Assessment of two planetary boundary layer schemes (ACM2 and YSU) within the Weather Research and Forecasting (WRF) model

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Introduction

The ***Weather Research and Forecasting (WRF)*** model is a mesoscale numerical weather prediction system utilized in both research and operational forecasting applications. The model is configurable to the users' requirements and suitable for a broad spectrum of weather regimes. The ***Air Force Weather Agency (AFWA)*** was interested in assessing a new combination of parameterizations for their operational configuration, including the Asymmetric Convective Model with non-local upward mixing and local downward mixing (ACM2) planetary boundary layer (PBL) scheme, the Pleim-Xiu two-layer land surface model (LSM) with vegetation and sub-grid tiling, and the Pleim-Xiu surface layer scheme. To address this request, the ***Developmental Testbed Center (DTC)*** performed a rigorous test and evaluation using the Advanced Research WRF (ARW) dynamic core. For this testing, the two configurations (see Table 1 below) will be referred to as ***AFWAOC*** and ***ACM2PX***.

Jonathan E. Pleim, 2007: A Combined Local and Nonlocal Closure Model for the Atmospheric Boundary Layer. Part I: Model Description and Testing. *J. Appl. Meteor. Climatol.*, **46**, 1383–1395.
Jonathan E. Pleim, 2007: A Combined Local and Nonlocal Closure Model for the Atmospheric Boundary Layer. Part II: Application and Evaluation in a Mesoscale Meteorological Model. *J. Appl. Meteor. Climatol.*, **46**, 1396–1409.
Aijun Xiu and Jonathan E. Pleim, 2001: Development of a Land Surface Model. Part I: Application in a Mesoscale Meteorological Model. *J. Appl. Meteor.*, **40**, 192–209.

Experiment Design

- **Code:**
  The end-to-end forecast system consisted of the WRF Preprocessing System (***WPS*** ***v3.6.1***, Gridpoint Statistical Interpolation (***GSI***) ***v3.3***, ***WRF v3.6.1***, Unified Post Processor (***UPP***) ***v2.2***, and Model Evaluation Tools (***MET***) ***v5.0***
- **Retrospective forecast period:**
  Forecasts were ***initialized every 36 hours*** with a ***6-hour "warm-start"*** spin-up (Fig. 1) from ***1 Aug 2013 – 31 Aug 2014*** and ***run out to 48 hours***

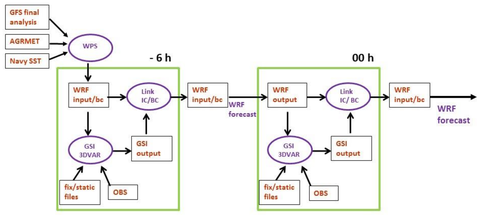


Figure 1. Data assimilation procedure using GSI

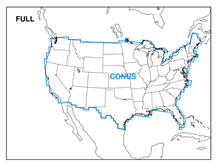


Figure 2. Computational domain (FULL) and verification domain (CONUS)

- **Model configurations:**
  A ***15-km contiguous U.S. (CONUS)*** grid (Fig. 2) was employed for this test to cover complex terrain, plains, and coastal regions in order to capture diverse regional effects for worldwide comparability

Table 1. Physics suites for AFWA Operational Configuration and ACM2PX replacement configuration

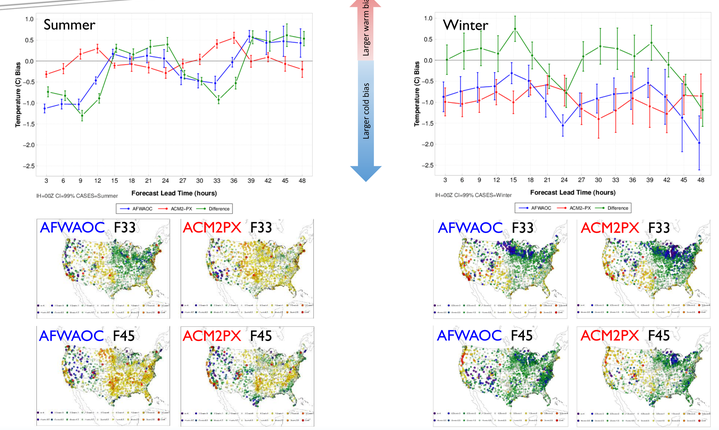
Physics Suite	AFWA Operational Configuration	ACM2PX replacement configuration
Microphysics	WRF Single-Moment 5 Scheme (opt 4)	WRF Single-Moment 5 Scheme (opt 4)
Radiation (sw/lw)	New Rapid Radiative Transfer Model (opt 4)	New Rapid Radiative Transfer Model (opt 4)
Sfc Layer	Monin-Obukhov Similarity Theory (opt 91)	Pleim Xiu (opt 7)
LSM	Noah (opt 2)	Pleim Xiu (opt 7)
PBL	Yonsei University Scheme (opt 1)	Asymmetric Convective Model 2 (opt 7)
Convection	Kain-Fritsch Scheme (opt 1)	Kain-Fritsch Scheme (opt 1)

