Global Monitoring Division

Gas Standards
and
Instrument Calibrations

Contents:

Gas Standards and Instrument Calibrations

A. Trace Gas Calibration Standards

High quality, stable trace gas standards are the basis for sustained atmospheric trace gas measurements on century time scales.

The Global Monitoring Division produces and maintains World Meteorological Organization sanctioned trace gas standards for the three most important long-lived greenhouse gases (CO_2, CH_4, N_2O). GMD also maintains in-house calibration scales for over 50 trace gases associated with climate forcing, ozone depletion, and air quality.

B. WMO World Primary and Secondary Total Column Ozone Standard Instruments.

The Global Monitoring Division maintains the WMO Primary and Secondary World Standard Total Column Dobson Spectrophotometers from which the five WMO Regional Standards are calibrated every four years and the five NOAA Observatory Dobson instruments are calibrated every two years.

C. Solar Radiation Calibration Standards.

The GMD Central Calibration Laboratory maintains systems for performing calibrations of solar UV monitoring instruments. Each year, over 100 instruments are calibrated in the laboratory. Additionally, many instruments are calibrated in the field using the portable field calibrator. The Calibration Laboratory's systems include: Irradiance scale transfer system, UV spectral responsivity measurement system, Angular response measurement system, Absolute spectral irradiance calibration system and the Portable field calibrator system.

A. GMD Trace Gas Calibration Standards

Accurate, reliable calibrations are an essential component of all high quality monitoring programs, and are required for proper interpretation of measurements of atmospheric gases. Long-term drift or bias among different instruments and components must be characterized or minimized. For data from multiple networks to be interpreted together, they must be linked to a common calibration scale. Many global atmospheric measurement communities rely on GMD to provide that linkage.

Most gases measured by GMD are traceable to primary standards developed by GMD. Two methods are used to prepare primary gas standards. Primary standards for CO_2 consist of compressed air in aluminum cylinders for which CO_2 mole fractions have been determined manometrically: that is, the mole fraction of CO_2 is determined by measuring state variables (pressure, temperature, volume) as CO_2 is extracted from air. For other gases (CH_4, CO, N_2O, halocarbons) primary standards are prepared gravimetrically by adding known masses of components together to create a gas mixture of known composition. In both cases, the results are traceable to national standards (mass, temperature, pressure) maintained by NIST.

GMD serves as the WMO/GAW Central Calibration Laboratory for CO_2, CH_4, CO, N_2O, and SF_6. In this capacity GMD maintains world reference calibrations scales and distributes calibrated gas mixtures to participating WMO/GAW laboratories. Distribution is not limited to WMO/GAW partners. GMD also provides calibrated gas mixtures of the gases listed above, and other gases such as halocarbons and chlorinated solvents, to laboratories in support of cooperative research on climate, ozone, and ocean tracer work. In all, GMD maintains calibration scales for over 50 different compounds.

Even though GMD prepares and maintains primary standards, these are used only to calibrate specific instruments in Boulder. Calibrations are transferred to other instruments within GMD and externally through gas cylinders containing real air, filled at a research site west of Boulder at ~3000m elevation. Gas cylinders are filled with air using techniques developed to ensure the integrity of the mixtures, calibrated in Boulder using dedicated instruments, and distributed world-wide. Over the last 20 years, approximately 2700 and 3600 gas mixtures have been prepared and calibrated for use within GMD and by other laboratories, respectively.

Trace Gas Calibration Scales Developed by GMD

Chlorofluorocarbons

CFC-11 CFC-114
CFC-12 CFC-115
CFC-113 CFC-13

Hydrochlorofluorocarbons

HCFC-22
HCFC-141b
HCFC-142b

Hydrofluorocarbons

HFC-134a HFC-365mfc
HFC-152a HFC-236fa
HFC-143a HFC-227ea
HFC-23 HFC-32
HFC-125

Solvents

CH_3CCl_3 TCE
CCl4 PCE
$CHCl_3$
CH_2Cl_2

Halons

halon-1211
halon-1301
halon-2402

Sulfur gases

COS
CS_2
SF_6
CF_3SF_5

Short-lived halocarbons

CH_3Br
CH_2Br_2
$CHBr_3$
CH_3Cl
CH_2BrCl
CH_3I
CH_2I_2
$CHBrCl_2$
$CHBr_2Cl$
CH_2BrI
CH_2ClI

