Coupling Boundary-Layer Turbulence to Shallow Cumuli in WRF

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Motivation

- How important are shallow cumuli?
  - Do they significantly change the amount of downwelling radiation available at the surface?
- How are they represented in models?
  - Are current methods adequate?
  - Can the prediction of amount of shallow cumuli be improved?

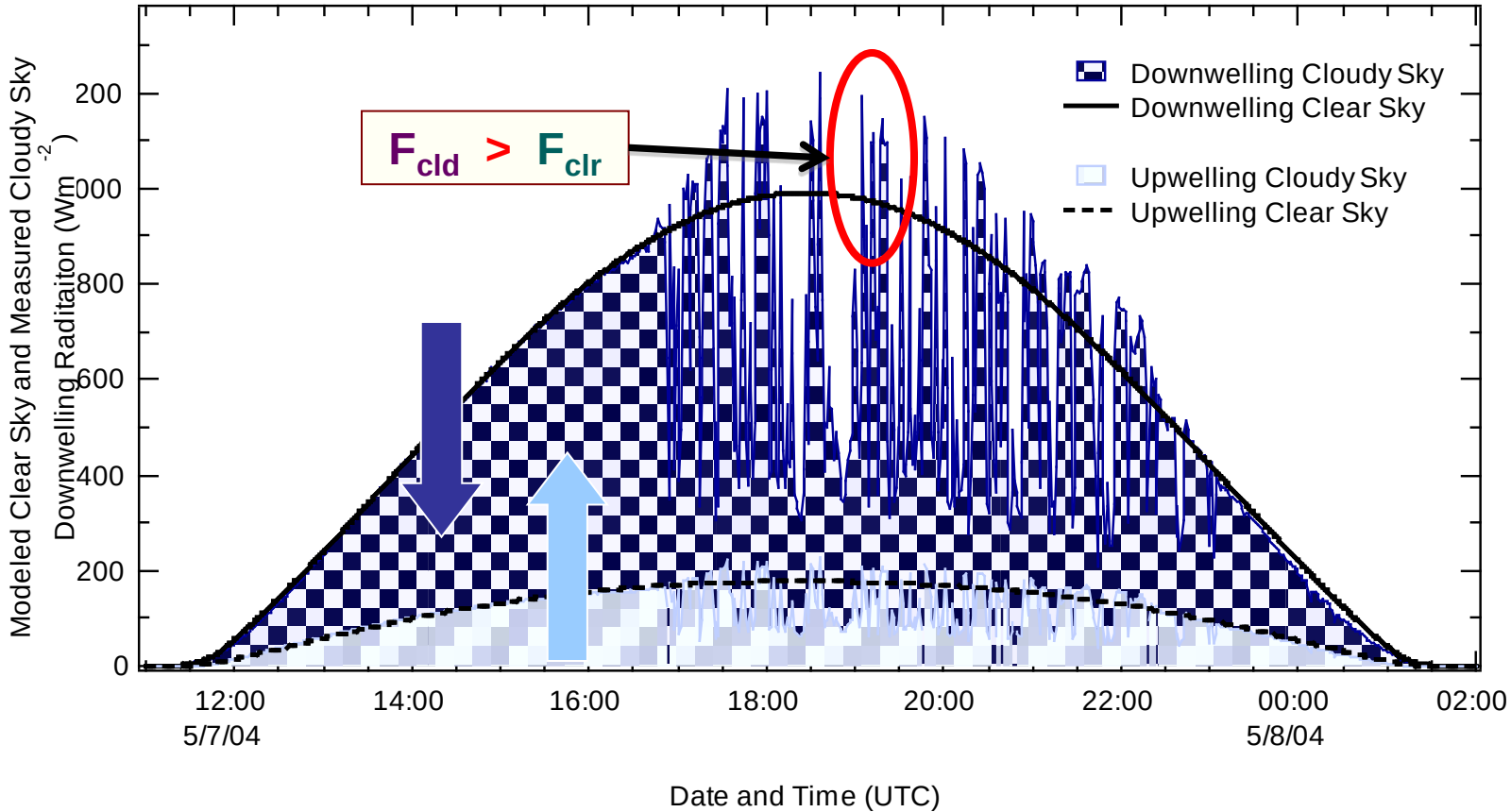
How Important Are Shallow Cu?

- Focused on a single mid-latitude site
  - U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Southern Great Plains site
  - Surface measurements: radiation and clouds
  - 8 summers (2000-2007)
  - Single-layer clouds
  - 202 days (898 hours) with shallow cu

