JP2.17 GLACIERS AND CLIMATE IN SOUTHERN ALASKA: PRESENT AND FUTURE

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1. Motivation and Introduction

The glaciers of Alaska, Yukon, and NW British Columbia probably form the largest single component of the non-polar global melting-glacier contribution to rising sea level (Meier, 1984), so it imperative to reduce the uncertainty of their future contributions to rising sea level.

Recent work with airborne laser altimetry (Arendt et al., 2002) has shown that thinning glaciers and ice fields in Alaska, Yukon, and NW British Columbia have contributed an estimated 52 +/- 15 km^3/yr water equivalent (w.e.), on average, to rising mean sea level from the mid-1950's to the mid-1990's. This is equivalent to about 7 to 12% of the mean annual rate of sea-level rise estimated by the Intergovernmental Panel on Climate Change (IPCC) during the past century. Melting of these glaciers from the mid-1990's to 2000/2001 contributed about 96 +/- 35 km^3/yr (w.e.) to mean sea-level rise, which is almost double their estimated contribution during the earlier time period and substantially larger than the ~51 km^3/yr contribution from melting of the Greenland ice sheet during the same time period (Krabill et al., 2000).

We are conducting an interdisciplinary study to (i) continue measuring the rapidly-changing glaciers of NW North America with aircraft laser altimetry to determine whether the accelerated thinning during the mid-1990's to 2000/'01 is a sustained trend or a temporary phenomenon; (ii) carry out repeat measurements of surface velocities on selected glaciers to determine whether changes in ice flow are contributing to the observed elevation changes; and (iii) relate these glacier changes to climatic change through mass balance modeling in conjunction with general circulation and regional modeling of the atmosphere. The goal of the modeling is to reduce the uncertainty of the estimated contribution from the glaciers of NW North America to rising sea level during the next century, which is the time period of interest to the IPCC. In this paper we present preliminary results from the atmospheric modeling component of this study.

2. Methodology

2.a. Overall Goals

In order to predict the impact of climate change on glaciers over the next 100 years, we must be able to reliably link global climate change scenarios to glacier mass balance. First, we are developing and validating our approach by using historical climate data as input to a glacier mass balance model and comparing it against observed glacier mass changes. We will employ coupled atmosphere/ocean/land general circulation (GCM) modeling, using a time slice strategy, to provide boundary conditions for regional climate modeling. Glacier mass change modeling, driven by a regional climate model forced by NCEP/NCAR reanalysis fields, will provide mass balance estimates that are testable by laser altimetry measurements.

As part of our methodology, we must “dynamically downscale” the regional model data for use in the glacier mass balance model, a process that will require tuning. There will likely be statistical adjustments, partly based on previous research, which will provide the best fit of temperature and precipitation for use in the glacier mass balance model. With the tuning complete, we will then be able to use GCM simulations, corresponding to IPCC global change scenarios over the coming century, to force the regional model in turn to downscale the temperature and precipitation information to daily values for use by the glacial mass balance model which will enable prediction of glacier response. This hierarchy of models will thereby provide a means of synthesizing information from the various temporal and spatial scales, and will allow us to estimate glacier mass balances and their associated uncertainties under IPCC climate change scenarios.

In this paper we present results from simulations with the regional model forced by the NCEP/NCAR reanalysis during the 2002-2003 period. We compare the observed station data to the downscaled model data and develop a strategy that we will use in the future scenario downscaling aspect of this research.

2.b. Description of Models

For the regional modeling component the Arctic MM5 modeling system (Zhang and Tilley, 2002, 2003) is centered around the Fifth-Generation Pennsylvania State University/NCAR Mesoscale Model (e.g., Grell et. al 1994). It simulates a sub-hemispheric sized area with grids ranging from 2-100 km. Like its namesake, the Arctic MM5 uses a terrain-following vertical coordinate system and can include up to 9 horizontally nested domains (grids). This allows for high-resolution simulations over a specific area of interest while maintaining a lower resolution depiction of processes over a larger area. The standard MM5 system comes with many possible options for the treatment of atmospheric physical processes. In order to adequately represent processes of other earth system components, the Arctic MM5 utilizes a state-of-the-art land surface model (NOAH; Mitchell et al 2002), a thermodynamic sea ice model (Zhang and Zhang 2001) and a mixed layer ocean model based on that of Kantha and Clayson (1996). Details of these sub-models can be found in the appropriate references and in Zhang and Tilley (2002).

