Earth System Research Laboratory
SCIENCE, SERVICE & STEWARDSHIP

Use of Solar Irradiance Measurements to Improve the Physical Parameterizations in the Rapid Refresh and High-Resolution Rapid Refresh Models

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RAP and HRRR: *Hourly-Updated* Weather Forecast Models

13-km Rapid Refresh (RAP)

Initial & Lateral Boundary Conditions

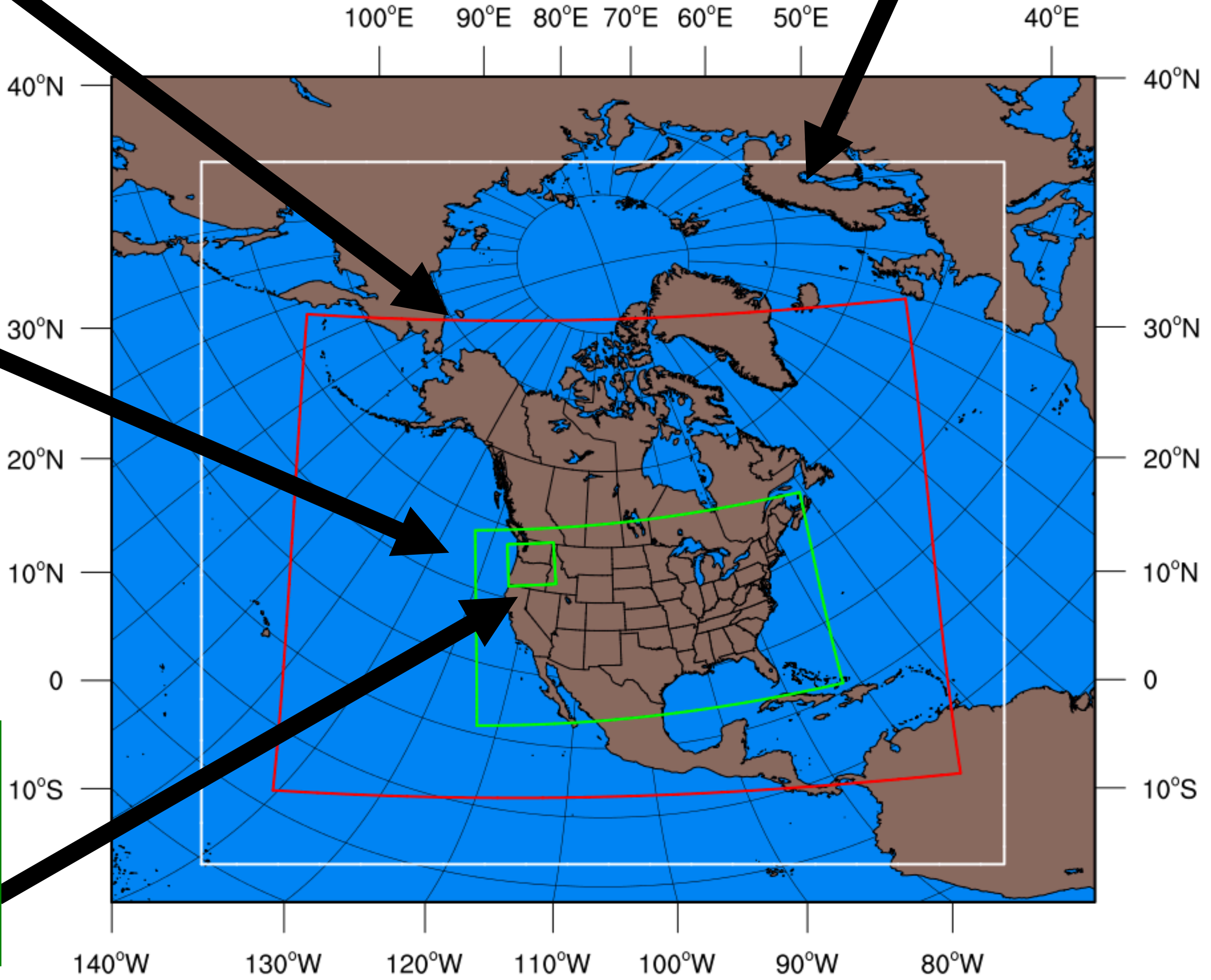
3-km High-Resolution Rapid Refresh (HRRR)

Initial & Lateral Boundary Conditions

750-m HRRR nest

(WFIP2, experimental)

Expanded RAP (Summer 2015)



ESRL RAP and HRRR Configurations

Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	North America	758 x 567	13 km	50	10 hPa	GFS	Hourly (cycled)
HRRR	CONUS	1799 x 1059	3 km	50	20 hPa	RAP	Hourly - RAP (no cycling)

Model	Version	Assimilation	Radar DA	Radiation LW/SW	Microphysics	Convection Deep/Shallow	PBL	LSM
RAP	WRF-ARW v3.6.1+	GSI Hybrid 3D-VAR/Ensemble	13-km DFI	RRTMG/RRTMG	Thompson-Eidhammer (aerosol-aware)	G3 / GFO	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.6.1+	GSI Hybrid 3D-VAR/Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson-Eidhammer (aerosol-aware)	**None / GFO**	MYNN	RUC 9-lev

Model	Horiz/Vert Advection	Scalar Advection	Upper-Level Damping	6th Order Diffusion	Radiation Update	Land Use	MP Tend Limit	Time-Step
RAP	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.12	20 min	MODIS Fractional	0.01 K/s	60 s
HRRR	5th/5th	Positive-Definite	w-Rayleigh 0.2	Yes 0.25 (flat terr)	15 min	MODIS Fractional	0.07 K/s	20 s

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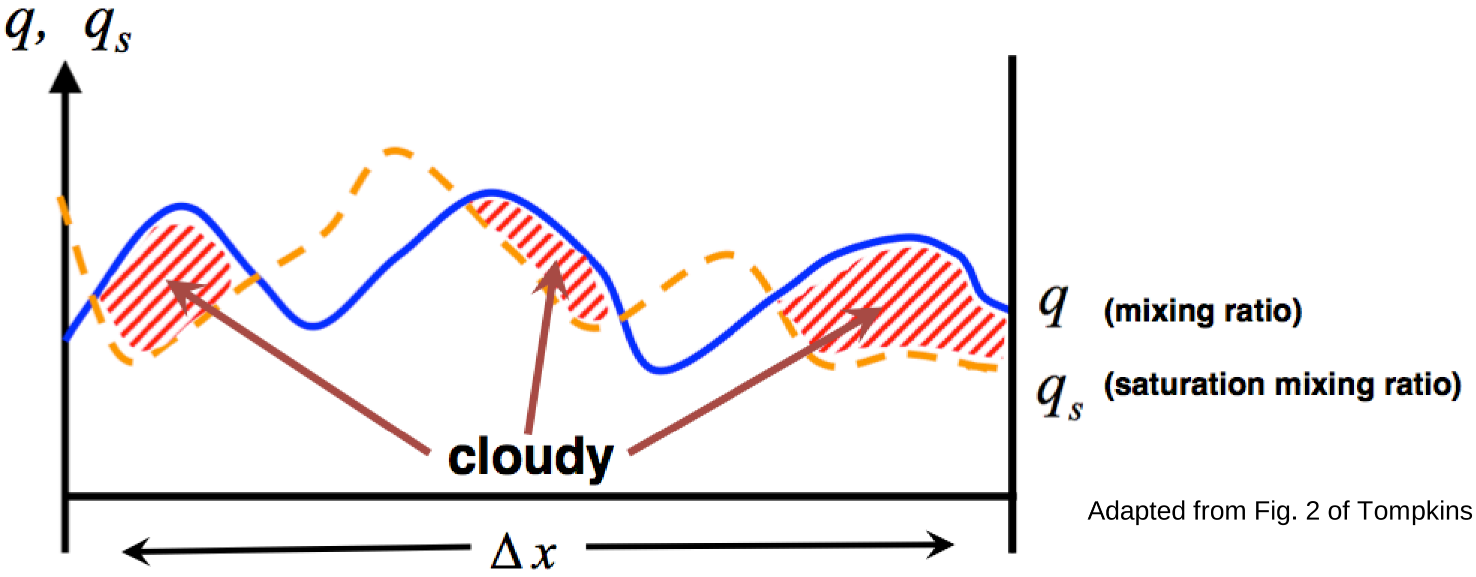
Cloud Representation in a Model