Cloud Radiative Forcing

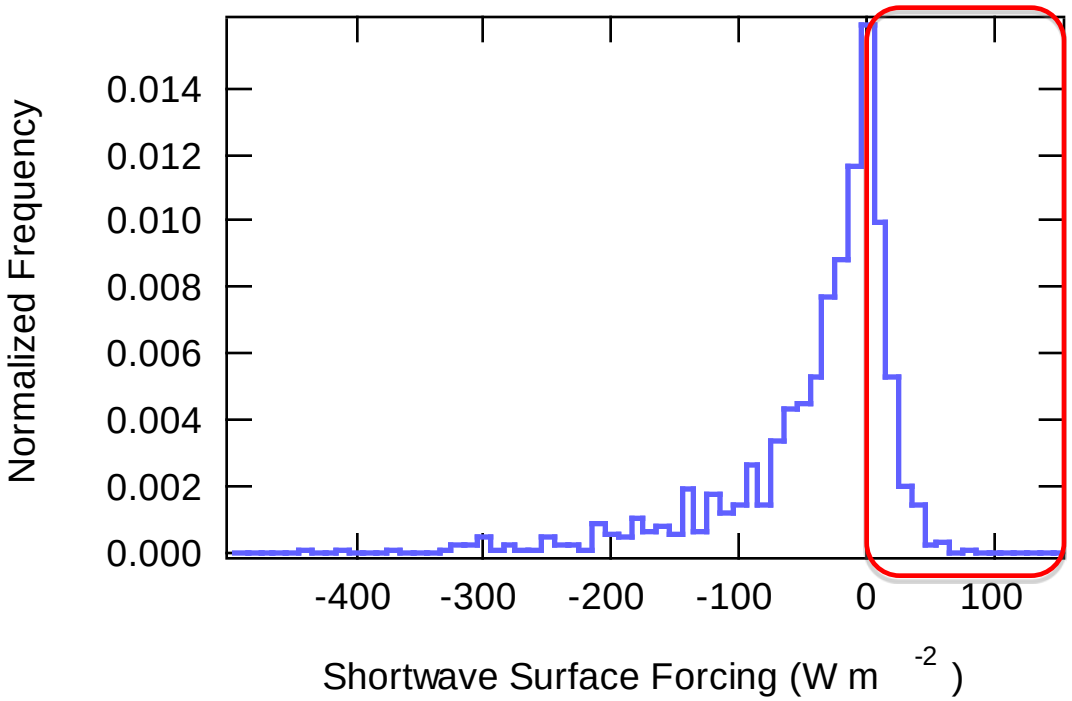
$$CRF = \left(F_{\downarrow,cld} - F_{\downarrow,clear}\right) - \left(F_{\uparrow,cld} - F_{\uparrow,clear}\right)$$

- F_{cld} from **observations** (radiometric instruments)
- F_{clr} from **model** (Long and Ackerman, JGR, 2000)



Cloud Radiative Forcing: Summer Averages

- SW CRF: -45.5 W m^{-2} (out of 612 W m^{-2})
  - Averaged over periods with cloud
  - Approximately 7% reduction in down-welling shortwave at the surface.



- Total change in energy at the surface: -176 MJ m^{-2} or -48 kWh m^{-2}
  - Integrated value for all shallow cu periods during the entire 7 years
  - Daily average change -0.87 MJ m^{-2} or -0.24 kWh m^{-2}.

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Berg et al. (JGR, accepted)

Modeling Shallow Cumuli

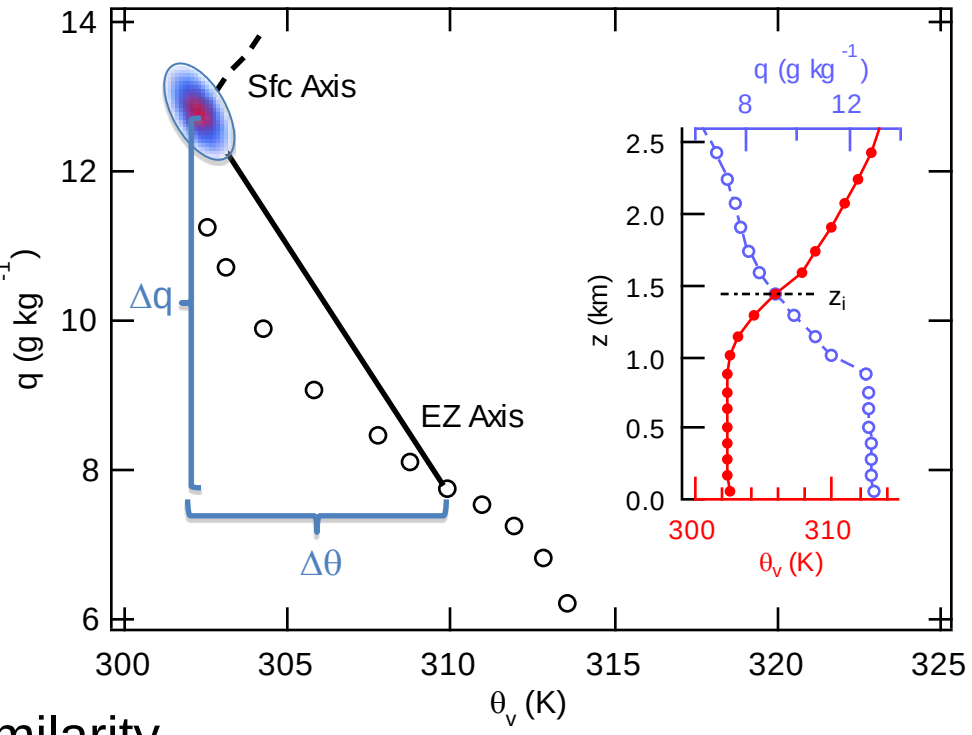
- Two parts to representing convective clouds
  - Do they form (the trigger)?
    - Kain Fritsch uses an ad-hoc temperature perturbation
  - How many form (the closure)?
    - Generally expressed as a mass flux
- Deep convection closure
  - Based on conditional instability or moisture convergence
- Shallow convection
  - Based on the strength of the capping inversion
  - Shallow cumuli are linked to the boundary layer, requiring a *coupling* between turbulence and convective parameterizations

