Microscale Alkenone Heterogeneity and Replicability of Ultra-High-Resolution SST Proxies in Laminated Marine Sediments

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Introduction

- Understanding natural climate variability is necessary to predict the plausible range of future climates[1]
- Marine paleoclimate records are too coarse in temporal resolution and show low reproducibility between nearby records[2]
  → either very noisy or stronger local climate variability than expected
- Mass spectrometry imaging (MSI) allows measuring proxies (e.g. $U_{37}^{K'}$ index) at µm scale spatial resolution[3], enabling monthly to annually resolved sea surface temperature (SST) reconstructions in laminated sediments[4]
- Replicates can be used to separate climate- and other variability ("stratigraphic noise", e.g. variation in deposition, etc.)[5] and to estimate an upper limit of the contained climate information per record[6,7]

Study Area

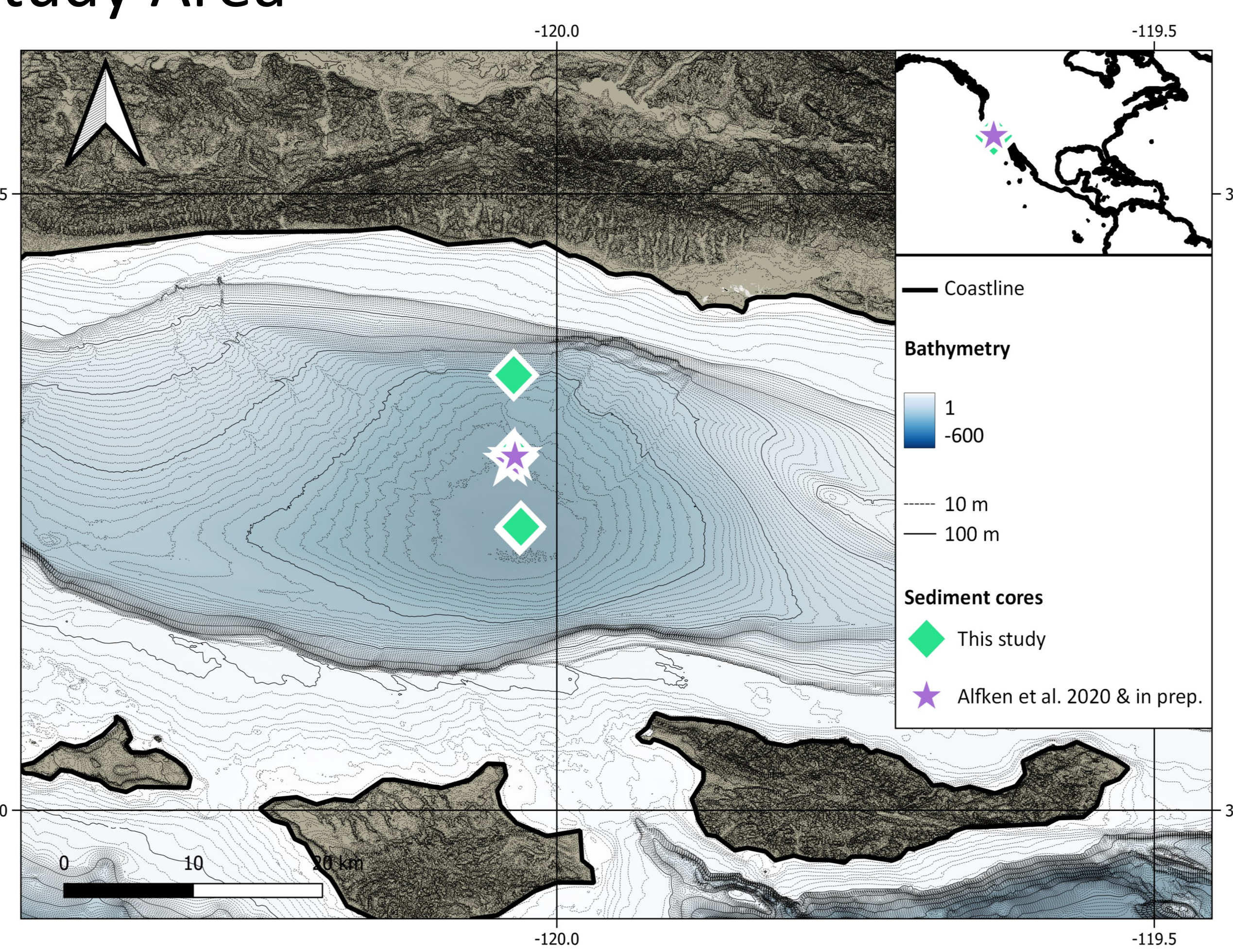


Fig. 1: Map of Santa Barbara Basin, California, USA

Workflow

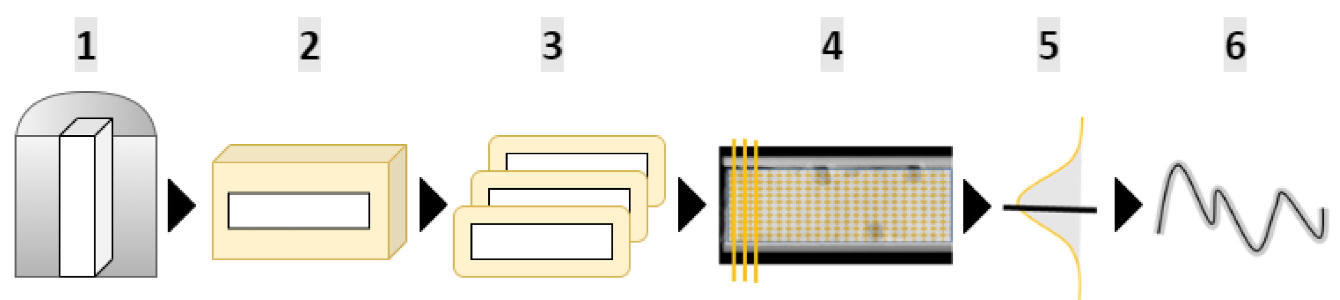


Fig. 2: Measurement workflow[8]:

1) Subsampling, Xrays, linescans and XRF scans

2) 5cm piecewise freeze drying, embedding

3) Thin sediment slices (60-100µm)

4) 2D µXRF (50µm res.), LDI-FT-ICR-MS (MSI) (100µm-200µm res.)

5) Spatial analyses and aggregation from 2D scans to depth/ time series

6) Time series analyses, time scale dependent replicability

Spatial Heterogeneity

- Spotwise $U_{37}^{K'}$ values show strong variation even within undisturbed horizons

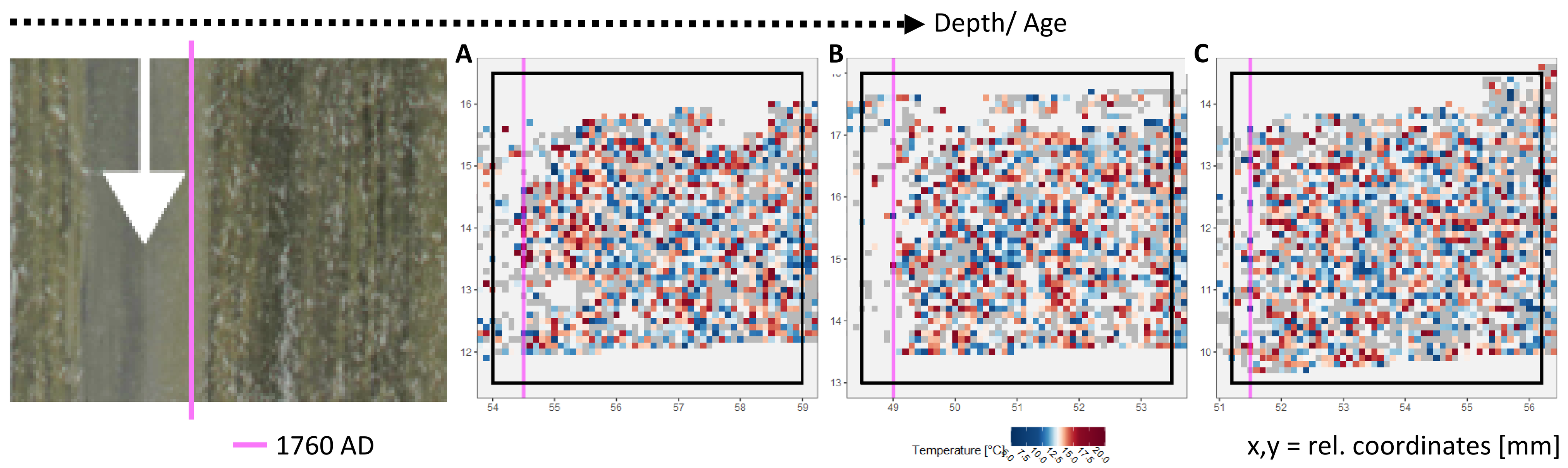


Fig. 3: Zooms of replicated (A, B, C) spotwise $U_{37}^{K'}$ measurements below a 1760 AD floodlayer (5x5mm, core MV1012-001KC)