Though initial and boundary conditions for the real-time Arctic MM5 system are derived from the NCEP Eta model (e.g, Rogers et al 1996), the model is readily adaptable to execute in a retrospective mode with initial and boundary conditions provided by archived reanalysis datasets. Overall in this study, we are conducting two sets of time-slice integrations, the first covering the past 4 decades, the second examining conditions over the period 2010-2099. The retrospective simulations are intended to be a validation set to ensure that the time-slice procedure will provide robust results for the future scenario simulations. As noted earlier, the daily averaged temperature and precipitation fields from the Arctic MM5 time-slice simulations are used as input to the precipitation-temperature-area-altitude (PTAA) glacial mass balance model (Tangborn 1999).

The PTAA mass balance model developed by Tangborn (1999), computes the mass balance variables within each element of altitude up the length of the glacier's area-altitude (AA) profile for each day of the year, a unique feature among glacier mass balance models. The model has been tested on 12 glaciers: two in Washington State and Alaska (Tangborn, 1997, 1999), one in Nepal (Tangborn and Rana, 2000), and nine that were measured with altimetry by Sapiano et al. (1998). These simulations yielded agreement with independent field and geodetic measurements mostly ranging from fair to excellent. The variables simulated include annual accumulation, winter accumulation, summer ablation, the balance within each altitude element, the equilibrium line altitude (ELA), the snowline altitude, the accumulation area ratio (AAR), the annual net mass balance of the entire glacier, and runoff. Runoff is derived from ablation of ice and snow, precipitation falling as rain, the change in the glaciers' internal water storage, and groundwater outflow.

2.c. Regional Model configuration

The model domain is centered at 62.0N lattitude and 155W longitude and has a horizontal coverage of 3700 km (east/west direction) X 3300 km (north/south direction), with a grid resolution of 20km (Fig. 1). We utilized a total of 42 vertically stretched sigma levels, which are more closely spaced near the ground, from the surface to the model top at 50 hPa. A model time step of 60 seconds is used.

Physical parameterization schemes used in this simulation study include the following: a) the modified Reisner explicit microphysics parameterization (Cassano et al. 2001); b) the Grell sub-grid scale cumulus scheme (Grell 1993); c) the MRF high-resolution PBL scheme (Hong and Pan,1996); d) the modified CCM2 radiative transfer scheme (Cassano et al. 2001); and e) the land surface model NOAH-LSM in which a thermodynamic sea ice model and mixed layer ocean model are coupled.

A series of simulations 120 hours in length were carried out August 1 2002 to July 31 2003. The NCEP/NCAR reanalysis data are used to initialize the model atmosphere and provide temporally evolving lateral boundary conditions. The initial sea ice concentration is from NCEP/NCAR climate data assimilation system (CDAS) in which sea ice concentration grids are constructed from the Special Sensor Microwave Imager (SSM/I) on the Defense Meteorological Satellite Program (DMSP) F-13 (11) satellite, derived with the bootstrap algorithm (Comiso 2002).

3. Selected Results

To ensure that the models and methodology will give us realistic estimates of glacial mass balance in the latter part of this century, the air temperature and precipitation obtained from dynamical downscaling should compare favorably with the observed station data. Further, the modeled glacial mass balance for the historical period (1958-2003) should closely match the observed mass measurements. In addition, the glacier mass balance model must be tested to determine which station data are most important for modeling the mass of each glacier of interest.

3.a. Dynamical Downscaling: 2002-2003 Period

As noted in the previous section the MM5 simulation was integrated for shorter periods rather than a continuous year because errors begin to build up in the precipitation simulations. These models are generally meant to be integrated for short periods of time (less than 7 days), however new techniques are being applied so that longer continuous integrations are feasible. We will follow a more traditional approach in our work.

The glaciers of south-central and southeast Alaska are most sensitive to meteorological conditions in nearby stations, namely, Cordova, Yakutat, and Juneau. The model output is carefully compared to observed station data at these stations, since these are the stations that must be most accurately downscaled. Daily Yakutat air temperature (Fig. 2, top panel) and precipitation (Fig. 2, bottom panel) are shown for the model and the observations. Fig. 2 compares model data that has been interpolated to the latitude and longitude of Yakutat. The time series from the nearest grid point was also examined. There is no clear reason based on a bias in either direction to choose either method. We are still considering which strategy to be use in this study.

The simulated temperatures in Yakutat for the Aug. 1, 2002-July 31, 2003 period are generally warmer than the observed temperatures. Forecast daily mean temperature and precipitation are verified statistically against the station observations, by comparing each available station to the model forecast that was interpolated to the station location. For the daily precipitation, the equitable threat score (ETS) is calculated at forecast time 24 hours and 120 hours and at thresholds of 0.01in., 0.10in., 0.25in. and 0.5in. A perfect ETS value is 1 and at the 24th forecast hour, the ETS with a threshold of 0.5(inch) is 0.394 in Yakutat, which is an acceptable value. For the daily mean temperature, we calculate the root-mean-square (RMS) and bias. The RMS of the daily mean temperature in Yakutat is about 3.0 and bias -2.2 degree. In general, the forecast temperature in summer and fall are better than that in winter and spring and the forecast precipitation shows the best ETS in the summer.