Modeling Shallow Cumuli

- New Cumulus Potential Scheme (Berg and Stull 2004, Berg and Stull 2005)
  - Introduce more realistic trigger function to the standard scheme
  - A set of simulations have been completed for the summer of 2004.
- Control simulations use standard Kain-Fritsch scheme
- VAPS from ARM
  - Cloud radar and lidar data to determine cloud boundaries (ARSCL)
  - Radiative fluxes (SWFLUXANAL)
  - Gridded surface flux data (SFCCLDGRID)

The CuP Scheme

- The Cumulus Potential (CuP) scheme has been implemented in WRF
  - JPDF of temperature and humidity in the boundary layer is based on properties of the:
    - surface
    - mid-mixed layer, and
    - entrainment zone (EZ)
  - Tilt of JPDF related to
    - Jumps in θ_v and q at the surface and EZ
  - Spread of JPDF based on similarity

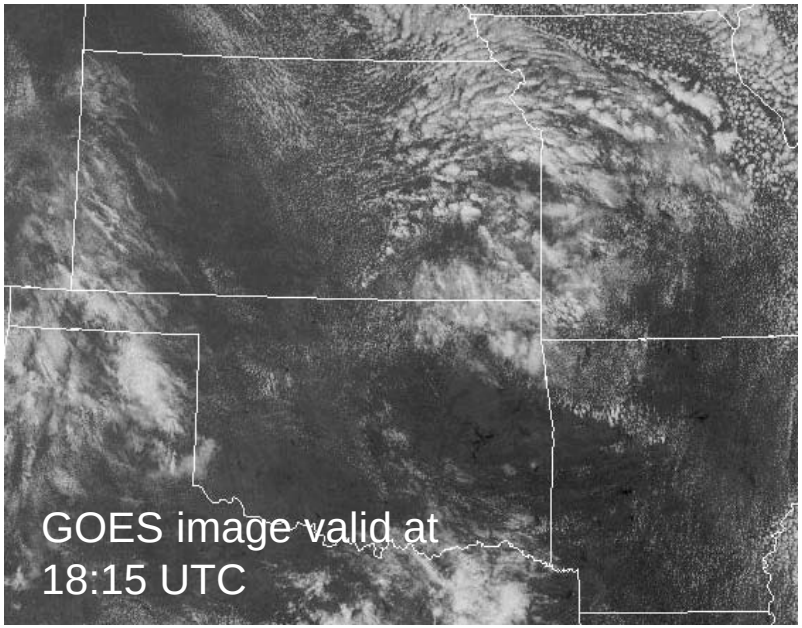


Berg and Stull (2004), Berg and Stull (2005)

