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Supplementary Material

CSIRO High-precision Measurement of Atmospheric CO_2 Concentration in Australia.

Part 1: Initial Motivation, Techniques and Aircraft Sampling

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Introduction

Table S1. Summary of key international CO_2 measurement programmes. This is not a complete list of contributors but summarizes the earlier and more sustained programmes. For more detail and for the global flask sampling network, see Pearman (1980), the Reports of the Global Atmospheric Watch (e.g. WMO, 1991, 1993) and the international CO_2 data archives (Carbon dioxide Information Analysis Center; http://mercury.ornl.gov/cdiacnew/: World Data Centre for Greenhouse Gases; http://ds.data.jma.go.jp/gmd/wdcgg/).

Nation	Location		Start date	Selected references
Australia	Cape Grim	145°E 41°S	1976	Beardsmore and others (1984)
	Macquarie Is.	159°E 54°S	1979	Beardsmore and others (1984)
	Mawson	61°E 68°S	1977	Beardsmore, Pearman, O'Brien. (1984)
	South-west Pacific		1972	Garratt and Pearman (1973); Pearman and Garratt (1973);Pearman and Beardsmore (1977); Beardsmore and others (1978)
Canada	Alert	62°W 82°N	1975	Wong (1984)
	Sable Is.	60°W 44°N	1975	Wong (1984)
	Weather ship P	145°W 50°N	1969	Wong (1984)
France	Amsterdam Is.	78°E 38°S	1980	Gaudry, Ascensio, Lambert. (1983); Ascensio-Parvy, Gaudry, Lambert (1984)
Germany	Schauinsland	8°E 48°N	1967	Levin, Graul and Trivett (1995)
Italy	Mt. Cimone	11°E 44°N	1978	Ciattaglia (1983); Ciattaglia, Cundari, Colombo (1987)
Japan	Syowa	40°E 69°S	1984	Tanaka, Nakazawa, Aoki (1983); Tanaka and others (1987)
	North-west Pacific		1978	Nakazawa and others (1991)
New Zealand	Baring Head	175°E 41°S	1972	Lowe (1974); Lowe, Guenther, Keeling (1979)
Sweden	North Atlantic		1961	Bischof (1865, 1971, 1973, 1975)
USA	Mauna Loa	156°W 20°N	1960	Pales and Keeling (1965); Keeling and others. (1976a); Peterson and others (1977)
	Barrow, Alaska	157°W 71°E	1961	Kelly (1969); Peterson and others (1982)
	South Pole	90°S	1957	Bronn and Keeling (1965); Keeling and others (1976b)
	Samoa		1973	Komhyr and others (1985)

CO_2 Concentration Measurements over Crops and Forests in Australia—Post 1970

Main Results (Aerodynamic Method)

The vertical transfer of CO_2 above a crop occurs primarily through the action of turbulence, with the vertical flux given by (e.g. Webb *et al*. 1980 – their Eqs. 15 and 16)

$$F_c = \overline{w\rho_c} \tag{1}$$

where w and ρ_c are the instantaneous vertical velocity and CO_2 density respectively. Here the overbar represents a time average (usually 0.5 to 1 h). This is the true surface flux, and to a high degree of approximation can be written as

$$F_c/\rho_a = \overline{w'c'} \tag{2}$$

where ρ_a is the mean density of dry air, the variable c is the CO_2 concentration or mass mixing ratio (see below) and the primed quantities are fluctuations from their mean

In the early 1970s the eddy covariance in Eq.2 could not be measured and so a flux-gradient relationship valid in the surface layer was used. In modern terminology this can be written using the Monin-Obukhov similarity theory (e.g. see Garratt 1994, Chapter 3). For steady-state and horizontally homogeneous conditions the vertical flux, F_s, of a property s is related to its vertical gradient via

$$F_s/\rho = -K_s \partial s/\partial z \tag{3}$$

where ρ is the mean air density and K_s is an eddy diffusivity given by

$$K_s = k u_* z/\varphi_s(z/L) \tag{4}$$

Here the von Karman constant, k = 0.4, u_* is the friction velocity, z is height, L is the Obukhov length, and the $\varphi\ (z/L)$ functions represent the effect of thermal stratification on the vertical transfer of any property s. Their empirical forms are now well-known, in part due to the work of Swinbank, Dyer, Webb and Hicks at CSIRO's Division of Meteorological Physics in the 1950s and 1960s (e.g. Swinbank and Dyer 1967; Dyer and Hicks 1970; Webb 1970). Both u_* and $\varphi\ (z/L)$ can be evaluated from wind speed and temperature profiles. In fact, for the Rutherglen data we use Eq. 3 in finite difference form since wind speed and temperature were available as vertical differences between heights of 1 m and 2 m above the crop (wind speed in fact was measured at several heights but not air temperature). For wind speed (u), $F_s/\rho = {u_*}^2$ so that Eq.3 can be written as,

