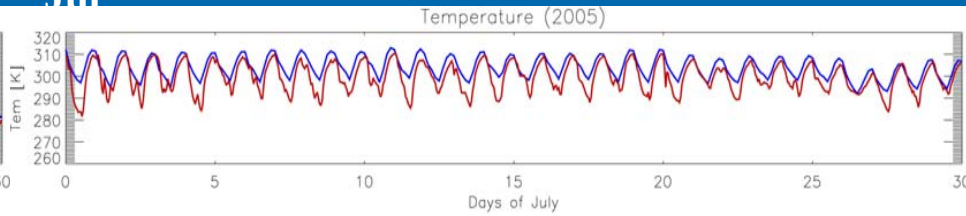
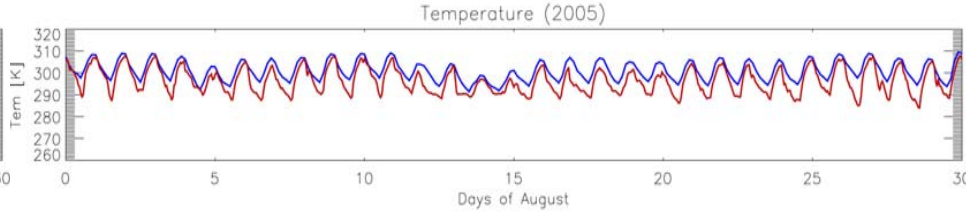
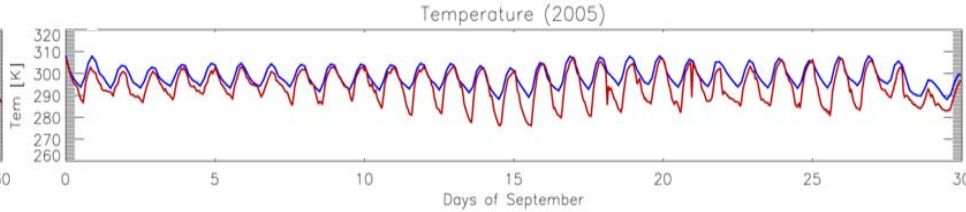
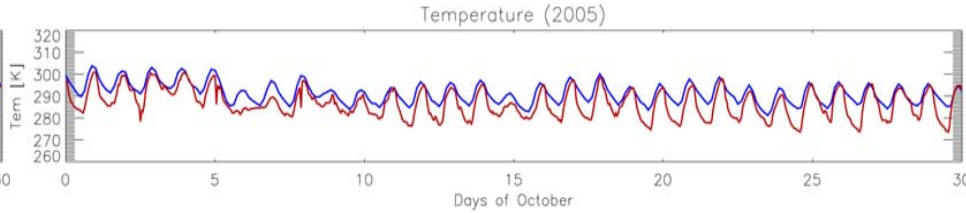
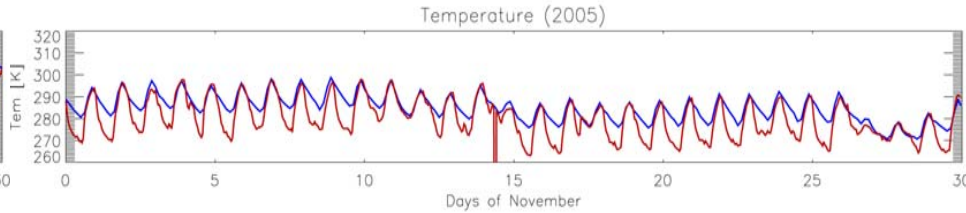
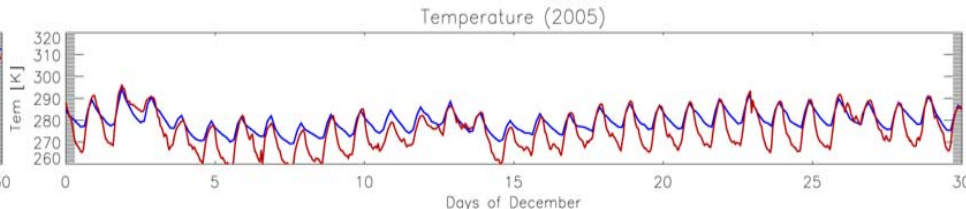






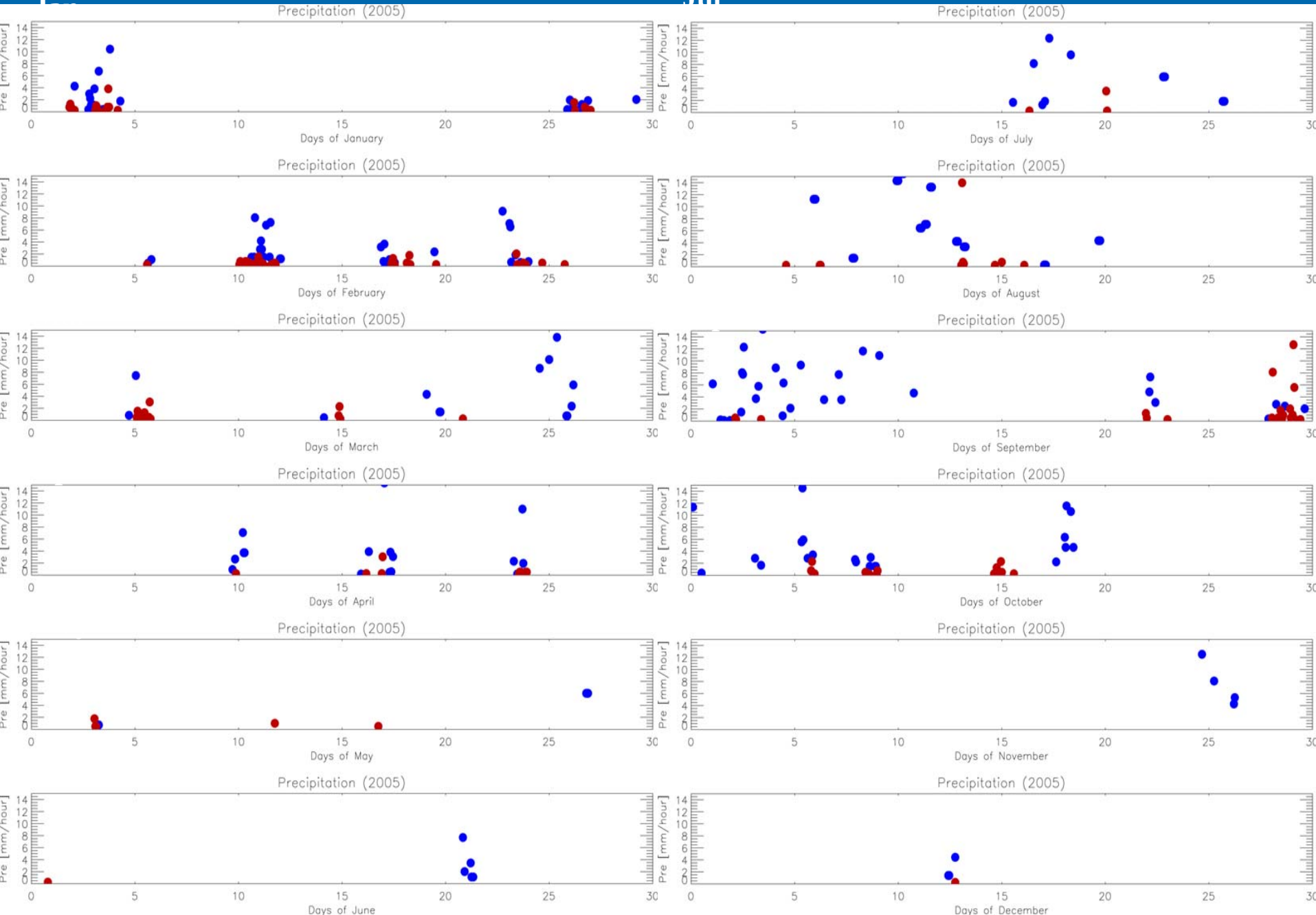






Precipitation @ SEV

NLDAS: blue OBS: red



Designed Experiments

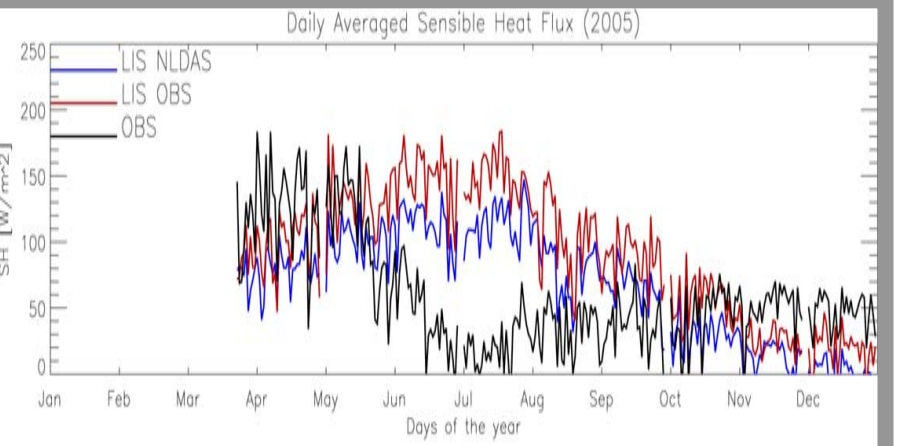
MODEL: LIS4.3 NOAH2.7.1

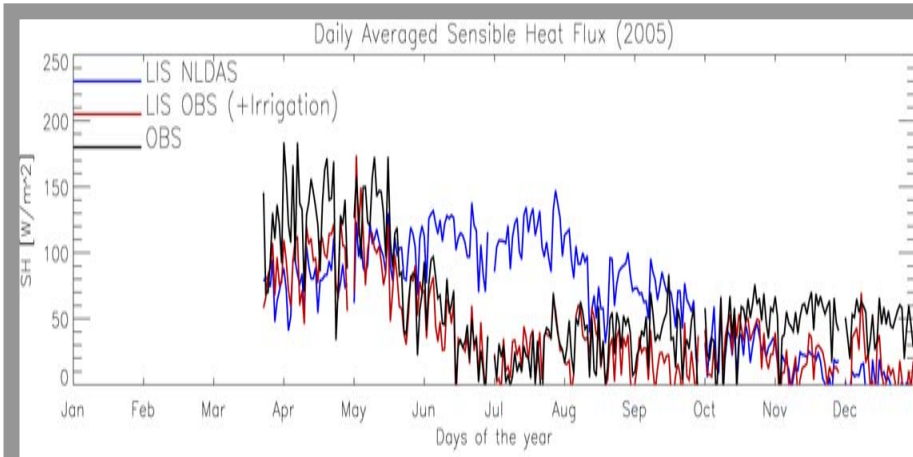
1. **LIS NLDAS: Using NLDAS forcing**
2. **LIS OBS: Using In Situ forcing**
3. **LIS OBSI: Using In Situ forcing (+Irrigation)**
4. **LIS OBSR: Using In Situ forcing (+Riparian)**

Spin-up over 01/01/2000 – 01/01/2005

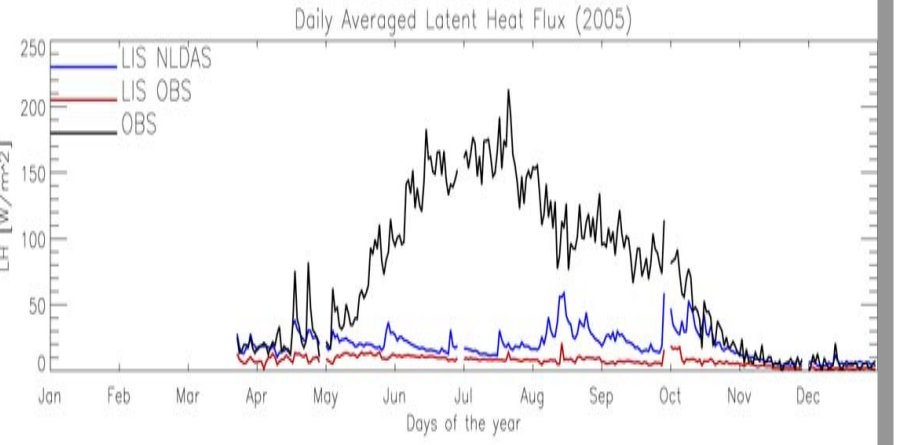
Daily Mean Flux

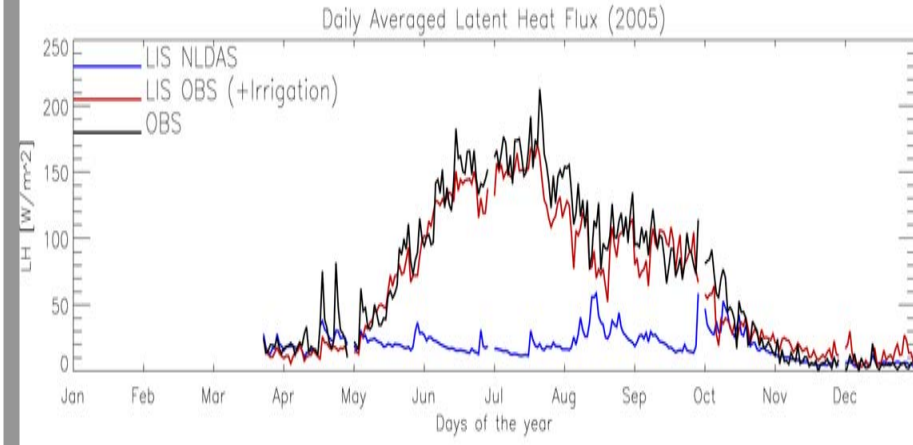
Irrigation Experiment (SEV)