- If model grid cells represented homogeneous volumes (in water vapor & temperature), only binary cloud fractions (*0 or 1*) would be needed

- **Reality:** grid cells represent ensemble averages, subgrid-scale variability exists, and fractional (non-binary) cloud coverage may exist

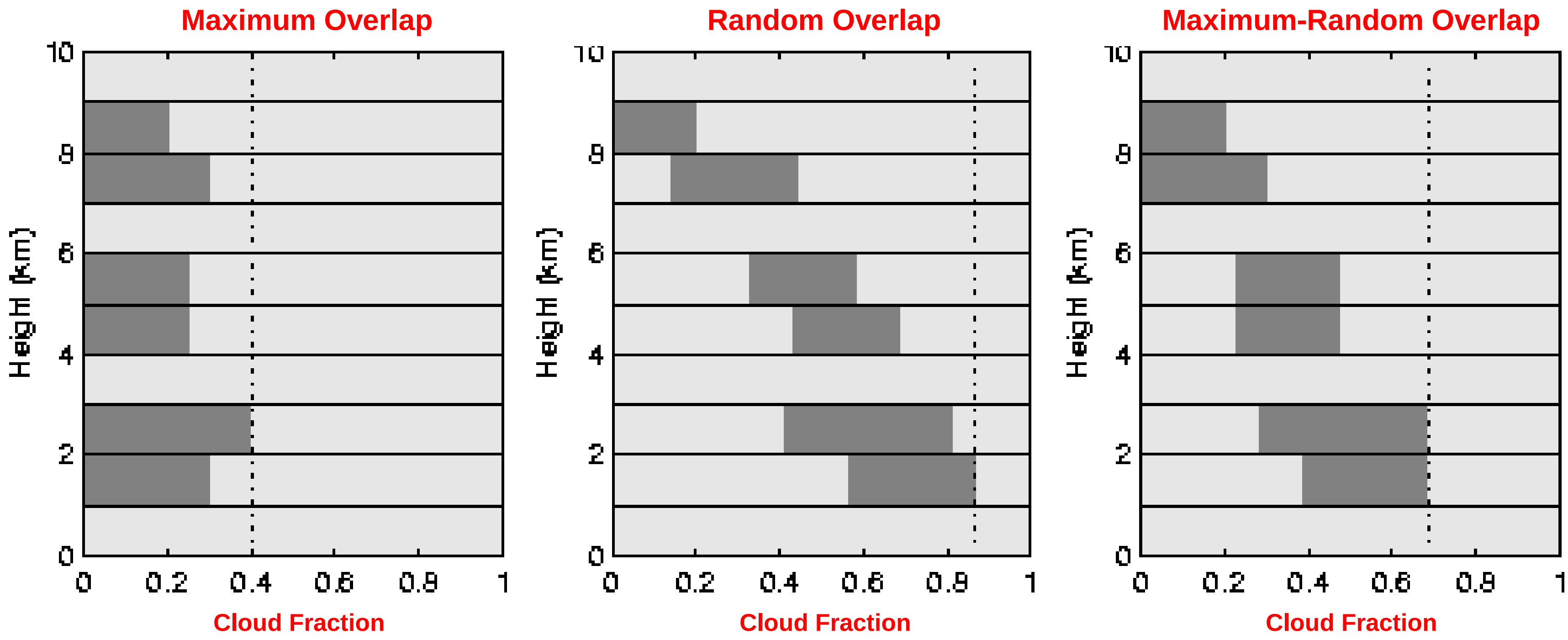


Adapted from Fig. 2 of Tompkins (2005)

- **Scientific Challenge #1**: modeling fractional cloud coverage requires that we make assumptions regarding subgrid-scale variability

Cloud−Radiation Coupling

Some Historically Common Cloud “Overlap” Approximations:

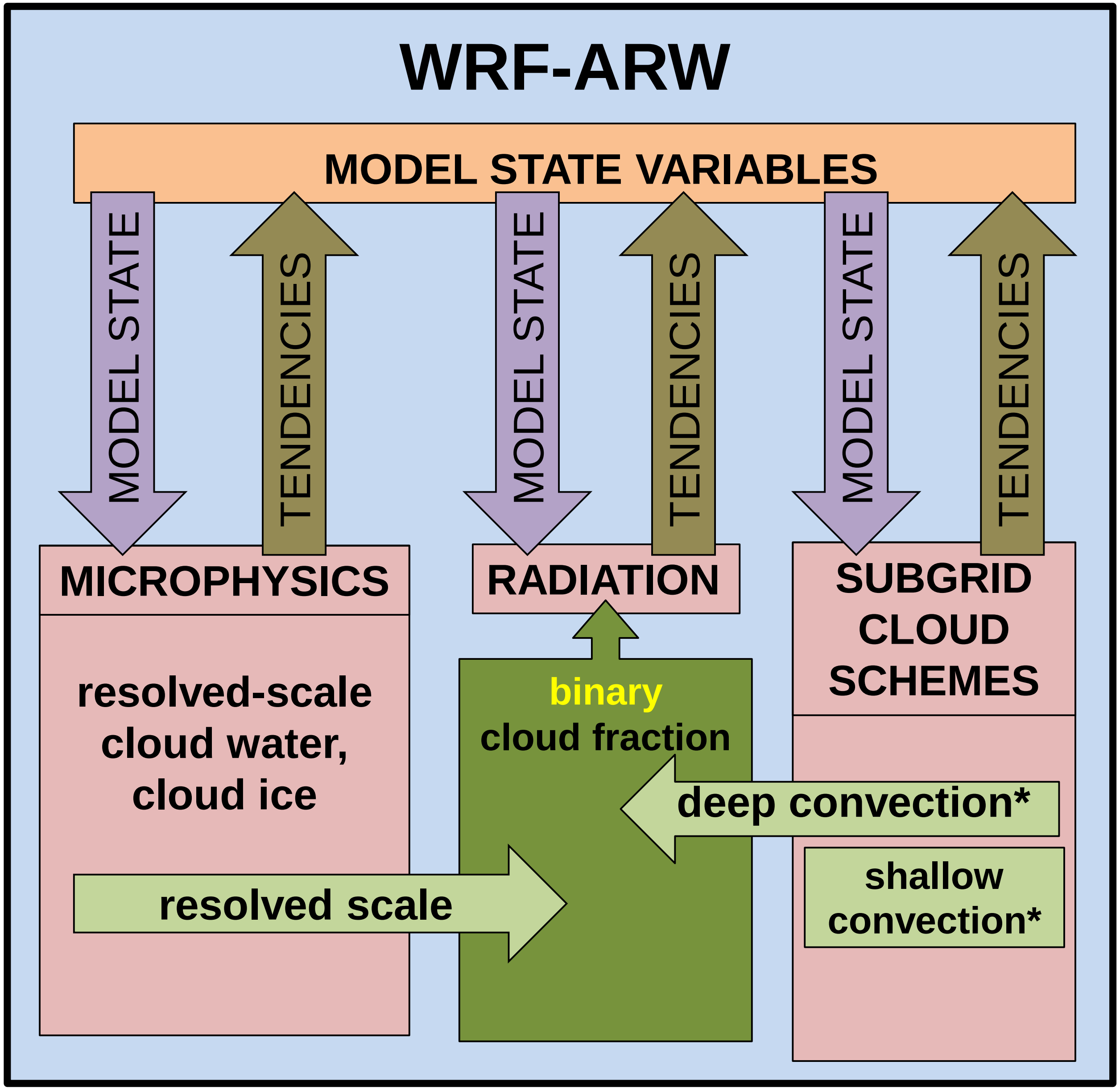


(Figure adapted from met.rdg.ac.uk/radar/research/cloudoverlap)

