

Supplement of *Clim. Past*, 14, 1625–1637, 2018
<https://doi.org/10.5194/cp-14-1625-2018-supplement>
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Supplement of

Burning-derived vanillic acid in an Arctic ice core from Tunu, northeastern Greenland

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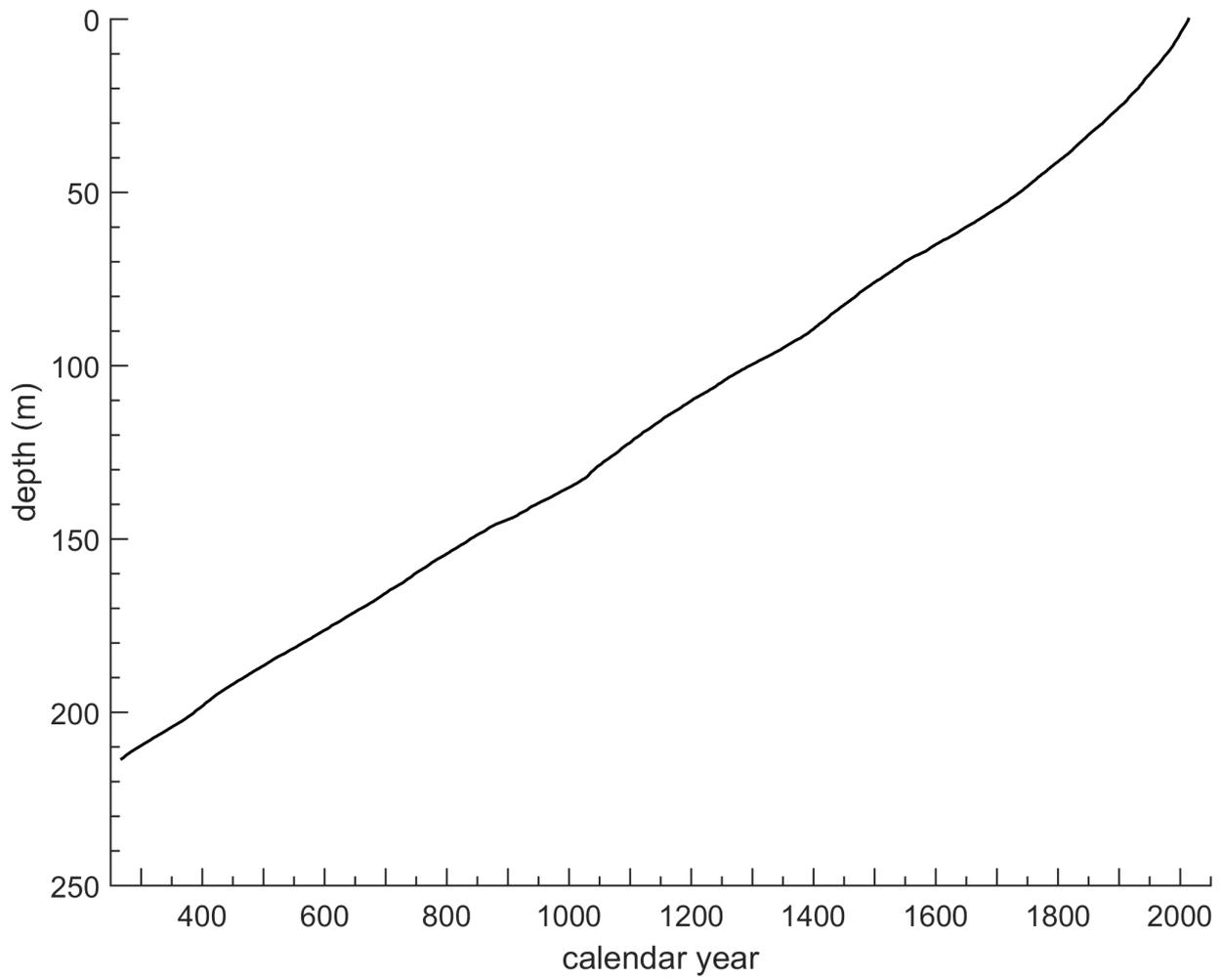


Figure S1. Tunu ice core depth-age scale.

