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Application of Global Positioning System (GPS) for Glacier Studies at Schirmacher Oasis, East Antarctica

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ABSTRACT

To give insight into the mass balance and future behaviour of the Schirmacher Glacier (Central Dronning Maud Land, Antarctica), two GPS campaigns were made during the summer season during 2003 and 2004. GPS data were collected at 21 sites and have been analyzed to estimate the site co-ordinates, baselines and velocities in ITRF2000. All the GPS points in the glacier have been constrained with the base station established at the Indian Antarctic Research Station MAITRI and the nearby IGS stations VESL and SYOG. Displacement measurements were made from the GPS sites in Schirmacher glacier, which is parallel to the Schirmacher Oasis. The velocity of the sites is found to he between 1.89 ± 0.007 - 10.88 ± 0.009 m yr$^{]}$ in NNE direction and the average velocity of the ice stream over the study region is 6.21 ± 0.007 m yr^{1}. The site velocity distribution is spatially correlated to the surface undulation gradients, crevasses, and blockage of Schirmacher Oasis. In this paper, we report the glacier velocity field derived from GPS and dynamic nature of the Schirmacher Glacier.

INTRODUCTION

Geodesy, the science of determining the three dimensional coordinates of a position in the surface of Earth, received an important boost with the advent of Satellite era. Global Positioning System (GPS) ins one of the satellite based navigation systems consists of 24 satellites with four in each six orbits at about 20,200 km altitude, with an orbital period of 12 hrs allows very precise determination of location and changes in the distance between observation points and it proved to be one of the most effective methods to measure glacier velocity.

Antarctic ice which contains 90% of the world's total ice and 70% of world's fresh water, has an active role in global climatic change (Meir, 1993; Zwartz et al., 1999), monitoring of surface mass balance of Antarctica is one of the key parameter to estimate glacier dynamics. Antarctica is mostly covered by thick glaciers that grow by continuous snowfalls, surface velocity field of the glaciers can provide useful information on phenomena such as glacier surges, icefall and the effect of global wanning. 90% of the discharge from the Antarctic sheet is drained through a small number of moving ice streams and outlet glaciers fed by relatively stable and inactive areas. Since these outlet glaciers play a vital role in Earth's geodynamics and climate systems, understanding of the complex dynamics of the glacial system requires fundamental information such as mass balance, depth and temperature of the ice, meteorological conditions, surface velocity vectors, strain rates, surface gradients, changes in the surface elevation, etc. To facilitate these studies, critical areas of the outlet regions through which most of the continent ice is discharged to the coast are required to be monitored. Some of such important outlet glaciers have been already studied e.g. Shirase Glacier (Pattyn and Naruse, 2003), Lambert basin Glacier (Manson et al., 2000), Dronning Maud Land (Scheinert, 2001).

The coastal region of Antarctica is the most sensitive part of the antarctic ice sheet, schirmacher glacier is one such important outlet glaciers in Central Dronning Maud Land (CDML), having a major role in the drainage of east Antarctica (Fig. 1). In 1980s glaciologists from East Germany explored some classical ice caves in scirmacher oasis, created by water flow. They are outflow conduits draining internal glacier waters. With the availability of this vast amount of different types of data for the past two decades, it has become a valuable site for observing the changes in the movement of the antarctic ice sheet caused by global warming.

With advancement in air borne and space borne geodetic techniques, now it is now feasible to monitor the dynamics of Antarctica glaciers. With high spatial coverage there are several well established space-borne geodetic techniques for this purpose e.g., Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Synthetic Aperture Radar (SAR), Global Positioning System (GPS) etc. Amongst these, the GPS has become the geodetic method of choice for studying the wide range of geophysical phenomena very precisely with cost-efficient, low power consumption, high memory, portable and requires a minimum logistic support. GPS became a standard and indispensable tool for determination of ice kinematics to a precision of few mrn/yr Schenert (2001) outlines a variety of geodetic

