Multiscale land surface impacts on regional weather and climate

Dev Niyogi

Indiana State Climatologist and Associate Professor

Department of Agronomy- Crops, Soils, Environmental Sciences

Department of Earth, Atmospheric and Planetary Sciences

Purdue University

climate@purdue.edu, Landsurface.org and iclimate.org

NSF CAREER (Prgm Dir: Dr.Anjuli Bamzai)

Physical Changes

- Deforestation
- Urbanization
- Irrigation
- Harvesting
- Intensification
- Floods
- Droughts

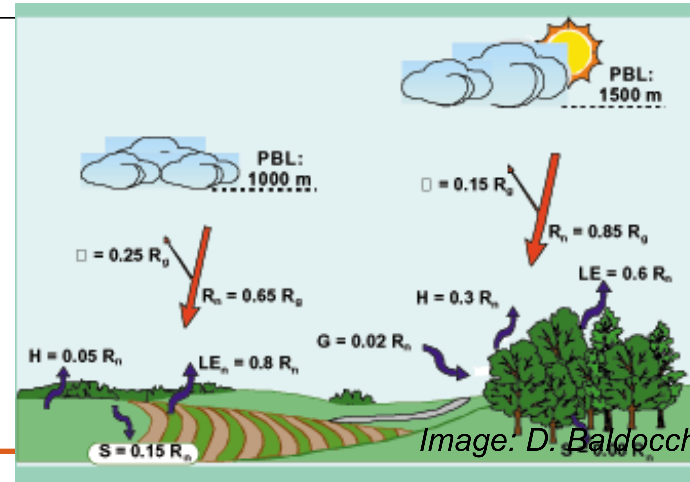


Image: D. Baldocchi

Feedbacks

- Energy Balance Changes
- Net Radiation and Partitioning Changes
- Boundary Layer Moisture changes
- Surface temperature changes
- Roughness changes
-Albedo changes

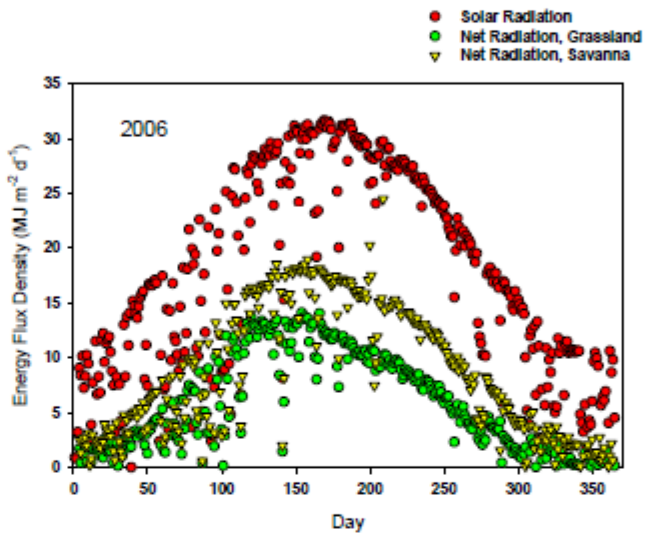
Interactions

Effects/Impacts

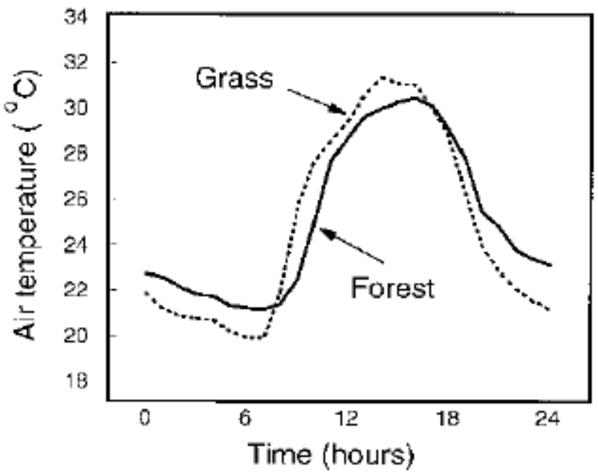
-Changes in convergence zones
-Modified surface temperature, boundary layer cooling/heating
-Rainfall changes
-**Subseasonal features?**

Local Scale Observations…

- Limited studies under contrasting field conditions despite many field programs
- Changes in energy balance, biogeochemistry, and boundary layer dynamics as a result of the LULCC



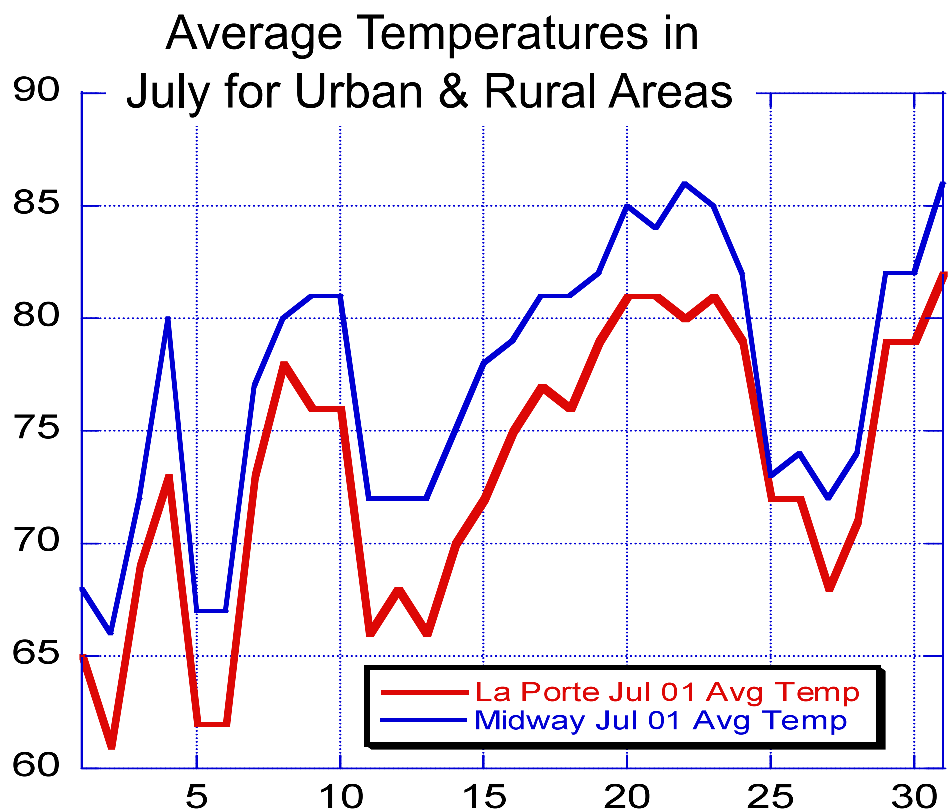
D. Baldocchi (California)

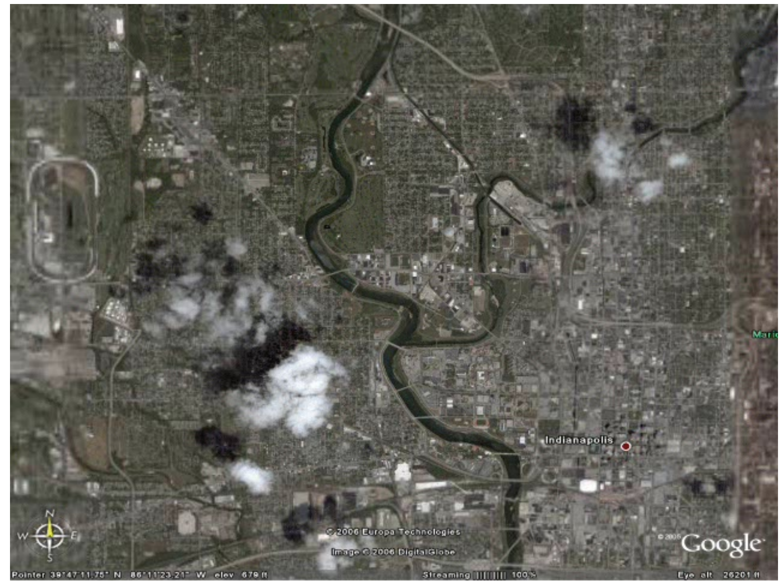


Nair et al. 2007 (Aus)

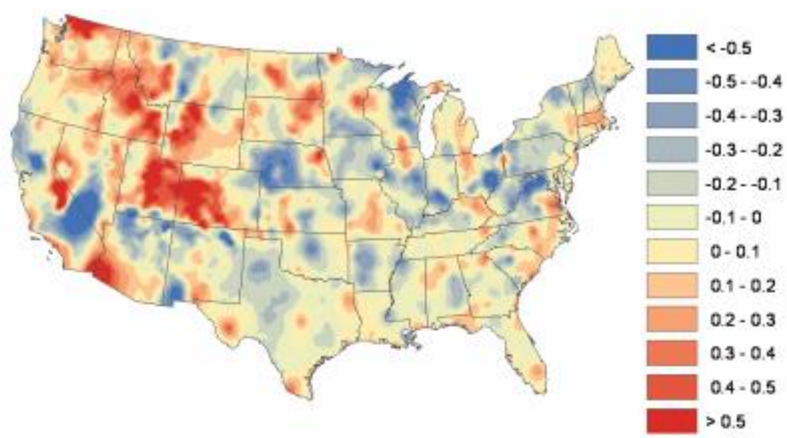
Deforestation in tropical region generally leads to drier, warmer boundary layer. This can interactively increase or suppress convection depending on soil moisture availability and albedo.

Urbanization and land use change leads to regional temperature changes (warming= Urban Heat Island)





Other ‘observed’ evidence of LCLUCC climate impacts (Fall et al. 2010 a,b; Lim et al. 2008) – “**Green is cool; US landscape is not**”



Adjusted observation minus reanalysis anomaly trend differences for 1979–2003

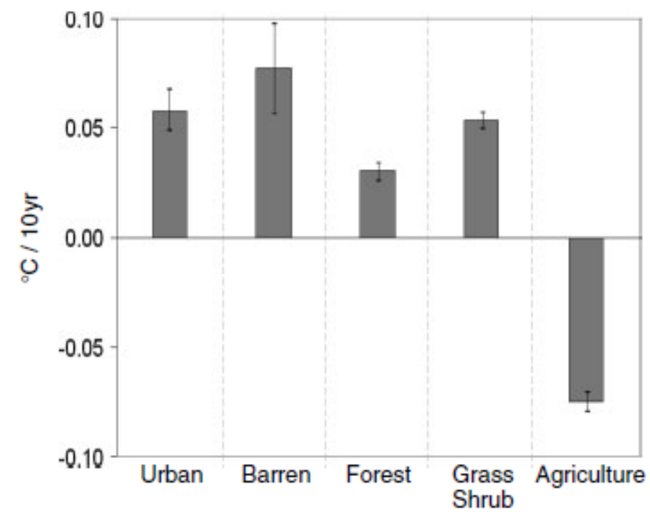
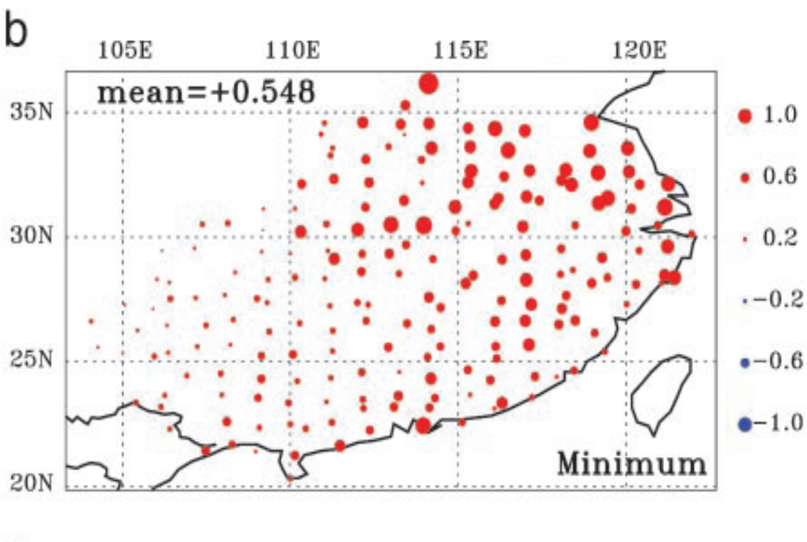


Figure 8. Decadal OMR trends of NLCD LULC types that did not change during 1992–2001. Error bars denote 95% confidence intervals.

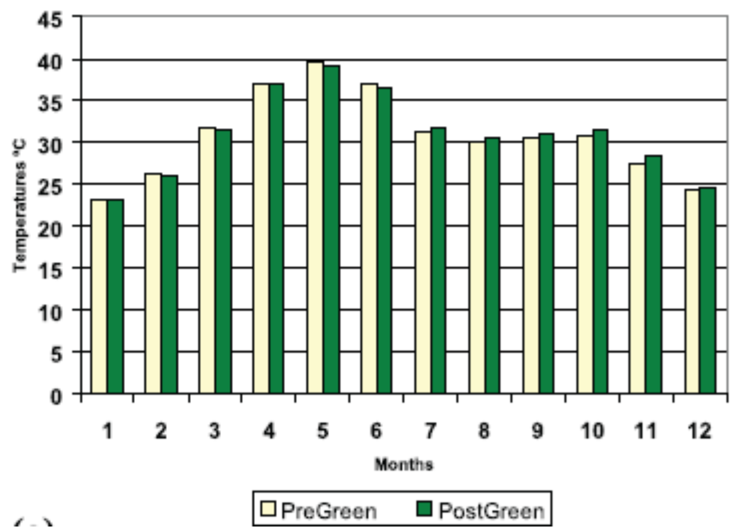
Additional impacts observed- cool anomaly (1.4 C in avg Max T) over western Oklahoma and Ogallala aquifer (Mahmood et al 2008) , and California (Christy et al. 2006; Lobell and Bonfils 2008); increase in dew point climatology over central US (McPherson et al. 2004) and extremes ie > 22C (Sandstorm et al. 2004).

