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The Mertz Glacier Tongue, East Antarctica. Changes in the past 100 years and its cyclic nature - Past, present and future

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ABSTRACT

The Mertz Glacier Tongue (MGT) in East Antarctica has been studied since 1911. Early expeditions produced maps using ground or ship-based observations followed later by vertical and/or oblique aerial photography from aircraft. In the modern era, extensive digital satellite imagery is available which has also been supplemented by the resurrection and scanning of some historic U.S., now 'declassified', film-based satellite images. Much of the MGT became detached and drifted away following the collision by the B-9B iceberg in February 2010 and a similar sequence, or extension-detachment cycle, must have occurred some-time after Mawson's 1911–1914 observations. All the available information on the position, shape or appearance of the MGT has been re-examined in an attempt to comprehensively study its past, present and possible future motion. Feature tracking cross correlation methods have been applied for suitably detailed image pairs to accurately measure the MGT advance velocity. The derived mean rate for 1947–2010 is 1180 ± 14 m y^{-1} with an accompanying ice-front loss rate of ~190 m y^{-1}. A simple model for the MGT exhibits a ~73 year quasi-periodic cycle of rebirth, growth and demise which will affect the volume of bottom water produced in the nearby polynya. Some evidence for this cyclic oceanographic change has recently been reported from regional sediment data. Somewhat speculatively, the model suggests a date of ~1937 for the previous MGT break-off and around or before ~2083 for the next. With the MGT being primed to break-off every ~73 years, the precise date being governed by unpredictable external events such as collisions by large icebergs, such cycles have probably occurred for many thousands of years.

1. Introduction

The Mertz Glacier and its floating tongue (MGT) have been studied in a variety of ways for many years. Observations date back to the first detailed exploration of the region by the Australasian Antarctic Expedition 1911–14 (Mawson, 1915) and the discovery and naming of the glacier. Infrequent visits to the region occurred over the following decades until more regular satellite observations commenced in the early 1970's. Some observations have also been recovered from the 1960's era using old weather satellite images (Meier et al., 2013) or declassified satellite images from the Corona Project (Bindschadler and Seider, 1998). A few studies have been made looking at pairs of relatively recent satellite images to derive the MGT flow speed, perhaps with some additional data from the past to look for any substantial change in this flow rate over a wider time span. Wendler et al. (1996) determined an annual flow speed of ~1.2 km y^{-1} between two JERS-1 images about 19 months apart during 1993–94 but only 0.9 km y^{-1} referenced back to an Australian map from 1963 (Australia, 1974). Frezzotti et al. (1998) were more concerned with the growth in area of the MGT as the tongue advances and the contemporary ice-front loss due to calving phenomena. Frezzotti et al. (1998) also provide a good summary of the various historical expeditions and mapping efforts in the area. Berthier et al. (2003) and Wuite (2006) have also studied the MGT motion by comparing pairs of images. The MGT height, freeboard and mass were not easy to estimate until the flight of ICESat with its laser altimeter and Wang et al. (2014) derived values of 210, 383 and 550 m for the minimum, average and maximum ice thickness respectively.

The Mertz Glacier drains approximately 83,000 km^2 of the grounded East Antarctic Ice Sheet (Rignot, 2002) where the confluence of tributaries leads to two major ice streams. Until recently, the MGT extended ~145 km from the grounding line, visually through two coastal buttresses, extending ~100 km out to sea from the George VI Land coast in 2009 (Legrésy et al., 2004). The two feeding ice streams seem to always flow in step as the MGT grows in a very straight form with no tendency to curve. This is in contrast to the nearby Ninnis Glacier which has a pronounced 'bend' (see Fig. 6 of Wendler et al., 1996). Any projections on the western edge of the MGT seem to become detached quite quickly, and this side becomes relatively straight and smooth as the tongue advances off-shore. The polynya which forms here between the MGT and the coast (Barber and Massom, 2007) is a large source of bottom water with forming sea ice being rapidly blown away to the west by

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strong katabatic winds. In contrast, the eastern side of the MGT maintains a relatively rugged profile with a large 'permanent' slab of multi-year fast ice (MYFI) preventing any fragments from escaping by locking them in place (Massom et al., 2010). This MYFI also prevents ocean swell from attacking the eastern edge of the MGT. The MYFI is rigidly attached to the side of the MGT and continuously carried offshore by it at ~3 m d^{-1} with new sea ice forming within the opening shoreline gap (Massom et al., 2010).

After passing through the coastal buttress gate, the surface of the MGT gradually takes on a clear tessellated appearance which was referred to as a cellular pattern by Wendler et al. (1996). It is this distinctive pattern which allows feature tracking software to study the motion and differential flow of the MGT. The tongue initially undergoes some lateral spreading and speeds up slightly, on the ocean surface, once it is unconstrained and free to do so. These aspects and a variety of physical effects on the MGT over the last ~20 years, such as collision or grounding events, have been discussed by Massom et al. (2015). Collision events are highly unpredictable but can have a dramatic effect on the MGT when they occur.

