A comprehensive evaluation of Polar WRF forecast performance in the Antarctic

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Outline

- Challenges/reasons for model application in Antarctica
- Benefits to AMPS community
- Recent developments in Polar WRF and future directions
- Polar WRF forecast performance (Bromwich et al. 2013 JGR)
- Work in progress

Challenges, observations and model applications in Antarctica

Understanding of long-term Antarctic climate variability (warming and accelerated ice loss) remains a big challenge

Advances in modeling, observation network and communication systems are increasing application of models (USAP, AMPS)

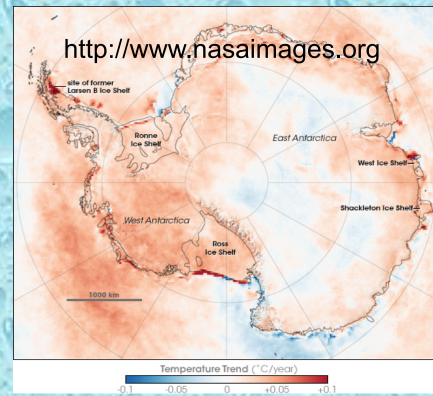
Relying on AMPS forecasts six ski-equipped LC-130 Hercules aircrafts flew missions in support of Operation Deep Freeze during the 2011-12 season

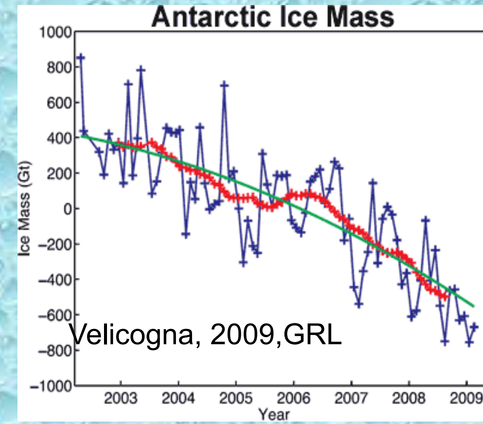
Together they transported at least 6600 people and 13 million pounds of equipment [Hannon, 2012]

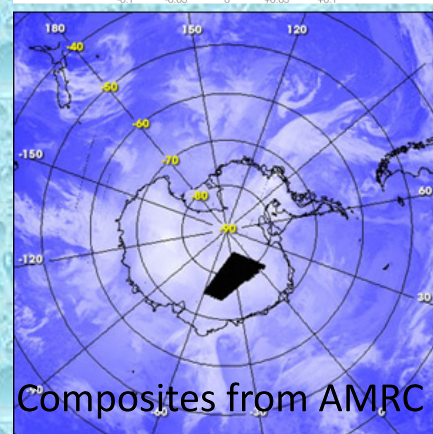
Number of staffed weather stations is still limited but satellite data e.g. AMRC are providing unprecedented coverage

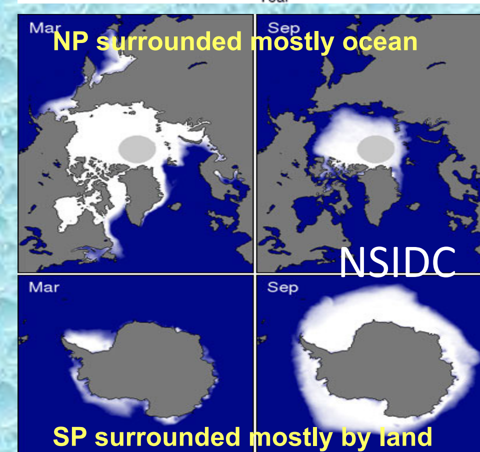
Coarse model resolution can substantially deteriorate forecast skill

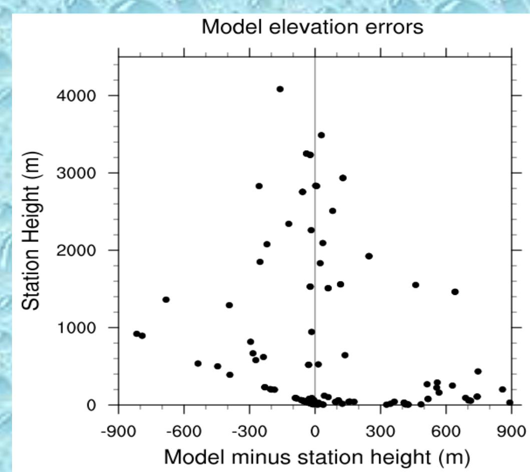
Warming trend NASA Earth Obs.

