Reducing WRF's high bias of shortwave radiation reaching the ground using new fractional cloudiness scheme and aerosol direct radiative effectA

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Outline

Aerosol "indirect effects" (aerosol-cloud-precip-radiation)

- Aerosol-aware Thompson & Eidhammer (2014,JAS); mp_physics=28

Aerosol "direct effects" (solar dimming)

- Builds upon Jose Arias-Ruiz (aer_opt=2); aer_opt=3
- Uses the same aerosol variables used by microphysics scheme (QNWFA & QNIFA)
- Aerosol Optical Depth (AOD) computed in 3D

Cloud fraction scheme w/ RRTMG

- Existing icloud=1 replacement (which tends to give binary 0 or 1 CF)
- icloud=3 currently only connected with RRTMG
- developed from Mocko et al (1995) & Sundqvist et al (1989)
- infantile attempt for scale insensitive
- not dependent on shallow or deep cumulus parameterizations

WRF aerosol scattering/absorption options

aer_opt:

Option 0

- no link between aerosols and optical properties

Option 1

- use climatological 3D Aerosol Optical Depth, (AOD) values from ECMWF for six different aerosol types (black carbon, organic carbon, sea-salt, dust, sulfates and volcanic sulfate).
- No dependence on relative humidity (RH)

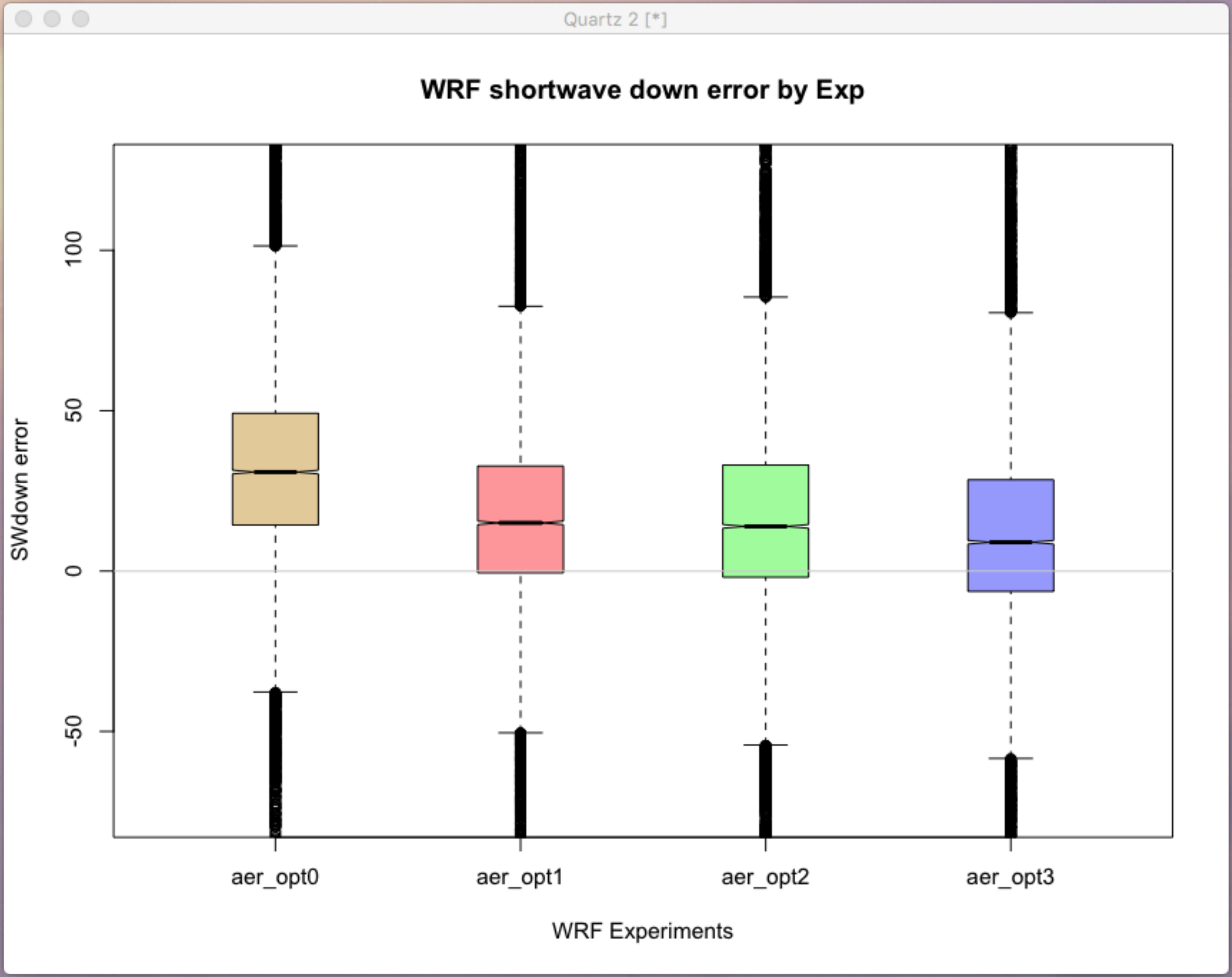
Option 2 (Ruiz-Arias)