An analysis of a regional sediment core spanning 250 years by Campagne et al. (2015) has recently shown that the physical state of the MGT modulates the local oceanography with a period of 60–80 years. In that study, the absence or presence of the MGT appeared to have a substantial effect on the downstream polynya surface conditions and its production of dense bottom water. The processes in this region, and a few other similar locations round the Antarctic coastline, could therefore potentially have a significant impact on global ocean and climate systems (Campagne et al., 2015). Since the general polynya region along the western side of the floating tongue is responsible for ~25% of the total formation of Antarctic Bottom Water (Jacobs, 2004) the MGT appears to have a disproportionally large impact.

In the present study we are concerned only with the ice-front advance or length of the MGT rather than its area, height, volume or differential motion. Various additional relevant information has become available since the studies of Wendler et al. (1996) and Frezzotti et al. (1998). In particular, ~80% of the MGT length became detached and drifted away following the collision by the B-9B iceberg in February 2010 (Mayet et al., 2013). The MGT remnant has then continued its outward flow in a similar fashion to that before the collision. Therefore, prompted by the MGT break-off and subsequent motion since 2010, all the available information on the position, shape or appearance of the MGT has been collected together in an attempt to comprehensively re-examine its past, present and possible future motion.

2. Image pre-processing, mapping and registration

Comparisons between the positions of various features on pairs of images were evaluated using a modified version of the IMCORR 'feature-tracking' software (Bindschadler and Scambos, 1991; Scambos et al., 1992). For suitable image pairs, IMCORR was used with big size tiles to check overall image registration on the coast and to get the pixel displacement of smaller sub-scene tiles to track the MGT tip movement. For the more recent images, which are all accurately mapped and co-registered, relative displacements are typically good to ~0.25 pixels. This level of accuracy was established in the earlier work of Giles et al. (2009) using pairs of images only a few days apart which treated the MGT as a 'stationary' test target. Earlier less precise images and maps have a more uncertain mapping which can lead to undefined error, particularly in the offshore distance scale. The general procedure is to match the coastline scale, orientation and position between the target image and one of two base images using two widely separated points along the coast. Details on the image registration procedure, registration points and base images can be found in the Supplementary Material.

3. Available maps and images

The range of observations and data obtained on the Mertz Glacier Tongue over the years since 1914 is quite considerable and Table 1 attempts to include the basic information to define the source material and images used in this study. Although details on image selection and processing can be found in the Supplementary Material, the following Subsections 3.1 and 3.2 describe some aspects of the oldest data. Table 1 intentionally lists the actual values measured from the images so that the required corrections for the ice-front losses, appropriate before 1984, are not 'hidden' within the tabulated numbers (see Section 4.2). Note that the lower quality early images do not allow meaningful positioning on the X axis. A mosaic of many of the derived sub-images is shown in Fig. 1.

3.1. Mawson expedition map – 1914

This map is the only identified information relating to the cycle of the MGT preceding all the other data presented in this paper. The map and MGT profile were produced from observations made during the Australasian Antarctic Expedition in 1911–14 (Mawson, 1915). The map as drawn is considered to be quite accurate (see Supplementary Material).

3.2. Operation Highjump aerial photography – 1947

Operation Highjump was a large US Navy program that occurred in Antarctica during early 1947 (Bertrand, 1967) and the aerial photographs obtained were examined to extract any useful information on the MGT. Crucially, for the purposes of this paper, inspection of the images from one flight shows that the aircraft flew across the MGT position, as recorded on Mawson's 1914 map, but this large feature was no longer present. Full details on the analysis of these images can be found in the Supplementary Material. In summary, the installed camera obtained views which sequentially showed coastal features and then the MGT in the distance to the south allowing the glacier position to be estimated in a two stage process. Firstly, the distance from the aircraft to the MGT is calculated and secondly, the best estimate of the actual aircraft position is determined. This latter part is examined by studying distant imaged features in the earlier stages of the flight and extrapolating the track to the time when the MGT was in view.

4. Combining all the above observations of the MGT

In Table 1, the tabulated X-Y offsets are in metres with the best error estimate included. For the high quality images these are formal errors but for poor images, earlier maps or approximate reconstructions these are only rough estimates based on uncertainties in the various calculations. The errors in the time interval between consecutive observations are negligible in comparison. These X-Y values are then plotted to scale in Fig. 2 which provides an accurate visual comparison of all the derived positions. The odd shape to the track past 1997 is due to a number of effects discussed in Massom et al. (2015). In summary the tongue becomes partially detached over time as the MGT tip comes into contact with the seabed, with splits opening on the east and west sides near −60 km on the Y axis in Fig. 2. Before discussing the cyclic nature of the MGT growth and re-birth there are several factors that need to be derived, estimated or considered.

4.1. Increasing flow velocity along the MGT length

Wendler et al. (1996) used their JERS-1 data to derive the average flow velocity within three transect lines crossing the MGT at various off-shore distances, the outermost transect being near the tongue tip. A mean value of 1010 m y^{-1} was quoted as little difference was found down the MGT indicating it was floating freely. However, accurate