The carbon cycle over the last 1000 years inferred from inversion of ice core data

Submitted for the degree of Doctor of Philosophy

by

Catherine Mary Trudinger, B.Sc. (Hons)

CRC for Southern Hemisphere Meteorology

Department of Mathematics and Statistics

Monash University

Australia

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Contents

Abstract

A new record of CO_2 and $\delta^{13}CO_2$ over the last 1000 years from air trapped in Antarctic ice is analysed. The ice core record, from Law Dome in Antarctica, has high time resolution and high precision, and overlaps the modern CO_2 record. A model of diffusion and bubble trapping in firn is developed and used to interpret the ice core measurements in terms of past atmospheric changes. The firn model quantifies the smoothing effects of diffusion and bubble trapping on atmospheric signals. A method for correcting firn and ice core $\delta^{13}C$ measurements for the fractionating effects of the firn diffusion process on different isotopes is developed and applied. The Law Dome ice core record is compared with other firn $\delta^{13}C$ records.

A 1-D global carbon cycle model is used to interpret variations in CO_2 and $\delta^{13}C$ in terms of natural and anthropogenic sources and sinks. A major feature in the ice core record is the decrease in CO_2, and increase in $\delta^{13}C$, through the 'Little Ice Age' period (roughly 1550–1800). Model calculations indicate that the observed decrease in CO_2 is consistent with either terrestrial or oceanic exchange, however the increase in $\delta^{13}C$ favours a terrestrial response to cooling and argues against an oceanic sink.

A new double deconvolution method using the Kalman filter is developed and applied to the Law Dome record. The method incorporates statistics into the carbon cycle modelling, and allows more detailed analysis of CO_2, $\delta^{13}C$ and flux variability. It removes the need to fit smoothing splines to the ice core measurements prior to interpretation. A particular advantage of the method is that uncertainties on the deduced fluxes are estimated as part of the calculation.

The double deconvolution calculation suggests that natural variability in CO_2 fluxes may be as large as 1 GtC y^{-1} on the time scale of just less than a decade. The Law Dome CO_2 measurements show a slight decrease in CO_2 around the 1940s. The firn and carbon cycle models suggest that about 3 GtC y^{-1} uptake (mostly oceanic) is required in the 1940s to match the ice core measurements. The estimates of variation in the terrestrial biospheric flux between 1950 and 1980 from the double deconvolution calculation are in very good agreement with estimates of the global terrestrial flux from a climate-driven ecosystem model of Dai and Fung (1993). A detailed comparison of estimates of the isotopic disequilibrium flux (isoflux) for ^{13}C is given.

This is to certify that this thesis contains no material that has been accepted for the award of any other degree or diploma in any university or other institution and that, to the best of my knowledge, it contains no material previously published or written by another person, except where due reference is made in the thesis.

Catherine Trudinger

Publications arising from and associated with this work:-

Trudinger, C.M., I.G. Enting, D.M. Etheridge, R.J. Francey, V.A. Levchenko, L.P. Steele, D. Raynaud and L. Arnaud, Modeling diffusion and bubble trapping in firn. *J. Geophys. Res., 102D,* p 6747-6763, 1997.

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Levchenko, V.A., D.M. Etheridge, R.J. Francey, C. Trudinger, C. Tuniz, E.M. Lawson, A.M. Smith, G.E. Jacobson, Q. Hua, M.A.C. Hotchkis, D. Fink, V. Morgan and J. Head. Measurements of the $^{14}CO_2$ bomb pulse in firn and ice at Law Dome, Antarctica, *Nucl. Instr. and Meth. Phys. Res. B., 123,* p 290-295, 1997.

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Rayner, P.J., R. Giering, T. Kaminski, R. Ménard, R. Todling and C.M. Trudinger, Exercises, in *Inverse Methods in Global Biogeochemical Cycles*, edited by P. Kasibhatla, M. Heimann, P. Rayner, N. Mahowald, R. Prinn and D. Hartley, American Geophysical Union Monograph 114, p 81-106, 2000.

