# Diurnal Water and Energy Cycles over the Continental United States

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# Overview

- Introduction and Background
- Comparison with ARM SGP observations
- Diurnal Variations in comparison to NARR
  - Surface energy
  - Surface water
  - Atmospheric water
  - Atmospheric energy

# Motivation for Diurnal Examination

- Data assimilation and reanalyses are now conducted on temporal scales that allow diurnal examinations
  - Test model physics and parameterizations at sub-seasonal scales
  - Identify land-surface, topographic, and dynamic features that create unique diurnal behaviors
  - Distinguish the relative ability to handle the diurnal cycles of the surface and atmospheric column

- Currently, atmospheric models tend to focus on the mean at the expense of extreme events
  - Too much drizzle, not enough floods or droughts
  - Too many warm days, not enough heat waves

- Goal is to simulate proper evolution, exchanges, and statistics of water and energy cycles throughout the day over diverse regions at multiple spatial scales
  - Are the diurnal statistics reliable at climate model resolutions?
  - Are the limitations in resolution or parameterization?

# Methodology

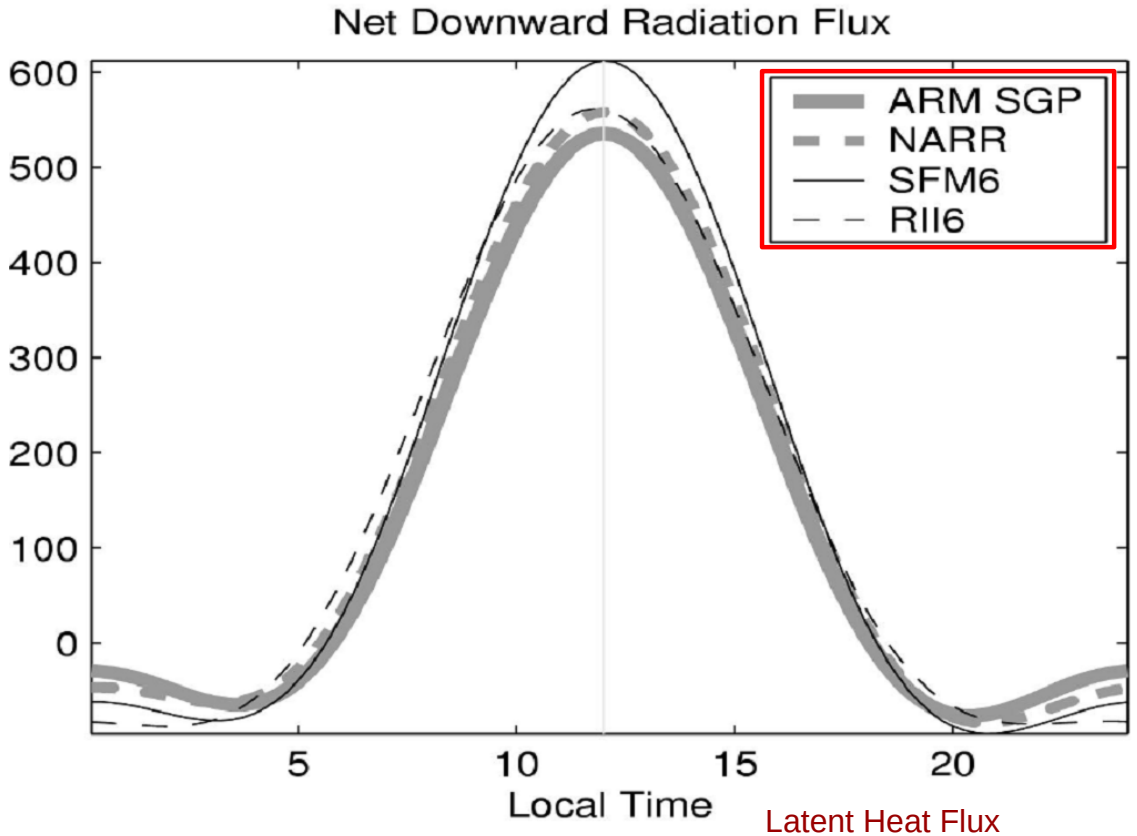
- North American examination based on reanalyses initialized 4x daily
  - An updated Seasonal Forecast Model Reanalysis (SFM6)
  - The NCEP/DOE Reanalysis-2 (RII6)
  - The North American Regional Reanalysis (NARR) smoothed to global grid (T62)