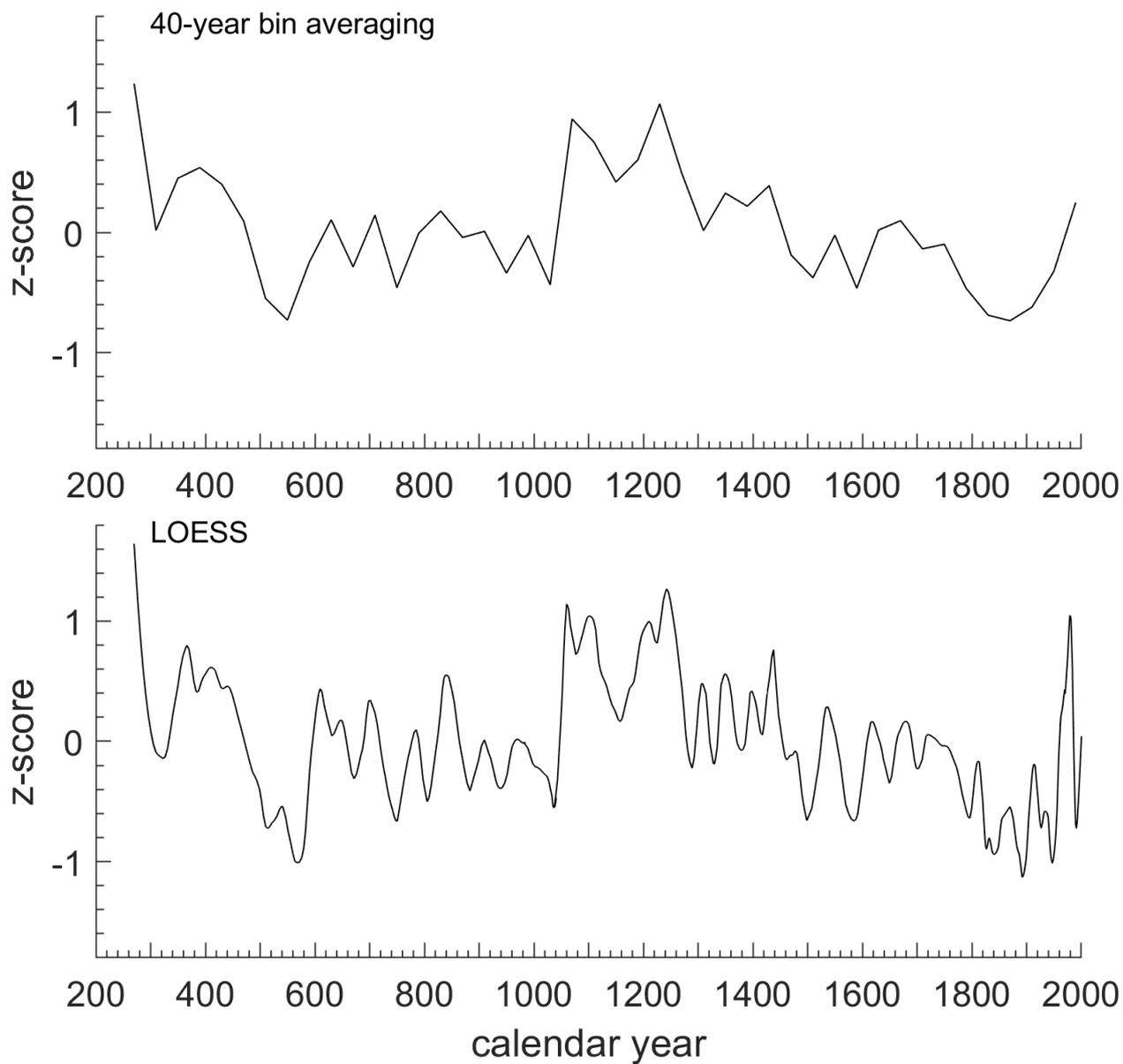


Figure S2. Tunu vanillic acid (top) using 40-year bin averaging (top) and LOESS smoothing (span = 0.04) (bottom) of the log transform. Data were normalized using the mini-max transformation and the z-score.

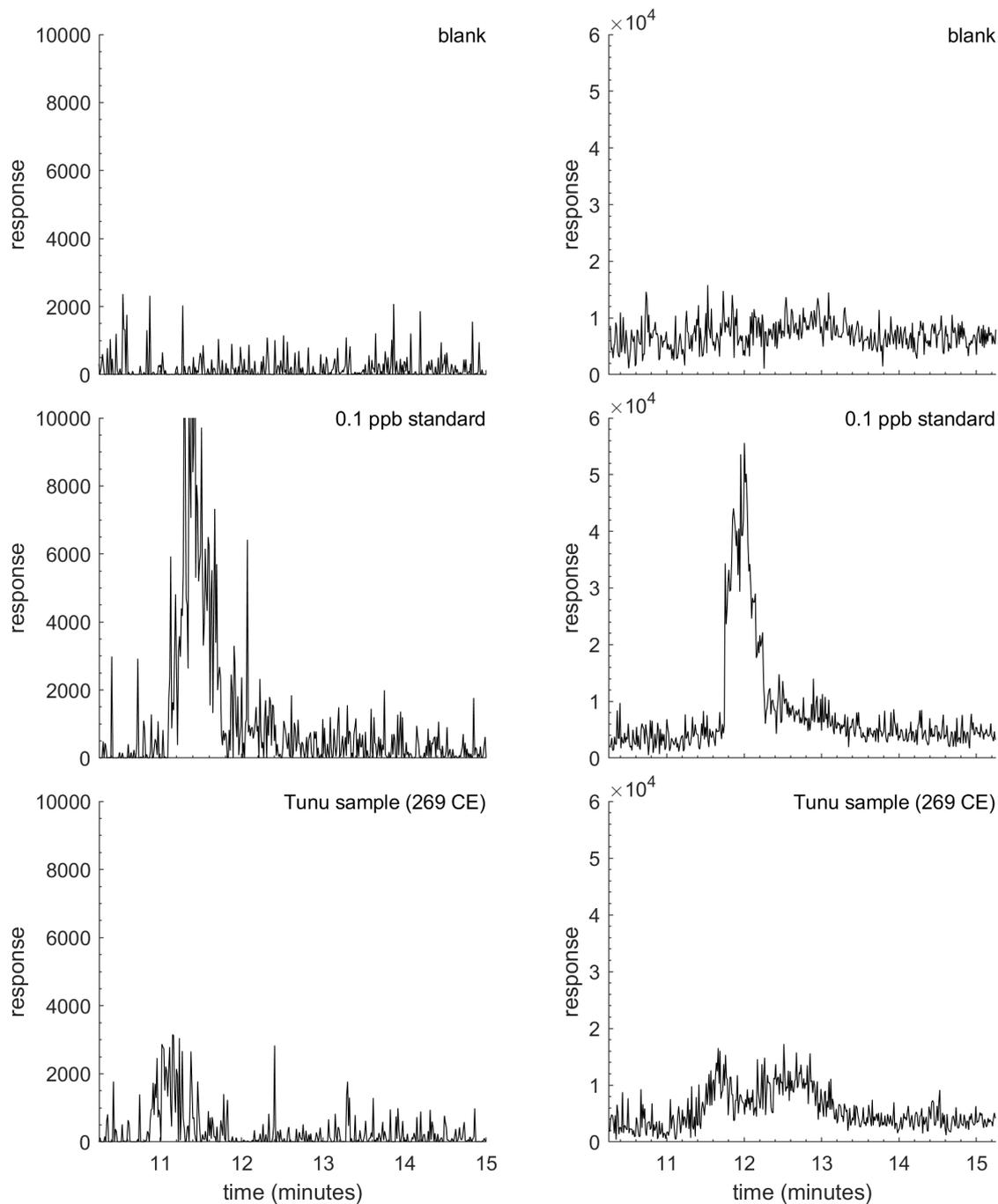


Figure S3. Vanillic (mass transition 167→108; left column) and p-hydroxybenzoic acid (mass transition 137→93; right column) analysis using anion-exchange chromatography and electrospray tandem mass spectrometry. From top: MillQ water blank, 0.5 ppb standard, Tunu ice core sample dated as 269 CE. Note that an additional peak appears after p-hydroxybenzoic acid at the 137→93 mass transition indicating the presence of an unknown interferent.