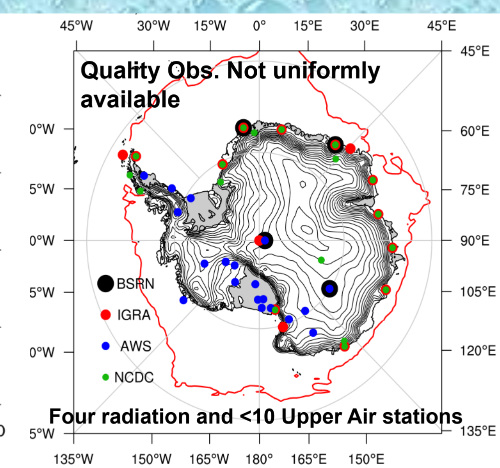


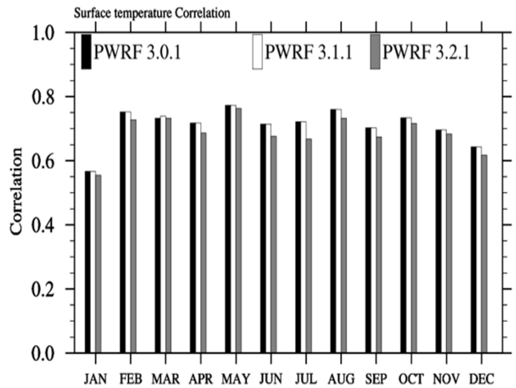


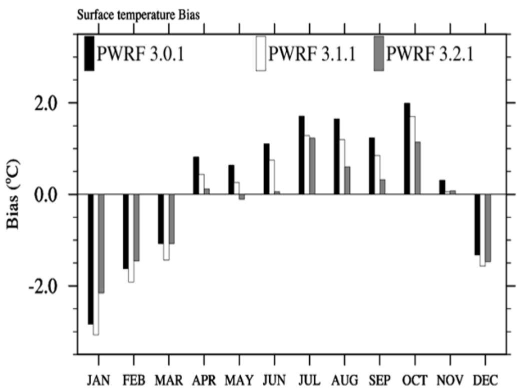


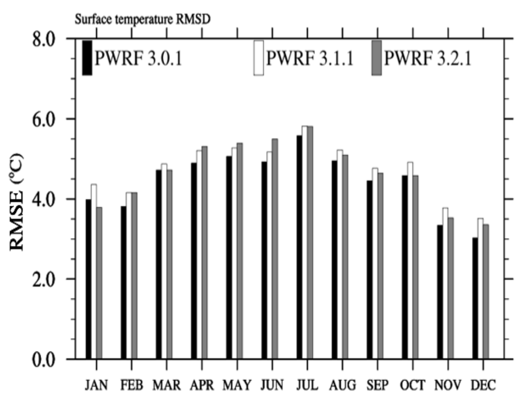












Polar WRF 3.0.1, 3.1.1 and 3.2.1 at 60 km in forecast mode

2m Air temperature

January has the lowest temperature correlations

Differences between model versions are small

Large variation in seasonal surface temperature bias; cold during summer, warm in winter months