Model Performance: Case study

WRF CuP

Simulations valid at 8/13/2004 18:00 UTC

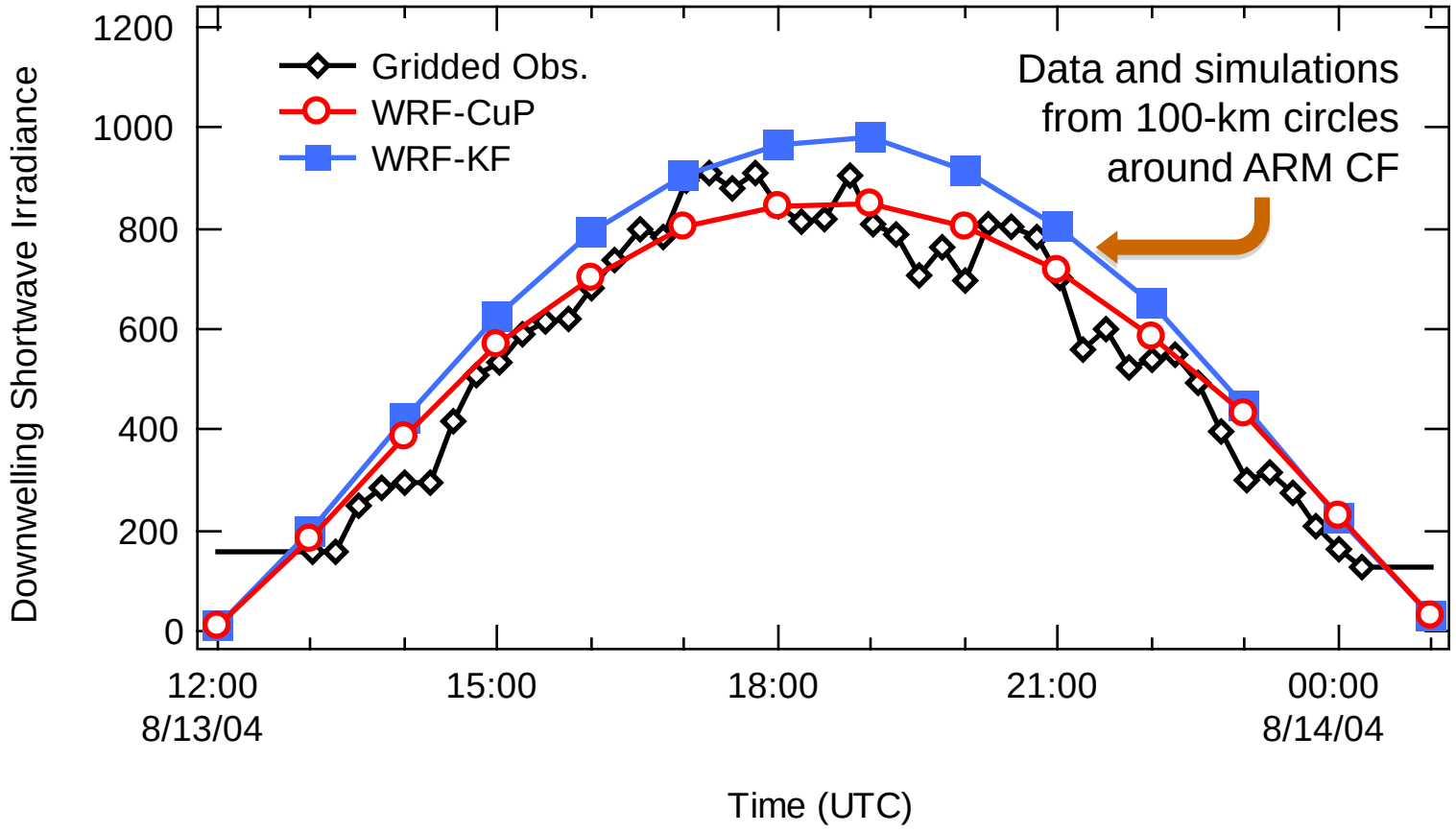


Gridded data from ARM radiometer network (Long et al. 2006)

WRF KF

Model Performance: Downwelling SW

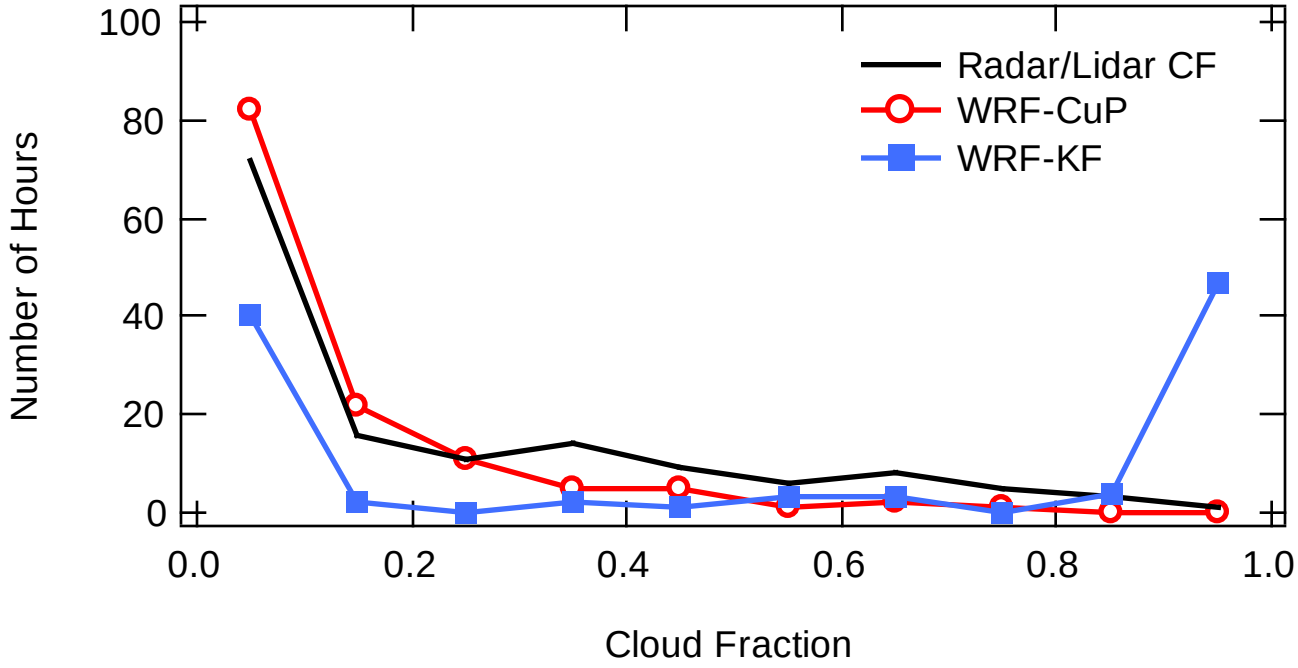
- Standard scheme underpredicts change in downwelling SW



