New Zealand National Report
for the 10th WMO/UNEP Ozone Research Managers Meeting
Geneva, March 2017

Introduction

In New Zealand, ozone- and UV-related research is undertaken by the National Institute of Water and Atmospheric Research (NIWA), Bodeker Scientific, and several of our Universities. Many relevant observations are taken at the Lauder Atmospheric Research Station in Central Otago. Lauder station (45°S, 170°E, 370 meters above sea level), a rural and clean background-level site, is representative of Southern mid-latitudes. It is a “Global” station of the WMO’s Global Atmosphere Watch Programme, and is also part of the Network for the Detection of Atmospheric Composition Change (NDACC). Ozone, as well as a number of parameters related to ozone depletion, is measured using a variety of techniques including Dobson spectrophotometry, UV-visible spectroscopy, infrared spectroscopy, microwave radiometry, electrochemical ozonesondes flown on balloons, ozone and aerosol LIDARs, and frost-point hygrometers. Solar UV radiation is measured at a number of sites across New Zealand. There also are measurement activities outside of New Zealand, such as in Antarctica and the Pacific Islands. Specific work in support of environmental conventions is also taking place. Due to its location in the Southern Hemisphere and proximity to Antarctica, New Zealand is particularly interested in the climate effects of stratospheric ozone depletion. The “Deep South” National Science Challenge is a 10-year research programme that aims to better our understanding of how changes in the Antarctic region affect New Zealand; the effect of ozone depletion and recovery on climate will form part of this programme.

1. OBSERVATIONAL ACTIVITIES

Ozone Research in New Zealand

Of the more than 70 active NDACC measurement sites in the world, only Lauder is equipped with a full complement of the five standard ground-based ozone profile measuring techniques, i.e. ozonesondes, Dobson Umkehr, LIDAR, FTIR, and microwave radiometry. Total column ozone is also measured at Lauder using UV/vis spectrometers and surface *in situ* observations are made using UV photometers. Other sites across New Zealand also have active surface ozone measurement programmes.

High quality, long time-series measurements are key to identifying trends; the Lauder measurement site hosts several on-going multi-decadal data sets relevant to ozone research.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

The following measurement programmes are all located at the Lauder research station:

- Stratospheric NO_2 since 1981 (36 years)
- Dobson Total Column Ozone since 1987 (30 years)
- UV Spectrometers since 1989 (28 years)
- TEI *in situ* ozone analyser since 2004 (13 years)

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

The following measurement programmes are all located at the Lauder research station:

- Ozonesondes, weekly launches since 1986 (31 years) which included radiosonde measurements of pressure, temperature and humidity
- Dobson Umkehr since 1987 (30 years)
- Ozone LIDAR since 1994 (23 years)
- Microwave radiometers since 1994 (23 years)

- FTIR since 1990 (27 years)
- NOAA frost-point hygrometers since 2004 (13 years)

1.3 UV measurements

Activities from NIWA's UV radiation programme are summarized at
https://www.niwa.co.nz/our-services/online-services/uv-ozone

Spectral: NIWA maintains spectral measurements at Lauder, as well as at Mauna Loa Observatory HI, Boulder CO, Alice Springs and Melbourne, Australia.
Summary data from the NDACC sites are archived at the NDACC database, and plans are underway to routinely archive spectral data from all five sites in the WOUDC database. Historical spectral data are also available from Tokyo, Japan, and Darwin, Australia.
Broadband: NIWA maintains 6 Yankee UVB-1 pyranometers (i.e., new generation Robertson Berger "RB-type" meters) in NZ and the South Pacific region. Data from these are archived in the NIWA climate database, and are used in regular reports by the New Zealand Ministry for the Environment (http://www.mfe.govt.nz/publications/environmental-reporting/environment-aotearoa-2015-atmosphere-and-climate/state-our). NIWA also assists Callaghan Innovation to process and archive data from their UVB-1 meters at 6 other sites in New Zealand.
Complementary Measurements:
In support of our UV measurement programme, the following are also available at Lauder:

- BSRN radiation suite (direct, diffuse, and global short wave radiation)
- Aerosol optical depth at several wavelengths, and from LIDAR (BSRN)
- All sky cameras
- Direct beam spectral irradiances
- Actinic flux measurements
- Sunshine recorders
- USDA radiation suite
- Meteorological data
- Trace gas measurements

Additionally, NIWA has been closely involved with the development and use of personal UV dosimeters.

1.4 Calibration activities

- The most recent inter-calibration against international standards (maintained at the Physikalisch-Metorologisches Observatorium Davos; PMOD) was at Lauder in February 2016. NIWA and PMOD spectra agreed within the PMOD standard error range.
- NIWA UV spectrometers have also been used to cross calibrate other spectrometers in Australasia
- Australian Radiation Laboratory (ARPANSA), at Melbourne Australia, in Dec.2015
- Callaghan Innovation (CI), at Lauder in Dec.2016
- Broadband meters are cross calibrated against spectroradiometers at Lauder
- Lauder Dobson (D072) NDACC calibration to the regional standard in Melbourne, Feb.2017
- NOAA travelling ozone standard was used with the TEIs at Lauder in 2016

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Through numerous publications (see below), conference presentations, seminars, and web pages. Results are updated at quadrennial NIWA Workshops (UV). See https://www.niwa.co.nz/our-services/online-services/uv-and-ozone/workshops

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

Through research papers, UNEP EEAP Reports, and WMO Ozone Assessment Reports.
UNEP: http://ozone.unep.org/en/assessment-panels/environmental-effects-assessment-panel
WMO: http://ozone.unep.org/en/assessment-panels/scientific-assessment-panel