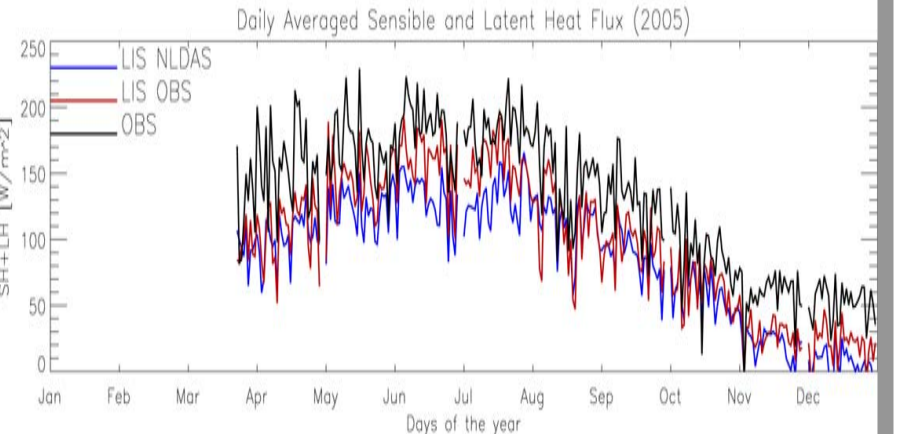


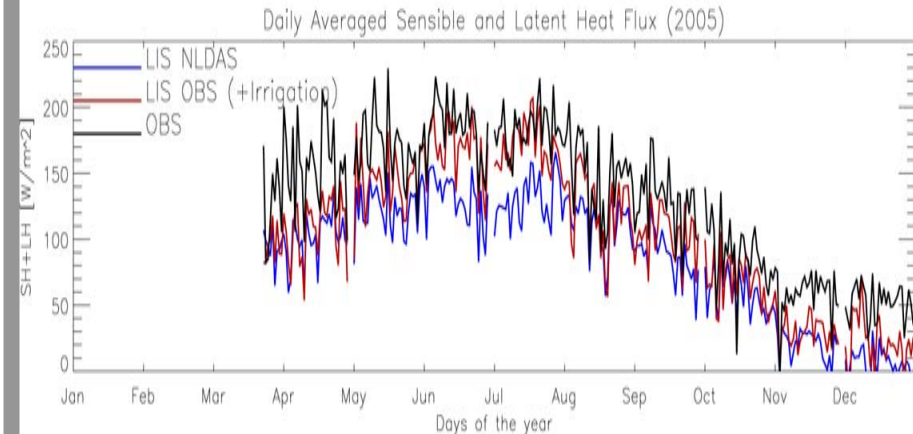
SH





LE



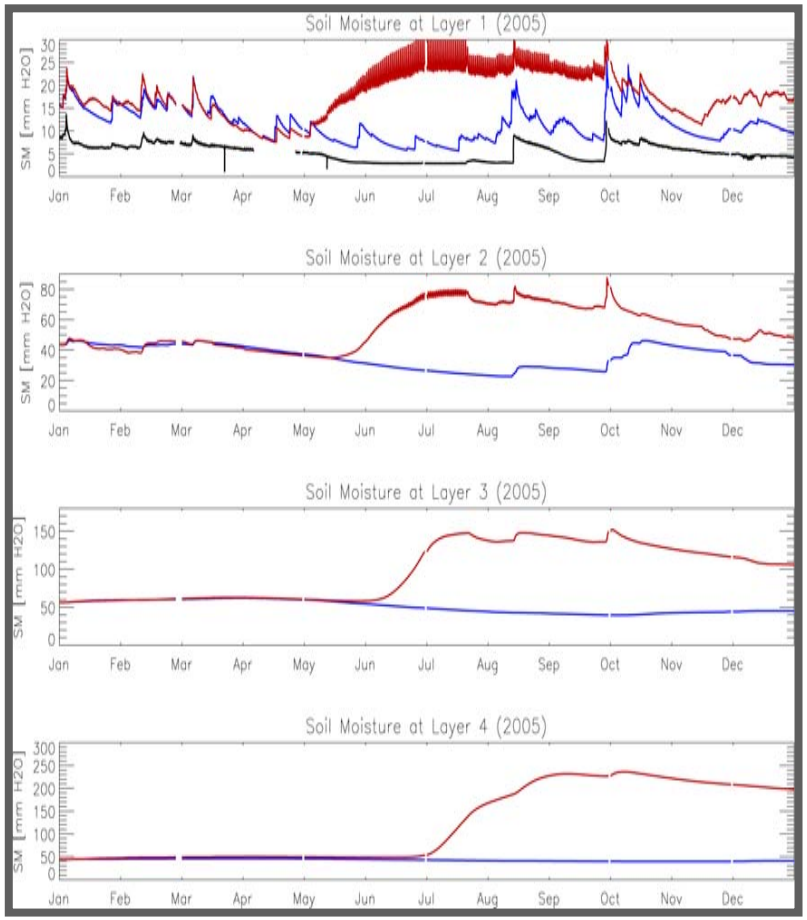


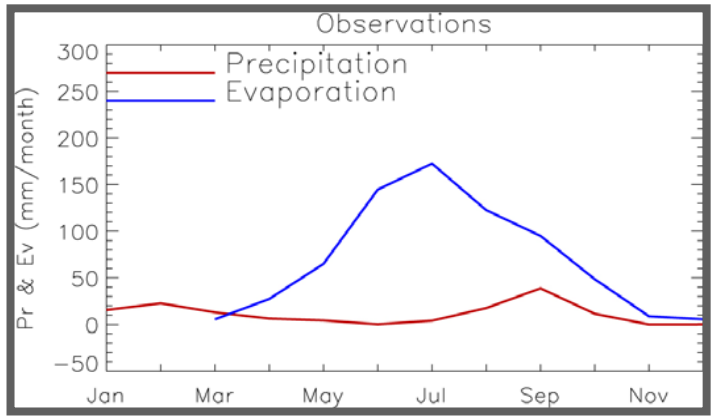
SH+

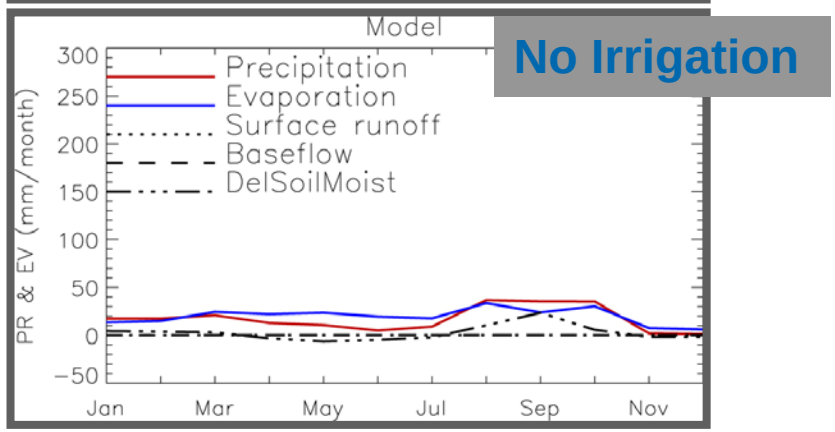
LE

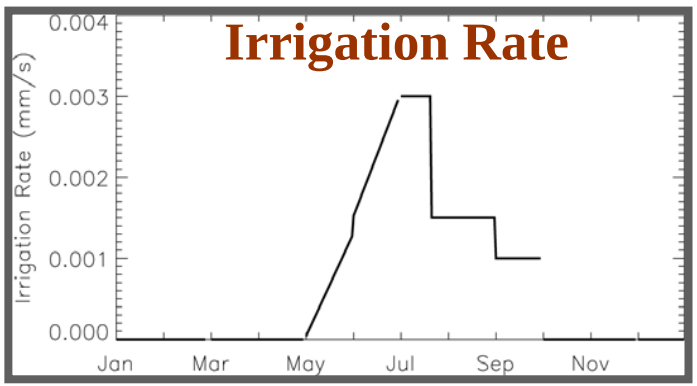
Soil Moisture | Irrigation Experiment (SEV Site) | Water Budget

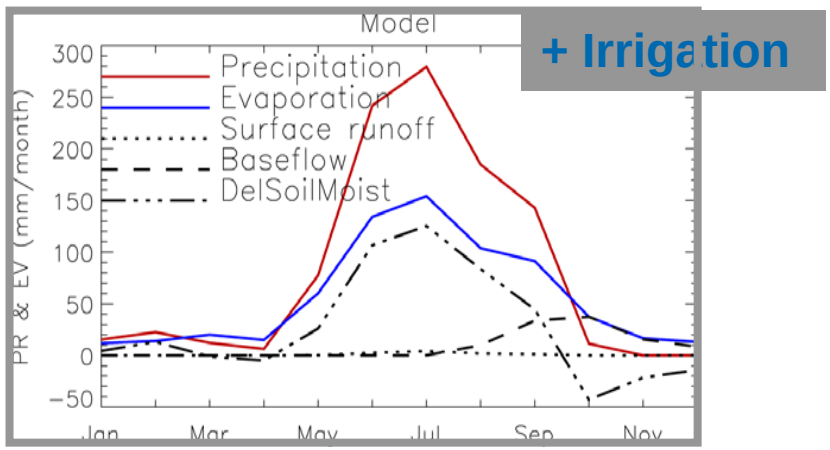
Obs. -- Blk
Model + Irrigation – Red
Model + No Irrigation -- Blue











