The role of terrestrial routing process and shallow groundwater in land-atmosphere coupling

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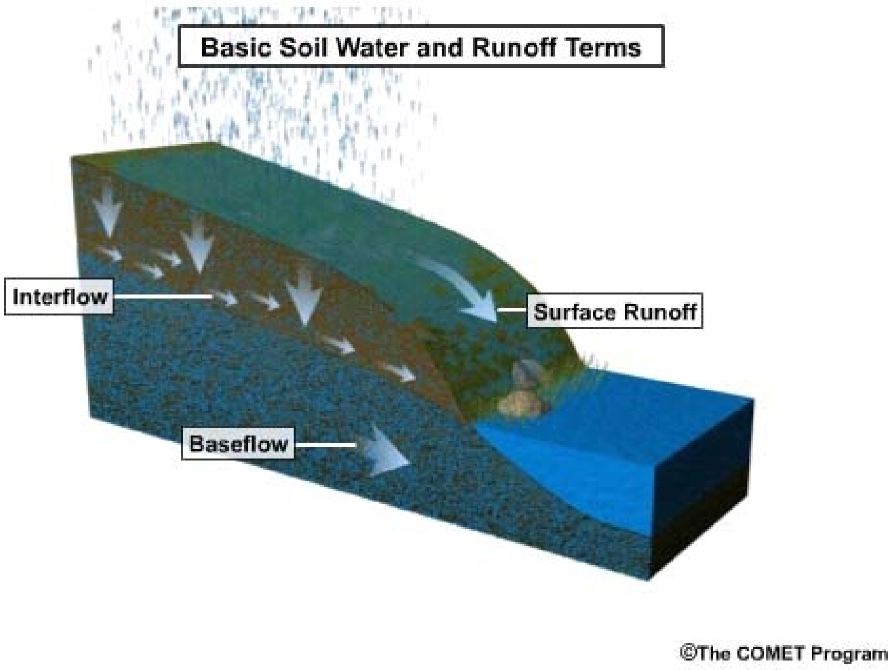
NCAR

Principle Questions

- How does land surface physiography (terrain features) affect the spatial and temporal distribution of moisture availability?
- How does the spatial distribution of soil moisture in complex terrain impact land-atmosphere fluxes and convective circulations?
- What forcing feedbacks do these circulations impart back to the land surface?

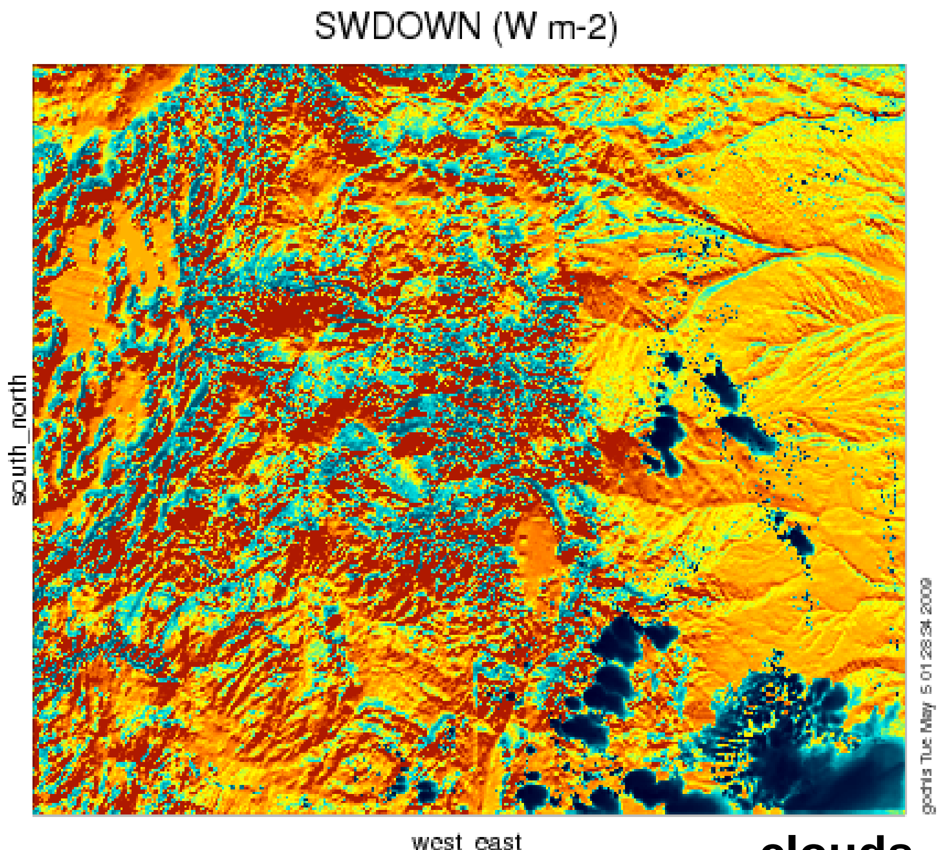
Background

- Terrain features affecting moisture availability (scales ~1km)
  - Routing processes: the redistribution of terrestrial water across sloping terrain
    - Overland lateral flow (dominates in semi-arid climates)
    - Subsurface lateral flow (dominates in moist/temperate climates)
    - Shallow subsurface waters (in topographically convergent zones)
  - Other land surface controls:
    - Terrain-controlled variations on insolation (slope-aspect-shading)
    - Soil-bedrock interactions



Background

- Terrain insolation (Zangl, Whiteman, Egger)
- Shallow groundwater (Fang, Miguez-Macho, Niu and Yang, Rajagopal)
- Terrain routing (Maxwell and Kollet)

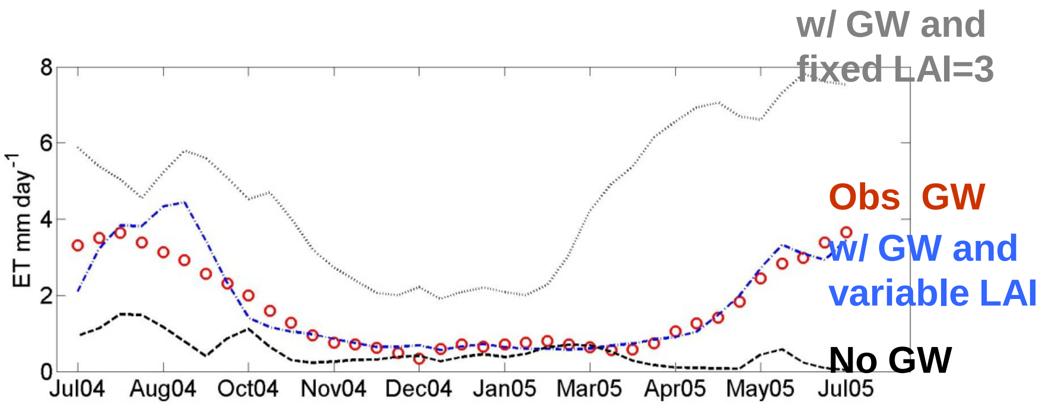


clouds

Range of SWDOWN: 0 to 1232.24 W m-2
Range of west_east: 0 to 600
Range of south_north: 0 to 500
Current Time: 7
Frame 8 in File data_6_21.nc

Background

- Terrain insolation (Zangl, Whiteman, Egger)



- Shallow groundwater (Fang, Miguez-Macho, Niu and Yang, Rajagopal)

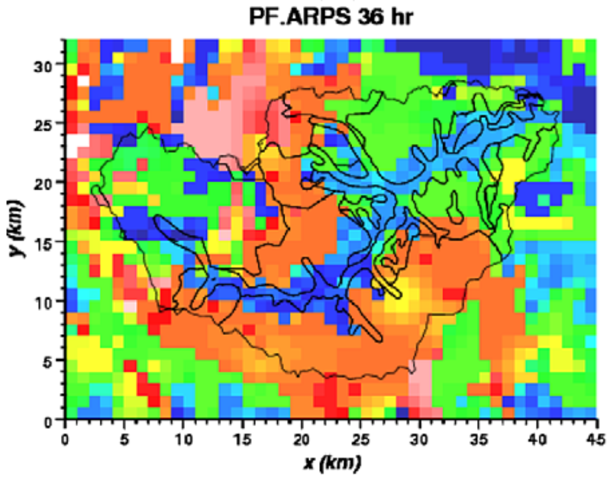
Sensitivity of Noah modeled LE to specification of water table depth
(Rajagopal et al, J. Hydromet, sub.)

Groundwater Depth (m)	Percent bias in ET (w.r.t. observed ET @ GW depth of 2.5m)
1.5	31.22
2.5	1.8
4.0	-38.8

- Terrain routing (Maxwell and Kollet)

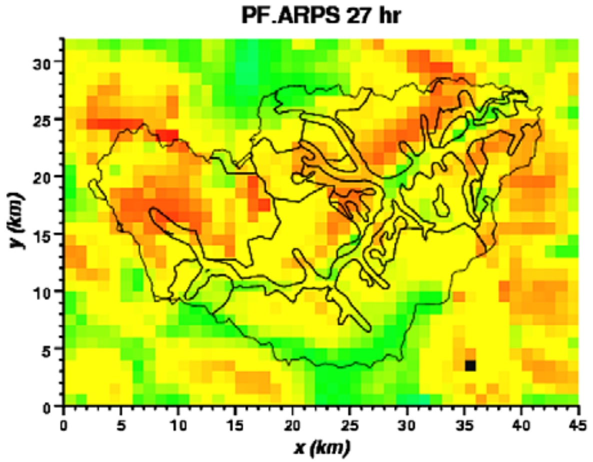
Background

- Terrain insolation (Zangl, Whiteman, Egger)



Soil moisture
(cool colors = high values)

- Shallow groundwater (1-D: Fang, Miguez-Macho, Niu and Yang, Rajagopal)



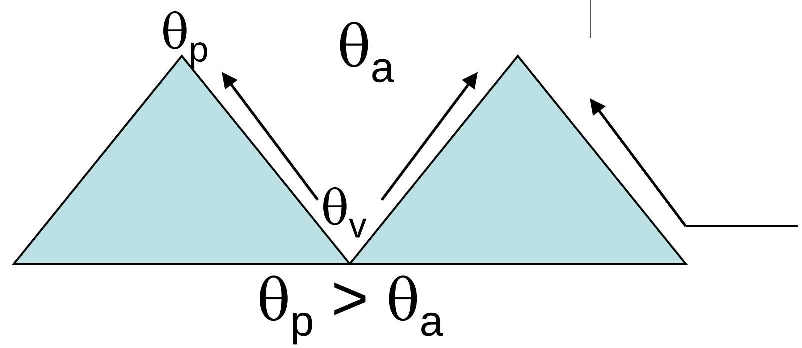
LE
(warm colors = high values)

- Terrain routing (3-D: Maxwell and Kollet, Famig.&Wood)