Bodeker Scientific is funded under the Deep South National Science Challenge to develop a long-term homogeneous total column ozone database. This database combines total column ozone measurements from 17 different satellite instruments, removing all offsets and drifts between the data sets, to create a seamless homogeneous database from November 1978 to the present. This data set is available from:
http://www.bodekerscientific.com/presentations/peer-reviewed-literature

With funding from the same source, Bodeker Scientific is also developing a new version of its vertically resolved monthly mean, zonal mean, global ozone database. This database extends from 1979 to the present and is provided on 70 vertical levels (both altitude and pressure). A gap filling technique is used to generate a database suitable for constraining global climate models that do not have a chemically interactive stratosphere, or to validate the ozone fields simulated by coupled chemistry-climate models. This data set is available from:
http://www.bodekerscientific.com/data/monthly-mean-global-vertically-resolved-ozone

NIWA is a major contributor to the Chemistry-Climate Model Initiative (CCMI), which i.a. is focusing on tropospheric and stratospheric ozone. In association with that, a research focus has been on linkages between Southern-Hemisphere climate change and ozone depletion, and related to that in the attribution of such change to ozone depletion and/or increasing long-lived greenhouse gases. The research is continued under the Deep South National Science Challenge, using the nascent New Zealand Earth System Model.
http://www.deepsouthchallenge.co.nz; http://blogs.reading.ac.uk

4. DISSEMINATION OF RESULTS

4.1 Data reporting

See above. NIWA UV data are archived at:

NDACC: http://www.ndsc.ncep.noaa.gov/data/ (spectral summaries)
WOUDC: http://woudc.org/ (not yet publically available)
NIWA: https://cliflo.niwa.co.nz/ (broad band)

Scientific papers, etc. (see below)

NDACC, WOUDC: Dobson total column ozone and Umkehr profiles
NDACC, WOUDC: Stratospheric microwave radiometer profiles
NDACC, WOUDC, GRUAN: Ozonesonde profiles
NDACC, GRUAN: Frost-point water vapour profiles
NDACC: FTIR ozone, total column and profiles
NDACC: LIDAR ozone profiles

4.2 Information to the public

NIWA web pages include UV forecasts, maps of ozone and UV, time series of ozone.
UV Index displays in public places, along with behavioural advice
Smartphone Apps that include variation over the day including cloud effects and corresponding behavioural advice. (https://www.niwa.co.nz/node/111461).

The uv2Day app (NZ – Australia – South Pacific – Antarctica only)
The GlobalUV app (Global, but with daily noon cloud cover only)

Interaction with NZ health providers regarding both positive and negative effects of UV. For example,
https://www.health.govt.nz/system/files/documents/publications/vitamind-sun-exposure.pdf
http://www.sunsmartschools.co.nz/PS_RisksBenefits_SunExposureSept08.pdf

4.3 Relevant scientific papers

Since 2014:

1. Andersson, M. E., P. T. Verronen, C. J. Rodger, M. A. Clilverd, and A. Seppala (2014), Missing driver in the Sun-Earth connection from energetic electron precipitation impacts mesospheric ozone, Nature Communications, 5, doi:10.1038/ncomms6197.
2. Badosa, J., J. Calbo, R. McKenzie, B. Liley, J. A. Gonzalez, B. Forgan, and C. N. Long (2014), Two Methods for Retrieving UV Index for All Cloud Conditions from Sky Imager Products or Total SW Radiation Measurements, Photochemistry and Photobiology, 90(4), 941-951, doi:10.1111/php.12272.
3. Bais, A. F., R. L. McKenzie, G. Bernhard, P. J. Aucamp, M. Ilyas, S. Madronich, and K. Tourpali (2015), Ozone depletion and climate change: impacts on UV radiation, Photochemical & Photobiological Sciences, 14(1), 19-52, doi:10.1039/c4pp90032d.
4. Ball, W. T., A. Kuchar, E. V. Rozanov, J. Staehelin, F. Tummon, A. K. Smith, T. Sukhodolov, A. Stenke, L. Revell, A. Coulon, W. Schmutz and T. Peter (2016), An upper-branch Brewer-Dobson circulation index for attribution of stratospheric variability and improved ozone and temperature trend analysis, Atmos. Chem. Phys., 16, 15485-15500, doi: 10.5194/acp-16-15485-2016.
5. Bart, M., D. E. Williams, B. Ainslie, I. McKendry, J. Salmond, S. K. Grange, M. Alavi-Shoshtari, D. Steyn, and G. S. Henshaw (2014), High Density Ozone Monitoring Using Gas Sensitive Semi-Conductor Sensors in the Lower Fraser Valley, British Columbia, Environmental Science & Technology, 48(7), 3970-3977, doi:10.1021/es404610t.
6. Björn, L. O., and R. L. McKenzie (2015), Ozone depletion and the effects of ultraviolet radiation, in Photobiology: the Science of Light and Life (3rd edition), edited by L. O. Björn, pp. 347-364, Springer, New York, doi:10.1007/978-1-4939-1468-5_22.
7. Bodeker, G.E.; Bojinski, S.; Cimini, D.; Dirksen, R.J.; Haeffelin, M.; Hannigan, J.W.; Hurst, D.F.; Leblanc, T.; Madonna, F.; Maturilli, M.; Mikalsen, A.C.; Philipona, R.; Reale, T.; Seidel, D.J.; Tan, D.G.H.; Thorne, P.W.; Vömel, H. and Wang, J. (2016), Reference Upper-Air Observations For Climate From Concept to Reality, American Meterological Society, 124-135, 2016.
8. Calbó, J., J.-A. González, J. Badosa, R. McKenzie, and B. Liley (2016), How large and how long are UV and total radiation enhancements?, in International Radiation Symposium, edited, IRS, Auckland, NZ.
9. Cherubini, F., et al. (2016), Bridging the gap between impact assessment methods and climate science, Environmental Science & Policy, 64, 129-140, doi:10.1016/j.envsci.2016.06.019.

