Progress Toward Improved Solar Forecasts in the Hourly Updated RAP and HRRR Models

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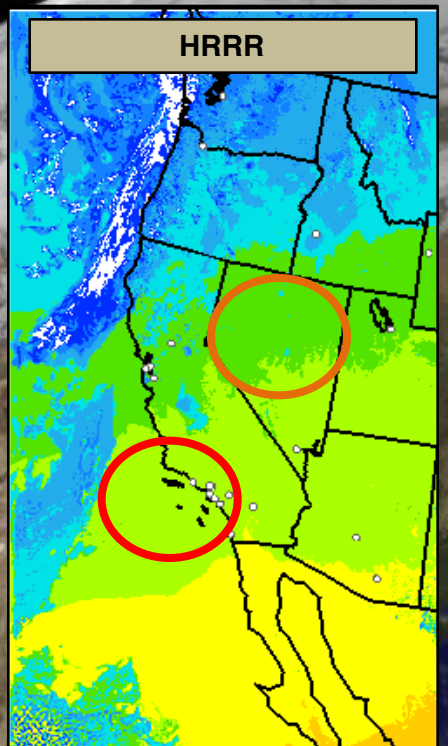
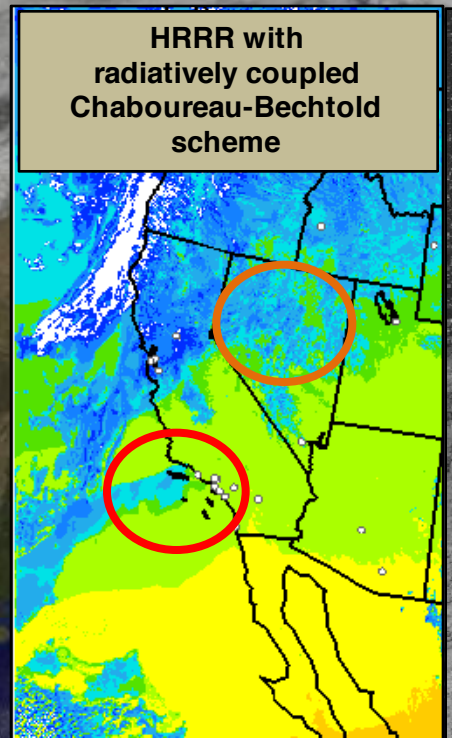
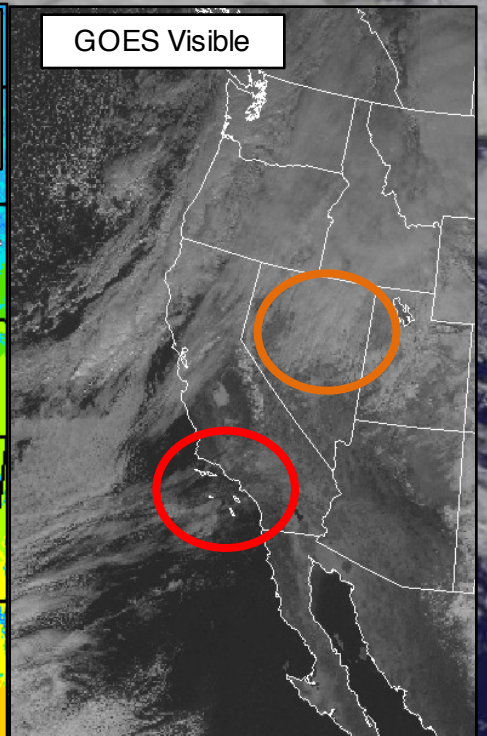


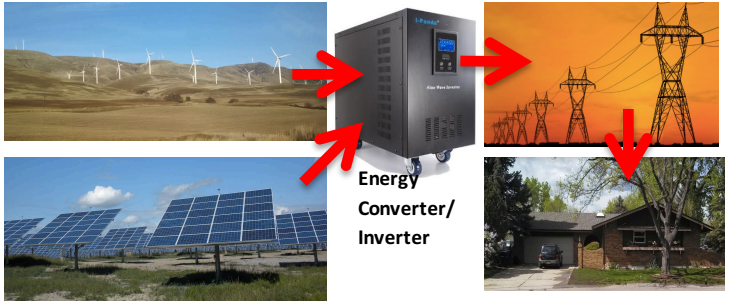




ESRL
GLOBAL SYSTEMS DIVISION

7th Conf. On Weather, Climate, New Energy Economy
11 January 2016
New Orleans, LA

Renewable Energy Challenges



Motivation

- Wind & solar are highly variable sources of energy; *accurate forecasts are needed* to integrate wind and solar energy into the electric grid

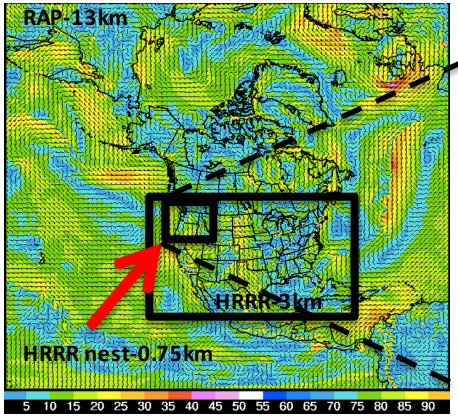
Benefits

- Reduce electricity costs (less penalties, less need for reserves)
- More stable electric grid (if forecasts are accurate)
- Reduction of CO_2 can mitigate climate change

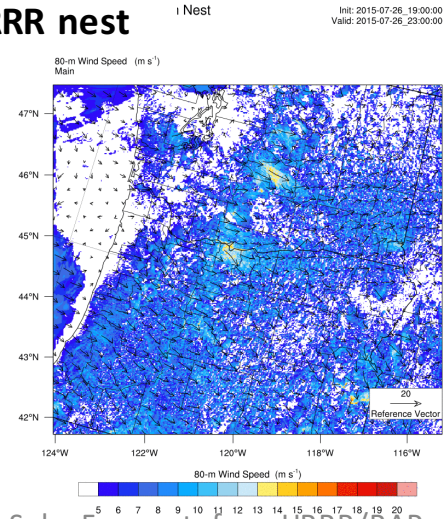
Improving RAP/HRRR for Renewable Energy Applications

- Improve understanding of physical processes (e.g., clouds & turbulence) important for wind & solar energy.
- Improve representation of these processes in our models:
  - Improve model physical parameterization schemes
  - Improved coupling of schemes
  - Make schemes scale-aware
- Improve data assimilation of clouds, lower troposphere, PBL

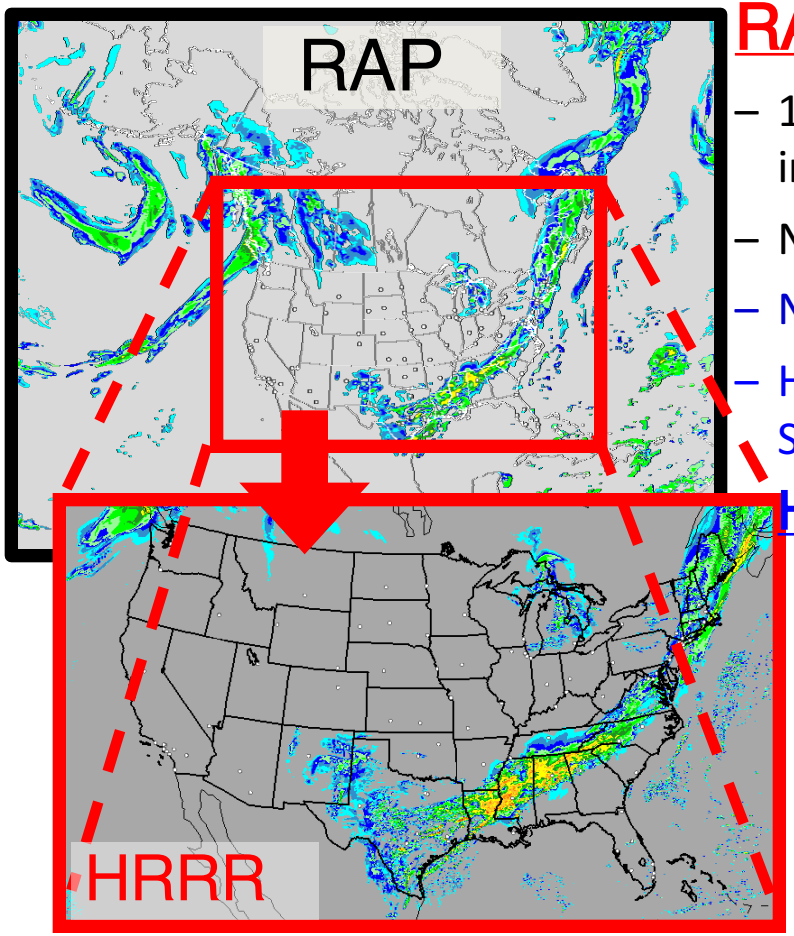
80m winds



HRRR nest



Current Status - NOAA Hourly Updated Models



RAP - Rapid Refresh

- 13km NOAA "situational awareness" model for high-impact weather
- New 18-24-hour forecast each hour
- NOAA/NCEP operational – May 2012, RAPv2 - Feb 2014
- Hourly use by National Weather Service, SPC/AWC/WPC, FAA, private sector

HRRR – High-Resolution Rapid Refresh

- 3km storm/ **energy** /aviation guidance
- Real-time operational – NCEP, and *experimental*- ESRL supercomputer
- NCEP implementation HRRRv1 - 30 Sept 2014
- **HRRRv2/RAPv3 - in real-time testing at ESRL, NCEP implementation estimated May 2016**