Anomalous increase in CAPE and extreme precipitation for 92 dam impoundments surveyed across North America (Degu et al. 2011)

Observed landuse climatic impacts over Asia region



0.05 C/ decade 'observed' warming impact of urbanization over China (Liming Zhou et al. 2004)



0.34C cooling during growing season due to agricultural 'green revolution' in India (Roy et al. 2007)

Summary from multiple studies and reviews
(e.g. Pielke, Pitman, Niyogi et al. Wiley Reviews on Climate Change, 2011)

- Land surface feedback and heterogeneity has a significant impact on the timing, location, intensity, and magnitude of mesoscale (regional) convection and rainfall

Effect of Land Surface Representation on Convection and Precipitation simulation

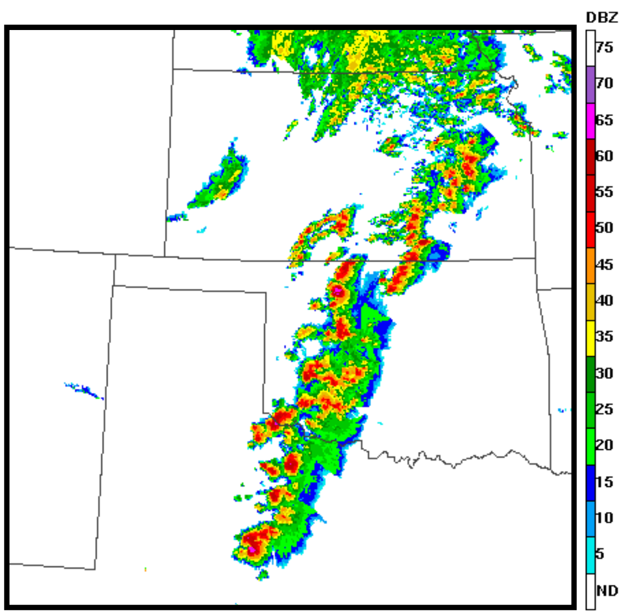
(Holt T., D. Niyogi , F. Chen, M. A. LeMone, K. Manning, A. L. Qureshi*, 2006, Effect of Land - Atmosphere Interactions on the IHOP 24-25 May 2002 Convection Case, Monthly Weather Review, 134, 113 – 133)

00 UTC 24 May – 12 UTC 25 May 2002 Nest 2 (4-km)

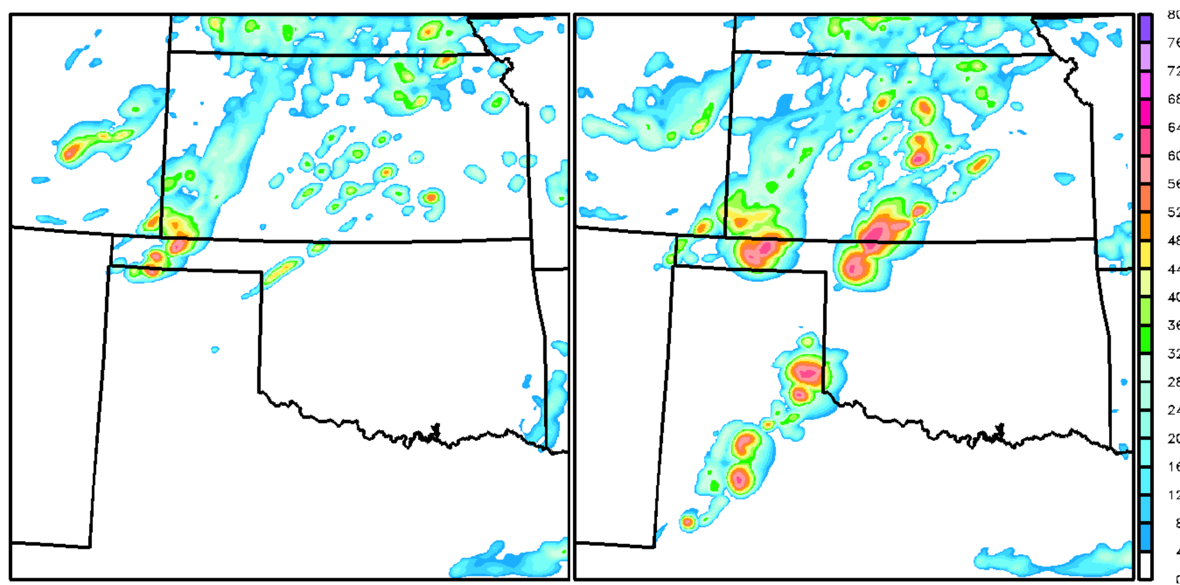
LSM impact in coupled model precipitation forecast (SLAB versus Noah LSM) – we need at least modestly complex LSMs

Radar reflectivity (dbZ) valid 00 UTC 25 May 2002

24-h forecast

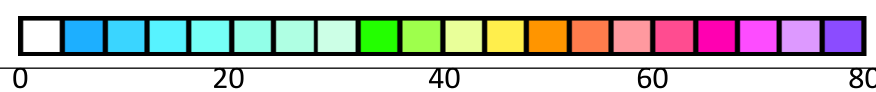


Observed 2-km Mosaic



SLAB

Noah LSM



Established need for a detailed LSM that at least has up to date land cover and modestly detailed vegetation/ transpiration processes (preferably photosynthesis based)

Jarvis Scheme vs Ball-Berry Scheme

Jarvis scheme

$$R_c = \frac{R_c\_\min}{LAI \times F1 \times F2 \times F3 \times F4}$$

LAI – Leaf Area Index,
F1 ~ f (amount of PAR)
F2 ~ f(air temperature: heat stress)
F3 ~ f(air humidity: dry air stress)
F4 ~ f(soil moisture: dry soil stress)

Fundamental difference: evapotranspiration as an 'inevitable cost' the foliage incurs during photosynthesis or carbon assimilation

↓

Ball-Berry scheme in GEM (Gas Exchange Model)

$$g_s = m \frac{A_n}{C_s} h_s p_s + b \qquad R_c = \frac{1}{g_s}$$

hs – relative humidity at leaf surface
ps – Surface atmospheric pressure
An – net CO2 assimilation or photosynthesis rate
Cs – CO2 concentration at leaf surface
m and b are linear coeff based on gas exchange consideration

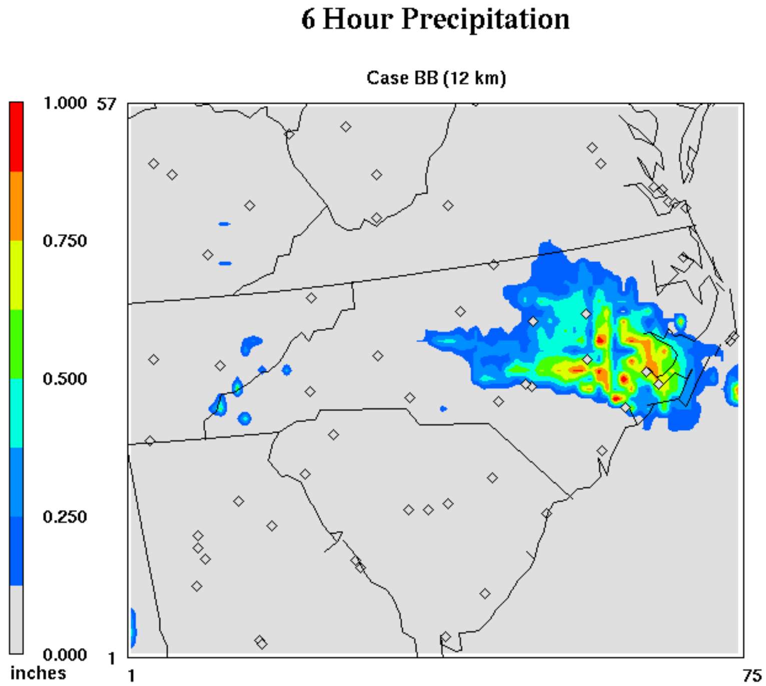
A_n: three potentially limiting factors:

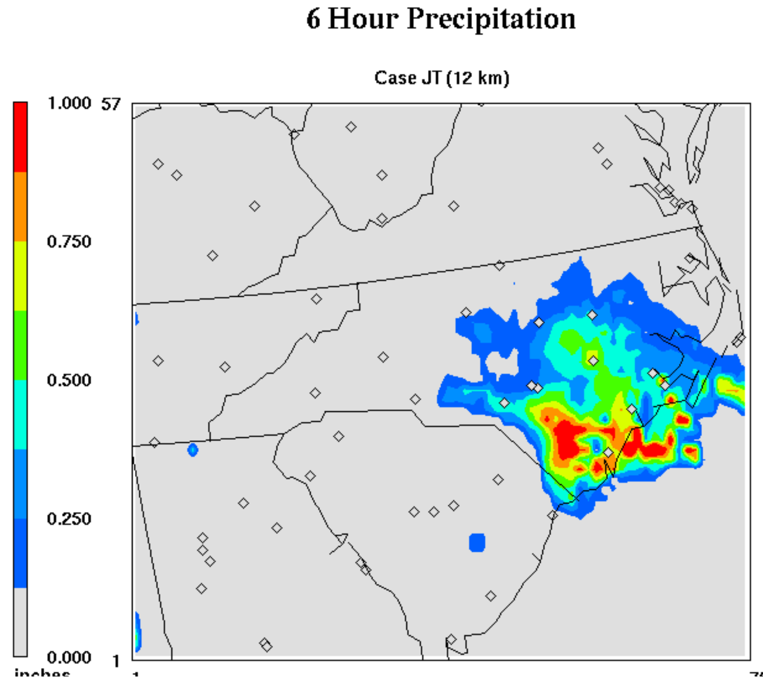
1. efficiency of the photosynthetic enzyme system
2. amount of PAR absorbed by leaf chlorophyll
3. capacity of the C3 and C4 vegetation to utilize the photosynthesis products

GEM model reference: Niyogi, Alapaty, Raman, Chen, 2010 , JAMC.

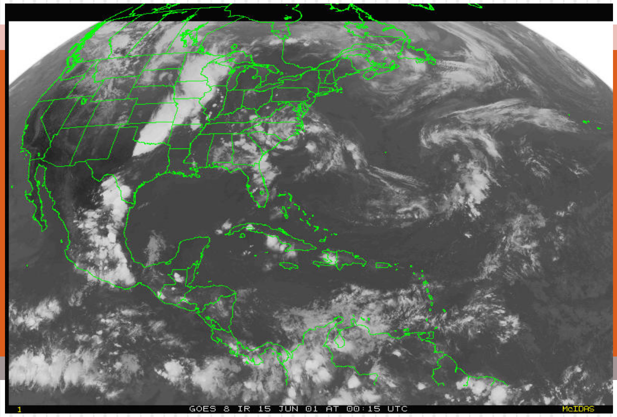
LSM representation impact not just significant for great plains but also for coastal regions

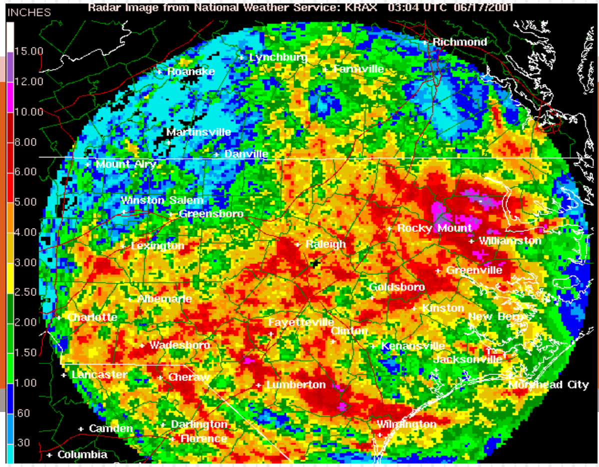
Better vegetation representation can improve LSM performance and ultimately the coupled model performance

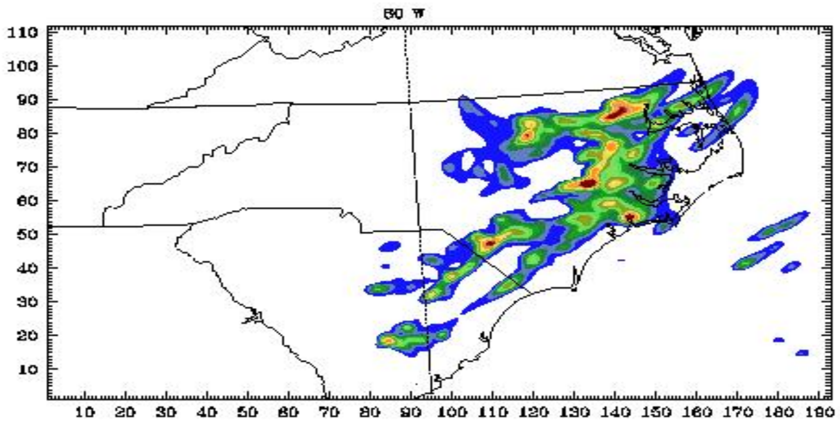


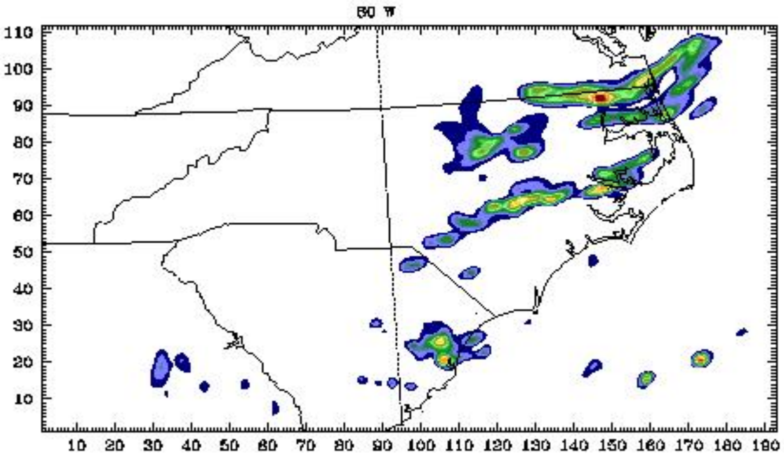


LULC impact important not just for calm conditions – but also important for active synoptic conditions (e.g. TS Alison 2001)





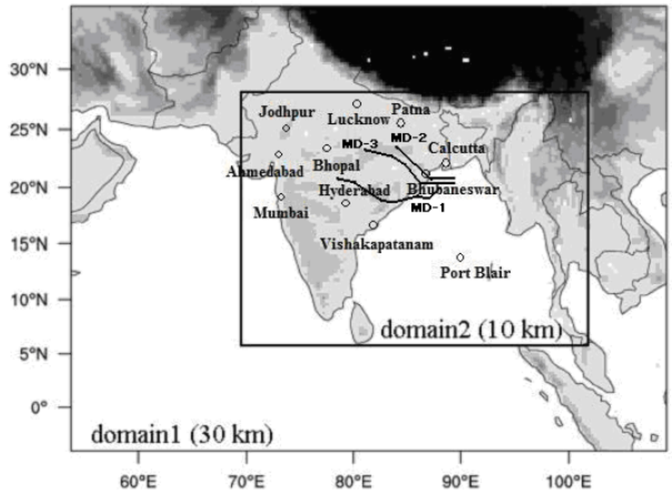


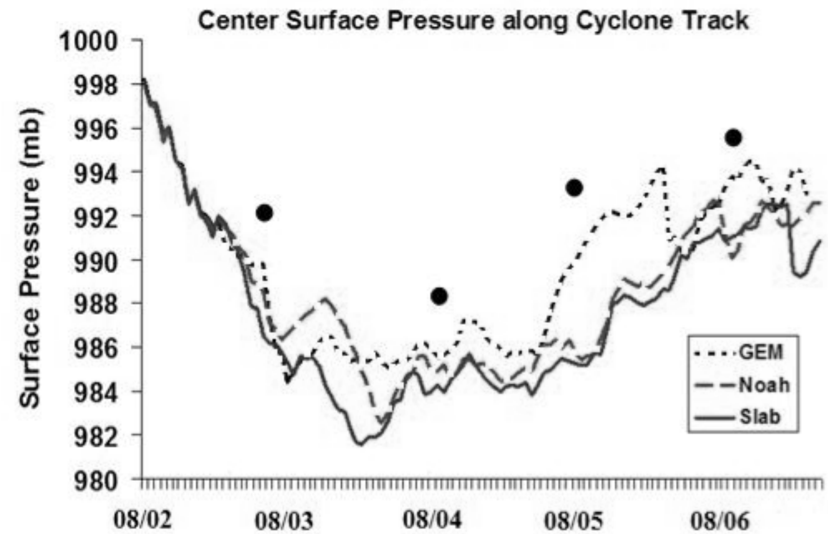


Making case for land feedbacks in predicting multi-week rain producing events – e.g. Monsoon Depressions, Tropical Cyclones

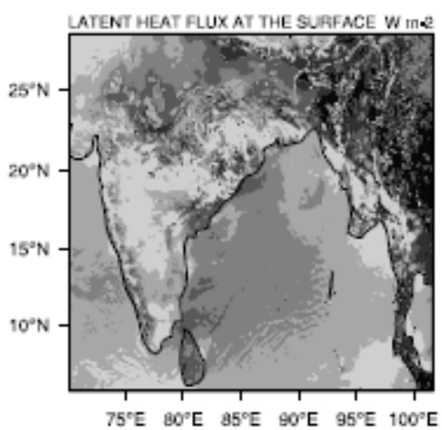
Some key results from our studies http://landsurface.org

- Land surface representation can (often dramatically) affect the track (not necessarily the intensity). Positive impact on rainfall prediction inland.
- Both observations and models indicate antecedent soil moisture can be a potential indicator for the post-landfall storm sustenance (wetter soil → longer inland sustenance; drier soils → quicker, shorter dissipation)
- Observations indicate soil heat flux can be a good indicator for inland sustenance; land models need to improve on the ability to reproduce this soil heat flux feedback well.

