

Inter-Comparison of the AFWA Operational and RRTMG-Replacement Configurations using WRFv3.3.1

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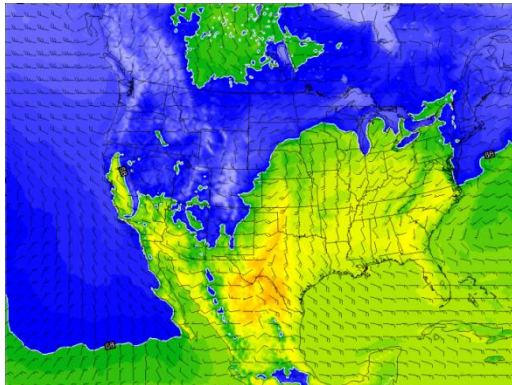
*National Center for Atmospheric Research
Research Applications Laboratory
and
Developmental Testbed Center*

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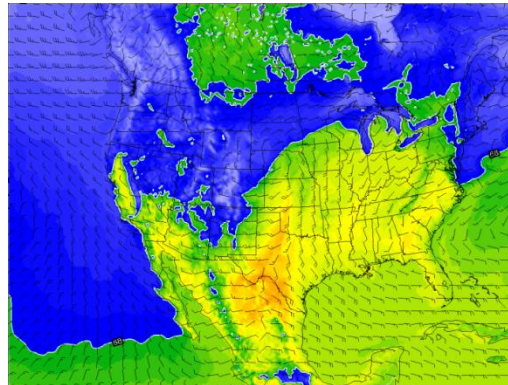
Overview

- **Motivation:** Assess performance of the updated Rapid Radiative Transfer Model (RRTMG) long- and short-wave radiation schemes
- **Experiment/Design:** Test two configurations – one based on the Air Force Weather Agency's (AFWA) Operational Configuration, and a second substituting AFWA's current operational long- and short-wave radiation schemes (RRTM/Dudhia) with the RRTMG radiation schemes
- **Results:** Overview of key verification results and computational demand of the two configurations

AFWA

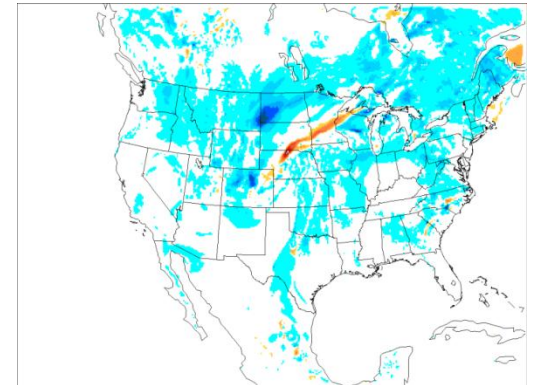


RRTMG



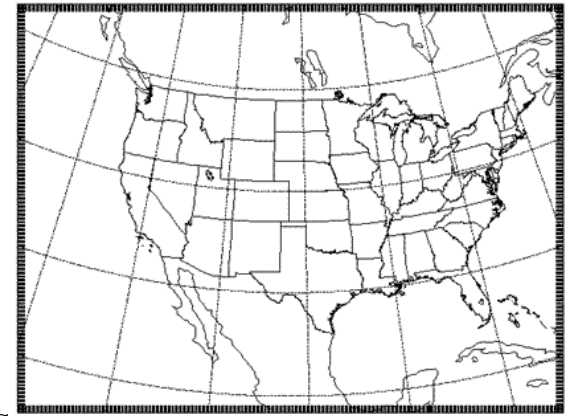
2-m Temperature

Difference (AFWA – RRTMG)



Experiment Design

- **End-to-end system:** WPS (v3.3.1), WRF (v3.3.1), UPP (v1.0), and MET (v3.0.1)
- **Test Period:** 2 June 2008 – 31 May 2009
- **Retrospective forecasts:** 48-h forecasts initialized every 36 h
- **Domain:** 15-km CONUS grid
- **Physics suite** for AFWA and RRTMG configurations.



