ALASKA NORTH SLOPE
WRF MODELING PROJECT

WRF METEOROLOGICAL MODELING:
SENSITIVITY STUDIES

Presented by Bart Brashers and Krish Vijayaraghavan, Ramboll

July 2020
OUTLINE

- INTRODUCTIONS AND ROLL CALL
- BRIEF REVIEW OF THE STUDY – WHY WE’RE HERE
- WRF SENSITIVITY TEST RESULTS
  - INPUT REANALYSIS DATASET
  - SEA SURFACE TEMPERATURE DATASET
  - NUMBER OF VERTICAL LEVELS
  - PLANETARY BOUNDARY LAYER PARAMETERIZATION
  - NUDGING SETUP
  - PRECIPITATION CHECK
- SUMMARY OF SUGGESTED INPUTS AND SETTINGS
- NEXT STEPS
- QUESTIONS
BACKGROUND

- BLM uses meteorological output from the Weather and Research Forecasting (WRF) model
  - Used to support management actions affecting the National Petroleum Reserve – Alaska, the North Slope, Prudhoe Bay, and other areas
  - Will be an integral part of multiple future National Environmental Policy Act (NEPA) projects, and future updates to the North Slope Regional Air Quality Model (NS-RAQM) project
- BLM has been using a 2009-2013 WRF dataset
  - From BOEM’s Arctic Air Quality Impact Assessment Modeling Study (2018)
- This study will produce WRF output for 2017-2019 using the same domain as the BOEM study
- Will leverage advancements in WRF model development and new input datasets
OVERALL APPROACH

- Same domains as BOEM study
- 2017-2019, with 2 weeks’ spin-up
- Latest version of Polar WRF is 4.1.1
  - We ported PWRF-4.1.1 changes to WRF-4.2 to take advantage of WRF bug fixes and advancements in Planetary Boundary Layer schemes
- WRF Sensitivity Testing to determine optimal settings
  - Jan, Feb, Jul, Nov, Dec 2017
- Verification using DS-3505 MET sites, and three independent sites
  - Independent: Atqasuk, Kaktovik, Inigok
## SUMMARY OF SENSITIVITY TESTS PERFORMED

<table>
<thead>
<tr>
<th>Test</th>
<th>Options</th>
<th>Winner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Reanalysis Dataset (IC/BC)</td>
<td>ERA5, GFS</td>
<td>ERA5</td>
</tr>
<tr>
<td>Sea Surface Temperature Dataset</td>
<td>UKMO, MUR, FNMOC</td>
<td>FNMOC</td>
</tr>
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<td>Number of Vertical Layers</td>
<td>33, 39</td>
<td>39</td>
</tr>
<tr>
<td>Planetary Boundary Layer Parameterization</td>
<td>YSU, MYNN2.5, MYNN3, MYJ</td>
<td>MYNN2.5-EDMF</td>
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<td>Nudging Methodology</td>
<td>A(36,12),O(4)</td>
<td>A(36,12),O(4)</td>
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<td>A(36,12)</td>
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<td>A(36)</td>
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Sensitivity tests performed for 2017:
Winter months (Nov, Dec, Jan, Feb) plus one summer month (Jul)
INTRODUCTION TO SOCCERPLOTS

- Plot monthly averages
  - Bias on X-axis
  - Error on Y-axis
  - Can be one station or averaged over many stations
- “Goal” values from:
  - Simple conditions: Emery et al. (2001) for MM5/WRF in continental conditions
  - Complex condition: Kemball-Cook et al. (2005) in Alaska and Rockies

![BLM Alaska North Slope d03 Wind Speed Performance](image)
INPUT REANALYSIS DATASET
Look for outliers.
INPUT REANALYSIS DATASET: 12KM

BLM Alaska North Slope d02 Wind Direction Performance
WPS - all

- Wind Direction Error (deg)
  - Feb + Mar × Apr ▲ May ▼ Jun ❌ Jul △ Aug ★ Sep ⚫ Oct ▲ Nov ● Dec
  - Complex Conditions
  - Simple Conditions

- GFS ▼ ERAS+FNMOD ▲ ERAS+MUR

BLM Alaska North Slope d02 Humidity Performance
WPS - all

- Humidity Error (g/kg)
  - Feb + Mar × Apr ▲ May ▼ Jun ❌ Jul △ Aug ★ Sep ⚫ Oct ▲ Nov ● Dec
  - Complex Conditions