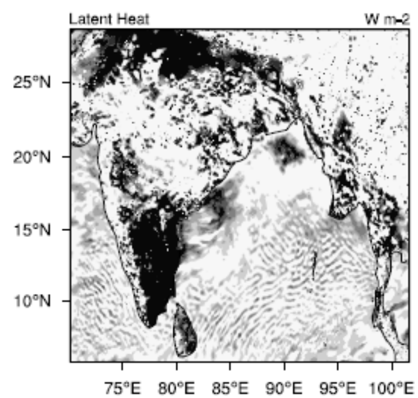




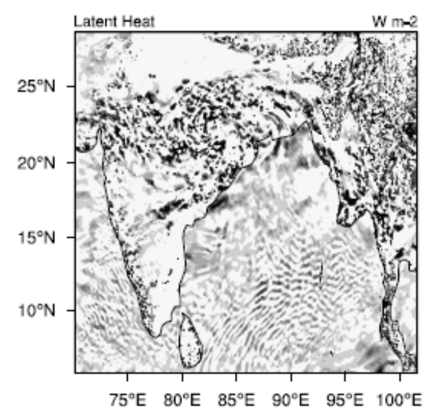
Noah LHF

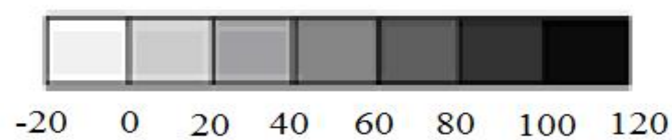


Slab minus Noah

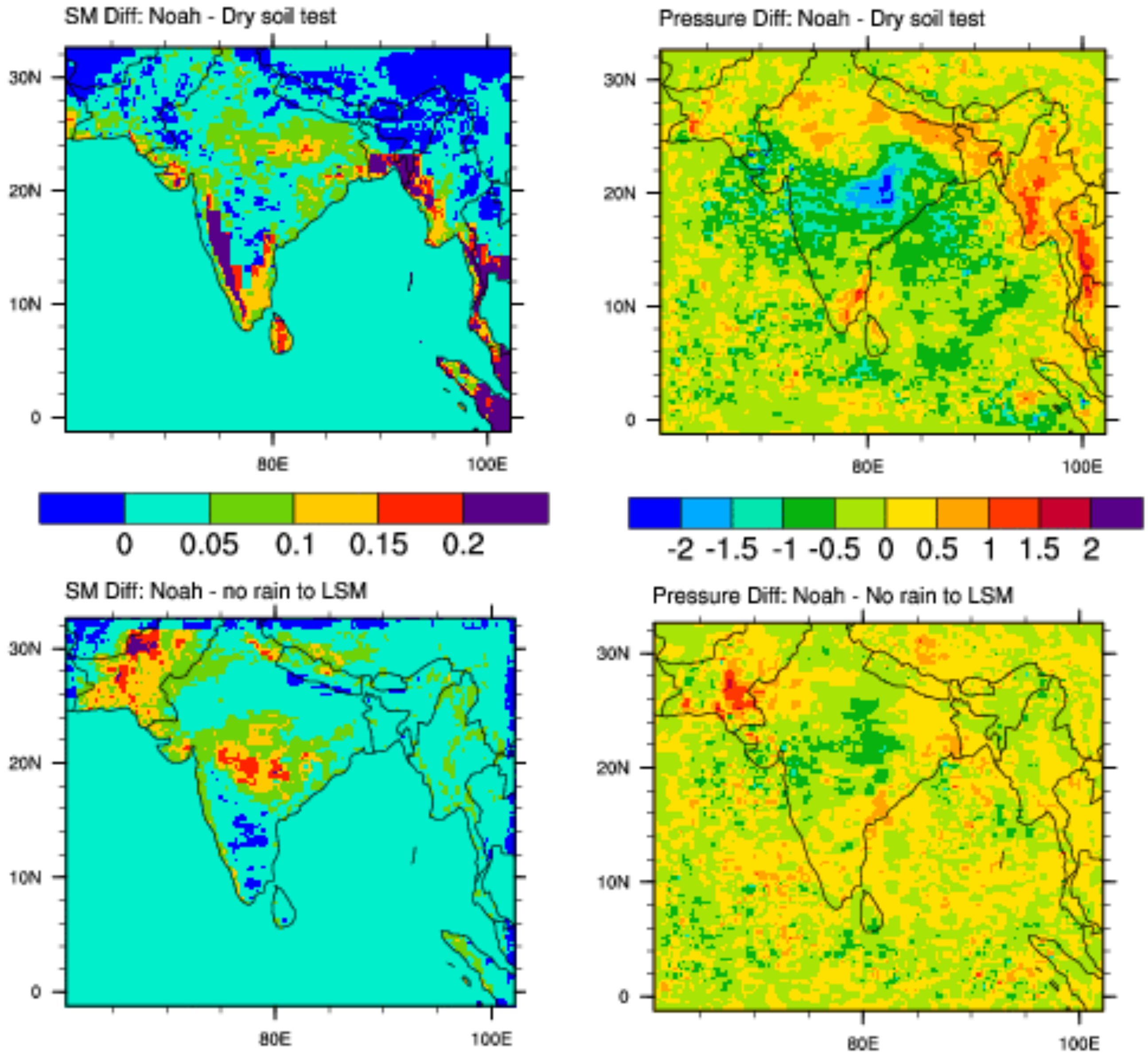


GEM minus Noah

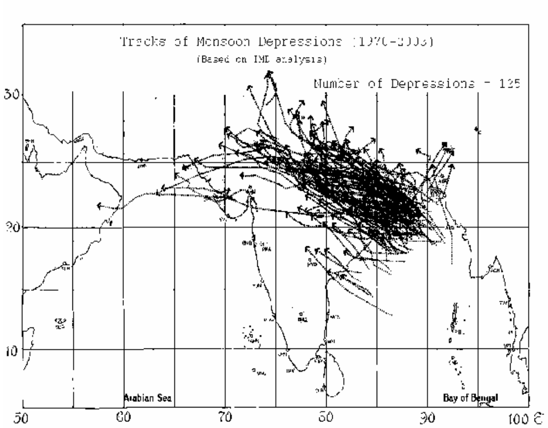




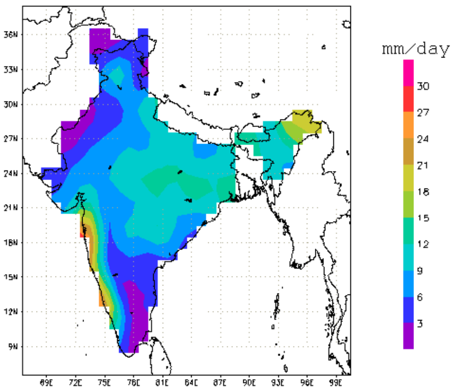
00Z 6 AUG 2006



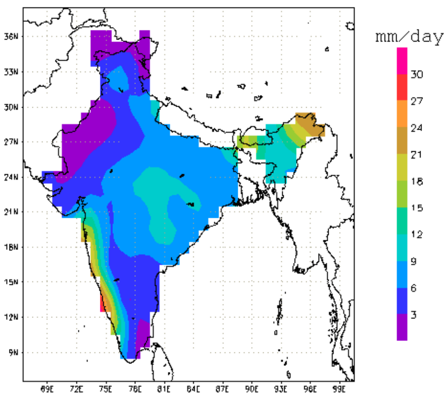
Wetter 7 d antecedent soils → longer inland sustenance



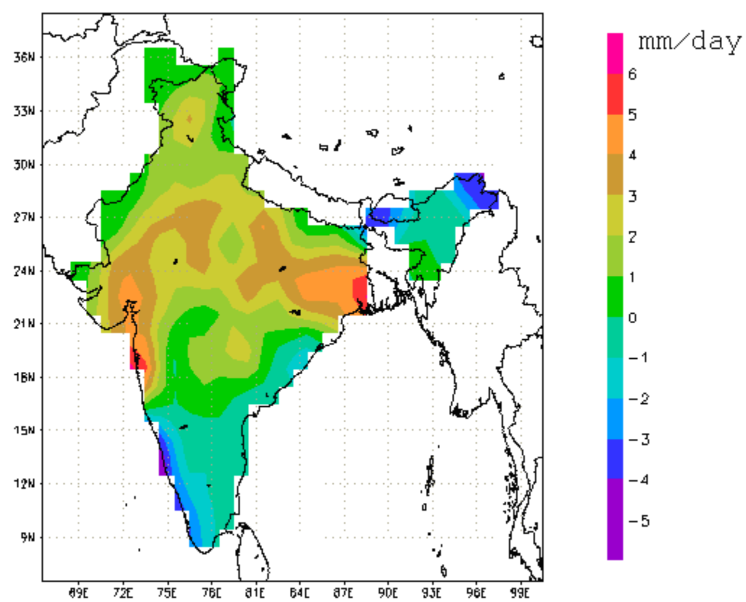
Long Inland Duration

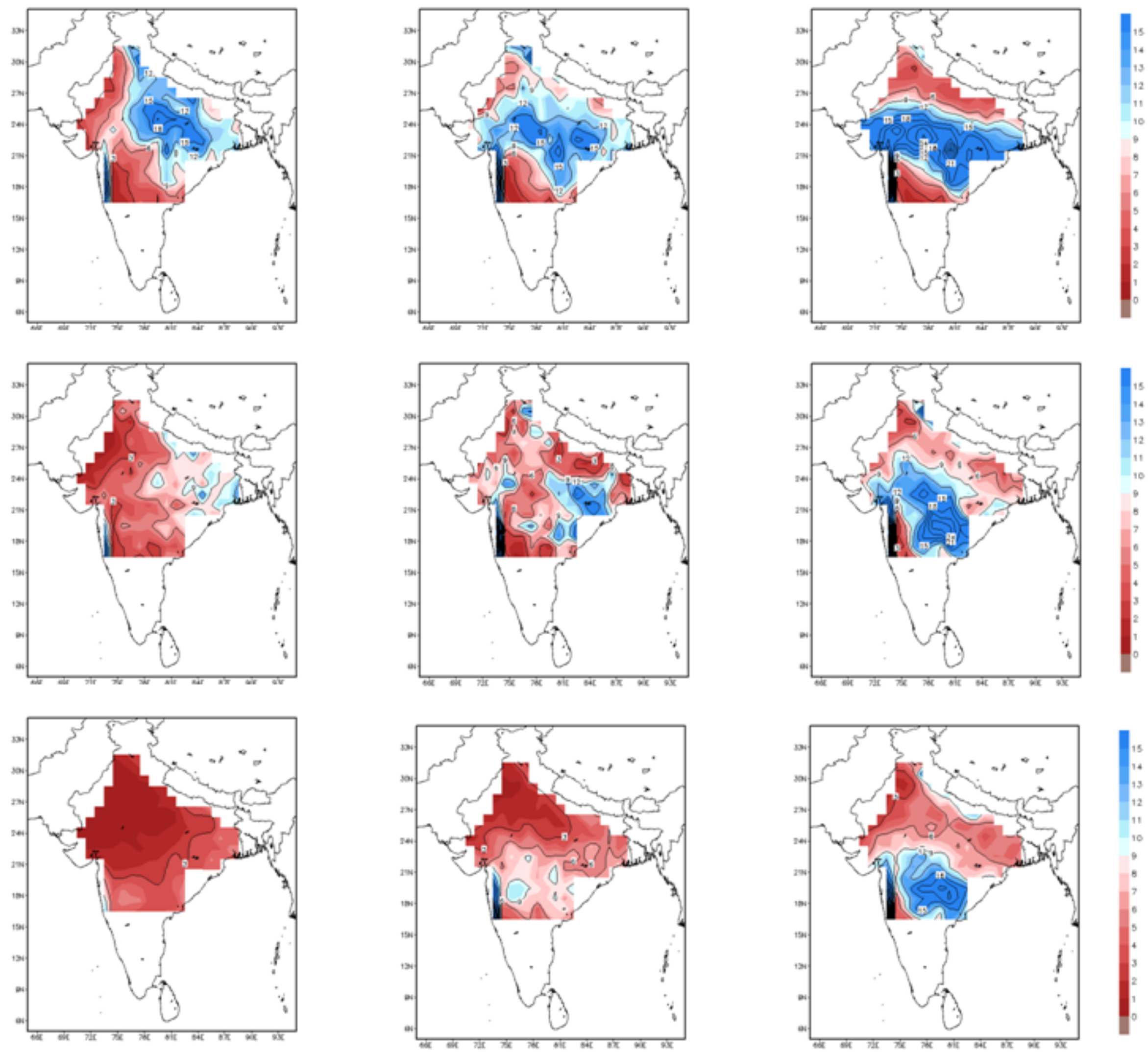


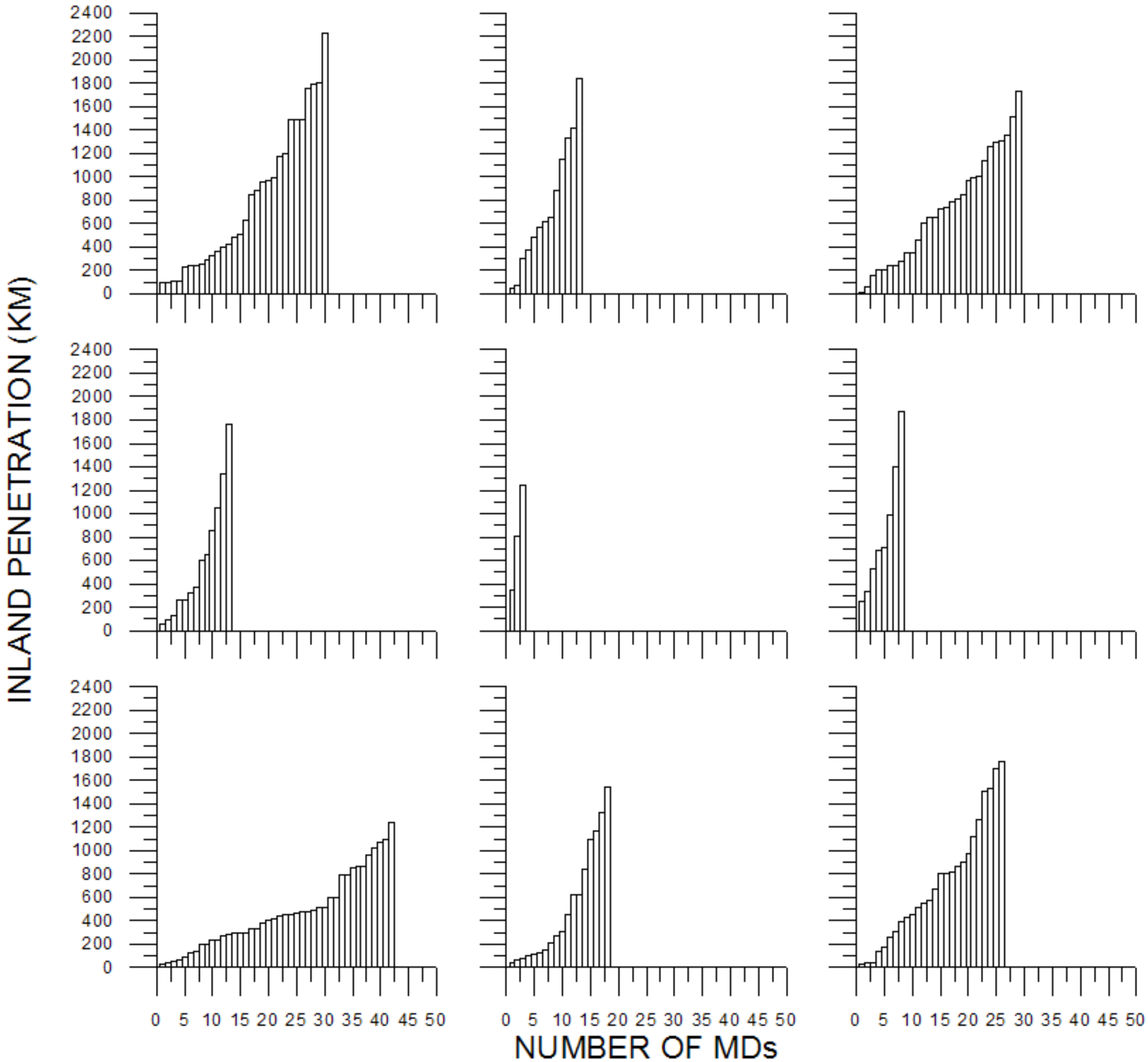
Short Inland Duration



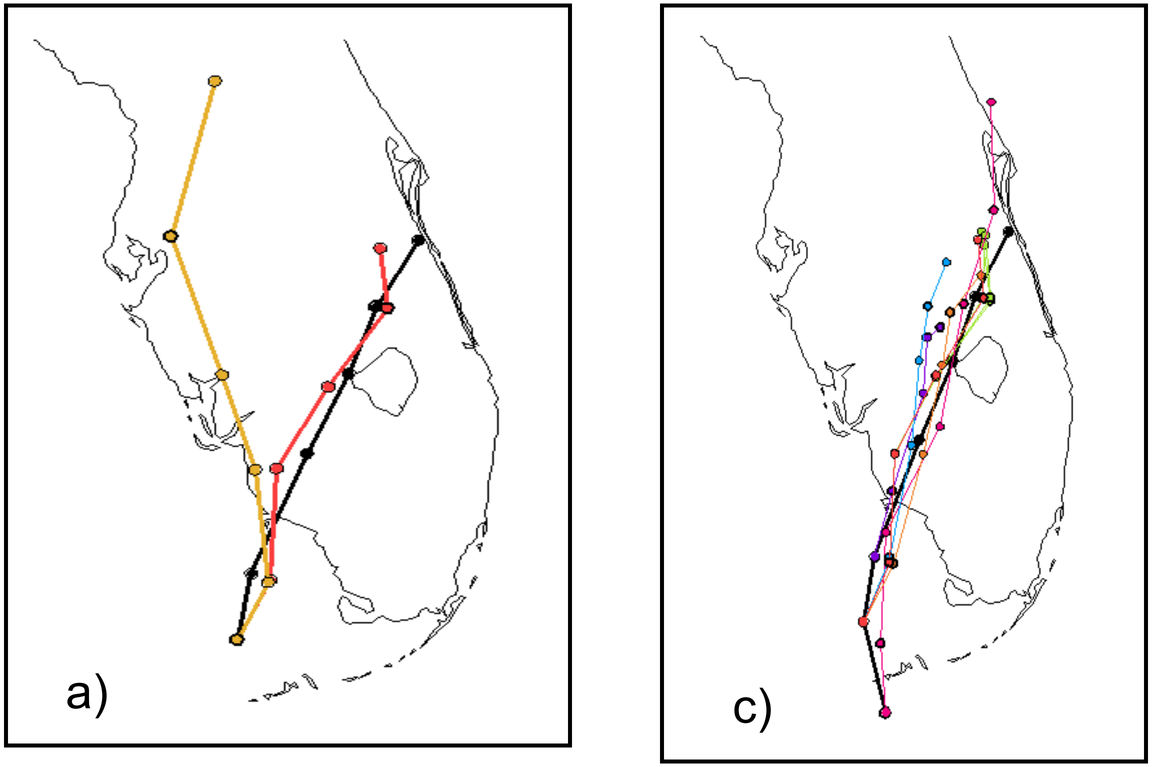
Difference






INLAND PENETRATION (KM)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0 5 10 15 20 25 30 35 40 45 50
NUMBER OF MDs

