New Zealand National Report
for the 11th WMO/UNEP Ozone Research Managers Meeting
Geneva, April 2020

Introduction

In New Zealand, ozone- and UV-related research is undertaken by the National Institute of Water & Atmospheric Research (NIWA), the University of Canterbury, the University of Otago, and Bodeker Scientific. Many relevant observations are taken at the Lauder Atmospheric Research Station in Central Otago. Lauder station, located at the Southern mid-latitudes (45°S, 170°E, 370 meters above sea level) is a rural and clean background-level site. It is a "Global" station of the World Meteorological Organization's Global Atmosphere Watch Programme, and is also part of several networks including the Network for the Detection of Atmospheric Composition Change (NDACC), GCOS Reference Upper Air Network (GRUAN), Baseline Surface Radiation Network (BSRN), etc. Ozone and several parameters related to ozone depletion are 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, *in situ* sampling, and frost-point hygrometers. Solar UV radiation is measured at several sites across New Zealand. There also are measurement activities outside of New Zealand, such as in Antarctica (Scott Base and Arrival Heights) and some sites in the Pacific Islands. Due to its location in the Southern Hemisphere and proximity to Antarctica, New Zealand is particularly interested in the effects of stratospheric ozone depletion. The "Deep South" National Science Challenge is a 10-year research programme (started in 2014) that aims to improve our understanding of how changes in the Antarctic region affect New Zealand; the effect of ozone depletion and recovery on climate is 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: ozonesondes, Dobson Umkehr, LIDAR, FTS, 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, including city council sites in Auckland and Christchurch as part of their urban air quality instrumentation.

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. New Zealand's Arrival Heights Research facility in Antarctica also hosts a similar suite of instruments that measure ozone and compounds relevant for ozone production and destruction.

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
- Dobson Total Column Ozone since 1987
- UV Spectrometers since 1989
- FTS, ozone total column and other ODS measurements since 1990
- TEI *in situ* ozone analyser since 2004

At Arrival Heights, Antarctica:

- Dobson Total Column Ozone since 1988
- TEI *in situ* ozone analyser since 2003
- FTS, ozone total column and other ODS measurements since 1996
- UV/vis total column NO_2 since 1991

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 which included radiosonde measurements of pressure, temperature and humidity
- Dobson Umkehr since 1987
- Ozone LIDAR since 1994
- Microwave radiometer profiling since 1994
- FTS (ozone and other ODSs) since 1990
- NOAA frost-point hygrometers since 2004

At Arrival Heights, Antarctica:

- Microwave radiometer profiling (ClO) since 1996
- FTS, ozone profile measurements since 1996

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 Hawaii, Boulder Colorado, Alice Springs and Melbourne, Australia. Data from these NDACC sites are archived at the NDACC database, and spectral data are archived from 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 New Zealand 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 NIWA's UV measurement programme, the following are also available at Lauder:

- TCCON (Total Carbon Column Observation Network)
- BSRN radiation suite (direct, diffuse, and global short-wave radiation)
- Aerosol optical depth at several wavelengths, and from LIDAR
- All sky cameras
- Direct beam spectral irradiances (285-600 nm)
- Actinic flux measurements (JNO_2)
- 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.

The new version of the Scienterra UV Dosimeter is currently in development, thanks to R&D funding from Callaghan Innovation. The new instrument is 60% smaller, and measures concurrent UVA, UVB, red, green, blue, and broadband white/IR wavebands, covering between 280-1000 nm. The SRF of the UVB channel matches the erythemal action spectrum, the green channel matches the photopic eye response, and the blue channel matches the melatonin suppression action spectrum. Additional functions include orientation, pedometry and GGIR-type motion analysis. This suite of measurements was designed by a panel of researchers to help untangle the convoluted influences of UV and other radiation, sleep, and exercise, and how they affect human health. Data are provided over Bluetooth to a smartphone app, with daily uploads to a cloud-based database. More information can be found at: http://scienterra.com/.

1.4 Calibration activities

- NIWA UV spectrometers are used to cross calibrate other spectrometers in Australasia.
- Broadband meters are cross calibrated against spectroradiometers at Lauder.
- Lauder Dobson (D072) NDACC calibration to the regional standard in Melbourne, Feb. 2017.
- Arrival Heights Dobson (D017) NDACC calibration to the regional standard in Melbourne, Nov. 2017.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

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

3. THEORY, MODELLING, AND OTHER OZONE RELATED RESEARCH

New Zealand efforts in theory and modelling, as with the measurements, are disseminated through research papers, UNEP EEAP Reports, and WMO Ozone Assessment Reports.
UNEP: https://ozone.unep.org/science/assessment/eeap
WMO: https://ozone.unep.org/science/assessment/sap

One example of this work is the Deep South-funded research whereby scientists at Bodeker Scientific have developed updated versions of the long-term homogeneous databases of (1) total column ozone and (2) vertically resolved monthly mean zonal mean ozone. Described here:

Total Column Ozone: The latest version 3.4 of the National Institute of Water & Atmospheric Research - Bodeker Scientific (NIWA-BS) total column ozone database is available from http://www.bodekerscientific.com/data/total-column-ozone. The database is constructed by combining measurements from 17 different satellite-based instruments and extends from 1 November 1978 to 31 December 2016. Offsets and drifts between the different data sets are resolved through comparisons with the Dobson and Brewer ground-based instruments and through inter-satellite instrument comparisons. This version of the database improves on previous versions by providing a 'machine-learning' based filled version of the total column ozone fields as described at http://www.bodekerscientific.com/data/total-column-ozone/tcofillingalgorithm.

Vertically resolved ozone database: The latest version of the Bodeker Scientific Vertically Resolved Ozone Database (BSVerticalOzone) is available on the Bodeker Scientific website (http://www.bodekerscientific.com/data/monthly-mean-global-vertically-resolved-ozone) and the database has been archived on Zenodo (https://zenodo.org/record/1217184). This database is constructed by combining measurements from several satellite-based instruments and ozonesondes and extends from 1979 to 2016. Monthly mean zonal mean ozone concentrations in mixing ratio and number density are provided in 5° latitude bins, spanning 70 altitude levels (1 to 70 km), or 70 pressure levels that are approximately 1 km apart (878.4 to 0.046 hPa). A gap filling technique is used to generate different data sets or 'Tiers'. The different Tier 1.X data sets can be used for comparisons with chemistry–climate model (CCM) simulations that do not exhibit the same unforced variability as reality (unless they are nudged towards reanalyses).

IGAC/SPARC Chemistry-Climate Model Initiative (CCMI): New Zealand has participated in this multi-model activity which during the reporting period has produced numerous publications. The aim of CCMI is to improve our understanding of these complex systems and help inform ozone, climate, and air quality assessments. CCMI simulations were used in the 2018 WMO Scientific Assessment of Ozone Depletion report.

NIWA is involved in the Aerosols and Chemistry Model Intercomparison Project (AerChemMIP) which amongst other topics assesses the role of ozone depletion in climate change. Partnering with the UK Met Office, UK Universities, and the Korean Meteorological Agency, NIWA has produced several climate model simulations using the UKESM1 model and is now participating in the evaluation of these simulations.

