INVESTIGATING AND PREDICTING WEST ANTARCTIC SURFACE MELTING WITH REANALYSIS- AND GCM-DRIVEN POLAR WRF

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ABSTRACT

Combining satellite remote sensing and atmospheric modeling with Polar WRF (PWRF), we will be attempting to diagnose the meteorological conditions associated with surface melting on the West Antarctic ice sheet. With these results, we plan to predict whether the regional warming associated with anticipated anthropogenic global warming and related atmospheric circulation changes will lead to a future increase of melting during peak months (Dec/Jan) of the melt season.

Work in the first two project years has produced (a) a 30-year (1979-2008) ERA Interim (ERAI)-based melt season climatology, (b) a 20-year (1989-2008), PWRF dataset driven by ERAI, (c) a 10-year (1989-1998), PWRF dataset driven by CCSM4, and (d) PWRF- and SOM-based studies of the 1991-92 West Antarctic melt event.

1. INTRODUCTION

The presence of surface melting on ice sheets and ice shelves marks an important climatic and geophysical threshold in the cryosphere. Wetting of snow reduces albedo and encourages additional melt, meltwater runoff contributes to mass loss from ice sheets, and penetration of meltwater to the glacier bed can lubricate faster flow and contribute to ice-sheet mass loss.

This project revolves around three main areas: (1) understanding modern surface melt as seen in satellite-based observations and WRF driven by ERA-Interim, (2) evaluating skill of GCMs in reproducing modern climate (through comparisons with ERA-Interim), and (3) using GCMs with WRF to predict future climate and associated surface melt. With respect to these topics, we have produced:

- a 30-year (1981-2010) Nov-Feb ERAI climatology;
- a 20-year (1989-2008), Dec/Jan ERAI-driven PWRF dataset and climatology, at 45- and 15-km resolution, covering the full continent and surrounding oceans;
- a 10-year (1989-1998), CCSM4-driven PWRF dataset and climatology (otherwise as above);
- a number of self organizing map (SOM)-based analyses of the 1991-92 West Antarctic melt event using ERAI and PWRF datasets.

2. DATA

2.1 *Satellite-based surface melt*

Our record of surface melt at 25-km spatial resolution was developed by C. Karmosky under the direction of Lampkin (Karmosky, 2013). Karmosky used passive microwave data (NSIDC, 2008) and the cross-polarized gradient ratio (XPGR) algorithm (Abdalati and Steffen, 1995) to create a daily record of surface melt across Antarctica for Nov-Feb 1988-2007.

2.2 *Polar WRF boundary conditions*

The ERAI archive (Simmons et al., 2007) is our reference dataset for PWRF boundary and initial conditions during the "modern" period. We supplement ERAI with NASA Bootstrap daily sea ice dataset sea ice concentrations (Comiso, 1999). These data are linearly interpolated to 6-hourly resolution during model preprocessing.

To date we have used CCSM4 as a GCM source of PWRF boundary/initial conditions but have plans for additional GCMs. Our modern period datasets are from CCSM4 1° 20th Century Ensemble Member #6 (MOAR), i.e., case name "b40.20th.track1.1deg.012". Studies of the future will start with CCSM4 1° RCP8.5 Ensemble Member #6 (MOAR), i.e., case name "b40.rcp8_5.1deg.007", and may expand to additional emissions scenarios. The RCP8.5 scenario assumes an 8.5 watts/m^2 increase over the 96-year GCM simulation. In all cases, we use datasets from the CCSM4 component models CAM (atmosphere), CLM (land) and CICE (sea ice).

3. MODELING

3.1 *Overview*

The project is using v3.3.1 of the WRF modeling system (Skamarock et al., 2005), with the corresponding polar modifications developed by the Polar Meteorology Group at the Byrd Polar Research Center, Ohio State University (released Nov 2011). For ERAI-based runs, the modeling philosophy is to use 72-hour simulations to create 24 hours of spinup (discarded) and 48 hours of forecast data. The latter are concatenated into long-term time series. GCM-based simulations run for 32 days and use grid nudging (FDDA) of the upper model layers to keep PWRF from converging on its climatology.

All simulations produce grids at 45 and 15 km each covering the entire Antarctic continent and surrounding oceans (Figure 1). Output files are saved every 6 hours for the outer grid and every 3 hours for the nested grid.

A modified version of Dr. Mark Seefeldt's wrfout_to_cf.ncl script is used to reduce the 15 km domain output to a manageable file size with standard variable names and only the variables of most interest. Modifications primarily concern switching to variable names matching the CMIP guidelines.

