

Numerical weather prediction for the Antarctic & the Arctic

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What is Polar WRF?

- Non-hydrostatic Weather Research and Forecasting WRF-ARW with polar modifications developed by The Ohio State University (Polar WRF)
- Multiple Development Tests (Greenland Ice Sheet, Western Arctic Ice Pack, Arctic Land, Pan-Arctic, and Antarctica)
- Polar modifications include improved heat transfer for snow and ice, fractional sea ice, time varying specified sea-ice albedo, sea-ice thickness, and snow cover on sea ice

A wide-angle photograph of an Antarctic landscape. In the foreground, a dark, calm body of water reflects the overcast sky. Several icebergs of various sizes are scattered across the water. To the left, a large, flat ice shelf or glacier extends towards the water. In the background, a range of rugged, snow-capped mountains rises against a sky filled with heavy, grey clouds. The overall scene is desolate and cold.

Antarctic NWP

The **A**ntarctic **M**esoscale **P**rediction **S**ystem (**AMPS**)

- Real-time, experimental NWP system for Antarctica, running since October 2000
- Stems from the need of high-resolution, polar-optimized model forecasts in Antarctica
- Primary purpose: provide NWP support for forecasters of the United States Antarctic Program (USAP)
- Funded by the National Science Foundation
- Collaboration between NCAR and the Byrd Polar Research Center of The Ohio State University
- Real-time forecast products available on the AMPS web site
- Recent overview of the AMPS project:
 - Powers et al., 2012: A decade of Antarctic science support through AMPS. *Bull. Amer. Meteor. Soc.*, 93, 1699-1712



McMurdo

AMPS supports USAP operations during the Antarctic field season



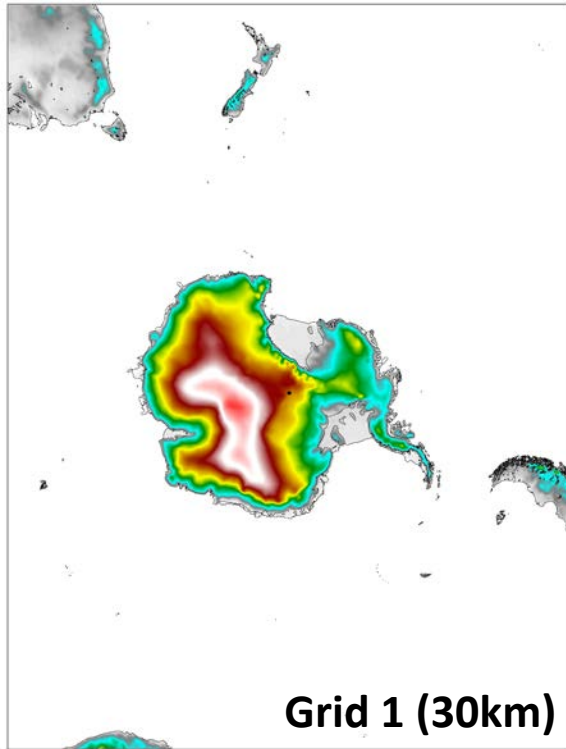
Photo: Air National Guard



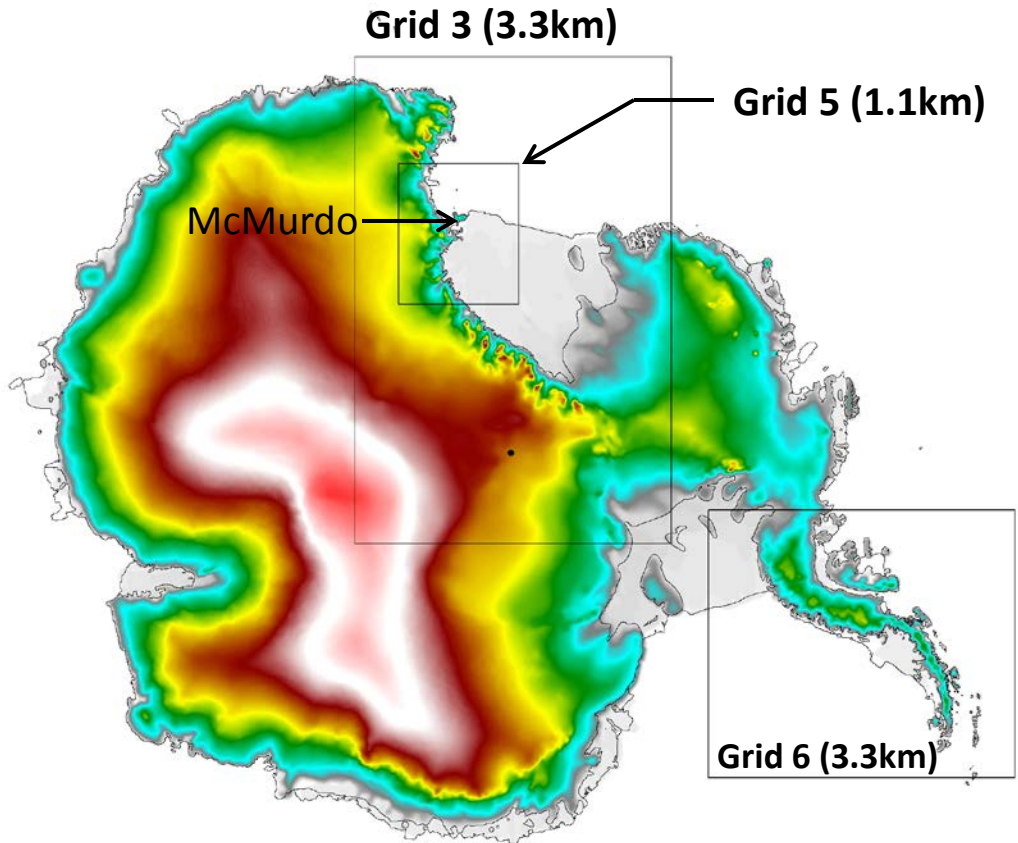
The AMPS system

- Forecasting model:
 - Non-hydrostatic WRF-ARW with polar modifications (Polar WRF)
 - Forecast skill of Polar WRF in the Antarctic - Bromwich et al. (2013). Issues with the forecast clouds and the stable boundary layer were the primary deficiencies.
- Model configuration:
 - 5 grids with two-way nested-domain setup
 - Horizontal grid-spacing from 30km for the outer domain to 1.1 km around McMurdo Station
 - 60 eta vertical levels (top at 10 hPa)
- First-guess field and lateral boundary conditions from NCEP Global Forecast System
- Sea-ice concentrations specified from daily SSM/I data
- 3D-Var data assimilation (WRFDA):
 - Conventional observations: surface, upper-air, aircraft
 - Satellite: AMSU, COSMIC, atmospheric motion vectors
- Twice-daily forecasts out to 5 days initialized at 00 & 12 UTC

AMPS domains

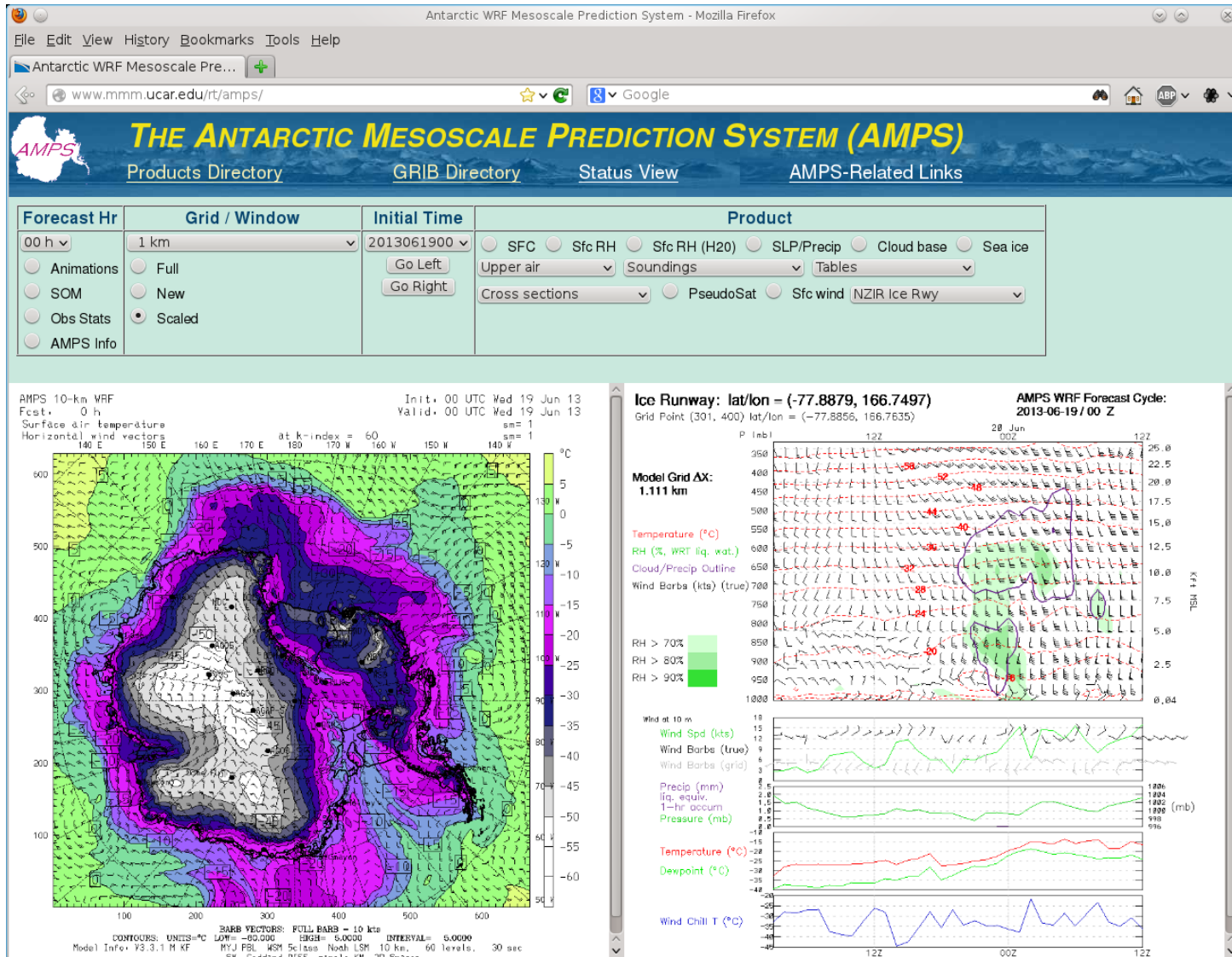


Grid 2 (10km)