WRF-ARW computational domain

Physics Suite	AFWA Configuration	RRTMG-replacement Configuration
Microphysics	WRF Single-Moment 5	WRF Single-Moment 5
Radiation (SW/LW)	Dudhia/RRTM	RRTMG/RRTMG
Surface Layer	Monin-Obukhov similarity theory	Monin-Obukhov similarity theory
Land Surface Model	Noah	Noah
PBL	Yonsei University	Yonsei University
Convection	Kain-Fritsch	Kain-Fritsch

Model Verification

- **Verification stratifications** include temporal and spatial aggregations
- **Grid-to-point** verification for surface and upper-air temp, dew point temp, and winds
 - BCRMSE and bias
 - GO Index
- **Grid-to-grid** verification for 3-h and 24-h QPF
 - GSS and frequency bias
- **Confidence intervals (CIs)** computed at the 99% level
- **Pair-wise difference** technique applied (**AFWA** – **RRTMG**)
- **Statistically significant (SS)** and **practically significant (PS)** differences identified
 - Large dataset increases number of pair-wise differences
 - SS: Objectively determined by using pair-wise difference technique
 - PS: Test results filtered to highlight pair-wise differences greater than a specified value



CONUS verification domain

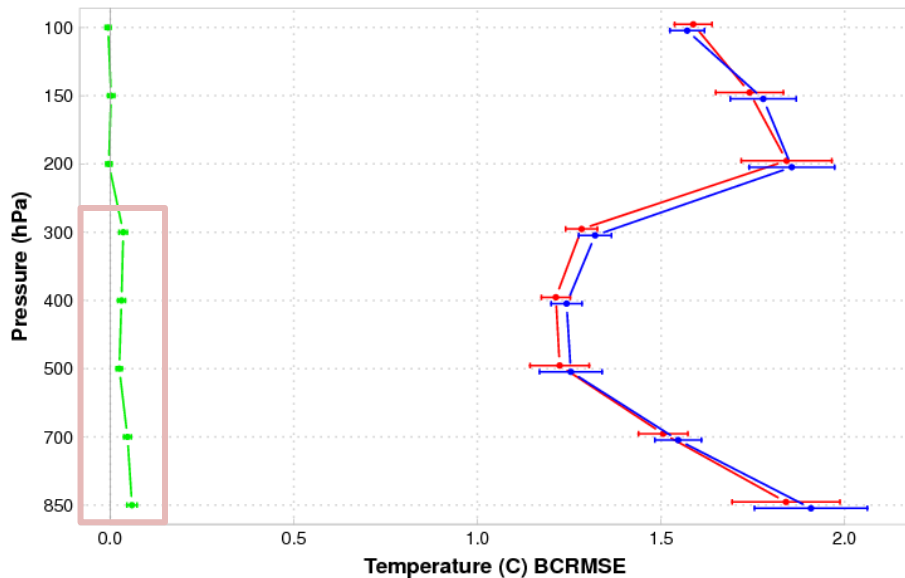
Verification Results

AFWA Operational Configuration (AFWA)

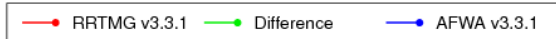
RRTMG-replacement Configuration (RRTMG)

Upper Air Temperature

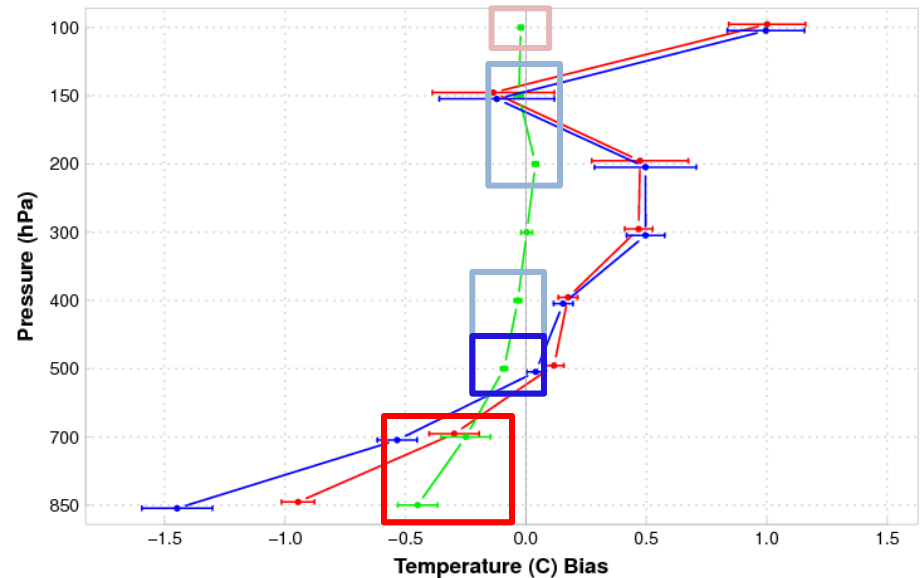
Temperature BCRMSE over CONUS Domain
Annual Aggregation: 48-h Lead Time