- Diurnal and semidiurnal harmonics least-squares fit onto mean diurnal cycle from July, August, and September 2001-2003
  - Forms smooth reconstruction of diurnal cycle with known mean, phase, and amplitude of each component

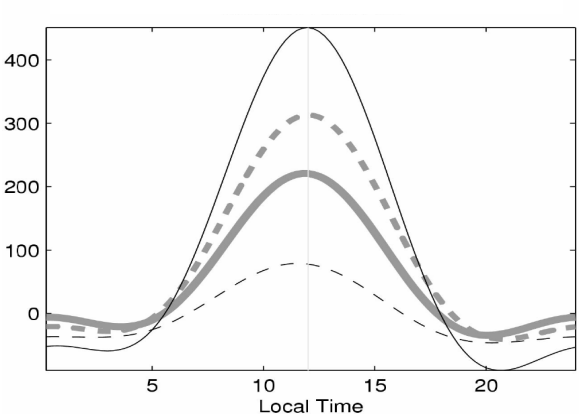
$$Q(t) \approx \overline{Q} + \sum_{h=1}^{H} A_h \cos\left(\frac{2p\left(t - f_h\right)}{P_h}\right)$$

# ARM SGP Surface Energy

- As expected, there is a strong and regular diurnal radiative forcing
  - Simulated diurnal cycles of surface energy components have phases consistent with observations and each other

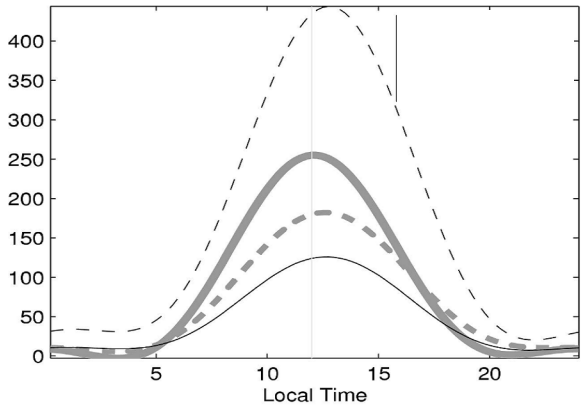



Sensible Heat Flux




- Bowen Ratio varies
  - SFM6 has high sensible heat flux and low latent heat flux
  - RII6 has opposite biases