Configuration
as of June 2013

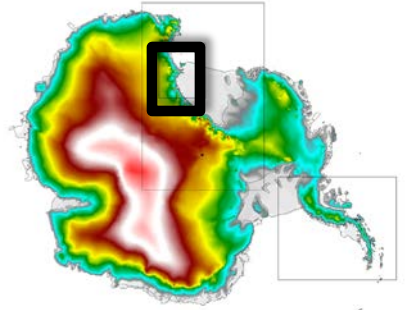
AMPS web interface



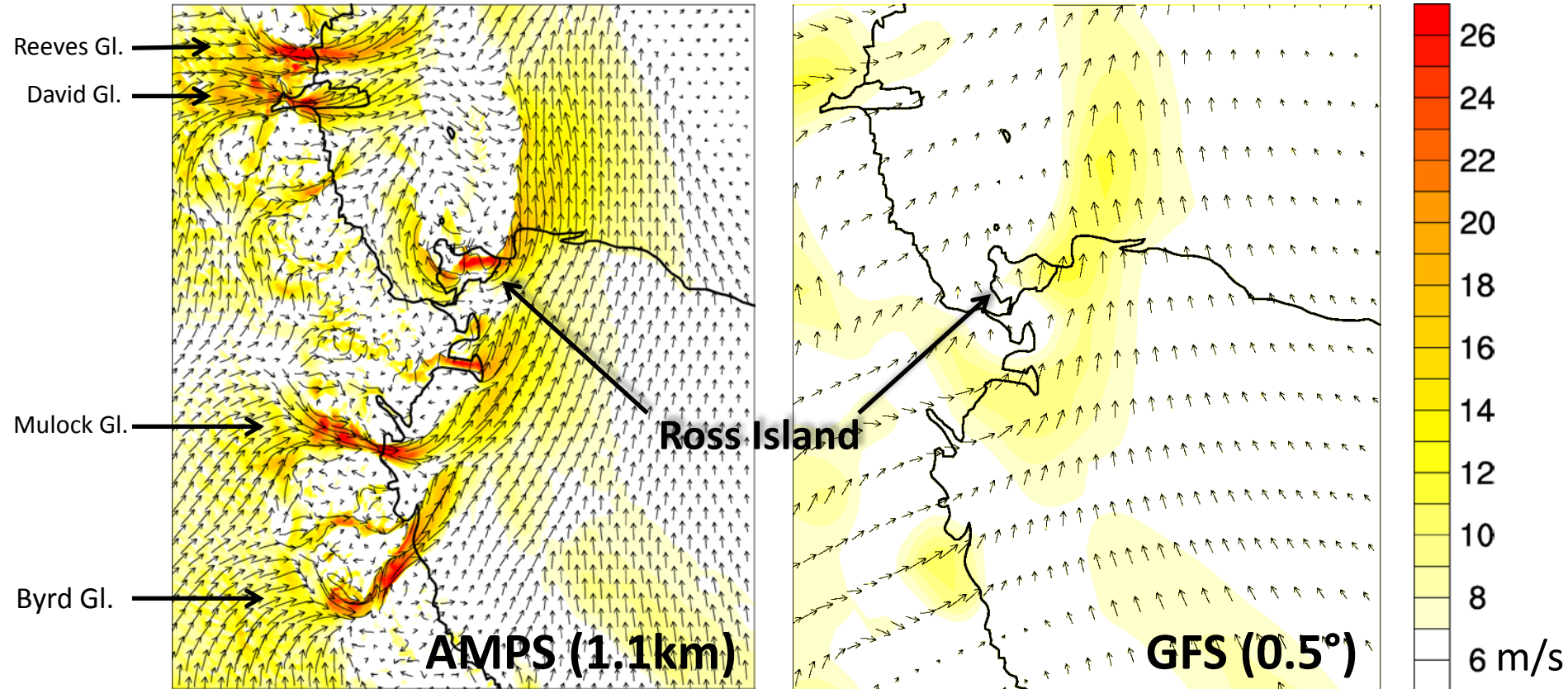
<http://www.mmm.ucar.edu/rt/amps/>

Benefits of high resolution

Example in the McMurdo region

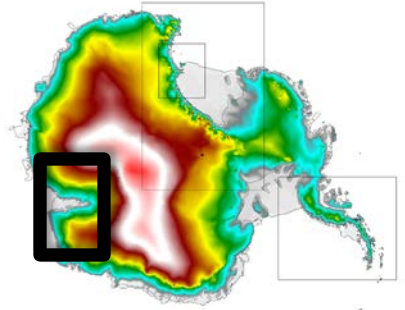


12h forecast of 10m wind field for 12UTC 17 June 2013



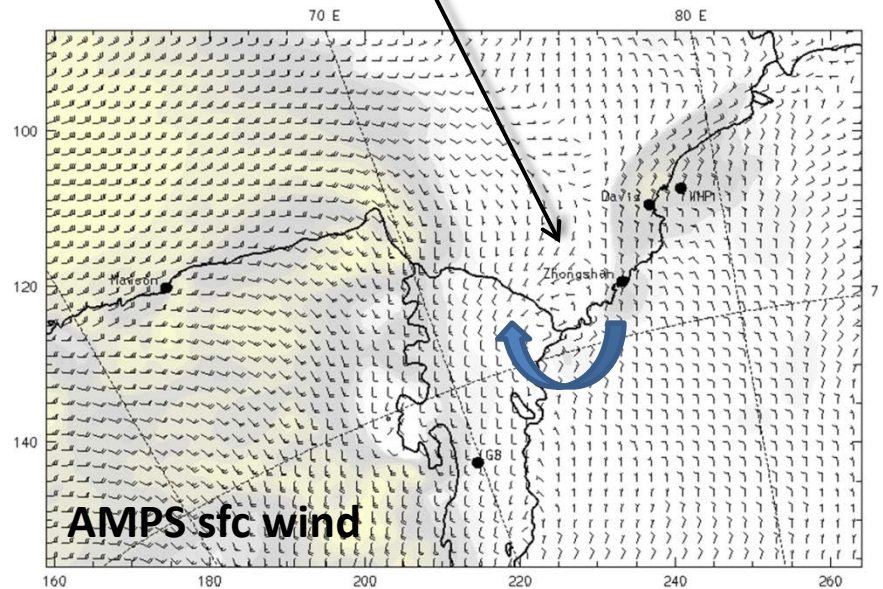
Benefits of high resolution

Example with the Prydz Bay Mesolow

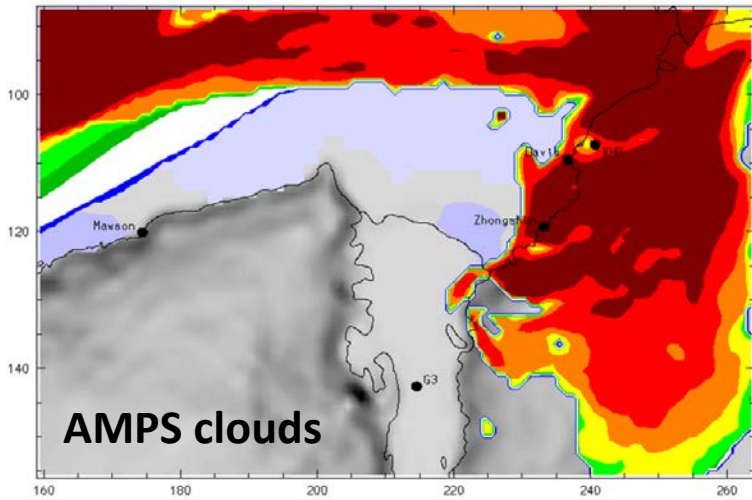


- Common occurrence during summer forecasting season, and throughout the year
- Brings low cloud and precipitation affecting aviation operations
- Shallow, transient, mesoscale feature
- Successfully forecast by AMPS, not the global forecast models

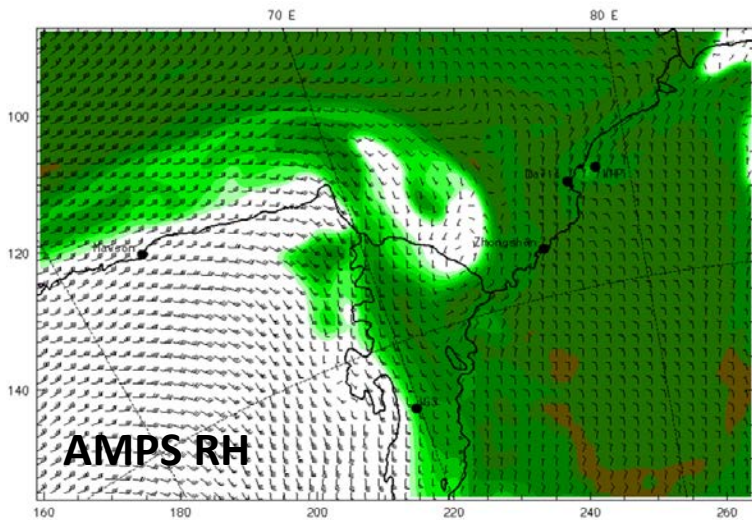
Mesolow near Amery Ice Shelf



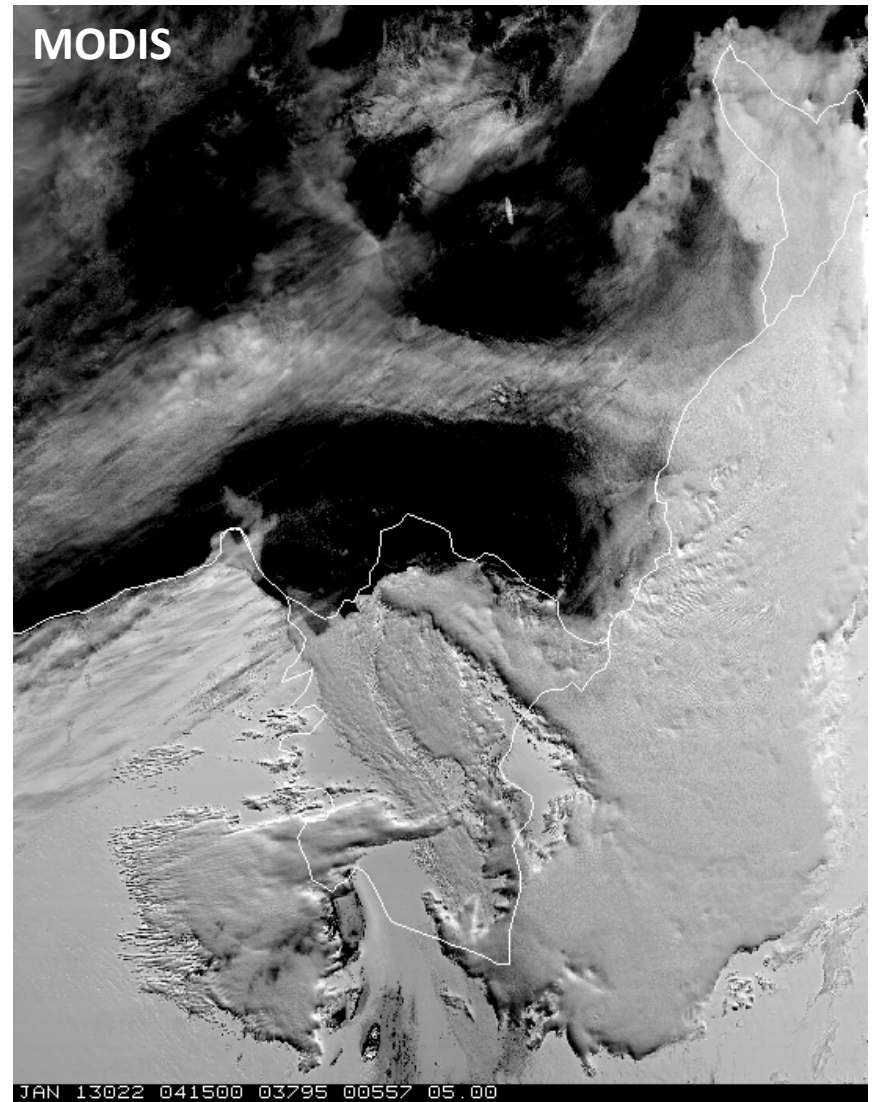
AMPS surface wind field for 06UTC 22 Jan 2013