Daily Mean Flux @ SEV

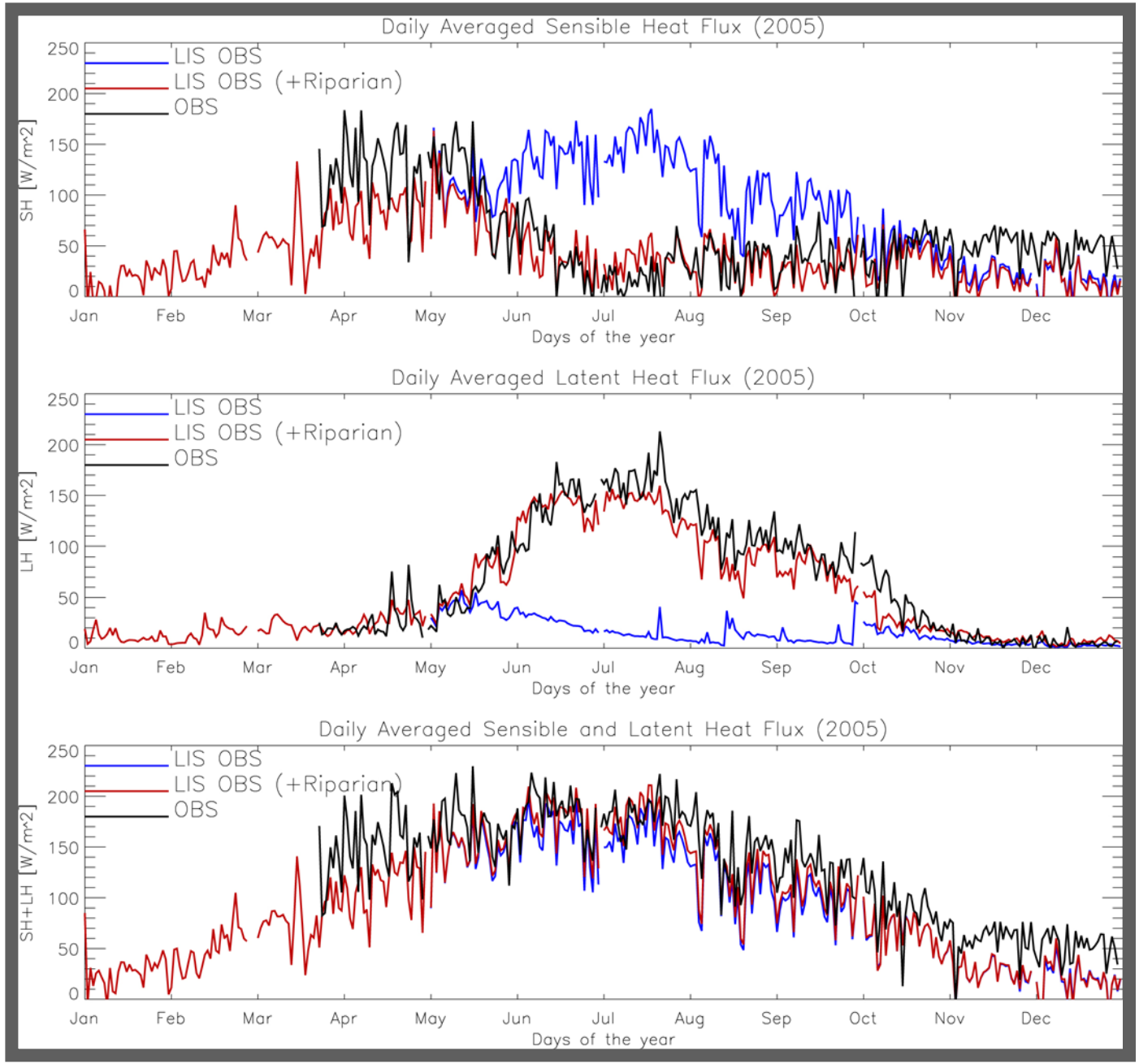
Riparian Experiment I

Riparian – Adjust Bottom Layer Only

SH

LE

SH+LE



Daily Mean Flux @ SHK

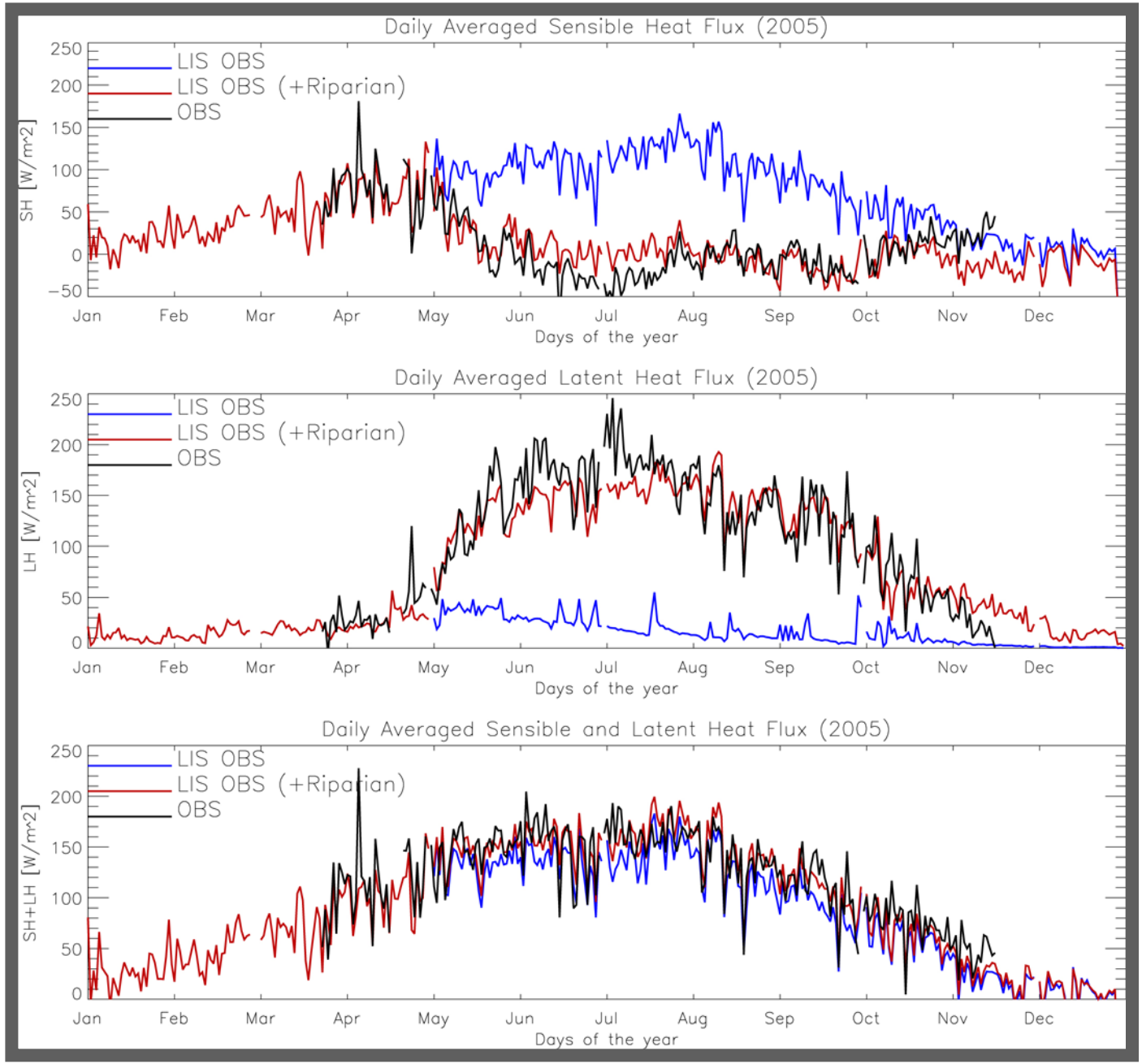
Riparian Experiment II

Riparian –Bottom 2 Layers

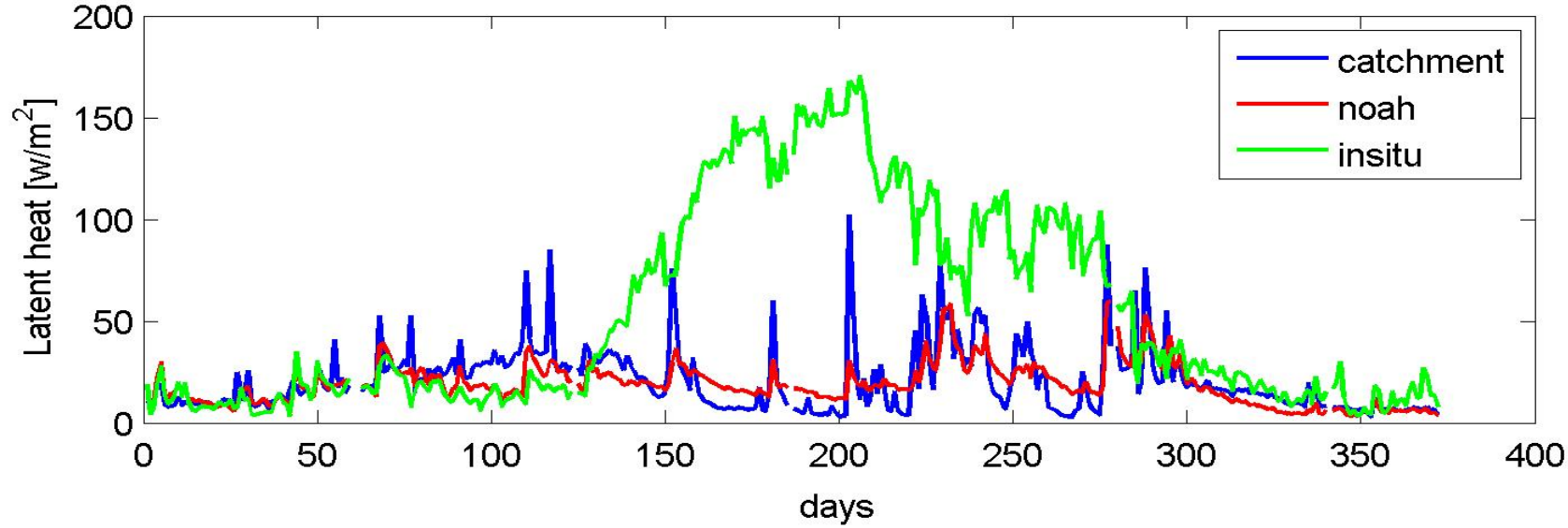
SH

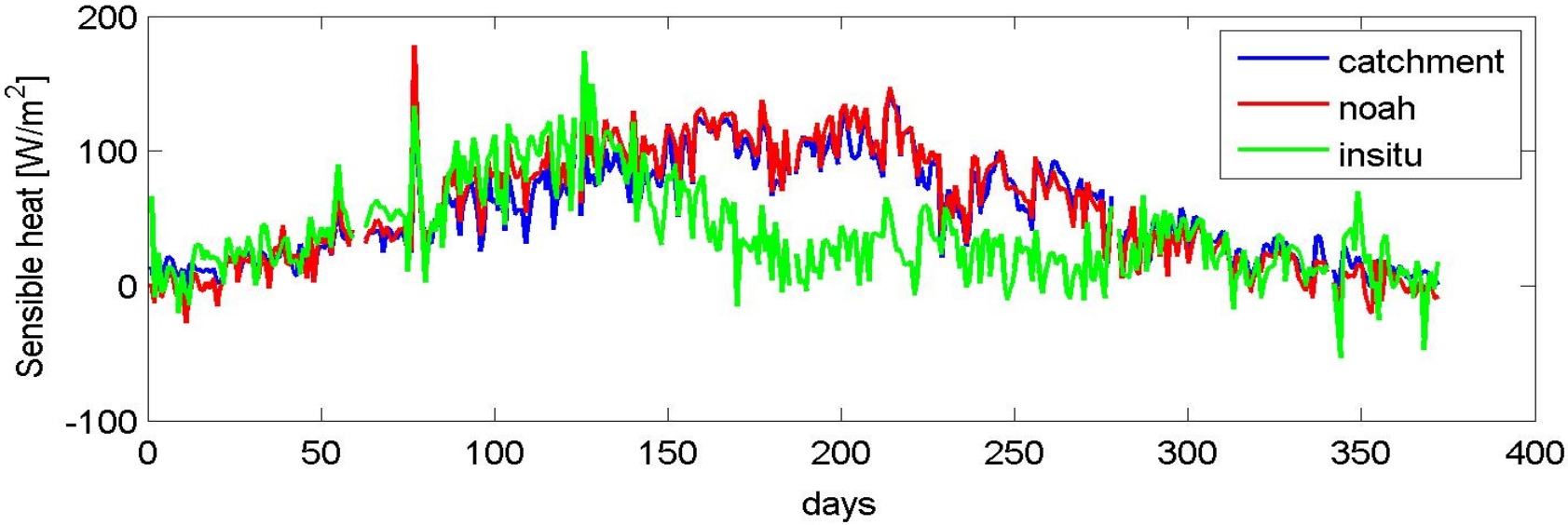
LE

SH+LE



Preliminary Results for LIS Catchment LSM for Middle Rio Grande



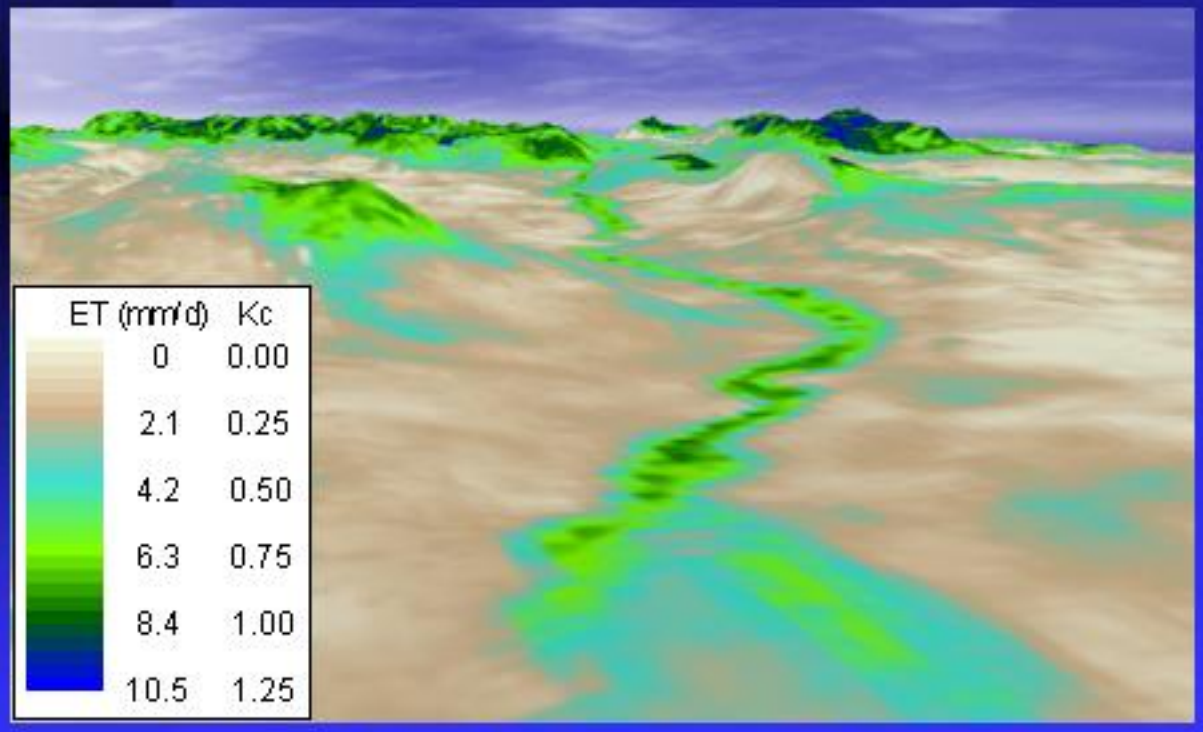


NASA Satellite Data for Evapotranspiration to AWARDS ET Toolbox (PI: Richard Allen, Univ. Idaho)