University of Otago was a key participant in the development of the first solar forcing proxy for energetic particle precipitation (EPP) to be used in chemistry-climate models. EPP influences polar mesospheric and upper stratospheric ozone variability, particularly during winter and spring seasons, with demonstrated links to regional climate variability. This proxy is used in the CMIP6 (Coupled Model Intercomparison Project Phase 6) global simulations. The CMIP6 EPP proxy is available from: https://solarisheppa.geomar.de/cmip6.

University of Otago is a major contributor to global climate modelling efforts. These climate model simulations aim to improve our understanding of solar influence (via EPP) on polar ozone, and to investigate the physical mechanisms driving predicted and detected surface level regional climate responses that arise from changes in ozone. This research is driven by the global need to improve our understanding of, and capability to simulate, background regional climate variability driven by solar activity.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

See above. NIWA UV data are archived at:

NDACC: http://www.ndaccdemo.org/ (spectral summaries)
WOUDC: http://woudc.org/
NIWA: https://cliflo.niwa.co.nz/ (broad band)
Surface in situ ozone: https://www.esrl.noaa.gov/gmd/ozwv/surfoz/data.html

Scientific papers, etc. (see 4.3 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: FTS ozone & ODSs, total column and profiles
NDACC: LIDAR ozone profiles

4.2 Information to the public

Information to the public are provided by:

- data archived at NDACC, WOUDC, GRUAN, etc., are all publicly accessible.
- NIWA provides information about UV forecasts, maps of ozone and UV, time series of ozone on their publicly available web pages.
- UV Index displays are located in public places, together with behavioural advice
- Smartphone Apps that show the UV variation during the course of the day and include 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 New Zealand 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 2017:

1. Anderson, Daniel C., Julie M. Nicely, Glenn M. Wolfe, Thomas F. Hanisco, Ross J. Salawitch, Timothy P. Canty, Russell R. Dickerson, Eric C. Apel, Sunil Baidar, Thomas J. Bannan, Nicola J. Blake, Dexian Chen, Barbara Dix, Rafael P. Fernandez, Samuel R. Hall, Rebecca S. Hornbrook, L. Gregory Huey, Beatrice Josse, Patrick Jöckel, Douglas E. Kinnison, Theodore K. Koenig, Michael Le Breton, Virginie Marécal, Olaf Morgenstern, Luke D. Oman, Laura L. Pan, Carl Percival, David Plummer, Laura E. Revell, Eugene Rozanov, Alfonso Saiz-Lopez, Andrea Stenke, Kengo Sudo, Simone Tilmes, Kirk Ullmann, Rainer Volkamer, Andrew J. Weinheimer, and Guang Zeng. “Formaldehyde in the Tropical

Western Pacific: Chemical Sources and Sinks, Convective Transport, and Representation in CAM-Chem and the CCMI Models." Journal of Geophysical Research: Atmospheres 122, no.20 (2017): 11,201-11,26. http://dx.doi.org/doi:10.1002/2016JD026121.

2. Andersson M.E., P.T. Verronen, D.R. Marsh, A. Seppälä, S.-M. Päivärinta, C.J. Rodger, M.A Clilverd, N. Kalakoski, and M. van de Kamp, Polar ozone response to energetic particle precipitation over decadal time scales: the role of medium-energy electrons. J. Geophys. Res., 123, 607-622, doi:10.1002/2017JD027605, 2018.
3. Boynard, A., Hurtmans, D., Garane, K., Goutail, F., Hadji-Lazaro, J., Koukouli, M. E., Wespes, C., Vigouroux, C., Keppens, A., Pommereau, J.-P., Pazmino, A., Balis, D., Loyola, D., Valks, P., Sussmann, R., Smale, D., Coheur, P.-F., and Clerbaux, C.: Validation of the IASI FORLI/EUMETSAT ozone products using satellite (GOME-2), ground-based (Brewer–Dobson, SAOZ, FTIR) and ozonesonde measurements, Atmos. Meas. Tech., 11, 5125-5152, https://doi.org/10.5194/amt-11-5125-2018, 2018.
4. Brönnimann, S., M. Jacques-Coper, E. Rozanov, A. M. Fischer, O. Morgenstern, G. Zeng, H. Akiyoshi, Y. Yamashita (2017), Tropical circulation and precipitation response to ozone depletion and recovery, Environ. Res. Lett. 12, doi:10.1088/1748-9326/aa7416.
5. Chipperfield, M.P.; Bekki, S.; Dhomse, S.; Harris, N.R.P.; Hassler, B.; Hossaini, R.; Steinbrecht, W.; Thiéblemont, R. and Weber, M., Detecting recovery of the stratospheric ozone layer, Nature, 548, 211-218, doi:10.1038/nature23681, 2017.
6. Chrysanthou, A., Maycock, A. C., Chipperfield, M. P., Dhomse, S., Garny, H., Kinnison, D., Akiyoshi, H., Deushi, M., Garcia, R. R., Jöckel, P., Kirner, O., Pitari, G., Plummer, D. A., Revell, L., Rozanov, E., Stenke, A., Tanaka, T. Y., Visioni, D., and Yamashita, Y.: The effect of atmospheric nudging on the stratospheric residual circulation in chemistry-climate models, Atmos. Chem. Phys., 19, 11559-11586, https://doi.org/10.5194/acp-19-11559-2019, 2019.
7. Dennison, F., J. Keeble, O. Morgenstern, G. Zeng, N. L. Abraham, and X. Yang (2019), Improvements to stratospheric chemistry in the UM-UKCA (v10.7) model: solar cycle and heterogeneous reactions, Geosci. Model Dev., 12, 1227-1239, https://doi.org/10.5194/gmd-12-1227-2019.
8. Dennison, F., McDonald, A., and Morgenstern, O.: The evolution of zonally asymmetric austral ozone in a chemistry–climate model, Atmos. Chem. Phys., 17, 14,075-14,084, doi:10.5194/acp-17-14075-2017, 2017.
9. Denton, M.H., R. Kivi, T. Ulich, C.J. Rodger, M.A. Clilverd, J.S. Denton, M. Lester, Observed response of stratospheric and mesospheric composition to sudden stratospheric warmings, J. Atmos. Sol. Terr. Phys., 191, 105054, doi:10.1016/j.jastp.2019.06.001, 2019.
10. Denton, M.H., R. Kivi, Th. Ulich, C.J. Rodger, M.A. Clilverd, R.B. Horne, and A.J. Kavanagh, Solar proton events and stratospheric ozone depletion over northern Finland, J. Atmos. Sol. Terr. Phys., 177, 218-227, doi:10.1016/j.jastp.2017.07.003, 2018.
11. Denton, M.H., R. Kivi, Th. Ulich, M.A. Clilverd, C.J. Rodger, and P. von der Gathen, Northern Hemisphere Stratospheric Ozone Depletion Caused by Solar Proton Events: The Role of the Polar Vortex, Geophys. Res. Lett., 45, 2115-2124, doi:10.1002/2017GL075966, 2018.
12. Dhomse, S., Kinnison, D., Chipperfield, M. P., Cionni, I., Hegglin, M., Abraham, N. L., Akiyoshi, H., Archibald, A. T., Bednarz, E. M., Bekki, S., Braesicke, P., Butchart, N., Dameris, M., Deushi, M., Frith, S., Hardiman, S. C., Hassler, B., Horowitz, L. W., Hu, R.-M., Jöckel, P., Josse, B., Kirner, O., Kremser, S., Langematz, U., Lewis, J., Marchand, M., Lin, M., Mancini, E., Marécal, V., Michou, M., Morgenstern, O., O'Connor, F. M., Oman, L., Pitari, G., Plummer, D. A., Pyle, J. A., Revell, L. E., Rozanov, E., Schofield, R., Stenke, A., Stone, K., Sudo, K., Tilmes, S., Visioni, D., Yamashita, Y., and Zeng, G. (2018), Estimates of Ozone Return Dates from Chemistry-Climate Model Initiative Simulations, Atmos. Chem. Phys., 18, 8409-8438, https://doi.org/10.5194/acp-18-8409-2018.
13. Dietmüller, S., Eichinger, R., Garny, H., Birner, T., Boenisch, H., Pitari, G., Mancini, E., Visioni, D., Stenke, A., Revell, L., Rozanov, E., Plummer, D. A., Scinocca, J., Jöckel, P., Oman, L., Deushi, M., Kiyotaka, S., Kinnison, D. E., Garcia, R., Morgenstern, O., Zeng, G., Stone, K. A., and Schofield, R.: Quantifying the effect of mixing on the mean age of air in CCMVal-2 and CCMI-1 models, Atmos. Chem. Phys., 18, 6699-6720, https://doi.org/10.5194/acp-18-6699-2018, 2018.
14. Eichinger, R., Dietmüller, S., Garny, H., Šácha, P., Birner, T., Bönisch, H., Pitari, G., Visioni, D., Stenke, A., Rozanov, E., Revell, L., Plummer, D. A., Jöckel, P., Oman, L., Deushi, M., Kinnison, D. E., Garcia, R., Morgenstern, O., Zeng, G., Stone, K. A., and Schofield, R.: The influence of mixing on the

