Reinvestigation of the Robustness of Martian Paleopole Reconstructions. P. Thomas[1], M. Grott[2], and A. Morschhauser[3] [1,2]Department of Planetary Physics, German Aerospace Center (DLR), Rutherfordstr. 2, 12489 Berlin, [1]paul.thomas@dlr.de, [2]matthias.grott@dlr.de, [3]GFZ, German Research Center for Geosciences, Potsdam, Germany, morsch@gfz-potsdam.de.

Introduction: The investigation of a planets paleopole positions can reveal informations regarding events like polar wander or pole reversals and therefore can help to understand a planets past [1,2,3,4]. One of the issues associated with many of these studies is the difficulty to give proper confidence intervals for the obtained paleopole positions, and only the best fits are usually reported. Here we present a method to self consistently calculate the best fit paleopole position together with its associated standard deviation and compare our results to those given in the literature. Paleopoles are calculated for the two volcanoes Apollinaris Patera and Australe Montes which have previously been studied by [2] and [4], respectively. Furthermore, we will investigate how the choice of the considered area influences the results.

Method: We applied the method of [5] to calculate paleopole positions in the study area. A number of N dipoles is distributed over the magnetic anomaly and the resulting magnetic field is calculated using a forward model similar to the Equivalent Source Dipole method (ESD) and compared to the magnetic model field of [6]. In the calculation, a fixed orientation for all N dipoles is assumed, which implies that the magnetization has been acquired during a phase of a constant main magnetic field [5]. This calculation is then repeated for different magnetization directions, and the misfits for these magnetization directions are obtained, and can then be statistically analyzed.

As has been shown by [5] it is sufficient to consider N observation points if N dipoles are used in the forward model. The dipoles should be equally distributed across the magnetic anomaly and for this purpose we chose a hexagonal grid. Furthermore the mean distance between the distributed dipoles is commonly taken to be equal to the observation altitude [2]. However we will also study the influence of different dipole distributions on the results. In total, we tested configurations with 7, 19 61 and 229 dipoles using spherical caps as observation areas with radii of 3°, 6°, 12° and 25° as measured from the center of the anomaly on surface height. To obtain the optimal magnetization direction 32400 forward models were calculated, one for every magnetization direction. The paleopole position can then be calculated from the magnetization vector using a coordinate transformation [7] that takes the location of the anomaly into account. In the transformation it is implicitly assumed that mars possessed an interior field with purely dipolar character in the past.

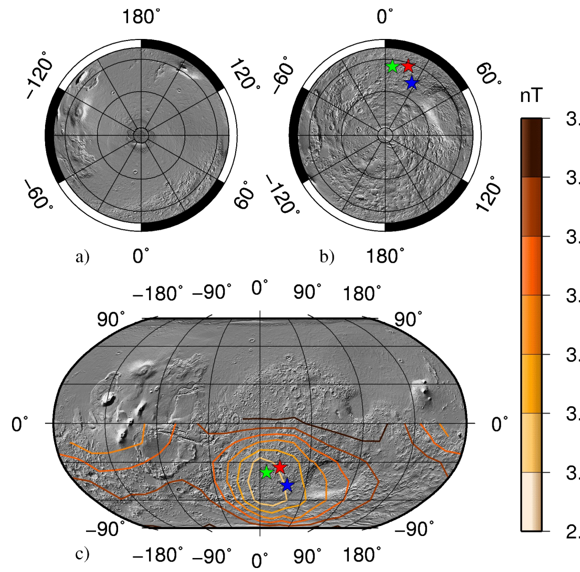

Fig. 1. *Results of the paleopole reconstruction of Australe Montes (80° S, 25°E). Color coded contour lines plotted on a MOLA shaded relief represent misfit between lithospheric magnetic field data and model. The green symbol represents the best fit (magnetic south) paleopole position obtained in the inversion. Red represents the mean paleopole position obtained using different dipole distributions. The mean result obtained by [4] is given as a reference (blue). a) and b) show stereographic projections of the north and south pole, respectively, while c) is a global map in Robinson projection.*

In order to compare the forward models to Martian magnetic field data we use the model of [6] which is based on the entire Mars Global Surveyor data set. The model uses spherical harmonic functions up to degree and order 110 to approximate the measurements and uses a modified Huber-norm to address data outliers. The model has a low noise level and is robust when downward continued to the surface.