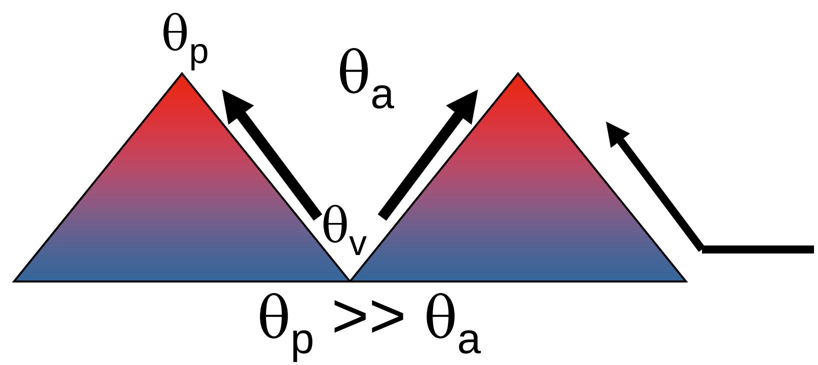
Maxwell et al., Adv. Water Res. 2007

Terrain circulations:

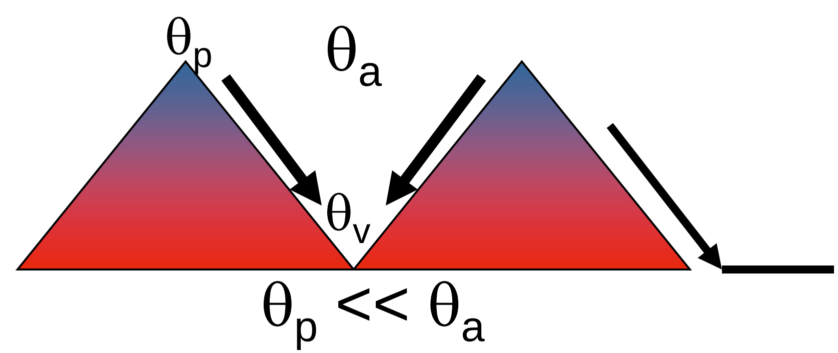
- Background circulation



- Increased circulation (dry peaks)



- Suppressed circulation (wet/snow peaks)



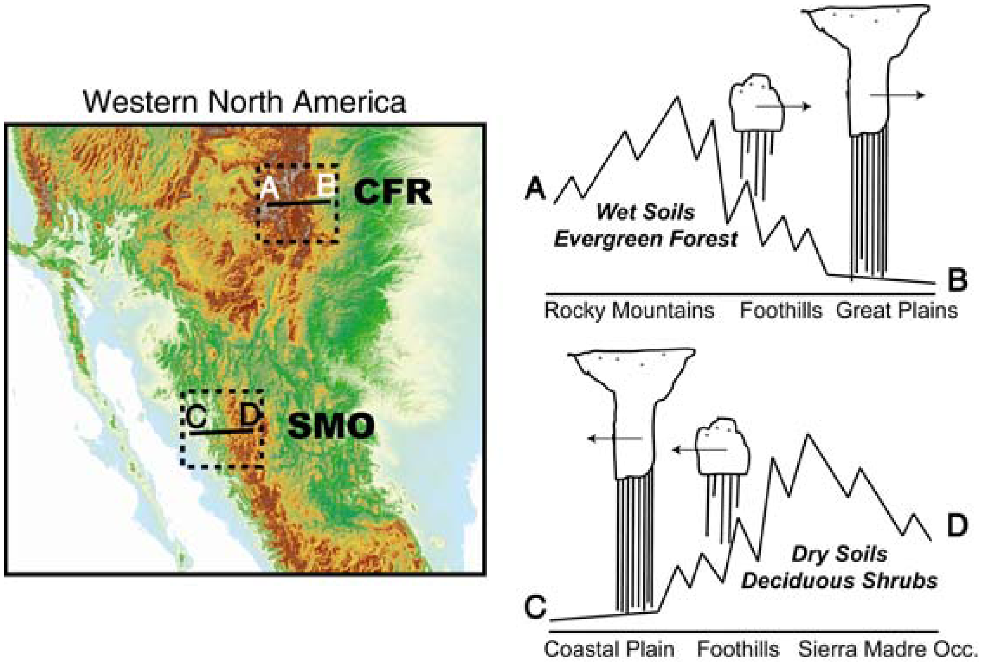
Terrain circulations: Complications

- How do routing processes influence these circulations?
  - How do wet valley-dry peak or dry valley-wet peak conditions influence the terrain circulation? Similarly for mountain-plain circulations?
  - At what spatial and temporal scales do these processes become significant?

  - Is there a detectable difference from an NWP/QPF perspective?
  - What are the potential reasons for such differences?

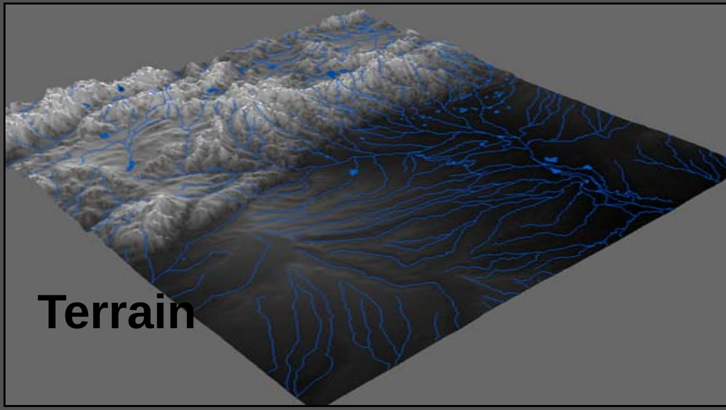
Outline

- Experiment: Explore the influence of routing processes on the simulation of a flood producing convective event in the lee of orography



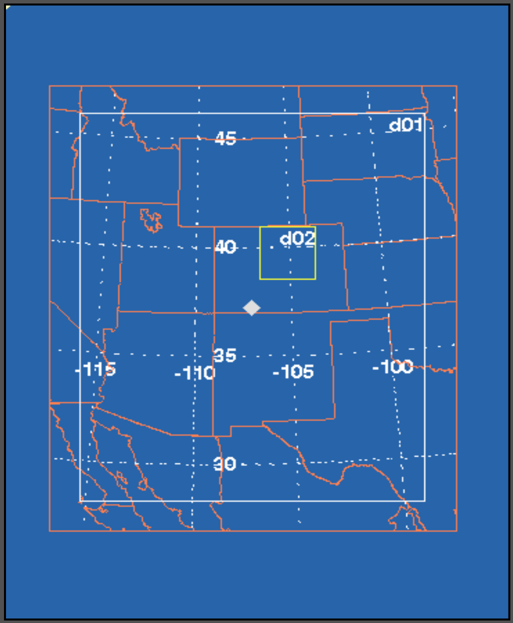
Courtesy E. Vivoni

Coupled WRF-Hydro Flash Flood Forecasting in the Colorado Front Range:



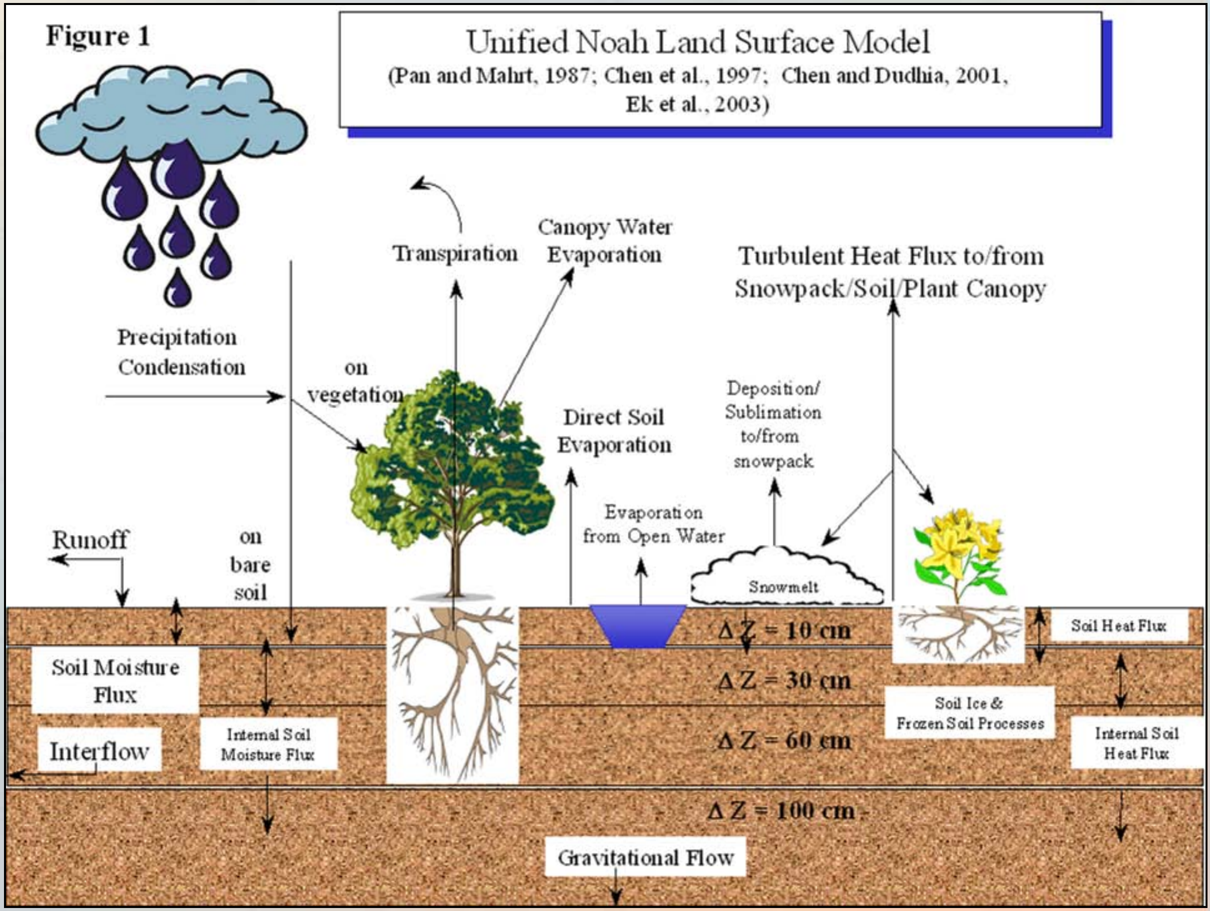
- WRF Model Options
  - No convection parameterization
  - Purdue/Lin 6-class microphysics
  - RRTM LW, Dudhia SW
  - Yonsei PBL, M-O sfc lyr
  - Noah land surface model w/ and w/out coupled Noah-distributed routing
  - Operational runs from 00z (research run from 12z)

4 km and 1 km WRF Domains



Recent Model Development Activities: Distributed hydrological routing

- Jointly developed LSM (NCAR, NCEP, AFWA, Universities)
- Full suite of land surface physics for energy and water exchange
- Capable of running coupled to NWP or 'offline'
- Center piece of the NCAR HRLDAS and NASA-LIS