AMPS cloud field for 06UTC 22 Jan 2013 showing low cloud associated with mesolow



AMPS 1km relative humidity for 06UTC 22 Jan 2013 showing low-level moisture wrapping around mesolow



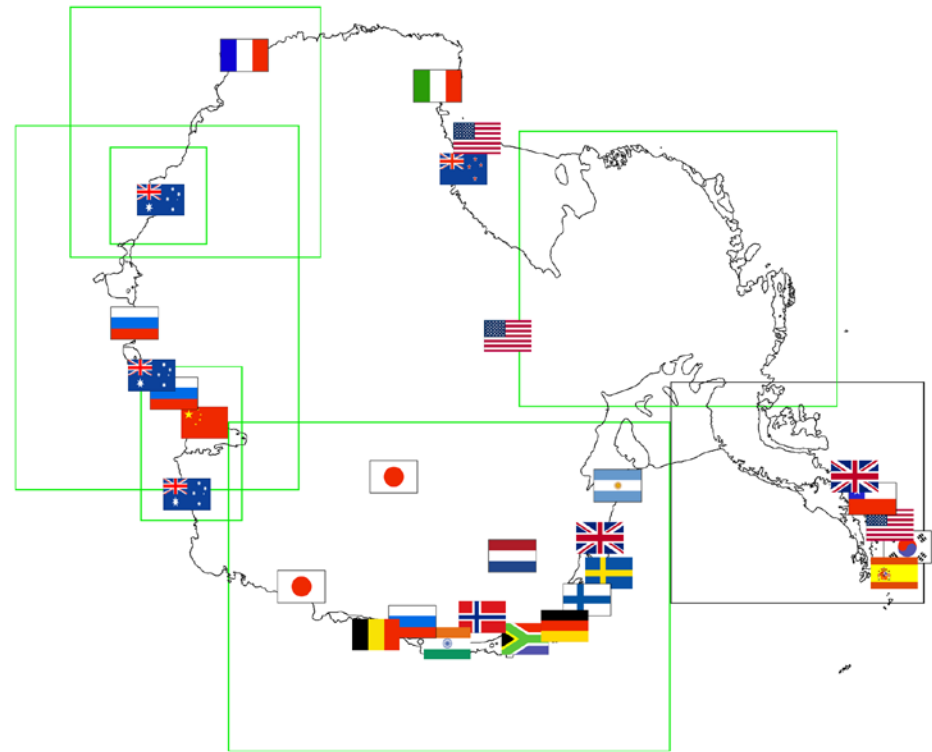
MODIS satellite image for 0415UTC 22 Jan 2013 showing low cloud consistent with AMPS 1km RH but **not** with AMPS cloud forecasts

Applications of AMPS

- NWP guidance/tailored products for USAP forecasters at McMurdo and Charleston, SC
- Support for scientific field campaigns:
 - One-way nests and plotting windows over field camps
 - Ship-following windows for research vessels
- Emergency situations:
 - Off-season medical evacuations from Antarctica
 - Ship rescues
- AMPS forecast archive (>10 years, now 60 TB/yr):
 - Used for model performance evaluation and Antarctic climate studies
 - Data housed on NCAR HPSS, by OSU's Polar Meteorology Group, and on the Earth System Grid Data Portal

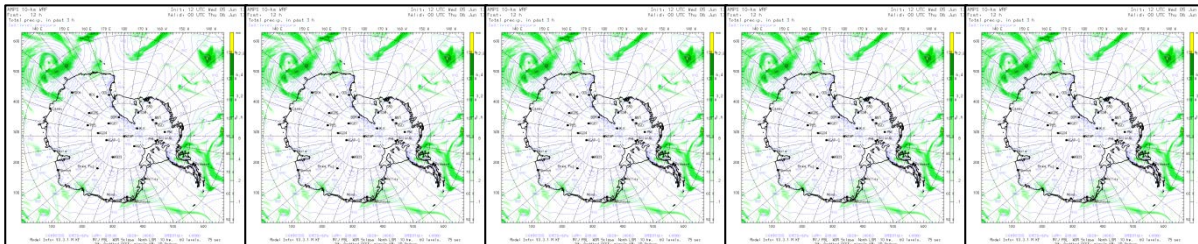
International use of AMPS

- AMPS users extend beyond USAP groups to Antarctic programs from other nations
- AMPS products tailored for international users:
 - Regional windows (e.g., Queen Maud Land, Davis-Mawson, Casey-DDU)
 - Station-specific data (e.g., soundings, meteograms)
- The annual Antarctic Meteorological Observation, Modeling, and Forecasting (AMOMF) Workshop serves as a forum for the U.S. and international community
 - June 2013: Madison, WI
 - June 2014: Charleston, SC
 - June 2015: Cambridge, UK



Under development: AMPS ensemble forecasting

- Approximately 10 members of the AMPS 30 and 10-km grids out to 5 days
- Same model physics – varying initial and boundary conditions
 - May later test different combinations of WRF physics packages
- Help quantify forecast uncertainty
 - How to best present this information to forecasters?

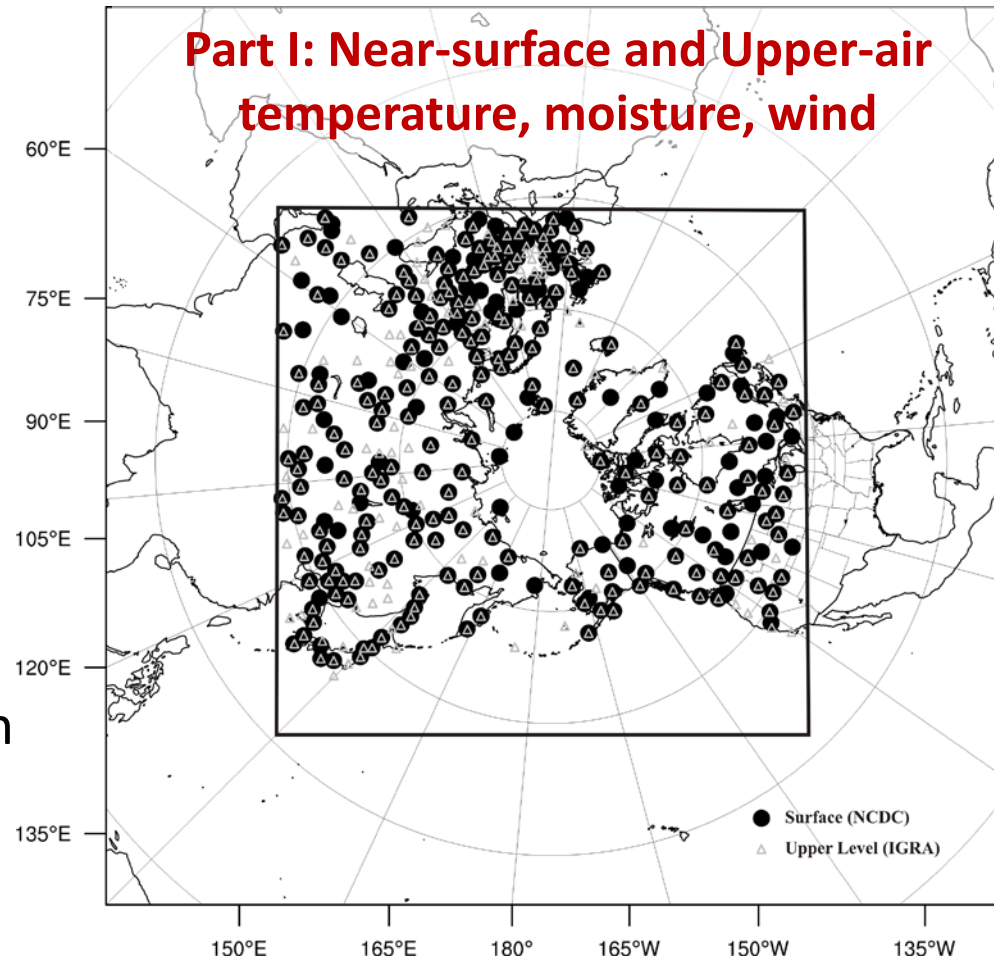


An aerial photograph of a vast, fragmented ice field in the Arctic. The ice consists of numerous irregular, interconnected floes of varying sizes, creating a complex, textured surface. The sky is filled with heavy, grey clouds, with a bright patch of light breaking through near the top center. The overall scene is desolate and captures the harsh, cold environment of the high northern latitudes.

Arctic NWP

Polar WRF Forecasts on the Arctic System Reanalysis Domain:

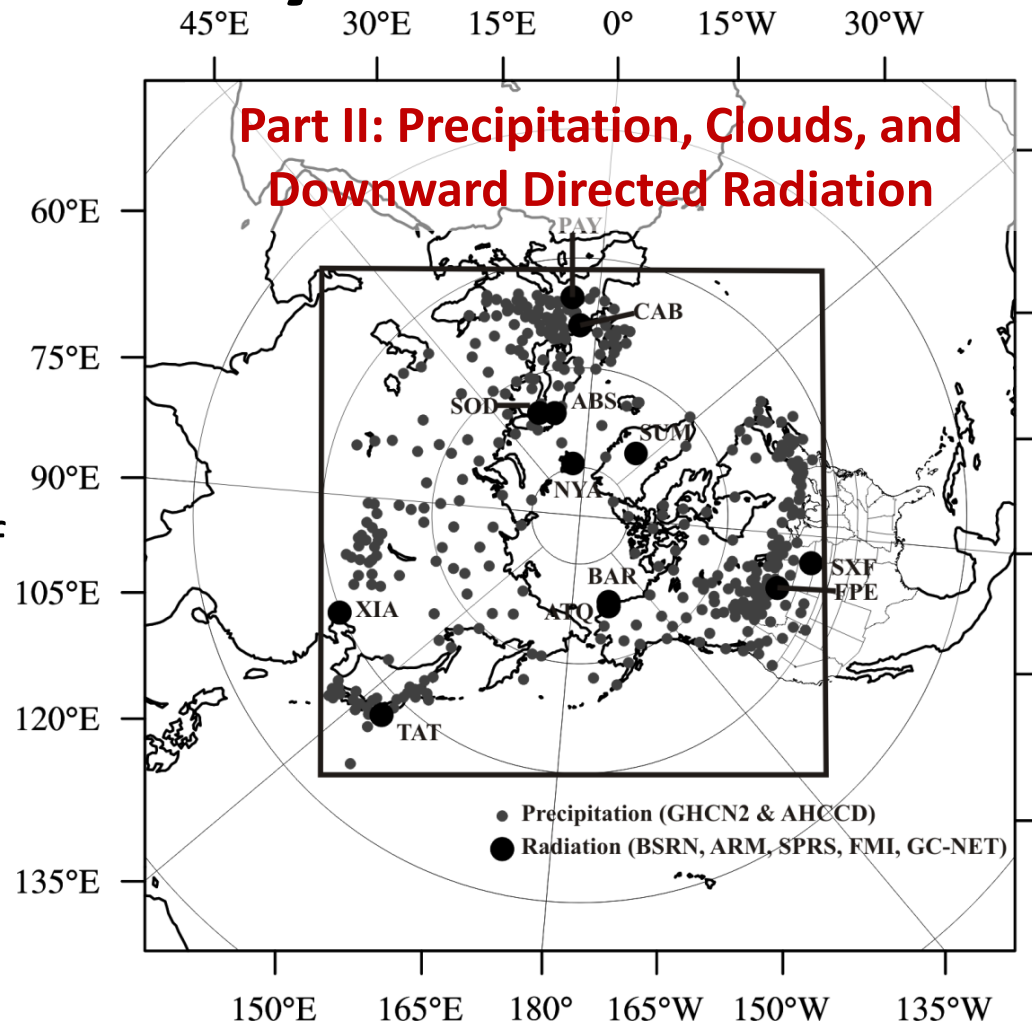
- Represents a pan-Arctic evaluation of Polar WRF
- Optimizing performance over the Arctic w/o penalty to other areas
- Evaluation of Polar WRF *short-term weather forecasts*
 - 60 km resolution
 - 2nd day of 48-hr forecasts with 24-hr spin up
 - NCEP FNL Operational Model Global Tropospheric Analyses



Wilson, A.B., D.H. Bromwich, and K.M. Hines, 2011: Evaluation of Polar WRF Forecasts on the Arctic System Reanalysis Domain: Surface and Upper Air. *J. Geophys. Res.*, **116**, doi:10.1029/2010JD015013.