Hydrocarbons

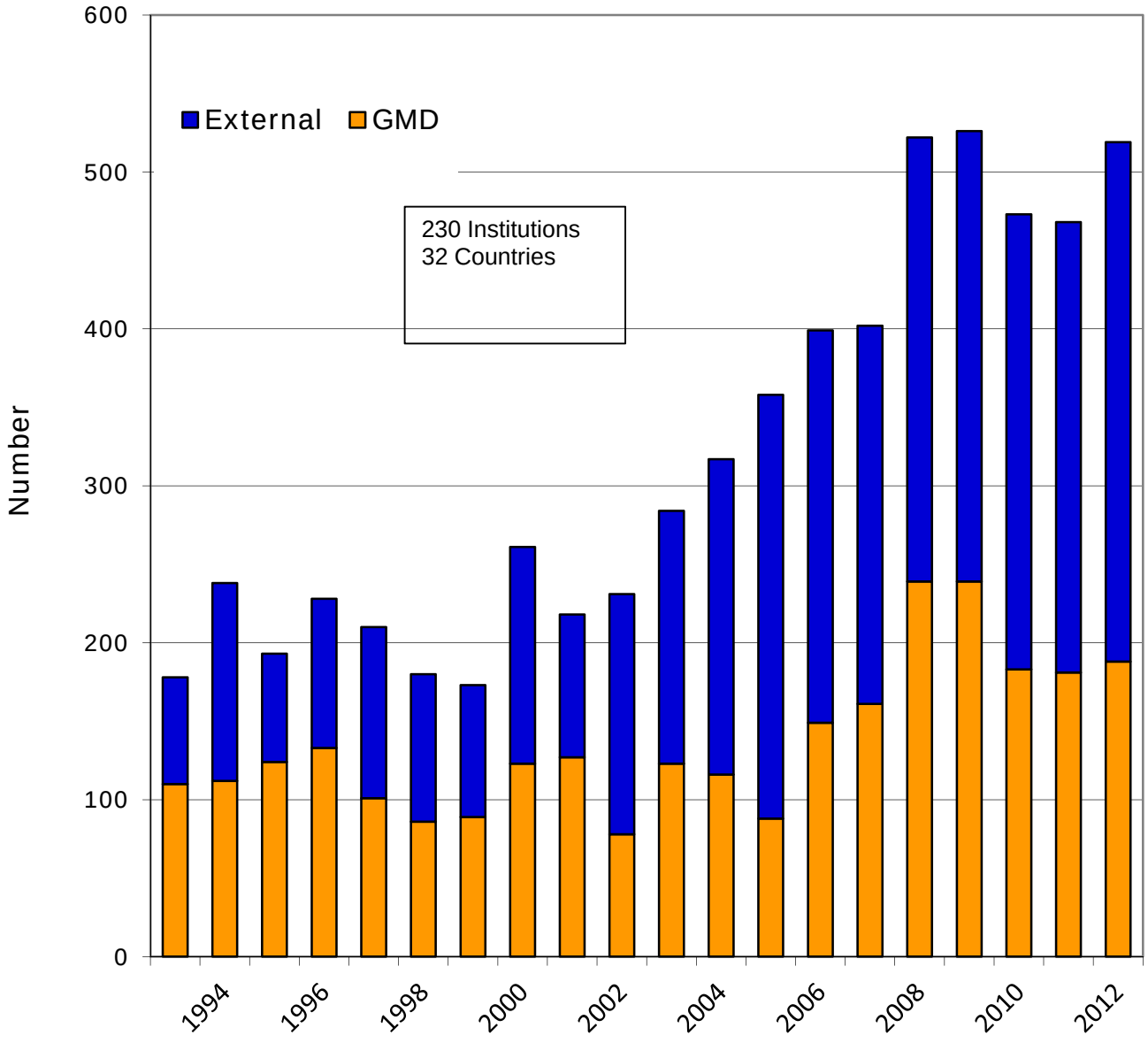
acetone
acetylene
ethane
propane
butane
iso-butane
pentane
iso-pentane
hexane
benzene
toluene

Other

CO_2
CH_4
N_2O
CO
hydrogen
peroxyacetylnitrate
water vapor
CF_4
C_2F_6

well-developed
semi-developed
very limited
WMO/GAW

Gas Cylinders Prepared and Calibrated Each Year Since 1993



Glass manifold on the CO_2 manometer used for extracting CO_2 from air. The manometer is used to determine the mole fraction of CO_2 on an absolute basis.

Moving gas cylinders into the CO_2 calibration laboratory. Here, CO_2 mole fractions are assigned based on the WMO X2007 scale.

Niwot Ridge, Colorado (~ 3000m a.s.l.), where gas cylinders are filled with clean background air as a first step in preparing a gas standard.

A step in preparing a gas standard by sealing a known amount of a specific gas into a glass capillary tube. The gas will later be added to a large tank of air to produce a standard.

Weighing cylinders on a special balance to determine how much gas was added. Gas added to the cylinders is weighed to milli- and microgram levels.

Measuring the concentration of carbon dioxide in cylinders of standard gases prepared in the GMD lab.

Institutions to which GMD Provided Trace Gas Standards in the Past 5 Years

Standards are provided on a cost basis.