- GFS ▼ ERAS+FNMOD ▲ ERAS+MUR

BLM Alaska North Slope d02 Wind Speed Performance
WPS - all

- Wind Speed RMSE (m/s)
  - Feb + Mar × Apr ▲ May ▼ Jun ❌ Jul △ Aug ★ Sep ⚫ Oct ▲ Nov ● Dec
  - Complex Conditions

- GFS ▼ ERAS+FNMOD ▲ ERAS+MUR

BLM Alaska North Slope d02 Temperature Performance
WPS - all

- Temperature Error (K)
  - Feb + Mar × Apr ▲ May ▼ Jun ❌ Jul △ Aug ★ Sep ⚫ Oct ▲ Nov ● Dec
  - Complex Conditions

- GFS ▼ ERAS+FNMOD ▲ ERAS+MUR

Look for outliers
INPUT REANALYSIS DATASET: 4KM

BLM Alaska North Slope d03 Wind Direction Performance
WPS - all

Wind Direction Bias (deg)

-20 -15 -10 -5 0 5 10 15

Wind Direction Error (deg)

0 20 40 60 80

Complex Conditions

Simple Conditions

BLM Alaska North Slope d03 Humidity Performance
WPS - all

Humidity Error (g/kg)

0.0 0.5 1.0 1.5 2.0 2.5 3.0

Complex Conditions

Simple Conditions

Look for outliers

BLM Alaska North Slope d03 Wind Speed Performance
WPS - all

Wind Speed Bias (m/s)

-2 -1 0 1 2

Wind Speed RMSE (m/s)

0.0 1.0 2.0 3.0

Complex Conditions

BLM Alaska North Slope d03 Temperature Performance
WPS - all

Temperature Bias (K)

-3 -2 -1 0 1 2

Temperature Error (K)

0 1 2 3 4

Complex Conditions

ERA5 Wins!
SEA SURFACE TEMPERATURE DATASET
SEA SURFACE TEMPERATURE (SST) VERIFICATION

- 16 buoys in and near Alaska waters downloaded from the National Data Buoy Center (NDBC)
- Buoy near the outflow from the Mackenzie River outflow decommissioned before 2017
- Only two buoys in 4km domain
- SST known to be important to meteorological modeling of Alaska
- Tested three leading SST products:
  - United Kingdom MET office (UKMO)
  - Navy’s Fleet Numerical Meteorology and Oceanography Center (FNMOC)
  - Multi-Scale Ultra High Resolution (MUR)
SEA SURFACE TEMPERATURE: 36KM DOMAIN
SEA SURFACE TEMPERATURE: 12KM DOMAIN
SEA SURFACE TEMPERATURE: 4KM DOMAIN

BLM Alaska North Slope d03 SST Performance
WPS - all

SST Bias (K)

SST Error (K)

Jan  ▲ Feb  + Mar  × Apr  ♦ May  ▽ Jun  ■ Jul  ★ Aug  ♦ Sep  ● Oct  ◆ Nov  □ Dec

○ UKMO  ● FNMOC  ◄ MUR

FNMOC Wins!
FNMOC SST FEATURES

- Two single times, one from early July (upper) and one from late July (lower) show the MacKenzie River outflow plume well.
- The SST gradient near the NW coast is also clearly seen in the upper snapshot.
- Wintertime SST snapshots do not show much, because the 4km domain coast is entirely covered with sea ice.
NUMBER OF VERTICAL LEVELS
NUMBER OF VERTICAL LEVELS: 4KM

NO DIFFERENCES, BUT 39 LEVELS HAD A LOT FEWER CFL ERRORS

39 Levels Wins!
PLANETARY BOUNDARY LAYER (PBL) SCHEME
PBL SCHEME: 36KM

BLM Alaska North Slope d01 Wind Direction Performance
WRF - all

BLM Alaska North Slope d01 Humidity Performance
WRF - all

BLM Alaska North Slope d01 Wind Speed Performance
WRF - all

BLM Alaska North Slope d01 Temperature Performance
WRF - all

YSU & MYJ
MYNN2.5
MYNN3 & MYNN-EDMF

Wind Direction Error (deg)
Wind Direction Bias (deg)
Humidity Error (g/kg)
Humidity Bias (g/kg)
Wind Speed Error (m/s)
Wind Speed Bias (m/s)
Temperature Error (K)
Temperature Bias (K)
PBL SCHEME: 12KM