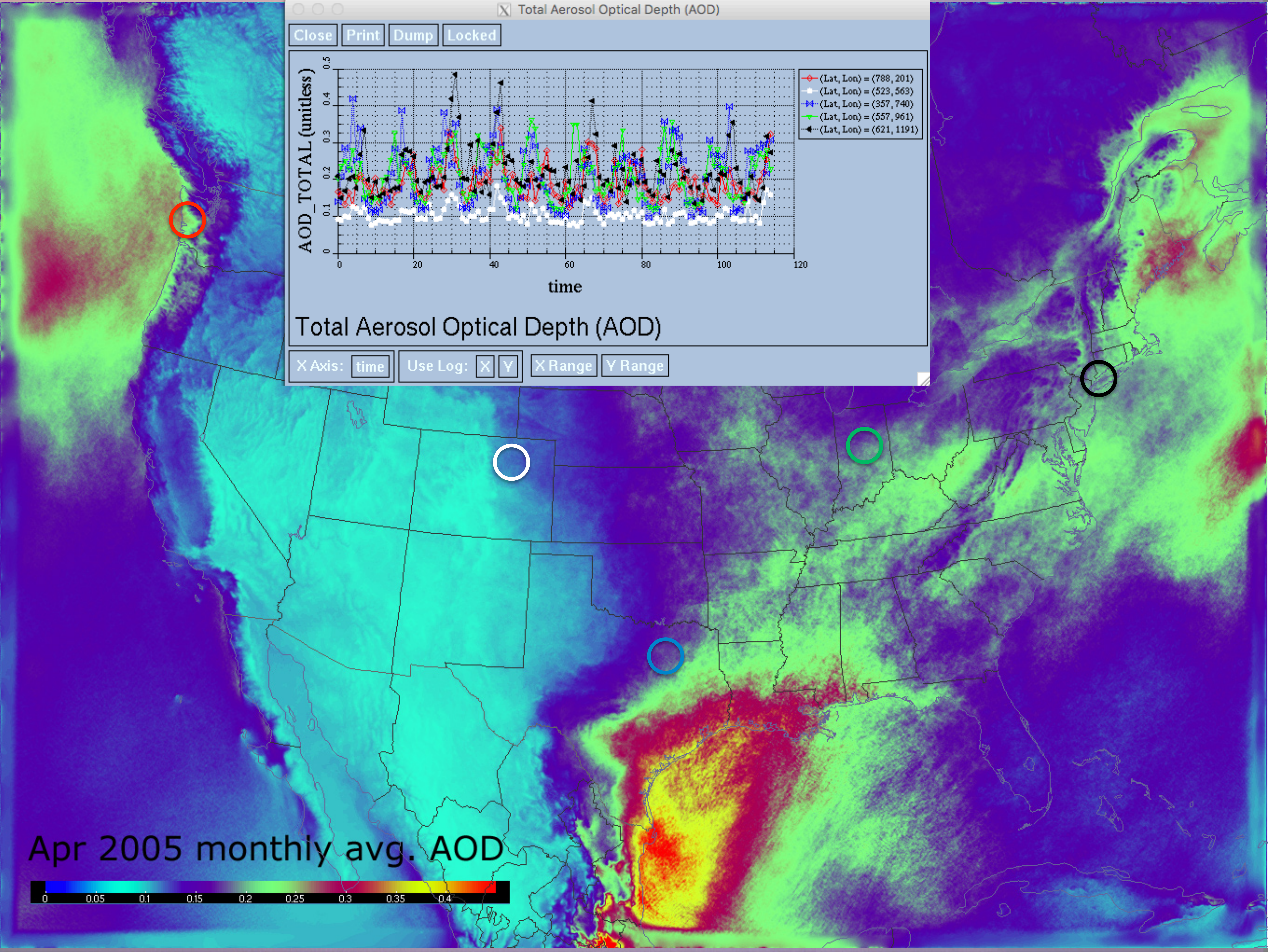
- 2D optical properties at 550 nm (AOD, + optional Angstrom exponent, single scattering albedo and asymmetry parameter) from input file.
  - Possibility to assume constant AOD over the entire domain
- Dependent on RH at the surface
- 2D optical parameters disaggregated into 3D based on assumed vertical aerosol distribution.
- Optical parameters at 550 nm disaggregated into other wavelengths, dependent on RH.

Option 3 (Eidhammer & Thompson)

- 3D optical properties at 550 nm (AOD, + optional Angstrom exponent, single scattering asymmetry parameter) evolve as the QNWFA and QNIFA aerosol variables evolve
- AOD calculation at each grid box and level applies RH (swelling) when calculating aerosol mean size
- computes 2D total AOD as diagnostic
- Same as option=2 with changing optical parameters at 550 nm applied to other wavelengths

Aerosol direct effect





Total Aerosol Optical Depth (AOD)
Close
Print
Dump
Locked
AOD_TOTAL (unitless)
0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
time
(Lat, Lon) = (788, 201)
(Lat, Lon) = (523, 563)
(Lat, Lon) = (357, 740)
(Lat, Lon) = (557, 961)
(Lat, Lon) = (621, 1191)
Total Aerosol Optical Depth (AOD)
X Axis:
time
Use Log:
X
Y
X Range
Y Range
Apr 2005 monthly avg. AOD
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

WRF cloud-radiation interactions

`icloud:`

Option 0

- ignore clouds entirely (solar radiation full strength through clouds)

Option 1

- clouds reflect solar and emit longwave radiation
- primitive cloud fraction scheme attributed to Xu and Randal
- rather typically creates binary zero or one, rarely produces “partly cloudy” pixels

