Sensitivity Analysis of WRF Forecasts in Arizona During the Monsoon Season Case Study: August 2, 2005 to August 3, 2005

Christopher L. Castro and Stephen Bieda III
University of Arizona

Susanne Grossman-Clarke
Arizona State University

Qingnong Xiao
National Center for Atmospheric Research

CPPA Principal Investigators Meeting
Silver Spring, Maryland
September 29 – October 1, 2008

THE UNIVERSITY OF ARIZONA

NCAR

ASU ARIZONA STATE UNIVERSITY

Presentation Outline

August 2005 severe weather event in the Phoenix metro area

Current problems in NWP for these types of events

New tools in WRF to address these problems:
adjoint model + urban modifications

Preliminary sensitivity experiments to demonstrate use of new WRF tools

Concluding points

Acknowledgements: Research funded by Science Foundation Arizona (CAA 0228-08) and the National Science Foundation (ATM-813656)

August 2, 2005 Severe Weather Event in Phoenix Metro Area: A "Rim Shot"

<u>**Had "typical" ingredients**</u>

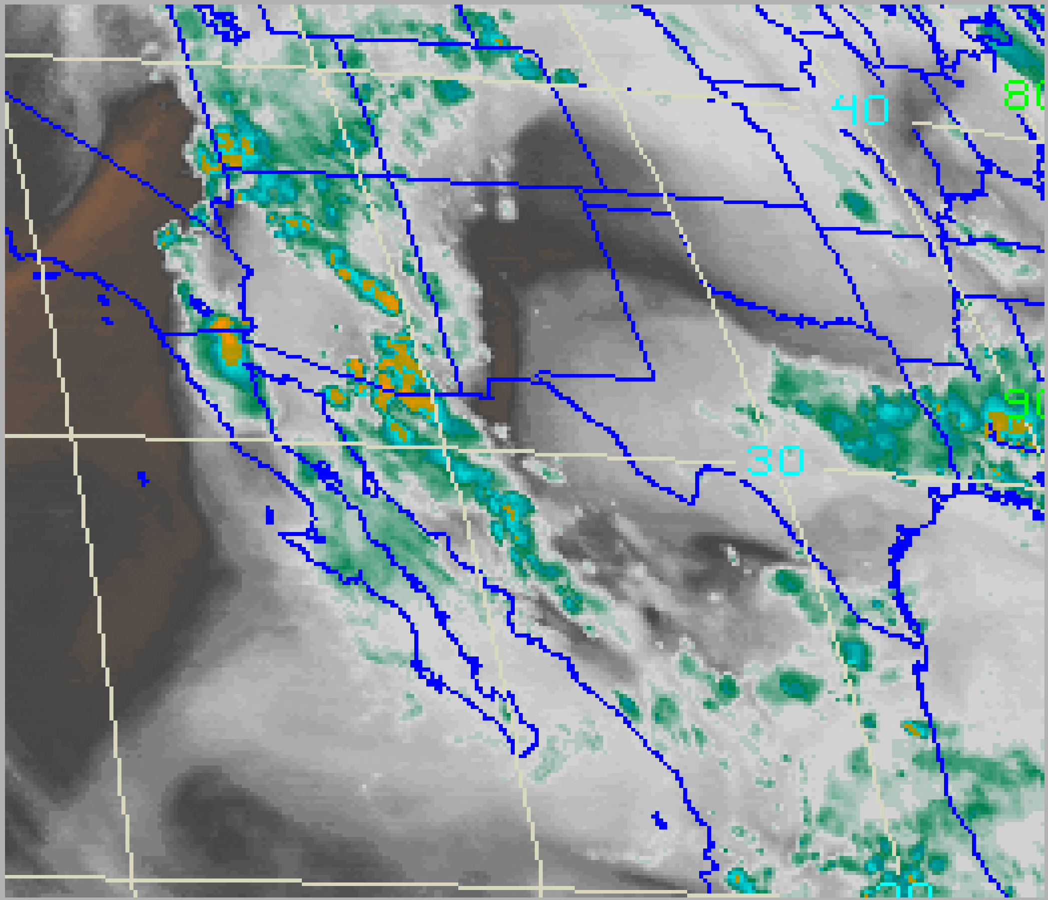
1. **Upper-level inverted trough**

2. Low-level surge of moisture from the Gulf of California.

<u>**Net result**</u>

Vertical wind shear, high θ_e in low levels, upper level divergence, and relatively high CAPE.

Terrain-induced convection can organize into MCSs west of Mogollon Rim.