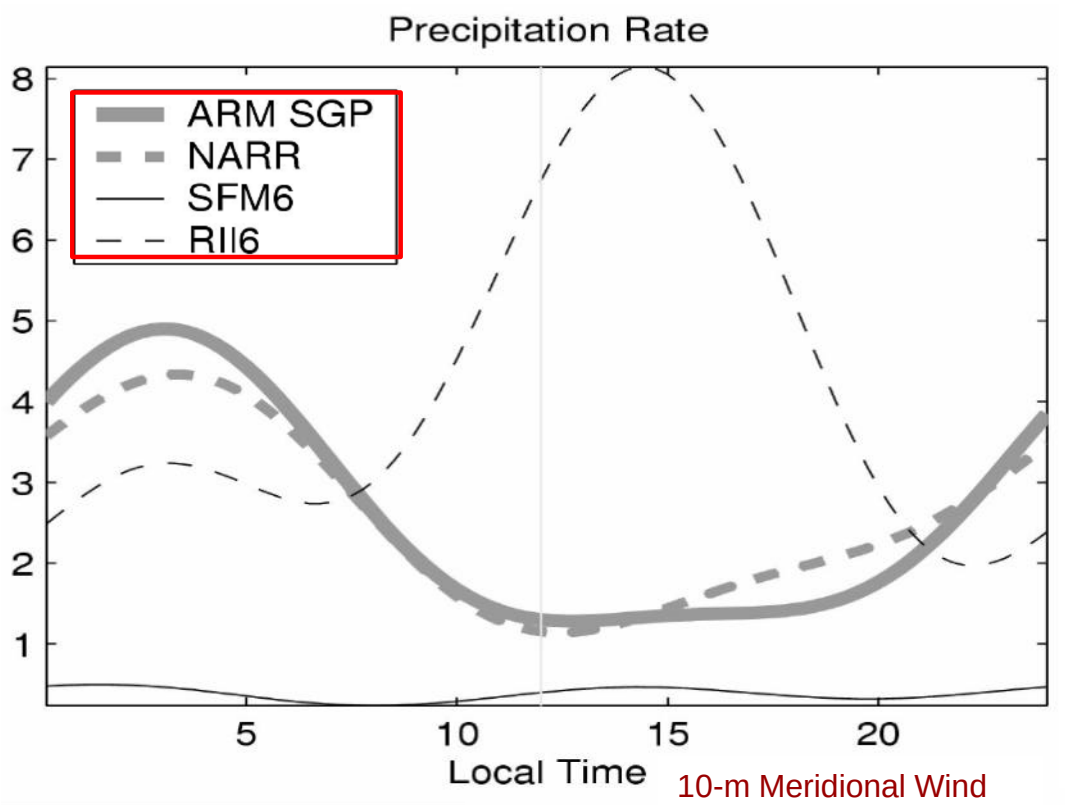
Latent Heat Flux



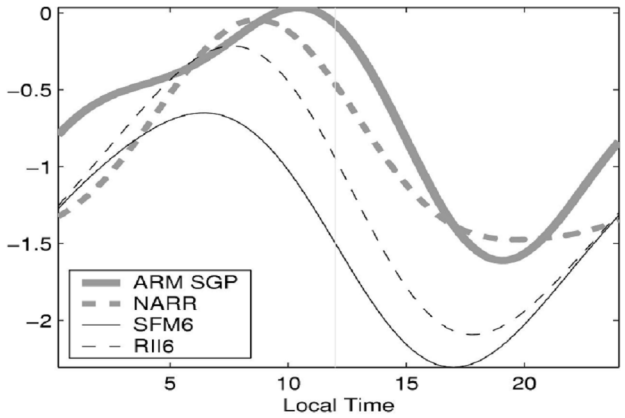
# ARM SGP Water

- Simulated diurnal cycle of precipitation at ARM SGP site shows wide variation
  - NARR assimilated precipitation matches observation
  - RII6 shows strong afternoon peak
  - SFM6 has low amplitude
  - Global analyses miss nocturnal peak

- Where do the models diverge in their response to the diurnal radiative forcing?