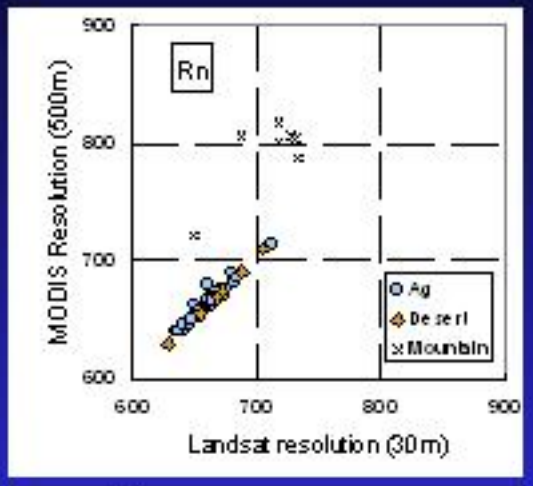
- Using SEBAL procedure (Surface Energy Balance Algorithm for Land) and METRIC, which is an extension of SEBAL, to generate ET maps
- MODIS and METRIC-based ET maps are designed to work within the AWARDS gridcells
- For the Middle Rio Grande METRIC-based ET are derived using multiple MODIS satellite imagery augmented by periodic high resolution Landsat imagery.
- ET derived from Landsat images may be used to validate MODIS-based ET maps,
- Developed Kc (Crop Coefficient) information to be fed into the AWARDS and ET Toolbox to be combined with daily reference ET to produce daily ET demands.

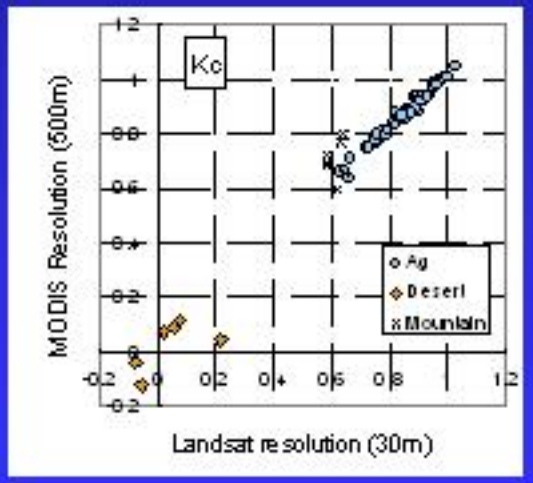
Translation of METRIC from Landsat to MODIS (R. Allen, University of Idaho)

Applications with MODIS were tested using the original Landsat basis in Idaho and New Mexico



MODIS derived 3-D Evapotranspiration map (MRG, NM, 8/26/2002)

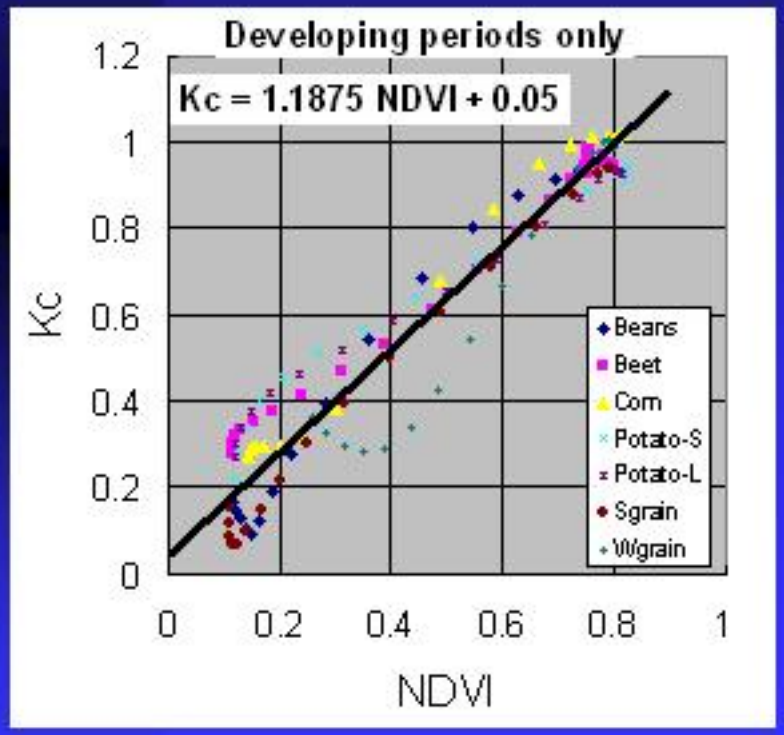




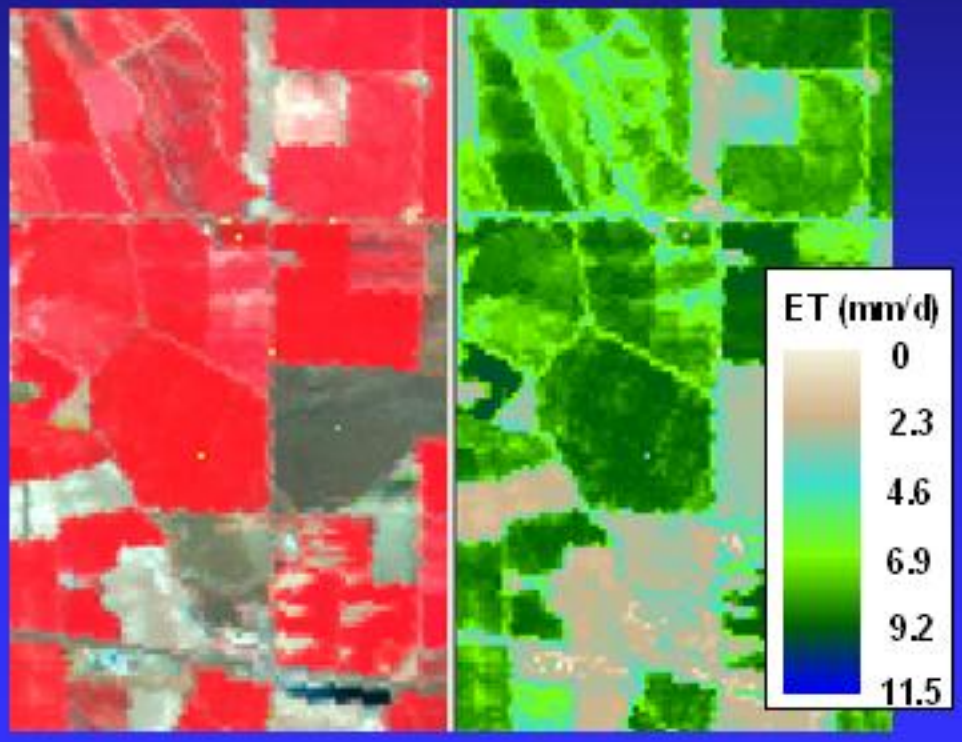
Comparison of Net Radiation and K_c estimation for MODIS and Landsat resolution.

Model Development for AWARDS K_c

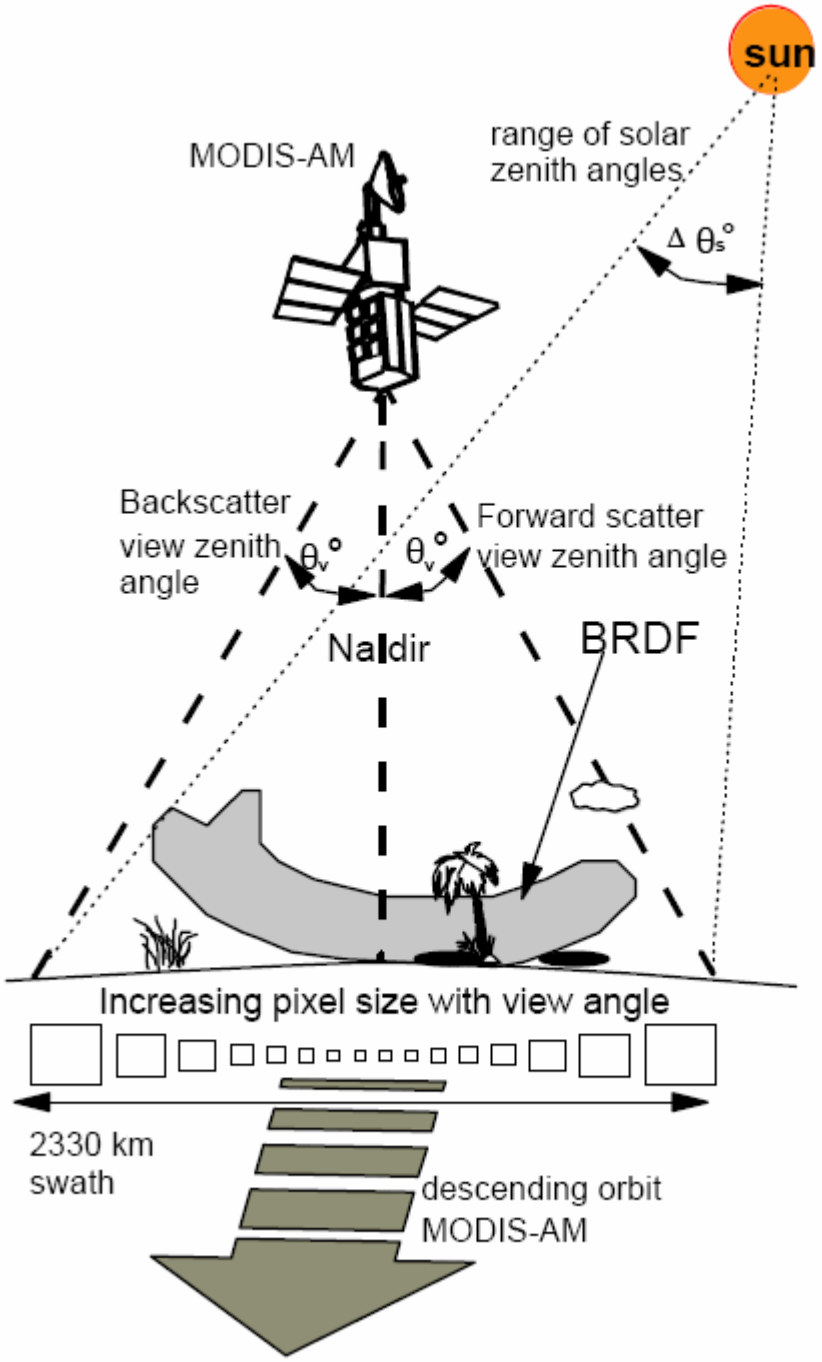
An NDVI based ET estimation method is being extended for future annual updates of AWARDS Kc.