Model Verification

- Stratified verification statistics temporally and spatially
- Computed confidence intervals (**CIs**) at the **99% level**
- Applied pair-wise difference methodology (**AFWAOC-ACM2PX**)
- Computed **statistical significance (SS)** and **practical significance (PS)**, where PS is determined by:
  WMO requirements for operational measurement uncertainty
  - Temperature and dew point temperature differences > 0.1K
  - Wind speed differences > 0.5 ms^{-1}
- **Grid-to-point verification:**
  Bias-Corrected Root Mean Square Error (BCRMSE) and ***Mean Error (Bias)*** for surface and upper-air ***temperature***, ***dew point temperature***, and ***wind speed***
- **Grid-to-grid verification:**
  Gilbert Skill Score (GSS) and ***Frequency Bias (Fbias)*** for ***3- and 24-hour precipitation accumulation*** intervals

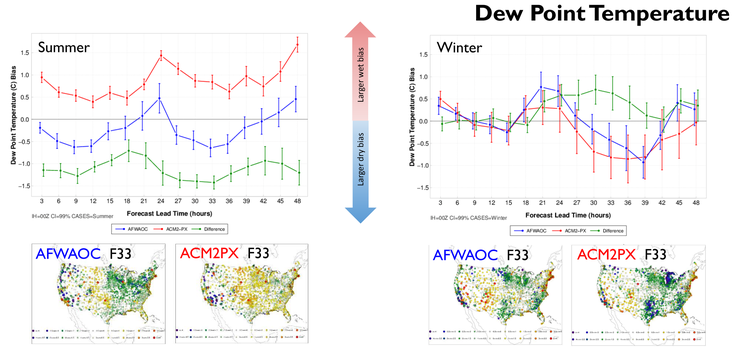
Season	Dates
Summer	Aug 2013, Jun-Aug 2014
Fall	Sep-Nov 2013
Winter	Dec 2013-Feb 2014
Spring	Mar-May 2014
Annual	Aug 2013-Aug 2014

Temperature



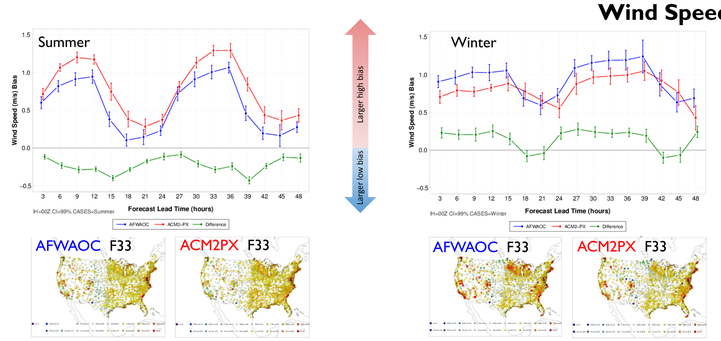
- Diurnal signal strongest in summer; AFWAOC: **SS** cold overnight, neutral/warm during day; ACM2PX: cold/neutral overnight, warm during day; Consistent cold bias for winter regardless of configuration or forecast hour
- Summer spatial plots: AFWAOC colder except Central US at F33, warmer across East at F45 vs. ACM2PX; Winter: strong cold bias in Upper-Midwest shifts east with ACM2PX at F33, and the West warms more at F45 vs. AFWAOC

Dew Point Temperature



- Regardless of configuration/season: Diurnal signal – drier overnight/early morning, wetter afternoon/evening
- Summer: ACM2PX consistently wetter than AFWAOC and has a **SS** wet bias for all lead times
- Winter: **SS** diffs beyond F18, but large CIs; AFWAOC median higher – better configuration depends on forecast hour
- Spatial plots: Largest differences between configurations over the eastern portions of US for summer/winter at F33; ACM2PX too wet in summer, too dry in winter; Both configurations too wet along northern East Coast both seasons

Wind Speed



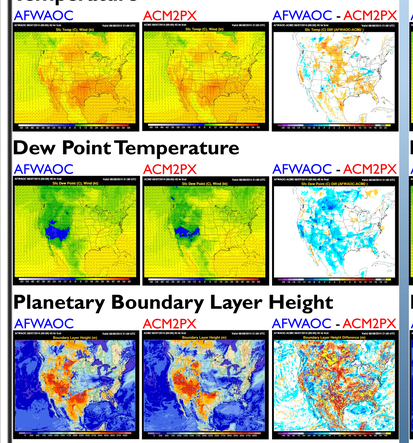
- Large diurnal signal with highest wind speed biases overnight and smallest during the day regardless of configuration
- Summer: AFWAOC has **SS** smaller biases at all forecast lead times
- Winter: ACM2PX has **SS** smaller biases during the overnight into early morning hours
- Spatial plots: Distribution of biases generally consistent between the two configurations; main exception showing stronger bias over Upper-Midwest and SW US during winter for AFWAOC