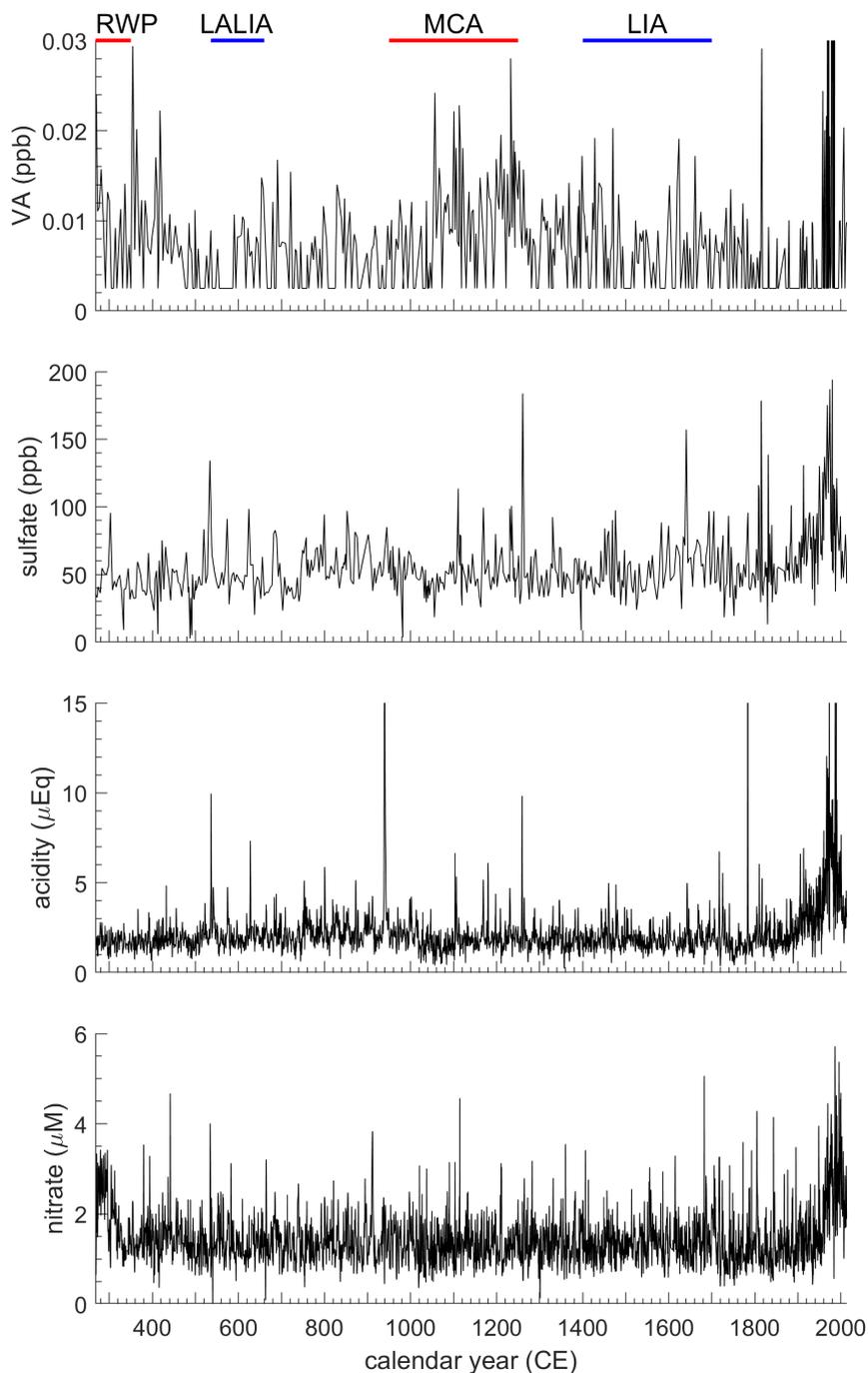


Figure S4. Relationship between Tunu vanillic acid, para-hydroxybenzoic acid, sulfate, acidity, and nitrate. Vanillic acid and sulfate were measured using the method described in the manuscript. Acidity and nitrate were measured at the Desert Research Institute (McConnell, 2016). The black horizontal lines are the Roman Warm Period (RWP), the Late Antique Little Ice Age (LALIA), the Medieval Climate Anomaly (MCA), and the Little Ice Age (LIA) (Büntgen et al., 2016; Mann et al., 2009; Wang et al., 2012).