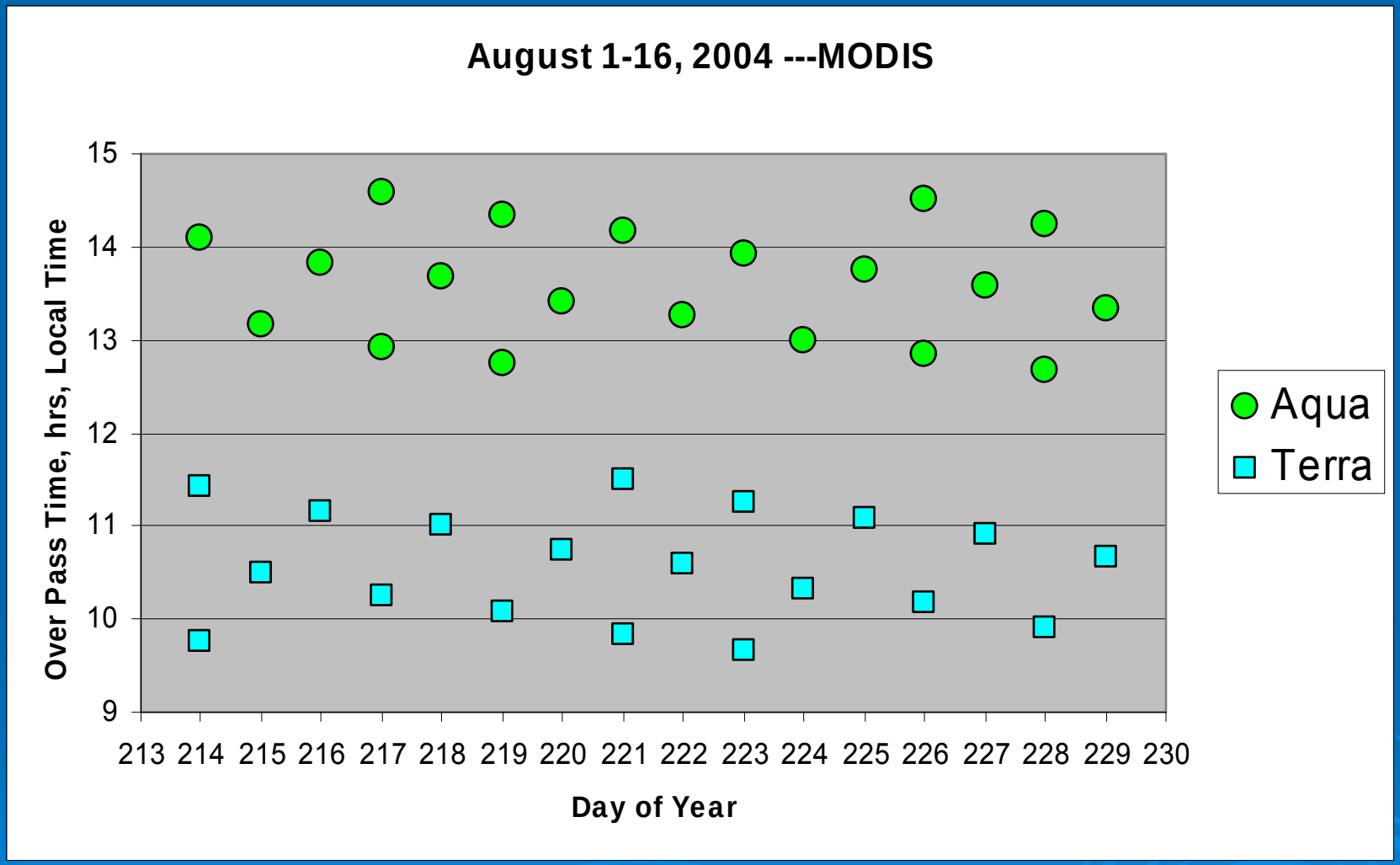
Average K_c vs. NDVI for a variety of crop types in Idaho



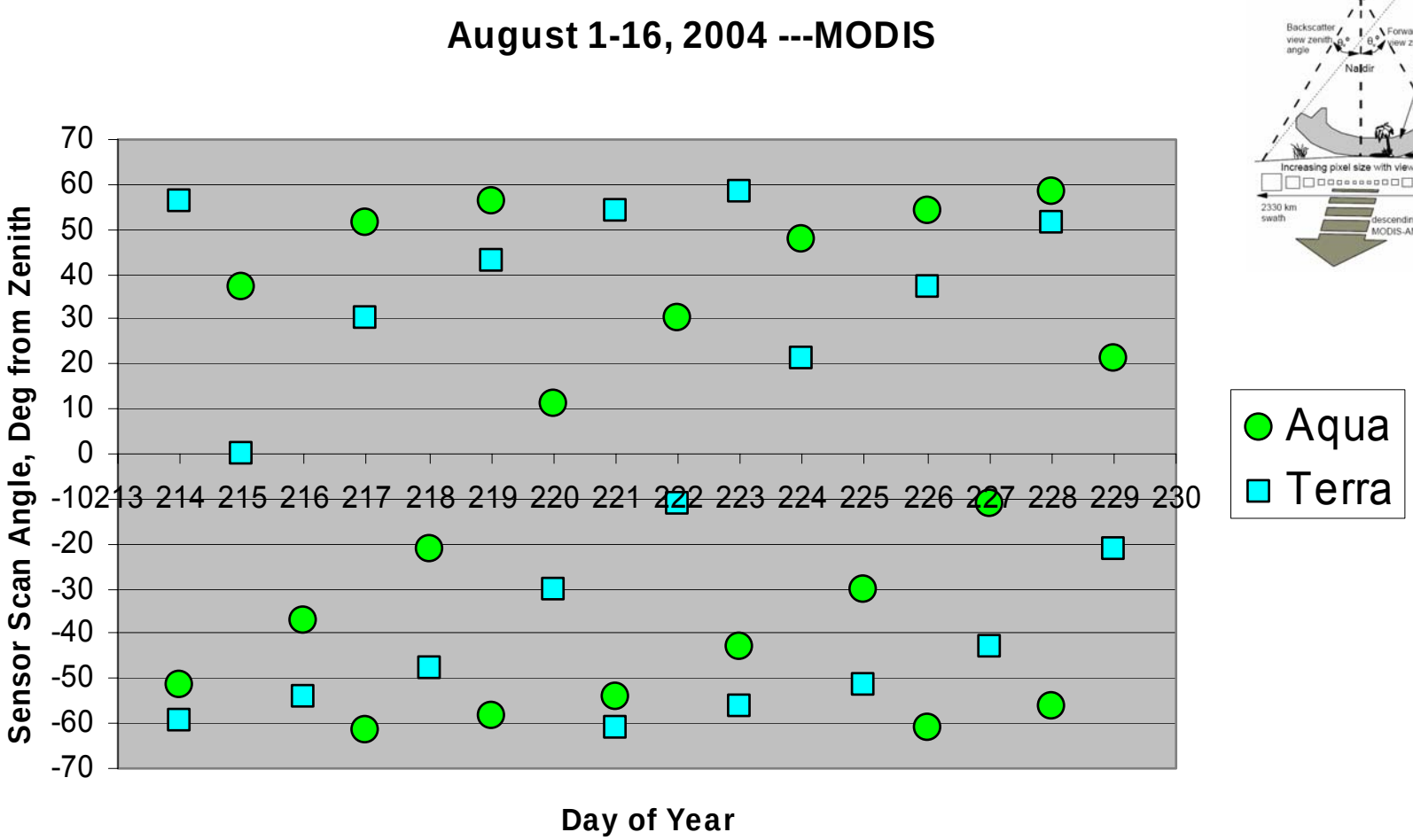
Landsat image and the corresponding ET estimated from NDVI in New Mexico.

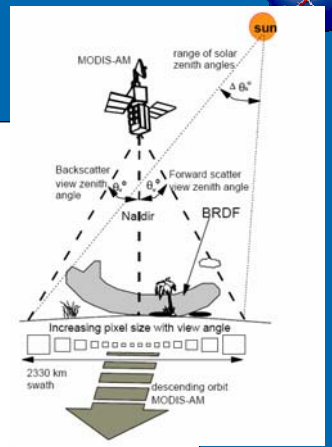

sun
MODIS-AM
range of solar
zenith angles
Δ θs°
Backscatter
view zenith
angle
θv°
θv°
Forward scatter
view zenith angle
Naldir
BRDF
Increasing pixel size with view angle
2330 km
swath
descending orbit
MODIS-AM

Over Pass Time, Twin Falls, Idaho

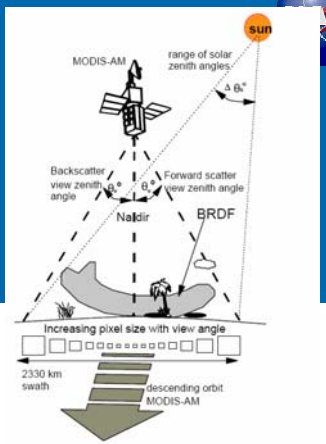


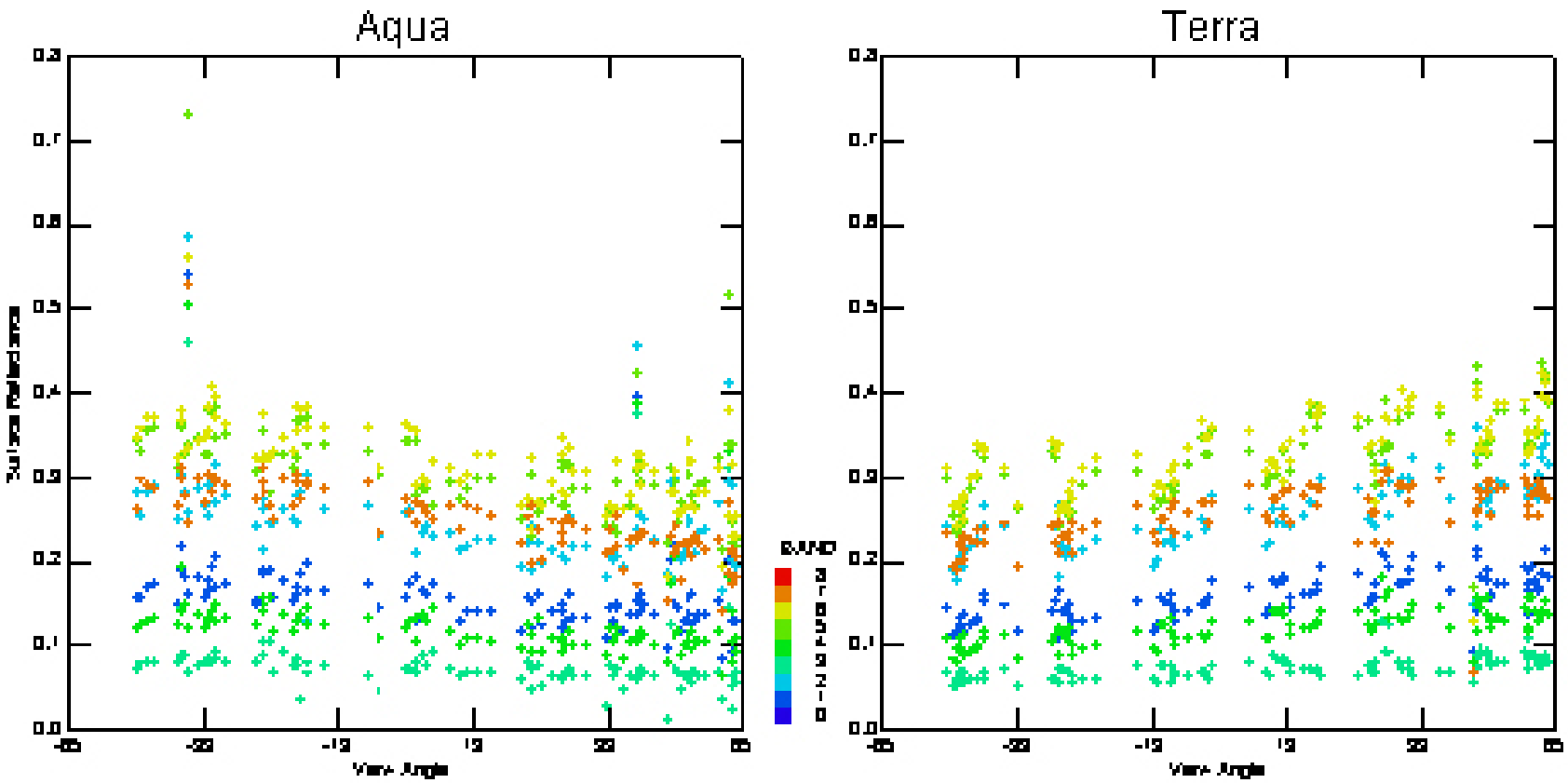
Scan Angle (from Zenith), Twin Falls, Idaho

