Antarctic sensitivity of Polar WRF simulations to lateral boundary conditions and interannual circulation variability

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Motivation

How well does Polar WRF perform in Antarctica due to recent advances in numerical weather prediction, observational networks and communication systems? Polar WRF was developed and tested primarily in Arctic environments.

As with WRF, the model is continuously developing and rapidly being refined by the community. A drawback to such a rapid development is the difficulty in repeating all previous verification experiments already completed with earlier versions every time a new one is released. The rapid development also impacts the Antarctic Mesoscale Prediction System (AMPS) which started with MM5 and may soon be using Polar WRF3.3, currently being developed by the Polar Meteorology Group.

Understanding of the present-day Antarctic dynamics is required to make accurate AMPS forecasts which support the various research and tourism activities on the continent. In the 2010-2011 field season, 406 LC-130 and 69 C-17 missions by the New York Air National Guard and U.S. Air Force transported at least 5500 people and 15 million pounds of equipment *(*Antarctic Sun 2011*)*.

Previous evacuations have involved only a few people. However recent statistics show tourist visits exceeding 30,000 annually (IAATO, 2010). The potential for a large scale evacuation clearly exists. Accurate forecasts are required for success.

Although model skill is affected by many factors, most studies focus on the impact of different physics parameterizations on the forecasts. What about interannual variations and changes in the driving data?

Motivation

Ultimately skillful models are needed not just for accurate AMPS forecasts but also to make inferences about future climates and to understand the role of Antarctica in different climates. Critical operational and economical decisions have to be made based on the forecasts.

Recent findings from the GRACE mission show accelerated Antarctic ice loss. Accurate predictions are required to understand the climate dynamics and impact of future warmer global surface temperatures on both the ice sheet and shelves.

This study extends Arctic evaluations of Polar WRF to Antarctica and is part of a series of studies documenting ongoing verification of Polar WRF at The Ohio State University. Such evaluations are an important source of guidance in the ongoing development of Polar WRF.

Objectives

We consider three factors that can influence the skill of Polar WRF: (i) model improvements (ii) the data used to drive the model and (iii) interannual variations in the large-scale atmospheric circulation.

1. How have recent model improvements (physics etc) affected the model skill? Some improvements such as code parallelism enhance computational efficiency while others make the model easier to use and have minor impact on forecast skill.
2. How sensitive are model skill statistics to the quality of the initial and lateral boundary conditions (GFS-FNL as used by AMPS vs. ERA-Interim)? Unlike in the NH limited amounts of synoptic data go into any analysis/reanalysis over Antarctica. Recent advances in data assimilation could impact these analyses and hence Polar WRF skill.
3. Are some years easier for Polar WRF to forecast than others? How do skill statistics vary between 1993 and 2007? An earlier Antarctic evaluation used 1993 on the assumption (based on Precipitation) of near normal Southern Hemisphere circulation (1985-95; Cullather et al. 1998). But anomalous circulation threaten Antarctic research and tourism activities more than average conditions. We use 2007 to take advantage of both recent improvements in Polar WRF and the observational network.

Experimental Design

Simulation year appears in the first column, lateral boundaries in the second and the versions of Polar WRF used in the last three;
A cross (X) indicates the experiment was performed while an empty box means it was not required. GFS-FNL is the forecasts from NCEP, ERA-INT and ERA-40 are the two reanalyses from ECMWF.

Year	Driving Data	Polar WRF 3.0.1	Polar WRF 3.1.1	Polar WRF 3.2.1
2007	GFS-FNL	X	X	X
2007	ERA-INT		X	
1993	ERA-INT		X	

- **Polar WRF3.3.0 is currently being developed and is not used in this study.**
- **Simulations in first row are used to examine the impact on model skill of the rapid model developments.**
- **Simulations in column 4 are used to assess the impact of the analysis data (GFS-FNL or ERA-INT) on Polar WRF forecast skill. Note that earlier Antarctic verification used1993 ECMWF-TOGA .**
- **Experiments in rows 2 and 3 are used to assess the impact of interannual variations in large scale circulation on forecast skill. Strictly speaking though the quality of a reanalysis depends on the number of observations assimilated and this may differ between 1993 and 2007.**
- **Goal is to identify skill on a slightly larger spatial and longer temporal scales in contrast to case studies of limited region, short duration and high impact events (e.g. the Ross Ice-Shelf; Steinhoff et al. 2008).**

Domain Configuration used

Terrain - from Radarsat Antarctic Mapping Project Digital Elevation Model Version 2 (RAMP-DEM- 1km; Lui et al. 2001).

SST – For 2007 used 0.5 Degree Real-time, global, Sea Surface Temperature analyses from NCEP (RTG 2007) and for 1993 Reynold’s Optimal Interpolated (OI 1993 from NOAA/NCEP).

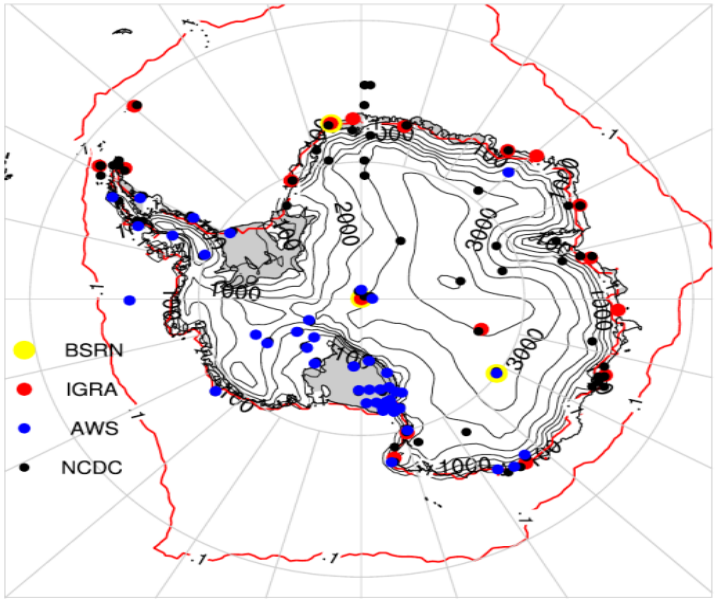
Sea Ice – from NSIDC passive microwave measurements using DMSP SMM/I. Sea ice effectively doubles the size of Antarctica (red contour) in winter.