$$(kz/u_*)\partial u/\partial z = \varphi_m(z/L) \tag{5}$$

and for the CO_2 flux (cf. Eq. 2),

$$F_c/\rho_a = -K_c \partial c/\partial z \tag{6}$$

with K_c given by Eq. 4 in terms of $\varphi_c(z/L)$. Thus we finally need to evaluate u_* and z/L and to do this we introduce the Richardson number, Ri,

$$Ri = 0.033[\partial\theta/\partial z][\partial u/\partial z]^{-2} \quad (7)$$

where the numerical factor 0.033 is simply g/θ, g being the acceleration due to gravity and θ is mean potential temperature. It is well-known that, for $\partial\theta/\partial z < 0$ ($Ri < 0, z/L < 0$), $z/L = Ri$ and for $\partial\theta/\partial z > 0$ ($Ri > 0, z/L > 0$), $z/L = Ri/(1 - 5Ri)$, and that

$$\varphi_c(z/L) = [[\varphi_m(z/L)^2] = (1 - 16Ri)^{-0.5} \quad (8)$$

for $Ri < 0$, and

$$\varphi_c(z/L) = \varphi_m(z/L) = [1 - 5Ri]^{-1} \quad (9)$$

for $Ri > 0$.

Taking the differential form for a vertical height increment Δz, we finally have for the vertical flux of CO_2,

$$F_c/\rho_a = -m\Delta u\Delta c \quad (10a)$$

and

$$m = [kz/\Delta z]^2/[[\varphi_c\,\varphi_m], \quad (10b)$$

where z is the geometric mean between heights 1 and 2.

For the Rutherglen data we have $\Delta z = 1$ m (for levels 1 m and 2 m above the crop), and $z_2 = 2 + h - d$, $z_1 = 1 + h - d$, h being the crop and d the zero-plane displacement, taken as $d = 2h/3$. For $h = 0$, $z = 1.41$ m; for $h = 0.3$ m, $z = 1.52$ m, $d = 0.2$ m, $z = 1.625$ m; for $h = 0.9$ m, $d = 0.6$ m, $z = 1.73$ m.

Note that u_* is evaluated here using the finite difference form of Eq.3, using Δu from the wind-speed measurements, as compared with using the integrated form of Eq. 3, using u at height z and an assumed value for the aerodynamic roughness length z_o. We have chosen the differential form so that this extra assumption is not required (z_o, as with d, is a function of h and hence of time).

To assess the reliability of this approach (using Δu) we took the integral form of Eq. 3 for neutrally stratified conditions

$$ku/u_* = \ln z/z_o \quad (11)$$

so that F_s can be calculated from

$$F_c/\rho_a = -m'u\Delta c \quad (12a)$$

with

$$m' = [k^2 z/\Delta z]/\ln z/z_o \ . \quad (12b)$$

Actually we took six individual times from the days shown in Fig.1 for which $-0.005 < Ri < 0.005$ and evaluated F_c using wind speed u at a single level. Thus, values of z_o that gave identical values of F_c from both differential and integral approaches were found to be 0.01 m (24 July), 0.03 m (7 August), 0.06 and 0.07 m (26 September) and 0.06 and 0.07 m (14 October). The corresponding values of z_o/h varied between 0.05 to 0.1, typical of crops and lending confidence to the F_c values evaluated throughout the season.

CSIRO Aspendale Aircraft Sampling Programme: 1972–92

Sampling Techniques

In late 1971 initial discussions were undertaken with the Department of Civil Aviation with a view to sampling air from their weekly training flights in a Fokker Friendship (F-27). The collection of air samples commenced in March 1972 over Bass Strait and south-eastern Australia using manually operated equipment carried on the F-27. Subsequently, routine flights at weekly or bi-weekly intervals were made to Tasmanian and several mainland airports, at altitudes up to 5 km. When the F-27 was unavailable, or when synoptic conditions were of special interest, flights were supplemented using several types of chartered light aircraft up to 1992.