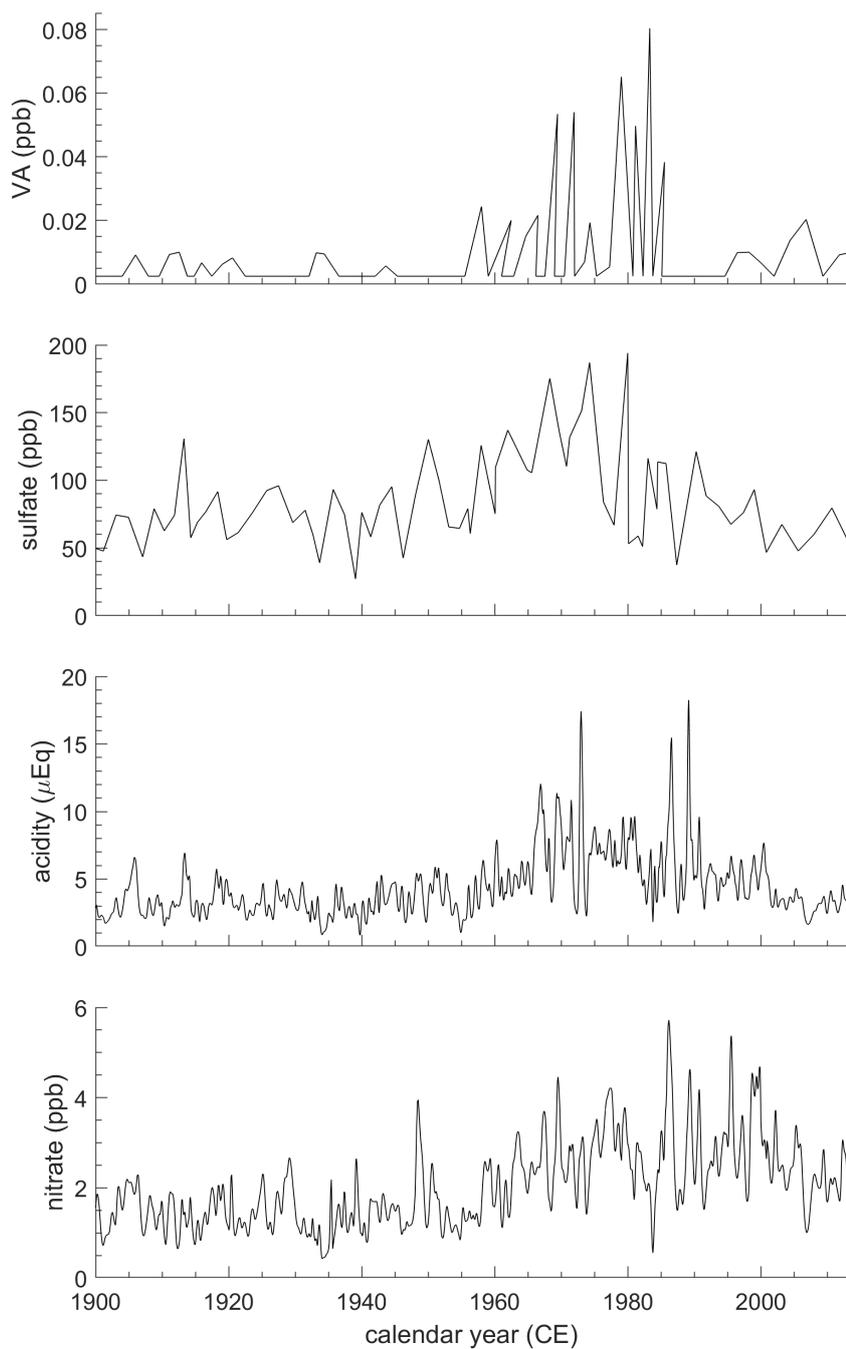


Figure S5. Relationship between Tunu vanillic acid, para-hydroxybenzoic acid, sulfate, acidity, and nitrate in the 20th century. Vanillic acid and sulfate were measured using the method described in the manuscript. Acidity and nitrate were measured at the Desert Research Institute (McConnell, 2016).

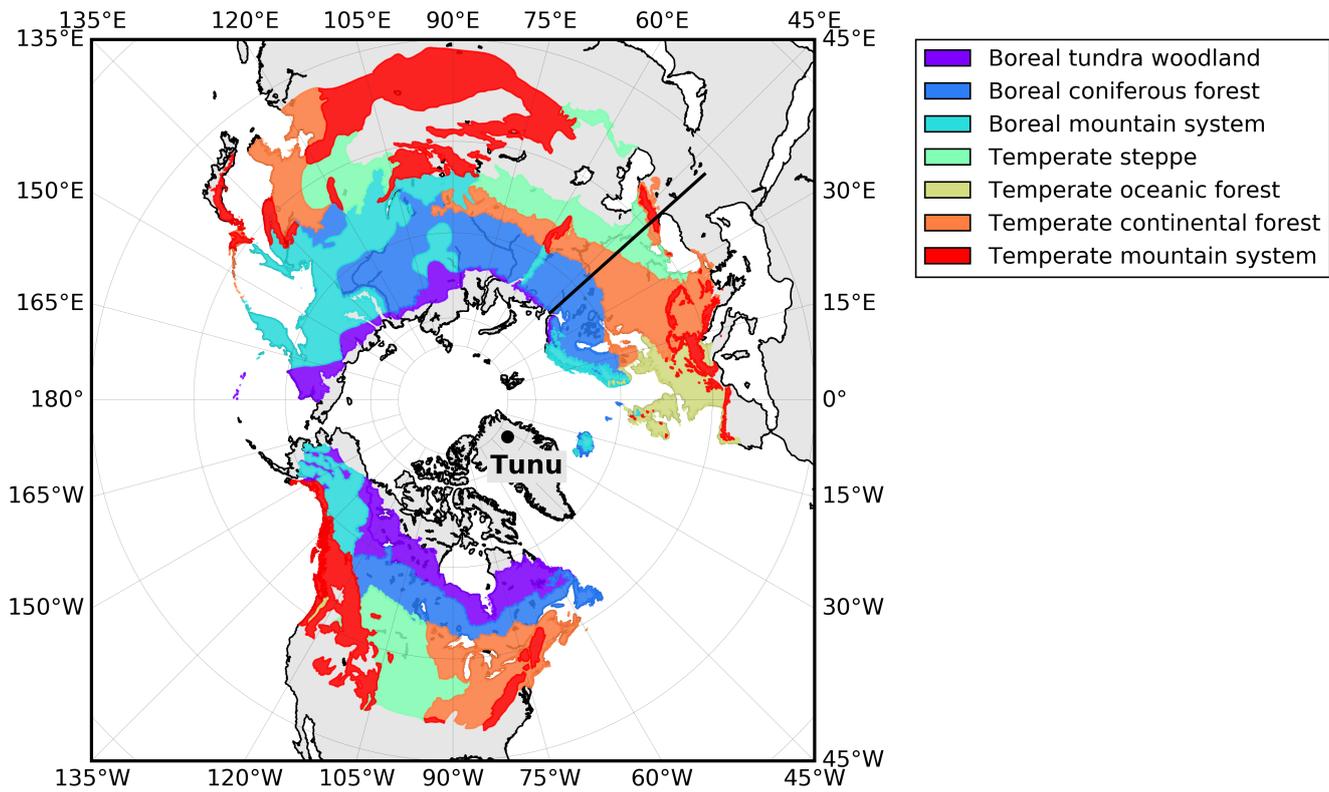


Figure S6. Ecofloristic zone classifications of the Food and Agriculture Organization (http://cdiac.ornl.gov/epubs/ndp/global_carbon/carbon_documentation.html; Ruesch and Gibbs, 2008).

