A simple rubric for Stratigraphic Fidelity (ß) of Pliocene paleoenvironmental time-series

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ABSTRACT: The Pliocene, specifically the late Pliocene, has been a focus of paleoclimate research for more than 25 years. Synoptic regional and global reconstructions along with high-resolution time-series have produced nuanced conceptual models of paleoenvironmental conditions and enhanced our understanding of climate variability and climate sensitivity from the late Pliocene, the most recent interval of global warmth similar to what is projected for the end of the 21st century. These data are used as a source of boundary conditions for climate models as well as a means of verification of global climate model experiments. In this note, we introduce a measure of stratigraphic fidelity, ß, used to characterize the chronology and achievable resolution of an ever-growing library of Pliocene paleoenvironmental time-series. The ß index serves as an aid to end-users by allowing selection of time-series that meet the stratigraphic requirements of a particular study.

INTRODUCTION

Geological archives are routinely used to develop verification data for deep-time paleoclimate model simulations. This is especially true for the Pliocene Model Intercomparison Project (PlioMIP). During the first phase of PlioMIP approximately 100 short sea surface temperature (SST) time-series were analyzed by the U.S. Geological Survey Pliocene Research, Interpretation and Synoptic Mapping group (PRISM) to produce single estimates of SST for verification of nine different coupled ocean-atmosphere climate model simulations that contributed to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (Dowsett et al. 2012, 2013, Masson-Delmotte et al. 2013). For those comparisons Dowsett et al. (2012) developed the λ confidence measure. λ ranks SST estimates based upon a number of factors including age control, sample density, sample quality, proxy method and proxy performance. λ is specific to the PRISM SST data set and time slab (3.264–3.025 Ma) and provides an overall confidence for the SST estimate by locality. It is important to note that λ uses the number of samples falling within this interval, not an estimate of sample spacing.

As part of the current PRISM4 work plan, 'community sourced' verification time-series are being analyzed for PlioMIP2 data-model comparison. Unlike the previous PRISM verification data, these are longer time-series, not restricted to the PRISM time interval, and include variables other than SST (e.g. oxygen and carbon isotopes, sea surface salinity, bottom water temperature, productivity, nutrient estimates and faunal diversity). While the information needed to assess the quality of these variables is different for each one, an understanding of the temporal stratigraphic framework for each time-series is a first-order requirement for inclusion of time-series in different types of paleoclimate studies.

Thus, a simple index or scheme is needed whereby time-series data can be categorized based upon stratigraphic attributes alone. The purpose of this note then is to introduce a scheme that has been developed for the PRISM4 Community Sourced Verification Data Set to place Pliocene paleoenvironmental time-series into categories that will aid end-users in choosing data for specific applications.

STRATIGRAPHIC FIDELITY (ß)

PRISM4 researchers have developed a measure of *stratigraphic fidelity*, ß, to characterize the accuracy of the stratigraphic framework surrounding the paleoenvironmental time-series. ß is expressed as a function of the type of chronology applied and the temporal resolution achieved based upon that chronology and sample spacing.

Type of Chronology

Three common methods for developing age models for Pliocene marine sequences are biostratigraphy, magnetostratigraphy and orbital tuning. These *types* of chronologic control are inherently different from one other.

Biochronology. Dating sequences using calibrated biostratigraphic events such as fossil evolutionary first and last appearances is common practice (e.g. Berggren 1978). The accuracy of age models created using biochronology is highly dependent upon the number of calibrated evolutionary events used and amount of diachrony exhibited by those events. While one can expect synchrony between the same events over short spatial distances, most biostratigraphic events exhibit diachrony within the same ocean basin.

Magnetochronology. Higher resolution dating of sequences can be attained based upon calibrated geomagnetic polarity reversals. This is an alternative to biochronology though the two are often combined (magnetobiochronology). Unlike paleontological events, magnetic reversals are not unique, but relative spacing back through the Pliocene is often diagnostic. Since polarity reversals have been radiometrically dated and the ages of paleomagnetic Chron and Subchron boundaries through the Pliocene are relatively stable between geologic time scales, reversals in a core provide a series of dated depths that can be used to develop an age model. While there is no *a priori* reason to assume synchrony of a biostratigraphic event, in the absence of stratigraphic complications, magnetic reversal boundaries *can* be considered synchronous. Thus an age model produced using a combination of paleomagnetic reversals and first and last occurrences of fossil species is somewhat stronger than if created using biotic events alone.

Orbital Tuning. Very high resolution age models can be obtained by correlating variability observed in the time-series to solar insolation, which in turn, is controlled by regular and well-known variations of the Earth's orbit (Hays, Imbrie and Shackleton 1976).