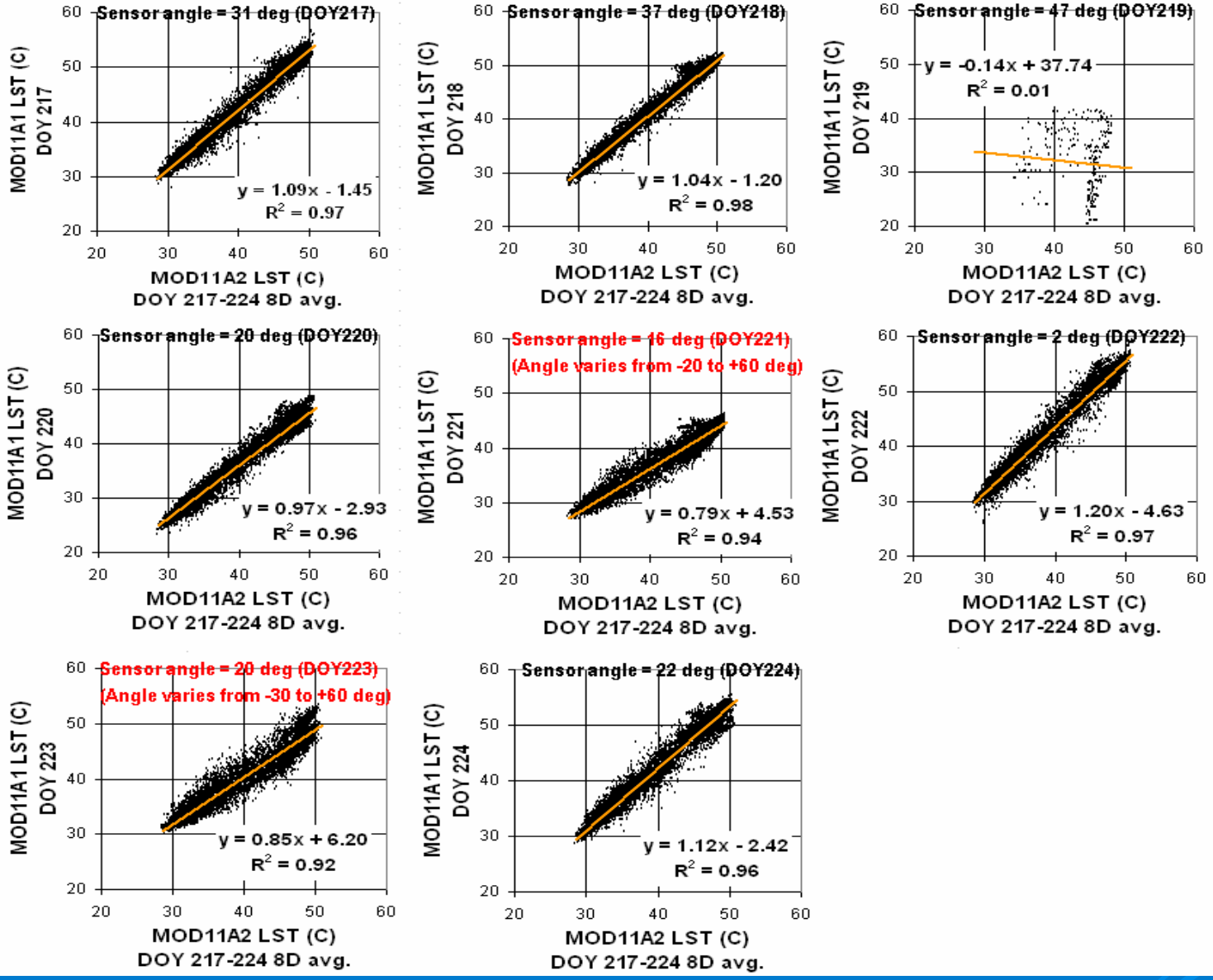




Scan Angle Effect on Reflectance, S. Idaho





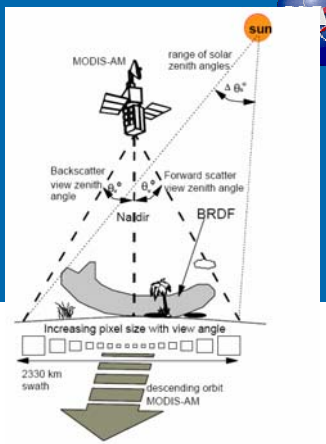


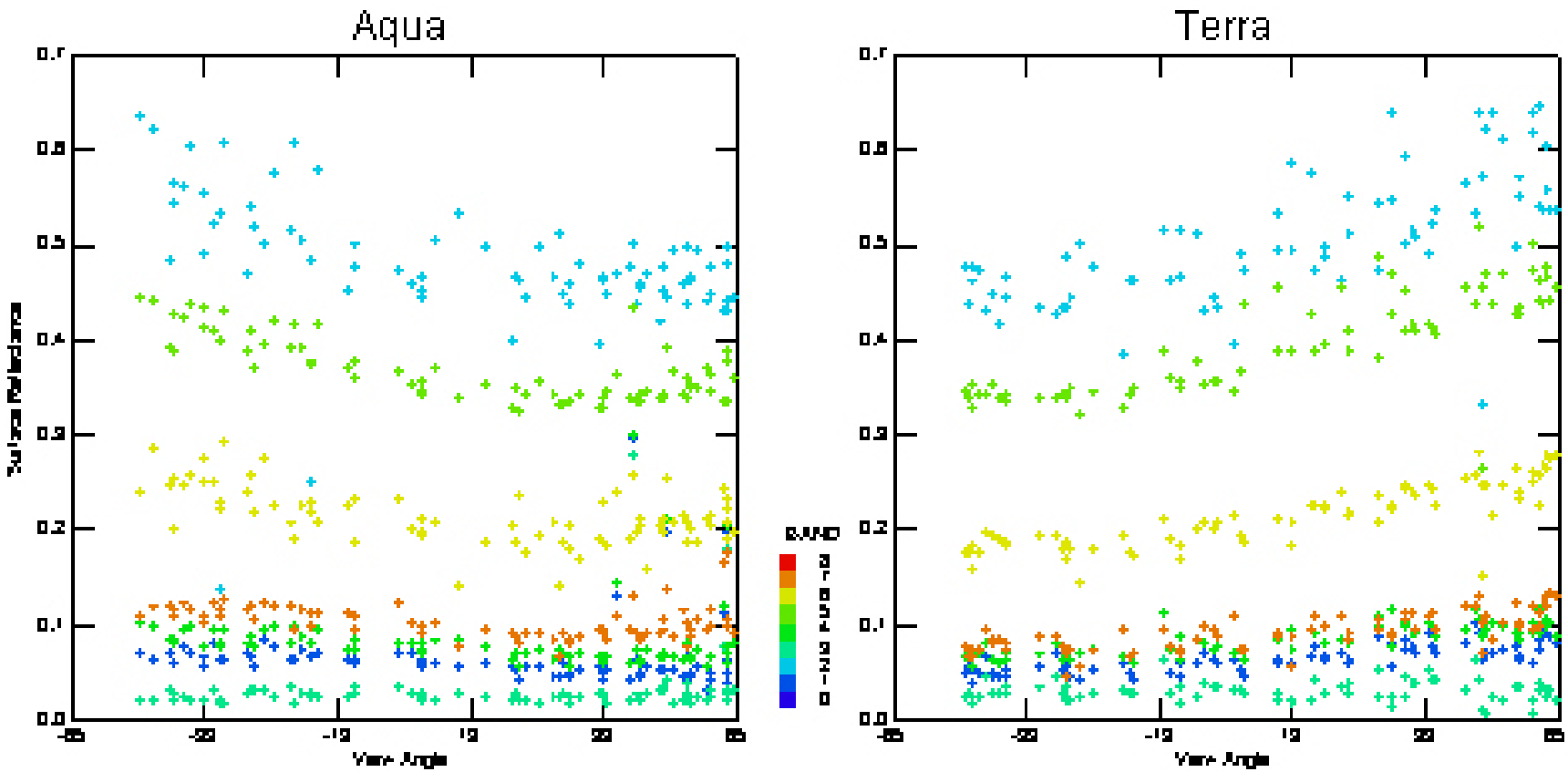
LST = Land Surface Temperature

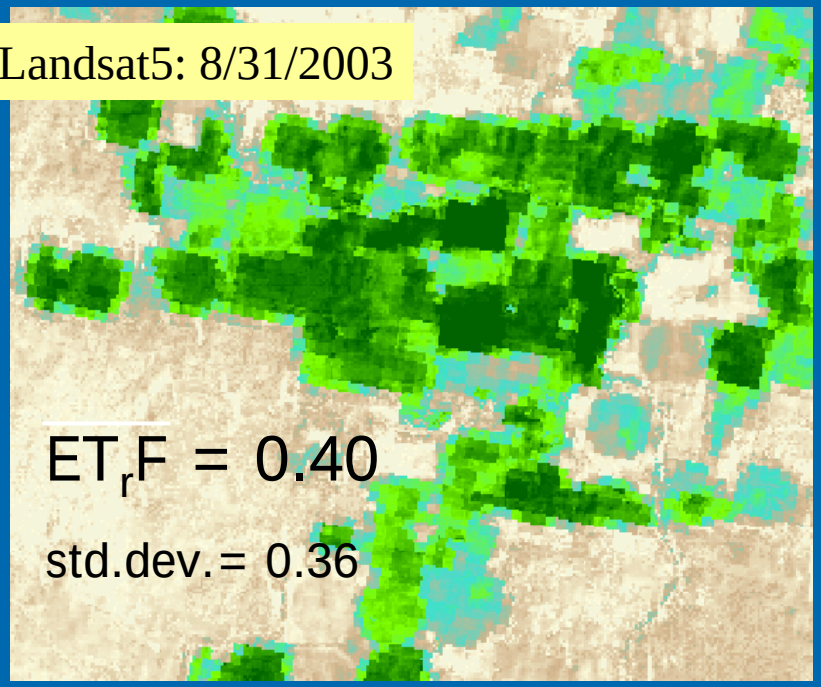
8-day LST is an average of each day, with equal weight given to all days and scan angles

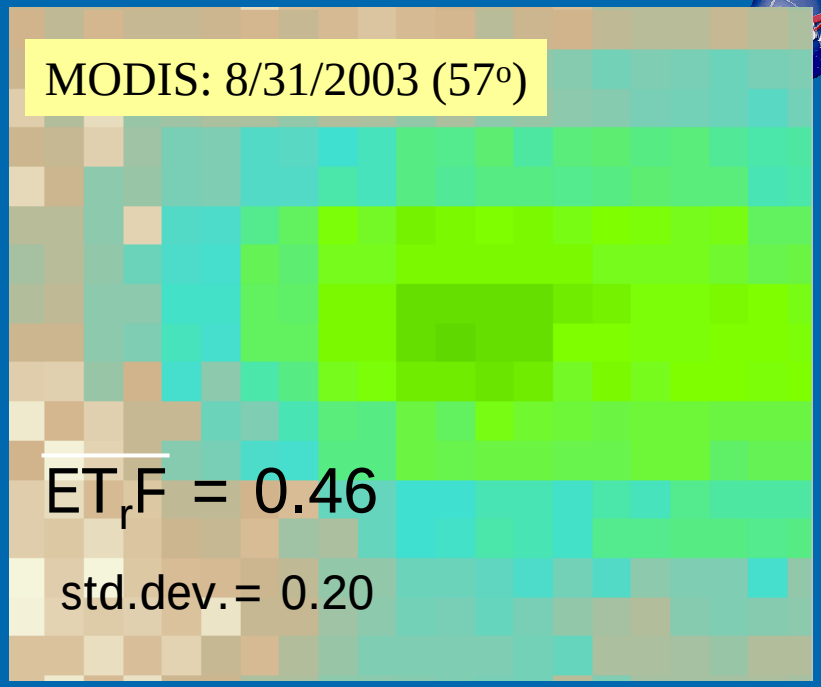
Conclusion: 8-day LST is strongly correlated with LST for each day, even though not 1:1. Therefore, dT vs. Ts from 8-day LST will probably work with any day.

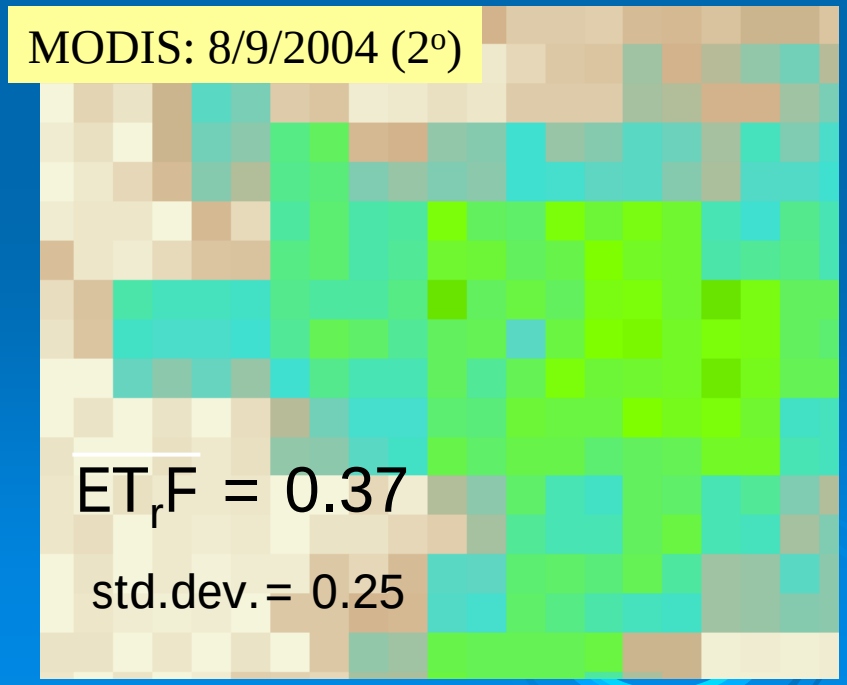
Scan Angle Effect on Reflectance, S. Idaho