10. Chipperfield, M. P., et al. (2014), Multimodel estimates of atmospheric lifetimes of long-lived ozone-depleting substances: Present and future, J. Geophys. Res. Atmos., 119, 2555–2573, doi:10.1002/2013JD021097.
11. Chipperfield, M. P., S. S. Dhomse, W. Feng, R. L. McKenzie, G. J. M. Velders, and J. A. Pyle (2015), Quantifying the ozone and ultraviolet benefits already achieved by the Montreal Protocol Nature Comms, 6(7233), 8, doi:10.1038/ncomms8233.
12. Cook, F. J., and F. M. Kelliher (2016), Nitrous oxide emissions from grazing cattle urine patches: Bridging the gap between measurement and stakeholder requirements, Environmental Modelling & Software, 75, 133-152, doi:10.1016/j.envsoft.2015.10.009.
13. Dennison, F. W., A. J. McDonald, and O. Morgenstern (2015), The effect of ozone depletion on the Southern Annular Mode and stratosphere-troposphere coupling. J. Geophys. Res. Atmos., 120, 6305–6312. doi: 10.1002/2014JD023009.
14. Dennison, F. W., A. J. McDonald, and O. Morgenstern (2016), The influence of ozone forcing on blocking in the Southern Hemisphere, J. Geophys. Res. Atmos., 121, 14,358–14,371, doi:10.1002/2016JD025033.
15. Gies, P., et al. (2015), An international intercomparison of solar UVR spectral measurement systems in Melbourne in 2013, Photochem. Photobiol., 91, 1237-1246.
16. Harris, N. R. P., Hassler, B., Tummon, F., Bodeker, G. E., Hubert, D., Petropavlovskikh, I., Steinbrecht, W., Anderson, J., Bhartia, P. K., Boone, C. D., Bourassa, A., Davis, S. M., Degenstein, D., Delcloo, A., Frith, S. M., Froidevaux, L., Godin-Beekmann, S., Jones, N., Kurylo, M. J., Kyrölä, E., Laine, M., Leblanc, S. T., Lambert, J.-C., Liley, B., Mahieu, E., Maycock, A., de Mazière, M., Parrish, A., Querel, R., Rosenlof, K. H., Roth, C., Sioris, C., Staehelin, J., Stolarski, R. S., Stübi, R., Tamminen, J., Vigouroux, C., Walker, K. A., Wang, H. J., Wild, J., and Zawodny, J. M. (2015): Past changes in the vertical distribution of ozone – Part 3: Analysis and interpretation of trends, Atmos. Chem. Phys., 15, 9965-9982, doi:10.5194/acp-15-9965-2015, 2015.
17. Kelliher, F. M., H. V. Henderson, and N. R. Cox (2017), The uncertainty of nitrous oxide emissions from grazed grasslands: A New Zealand case study, Atmospheric Environment, 148, 329-336, doi:10.1016/j.atmosenv.2016.11.005.
18. Kotkamp, M., R. McKenzie, H. Shiona, S. Rhodes, P. Disterhoft, and G. Bernhard (2014), Materials-damaging UV radiation in New Zealand: Comparison with other locations, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
19. Kreher, K.; Bodeker, G.E. and Sigmond, M. (2015), An objective determination of optimal site locations for detecting expected trends in upper-air temperature and total column ozone, Atmos. Chem. Phys., 15, 7653-7665, 2015.
20. Kremser, S., et al. (2016), Stratospheric aerosol-Observations, processes, and impact on climate, Reviews of Geophysics, 54(2), 278-335, doi:10.1002/2015rg000511.
21. Kremser, S., N. B. Jones, M. Palm, B. Lejeune, Y. T. Wang, D. Smale, and N. M. Deutscher (2015), Positive trends in Southern Hemisphere carbonyl sulfide, Geophysical Research Letters, 42(21), 9473-9480, doi:10.1002/2015gl065879.
22. Kremser, S.; Thomason, L.W.; von Hobe, M.; Hermann, M.; Deshler, T.; Timmreck, C.; Toohey, M.; Stenke, A.; Schwarz, J.P.; Weigel, R.; Fueglistaler, S.; Prata, F.J.; Vernier, J.; Schlager, H.; Barnes, J.E.; Antuña-Marrero, J.-C.; Fairlie, D.; Palm, M.; Mahieu, E.; Notholt, J.; Rex, M.; Bingen, C.; Vanhellemont, F.; Bourassa, A.; Plane, J.M.C.; Klocke, D.; Carn, S.A.; Clarisse, L.; Trickl, T.; Neely, R.; James, A.D.; Rieger, L.; Wilson, J.C. and Meland, B. (2016), Stratospheric aerosol - Observations, processes, and impact on climate, Rev. Geophys., 54, 2016.
23. Kuttippurath, J.; Bodeker, G.E.; Roscoe, H.K. and Nair, P.J. (2015), A cautionary note on the use of EESC-based regression analysis for ozone trend studies, Geophys. Res. Lett., 42, 162-168, 2015.