Water vapor imagery on Aug. 3, 2005 at 15Z

Severe thunderstorm in Phoenix area: Approx. 6Z, 3 Aug. 2005

<u>Produced</u>

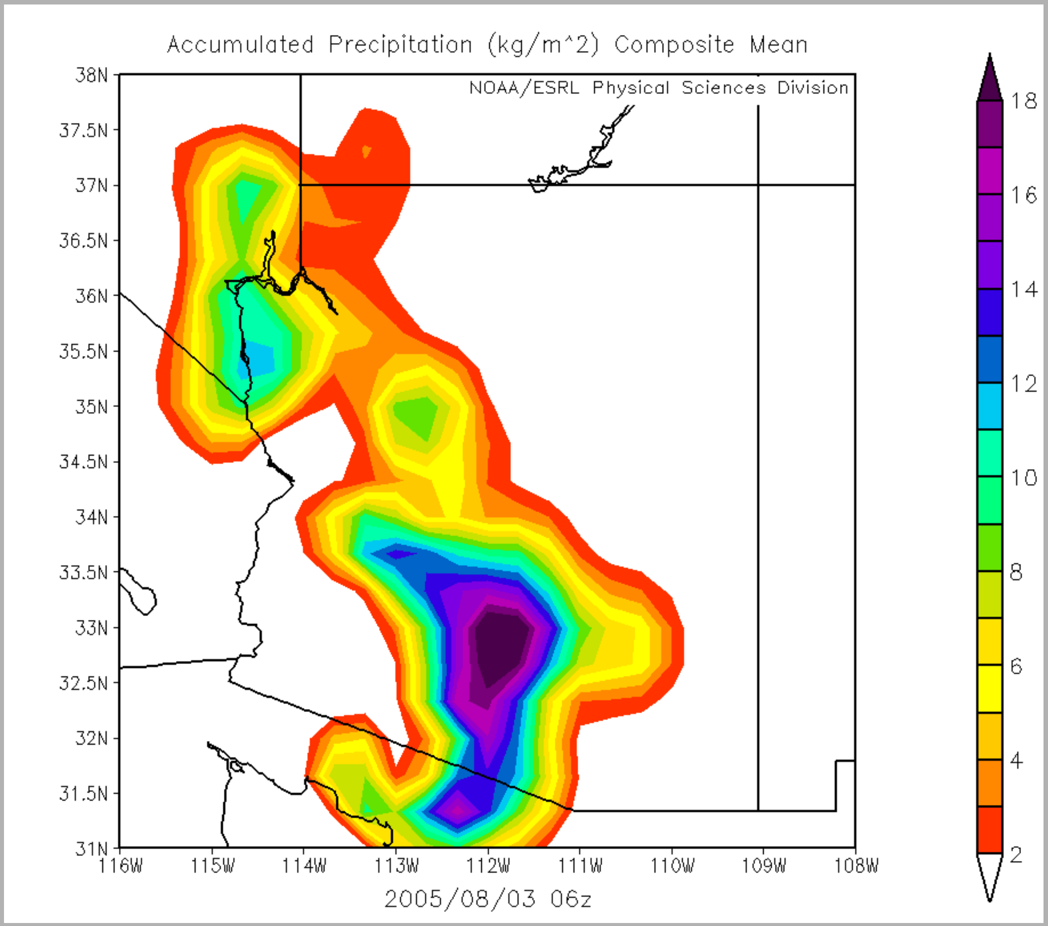
Major dust storm

Golf-ball size hail

Damaging winds

Urban flooding

Close to an inch or two or rain in isolated locations.



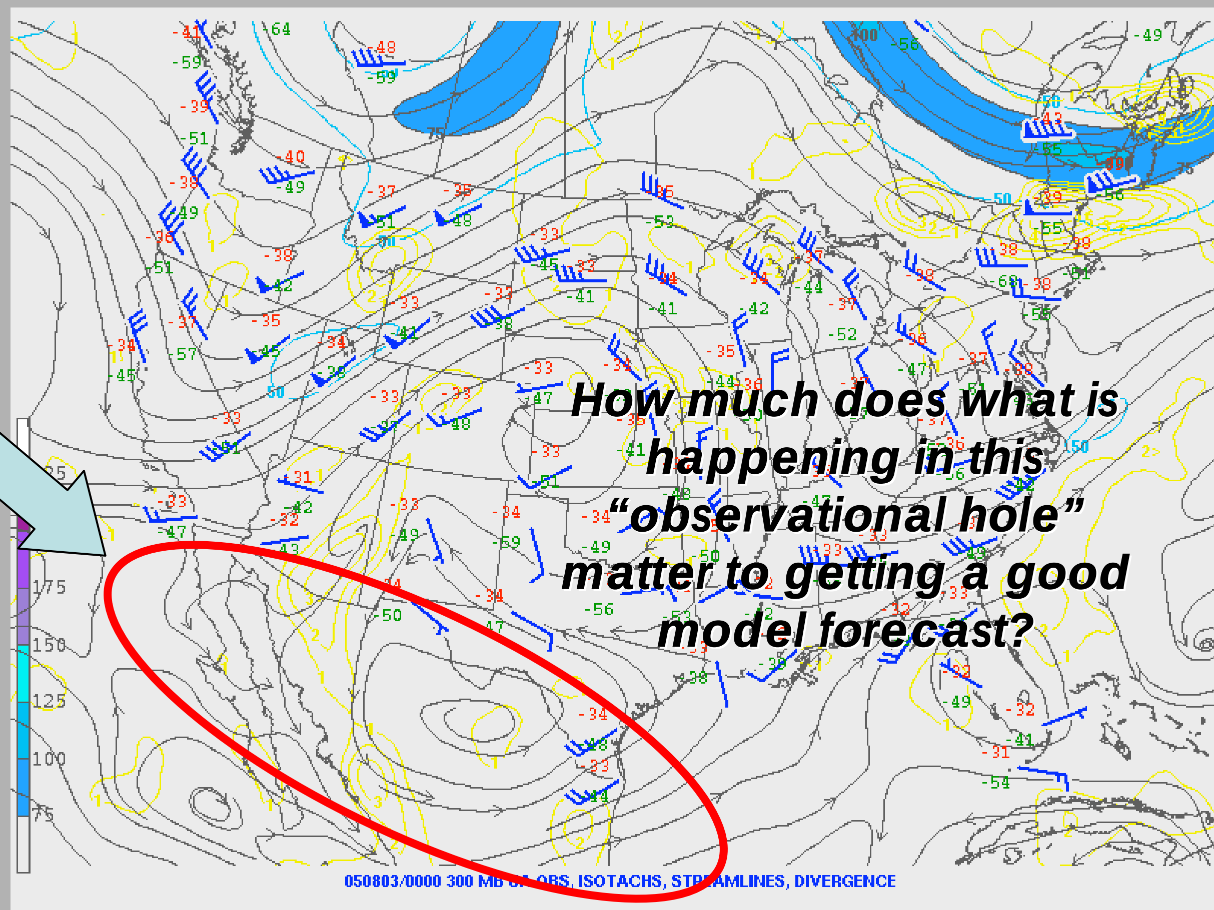
3h accumulated rainfall, 3Z to 6Z, 3 Aug. 2005 (NARR product, NOAA ESRL).

Forecast model problem #1: A Lack of Observations

There have been virtually no upper air observations in northern Mexico since the end of NAME.

Also no data along the Gulf of California to track gulf surges.

A consistent problem noted by Tucson and Phoenix WSFOs during the monsoon.