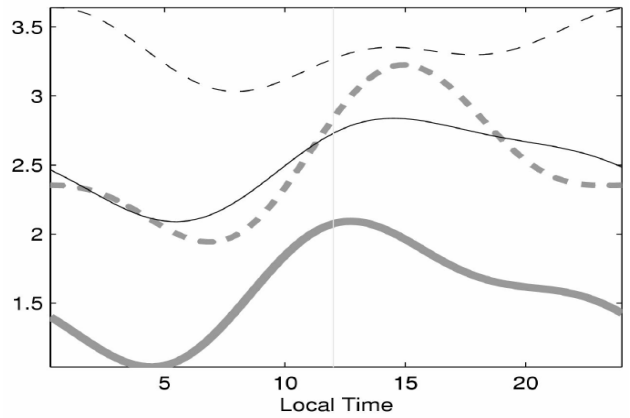



10-m Zonal Wind



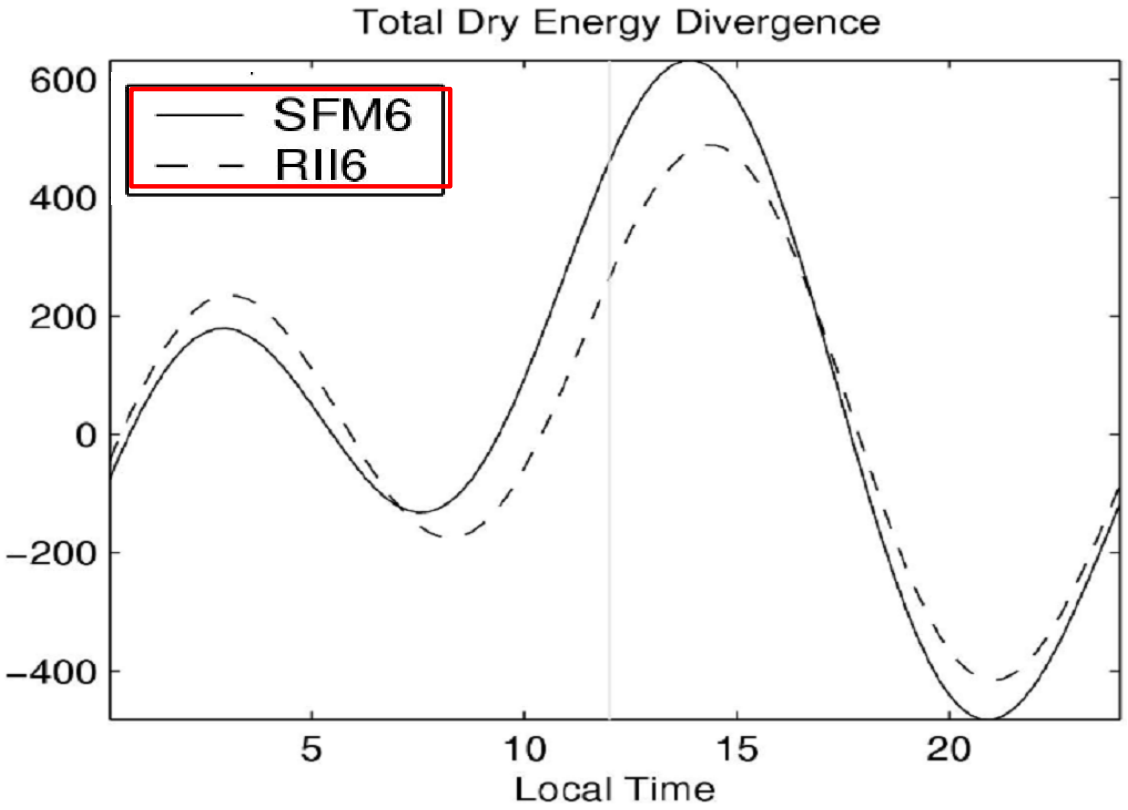

- Diurnally driven dynamics in this region are not well-simulated

10-m Meridional Wind



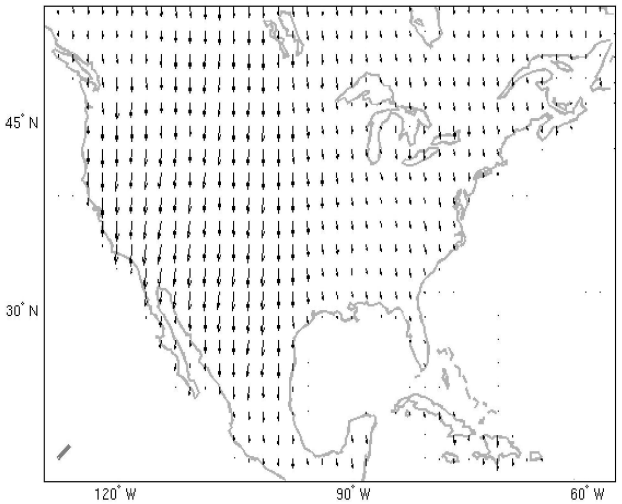
# ARM SGP Atmospheric Energy

- Atmospheric energy reservoir is strongly affected by semidiurnal thermal tides
- Peak atmospheric energy divergence corresponds to afternoon maximum in temperature