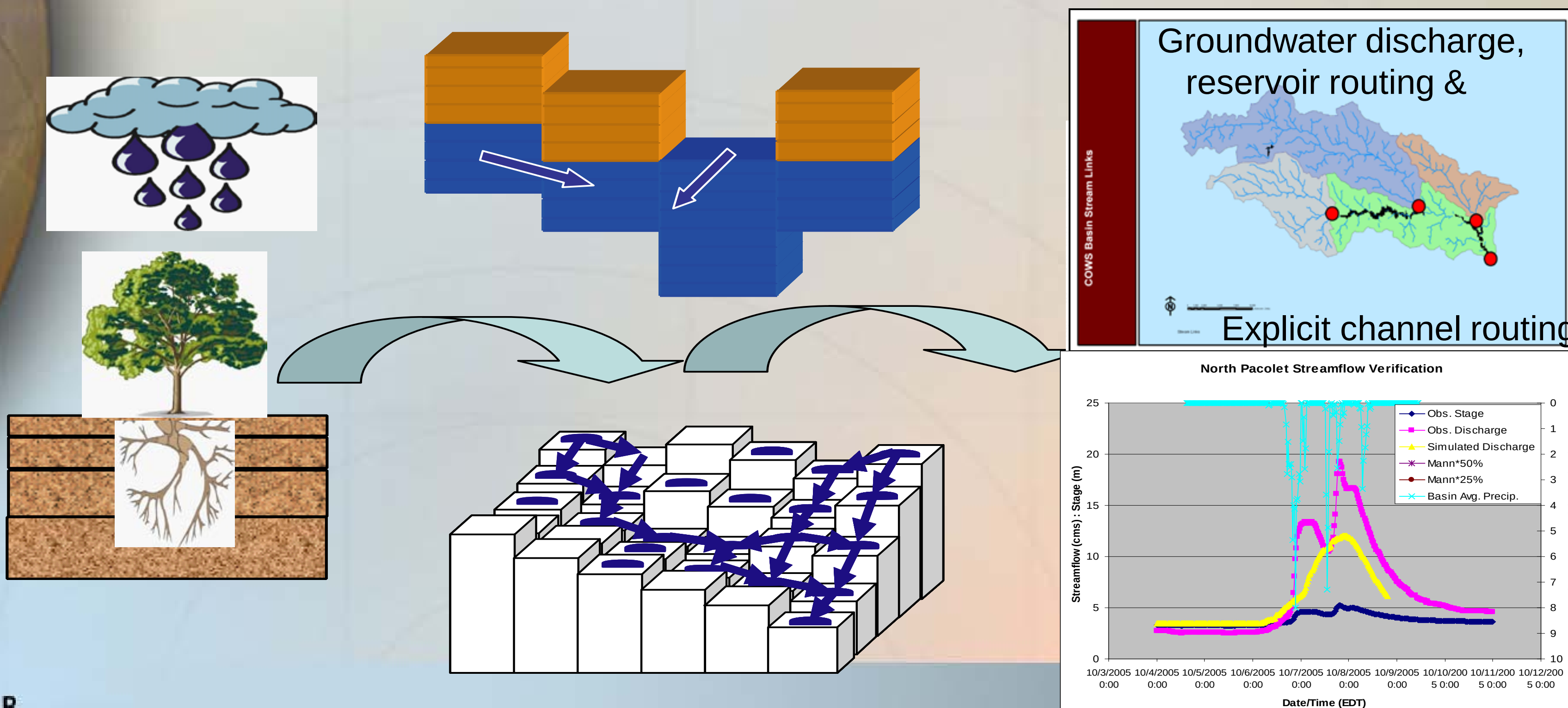


The National Center for Atmospheric Research

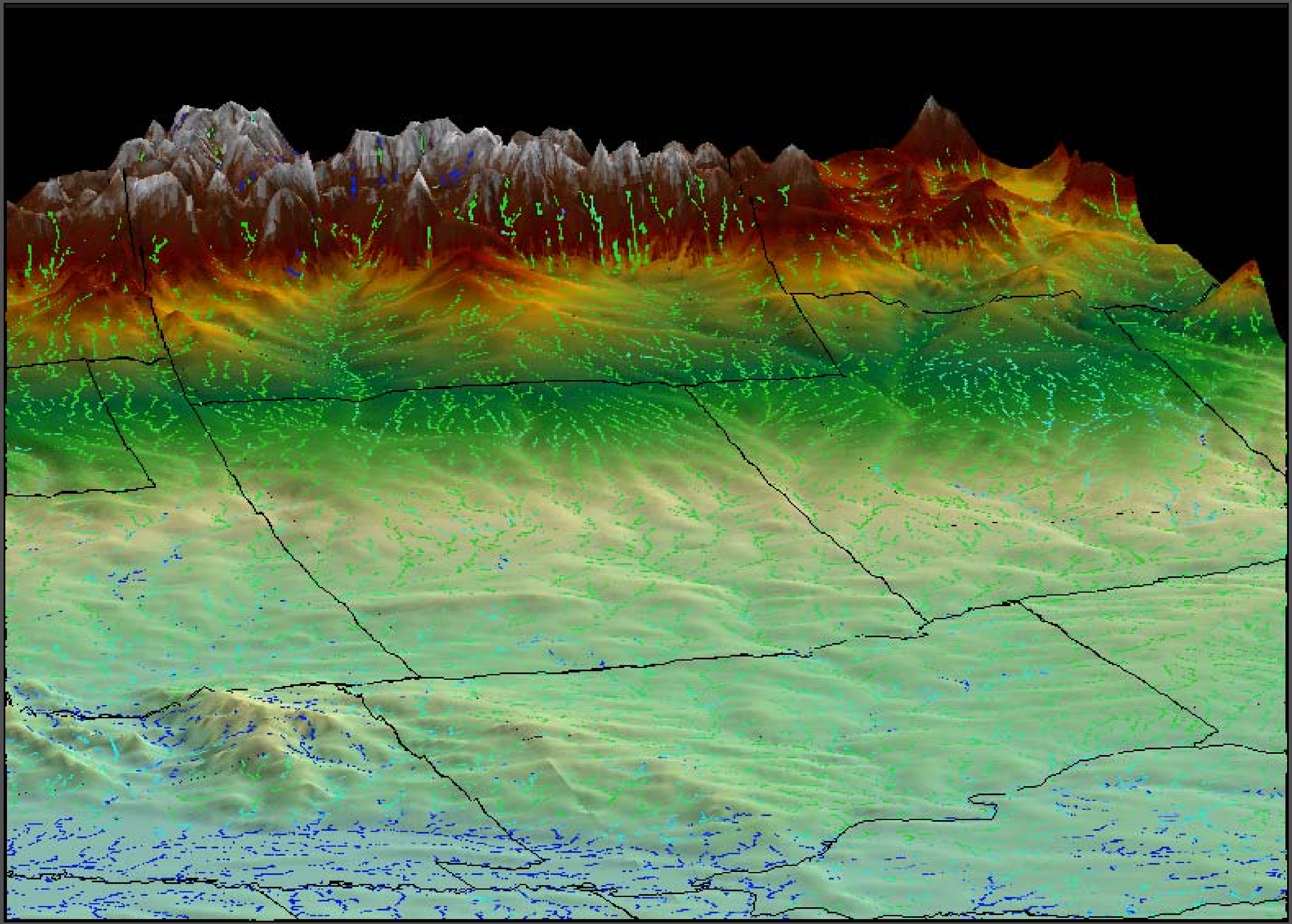
NCAR

Recent Model Development Activities: Distributed hydrological routing

- Explicit dynamical hydrologic/hydraulic modeling (< 1km):
  - Integration of landscape resolving LSMs with Cloud Resolving Models
  - Parallelized for High Performance Computing Platforms



Distributed routing processes in Noah:



Model Experiments

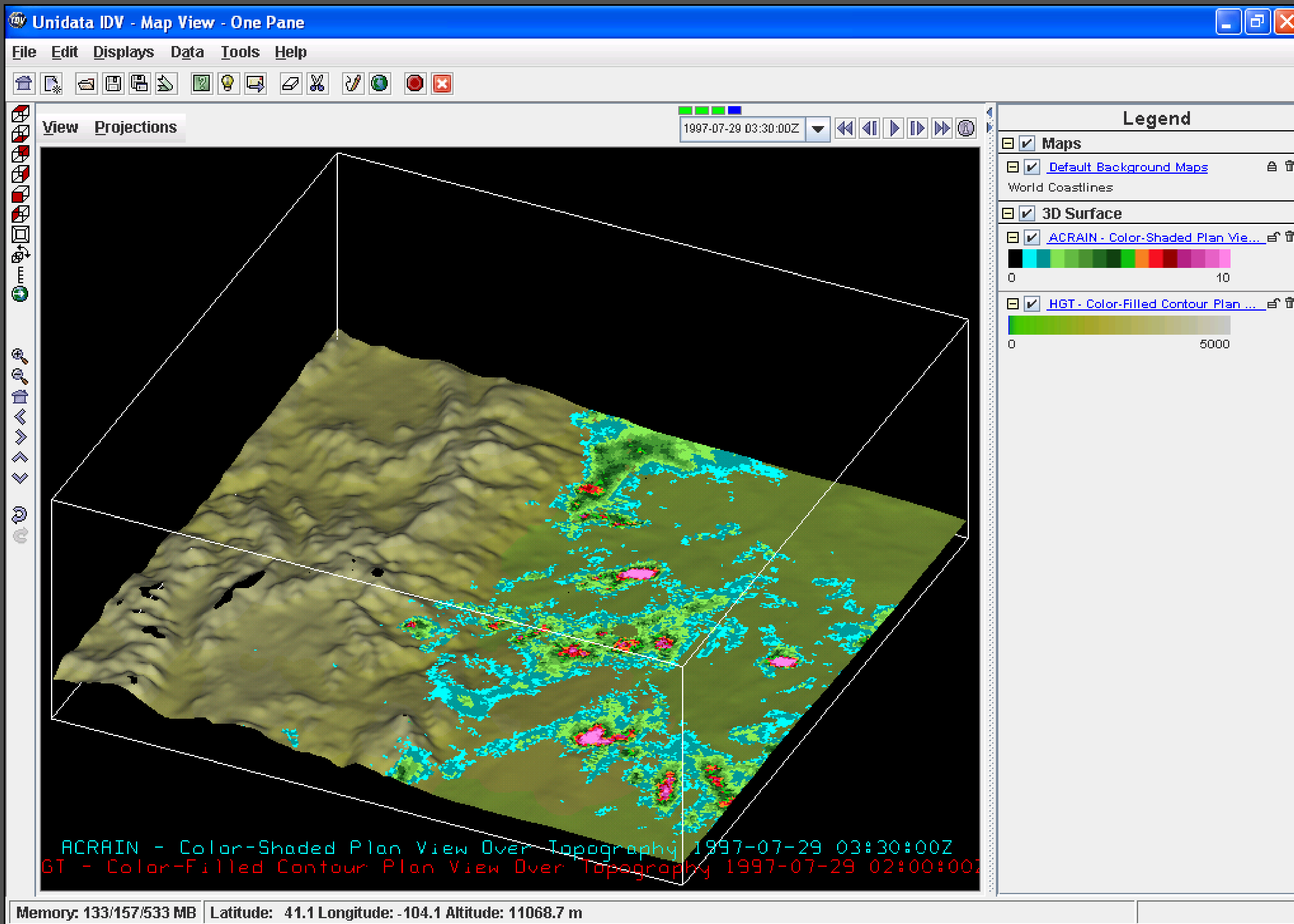
NCAR

- July 28, 1997 Fort Collins flood event

  1. Spin up land surface initial conditions with and without terrestrial routing (2mo. spin-up, avoiding snowmelt)
  2. (NOT SHOWN) Run WRF with fully-coupled routing and compare against fully-coupled non-routing case: Some minor differences in QPF over timescale on the order of 18-24 hours but largely offsetting in space (similar to Trier et al., 2008)
  3. Compare/contrast fully-coupled WRF simulations with spun-up land surface conditions (w/ and w/out routing) but no routing during simulation