Polar WRF Forecasts on the Arctic System Reanalysis Domain:

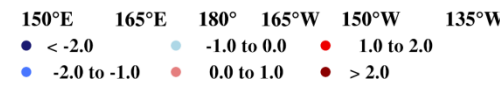
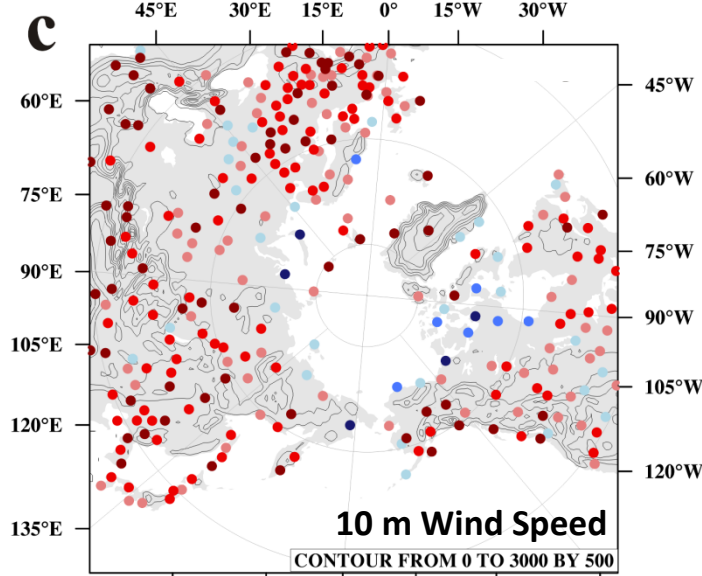
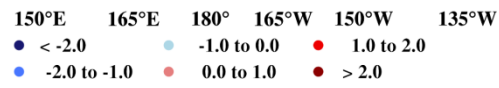
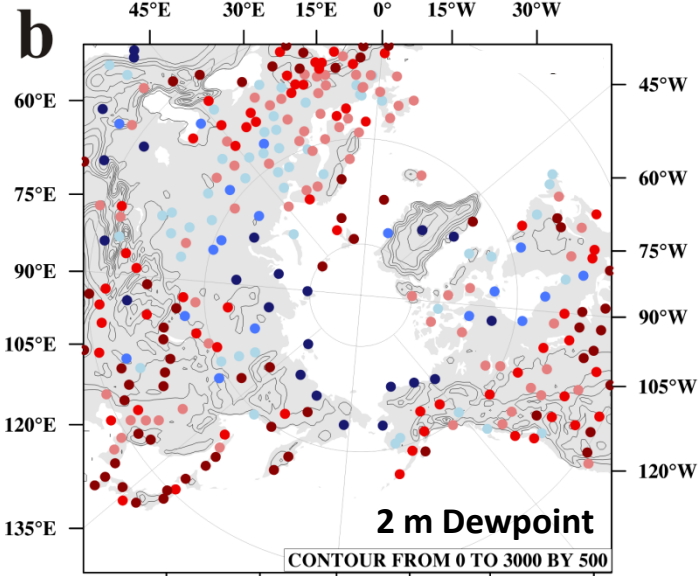
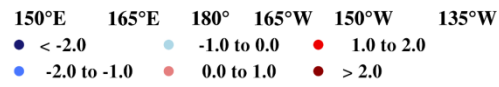
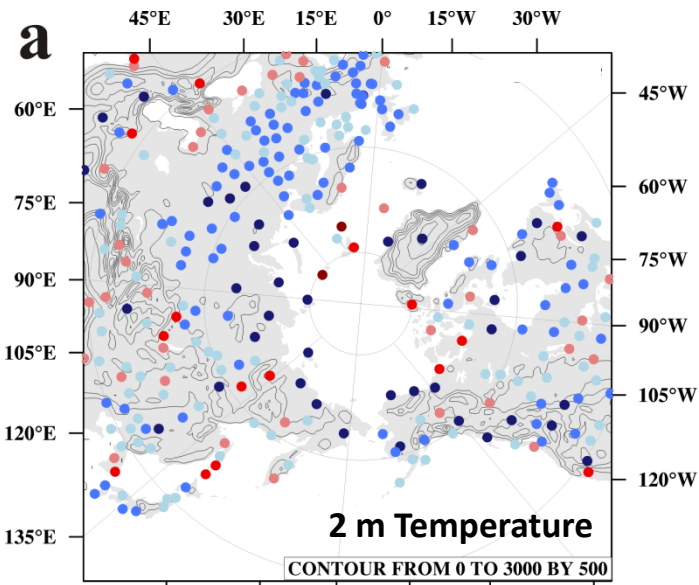
- Fractional sea ice
- Seasonal transition of sea-ice albedo
 - Fixed albedo winter and spring 0.82
 - June: Linear decrease in albedo 0.5 by the end of the month representing a mix of bare ice and melt ponds
 - July: As ponds deepen and become less reflective albedo increases to 0.65 (representing bare ice only)
 - August 15: 21 day linear increase of albedo to 0.82



Wilson, A.B., D.H. Bromwich, and K.M. Hines, 2012: Evaluation of Polar WRF Forecasts on the Arctic System Reanalysis Domain. 2: Atmospheric Hydrologic Cycle. *J. Geophys. Res.*, **117**, doi:10.1029/2011JD0016765.

Annual Mean Surface Variables

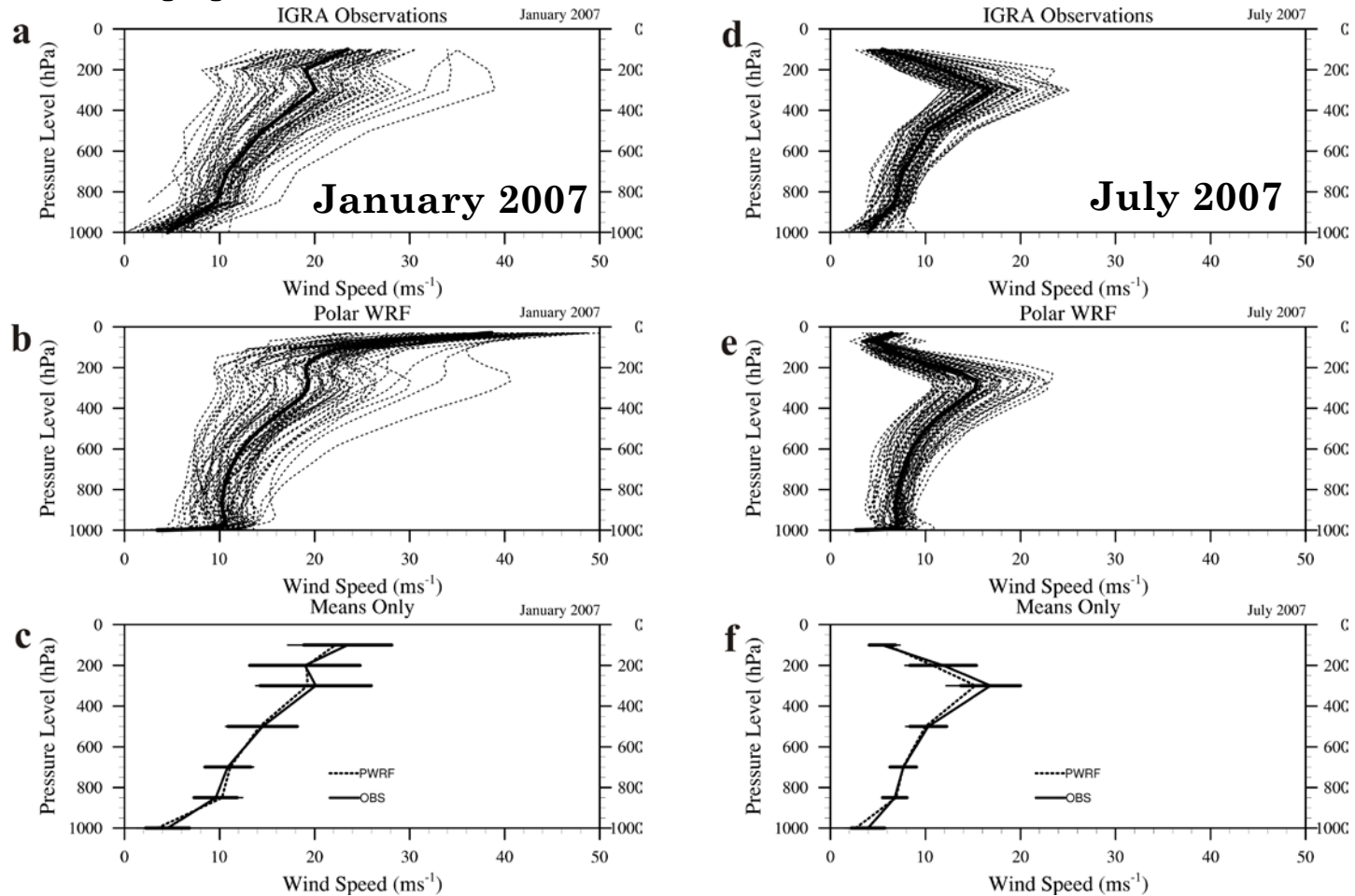
Variable	Bias	RMSE	Correlation
2m Temp (°C)	-1.1	3.9	0.80
2m Dew (°C)	0.3	4.0	0.72
Surface Pressure (hPa)	-1.1	3.1	0.95
10m Wind Speed (m s ⁻¹)	0.7	2.7	0.52