Magnetobiochronology is less likely to provide a correct absolute age for a sample than correlation of a time-series to the astronomical time scale. In addition, unless a graphic correlation model (*sensu* Shaw 1964) is employed, magnetobiochronology does not address change in accumulation rates between tie points.

The relative strengths of these techniques, prescribes a three-part relative scale of chronology for ß. Age models constructed using calibrated biostratigraphic events are designated GOOD. Those time-series with age models based upon magnetostratigraphy are designated BETTER and orbitally tuned time-series, with the greatest potential to illuminate missing section and changes in relative sedimentation rate between tie points, are designated BEST (text-figure 1).

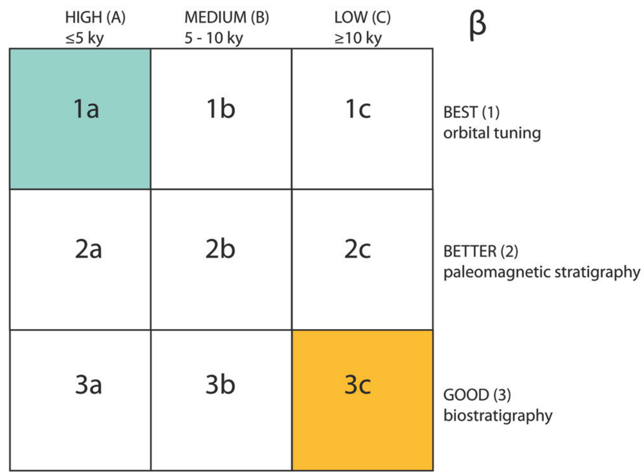
Magnetobiochronologic age models default to BETTER and orbitally tuned sequences, regardless of how tie points are determined, are considered BEST.

Achievable Resolution

The second part of our *stratigraphic fidelity* scheme is based upon the temporal density of samples in a time-series. Regardless of the technique used to determine chronology, the density of samples with respect to time will dictate the highest frequency variability that can be resolved from within a given sedimentary sequence.

We use variability to characterize sample spacing into three categories capable of resolving variation on precession, obliquity and lower frequency time scales. While sample spacing less than 10 ky is theoretically capable of resolving precession cycles, for practical purposes we suggest less than 5 ky be considered HIGH resolution. Those data sets with sample spacing averaging between 5 and 10 ky, should be capable of resolving obliquity scale variability, and are designated MEDIUM resolution and those sequences with temporal sample spacing averaging >10 ky are considered LOW resolution.

Thus the ß index gives nine categories of *stratigraphic fidelity* ranging from BEST, HIGH resolution (ß=1a) to GOOD, LOW resolution (ß=3c) (text-figure 1).



TEXT-FIGURE 1
Rubric for stratigraphic fidelity (ß) index. ß ranges from 3c (orange; low resolution sampling of a sequence dated using biochronology), to 1a (teal; orbitally tuned sequences with sample spacing =5 ky).

SUMMARY AND CONCLUSION

The PlioMIP2 experimental protocols call for climate models to be initiated with orbit and boundary conditions representative of 3.205 Ma, corresponding to Marine Isotope Stage KM5c (Haywood et al. 2016). Verification data will generally require BEST, HIGH resolution (ß=1a) time-series for data-model comparison studies.

However, there are other paleoclimate studies that will be compared to PlioMIP2 simulations that have other, less stringent stratigraphic requirements. For example, a study of changes in seasonality throughout the late Pliocene will be based upon a variety of data. Time-series from sclerochronological and isotopic analyses of single mollusk shells from a coastal plain outcrop yield *monthly* isotopic and temperature estimates representing up to two years of growth. This would clearly fall within the HIGH resolution bin. These time-series (individual mollusk shells) are dated using biostratigraphic techniques (ranked GOOD in our scheme). Where the two-year time-series is placed, in absolute age, may only be known to ± 500 ky. For this application, time-series designated 3a and better (3a to 1a) can be utilized.

It is important to note the subtle difference between ß and the former λ confidence measure. λ provided a single overall confidence in the SST estimate from a locality, integrating multiple temperature proxies. In contrast, ß describes individual time-series and two different time-series from the same locality may have very different ß values.

The ß index provides a simple scheme to group time-series based upon two important attributes: methodology used to create the age model and the resolution achievable through sample density. All data series included in the PRISM4 Community Sourced Verification Data Set will be ranked using the ß index. This will provide a better understanding of the stratigraphic fidelity of the data.

ACKNOWLEDGMENTS

This work contributes to the PlioMIP2 and PRISM4 efforts and was funded by the U.S. Geological Survey Climate and Land Use Research and Development Program.

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