

Reply to the Short comment on “Stratification of surface waters during the last glacial millennial climatic events: a key factor in subsurface and deep water mass dynamics” by M. Wary et al., by Lukas Jonkers, Received and published: 17 July 2015

We first would like to thank Dr. Lukas Jonkers for taking part in the discussion of our manuscript and for providing valuable comments.

Among the different points addressed by Dr. Jonkers, a great part have already been treated in the reply to the review made by Anonymous Referee 1 (<http://www.clim-past-discuss.net/11/C879/2015/cpd-11-C879-2015.pdf>).

However, we would like to stress again that F-Temp are not interpreted as subsurface absolute reconstructions, but as subsurface relative estimations. In our reply to the review made by Referee 1 we explained why doing so while using the original modern database (with SST extracted at 10 m water depth) is coherent. This was surely not stated clearly enough and not discussed sufficiently in the submitted manuscript, but we are currently fixing that in the revised manuscript.

We also would like to use the present reply as an opportunity to add some additional arguments. Our planktonic foraminifera (PF) -derived data (see additional figure below) are consistent with previous findings also based on PF records from the study area (e.g. Rasmussen et al., 1996a,b, 1997, 1999, 2002a,b, 2004, 2008). Our interpretations are also similar (interstadial faunas related to enhanced flow of Atlantic waters) except that those previous studies did not include dinocyst-derived data, and related the PF-derived features to sea-surface conditions. However, as Dr. Jonkers agrees with, PF are known to inhabit a relatively wide depth range (e.g. Schiebel et al., 2001). Studies dealing with different SST estimates are generally also confronted to discrepancies between SST records, and authors often interpret these discrepancies as the result of differences in depth habitats (e.g. de Vernal et al., 2005, 2006; Penaud et al., 2011) and/or in growth seasons of the related organisms (e.g. Mazaud et al., 2002). We would like to draw a peculiar attention on two of these studies, i.e. de Vernal et al. (2005, 2006), who **compared PF-derived and dinocysts-derived SST reconstructions obtained identically as in our study (i.e. using transfer functions with SST extracted at 10 m water depth in the respective modern databases)**, as well as alkenone-derived SST, during the Last Glacial Maximum (LGM) and in the North Atlantic and adjacent Seas. The authors noted that alkenone and dinocyst-derived SST were similar to each other but different from PF-derived SST. **Such as we do in our study, the authors reconciled the 3 proxies by attributing these discrepancies exclusively to differences in depth habitats.** Given the similarity of our records, we can use similar arguments to the ones they used: (1) **dinocysts are restricted to the euphotic layer whereas PF may live deeper, which is particularly true for the main species composing our PF assemblages which do not bear any symbiont**, and (2) **dinocyst recorded relatively low SSS throughout the last glacial period (mean of 31 and 32 psu for summer and winter SSS respectively), while the PF species identified in our assemblages (cf. figure below) barely tolerate such salinities** (Tolderlund and Bé, 1971).

Besides, de vernal et al. (2005, 2006) stated the existence of a halocline during the LGM to reconcile the low SSS values and high seasonal contrasts stemming from dinocysts and the higher salinities in the mesopelagic layer as evidenced through PF assemblages and isotopic content. The same reasoning can be applied in our case. And as already mentioned in the manuscript, such a pattern is also indicated through the strong dominance of a dinocyst taxa strongly related to stratified surface waters (i.e. *B. tepikiense*).

Then, concerning $\delta^{18}\text{O}_{\text{sw}}$ estimates, as isotopes and foraminiferal counts are made on several specimens from a sediment sample that represents several (tens of) years, we believe that intra- and probably inter-annual variations in growth period and calcification depth are softened. Furthermore, according to Telford et al. (2013) "*For cores north of 25°N, the [paleo]reconstructions from different depths and seasons resemble one another, with an offset*" and winter, summer, spring, autumn and annual F-Temp reconstructed from our PF assemblages provide indeed synchronous and similar variations. Hence, whatever the depth and season considered for the reconstructed F-Temp signal, the reconstructed $\delta^{18}\text{O}_{\text{sw}}$ signal would resemble the one presented in the present manuscript.