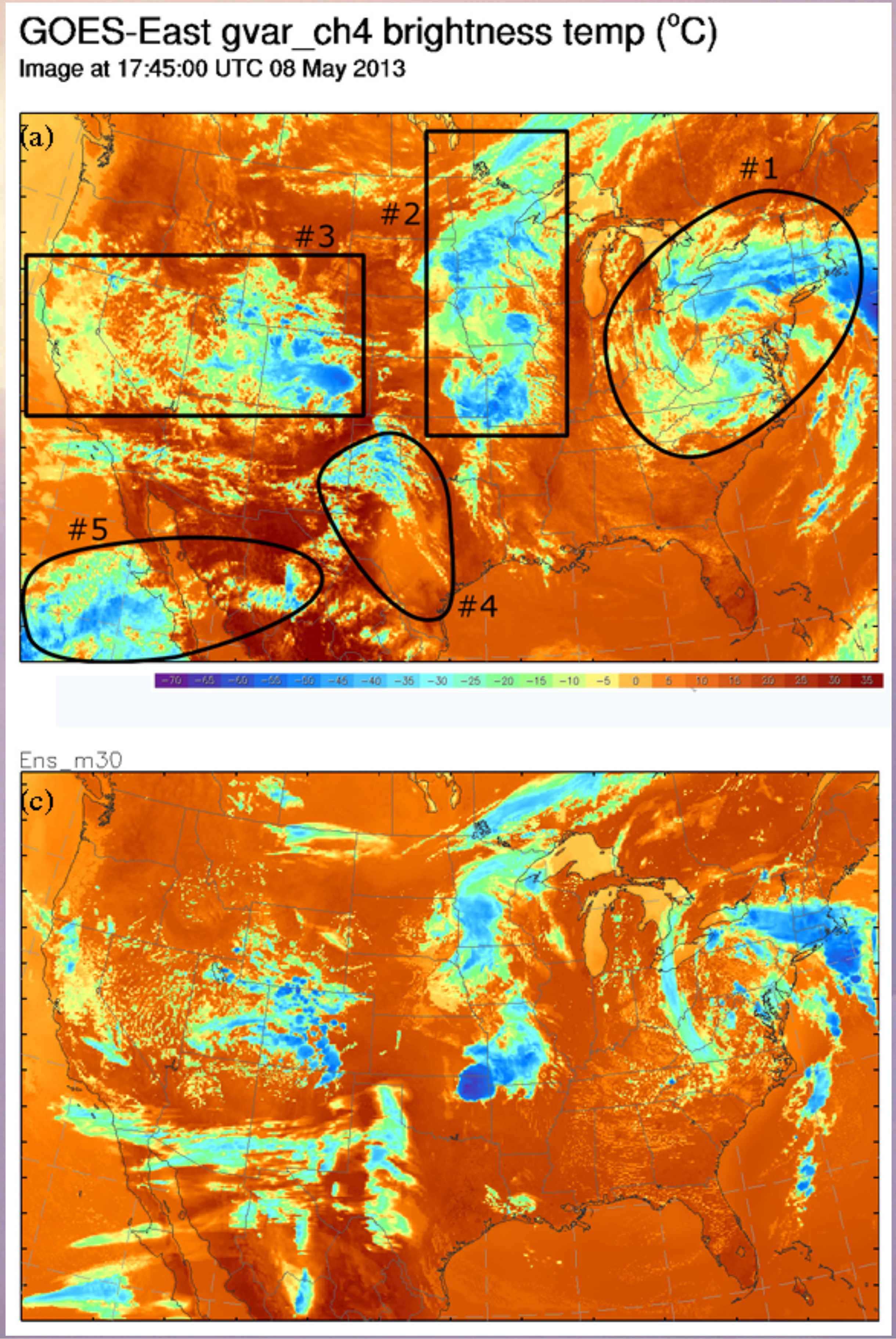
Option 2

- Explicit (MP-predicted) water/ice clouds gives 100% cloud fraction; zero water/ice clouds gives 0%

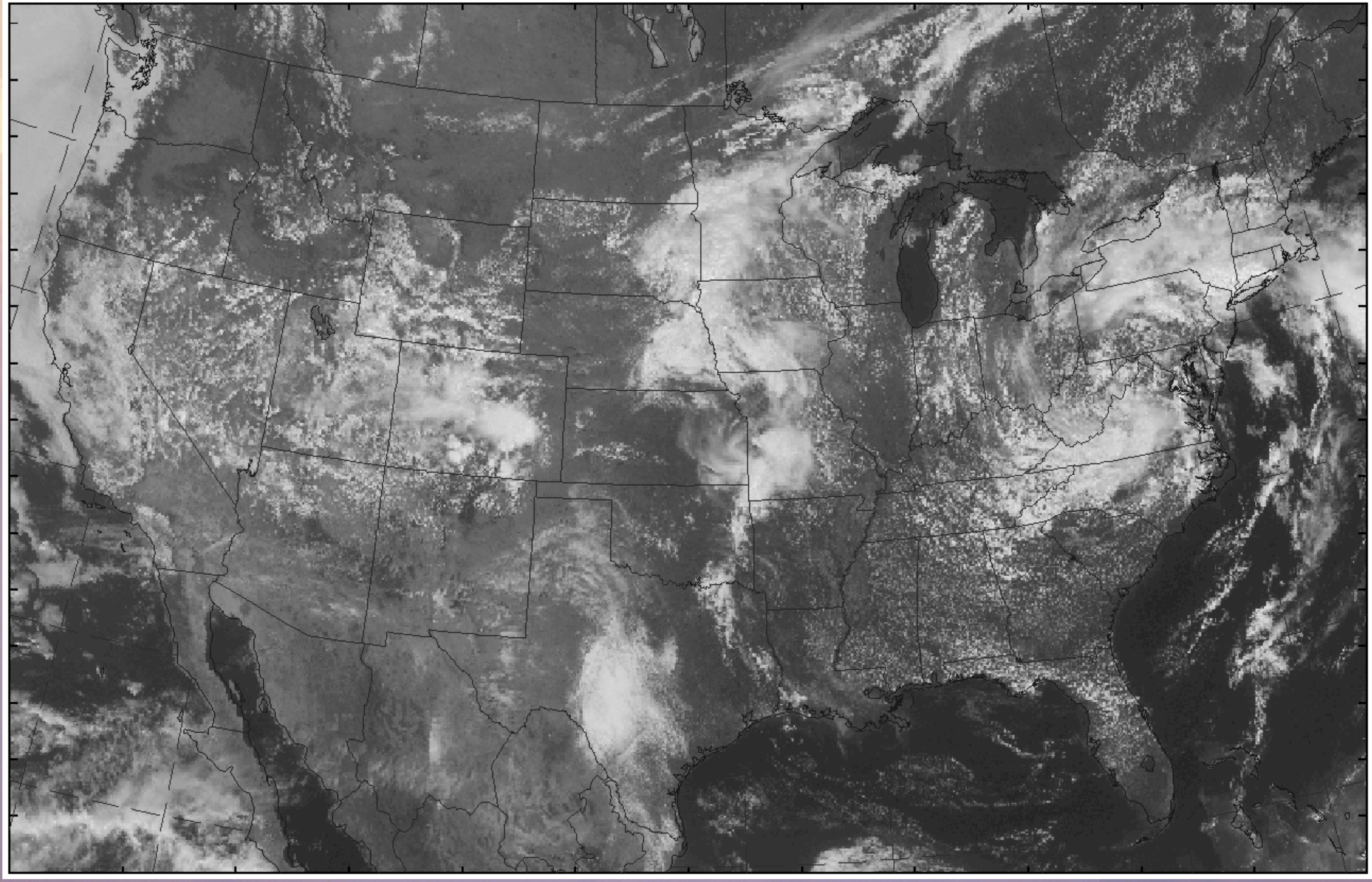
Option 3 (revised; update for V3.8.1)

- Existing grid-resolved (MP-scheme) water/ice clouds give 100% cloud fraction
- Sundqvist et al (1979) cloud fraction as function of RH; starting at RH-critical, which has an elementary grid-scale dependence
- RRTMG requires a liquid/ice water content (LWC/IWC) – seriously difficult
- Entrainment factor times adiabatic LWC/IWC in cloud layers (multiple WRF levels)
- Now incorporates Judith Berner’s “Stochastic Parameter Perturbation (SPP)” for entrainment factor