stratospheric age of air changes in the 21st century, Atmos. Chem. Phys., 19, 921-940, https://doi.org/10.5194/acp-19-921-2019, 2019.
15. Gage, R., Barr, M., Stanley, J., Reeder, A., Mackay, C., Smith, M., Chambers, T., Leung, W., Signal, L. Sun protection and shade availability in New Zealand's outdoor recreational spaces. NZ Medical Journal, 2018; 131:1484, in press.
16. Gage, R., Leung W., Stanley, J., Reeder, A., Mackay, C., Chambers, T., Barr, M., Signal, L. Studying third parties and environments: New Zealand sun-safety research. Health Promotion International, 2017. https://doi.org/10.1093/heapro/dax094
17. Gage, R., Leung, W., Stanley, J., Reeder, A.I., Barr, M., Chambers, T., Smith, M., Signal, L. Clothing Protection from Ultraviolet Radiation: A New Method for Assessment. Photochemistry and Photobiology, 2017, https://doi.org/10.1111/php
18. Gage, R., Leung, W., Stanley, J., Reeder, A.I., Mackay, C., Smith, M., Barr, M., Chambers, T., Signal, L. Sun protection among New Zealand primary school children. Health Education and Behavior, 2017, https://doi.org/10.1007/s10900-018-0522-0
19. Gage, R., O'Toole, C., Robinson, A., Reeder, A., Signal, L., & Mackay, C. Wellington playgrounds uncovered: An examination of solar ultraviolet radiation and shade protection in New Zealand. Photochemistry & Photobiology, 2018, 94:357-361. doi: 10.1111/php.12855
20. Gage, R., Wilson, N., Signal, L., Barr, M., Mackay, C., Reeder A., Thomson, G. Using Google Earth to assess shade for sun protection in urban recreation spaces: Methods and results. Journal of Community Health, 2018, https://doi.org/10.1007/s10900-018-0522-0
21. Gaudel, A., Cooper, O. R., Ancellet, G., Barret, B., Boynard, A., Burrows, J. P., Clerbaux, C., Coheur, P. F., Cuesta, J., Cuevas, E., Doniki, S., Dufour, G., Ebojie, F., Foret, G., Garcia, O., Granados-Munoz, M. J., Hannigan, J. W., Hase, F., Hassler, B., Huang, G., Hurtmans, D., Jaffe, D., Jones, N., Kalabokas, P., Kerridge, B., Kulawik, S., Latter, B., Leblanc, T., Le Flochmoen, E., Lin, W., Liu, J., Liu, X., Mahieu, E., McClure-Begley, A., Neu, J. L., Osman, M., Palm, M., Petetin, H., Petropavlovskikh, I., Querel, R., Rahpoe, N., Rozanov, A., Schultz, M. G., Schwab, J., Siddans, R., Smale, D., Steinbacher, M., Tanimoto, H., Tarasick, D. W., Thouret, V., Thompson, A. M., Trickl, T., Weatherhead, E., Wespes, C., Worden, H. M., Vigouroux, C., Xu, X., Zeng, G., & Ziemke, J. (2018). Tropospheric Ozone Assessment Report: Present-day distribution and trends of tropospheric ozone relevant to climate and global atmospheric chemistry model evaluation. Elementa-Science of the Anthropocene, 6. doi:10.1525/elementa.291
22. Gillett, Z.E., J.M. Arblaster, A.J. Dittus, M. Deushi, P. Jöckel, D.E. Kinnison, O. Morgenstern, D.A. Plummer, L.E. Revell, E. Rozanov, R. Schofield, A. Stenke, K.A. Stone, and S. Tilmes: Evaluating the Relationship between Interannual Variations in the Antarctic Ozone Hole and Southern Hemisphere Surface Climate in Chemistry–Climate Models. J. Climate, 32, 3131–3151, https://doi.org/10.1175/JCLI-D-18-0273.1, 2019.
23. Gordon, E., A. Seppälä, and J. Tamminen, EPP-NOx in Antarctic springtime stratospheric column: Evidence from observations and influence of the QBO, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2019-1035, 2019.
24. Harari, O., Garfinkel, C. I., Ziskin Ziv, S., Morgenstern, O., Zeng, G., Tilmes, S., Kinnison, D., Deushi, M., Jöckel, P., Pozzer, A., O'Connor, F. M., and Davis, S. (2019), Influence of Arctic stratospheric ozone on surface climate in CCMI models, Atmos. Chem. Phys., 19, 9253-9268, https://doi.org/10.5194/acp-19-9253-2019.
25. Hassler, B.; Kremser, S.; Bodeker, G.E.; Lewis, J.; Nesbit, K.; Davis, S.; Chipperfield, M.; Dhomse, S. and Dameris, M., An updated version of a gap-free monthly mean zonal mean ozone database, Earth System Science Data Discussions, 2018.
26. Huang, G. Y., Liu, X., Chance, K., Yang, K., Bhartia, P. K., Cai, Z. N., Allaart, M., Ancellet, G., Calpini, B., Coetzee, G. J. R., Cuevas-Agullo, E., Cupeiro, M., De Backer, H., Dubey, M. K., Fuelberg, H. E., Fujiwara, M., Godin-Beekmann, S., Hall, T. J., Johnson, B., Joseph, E., Kivi, R., Kois, B., Komala, N., Konig-Langlo, G., Laneve, G., Leblanc, T., Marchand, M., Minschwaner, K. R., Morris, G., Newchurch, M. J., Ogino, S. Y., Ohkawara, N., Piters, A. J. M., Posny, F., Querel, R., Scheele, R., Schmidlin, F. J., Schnell, R. C., Schrems, O., Selkirk, H., Shiotani, M., Skrivankova, P., Sutbi, R., Taha, G., Tarasick, D. W., Thompson, A. M., Thouret, V., Tully, M. B., Van Malderen, R., Vomel, H., von der Gathen, P., Witte, J. C., & Yela, M. (2017). Validation of 10-year SAO OMI Ozone Profile (PROFOZ) product using

ozonesonde observations. Atmospheric Measurement Techniques, 10(7). doi:10.5194/amt-10-2455-2017