In early 1972, after earlier discussions with Qantas Airways, which led to further development of sampling equipment for automatic operation by the on-board navigator, the aircrew began sampling over the Tasman Sea, at the cruise levels of Boeing 707 aircraft flying on routine commercial flights between Melbourne and New Zealand. On these flights, at intervals of two to three weeks, samples were collected between heights of 9 and 13 km, and thus occasionally in the lower stratosphere. CSIRO personnel also collected samples, at intervals of 8 to 10 weeks, from Boeing 747 aircraft operating between Sydney and Melbourne on training flights. On most of such flights samples were collected at various altitudes as aircraft climbed to, or descended from, their operating altitude of 11–12 km.

Discussions with Trans Australia Airlines in 1972 and early 1973 led to their agreeing to the periodic installation of a 5 L air sampling system mounted into the tail engine of a Boeing 727 aircraft, automatically sampling at cruise altitude (between 8.5 and 13 km) on commercial flights between Melbourne and Sydney, Brisbane and Perth. Regular sampling over the Great Australian Bight commenced in December 1973, continuing throughout the 1970s and much of the 1980s over and around the Australian continent, including the Tasman Sea. The sampling programme was replaced in 1989 by an international coordinated programme (see main text).

On all aircraft, with the exception of the Boeing 727, air was pumped from a cabin air conditioning outlet and collected in glass flasks of nominal volume 0.5 L. Sets of 6 to 10 flasks were fitted into special carrying cases for safe transportation and ease of access to individual flasks inside aircraft. Air was dried by passing it through a tower of magnesium perchlorate prior to entering each flask, and then each flask was filled to an overpressure of one atmosphere (100 kPa), but only after 2 to 3 min of pumping to ensure a complete purging of the system. After each flask was filled, time, aircraft location and altitude were noted.

On the Boeing 727 aircraft sampling involved a self-contained automatic unit fitted into the tail section. This unit connected directly into the main air-conditioning duct, with air drawn into a cadmium plated steel cylinder of volume 3.8 L. After aircraft ascent through a pre-set altitude (typically 8.5 km) a altitude3-sensitive (pressure) sampling valve activated a time delay, the delay being determined prior to each flight to allow the aircraft to reach cruise altitude and enter the area from which the air sample is required. After the delay time had expired inlet and outlet valves were opened, the cylinder flushed for 3 min at about 12 L min^{-1}, the outlet valve then closed and a pressurised sample taken. Data were later provided by the Department of Transport to allow the time, location and height of each sample to be calculated.

Tropospheric Profiles and Bulk Eddy Viscosity (K)

We make use of the mean Northern Hemisphere vertical profiles in Stephens *et al.* (2007, Figs.1 and 3) and deduce an effective bulk tropospheric K value by using published carbon fluxes, essentially available north of about 30°N. This allows us to assess the validity of earlier assumed K values and that assumed in Garratt and Pearman (1973a).

(i) For winter, the estimated gradient of –0.35 ppm km^{-1} (viz. a mean decrease of 2.3 ppm from heights of 1.5 and 8 km) implies a net surface source. Now Fig.7 of Pearman *et al.* (1983) and Fig.1 of Miyazaki *et al.* (2008) suggest a net winter flux of about 2 x 10^{-9} kgC m^{-2} s^{-1} (for 1980 – the former and for 2000 – the latter), and combined with the above concentration gradient gives K = 20 m^2 s^{-1}, noting that we have converted from $kgCO_2$ to kgC.

(ii) For the mean annual profile, the estimated vertical gradient of –0.07 ppm km^{-1}, again implies a net surface source. Using Fig.7 of Pearman *et al.* (1983) and now Fig.8 of Le Quere *et al.* (2016) suggests a net annual flux of about 1 x 10^{-9} kgC m^{-2} s^{-1} (for years 1980 and 1990–95 respectively), and combined implies K = 50 m^2 s^{-1}, somewhat larger than earlier estimates and assumptions.

(iii) Finally we use the winter and annual concentration gradients given in Fig.3 of Stephens *et al.*, valid for the height range 1 to 4 km, and with the above fluxes yields a K range of 10 to 20 m^2 s^{-1}. These lower estimates of K merely reflect the use of a shallower layer depth (1 to 4 km heights) and a lower mean height, consistent with Bolin and Bischof (1970).

Taking the above estimates into account, together with the range suggested by Bolin and Bischof (1970), we are inclined to use K = 25 (±10) m^2 s^{-1} for the Southern Hemisphere troposphere and for seasonally-averaged profiles.