Detecting climate in noisy biomarker maps

- Variation **within horizons** contains intrinsic, **baseline noise** due to production, deposition, measurement, ….
  Variation **across depth** contains baseline **noise + climate** variation
- Variograms can help to detect spatial patterns and directional differences
  Separated into vertical and horizontal variation (10° tolerance, 200µm bins)
- Biomarker (indiv. Alkenones, Pyropheophorbide α, spotwise $U_{37}^{K'}$) show most similarity over the near <~0,5mm range (*clustering*)
- Pyropheophorbide α (primary productivity) shows clearest signal (most abundant, highest intensities), alkenones noisy
- Variation over depth is higher than within horizons (noise + added climate variation)
  In ideal conditions seasonal (dis)similarity patterns can be visible
  Variation within horizons increase more slowly with distance (= more similar within horizons vs. across depth)

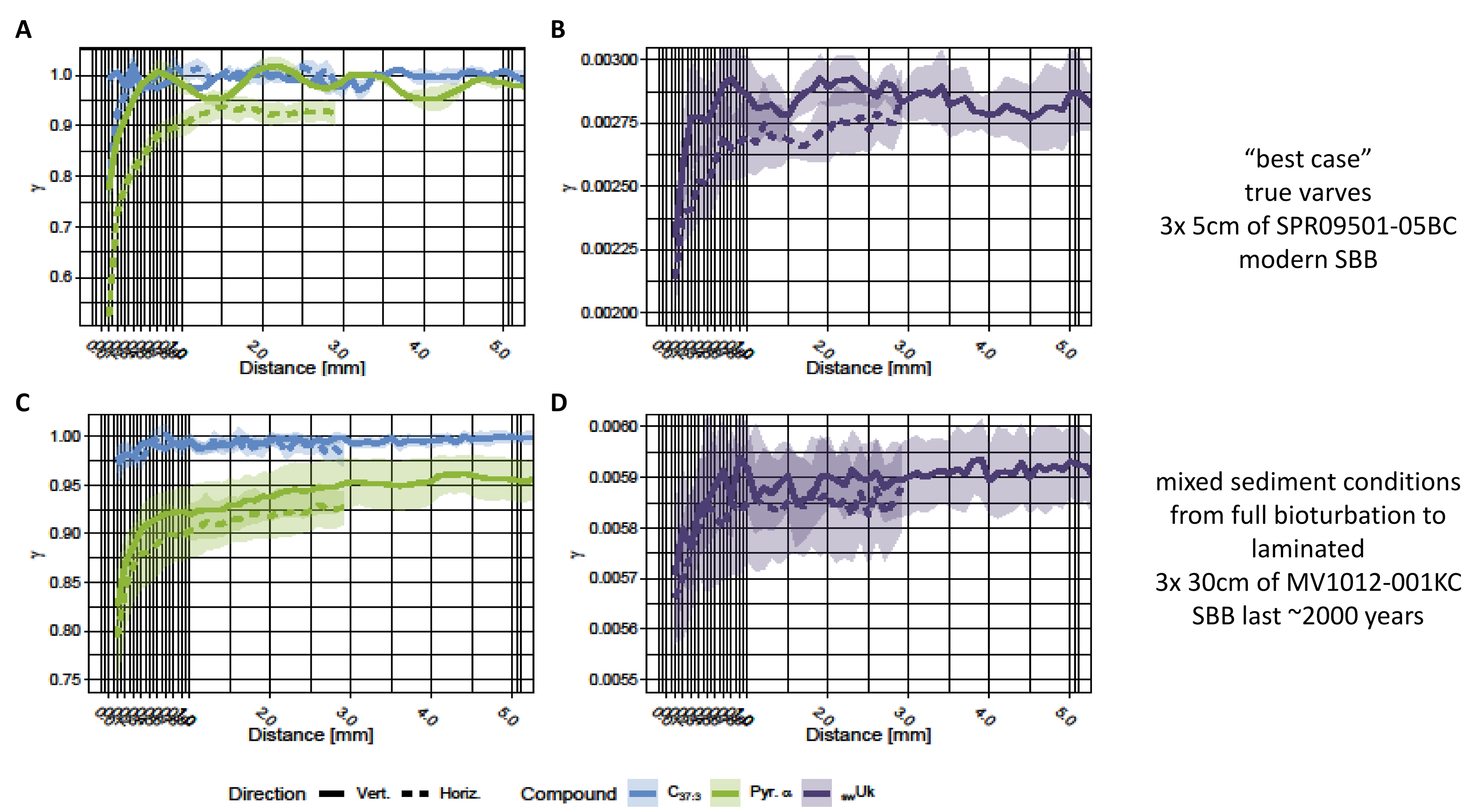
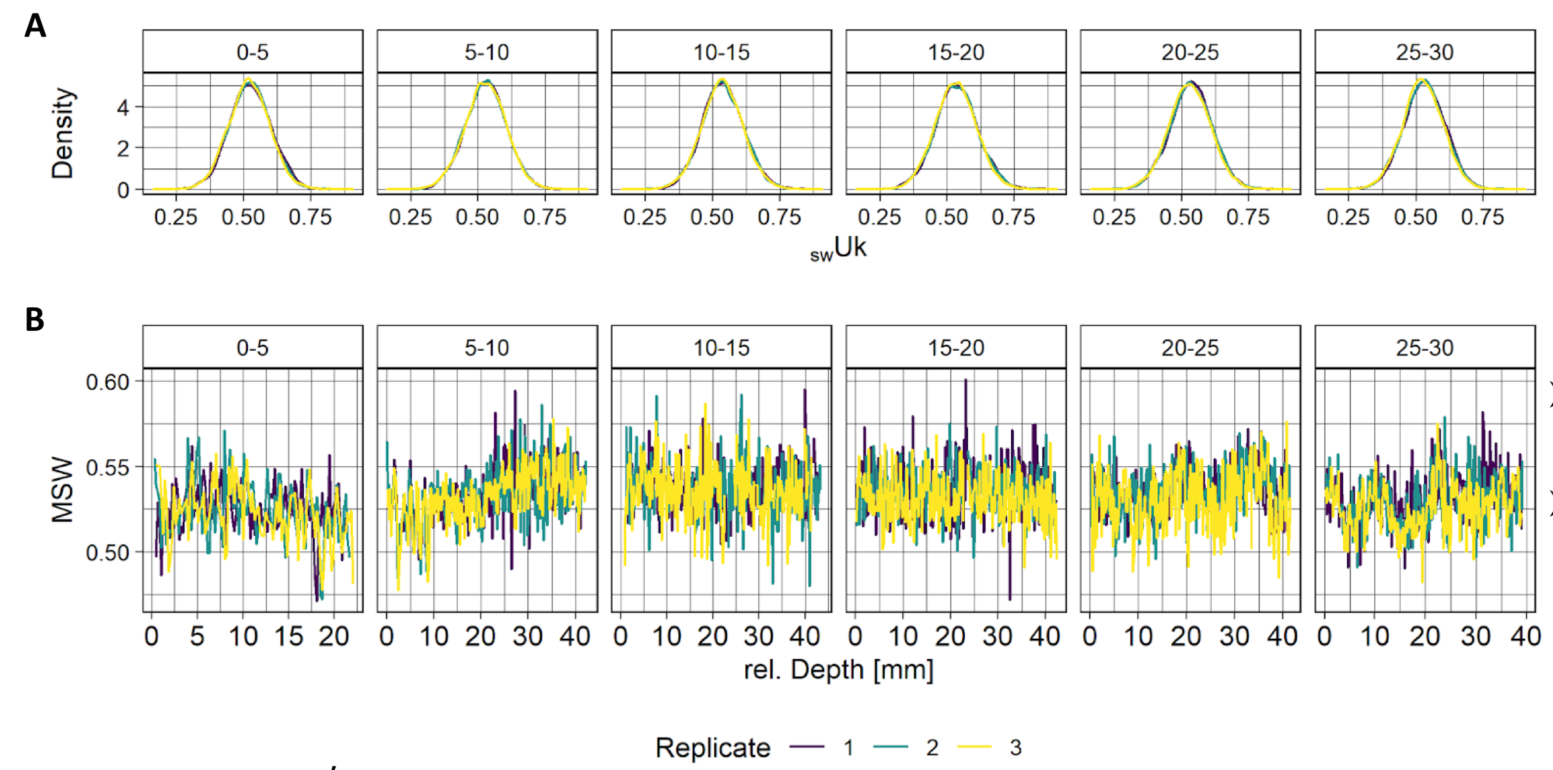


Fig. 4: Variograms of biomarkers (A, C) and spotwise $U_{37}^{K'}$ (B, D) for replicates of perfectly varved conditions (A, B) and sediment conditions ranging from fully bioturbated to well preserved laminae, representative of the conditions of the last 2000 years (potentially up to late Pleistocene[9])

Replicability



- High analytical precision between pooled replicates (no spatial information)
- Time series disagree at fast time scales (aggregation of spatial data to time series)
- (Independent) noise contributions and distortions + common climate signal between replicates

Fig. 5: Spotwise $U_{37}^{K'}$ values for segments 0 – 30 rel. cm of MV1012-001KC. 3x replicates per depth interval, as density distribution (A) and aggregated to time series (B).