- RRTMG scheme assumes a cloud overlap according to the Monte-Carlo Independent Column Approximation (McICA) (Pincus et al. 2003)

- **Scientific Challenge #2**: modeling cloud−radiation interaction requires additional assumptions

RAP / HRRR Cloud Representation: Recent Past



WRF-ARW

MODEL STATE VARIABLES

MODEL STATE

TENDENCIES

MODEL STATE

TENDENCIES

MODEL STATE

TENDENCIES

MICROPHYSICS

resolved-scale cloud water, cloud ice

resolved scale

RADIATION

binary cloud fraction

SUBGRID CLOUD SCHEMES

deep convection*

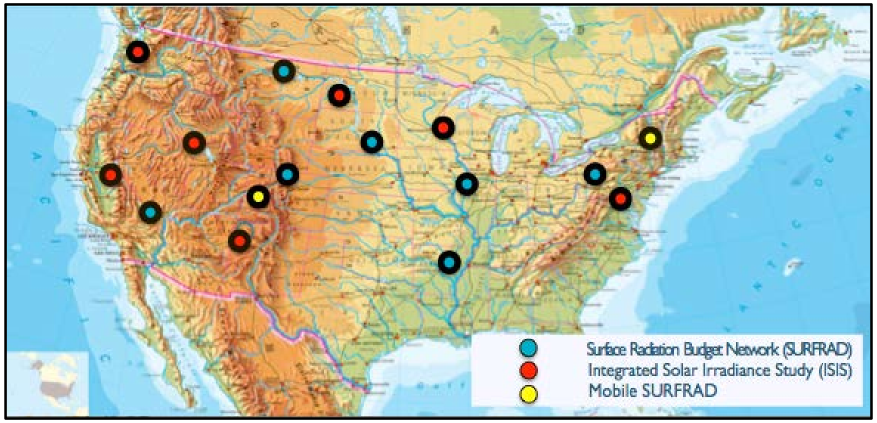
shallow convection*

“Deep” Convection

“Shallow” Convection

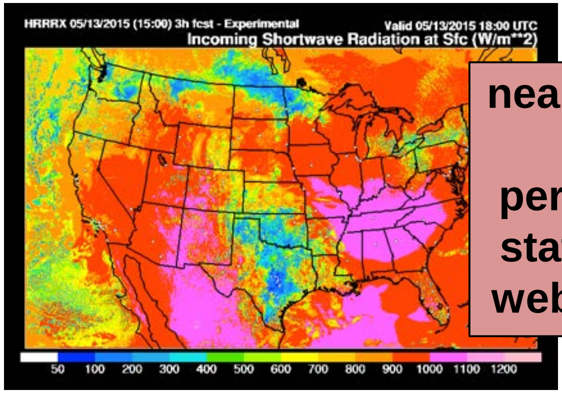
*RAP only

RAP / HRRR Irradiance Verification from GMD's SURFRAD / ISIS

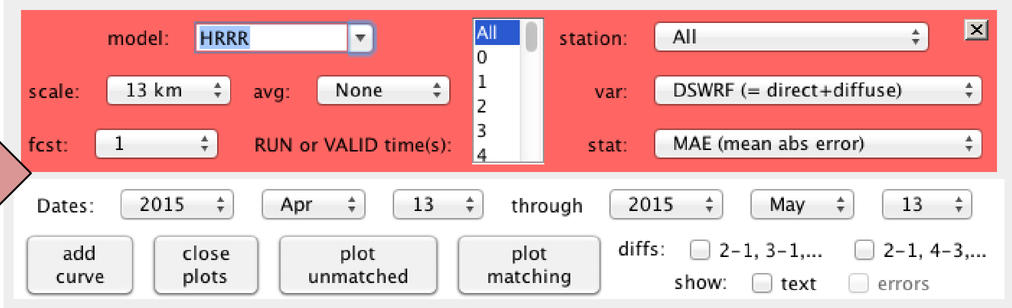


14 SURFRAD / ISIS sites

near-real-time data processing



near-real-time model performance statistics via web interface



model: HRRR

station: All

scale: 13 km

avg: None

var: DSWRF (= direct+diffuse)

fcst: 1

RUN or VALID time(s): All

stat: MAE (mean abs error)

Dates: 2015 Apr 13 through 2015 May 13

diffs: ☐ 2-1, 3-1,... ☐ 2-1, 4-3,...

show: ☐ text ☐ errors

- **GMD's SURFRAD / ISIS measurements provide a unique model assessment capability:**

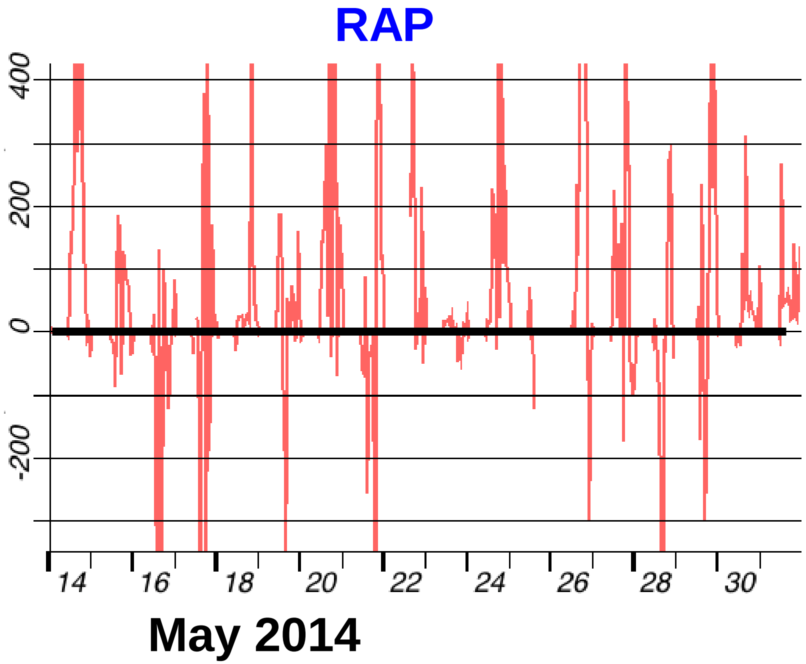
  (1) Directly quantify **surface energy budget** issues

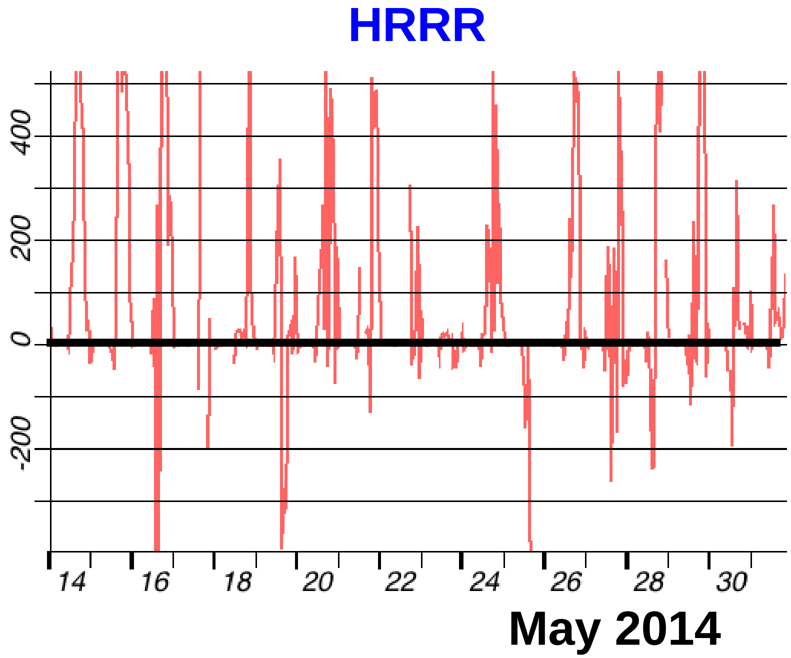
  (2) Conventional "surface" variables (e.g., 2-m temperature) are **diagnosed** in the model