Ensemble LSM response on TS Fay (2008) track (Bozeman et al. 2011)



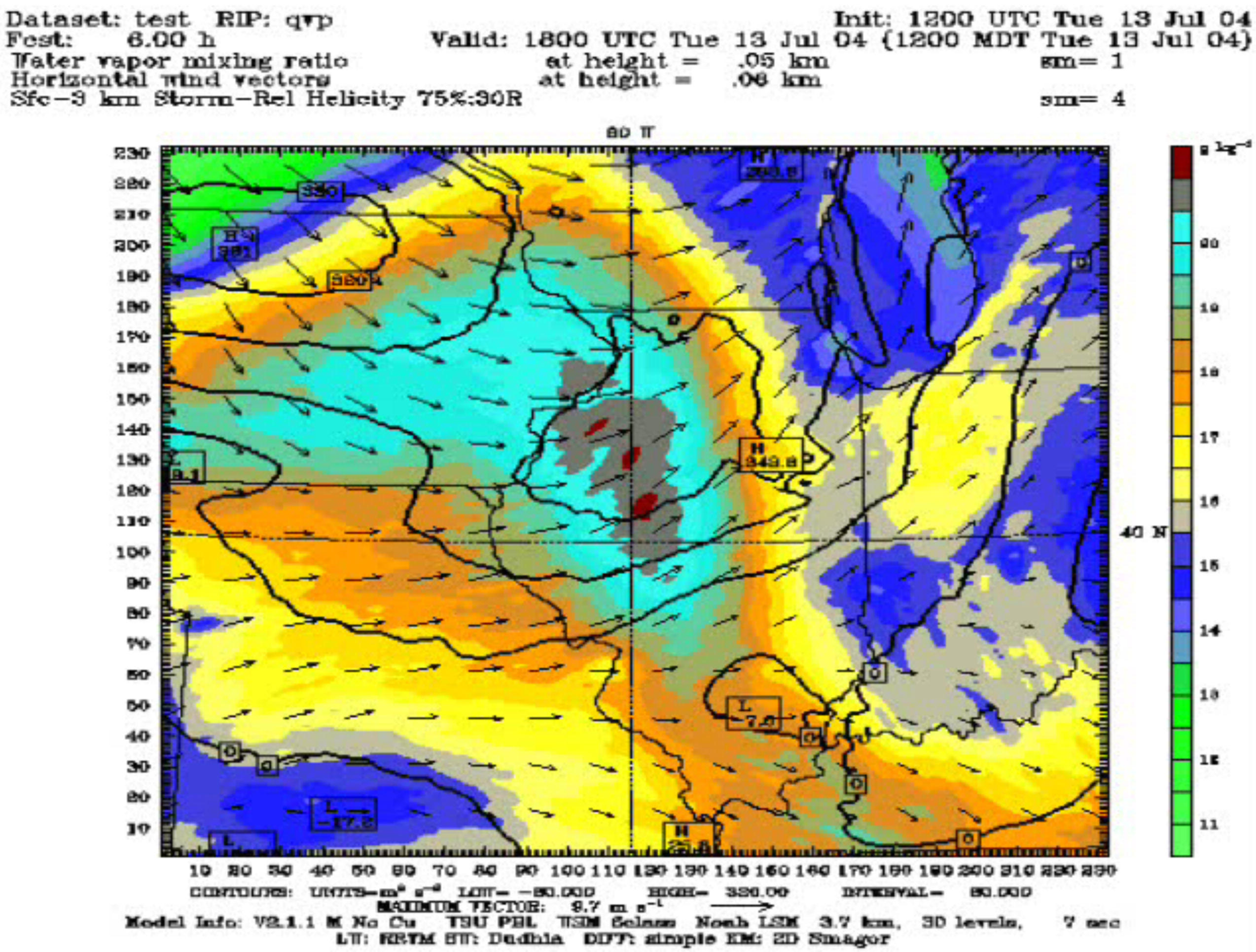
Black – NHC best track observations
Red – Noah LSM (dynamic soil moisture/temperature)
Yellow -Simple Slab land model (constant soil moisture)

Landscape feedback appears to help modulate track of some landfalling storms (and associated rainfall/flood potential).

Making case for explicit agricultural landuse/cover feedbacks in LSMs

IL-IN F4 Tornado simulation (13 July 2004)

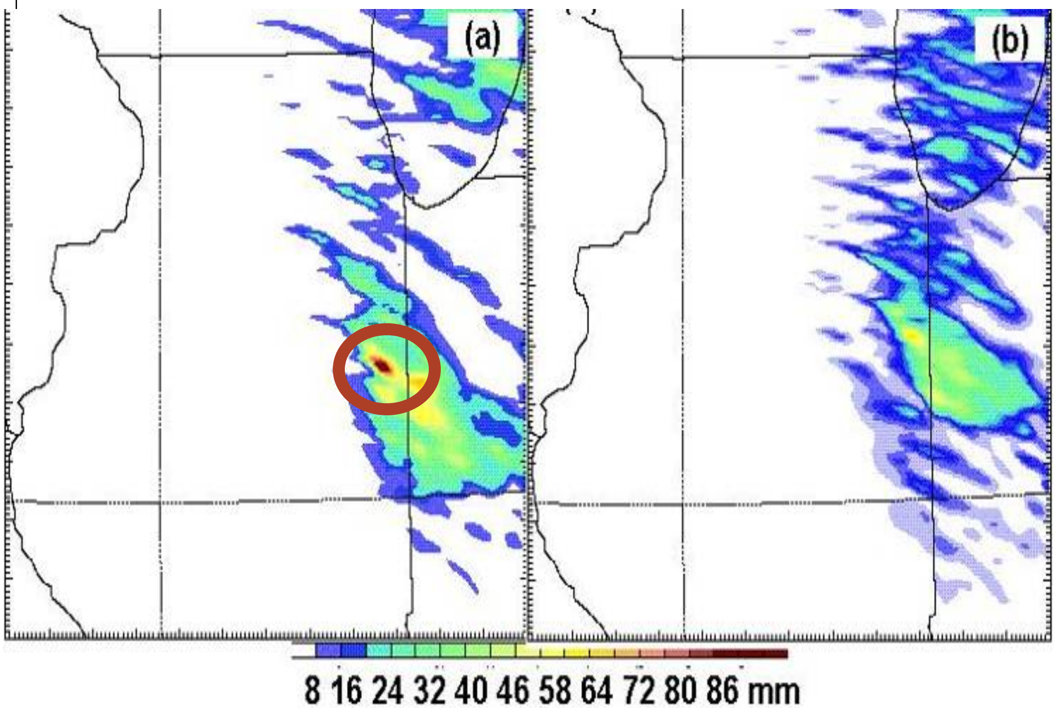
Effect of agriculture and transpiration on thunderstorms



More agricultural landscape → transpiration → more water vapor in the atmosphere → more potential for thunderstorms? (Kumar et al. 2011)

Explicit consideration for Soybean and Corn

Default



Considering Agriculture

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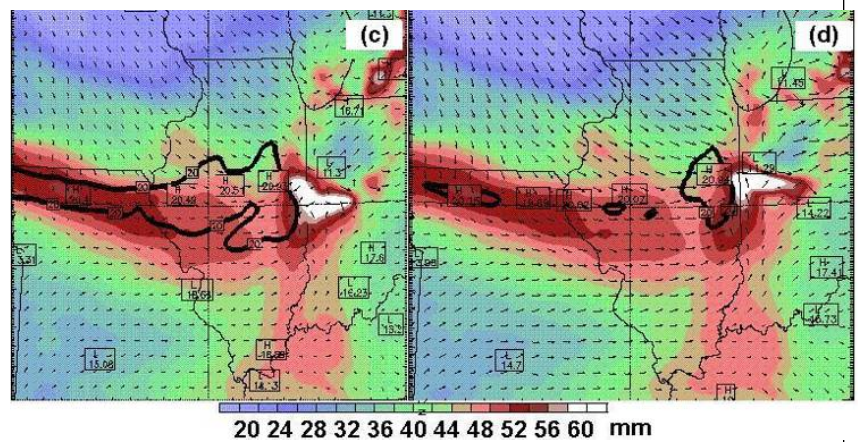
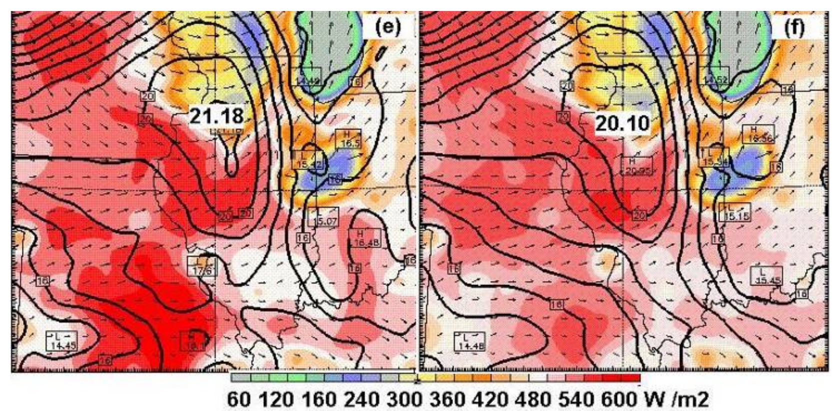


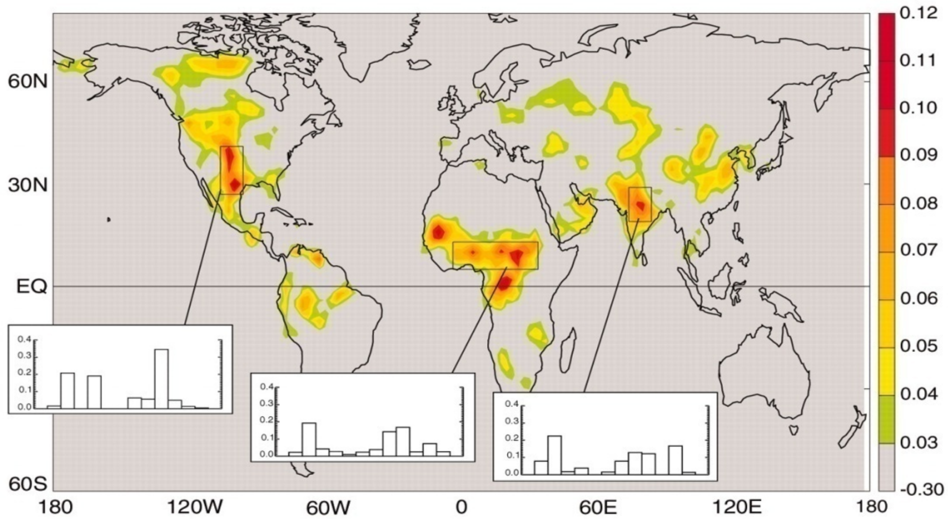
Precipitable water (color shade), high vapor mixing ratio (dark line)



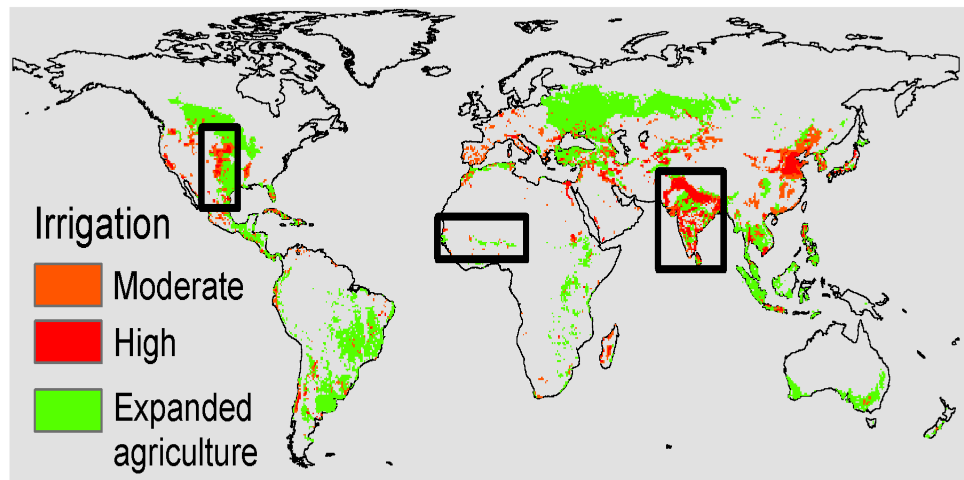
Latent heat W/m2 (color shade), high vapor region (contour)

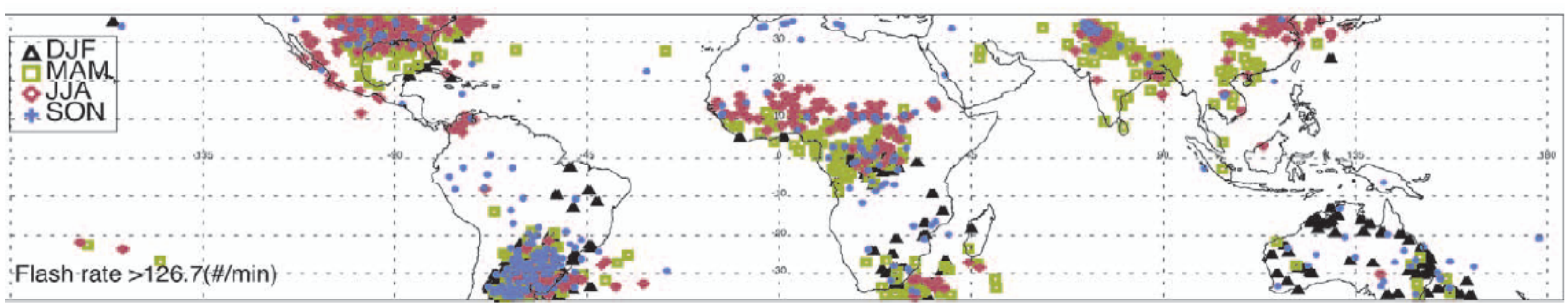
Land surface feedback relevant to the human centric activities: Agricultural Intensification, urbanization, Land Atmosphere Coupling, and Preferential zones for severe thunderstorms– Is there a relation?

