# Satellite-derived fields for Estimating Soil Moisture for Regional WRF Model Initialization

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Collaborators

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**Supported by:**

**The NASA SPoRT Initiative**

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## OUTLINE

1. Atmospheric Land EXchange Inverse (ALEXI) model
    - *Turbulent Fluxes, Available Soil Water*
2. ALEXI Soil Moisture Validation
    - *Comparison to regional soil moisture measurements*
3. WRF Model Initialization with ALEXI (versus EDAS)
    - *Progress toward routine usage*

# Overview: UAH Contributions

- **Diagnostics:** ALEXI land-surface ($S_o$, $A_w$, $R_{net}$, $ET$) fields, ADAS surface $T_a$. All at 2-10 km resolution.
- **Nowcasting (0-6 h):** Convective initiation (CI), Lightning Initiation & First Lightning; "*CI Index*" for 2-6 h CI (based on satellite & NWP model fields). Aviation Safety (ASAP).
- **Short-term Prediction (6-24 h):** Utilize "diagnostics" as satellite-based boundary conditions, ADAS populated by remote sensing data (satellite & radar) toward a high-resolution (5-10 km) regional initialization for ARPS, WRF, etc.
- **UAH Graduate students:** NWS SCEP, MS/Ph.D. studies that involve NWS interactions. Developing "*in-house*" nowcasting expertise.

**An ability to Leverage from other NASA, NSF, etc. projects, to the SPoRT Center**

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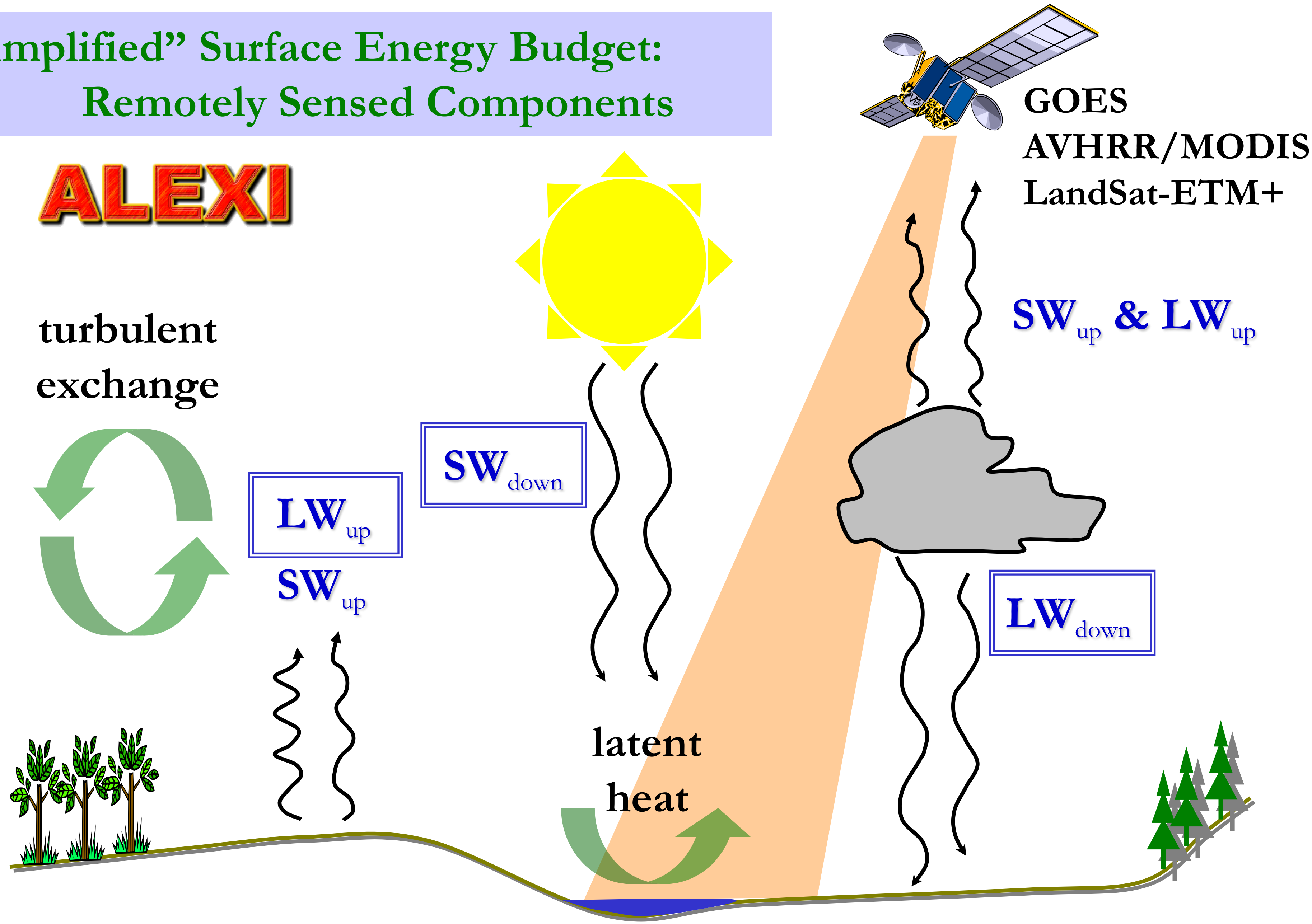
# "Simplified" Surface Energy Budget: Remotely Sensed Components



# Surface Energy Balance Equation

$$R_{net} = H + LE + G$$ (Retrieval/Remote Sensing)

$$R_{net} = SW_{\mathrm{down}} + LW_{\mathrm{up/down}}$$ (Remote Sensing)

## Components Measured through Remote Sensing:

**Shortwave Down** ($SW_{\mathrm{down}}$, $S_{\mathrm{o}}$): Diak et al. (1996)

**Surface Turbulent Fluxes** ($H$, $LE$) **and Soil Flux** ($G$): ALEXI

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# Component Methodologies

## Solar ($SW_{down}/S_{o}$):

- One of the (under-utilized) success stories of satellite meteorology
- Many "snapshots" (hourly) results from geostationary platforms, time-integrated
- Simple atmospheric physical model with measured surface albedo used for cloud detection, quantifying cloud albedo, radiative transfer effects in clear and cloudy atmospheres
- Several methods using GOES/Meteosat/GMS data by independent investigators
- Daily $S_o$ usually with < 10% error versus pyranometers
- 20 km resolution $S_o$ Product: North and South America, Australia, Europe

