AMPS CONTRIBUTIONS TO THE YEAR OF POLAR PREDICTION–SOUTHERN HEMISPHERE (YOPP–SH)

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1. INTRODUCTION

The Antarctic Mesoscale Prediction System (AMPS) is a real-time numerical weather prediction (NWP) capability covering Antarctica and the high southern latitudes (Powers et al. 2012). While its primary mission is to provide guidance for the weather forecasters of the U.S. Antarctic Program, it also assists a wide range of international programs. In addition, AMPS supports researchers, students, and field campaigns. AMPS's main forecast model is the Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008; Powers et al. 2017) that has polar physics enhancements (Bromwich et al. 2013). AMPS also, however, runs the global Model for Prediction Across Scales (MPAS) (Skamarock et al. 2012).

To promote international research toward improved weather prediction services for the polar regions, the World Meteorological Organization (WMO) is leading the Polar Prediction Project (PPP) (http://www.polarprediction.net/). A cornerstone activity of the PPP is the Year of Polar Prediction (YOPP) program, and this includes the YOPP-Southern Hemisphere effort focused on the high southern latitudes and coordinated by D. Bromwich of The Ohio State University (Jung et al. 2016). Running from 2017 to 2019, the YOPP features Special Observing Periods (SOPs) of coordinated intensive atmospheric measurement aimed to supplement routine weather observations and bolster polar observational coverage. A goal of the YOPP observing efforts is to improve atmospheric prediction capabilities over both polar regions, and one path to this is through NWP experiments applying the SOP observations.

The YOPP-SH SOP will run from November 16, 2018–February 15, 2019. There will be extra surface observations and additional radiosonde launches from various sites (e.g., 4/day from Neumayer and Dumont D'Urville stations), and the number of Southern Ocean drifting buoys will more than double. These extra observations will enhance the high-latitude atmospheric database for both meteorological analysis and NWP.

Summarized here are the plans to use AMPS to exploit the SOP data in furtherance of the goals of the PPP and YOPP-SH. Specifically, in a collaboration of the National Center for Atmospheric Research (NCAR) and The Ohio State University, the AMPS framework will be used to investigate the impact of the SOP observations on Antarctic numerical forecasts. The study will consist of WRF data assimilation (DA) experiments incorporating the SOP measurements while testing different assimilation approaches. The core experiments will involve parallel simulations first ingesting the routine weather observations and then adding the SOP observations. As resources allow, the study will also look at the impact of observations from the Ocean Observatories Initiative (OOI) Global Southern Ocean (GSO) mooring (http://oceanobservatories.org/array/global-southern-ocean) at 55°S, 90°W. The main aims of the effort are to determine the effects the YOPP-SH enhanced polar observations and to examine new DA approaches in AMPS for improved Antarctic prediction.

2. MODEL EXPERIMENTS

a. AMPS Operational Setups

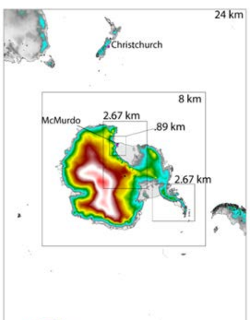
AMPS's current WRF configuration is shown in Fig. 1. This has two outer model forecast grids of 24- and 8-km horizontal grid spacing (Fig. 1(a)), with the 8-km nest covering the Antarctic continent. Finer, 2.67-km grids cover the Ross Sea/Ice Shelf sector and the Antarctic Peninsula (Fig. 1(b)). An innermost nest over the Ross Island region has 0.89-km spacing (Fig. 1(b)). The main AMPS forecasts use this 5-domain setup for deterministic predictions. AMPS also runs an ensemble of WRF with a set of 15 forecasts on the 24- and 8-km grids. The ensemble members are initialized from NCEP's Global Ensemble Forecasting System (GEFS; Zhou et al. 2017). The ensemble is used for predictive guidance as well as for providing error covariance input to the hybrid data assimilation method used for the main AMPS deterministic runs.

b. Experiment Overview

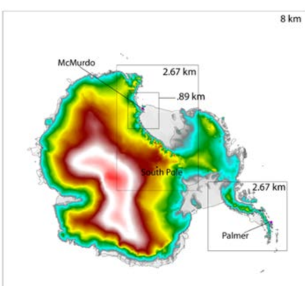
The experiment framework consists of parallel WRF simulations applying different observation sets and

DA procedures. Table 1 (at end) summarizes the experiments, detailed below. The first configuration focus is the datasets used. In these tests, the control configuration assimilates the operational set of observations (described below), those available prior to the SOP. In contrast, the SOP configuration adds the SOP observations to these. The second configuration target is the DA process. These tests vary the techniques for generating the DA input, while using both the standard and SOP datasets.