Country	Institution
Argentina	DNA
Australia	CSIRO
Australia	Monash U., School of Geography and Environmental Science
Belgium	Universite de Liege
Bermuda	Bermuda Institute of Ocean Sciences
Brazil	Fundacao de Pesquisa do estado de Sao Paulo
Brazil	Instituto de Pesquisas Energeticas e Nucleares, IPEN
Canada	Agriculture and Agri-food Canada
Canada	Bedford Institute of Oceanography
Canada	Dalhousie Univ.
Canada	Environment Canada EC
Canada	Pro-Oceanis
Canada	UBC Land & Food Systems
Canada	Univ. Guelph, Ontario
Canada	Univ. of Manitoba
Canada	York University
Chile	Univ. Concepcion
China	Chinese Meteorological Admin. (CMA)
China	Hong Kong Observatory
China	National Huayan Technology Development Corp
China	Xiamen University
Denmark	GEUS
Denmark	Niels Bohr Institute, Copenhagen Univ.
Finland	Finnish Meteorological Institute, FMI
France	CEA Glaciology, Grenoble

France	Laboratoire de Glaciologie Geophysique
France	LSCE
France	UNIVERSITE DE REIMS
Germany	Alfred Wegener Institute for Polar and Marine Research
Germany	Baltic Sea Research Inst
Germany	DLR, Institut fuer Physik der Atmosphere, Oberpfaffenhofen, Germany
Germany	German Environmental Lab (UBA)
Germany	German Weather Service
Germany	IFM-FKU
Germany	IFM-GEOMAR
Germany	IFU iup-hd
Germany	LEBNIZ CENTER for TROPICAL MARINE ECOLOGY, BREMEN
Germany	MAX PLANCK INST.
Germany	Riemer Messtechnik
Germany	Univ Frankfurt
Germany	Univ. Bremen
Germany	Univ. Hamburg
Germany	Univ. Kiel
Germany	Univ. of Heidelberg
Germany	Univ. Weupertal
Hungary	Hungarian Meteorological Service
India	Indian Institute of Tropical Meteorology
India	National Institute of Oceanography, NIO
Israel	Weizmann Institute of Science, Dan Yakir
Italy	CISE
Italy	CRN
Italy	ENEA Lapadusa
Italy	European Commission Joint Research Centre
Italy	Orion-Srl
Italy	Ricerca Systema Energetico, CESI
Italy	SIAD SPA
Italy	Univ. Urbino, Monte Chimone
Japan	NIES
Japan	NIPPON EXPRESS USA
Japan	Nissan Shoji

Japan	Suzuki Shokan, JMA
Korea	Dae Deok Ind. Gases
Korea	EO Technics
Korea	Inter-Scientifics
Korea	JCGAS
Korea	Jusun Instruments
Korea	Korea Ocean Research and Development Institute, KORDI
Korea	Korean Institute of Geoscience and Mineral Resources
Korea	KRISS
Korea	Kwanak-gu School of Environmental Sciences
Korea	Metacom
Korea	POLAR RESEARCH INSTITUTE KOPRI
Korea	Postech School of Environmental Science and Engineering
Korea	Sam-In Science
Korea	Seoul National Univ.
Mexico	CICESE
Mexico	Climate Institute
Netherlands	ECN
Netherlands	NIOZ
Netherlands	Royal Netherlands Institute for Sea Research
Netherlands	RUG
Netherlands	Scott Gas
New Zealand	NIWA
Norway	NILU
Norway	Univ. Bergen
Peru	Huancayo Site Operations
Russia	Russia GGO State Geophysical Observatory, St Petersburg
Singapore	Singapore SMART-MIT
South Africa	South African Weather Service SAWS
Spain	Consejo Superior de Investigaciones Cientificas CSIC
Spain	Izana obs. inm
Spain	Spain FUNDACIÓ INSTITUT CATALÀ DE CIENCIES DEL CLIMA
Spain	Univ. LAS PALMAS
Spain	Univ. of Valladolid

Sweden	Gothenburg Univ.
Sweden	Stockholm Univ., MISU-ITM
Switzerland	Switzerland, EMPA
Switzerland	Univ. Bern
Taiwan	Chung Chou Univ. of Science and Technology
Taiwan	Jusun Instruments
Taiwan	Ko Hsieh Instruments
Taiwan	Le & Der Co
Taiwan	Lein Wei Chemistry Apparatus Co.
Taiwan	National Central Univ.
Taiwan	National Univ. Taiwan
Taiwan	Taiwan Department of Atmospheric Sciences
Taiwan	Tungsten International for Fulgent Scientific
Turkey	Hacettepe University
UK	British Antarctic Survey
UK	Cambridge Univ.
UK	Cranfield Univ., Facility for Airborne Atmospheric Measurements
UK	National Physical Laboratory, NPL
UK	Southampton Oceanography Center
UK	NUIG, U. of Ireland Galway
UK	Plymouth Marine Laboratory
UK	Royal Holloway, Univ. of London
UK	Scotland cntr for ecology and hydrology
UK	UK Univ. of York, Lucy Carpenter
UK	Univ. East. Anglia, School of Environmental Sciences, Norwich
UK	Univ. of East Anglia, Marie-Jose Messias
UK	Univ. of York, Cranfield Univ., FAAM
US	Aerodyne Research Inc.
US	Air Resources Laboratory, NOAA
US	Antarctic Support Association
US	Atlantic Oceanic Marine Laboratories
US	Atmospheric Observing Systems, Boulder, CO.
US	AWS Convergence Technologies, Earth Networks
US	Battelle Inst, Ohio State
US	Bigelow Laboratory for Ocean Studies