Land-atmosphere coupling strength (JJA), averaged across AGCMs

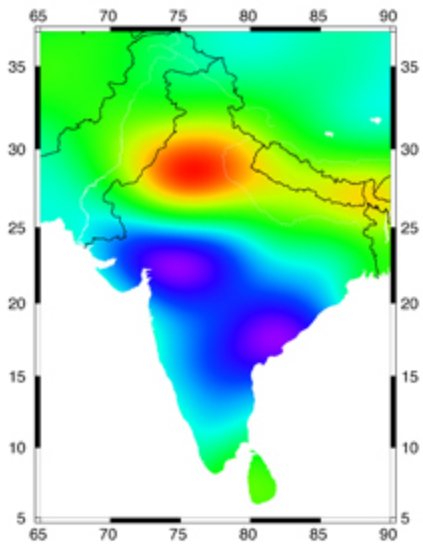


Regions of Expanded Agriculture and Irrigation





Example of LULCC rainfall impacts – Indian monsoon region (Niyogi et al. 2010)



Rodell et al. (2009) groundwater changes in India (2002-08), GRACE estimated rate of depletion in NW India is 33 cm/yr

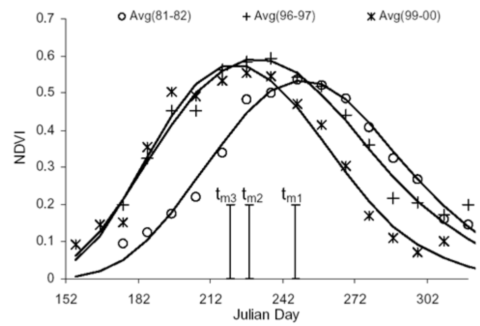


Fig. (Extra-3). Average NDVI growth profile of rice-dominated grid estimated using NOAA–AVHRR NDVI data during kharif season and model fit over 0.50 grid covering Ludhiana district, Punjab. t_{m1}, t_{m2}, t_{m3} represents mean peak vegetative stage of crop during 1981–82, 1996–97 and 1999–2000 respectively (from Singh et al, 2006).

Shift in the NDVI peak greenness with ag intensification by 30 days over 2 decades

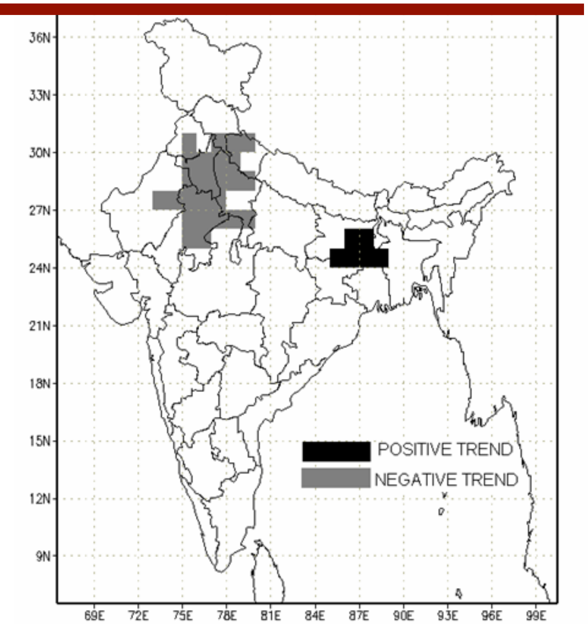


Figure 3: Regions of strong positive and negative trends in monsoon seasonal rainfall determined by GA approach

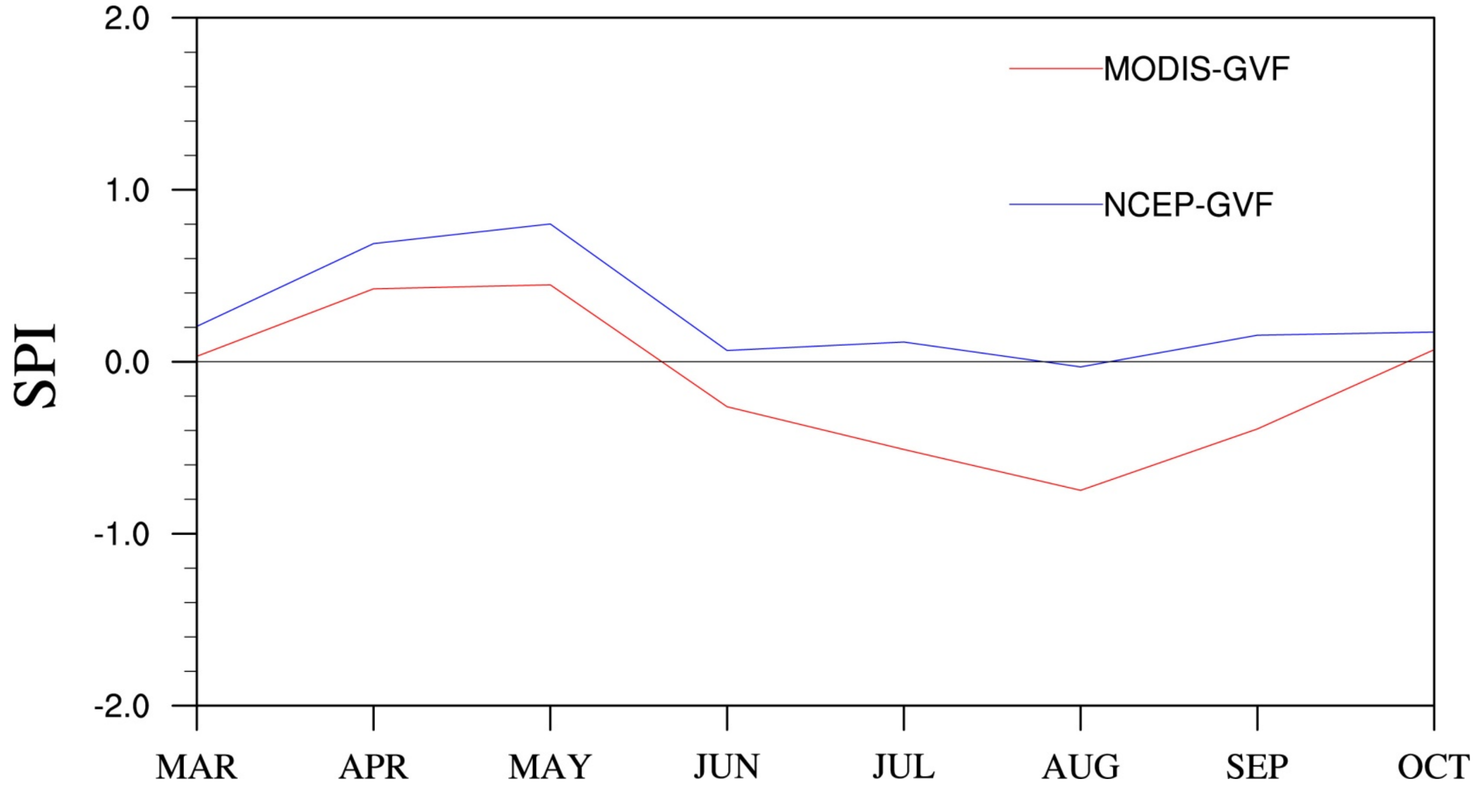
Reduction in rainfall over NW India as a causal response of April NDVI and ag intensification leading to weaker monsoon heat low and divergence at 200 mb.

Agricultural intensification → shift in peak NDVI / increased irrigation need → Weaker monsoon low and rainfall over NW India…..
Reduced rainfall → increased irrigation need → feedback loop…

(For US irrigation has opposite effect leading to increased rainfall over SGP)

SPI monthly time series averaged over all station lies within midwest region.

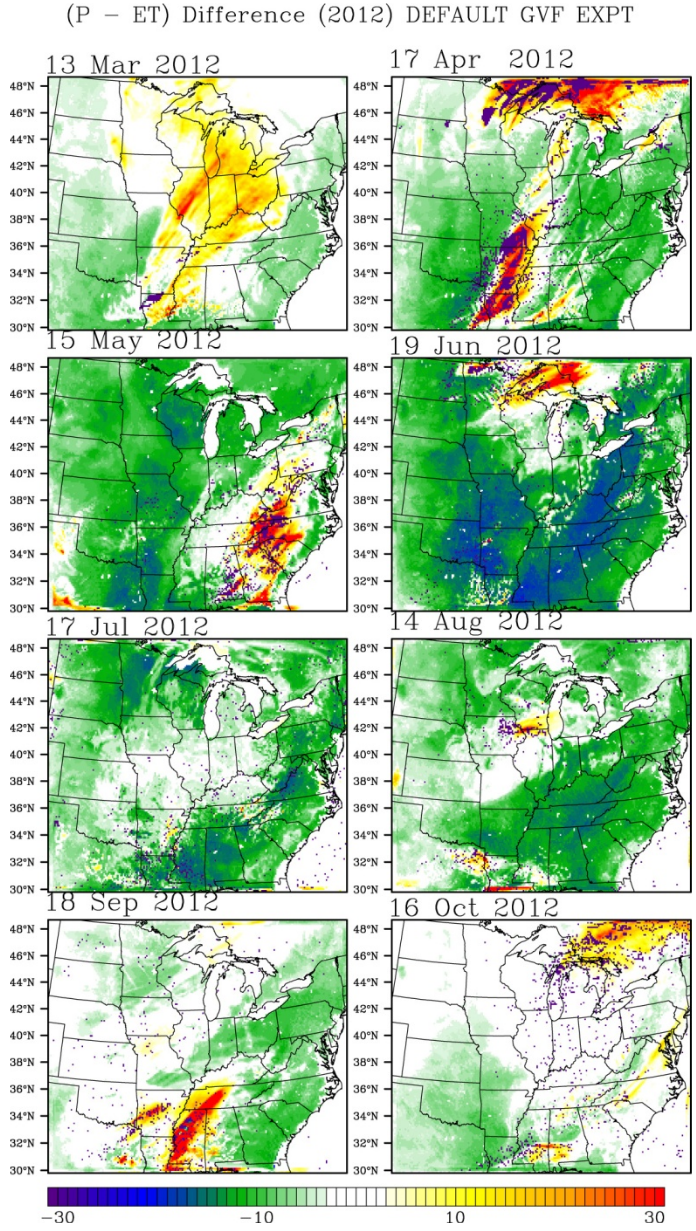
Considering Agricultural Planting in LSM Shows Better Ability to capture the 2012 Drought Intensity



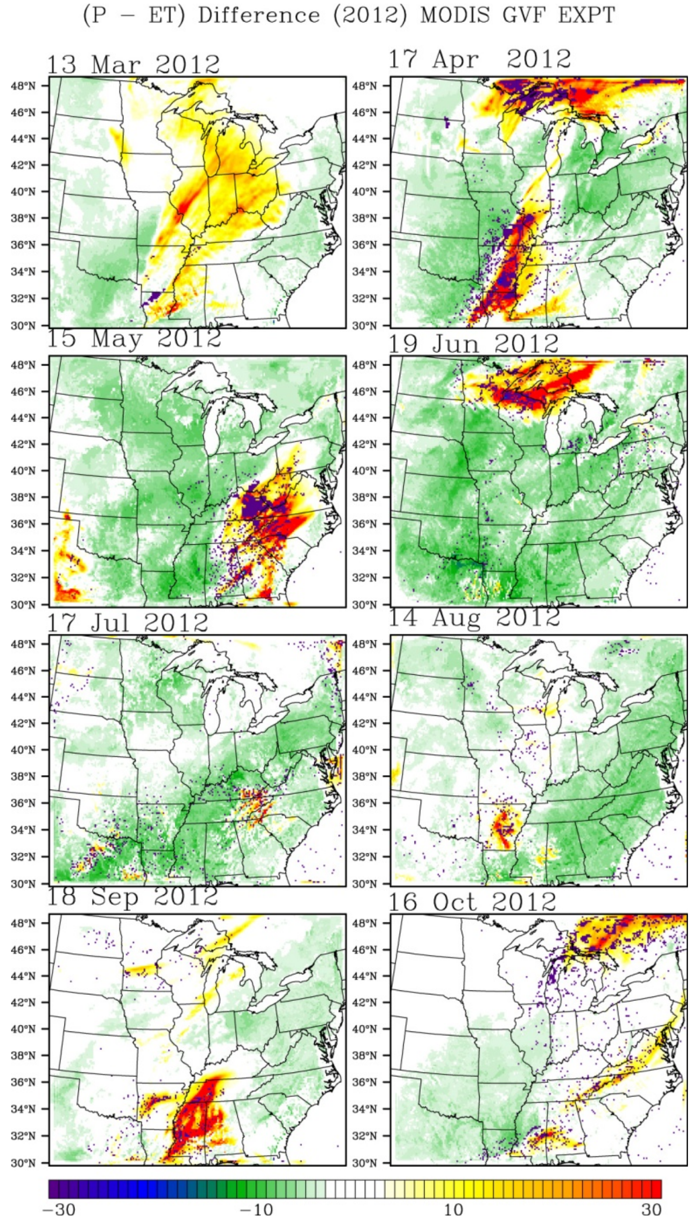
MODIS-GVF experiment shows some form of drought condition as seen in 2012 year. (negative values of SPI represents dry conditions)

Precip – ET

CLIM GVF



MODIS GVF

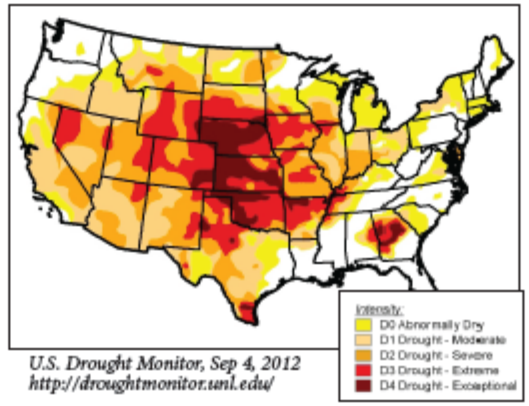


An Interpretation of the Origins of the 2012 Central Great Plains Drought

An Assessment Report of the NOAA Drought Task Force Narrative Team

Historical Context - How do 2012 rainfall amounts and high temperatures compare to years past?

Precipitation deficits for the period May through August 2012 were the most severe since official measurements began in 1895, eclipsing the driest summers of 1934 and 1936 that occurred during the height of the Dust Bowl. This prolonged period of precipitation deficits, along with above normal temperatures, resulted in the largest area of the contiguous United States in drought since the U.S. Drought Monitor began in January 2000. By early September, over three-quarters of the contiguous U.S. was experiencing at least abnormally dry conditions with nearly half of the region (the Central Plains in particular) experiencing unprecedented severe drought.



U.S. Drought Monitor, Sep 4, 2012
http://droughtmonitor.unl.edu/

What caused the 2012 Central Great Plains Drought?

The central Great Plains drought during May-August of 2012 resulted mostly from natural variations in weather.

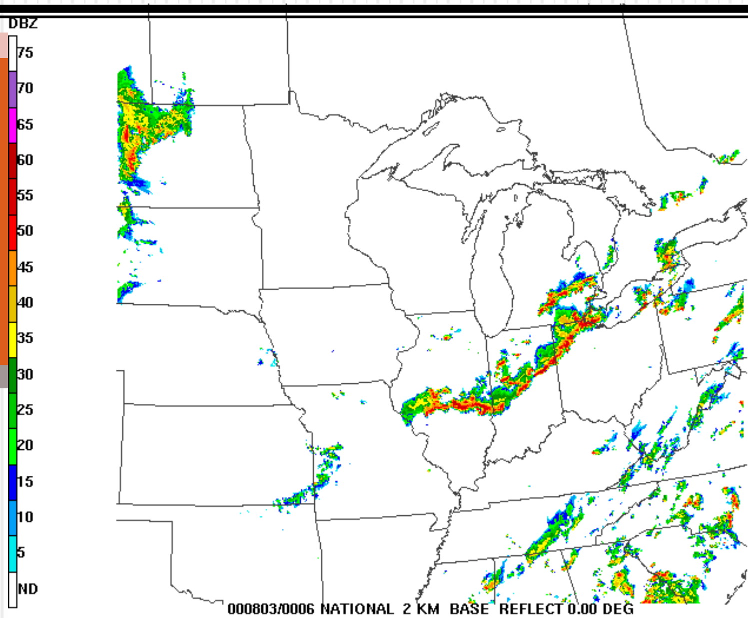
- Moist Gulf of Mexico air failed to stream northward in late spring as cyclone and frontal activity were shunted unusually northward.
- Summertime thunderstorms were infrequent and when they did occur produced little rainfall.
- Neither ocean states nor human-induced climate change, factors that can provide long-lead predictability, appeared to play significant roles in causing severe rainfall deficits over the major corn producing regions of central Great Plains.

