SciVerse ScienceDirect

Physics Procedia 22 (2011) 292 – 298

Physics Procedia

2011 International Conference on Physics Science and Technology (ICPST 2011)

A Southern Greenland Ice Sheet Glacier Discharge Reconstruction: 1958-2007

Lei Yang[a]*

[a]State Key Laboratory of Tropical Oceanography,The South China Sea Institute of Oceanology,Chinese Academy of Sciences, Guangzhou 510301. China

Abstract

The Greenland ice sheet has been observed to discharge more ice volume between 1996 and 2005 in apparent response to surface climate warming at glaciers south of 70° N latitude. We find that melt rates explain 60-90% of the ice discharge increase, with highest apparent sensitivity evident for the southwestern region. An empirical melt sensitivity model is then used to reconstruct total ice discharge variations due to apparent melt sensitivity from the southern Greenland ice sheet over 50 years (1958-2007). Recent increases in reconstructed southern glacier discharge exceed one standard deviation of the 1958-2007 mean in two years: 2003 and 2007. The 2007 estimated ice discharge value nearly exceeds the reconstruction uncertainty determined using Monte Carlo methods. In combination with climatological surface mass balance estimates, the reconstructed ice discharge suggests that Greenland's sea level contribution during 1961 to 2003 resolves over half of the unexplained IPCC [2007] global sea level rise.

Selection and/or peer-review under responsibility of Garry Lee.

Keywords: Greenland ice sheet; Glaciers; Discharge; Reconstruction; Sea level

1. Introduction

Several Greenland outlet glaciers have been observed to be in a state of significant thinning, acceleration and retreat after 1995 [1-6], coinciding with strong recent temperature increases. Accompanying glacier acceleration and retreat, the rate of the ice sheet mass loss to the ocean increased contributing significantly to global sea level rise [8]. Estimates of ice discharge from Greenland outlet glaciers have been made by combining observed ice velocity and thickness at glacier front or several

* Corresponding author. Tel.: +86-20-89023199; fax: +0-000-000-0000 .
E-mail address: leiyang@scsio.ac.cn.

 doi:10.1016/j.phpro.2011.11.046

kilometer upstream complemented by estimated surface mass balance between the flux gate and the ice front [8-10]. Reduction of "back stress" and its resultant increased longitudinal stress are identified as main dynamic causes associated with the recent accelerated thinning and ice mass loss for tidewater glaciers, such as Columbia Glacier [11-13], Ilulissat Glacier [14-15], and glaciers in west Antarctica [16]. However, the trigger to the initiation of glacier retreat remains mysterious and debated. Further, intermittent thinning was accompanied with several standstills and advances events since the Little Ice Age (LIA) at Ilulissat Gl. [15]. Outlet glacier behavior thus represents a complex ice-dynamical response to the combined effects of local climate forcing and interactions with the inland ice.

Using the Rignot and Kanagaratnam [8], hereinafter referred to as RK06, ice discharge data, tabulated for 1996, 2000 and 2005, and surface air temperature data from calibrated regional climate model simulations based on Box et al. [17], this study explores the apparent ice discharge sensitivity to surface climate. To the extent that glacier discharge can be explained by surface melting, this work develops an annual ice discharge reconstruction for a 50-year period, that is, 1958-2007. Our ice discharge melt sensitivity model resolves only changes due to melt and thus underestimates total ice discharge variability. Other important factors include: bed topography [5], development of sub-glacier drainage networks [18, 19], ice dynamics [11, 13 and16]. Nonetheless, given any inherent empirical and statistically significant ice dynamical sensitivity to surface climate [8, 18 and 20] combined with likely future warming [21], the surface climate factor related to ice discharge deserves a full development [22] and a longer temporal perspective.

2. Data and Methods

An ice discharge sensitivity model is based on least-squares regression between inter-annual anomalies in a modeled melt-index (independent variable) and the ice discharge (dependent variable) estimates from RK06. The gradient between the two variables allow melt records of longer duration drive a 50-year discharge reconstruction.

The Polar MM5 regional atmospheric model [23-24] was run using ERA-40 atmospheric analysis data [25] and ECMWF operational forecasts post-2002 in a data assimilation and downscaling configuration to produce 3-hourly 2 m surface air temperature (T_{2m}) data spanning 1958-2007. The 1958-2007 time series at the outlet glacier locations is extracted to represent local melting. Melting is represented by summer (June-August) seasonal temperature anomalies with respect to the 1961-1990 base period.

Model errors are minimized in a series of steps. First, monthly lapse rate adjustments after Steffen and Box [26] are applied to remove the effect of model low elevation bias that causes up to 4 K monthly warm biases at the outlet glacier grid locations. Residual inherent atmospheric model T_{2m} biases are quantified using inland ice in-situ observations that notably independent of the ERA-40 and ECMWF assimilation data. 175 station-months of mean temperature spanning 1958-1996 are taken primarily from Ohmura [27] but also from Shuman et al. [28]. 1223 station-months spanning 1995-2005 from Greenland Climate Network (GC-Net) inland ice automatic weather stations [29] are used to quantify more recent T_{2m} errors. A spherical Kriging procedure is applied to interpolate the spatial patterns of Polar MM5 temperature bias with respect to the independent in-situ observations. We found that a Kriging nugget value of 0 K^2 and range of 540 km were consistent monthly. The spatial distribution of bias pattern, once subtracted from the temperature grids, shift monthly model T_{2m} bias over ice stations from +2.3 K to -0.1 K; reducing the overall residual root mean square error (RMSE) for monthly-mean temperatures from ±3.0 K to ±1.1 K.

Ice discharge data from RK06 are normalized to produce a dimensionless index by dividing the ice discharge by the maximum among the three observation years: 1996; 2000; and 2005. With inter-annual variability in ice discharge expressed as an index, an empirical melt-sensitivity is defined for a collection