DENMARK

OBSERVATIONAL ACTIVITIES

The Danish Meteorological Institute (DMI), in collaboration with the Danish Environmental Protection Agency, conducts permanent measurements of the stratospheric ozone layer. Daily ground-based measurements of the ozone layer thickness as well as weekly balloon based measurements of the vertical ozone profiles are performed in Denmark and Greenland. The measurements are reported to international databases. In addition the measurements are incorporated in validation of satellite measurements, e.g. measurements from ENVISAT and AURA. Balloon-based measurements of the ozone layer are often conducted as part of larger international projects.

Column measurements of ozone and other gases/variables relevant to ozone loss
Daily observations of total ozone are performed by the DMI in Denmark and Greenland:

Station	Location	Instrument	Start of observations
Copenhagen	56°N, 12°E	Brewer Mark IV	May 1992
Sondre Stromfjord (Kangerlussuaq)	67°N, 51°W	Brewer Mark II	September 1990
Thule Air Base (Pituffik)	77°, 69°W	SAOZ 1024 diode array	September 1990

On non-regular basis, total ozone has also been measured from Qaanaaq (78°N, 69°W) in Greenland, using the DMI Dobson #92 instrument since early 2000.

Profile measurements of ozone and other gases/variables relevant to ozone loss
Weekly ozone soundings have been performed using balloon-borne EEC sensors from Scoresbysund (Illoqqortoormiut, 71°N, 22°W) since January 1993. Ozone soundings have also been performed on campaign basis from Thule Air Base each winter since January 1992 and occasionally from Copenhagen.

UV measurements

Broadband measurements
A Yankee Environmental Systems model UVB-1 radiometer has been operated by DMI in Copenhagen since 1996. A custom UV radiometer (erythemally weighted UV and total UV-A) has been in operation in Thule (Pituffik) since 1993. The latter instrument is owned by the Health Protection Agency in the U.K. (former National Radiological Protection Board) and the UV-B part of the instrument is similar to the Solar Light model 500.

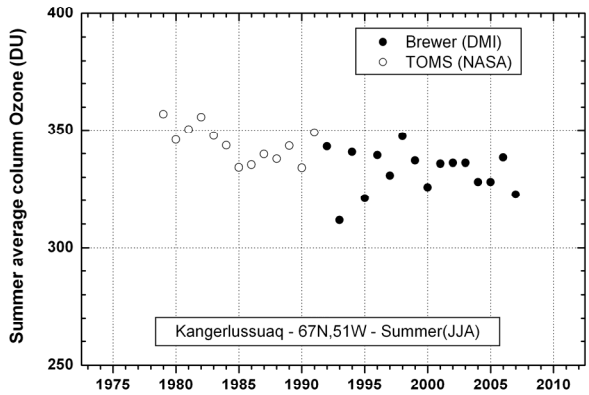
Narrowband filter instruments
A narrowband filter instrument – Biospherical Inc., model GUV2511 – has been operated on the east coast of Greenland at Scoresbysund (Illotoorqqortoormiut) by DMI since 2008.

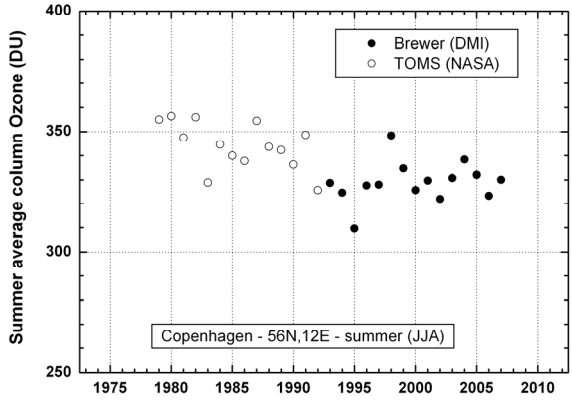
Spectroradiometers
Daily measurements of the surface UV radiation are performed by DMI at Thule (Pituffik), using a high resolution spectroradiometer, since summer 1994. The Brewer MkII instrument at Sondre Stromfjord (Kangerlussuaq) has measured spectral UV-B (290-325nm) since late 1990.

Calibration activities
DMI has contributed with ozone measurements from Greenland to the international projects CINAMON (AO-ID 158), OMI cal/val and GOME-2 validation as proposed in connection with ESA/NASA/EUMETSATS's "announcement of opportunities" concerning the ENVISAT, AURA and METOP satellite missions.

RESULTS FROM OBSERVATIONS AND ANALYSIS

Summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2007) from Kangerlussuaq, Greenland, are shown in left-hand side in the figure below. The whole data series shows a significant trend of -2.1±1.1% per decade (2 σ) while there is no significant trend during the past 15 years.