Atmospheric data: Lateral boundary conditions depend on the experiment (previous table) .

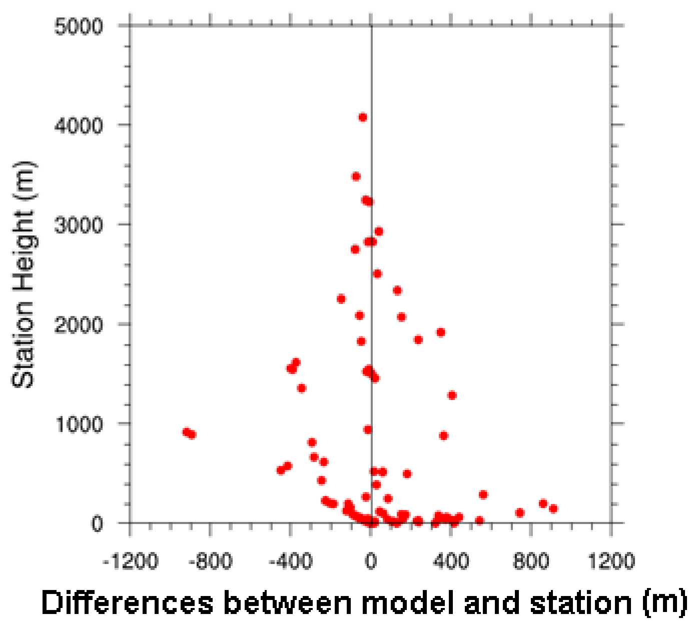
Not many upper air stations, most are located near the coast. No soundings over the Southern Ocean hence ERA-INT is used.

Clustering of stations necessitates careful site selection to minimize spatial bias and to avoid the large model to station elevation errors associated with low elevation stations. (Can exceed 500m).

Domain with terrain, seaice and station sites



Location errors by elevation



WRF Physics Configuration and options used

Model	Polar WRF3.0.1/3.1.1/3.2.1
Microphysics	WRF single Moment 5 (in 3.0.1 and 3.2.1) and 6 Class (in 3.1.1)
Longwave	Rapid Radiative Transfer Model (RRTM in 3.0.1 RRTMG otherwise); A sensitivity test is done using CAM
Shortwave	Goddard Short Wave in 3.0.1 and 3.1.1; RRTMG in 3.2.1; Sensitivity to CAM. Albedo set to 0.88.
Land surface	Noah Land Surface with optimized ice temperature profiles based on observed temperatures
Planetary Boundary Layer	Mellor Yamada-Janjic (Eta) TKE scheme
Surface layer	Monin-Obukhov (Janjic-eta) scheme
Cumulus Parameterization	Grell-Devenyi
Horizontal resolution	60 km
Lat/Lon	121x121
Relaxation zone	10 grid points
Vertical resolution	39 eta levels
Time step	120s
Model Top	10 mb; Damped over 8 km depth
Base State Temperature	273.16 K
Gravity Wave Option	On Only in Polar WRF 3.2.1, off otherwise
SST	Real-time, global SST NCEP in 2007
Integration	24 hour forecast, 24 hour spin up

Physics combination favor recent developments for a particular scheme e.g. RRTM to RRTMG
Most of the experiments are conducted with the well tested Polar WRF 3.1.1

Results

Changing model version

Different years (interannual variation)

Different radiation schemes (CAM vs. RRTM)

Driving data versus physics

Summary statistics

Temperature and Dew Points

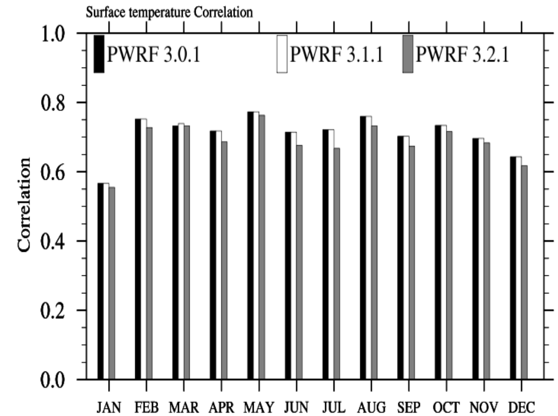
2m Temperature variability is captured with a correlation greater than 0.7 except in Jan.

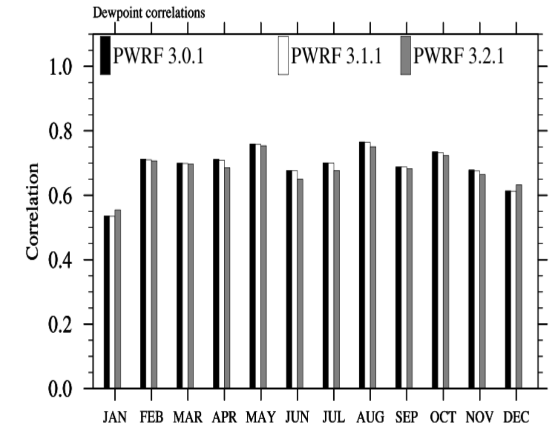
There is a strong seasonal cycle in the temperature bias; Colder in summer warmer in winter; Polar WRF3.2.1 has smaller bias.