RAP and HRRR: Hourly-Updated Forecast Models

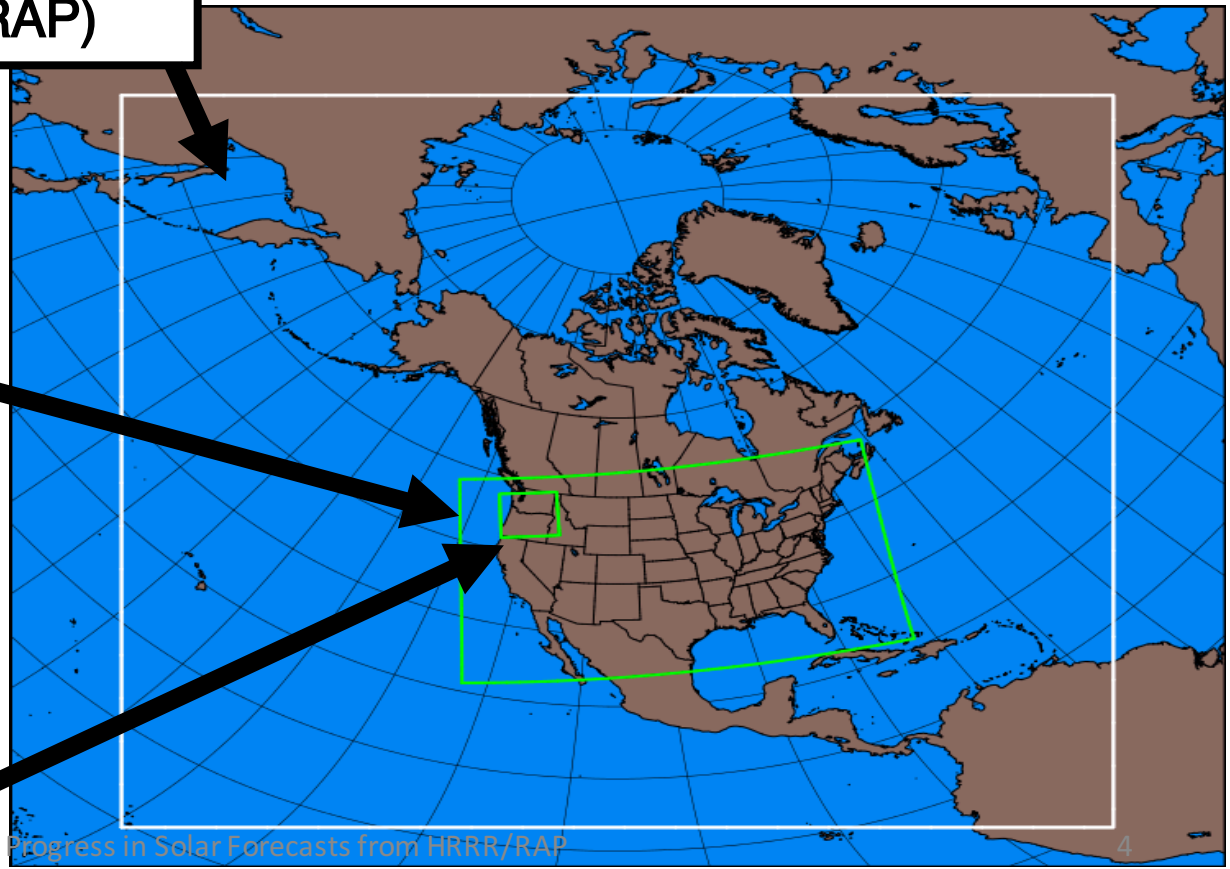
13-km Rapid Refresh (RAP)

Initial & Lateral Boundary Conditions

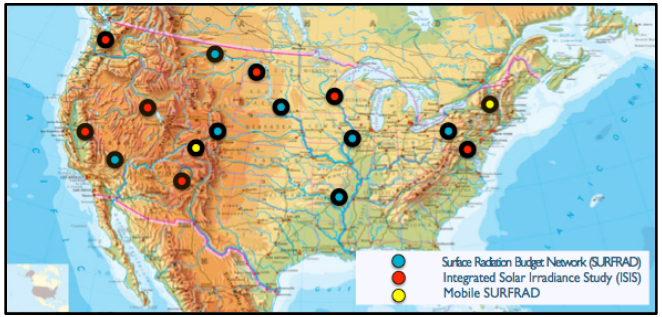
3-km High-Resolution Rapid Refresh (HRRR)

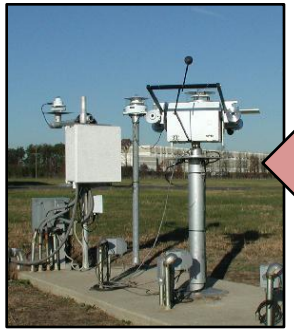
Initial & Lateral Boundary Conditions

750-m HRRR-WFIP2 nest



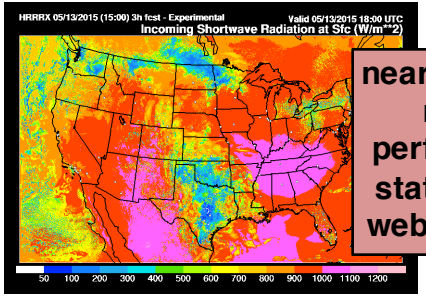
RAP / HRRR Irradiance Verification from ESRL/GMD's SURFRAD / ISIS



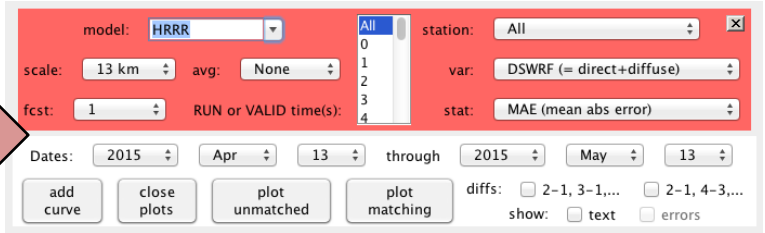


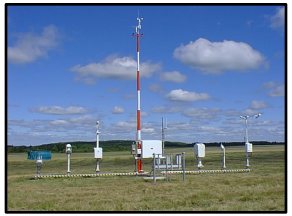
14 SURFRAD / ISIS sites

near-real-time data processing



near-real-time model performance statistics via web interface





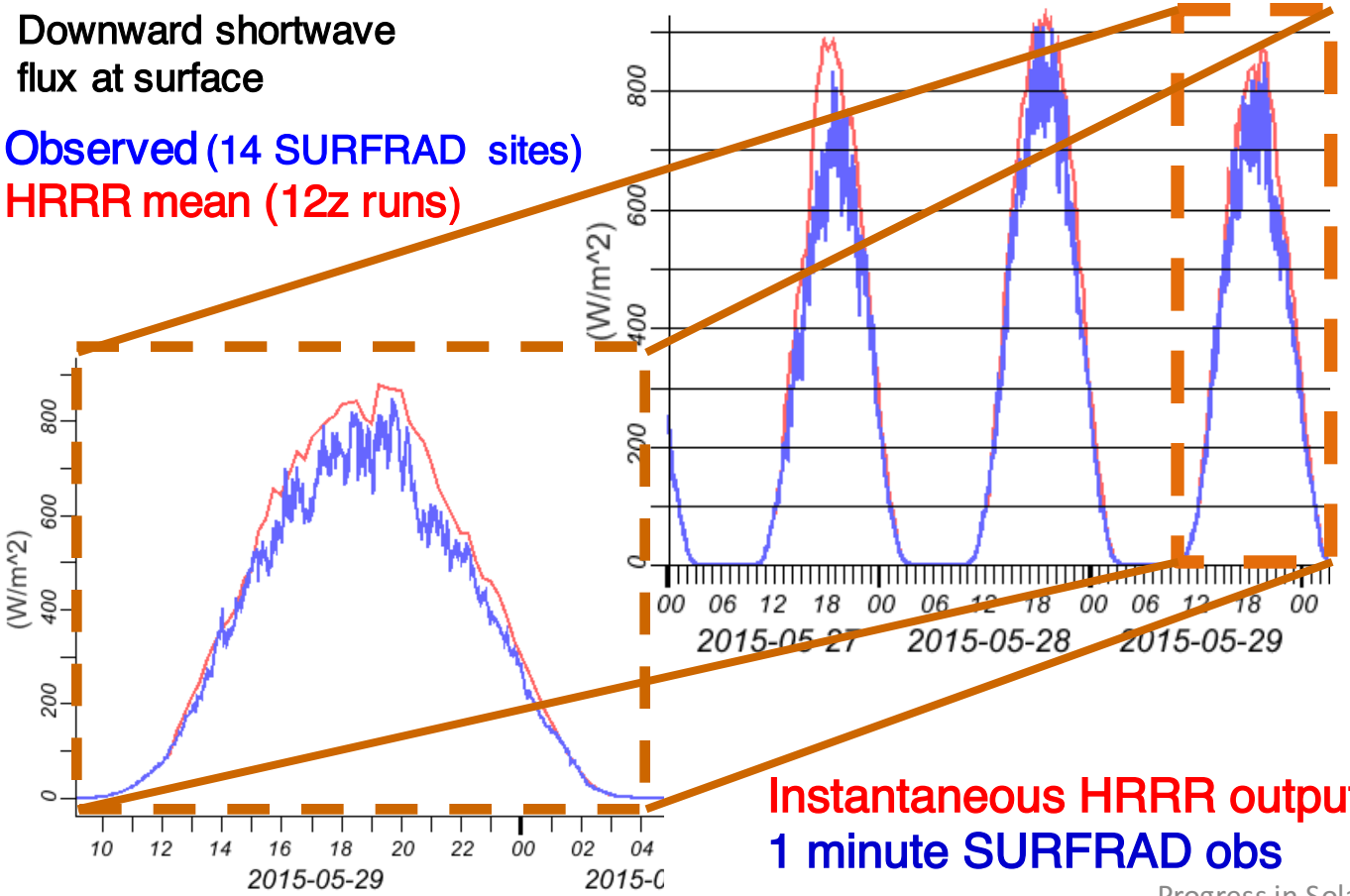
- **GMD's SURFRAD / ISIS measurements provide a unique model assessment capability:**
- Directly quantify **surface energy budget** issues

