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Climate of the Past Discussions

Interactive comment on "Surface thermal perturbations of the recent past at low latitudes - inferences based on borehole temperature data from Eastern Brazil" *by* V. M. Hamza et al.

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Reply to Comments by Referees

We are thankful to the comments and suggestions made by referees (1) and (2). These have contributed to significant improvements in the revised version of the manuscript. The data set has been revised and some new and deep borehole data introduced. Most of the data reported are for boreholes with depths greater than 200 meters. Some log data for depths less than 200 meters are also considered, as they provide complementary information on GST variations encountered in deeper boreholes of the same general area. Figures (1) and (2) have been merged to a single one in the revised version. Similarly, the separate parts of Tables (2abc) and (3abc) have been merged into new tables 2 and 3 respectively. Also, figures (3abc) and (4abc) have been merged into new figures (3) and (4) respectively. As per recommendation, the figures of air temperature data have been deleted. There are some slight modifications in the description of the methods employed. The text also points out the strong and weak points of the models considered, taking care to avoid reproducing textbook stuff. The forward models are referred to in the revised version as the Classical Inversion Method. The other one (Functional Space Inversion) is described as the Bayesian Inversion method. We hope that the explanation provided below may contribute to clear up any eventual misunderstandings.

Reply to Referee 2 Most of the modifications suggested by referee 2 has been incorporated in the modified version (See comments provided in earlier sections and also reply to referee 1). Thus we limit our reply here to issues that are described in the items below:

A) Temporal Extent of Inversion: We share the essence of the argument that deep borehole data are of considerable value in reconstructing climate history. In the revised version we have limited the time period for shallow boreholes (depths less than 200 meters) to the last 250 years. Time periods extending to 1500 years is considered only for boreholes with depths greater than 300 meters. The essence of the comments of the referee on this issue is clear but the wording gives the apparent impression that there is a one-to-one correspondence between borehole depth and time elapsed. This is not necessarily true as climate signals of earlier periods are spread out over relatively much large depth ranges than those which originate from recent changes in GST. This point was noted by Birch (1948) in his classic study on perturbing effects of Pleistocene glaciations in borehole temperatures. In the study of Birch (1948) the ability of the ground to “remember” past climate changes is represented in terms of what he calculated as “recollection index”. At 200 meter depth, the maximum in recollection index (in other words, the strength of the climate signal) occurs during the period of 1600 to 1800 A.D. At 300 meter depth, the index is maximum for climate events that

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took place during the period of 1200 to 1500 A.D. This is actually textbook stuff and has been included here exclusively for the purpose of illustrating the arguments.

B) Absence of clear indications of Cooling Events in Forward Models In the forward model approach the residual temperature depth profiles are obtained by subtracting a linear steady state T-z profile from the measured T-z data. Since the steady state T-z profile is determined from the bottom part of the T-z data, which is incorrectly assumed to be free of transient perturbations, the procedure essentially precludes the presence of a cooling trend, in most cases. On the other hand, the FSI formulation does not pre-determine the steady state T-z profile. Nevertheless, a careful examination of figure (3) reveals that some of the transient temperature profiles do have small negative values for depth intervals corresponding to the bottom parts of the transient sections. Such negative residuals are consequences of cooling events prior to recent warming episodes, but often go unnoticed. Similar features can also be noticed in residual profiles reported by Golovanova et al (2001) and Roy etal (2002). In other words, there are indications of cooling events also in the forward models, but it is relatively subdued. This is a limitation of the classical inversion method, which resolves mainly for the first-order features in the GST history.

C) Is the cooling event an artifact of FSI method? Preparatory steps in the use of FSI method include specification of the depth at which the thermal regime is supposedly untouched by the GST variations and of the time limit beyond which GST variations cannot be recovered from the given temperature log data. These estimates are chosen in accordance with the depth extent of the available temperature log data and the time extent for which the GST history is sought. In particular, the depth estimate must be greater than the deepest data point because the calculated data are projected (interpolated) from the finite element solution. As for the time limit there is no harm in setting values compatible with the depth extent of the borehole (Shen and Beck, 1992). On the other hand, use of a shorter-than-necessary time span would end up in “telescoping” the GST history. Unless there are independent evidences indicating a

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rapid return to unperturbed conditions it seems prudent to assume that this return take place gradually. The influence of setting different values for the time span have been investigated for T-z profiles of two boreholes (443 meter deep borehole in Jacobina and the shallow 300 meter deep borehole in Seropedica). The results indicate that use of shorter time spans lead to small reductions in the magnitude and in the duration of the cooling events of the earlier periods.

D) Do different inverse models lead to different results? Unless dramatically different a priori information has been used the differences in final results should be small. For example, if the a priori information has been incorporated solely to circumvent the non-uniqueness and instability of the solution, but NOT to over-ride the data, then essentially the same solution should be obtained in all inverse models.

E) Low values of RMS Misfit in Forward Models The values of misfit are calculated as the root mean square deviations between the observational data and model values. The values obtained in our work are comparable to those reported in the literature. In cases where temperature measurements have been carried out at closely spaced intervals and where the choice of model parameters is good, the rms misfit values are relatively low. It has nothing to do with the accuracy of the temperature sensors.

F) Comparisons with results from other continents The main purpose in comparing the results for selected sites in Brazil with those for other parts of the world is to point out that the main features in GST history are similar. The main difference is that the deviations are smaller for the period 1700 to 1900. The figure caption has been modified accordingly.

G) References We are surprised with the comment that the references are somewhat outdated. The references cited are indicative of the database collected and the methods employed in data analysis (Classical and Bayesian Inversions). The subject of climate variations is extensive and multidisciplinary in character and it is possible that we may have overlooked some references.

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H) Availability of Original Data Base Parts of data have already been made available through the IHFC Climate database. Most of the remaining database are available as part of thesis works of graduate students, the PDF files being available through websites. This may not be a satisfactory solution because of the language barriers. An appendix can be added to the paper giving raw data, provided there are no space limitations. We leave this problem and the final decision to the Managing Editor of CP.

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