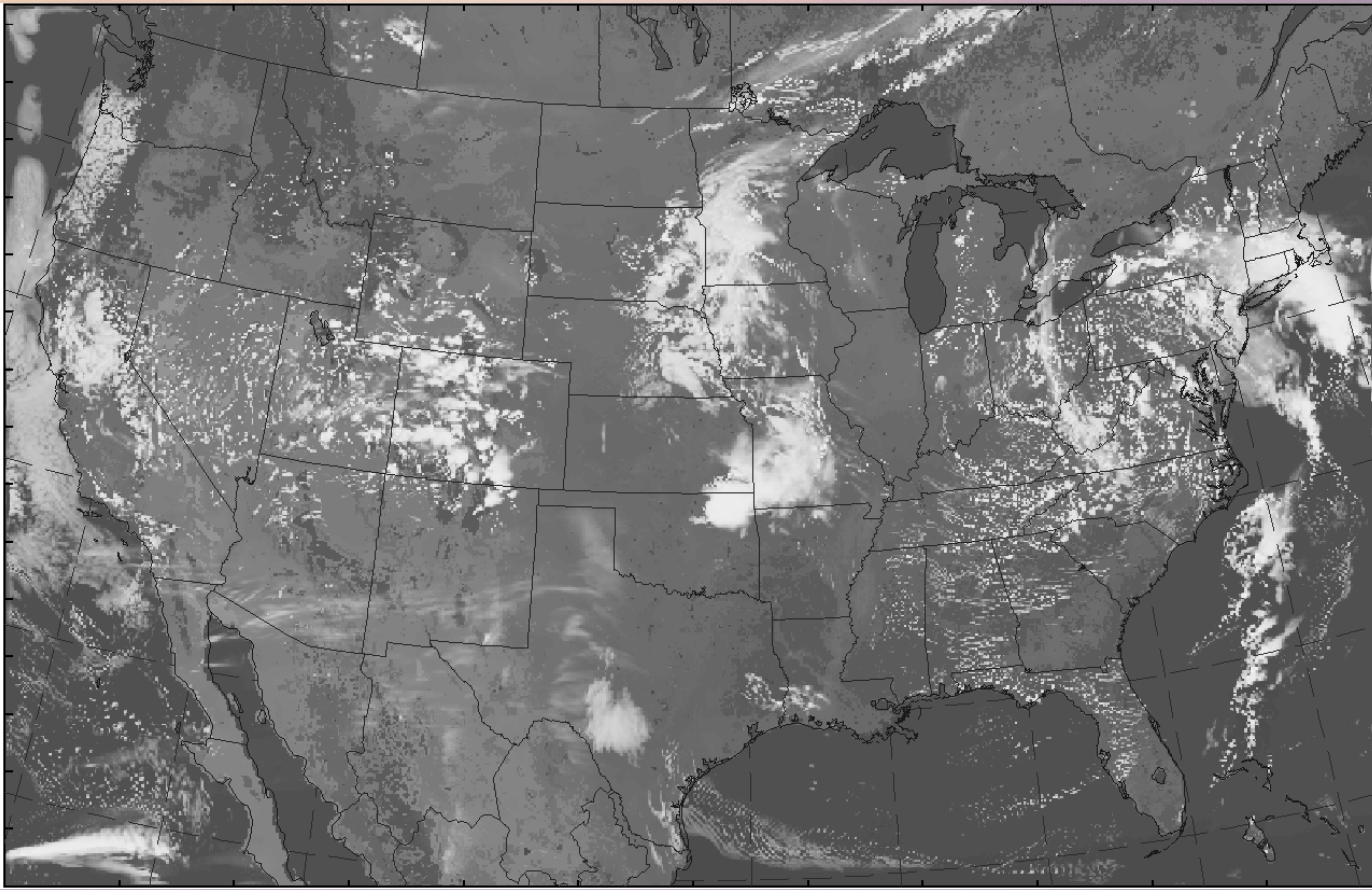
GOES vs. WRF synthetic satellite



GOES-13 Visible image 17:45 UTC 8 May 2013

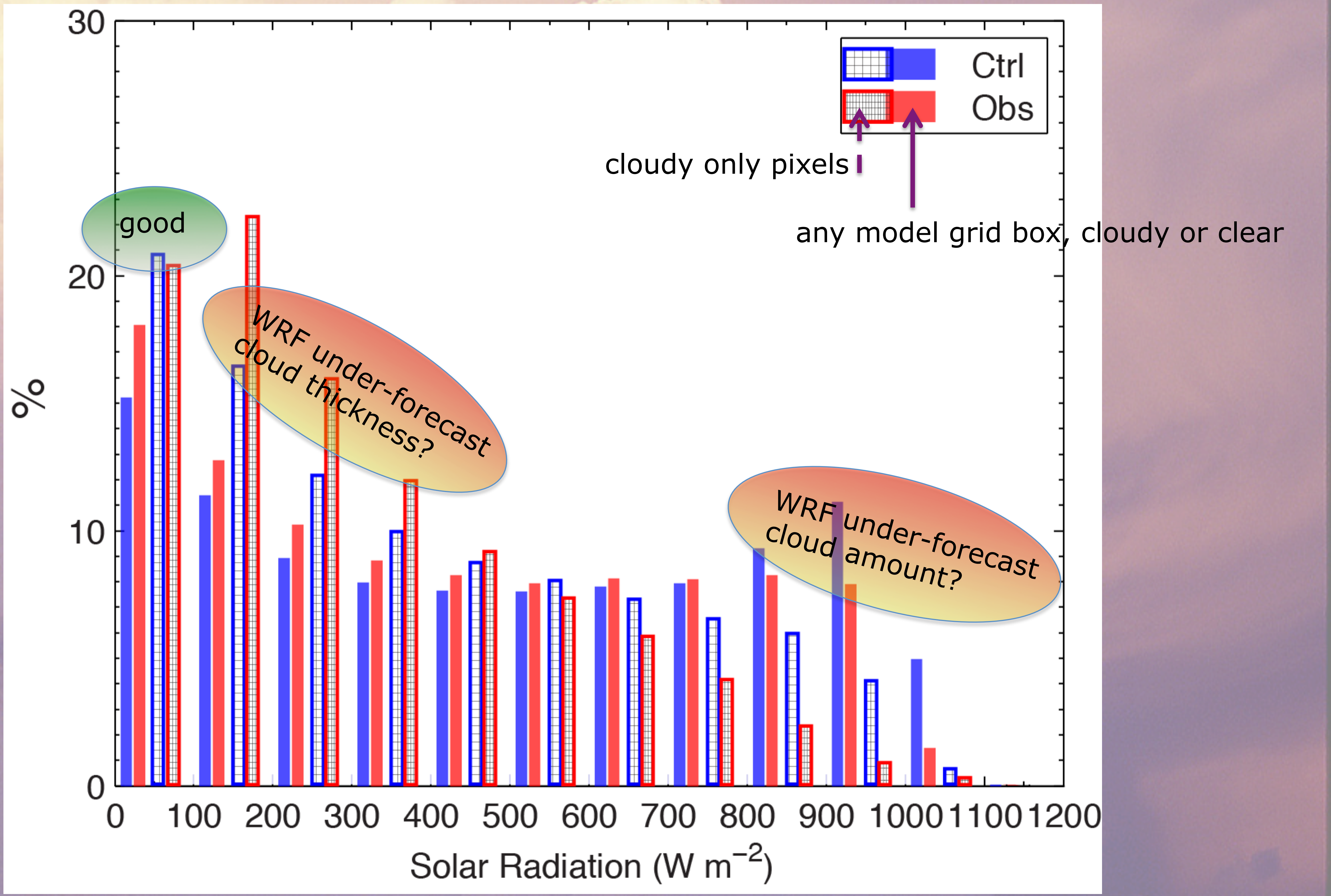


WRF pseudo-visible image 18:00 UTC 8 May 2013



Results: shortwave radiation

2013 all 28 days (control member) vs. USCRN data