15-min Validation of HRRR/RAP forecasts

Downward shortwave flux at surface

Observed (14 SURFRAD sites)

HRRR mean (12z runs)



Instantaneous HRRR output

1 minute SURFRAD obs

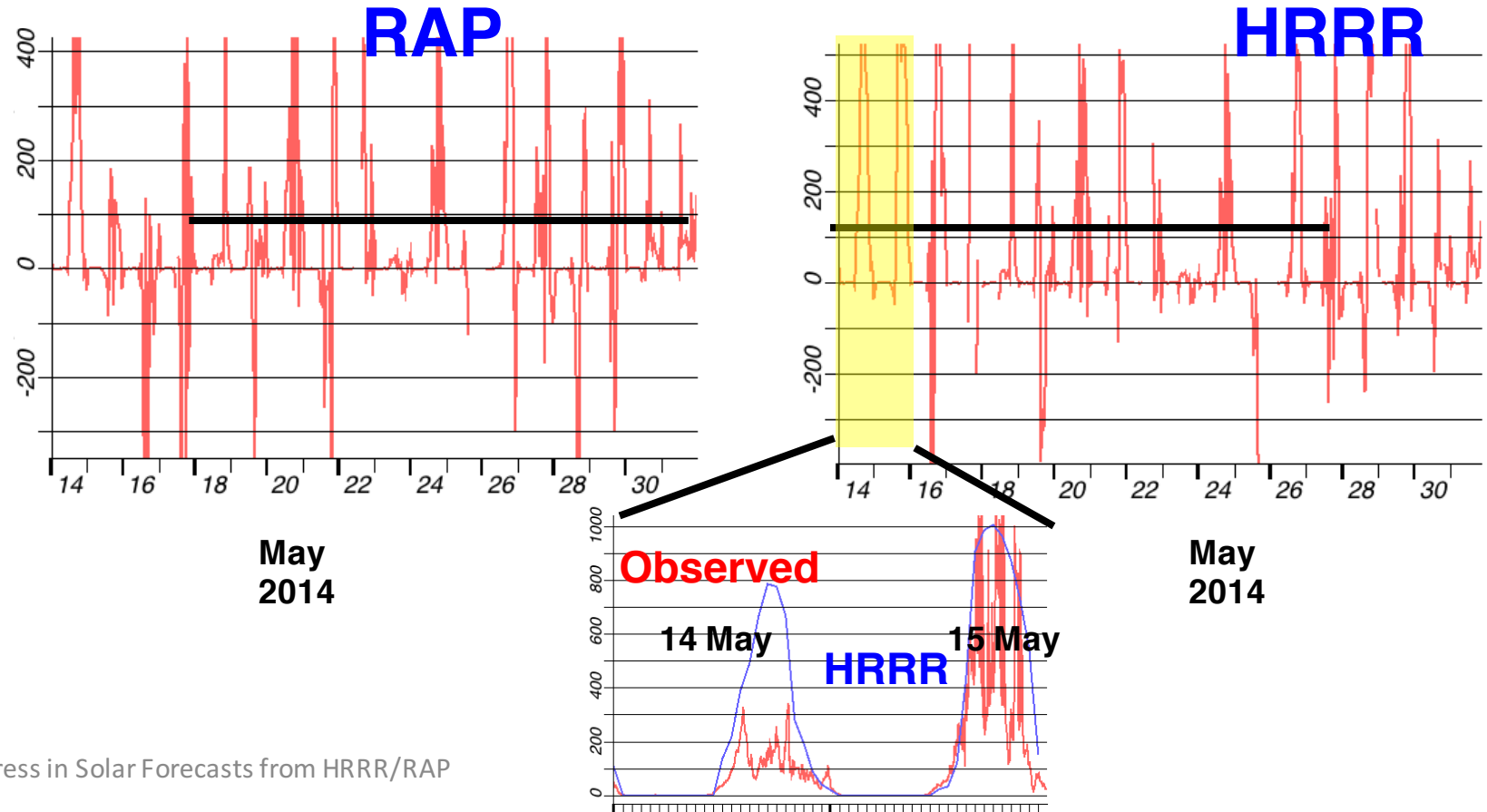
Q: Subgrid cloud issues even at 3km HRRR/ARW-WRF resolution?

A: Yes.

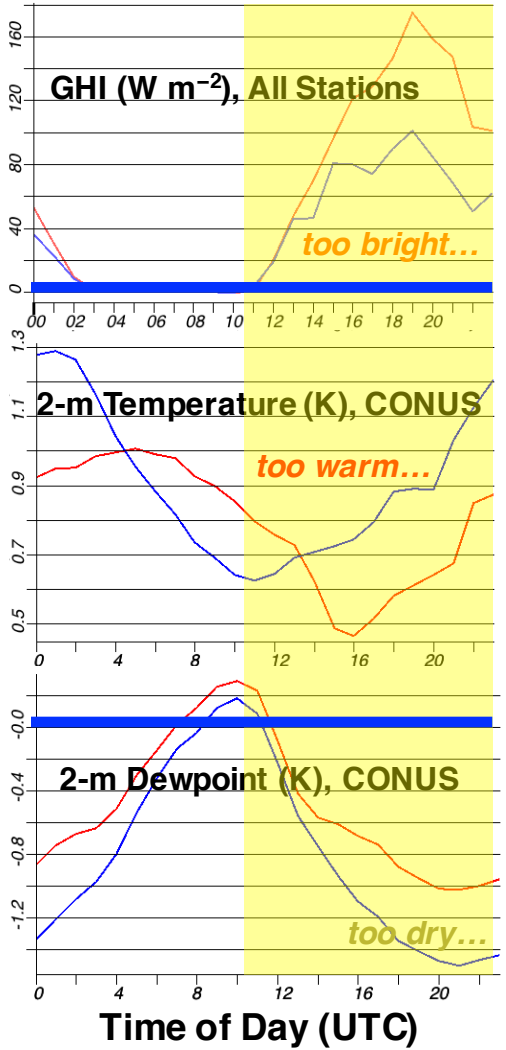
10% of global cloudiness <10km, below 4dx with 3km HRRR resolution

Summer 2014: Excessive Surface Irradiance in RAP and HRRR

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



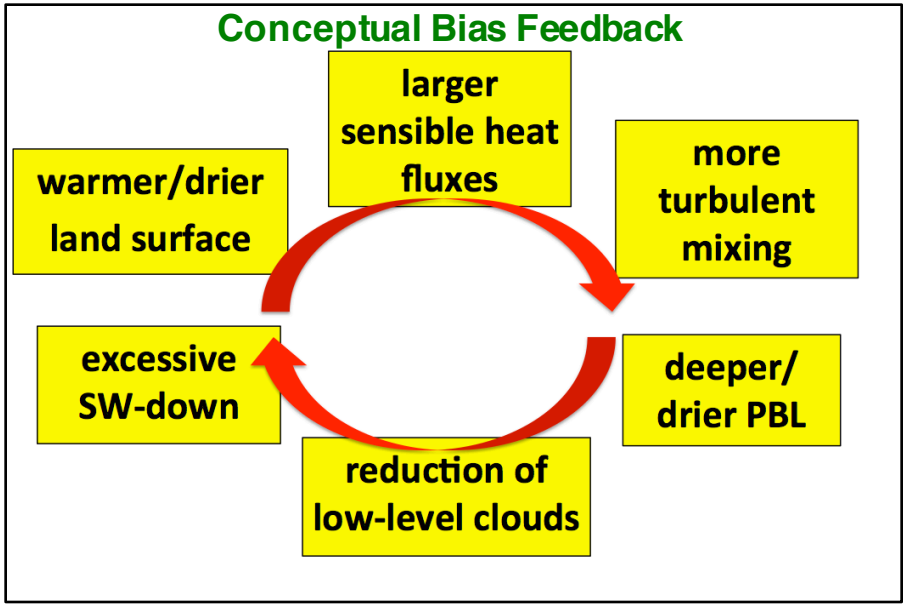
Low-Level Warm–Dry Bias in 2014 HRRR/RAP



12-h Forecast Biases, 14–31 May 2014

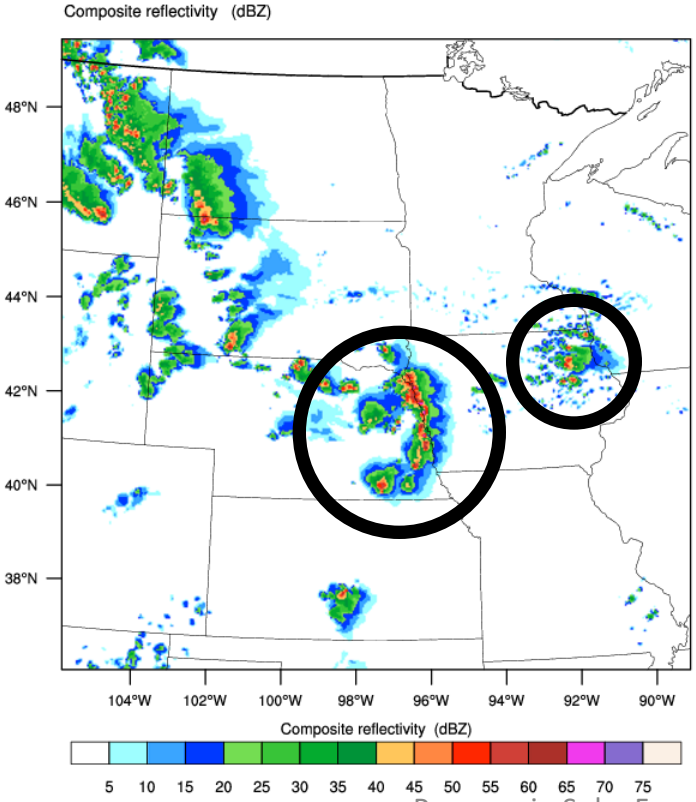
HRRR
RAP

Energy balance at earth's surface. With incorrect components, model will seek its own equilibrium.