Gridded data from ARM radiometer network (Christy and Long 2003)

Model Performance: Seasonal CF

- Summer time cloud fraction (at Central Facility)
  - KF-Standard underpredicts cloud frequency of small cloud fraction, overpredicts frequency of large cloud fraction
  - KF-CuP does a better job matching observations

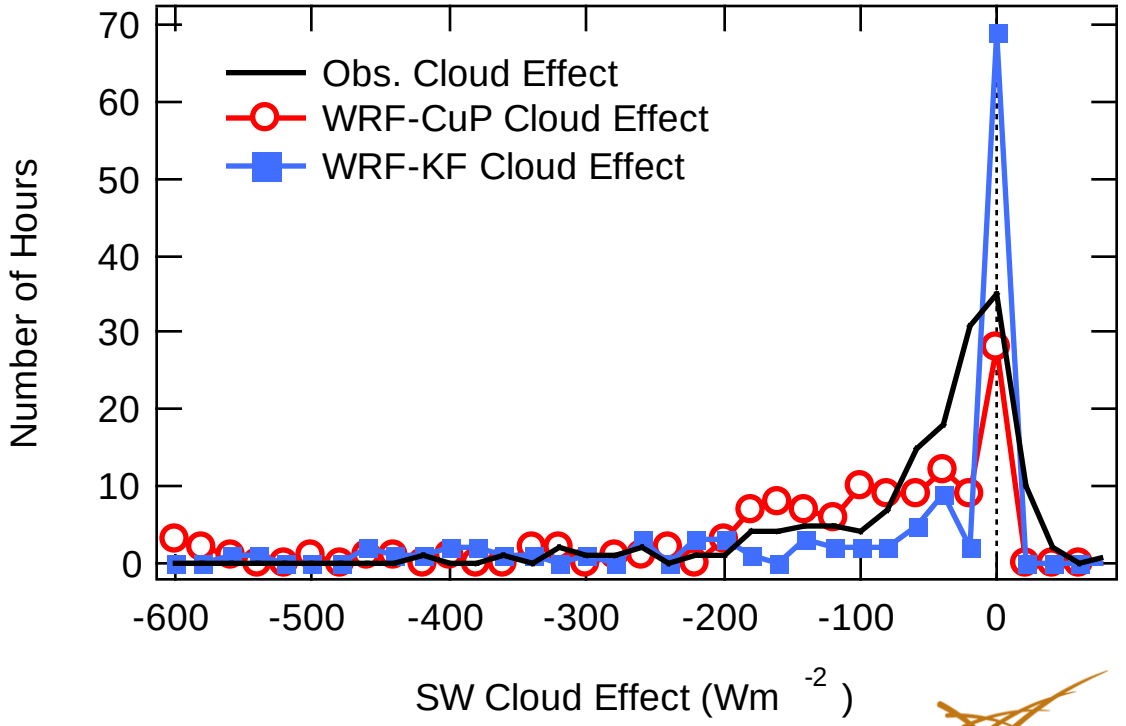


All days with shallow cumuli during the summer of 2004

Model Performance: SW Cloud Effect

- SW cloud effect [$SW_{CE} = \left(F_{\downarrow,cld} - F_{\downarrow,clear}\right)$]
  - KF-Standard underpredicts SW cloud effect—many cases with no impact
  - KF-CuP does a better job matching observations of SW cloud effect
- Cloud forcing
  - WRF-CuP: -116 W m^{-2} out of 728 W m^{-2}
  - WRF-KF: -116 W m^{-2} out of 335 W m^{-2}