Surface temperature RMSEs larger during winter than in summer

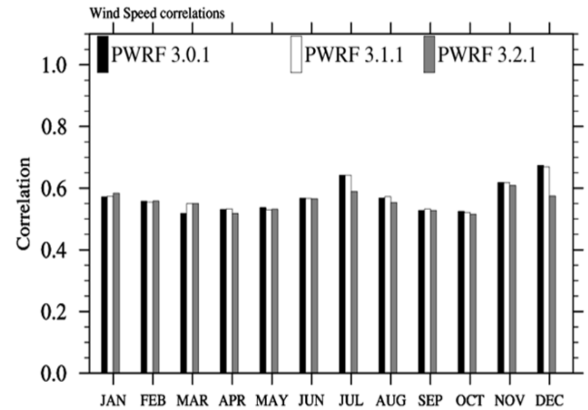
Surface wind speed

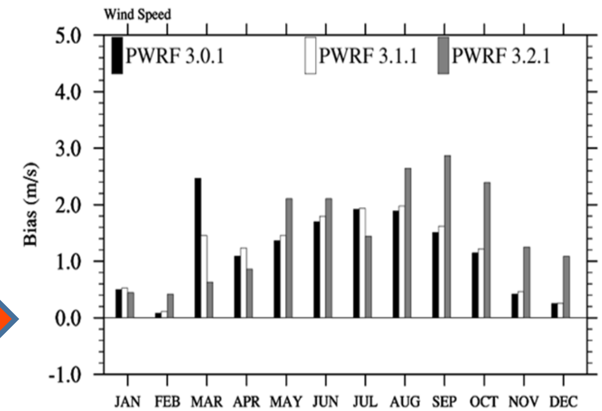
Correlations for forecast monthly wind speed exceed ~0.50 throughout the year

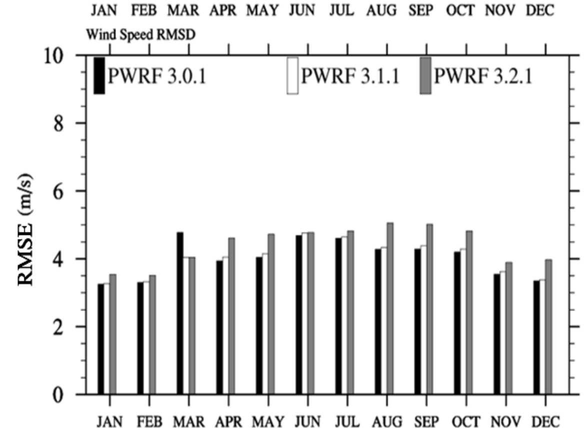
Stronger than observed wind speed all year round (max. in winter). Impacts winter downward sensible heat flux

Differences in RMSEs are smaller than 1 m/s

Little difference between different versions







Statistics from 3-hourly analysis

Wind speeds by regions

Domain averages in previous figure mask substantial biases in different areas

D-47 has the strongest observed and forecast wind speed

Wind speed bias is largest at a number of coastal sites where terrain is complex

Forecast wind direction generally falls within the same quadrant as the observed

Surface wind speed statistics from 3-hourly observations of a representative subset of stations for January 2007.

Jan-07	Most Freq. Dir.		Most Freq. Speed	
	OBS	W321	OBS	W321
		Coastal		
Rothera	22	45	6	9
Syowa	67	90	5	7
Neumayer	90	90	9	10
Mirnyj	135	90	6	15
Casey	180	90	4	13
D-47	157	135	13	17
Arelis	180	225	7	14
Lola	202	270	7	19
Rita	270	225	10	7
		Ice Shelf		
Vito	180	180	5	6
Lorne	202	180	7	9
Linda	202	225	9	10
Ferrell	202	180	7	10
		Interior		
Sky Blu	22.5	45	4	6
Nico	337	0	5	6
Amundsen	90	90	5	5
Henry	157	90	4	6
Concordia	180	225	4	5