24. Liley, B., R. McKenzie, and M. Kotkamp (2014), Inferring UV intensity from visible light or solar warmth, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
25. Liley, B., R. McKenzie, P. Johnston, and M. Kotkamp (2016), 25 years of solar spectral UV measurements at 45°S, in International Radiation Symposium, edited, IRS, Auckland, NZ.
26. López-Comí, L., Morgenstern, O., Zeng, G., Masters, S. L., Querel, R. R., and Nedoluha, G. E. (2016): Assessing the sensitivity of the hydroxyl radical to model biases in composition and temperature using a single-column photochemical model for Lauder, New Zealand, Atmos. Chem. Phys., 16, 14599-14619, doi:10.5194/acp-16-14599-2016, 2016.
27. McKenzie, R. (2014), UV in New Zealand and Australia: What makes us different?, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
28. McKenzie, R. (2016), UV radiation in the melanoma capital of the world: What makes New Zealand so different?, in International Radiation Symposium, edited, IRS, Auckland, NZ.
29. McKenzie, R., B. Liley, and P. Disterhoft (2016), Peak UV: Spectral contributions from cloud enhancements, in International Radiation Symposium, IRS, Auckland, NZ.
30. McKenzie, R., B. Liley, M. Kotkamp, H. Shiona, and L. Lopez (2014), Long term changes in UV in New Zealand due to ozone depletion and other causes, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
31. McKenzie, R., B. Liley, P. Johnston, R. Scragg, A. Stewart, A. Reeder, and M. Allen (2014), Effects of measured UV exposure on Vitamin D status of New Zealanders: Implications for seasonal exposures required, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
32. McKenzie, R., G. Bernhard, S. Madronich, and F. Zaratti (2015), Comment on “Record solar UV irradiance in the tropical Andes, by Cabrol et al.”, Frontiers in Environmental Science, 3:26, doi:10.3389/fenvs.2015.00026.
33. McKenzie, R., M. Blumthaler, S. Diaz, V. Fioletov, J. Herman, G. Seckmeyer, A. Smedley, and A. Webb (2014), Rationalising nomenclature for UV doses and effects on humans, CIE Journal, 211, 14 pp.
34. Miskell, G., J. Salmond, and D. E. Williams (2017), Low-cost sensors and crowd-sourced data: Observations of siting impacts on a network of air-quality instruments, Science of the Total Environment, 575, 1119-1129, doi:10.1016/j.scitotenv.2016.09.177.
35. Morgenstern, O., G. Zeng, S. M. Dean, M. Joshi, N. L. Abraham, and A. Osprey (2014), Direct and ozone-mediated forcing of the Southern Annular Mode by greenhouse gases, Geophys. Res. Lett., 41, 9050–9057, doi:10.1002/2014GL062140.
36. Morgenstern, O., R. McKenzie, A. van Dijk, and P. Newman (2014), New Zealand’s "World Avoided" by the Success of the Montreal Protocol, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
37. Morgenstern, O., M. I. Hegglin, E. Rozanov, F. M. O'Connor, N. L. Abraham, H. Akiyoshi, A. T. Archibald, S. Bekki, N. Butchart, M. P. Chipperfield, M. Deushi, S. S. Dhomse, R. R. Garcia, S. C. Hardiman, L. W. Horowitz, P. Jöckel, B. Josse, D. Kinnison, M. Lin, E. Mancini, M. E. Manyin, M. Marchand, V. Marécal, M. Michou, L. D. Oman, G. Pitari, D. A. Plummer, L. E. Revell, D. Saint-Martin, R. Schofield, A. Stenke, K. Stone, K. Sudo, T. Y. Tanaka, S. Tilmes, Y. Yamashita, K. Yoshida, and G. Zeng (2017), Review of the global models used within the Chemistry-Climate Model Initiative (CCMI), Geosci. Model Dev., doi:10.5194/gmd-2016-199, to appear.
38. Nair, P. J., L. Froidevaux, J. Kuttippurath, J. M. Zawodny, J. M. RussellIII, W. Steinbrecht, H. Claude, T. Leblanc, J. A. E.van Gijsel, B. Johnson, D. P. J. Swart, A. Thomas, R. Querel, R. Wang, and J. Anderson (2015), Subtropical and midlatitude ozone trends in the stratosphere: Implications for recovery. J. Geophys. Res. Atmos., 120, 7247–7257. doi: 10.1002/2014JD022371.