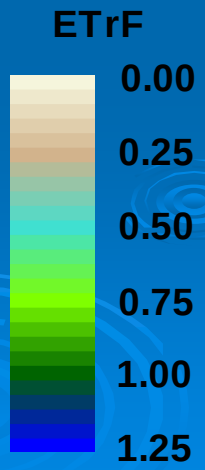






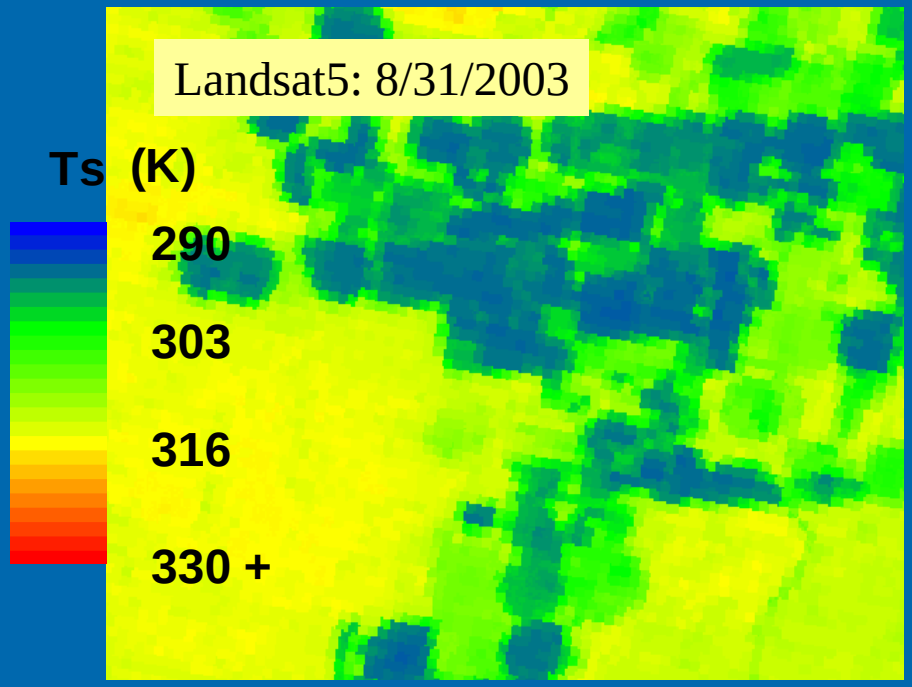


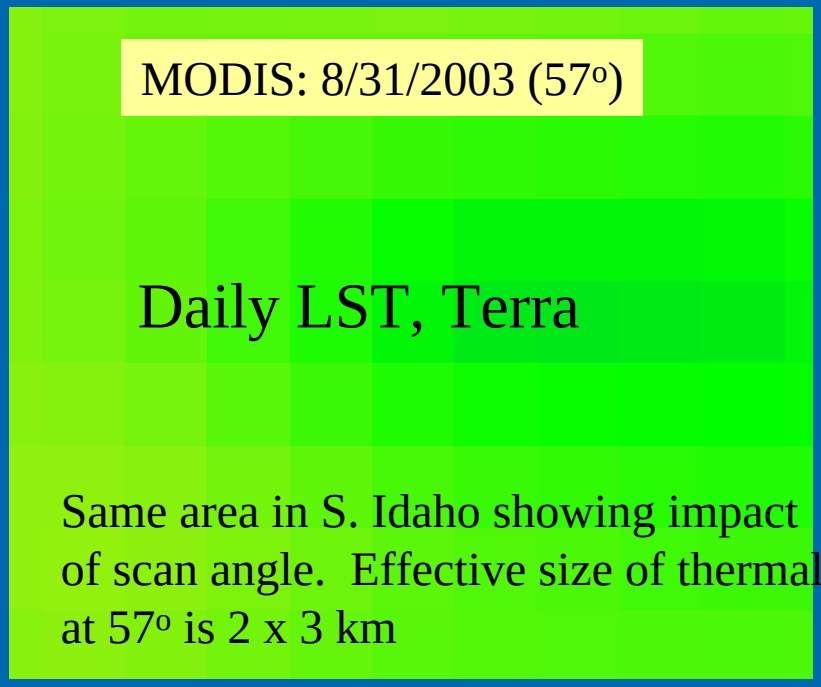
$$ET_rF = \frac{ET}{ET_r}$$

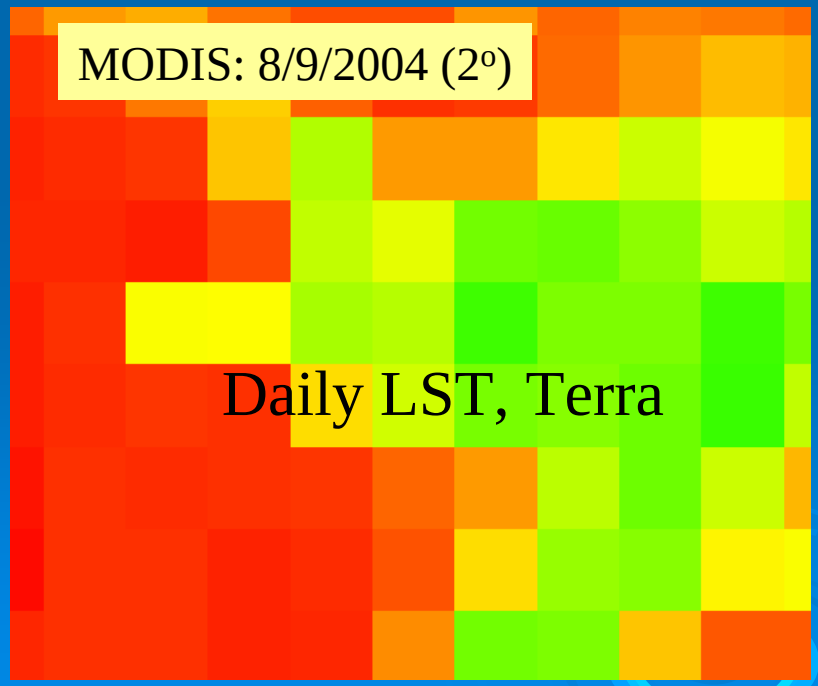


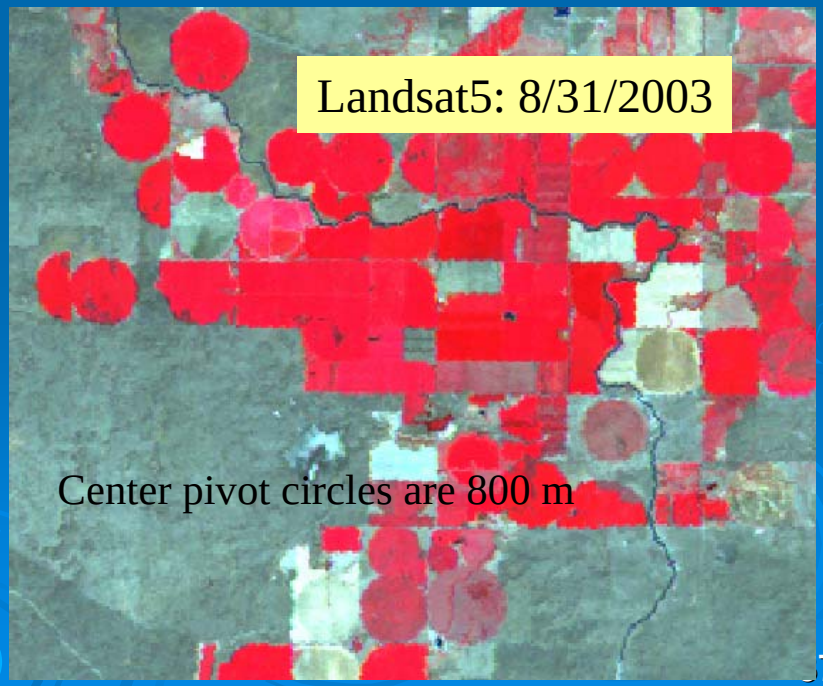
ET_rF by METRIC

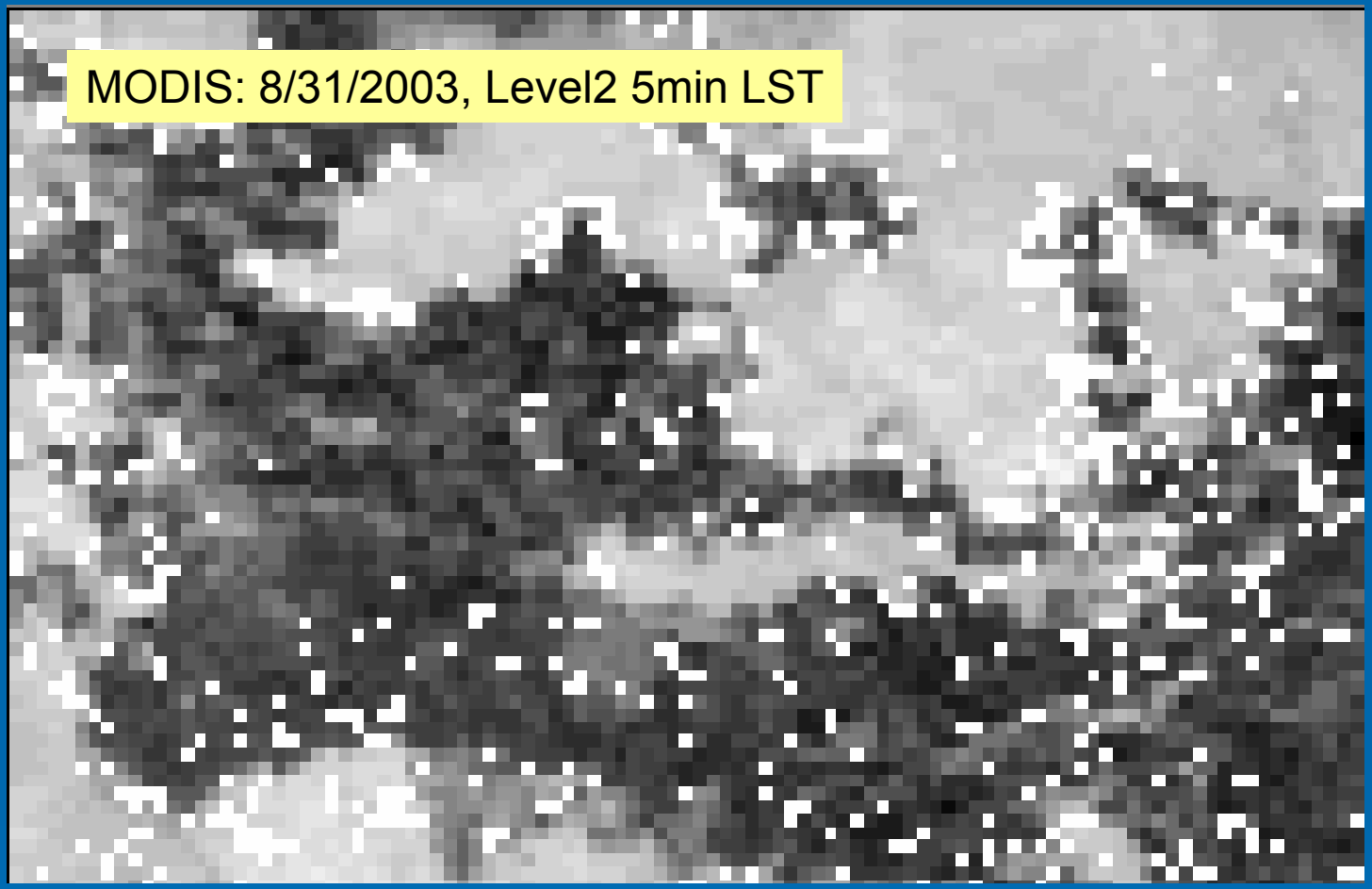
(Same area in S. Idaho showing impact of MODIS scan angle)


Landsat5: 8/31/2003
Ts (K)
290
303
316
330 +


MODIS: 8/31/2003 (57°)
Daily LST, Terra
Same area in S. Idaho showing impact of scan angle. Effective size of thermal at 57° is 2 x 3 km