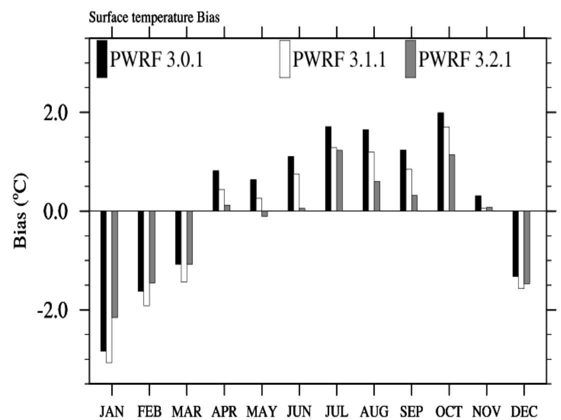
RMSD is largest in winter and least in summer. Strong winter circulations may be impacting temperature more.

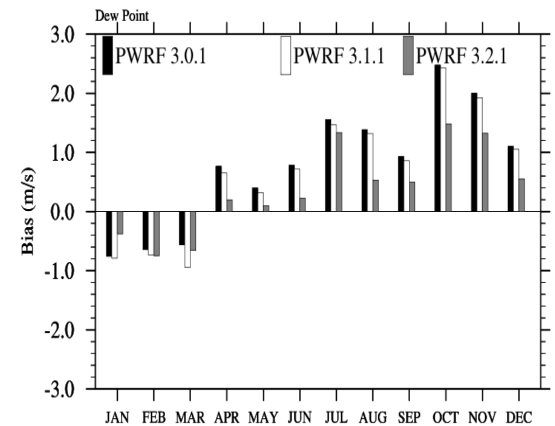
Dewpoint temperature statistics are comparable.

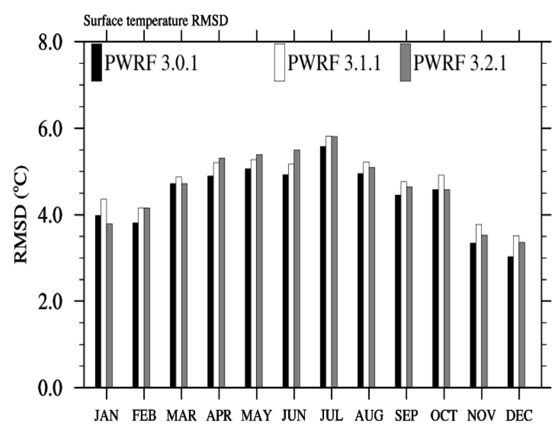
All three versions show similar temperature forecast skill; Seasonal differences are bigger than differences between model versions