# Physical Model

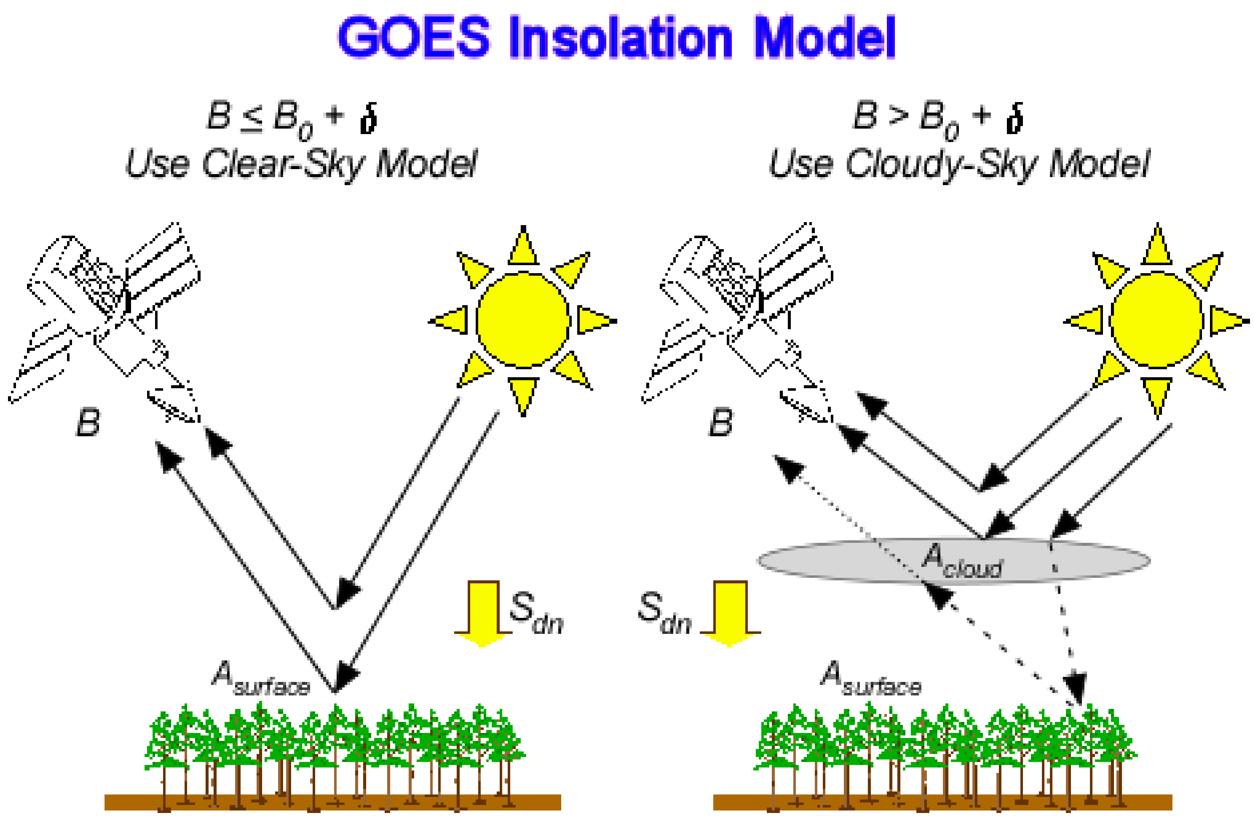


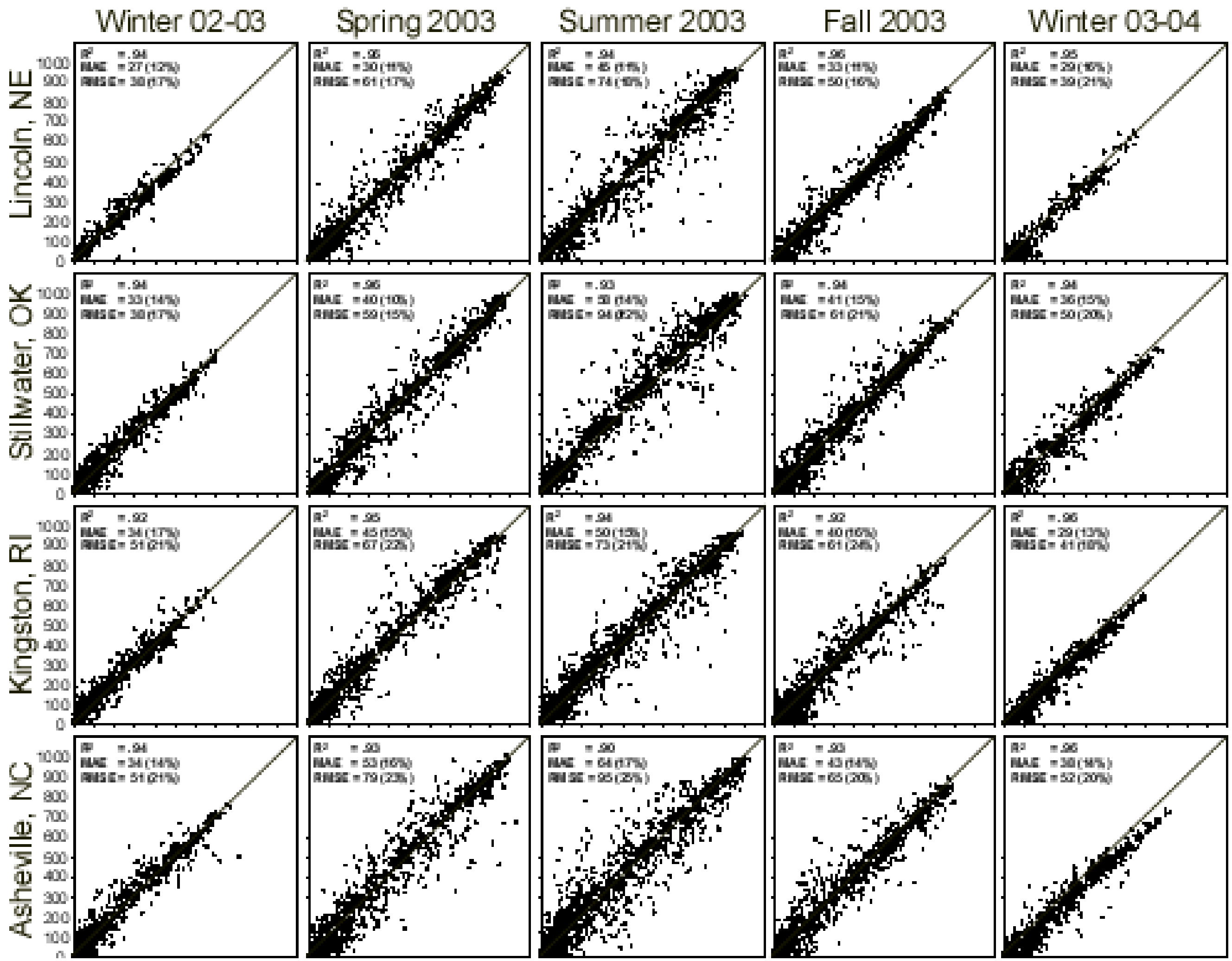

Fig. 1 Graphical depiction of the physical model employed for clear-sky conditions (left-hand side) and for cloudy-sky conditions (right-hand side). B refers to the brightness observed by the satellite, $S_{dn}$ refers to the downward shortwave radiation flux, and $A_{surface}$ and $A_{cloud}$ refer to the surface and cloud albedos, respectively.

# Solar Insolation Validation & Products

**Hourly GOES Insolation**

versus

**Surface Observations**

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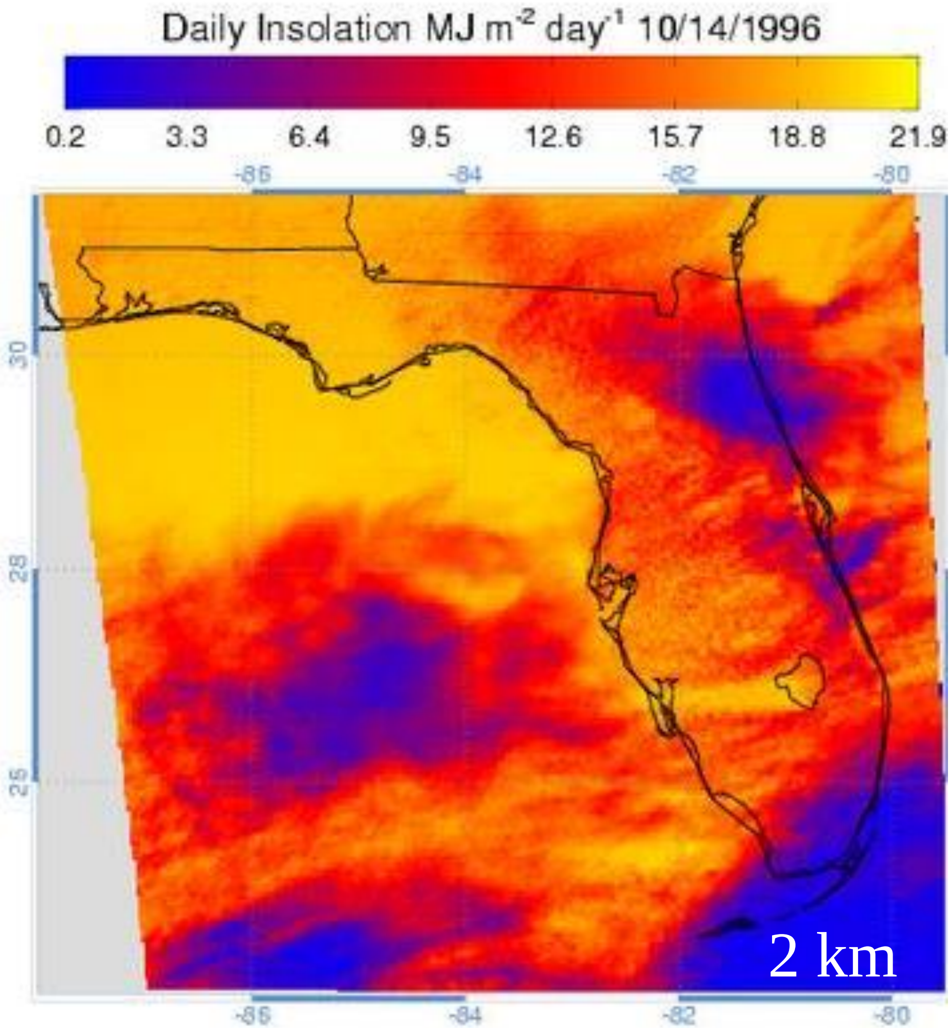
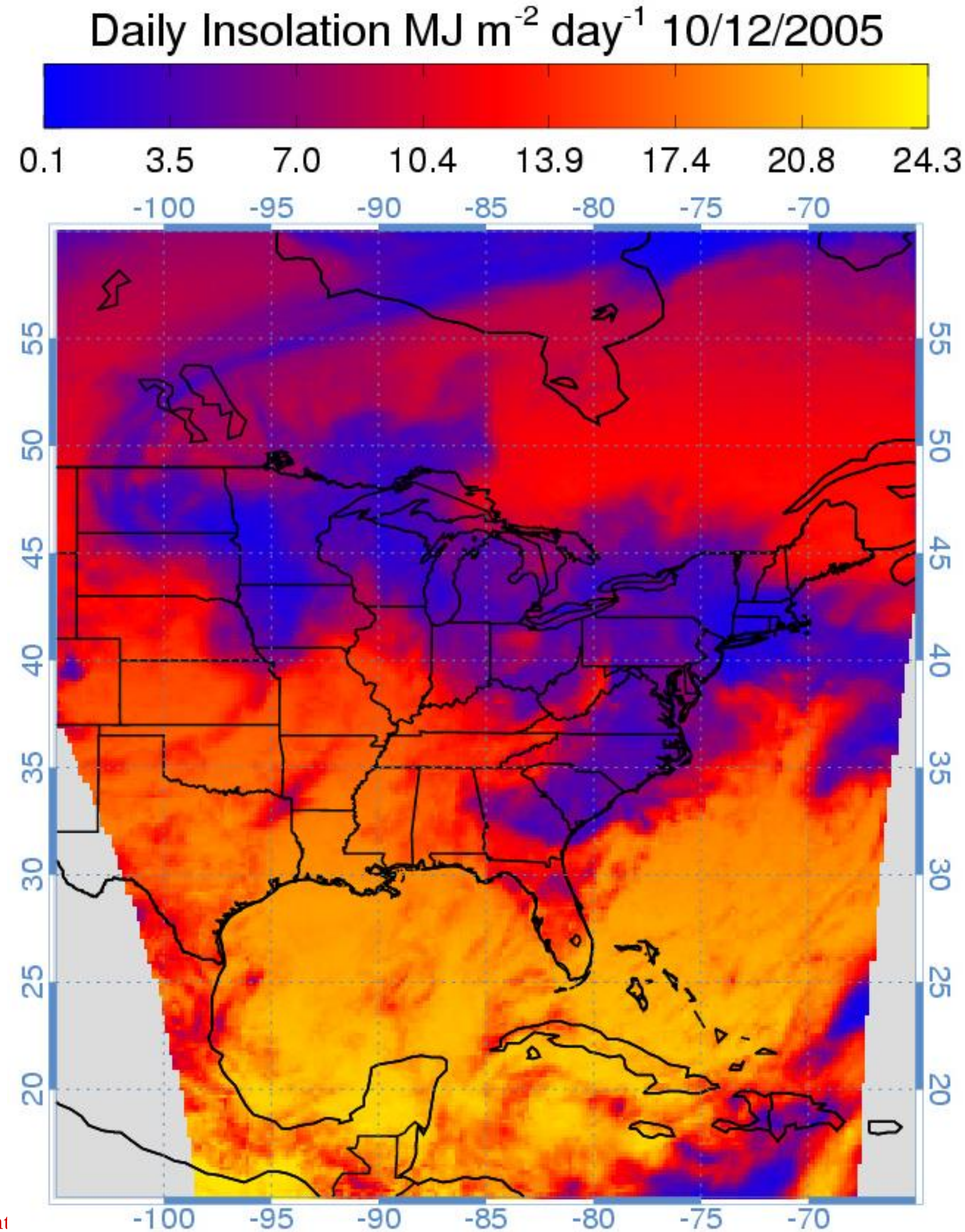
# **Solar Insolation:** ALEXI Input