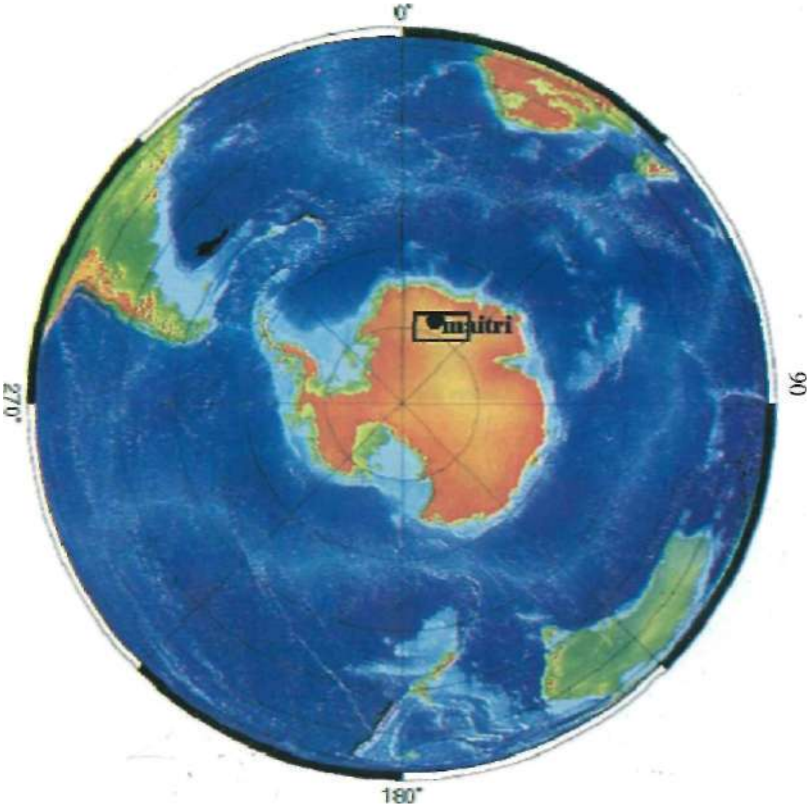

Fig. 1: Antarctic continent with the present study area in rectangle

observation techniques, which were applied to investigate geodynamic phenomena in Schirmacher Oasis region. In this paper, we describe two GPS campaigns undertaken in Schirmacher glacier during 2003 and 2004 and present the velocity distribution over the region.

GEOLOGICAL SETTINGS

The studied Schirmacher glacier situated in Schirmacher region of cDML in East Antarctica, is part of the Antarctic rift system that has evolved in different stages since the Gondwana break-up in the Jurasic time (Lawver et al., 1992). The study area covers inland plateau, marginal oasis and coastal shelf-ice and bounded by longitude from 11°15'E to 12°15'E and latitude from 70°30'S to 71°00'S in. The region of Schirmacher glacier is blocked by of Schirmacher Oasis, a low lying nunatak in north (Ice-free rocky hill range that exposes granulite to amphibolite facies rocks like charnockites, enderbites, garnet-sillimanite gneiss, garnet-biotite gneiss, dolerite etc. covers an area of 34 km^2 and elevation varying from 0-228 m above the msl, located 100 km south of Lazarev Sea and Nivlisen shelf ice) (Sengupta, 1986 and Hermichen, 1995) and Woltaht mountain ranges in the southern part (Fig.2).

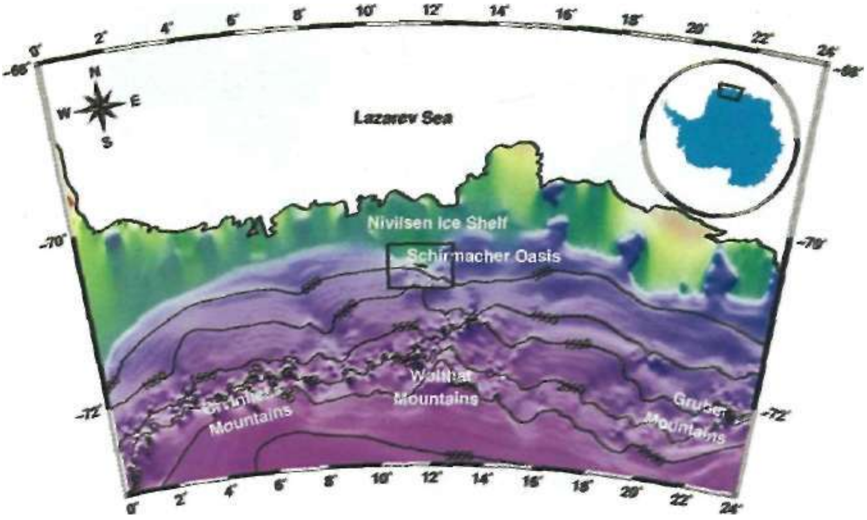

Fig. 2: Location map of central Maud Land in East Antarctica with study area of Schirmacher region in rectangle (Elevation contours derived from GTOPO30 topographic data)

The study area is divided (elevation ranges from 0 to 1000 meters) topographically in to four distinct units, the southern continental ice sheets, rocky hill slopes and northern undulatory shelf ice (Ravindra et al., 2001). This outlet glacier is characterised by steep gradient surface slopes, crevases and NE-SW to NNE-SSW trending crisscrossed fractures near to the Schirmacher range (south of Oasis) and relatively gentle slope in the inland area near to the nunataks viz. Tallaksenvarden, Hagladtoppen, Pevikhornet etc. (Fig. 3). The north of Schirmacher Oasis comprises shelf ice with pressure ridges, fractures and crevasses. The contact between shelf ice and eastern rocky slopes is marked by a prominent 3 km long, NNE-SSW trending lineament.