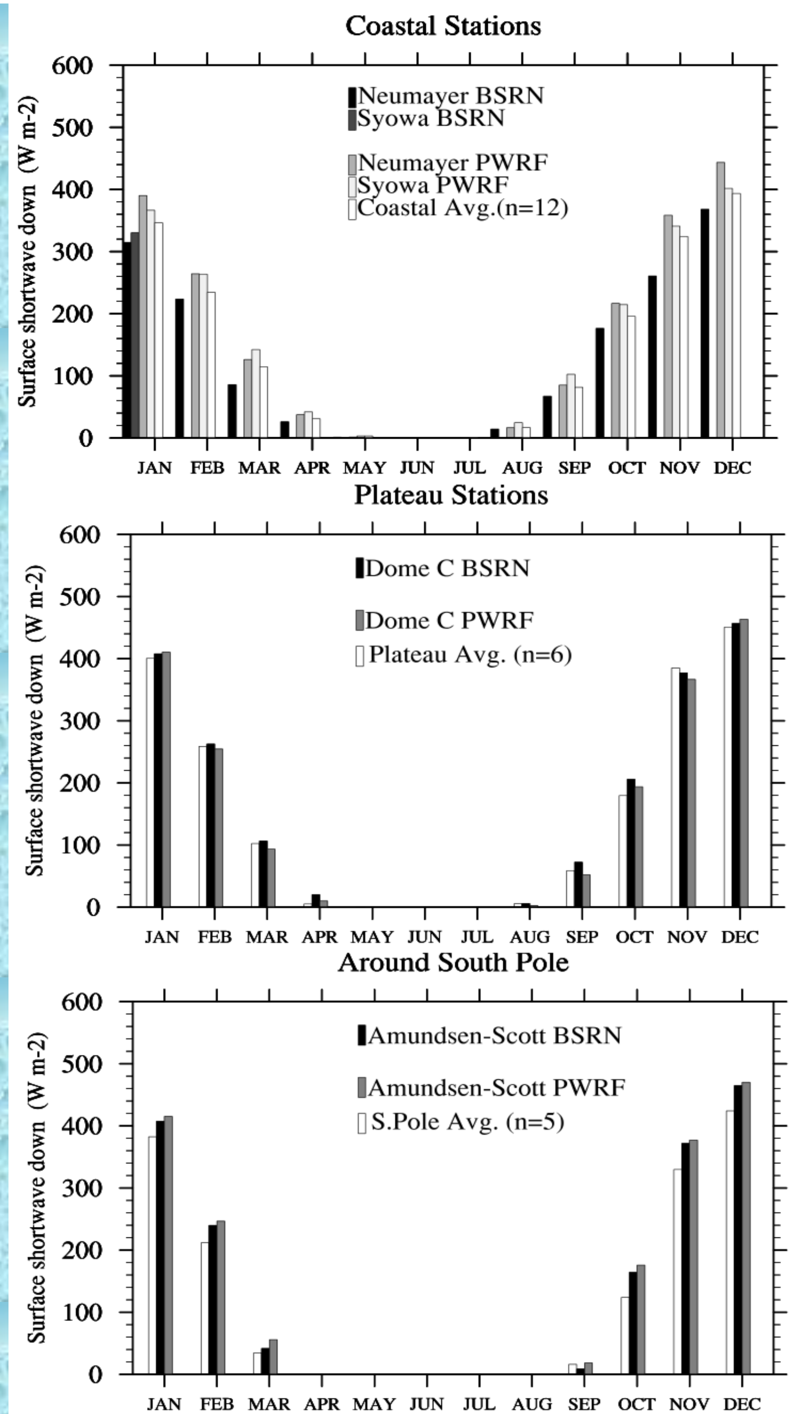
Downwelling Shortwave Radiation

Can errors in surface radiation and sensible heat fluxes account for the model biases above?

Polar WRF overpredicts *(relative to BSRN obs.)* the downwelling shortwave radiation at Neumayer, Syowa and South Pole

The biases at Neumayer and Syowa are representative of coastal sites

Forecast for Dome C exhibits a slightly different pattern (suggesting more clear skies)