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# ALEXI Characteristics

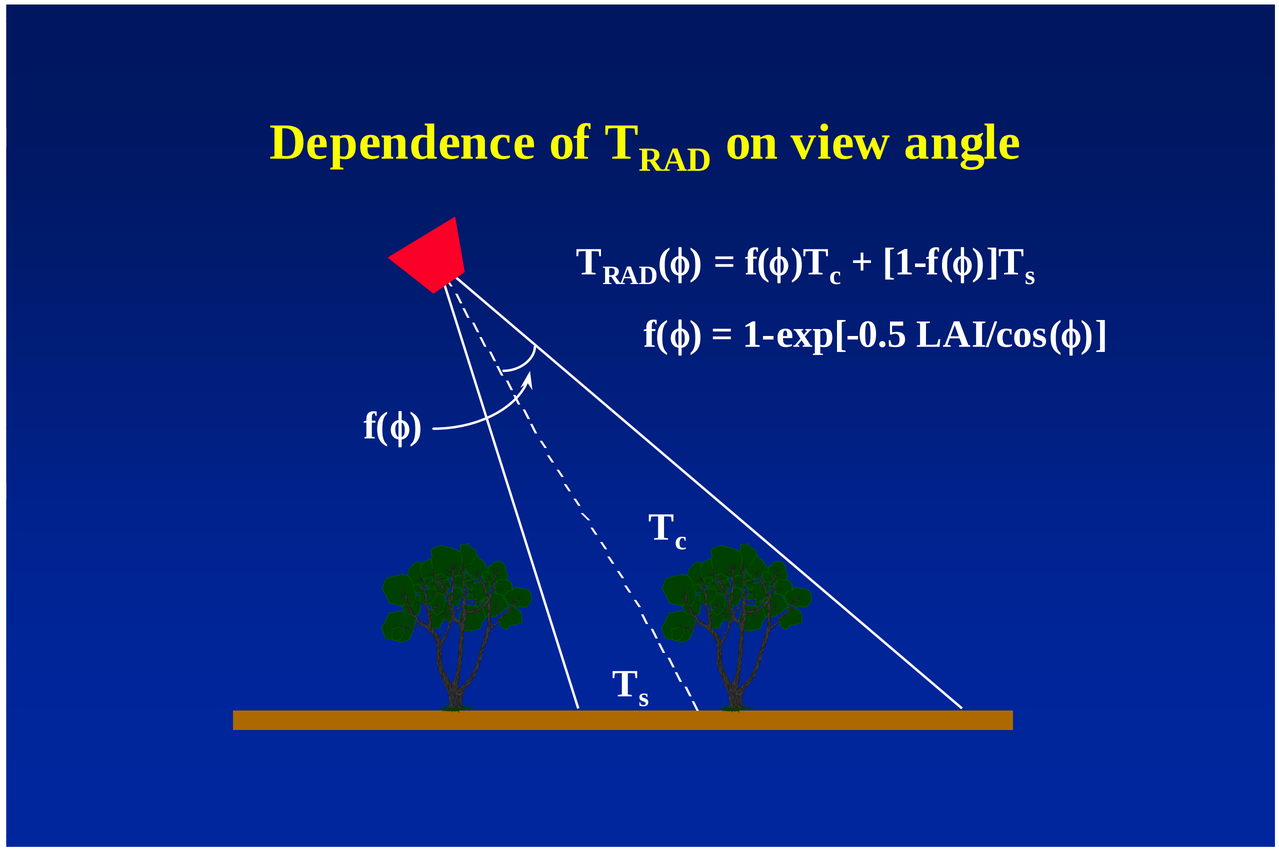
- Takes into account angular dependence of $T_b$ on view angle using "two-source" model

- Uses time-difference, reduce bias other errors PBL closure (instead of measurements at anemometer height) reduce sensitivity to BC

- Computes $T_a$ from PBL closure rather than requiring a measurement

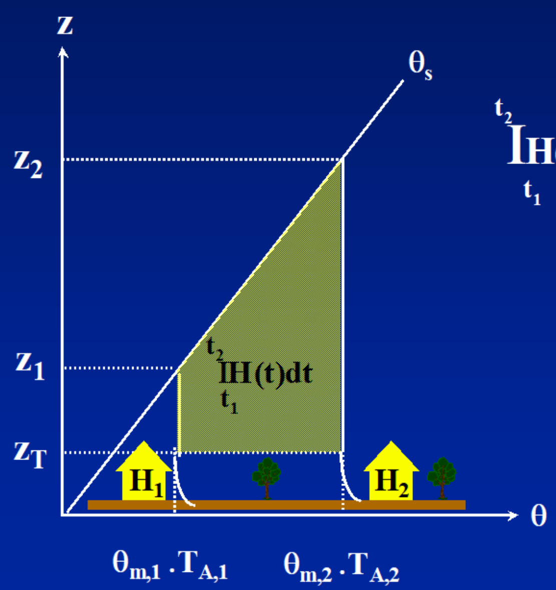
- Linked to MM5 forecast model for required input meteorology

- Nearly 10-years of development



# "Time-Integrated"

*Planetary Boundary Layer Component*



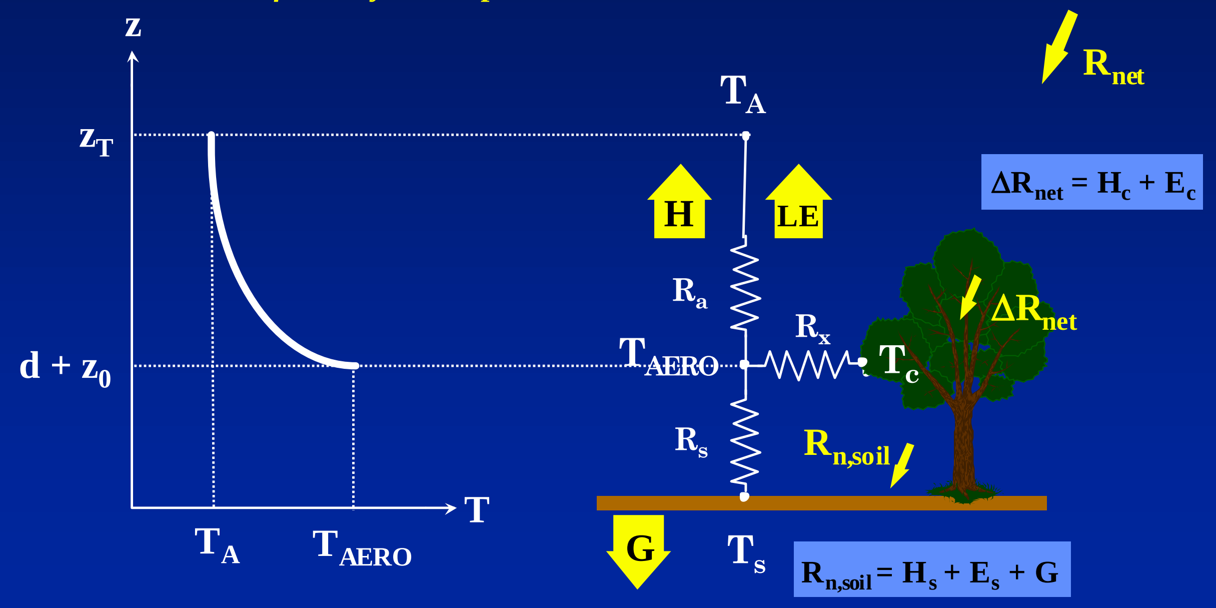

$$\int_{t_1}^{t_2} H(t)dt = \rho c_p(z_2\theta_{m,2} - z_1\theta_{m,1}) - \int_{z_1}^{z_2} \theta_s(z)dz$$

$$\sim \int_{t_1}^{t_2} \frac{H_N}{T}\, tdt$$

$$= \frac{1}{2}\left[ H_2 t_2 - H_1 t_1 \right]$$

# "Two-Source"

*Surface Layer Component*

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# Surface turbulent fluxes (*H*, *LE*) and soil flux (*G*)

*Primary satellite inputs*: 1) Time Change Radiometric Temperatures (GOES)
2) Fraction Cover from NDVI (AVHRR, MODIS)

## ALEXI Inputs and Outputs

**Required Input:**

- Surface brightness temperature (2x)
- Insolation (2x)
- Near-surface time-averaged wind speed
- Surface albedo
- Canopy height & cover (NDVI)
- Canopy greenness
- Average leaf size
- Early morning atmospheric lapse rate
- Near-surface VP (2x)

**Computed Output:**

- Canopy/soil/net sensible & latent heat fluxes
- Soil heat conduction flux
- Canopy/soil thermodynamic temperatures
- Near-surface air temperature
- Carbon assimilation rate

# MODIS Data Usage within ALEXI

- Employ disaggregation using ALEXI ("DisALEXI") with MODIS thermal data as twice-daily input.
- MODIS 250 m visible to sharpen thermal data to >1 km resolution.
- Develop regional-scale (e.g., over continental U.S.) disaggregation procedures that relies on MODIS imagery when available.
- Develop field-scale available water data sets at MODIS resolution for agriculture and NWP applications.
- Use MODIS land-surface products (e.g., NDVI, LAI).