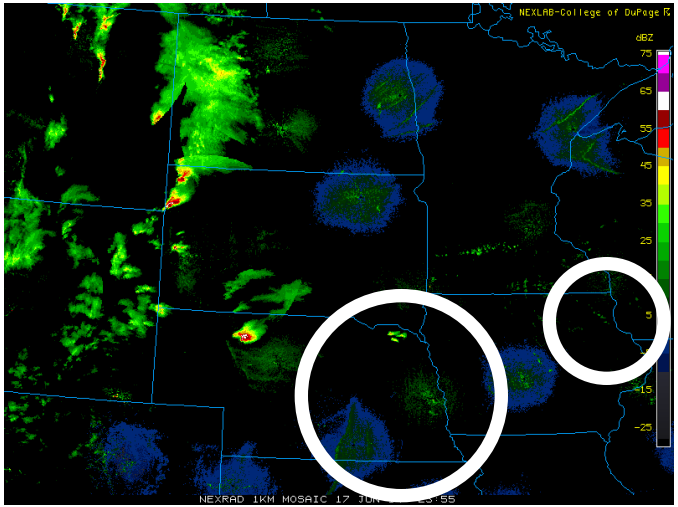


Related Effect: Excessive Deep Convection in HRRR

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



Observed



Source: UCAR

Warm-dry bias
Errors in thunderstorm forecasting
Errors in solar forecasting, high SW bias overall

ESRL RAP and HRRR Configurations
- Key components for solar forecasting

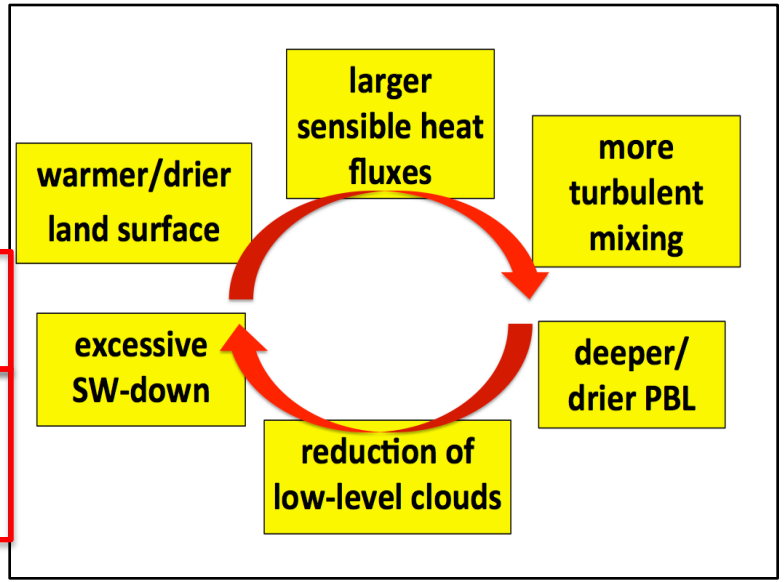
Model	Domain	Grid Points	Grid Spacing	Vertical Levels	Pressure Top	Boundary Conditions	Initialized
RAP	North America	758 x 567	13 km	50	10 hPa	GFS	Hourly (cycled)
HRRR	CONUS	1799 x 1059	3 km	50	20 hPa	RAP	Hourly - RAP (no cycling)

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)	Grell-Freitas-Olson	MYNN	RUC 9-lev
HRRR	WRF-ARW v3.6.1+	GSI Hybrid 3D-VAR/Ensemble	3-km 15-min LH	RRTMG/ RRTMG	Thompson-Eidhammer	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 ter	15 min	MODIS Fractional	0.07 K/s	20 s

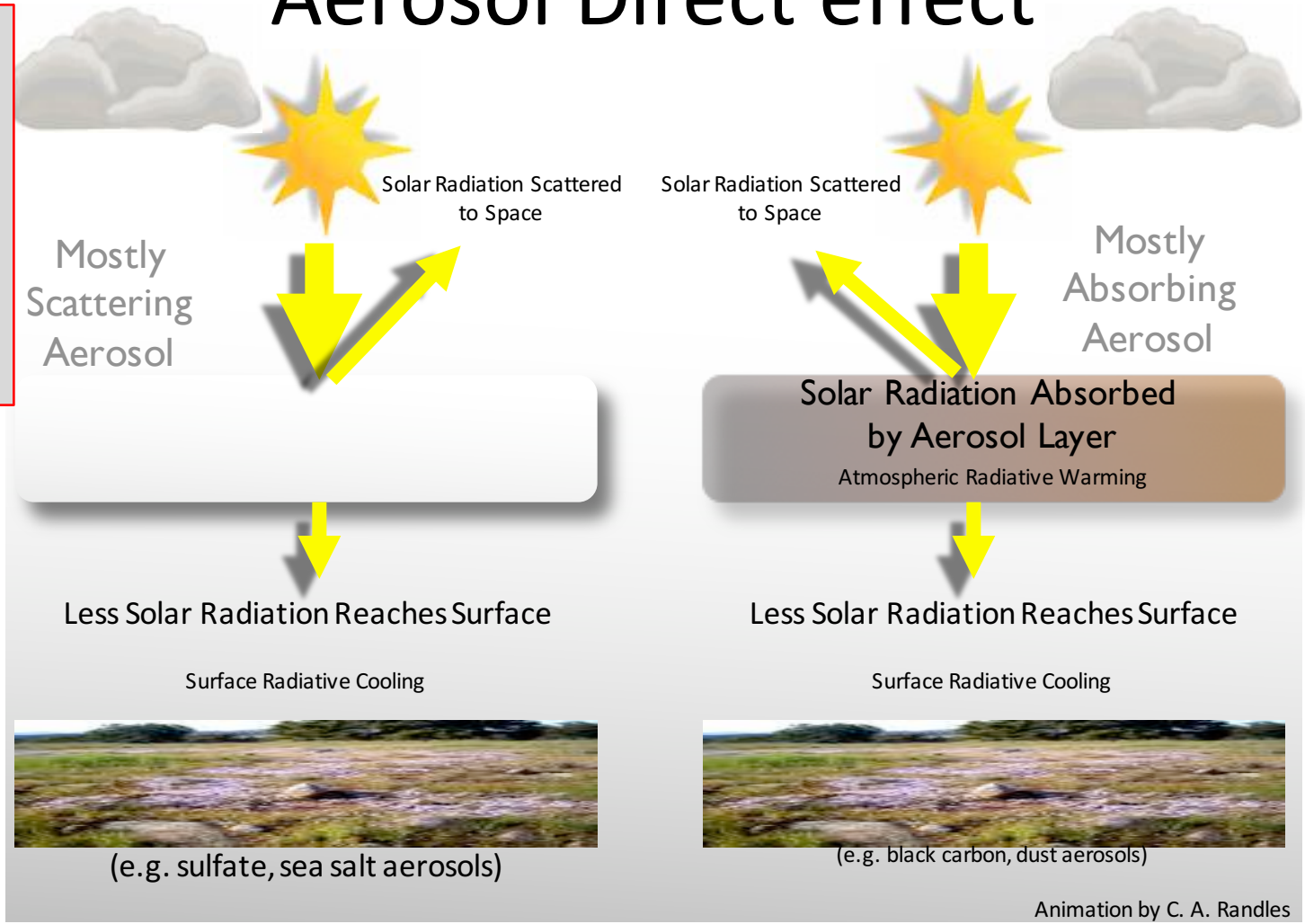
Solutions/mitigations in HRRR/RAP model/ assimilation to address warm/dry bias

Component	Mitigating Items
GSI Data Assimilation	Canopy water cycling Temp pseudo-innovations thru model boundary layer More consistent use of surface temp/dewpoint data
GFO Convective Parameterization	Shallow cumulus radiation attenuation Improved retention of stratification atop mixed layer
Thompson Microphysics	Aerosol awareness for resolved cloud production Attenuation of shortwave radiation
MYNN Boundary Layer	Mixing length parameter changed Thermal roughness in surface layer changed Coupling boundary layer clouds to RRTMG radiation
RUC Land Surface Model	Reduced wilting point for more transpiration Keep soil moisture in croplands above wilting point



Aerosol Direct effect

Solutions:
aerosol effects in HRRRv2/RAPv3 using Thompson aerosol-aware cloud microphysics