US	Boston college
US	Bowdoin College, Maine
US	California Air Resources Board, CARB
US	California Institute of Technology
US	Campbell Scientific, UT
US	Carnegie Inst.
US	Colorado State Univ.
US	University of Colorado, INSTAAR
US	Columbia U., Lamont Doherty
US	Columbia Univ.
US	Duke Univ.
US	Florida State Univ.
US	Harvard Univ.
US	Idaho Stable Isotopes Laboratory, Idaho College
US	Indiana State Univ.
US	Indiana Univ.
US	Jet Propulsion Laboratory
US	Kansas State Univ.
US	Lawrence Livermore National Security LLNS
US	LBL Lawrence Berkeley National Laboratory
US	Licor Inc.
US	Los Alamos National Laboratory, LANL
US	Los Gatos Research, CA
US	Massachusetts Institute of Technology, Kat Potter
US	Monterey Bay Aquarium Research Inst., MBARI
US	NASA Ames
US	NASA LARC
US	NASA OAK RIDGE ASSOCIATED UNIVERSITIES
US	NCAR/UCAR
US	NEON INC
US	NIST, Gaithersburg
US	NOAA ARL Idaho
US	NOAA ATDD, Tennessee
US	NOAA Chemical Sciences Division
US	NOAA-Fisheries

US	Northwestern Univ., Illinois
US	Nova wave Technologies, California
US	Oak Ridge National Lab
US	Old Dominion Univ.
US	Oregon State Univ., College of Forestry
US	Pacific Marine Environmental Laboratories
US	PENN STATE Univ.
US	PLANETARY EMISSIONS MANAGEMENT
US	Princeton Univ.
US	PURDUE
US	Research Institute of Hawaii, Univ. of Hawaii
US	Rutgers Univ.
US	San Diego State Univ.
US	Sandia Nat'l Laboratories
US	Southwest Sciences
US	State Univ. of New York, Geneseo
US	Stony Brook Univ., New York
US	Sunburst Sensors
US	Testmark Laboratories
US	Texas A&M Univ.
US	Thermo Fisher Scientific
US	Univ. Alabama
US	Univ. Arizona, Biosphere 2
US	Univ. Cal, Laurence Berkeley lab
US	Univ. California, Irvine
US	Univ. California, Scripps
US	Univ. Colorado
US	Univ. Florida
US	Univ. Georgia
US	Univ. Hawaii
US	Univ. Idaho
US	Univ. Maine
US	Univ. Mass., Boston
US	Univ. Miami
US	Univ. Missouri

US	Univ. Montana
US	Univ. Nebraska
US	Univ. New Hampshire
US	Univ. of California, Santa Barbara
US	Univ. of Georgia
US	Univ. of Illinois
US	Univ. of Minnesota
US	Univ. of Missouri
US	Univ. of Nebraska
US	Univ. of New Hampshire
US	Univ. of New York, Stoneybrook
US	Univ. of Pennsylvania, Leidy Labs
US	Univ. of Utah
US	Univ. of Washington
US	Univ. of Wisconsin, Madison
US	Univ. Ohio, Toledo
US	Univ. Oregon
US	Univ. Texas
US	Univ. Utah
US	Univ. Washington
US	Univ. Washington, Bothell
US	Univ. Wyoming
US	US DOE
US	US EPA
US	USDA
US	USFS
US	USGS
US	Woods Hole Oceanographic Institution WHOI
Venezuela	VENEZUELA, LAB. QUIMICA ATMOSFERICA