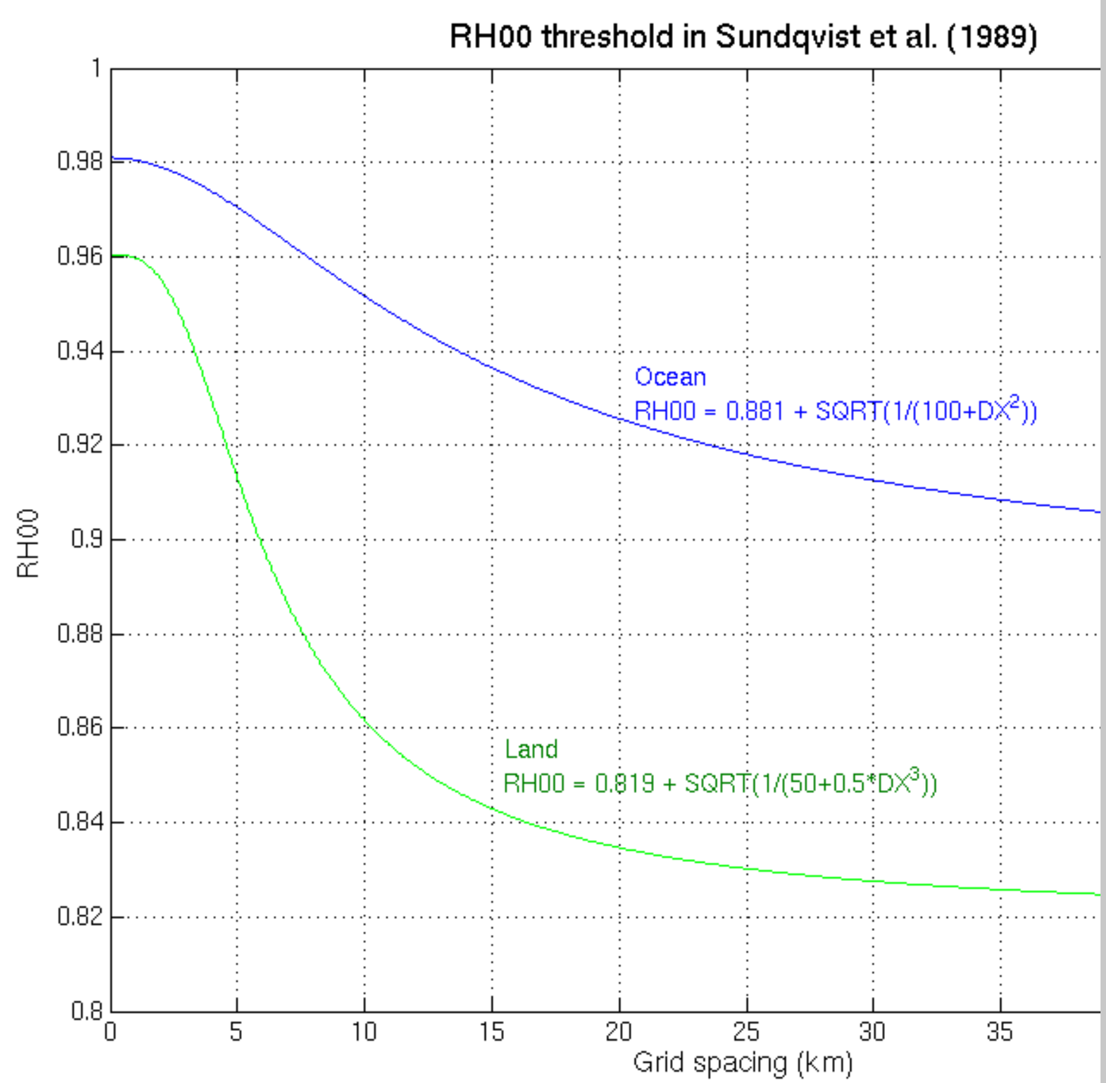


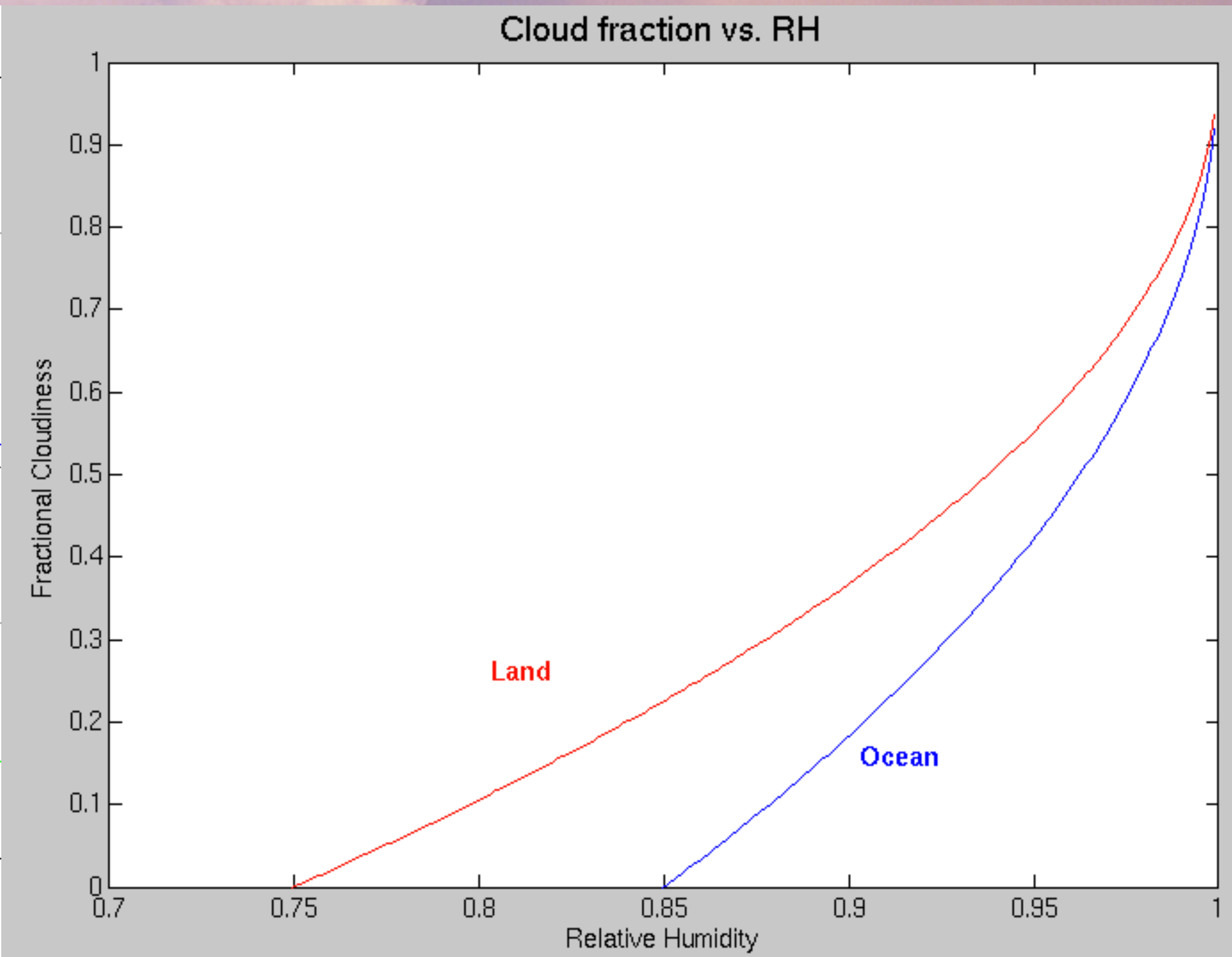
Thompson et al, 2016: Explicitly-coupled cloud physics and radiation parameterizations and subsequent evaluation in WRF high-resolution convective forecasts. *Atmos. Res.*, **168,** 92-104.A