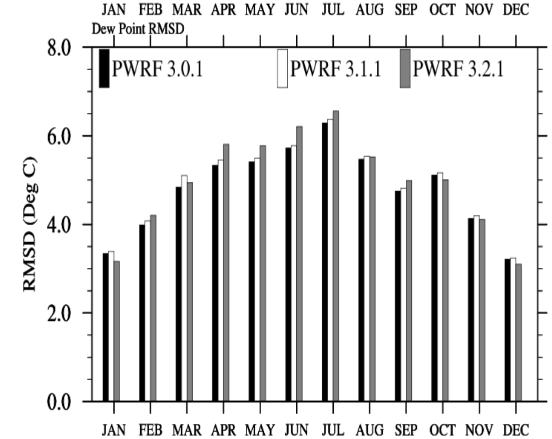












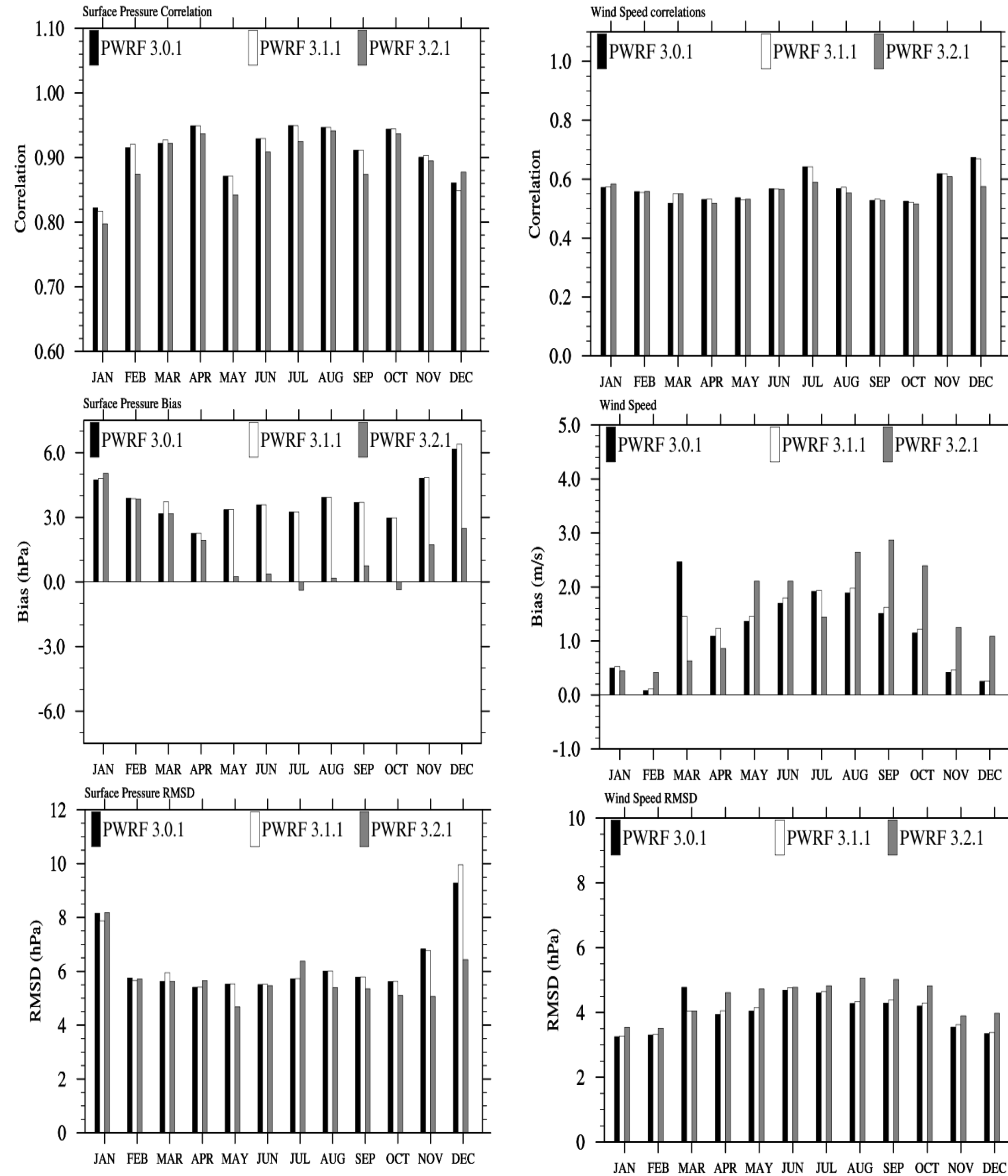
Surface Pressure and Wind Speeds

Average correlations are ~0.9 except during austral summer; Wind speed correlations are lower and show little seasonal variation in all versions.

Polar WRF 3.2.1 has the lowest PSFC bias in austral winter but shows the largest seasonal variation.

Bias in wind speed is largest during winter

PSFC and wind speed variability are again captured with near similar skill by all versions; Except for wind speed Polar WRF 3.2.1 forecasts the magnitudes better than the earlier versions; The Gravity wave option in 3.2.1 does not appear to change the forecast skill for wind speed

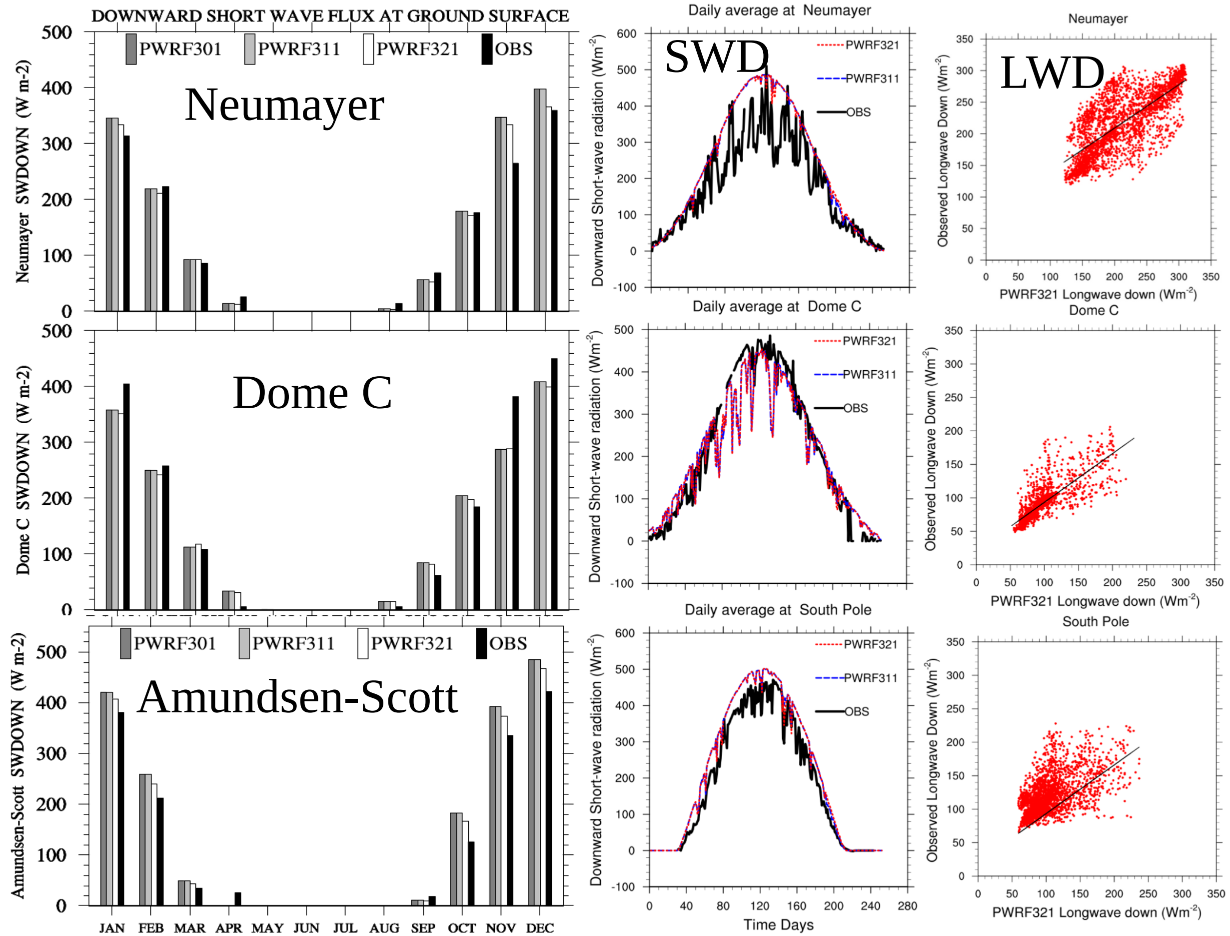


Short and Longwave radiation

All three versions have higher than observed SWD at Neumayer and the Differences between them (height of bars) are small

At Dome C the model has a less SWDOWN compared to observations

Positive bias at Amundsen-Scott similar to Neumayer above



·**The daily averages suggest that the model does capture peak observed SWDOWN at Neumayer but not the minimum (associated with cloudiness)**

·**At Dome C the model SWDOWN varies more than observed (but we had fewer obs.)**

·**At Amundsen-Scott neither the summer peak or minimum in SWDOWN is properly represented; As at Neumayer the model variations are less the observations**

The scatter plots of LWDOWN suggest that cloud variability in the model is poorly represented especially at higher values