Observed: -45.5 W m^{-2} out of 615 W m^{-2}



All days with shallow cumuli during the summer of 2004

Summary

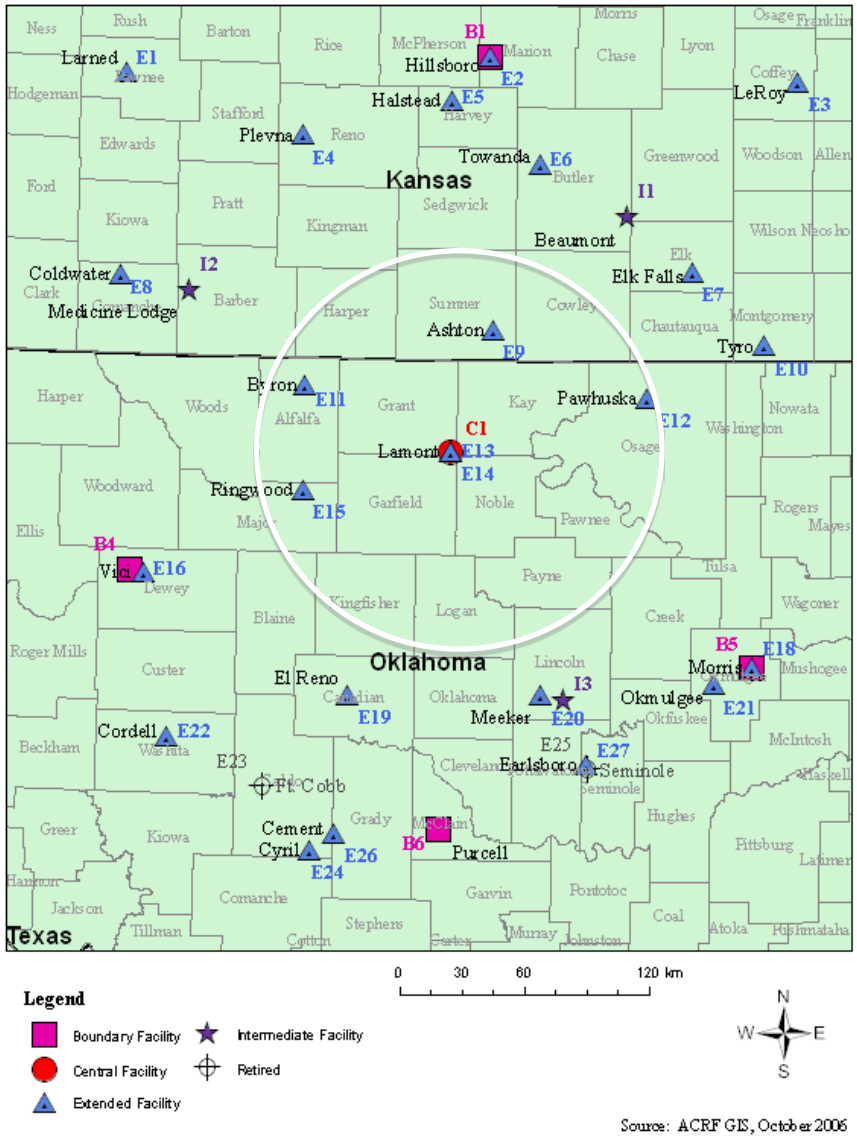
- How important are shallow cumuli?
  - Shallow cumuli do have an impact on the surface radiation budget
  - Reduction of downwelling shortwave of -45.5 W m^{-2} (out of 612 W m^{-2})
- How are they represented in models?
  - Standard WRF parameterization underpredicts small cloud amounts, overpredicts large cloud amounts
  - A new scheme has been implemented that improves the prediction of shallow cloud amount and radiative forcing

Acknowledgments: This work has been supported by the DOE Atmospheric Radiation Measurement and Atmospheric Systems Research programs.

Backup material

ARM SGP Site

- ARM radiation measurements
  - Made at 23 extended facilities
  - 5 extended facilities within 100 km of CF (plus 2 further south)