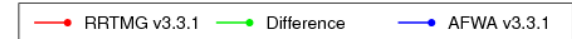
IH=00 and 12 UTC CASES=YEAR CI=99%



Temperature Bias over CONUS Domain
Annual Aggregation: 48-h Lead Time



IH=00 and 12 UTC CASES=ANNUAL CI=99%



Upper Air SS/PS (AFWA – RRTMG)

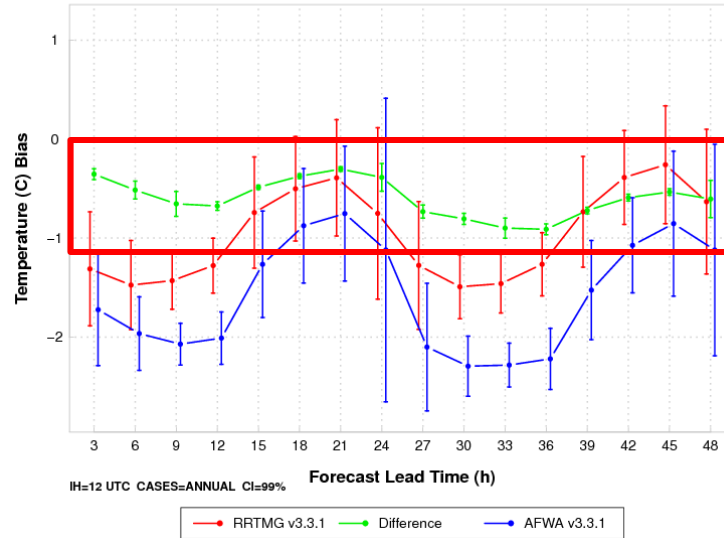
SS (light shading) and PS (dark shading) differences for the annual aggregation of upper air temperature and dew point temperature *BCRMSE* and *bias*

Upper Air Temperature		Annual				Summer				Winter			
		f12	f24	f36	f48	f12	f24	f36	f48	f12	f24	f36	f48
BCRMSE	850	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
	700	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
	500	--	RRTMG	RRTMG	RRTMG	--	--	--	--	--	RRTMG	RRTMG	RRTMG
	400	RRTMG	RRTMG	RRTMG	RRTMG	--	--	--	--	RRTMG	RRTMG	RRTMG	RRTMG
	300	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	--	--	RRTMG	RRTMG	RRTMG	RRTMG
	200	--	--	AFWA	--	--	--	--	--	--	--	--	--
	150	--	--	--	--	--	AFWA	AFWA	AFWA	--	--	--	--
	100	RRTMG	--	AFWA	--	--	--	--	--	RRTMG	--	--	--
Bias	850	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	--	RRTMG	RRTMG	RRTMG
	700	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	--	RRTMG	RRTMG	RRTMG
	500	--	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	--	--	RRTMG	RRTMG
	400	--	--	AFWA	AFWA	RRTMG	RRTMG	--	--	AFWA	AFWA	AFWA	AFWA
	300	--	--	RRTMG	--	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA
	200	--	RRTMG	RRTMG	RRTMG	--	--	--	--	RRTMG	RRTMG	RRTMG	RRTMG
	150	AFWA	AFWA	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA	--	--	--	--
	100	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	--	--	--	--
Upper Air Dew Point Temperature		Annual				Summer				Winter			
		f12	f24	f36	f48	f12	f24	f36	f48	f12	f24	f36	f48
BCRMSE	850	RRTMG	RRTMG	RRTMG	RRTMG	--	--	RRTMG	RRTMG	RRTMG	--	RRTMG	--
	700	RRTMG	--	--	--	--	--	--	--	RRTMG	RRTMG	--	--
	500	--	--	--	--	--	--	--	RRTMG	--	--	--	--
Bias	850	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	RRTMG	--	AFWA	AFWA	AFWA
	700	AFWA	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA
	500	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA

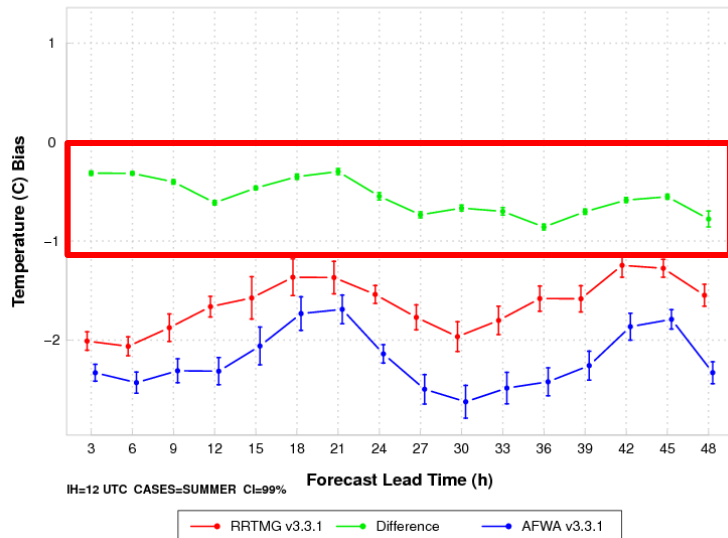


2-m Temperature

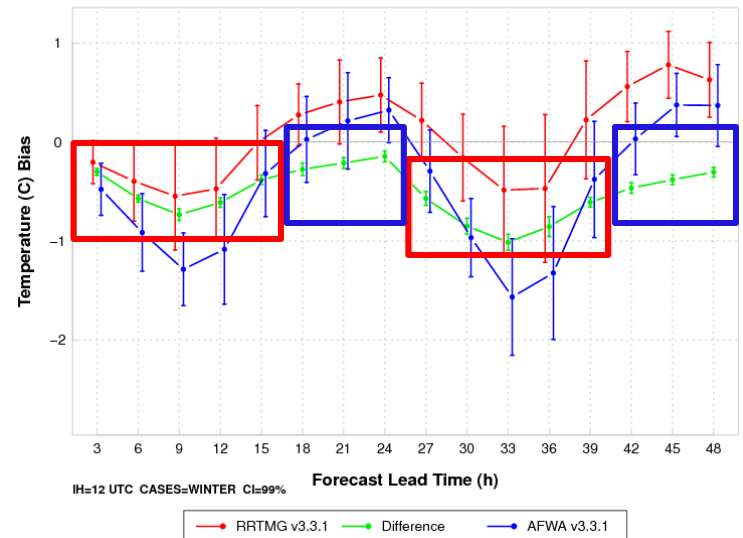
Temperature Bias over CONUS Domain
Annual Aggregation: 12 UTC Initialization