Aerosol INDirect effect

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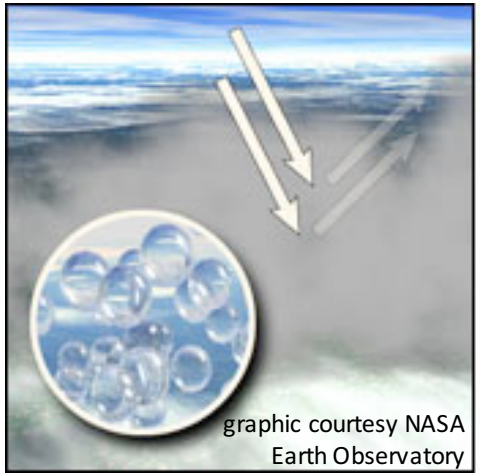
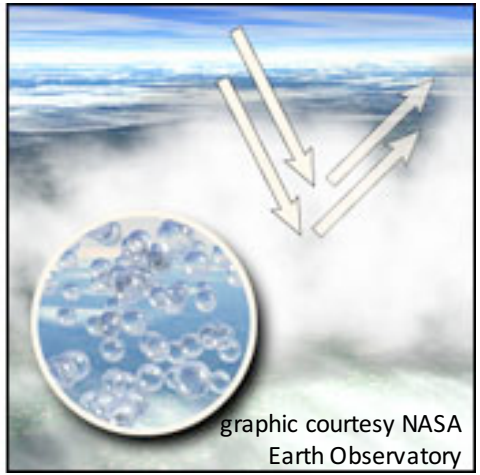


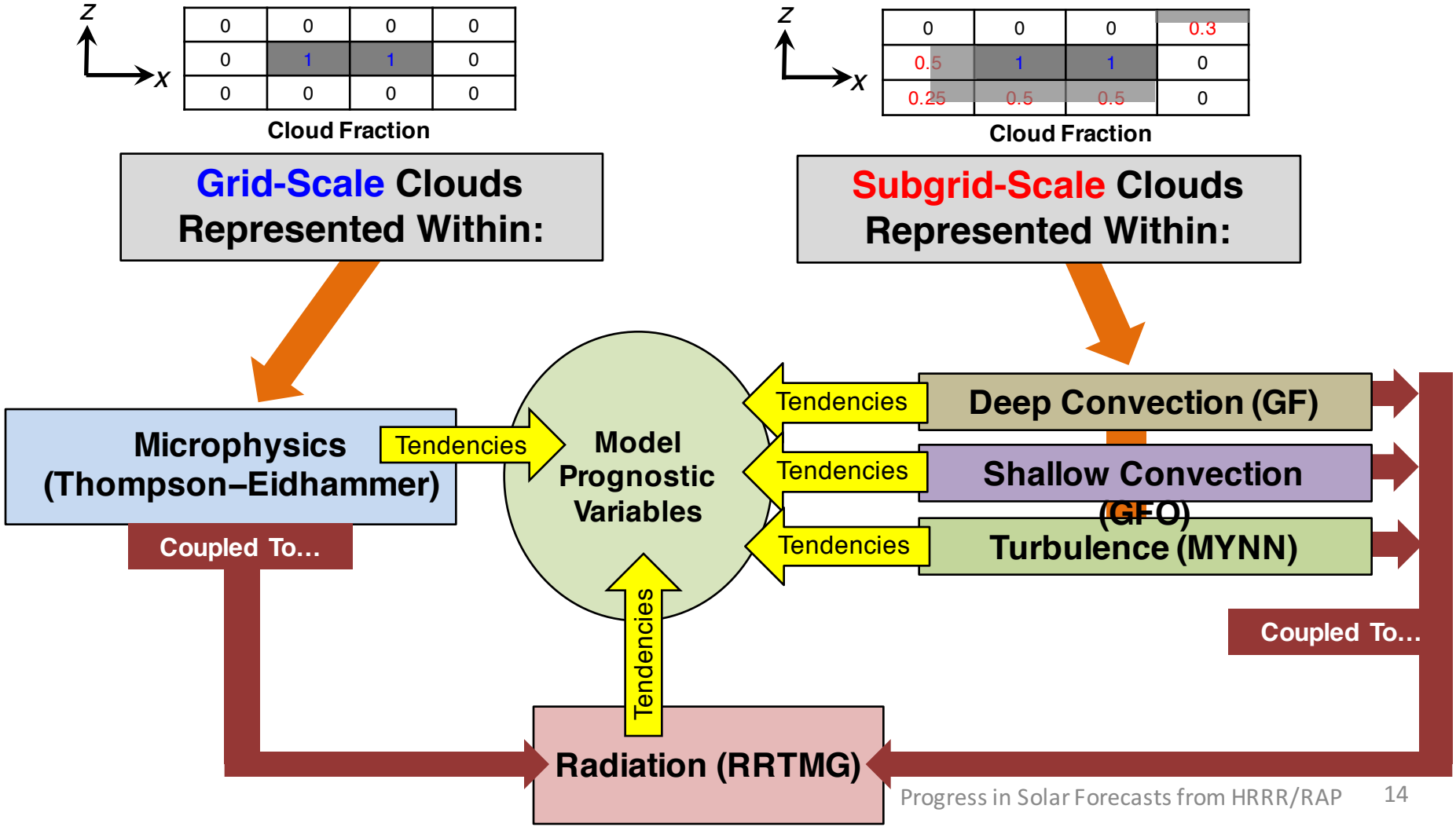


Larger cloud droplets, less reflective cloud. → Twomey Effect → Smaller cloud droplets, more reflective cloud.

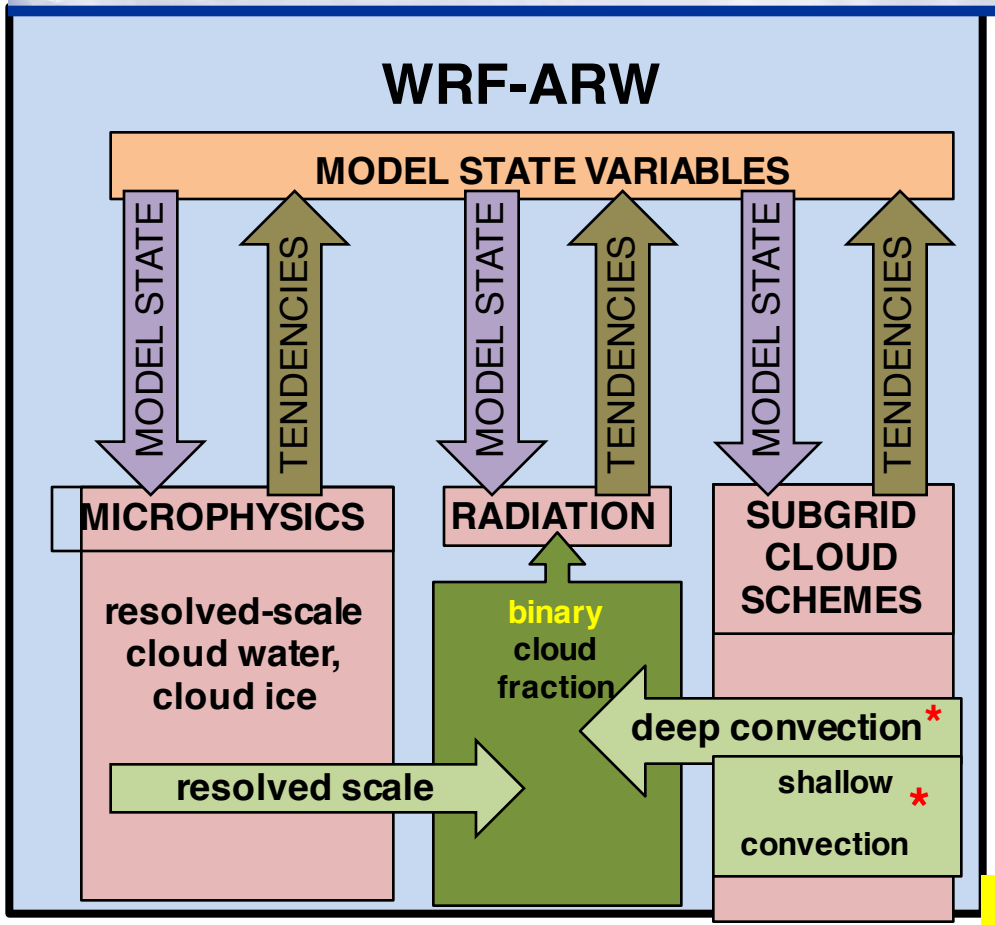
Less Aerosols **Increased Cooling by Clouds** More Aerosols

Larger cloud droplets, droplets rain out easier, clouds dissipate quicker. → Albrecht Effect → Smaller cloud droplets, droplets rain out less, longer-lived clouds.