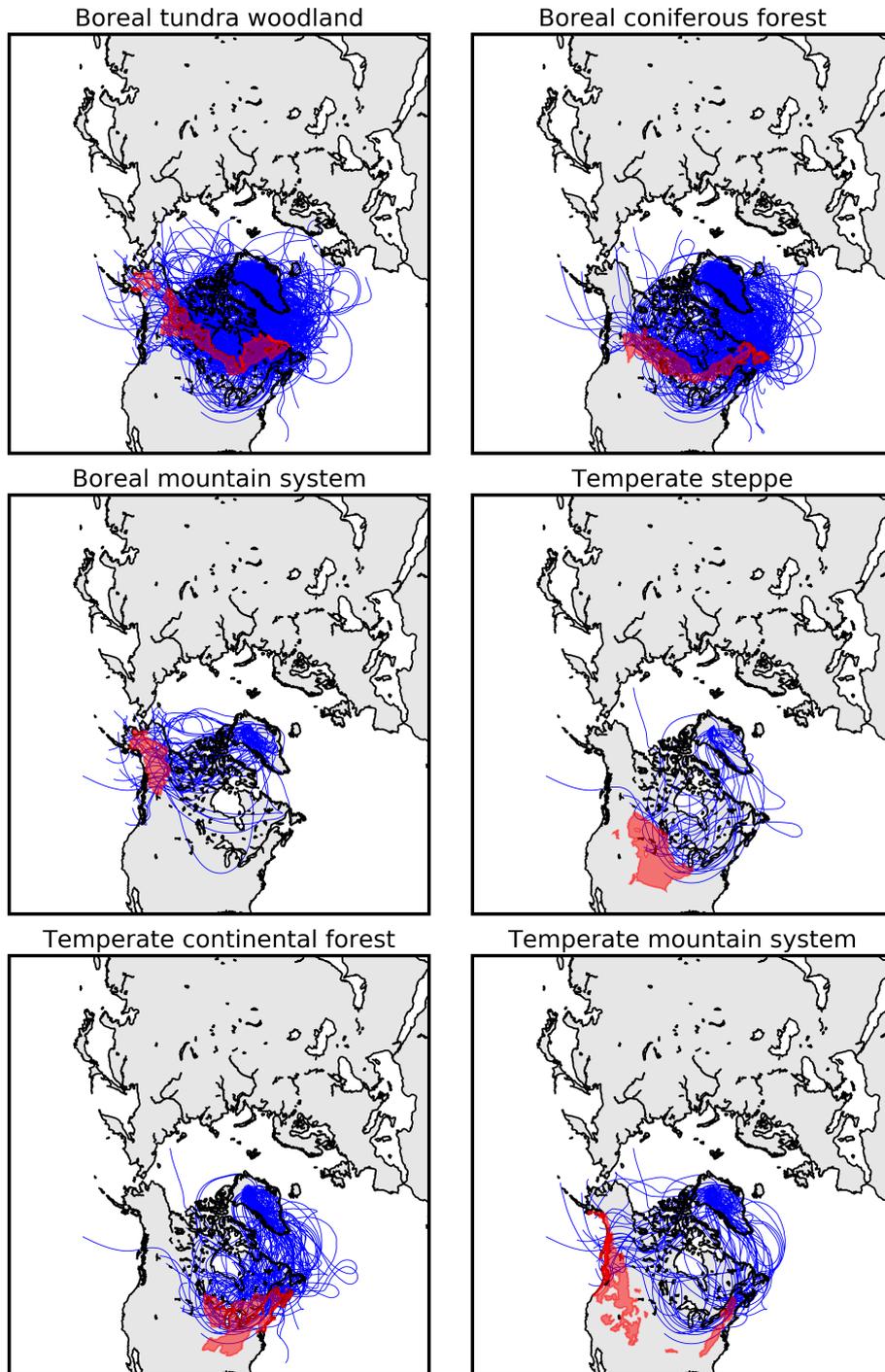


Figure S7. Back trajectories that transect North American ecoregions. Blue lines are back trajectories crossing over the labeled ecoregions from March-November 2006-2015. Ecoregions are the red areas.