Proxy series signal content

- Separating shared signal and independent noise[7,10] between replicates yields SNRs close to 0 for fully bioturbated and around 3 for varved sections
- The degree of bioturbation clearly determines SNR, where laminated sections of lower SBB can reach SNRs close to the "best case" varves

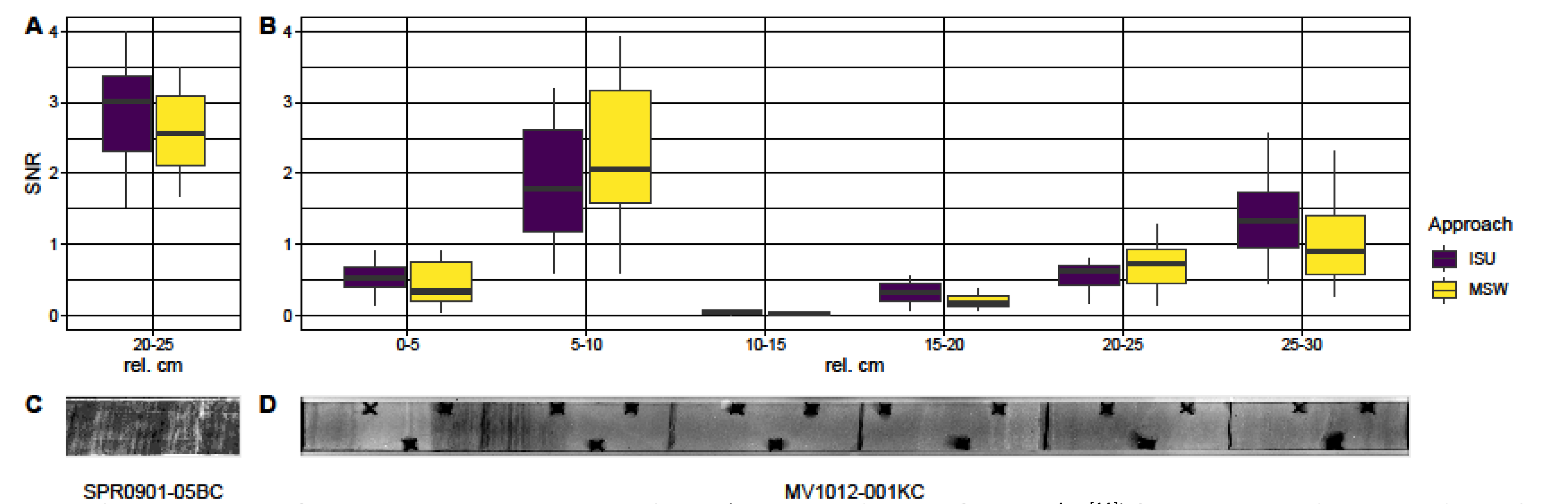


Fig. 6: Signal to noise ratios of time series at 0.2-1.4 mm resolution (average sed. rates of 1.4mm/yr [11]) from varying sediment conditions based on two different aggregation methods ("individual sum" ISU & "mean spotwise" MSW). SNRs (A) and Xray (C) for a "best case" varved example and for 30 cm of varying degrees of bioturbation, representative for common era SBB sediments (B & D).

Conclusion

- Biomarkers (Alkenones, Pyropheorbide α, $U_{37}^{K'}$ proxy) show strong heterogeneity at 100µm scales and within presumed homogenous horizons
- Despite the strong noise, directional differences can be detected with longer similarity ranges within the direction of horizons and stronger variations over depth, indicative of climate signal
- Undisturbed sections can be detected by characteristic (seasonal) variation over depth
- Aggregation methods from 2D spatial to 1D temporal data need to account for noisiness and nonuniform spatial distribution of the signals
- Replicated measurements show strong influence of sediment conditions and bioturbation on the signal content of individual high-res. time series
- For high-resolution time series (0.2-1.4mm steps, ~annual res.) SNRs range from close to 0 in known mixed, "grey layers" and reaching ~3 for well laminated sections representative of the varying conditions throughout lower SBB sediment sequences, almost paralleling the SNRs for modern "best case" varved end members, stronger temporal aggregation further increases SNR
- MSI derived high-resolution time series show high potential for reconstructing SST variability over the common era of SBB

References

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