Animation by C. A. Randles


z
x
0 0 0 0
0 1 1 0
0 0 0 0
Cloud Fraction
z
x
0 0 0 0.3
0.5 1 1 0
0.25 0.5 0.5 0
Cloud Fraction
Grid-Scale Clouds Represented Within:
Subgrid-Scale Clouds Represented Within:
Microphysics (Thompson–Eidhammer)
Tendencies
Model Prognostic Variables
Tendencies
Tendencies
Tendencies
Deep Convection (GF)
Shallow Convection (GFO)
Turbulence (MYNN)
Coupled To…
Coupled To…
Tendencies
Radiation (RRTMG)

RAP / HRRR Cloud Representation: Recent Past



"Deep" Convection

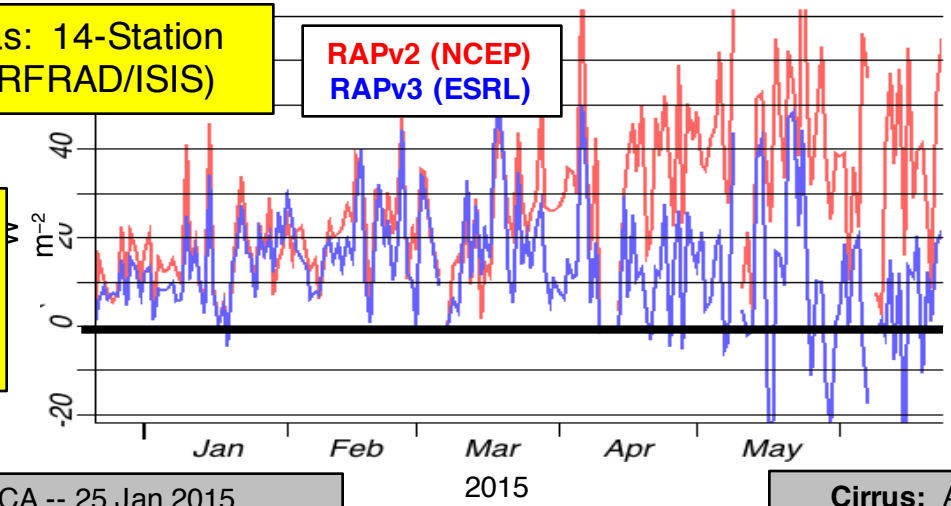
"Shallow" Convection

*RAP only

RAP Solar Irradiance (GHI) Biases

6-h Forecast Bias: 14-Station Daily Mean (SURFRAD/ISIS)

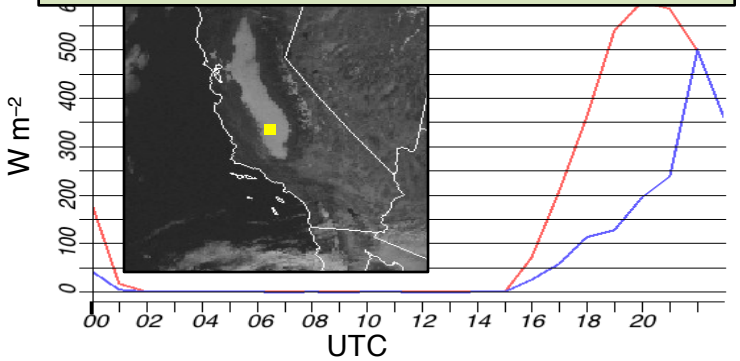
Improvement in RAPv3 cloudiness….
But still some ways to go.



Shallow Cumulus

Stratus: Hanford, CA -- 25 Jan 2015

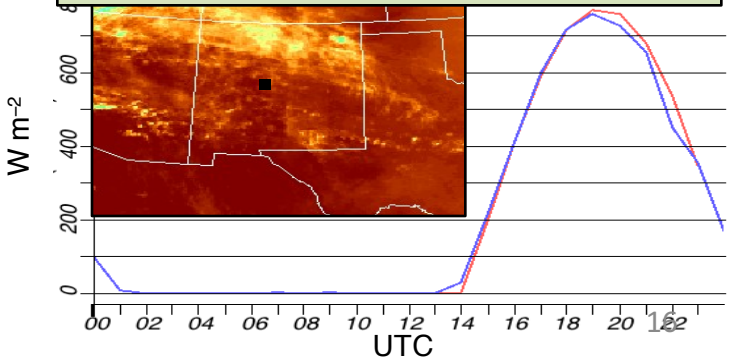
KVIS 251835Z AUTO 00000KT 1/4SM **OVC002**



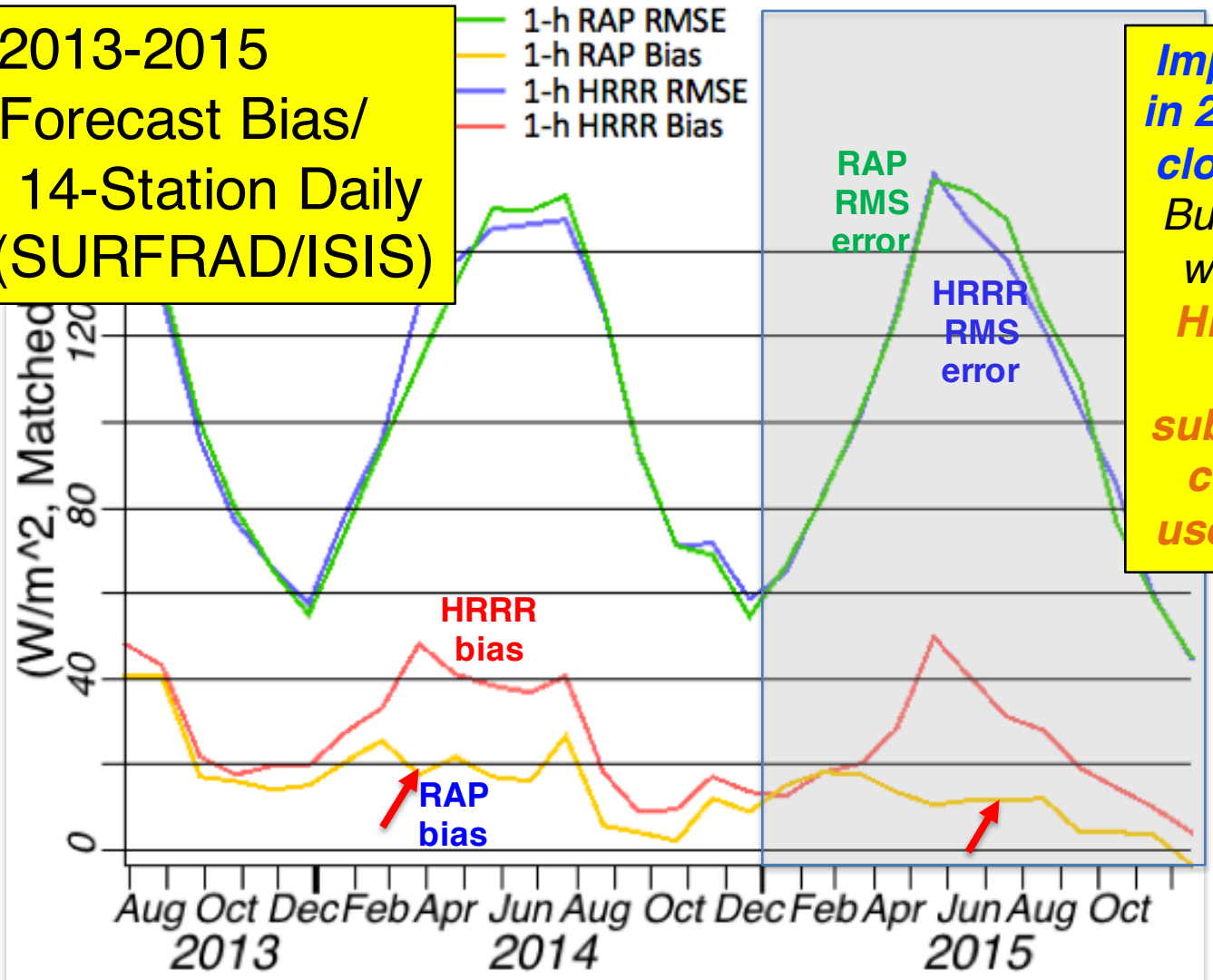
6-h Forecast: RAPv3
Measured: ISIS

Cirrus: Albuquerque, NM -- 19 Feb 2015

KABQ 192052Z 21005KT 10SM **SCT250**



2013-2015 6-h Forecast Bias/ RMS: 14-Station Daily Mean (SURFRAD/ISIS)

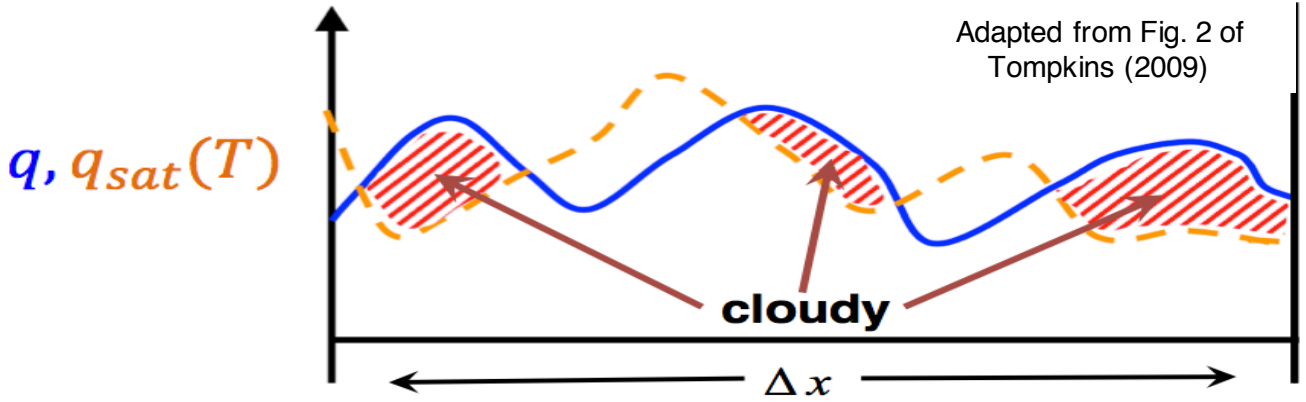


Improvement in 2015 RAPv3 cloudiness....

But still some ways to go.