- Cold and winds too strong throughout most of the domain, but biases are small

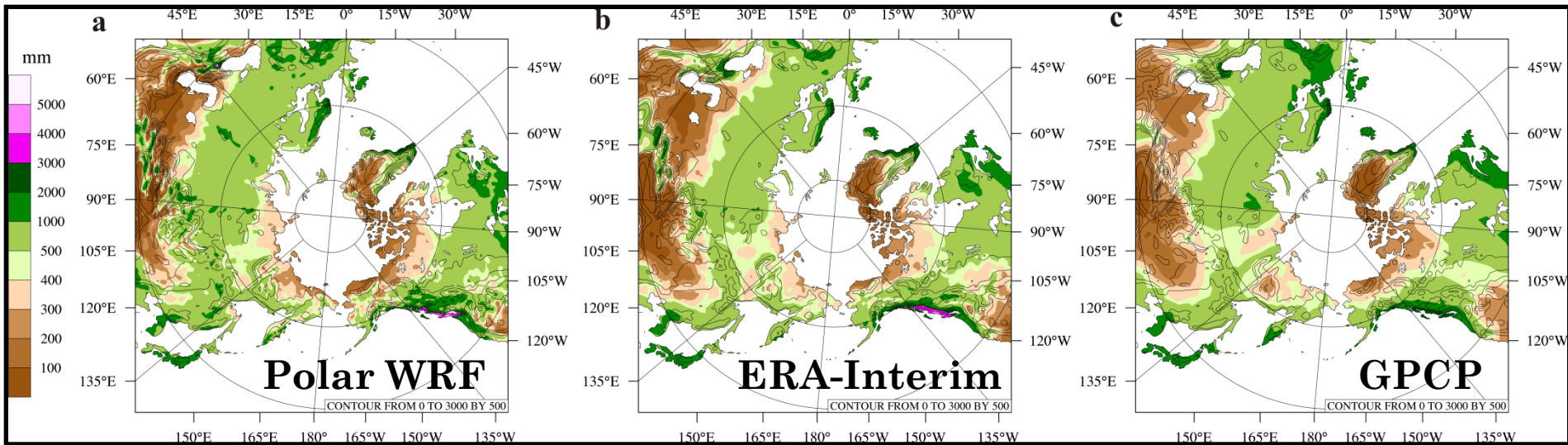
- High dewpoints linked to evaporation
- Pressure field (not shown) very well captured

Upper Level Winds in the Arctic



- PWRF mean profile compares well with IGRA
- Differences are small and insignificant though all the profiles reflect strong spread among individual stations

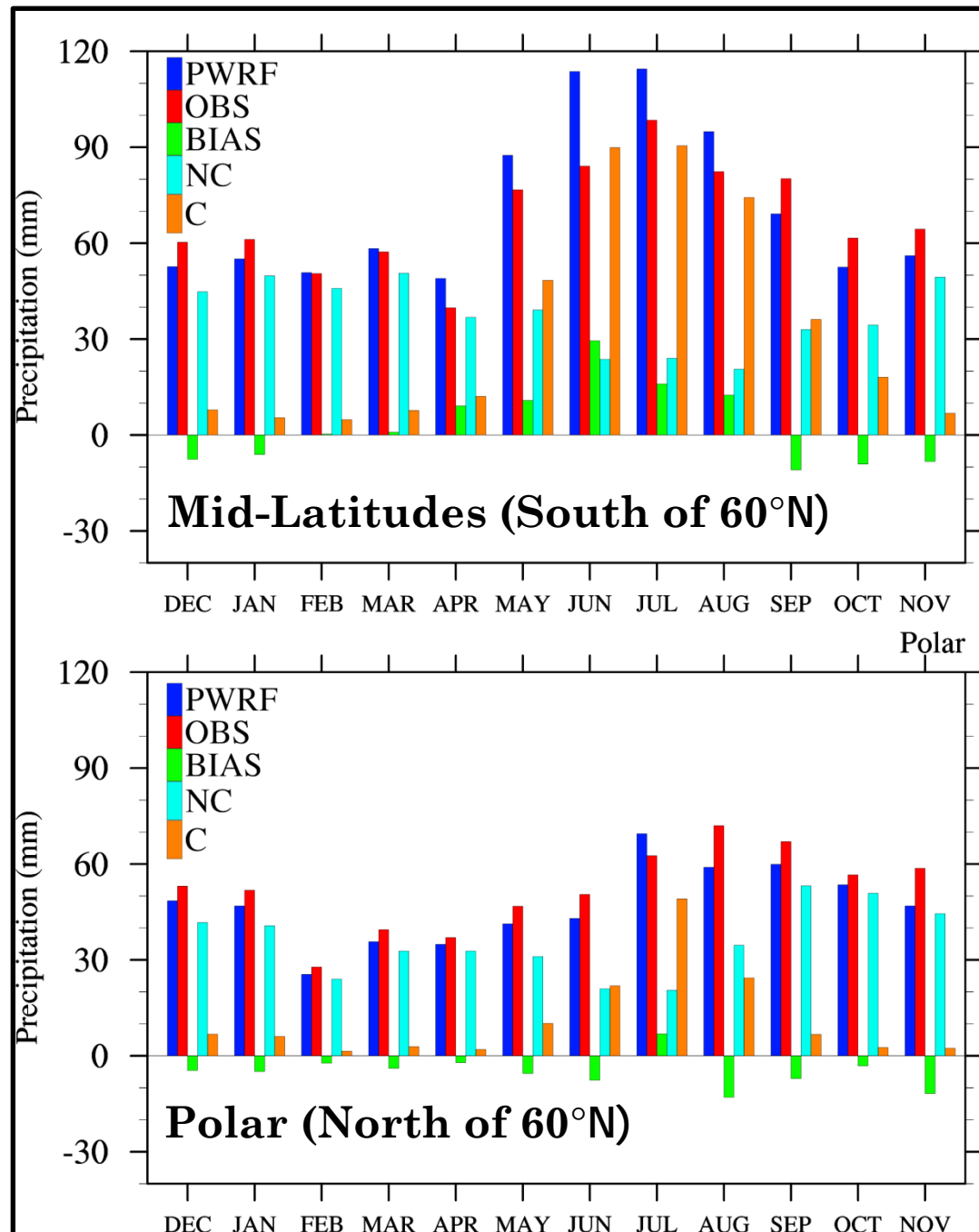
Annual Precipitation: Spatial Comparison



- Spatially consistent with ERA-Interim and GPCP
 - Highest Precipitation totals located throughout the mid-latitudes and sub-polar storm track regions
 - Dry throughout the Canadian Archipelago
- Slightly higher totals in Pacific NW N. America
 - Both PWRF and ERA-Interim are higher than GPCP here

Monthly Precipitation

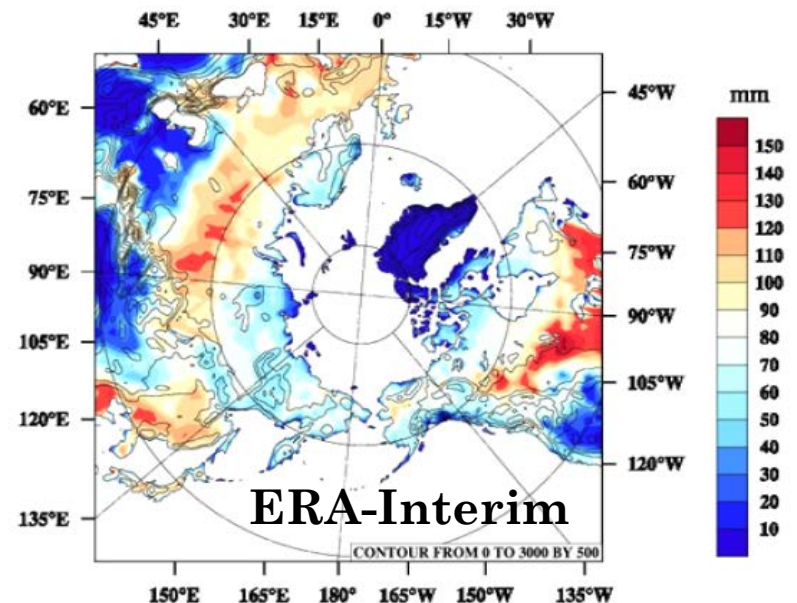
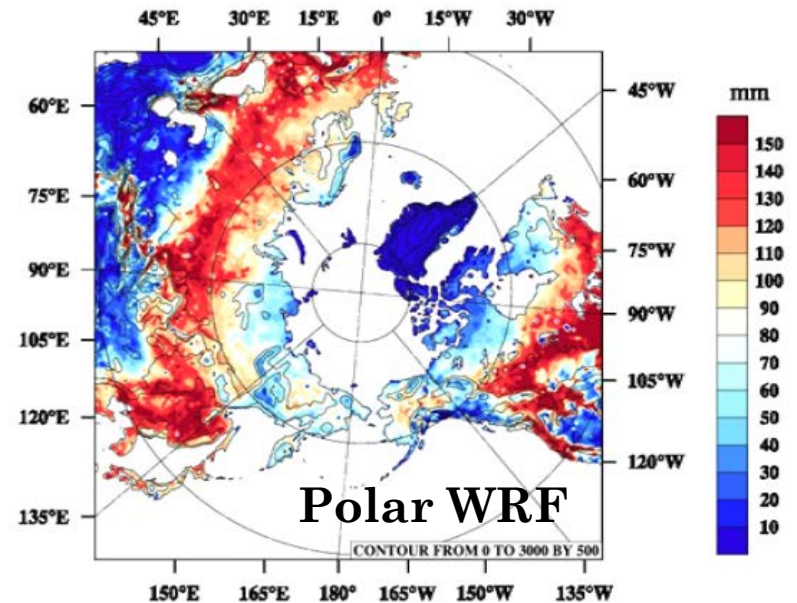
- Mid-Latitudes warm/cool season discrepancy
 - Cool months: Negative biases when precipitation synoptically driven
 - Large (+) Biases in Spring and Summer (Jun: 35.2%, Jul: 16.2%, Aug: 15.2%)
 - Warm months tied to convection
- Polar
 - Dry throughout the year (-5% to -20%)
 - Positive bias only in July due to convection near stations in the southern part of boundary



Evaporation

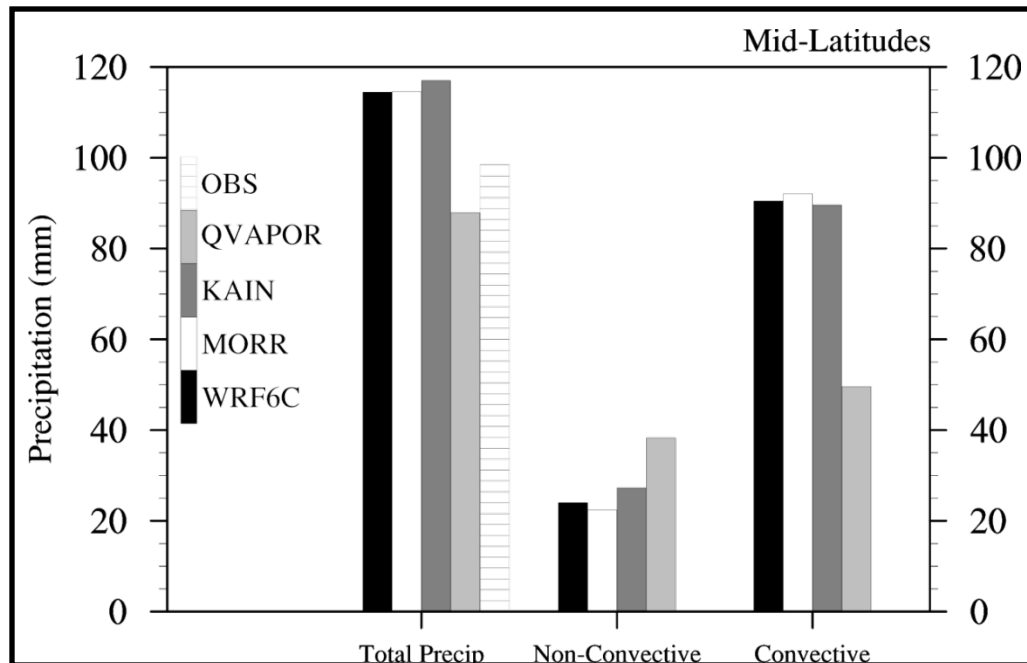
JULY 2007

- Annual mean 2 m dew point temperature biases in the mid-latitudes led to an investigation of evaporation
- ERA-Interim 2 m dew point biases are smaller compared to observations than Polar WRF
- Total evaporation on land shows Polar WRF over predicts evaporation for July compared to ERA-Interim especially for mid-latitudes
- Some regions of the Arctic under predicted and may help explain negative precipitation biases