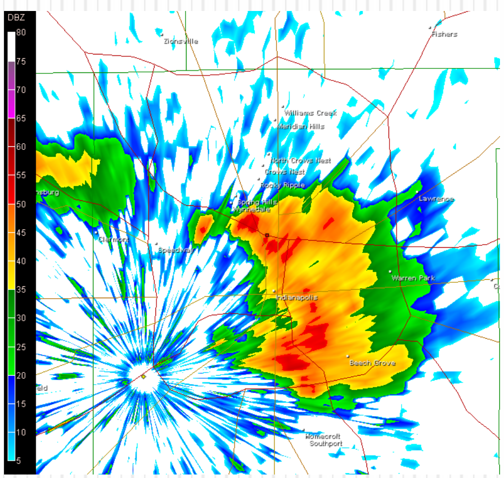
Contacts: Marty Hoerling (martin.hoerling@noaa.gov)
Annarita Mariotti (annarita.mariotti@noaa.gov)

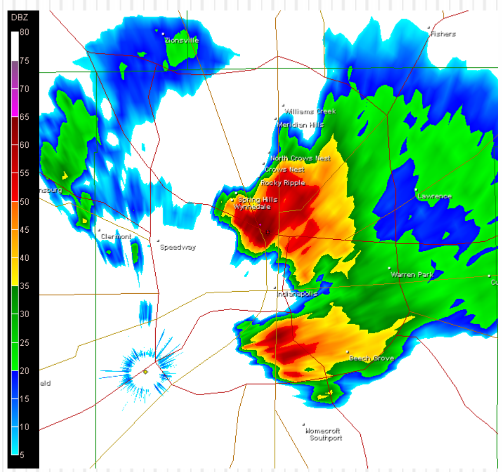
The full report can be downloaded from:
http://www.drought.gov/drought/content/resources/reports

Making case for explicit urban feedbacks in LSMs

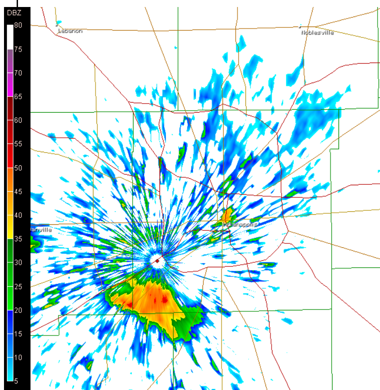
Urban landscape change cause heat islands and can also lead to rainfall changes! Thunderstorms can be a major cause of heavy rainfall



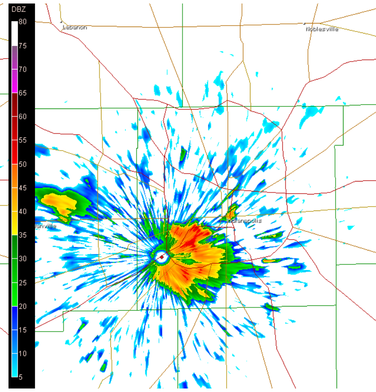




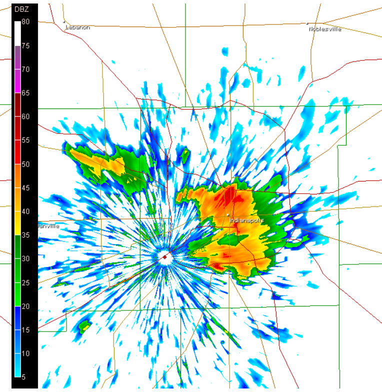
June 13th, 2005 Radar Analysis
Individual storms show urban feedbacks



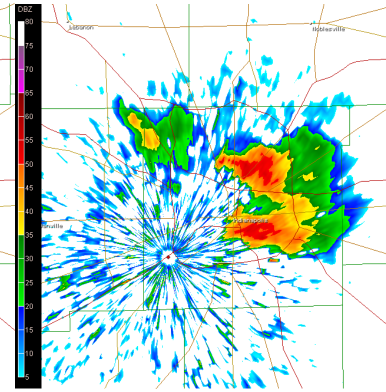
0002 UTC 14 June



0015 UTC 14 June



0029 UTC 14 June



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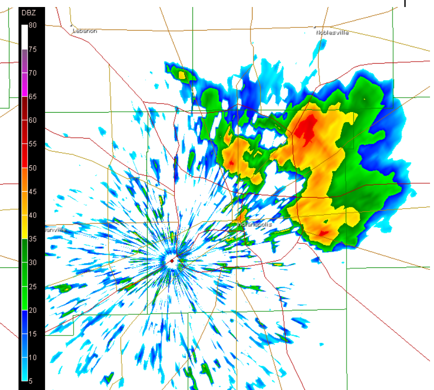

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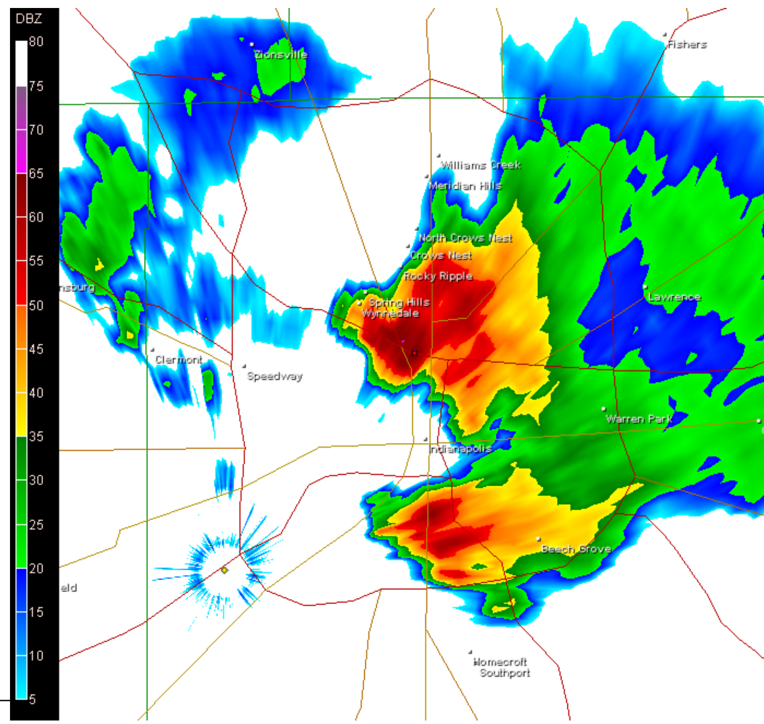
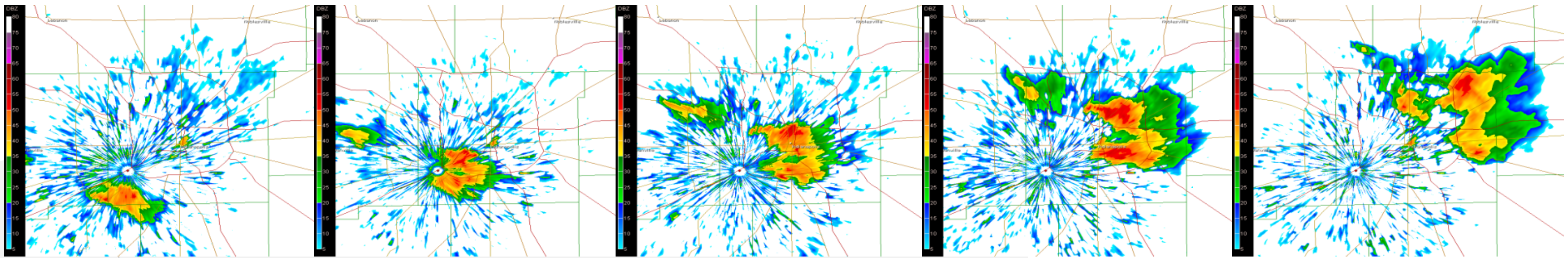
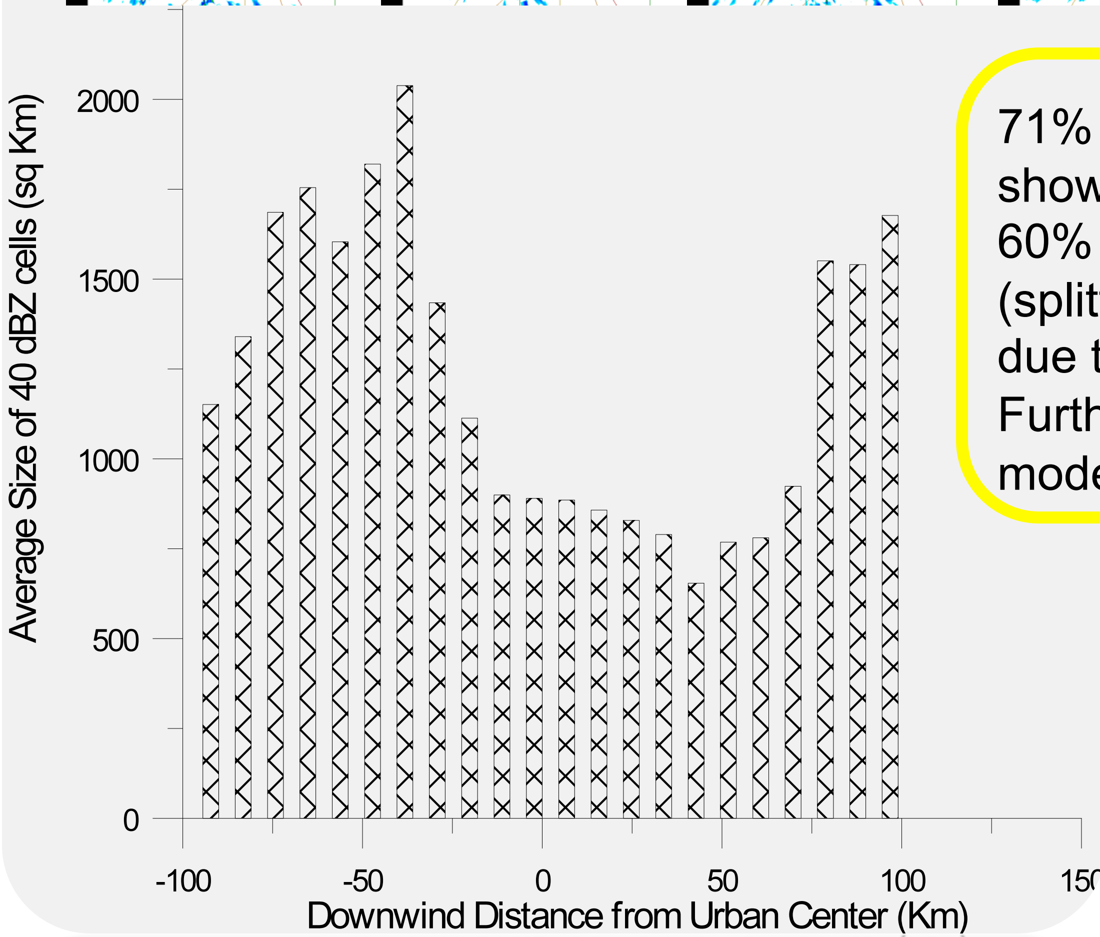


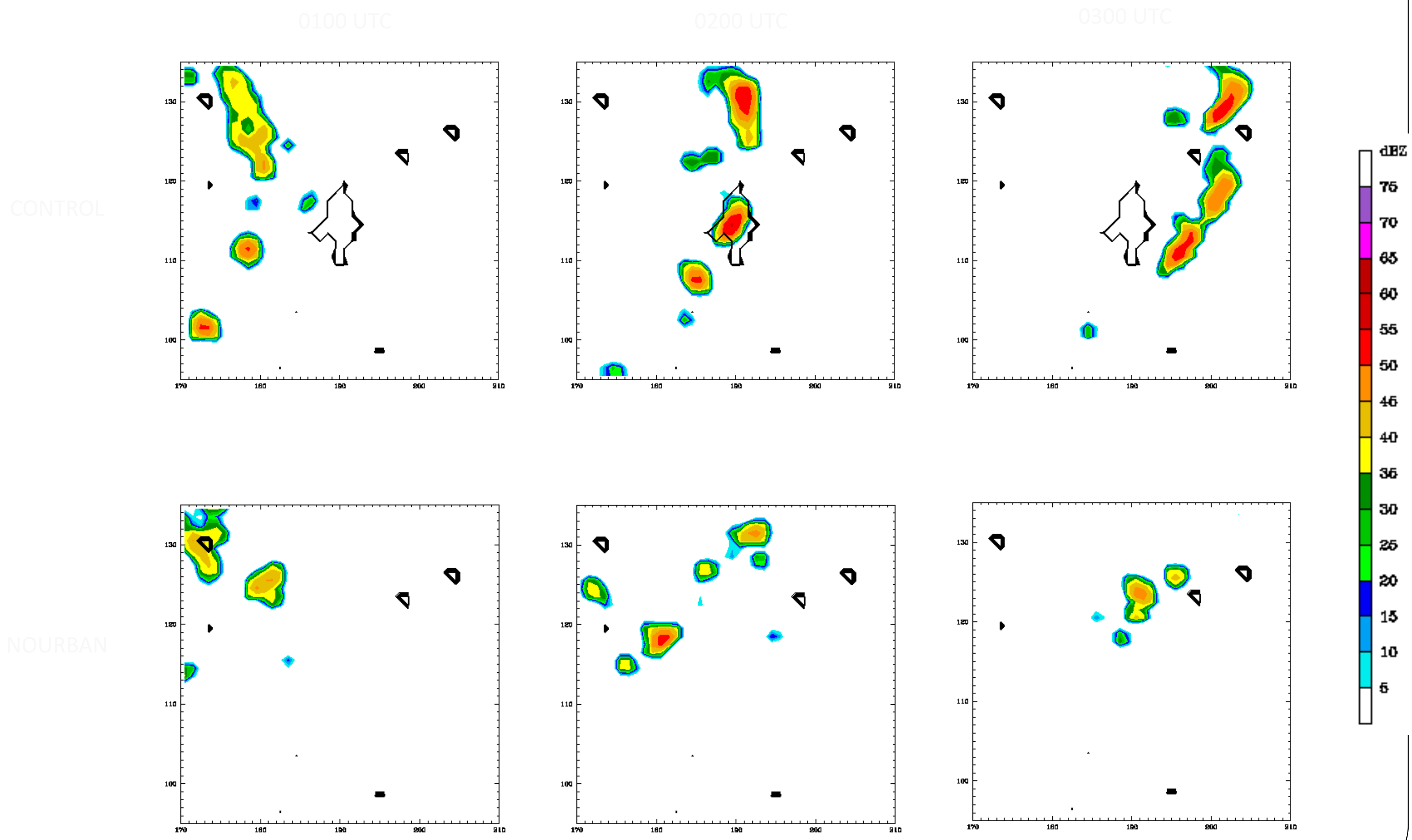
Urban LULCC impact on rainfall climatology – example over US





71% of day vs 25% night storms showed urban impact.
60% of storms showed change (splitting/ merging/ reintensification) due to urbanization
Further attribution using coupled models

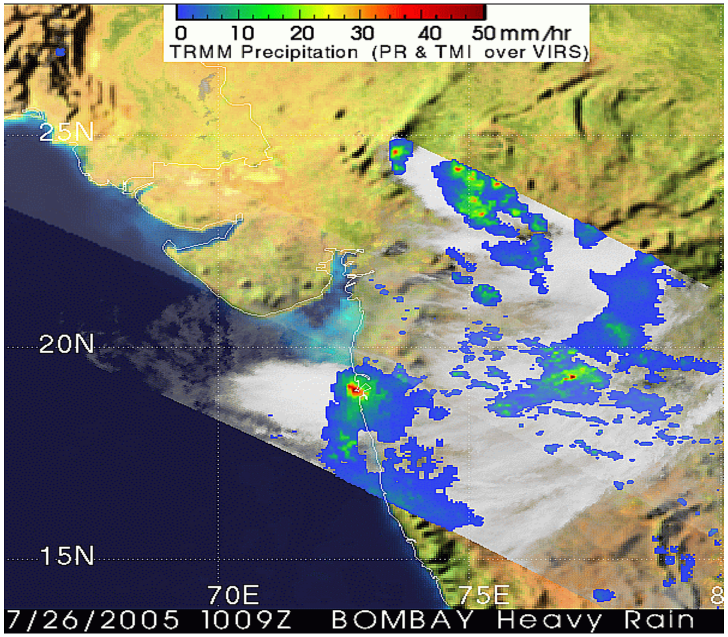
WRF Model runs – the enhanced convection, splitting and rainfall change is simulated only when urban feedback/ heterogeneity exists