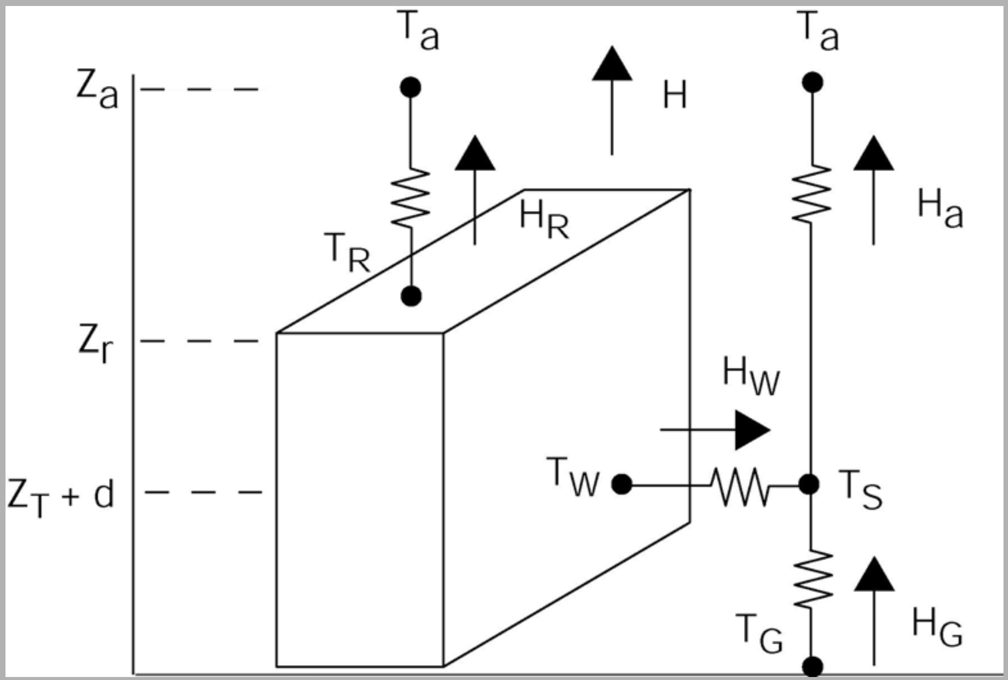


300-mb winds and streamlines

Forecast model problem #2
Lack of urban representation

The 24-category U.S. Geological Survey (USGS) land use/cover (LULC) system is the standard input for running WRF.

The extent and heterogeneity of urban land use are underrepresented in this dataset for Phoenix.



A simple single-layer urban canopy model

WRF (V3) NWP Simulation of Aug. 2005 Event

24 h simulation starting at 12 Z Aug. 2.

Western U.S. domain

27 km grid spacing on coarsest grid, nesting to 3 km over Phoenix metro

GFS model lateral boundary forcing

"Standard" WRF parameterizations

Adjoint sensitivity + urban modifications performed

Brief Overview of Adjoint Modeling

Technique to determine the sensitivity of a NWP forecast for a selected target region to specification of initial conditions within the model domain.

High sensitivity regions and atmospheric parameters in which small perturbations can produce large effects on forecast features that can be identified.

Adjoint model is the transpose of the tangent linear operator of the given NWP model. An estimate of a differentiable model forecast state (response function R) defined at a given forecast verification time (t_f) can be produced through a modifiable initial state (X^0).

Adjoint Sensitivity of a Simple Response Function (*R*), defined at verification time (*f*)

$$R = \frac{1}{2}\sum_{i,j}\left[\left(u_{i,j}^{f}\right)^2 + \left(v_{i,j}^{f}\right)^2\right]$$

u, v = **Horizontal winds**

X^{o} = **Model initial state**

X^{f} = **Model final state**

$$\frac{\partial R}{\partial X^{o}} = L^{*}\,\frac{\partial R}{\partial X^{f}}$$

Gradient of response function at start of model integration (adjoint sensivitity)