3.2 *Key options*

Physics, dynamics and numerous other settings were guided by advice from Francis Otieno (BPRC) and those used operationally by AMPS[**]. Along with enabling `fractional_sea_ice`, key options are:

- `mp_physics` (microphysics) = WSM 5-class scheme
- `ra_lw_physics` (longwave radiation) = rrtmg scheme
- `ra_sw_physics` (shortwave radiation) = rrtmg scheme
- `sf_sfclay_physics` (surface-layer option) = Monin-Obukhov (Janjic Eta) scheme
- `sf_surface_physics` (land-surface option) = unified Noah land-surface model
- `bl_pbl_physics` (boundary-layer option) = Mellor-Yamada-Janjic (Eta) TKE scheme
- `cu_physics` (cumulus option) = Grell-Devenyi ensemble scheme

4. STATUS

4.1 *The Dec/Jan 1991-92 melt event*

As documented in the XPGR-based record, a large melt event developed in West Antarctica in late December 1991 and persisted through mid-January 1992. Figure 2 shows the event near maximum extent. Initial work focused on the three years centered on the event, i.e., Dec/Jan 1990-91, Dec/Jan 1991-92 and Dec/Jan 1992-93. SOM-based frequency analysis of both ERA-Interim and Polar WRF data for this period confirmed that for days during the melt event, warm T-2m anomaly patterns were most common. Likewise for days outside the melt event for cool T-2m anomaly patterns. As expected, the higher spatial resolution of the Polar WRF data did a better job with locating the temperature anomalies with respect to the observed melt location. Figure 3 provides single-day comparisons of ERA-Interim and Polar WRF T-2m during this study period.

Most recently we expanded the SOM analysis to five years and a total of three variables: T-2m, v-wind and sea level pressure. The behavior during the event was studied by frequency analysis of just the January 1992 data. The month was first split into melt (January 1-14) and no-melt (January 15-31) periods. The melt period was further split (Jan 1-6, 7-14) to examine peak and declining periods more closely. Figure 4 shows the most common patterns for each period. During the first part of the melt period, There is a warm anomaly in T-2m, the v-wind anomaly indicates northerly (warm) air advection, and SLP shows a high pressure pattern over the region. In the later stages of melt, average T-2m has decreased over the domain (-6.4 °C to -8 °C), the T-2m anomaly has decreased, a southerly wind anomaly is present and the area is under low pressure. In the last half of the month, after the melt event, northerly advection of warm air has returned but average temperatures appear to be too low to break the melting threshold.

4.2 *Evaluating Modern GCMs*

As one step in evaluating GCMs for use in future projections, we produced a 10-year WRF dataset using CCSM4 instead of ERAI. To compare this dataset to our reference, a SOM analysis of T-2m from both WRF datasets was done. Frequency maps using just the data from each original dataset allow us to compare variability between ERAI-WRF and CCSM4-WRF (Figure 5). If the datasets were the same, the frequency maps would be the same. Differences in frequencies indicate differences in the variability between datasets. As seen in the most common patterns in Figure 5, the different boundary conditions produce relatively similar results over the continent but notably different results over the ocean. We think this may be related to the lower average temperatures in the CCSM4 dataset over the ocean.

5. FUTURE WORK

We are still developing our calibration of model data to observed melt for the recent period and plan to complete this soon. We will be running new PWRF simulations driven by the CCSM4 RCP 8.5 emissions scenario as well as additional CMIP5 GCMs, all to assess future melt occurrence. There is also much work to be done in evaluating GCM-based results (e.g., why is T-2m lower over the ocean in CCSM4?).

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REFERENCES

Abdalati, W. and K. Steffen, 1995: Passive microwave-derived snow melt regions on the Greenland ice sheet. *Geoph. Res. Letters*, **22,** 787-790.

Comiso, J. C.: Bootstrap sea ice concentrations from NIMBUS-7 SMMR and DMSP SSM/I. [Available online from http://nsidc.org/data/nsidc-0079.html.]

Karmosky, C., 2013: Synoptic And Mesoscale Climate Forcing On Antarctic Ice Shelf Surface Melt Dynamics, Department of Geography, Pennsylvania State University.

NSIDC, cited 2009: DMSP SSM/I Pathfinder Daily EASE-Grid Brightness Temperatures. [Available online from http://nsidc.org/data/docs/daac/nsidc0032_ssmi_ease_tbs.gd.html.]

Simmons, A., S. Uppala, et al., 2007: ERA-Interim: New ECMWF reanalysis products from 1989 onwards. *Newsletter 110 - Winter 2006/2007*, 11.

Skamarock, W. C., J. B. Klemp, et al., 2005: A description of the advanced research WRF version 2, 88 pp.

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** Copies of parameter files available on request.