4. Summary

The goal of this research is to reduce the uncertainty of the estimated contribution from the glaciers of NW North America to rising sea level during the next century. We bring together a multi-disciplinary group of modelers (glacier mass balance, regional scale modeling, and GCM) and experimentalists in order to be able to examine this problem from all sides. This paper presents results from the first part of our modeling work, which employs historical meteorological data to force a regional climate model as well as a glacier mass balance model. This stage of the research identifies the biases that are present in our ‘dynamical downscaling’ and glacier mass balance modeling. Based on these biases, strategies will be developed for applications of this procedure to enhanced CO2 scenario situations.

Acknowledgment: We thank the Interdisciplinary Science in the NASA Earth Science Enterprise Program for supporting this work with grant NNG04GH64G.

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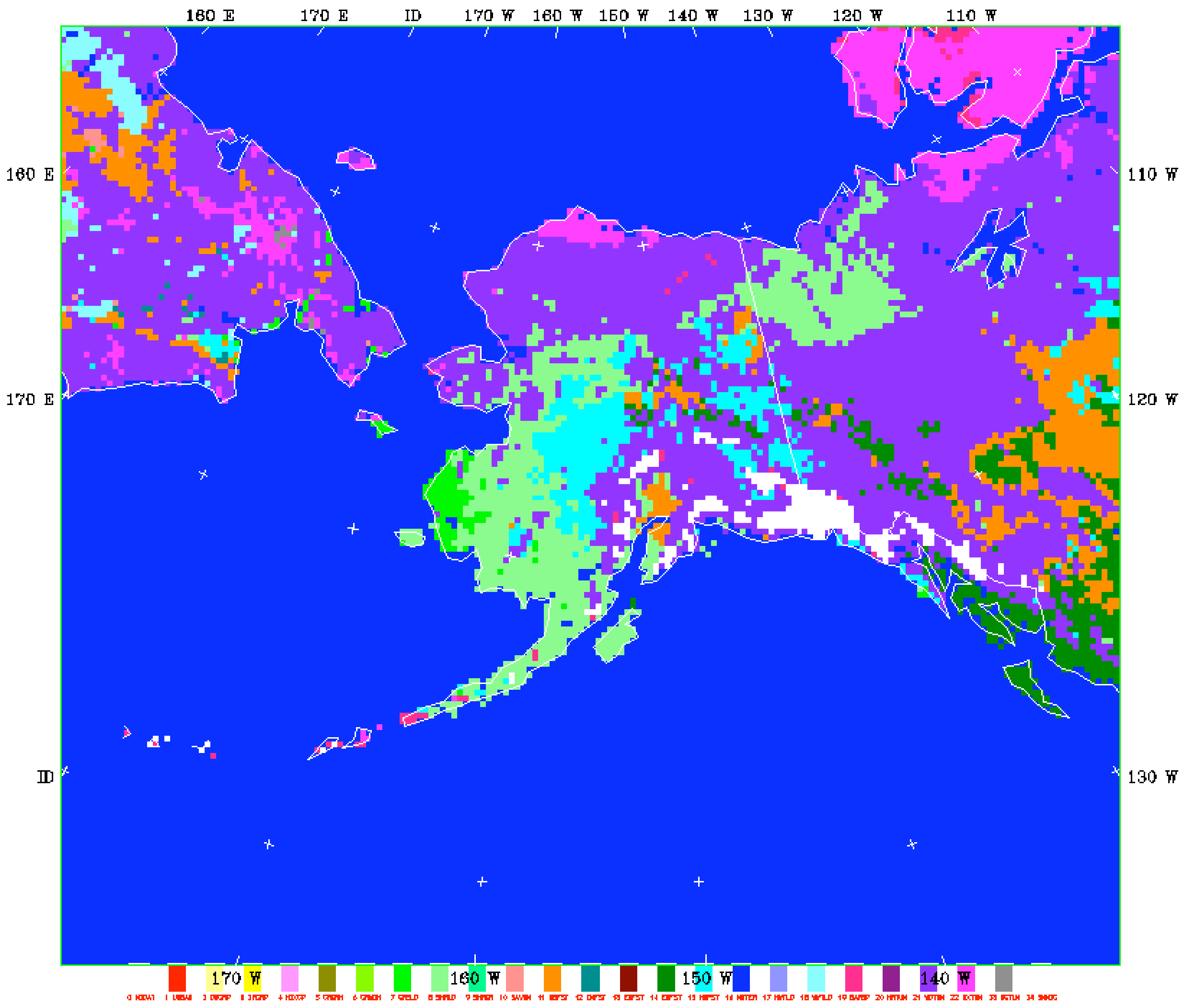

Figure 1. Model domain with the type of terrain identified. Note the ice (white) fields in south-east Alaska.