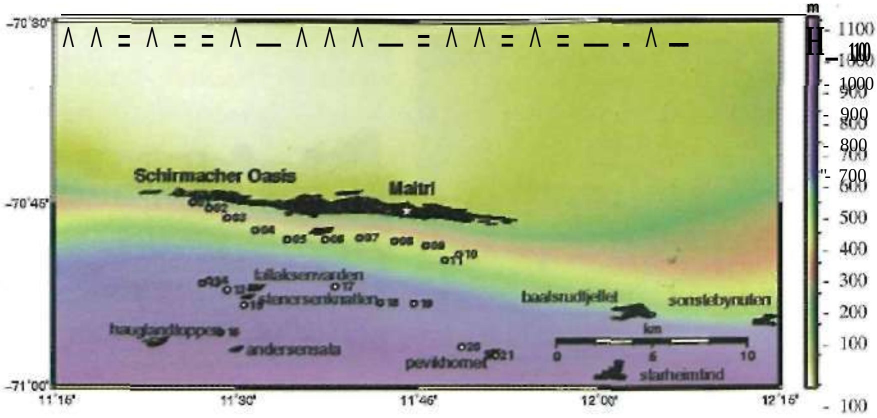

Fig. 3: Network of 21 GPS sites in Schirmacher glacier superposed on shaded relief map of GTOPO30 topographic data. The GPS locations in glacier are shown as open circles and various coastal nunataks Including Schirmacjer Oasis are shown as black patches. The color scale indicates the topographic elevation in meters.

DATA COLLECTION AND ANALYSIS

Fig.3 shows the network of 21 sites with ~ 5 km inter-station spacing and spreading over an area of 25 x 50 sq km. For GPS data collection, dual frequency (L1/L2) geodetic Trimble 4000SSi receivers with choke ring antenna were used. Each antenna was fixed on a 1.5 cm diameter threaded steel bolt fixed on a wooden block of 1 x 1 x 1 ft which is embedded in the ice to a depth of 1.5 ft (Fig.4a). The first and second campaigns were made during January - March 2003 and January - March 2004 respectively. At each site the data were collected for about 48 hours with 30 seconds sampling interval and 15°-elevation mask. The Indian Antarctic Research Station, Maitri established in 1989 by Indian Antarctica expedition ~ 15 km from the survey region, and near to Maitri one base station GPS site is setup on exposed bedrock (Fig. 4b). The GPS receivers were transported from Maitri to field sites by Helicopters and Snow Vehicles. The GPS receivers were powered by specially sealed 12V, 72AH charged batteries enclosed in non-conducting boxes. During the second GPS'campaign, the data were collected at only 15 sites (out of 21 sites) due to logistic problems. Data have been downloaded to the Notebook PC and converted to Receiver Independent Exchange (RINEX) format at each site.

The GPS data obtained during the two campaigns were organized into 24 hours segments covering a UTC day to facilitate the processing relative

(a) (b)

Fig. 4: Photos show (a) GPS antenna mounted on wooden platform fixed on the glacier and (b) GPS base station set up on exposed bedrock near the Maitri station

to nearby IGS (International GNSS Service) network sites VESL and S YOG (Fig. 5). As a first step, we analysed all pseudorange and phase GPS data using GAMIT post-processing software developed by Massachusetts Institute of Technology and Scripps Institution of Oceanography (King and Bock, 2000). To produce estimates and an associated covariance matrix of station positions, we solve for satellite state vectors, tropospheric zenith delay parameters and phase ambiguities using doubly differenced GPS phase measurements. Thus, for each session, a "loose solution" (Feigl et al., 1993) defined in the International Terrestrial Reference Frame 2000 (ITRF2000) (by using precise orbits from anonymous ftp site 'lox.ucsd.edu') has been obtained and then passed to a Kalman filter (Herring et al., 1990). In the second step, these loosely constrained solution files (h-files) combined with the global solution files (IGS h-files) from the IGS daily processing routinely done at Scripts Institute of Oceanography (SIO) by using the GLOBK software (Herring et al., 1990, Dong et al., 1998). We then impose the ITRF2000 reference frame using this combined solution by minimizing the position and velocity deviation of IGS core stations SYOG and VESL with respect to the ITRF2000 for the estimation of consistent set of coordinates and velocities of each GPS sites.