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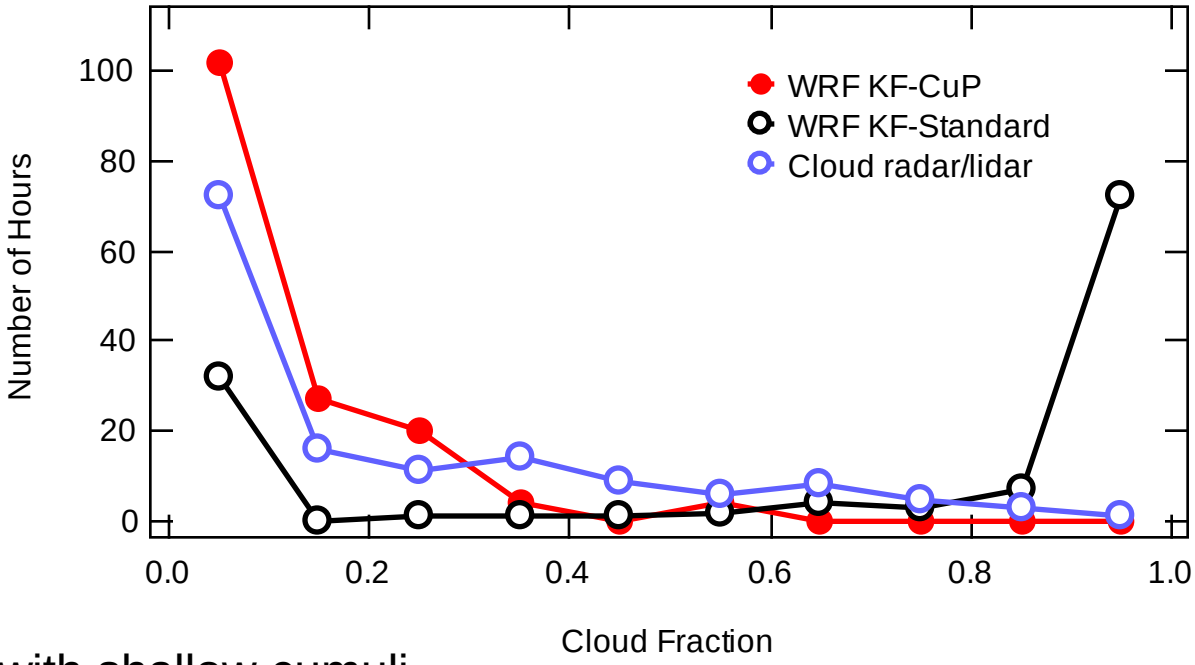
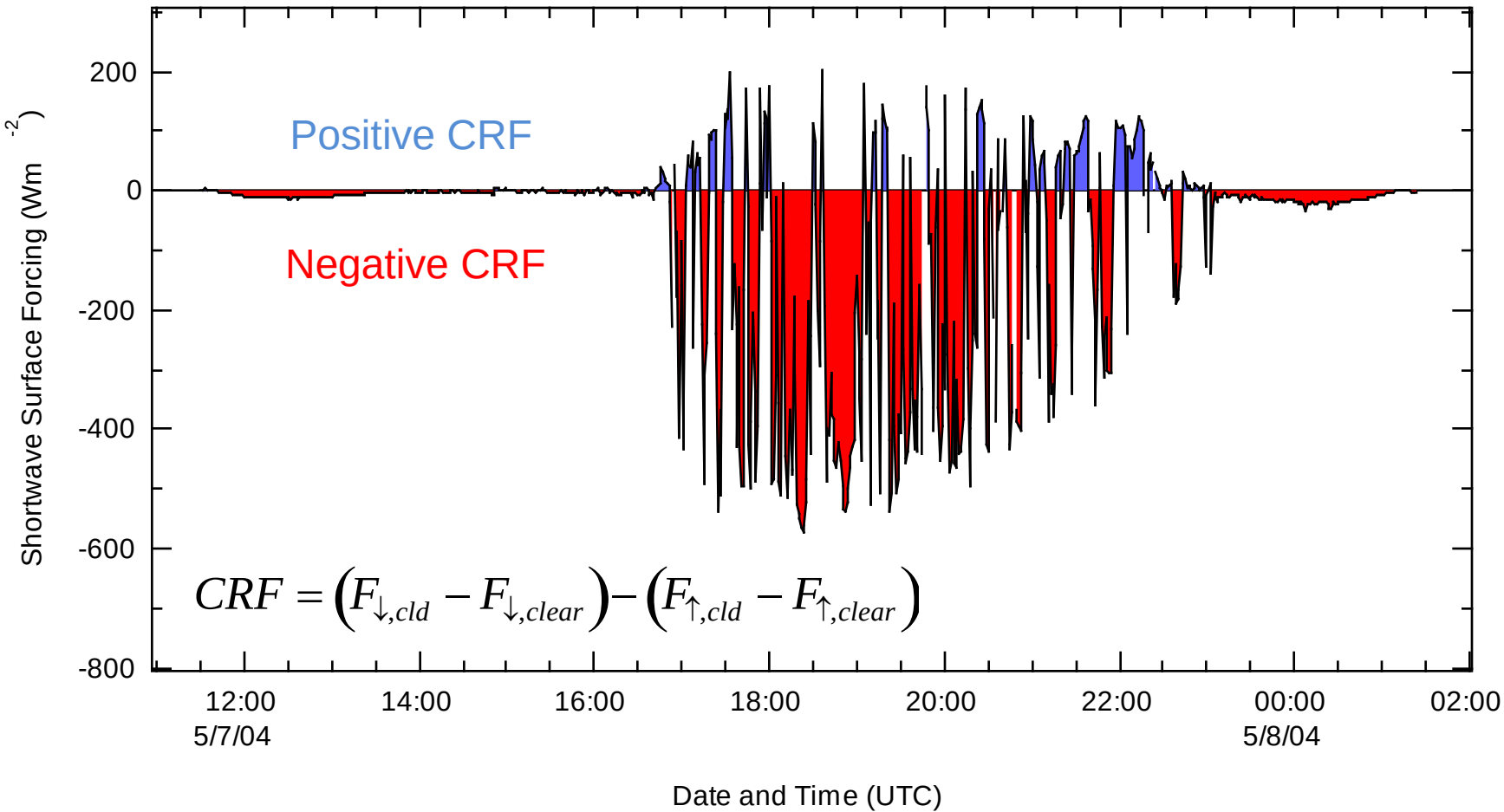