The experiments will be done in two different settings. A first set of experiments will consist of WRF forecasts over two-week periods in the early, middle, and late phases of the SOP. These will use the two outer AMPS domains (Fig. 1(a)). These run periods will reveal effects emerging over longer timescales and impact sensitivity to evolving seasonal regimes—austral spring, summer, and late summer. For these period tests, statistical verifications of forecast parameters will be the focus.



(a)



(b)

Fig. 1: AMPS WRF forecast grids. (a) 24- and 8-km grids, with finer, regional nests shown. 24- and 8-km grids will be run for the forecast experiments and in the ensembles supporting the DA experiments. (b) 8-km Antarctic continental and 2.67-km Ross Ice Shelf/Sea and Antarctic Peninsula grids. .89-km McMurdo region grid also shown

A second set of experiments targets significant weather events. These will consist of higher-resolution (i.e., finer than 8-km) simulations of cases within the SOP that affect operations at the main U.S. Antarctic station areas. Candidates are strong cyclones affecting McMurdo Station and Palmer Station, blowing snow events at South Pole, and medevacs or incidents involving planes or ships around the continent.

As resources allow, we will also assess the impact of observations from the GSO mooring located at approximately 55°S, 90°W (http://oceanobservatories.org/array/global-southern-ocean) (Fig. 2). The data from this platform will be added in DA experiments, and the focus will be on the Antarctic Peninsula to southern South America region to assess the influence of this unique Southern Ocean asset.

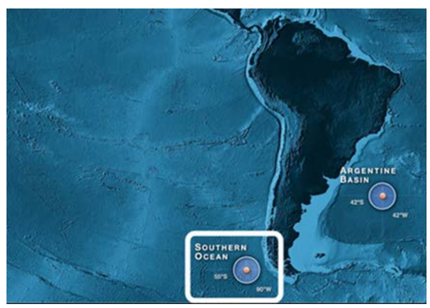


Fig. 2: The Ocean Observatories Initiative (OOI) Global Southern Ocean (GSO) mooring in the southeastern Pacific Ocean just northwest of Drake Passage.

c. Data Assimilation Approaches

Currently, the DA system used in AMPS is WRFDA (the WRF data assimilation system) (Barker et al. 2012), and it applies a hybrid 3-dimensional ensemble/variational approach (3DEnVar) (Wang et al. 2008). For model initialization the first-guess/background fields come from analyses from the Global Forecasting System (GFS), the National Centers for Environmental Prediction's global atmospheric model (NOAA 2003). The hybrid 3DEnVar approach blends static background error (BE) covariances calculated from previous WRF forecasts with flow-dependent covariances derived from the forecasts of the AMPS ensemble. The hybrid system thus incorporates a measure of flow-dependent information into the assimilation process.

The operational DA process in AMPS presents an issue for the planned testing in that, because the SOP observations will be transmitted to the GTS, the GFS-derived background fields will have included the data. To avoid this, WRF forecasts themselves will be used as the backgrounds. This will employ cycling, in which a new analysis is performed every 6 h using the previous 6-h WRF forecast as the background. 3DEnVar will be used for the initializations of these cycled WRF runs, but there will be two variations in the approaches for their BE generation (described below). The WRF forecasts to be analyzed for data impact will be those initialized at 0000 and 1200 UTC. They will extend to five days to reveal the influences over the usual AMPS forecast period.

The basic set of observations to be assimilated is that currently ingested in AMPS: surface data (AWS, SYNOP, METAR); upper-air soundings; aircraft observations; ship and buoy observations; geostationary and polar-orbiting satellite AMVs (atmospheric motion vectors); GPS radio occultations; and AMSU (Advanced Microwave Sounding Unit) radiances. The SOP observations will be gathered from the real-time GTS feeds, and for the data assimilation experiment, the set of SOP observations will be added to the control data (Table 1).

The DA tests will both use 3DEnVar, but two different approaches will be used for the ensemble contribution. Furthermore, instead of 15 members as in the operational AMPS ensemble, the testing ensembles will use have at least 40 members generating short (i.e., 6-h) forecasts. The purpose of the increased ensemble size is to have a more robust system, one capturing more spread and providing a better EnKF approximation to the theoretical Kalman filter solution, as BE covariances are better estimated from the use of larger ensembles. A goal of this approach testing is to explore whether a different procedure can be applied to improve AMPS in furtherance of the PPP and YOPP.