**250 m resolution MODIS**


**MODIS direct broadcast capabilities at UW**

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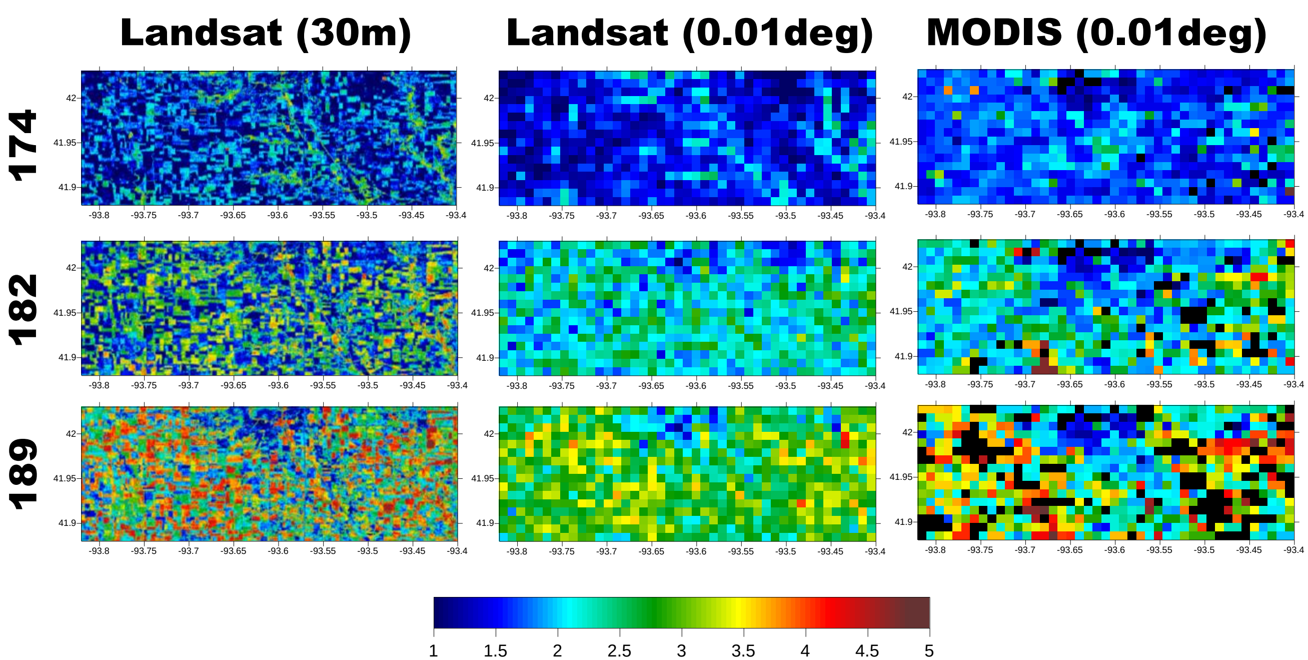
# ALEXI Components: Driven by MODIS

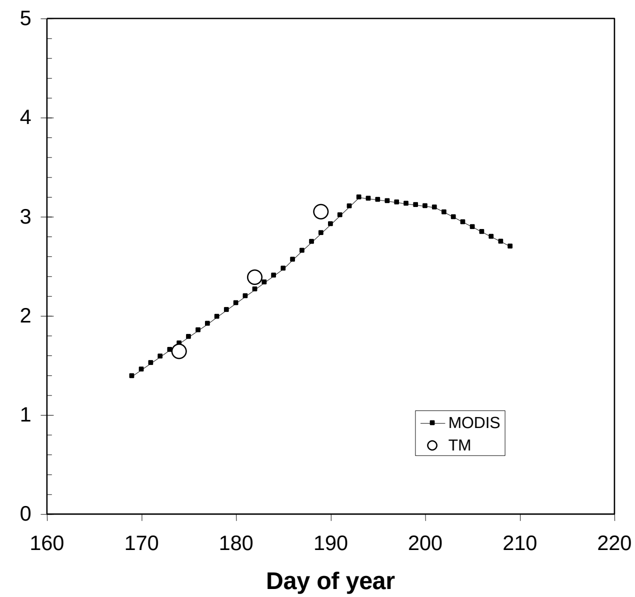
## MODIS Land-Cover Data:

- Transition from AVHRR NDVI & fraction vegetation cover to MODIS ("**MOD15A**" Collection 4)
- Anderson et al. (2006); Dr. M. C. Anderson (with NASA funds) gets credit for this development




Leaf Area Index

MODIS vs. LandSat

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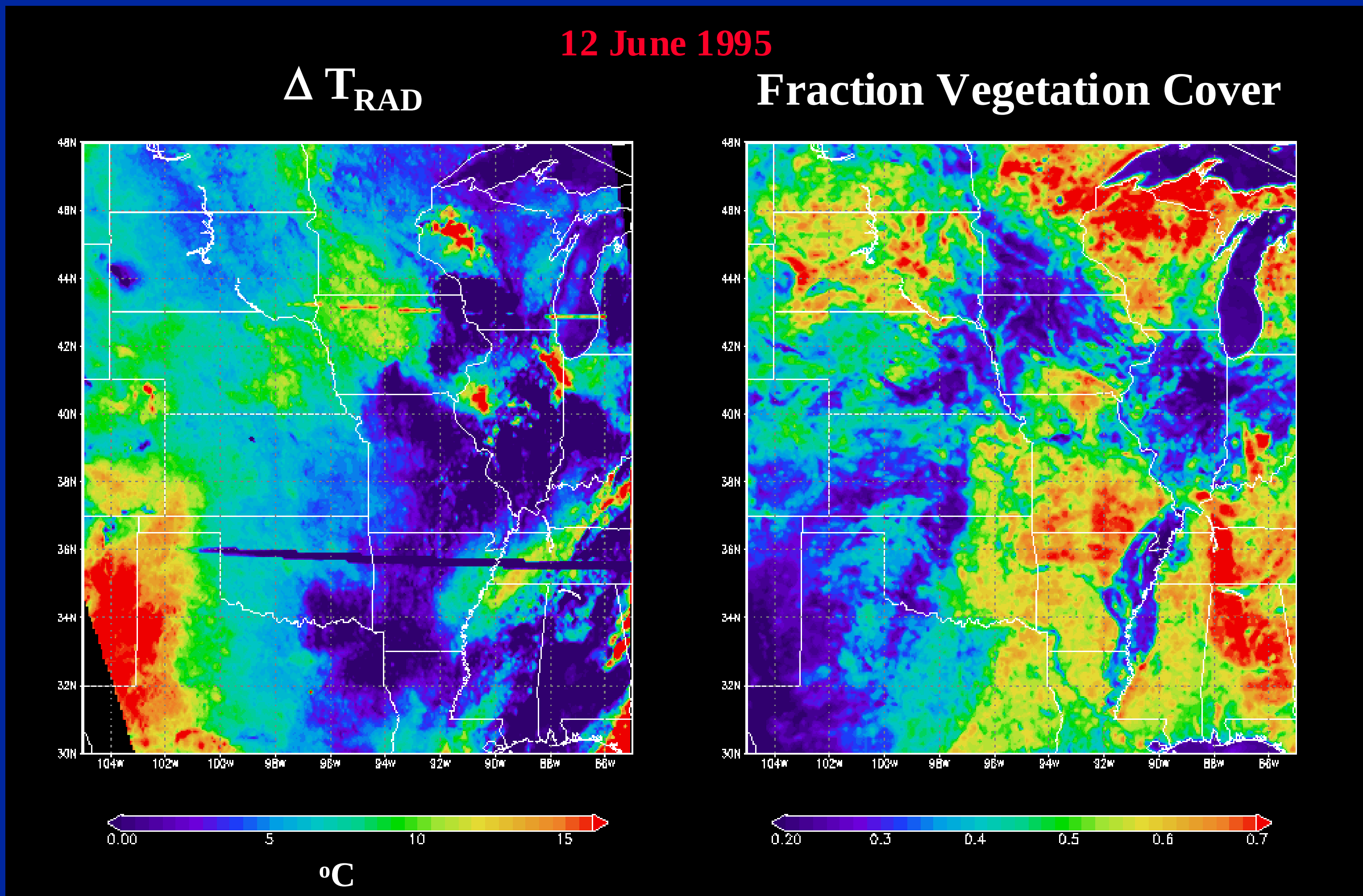
# Examples of Satellite Inputs for ALEXI