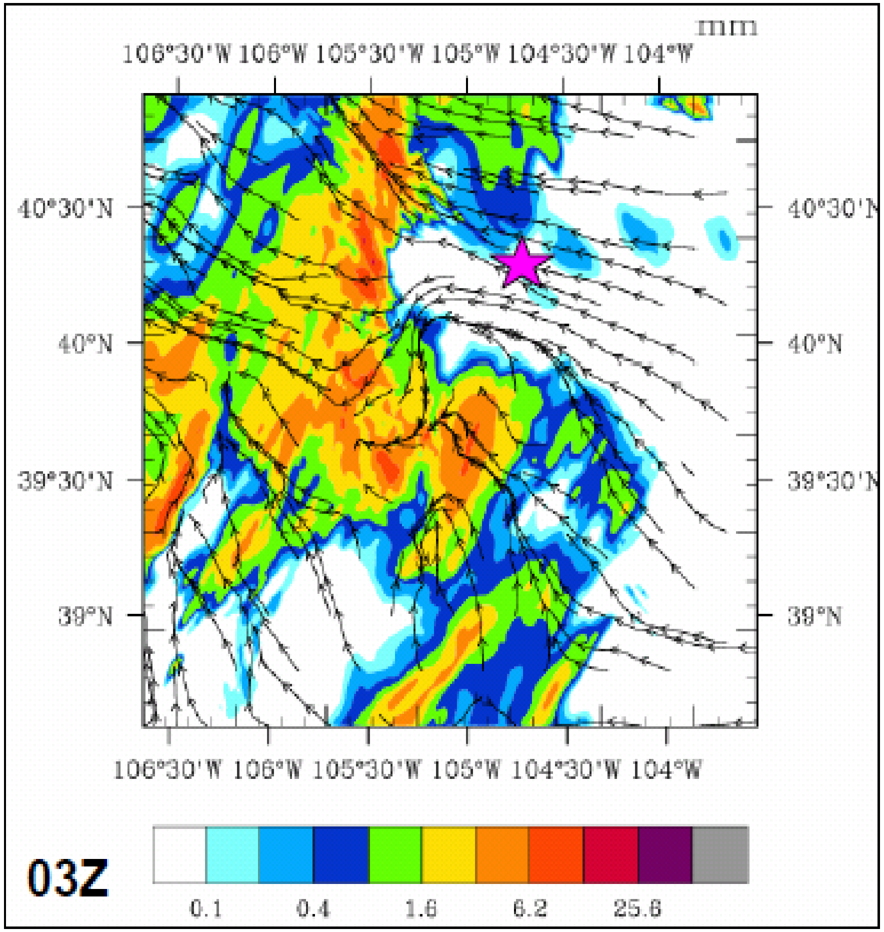
- Aim: Assess the impact of land surface initializations on simulated storm event

The 1997 Forth Collins Flood:



Case Study: 1997 Ft. Collins Flood Event Mesoscale Analysis

1 km WRF-w/out routing:
Init. July 27 12z



1 km WRF-w/ routing:
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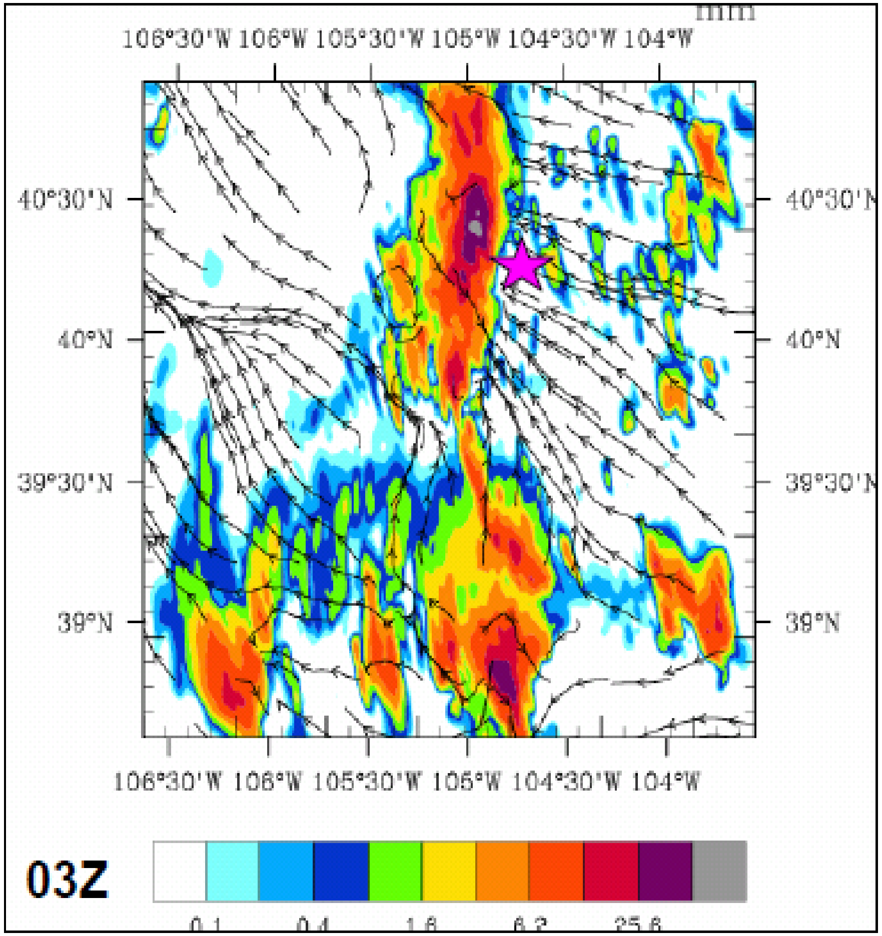


Case Study: 1997 Ft. Collins Flood Event

Mesoscale Analysis

"Denver Cyclone"

Observed Analysis

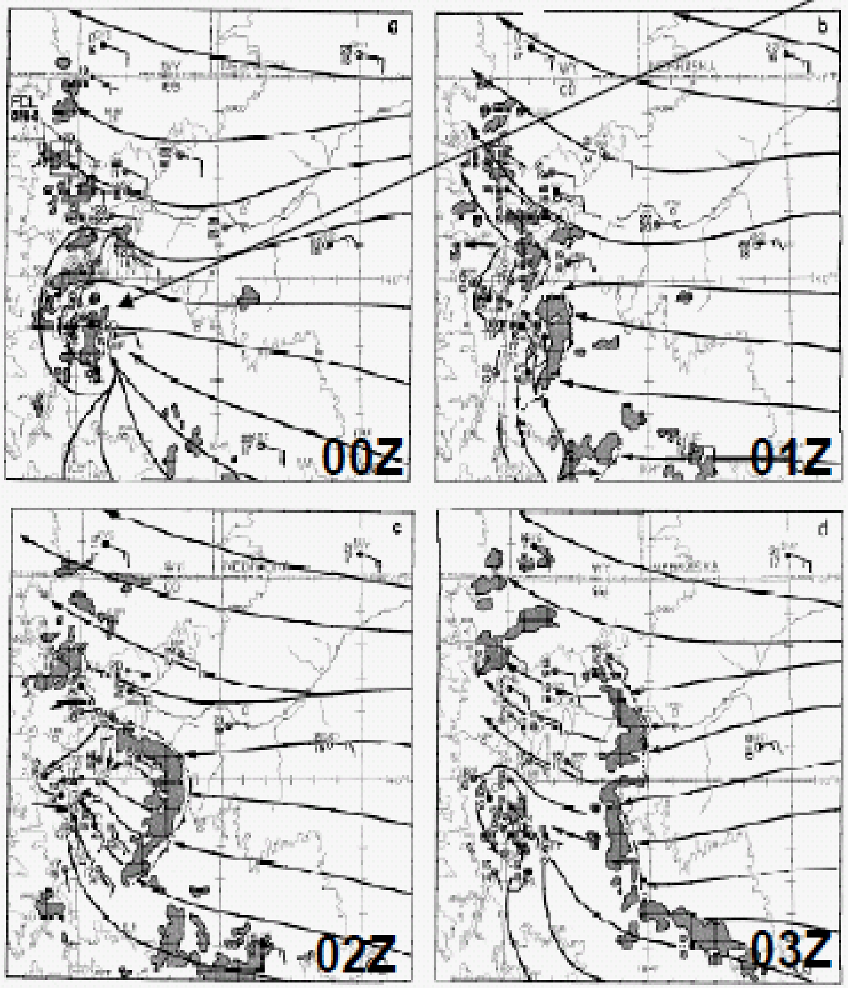
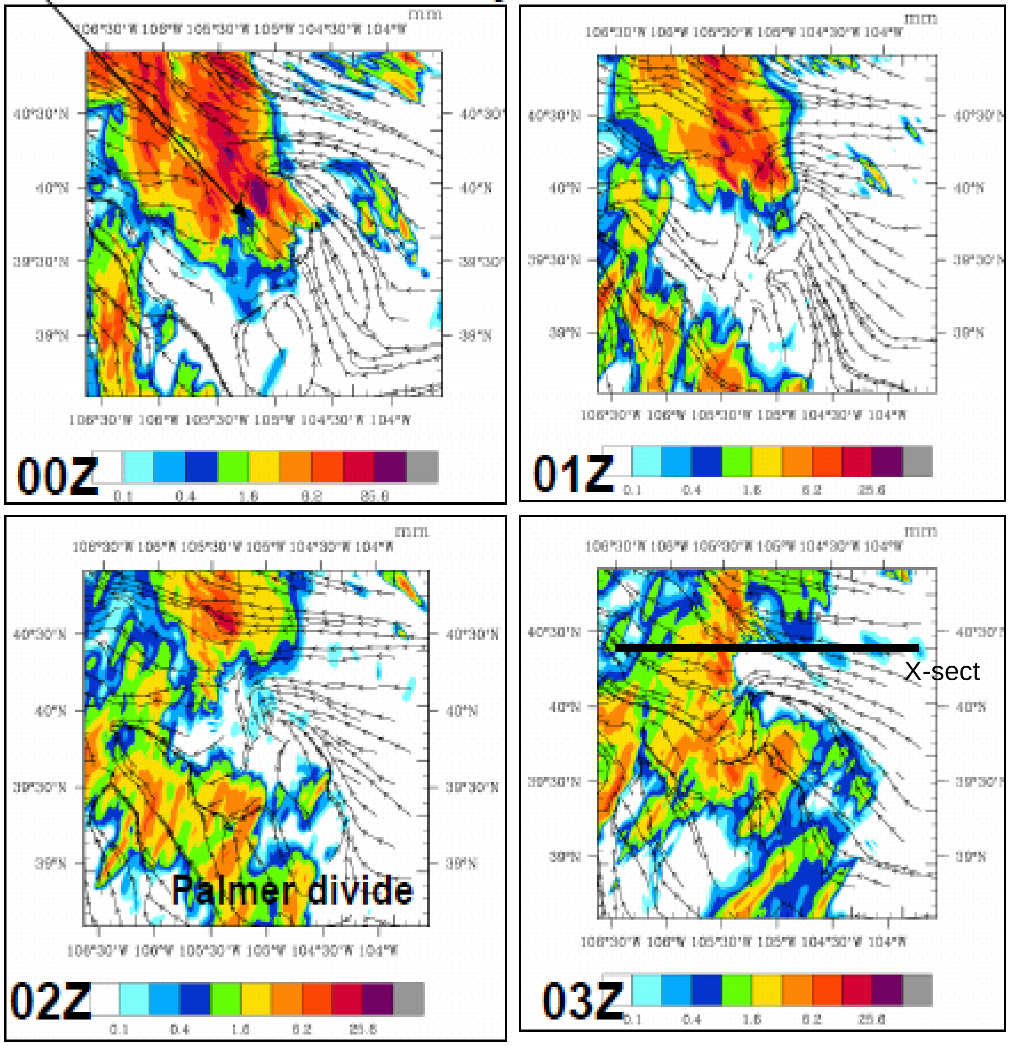