39. Nedoluha, G. E., Boyd, I. S., Parrish, A., Gomez, R. M., Allen, D. R., Froidevaux, L., Connor, B. J., and Querel, R. R. (2015): Unusual stratospheric ozone anomalies observed in 22 years of measurements from Lauder, New Zealand, Atmos. Chem. Phys., 15, 6817-6826, doi:10.5194/acp-15-6817-2015, 2015.
40. Nedoluha, G.E.; Connor, B.J.; Mooney, T.; Barrett, J.W.; Parrish, A.; Gomez, R.M.; Boyd, I.; Allen, D.R.; Kotkamp, M.; Kremser, S.; Deshler, T.; Newman, P. and Santee, M.L. (2016), 20 years of ClO measurements in the Antarctic lower stratosphere, Atmos. Chem. Phys., 16, 10725-10734, 2016.
41. Nurse, V., C. Y. Wright, M. Allen, and R. L. McKenzie (2015), Solar ultraviolet radiation exposure of South African marathon runners during competition marathon runs and training sessions: A feasibility study, Photochem. Photobiol., doi:10.1111/php.12461.
42. Oberländer-Hayn, S., E. P. Gerber, J. Abalichin, H. Akiyoshi, A. Kerschbaumer, A. Kubin, M. Kunze, U. Langematz, S. Meul, M. Michou, O. Morgenstern, and L. D. Oman (2016), Is the Brewer-Dobson circulation increasing or moving upward?, Geophys. Res. Lett., 43, 1772–1779, doi:10.1002/2015GL067545.
43. O'Connor, F. M., Johnson, C. E., Morgenstern, O., Abraham, N. L., Braesicke, P., Dalvi, M., Folberth, G. A., Sanderson, M. G., Telford, P. J., Voulgarakis, A., Young, P. J., Zeng, G., Collins, W. J., and Pyle, J. A. (2014): Evaluation of the new UKCA climate-composition model – Part 2: The Troposphere, Geosci. Model Dev., 7, 41-91, doi:10.5194/gmd-7-41-2014, 2014.
44. Parrish, A.; Boyd, I.S.; Nedoluha, G.E.; Bhartia, P.K.; Frith, S.M.; Kramarova, N.A.; Connor, B.J.; Bodeker, G.E.; Froidevaux, L.; Shiotani, M. and Sakazaki, T. (2014), Diurnal variations of stratospheric ozone measured by ground-based microwave remote sensing at the Mauna Loa NDACC site: measurement validation and GEOSCCM model comparison, Atmos. Chem. Phys., 14, 7255–7272, 2014.
45. Petrie, T., T. K. Stump, L. G. Aspinwall, P. Cassidy, J. Taber, S. Jacques, P. Tanner, R. McKenzie, B. Liley, and S. Leachman (2014), Mining dosimetry data: Sun exposure behaviors in hereditary melanoma participants, paper presented at NIWA UV Workshop, Auckland, New Zealand, 15-17 April.
46. Reeder, A. I., A. R. Gray, J. B. Liley, R. K. R. Scragg, R. L. McKenzie, and A. W. Stewart (2016), Factors associated with photoprotection by body clothing coverage, particularly in non-summer months, among a New Zealand community sample, Photochem. Photobiol. Sci., 15, 389-397, doi:10.1039/C5PP00431D.
47. Revell, L.E.; Peter, T.; Tummon, F.; Stenke, A.; Sukhodolov, T.; Coulon, A.; Rozanov, E.; Garny, H. and Grewe, V. (2015), Drivers of the tropospheric ozone budget throughout the 21st century under the medium-high climate scenario RCP 6.0, Atmos. Chem. Phys., 15, 5887-5902, 2015.
48. Revell, L.E.; Tummon, F.; Salawitch, R.J.; Stenke, A. and Peter, T. (2015), The changing ozone depletion potential of N_2O in a future climate, Geophys.Res. Lett., 42, 10047-10055, 2015.
49. Revell, L.E.; Stenke, A.; Rozanov, E., Ball, W., Lossow, S. and Peter, T. (2016), The role of methane in projections of 21st century stratospheric water vapour, Atmos. Chem. Phys., 16, 13067-13080, doi:10.5194/acp-16-13067-2016.
50. Rex, M.; Kremser, S.; Huck, P.; Bodeker, G.; Wohltmann, I.; Santee, M.L. and Bernath, P. (2014), Technical Note: SWIFT – a fast semi-empirical model for polar stratospheric ozone loss, Atmos. Chem. Phys., 14, 6545–6555, 2014.
51. Sakai, T., O. Uchino, T. Nagai, B. Liley, I. Morino, and T. Fujimoto (2016), Long-term variation of stratospheric aerosols observed with lidars over Tsukuba, Japan, from 1982 and Lauder, New Zealand, from 1992 to 2015, Journal of Geophysical Research-Atmospheres, 121(17), 10283-10293, doi:10.1002/2016jd025132.