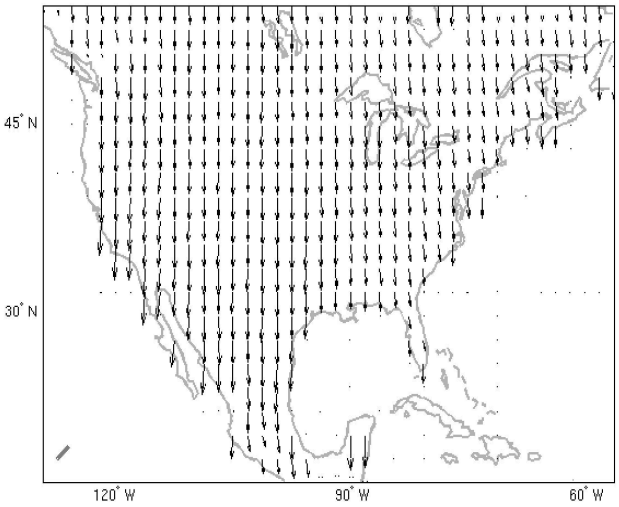


# Diurnal Cycle of Surface Energy

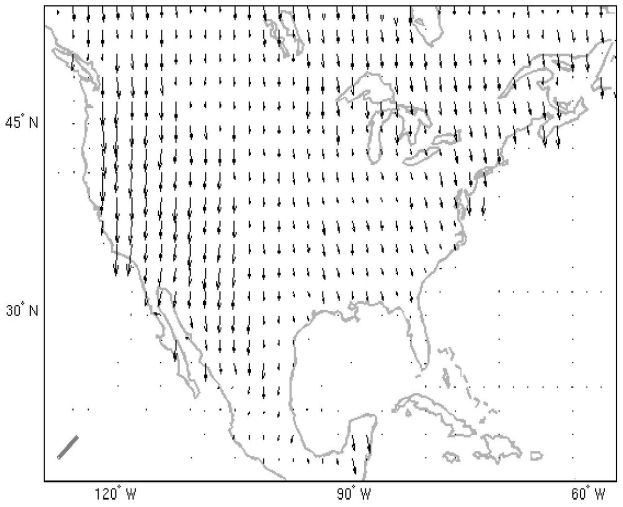
**NARR Sensible Heat Flux**




**SFM6 Sensible Heat Flux**




**RII6 Sensible Heat Flux**

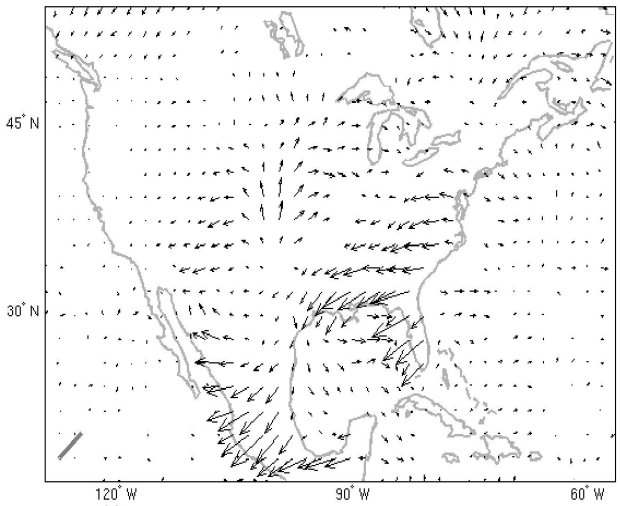



- Sensible heat peaks near local noon across entire continent
  - Very little variation in phase over regions featuring diverse:
    - Soils
    - Topographies
    - Vegetation
  - Amplitude differences in NARR and RII6 reflect underlying soil moisture

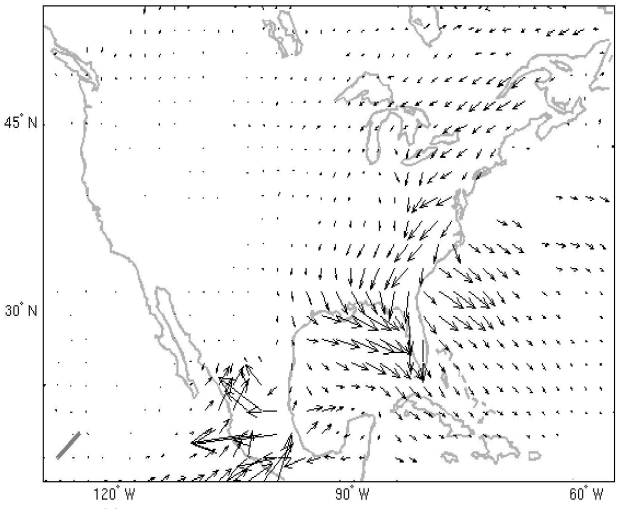
- Amplitude and phase remarkably consistent
- Higher diurnal amplitude over arid regions