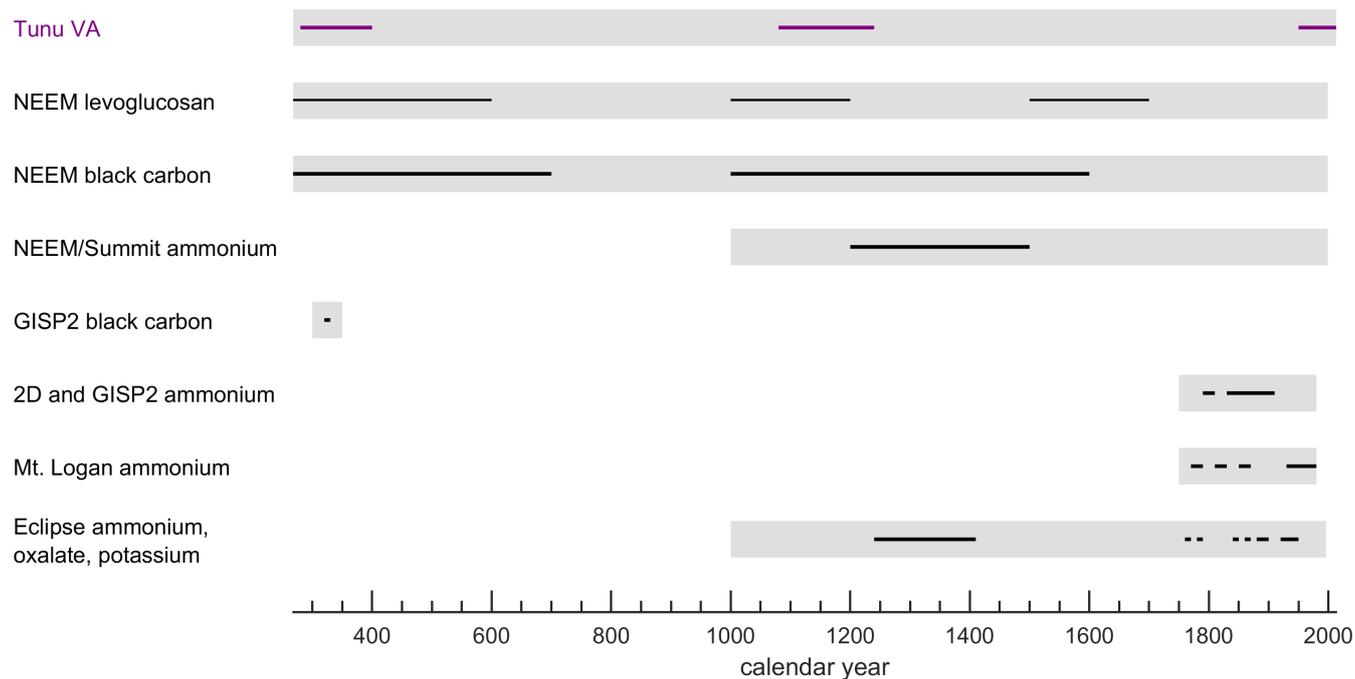


Figure S8. Timeline of elevated biomass burning periods in Greenland and Canadian ice core records. From Top: Tunu vanillic acid (VA); NEEM levoglucosan and black carbon (Zennaro et al., 2014); NEEM and Summit ammonium (Legrand et al., 2016); GISP2 black carbon (Chýlek et al., 1995); 2D, GISP2, and Mt. Logan ammonium (Whitlow et al., 1994); Eclipse ammonium, oxalate, and potassium (Yalcin et al., 2006). Lines are elevated biomass burning periods. Gray areas are the time periods analyzed in ice core.

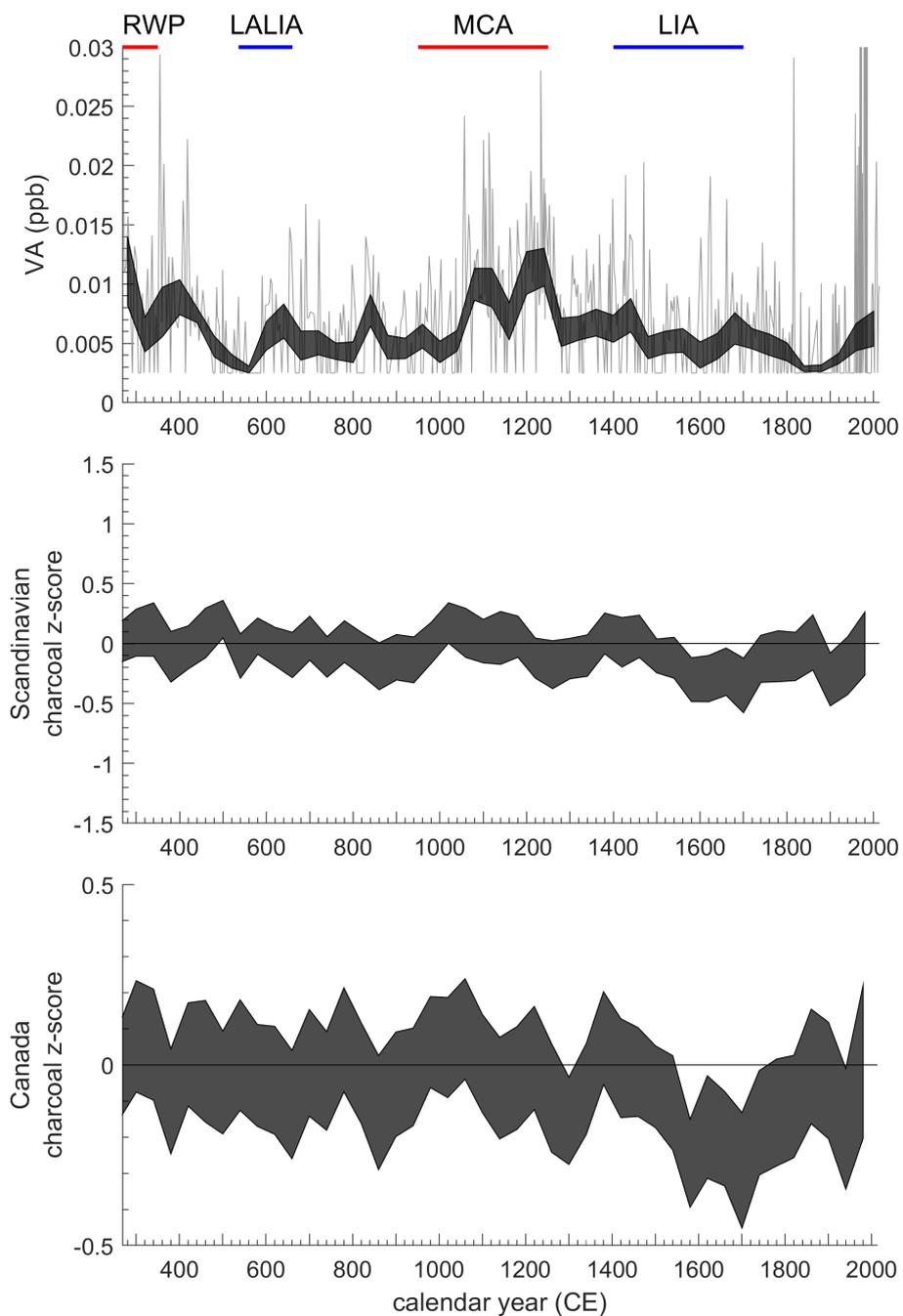


Figure S9. Comparison between Tunu vanillic acid (VA) and charcoal records. Tunu VA (Top): the gray filled lines are ± 1 standards errors of the 40-year bin averages of the data. Composites of 19 charcoal records from Scandinavia (middle, 50° - 70° N, 0° - 40° E) and 179 charcoal records from Canada (bottom, 40° - 70° N, 10° - 160° W). The gray filled lines are the 95% confidence intervals.