1993 vs. 2007: SFC

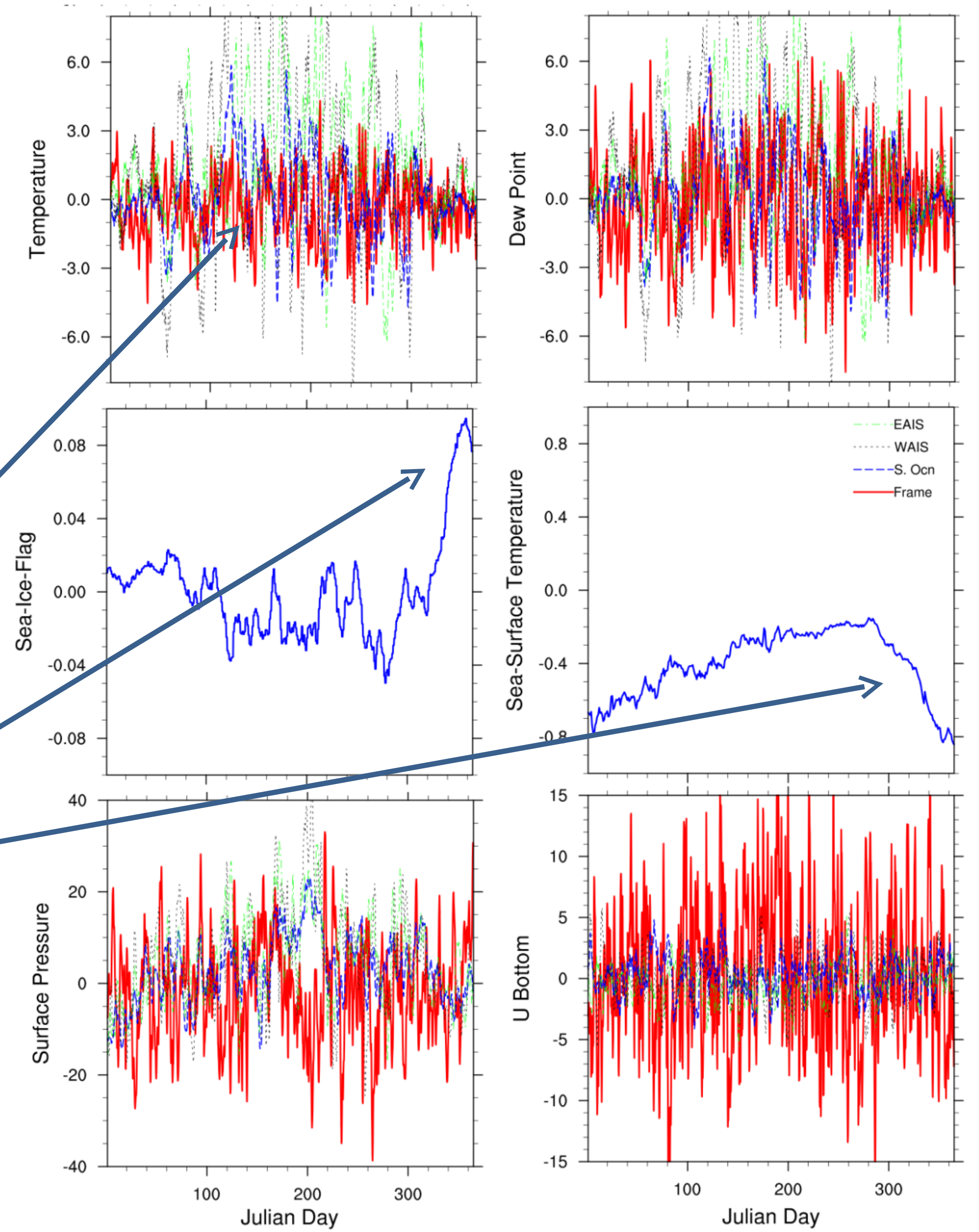
Interannual differences are communicated to through lateral and initial boundary conditions. First we examine how different 2007 is from 1993 based on ERA-INT.

Divided the domain into four parts and took grid point differences: **WAIS (EAIS)** all land points in **western (eastern)** hemisphere. S. Ocean all ocean points and **Frame**-the **15-grid points** around the domain where lateral boundaries are specified during a forecast.

2m air temperatures varies less ±3 K in the Frame (red); More variation occurs over land points (green and black).

In 2007 there was more sea ice in austral spring than in 1993; Consistent with colder SSTs. Therefore the primary surface differences for Polar WRF is the higher sea ice and lower SST concentrations in 2007.

Other differences are nearly symmetrical (no trend) about zero and indicate a possible range of variability in values that can be specified in the initial conditions;