27. Knepp, T. N., Querel, R., Johnston, P., Thomason, L., Flittner, D., & Zawodny, J. M. (2017). Intercomparison of Pandora stratospheric NO2 slant column product with the NDACC-certified M07 spectrometer in Lauder, New Zealand. Atmospheric Measurement Techniques, 10(11), 4363-4372. doi:10.5194/amt-10-4363-2017
28. Kreher, K., Van Roozendael, M., Hendrick, F., Apituley, A., Dimitropoulou, E., Frieß, U., Richter, A., Wagner, T., Abuhassan, N., Ang, L., Anguas, M., Bais, A., Benavent, N., Bösch, T., Bognar, K., Borovski, A., Bruchkouski, I., Cede, A., Chan, K. L., Donner, S., Drosoglou, T., Fayt, C., Finkenzeller, H., Garcia-Nieto, D., Gielen, C., Gómez-Martín, L., Hao, N., Herman, J. R., Hermans, C., Hoque, S., Irie, H., Jin, J., Johnston, P., Khayyam Butt, J., Khokhar, F., Koenig, T. K., Kuhn, J., Kumar, V., Lampel, J., Liu, C., Ma, J., Merlaud, A., Mishra, A. K., Müller, M., Navarro-Comas, M., Ostendorf, M., Pazmino, A., Peters, E., Pinardi, G., Pinharanda, M., Piters, A., Platt, U., Postylyakov, O., Prados-Roman, C., Puentedura, O., Querel, R., Saiz-Lopez, A., Schönhardt, A., Schreier, S. F., Seyler, A., Sinha, V., Spinei, E., Strong, K., Tack, F., Tian, X., Tiefengraber, M., Tirpitz, J.-L., van Gent, J., Volkamer, R., Vrekoussis, M., Wang, S., Wang, Z., Wenig, M., Wittrock, F., Xie, P. H., Xu, J., Yela, M., Zhang, C., and Zhao, X.: Intercomparison of NO2, O4, O3 and HCHO slant column measurements by MAX-DOAS and zenith-sky UV-Visible spectrometers during the CINDI-2 campaign, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2019-157, in review, 2019.
29. Kuchar, Ales, William T. Ball, Eugene V. Rozanov, Andrea Stenke, Laura Revell, Jiri Miksovsky, Petr Pisoft, and Thomas Peter. “On the Aliasing of the Solar Cycle in the Lower Stratospheric Tropical Temperature.” Journal of Geophysical Research: Atmospheres 122, no. 17 (2017): 9076-93. http://dx.doi.org/doi:10.1002/2017JD026948.
30. Lamy, K., Partafaix, T., Josse, B., Brogniez, C., Godin-Beekmann, S., Bencherif, H., Revell, L., Akiyoshi, H., Bekki, S., Hegglin, M. I., Jöckel, P., Kirner, O., Liley, B., Marecal, V., Morgenstern, O., Stenke, A., Zeng, G., Abraham, N. L., Archibald, A. T., Butchart, N., Chipperfield, M. P., Di Genova, G., Deushi, M., Dhomse, S. S., Hu, R.-M., Kinnison, D., Kotkamp, M., McKenzie, R., Michou, M., O’Connor, F. M., Oman, L. D., Pitari, G., Plummer, D. A., Pyle, J. A., Rozanov, E., Saint-Martin, D., Sudo, K., Tanaka, T. Y., Visioni, D., and Yoshida, K.: Clear-sky ultraviolet radiation modelling using output from the Chemistry Climate Model Initiative, Atmos. Chem. Phys., 19, 10087-10110, https://doi.org/10.5194/acp-19-10087-2019 , 2019.
31. Lu, X., Zhang, L., Zhao, Y. H., Jacob, D. J., Hu, Y. Y., Hu, L., Gao, M., Liu, X., Petropavlovskikh, I., McClure-Begley, A., & Querel, R. (2019). Surface and tropospheric ozone trends in the Southern Hemisphere since 1990: possible linkages to poleward expansion of the Hadley circulation. Science Bulletin, 64(6), 400-409. doi:10.1016/j.scib.2018.12.021
32. Matthes, K., B. Funke, M.E. Andersson, L. Barnard, J. Beer, P. Charbonneau, M.A. Clilverd, T. Dudok de Wit, M. Haberreiter, A. Hendry, C.H. Jackman, M. Kretzschmar, T. Kruschke, M. Kunze, U. Langematz, D.R. Marsh, A.C. Maycock, S. Misios, C.J. Rodger, A.A. Scaife, A. Seppälä, M. Shangguan, M. Sinnhuber, K. Tourpali, I. Usoskin, M. van de Kamp, P.T. Verronen, and S. Versick, Solar forcing for CMIP6 (v3.2), Geosci. Model Dev., 10, 2247-2302, doi:10.5194/gmd-10-2247-2017, 2017.
33. Maycock, A. C., Matthes, K., Tegtmeier, S., Schmidt, H., Thiéblemont, R., Hood, L., Akiyoshi, H., Bekki, S., Deushi, M., Jöckel, P., Kirner, O., Kunze, M., Marchand, M., Marsh, D. R., Michou, M., Plummer, D., Revell, L. E., Rozanov, E., Stenke, A., Yamashita, Y., and Yoshida, K.: The representation of solar cycle signals in stratospheric ozone – Part 2: Analysis of global models, Atmos. Chem. Phys., 18, 11323-11343, https://doi.org/10.5194/acp-18-11323-2018, 2018.
34. Maycock, Amanda C., William J. Randel, Andrea K. Steiner, Alexey Yu Karpechko, John Cristy, Roger Saunders, David W. J. Thompson, Cheng-Zhi Zou, Andreas Chrysanthou, N. Luke Abraham, Hiderahu Akiyoshi, Alex T. Archibald, Neal Butchart, Martyn Chipperfield, Martin Dameris, Makoto Deushi, Sandip Dhomse, Glauco Di Genova, Patrick Jöckel, Douglas E. Kinnison, Oliver Kirner, Florian Ladstädter, Martine Michou, Olaf Morgenstern, Fiona O’Connor, Luke Oman, Giovanni Pitari, David A. Plummer, Laura E. Revell, Eugene Rozanov, Andrea Stenke, Daniele Visioni, Yousuke Yamashita, Guang Zeng (2018), Revisiting the mystery of recent stratospheric temperature trends, Geophys. Res. Lett., https://doi.org/10.1029/2018GL078035