Extended Reference List

Introduction

J. R. Arnold, E. C. Anderson, 'The distribution of carbon-14 in nature', *Tellus*, 9 (1957), 28–32.

S. Arrhenius, Lehrbuch der kosmichen Physik 2. Leipzig, Hirzel, 1903.

J. M. Ascensio-Parvy, A. Gaudry, G. Lambert, 'Year-to-year CO_2 variations at Amsterdam Island', *Geophysical Research Letters*, 11(12) (1984), 1215–1217.

D. J. Beardsmore, G. I. Pearman, P. J. B. Fraser, J. G. O'Toole, 'The CSIRO (Australia) atmospheric carbon dioxide monitoring program: The first six years of data', *Technical Paper* No. 35, CSIRO Division of Atmospheric Physics, (Melbourne, 1978), 71 pp.

D. J. Beardsmore, G. I. Pearman R. C. O'Brien, 'The CSIRO (Australia) atmospheric carbon dioxide monitoring program: Surface data', *Technical Paper* No. 6, CSIRO Division of Atmospheric Research, (Melbourne, 1984), 115 pp.

D. J. Beardsmore, G. I. Pearman P. Zwack, 'Atmospheric carbon dioxide measurements in a semi-urban locality', *Clean Air*, 19(4) (1985), 123–127.

W. Bischof, 'Carbon dioxide in the upper troposphere and lower stratosphere. I', *Tellus*, 17 (1965), 395–402.

W. Bischof, 'Carbon dioxide in the upper troposphere and lower stratosphere-II', *Tellus*, 23 (1971), 558–561.

W. Bischof, 'Carbon dioxide in the upper troposphere and lower stratosphere-III', *Tellus*, 25 (1973), 305–308.

W. Bischof, 'The influence of the carrier gas on the infrared gas analysis of atmospheric CO_2', *Tellus*, 27 (1975), 59–61.

W. Bischof, P., Fabian R. Borchers, 'Decrease in CO_2 mixing ratio observed in the stratosphere', *Nature*, 288 (1980)**,** 347–348.

B. Bolin, W. Bischof, 'Variations of the carbon dioxide content of the atmosphere in the northern hemisphere', *Tellus*, 22(4) (1970), 431–441.

G. W. Brailsford, B. B. Stephens, A. J. Gomez, K. Riedel, S. E. Mikaloff Fletcher, S. E. Nichol M. R. Manning, 'Long-term continuous atmospheric CO_2 measurements at Baring Head, New Zealand', *Atmospheric Measurement Techniques*, 5 (2012), 3109–3117.

G. S. Callender, 'The effect of fuel combustion on the amount of carbon dioxide in the atmosphere'. *Tellus*, 9 (1957), 421–422.

T. C. Chamberlin, 'An attempt to frame a working hypothesis of the cause of glacial periods on an atmospheric basis', *Journal of Geology*, 7 (1899), 575, 667, 751.

L. Ciattaglia, 'Interpretation of atmospheric CO_2 measurements at Mt. Cimone (Italy) related to wind data', *Journal of Geophysical Research*, 88C2 (1983), 1331–1338.

L. Ciattaglia, V. Cundari, T. Colombo, 'Further measurements of atmospheric carbon dioxide at Mt. Cimone, Italy: 1979–1985', *Tellus*, 39B, 123–120 (1987), 1987.

H. Craig, 'The natural distribution of radiocarbon and the exchange time of carbon dioxide between atmosphere and sea', *Tellus*, 9(1) (1957), 1–17.

W. G. Fastie, A. H. Pfund, 'Selective infra-red gas analyzers', *Journal of the Optical Society of America*, 3(10) (1947), 762–768.

S. Fonselius, F. Koroleff, K. Wärme, 'Carbon dioxide variations in the atmosphere', *Tellus*, 8 (1956), 176.

J. R. Garratt, G. I. Pearman, 'Space and time variations of carbon dioxide in the atmospheric boundary layer', *IAMAP/IAPSO Combined First Special Assemblies*, 1 (1973), SB-I-2.

A. Gaudry, J. M. Ascensio, G. Lambert. 'Preliminary study of CO_2 variations at Amsterdam Island (Territoire des Terres Australes et Antarctiques Francaises)', *Journal of Geophysical Research*, 88 (1983), 1323–1329.