For my father, Wal Trudinger

in loving memory

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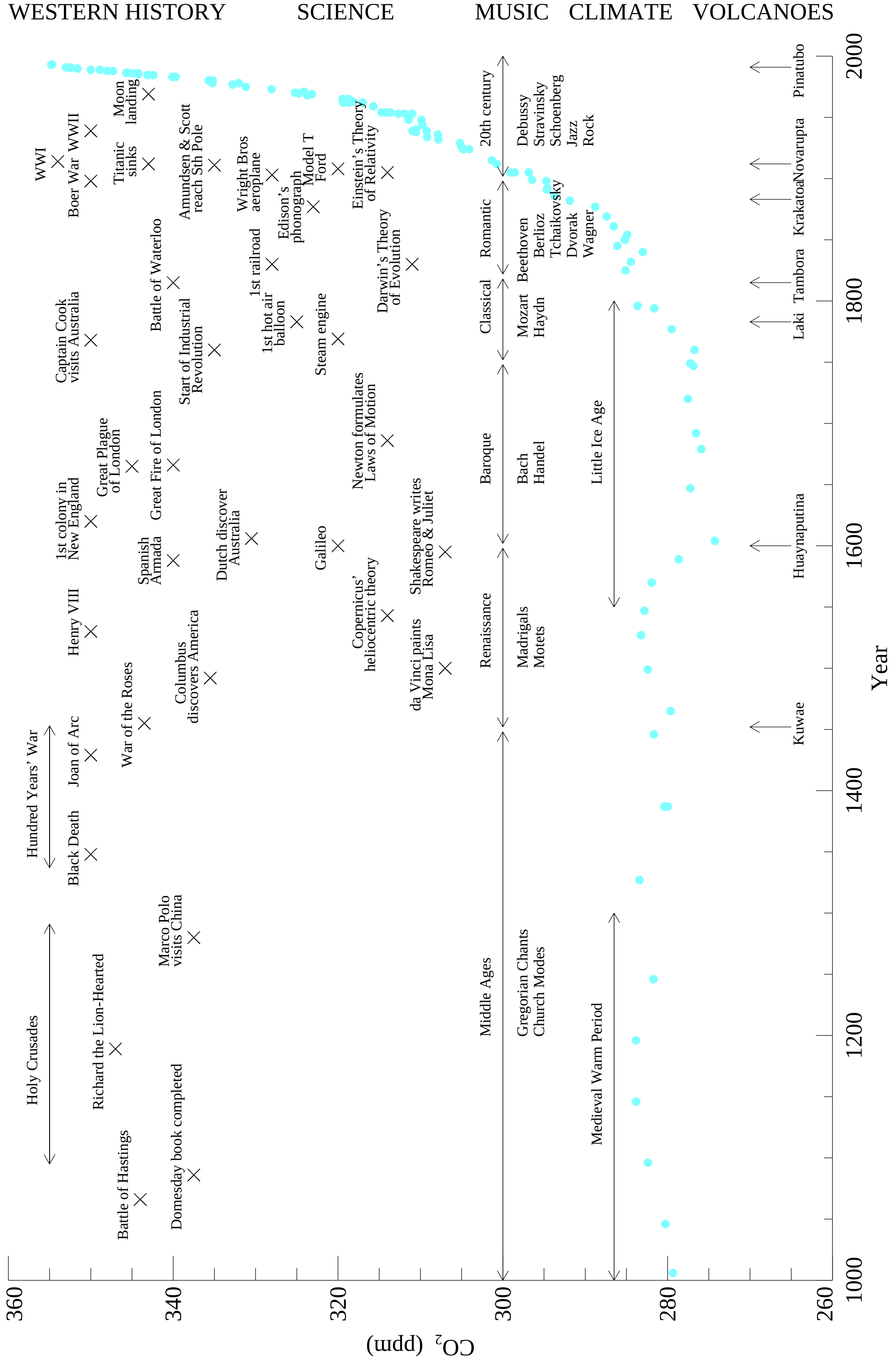

Figure 1: Law Dome CO_2 ice core record (grey dots) and selected events from the second millennium AD