B. WMO World Primary and Secondary Total Column Ozone (Dobson) Standards.

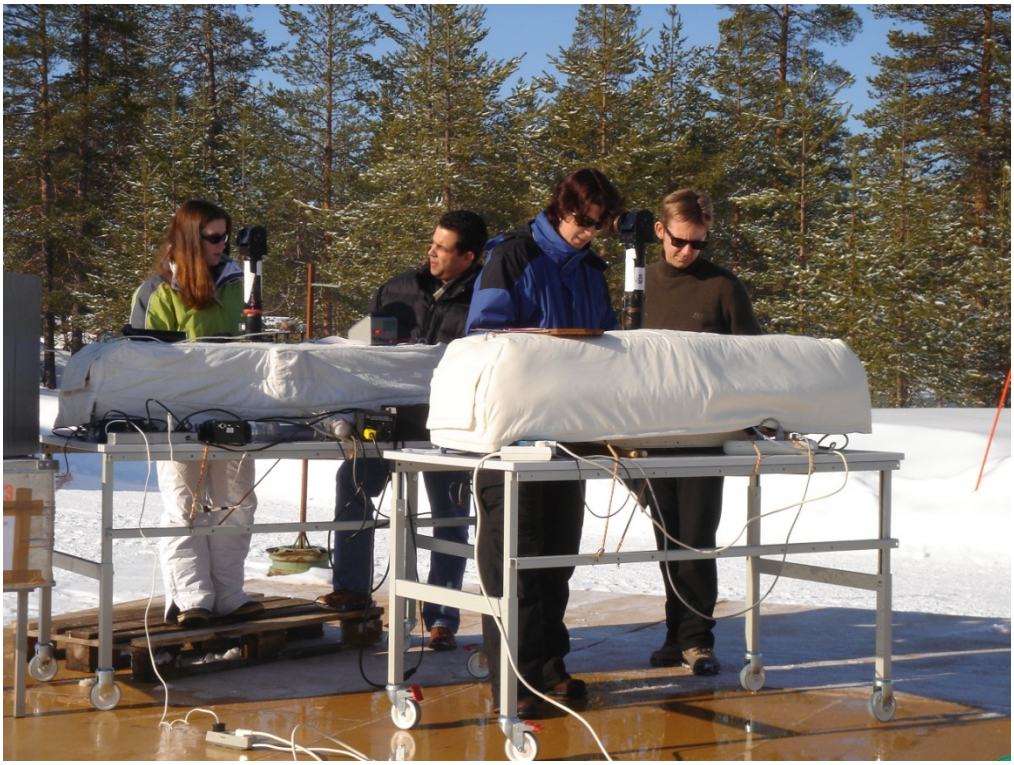
Institutions/Countries the Global Monitoring Division Provides World Reference Dobson Ozone Spectrophotometer Calibrations.

Aerological Observatory, Tsukuba, Japan
Algeria
Botswana
Buenos Aires Observatory, Argentina
Bureau of Meteorology Melbourne, Australia
China
CSIRO Perth
Egypt
India
Kenya
L'observatoire du Haute Provence, France
Marcapomacocha, Peru
Meteorological Observatory Hohenpeissenberg, Germany
Mexico
NASA Wallops, Langley and Goddard
NIWA, Lauder New Zealand
Pakistan
Peru
Philippines
Seychelles
Singapore
South Africa
Thailand
U of Alaska, Fairbanks
Uganda

GMD Stations Where Dobson World Standard Calibrations are Undertaken

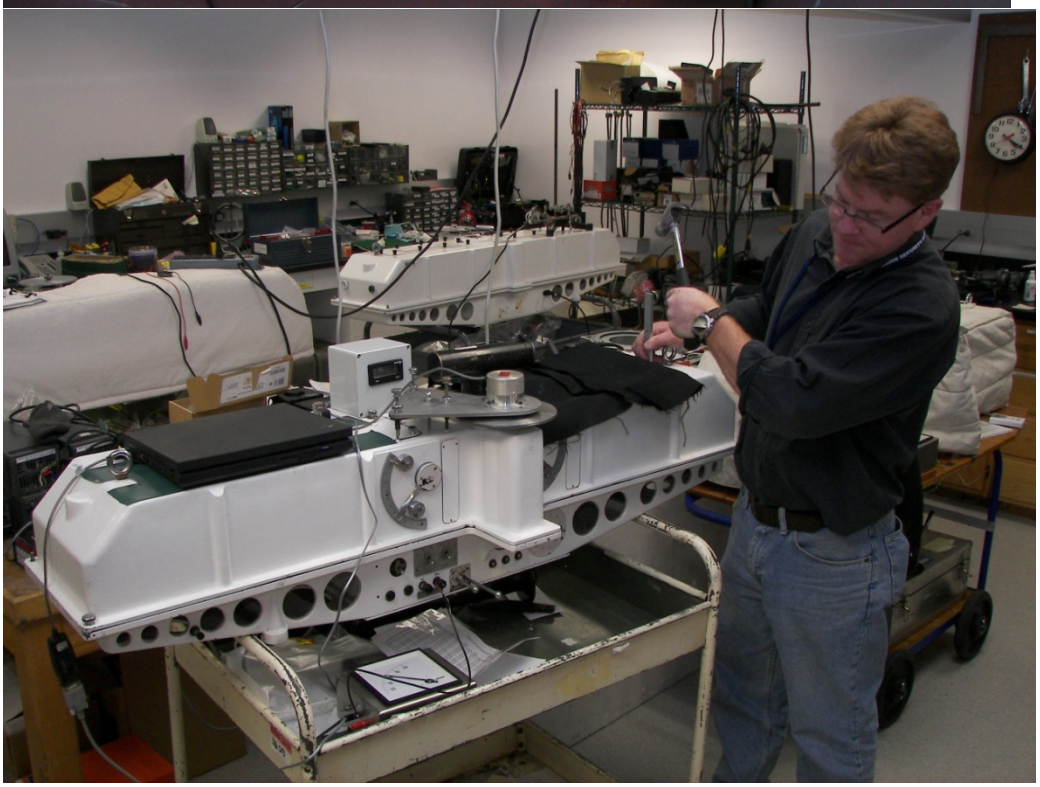
Barrow, AK
Bismark, ND
Caribou, MN
Nashville, TN
Hanford, WA
Mauna Loa, HI
American Samoa
South Pole, Antarctica

Global Monitoring Division World Secondary Standard Dobson 65 in a WMO sponsored South American Dobson intercomparison, Buenos Aires, Argentina. Robert Evans, GMD, third from front is operating the Standard Dobson total column ozone instrument.