Methodology: creating "artificial" clouds

Sundqvist et al (1989) cloud fraction

- Found by Mocko et al (1995) to work well in CSU-RAMS
- Adaptations/changes by G. Thompson:
  - RH-critical depends on DX
  - land vs. ocean points differ (warmer than -12C only)
  - overrides for sfc to LCL in case of well-mixed BL

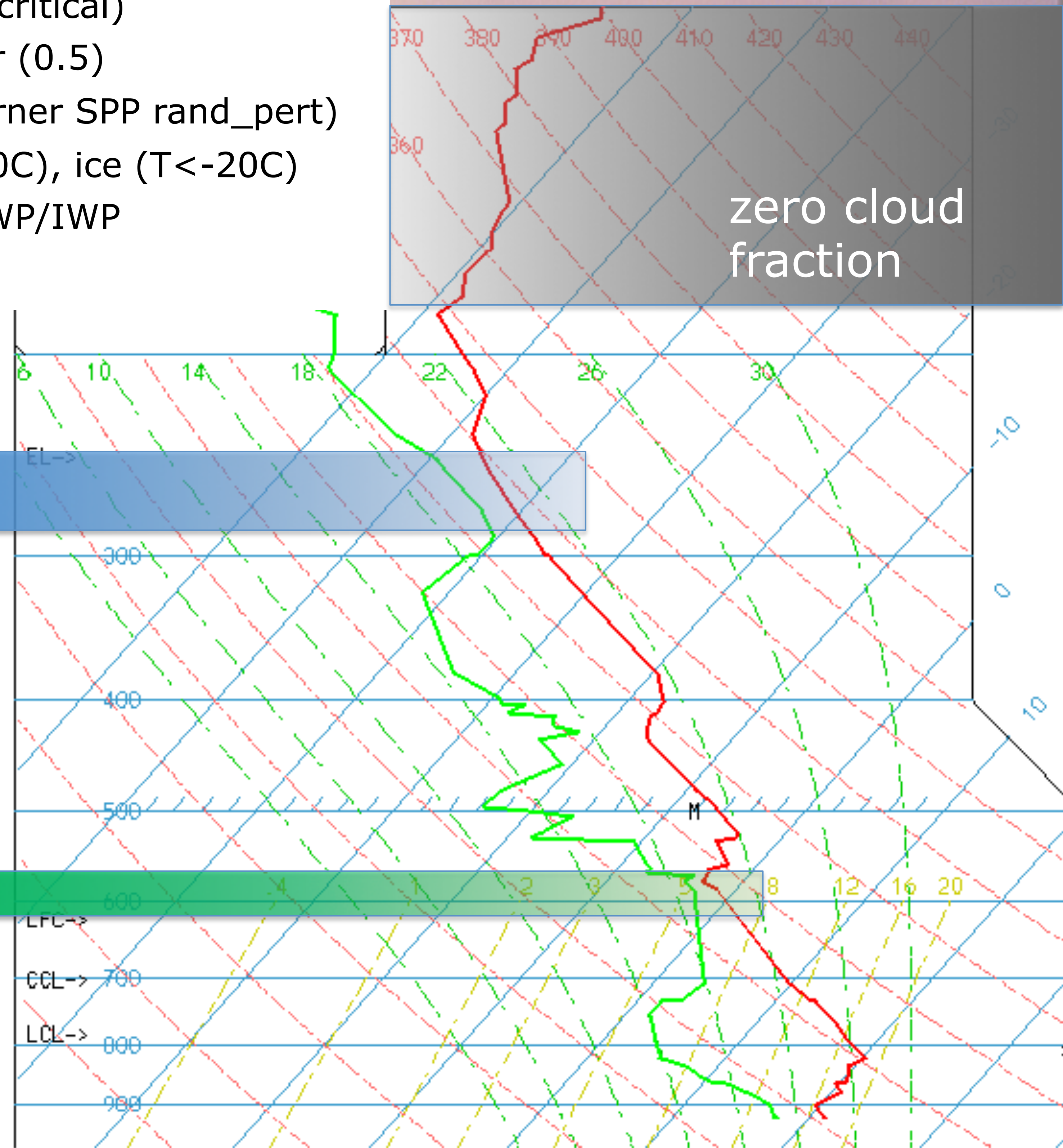




Methodology: creating "artificial" clouds

RRTM assumed LWC/IWC

- only below diagnosed tropopause
- multiple consecutive layers of clouds (RH > RH-critical)
- adiabatic water/ice content * entrainment factor (0.5)
- entrainment factor -> possibly stochastic (J. Berner SPP rand_pert)
- water clouds (T>-12C), mixed phase (-12 to -20C), ice (T<-20C)
- not permitted to make more than 1 mm total LWP/IWP