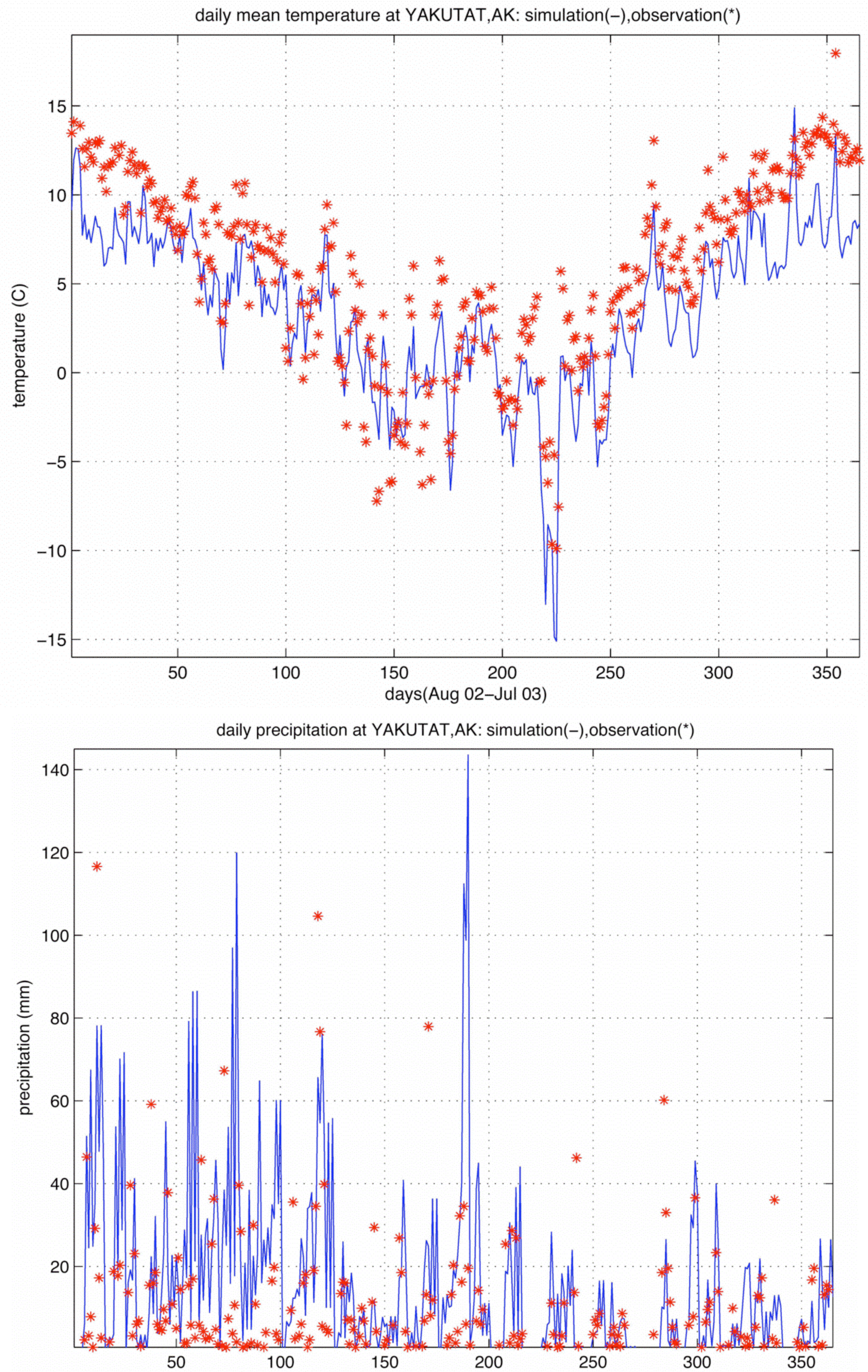

Figure 2. Top Panel: Model (blue line) and observed daily air temperature (red stars) in Yakutat from August 1, 2002 to July 31, 2003. **Bottom Panel:** Model (blue line) and observed daily precipitation (red stars) in Yakutat from August 1, 2002 to July 31, 2003.