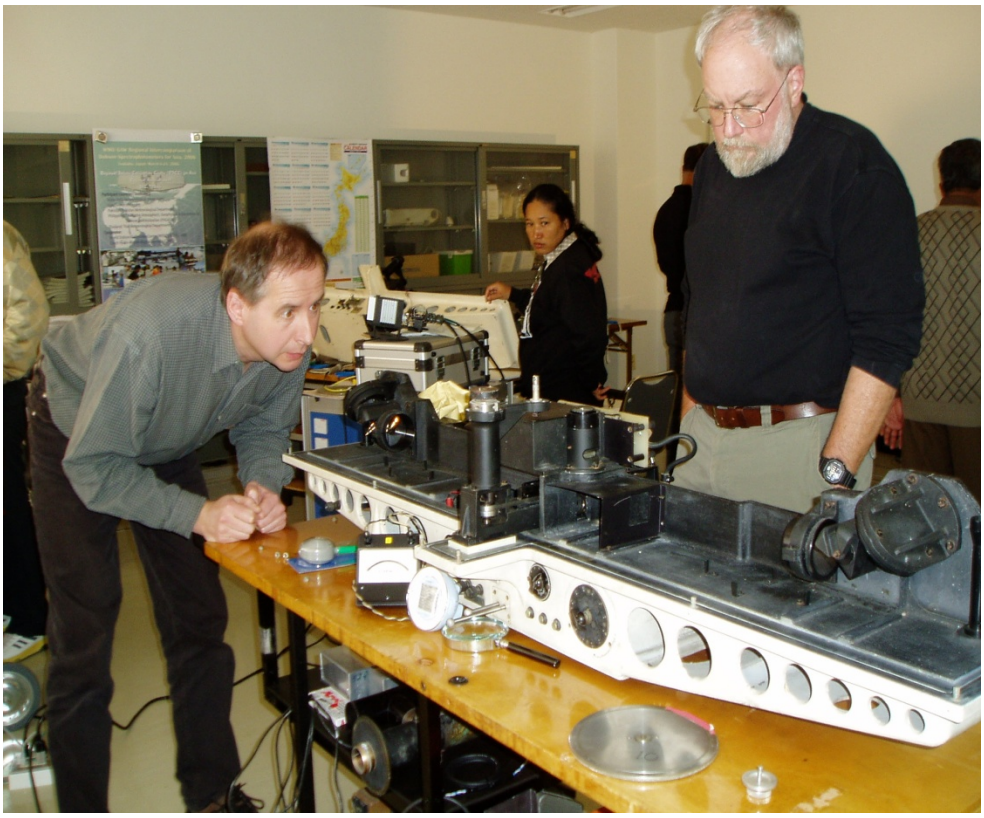


Comparing Dobson measurements in Soldankya, Finland above the Arctic Circle to see how the instruments operate at high latitudes.

Sunrise Dobson calibrations, Boulder, Colorado.



Adjusting a repaired Dobson, GMD laboratory, Boulder, Colorado.



OK. Now why does it not work? It did before we changed the mirrors! Instrument 52 from Manila, Philippines at Tsukuba, Japan intercomparison. (L) Martin Stanch, Czech Republic and (R) Robert Evans GMD.

Conducting Dobson total column ozone measurements during the annual Antarctic Ozone Hole from the Atmospheric Research Observatory, South Pole.

The measurements are conducted at ambient temperatures with windows open to the outside where the temperatures may reach -80C.

C. Solar Radiation Calibration Standards.

Institutions to which the Global Monitoring Division Provides Reference Solar Radiation Calibrations