# Diurnal Cycle of Surface Water

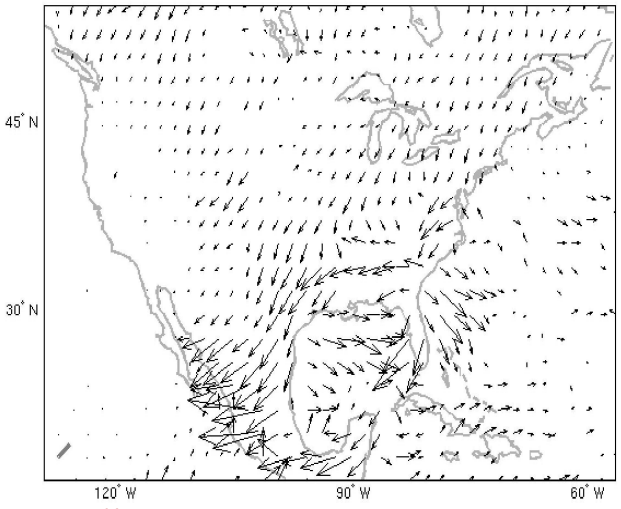
**NARR Precipitation Rate**




**SFM6 Precipitation Rate**




**RII6 Precipitation Rate**

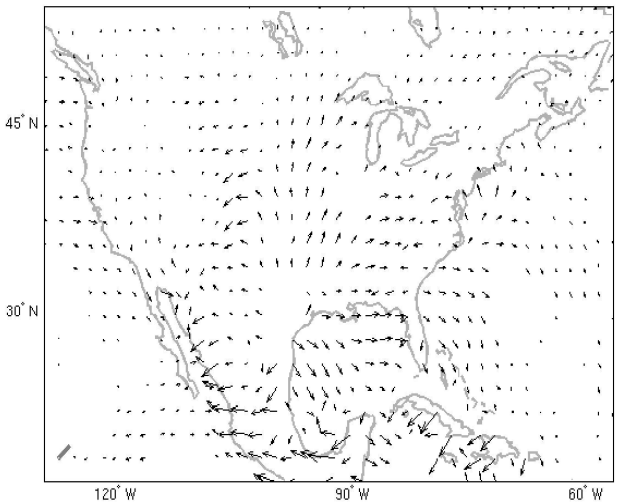



- Assimilated NARR precipitation shows diurnal phase spiral centered near Oklahoma
  - Likely influenced by the Great Plains low-level jet
  - Features nocturnal peak in Upper Midwest from propagating storms
- Global analyses cannot reproduce this continental pattern
  - Land points feature mid-afternoon peak
  - Oceans have late morning peak

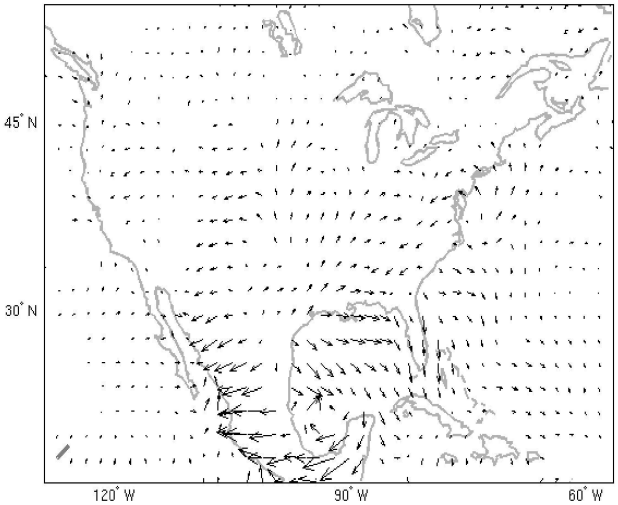
- Significant diurnal cycle only in Sierra Madre and Eastern U.S.
- High diurnal amplitude, includes mountain signal