BLM Alaska North Slope d02 Wind Direction Performance
WRF - all

Wind Direction Error (deg)

0 20 40
-20 -10 0 10 15

Wind Direction Bias (deg)

Simple Conditions

Jan Feb Jul Nov Dec

Blended Conditions

ERAS_YSU ERAS_MYY ERAS_MYNN2.5 ERAS_MYNN3 ERAS_MYNN2.5-EDMF

BLM Alaska North Slope d02 Humidity Performance
WRF - all

Humidity Error (g/kg)

0.0 0.5 1.0 1.5 2.0 2.5 3.0

Humidity Bias (g/kg)

Jan Feb Jul Nov Dec

Simple Conditions

ERAS_YSU ERAS_MYY ERAS_MYNN2.5 ERAS_MYNN3 ERAS_MYNN2.5-EDMF

BLM Alaska North Slope d02 Wind Speed Performance
WRF - all

Wind Speed RMSE (m/s)

0.0 1.0 2.0 3.0

Wind Speed Bias (m/s)

Simple Conditions

Jan Feb Jul Nov Dec

ERAS_YSU ERAS_MYY ERAS_MYNN2.5 ERAS_MYNN3 ERAS_MYNN2.5-EDMF

BLM Alaska North Slope d02 Temperature Performance
WRF - all

Temperature Error (K)

0 1 2 3 4 5 6 7

Temperature Bias (K)

Jan Feb Jul Nov Dec

Simple Conditions

ERAS_YSU ERAS_MYY ERAS_MYNN2.5 ERAS_MYNN3 ERAS_MYNN2.5-EDMF
PBL SCHEME: 4KM

Temperature Bias

Negative Speed Bias

Temperature Bias

BLM Alaska North Slope d03 Wind Direction Performance
WRF - all

BLM Alaska North Slope d03 Humidity Performance
WRF - all

BLM Alaska North Slope d03 Wind Speed Performance
WRF - all

BLM Alaska North Slope d03 Temperature Performance
WRF - all
4KM WIND SPEED PERFORMANCE

- All PBL schemes have wintertime negative wind speed bias.
- MYJ (blue) has least wind speed bias.
- MYNN2.5-EDMF (brown) is next-best.
4KM TEMPERATURE PERFORMANCE

- MYJ & YSU are not within Complex goals
- MYNN2.5 (green), MYNN3 (red) and MYNN2.5-EDMF (brown) all within Complex goals
- MYNN3 (red) and MYNN2.5-EDMF (brown) have much better summertime performance

BLM Alaska North Slope d03 Temperature Performance

WRF - all

Temperature Error (K)

Temperature Bias (K)

MYNN2.5-EDMF Wins!
ANALYSIS AND OBSERVATIONAL NUDGING TESTS
NUDGING OPTIONS: 12KM

ANALYSIS NUDGING ON 12KM GRID HELPS

BLM Alaska North Slope d02 Wind Direction Performance

BLM Alaska North Slope d02 Humidity Performance

BLM Alaska North Slope d02 Wind Speed Performance

BLM Alaska North Slope d02 Temperature Performance
NUDGING OPTIONS: 4KM

ADDING OBS NUDGING HELPS MORE
Analysis & OBS nudging:
Shows improvement at independent sites
HOW OFTEN TO NUDGE (INTERVAL): 4KM

ERA5 HAS HOURLY ANALYSES

6-hourly has best performance
PRECIPITATION
PRECIPITATION ISSUES

- Precipitation depends on many WRF settings
  - Moist physics scheme
  - Cumulus scheme
  - PBL scheme
  - Nudging
- The MYNN-based PBL schemes performed best, but do not yet work with the multi-scale Kain-Fritsch cumulus scheme
- Grell-Freitas cumulus scheme requires a specific compiler for optimizations
- Our position: verify monthly average precipitation totals vs. Global Precipitation Measurement (GPM) satellite-based retrievals
  - Make sure precipitation is doing OK, and don’t optimize if it’s not needed
JANUARY 2017: 36KM