D. C. Harris, 'Charles Keeling and the story of atmospheric CO_2 measurements', *Analytical Chemistry*, 82 (2010), 7865–7870.

M. B. Jaffe, 'Infrared measurement of carbon dioxide in the human breath: "Breath through" devices from Tyndall to the present day', *Anesthesia and Analgesia*, 107 (2008), 890–904.

C. D. Keeling, R. B. Bacastow, A. E. Bainbridge, C. A. Ekdahl, P. R. Guenther, L. S. Waterman, J. F. S. Chen, 'Atmospheric carbon dioxide variations at Mauna Loa Observatory, Hawaii', *Tellus*, 28(6) (1976a), 538–551, 1976a.

C. C. Keeling, J. A. Adams, C. A. Ekdahl, P. R Guenther, 'Atmospheric carbon dioxide variations at the South Pole', *Tellus*, 28 (1976b), 552–264.

J. J. Kelly, 'An analysis of carbon dioxide in the Arctic atmosphere near Barrow, Alaksa, 1961 to 1967', University of Washington, Department of Atmospheric Sciences, Scientific Report, Navel Research Contract no. 614-67-A-0103-0007, NR, (Seattle, 1969), 307–252.

W. D. Komhyr, R. H. Gammon, T. B. Harris, L. S. Waterman, T. J. Conway, W. R. Taylor, K. W. Thoning, 'Global atmospheric CO_2 distribution and variations from 1968–1982 NOAA/GMCC CO_2 flask-sample data', *Journal of Geophysical Research*, 90 (1985), 5567–5596.

I. Levin, R. Graul, N. B. A. Trivett, 'Long-term observations of atmospheric CO_2 and carbon isotopes at continental sites in Germany', *Tellus*, 47B (1995), 23–34.

D. C. Lowe, 'Atmospheric carbon dioxide in the Southern hemisphere', *Clean Air*, 8 (1974), 12–15.

D. C. Lowe, P. R. Guenther, C. D. Keeling, 'The concentration of atmospheric carbon dioxide at Baring Head, New Zealand', *Tellus*, 31 (1979), 58–67.

T. Nakazawa, S. Miyashita, S. Aoki, M. Tanaka, 'Temporal and spatial variations of upper tropospheric and lower stratospheric carbon dioxide', *Tellus*, 43B (1991), 106–117.

J. C. Pales, C. D. Keeling, 'The concentration of atmospheric carbon dioxide in Hawaii', *Journal of Geophysical Research*, 70 (1965), 6053–6076.

G. I. Pearman, J. R. Garratt, 'Space and time variations of tropospheric carbon dioxide in the Southern Hemisphere', *Tellus*, 25 (1973), 309–311.

G. I. Pearman, J. R. Garratt, 'The Aspendale atmospheric carbon dioxide monitoring programme – two years of data', *IAMAP/IAPSO Combined First Special Assemblies Meeting*, 1974.

G. I. Pearman, D. J. Beardsmore, 'Atmospheric carbon dioxide concentrations over south east Australia during November 1976. Interhemispheric Survey of Upper Atmospheric Constituents during October–November 1976', *NASA Technical Memo. Lewis Research Centre*, TM-73630 145–154. 1977.

G. I. Pearman, 'Global atmospheric carbon dioxide measurements: A review of methodologies, existing programmes and available data', WMO Project on Research and Monitoring of Atmospheric CO_2, *WMO Report No.3*, WMO, (Geneva, 1980), 42 pp.

G. I. Pearman, 'Temporal and spatial variations in background carbon dioxide measurements: some aspects of data selection and interpretation', Proceedings WMO Technical Conference on Regional Climate. *WMO Special Environmental Report* 14 (1980), 265–272.

J. T. Peterson, W. D. Komhyr, T. B. Harris, J. F. S. Chin, 'NOAA carbon dioxide measurements at Mauna Loa Observatory, 1974–1976', *Geophysical Research Letters*, 4 (1977), 354–356.

J. T. Peterson, W. D. Komhyr, T. B. Harris, L. S. Waterman, 'Atmospheric carbon dioxide measurements at Barrow, Alaska, 1973–1979', *Tellus*, 34 (1982), 166–175.

R. Revelle, H. E. Suess, 'Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades', *Tellus*, 9, 18–27, 1957.

M. Tanaka, T. Nakazawa, S. Aoki, 'Concentration of atmospheric carbon dioxide over Japan,' *Journal of Geophysical Research,* 88C2 (1983), 1339–1344.