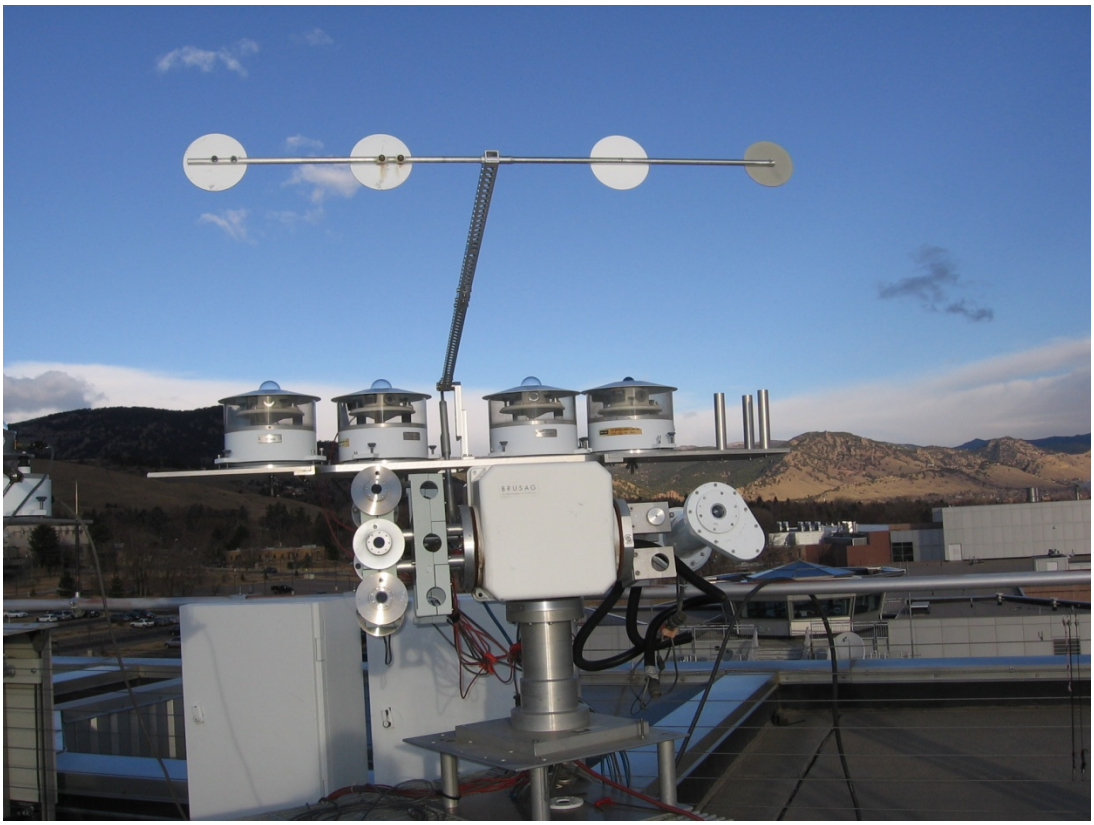
Biospherical Instruments Inc.
Battelle Labs
Bureau of Land Management
Chinese BSRN (Baseline Surface Radiation Network) sites
Colorado State University: IR Calibration exchange and UV calibrations.
DOE/ARM
DRI: Calibrations
Eastern New Mexico University
ENA, Italy, Calibrations
Eppley Laboratory
EU Joint Research Center at Ispra
Global Atmospheric Watch
Hampton University: Balloon-borne radiative flux measurements.
INDOEX (International Experiment in the Indian Ocean)
Kansas State University
METEO Swiss: Calibrations
NASA Goddard
NASA Langley
National Institute of Water & Atmospheric Research (NIWA)
National Renewable Energy Laboratory
National Weather Service
NCAR
NCAR Flight Facility
NOAA Chemical Science Division
NOAA Flight Facility
NOAA ISIS
NOAA Mesonet
Queensland University of Technology : Calibrations.
Rosario National University, Argentina, Calibrations
School of Geography & Environmental Studies
Scripps
Sinte Gleska University, South Dakota: Educational partnership
Smithsonian Institute, SERC

Surfrad (NOAA)
Swiss Institute of Technology (ETH), Zurich: BSRN calibrations.
Tiksi, Russia (Roshydromet)
University of Alabama: Cloud detection automation.
University of California, San Diego, Scripps: ABC radiation calibrations.
University of Colorado
University of Houston Institute for Climate & Atmospheric Science: Cals.
University of Idaho: Dome Concordia (Antarctica) Satellite (AIRS)
U of Kentucky
University of Maryland: Radiometer calibrations
University of Rome
University of Tasmania, School of Geography
University of Texas El Paso (UTEP): Calibrations
University of Toronto, Canada: SEARCH and CNDAC
University of Washington: Study of snow-air interactions and radiation
US Navy
USDA
Various NOAA campaign projects: SEARCH, SHEBA, ACE, NINA
WMO, Geneva: Calibrations
Woods Hole
WPL/ETL/PSD

Institutions to which the Global Monitoring Division Provides World Reference Solar Calibrations In Situ at Mauna Loa Observatory, Hawaii