Convective Precipitation

Sensitivity simulations for July 2007

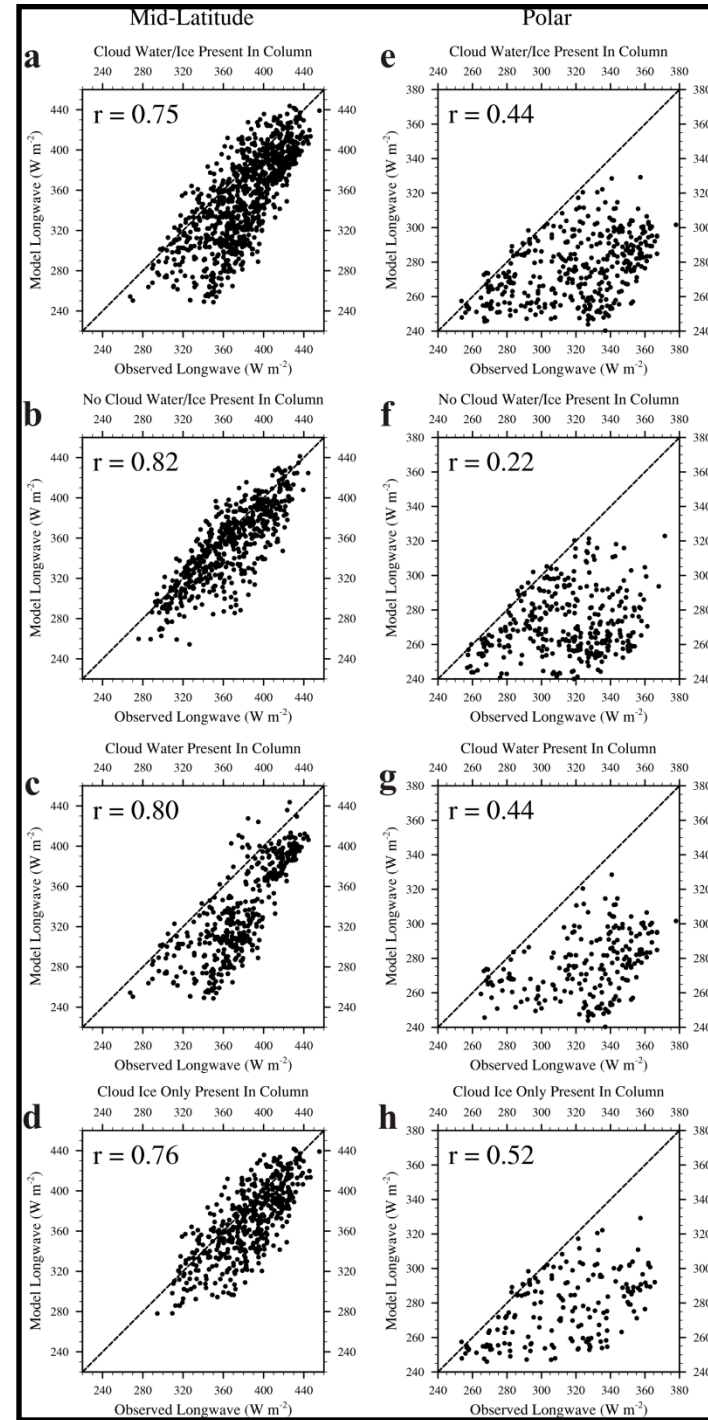


- 3 Sensitivity Simulations (WRF6C, Morrison, Kain-Fritsch)
 - Little change in the overall total and convective precipitation (WRF6C, Morrison, Kain-Fritsch)
- Grid-nudging of specific humidity towards a drier state in the lower atmosphere
 - yields negative precipitation bias (25% decrease) and ~1/2 convection
- Other areas to investigate include soil moisture and interaction with PBL scheme

Cloud Water/ Cloud Ice

JULY 2007

- WRF 6-Class Microphysics Scheme
- Scatter plots of Model LW vs. Observed Longwave for various model cloud species
 - (a) Cloud water and/or cloud ice available
 - (b) No Cloud water or ice
 - (c) Cloud water regardless of cloud ice
 - (d) Cloud ice only
- Mid-latitudes
 - LW correlations are strong for all 4 cases
 - When cloud water or ice is available, model biases are negative
 - “Model Clear Sky”: Correlations increase and model agrees better with observations
 - Again, when cloud water is present (c) the model performs worse (Cloud ice has a zero effect on switch in RRTM scheme)
- Polar Region
 - Model LW suffers greatly compared to observations
 - Apparent insensitivity between cloud water/cloud ice conditions and “clear sky”

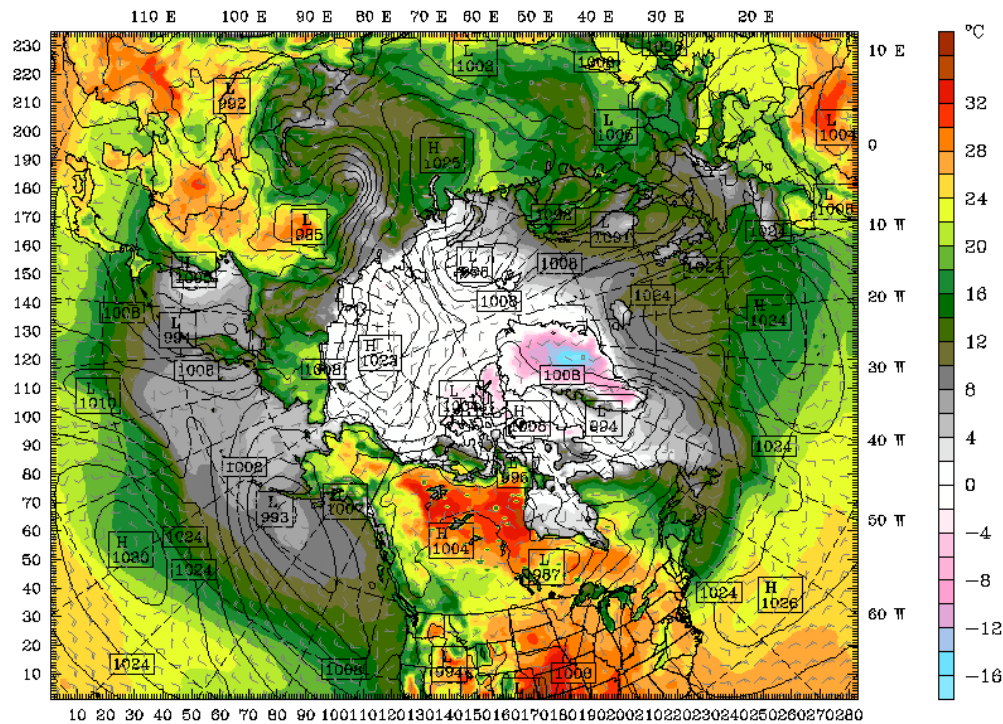


Operational Polar WRF

http://polarmet.osu.edu/nwp/?model=arctic_wrf

Arctic NWP
 Fcst: 96.00 h
 Surface air temperature
 Sea-level pressure
 Horizontal wind vectors
 at height = 0.010 km

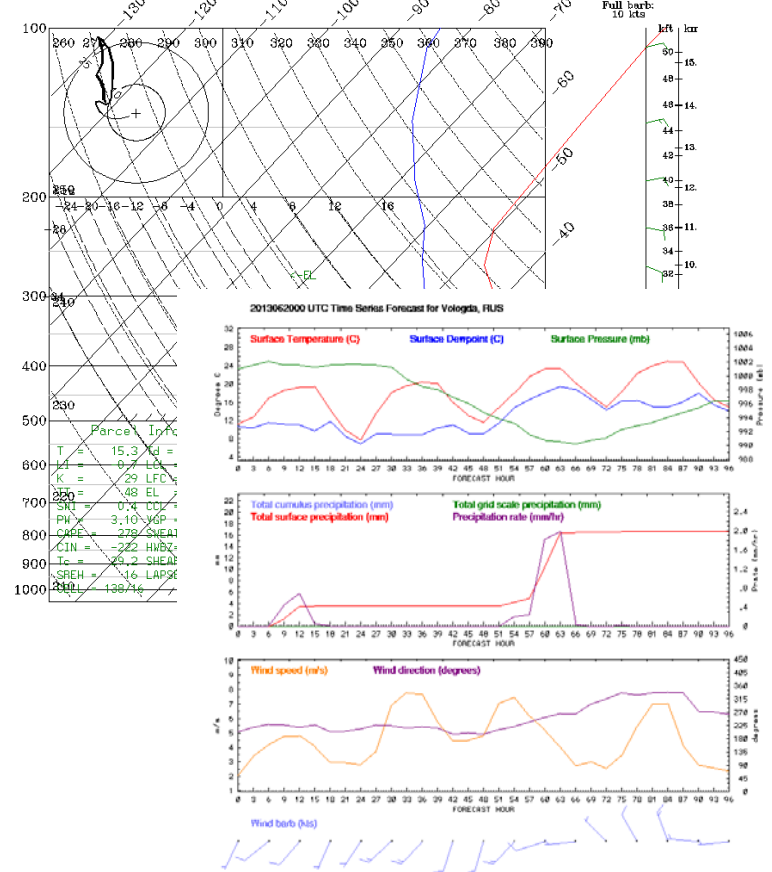
Init: 0000 UTC Thu 20 Jun 13
 Valid: 0000 UTC Mon 24 Jun 13 (2000 EDT Sun 23 Jun 13)



Model Info: V3.1.1 G3 MYNN2 PB Morrison Noah LSM 45 km, 38 levels, 90 sec
 LW: RRTMG SW: RRTMG DIFF: simple KM: 2D Smagor

Arctic NWP
 Fcst: 96.00 h
 Temperature
 Dewpoint temperature
 Horizontal wind vectors

Valid: 0000 UTC Mon 24 Jun 13 (2000 EDT Sun 23 Jun 13)
 x,y=172.73,195.18 lat,lon= 59.32, 39.92 stn=ULWW,27037
 x,y=172.73,195.18 lat,lon= 59.32, 39.92 stn=ULWW,27037
 x,y=172.73,195.18 lat,lon= 59.32, 39.92 stn=ULWW,27037



Twice Daily 96-hr Forecasts @ 45 km

Conclusions

- AMPS is the primary regional NWP effort in Antarctica and the main forecasting support for the United States Antarctic Program (USAP).
 - The value of AMPS is widely acknowledged by the Antarctic community.
 - Extremely high resolution leads to more accurate weather forecasts (e.g., surface wind, mesolows, precipitation).
 - Model Improvements are on-going (e.g., cloud and stable boundary layer)
- Polar WRF short-term weather forecasts show skill in the Arctic
 - Near-surface and upper-air variables compare well with observations & ERA-Interim.
 - However, continued investigation of forecast clouds and associated radiative effects is needed, especially for mixed-phase processes in the Arctic.
 - This knowledge is being used to guide development of the Arctic System Reanalysis.