M. Tanaka, T. Nakazawa, M. Shiobara, H. Ohshima, S. Aoki, S. Kawaguchi, T. Yamanouchi, Y. Makino, H. Murayama, 'Variations of atmospheric carbon dioxide concentration at Syowa Station', (69°00'S, 39°35'E, Antarctica', *Tellus*, 39B (1987), 72–79.

C. S. Wong, 'Trends of atmospheric CO_2 over Canadian WMO background stations at Ocean Weather Station P, Sable Island and Alert', *Journal of Geophysical Research*, 89D6 (1984), 9527–9539.

WMO, Provisional daily atmospheric carbon dioxide concentrations, as measured at (GAW)-BAPMoN sites for year 1991, World Meteorological Organisation, Global Atmospheric Watch, 84, 1991.

WMO, Report of the Fourth International CO_2 Conference, Carqueiranne, France, September 13–17, World Meteorological Organisation, Global Atmospheric Watch, 89, 1993.

CO_2 Concentration Measurements over Crops and Forests in Australia—Post 1970

A. J. Dyer, B. B. Hicks, 'Flux-gradient relationships in the constant-flux layer', *Quarterly Journal of the Royal Meteorological Society*, 96 (1970), 715–721.

G. W. Paltridge, J. V. Denholm, 'Plant yield and the switch from vegetative to reproductive growth', *Journal of Theoretical Biology*, 44 (1974), 23–34.

G. I. Pearman, J. R. Garratt, 'Carbon dioxide measurements above a wheat crop. I: Observations of vertical gradients and concentrations', *Agricultural Meteorology* 12 (1973), 13–25.

M. L. Roderick, G. D. Farquhar, S. L. Berry, I. R. Noble, 'On the direct effect of clouds and atmospheric particles on the productivity and structure of vegetation', *Oecologia*, 129 (2001), 21–30.

W. C. Swinbank, A. J. Dyer, 'An experimental study in micrometeorology', *Quarterly Journal of the Royal Meteorological Society*, 93 (1967), 494–500.

M. Tanaka, T. Nakazawa, S. Aoki, 'Concentration of atmospheric carbon dioxide over Japan', *Journal of Geophysical Research*, 88C2 (1983), 1339–1344.

E. K. Webb, 'Profile relationships: the log-linear range, and extension to strong stability', *Quarterly Journal of the Royal Meteorological Society*, 96 (1970), 67–90.

X.-G. Zhu, S. P. Long, D. R. Ort, 'What is the maximum efficiency with which photosynthesis can convert solar energy into biomass?' *Current Options in Biotechnology*, 19 (2008), 153–159.

CSIRO Aspendale Aircraft Sampling Programme: 1972–92

B. Bolin, W. Bischof, 'Variations of the carbon dioxide content of the atmosphere in the northern hemisphere', *Tellus*, 22(4) (1970), 431–441.

J. R. Garratt, G. I. Pearman, 'CO_2 concentration in the atmospheric boundary-layer over south-east Australia', *Atmospheric Environment*, 7 (1973**)**, 1257–1266.

D. Lowe, C. P. R. Guenther, C. D. Keeling. 'The concentration of atmospheric carbon dioxide at Baring Head, New Zealand', *Tellus*, 31 (1979), 58–67.

G. I. Pearman, J. R. Garratt, 'Carbon dioxide measurements above a wheat crop. I: Observations of vertical gradients and concentrations', *Agricultural Meteorology*, 12 (1973), 13–25.

Dealing with Instrumental and Measurement Issues

R. F. Keeling, P. Guenther, S. Walker, D. Moss, *Scripps reference gas calibration system for carbon dioxide-in-nitrogen and carbon-dioxide-in-air standards: Revision of 2016.* http://scrippsco2.ucsd.edu/assets/publications/manometry_report_scripps_ref_gas_calibration_revision_of_2012_pub_2016.pdf, 2016.

Summary and Conclusions

SCEP, *Man's Impact on the Global Environment.* Report of the study of Critical Environmental Problems Committee, MIT press, London, 1970.

SCOPE, Global Environmental Monitoring, SCOPE 1. A Report submitted to the United Nations Conference on the Human Environment, Stockholm 1972, by the Commission on Monitoring, of the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions, Stockholm, 67 pp., 1971.

SMIC, *Inadvertent Climate Modification*. Report of the Study of Man's Impact on Climate. MIT Press, Massachusetts, 1971.