52. Schnell, J. L., M. J. Prather, B. Josse, V. Naik, L. W. Horowitz, G. Zeng, D. T. Shindell, and G. Faluvegi (2016), Effect of climate change on surface ozone over North America, Europe, and East Asia, Geophys. Res. Lett., 43, 3509–3518, doi:10.1002/2016GL068060.
53. Schnell, J. L., Prather, M. J., Josse, B., Naik, V., Horowitz, L. W., Cameron-Smith, P., Bergmann, D., Zeng, G., Plummer, D. A., Sudo, K., Nagashima, T., Shindell, D. T., Faluvegi, G., and Strode, S. A. (2015): Use of North American and European air quality networks to evaluate global chemistry–climate modeling of surface ozone, Atmos. Chem. Phys., 15, 10581-10596, doi:10.5194/acp-15-10581-2015, 2015.
54. Scragg, R., A. Stewart, R. McKenzie, A. Reeder, B. Liley, and M. Allen (2014), Association between sun exposure and serum 25-hydroxyvitamin D3 levels, in NIWA UV Workshop, edited by R. L. McKenzie, Auckland, New Zealand.
55. Södergren, A.H.; Bodeker, G.E.; Kremser, S.; Meinshausen, M. and Mcdonald, A.J. (2016), A probabilistic study of the return of stratospheric ozone to 1960 levels, Geophys. Res. Lett., 43, 2016.
56. Sofieva, V.F.; Tamminen, J.; Kyrölä, E.; Mielonen, T.; Veefkind, P.; Hassler, B. and Bodeker, G.E. (2014), A novel tropopause-related climatology of ozone profiles, Atmos. Chem. Phys., 14, 283-299, 2014.
57. Stone, K. A., Morgenstern, O., Karoly, D. J., Klekociuk, A. R., French, W. J., Abraham, N. L., and Schofield, R. (2016): Evaluation of the ACCESS – chemistry–climate model for the Southern Hemisphere, Atmos. Chem. Phys., 16, 2401-2415, doi:10.5194/acp-16-2401-2016, 2016.
58. Tummon, F.; Hassler, B.; Harris, N.R.P.; Staehelin, J.; Steinbrecht, W.; Anderson, J.; Bodeker, G.E.; Bourassa, A.; Davis, S.M.; Degenstein, D.; Frith, S.M.; Froidevaux, L.; Kyrölä, E.; Laine, M.; Long, C.; Penckwitt, A.A.; Sioris, C.E.; Rosenlof, K.H.; Roth, C.; Wang, H.-J. and Wild, J. (2015), Intercomparison of vertically resolved merged satellite ozone data sets: interannual variability and long-term trends, Atmos. Chem. Phys., 15, 3021-3043, 2015.
59. Vigouroux, C., et al. (2015), Trends of ozone total columns and vertical distribution from FTIR observations at eight NDACC stations around the globe, Atmospheric Chemistry and Physics, 15(6), 2915-2933, doi:10.5194/acp-15-2915-2015.
60. Weissert, L. F., J. A. Salmond, G. Miskell, M. Alavi-Shoshtari, S. K. Grange, G. S. Henshaw, and D. E. Williams (2017), Use of a dense monitoring network of low-cost instruments to observe local changes in the diurnal ozone cycles as marine air passes over a geographically isolated urban centre, Science of the Total Environment, 575, 67-78, doi:10.1016/j.scitotenv.2016.09.229.
61. Williamson, C. E., et al. (2014), Solar ultraviolet radiation in a changing climate, Nature Climate Change, 4(6), 434-441, doi:10.1038/nclimate2225.
62. Zaratti, F., R. D. Piacentini, H. A. Guillén, S. H. Cabrera, J. B. Liley, and R. L. McKenzie (2014), Proposal for a modification of the UVI risk scale, Photochem. Photobiol. Sci., 13(7), 980-985, doi:10.1039/C4PP00006D.
63. Zeng, G., Blown with the wind, NATURE GEOSCI., 7, 2, 88-89, DOI:10.1038/ngeo2077, 2014.

5. PROJECTS, COLLABORATION, TWINNING AND CAPACITY BUILDING

National Projects

Ozone and related research in New Zealand are undertaken primarily through the Understanding Atmospheric Composition and Change programme, which includes various measurement activities of ozone and associated species, primarily at Lauder, New Zealand, and Arrival Heights, Antarctica, measurement of physical variables such as UV, as well as global chemistry-climate modelling. UV measurements at Lauder are part of a larger research effort, spanning the physical and medical sciences communities, on the impact of UV on human health (both positive and negative effects), materials, and the biosphere. This research is informing health organizations such as the New Zealand Cancer Society.

International Projects

Ozone research in New Zealand is undertaken in close collaboration with many international partners and contributes to a wide range of international projects. Selected current international projects are:

- NDACC (Network for the Detection of Atmospheric Composition Change), for which Lauder is the primary southern mid-latitude site, has been the principal focus of ozone-related work by NIWA at Lauder for more than three decades. NIWA reports a variety of profile, total column, and surface *in situ* measurements of ozone and associated species to NDACC, taken at its primary locations at Lauder, NZ, and Arrival Heights, Antarctica, and also UV/Vis measurements of total-column NO_2 from Macquarie Island, Australia, taken in collaboration with the Bureau of Meteorology, and Mauna Loa, Hawaii, in collaboration with NOAA.
- IGAC/SPARC CCMI-1 (Chemistry Climate Modelling Initiative phase 1): Contributing CCM simulations to the CCMI archive and participating in process-oriented validation of CCMs. CCMI is the latest in a series of chemistry-climate modelling activities involving NIWA; previously, NIWA contributed to CCMVal-1 (informing the 2006 WMO Ozone Assessment), CCMVal-2 (informing the 2010 Ozone Assessment), and ACCMIP (informing the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) on tropospheric composition change). Unlike these predecessor activities, the aim of CCMI is to perform and assess whole-atmosphere chemistry-climate model simulations that will inform upcoming ozone, tropospheric air quality, and climate assessments, all with the same class of model. NIWA is participating in the development of the MetOffice Unified Model which, in different versions, has been used for all of these purposes, and is also working with Australian partners on their contribution to CCMI, using the ACCESS model. Through a sub-contract with ETH Zurich (Switzerland), Bodeker Scientific has also contributed simulations to CCMI with the SOCOLv3 (Solar Climate Ozone Links version 3) chemistry-climate model.
- GRUAN (GCOS Reference Upper Air Network): Measurements of ozone, water vapour and meteorological parameters using ozonesondes and high-quality radiosondes are made at Lauder, a site hosting a GRUAN-certified measurement programme. Radiosonde measurements at Invercargill are submitted to GRUAN as a collaboration between NIWA and the New Zealand Metservice. In support of GRUAN activities, NIWA has introduced additional quality checks to radiosonde preparations and has installed a GPS/GNSS receiver used for measuring total water vapour column abundance.
- BSRN (Baseline Surface Radiation Network): Various measurements of radiation, particularly of UV, are supplied to this international network.
- SAGE-III-ISS Validation: Validation campaign, planned for 2017, of ozone and aerosol soundings, to validate the SAGE-III instrument on board the International Space Station, on contract with NASA.