(i) Approach 1: Hybrid DA Using a GEFS-based WRF Ensemble

AMPS employs the hybrid 3DEnVar DA approach that uses elements of both variational and ensemble DA techniques (Wang et al. 2008). While 3DVAR relies on a static covariance model to specify the BEs, the hybrid system uses a combination of static BE covariances plus BE covariances estimated from an ensemble, with the latter introducing flow-dependent error estimates. The current configuration of the hybrid in AMPS uses an even weighting of the static and ensemble BE covariances.

The first DA approach will use 3DEnVar taking its ensemble input from a GEFS-based WRF ensemble as in AMPS (Fig. 3(a)). However, as noted above, the ensemble used will contain at least 40 members, instead of 15. We note that if the SOP observations are ingested for the GEFS analyses, our ensemble members would have some connection to SOP information. However, this would be an attenuated link. First, while the GEFS analyses will be used to initialize WRF model ensemble members (Fig. 3(a)), over the 6-h forecast periods, the model will move away from analysis states. Second, the GEFS members themselves reflect perturbed analyses, and are thus pulled away from the initial data, reflecting influences other than the data's assimilation.

(ii) Approach 2: Hybrid DA Using a Stand-Alone WRF Ensemble

In the second approach (Fig. 3(b)), for the ensemble contribution to the hybrid DA, the WRF ensemble will itself be cycled, rather than using GEFS for member backgrounds. Furthermore, the initialization of its members will include DA using an Ensemble Kalman Filter (EnKF) approach (Houtekamer and Zhang 2016). EnKF DA has the potential to be a superior method for generating flow-dependent BE covariances.

Here, the members of the WRF ensemble will be continuously cycled and updated every 6h via EnKF DA (Fig. 3(b)) using NCAR's Data Assimilation Research Testbed (DART) (Anderson et al. 2009). DART is an NCAR community facility that supports ensemble-based DA research and provides an EnKF DA capability for updating ensemble members with observations. The primary benefit of continuously-cycling EnKF DA is the production of dynamically-consistent initial ensembles that more accurately represent BEs than an external model. Applying DART here offers the potential for improved DA for AMPS via time-evolving, flow-dependent, better-estimated BE statistics which should benefit the hybrid analyses and support improved forecasts (see, e.g., Schwartz et al. 2015). In addition, DART has methods to apply covariance inflation and lateral boundary condition perturbations (see Torn et al. 2006) that will be applied to each ensemble member to maintain appropriate ensemble spread.

In this approach, the only use of GEFS members is for WRF ensemble BCs, which will be perturbed. As in the first experiment, the 0000 and 1200 UTC hybrid analyses generated will initialize deterministic, 5-day WRF forecasts for verification. Figure 3 illustrates the two paths for the DA process in the experiments.

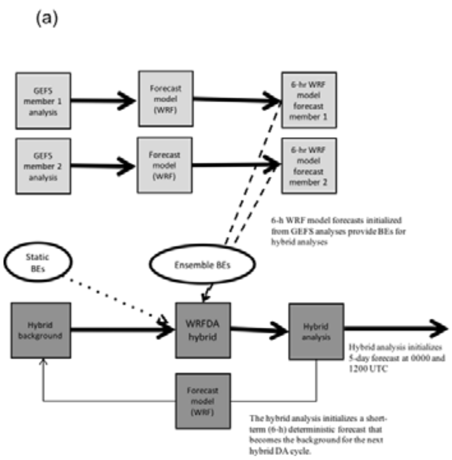
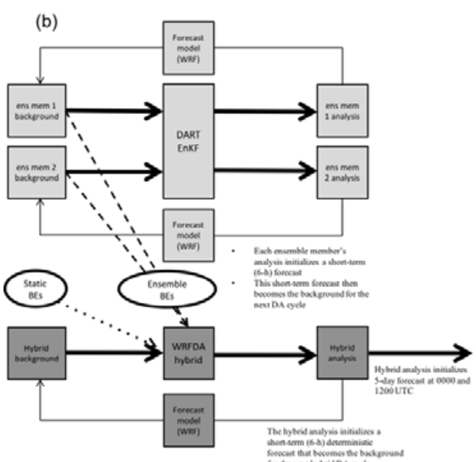


Fig. 3: Schematic diagrams of two DA systems where ensemble BE covariances are provided by (a) a set of 6-h WRF model forecasts initialized from GEFS members and (b) a continuously-cycling WRF ensemble supporting an EnKF DA system using DART.



4. SUMMARY

To directly address the aims of the Polar Prediction Project and the YOPP, the AMPS framework will be used to examine the value of expanded Southern Hemisphere observations for polar NWP and to assess different DA techniques for future operational application. The study will consist of data assimilation impact experiments in which both routine observations and YOPP-SH SOP observations are ingested in initializing WRF forecasts. The study will examine the impact of adding the SOP data in forecasts of sub-seasonal periods as well as in specific weather events. The aims are to understand the potential benefits to polar NWP of the enhanced Southern Hemisphere meteorological data and to advance the data assimilation component of AMPS, with the latter ultimately providing improved Antarctic predictions for the USAP and for international activities across the Ice.