  (3) "Upper-air" variables verified against **twice-daily** radiosondes

Summer 2014: Excessive Surface Irradiance in RAP and HRRR

12-h GHI Forecast Bias at Bondville, Illinois (W m $^{-2}$)





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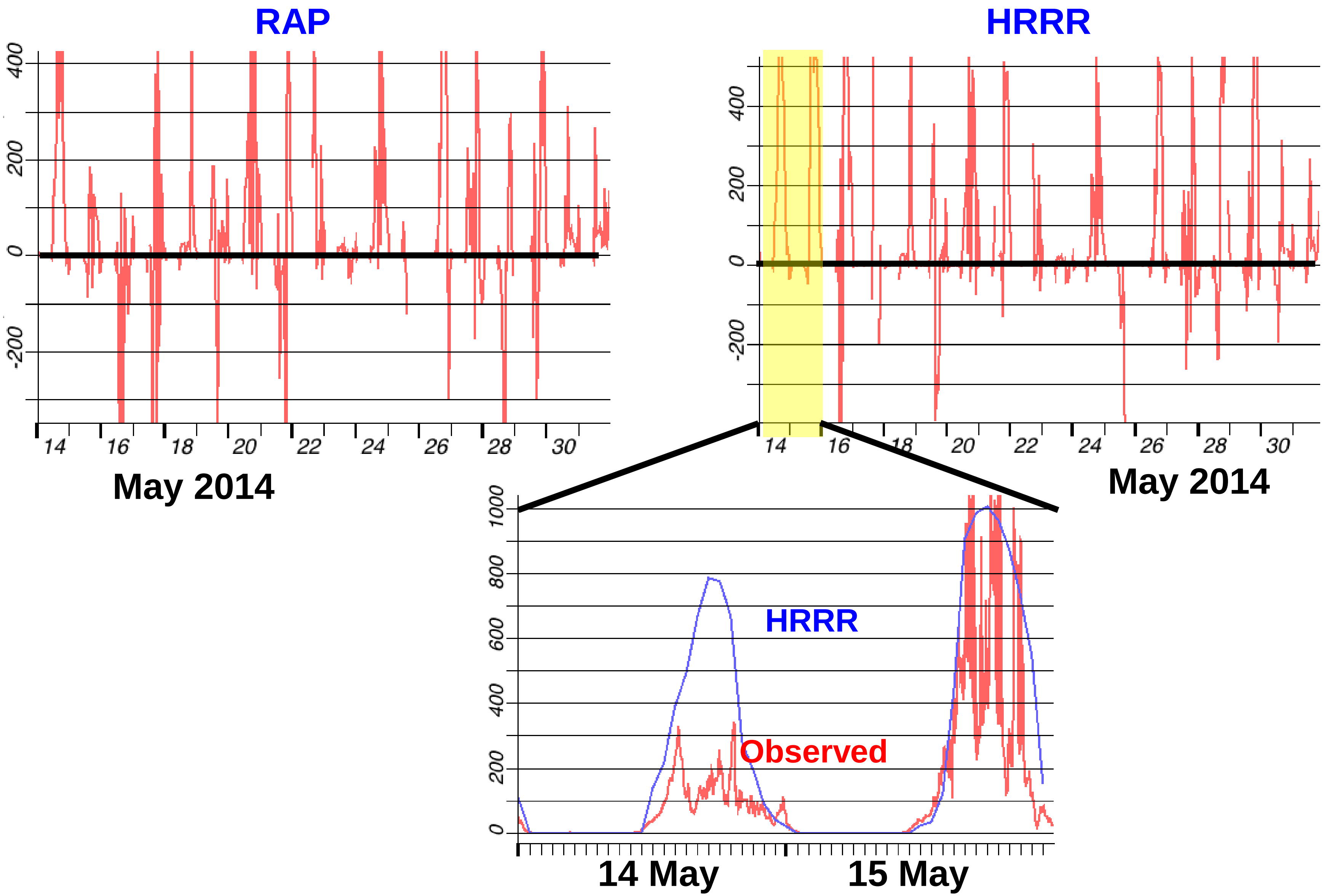
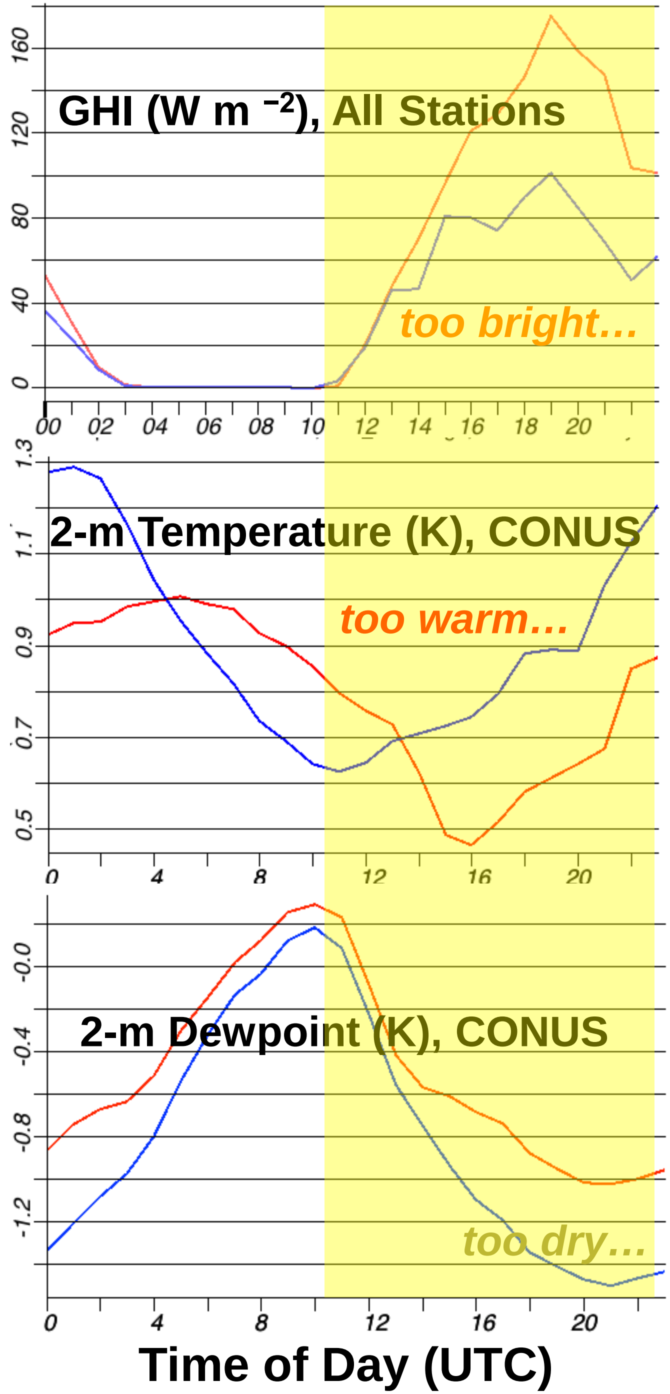
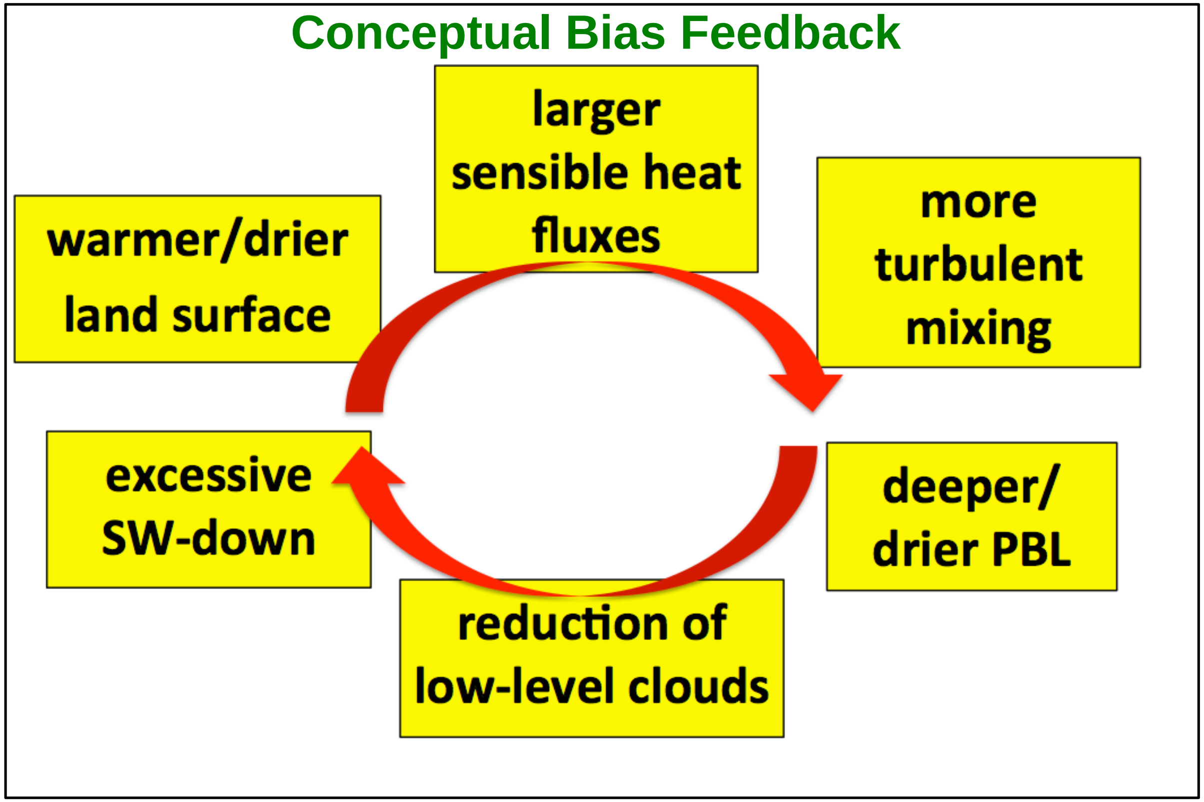