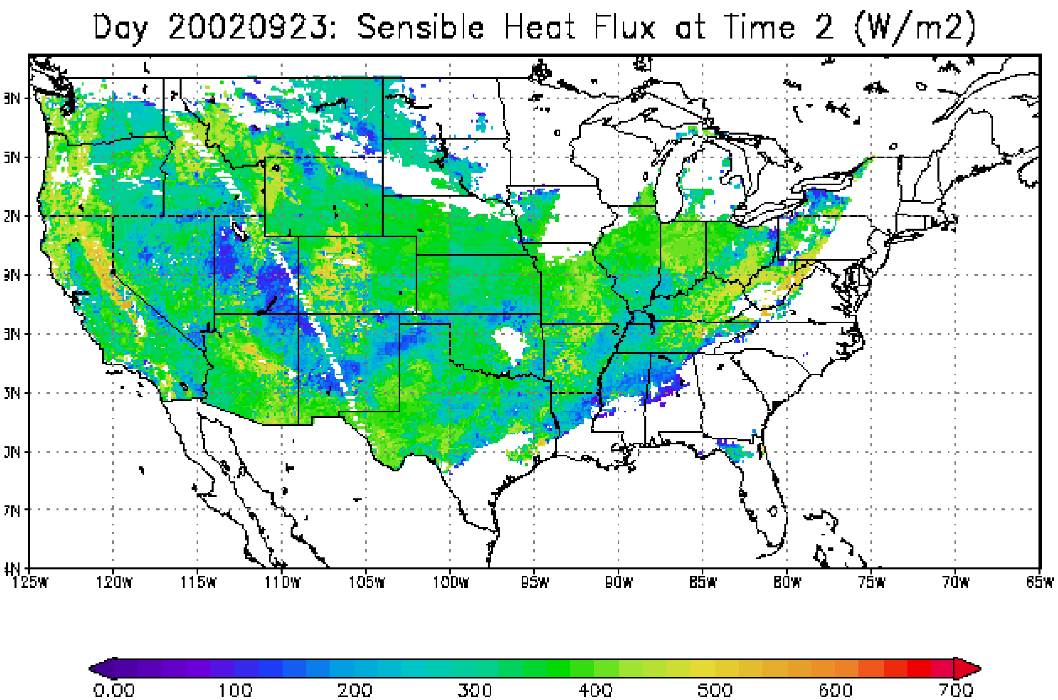


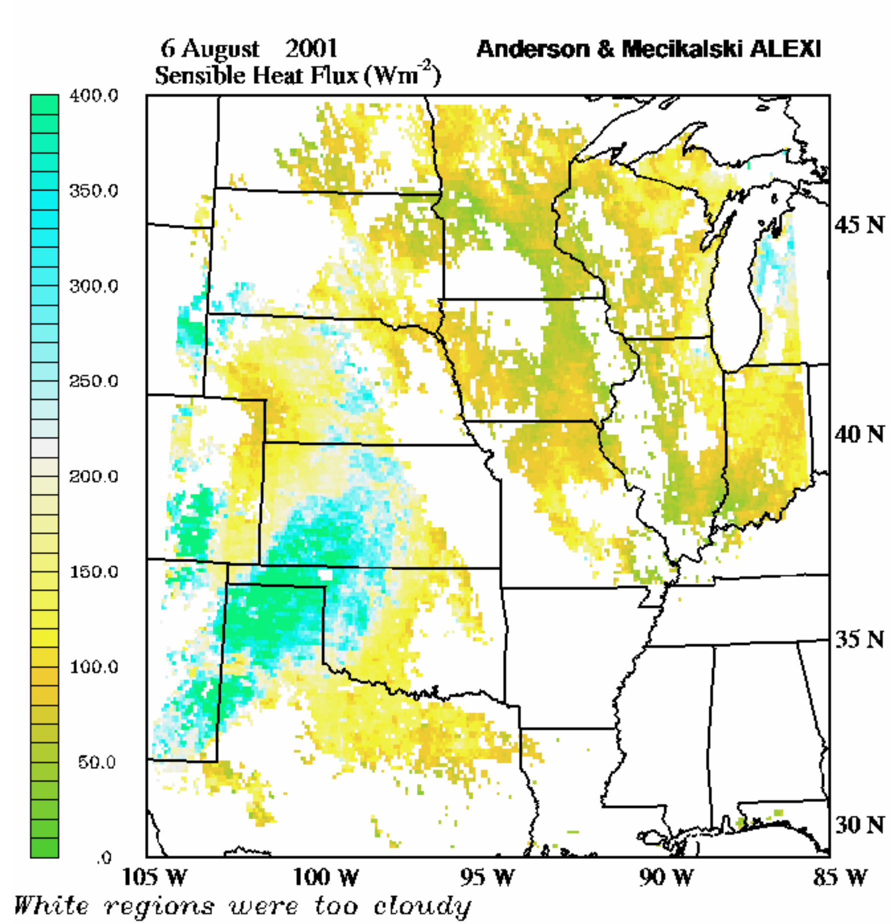
# ALEXI Daily Fluxes & Flux Climatologies

- Daily at 5- and 10-km resolution fluxes for the U.S.; driven by satellite-estimated radiation streams from GOES & AVHRR.
- High resolution fields (250 m–1 km) soil conditions, ET, etc. for agriculture.
- "*Available Water*" computed using fluxes for soil and vegetation when clear. Carried through when cloudy using satellite radiation estimates to maintain continuous daily flux budgets. For NWP data initialization.
- In the process of developing a 4-year flux climatology over seasons, months, and over various regions of the U.S.

# ALEXI Model: Daily Regional Flux Mapping

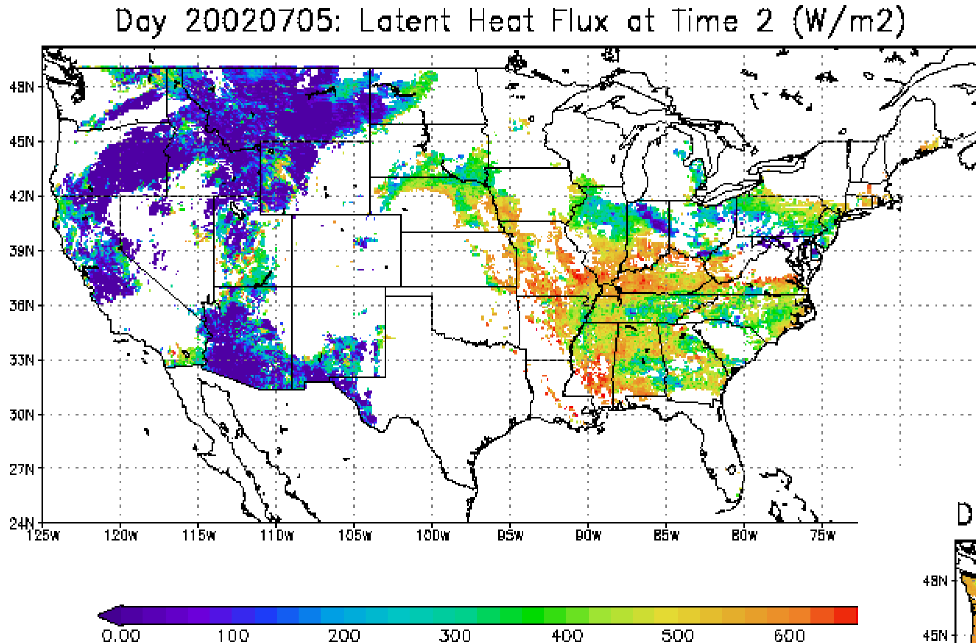
United States Fluxes (Wm$^{-2}$):
10 km Resolution



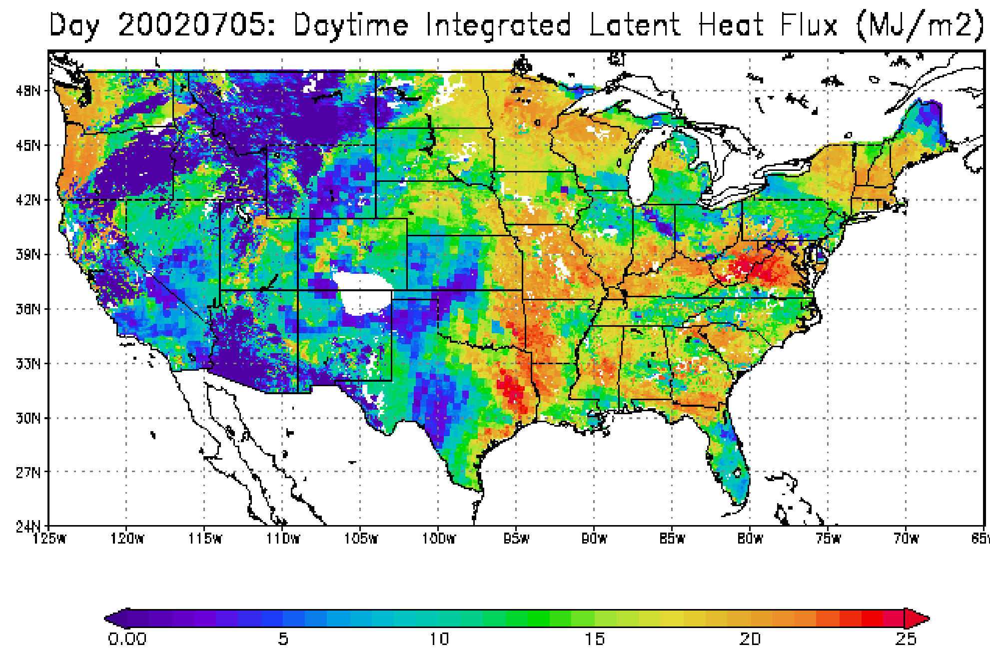




Region Fluxes (Wm$^{-2}$):
5 km Resolution

# ALEXI Model: Daily Regional Flux Mapping




Instantaneous Fluxes ($Wm^{-2}$):
At Local Noon-1.5 h




Daily Average Fluxes ($MJm^{-2}$):
Clear & Cloudy Regions

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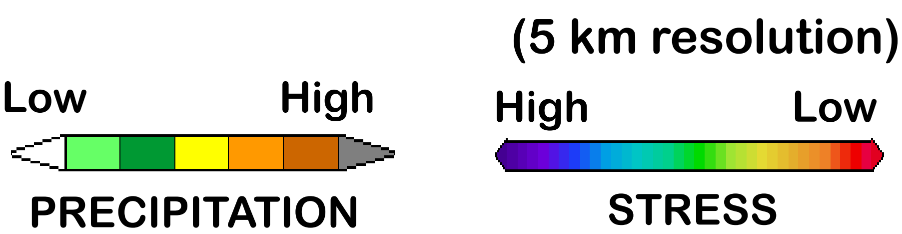
# ALEXI Derived Soil "Root Zone" Available Water