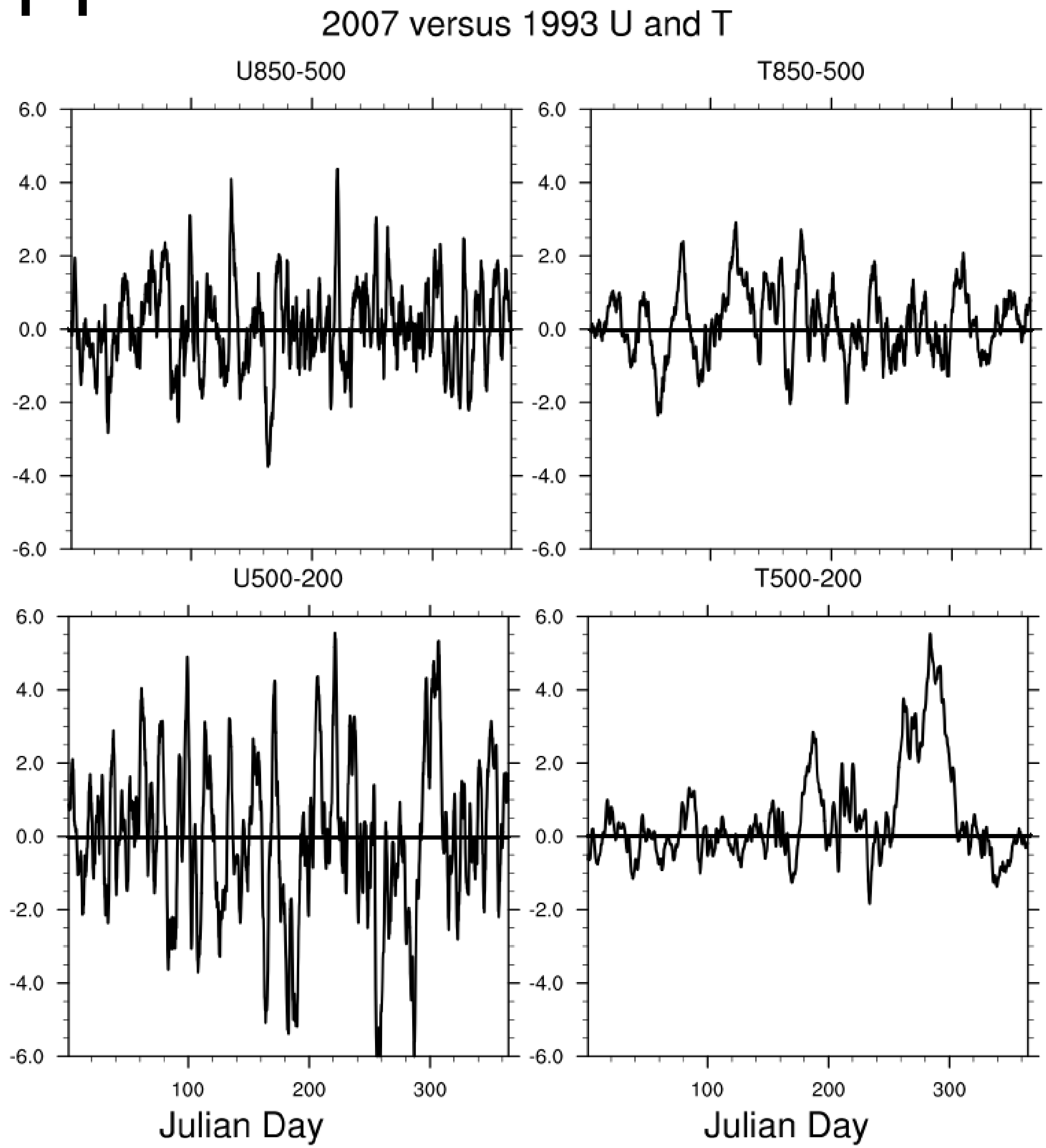
1993 vs. 2007:Upper Air

Differences in upper air zonal wind speed and air temperature in the layers 850-500hPa and 500-200hPa. Average differences are taken at all grid points.

Mean differences in zonal wind near the surface is about half that in the upper levels and again show no systematic differences between 1993 and 2007 zonal wind speeds.

Except during austral spring , the interannual temperature differences are within ±2K

Therefore the primary difference in upper level forcing data between 1993 and 2004 is found in temperatures above 500 hPa



Forecast 2m Air temperature

Polar WRF.31.1 driven with ERA-INT

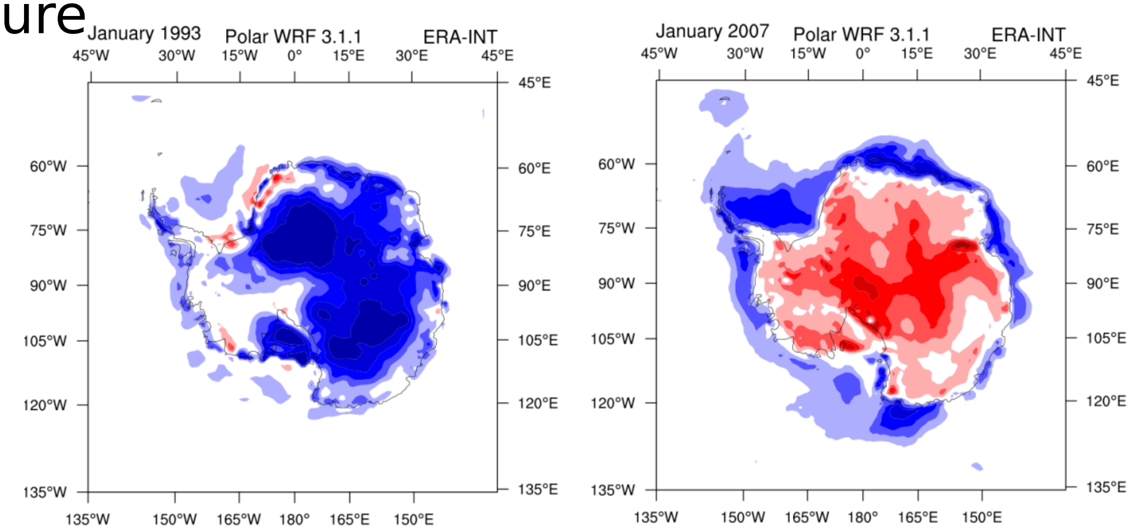
·**During summer larger differences (Polar WRF with GFS-FNL minus ERA-INT) occur over land; Over the ocean differences are smaller in Jan 1993**

·**The two years show different anomalies. Polar WRF is colder than ERA-INT in Jan 1993 but warmer in Jan 2007.**