Table Summary Statistics

Forecast Hour		f03	f06	f09	f12	f15	f18	f21	f24	f27	f30	f33	f36	f39	f42	f45	f48
2m Temp	Annual	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	--	--	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	--	--	ACM2PX *
	Summer	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	AFWAOC *	AFWAOC *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *
	Fall	--	--	--	ACM2PX *	AFWAOC *	AFWAOC *	AFWAOC *	ACM2PX *	--	--	ACM2PX *	ACM2PX *	AFWAOC *	AFWAOC *	AFWAOC *	ACM2PX *
	Winter	--	--	--	--	AFWAOC *	--	ACM2PX *	ACM2PX *	--	--	--	--	--	--	ACM2PX *	ACM2PX *
	Spring	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	--	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *
2m Dew Point	Annual	AFWAOC *	AFWAOC *	ACM2PX *	ACM2PX *	AFWAOC *	AFWAOC *	--	--	AFWAOC *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	--	--
	Summer	AFWAOC *	AFWAOC *	ACM2PX *	ACM2PX *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *
	Fall	AFWAOC *	AFWAOC *	ACM2PX *	ACM2PX *	ACM2PX *	AFWAOC *	--	AFWAOC *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	ACM2PX *	--	--
	Winter	--	--	--	--	--	--	ACM2PX *	ACM2PX *	AFWAOC *	AFWAOC *	AFWAOC *	AFWAOC *	--	--	ACM2PX *	--
	Spring	AFWAOC *	AFWAOC *	ACM2PX *	ACM2PX *	AFWAOC *	--	ACM2PX *	ACM2PX *	--	--	--	--	--	--	--	--
10m Wind Speed	Annual	--	AFWAOC	AFWAOC	--	AFWAOC	AFWAOC	AFWAOC	--	--	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC
	Summer	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC
	Fall	AFWAOC	AFWAOC	AFWAOC	--	AFWAOC	AFWAOC	AFWAOC	--	--	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	AFWAOC	--
	Winter	ACM2PX	ACM2PX	ACM2PX	ACM2PX	ACM2PX	AFWAOC	--	ACM2PX	ACM2PX	ACM2PX	ACM2PX	ACM2PX	ACM2PX	AFWAOC	--	ACM2PX
	Spring	ACM2PX	--	--	--	AFWAOC	AFWAOC	AFWAOC	AFWAOC	ACM2PX	--	--	--	--	AFWAOC	AFWAOC	AFWAOC

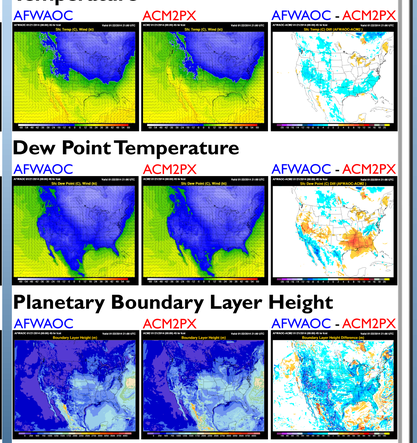
- Temperature: ACM2PX better when **PS** differences noted except during summer/fall between15-21 UTC valid times
- Dew Point: Fewest **PS** differences in winter/spring; AFWAOC **PS** better more often in summer, ACM2PX in fall
- Wind Speed: No **PS** differences; AFWAOC **SS** better except overnight/morning during winter

Summer Case Study
20140807 00 UTC F45 (valid 21 UTC)



- TMP: AFWAOC generally warmer through the Northern/Southern Plains states and across the SE US
- DPT: AFWAOC consistently drier over the West/South; Configurations similar across Great Lakes and NE US
- PBLH: Consistent with a warmer/drier surface, AFWAOC PBL heights are higher over Plains/SE US but trend toward higher heights over Nevada into the Pacific NW

Winter Case Study
20140121 00 UTC F45 (valid 21 UTC)



- TMP: AFWAOC generally colder across the West and South but warmer on the leeward side of the Great Lakes
- DPT: Varies by location; Areas where AFWAOC was colder tend to be wetter, AFWAOC is drier in extreme SW US
- PBLH: AFWAOC has consistently lower PBL heights across most of the US

An end-to-end sensitivity test was conducted to evaluate the resulting forecast performance when substituting AFWA's current operational PBL and land surface schemes. A large number **PS** differences between the two configurations was seen for temperature and dew point temperature. Results were strongly dependent on temporal and spatial aggregations, as well as valid time. In general terms, ACM2PX tended to outperform AFWAOC for temperature, while the opposite was true for dew point temperature. **SS** differences for wind speed indicated that AFWAOC is generally the better performer for all seasons except winter.

While surface variables are the focus of this presentation, additional vertical levels, as well as a precipitation analysis, was conducted. Further information about all aspects of the test are available on the project's webpage:
http://www.dtcenter.org/eval/meso_mod/afwa_test/wrf_v3.6.1/index.php

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