Now, concerning changes in calcification depth and season as a function of climate, they are probably inherent to all reconstructions based on PF (including geochemical ones). Concerning changes in seasonality, Jonkers and Kucera (2015) evidenced that warmings as well as coolings always result in underestimation of the amplitude of environmental change in PF records, but they did not mention any reverse environmental change in PF records due to changes in seasonality. Concerning changes in calcification depth, every study dealing with PF-derived reconstructions (MAT, $\delta^{18}\text{O}$, Mg/Ca, ...) assumes, as first postulate, that changes in temperature resulting from changes in calcification depth are largely inferior to changes in temperature resulting from environmental changes (e.g. Peck et al., 2008). In our case, it is very likely that changes in depth accentuated the recorded environmental changes: during stadials the low saline surface layer forces PF to migrate down and thus to record colder temperatures, and during interstadial the reduction of upper stratification enables PF to migrate up and to record warmer temperatures. All of this implies that, despite biases linked to changes in calcification depth and growth season through time, and despite the fact that these biases are probably accentuated because we combined PF assemblages-derived temperatures to PF monospecific $\delta^{18}\text{O}$ measurements, the relative variations of the reconstructed $\delta^{18}\text{O}_{\text{sw}}$ signal are thought to be robust in terms of trends and timings (the only way we discuss them) and similar to the ones we could have obtained using a temperature signal derived from monospecific PF samples (such as Mg/Ca).

Finally, we attach great importance to the other points raised by Dr. Jonkers given his experience and expertise in this field. We are presently working on the revised version of the manuscript, and we will take those comments into account and discuss them in more detail in the revised manuscript.

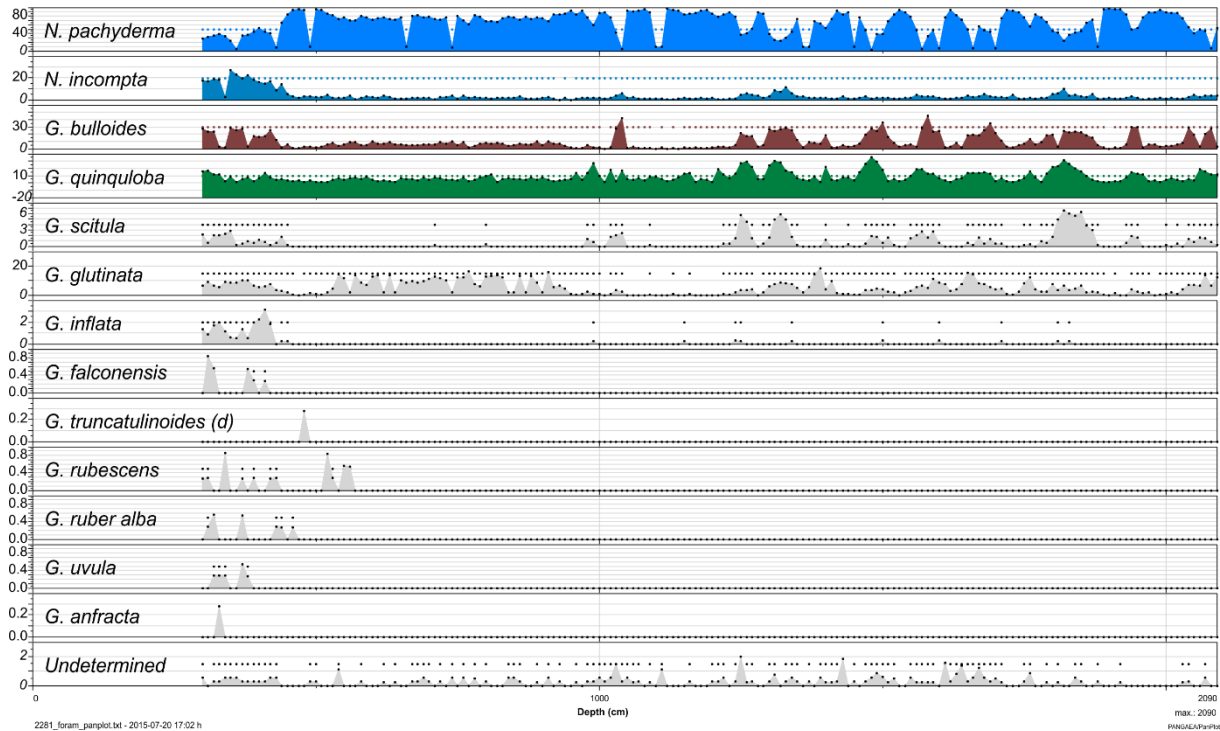


Figure: Planktonic foraminifera relative abundances as a function of depth. All taxa identified in the study core MD99-2281 are represented.