Fig. 7. Hourly mesoscale analyses for 1800–2100 MDT 28 July 1997 (0000–0300 UTC 29 July 1997). Surface streamlines are in solid arrows. Wind barbs plotted as in Fig. 6; temperature and dewpoints in °C. Mesoscale boundaries are indicated as in Fig. 5. Regions of radar reflectivity ≥ 35 dBZ are shaded: (a) 1800 (0000), (b) 1900 (0100), (c) 2000 (0200), and (d) 2100 MDT (0300 UTC).

1 km WRF-no routing: Init. July 27 12z



Case Study: 1997 Ft. Collins Flood Event

Mesoscale Analysis

Observed Analysis

"Denver Cyclone"

1 km WRF-w/ routing: Init. July 27 12z

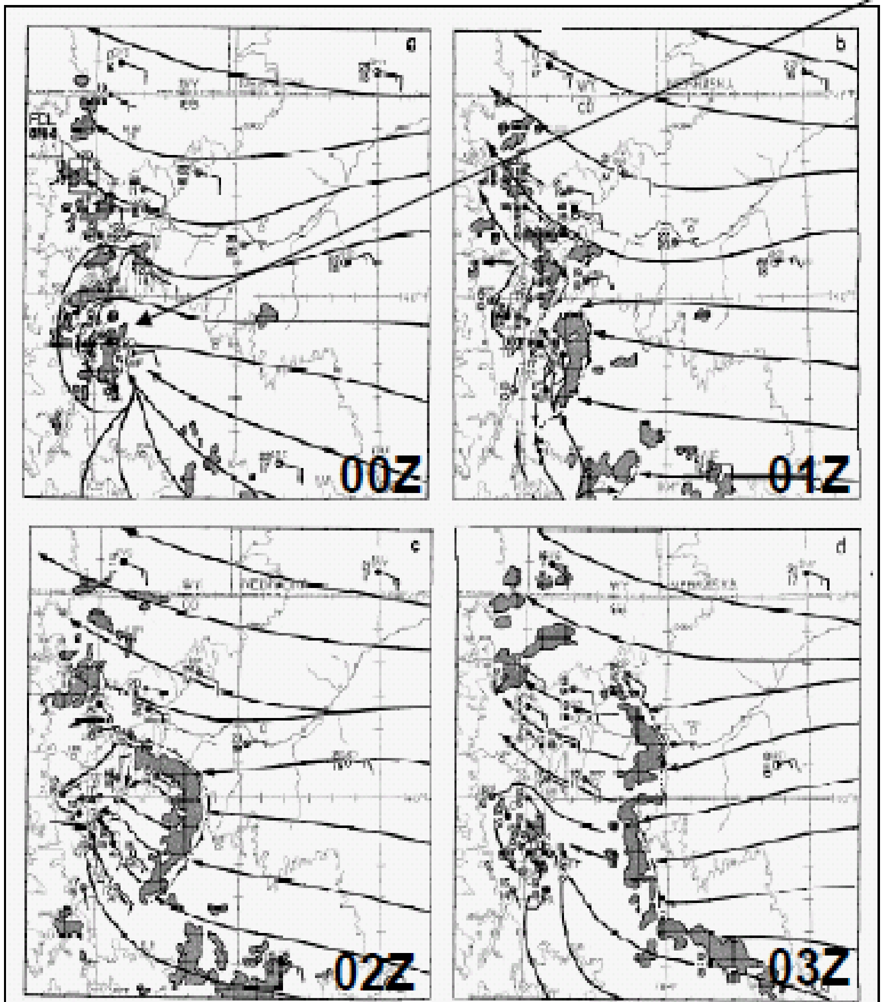
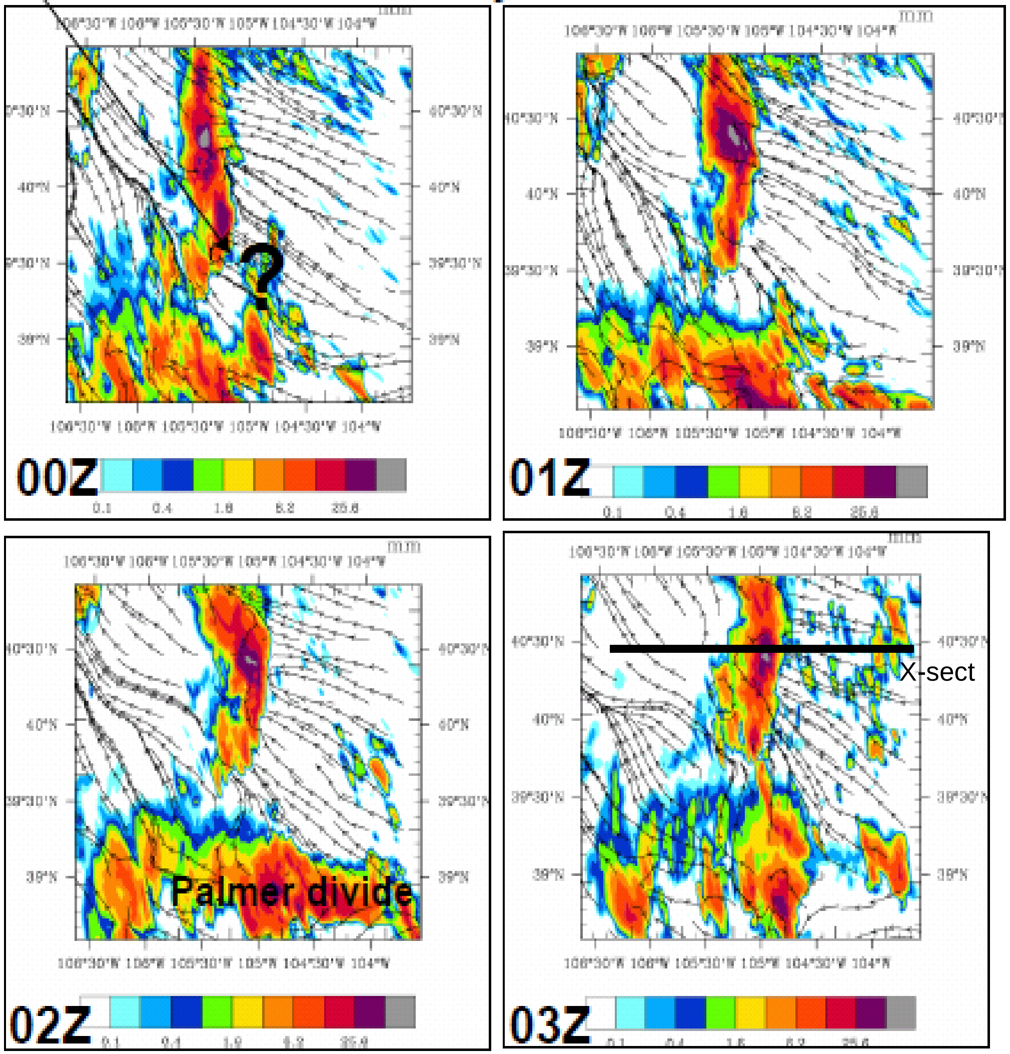


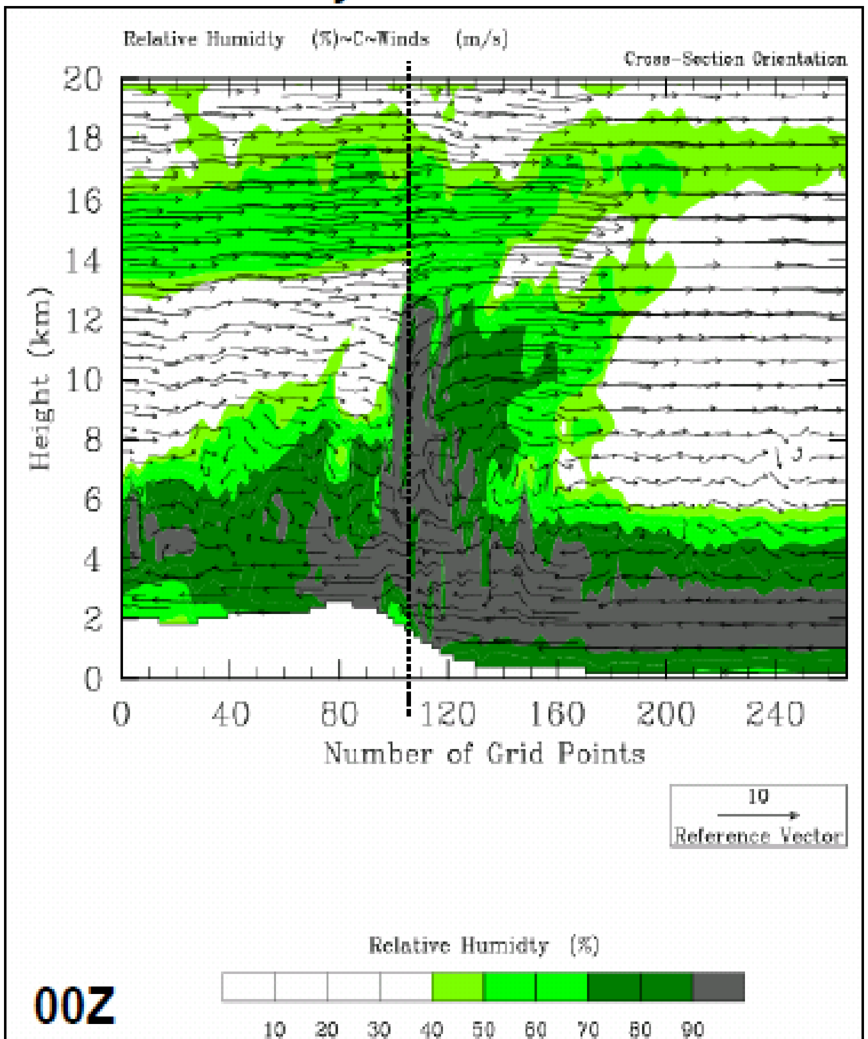
FIG. 7. Hourly mesoscale analyses for 1800–2100 MDT 28 July 1997 (0000–0300 UTC 29 July 1997). Surface streamlines are in solid arrows. Wind barbs plotted as in Fig. 6; temperature and dewpoints in °C. Mesoscale boundaries are indicated as in Fig. 5. Regions of radar reflectivity ≥ 35 dBZ are shaded: (a) 1800 (0000), (b) 1900 (0100), (c) 2000 (0200), and (d) 2100 MDT (0300 UTC).