Adjoint model

Gradient of response function at forecast verification time

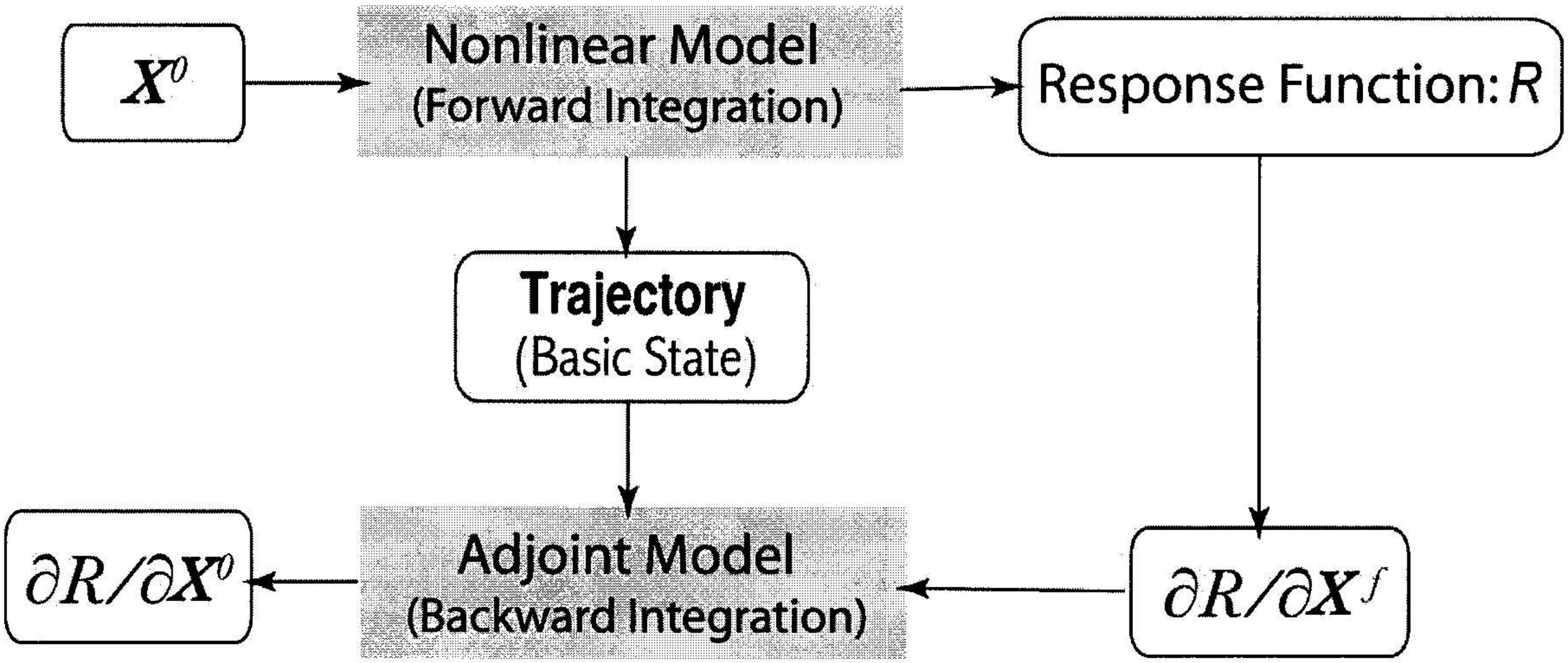
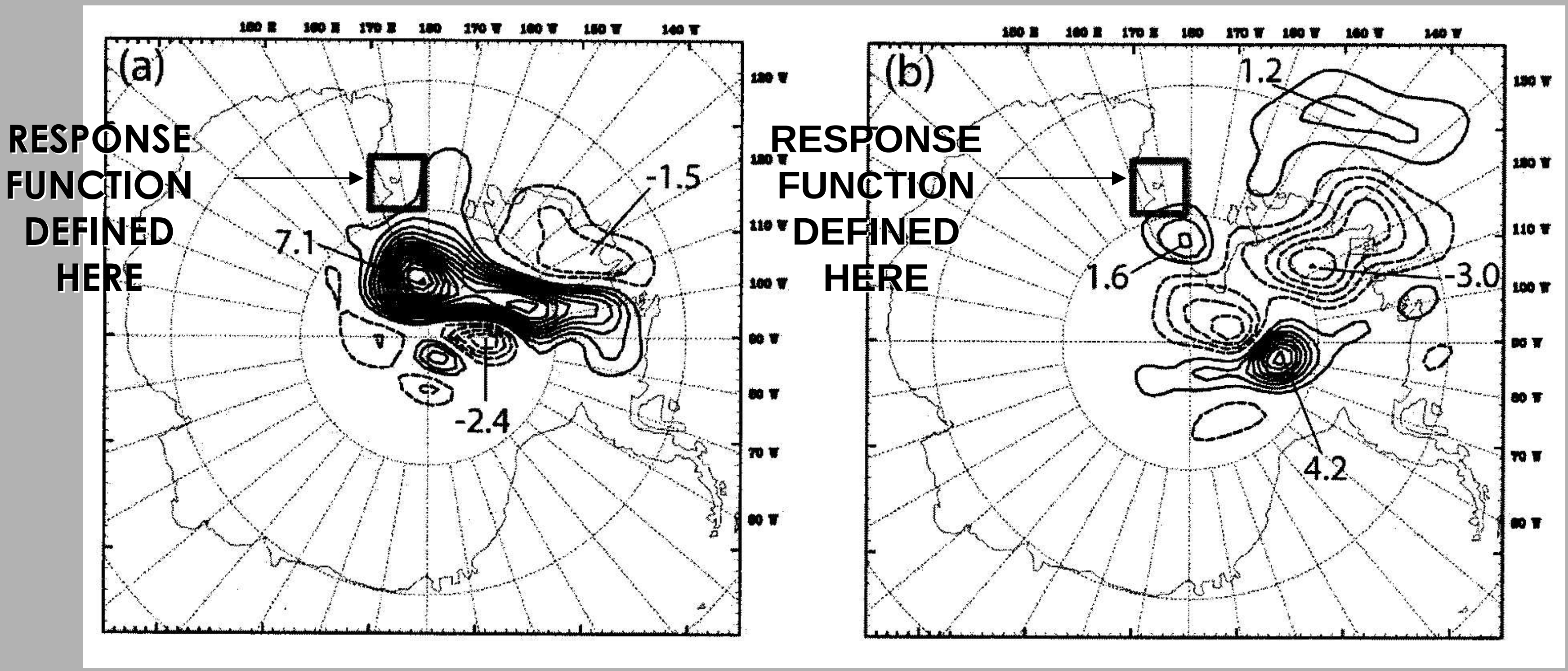


Figure 7: Schematic outlining the flow chart of adjoint sensitivity calculation.

(Xiao et al. 2008)

Antarctic Windstorm Case
First demonstration with WRF-VAR

Adjoint Sensitivity to low level u | **Adjoint Sensitivity to low level v**



Units: m s^{-1}

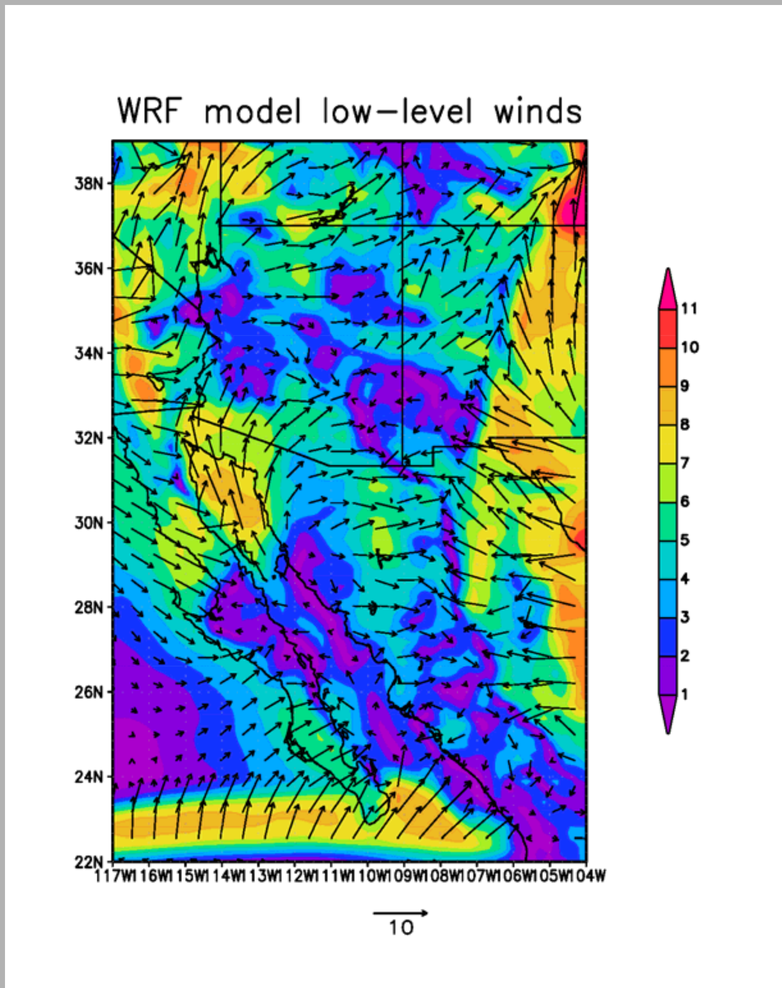
(Xiao et al. 2008)