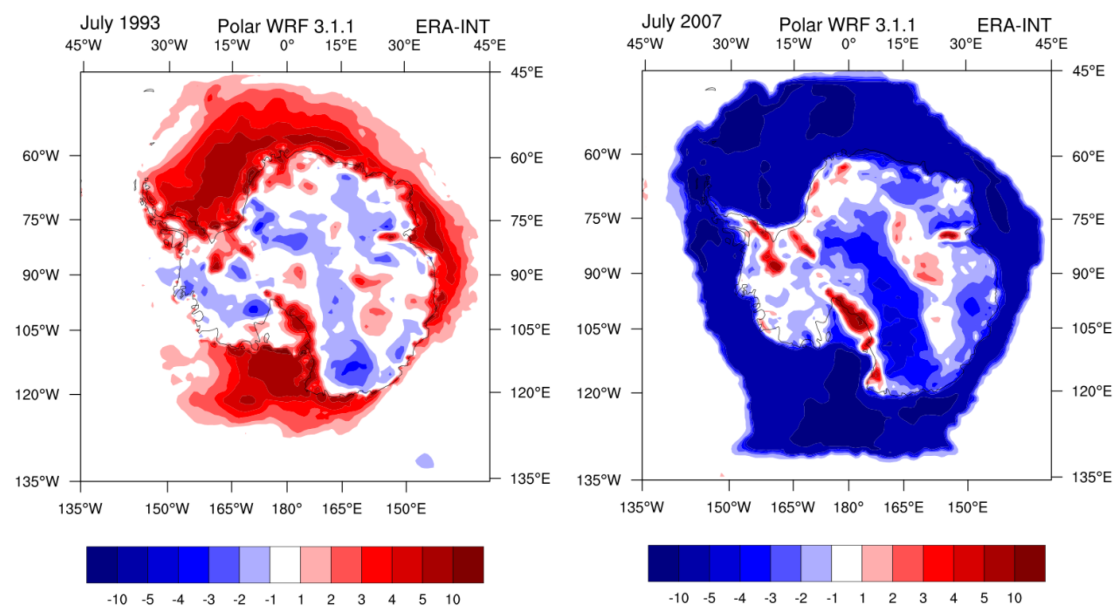
·**Winter differences are in general smaller than in the summer over land. But differences over the ocean can be very large and are related to the sea ice distribution. ERA-INT forecasts not made with NSIDC seaice as used in Polar WRF.**

·**Colder differences occur over land during winter in both years.**

·**Differences in surface pressure are small except along the coast; Probably related to differences in ERA-INT and Polar WRF Topography**



Polar WRF relative to ERA-INT for 2007 and 1993



Differences due to Physics change (RRTM/CAM)

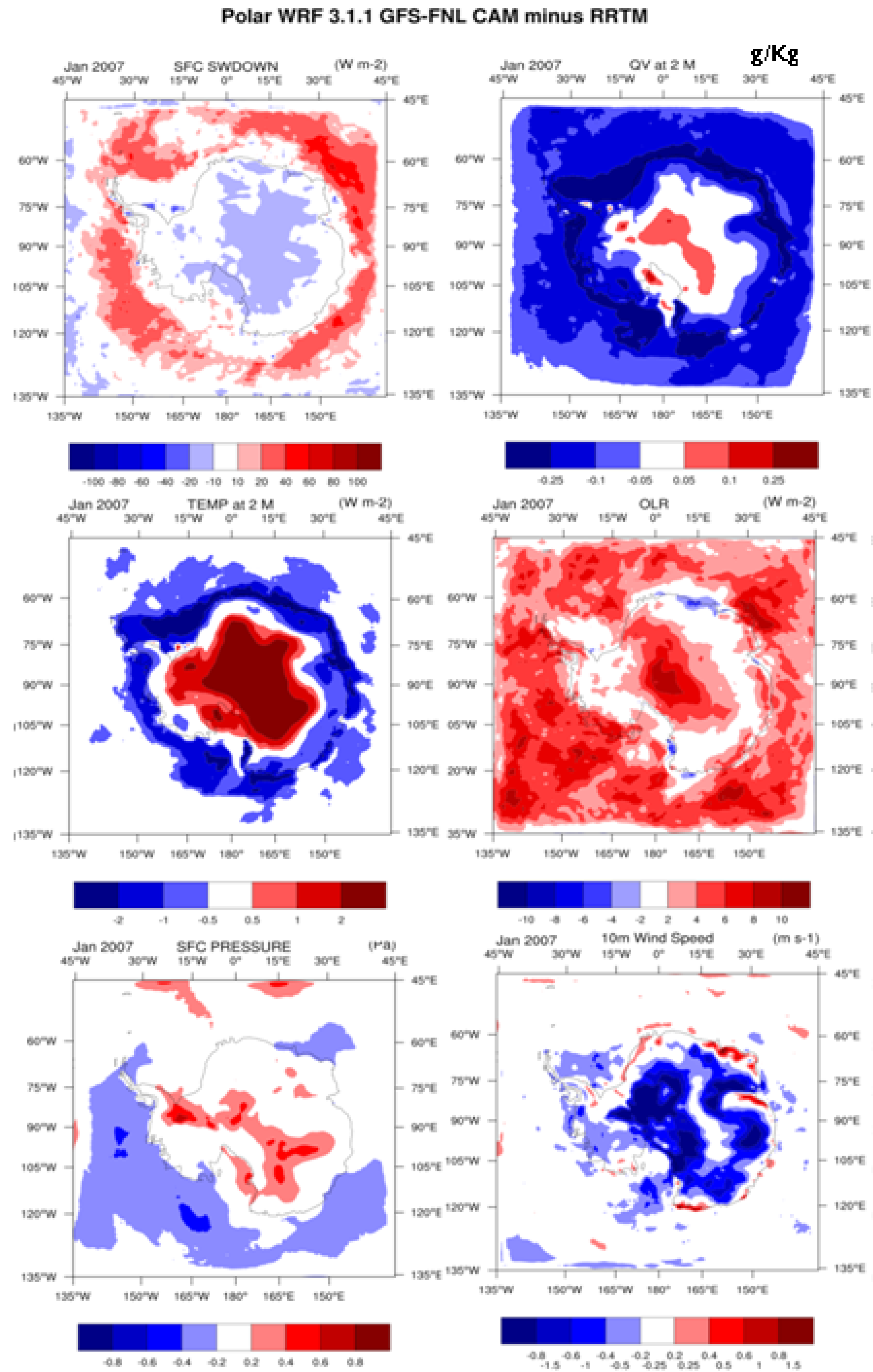
Polar WRF predicts less SWDOWN on the ice sheet and a more over the Southern Ocean when using CAM.