Likewise summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2007) from Copenhagen, Denmark, are show in the right-hand side of the figure. The whole data series shows a significant trend of -2.6±1.2% per decade (2 σ) while there is no significant trend during the past 15 years.

THEORY, MODELLING, AND OTHER RESEARCH

DMI has participated in major European Arctic and tropic campaigns since the beginning of the 1990's including EASOE, SESAME, THESEO, THESEO-2000-SOLVE, VINTERSOL, HIBISCUS, and Scout-AMMA, as well as a long series of EU-projects. The research is based on a broad spectrum of accessible observations, including data from the European environmental satellite ENVISAT and analyses of meteorological conditions in the stratosphere. The research includes analysis of transport of ozone depleted air masses from Arctic areas to mid-latitudes and experimental and theoretical studies of polar stratospheric clouds. In addition research is carried out on cirrus clouds from airplane condensation trails, and on cirrus clouds in the tropics, which is important for transport of water vapour to the stratosphere. Studies are performed on the downward influence from the stratosphere on tropospheric climate.

DISSEMINATION OF RESULTS

Data reporting

The measurements are reported to databases under Network for the Detection of Atmospheric Composition Change (NDACC) and World Ozone and UV-radiation Data Center (WOUDC) under the WMO-programme Global Atmosphere Watch (GAW).

Information to the public

UV-index forecasts, based on Danish total ozone measurements, were initiated at DMI in summer 1992. This public service runs every summer season, made public on the Internet and in several media. DMI is responsible for the Near Real Time UV-index processing as part of the EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring and provides daily global maps of clear sky UV-indices. As part of the ESA-GMES Service Elements project Promote,

DMI has initiated a UV service for Greenland in collaboration with the Greenland Directorate for Health. DMI's ozone measurements are made available on the Internet (www.dmi.dk) together with a status report (in Danish language).

Relevant scientific papers

Christensen, T., B. Knudsen, J.-P. Pommereau, G. Letrenne, A. Hertzog, F. Vial, J. Ovarlez, and M. Piot: Evaluation of ECMWF ERA-40 temperature and wind in the lower tropical stratosphere since 1988 from past long-duration balloon measurements. Atmospheric Chemistry and Physics, 7, 3399-3409, 2007.

Daerden, F., N. Larsen, S. Chabrillat, Q. Errera, S. Bonjean, D. Fonteyn, K. Hoppel, and M. Fromm: A 3D-CTM with detailed online PSC-microphysics: analysis of the Antarctic winter 2003 by comparison with satellite observations. Atmospheric Chemistry and Physics, Vol. 7, 1755-1772, 2007.

Kivi, R., E. Kyrö, T. Turunen, N.R.P. Harris, P. Von der Gathen, M. Rex and S.B. Andersen: Ozonesonde observations in the Arctic during 1989-2003: ozone variability and trends in lower stratosphere and free troposphere, accepted, J. Geophys. Res. 2007.
Nielsen, J.K., N. Larsen, F. Cairo, G. Di Donfrancesco, J. M. Rosen, G. Durry, G. Held, and J. P. Pommereau: Solid particles in the tropical lowest stratosphere. Atmospheric Chemistry and Physics, 7, 685-695, 2007.

Andersen, S.B. and B.M. Knudsen The influence of polar vortex ozone depletion on NH mid-latitude ozone trends in spring. Atmos. Chem. Phys., 6, 2837-2845, 2006.
Andersen, S.B.; Weatherhead, E. C.; Stevermer, A.; Austin, J.; Brühl, C.; Fleming, E. L.; de Grandpré, J.; Grewe, V.; Isaksen, I.; Pitari, G.; Portmann, R. W.; Rognerud, B.; Rosenfield, J. E.; Smyshlyaev, S.; Nagashima, T.; Velders, G. J. M.; Weisenstein, D. K.; Xia, J. Comparison of recent modeled and observed trends in total column ozone. J. Geophys. Res., Vol. 111, No. D2, D02303, 10.1029/2005JD006091, 2006

Höpfner, M., N. Larsen, R. Spang, B.P. Luo, J. Ma, S.H. Svendsen, S.D. Eckermann, B. Knudsen, P. Massoli, F. Cairo, G. Stiller, T. v. Clarmann, and H. Fischer: MIPAS detects Antarctic stratospheric belt of NAT PSCs caused by mountain waves, Atmospheric Chemistry and Physics , 6, 1221-1230, 2006.