Downwelling Shortwave Radiation

Model gets the highest daytime values better than the lowest

Forecast max generally exceeds observed and leads to the excess SWDOWN

Larger variation at Neumayer (more cloudy) than at Dome C

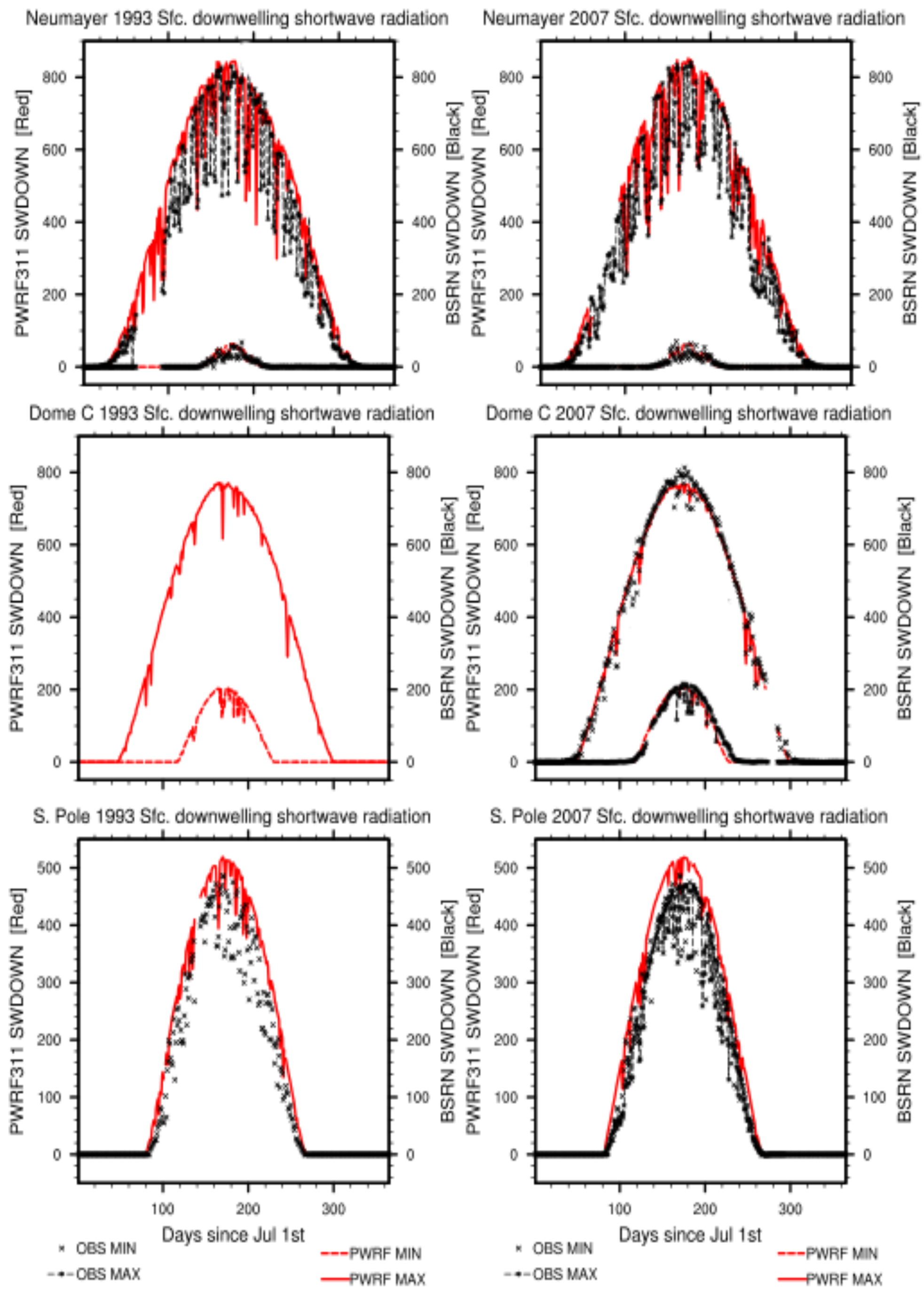
The model clearly over predicts downwelling shortwave radiation at South Pole in both years

Excess downwelling shortwave puts more energy at the surface. So why a cold bias?

(a) Albedo 80%

(b) deficit in cloud cover

Excess SWDOWN plays secondary role in the summer sfc. energy balance because most of it is reflected.