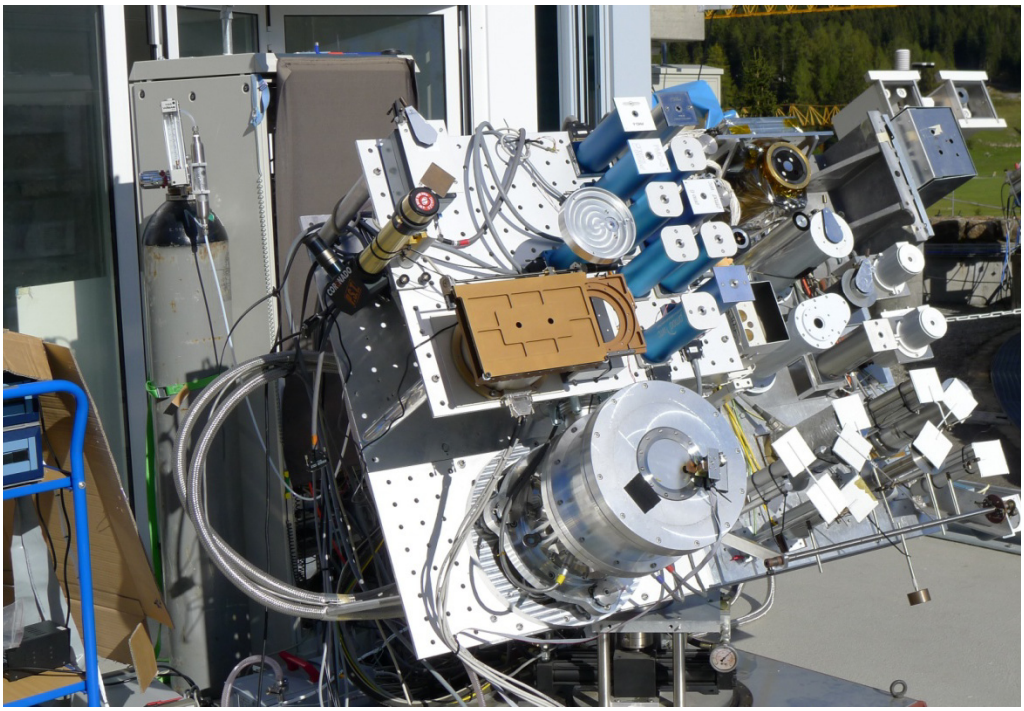
Colorado State University
Environment Canada
Geronimo Peak Observatory
NASA AERONET, Goddard Space Flight Center
NCAR HAO
NIES, Japan
NIWA, New Zealand
Solar Light Corp.
University of Denver
US Department of Agriculture

One year long pyrheliometer intercomparison and calibration at the NREL Solar Radiation Research Laboratory. In this test, commercial radiometers were being tested against GMD and NREL standards.



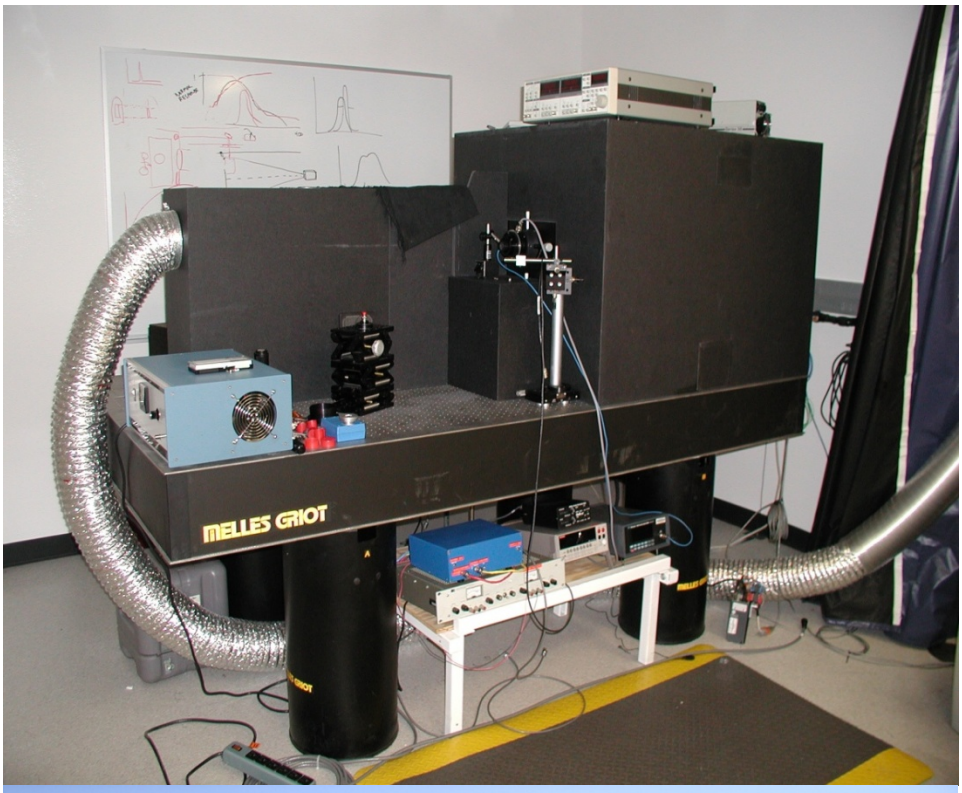
Diffuse and direct solar radiation instrument calibrations at the GMD Boulder, Colorado rooftop facility.

International pyrheliometer comparison Davos, Switzerland, 2010. GMD scientists are testing GMD instruments against the World Radiometric References.



The World Radiometric Reference for solar measurements, Davos, Switzerland.

GMD Surface Radiation (SURFRAD) network site at Pennsylvania State University near State College, PA. The data from this and 6 other SURFRAD sites distributed across the U.S. are transmitted daily to GMD, Boulder.



GMD Central UV Calibration Facility (CUCF) spectral calibration bench.

GMD Table Mountain Solar Radiation Calibration Facility showing an array of solar and UV radiometers being calibrated.