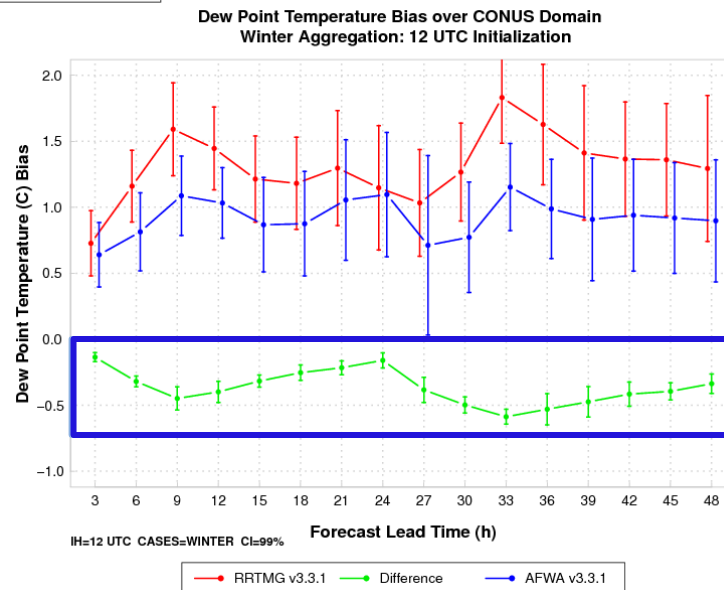
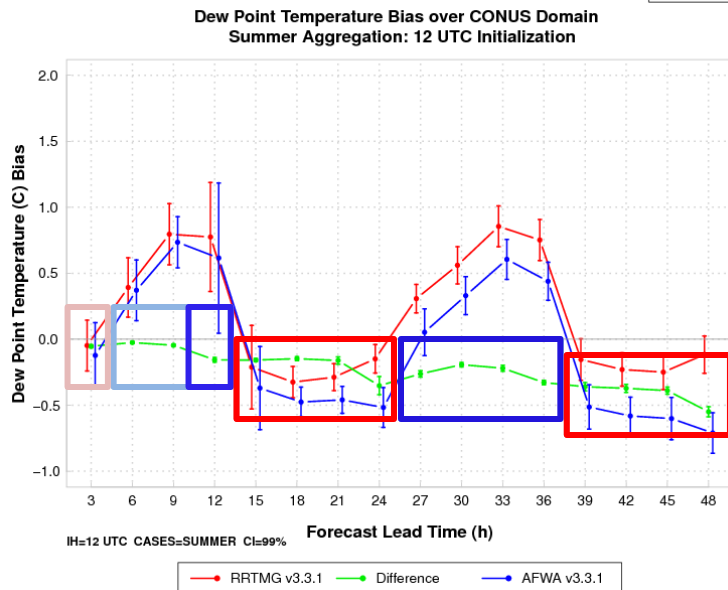
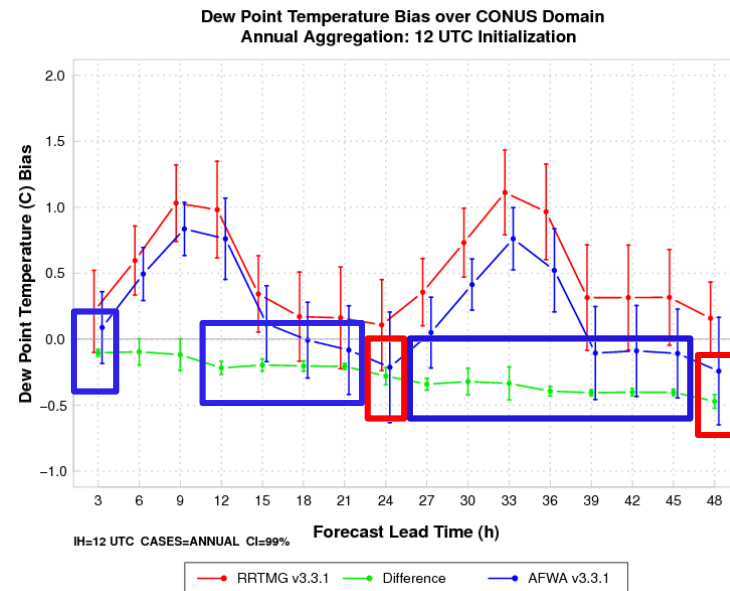
Temperature Bias over CONUS Domain
Summer Aggregation: 12 UTC Initialization



Temperature Bias over CONUS Domain
Winter Aggregation: 12 UTC Initialization



2-m Dew Point Temperature



2-m SS/PS Tables (AFWA – RRTMG)

SS (light shading) and PS (dark shading) differences for *BCRMSE* and *bias* by init time, lead time, and season