RESULTS AND DISCUSSIONS

The magnitudes of surface horizontal velocity estimated at each site of Schirmacher glacier and the velocity vectors are shown in Fig. 5 (for 15 sites out of 21 sites). The maximum and minimum velocities are 10.88 ± 0.009 m yr^{1} and 1.89 ± 0.007 m yr^{1} seen in North-East part and Southern

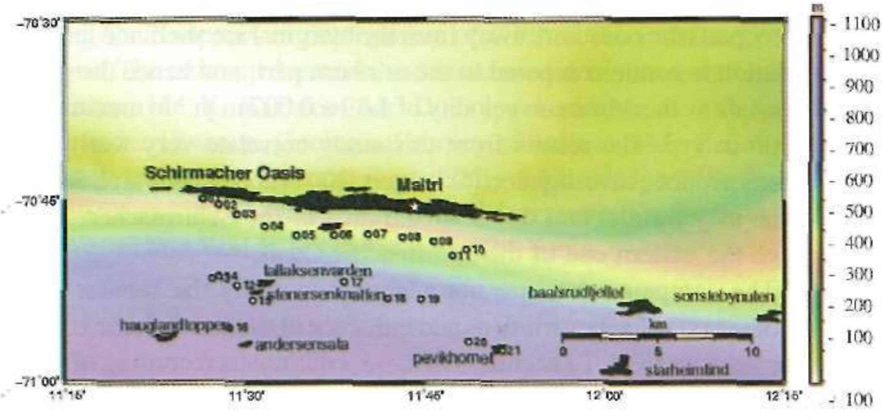

Fig. 5: Horizontal velocity vectors (with 95% confidence ellipses) for the GPS network in Schirmacher glacier, superposed on shaded relief map of GTOPO30 data

part of the study area respectively. The average velocity of the glacier is 6.21 ± 0.007 m yr^{1} in NNE direction. In general, the more velocity is seen at the sites located at maximum steepness of the glacier or/and away from the blockage of Schirmacher Oasis. Comparing to the maximum velocity of other glaciers in east Antarctica e.g. Shirase (Pattyn and Naruse, 2003) and Lambert Glaciers (Manson and others, 2000) with velocities approximately 1200 m yr''' and 2500 m yr^{1} respectively, the velocity of Schirmacher glacier is very low i.e. ~ 11 m yr^{1}. The reason for the low velocity might be that (driven by gravity) is resisted by the friction from clean undulated bedrock and the area is located in the transition zone between the floating shelf ice and the grounded inland ice. The Schirmacher oasis and other nunataks exposed in the study region which are extended along the grounding line also significantly offers its resistance to the flow of this glacier.

The velocity gradient map clearly shows the high velocity region (fast-zone) delineated which consists of the GPS sites 09, 11, 18 & 19. Though the elevation gradient of this region is gentle, the velocity is maximum because the blockage of the Schirmacher Oasis is minimum. The shear stress of gravitational driving force caused due to the number of steep crevasses noticed during the field observation along this zone. GPS sites 02, 05, 06 & 07, despite being situated over the steep gradient region, have relatively low velocity because of the blocking by Schirmacher Oasis. The velocity of site 02 is very low i.e. 2.37 ± 0.005 m yr^{1} as this site is very close to the Schirmacher Oasis. In the region away from the Schirmacher Oasis (SE and S W part) the points are away from the marginal ice shelf and the surface undulation is gentle compared to the northern part, and hence the points in this part show the minimum velocity of 1.89 ± 0.007 m yr' to maximum 4.85 ± 0.006 m yr^1. The results from this study correlate very well with the previous geodetic investigation (Scheinert, 2001) done in this area and shows that the major outlet and down stream area of the Schirmacher glacier is through the eastern end of the Schirmacher Oasis.

The campaign data are not adequate to study the secular (at time scale of years) velocity variations and influence of the atmospheric conditions on the velocity field. To accomplish these, continuous recording of gps data (with met package) at selected sites on the schirmacher glacier has been planned. To model the glacier dynamics and estimate the mass balance changes, in addition to the rheology of the ice, it requires the knowledge of glacier geometry, boundary conditions, deformational and basal components of the glacier velocity.

CONCLUSIONS

To investigate the dynamics of Schirmacher Glacier in East Antarctica, GPS data have been collected for two campaigns during 2003-2004 and analyzed using GAMIT/ GLOBK. The results show that the magnitude of the horizontal velocity (in itrf2000) is in the range of 1.89 ± 0.007 m yr^1 to 10.88 ± 0.009 m yr^1 with an average of 6.21 ± 0.007 m yr^1 in cal direction. The distribution of velocity is spatially correlated to the surface undulation gradients, crevasses (coinciding with the fast-zone), and influenced by the blockage of Schirmacher Oasis. To facilitate the intricate study of this glacier we compared our results with the previous geodetic work in this area and it is planned to make a third campaign during 2005. Other technique InSAR also extensively being used for the measurement of glacier velocity e.g. Rutford Ice Stream in Western Antarctica (Goldstein and others, 1993), and suitable SAR scenes are being acquired for Schirmacher region. The InSAR results with good vertical resolution can supplement the GPS results with good horizontal resolution.

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