Shortwave and longwave down statistics

Both Neumayer and South Pole show a longwave deficit

The bias in downwelling shortwave confirms the excess in the previous figures

	Shortwave Down PWRF311		Shortwave Down PWRF321	Longwave Down PWRF311		Longwave Down PWRF321
CORR						
	1993	**2007**	**2007**	**1993**	**2007**	**2007**
Neumayer	0.94	0.95	0.94	0.65	0.77	0.76
Dome C	-	0.98	0.98	-	0.79	0.80
South Pole	0.70	0.97	0.97	-	0.63	0.60
BIAS						
Neumayer	47.8	32.8	27.5	-18.8	-9.4	-12.9
Dome C	-	19.9	8.0	-	6.2	5.8
South Pole	53.3	66.0	54.2	-	-23.4	-23.8
RMSE						
Neumayer	108.0	88.7	90.9	40.6	35.8	36.3
Dome C	-	46.3	51.1	-	21.3	19.7
South Pole	73.8	58.2	46.8	-	29.2	30.4

Cloud fraction

High frequency of overcast and broken cloud categories at Neumayer are consistent with the high SWDOWN variations shown earlier

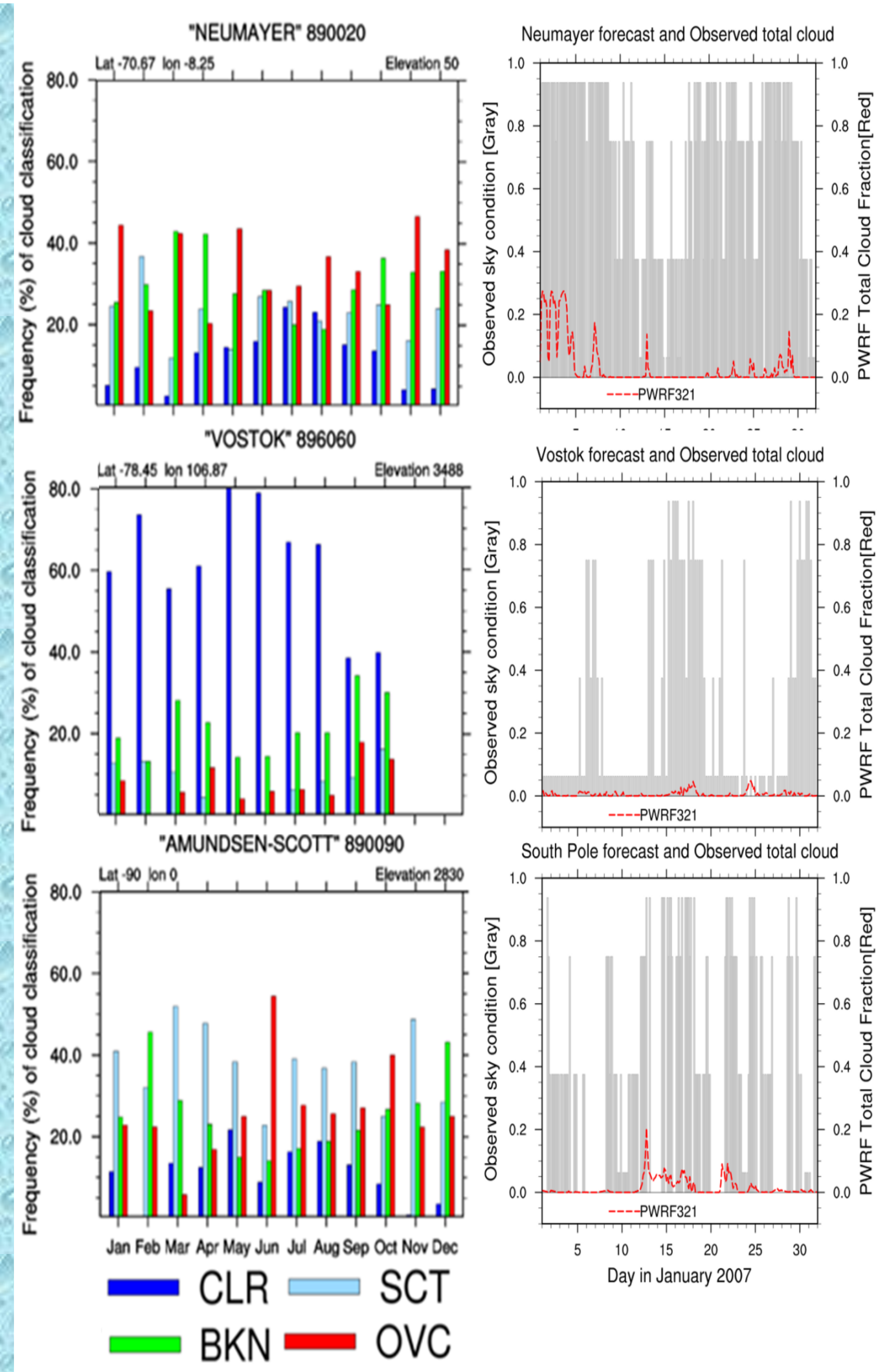
Skies at Vostok (proxy for Dome C) tend to be clearer