HRRR-2016 will use subgrid-scale cloud (not used in 2015)

In progress: Toward Improved Subgrid-scale Clouds



Overview of Statistical Cloud Parameterizations

$$Var(s) \propto Var(q) + Var(T) - Cov(q, T)$$

Assume a PDF of *s* *(saturation ratio)*

Retrieve Cloud Fraction, Cloud Condensate

Parameterize:
***assume* subgrid PDFs for thermodynamic variables**

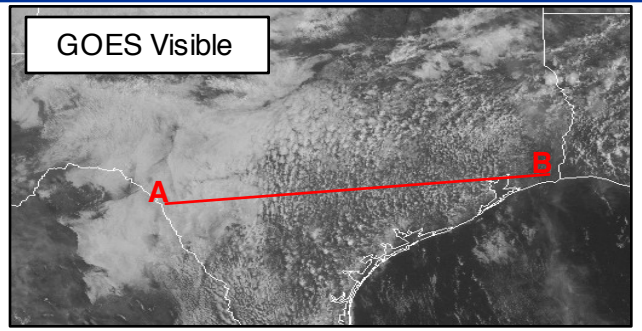
Sommeria and Deardorff (1977) and Mellor (1977)

- Gaussian joint distributions

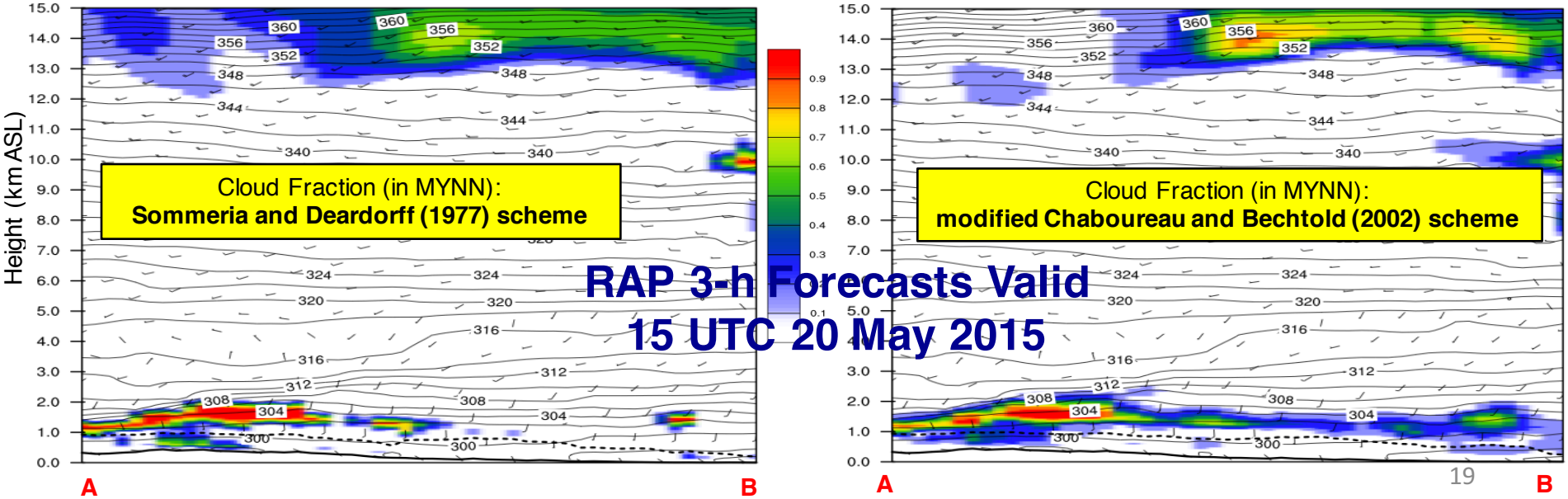
Chaboureau and Bechtold (2002)

- Allows for skewed distributions
- May be implemented diagnostically or prognostically

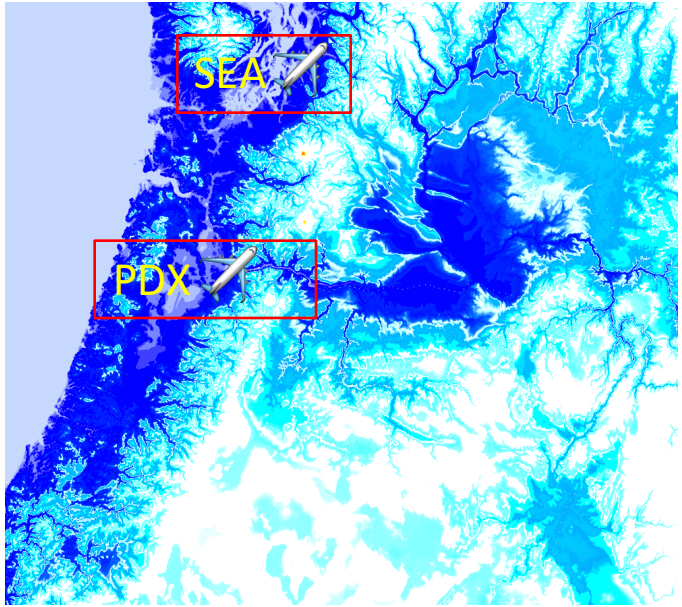
Improved representation of subgrid-scale clouds



- Chaboureau and Bechtold (2002) scheme is "active" in stratocumulus, cumulus, and cirrus regions
- Better able to represent low–intermediate cloud fractions