35. McKenzie, R, G. Bernhard, B. Liley, P. Disterhoft, S. Rhodes, A. Bais, O. Morgenstern, P. Newman, L. Oman, C. Brogniez and S. Simic, Success of Montreal Protocol demonstrated by comparing high-quality UV measurements with “World Avoided” calculations from two chemistry-climate models, Scientific Reports, 2019, 9, 12332
36. McKenzie, R. L. and R. M. Lucas, Flawed UV advice for outdoor pursuits, Parks & Leisure Australasia, 2018.
37. McKenzie, R. L. and R. M. Lucas, Reassessing impacts of extended daily exposure to low level solar UV radiation, Scientific Reports, 2018.
38. McKenzie, R., G. Bernhard, B. Liley, P. Disterhoft, S. Rhodes, A. Bais, O. Morgenstern, P. Newman, C. Brogniez, and S. Simic (2019), Success of Montreal Protocol demonstrated by comparing high-quality UV measurements with “World Avoided” calculations from two chemistry-climate models, Scientific Reports, 9, 12332, https://www.nature.com/articles/s41598-019-48625-z
39. McLeod, G.F.H., Dhakal, B., Reeder A.I., McGee, R. Sunburn paradoxes and the New Zealand population. Journal of Public Health: From Theory to Practice. In press. https://doi.org/10.1007/s10389-019-01142-9
40. McLeod, G.F.H., Reeder, A.I., Gray, A.R., McGee, R. Unintended sunburn: A potential target for sun protection messages. Journal of Skin Cancer, 2017, https://doi.org/10.1155/2017/6902942
41. McNoe, B.M., Reeder, A.I. Sun protection policies and practices in New Zealand primary schools. New Zealand Medical Journal. In press.
42. McNoe, B.M., Reeder, A.I., de Lange, M.P. SunSmart schools: a New Zealand skin cancer primary prevention intervention blueprint for primary school settings. British Journal of Dermatology 2018; doi: 10.1111/bjd.16670 (Research letter).
43. 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. “Review of the Global Models Used within Phase 1 of the Chemistry–Climate Model Initiative (CCMI).” Geosci. Model Dev. 10, no. 2 (2017): 639-71. http://dx.doi.org/10.5194/gmd-10-639-2017.
44. Morgenstern, O., Stone, K., Schofield, R., Akiyoshi, H., Yamashita, Y., Kinnison, D. E., Garcia, R. R., Plummer, D. A., Scinocca, J., Zeng, G., Rozanov, E., Stenke, A., Revell, L. E., Pitari, G., Mancini, E., Di Genova, G., Visioni, D., Dhomse, S. S., and Chipperfield, M. P. (2018), Ozone sensitivity to varying greenhouse gases and ozone-depleting substances in CCMI simulations, Atmos. Chem. Phys., 18, 1091–1114, doi:10.5194/acp-18-1091-2018.
45. Newnham, D.A., M.A. Clilverd, M. Kosch, A. Seppälä, and P.T. Verronen, Simulation study for ground-based Ku-band microwave observations of ozone and hydroxyl in the polar middle atmosphere, Atmos. Meas. Tech., 12, 1375–1392, doi:10.5194/amt-12-1375-2019, 2019.
46. Orbe, C., H. Yang, D. W. Waugh, G. Zeng, O. Morgenstern, D. E. Kinnison, J. F. Lamarque, S. Tilmes, D. A. Plummer, J. F. Scinocca, B. Josse, V. Marecal, P. Jöckel, L. D. Oman, S. E. Strahan, M. Deushi, T. Y. Tanaka, K. Yoshida, H. Akiyoshi, Y. Yamashita, A. Stenke, L. Revell, T. Sukhodolov, E. Rozanov, G. Pitari, D. Visioni, K. A. Stone, R. Schofield, and A. Banerjee. “Large-Scale Tropospheric Transport in the Chemistry–Climate Model Initiative (CCMI) Simulations.” Atmos. Chem. Phys. 18, no. 10 (2018): 7217-35. http://dx.doi.org/10.5194/acp-18-7217-2018.
47. Orsolini, Y.J., C. Smith-Johnsen, D.R. Marsh, F. Stordal, C. J. Rodger, P.T. Verronen, and M.A. Clilverd, Mesospheric nitric acid enhancements during energetic electron precipitation events simulated by WACCM-D, J. Geophys. Res., 123, 6984-6998, doi:10.1029/2017JA025002, 2018.
48. Peters, E., Pinardi, G., Seyler, A., Richter, A., Wittrock, F., Bosch, T., Van Roozendael, M., Hendrick, F., Drosoglou, T., Bais, A. F., Kanaya, Y., Zhao, X. Y., Strong, K., Lampel, J., Volkamer, R., Koenig, T., Ortega, I., Puentedura, O., Navarro-Comas, M., Gomez, L., Gonzalez, M. Y., Piters, A., Remmers, J., Wang, Y., Wagner, T., Wang, S. S., Saiz-Lopez, A., Garcia-Nieto, D., Cuevas, C. A., Benavent, N., Querel, R., Johnston, P., Postylyakov, O., Borovski, A., Elokhov, A., Bruchkouski, I., Liu, H. R., Liu, C., Hong, Q. Q., Rivera, C., Grutter, M., Stremme, W., Khokhar, M. F., Khayyam, J., & Burrows, J. P. (2017). Investigating differences in DOAS retrieval codes using MAD-CAT campaign data. Atmospheric