Low-Level Warm−Dry Bias

12-h Forecast Biases,
14−31 May 2014

HRRR
RAP



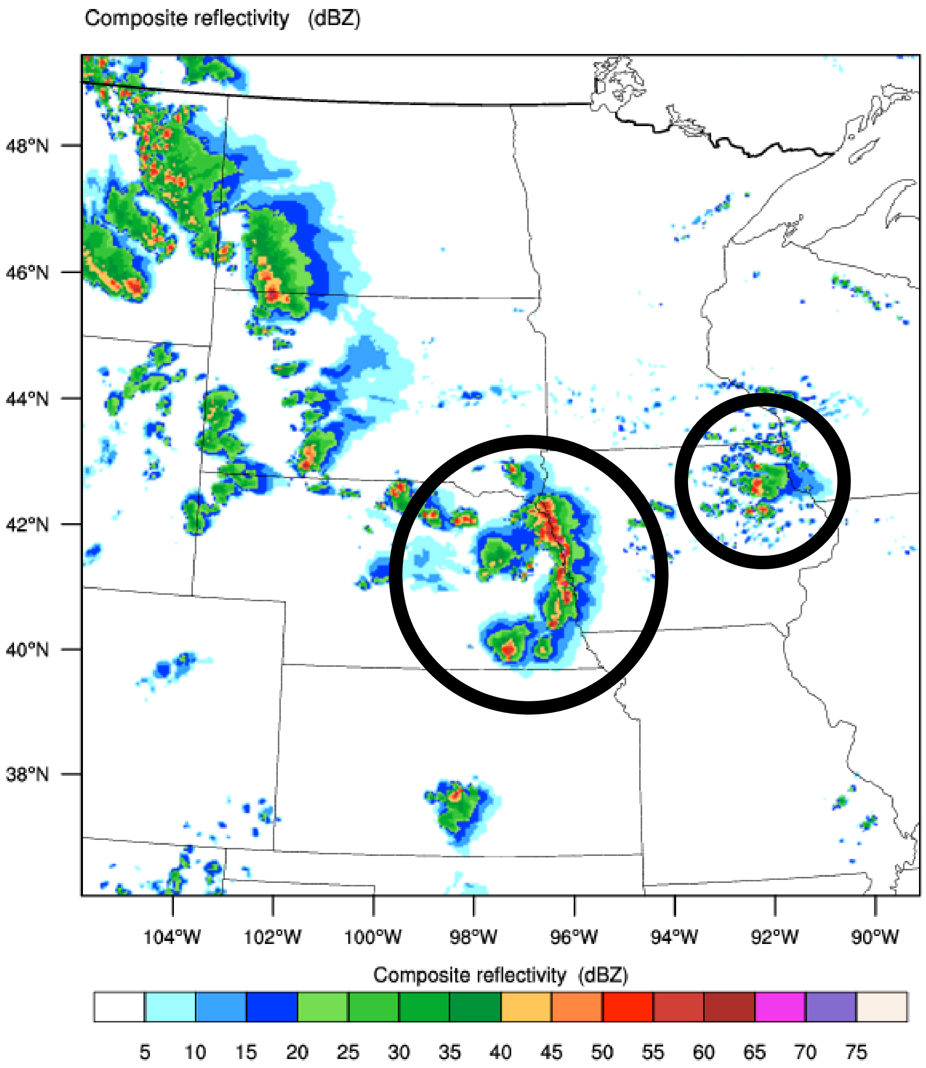


Conceptual Bias Feedback

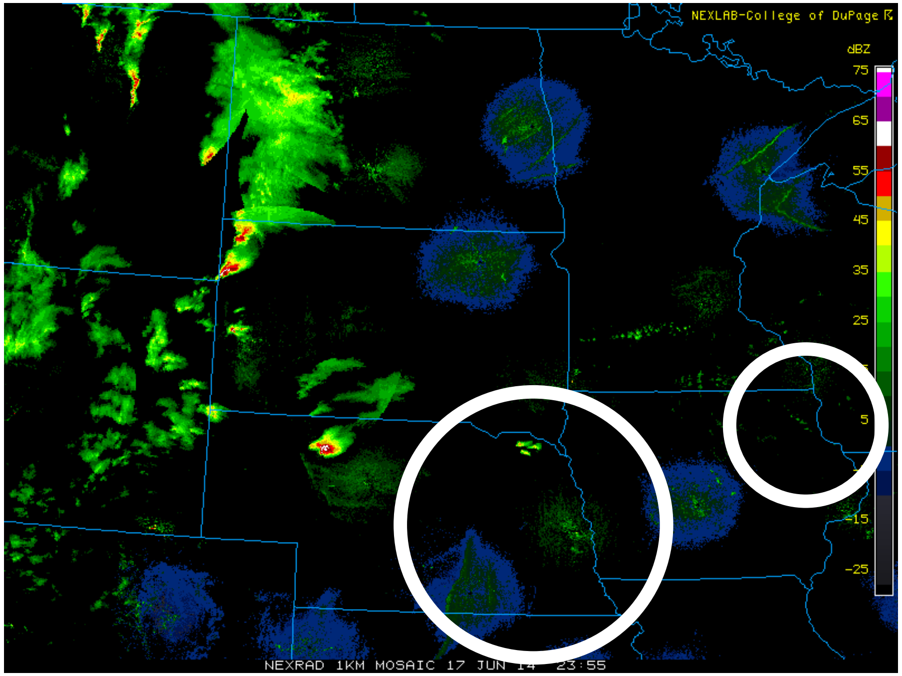
- larger sensible heat fluxes
- more turbulent mixing
- deeper/ drier PBL
- reduction of low-level clouds
- excessive SW-down
- warmer/drier land surface