# Diurnal Cycle of Atmospheric Water

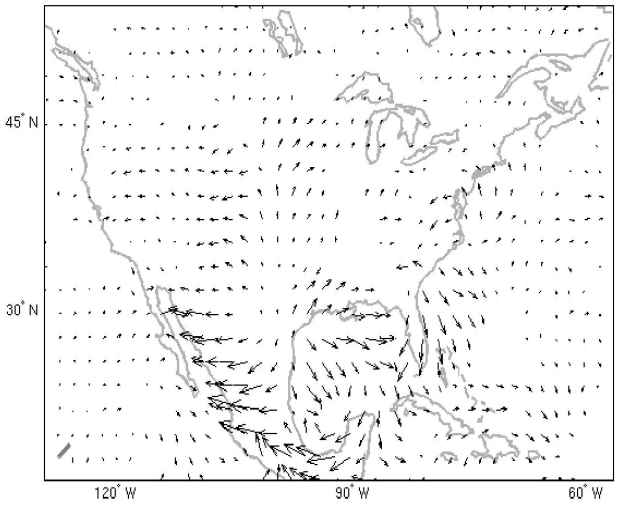
**NARR Vapor Convergence**




**SFM6 Vapor Convergence**




**RII6 Vapor Convergence**

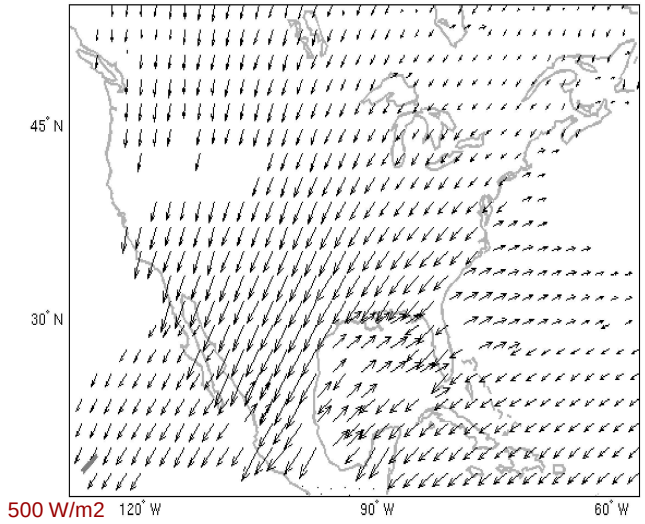



- Diurnal cycle in atmospheric water vapor convergence matches assimilated precipitation pattern
  - True in NARR and global analyses
  - Precipitation parameterizations appear to be too dominant
    - Arakawa-Schubert based parameterizations prematurely initiate convection
    - Inhibition and moisture supply are less important

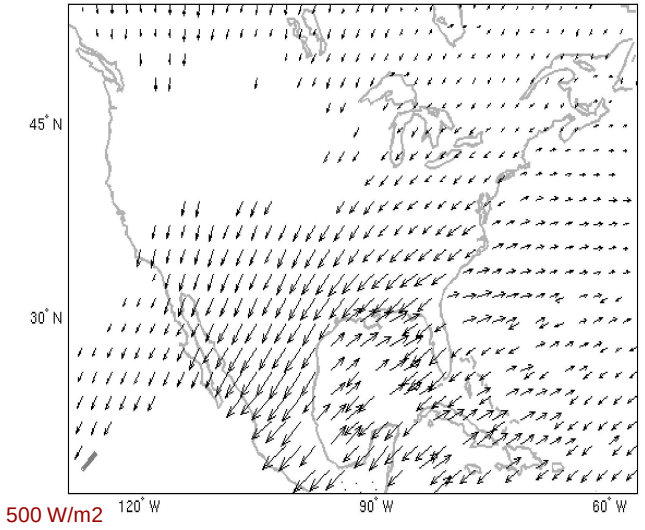
- Evidence of low-level jet delivering nocturnal vapor convergence to Upper Midwest
- Continental phase pattern shifted south toward Gulf Coast

# Diurnal Cycle of Atmospheric Energy

**SFM6 Atmospheric Energy Divergence**




**RII6 Atmospheric Energy Divergence**




- Maximum divergence corresponds to afternoon peak in temperatures
  - Slightly earlier over arid regions where sensible heat is stronger
  - Tropics and Oceans feature more semidiurnal behavior
  - Land surface introduces stronger diurnal behavior