Measurement Techniques, 10(3), 955-978. Retrieved from <Go to ISI>://WOS:000397476400003. doi:10.5194/amt-10-955-2017
49. Petersen, E., Richards, R., McNoe, B., Reeder, A.I. SunSmart news? Traditional media coverage of sun protection issues during springtime in New Zealand. Health Promotion Journal of Australia, 2019; 30:272-5
50. Pettit, J., C.E. Randall, E.D. Peck, D.R. Marsh, X. Fang, M. van de Kamp, C.J. Rodger, and B. Funke, Atmospheric Effects of >30 keV Energetic Electron Precipitation in the Southern Hemisphere Winter during 2003, J. Geophys. Res., 124, doi:10.1002/2019JA026868, 8138-8153, 2019.
51. Polvani, L. M., L. Wang, M. Abalos, N. Butchart, M. Chipperfield, M. Deushi, P. Jöckel, D. Kinnison, M. Michou, O. Morgenstern, L. Oman, D. Plummer, K. Stone (2019), Large impacts, past and future, of ozone depleting substances on Brewer-Dobson circulation trends: A multi-model assessment, J. Geophys. Res. Atmos., 124, https://doi.org/10.1029/2018JD029516.
52. Querel, R., 2018. What's happening to ozone in this part of the world? NIWA UV Workshop, Wellington, New Zealand.
53. Revell, L. E., A. Stenke, B. Luo, S. Kremser, E. Rozanov, T. Sukhodolov, and T. Peter. "Impacts of Mt Pinatubo Volcanic Aerosol on the Tropical Stratosphere in Chemistry–Climate Model Simulations Using CCMI and CMIP6 Stratospheric Aerosol Data." Atmos. Chem. Phys. 17, no. 21 (2017): 13139-50. http://dx.doi.org/10.5194/acp-17-13139-2017.
54. Revell, L. E., A. Stenke, F. Tummon, A. Feinberg, E. Rozanov, T. Peter, N. L. Abraham, H. Akiyoshi, A. T. Archibald, N. Butchart, M. Deushi, P. Jöckel, D. Kinnison, M. Michou, O. Morgenstern, F. M. O'Connor, L. D. Oman, G. Pitari, D. A. Plummer, R. Schofield, K. Stone, S. Tilmes, D. Visioni, Y. Yamashita, and G. Zeng. Tropospheric Ozone in CCMI Models and Gaussian Process Emulation to Understand Biases in the SOCOLv3 Chemistry–Climate Model. Atmos. Chem. Phys. 18, no. 21 (2018): 16155-72. http://dx.doi.org/10.5194/acp-18-16155-2018.
55. Revell, L.E.; Stenke, A.; Luo, B.P.; Kremser, S.; Rozanov, E.; Sukhodolov, T. and Peter, T., Impacts of Mt Pinatubo volcanic aerosol on the tropical stratosphere in chemistry-climate model simulations using CCMI and CMIP6 stratospheric aerosol data, Atmospheric Chemistry and Physics, 17, 13139-13150, doi:10.5194/acp-17-13139-2017, 2017.
56. Scragg, R.K.R., Stewart, A.W., McKenzie, R.L., Reeder, A.I., Liley, J.B., Allen, M.W. Sun exposure and 25-hydroxyvitamin D3 levels in a community sample: quantifying the association with electronic dosimeters. Journal of Exposure Science and Environmental Epidemiology, 2017, 27:471-7, doi:10.0138/jes.2016.51.
57. Sellar, A. A., C. G. Jones, J. Mulcahy, Y. Tang, A. Yool, A. Wiltshire, F. M. O'Connor, M. Stringer, R. Hill, J. Palmieri, S. Woodward, L. de Mora, T. Kuhlbrodt, S. Rumbold, D. I. Kelley, R. Ellis, C. E. Johnson, J. Walton, N. L. Abraham, M. B. Andrews, T. Andrews, A. T. Archibald, S. Berthou, E. Burke, E. Blockley, K. Carslaw, M. Dalvi, J. Edwards, G. A. Folberth, N. Gedney, P. T. Griffiths, A. B. Harper, M. A. Hendry, A. J. Hewitt, B. Johnson, A. Jones, C. D. Jones, J. Keeble, S. Liddicoat, O. Morgenstern, R. J. Parker, V. Predoi, E. Robertson, A. Siahaan, R. S. Smith, R. Swaminathan, M. T. Woodhouse, G. Zeng, and M. Zerroukat (2019), UKESM1: Description and evaluation of the UK Earth System Model, J. Adv. Model. Earth Sys., doi: 10.1029/2019MS001739
58. Seppälä A., E. Douma, C.J. Rodger, P.T. Verronen, M.A. Clilverd, and J. Bortnik. Relativistic electron microburst events: modeling the atmospheric impact. Geophys. Res. Lett., 45, doi:10.1002/2017GL075949, 2018.
59. Shi, Y., M. Manco, D. Moyal, G. Huppert, H. Araki, A. Banks, H. Joshi, R. McKenzie, A. Seewald, G. Griffin, E. Sen-Gupta, D. W. Bastien, F. Valceschini, S. Seité, J. A. Wright, R. Ghaffari, J. Rogers, G. Balooch and R. M. Pielak, Soft, stretchable, epidermal sensor with integrated electronics and photochemistry for measuring personal UV exposures, PloS ONE, 2018, 13, e0190233.
60. Son, S.-W., B.-R. Han, C. I. Garfinkel, S.-Y. Kim, R. Park, N. L. Abraham, H. Akiyoshi, A. Archibald, N. Buthart, M. P. Chipperfield, M. Dameris, M. Deushi, S. S. Dhomse, S. C. Hardiman, P. Jöckel, D. Kinnison, M. Michou, O. Morgenstern, F. M. O'Connor, L. D. Oman, D. A. Plummer, A. Pozzer, L. E. Revell, E. Rozanov, A. Stenke, K. Stone, S. Tilmes, Y. Yamashita and G. Zeng (2018), Tropospheric jet response to Antarctic ozone depletion: An update with Chemistry--- Climate Model Initiative (CCMI) models, Environ. Res. Lett., 13 (2018) 054024, https://doi.org/10.1088/1748-9326/aabf21

61. SPARC/IO3C/GAW, 2019: SPARC/IO3C/GAW Report on Long-term Ozone Trends and Uncertainties in the Stratosphere. I. Petropavlovskikh, S. Godin-Beekmann, D. Hubert, R. Damadeo, B. Hassler, V. Sofieva (Eds.), SPARC Report No. 9, GAW Report No. 241, WCRP-17/2018, doi: 10.17874/f899e57a20b
62. Staehelin, J.; Tummon, F.; Revell, L.E.; Stenke, A. and Peter, T., Tropospheric ozone at northern mid-latitudes: Modeled and measured long-term changes, Atmosphere, 8, 163, doi:10.3390/atmos8090163, 2017.
63. Steinbrecht, W.; Froidevaux, L.; Fuller, R.; Wang, R.; Anderson, J.; Roth, C.; Bourassa, A.; Degenstein, D.; Damadeo, R.; Zawodny, J.; Frith, S.; Mcpeters, R.; Bhartia, P.; Wild, J.; Long, C.; Davis, S.; Rosenlof, K.; Sofieva, V.; Walker, K.; Rahpoe, N.; Rozanov, A.; Weber, M.; Laeng, A.; VonClarmann, T.; Stiller, G.; Kramarova, N.; Godin-beekmann, S.; Leblanc, T.; Querel, R.; Swart, D.; Boyd, I.; Hocke, K.; Kämpfer, N.; Barras, E.M.; Moreira, L.; Nedoluha, G.; Vigouroux, C.; Blumenstock, T.; Schneider, M.; García, O.; Jones, N.; Mahieu, E.; Smale, D.; Kotkamp, M.; Robinson, J.; Petropavlovskikh, I.; Harris, N.; Hassler, B.; Hubert, D. and Tummon, F., An update on ozone profile trends for the period 2000 to 2016, Atmospheric Chemistry and Physics, 17, 10675-10690, doi:10.5194/acp-17-10675-2017, 2017.
64. Sukhodolov, T., J. X. Sheng, A. Feinberg, B. P. Luo, T. Peter, L. Revell, A. Stenke, D. K. Weisenstein, and E. Rozanov. “Stratospheric Aerosol Evolution after Pinatubo Simulated with a Coupled Size-Resolved Aerosol–Chemistry–Climate Model, SOCOL-Aerv1.0.” Geosci. Model Dev. 11, no. 7 (2018): 2633-47. http://dx.doi.org/10.5194/gmd-11-2633-2018.
65. Tradowsky, J.; Bodeker , G.E.; Querel, R.R.; Builtjes, P.J.H. and Fischer, J., Combining data from the distributed GRUAN site Lauder–Invercargill, New Zealand, to provide a site atmospheric state best estimate of temperature, Earth Syst. Sci. Data, 10, 2195-2211, doi:10.5194/essd-10-2195-2018, 2018.
66. Wales, P. A., R. J. Salawitch, J. M. Nicely, D. C. Anderson, T. P. Canty, S. Baider, B. Dix, T. K. Koenig, R. Volkamer, D. Chen, L. G. Huey, D. J. Tanner, C. A. Cuevas, R. P. Fernandez, D. E. Kinnison, J.-F. Lamarque, A. Saiz-Lopez, E. L. Atlas, S. R. Hall, M. A. Navarro, L. L. Pan, S. M. Schauffler, M. Stell, S. Tilmes, K. Ullmann, A. J. Weinheimer, H. Akiyoshi, M. P. Chipperfield, M. Deushi, S. S. Dhomse, W. Feng, P. Graf, R. Hossaini, P. Jöckel, E. Mancini, M. Michou, O. Morgenstern, L. D. Oman, G. Pitari, D. A. Plummer, L. E. Revell, E. Rozanov, D. Saint-Martin, R. Schofield, A. Stenke, K. Stone, D. Visioni, Y. Yamashita, and G. Zeng (2018), Stratospheric injection of brominated very short lived substances inferred from aircraft observations of organic bromine and BrO in the Western Pacific, J. Geophys. Res. Atmos., 123, 5690–5719. https://doi.org/10.1029/2017JD027978
67. Weatherhead, E.C.; Harder, J.; Araujo-Pradere, E.A.; Bodeker, G.E.; English, J.M.; Flynn, L.E.; Frith, S.M.; Lazo, J.K.; Pilewskie, P.; Weber, M. and Woods, T.N., How long do satellites need to overlap? Evaluation of climate data stability from overlapping satellite records, Atmospheric Chemistry and Physics, 17, 15069-15093, doi:10.5194/acp-17-15069-2017, 2017.
68. WMO (World Meteorological Organization), Scientific Assessment of Ozone Depletion: 2018, Global Ozone Research and Monitoring Project–Report No. 58, 588 pp., Geneva, Switzerland, 2018. Olaf Morgenstern is a contributor to chapter 3 (“Update on Global Ozone: Past, Present, and Future”) and a lead reviewer of chapter 5 (“Stratospheric Ozone Changes and Climate”).
69. Wright, C.Y., Albers, P.N., Reeder, A.I., Mathee, A. Sunbeds and skin cancer risk: Quantifying a baseline estimate of sunbed facilities in South Africa prior to implementation of sunbed regulations. Pan African Medical Journal, 2017; 26 (188): doi:10.11604/pamj.2017.26.188.10176.
70. Young PJ, Naik V, Fiore AM, Gaudel A, Guo J, Lin MY, Neu J, Parrish D, Reider HE, Schnell JL, Tilmes S, Wild O, Zhang L, Brandt J, Delcloo A, Doherty RM, Geels C, Hegglin M, Hu L, Im U, Kumar R, Luhar A, Murray L, Plummer D, Rodriguez J, Saiz-Lopez A, Schultz MG, Woodhouse M, Zeng G & Ziemke J (2018), Tropospheric Ozone Assessment Report: Assessment of global-scale model performance for global and regional ozone distributions, variability, and trends. Elem Sci Anth.,2018;6(1):10. DOI: http://doi.org/10.1525/elementa.265.
71. Zeng, G., O. Morgenstern, H. Shiona, A. T. Thomas, R. Querel, S. E. Nichol (2017), Attribution of recent ozone changes in the Southern Hemisphere mid-latitudes using statistical analysis and chemistry-climate model simulations, Atmos. Chem. Phys., 17, 10495–10513, https://doi.org/10.5194/acp-17-10495-2017.
72. Zhang, Jiankai, Wenshou Tian, Fei Xie, Martyn P. Chipperfield, Wuhu Feng, Seok-Woo Son, N. Luke Abraham, Alexander T. Archibald, Slimane Bekki, Neal Butchart, Makoto Deushi, Sandip Dhomse,