Related Effect: Excessive Deep Convection in HRRR

4-h forecast of composite reflectivity (valid 0000 UTC 18 Jun 2014)



Observed



Source: UCAR

Successful RAP / HRRR Bias Mitigation Strategies

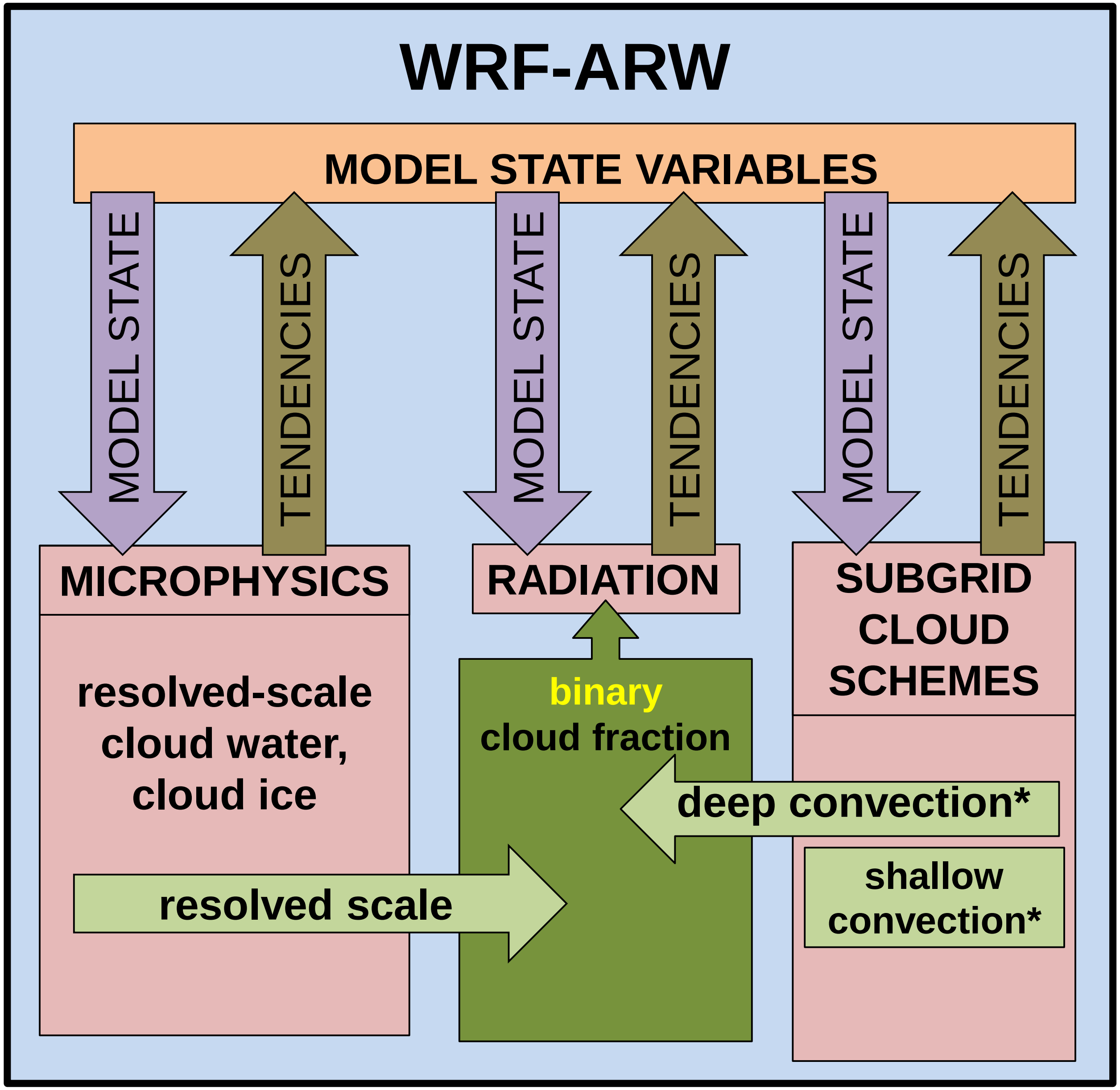
- **(1) Modify the RUC land-surface model (RUC-LSM)**
  - Reduce vegetation wilting points
  - Prevent wilting of cropland areas (i.e., “parameterize” irrigation)

- **(2) Improve the parameterization of subgrid-scale shallow cumulus**

  ➔ and fully couple to radiation

  - Develop Grell−Freitas−Olson shallow cumulus scheme
  - Develop a supplemental cloud fraction (in PBL scheme) for passive-phase (“forced”) shallow cumulus and stratus clouds