Surface Temperature			f03	f06	f09	f12	f15	f18	f21	f24	f27	f30	f33	f36	f39	f42	f45	f48	
BCRMSE	00 UTC Init	Annual	RRTMG	--	AFWA	--	RRTMG	--	--	RRTMG	--	--	--	RRTMG	RRTMG	RRTMG	--	RRTMG	
		Summer	RRTMG	--	--	RRTMG	RRTMG	AFWA	AFWA	--	RRTMG	--	RRTMG	RRTMG	--	--	--	--	RRTMG
		Winter	RRTMG	--	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	--	--	--	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
	12 UTC Init	Annual	--	--	--	RRTMG	--	--	--	--	RRTMG	RRTMG	--	RRTMG	RRTMG	RRTMG	--	--	RRTMG
		Summer	--	--	AFWA	--	RRTMG	RRTMG	--	RRTMG	RRTMG	--	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
		Winter	RRTMG	--	RRTMG	RRTMG	--	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	--	--	--
Bias	00 UTC Init	Annual	--	--	--	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	
		Summer	RRTMG	RRTMG	--	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	
		Winter	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	
	12 UTC Init	Annual	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	
		Summer	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	
		Winter	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	
Surface Dew Point Temperature			f03	f06	f09	f12	f15	f18	f21	f24	f27	f30	f33	f36	f39	f42	f45	f48	
BCRMSE	00 UTC Init	Annual	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	--	--	AFWA	AFWA	
		Summer	RRTMG	RRTMG	RRTMG	RRTMG	--	AFWA	AFWA	AFWA	--	--	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA	
		Winter	RRTMG	--	--	--	--	AFWA	AFWA	--	--	--	--	--	--	--	--	--	
	12 UTC Init	Annual	--	AFWA	AFWA	AFWA	AFWA	--	RRTMG	RRTMG	--	AFWA	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	
		Summer	--	AFWA	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA	--	RRTMG	RRTMG	RRTMG	
		Winter	--	AFWA	AFWA	--	--	--	--	RRTMG	RRTMG	--	AFWA	--	--	--	--	--	
Bias	00 UTC Init	Annual	--	--	--	--	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	RRTMG	AFWA	AFWA	AFWA	AFWA	
		Summer	RRTMG	RRTMG	--	RRTMG	AFWA	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA	
		Winter	RRTMG	RRTMG	RRTMG	RRTMG	--	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	
	12 UTC Init	Annual	AFWA	--	--	AFWA	AFWA	AFWA	AFWA	RRTMG	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	
		Summer	RRTMG	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	AFWA	AFWA	AFWA	AFWA	RRTMG	RRTMG	RRTMG	RRTMG	
		Winter	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	AFWA	



General Operations (GO) Index

- Skill scores (S) calculated for a variety of variables, levels, and lead times:

$$S = 1 - \frac{(RMSE_{RRTMG})^2}{(RMSE_{AFWA})^2}$$

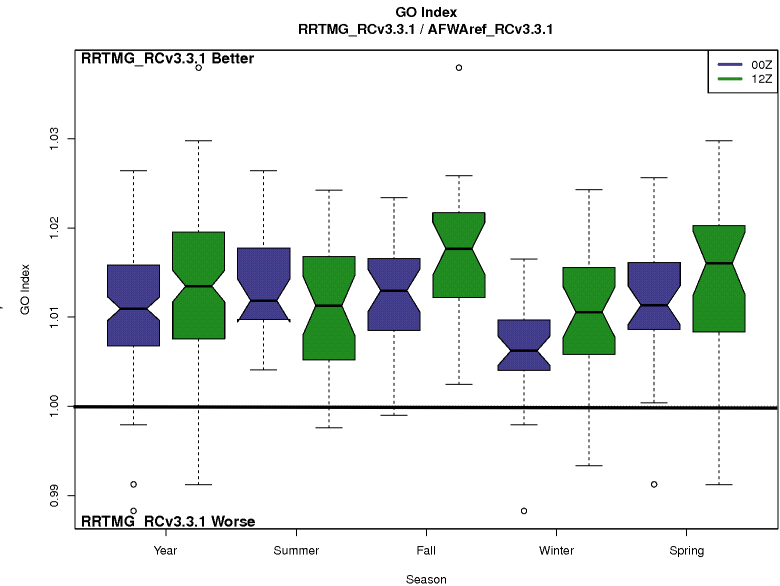
- Predefined weights (w_i) are applied for each variable, level, and forecast hour and are then and a weighted sum, S_w , is computed:

$$S_w = \frac{1}{\sum_i w_i} \left(\sum_i (w_i S_i) \right)$$

- Once S_w is computed, the index value (N) is defined as:

$$N = \sqrt{\frac{1}{1 - S_w}}$$

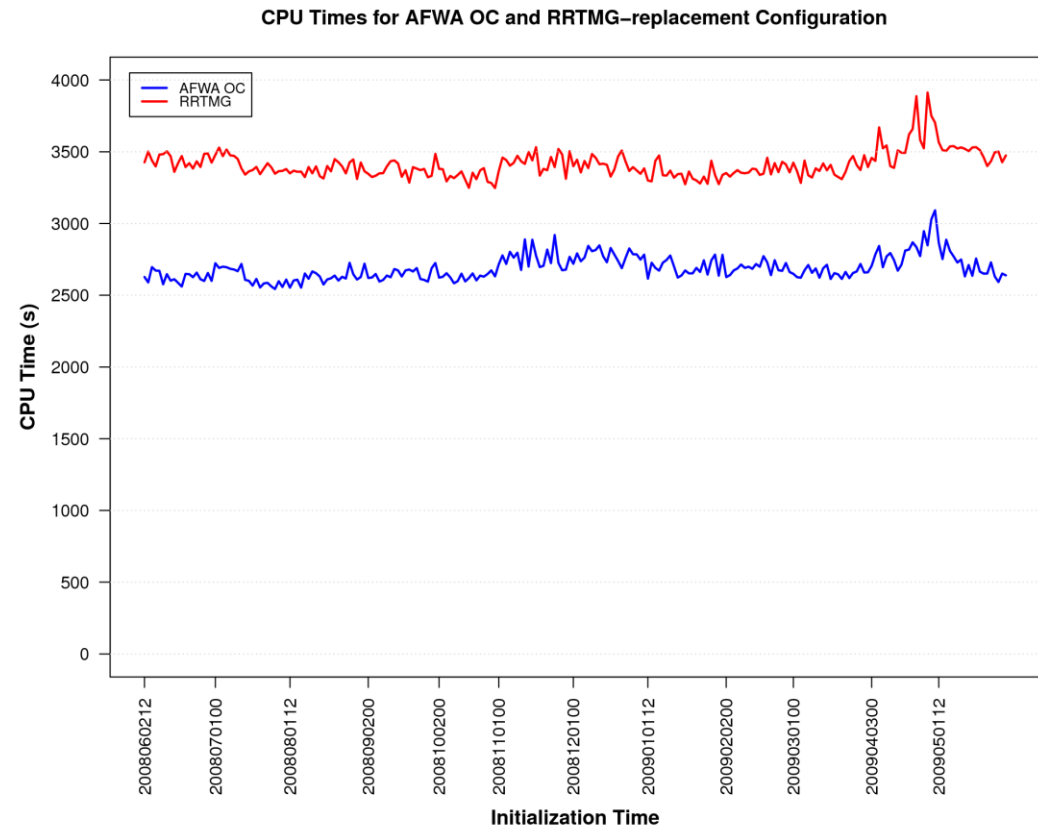
- Given this definition, N values *less than one* indicate the *AFWA configuration has higher skill* and values *greater than one* indicate the *RRTMG configuration has higher skill*



Regardless of initialization or temporal aggregation, the **RRTMG configuration displays more skill than the AFWA configuration**

Computational Efficiency

- CPU time required to run WRF calculated to assess computational demands on new radiation schemes
- Testing was conducted on an IBM system utilizing 64 processors
- **Updated RRTMG schemes** consistently displayed longer computational run times than the RRTM/Dudhia schemes, on average taking **~27% longer to run to completion**; however, updated RRTMG schemes **displayed increased forecast performance**



Key Verification Results

- **Upper air temperature bias:** PS pair-wise differences favoring the RRTMG configuration at and below 700 hPa
- **Upper air dew point temperature bias:** PS pair-wise differences generally favor the AFWA configuration, with exception to several lead times in the summer aggregation
- **Surface temperature bias:** SS/PS pair-wise differences predominantly indicate the RRTMG configuration is a better performer, with a consistent exception during the winter aggregation for forecast lead times valid between 06 – 09 UTC, which favor the AFWA configuration
- **Surface dew point temperature bias:** RRTMG configuration is generally favored during the overnight/early morning hours during the summer aggregation; for all other times, many PS differences are noted and favor the AFWA configuration
- **Surface wind BCRMSE:** Many SS pair-wise differences are seen, with nearly all favoring the RRTMG configuration, none are PS
- **Surface wind bias:** Many SS pair-wise differences are seen, with nearly all favoring the AFWA configuration, none are PS
- **GO Index:** Regardless of initialization or temporal aggregation, the RRTMG configuration displays more skill than the AFWA configuration



Summary & Current Activities

- Configuration descriptions, executive summaries, graphics, documentation, and a full suite of verification results from the inter-comparison of the AFWA operational and RRTMG-replacement configurations are found at: http://www.dtcenter.org/eval/afwa_test/
- Both configurations are designated as Reference Configurations with stand-alone verification results available at: <http://www.dtcenter.org/config/>
- Extensive T&E currently being conducted for AFWA:
 - Functionally similar operational environment, including integrating data assimilation with 6-hour “warm” start
 - Inter-comparison of Noah land surface model versions (WRFv3.3 vs. WRFv3.4)



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