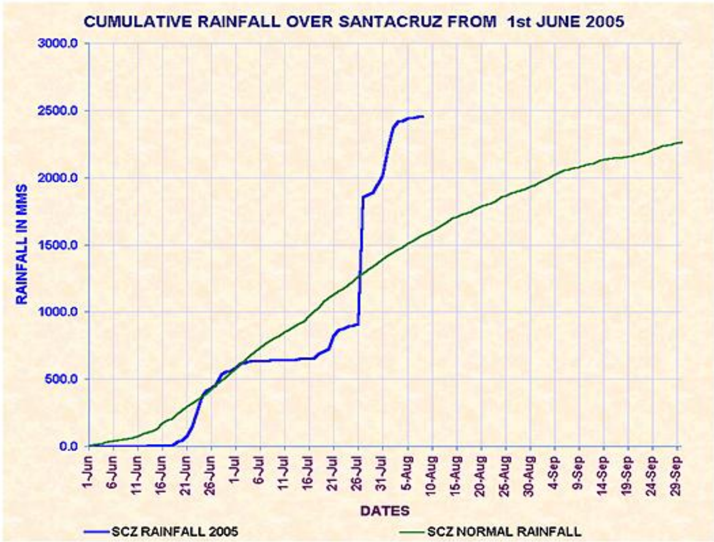


- Urbanization feedbacks important not just for high impact weather forecasts but also seasonal to longer term climate studies

Mumbai Metropolitan Heavy Rain

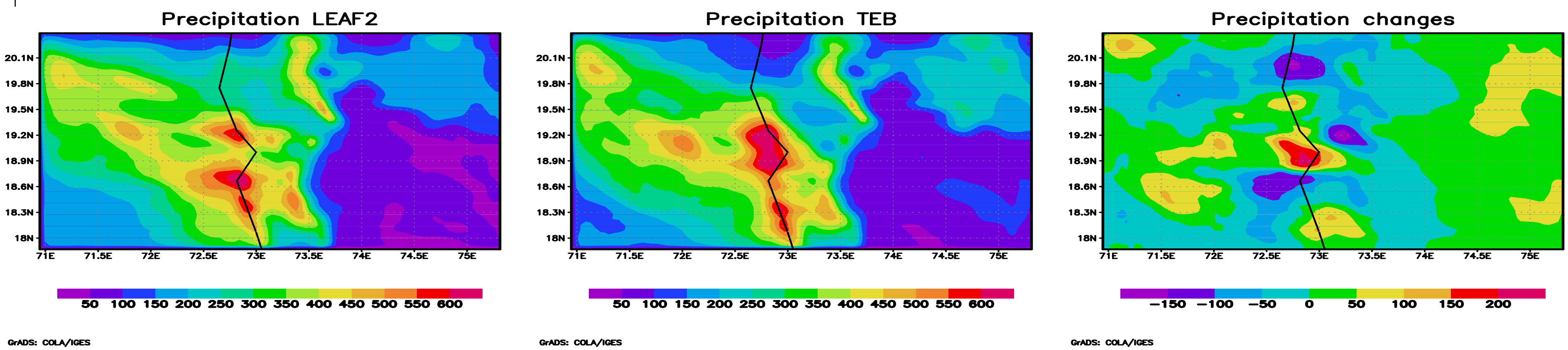
- July 26 2005, Mumbai (Bombay, western India) had 37.1 inches rain within 24 hours in Bombay, India.
- $3.5 billion economic loss and more than 1000 people lost their lives.
- **These heavy rain instances are not isolated and seen across many urban regions in India and China.**



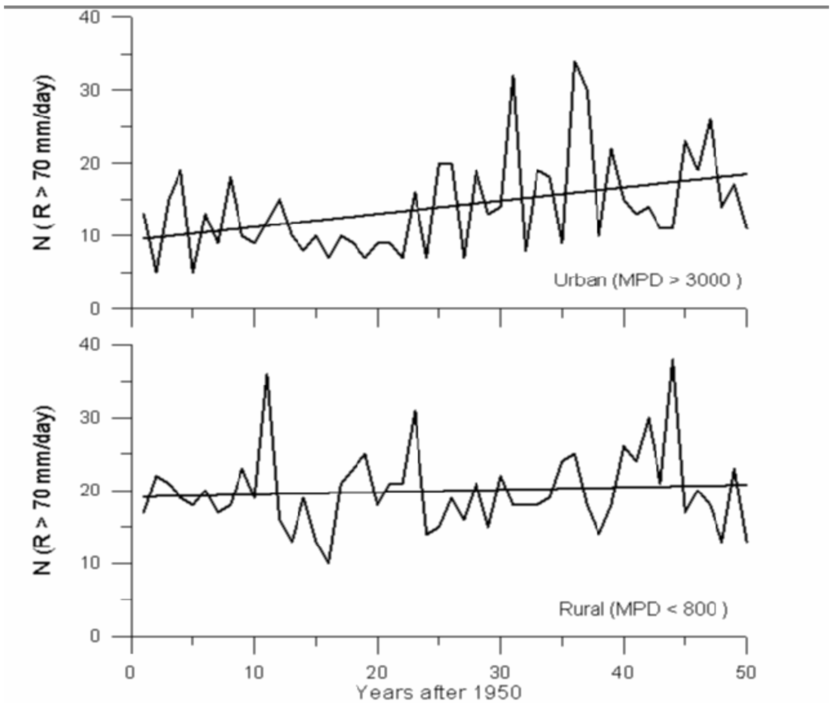


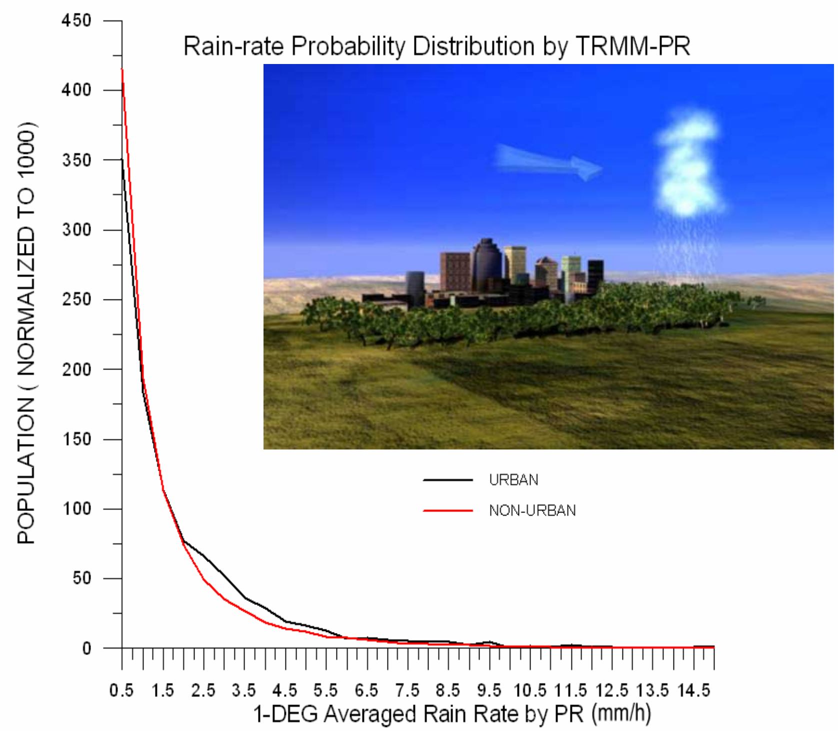
Urban landsurface contributed to the record breaking rainfall over Mumbai

- Mumbai, India heavy rain event (Jul.26 2006) case study 1000+ mm rain in 24h



Urban Signature in Increased heavy rainfall climatology over Indian monsoon region (Kishtawal et al. 2010)





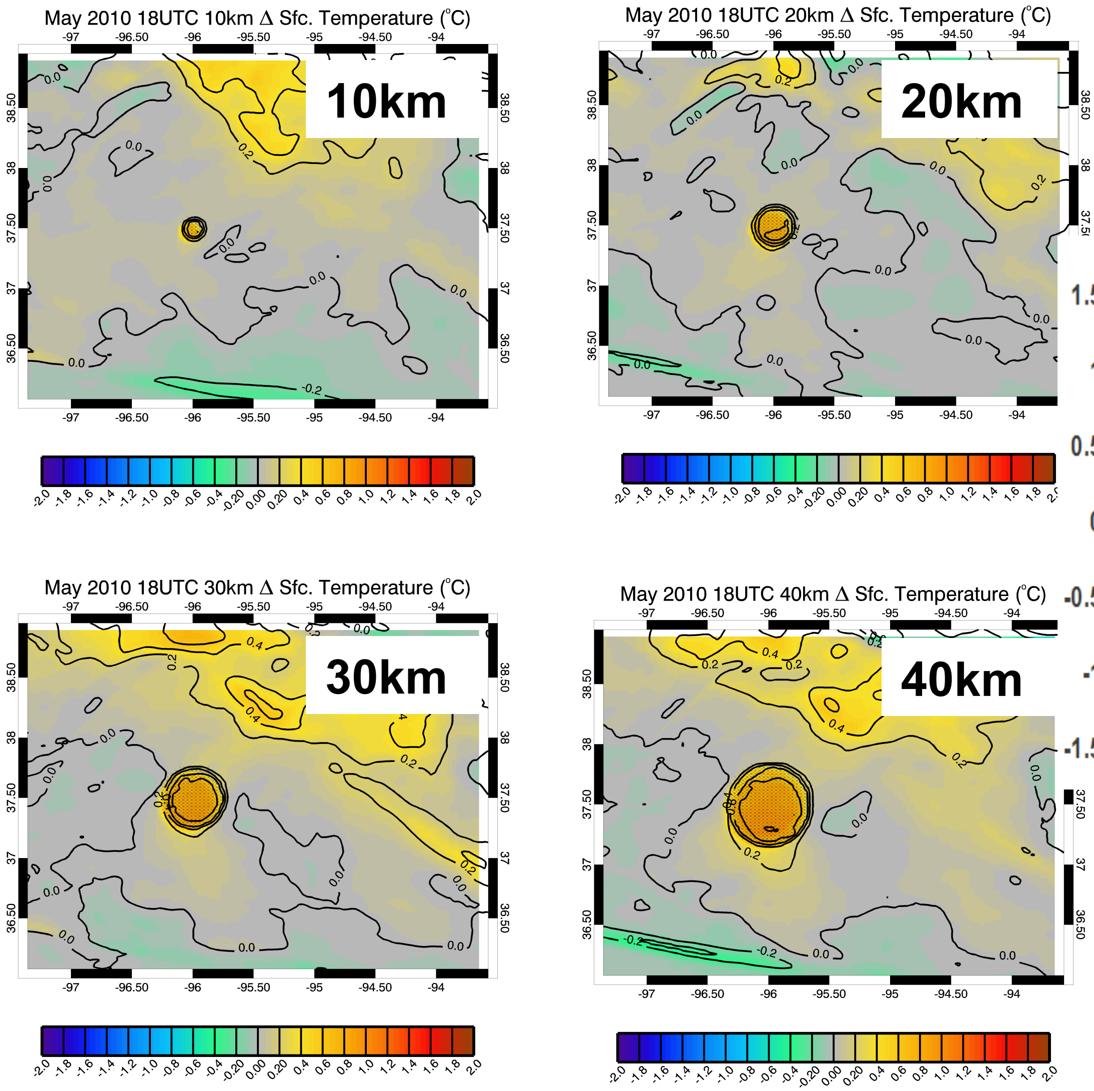
OLS night light data, population datasets, insitu and TRMM based rainfall data analysis the reported increase in heavy rainfall climatology over the IMR is seen only for urban stations – possible dynamical and aerosol feedback as a result of urbanization.

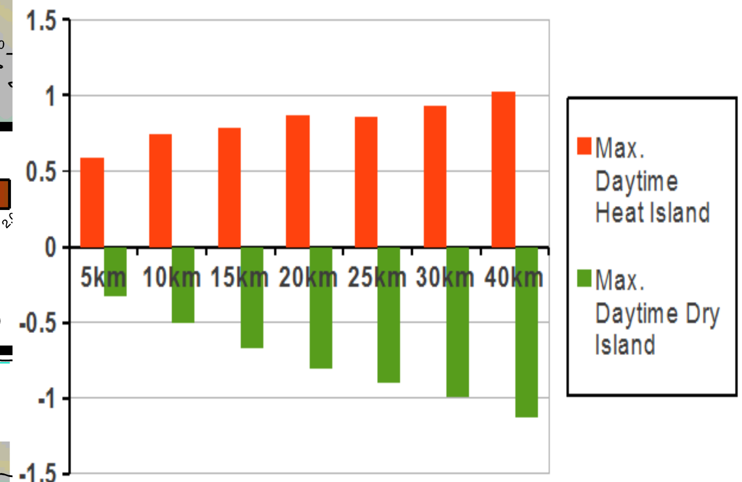
What is the minimal City Size for thunderstorm impacts? (Schmid & Niyogi, 2013, GRL)

- Study introduced Real Atmosphere, Idealized Land-surface (RAIL) method
  - Flat, homogeneous terrain
  - Circular cities of varying radii (5km to 40km) placed in path of weak-linear convection
- Attempts to isolate urban land-surface contribution to temperature and precipitation anomalies
  - Heat island
  - Vertical motion and momentum transfer
  - Effects on mesoscale precipitation system

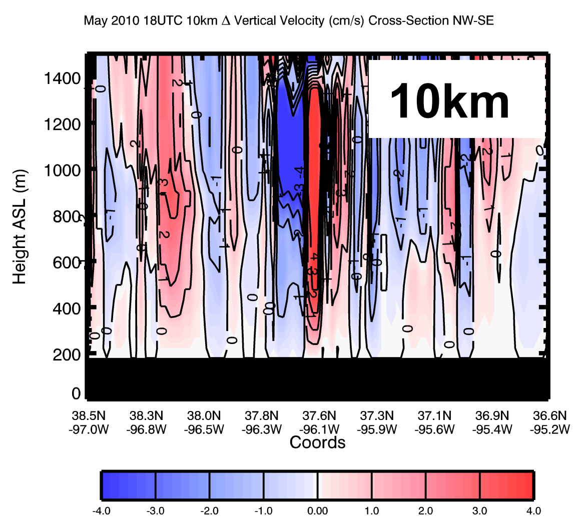
20-25km city radius needed.