Results: The applied method has been verified using synthetic magnetic field data with known dipole distributions, orientations, and magnetization strengths. Inverted dipole orientations perfectly reproduce the prescribed orientations and magnetization strengths. Number of dipoles and the extend of the observation area do not have any influence on the inversion. This is due to the fact that in the synthetic data all orientations are uniformly aligned and that no perturbations due to surrounding fields are present.

Results of the calculation for the inversion of the Australe Montes magnetic anomaly [4] are presented in Fig. 1, where a contour plot of the color coded misfit between calculated and model of the observed field is shown as a function of paleopole location. The green symbol represents the best fit (magnetic south) paleopole position obtained in the inversion, using the first listed configuration in Tab. 1, with a dipole distribution centered at 80°S / 25°E. Red represents the mean paleopole position obtained from all calculated dipole distributions. The results obtained by [4] are given as a reference (blue). Note that [4] uses paleopole positions representing magnetic north, while magnetic south poles are determined here [7].

Contour lines around the anomalies center shown in Fig. 1 are roughly concentric with respect to the best fit, which has a minimum average misfit of 1.82 nT and is located at 6°E / 38°S. As already pointed out by [5], the problem now consists of defining a value for the acceptable misfit range, and in principle the uncertainty of the used magnetic field data should be used to derive this value. This can be done by analyzing the covariance matrix of the gauss coefficients of the applied lithospheric magnetic field model [6]. But this has not been implemented at this stage. Arbitrarily choosing a factor of 1.6 for the misfit as the confidence limit for illustration purposes results in a reconstructed paleopole position between 10°W / 25°E and 25°S / 70°S, which is close to the mean paleopole position of 27°E / 48°S determined by [4].

Results for different configurations of dipole distributions and observation radii are summarized in Tab. 1 for the inversion of the Australe Montes anomaly. Results are consistent irrespective of the chosen number of dipoles, and spatially better resolved models appear to give less scattered results. This is also evident from Fig. 1 where the average best fit position across all geometric configurations is close to the overall best fitting result.

This is in contrast to the results we obtained for the Apollinaris Patera magnetic anomaly, which strongly depend on the spatial extend of the study region (compare Tab. 1). This is attributed to the fact that Apollinaris Patera itself is located within a region of strong remanent magnetic fields. Choosing large radii for the ESD inversion then results in fitting part of this unwanted signal, therefore the results obtained by [2] could only be reproduced for paleopoles located at the northern hemisphere, with an assumed radial extend of the investigated area of 3°. A further evaluation of the results is necessary.

Conclusions: We have presented a method for reconstructing the position of Martian paleopoles which allows for an estimation of the position uncertainty. The method has been validated using synthetic magnetic field data. Furthermore results obtained previously for the paleopole directions of the Apollinaris Patera [2] and Australe Montes [4] magnetic anomalies have been reproduced. We have shown that robust results are obtained if either the studied anomaly is well isolated from surrounding fields, or if the study radius is chosen appropriately. In this regard it is promising to investigate the isolated anomalies identified by [6], as these can be expected to yield robust paleopole locations. In order to better quantify the uncertainty of the obtained paleopole locations, the uncertainty associated with the available magnetic field data needs to be taken into account. In addition we will invert the model for different observation heights with direct investigation of the Martian magnetic surface field which is possible due to the use of the model of [6].

Table 1: *Compilation of selected results for different spatial configurations of the ESD's in terms of ESD number, ESD distribution, and observation radius.*

Number of Dip.	Distribution radius	Observ. radius	Paleopole Location
Australe Montes			
7	3°	5°	6°E / 38°S
19	3°	6°	14°E / 39°S
19	6°	9°	4°E / 38°S
61	3°	3°	21°E / 30°S
61	6°	9°	10°E / 34°S
Mean result from [4]			27°E / 48°S
Apollinaris Patera			
7	3	3	143°W / 67°N
7	3	6	171°E / 7°S
61	12	12	89°E / 82°S
229	3	3	155°W / 76°N
229	25	25	107°E / 51°N

References:
[1] Parker R.L. (2003) *J. Geophys. Res., 108*. [2] Langlais et al. (2007) *Plan. Space Sci., 55,* 270-279. [3] Milbury et al. (2012) *J. Geophys. Res., 117,* E10007. [4] Plattner et al. (2015) *J. Geophys. Res. Planets, 120,* 1543-1566. [5] Parker R.L. (1991) *J. Geophys. Res., 96,* 16/110-16/112. [6] Morschhauser et al. (2014) *J. Geophys. Res. Planets, 119(6),* 1162-1188. [7] Butler R.F. (1992) *Blackwell Sci.,* 121–135.