Total WRF Precipitation (setting: ERAS_MNHN2) for 2017-01
WRF Domain Statistics: 10th=5.14 Median=13.09 Average=37.60 90th=115.34 Convective fraction= 0.63

Total GPM Precipitation for 2017-01
Contiguous U.S. Statistics: 10th=7.42 Median=31.49 Average=54.86 90th=127.56 (mm/hr)
JULY 2017: 36KM

Total WRF Precipitation (setting: ERA5, MNNM) for 2017-07
WRF Domain Statistics: 10th=6.15 Median=22.69 Average=30.03 90th=61.28 Convective fraction= 0.11

Total GPM Precipitation for 2017-07
Contiguous U.S. Statistics: 10th=20.28 Median=57.29 Average=65.48 90th=118.27 (mm/hr)
KF on 36/12 is OK!
CONCLUSIONS: PROPOSED WPS INPUTS AND SETTINGS BASED ON RESULTS OF SENSITIVITY TESTING

WRF Pre-Processing System (WPS) Settings/Inputs

• European Centre for Medium-range Weather Forecasting’s ERA5 0.25 deg IC/BC dataset
• Navy’s Fleet Numerical Meteorology and Oceanography Center (FNMOC) SST and SEAICE
  • 6-hour frequency, a blend of satellite and in-situ observations
• Polar WRF sea-ice fields supplied by the Byrd Polar Research Center
  • Albedo of sea-ice/snow system (ALBSI), Ice depth (ICEDEPTH), Snow depth on sea-ice (SNOWSI)
• OBSGRID re-analysis package using MADIS & DS-3505 surface & upper-air observations
  • MQD oa type (from BOEM work)
CONCLUSIONS: PROPOSED WRF INPUTS AND SETTINGS BASED ON RESULTS OF SENSITIVITY TESTING

WRF Settings

- 39 Vertical Levels (more than BOEM’s 33 levels): no performance gain, but more stable runs
  - Note: hybrid vertical coordinate scheme not supported by MMIF, so will not be used (hybrid_opt = 0)
- Planetary Boundary Layer scheme: MYNN2.5 with the eddy-diffusivity / mass-flux (EDMF) settings (think HRRR)
  
  ```
  bl_mynn_edmf = 1  bl_mynn_edmf_mom = 1  bl_mynn_edmf_tke = 1  icloud_bl = 1
  bl_mynn_cloudpdf = 2  bl_mynn_mixlength = 2  bl_mynn_mixqt = 0  the rest are default
  ```
- Kain-Fritsch Cumulus scheme on 36 & 12 km domains, Thompson moist physics scheme
- Analysis nudging on 36 & 12 km domains, observational nudging on 4km domain
  - 6-hourly interval for analysis nudging
- Other settings based on our past experience
**NEXT STEPS**

- Group to review proposed WRF inputs and settings, and accept them—or propose more tests
  - Comments due by July 24, 2020
- WeatherFlow
  - Runs WRF Pre-processor System (WPS)
  - Scripts already delivered to WeatherFlow, they are testing and downloading data
- Ramboll
  - Downloads WPS outputs (WRF inputs) from WeatherFlow
  - Runs WRF for 3 years
  - Performs QA
  - Writes Model Performance Evaluation and Final Report, with input from WeatherFlow
  - Delivers WRF output to BLM on external hard disks
THANK YOU

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SUPPLEMENTAL SLIDES
NUMBER OF VERTICAL LEVELS: 36KM

BLM Alaska North Slope d01 Wind Direction Performance

- Wind Direction Error (deg)
- Wind Direction Bias (deg)
- Conditions: Complex, Simple
- Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
- ERAS_33, ERAS_39

BLM Alaska North Slope d01 Humidity Performance

- Humidity Error (g/kg)
- Humidity Bias (g/kg)
- Conditions: Complex, Simple
- Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
- ERAS_33, ERAS_39

BLM Alaska North Slope d01 Wind Speed Performance

- Wind Speed RMSE (m/s)
- Wind Speed Bias (m/s)
- Conditions: Complex, Simple
- Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
- ERAS_33, ERAS_39

BLM Alaska North Slope d01 Temperature Performance

- Temperature Error (K)
- Temperature Bias (K)
- Conditions: Complex, Simple
- Months: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
- ERAS_33, ERAS_39
NUMBER OF VERTICAL LEVELS: 12KM
NOVEMBER 2017: 36KM