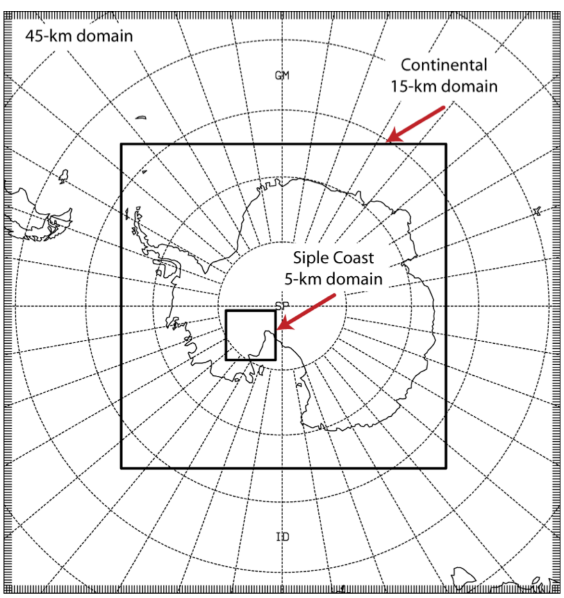

Figure 1. Project model domains (5-km domain was only used in benchmarking). Outer grid is 210 x 220. Inner grid is 367 x 367.

Figure 2. XPGR-based surface melt (light red) for January 1, 1992.

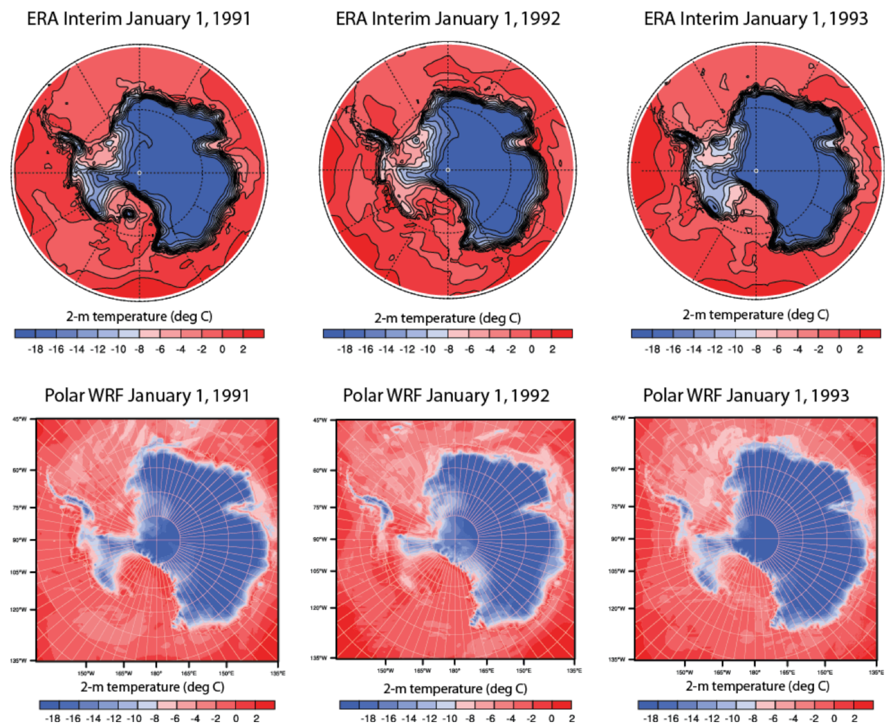

Figure 3. ERA-Interim (top) and Polar WRF (bottom) T-2m for January 1, 1991-1993, i.e., mid-melt season during the Dec/Jan 1990-1993 case study.