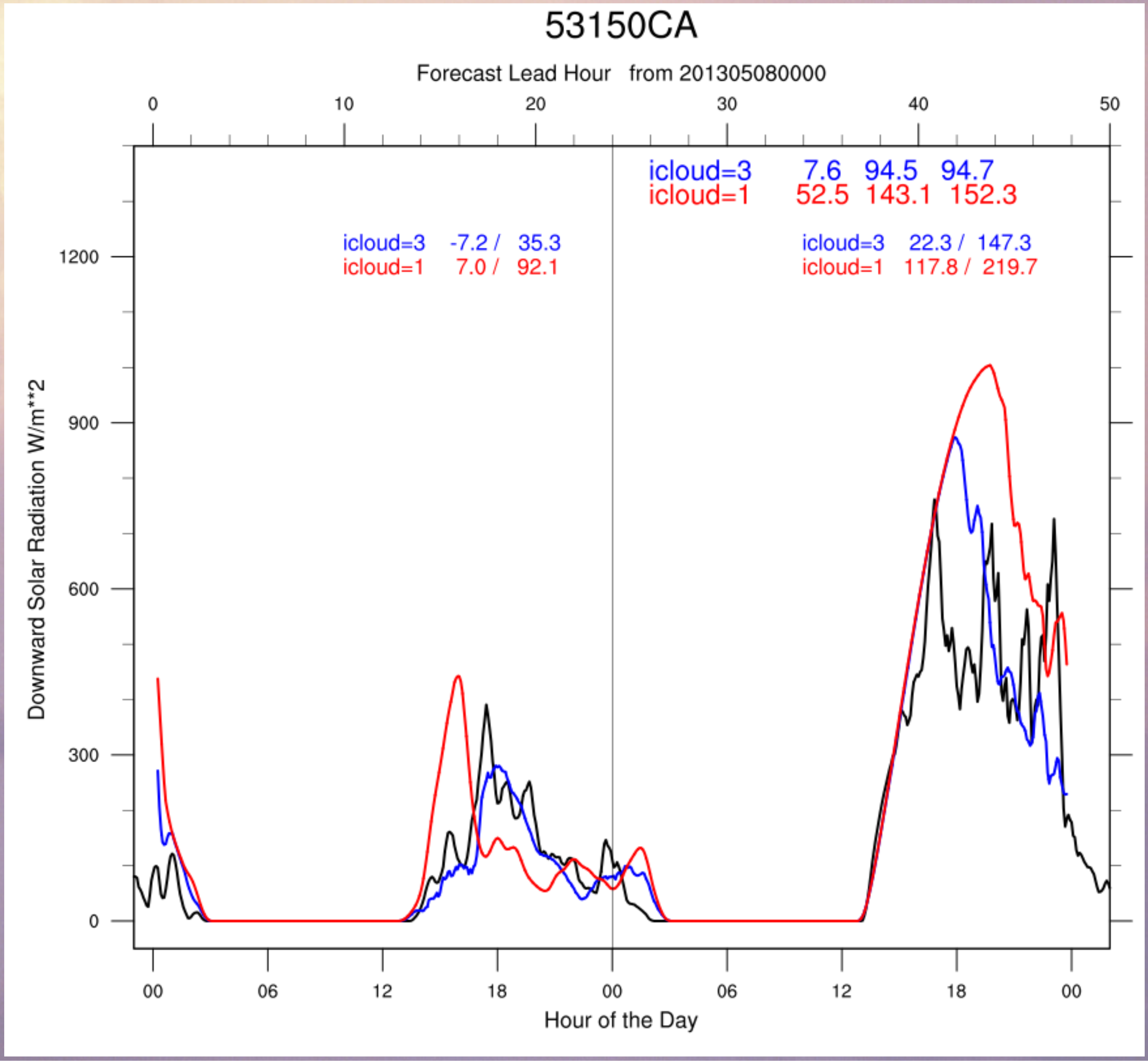


30% cloudy adjusted Q_i

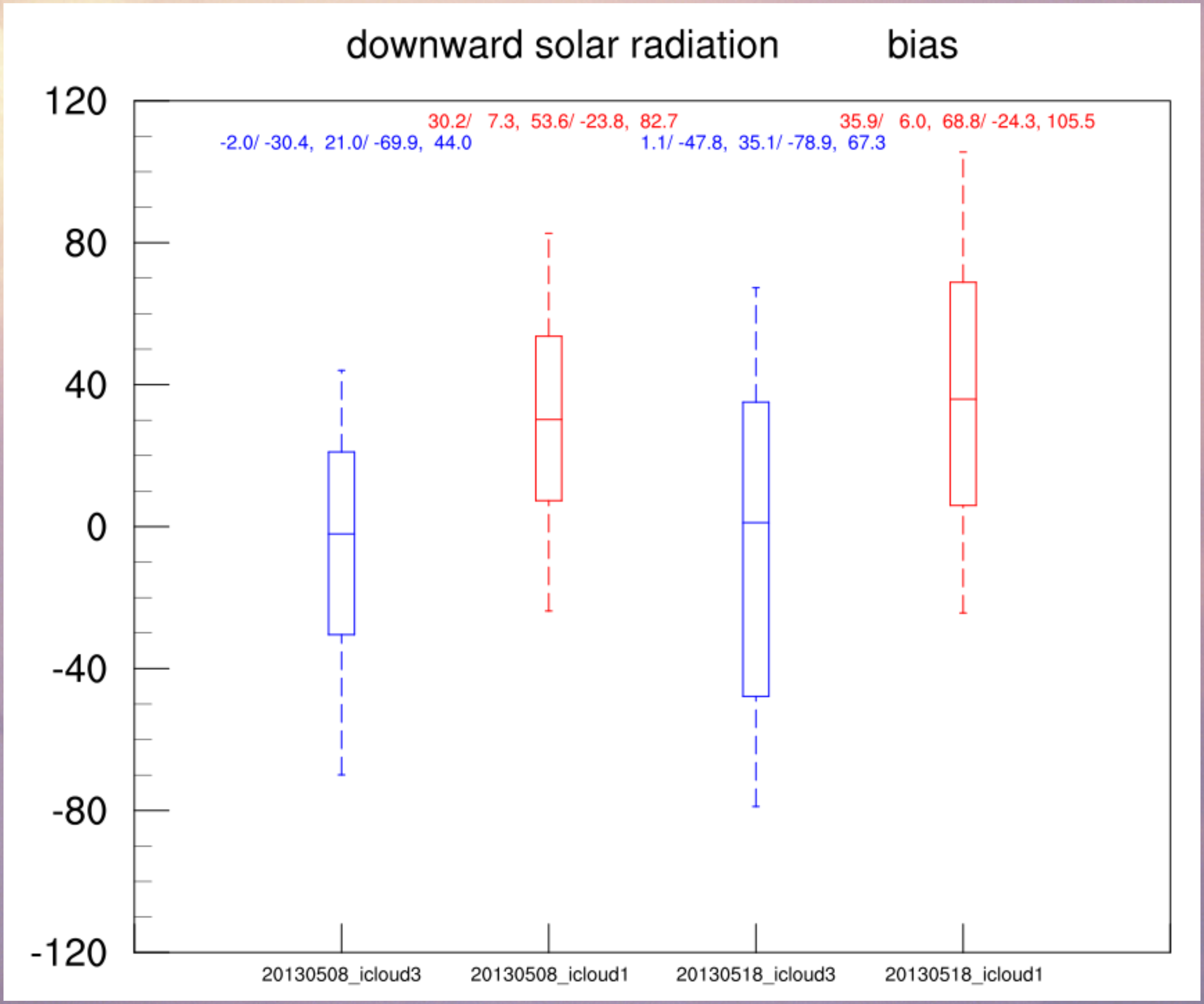
15-50% cloudy adjusted Q_w

USCRN radiation sites (116)