Total WRF Precipitation (setting: ERAS_MNIN3) for 2017-11
WRF Domain Statistics: 10th=2.01 Median=16.02 Average=31.60 90th=74.09 Convective fraction= 0.03

Total Precipitation (mm)

Total GPM Precipitation for 2017-11
Contiguous U.S. Statistics: 10th=8.73 Median=57.84 Average=74.05 90th=149.11 (mm/hr)
## ALASKA NORTH SLOPE

**WRF MODELING PROJECT, SENSITIVITY STUDY**

<table>
<thead>
<tr>
<th>Cmt #</th>
<th>Slide #</th>
<th>Commenter Name/Affiliation</th>
<th>Comment</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>8</td>
<td>Jay McAlpine, EPA R10</td>
<td>It would be useful to provide maps of each domain with markers at each surface station location with shading (or other signifier) representing the model bias and error. This would help the evaluator get a sense of the spatial distribution of bias/error and regions where the model may be performing better or worse. This comment applies to each of the sensitivity cases presented. It is understood we had limited time to discuss model performance in this presentation – these maps would be a useful addition to the final model performance report.</td>
<td>Suggested maps were developed as part of the MPE portion of the WRF modeling report (see Section 4.2.4). Example spatial plots (dot plots) were included as as Figures 11 through 16 of the report, and the full set of 216 plots were included electronically as an attachment to the report.</td>
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<td>2.</td>
<td>12</td>
<td>Jay McAlpine, EPA R10</td>
<td>For the SST performance evaluation: it could be useful to provide visuals of the monthly average SSTs for the three leading products, to provide the opportunity for a qualitative examination of the datasets, particularly the Arctic Ocean where observational data are sparse. A qualitative look at the SST distributions may provide the opportunity to compare and contrast the datasets at specific known features such as river outflow regions, coastal gradients, etc.</td>
<td>The contractor tested developing the requested contour plots using Python and determined, in conversations with BLM, that this was a task that would require a more intensive level of effort beyond the scope of the contract. However, individual snapshots were developed to show gradients near the coast and the Mackenzie River outflow and added to an updated version of the sensitivity analysis PowerPoint presentation, available as an attachment to the WRF modeling report.</td>
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## WRF MODELING PROJECT, SENSITIVITY STUDY

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<thead>
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<td>3.</td>
<td>23</td>
<td>Jay McAlpine, EPA R10</td>
<td>North Slope D03 temperature performance: The negative temperature bias in winter has been observed in other North Slope WRF modeling efforts (e.g., 2016 EPA Alaska run). The MYNN3 and MYNN2.5 performance is promising, since these schemes are resulting in a slight warm bias (versus extreme cold bias). Is there the opportunity, perhaps in the MPE report, to look deeper into why these models are performing differently?</td>
<td>Per discussion with Jay McAlpine on 8/18/20, this was determined to be a level of effort far beyond the scope of this contract.</td>
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<td>4.</td>
<td>32-37</td>
<td>Jay McAlpine, EPA R10</td>
<td>Through discussion and a careful look at the graphics, we were able to get a good sense of precipitation performance. However, I would recommend thickening and darkening the outlines of the coast to help future readers of the MPE report – it was quite difficult to make out the outline of the coast. The GPM dataset looks a bit noisy and appears to have a different horizontal resolution by season. It might be useful to consider comparison to other hybrid satellite/measurement precipitation datasets as well, such as the NOAA “nClimGrid” dataset, from the Global Historical Climatology Network; etc.</td>
<td>The coastal outlines have been darkened and revised graphics included in an updated version of the sensitivity analysis PowerPoint presentation, available as an attachment to the WRF modeling report. Comparisons to the nClimGrid dataset were made and included in Figures 17 and 18 and Appendix B of the Draft WRF Modeling Report. Section 4 of this report describes the MPE results. Comparisons to nClimGrid confirming the conclusions shown in the presentation of results of the WRF sensitivity testing that overall, WRF shows reasonably good precipitation performance.</td>
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<td>5.</td>
<td>conclusion</td>
<td>Jay McAlpine, EPA R10</td>
<td>The settings and schemes selected seem reasonable based on the theoretical aspects discussed orally and performance results shown in the presentation. The new PBL scheme results seem especially promising.</td>
<td>No response needed.</td>
</tr>
</tbody>
</table>