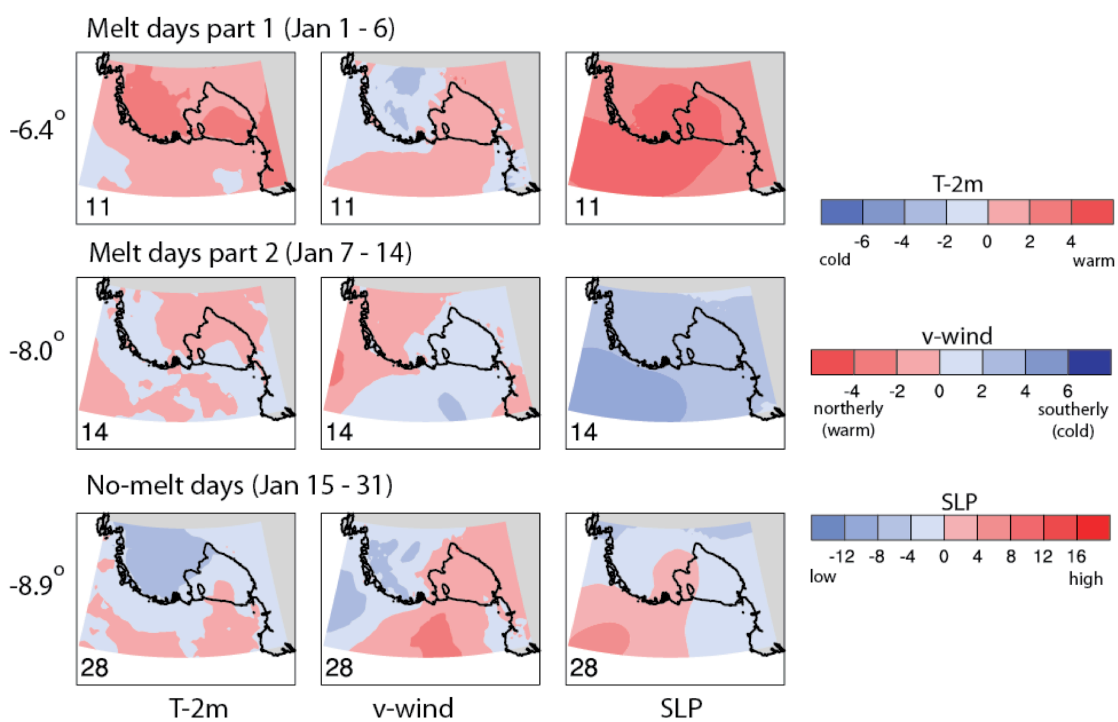

Figure 4. Most common patterns by period from a multivariable SOM analysis of 3-hourly PWRF data for January, 1990 to 1994. Values at left show domain average temperature for each period. See Figure 2 for location and extent of surface melting. Data originally at 15 km, resampled to 45 km for efficiency.

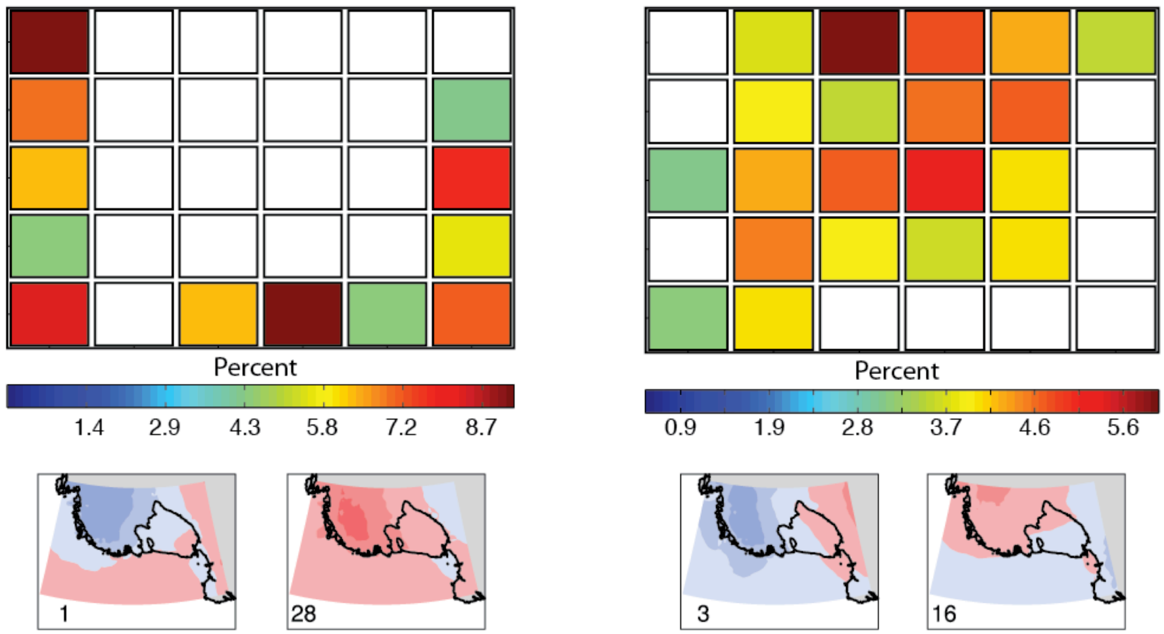

Figure 5. Frequency maps of ERAI-driven PWRF (left) and CCSM4-driven PWRF (right) from a SOM analysis of T-2m from 10 years (January, 1989-1998) of both datasets. Frequencies below the mean have been changed to white to emphasize more common patterns. T-2m spatial patterns below each frequency map are the two most common for each dataset. That the ERAI-based frequencies do not match well with the CCSM4-based frequencies is an indication of differences in the two driving datasets. A lower average T-2m over the ocean in CCSM4 may be involved.