MODIS: 8/9/2004 (2°)
Daily LST, Terra


Landsat5: 8/31/2003
Center pivot circles are 800 m

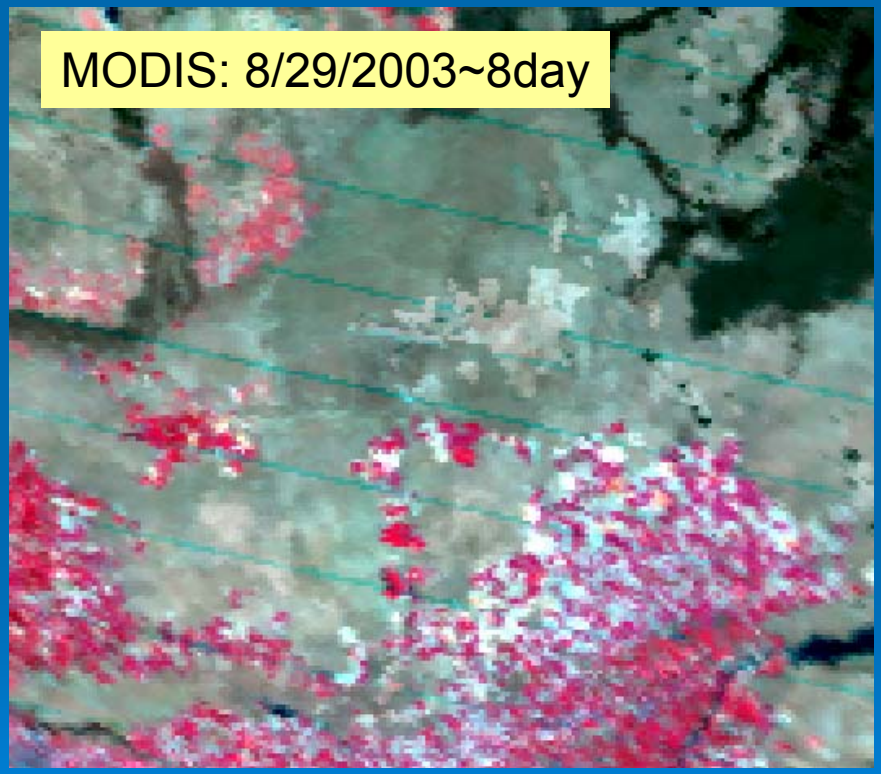


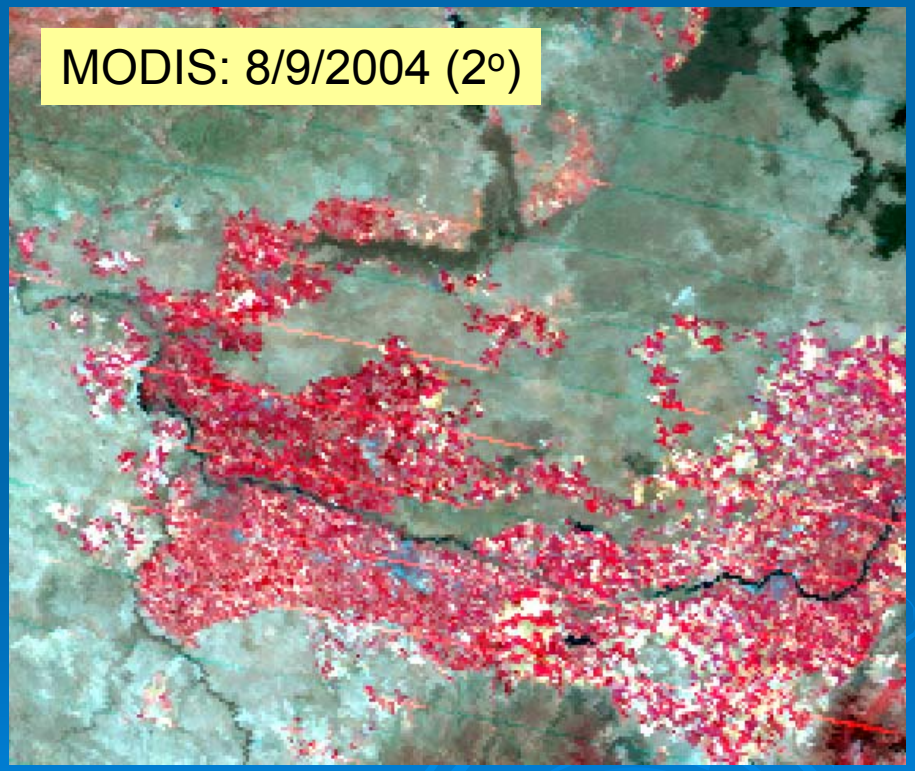
Level 2 5min LST represents a daily instantaneous LST image.
White locations are ‘missing’ LST due to missing thermal emissivity due to mis-categorization of pixel as a cloud near irrigated/desert boundaries.

Daily LST products have these fall-outs also, but the number of the holes is less, primarily because of the smearing effect of resampling.

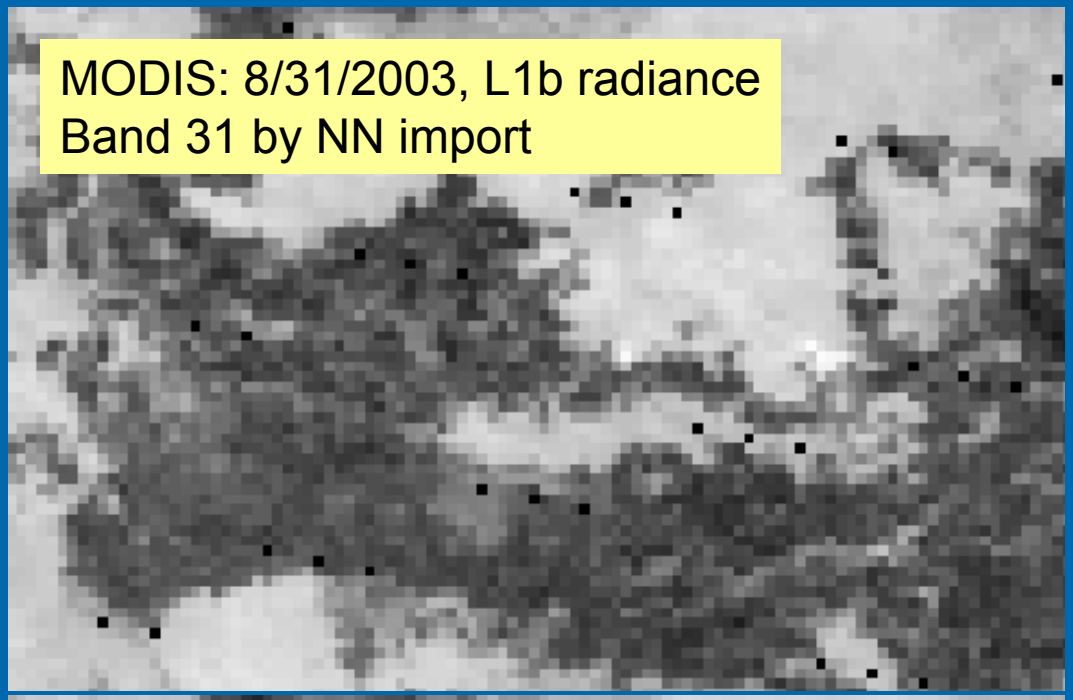
Currently, METRIC uses Level 1 radiance (using calibration of LST vs. radiance by regression of ‘good’ pixels in LST image). Level 3 8-day LST may also be useable

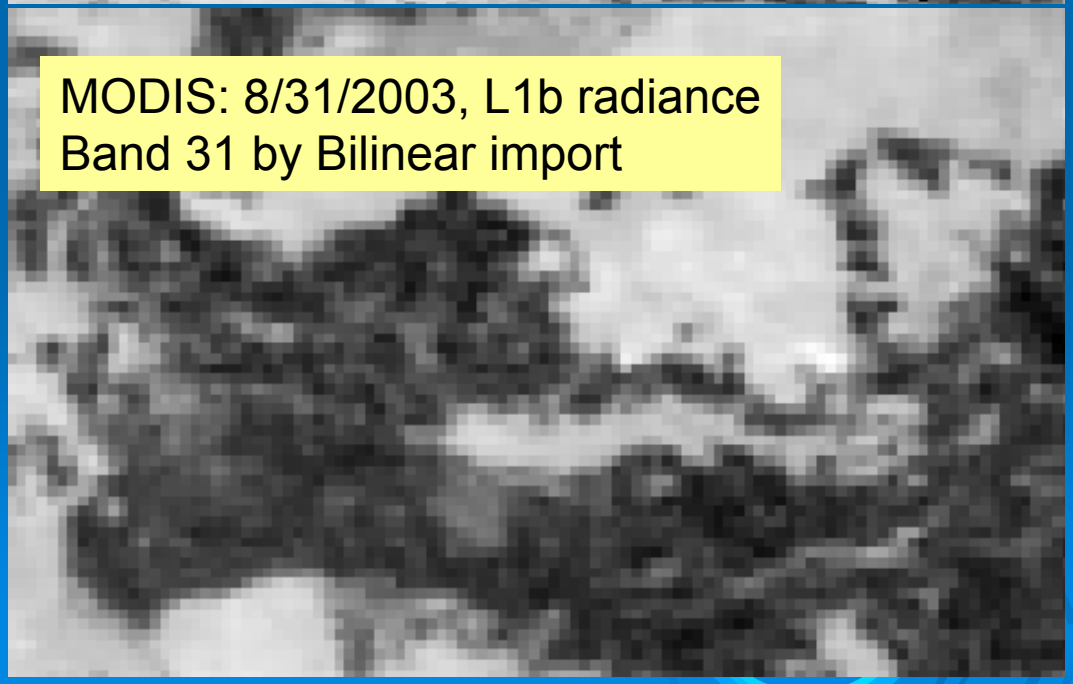
Another problem with MODIS Sensors:
Band 5 (2nd NIR) has been having striped output.
Stripes are present in all Level 1 – 3 products.
This problem has been reported for many bands as “known issues”.
http://modland.nascom.nasa.gov/cgi-bin/QA_WWW/getSummary.cgi?esdt=MOD09





These two images false color using Bands 5-1-4.
Solution: Omit band 5 from albedo computations.





Level 1 calibrated radiance, imported using nearest neighbor resampling, has "holes" *for all* evaluated *shortwave* and *longwave* bands (i.e. bands 1~7 and 31&32).

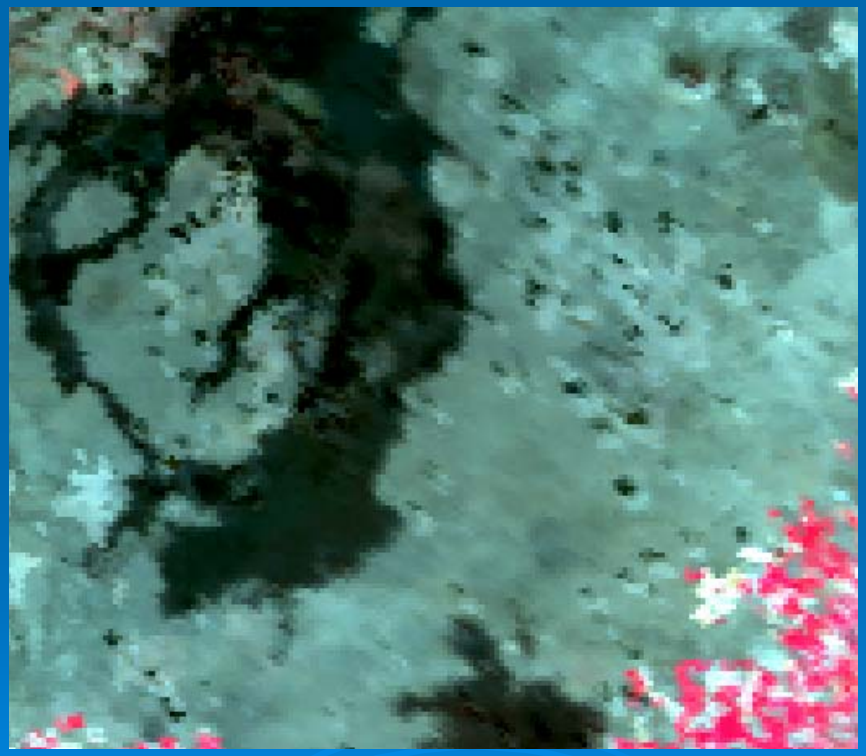
When imported using Bilinear resampling, holes disappeared due to averaging from surrounding pixels. However, smearing increases and information is lost.

Problem in 8-day reflectance product:

One image (date) is selected to represent reflectance for each pixel, based on a 'minimum Blue-Band (MinB) method.' This method generally selects near-Nadir image pixels and generally works well. However:

a) The method tends to select shadows by clouds (low in blue band)

b) Each pixel can potentially come from a different date (therefore, confusion in Energy balance as to which cos(θ) to use.



MODIS: 8/29/2003~8day

Takeuchi,W. and Yasuoka,Y. (2005). Comparison of composite algorithm for South East Asia using MODIS data. Photogrammetory and Remote Sensing (accepted), written in Japanese.

SUMMARY AND FUTURE DIRECTIONS

- NASA Satellite and Modeling of ET fluxes show potential promise to improve USBR AWARDS ET Toolbox performance
- Adapt NASA LIS Noah and Catchment LSMs for ET Toolbox to provide short-term predictions of water availability with an emphasis on ET.
- Quantify hourly to yearly LIS LSM water outputs from 2-sites to ~4-5 sites
- Further evaluate METRIC ET of MODIS data for Middle Rio Grande
- Intercompare ET Toolbox, METRIC ET and LIS ET for monthly flow
- The ET Toolbox DST with in situ and enhanced NASA products are behaving properly and thus leading to an eventual Benchmark report
- Benchmark use of NASA METRIC ET, NASA LIS Noah ET, and NASA LIS Catchment ET for improved AWARDS ET Toolbox water loss estimation