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Interactive Comment

# *Interactive comment on* "A 60 000 year Greenland stratigraphic ice core chronology" *by* K. K. Andersen et al.

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Here we make some considerations about the uncertainty estimate of the GICC05 time scale in the glacial period, which is a major concern of all three reviewers and the comment by Eric Wolff.

For years paleoclimatologists have been applying ice core time scales generally without considering error estimates. This is partly because some time scales are based on models, from which error estimates are not easily derived, and partly because the time scales do often not provide a well defined error estimate. Even when an error estimate is actually provided, as for example for the GISP2 time scale, it is often not considered in applications.

For the construction of GICC05 we found it crucial to provide a quantitative and independent error estimate. Because only when time scales are given with error estimates they can realistically be compared to other independent time scales. This is crucial when we want to identify differences between time scales from different paleoarchives and ultimately to determine if those differences are due to actual asynchronieties of the records or if they are caused by artifacts of the time scales.

For the GICC05 error estimate there are several criteria that we want to meet:

1) Independent estimate - no calibration by other time scales. We want both the time scale and the error estimate to be obtained independently of other dating methods. This is the only way to enable true age comparisons and to efficiently avoid circular arguments when comparing records. For many other paleorecords such an approach is not feasible, but with the NorthGRIP datasets we actually have that possibility and we should take it. It has been suggested - among others by reviewers of the published GICC05 papers - that we should calibrate the absolute time and/or the error estimate by some other independent "absolute" time scale. However, one of the reasons for the intensive debate about time scales is that ALL dating techniques have their own problems - including radiometric dating - and we prefer to stay fully independent from those.

2) Simple and quantitative approach - no sophisticated statistics. We want the error estimate to be obtained by as simple methods as possible so that everybody can easily see what has been done.

3) Realistic error estimate - not too high and not too low. With respect to the magnitude of the error estimate, we certainly want it to be as realistic as possible. We have no interest in providing a too low estimate that we would have to "over-rule" in a later publication. On the other hand, we also have no interest in providing an unrealistically large error, because this would allow justification of unrealistic age estimates by referring to GICC05. We, therefore, make every effort we can to be within a realistic range.

The GICC05 uncertainty estimate is introduced by assigning a certain or an uncertain



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mark to each identified "annual layer" in the profile. This approach is mostly taken for practical reasons and it does not imply that we know the exact likelihood for each peak in the record of being an annual layer or not. As Eric Wolff points out, in reality there is no way we can objectively judge whether an uncertain annual layer is within the 0-25 %, the 25-75 %, or the 75-100 % probability range (this notation is introduced in Andersen et al., 2006). We are aiming for those intervals but we could as well have used terms such as "unlikely", "uncertain", and "likely". The mark assignment of the individual layer should be regarded as our best estimate.

Throughout the 60 kyr dated period we have had several experienced counters setting marks within the same sections of ice, often multiple times. In the case of thin annual layers and few high-resolution records to base the counting on those counters will rarely indicate exactly the same certain and uncertain years within a given section. However, it is our experience that when the counters have practiced they will typically end up with consistent durations and error estimates for the same sections of ice. This observation is an important rationale behind the error estimate provided with the time scale. It means that even if individual marks within a short time window can be questioned, the average error estimate over a longer section may still be accurate. Sections where the counters end up with deviating durations or error estimates are being reviewed.

We fully agree with several past and present reviewers and with Eric Wolff, that several of the certain, the uncertain, and the absent annual marks in the examples shown in Figures 1 and 2 in the present manuscript (and corresponding figures in published manuscripts) are to some degree questionable. In fact, this would probably be the case no matter what glacial sections we had chosen to show in the figures. Experience shows that even when the same person counts the same section several times he/she will typically not put the marks in exactly the same positions. Generally, however, the accumulated difference from one counting to the next will be small and normally within the error estimate. Therefore, despite the numerous arguments that can be made for or against the individual marks shown in the figures, we are confident that the overall estimate of both the duration and the counting error are reasonable.

At this point, one could argue that the term *maximum* counting error is misleading, because, strictly speaking, we do not include all of the possible uncertainty in the estimate. The maximum term is, however, justified by the way the errors are summed up. We acknowledge that the counting is likely to have some degree of biasing. For example, when the data resolution is limited or when several records show frequent multiple peaks within an annual layer. Therefore, we do not treat the uncertain marks as independent events, which would allow us to give a counting error of a sqrt(N)/2 type (N being the number of uncertain marks). Instead, we take the more conservative approach of summing up all the uncertain layers, which leads to the N/2 uncertainty estimate that we define as the maximum counting error (see discussion in Rasmussen et al., 2006). We see this as the simplest and most practical way to provide a realistic overall uncertainty estimate that takes into account all of the missing, the wrongly set, and the extra marks.

Finally, because there are several ways that the maximum counting error could be related to the more commonly applied sigma-error, we want to define this relation so that everyone uses the same notation. We make this relation the simplest way we can think of, namely by setting the maximum counting error (N/2) equal to 2-sigma. We agree that the maximum counting error is, strictly speaking, not a 2-sigma error, but if the maximum counting error is used in a sigma-error framework, we think that the above convention is the most reasonable option.

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