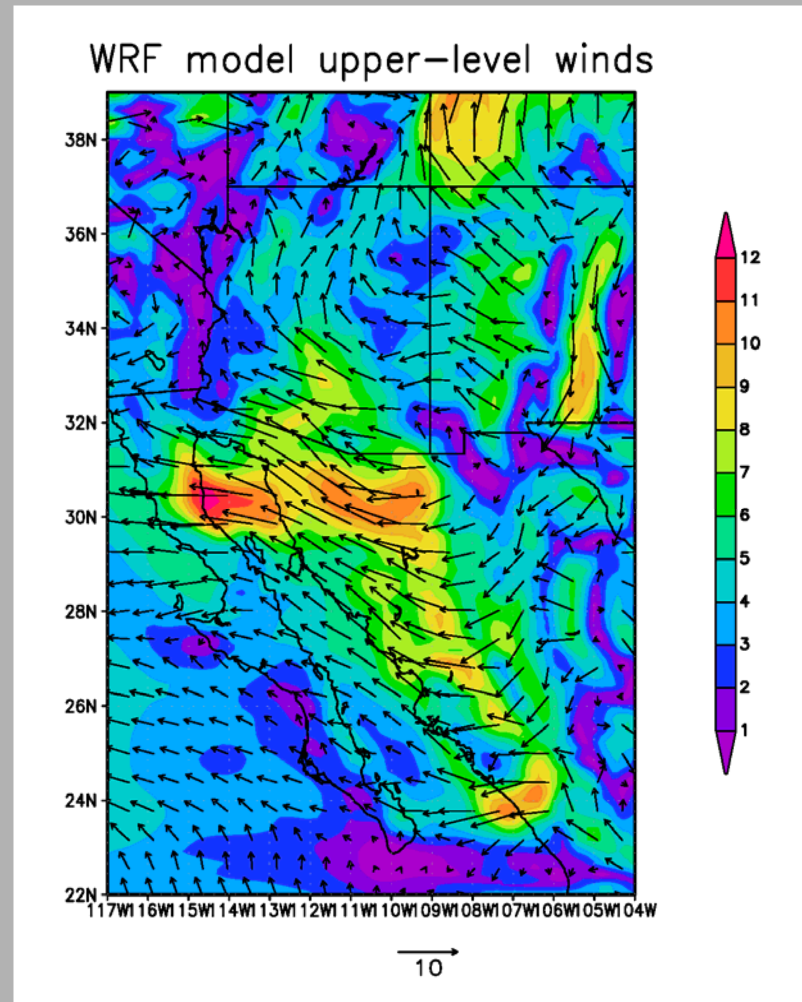
Adjoint model caveats for monsoon convection

1. Does the linearity assumption hold?

2. Parameterized processes are not accounted for in the adjoint model yet. Sensitivity only to dry dynamics.

Forward integration results
Aug. 2005 case: 0Z





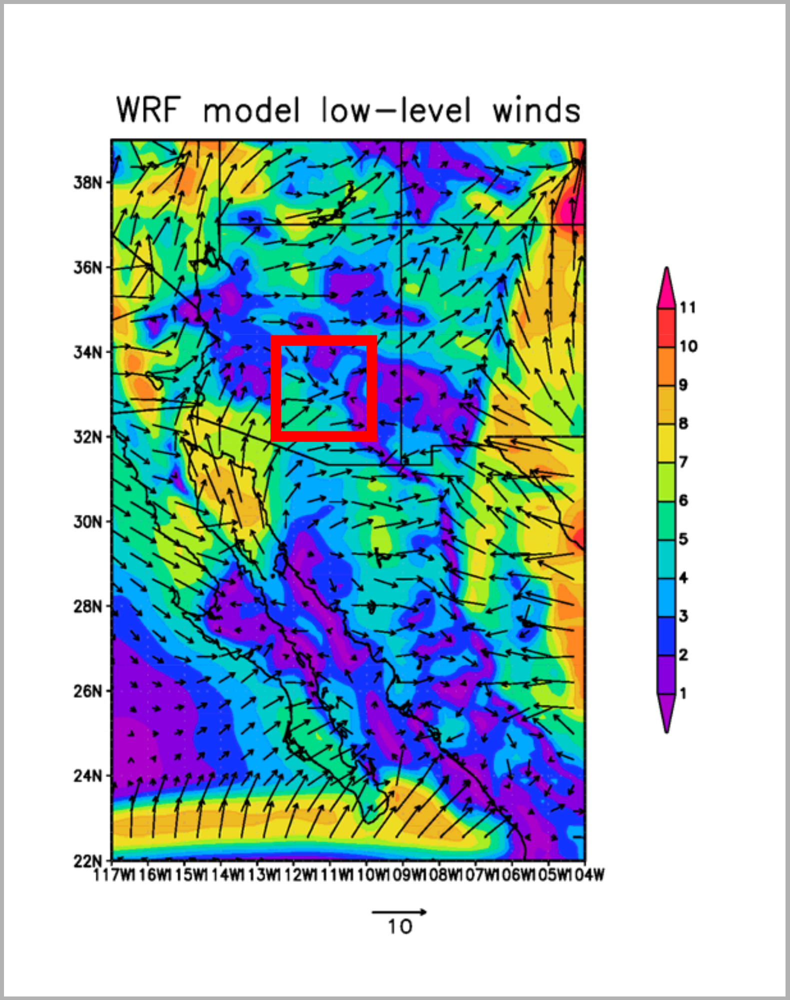
Units: m s^{-1}

Response Function (R)