Yuanyuan Han, Patrick Jöckel, Douglas Kinnison, Ole Kirner, Martine Michou, Olaf Morgenstern, Fiona M. O'Connor, Giovanni Pitari, David A. Plummer, Laura E. Revell, Eugene Rozanov, Daniele Visioni, Wuke Wang, and Guang Zeng. "Stratospheric Ozone Loss over the Eurasian Continent Induced by the Polar Vortex Shift." Nature Communications 9, no. 1 (2018/01/15 2018): 206. http://dx.doi.org/10.1038/s41467-017-02565-2.

73. Zhao, Yuanhong, Marielle Saunois, Philippe Bousquet, Xin Lin, Michaela I. Hegglin, Josep G. Canadell, Robert B. Jackson, Didier A. Hauglustaine, Sophie Szopa, Ann R. Stavert, Nathan Luke Abraham, Alex T. Archibald, Slimane Bekki, Makoto Deushi, Patrick Jöckel, Béatrice Josse, Douglas Kinnison, Ole Kirner, Virginie Marécal, Fiona M. O'Connor, David A. Plummer, Laura E. Revell, Eugene Rozanov, Andrea Stenke, Sarah Strode, Simone Tilmes, Edward J. Dlugokencky, Bo Zheng, and Antoine Berchet: Inter-model comparison of global hydroxyl radical (OH) distributions and their impact on atmospheric methane over the 2000–2016 period, Atmos. Chem. Phys., 19, 13701–13723, https://doi.org/10.5194/acp-19-13701-2019, 2019.

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 (NIWA), which includes various measurement activities of ozone and associated compounds, primarily at Lauder, New Zealand, and Arrival Heights, Antarctica, measurement of physical variables such as UV, as well as global chemistry-climate modelling at NIWA and New Zealand's Universities. 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.

MBIE Endeavour project 'Extreme events and the emergence of climate change' led by Dave Frame at Victoria University, will be looking at the role of ozone destruction and recovery in climate change emergence patterns.

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 compounds to NDACC, taken at its primary locations at Lauder, New Zealand, and Arrival Heights, Antarctica, and also UV/Vis measurements of total-column NO_2 from Macquarie Island, Australia, taken in collaboration with the Australian Bureau of Meteorology.

- Tropospheric Ozone Assessment Report (TOAR), data submission and participation.

- SPARC LOTUS activity (Long-term Ozone Trends and Uncertainties in the Stratosphere), data submission and participation.

- CAMS project (Copernicus Atmosphere Monitoring Service), data submission.

- TROLIX'19 (TROPOMI Validation Experiment 2019), MAXDOAS participation.

- IGAC/SPARC CCMI-1 (Chemistry Climate Modelling Initiative phase 1): Contributing CCM simulations to the CCMI archive and participating in process-oriented validation of CCM output. 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): Measurements of global, diffuse, and direct radiation at Lauder, to the standards of BSRN, have been made continuously at Lauder since 1999, with the results available from the BSRN archive used in satellite validation and studies of global radiative energy balance. They also support the understanding of UV measurements at Lauder and other NDACC sites.

- SAGE-III-ISS Validation: An ongoing validation effort is underway at Lauder with several balloon payloads launched annually in coordination with ISS overpasses. These payloads included ozonesondes, frost-point hygrometers, and more recently a POPS aerosol measuring instrument.

- SOLARIS-HEPPA - Solar influences for SPARC (Stratosphere-troposphere processed and their role in climate): University of Otago is a key participant in the development of solar forcing parameters used by the so-called high-top models with interactive ozone chemistry CMIP6 simulations.

- A continuous record of stratospheric aerosol profiles over Lauder, started in November 1992, continues thanks to support from MRI and NIES in Japan. The lidar was upgraded in 2009 for dual-wavelength and depolarisation in daytime to support Total Carbon Column Observing Network (TCCON) measurements of GHG over Lauder by near-infrared.