National collaborators

NIWA

Richard Querel, Lauder: Ozone measurements project manager; GRUAN

Ben Liley, Lauder: UV, clouds, aerosols

Richard McKenzie (Emeritus), Lauder: UV

Olaf Morgenstern, Wellington: Programme Leader – New Zealand Regional Atmosphere (until Sep. 2016); Chemistry-climate modelling

Guang Zeng, Wellington: Chemistry-climate modelling

Mike Harvey, Wellington: Programme Leader – Measuring Atmospheric Composition (since Sep. 2016)

Wills Dobson, Lauder: Ozonesonde project, Dobson measurements

Dan Smale, Lauder: TEI and FTIR *in situ* ozone measurements

Sylvia Nichol, Wellington: Dobson measurements

Hisako Shiona, Christchurch: Dobson measurements, ozonesonde project, chemistry-climate modelling.

Adrian McDonald, University of Canterbury: Stratospheric ozone and dynamics, model analysis.

Tony Reeder, University of Otago: Effects of UV overexposure in humans.

Martin Allen, Univ Canterbury: UV dosimetry

Barbara Hegan, Cancer Society: UV Public health advisory

Karin Kreher, Bodeker Scientific: UV/Vis measurements of atmospheric composition

Greg Bodeker, Bodeker Scientific: GRUAN, simplified ozone chemistry

Stefanie Kremser, Bodeker Scientific

Birgit Hassler, Bodeker Scientific

Laura Revell, Bodeker Scientific and ETH Zurich: Chemistry-climate modelling, stratospheric ozone chemistry.

Robert Scragg & Alistair Stewart, Univ Auckland: UV, vitamin D and Health

Kathy Nield & Neil Swift, Callaghan Institute/MSL: Irradiance calibration issues, RB meters

Martin Allen, Univ Canterbury: Dosimeters

Zim Sherman, Scienterra, Timaru: Dosimeters

Health agencies including HPA and Cancer Society, Melnet, NZ Dermatological Association
NZ Meteorological Service (provision of UVI forecasts)

Australian collaborations

Peter Gies, Australian Radiation Protection and Nuclear Safety Authority: UV and behavioural studies

David Griffith & Nicholas Jones, University of Wollongong: Collaboration on FTS measurements, especially related to biomass burning

Bruce Forgan, Bureau of Meteorology: Spectral and broadband radiation and aerosols

David Karoly, U Melbourne: Collaboration on coupled chemistry climate modelling

Andrew Klekociuk, Australian Antarctic Division: Collaboration on coupled chemistry-climate modelling.

Janet Bornman (Curtin, Australia), United Nations UNEP: Environmental Effects of UV radiation

Robyn Lucas (ANU): UNEP also UV Workshop

Peter Gies (ARPANSA), Michael Kimlin (QUT): UV Workshop

USA and Canada collaborations

NOAA

Dale Hurst, GMD: Funder and co-investigator on frost point hygrometer flights at Lauder, provision of surface ozone instruments, data sharing and interpretation

Patrick Disterhoft, CSD, CUCF: Global variability of UV (Mauna Loa and Boulder), Calibration of spectroradiometers

Robert Evans & Irina Petropavlovskikh, GMD: Dobson total-column ozone measurements

GMD = Global Monitoring Division (was CMDL); CSD = Chemical Sciences Division (was aeronomy laboratory); CUCF = Colorado Ultraviolet Calibration Facility
NOAA, Maryland USA. Data for UVI Apps (uv2Day and GlobalUV)

NASA

Richard McPeters, GSFC: Provision of Total Ozone Mapping Spectrometer (TOMS) satellite-based total column ozone measurements

Jay Herman, GSFC: Validation of satellite derived UV, UV units

Larry Thomason, LaRC: Provision of Stratospheric Aerosol and Gas Experiment (SAGE) satellite-based measurements of trace gases and aerosols. Lead investigator of the SAGE-III campaign.

Michael Kurylo, NDACC: NDACC data archival, meta data

Qing Liang, Margaret Hurwitz, Paul Newman, GSFC: Chemistry-climate modelling

GSFC = Goddard Space Flight Center; LaRC = Langley Research Center; NDACC = Network for the Detection of Atmospheric Composition Change

USA Universities

Wei Gao & Marek Uliasz, Colorado State University/USDA: Global variability of UV, USDA radiation suite; collaboration on dispersion modelling

Alan Parrish, University of Massachusetts: Co-investigator on microwave radiometers for ozone profiling

Darryn Waugh, Johns Hopkins University: Collaboration on chemistry-climate modelling

USDA = United States Department of Agriculture

Other USA and Canada

Gerald Nedoluha, Naval Research Laboratories (NRL): Co-investigator on microwave radiometers

R Booth & G Bernhard, Biospherical Instruments: Validation of UV from spectrometers

Sasha Madronich, NCAR: TUV Radiative transfer model, aerosol studies, UNEP

Sancy Leachman, Utah: UV dosimeters and health

Tracy Petrie, Oregon: UV dosimeters and health

Charles N. Long, Pacific Northwest National Laboratory (PNNL): Radiation Studies

Vitali Filetov, Environment Canada: UVI

NCAR = National Center for Atmospheric Research

Collaborations with Europe

Neal Butchart & Fiona O'Connor, UK Met Office: Collaboration on chemistry-climate modelling

John Pyle, Alex Archibald, Luke Abraham, University of Cambridge: Chemistry-climate modelling

Ann Webb (and several others), Univ Manchester: Rationalising UV units for CIE

Jordi Badosa, Laboratoire de Meteorologie Dynamique (LMD), Ecole Polytechnique, Palaiseau, France: Radiation Studies