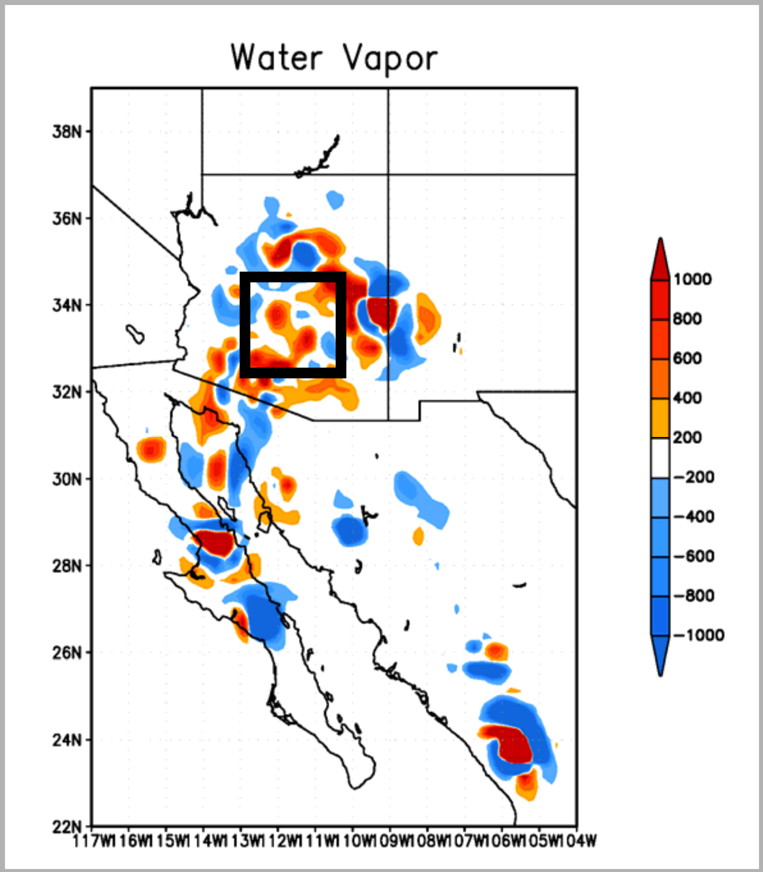
$$R = \frac{1}{2}\sum_{i,j}\left[\left(u_{i,j}^{f}\right)^2 + \left(v_{i,j}^{f}\right)^2\right]$$

Defined in a 10 x 10 grid point box over central Arizona

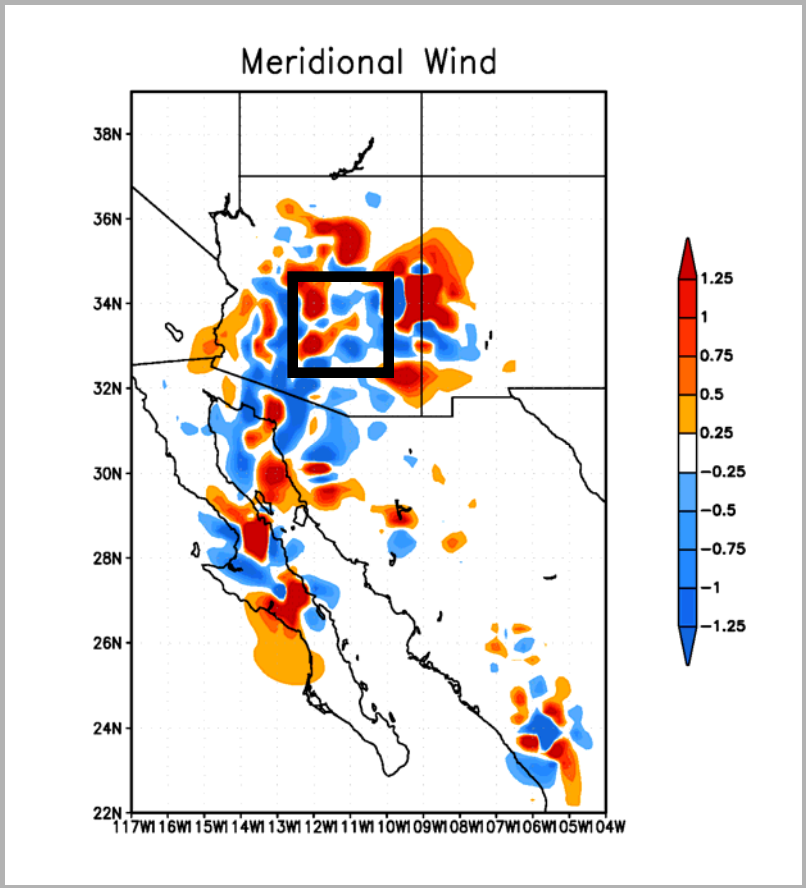
Verification time is 6Z, Aug. 3 (Simulation hour 18)