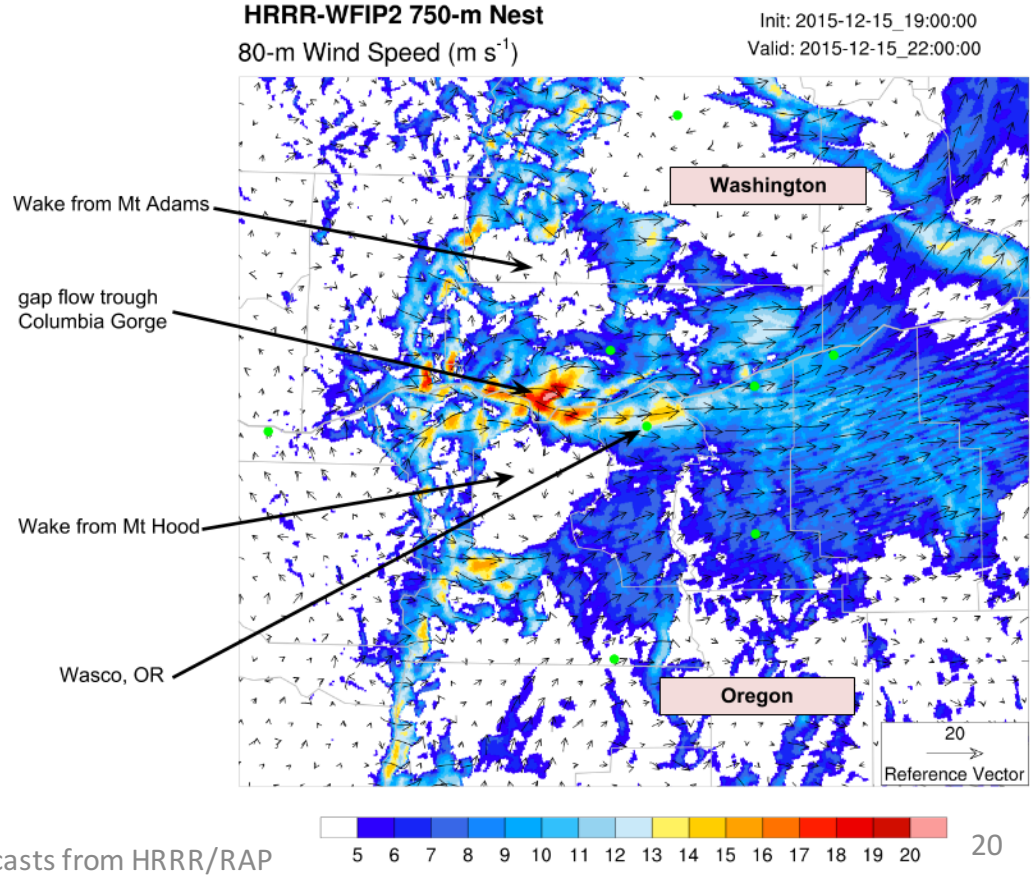


HRRR-WFIP2
Proving Ground for improving PBL/cloud physics

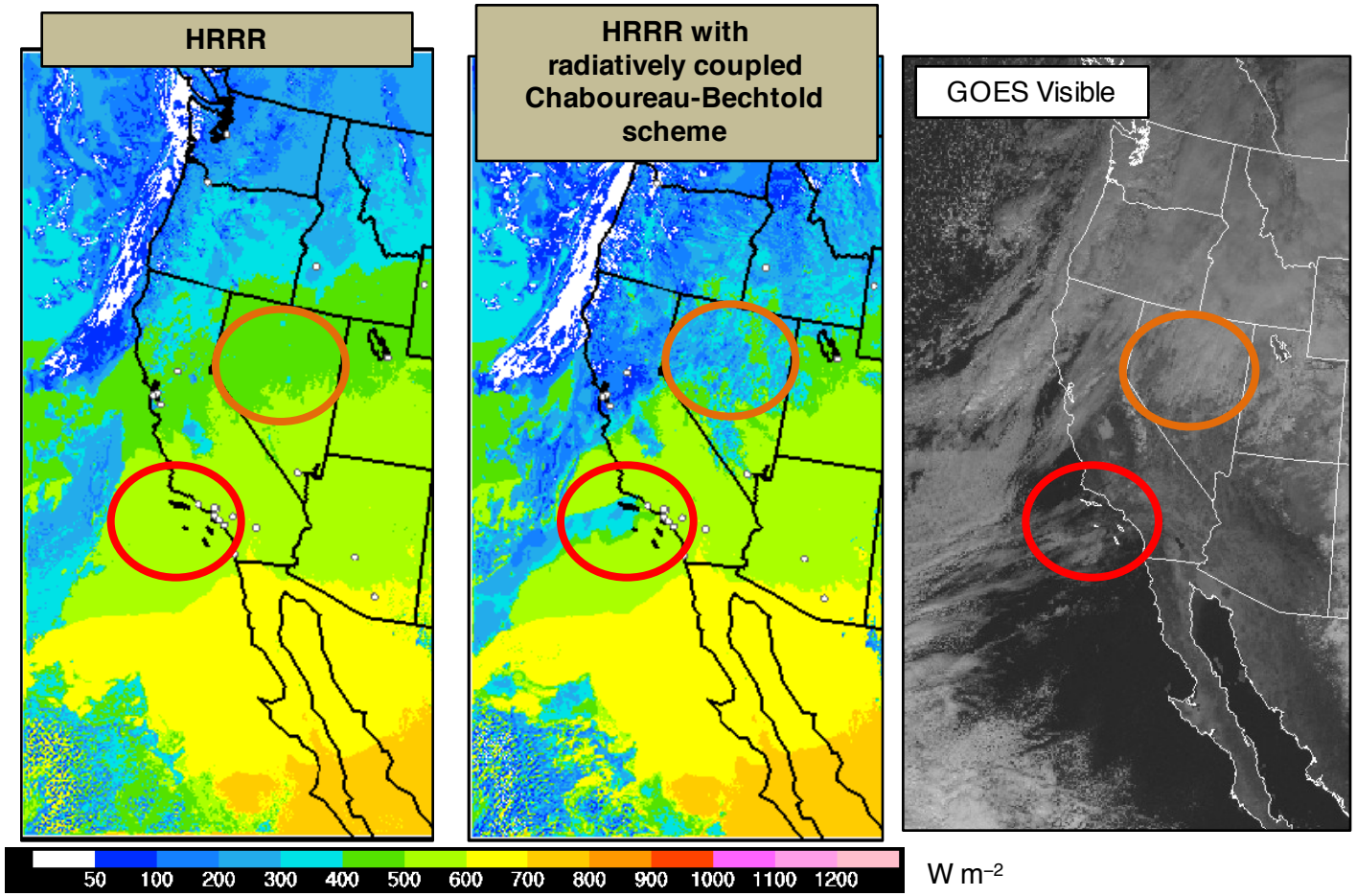


750m HRRR WFIP2 nest

3km HRRR US domain



Example: HRRR 1-h GHI Forecasts Valid 19 UTC 27 Dec 2015

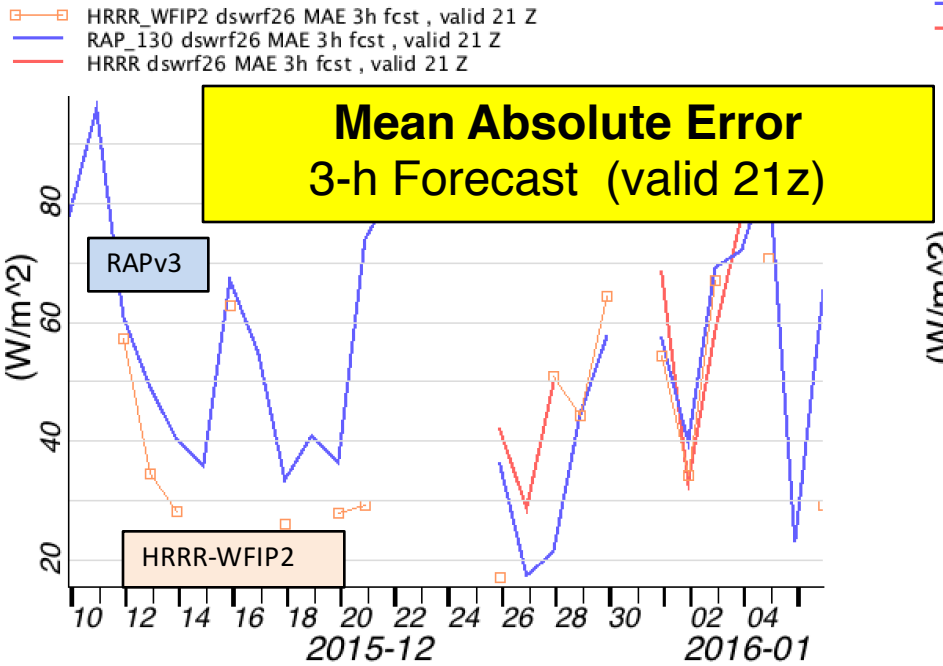


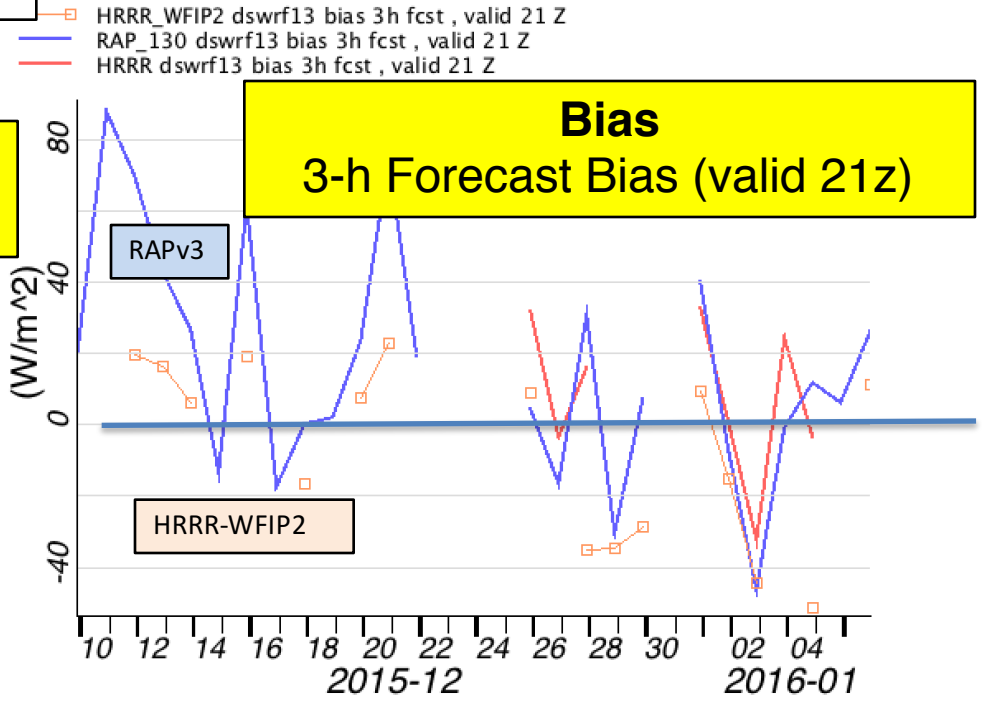
- Chaboureau and Bechtold (2002) scheme provides additional source of subgrid clouds for radiative flux forecasts

RAP/HRRR Solar Irradiance (GHI) Errors

RAPv3 (ESRL)
HRRR-WFIP2 w/ CB subgrid cloud within MYNN PBL

3-h Forecast Bias: 14-Station Daily Mean (SURFRAD/ISIS)

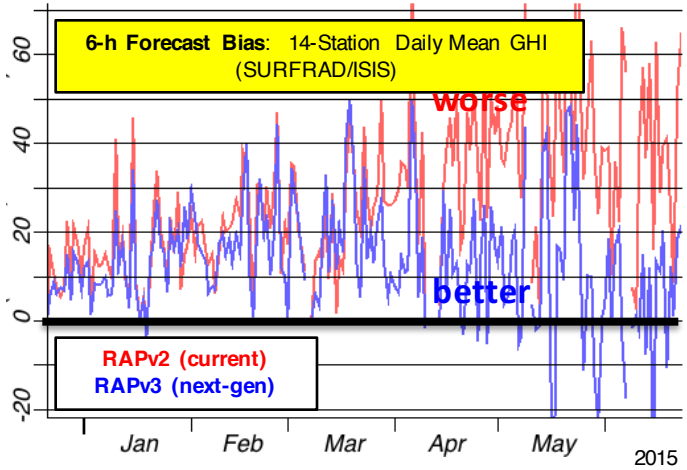




Summary – Part 1

Solar

- Improved forecasts of GHI by better representation shallow-cumulus (figure on right).
- Further improvements from better representation of stratus is necessary to fix remaining bias (figure on right).
- Aerosol-aware microphysics.
- Improved cloud/hydrometeor assimilation



Wind

- Promising test results for MYNN-MassFlux.
- More improvements from mixing length revision.
- Future development work: momentum flux in mass-flux scheme.

Ongoing Collaborations

- Solar Forecast Improvement Project (SFIP; Dept. of Energy) *(project on hiatus with NOAA/ESRL)*
- Wind Forecast Improvement Project II (WFIP2; Dept. of Energy)

http://rapidrefresh.noaa.gov/HRRRwfipsubh/Welcome.cgi
http://www.esrl.noaa.gov/psd/psd3/wfip2/

Summary – Part 2

- ***Progress toward Improved Solar Forecasts in HRRRv2/RAPv3 (ESRL now, NCEP May 2016)***
  - Energy-related improvements in HRRR/RAP also benefit severe-weather, aviation, hydrology forecasts
  - ***Direct SW, 15-min mean fields added to GHI in RAPv3/HRRRv2 output***

- Improved subgrid-scale cloud scheme in development
  - Provides representation of subgrid stratus, cirrus
  - In ESRL HRRRv3/RAPv4 starting March 2016