Substantial cloudiness at South Pole likely misrepresented in the model and hence the excess shown earlier

Forecast total cloud (*RHS red curve*) is always smaller than observed (*gray bars*)

Forecast cloud frequently remains near zero but increases during overcast conditions

There are uncertainties in both observed and computed total cloud fraction. But taken together with results from downwelling longwave radiation (above) the results support a hypothesis of deficient model cloud cover



CAM versus ERA-Interim

Need to evaluate model sensitivity in areas without much observational data in the Southern Ocean and on the East Antarctic plateau

Left panel impact of analysis (ERA-Interim versus GFS-FNL); right panels depict model sensitivity to change in the radiation physics (CAM versus RRTMG)

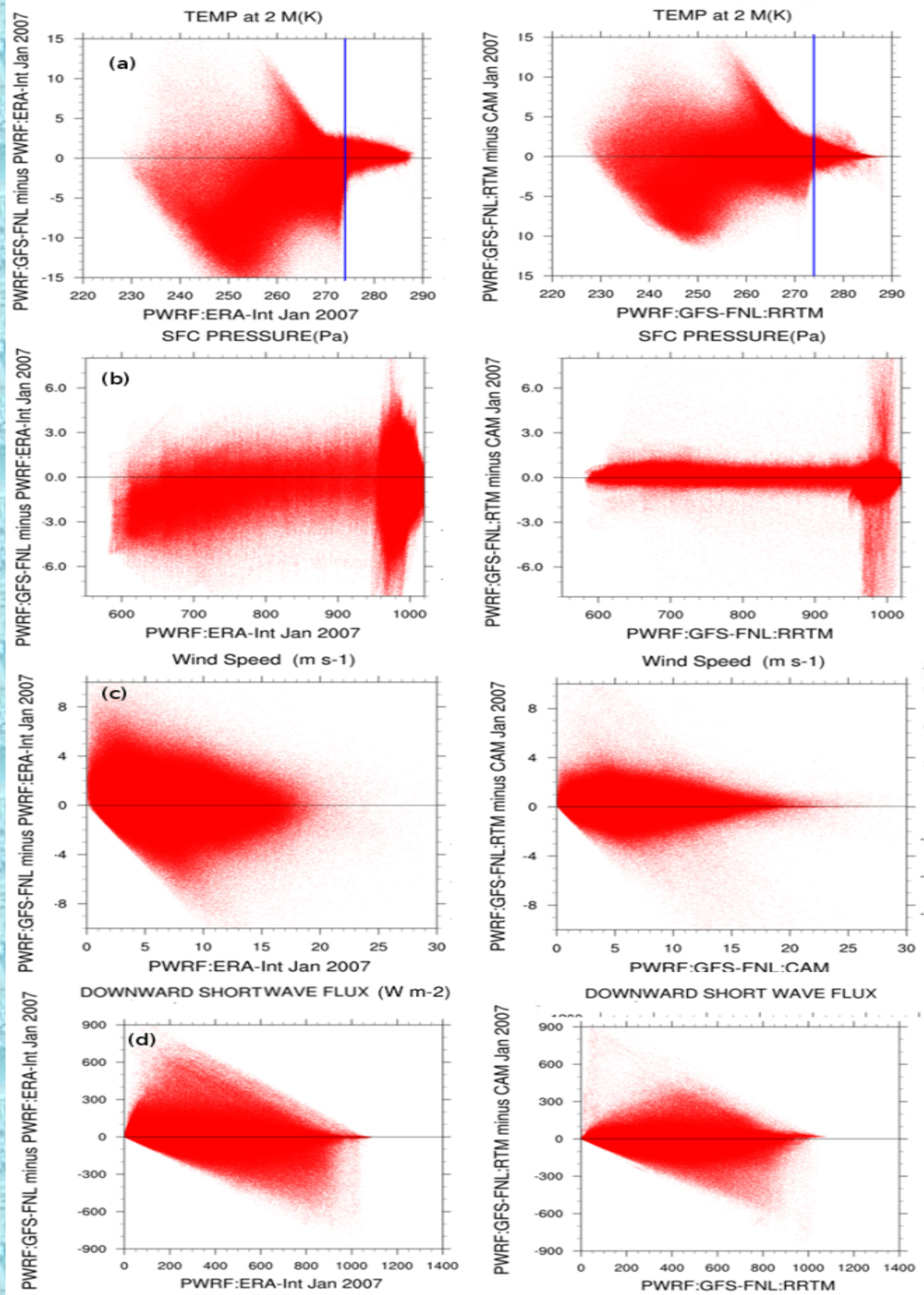
More locations are warmer in the ERA-Interim run than in the GFS-FNL run for temperatures below 270 K