Josep Calbo, Departament de Fısica, Universitat de Girona (UdG), Girona, Spain: Radiation Studies

Daan Swart: National Institute for Public Health and Environmental Protection, The Netherlands: Ozone LIDAR measurements of vertical ozone profiles at Lauder

Ulrich Platt, University of Heidelberg, Germany: Development of instruments and techniques, data sharing and interpretation

Martin Dameris & Hella Garny: DLR-Institut für Physik der Atmosphäre, Germany: Collaboration on chemistry-climate modelling

Mario Blumthaler: Medical University of Innsbruck, Austria: Inter-comparisons and sky radiances

Dietrich Häder: University of Erlangen, Germany: Global variability of UV Eldonet instrument network

Günther Seckmeyer: University of Hannover, Germany: Sky imagery and pollution effects

Michiel van Roozendael, Belgium Institute of Space Aeronomy: Maintain UV/Visible trace gas standards and development of new techniques (NDACC)

Martine de Mazière, BIRA, Belgium: Interpretation of FTS measurements and validation of satellite data

Alkis Bais (Thessaloniki, Greece): UNEP

Lars Olof Bjørn, Lund Univ, Sweden: UNEP FAQs

FMI, Finland. Data for UVI Apps (uv2Day and GlobalUV)

Thomas Peter, Andrea Stenke, Fiona Tummon, Will Ball (ETH Zurich) and Eugene Rozanov (ETH/PMOD), Switzerland: Collaboration on chemistry-climate modelling.

Collaborations with Africa

Piet Aucamp (Private consultant, South Africa): UNEP FAQs

Caradee Wright, South African Medical Research Council: UV dosimeters

Collaborations with Southeast Asia and Japan

Hideaki Nakajima, National Institute for Environmental Studies, Japan: Provision of Improved Limb Atmospheric Spectrometer (ILAS) satellite-based measurements of trace gases

Tetsu Nagai, Meteorological Research Institute of Japan: Aerosol LIDAR

Osamu Uchino, National Institute of Environmental Studies, Japan: Aerosol LIDAR

Yoshihiro Kondo: University of Tokyo, Japan: Spectral irradiance & actinic flux in polluted sites, aerosol studies

Collaborations with South America

Francesco Zaratti, Univ San Andreas, La Paz, Bolivia: Dissemination of UVI information

Sergio Cabrera, Univ de Chile, Santiago, Chile: Dissemination of UVI information

Ruben Piacentini, CONICET, Rosario, Argentina: Dissemination of UVI information

Hector Guillen, Soc Photobiology, Arequipa, Peru: Dissemination of UVI information

Susana Diaz, CONECIT, Buenos Aires, Argentina: UVI/WMO

6. IMPLEMENTATION OF THE RECOMMENDATIONS OF THE 9th OZONE RESEARCH MANAGERS MEETING

In line with the recommendations of the 9th ORM, New Zealand is continuing to fund the high-quality trace gas measurements being made at its atmospheric research facilities. There is an effort underway to homogenise Lauder's historical ozonesonde data set (1987 to present). As mentioned above in item 3 there are also new developments in the areas of chemistry-climate modelling and satellite-based data assimilation products. A new version of the National Institute of Water and Atmospheric Research - Bodeker Scientific (NIWA-BS) total column ozone database has been generated, incorporating updated corrections and new satellite data sets (http://www.bodekerscientific.com/data/total-column-ozone). This assimilated ozone data set has previously featured in the WMO/UNEP report, Scientific Assessment of Ozone Depletion Ozone.

7. FUTURE PLANS

- Future-proof NIWA UV spectrometer systems at Lauder, including conversion of the legacy Visual Basic operating and processing software.
- Maintain and continue operation of all ozone measuring instrumentation at Lauder, Baring Head, and Arrival Heights.
- Continue ozonesonde launches at Lauder under the current 1 per week schedule.
- Work with RIVM to assure continued operation of ozone LIDAR at Lauder
- An intercomparison study of Lauder ozone instrumentation is underway.

8. NEEDS AND RECOMMENDATIONS

The following needs and recommendations require attention:

- Particularly in the tropics, there is some disagreement between different datasets and model results, regarding the trends since 2000 of total column ozone. Detection of ozone recovery in this region would benefit from resolving these discrepancies.
- The effects of stratospheric change on surface climate change, and the mechanisms involved, need to be better quantified. There is now largely a consensus in the literature that seasonally past ozone depletion has been the dominant driver of climate change in the Southern Hemisphere, and future ozone recovery will remain an important driver of climate change, but large uncertainties remain about the regional impacts of both.
- In particular, the links, if any, between ozone depletion and expanding sea ice around Antarctica remain poorly understood and are generally not captured by general circulation models. This casts doubt on climate projections of the Southern Hemisphere.
- Changes in ozone in the upper troposphere and lower stratosphere, especially in the tropics, need to be better quantified and the effects of changes in ozone in this region of

the atmosphere on the temperature structure of the atmosphere need to be better quantified.

- An ongoing debate about ‘optimal’ levels of UV exposure indicates that further research on vitamin D production and its health effects would be useful.
- A better quantification of natural sources of bromine in the troposphere is needed. Particularly, a possible intensification of the aquaculture of kelp, either for food production and carbon capture, would cause a potentially significant increase in the production of bromocarbons, which can affect the stratospheric ozone layer. This risk needs to be understood.
- Continuing support for long-term, high quality measurement sites.