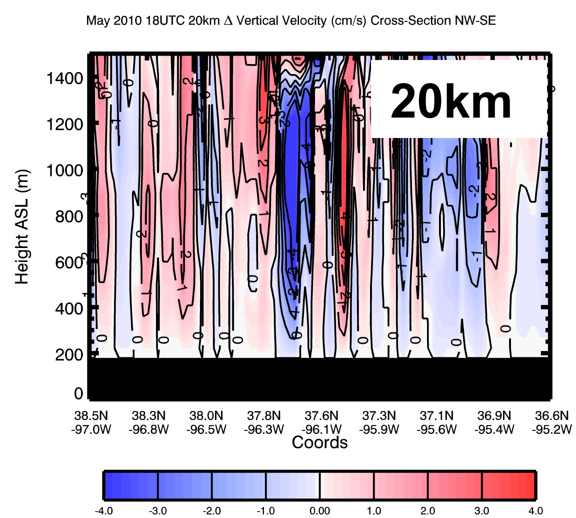
Heat Island

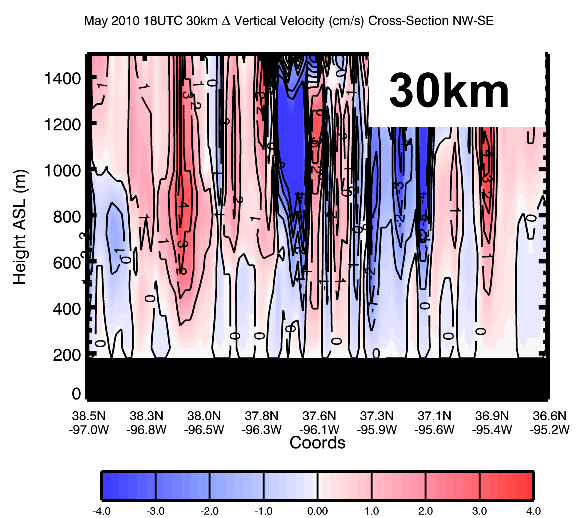

May 2010 18UTC 10km Δ Sfc. Temperature (°C)
10km
May 2010 18UTC 20km Δ Sfc. Temperature (°C)
20km
May 2010 18UTC 30km Δ Sfc. Temperature (°C)
30km
May 2010 18UTC 40km Δ Sfc. Temperature (°C)
40km

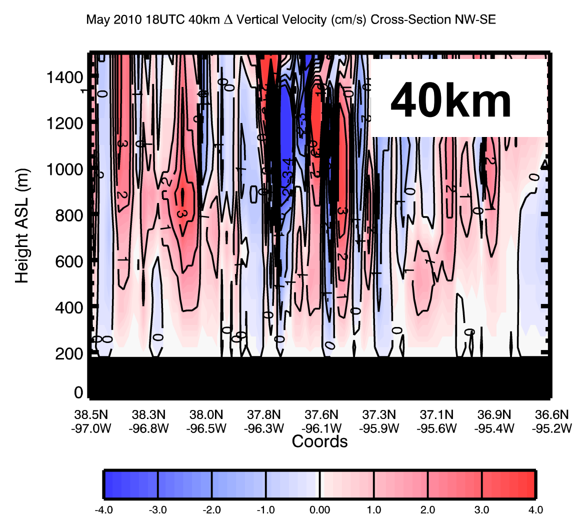

1.5
1
0.5
0
-0.5
-1
-1.5
5km 10km 15km 20km 25km 30km 40km
Max. Daytime Heat Island
Max. Daytime Dry Island

Vertical Motion Cross Sections



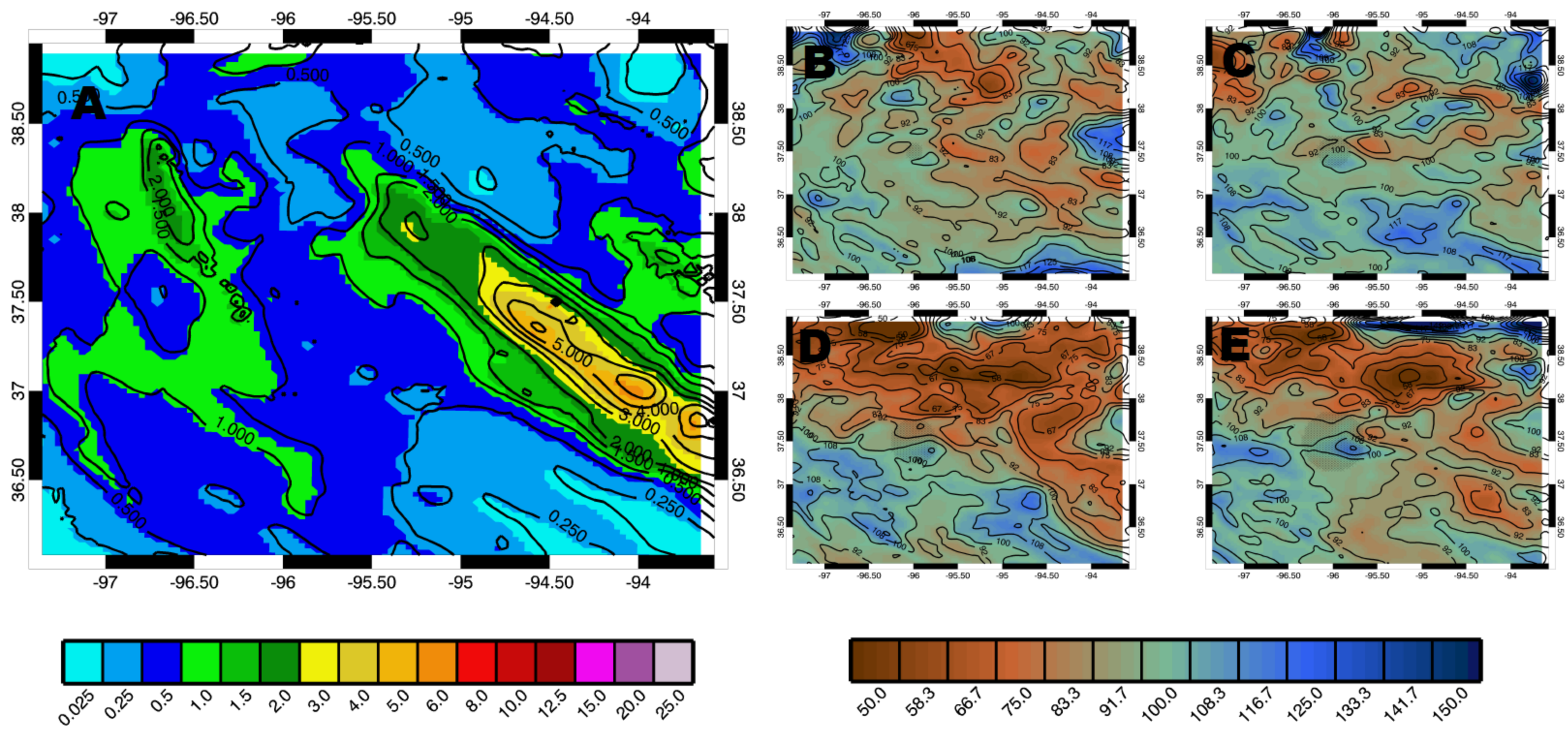






- Increased city size affects
  - 1) Peak urban updraft/downdraft velocity
  - 2) Size of updraft field
- *Does not* affect
  - 1) Individual updraft size
  - 2) Preference of city-edge updraft or downdraft

Resulting Precipitation Modification



Making Case for socioeconomic/ dynamic links within weather and seasonal forecasts through land models

Emerging approaches 2d → 3d morphology → agent models for socioeconomic impacts

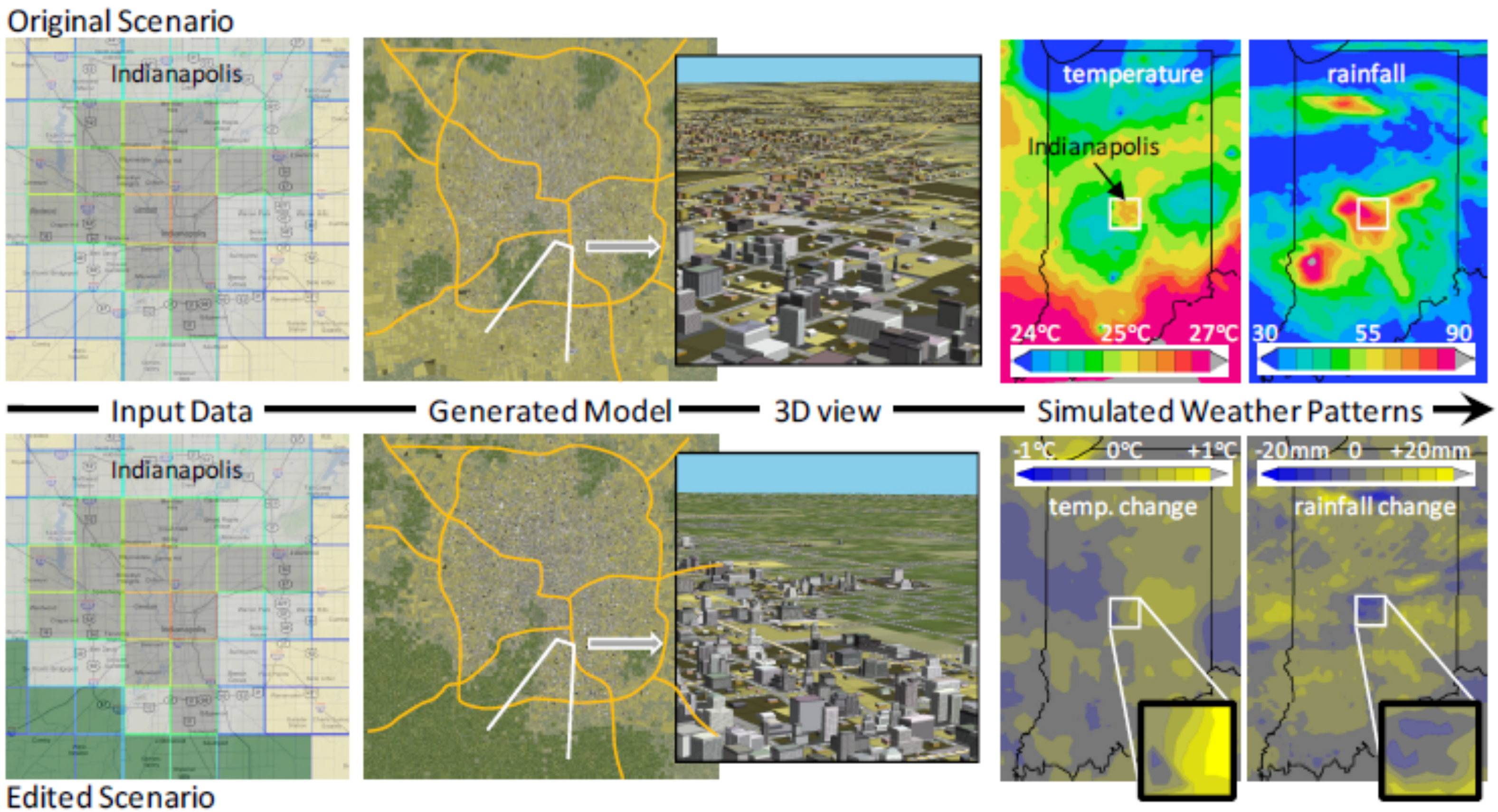
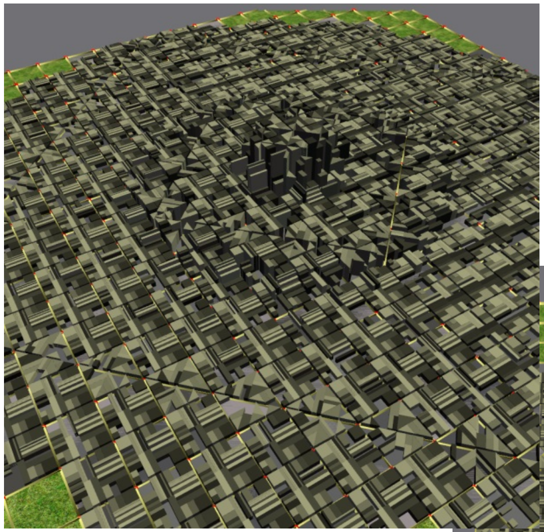


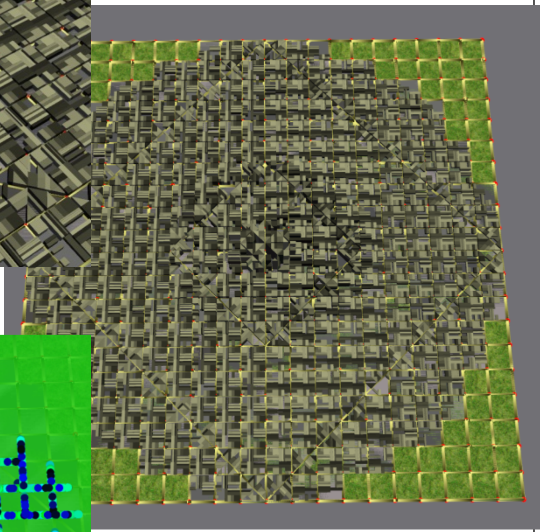
Figure 1. Visualization-based Decision Support System. *Top*: original urban scenario for Indianapolis, IN. *Bottom*: hypothetical (edited) urban scenario where the southwest corner became parks. Using LULC data (*left column*), complemented by population and terrain data, our DSS automatically produces a plausible 3D city model (*second and third columns*) from which urban morphology parameters are extracted for a regional weather simulation over Indiana (*fourth and rightmost columns*). The ability to quickly edit the city model and automatically produce a plausible city and urban morphology parameters offers a substantial step forward in building integrated visualization and

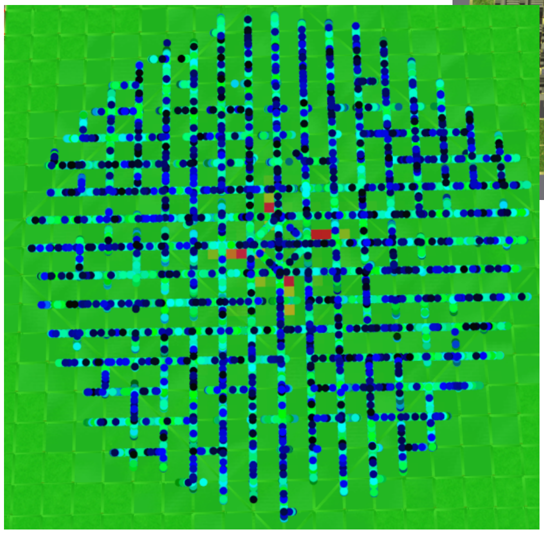
- Making case for LSM evolution particularly for NWP and subseasonal projections to include urban/rural aerosol heterogeneity feedbacks
  - How do the two interact and affect storm dynamics.
  - Typical life span 2 weeks for aerosols

Urban land cover+ Traffic → Aerosols

- Circular RAIL setup: 10km radius urban area
  - Includes downtown & suburbs
  - Isolated urban area ~ size of Raleigh, NC
- 600,000 people: slightly more dense than average American city.
  - Compromise of needed size for weather modification
  - Capacities of urban weather model

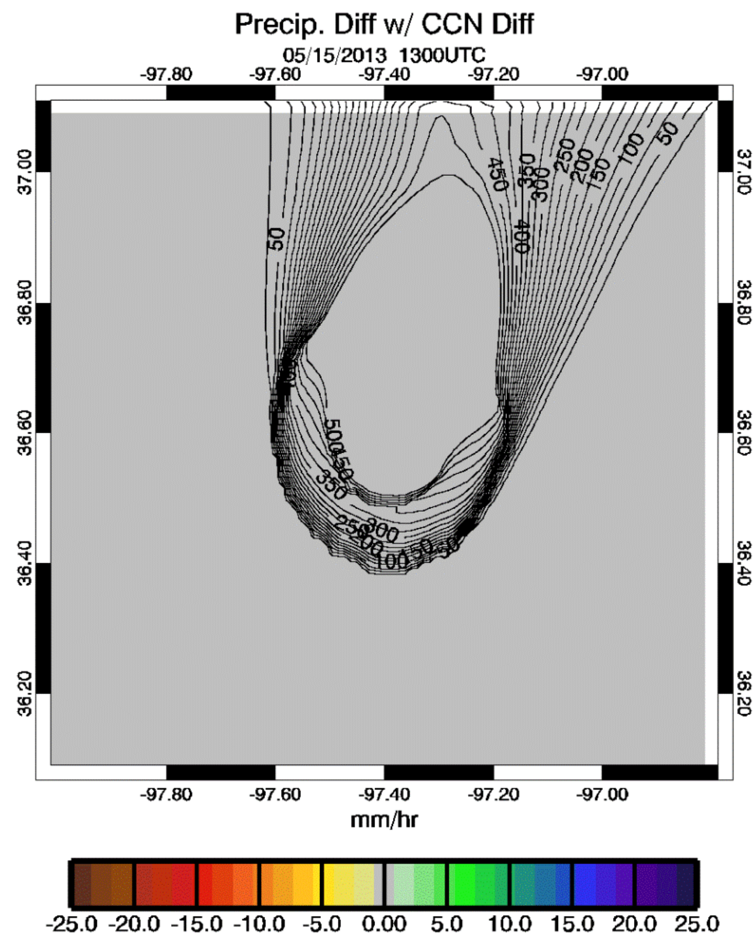






Urban emissions module

- Coupled air quality model with cloud physics
  - Sulfate => urban CCN
  - $PM_{2.5}$ => urban GCCN
- Emissions rate based on time of day & day of week
- Heterogeneous urban aerosol field
  - Downwind aerosols advected from urban center
  - Urban concentrations appear at urban/rural boundary



Other outstanding issues

- **Why are the results from improved LSM sometimes only modestly better?**
  - Conservative land – atmospheric coupling to avoid errors from uncertainties from land to affect the atmosphere. This same poor coupling is inhibiting the transference of the enhanced land information to atmosphere.
- **How can we improve the land models?**
  - Significant uncertainty in the details of the subcategories, coefficients.
  - Processes outlined – agriculture, aerosols, urbanization, human components need to be considered (more socioeconomic considerations and dynamic information needed), engineering options available.

Thank you

Email: CLIMATE@PURDUE.EDU

Web: http://LANDSURFACE.ORG

http://ICLIMATE.ORG