RAP / HRRR Cloud Representation: Recent Past



WRF-ARW

MODEL STATE VARIABLES

MODEL STATE

TENDENCIES

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TENDENCIES

MICROPHYSICS

resolved-scale
cloud water,
cloud ice

resolved scale

RADIATION

binary
cloud fraction

SUBGRID
CLOUD
SCHEMES

deep convection*

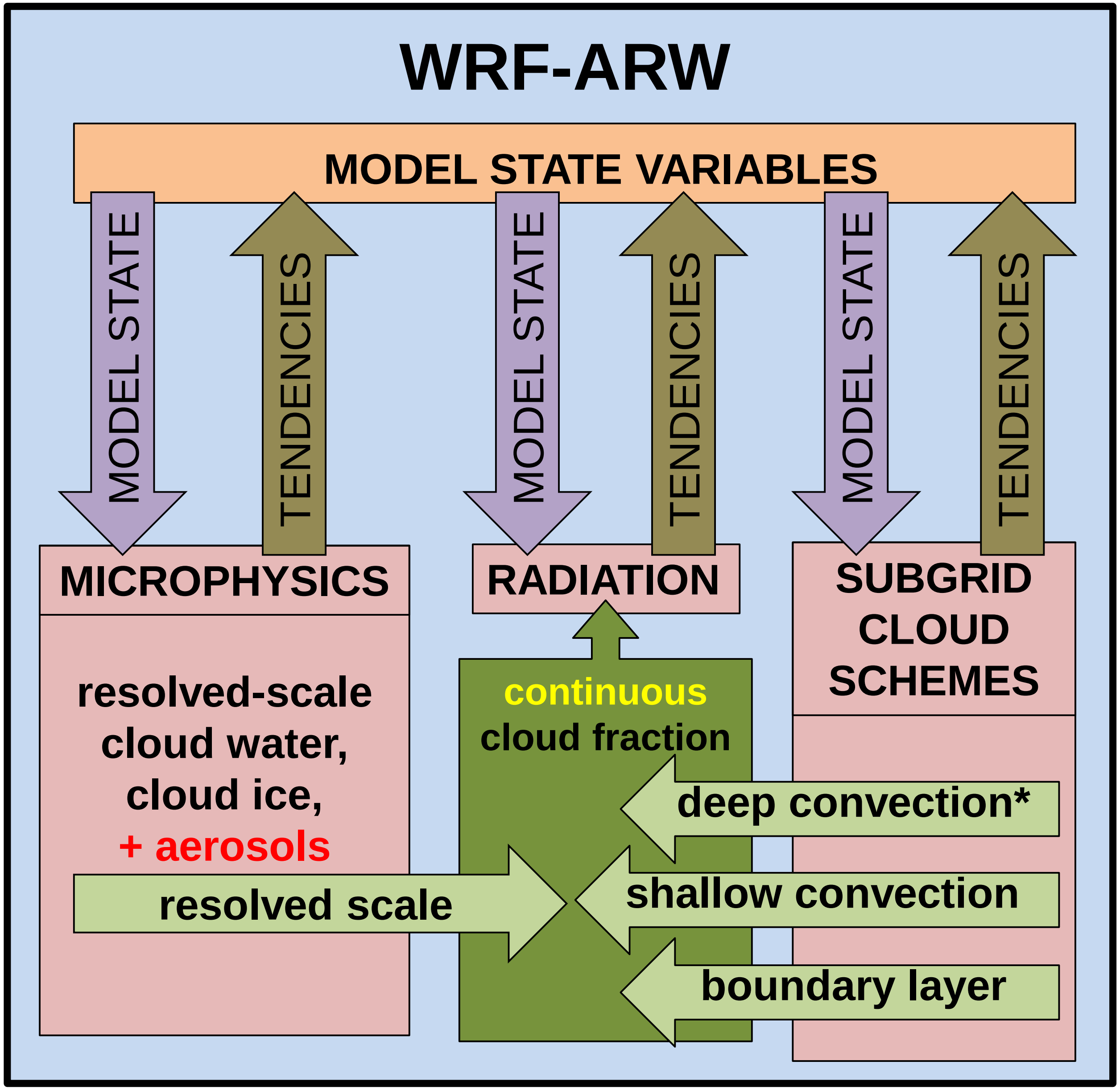
shallow
convection*

“Deep” Convection

“Shallow” Convection

*RAP only

RAP / HRRR Cloud Representation: New Approach



WRF-ARW

MODEL STATE VARIABLES

MODEL STATE

TENDENCIES

MODEL STATE

TENDENCIES

MODEL STATE

TENDENCIES

MICROPHYSICS

resolved-scale cloud water, cloud ice, + aerosols

resolved scale

RADIATION

continuous cloud fraction

SUBGRID CLOUD SCHEMES

deep convection*

shallow convection

boundary layer

“Deep” Convection

“Shallow” Convection

Stratus

*RAP only

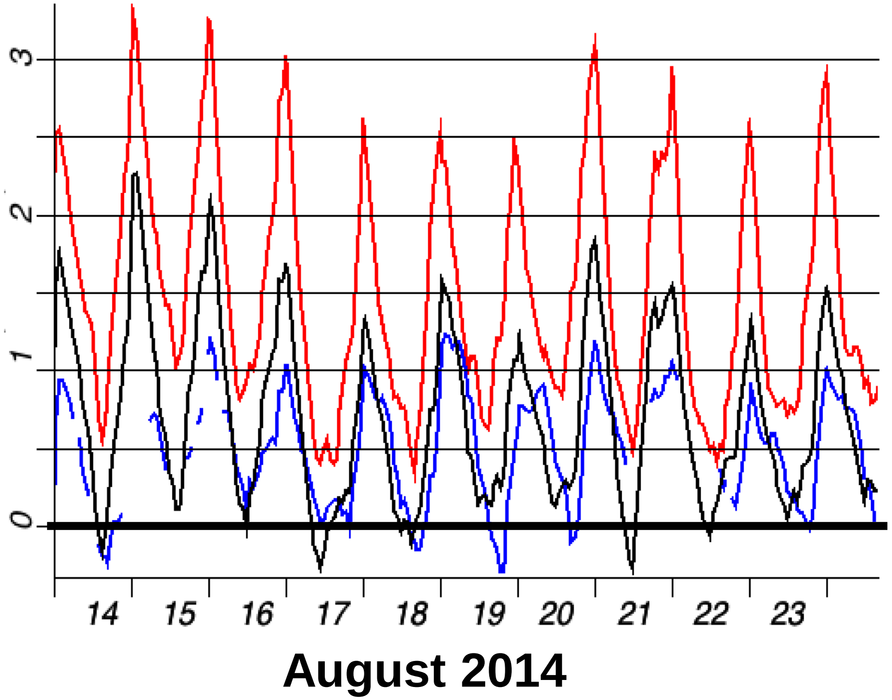
Results: Improved Low-Level Temperature Forecasts

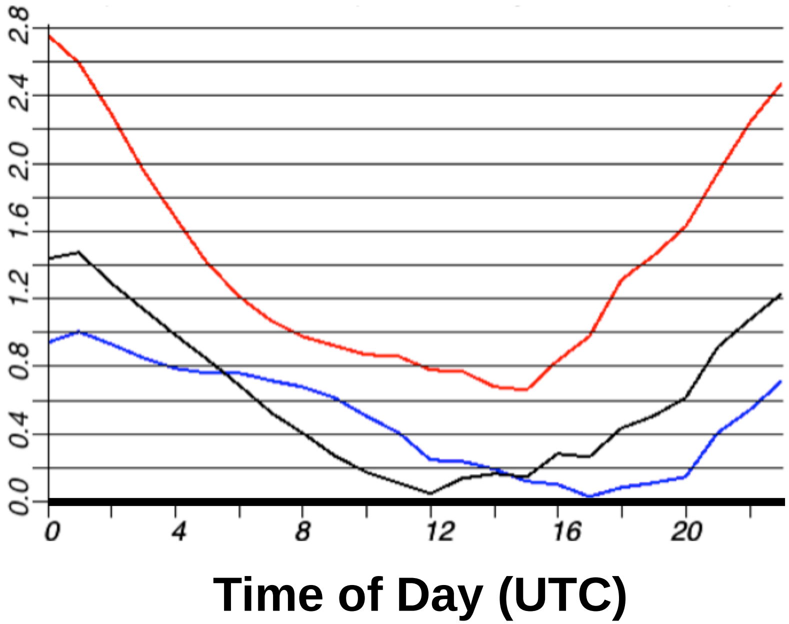
2-m Temperature Bias (K), 12-h Forecasts, CONUS

Control (Unmodified)