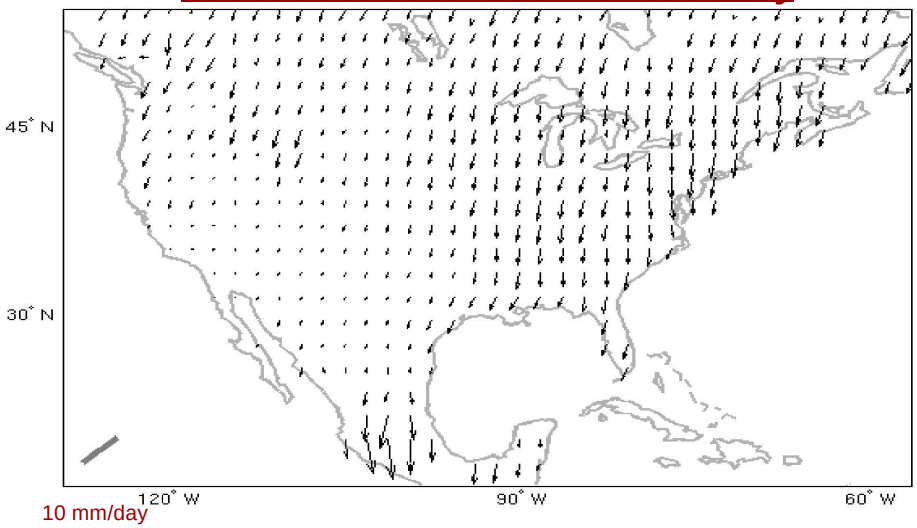
- This variable is not available in NARR

- Arrows pointing at each other in the Southern Atlantic indicate stronger semidiurnal behavior

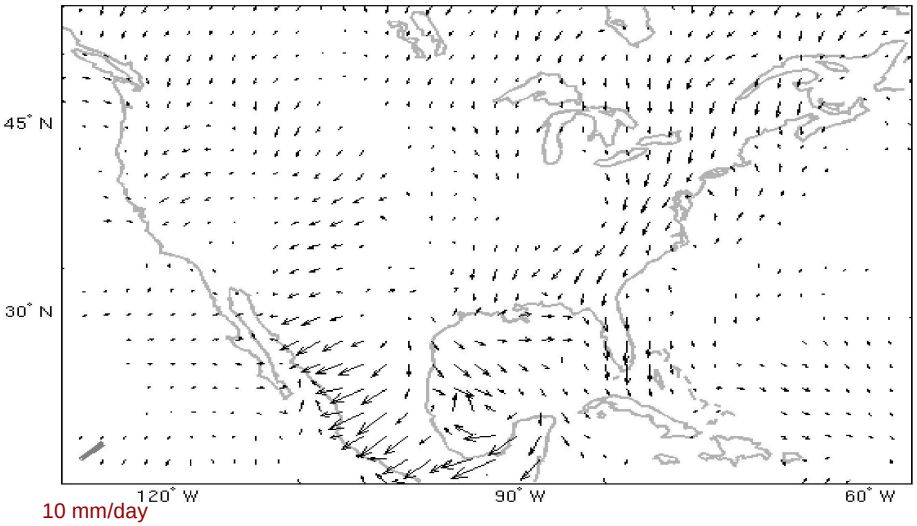
# Role of Reservoir Terms

- The reservoir tendency terms are significant on the diurnal scale
  - Surface Water tendency counters evaporation
  - Precipitable water shows the continental phase pattern
    - Fluctuates in reaction to the vapor convergence and parameterized convection being out of step

**-1 * SFM6 Surface Water Tendency**




**SFM6 Precipitable Water Tendency**



# Conclusions

- The model experiments produce many interesting diurnal features
  - The surface energy cycle's diurnal variation is dictated mostly by local thermodynamics
  - Column energy and water diurnal variations have regional influences
  - Dynamics and reservoir terms are important
    - Regional differences in precipitation affected by diurnal dynamic features
    - Convective parameterizations produce consistent afternoon maxima over land, even where dynamics produce appropriate vapor supplies
    - Reservoir terms have large tendencies to counter parameterizations
- Sub-seasonal statistics must be examined for diurnal reliability
- Future Work
  - Diurnal cycles in different global locations and/or seasons
  - Contrast analysis and forecast diurnal cycles to determine biases
  - Test the sensitivity and tuning of parameterizations to the diurnal forcing