National collaborators

NIWA

Richard Querel, Lauder: Ozonesondes, ozone LIDAR, Dobson; GRUAN

Ben Liley, Lauder: UV, clouds, aerosols

Richard McKenzie (Emeritus), Lauder: UV

Olaf Morgenstern, Wellington: Chemistry-climate modelling

Guang Zeng, Wellington: Chemistry-climate modelling

Mike Harvey, Wellington: Atmospheric emissions

Dan Smale, Lauder: *In situ* ozone (TEI) measurements, FTS column and profile measurements

Penny Smale, Lauder: Ozonesondes, Dobson, TEI

Michael Kotkamp, Lauder: Ozone microwave radiometer, UV instrumentation

Alex Geddes, Lauder: UV measurements, ozonesonde processing

Sylvia Nichol, Wellington: Dobson measurements

Hisako Shiona, Christchurch: Dobson measurements, ozonesonde processing

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

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

Annika Seppälä, University of Otago: Space weather (EPP) effects on the stratosphere and ozone. Chemistry-climate modelling.

Martin Allen, Univ Canterbury: UV dosimetry

Barbara Hegan, Cancer Society: UV Public health advisory

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

Greg Bodeker, Bodeker Scientific: Ozone database construction

Stefanie Kremser, Bodeker Scientific: Ozone database construction

Laura Revell, Univ Canterbury: Chemistry-climate modelling, stratospheric ozone chemistry.

Dave Frame, Victoria University: Climate dynamics

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

Stephen Wilson, University of Wollongong: MAXDOAS measurements

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

Matt Tully, Bureau of Meteorology: Ozonesondes, Dobson intercomparison

Steve Rhodes, Bureau of Meteorology: Dobson intercomparison, MAXDOAS

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

Michael Kimlin (QUT): UV Workshop

Robyn Schofield, Univ Melbourne: MAXDOAS measurements

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

Audra McClure, GMD: *In situ* ozone measurements

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

Irina Petropavlovskikh, GMD: Dobson total-column ozone measurements

Glen McConville, CIRES, GMD: Dobson

Koji Miyagawa, NOAA, GMD: Dobson

GMD = Global Monitoring Division (was CMDL); CSD = Chemical Sciences Division (was aeronomy laboratory); CUCF = Colorado Ultraviolet Calibration Facility; CIRES (Cooperative Institute for Research in Environmental Sciences)

NASA

Anne Thompson, GSFC: Ozonesondes

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.

Jeannette Wild, NDACC: NDACC data archival, meta data

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

Susan Strahan, GSFC: Modelling activities

Thierry Leblanc, JPL: Ozone LIDAR

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

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

Daniel R. Marsh, NCAR (also University of Leeds, UK): Chemistry-Climate modelling

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

Vitali Filetov, Environment Canada: UVI

Jim Hannigan, NCAR: FTS measurements.

NCAR = National Center for Atmospheric Research

Collaborations with Europe

Christoph Zellweger. WCC-Empa, Empa Dübendorf, Switzerland. In situ ozone calibration

Wolfgang Steinbrecht, Germany. Ozone LIDAR

Monika Szelag (previously Andersson), Niilo Kalakoski, Johanna Tamminen, Finnish Meteorological Institute: Chemistry-Climate modelling, satellite observations of stratospheric composition.

Pekka T. Verronen, Esa Turunen, Jia Jia, Sodankylä Geophysical Observatory: Ion-Chemistry modelling, mesospheric ozone observations.

Mark A. Clilverd, David A. Newnham, British Antarctic Survey: Radiometer observations of polar mesosphere composition, development of solar forcing proxies for climate models.

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

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

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

Michel 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

Corinne Vigouroux, BIRA, Belgium: FTS, MAXDOAS

Daan Hubert, BIRA, Belgium: LOTUS, satellite ozone trends

Emmanuel Mahieu, Univ. Liege, Belgium: FTS measurements

Herman Smit, Research Centre Juelich GmbH, Germany: Ozonesondes

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, Will Ball (ETH Zurich) and Eugene Rozanov and Timofei Sukhodolov (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

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 10th OZONE RESEARCH MANAGERS MEETING

In line with the recommendations of the 10th ORM, New Zealand is continuing to fund high-quality trace gas measurements being made at atmospheric research facilities around the country.

Work is underway at NIWA to continue to future-proof and modernise aging instrumentation to ensure continuity of the ozone measurement time-series datasets.

In response to the call for 'studies characterising and better quantifying the measurement uncertainties of ozone and associated parameters by various monitoring instrument types', scientists from Bodeker Scientific have been working with Dr Larry Thomason (NASA) to develop new data-screening recommendations for SAGE II ozone measurements which are based on how the measurements were made. Our ability to accurately detect small, but important, changes in concentrations of constituents, such as ozone, is challenged by measurement uncertainties. Since SAGE II measurements of ozone started, a plethora of 'generally accepted' screening methods have been developed. These methods are often inconsistent, ad-hoc, and untraceable and seldom revised even after significant revisions to the data themselves. A publication is currently in development and will be submitted at the end of February 2020.

The construction of the homogenized total column ozone and vertically resolved ozone databases (see above) responds to the call for 'continued studies for homogenising long-term ozone data records obtained from various measurement systems'. The Weatherhead et al. (2017) paper listed above on which Bodeker Scientific scientists collaborated, also responds to this recommendation.

In response to 'Improve the understanding and accuracy of future projections of global ozone amounts,' work at NIWA and the University of Canterbury has contributed to future ozone projections via the framework of CCMI, including the roles of GHGs and ODSs in ozone recovery. Recent research led by the University of Canterbury resulted in an improved representation of tropospheric ozone in a chemistry-climate model.

7. FUTURE PLANS

- Use long-term stratospheric trace gas measurements to observe global circulation (Brewer-Dobson) dynamical changes, in combination with chemistry-climate modelling study.
- Updating NIWA UV spectrometer systems at Lauder (and abroad), including the conversion of legacy control and processing software and all custom hardware as required.
- Maintain and continue operation of all ozone and ODS measuring instrumentation at Lauder, Baring Head, and Arrival Heights.
- Participate in instrument intercomparison and calibration campaigns
- Upgrade the Lauder stratospheric ozone LIDAR (LauSOL) that is nearing end-of-life
- Continue weekly ozonesonde launches at Lauder.
- An intercomparison study of UV and ozone measuring instrumentation at Lauder is currently underway.
- A new diode-array UV spectrometer at Lauder will be used to study cloud effects on UV, including wavelength dependence of enhancement, in the vicinity of clouds as they transit the sun.
- University of Canterbury: producing chemistry-climate model projections of stratospheric ozone in response to changing GHG and ODS concentrations; understanding how stratospheric chemistry influences surface climate and the emergence of climate change in the Southern Hemisphere.

8. NEEDS AND RECOMMENDATIONS

The following needs and recommendations require attention:

- Polar ozone plays a critical role in regional climate variability at high and mid-latitude regions. With decreasing stratospheric ozone depleting substances (ODSs) and the projected strengthening Brewer-Dobson circulation due to climate change, the role of solar forcing (including energetic particle precipitation) is likely to become more pronounced. To quantify the impact on polar ozone, continued, long term (over decades), high quality, polar stratospheric and mesospheric profiles of ozone, dynamical tracers, and ozone depleting nitrogen family gases such as NO and NO_2 are needed from both satellite and ground-based instruments. This includes observations made during polar night conditions.
- 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 a scientific 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 the model projections of Southern Hemispheric climate.
- Changes in ozone in the upper troposphere and lower stratosphere, especially in the tropics, and its effect on atmospheric temperature 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. The possible intensification of kelp aquaculture for food production and/or 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.
- Continued monitoring of unexpected emissions.
- Understand the effect of ozone and ODSs on radiative forcing, their role in Arctic warming.