w/ Improved Subgrid Clouds

w/ Improved Subgrid Clouds and Land Surface

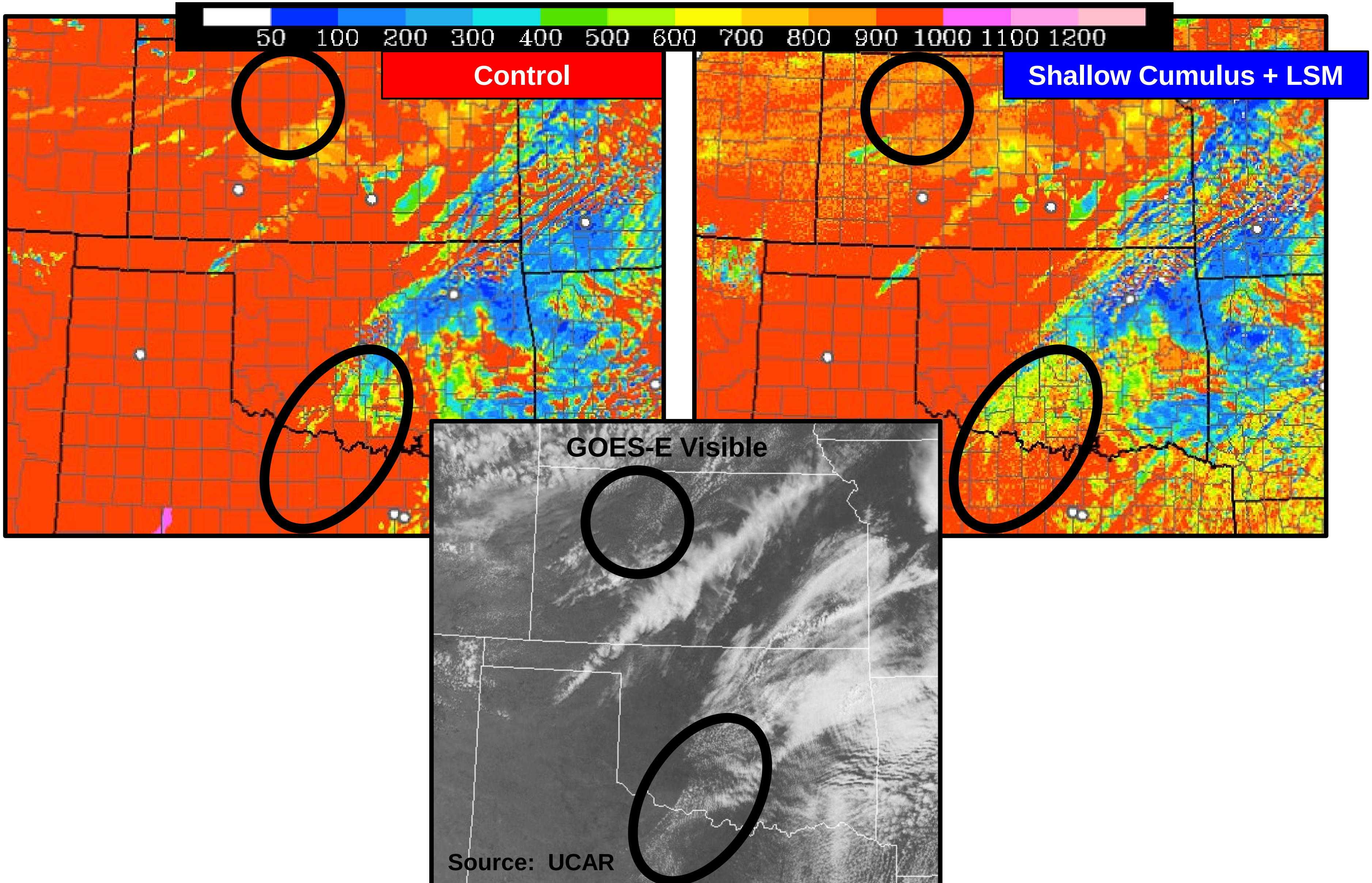




~2-K reduction in late-afternoon warm bias; smaller diurnal bias variation

Results: Improved Cloud Representation

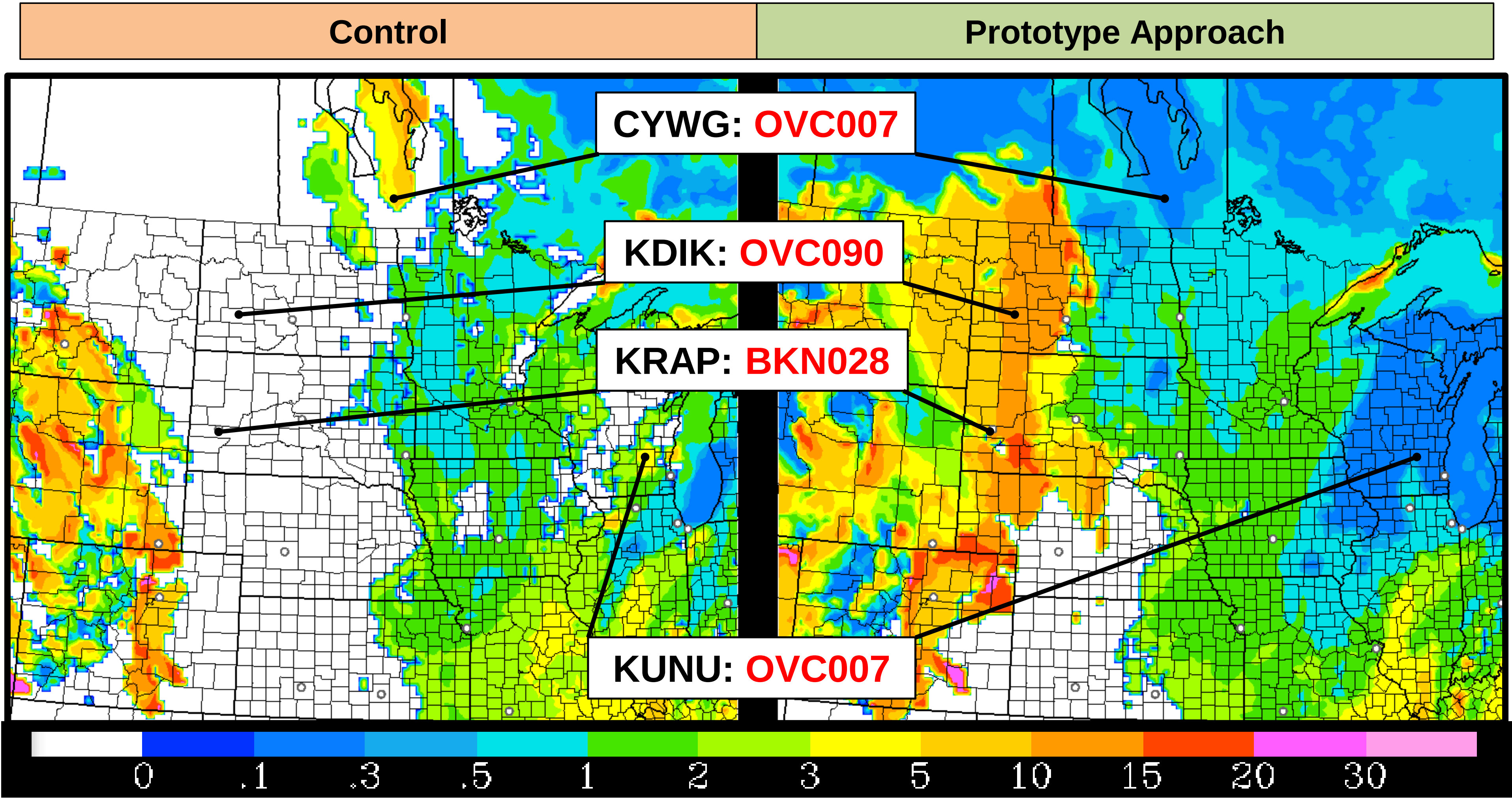
8-h forecasts of surface GHI (W m^{-2}) valid 1700 UTC 20 May 2013



Source: UCAR

Results: Improved Cloud Ceiling Forecasts

selected ceiling reports versus 12-h ceiling forecasts (valid 2000 UTC)



kft (AGL)

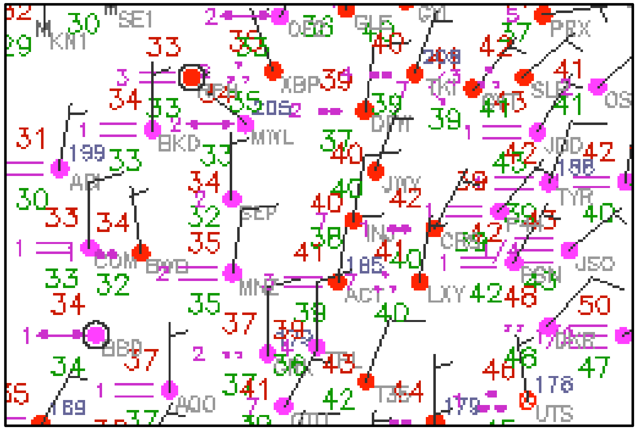
Conclusions

- SURFRAD / ISIS measurements from GMD have facilitated RAP / HRRR model improvements

- New physical parameterizations will provide
  (1) **better RAP / HRRR solar irradiance and cloud ceiling forecasts**

  (2) **better RAP / HRRR forecasts overall**

  (3) **improved internal model physics**



- Ongoing & future work will:
  - Consolidate disparate cloud schemes
  - Develop prognostic cloud representations
  - Improve "scale-aware" aspects for finer model grid spacing