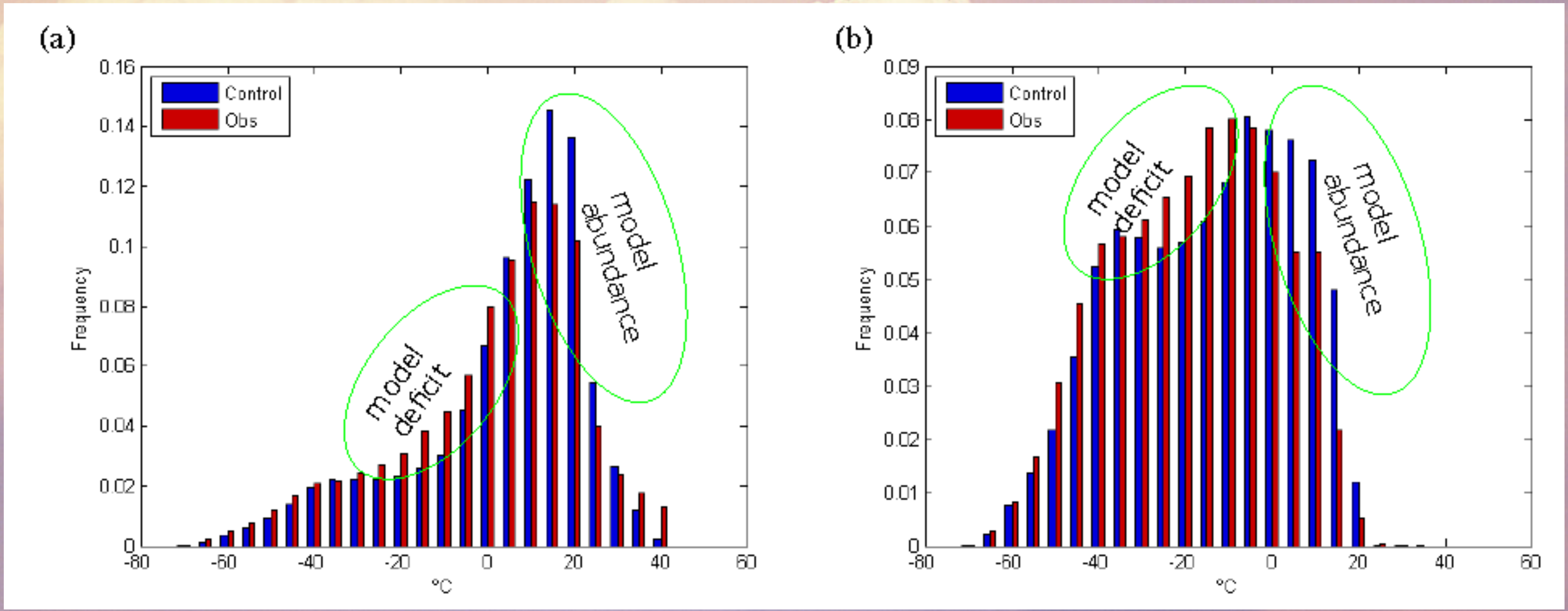
Preliminary Results



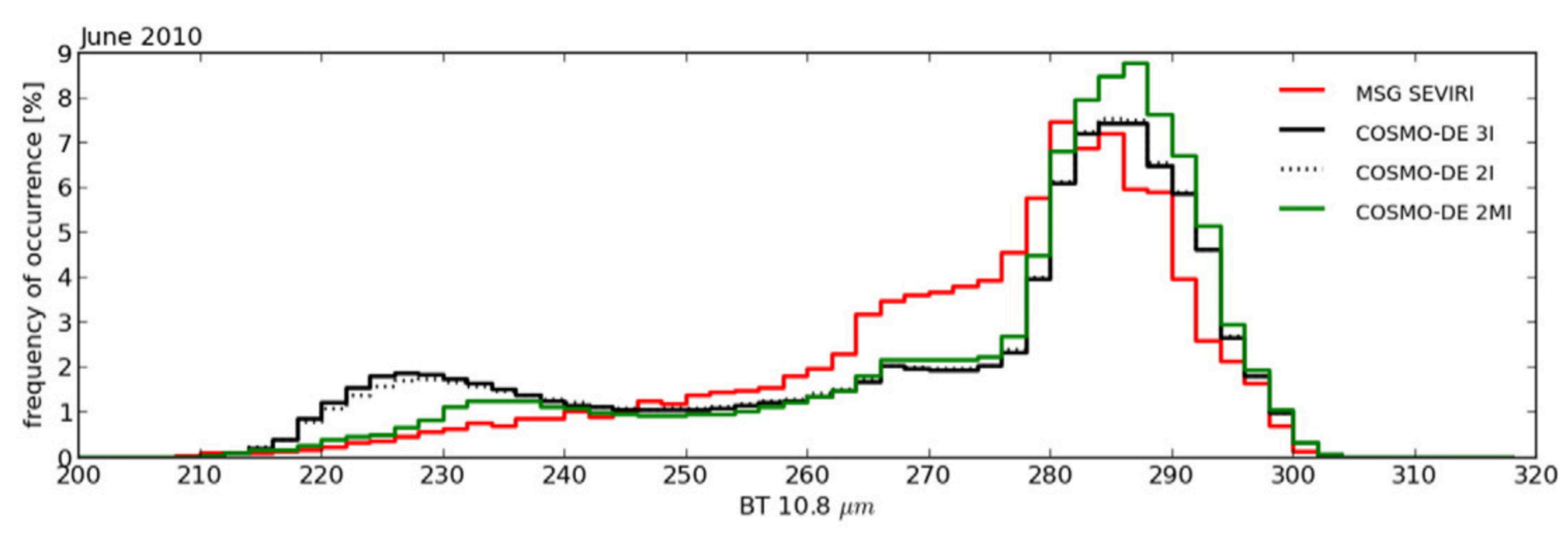
Preliminary Results



Results: cloud-top temp comparison



S. Eikenberg et al. / Atmospheric Research 156 (2015) 67–79



Conclusions

- Aerosol direct radiative effects now considered (aer_opt=3)
  - Same aerosol species as microphysics considers
  - Not yet treating black carbon, i.e., forest fires
- Newly introduced cloud fraction scheme (icloud=3)
  - Alternative scheme to icloud=1
  - only RRTMG radiation but potentially any microphysics scheme
  - Nicely reduces a 30-40 W/m^2 shortwave radiation bias (reaching ground) to near zero
  - Promotes the explicit creation of grid-resolved clouds due to LW cloud-top cooling effect
- More R&D needed:
  - DX dependency completely untested
  - 52-week tests to determine usefulness all-seasons
  - add-on with deep/shallow convection or excessive (double-counting)?
  - provide same “artificial” cloud amounts to turbulent mixing scheme?
  - incorporate concept directly into sub-grid condensation scheme?

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Thank you!!