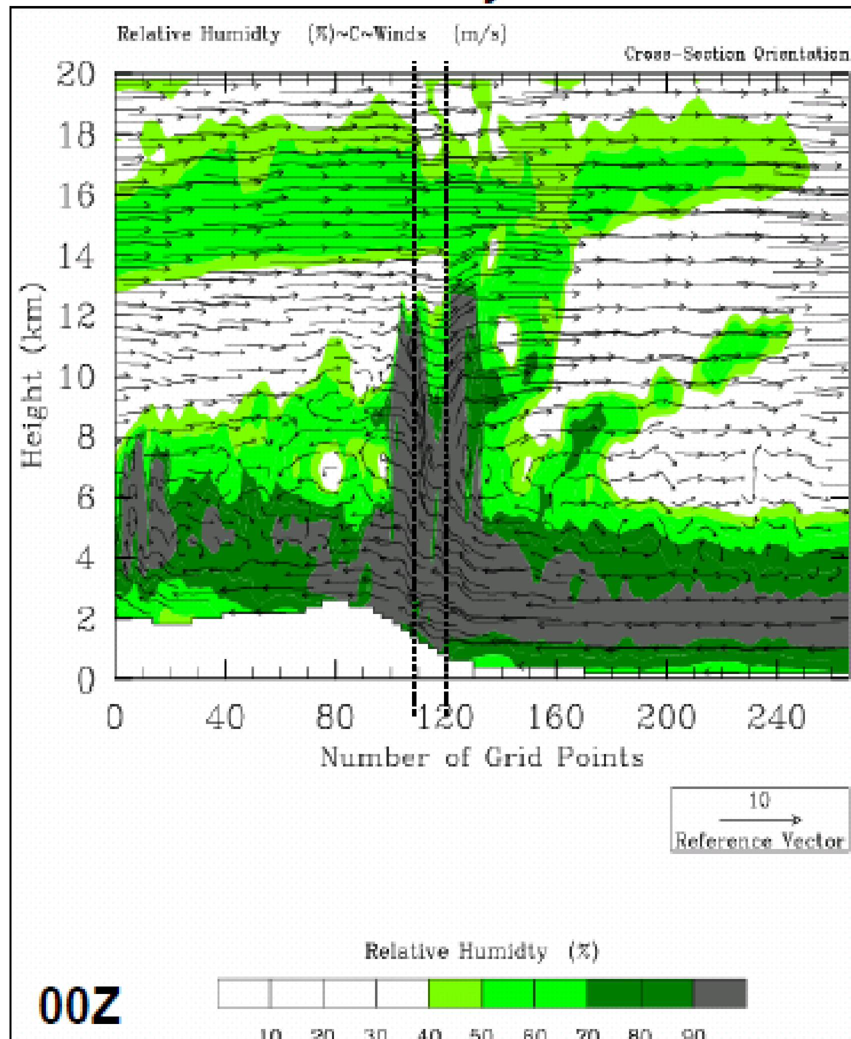
Case Study: 1997 Ft. Collins Flood Event

Mesoscale Analysis

1 km WRF-w/out routing:
Init. July 27 12z



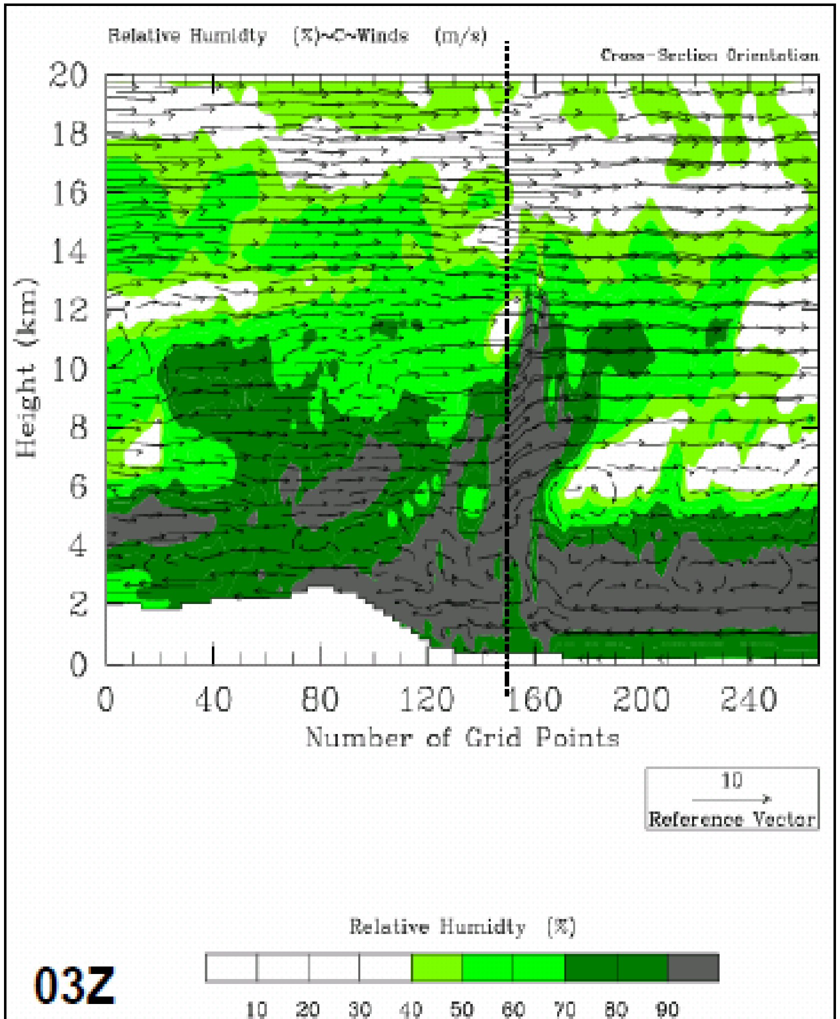
1 km WRF-w/ routing:
Init. July 27 12z



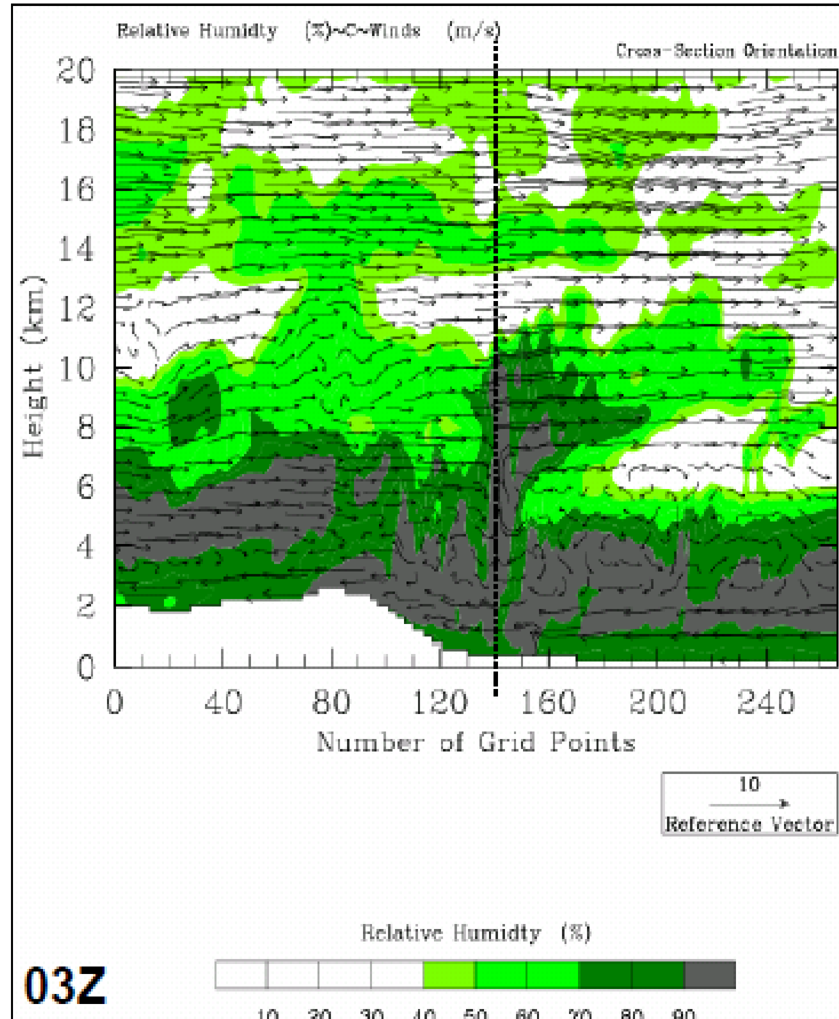
Case Study: 1997 Ft. Collins Flood Event