All days with shallow cumuli during the summer of 2004

Cloud Radiative Forcing

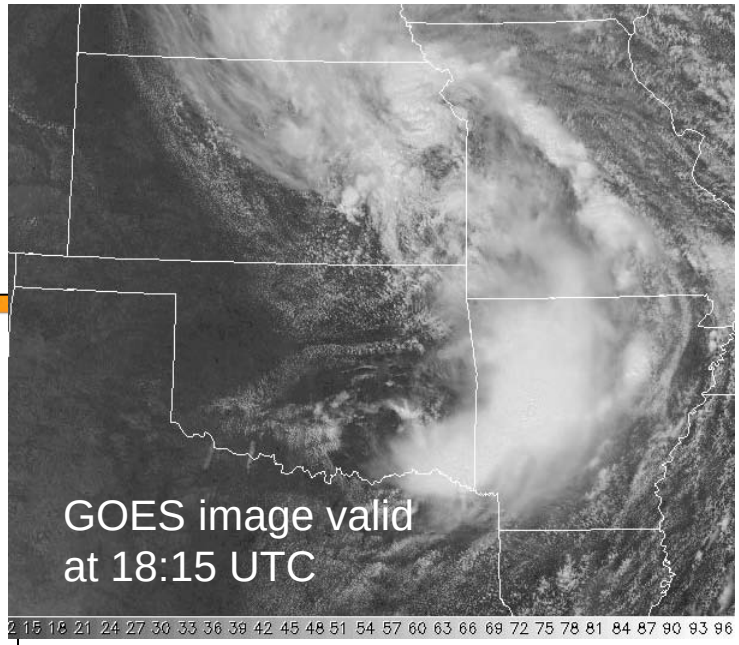
- Cloud Radiative Forcing (CRF): Difference in radiation at the surface in cloudy and clear conditions



Model Performance: Case study

WRF CuP

Simulations valid at 7/2/2004 18:00 UTC



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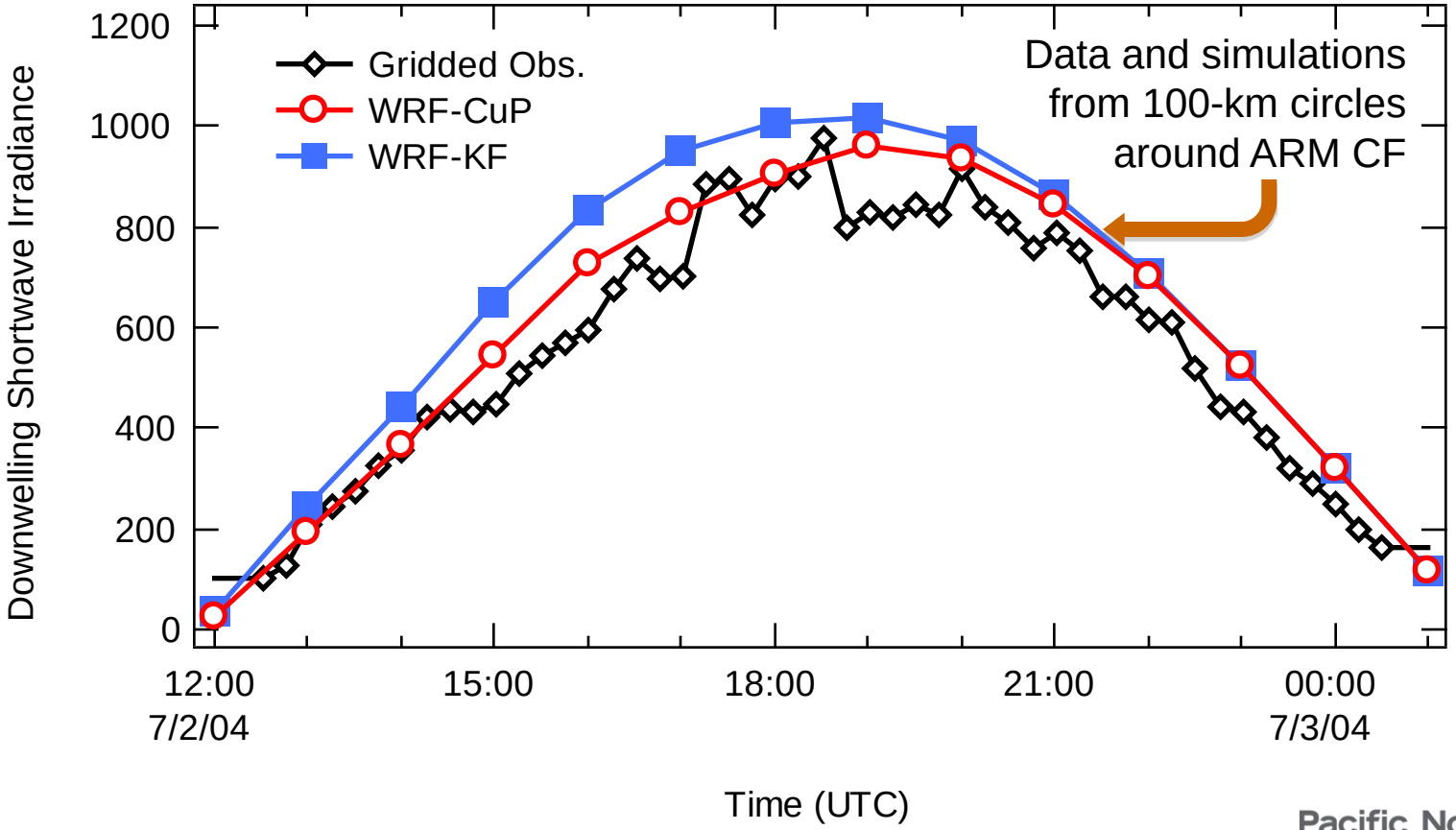

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