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REFERENCES

Anderson, J., T. Hoar, K. Raeder, H. Liu, and N. Collins, 2009: The Data Assimilation Research Testbed: A community facility. *Bull. Amer. Meteor. Soc.*, **90**, 1283–1296. doi:10.1175/2009BAMS2618.1

Barker, D.M., and Co-Authors, 2012: The Weather Research and Forecasting Model's community variational/ensemble data assimilation system: WRFDA. *Bull Amer. Meteor. Soc.*, **93**, 831–843.

Bromwich, D. H., F. O. Otieno, K. M. Hines, K. W. Manning, and E. Shilo, 2013: Comprehensive evaluation of polar weather research and forecasting performance in the Antarctic. *J. Geophys. Res.*, **118**, 274-292, doi: 10.1029/2012JD018139.

Houtekamer, P. L., and F. Zhang, 2016: Review of the ensemble Kalman filter for atmospheric data assimilation. *Mon. Wea. Rev.*, **144**, 4489–4532.

Jung, T., and Coauthors, 2016: Advancing polar prediction capabilities on daily to seasonal time scales. *Bull. Amer. Meteor. Soc.*, **97**, 1631–1647. doi:10.1175/BAMS-D-14-00246.1.

NOAA Environmental Modeling Center, 2003: The GFS Atmospheric Model. NCEP Office Note 442. 14 pp. [Available from U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Centers for Environmental Prediction, 4700 Silver Hill Rd., Mail Stop 9910, Washington, DC, 20233.]

Powers, J.G., K.W. Manning, D.H. Bromwich, J.J. Cassano, and A.M. Cayette, 2012: A decade of Antarctic science support through AMPS. *Bull. Amer. Meteor. Soc.*, **93**, 1699–1712. (PR-AMPS)

Powers, J. G., and Coauthors, 2017: The Weather Research and Forecasting Model:
Overview, system efforts, and future directions. *Bull. Amer. Meteor. Soc.*, **98**, 1717–1737. doi:10.1175/BAMS–D–15–00308.1.

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Schwartz, C. S., G. S. Romine, M. L. Weisman, R. A. Sobash, K. R. Fossell, and K. W. Manning, and S. B. Trier, 2015: A real-time convection-allowing ensemble prediction system initialized by mesoscale ensemble Kalman filter analysis. *Wea. Forecasting*, **30**, 1158–1181.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. G. Duda, X.-Y. Huang, W. Wang, and J. G. Powers, 2008: A description of the Advanced Research WRF Version 3. NCAR Tech. Note, NCAR/TN-475+STR, 113 pp.

Skamarock, W. C., J. B. Klemp, M. G. Duda, L. Fowler, S.-H. Park, and T. D. Ringler, 2012: A multi-scale nonhydrostatic atmospheric model using centroidal Voronoi tessellations and c-grid staggering. *Mon. Wea. Rev.*, **240**, 3090–3105. doi:10.1175/MWR-D11-00215.1

Torn, R. D., G. J. Hakim, and C. Snyder, 2006: Boundary conditions for limited-area ensemble Kalman filters. *Mon. Wea. Rev.*, **134**, 2490–2502.

Wang, X., D. M. Barker, C. Snyder, and T. M. Hamill, 2008: A hybrid ETKF–3DVAR data assimilation scheme for the WRF model. Part I: Observing system simulation experiment. *Mon. Wea. Rev.*, **136**, 5116–5131.

Zhou, X., Y. Zhu, D. Hou, Y. Luo, J. Peng, and R. Wobus, 2017: Performance of the new NCEP Global Ensemble Forecast System in a parallel experiment. *Wea. Forecasting*, **32**, 1989–2004.

Table 1: YOPP-SH SOP Data Assimilation Experiments

STD= Current operational standard observations
SOP= YOPP-SH Special Observing Period observations

Experiment	Obs Assimilated	DA Process and Ensemble BE Generation
Control	STD	6-h WRF model forecasts initialized from GEFS analyses (Fig. 3a)
SOP	STD + SOP	6-h WRF model forecasts initialized from GEFS analyses (Fig. 3a)
Control_Cycle	STD	6-h WRF model forecasts produced from continuously cycling DA (Fig. 3b)
SOP_Cycle	STD + SOP	6-h WRF model forecasts produced from continuously cycling DA (Fig. 3b)