**a)** 6-day composite of system (soil+canopy) potential ET fraction estimates from the ALEXI model, ending 1 July 2002.

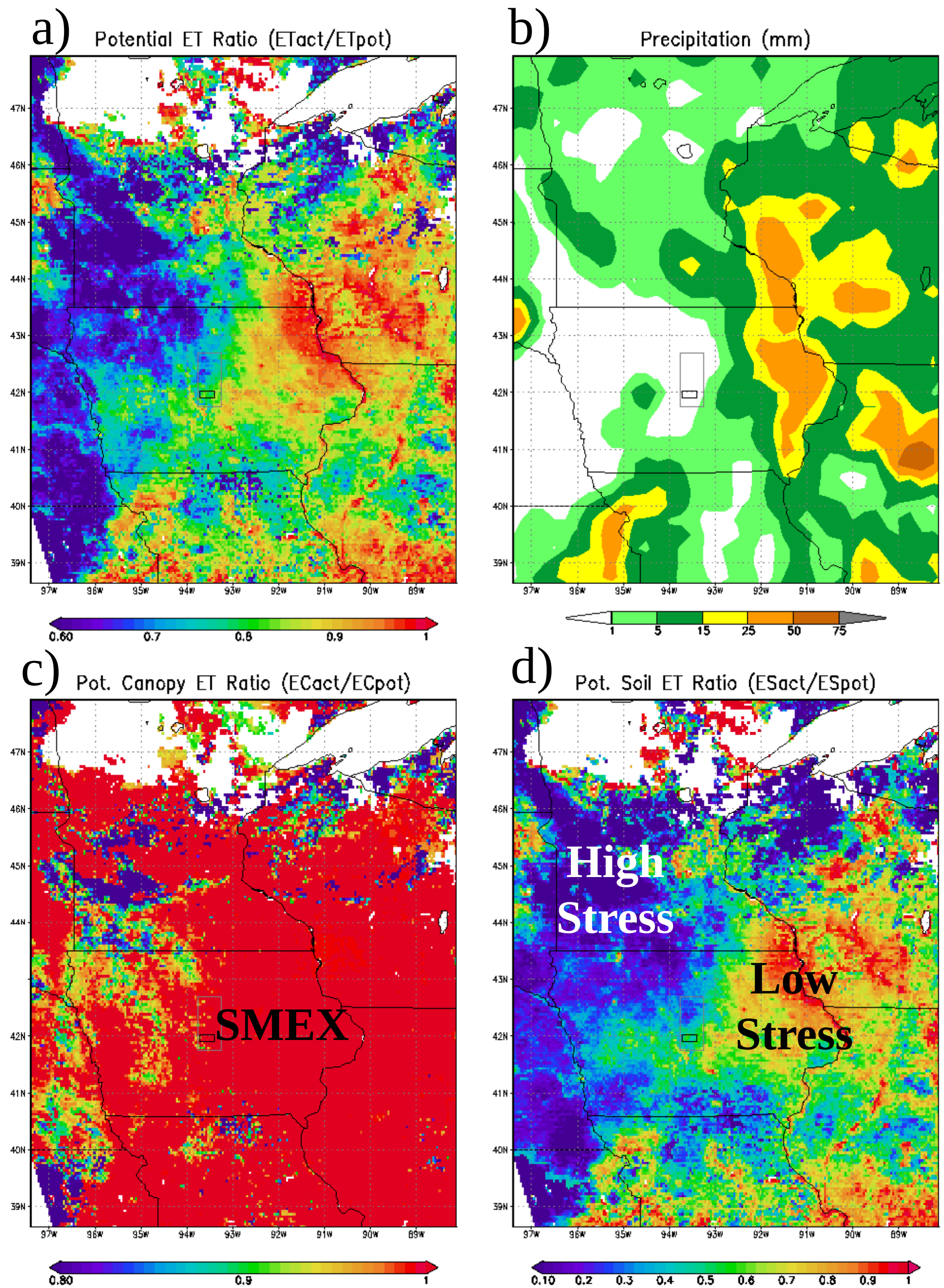
**b)** 6-day Accumulated Precipitation

**c)** Canopy Potential ET fraction (*Root Zone Available Water*).

**d)** Soil Potential ET fraction with lowest stress in red (*Surface Layer Available Water*)

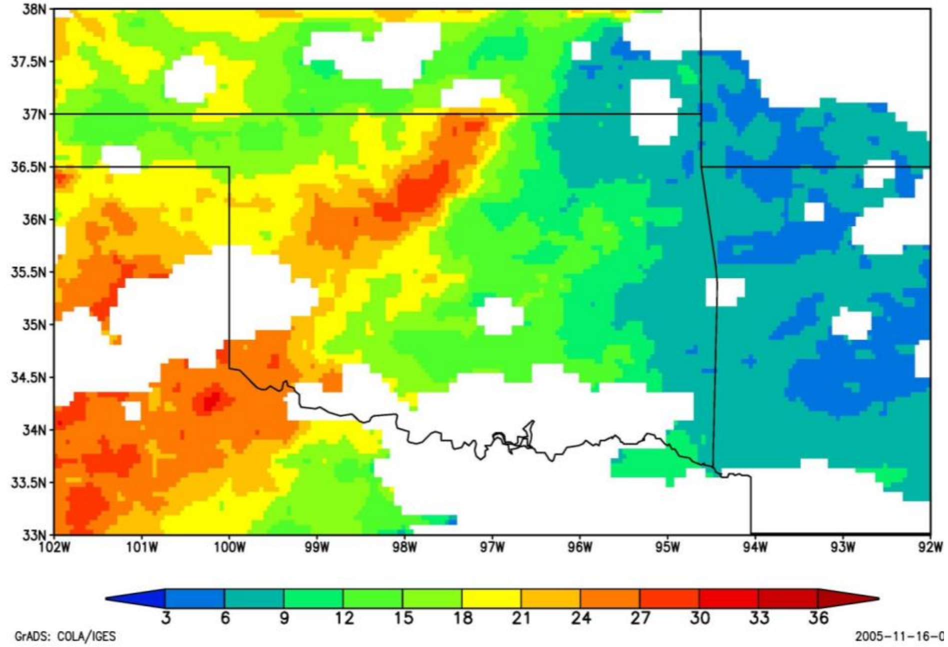



**Anderson et al. (2003)**

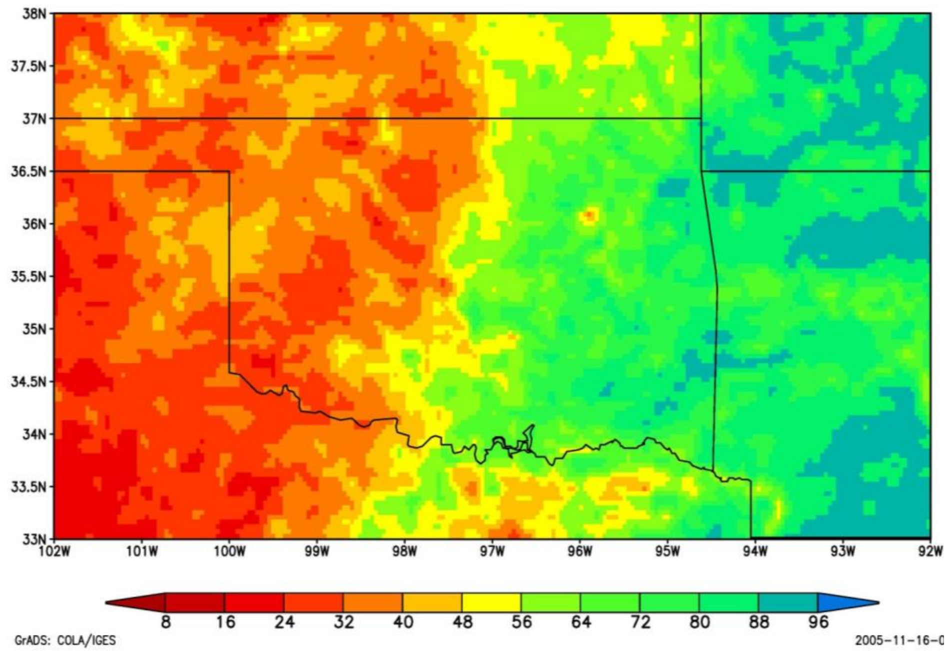


# An Example over the Oklahoma Mesonet:

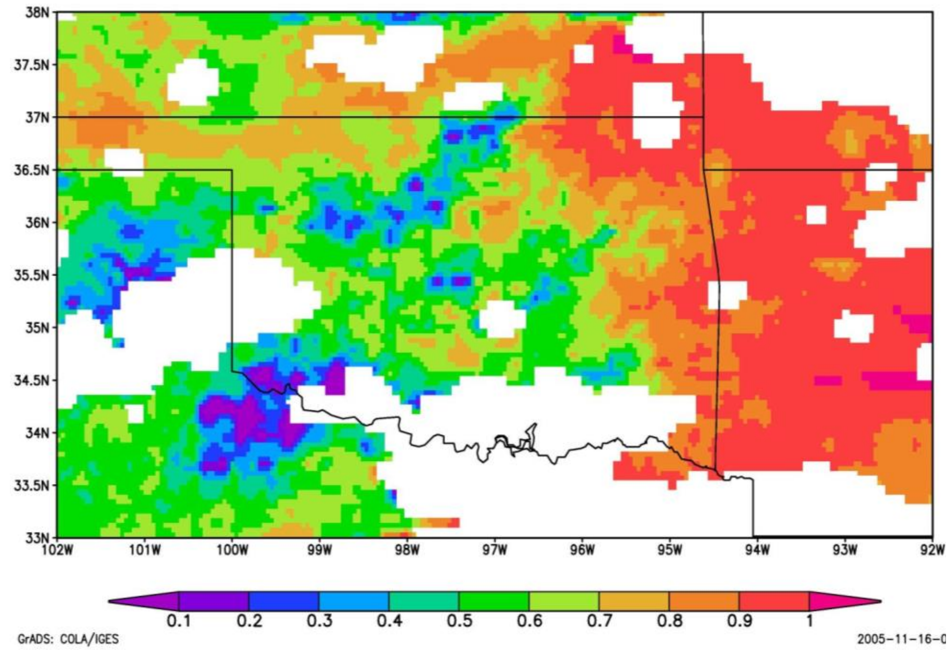
**Chris Hain (UAH)**




**July 15, 2003 Radiometric ΔT**



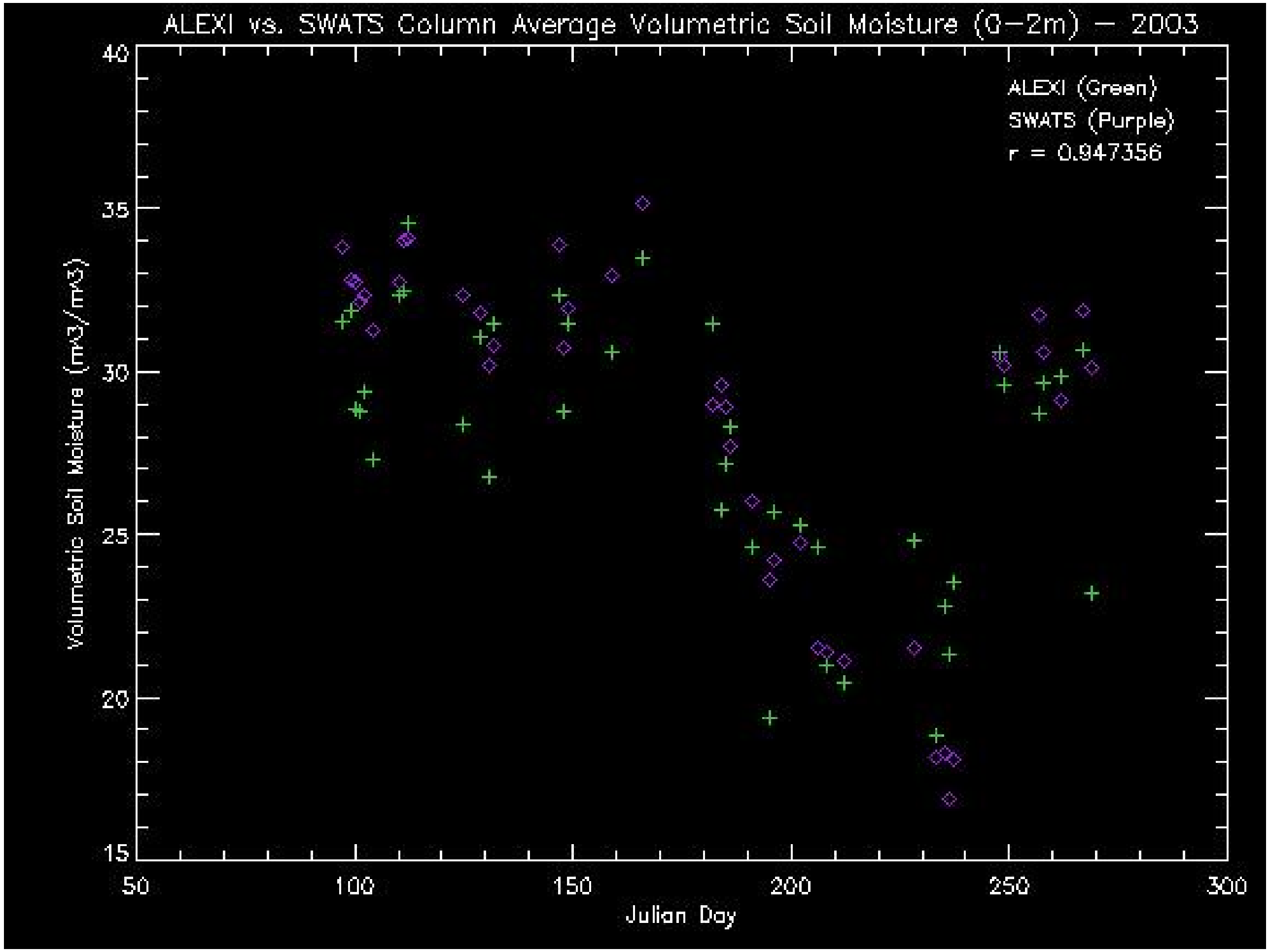

**July 15, 2003 Vegetative Cover**




**July 15, 2003 Total System ET**

## Verification of soil moisture products can be very difficult :

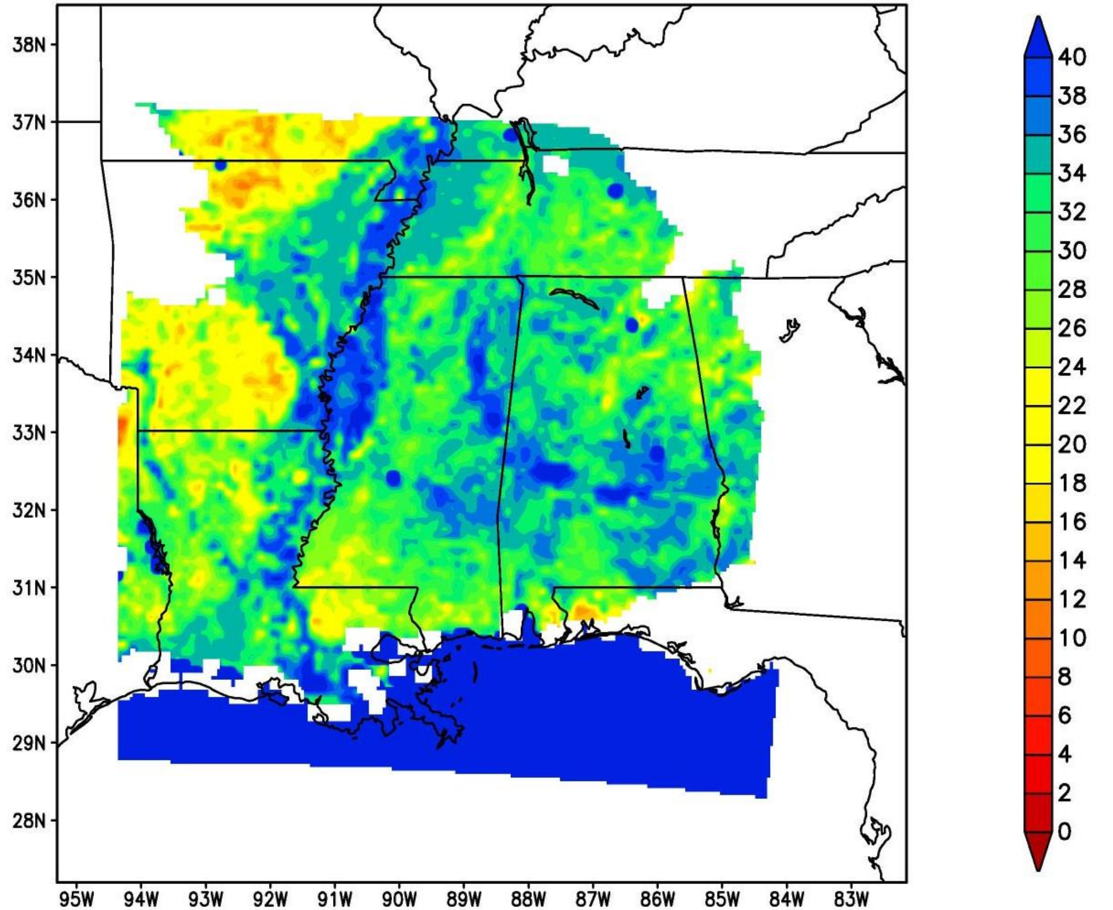
- Lack of large observational soil moisture networks
- Problems verifying a point observation with a 10km x 10km pixel (ALEXI)
- Have chosen to verify ALEXI through time series correlations using spatially averaged soil moisture observations from the OK Mesonet and SWATS soil moisture observations.



• Assume that ALEXI's total system evapotranspiration is an integrated average of available water within the *0-200 cm soil column*. Unfortunately, we know very little about the distribution of available water within that 0-200 cm soil column.

• Using the available water profile from NAM/EDAS initialization fields as a first guess of the soil profile, and adjust this profile to fit the integrated average of available water from ALEXI.