Adjoint sensitivity to initial conditions: Model level 5

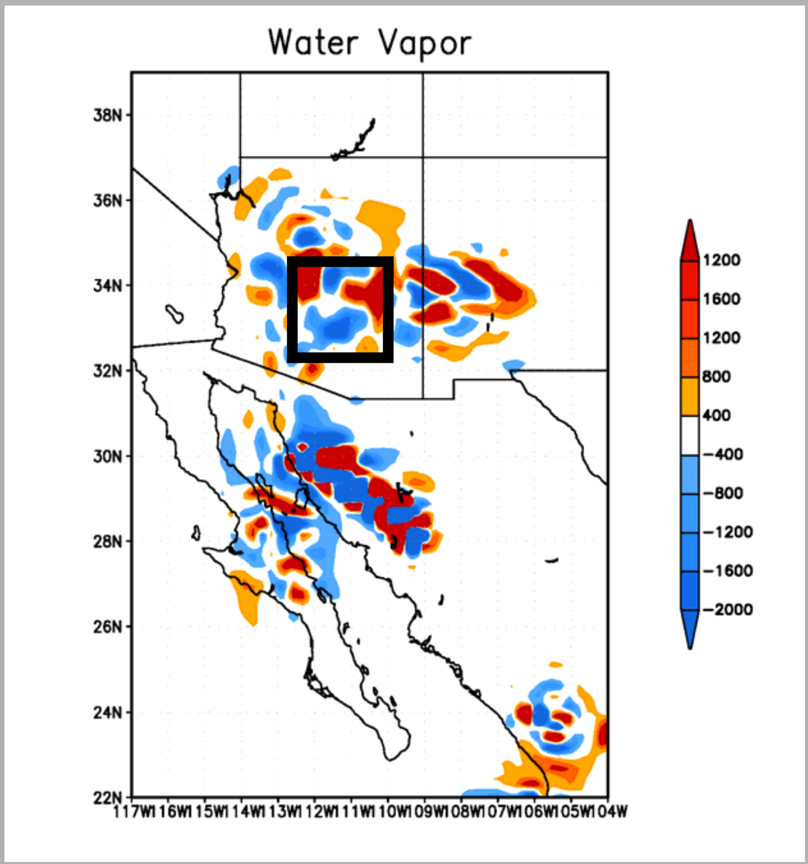


Units: m² s⁻² kg kg⁻¹

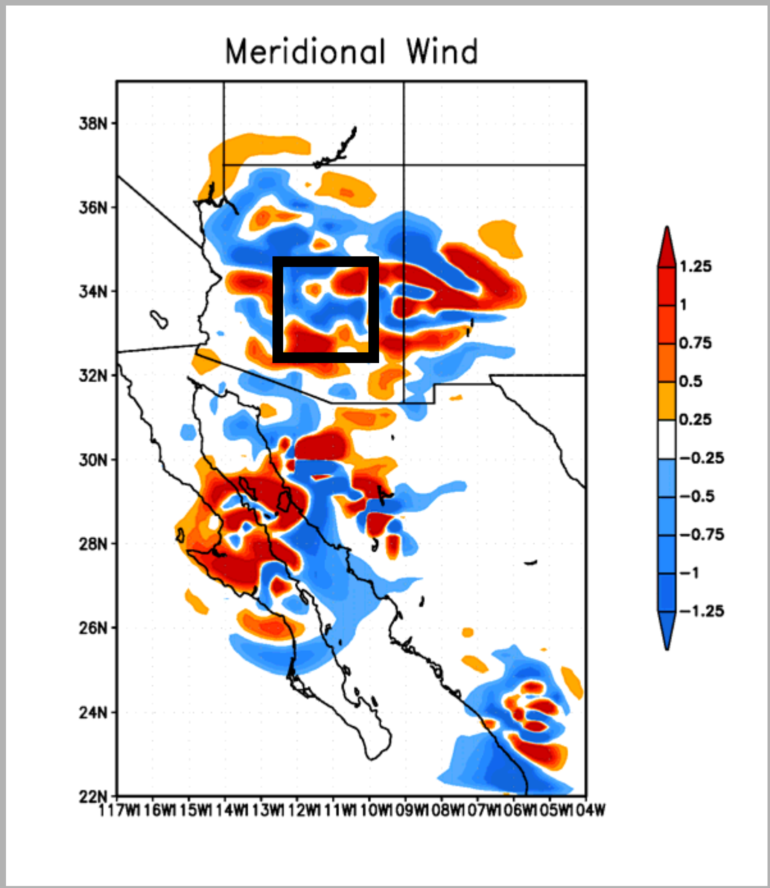


Units: m s⁻¹

Adjoint sensitivity to initial conditions: Model level 20



Units: $m^2\ s^{-2}\ kg\ kg^{-1}$



Units: $m\ s^{-1}$

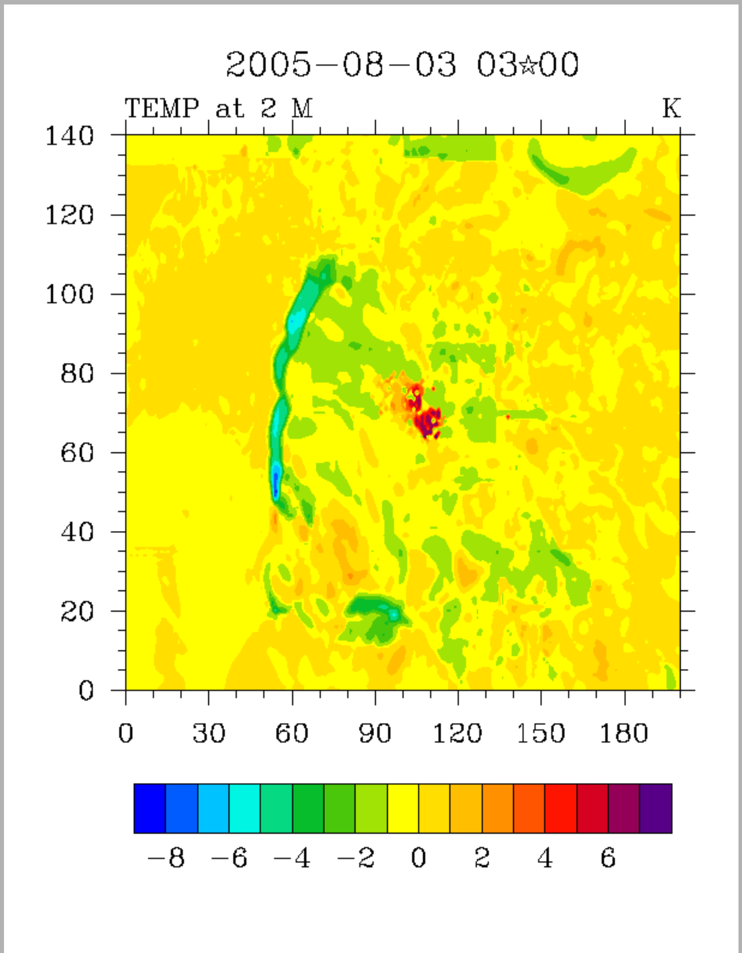
WRF modifications for representation of urbanization in Phoenix