Mesoscale Analysis

1 km WRF-w/out routing:
Init. July 27 12z



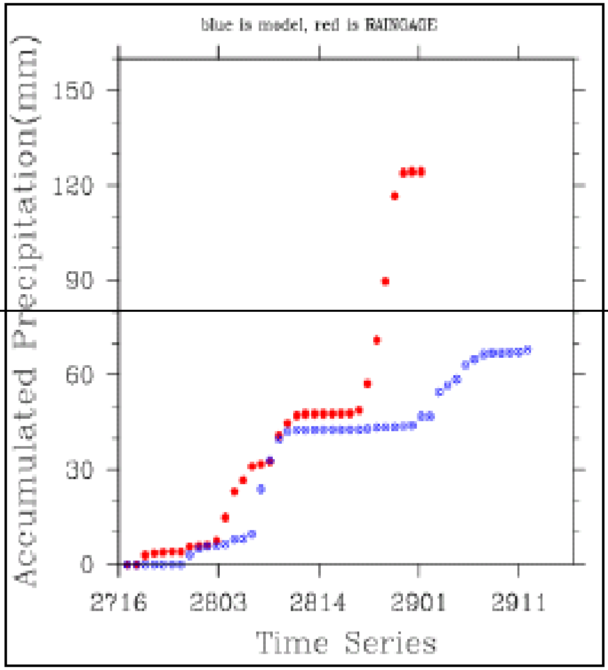
1 km WRF-w/ routing:
Init. July 27 12z



Case Study: 1997 Ft. Collins Flood Event

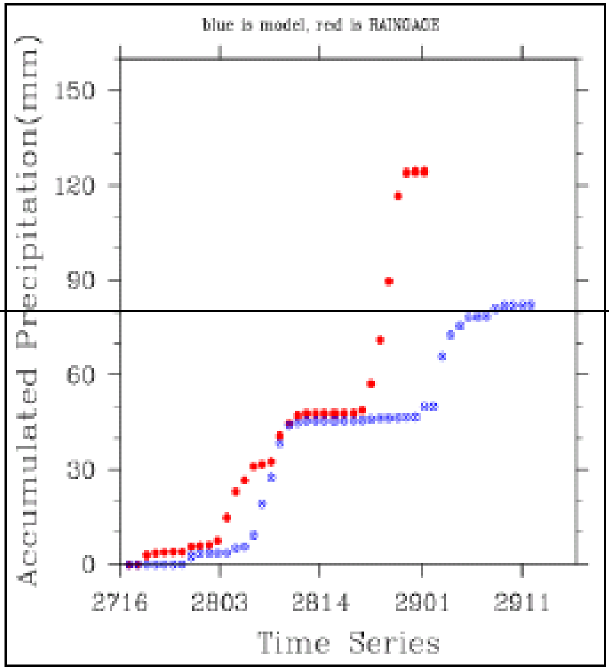
Accumulated Precipitation

WRF vs. Rain Guages



1 km WRF-no routing:
Init. July 27 12z

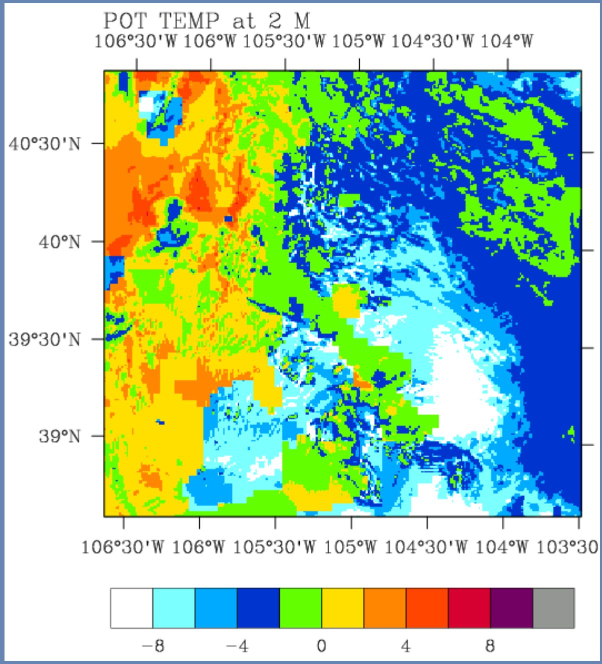
WRF vs. Rain Guages



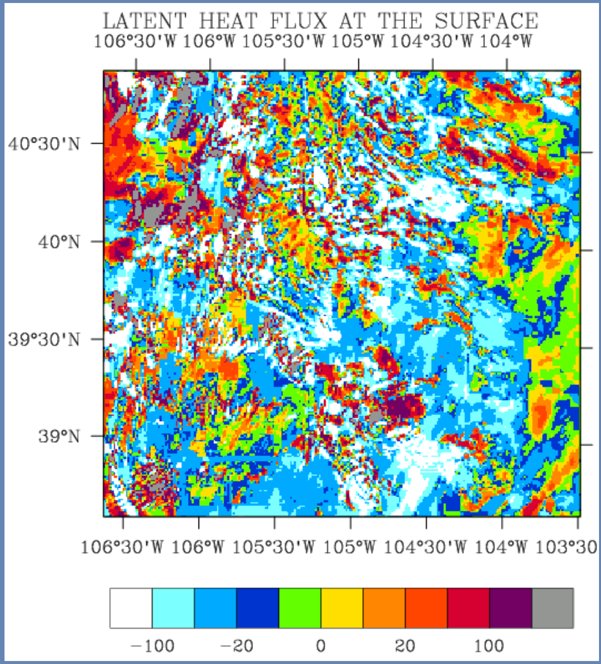
1 km WRF-with routing:
Init. July 27 12z

Results: Untangling land-atmo feedbacks

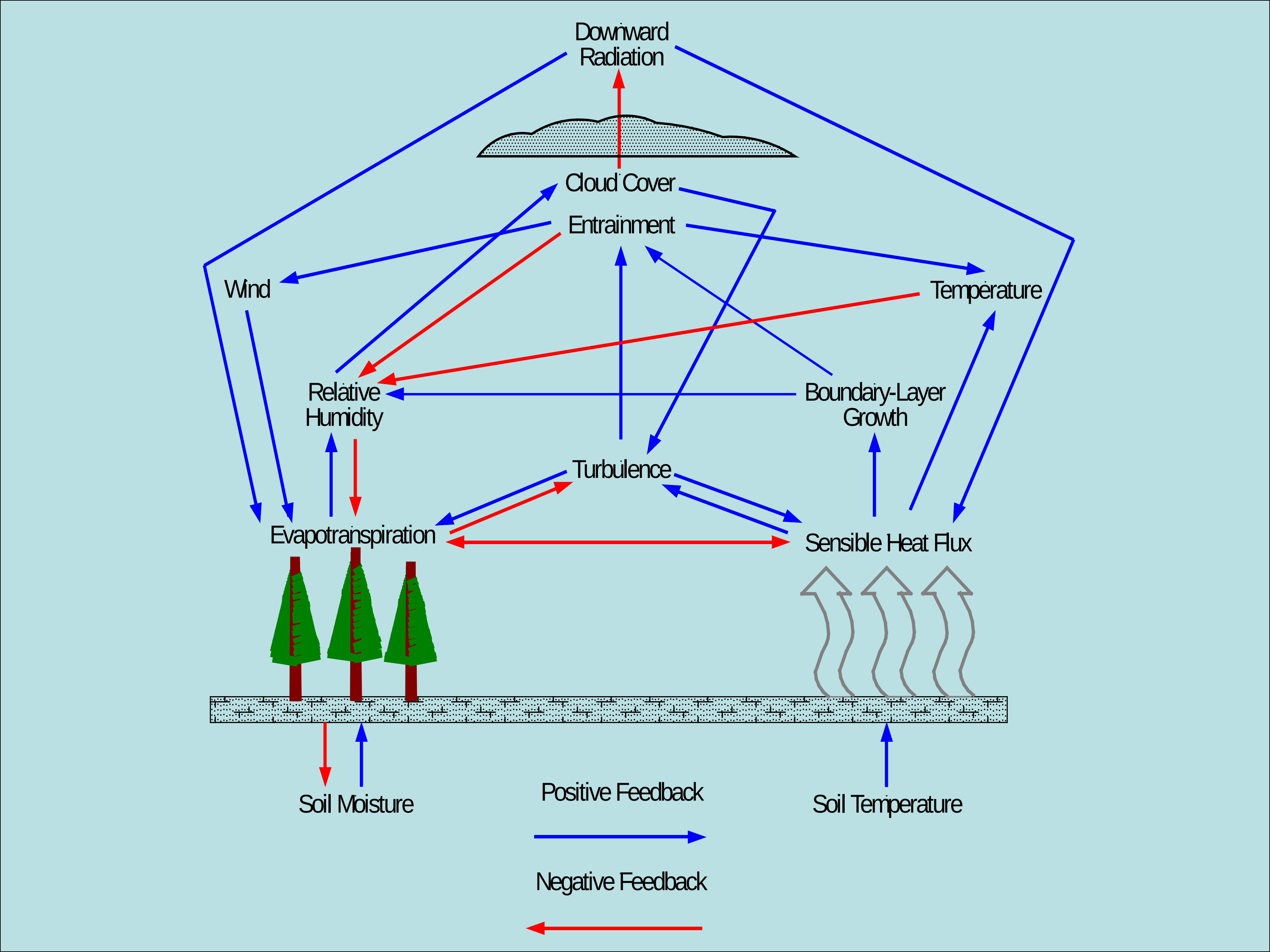
- Trying to diagnose the 'pre-storm' mechanisms causing the difference in a fully coupled mode for a single event is difficult due to:
  - Internal feedbacks
  - Differing cloud fields
  - Differing amounts of surface available energy
  - Changes in advective fields

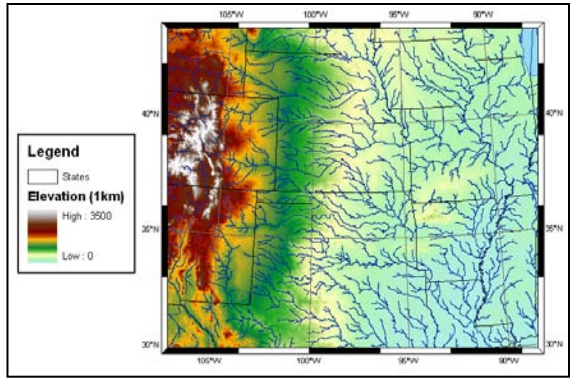


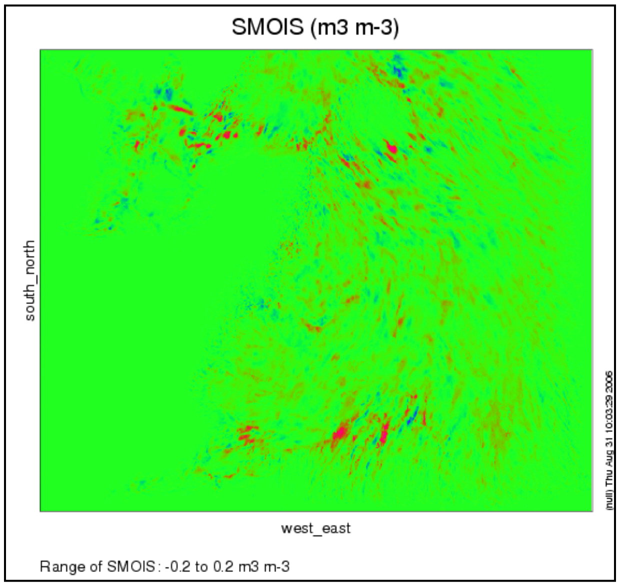
No rtng minus rtng 18z 2m Pot. Temp.