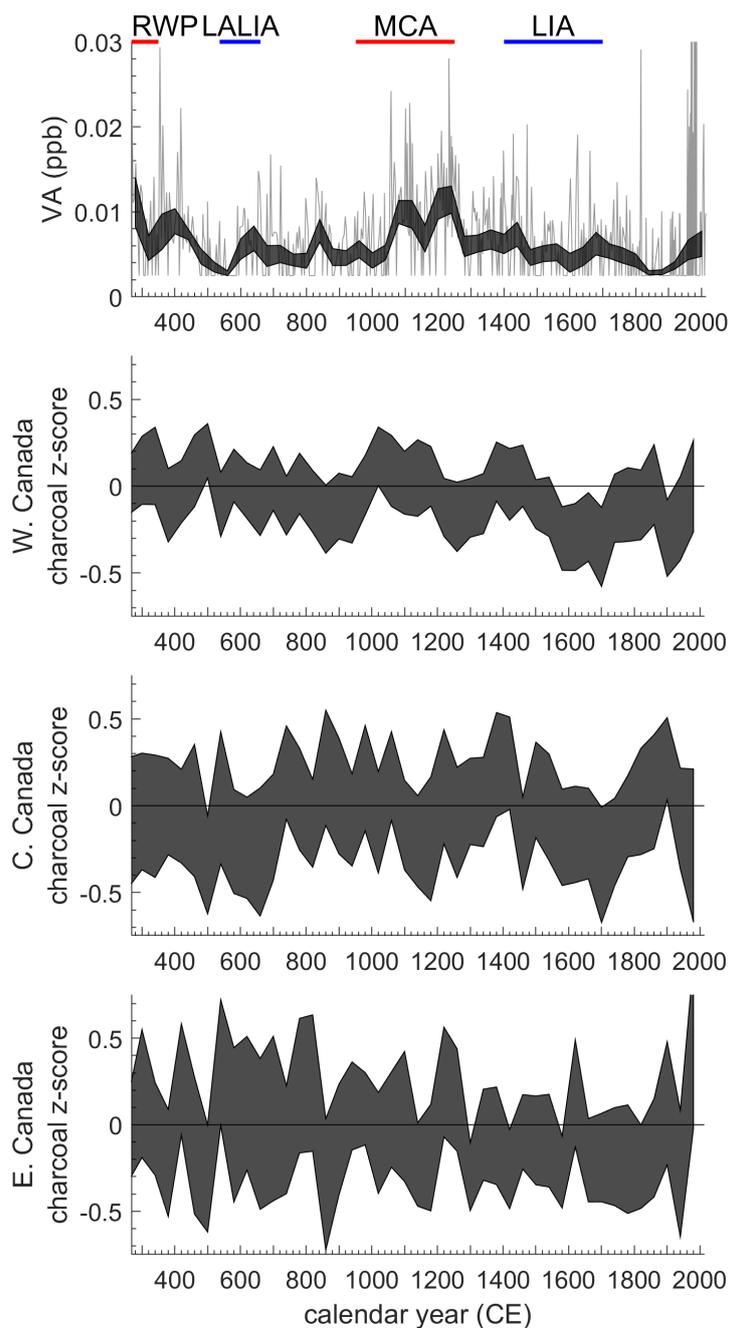


Figure S10. Comparison between Tunu vanillic acid (VA) and regional Canadian charcoal records. Tunu VA (Top): the gray filled lines are ± 1 standards errors of the 40-year bin averages of the data. From top: 77 charcoal records from western Canada (40° - 80° N, 110° - 180° W), 34 charcoal records from central Canada (40° - 80° N, 80° - 110° W), and 60 charcoal records from eastern Canada (40° - 80° N, 10° - 10° W). The gray filled lines are the 95% confidence intervals.