Knudsen, B.M., T. Christensen, U, A. Hertzog, A. Deme, F. Vial, J.-P. Pommereau, Accuracy of analyzed temperatures, winds and trajectories in the Southern Hemisphere tropical and midlatitude stratosphere as compared to long-duration balloon flights, Atm. Chem. Phys., Vol. 6, 5391-5397, 2006.

Rex, M., R. Salawitch, H. Deckelmann, P. von der Gathen, N. Harris, M. Chipperfield, B. Naujokat, E. Reimer, M. Allaart, S. B. Andersen, R. Bevilacqua, G. Braathen, H. Claude, J. Davies, H. De Backer, H. Dier, V. Dorokov, H. Fast, M. Gerding, K. Hoppel, B. Johnson, E. Kyrö, Z. Litynska, D. Moore, T. Nagai, C. Parrondo, D. Risley, P. Skrivankova, R. Stübi, C. Trepte, P. Viatte, V. Yushkov and C. Zerefos: Arctic winter 2005: Implications for stratospheric ozone loss and climate change. Geophys. Res Lett., VOL. 33, L23808, doi:10.1029/2006GL026731, 2006

Rivière, Emmanuel D., Virginie Marécal, Niels Larsen, and Sylvie Cautenet: Modelling study of the impact of deep convection on the UTLS air composition. Part 2: Ozone budget in the TTL. Atmospheric Chemistry and Physics, 6, 1585-1598, 2006.

Streibel, M., M. Rex, P. von der Gathen, N.R.P. Harris, G.O. Braathen, E. Reimer, H. Deckelmann, M. Chipperfield, G. Millard, M. Allaart, S.B. Andersen, H. Claude, J. Davies, H. De Backer, H. Dier, V. Dorokov, H. Fast, M. Gerding, E. Kyrö, Z. Litynska, D. Moore, E. Moran, T. Nagai, H. Nakane, C. Parrondo, P. Skrivankova, R. Stübi, G. Vaughan, P. Viatte, V. Yushkov: Chemical ozone loss in the Arctic winter 2002/03 determined with Match, Atmos. Chem. Phys., 6, 2783-2792, 2006.

Sugita, T., H. Nakajima, T. Yokota, H. Kanzawa, H. Gernandt, A. Herber, P. von der Gathen, G. König-Langlo, K. Sato, V. Dorokhov, V. A. Yushkov, Y. Murayama, M. Yamamori, S. Godin-Beekmann, F. Goutail, H. K. Roscoe, T. Deshler, M. Yela, P. Taalas, E. Kyrö, S. Oltmans, B. Johnson, M. Allaart, Z. Litynska, A. Klekociuk, S. B. Andersen, G. O. Braathen, H. De Backer,C. E. Randall, R. M. Bevilacqua, G.. Taha, L.W. Thomason, H. Irie, M. K. Ejiri, N. Saitoh, T. Tanaka, Y. Terao, H. Kobayashi, and Y. Sasan: Ozone profiles in high-latitude stratosphere and lower mesosphere measured by the Improved Limb Atmospheric Spectrometer (ILAS)-II: Comparison with other satellite sensors and ozonesondes. J. Geophys. Res. 111, D11S02, doi:10.1029/2005JD006439, 2006.

Weisser, C., K. Mauersberger, J. Schreiner, N. Larsen, F. Cairo, J. Ovarlez, and T. Deshler: Composition analysis of liquid particles in the Arctic stratosphere under synoptic conditions. Atmos. Chem. Phys. 6, 689-696, 2006.

Weatherhead, E.C. and S.B. Andersen: The Search for Signs of Recovery of the Ozone Layer. Nature, 441, 39-45, doi:10.1038/nature04746, 2006.

Christensen, T., B. M. Knudsen, M. Streibel, S. B. Andersen, A. Benesova, G. Braathen, H. Claude, J. Davies, H. De Backer, H. Dier, V. Dorokhov, M. Gerding, M. Gil, B. Henchoz, H. Kelder, R. Kivi, E.

Kyrö, Z. Litynska, D. Moore, G. Peters, P. Skrivankova, R. Stübi, T. Turunen, G. Vaughan, P. Viatte, A. F. Vik, P. von der Gathen, I. Zaitcev,: Vortex-averaged Arctic ozone depletion in the winter 2002/2003. Atmospheric Chemistry and Physics, 5, 131-138, 2005.

Goutail, F., J.-P. Pommereau, F. Lefèvre, M. Van Roozendael, S.B. Andersen, B.-A. Kåstad Høiskar, V. Dorokhov, E. Kyro, M. Chipperfield and W. Feng, 2004: Early unusual ozone loss during the Arctic winter 2002/03 compared to other winters. Atmos. Chem. Phys., 5, 665-677, 2005.