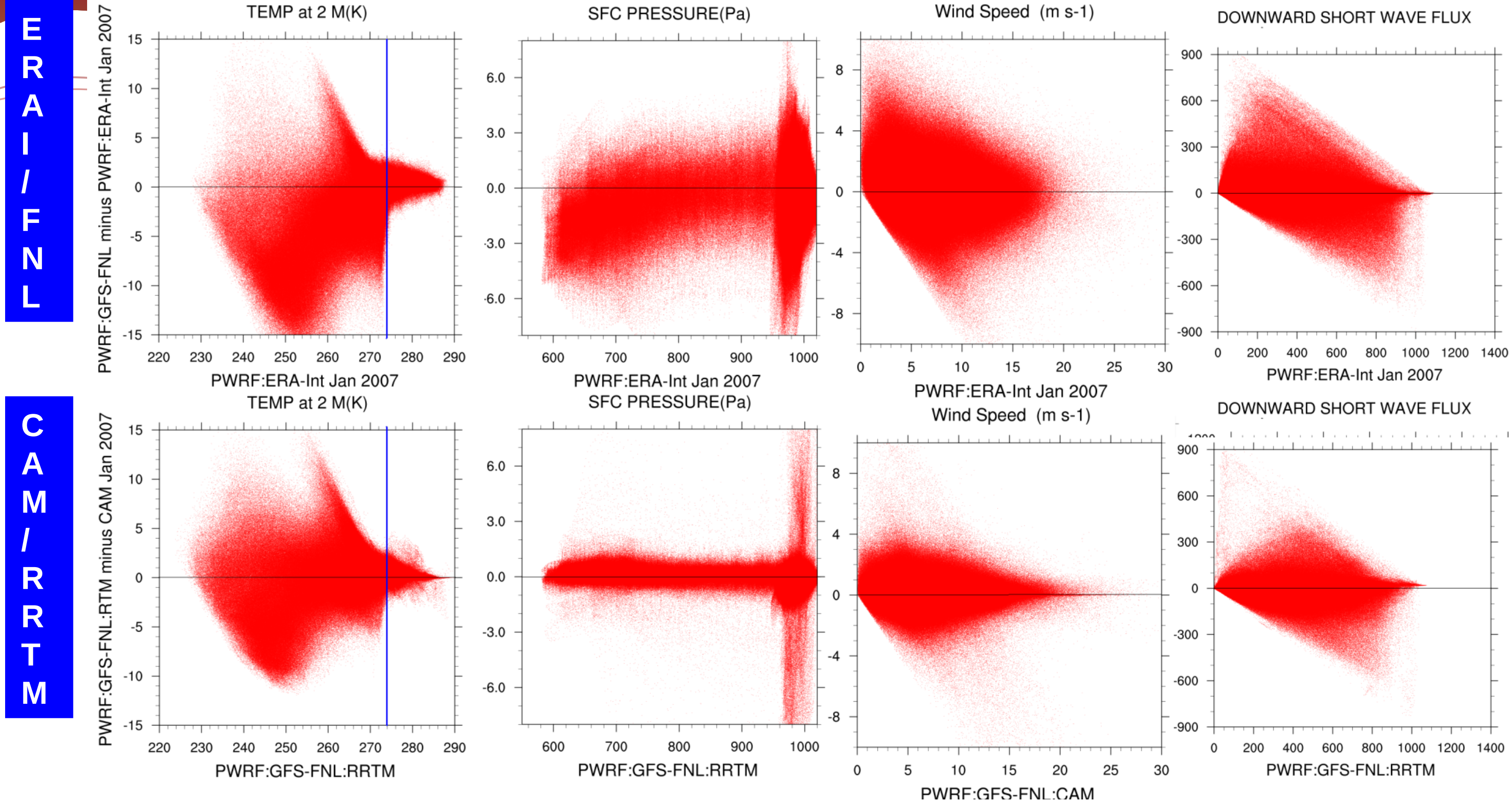
Using CAM produces less water vapor at 2m over the ocean than on land.

Using CAM reduces the cold January bias over land.

CAM physics produces more OLR than RRTM.

Differences in forecasts of surface pressure due to the physics change are less than 1.0 hPa. The associated winds are also weaker.





All model grid points are included; More spread in the scatter plots implies larger differences between the forecasts

- **Differences in Polar WRF forecasts resulting from changes in physics are generally less than those from changing the driving data from GFS-FNL to ERA-Interim.**

- **The differences are larger in areas where temperatures are lower than 270 K (blue line)**
- **Forecast surface pressure differences are greatest in the Southern Ocean. Most likely from differences in location of cyclones centers.**

- **Differences are modest for higher wind speeds and downward shortwave.**

Polar WRF 3.1.1 January statistics

	1993 ERA-INT		2007 ERA-INT		2007 FNL-RRTM		2007 FNL-CAM	
	CORR	**BIAS**	**CORR**	**BIAS**	**CORR**	**BIAS**	**CORR**	**BIAS**
PSFC	*0.88*	*0.5*	0.97	-0.05	0.95	-0.4	0.95	-0.5
2m TEMP	*0.53*	*-2.1*	0.61	-0.3	0.60	-3.3	0.57	-3.1
Wind Speed	*0.72*	*0.4*	0.57	2.2	0.57	1.8	0.58	1.6

Interannual variability is more important than changes in physics or driving data.

Conclusions

Polar WRF forecasts are more sensitive to both interannual variations in surface and atmospheric circulation than to differences in radiation schemes.
The primary source of interannual variability in model boundary conditions likely emanates from variations in sea ice distribution.
The CAM radiation scheme improves forecast summer surface temperature.
Accurate Antarctic forecasts are only going to become more critical operationally and in potential evacuations in the future.