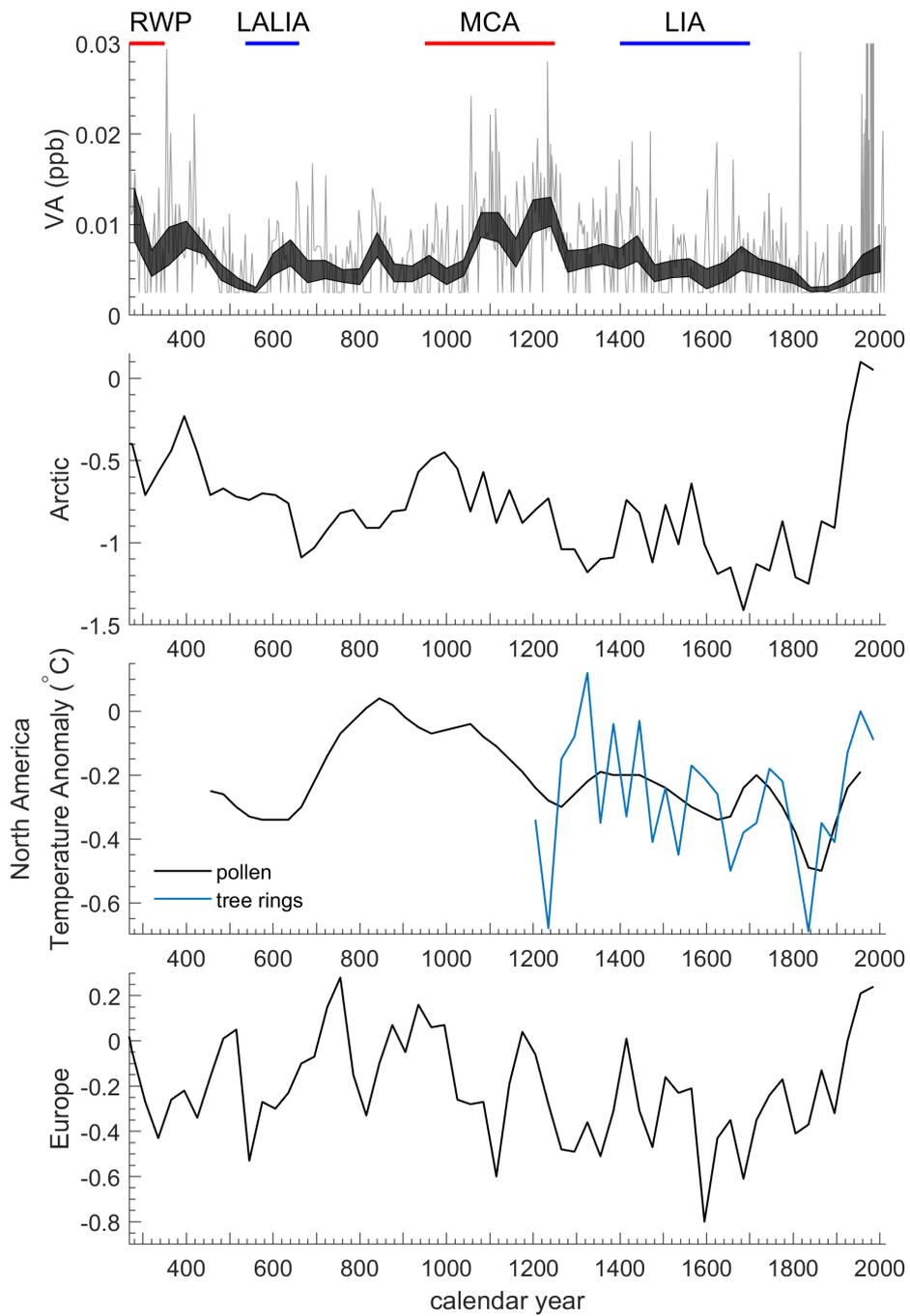


Figure S11. Comparison between Tunu vanillic acid (VA) and regional temperature records. Tunu VA (Top): the gray filled lines are ± 1 standards errors of the 40-year bin averages of the data. From top: 30-year-averaged Arctic, North American, and European temperature anomalies (Pages2k, 2013).

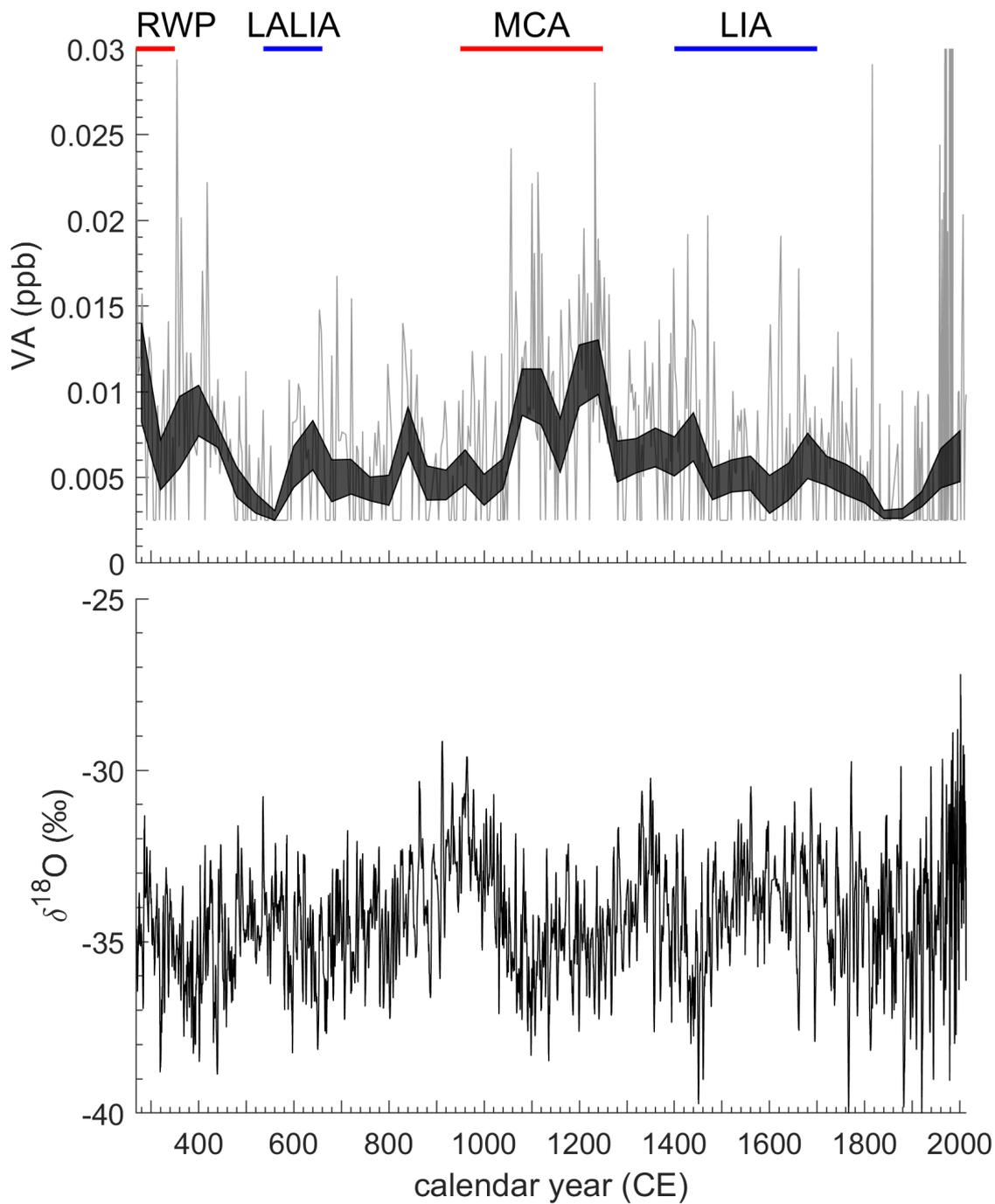


Figure S12. Comparison between Tunu vanillic acid (VA) and Tunu $\delta^{18}\text{O}$ (McConnell, 2016). VA: Top: the gray filled lines are ± 1 standard errors of the 40-year bin averages of the data.

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