Temperature differences become smaller for temperatures above 274 K (blue vertical line)

Larger surface pressure differences near 1000 hPa (*over the ocean primarily*)

GFS-FNL run forecasts more surface downwelling radiation than the ERA-Interim for values less than 400 Wm^{-2}

Changes due to radiation physics results in smaller scatter than from use of different analysis



Forecast sensitivity to year, model version, analysis and physics

Ran Polar WRF for 1993 and 2007, with different analyses (2007 GFS/ ERA-Interim) and physics schemes (MYJ,MYNN,CAM,RRTMG)

Sensitivity experiments using GFS have cold summer and warm winter biases which is drastically reduced with ERA-Interim

All the experiments irrespective of analysis and PBL scheme used have a positive wind bias

Polar WRF 3.3.1 ranks highest (rank score) in January while Polar WRF 3.1.1 does in July

It is hard to discern impact on forecast skill of interannual differences because the number of useful observations also differs substantially

Work in Progress

We have seen that clouds in the model are inadequately represented. Since cloud effects in the model are parameterized using the microphysics scheme, we are contrasting forecasts which use the Morrison double moment microphysics with midlatitude and with MPACE ice nucleation settings.

Two main sources of energy during July (*warm bias*) are downwelling longwave radiation (*deficient*) and downward sensible heat flux which may be enhanced by overly strong winds. We are investigating accuracy of stable PBLs and surface layer using the MYNN PBL and the revised MM5 surface-layer schemes.

Concluding remarks

Recent versions of Polar WRF have skill that is comparable to a recent Arctic evaluation [*Wilson et al.,* 2011, 2012] and representative for AMPS.

The model exhibits a cold summer and a warm winter bias in 2 m air temperatures.

Biases in both the forecast wind speed and surface pressure are positive.

Deficiencies in downward longwave radiation and cloud representation enhance longwave radiative loss leading to the summer cold bias.

Anomalous flux of sensible heat toward the surface generated by the positive wind speed bias in the stable boundary layer produces the warm winter bias.

The most skillful forecasts are those using the ERA-Interim reanalysis for initial and lateral boundary conditions. Likely related to higher precipitable water amounts.

Model skill is affected more by the analysis used than by the changes to parameterization physics or year to year differences. Improving the network of verification observations and quality of Antarctic analysis must remain a top priority for further development of numerical modeling in Antarctica.