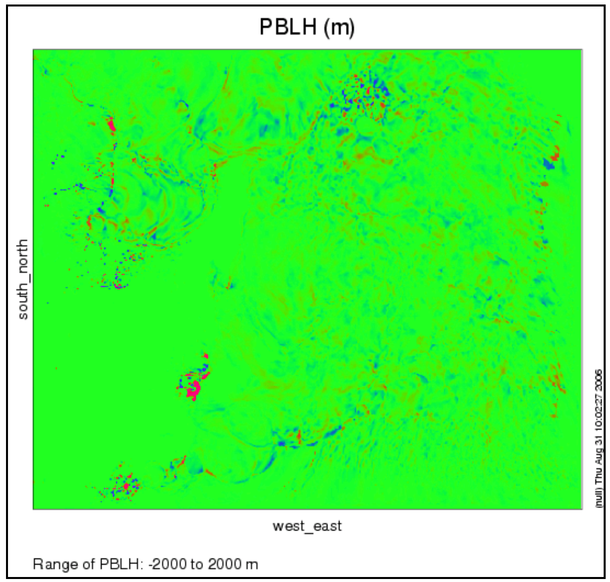


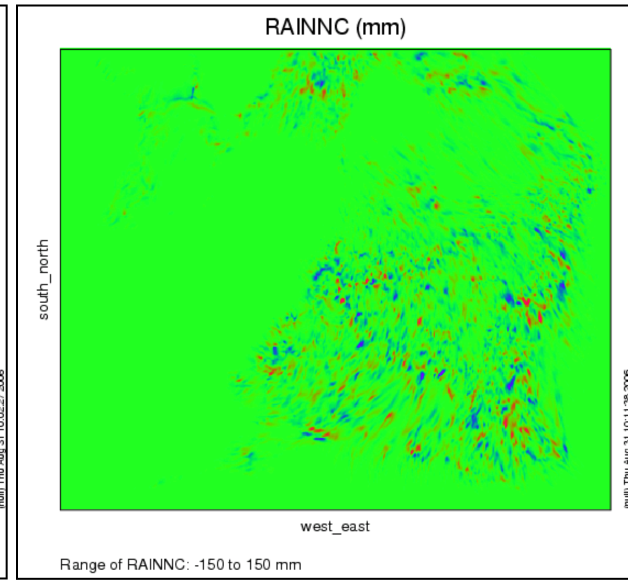
No rtng minus rtng 18z Sfc. Latent Heat Flux


Downward Radiation
Cloud Cover
Entrainment
Wind
Temperature
Relative Humidity
Boundary-Layer Growth
Turbulence
Evapotranspiration
Sensible Heat Flux
Soil Moisture
Positive Feedback
Soil Temperature
Negative Feedback





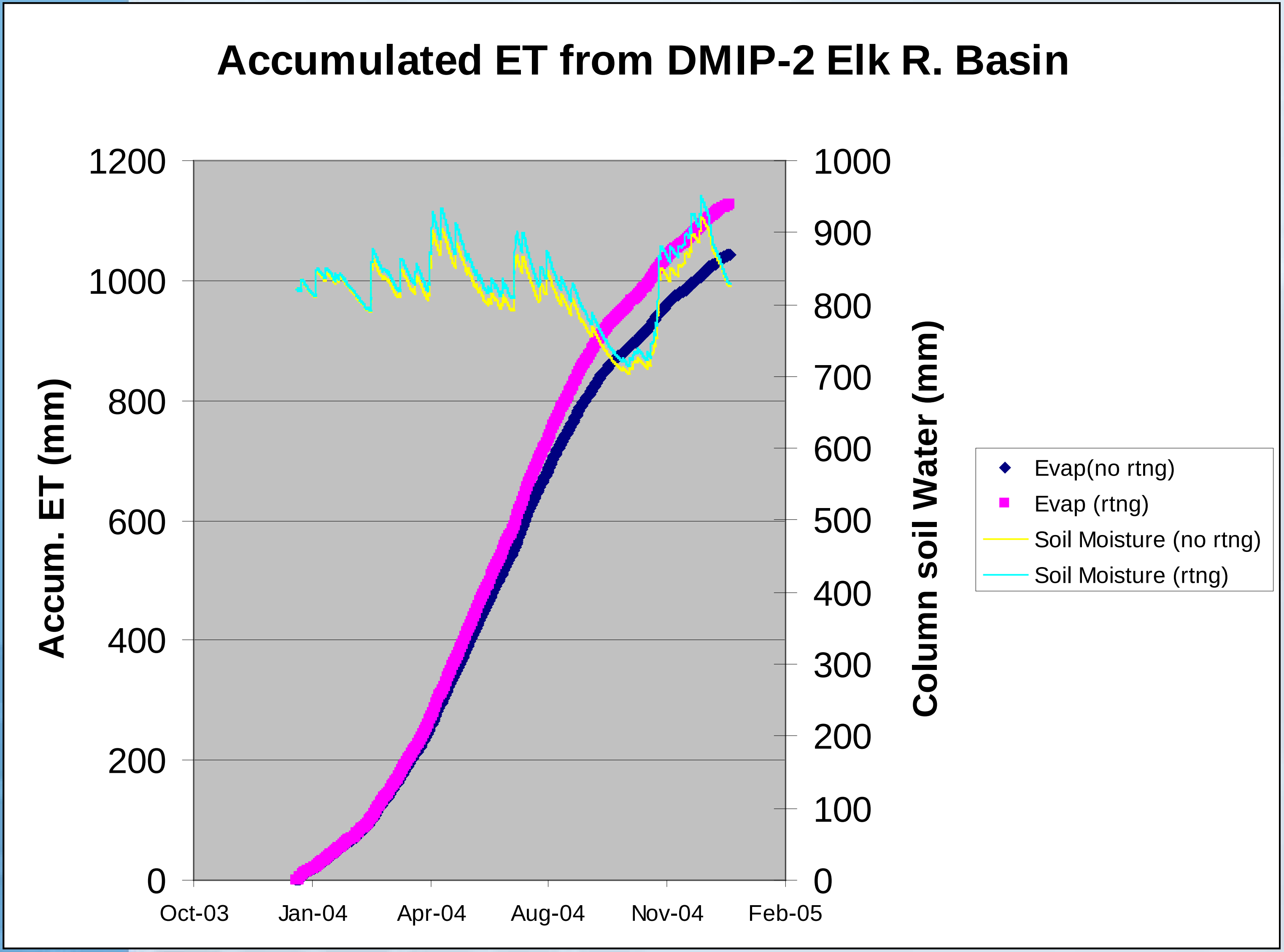


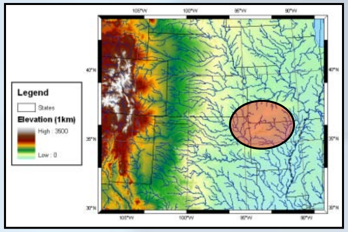


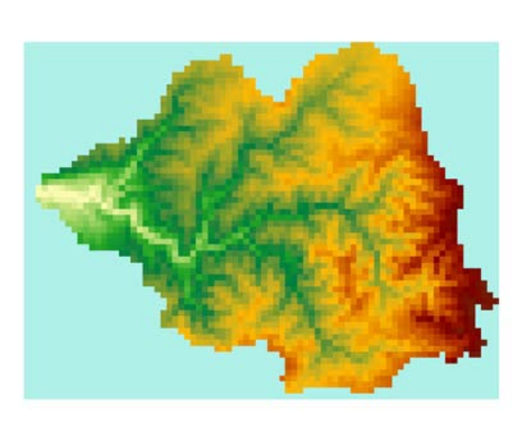
June 21 2001, 14 hr simulation (12z-02z), IHOP Field Campaign

- Identical initial conditions, coupled WRF sims w/ and without routing
- Detectable differences with some spatial coherence
- However differences in precipitation largely offset one another (i.e. shifting of events

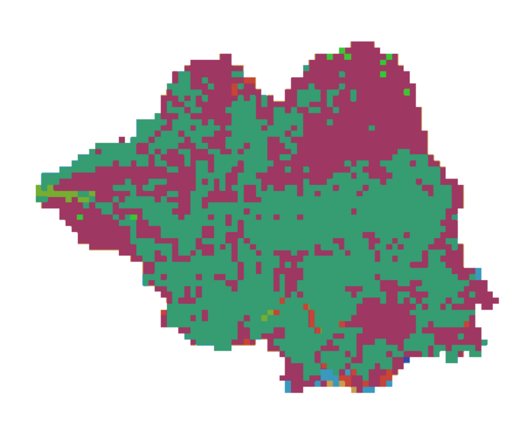
Complicating Factor: Model Calibration



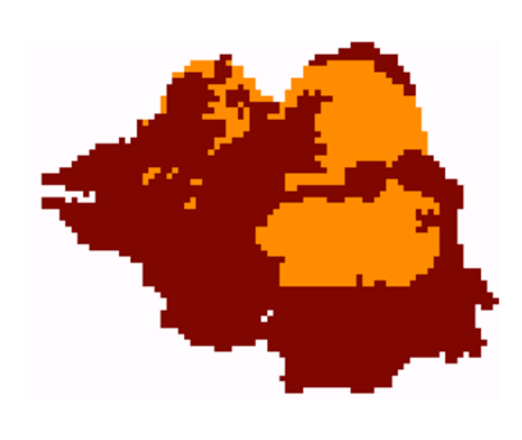




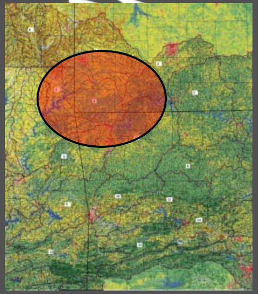
1 km topo

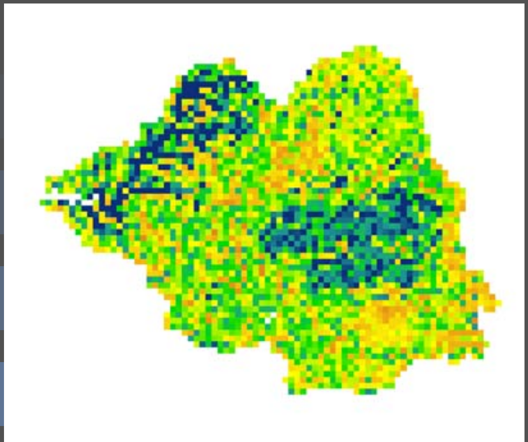


NLCD LU

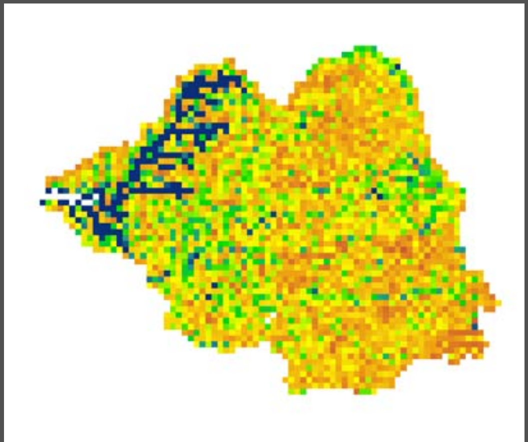


STATSGO Soils

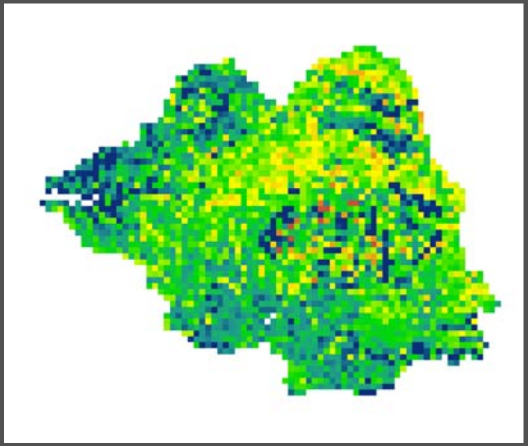




Surface Evap (0-250 mm)



Deep Drainage (0-500 mm)



Deep soil moisture (+/- 1%)

- Routing minus no-routing simulations show more soil moisture, more surface evap and more deep drainage in routing case
- Spatial patterns of differences exhibit complex interplay between terrain and soils

Conclusions

- Several modeling studies now showing that routing processes can be important to high resolution NWP, but how real is this sensitivity and are there any consistent mechanisms?
- For the Ft. Collins flash flood case study:
  - Use of routing during coupled runs had minimal impact over the timescale of the event studied
  - In routing vs. no-routing spin-up experiment, storm initiation was earlier and had slow movement compared to when routing is not used during spin-up
  - Due to internal feedbacks (cloud forcing) it is likely that impacts of routing, like in other convective studies, will be difficult to generalize
- For Noah-d, permitting routing changes the soil moisture climatology to wetter conditions if re-calibration is not taken into account