References:

- De Vernal, A., A. Rosell-Melé, M. Kucera, C. Hillaire-Marcel, F. Eynaud, M. Weinelt, T. Dokken, and M. Kageyama (2006), Comparing proxies for the reconstruction of LGM sea-surface conditions in the northern North Atlantic, *Quaternary Science Reviews*, 25(21-22), 2820-2834.
- De Vernal, A., et al. (2005), Reconstruction of sea-surface conditions at middle to high latitudes of the Northern Hemisphere during the Last Glacial Maximum (LGM) based on dinoflagellate cyst assemblages, *Quaternary Science Reviews*, 24(7-9 SPEC. ISS.), 897-924.
- Jonkers, L., and M. Kučera (2015), Global analysis of seasonality in the shell flux of extant planktonic Foraminifera, *Biogeosciences*, 12(7), 2207-2226.
- Mazaud, A., M. A. Sicre, U. Ezat, J. J. Pichon, J. Duprat, C. Laj, C. Kissel, L. Beaufort, E. Michel, and J. L. Turon (2002), Geomagnetic-assisted stratigraphy and sea surface temperature changes in core MD94-103 (Southern Indian Ocean): Possible implications for North-South climatic relationships around H4, *Earth and Planetary Science Letters*, 201(1), 159-170.
- Peck, V. L., I. R. Hall, R. Zahn, and H. Elderfield (2008), Millennial-scale surface and subsurface paleothermometry from the northeast Atlantic, 55-8 ka BP, *Paleoceanography*, 23(3).
- Penaud, A., F. Eynaud, A. Voelker, M. Kageyama, F. Marret, J. L. Turon, D. Blamart, T. Mulder, and L. Rossignol (2011), Assessment of sea surface temperature changes in the Gulf of Cadiz during the last 30 ka: Implications for glacial changes in the regional hydrography, *Biogeosciences*, 8(8), 2295-2316.
- Rasmussen, T. L., and E. Thomsen (2004), The role of the North Atlantic Drift in the millennial timescale glacial climate fluctuations, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 210(1), 101-116.

- Rasmussen, T. L., and E. Thomsen (2008), Warm Atlantic surface water inflow to the Nordic seas 34-10 calibrated ka B.P, *Paleoceanography*, 23(1).
- Rasmussen, T. L., T. C. E. Van Weering, and L. Labeyrie (1997), Climatic instability, ice sheets and ocean dynamics at high northern latitudes during the last glacial period (58-10 KA BP), *Quaternary Science Reviews*, 16(1), 71-80.
- Rasmussen, T. L., E. Thomsen, L. Labeyrie, and T. C. E. Van Weering (1996a), Circulation changes in the Faeroe-Shetland Channel correlating with cold events during the last glacial period (58-10 ka), *Geology*, 24(10), 937-940.
- Rasmussen, T. L., E. Thomsen, T. C. E. Van Weering, and L. Labeyrie (1996b), Rapid changes in surface and deep water conditions at the Faeroe Margin during the last 58,000 years, *Paleoceanography*, 11(6), 757-771.
- Rasmussen, T. L., E. Balbon, E. Thomsen, L. Labeyrie, and T. C. E. Van Weering (1999), Climate records and changes in deep outflow from the Norwegian Sea ~ 150-55 ka, *Terra Nova*, 11(2-3), 61-66.
- Rasmussen, T. L., E. Thomsen, S. R. Troelstra, A. Kuijpers, and M. A. Prins (2002a), Millennial-scale glacial variability versus Holocene stability: Changes in planktic and benthic foraminifera faunas and ocean circulation in the North Atlantic during the last 60 000 years, *Marine Micropaleontology*, 47(1-2), 143-176.
- Rasmussen, T. L., D. Bäckström, J. Heinemeier, D. Klitgaard-Kristensen, P. C. Knutz, A. Kuijpers, S. Lassen, E. Thomsen, S. R. Troelstra, and T. C. E. Van Weering (2002b), The Faeroe-Shetland Gateway: Late Quaternary water mass exchange between the Nordic seas and the northeastern Atlantic, *Marine Geology*, 188(1-2), 165-192.
- Schiebel, R., J. Waniek, M. Bork, and C. Hemleben (2001), Planktic foraminiferal production stimulated by chlorophyll redistribution and entrainment of nutrients, *Deep-Sea Research Part I: Oceanographic Research Papers*, 48(3), 721-740.
- Tolderlund, D. S., and A. W. H. Bé (1971), Seasonal Distribution of Planktonic Foraminifera in the Western North Atlantic, *Micropaleontology*, 17(3), 297-329.