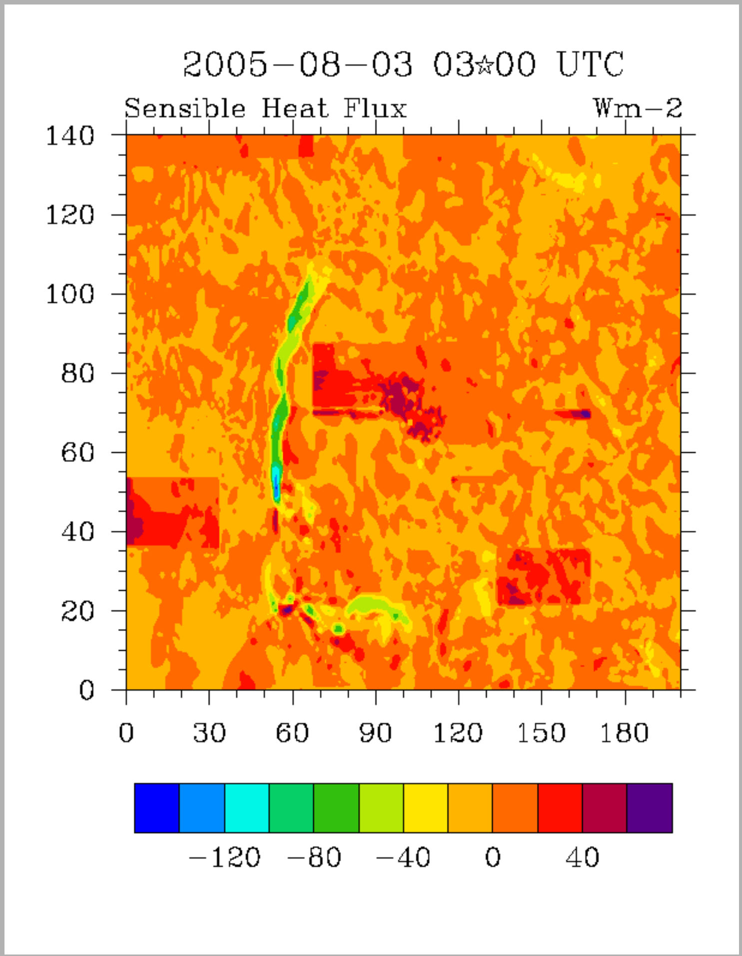
Urban canopy model (UCM) by Kusaka and Kimura (2004) with code modifications to consider specific conditions in the Phoenix region.

12 category 2005 land use classification available for Phoenix at the spatial resolution of 30 meters, from Landsat. 12-category LULC map was merged with the WRF 24-category land cover data using GIS techniques.

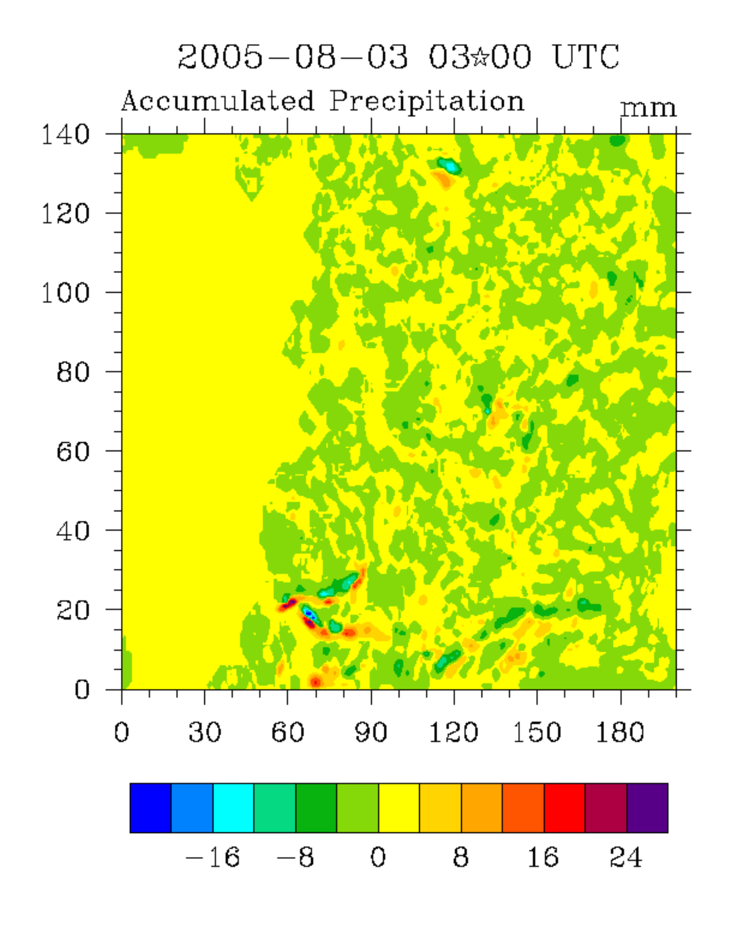
The revised land use/cover classifications used as input into WRF was one of the four following categories: urban commercial/industrial; urban mesic residential; urban xeric residential; or undisturbed desert. Categories differ by their type of vegetation and irrigation.

Urban – non urban difference in 2 m air temperature and SH flux (3 km grid over Phoenix metro)





Urban – non urban difference in 2 m air temperature and SH flux (3 km grid over Phoenix metro)



There are very localized differences in accumulated rainfall, mainly at the same spatial scale of sensible heat flux differences.

Concluding points

Forecasting of severe weather events during the monsoon is a problem of importance within Arizona to a variety of stakeholders

Current weaknesses in regional model forecasts include a lack of data, specifically from Mexico, and a lack of representation of urban areas. These were investigated in a preliminary model test case for Aug. 2005.

Adjoint sensitivity results appear to confirm that model forecasts of these types of events are very sensitive to initial data specification in Mexico. Similar experiments for a variety of cases should successfully identify sensitivity “hot spots” and provide guidance toward establishment of a permanent long-term monsoon observing system.

WRF modifications accounting for urbanization did not appear to greatly impact model simulated precipitation for this case.