**ALEXI Volumetric Soil Moisture (0 – 10 cm) – Sept 29, 2003**

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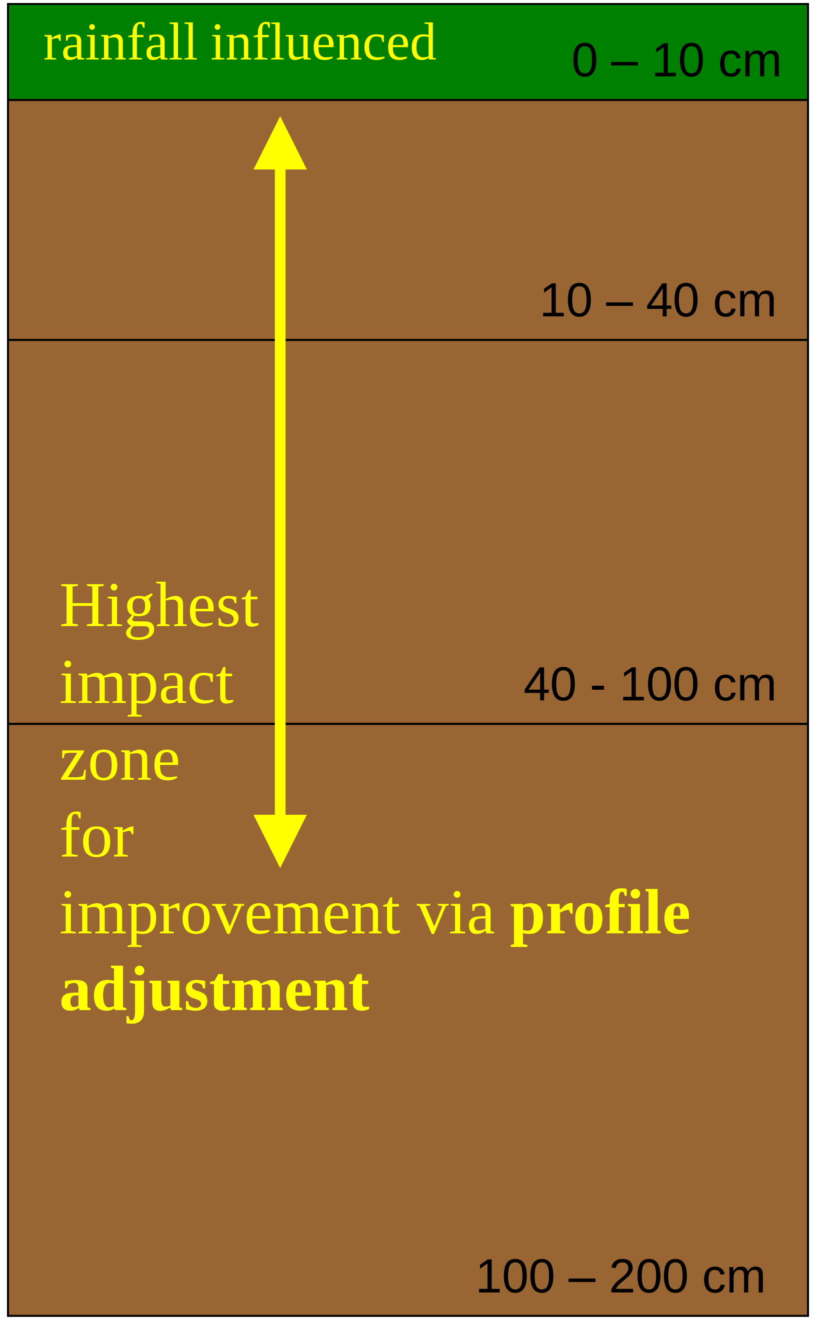
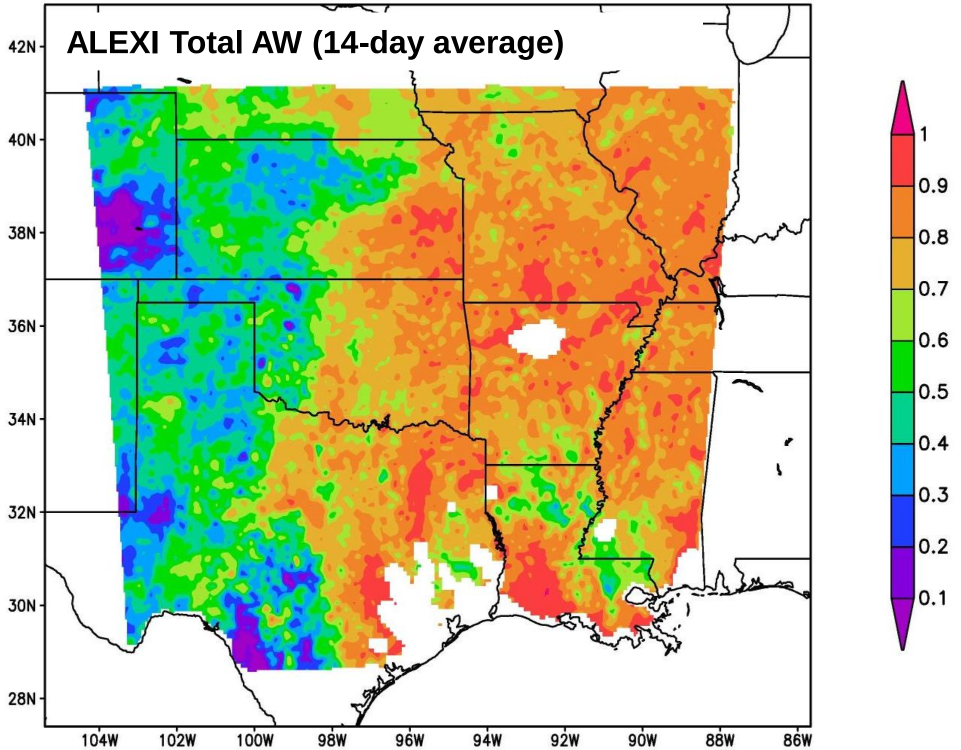
**Current mesoscale numerical models use sophisticated land-surface models to handle the coupling between the surface and the atmosphere.**

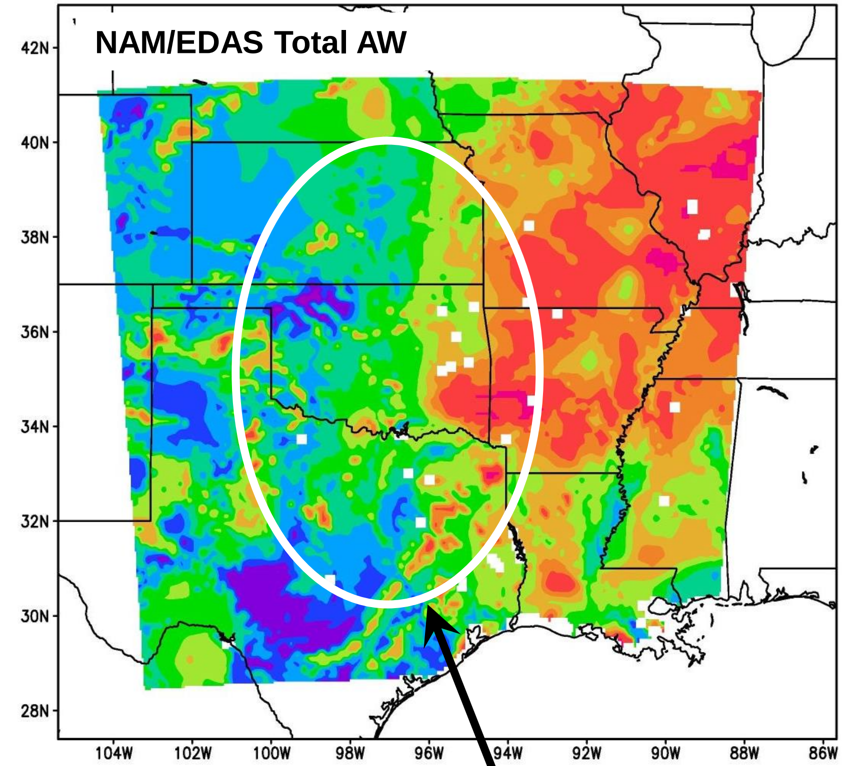
The NOAH-LSM uses a 4-layer soil moisture model to handle the exchange of soil water between the surface, sub-surface and atmosphere.

Under high vegetative cover, ALEXI loses some sensitivity to handle the surface layer (0-10 cm), and under low vegetative cover, ALEXI loses some sensitivity to the sub-surface layers (10-200 cm).

We assume that a fraction of evapotranspiration is directly (1:1) related to a fraction of available water, which in turn can be used to calculate a volumetric soil moisture, given values of field capacity and permanent wilting point for the soil type.





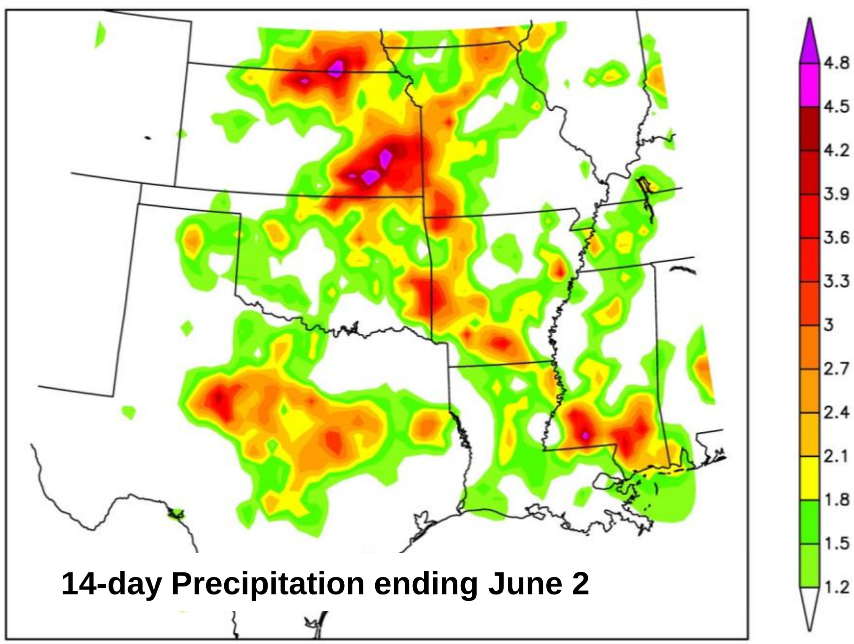




## Soil Moisture Initialization

2 June 2002

WRF Model Experiments

Chris Hain (UAH)

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# *Data Assimilation plans for 2006*

**Theme 1:** Continued ALEXI $A_w$ initialization into WRF via ADAS; work towards routine (daily) assimilation within SPoRT WRF (in conjunction with MODIS SSTs).

**Theme 2:** Work ALEXI into an integrated Soil Moisture assimilation scheme that takes advantage of Microwave moisture estimates.

**Theme 3:** Begin the assimilation of ARMOR radar product fields (with Walt Petersen).

**Theme 4:** Routine ADAS analyses for NWS ("*surface-only*" and "*regional-3D*")

**Theme 5:** MIPS-based "sensitivity-driven" (via Ensemble Kalman Filter) assimilation tool.

# Contact Information/Publications

***Contact Info:***

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Chris Hain: *hain@ssec.wisc.edu*
Martha C. Anderson: USDA (see me for email)

***Web Page:***

nsstc.uah.edu/johnm/alexi/

***Publications:***

Hain, C., and J. Mecikalski, 2006a: ALEXI soil moisture validation… Conf. Satellite Meteorology and Oceanography. Atlanta, GA

Hain, C., and J. Mecikalski, 2006b: WRF-model initialization with ALEXI available soil moisture estimations… Conf. Satellite Meteorology and Oceanography. Atlanta, GA

Hain et al., 2006/07: Formal publication. In preparation. *J. Hydrometeor.*