Karpetchko, A., E. Kyro, B. Knudsen, Arctic and Antarctic polar vortices 1957-2002 as seen from the ERA-40 reanalyses, J. Geophys. Res., 110, D21109, doi:10.1029/2005JD006113, 2005.

Knudsen, B.M., Jønch-Sørensen, H., Eriksen, P., Johnsen, B.J., and Bodeker, G.E.: UV radiation below an Arctic vortex with severe ozone depletion. Atmos. Chem. Phys., 5, 2981-2987, 2005.

Scarchilli, C., A. Adriani, F. Cairo, G. Di Donfrancesco, C. Buontempo, M. Snels, M. Luisa Moriconi, T. Deshler, N. Larsen, B. Luo, K. Mauersberger, J. Ovarlez, J. Rosen and J. Schreiner: Determination of PSC Particle Refractive Indexes using In Situ Optical Measurements and T-Matrix Calculations, App. Optics, 44, 3302-3311, 2005.

Svendsen, S.H., N. Larsen, B. Knudsen, S.D. Eckermann , and E.V. Browell: Influence of mountain waves and NAT nucleation mechanisms on Polar Stratospheric Cloud formation at local and synoptic scales during the 1999-2000 Arctic winter. Atmospheric Chemistry and Physics, Atmos. Chem. Phys., 5, 739-753, 2005.

Weatherhead, Betsy, Aapo Tanskanen, Amy Stevermer, Signe Bech Andersen, Antti Arola, John Austin, Germar Bernhard, Howard Browman, Vitali Fioletov, Volker Grewe, Jay Herman, Weine Josefsson, Arve Kylling, Esko Kyrö, Anders Lindfors, Drew Shindell, Petteri Taalas, David Tarasick , Valery Dorokhov, Bjorn Johnsen, Jussi Kaurola, Rigel Kivi, Nikolay Krotkov, Kaisa Lakkala, Jacqueline Lenoble, David Sliney: Arctic Climate Impact Assessment: Chapter5, Atmospheric Ozone and UV Radiation. Cambridge University Press, 2005.

PROJECTS AND COLLABORATION

Thule and Sondre Stromfjord are primary Arctic stations within the Network for the Detection of Atmospheric Composition Change. In addition to the DMI instrumentation, aerosol lidars are operated at these stations by the University of Rome (Italy) and SRI International (USA), respectively, together with an FTIR spectrometer at Thule, operated by National Center for Atmospheric Research (USA). DMI also collaborates with Service d'Aeronomie du CNRS (France) for daily total ozone measurements by a SAOZ instrument at Scoresbysund which is a supplementary NDACC-station. DMI participates in the EU-project Global Earth Observation and Monitoring (Geomon) providing SAOZ total ozone data from Greenland.

Within the current EU-project Stratosphere-Climate links with emphasis on the UTLS (Scout-O3) DMI is involved in modelling aspects of the stratosphere-troposphere coupling, investigating to what extent the downward propagation can increase the performance of operational dynamical seasonal-prediction models, and to what extent a well-resolved stratosphere is important for the modelling of the tropospheric climate. In Scout-O3 DMI is also involved in tropical balloon-borne investigations of transport of water vapour to the stratosphere.

The DMI participates in EUMETSAT's Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring, developing operational UV-index products, based on satellite measurements of the ozone layer, and DMI participates in the EU-project Global Earth-System Monitoring Using Satellite and In-Situ Data (GEMS) concerning validation of UV-indices.

FUTURE PLANS

National funding for ozone and UV monitoring in Denmark and Greenland is secured until the end of 2009. After this period the funding situation will be renegotiated.

Research efforts will be directed towards improved understanding of the role of stratospheric changes for tropospheric climate including the dynamical coupling between the troposphere and the stratosphere, and to assess how well this coupling is included in current chemistry-climate

models. It is intended to include a stratospheric representation in new developments of an Earth System model complex. In addition research efforts will be directed towards cirrus cloud formation in the tropical tropopause layer and transport of water vapour to the stratosphere, based on improved microphysical modelling and combining experimental balloon-borne experiments with satellite measurements from the International Space Station.

NEEDS AND RECOMMENDATIONS

It is considered important to monitor the recovery of the ozone layer at high latitudes during changing stratospheric climatic conditions (decreasing temperatures, perhaps increased water vapour concentrations and other changes in chemical composition, changes in stratospheric dynamics). Maintaining and running stratospheric monitoring stations in the Arctic and elsewhere is becoming an increasingly heavy burden on national funding sources and possibilities for direct funding of ground-based monitoring activities and data provision should be considered to be included in major international programmes such as the European Global Monitoring for Environment and Security (GMES).

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