BYRD POLAR RESEARCH CENTER

THE OHIO STATE UNIVERSITY

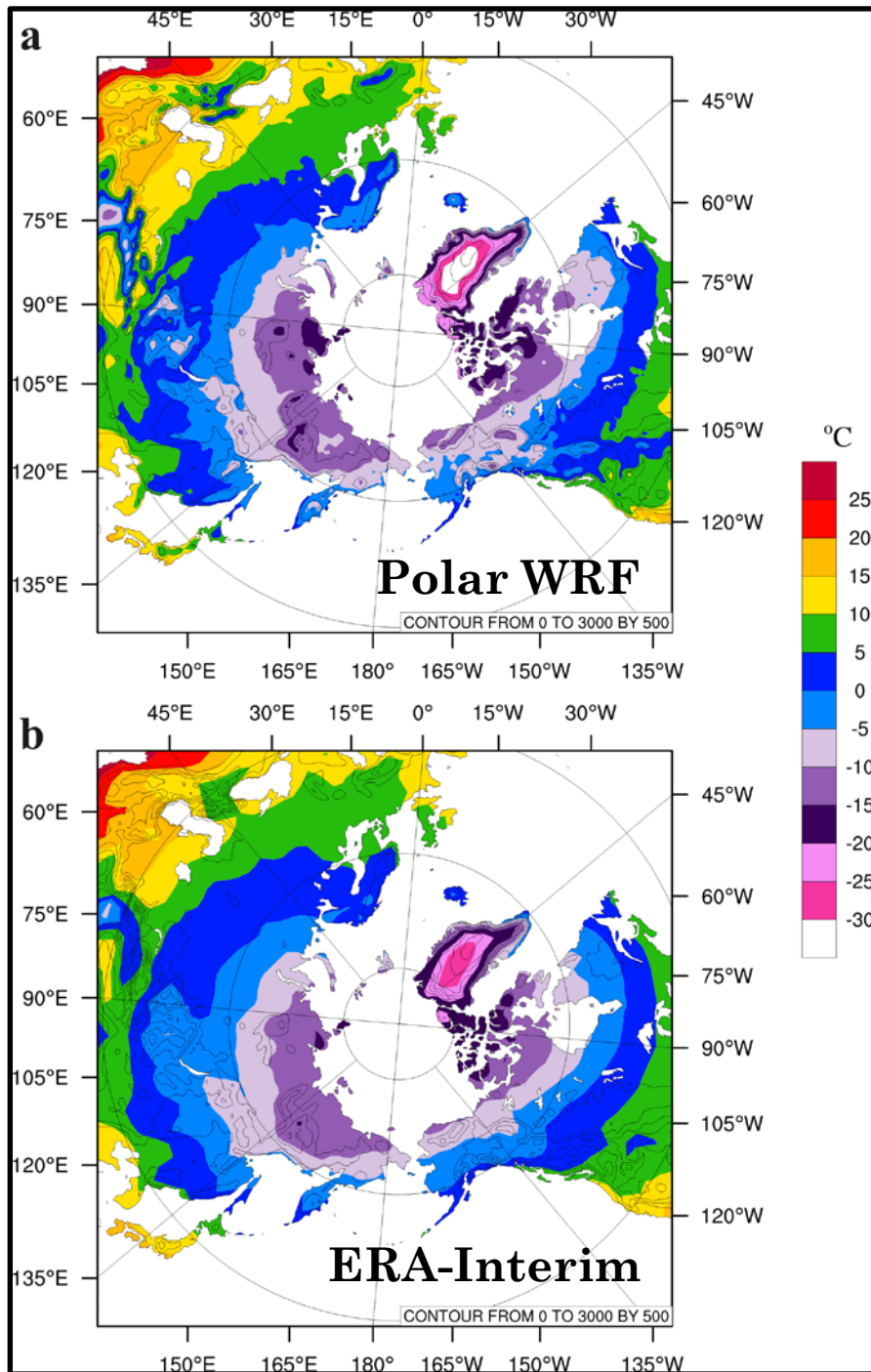
<http://bprc.osu.edu/>

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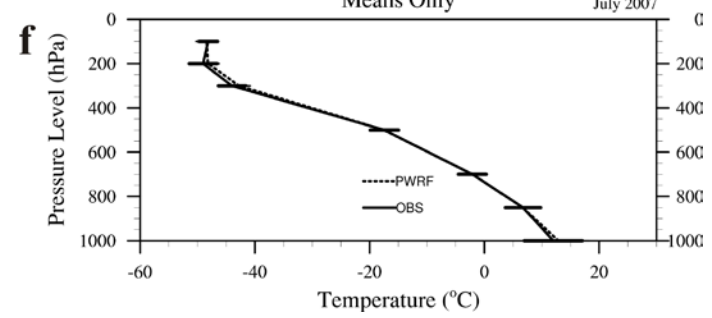
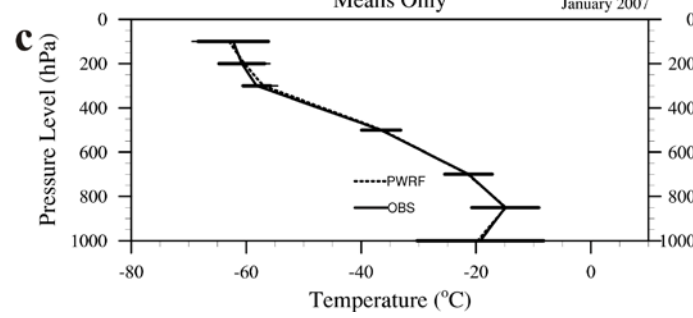
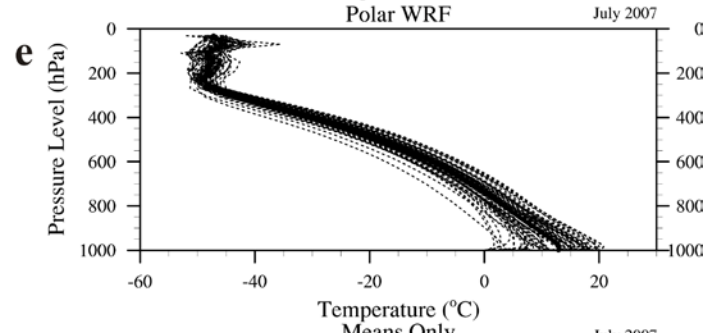
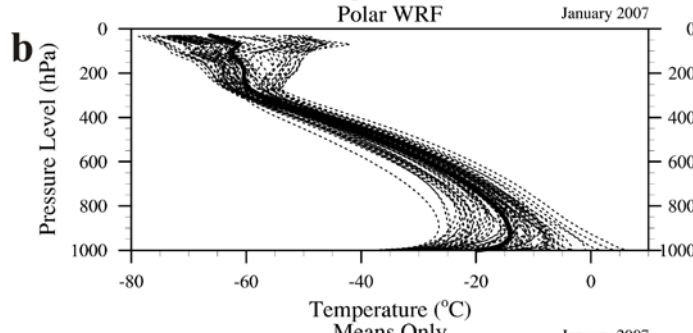
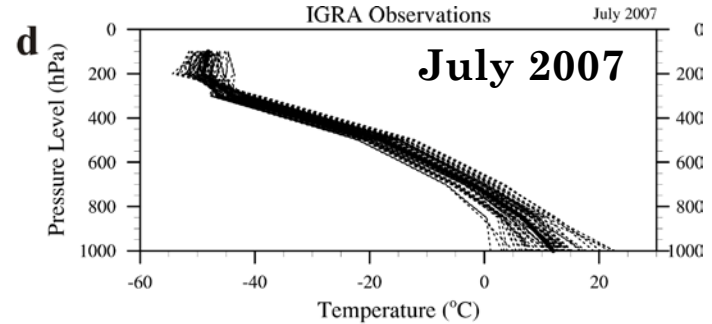
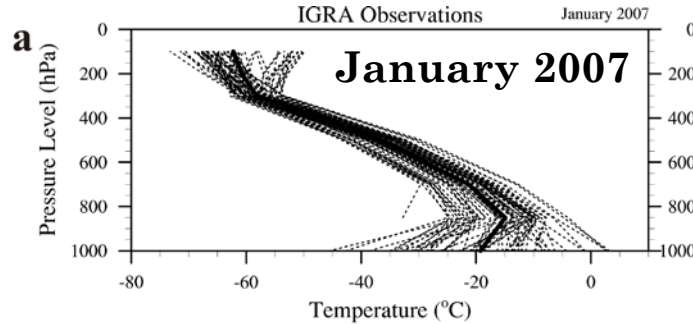
Extra Slides

2007 Annual Mean Temperature Comparison with ERA-I



- Polar WRF provides a higher degree of detail across the domain, especially in regions of higher elevation.
- Coldest annual simulated mean surface air temperatures are found just north of the highest elevations over the Greenland ice sheet, with annual mean temperatures ranging from -25°C to -35°C .
- Spatially, agrees well with previous mesoscale modeling studies of Greenland using Polar MM5 [Cassano et al., 2001] as well as ERA-Interim.
- The warmest temperatures in the domain are found in the Persian Gulf region and deserts of Eurasia, with annual mean temperatures exceeding 15°C .

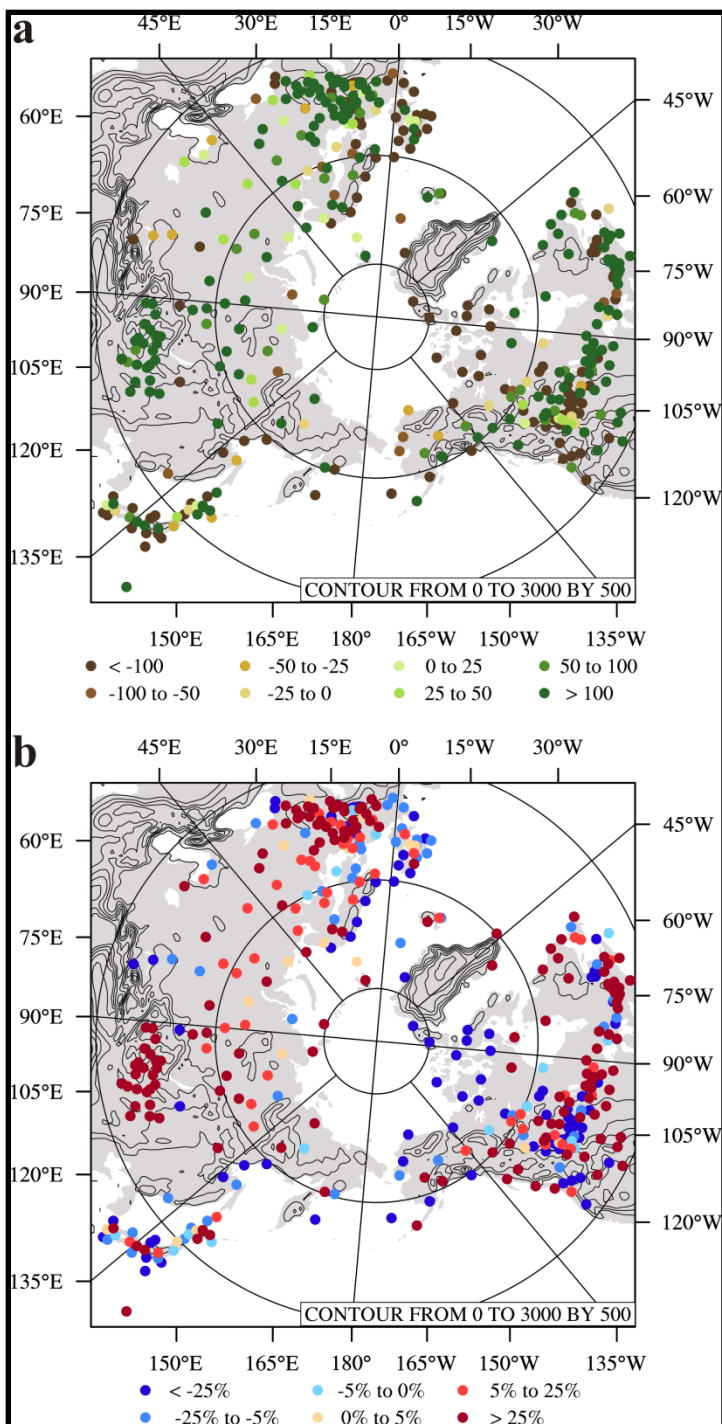
Upper Level Temperatures in the Arctic



- Monthly mean vertical temperature profiles for 68 polar region stations (dashed line) and the polar region mean (solid line) for January 2007 and July 2007 for both IGRA observations and Polar WRF, along with the means only (Polar WRF dashed and observations solid).
- Smaller biases especially during summer $\pm 1^{\circ}\text{C}$
- Largest spread near the surface and near the top
- Slightly warmer than IGRA at levels above 500 hPa-Lower than observed tropopause heights.

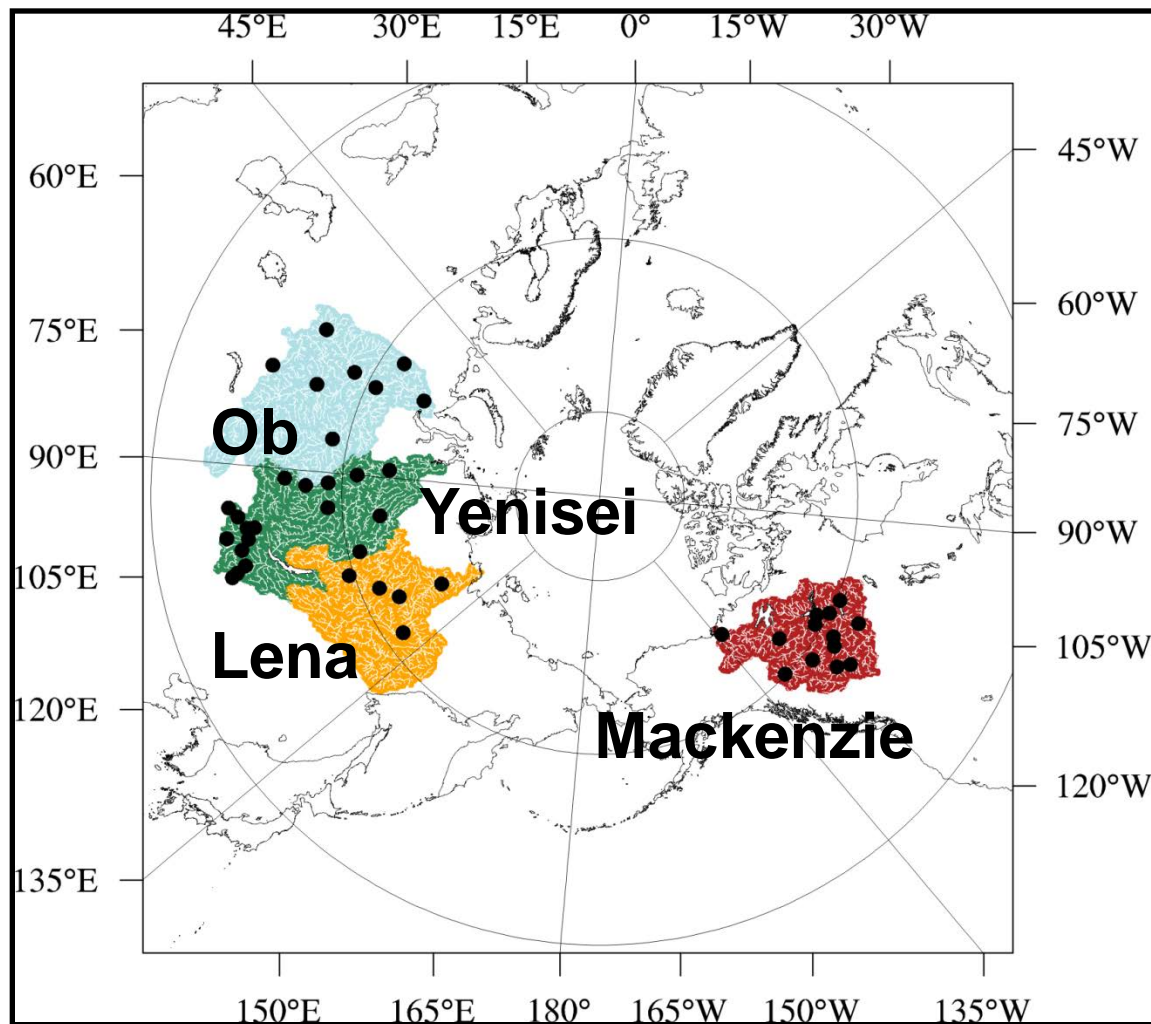
Station Observations

- Mid-Latitudes (305): +37.3 mm (+4.6%)
 - 62% within $\pm 50\%$ (35% within 25%)
 - NA, Europe, Asian regions: similar results
- Polar (78): -58.8 mm (-9.4%)
 - 69% within $\pm 50\%$ (44% within 25%)
- Few stations within 5%
- NOT spatially homogenous
- Canadian Archipelago
 - Dry throughout the entire year
 - Winds are inconsistent with equatorward transport of water vapor in this region.

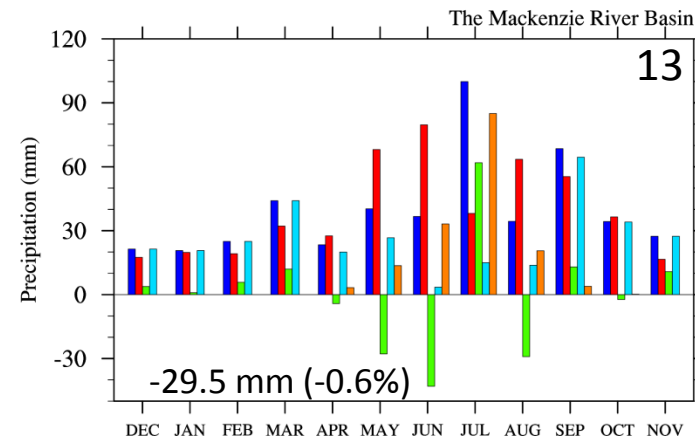
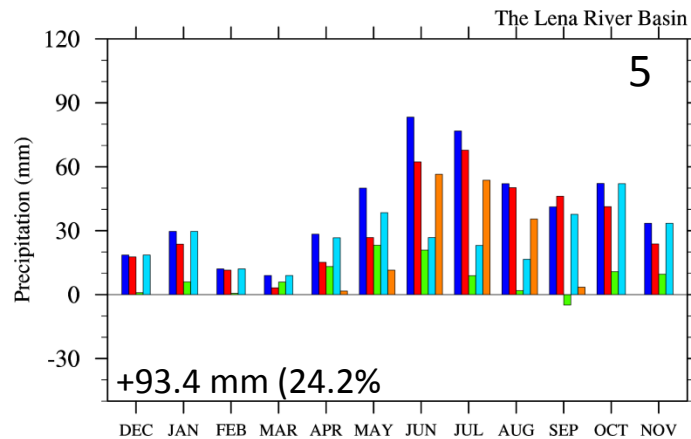
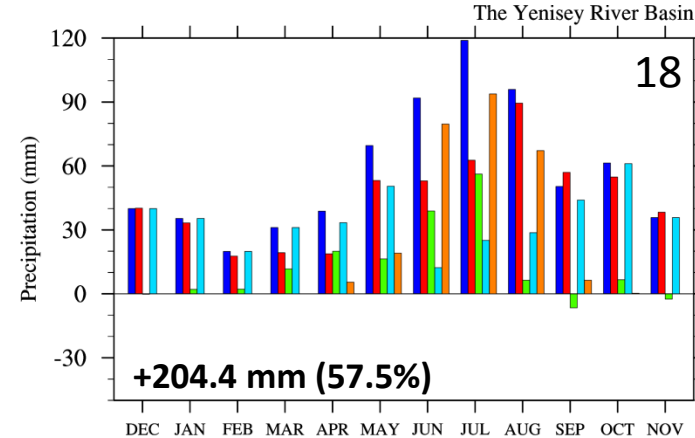
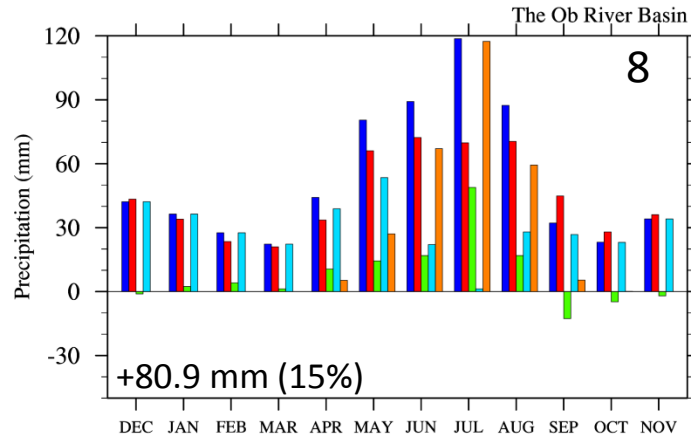


Arctic River Basins

- Important for the fresh water supply to the Arctic Ocean
- Headwaters begin as far south as 45°N representing a strong link between mid-latitude atmospheric processes and effects in the Arctic.
- Arctic climate system and global ocean circulation



Precipitation: Arctic River Basins



- Convection in spring and summer for the Russian rivers lead to large positive summer biases
- Errors in Mackenzie River biases related to smoothed terrain effects
 - Negative overall precipitation especially in late spring
 - Southern extent of the region influence by Gulf of Mexico through Great Plains low level jet and cyclogenesis
 - Single events of > 100 mm are observed (MAGS)-not well captured by PWRP

JULY 2007

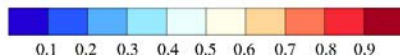
Clouds

PWRF (a)

PWRF (b)

MODIS

CloudSAT/Calipso



- Summer 2007 had 2nd Lowest Sea-ice Extent and Large Beaufort Sea High with Anomalously Few Clouds in the Western Arctic
- (a) Estimated Cloud Fraction (CF) based on integrated cloud liquid water and cloud ice
- (b) Cloud frequency defined by the ratio of the 3-hr forecasts where $CF > 0$
- Storm tracks well depicted
- North Slope CF reasonably well captured with MODIS and CloudSat/Calipso
 - No increase in cloudiness adjacent to the coast as in MODIS
- Conservative method yields results that approach observed

