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Asia-Pacific GAW on Greenhouse Gases

Newsletter

Volume 9
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책임운영기관
National Institute of Meteorological Sciences

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

Korea Meteorological Administration

NIWA
Taihoro Nukurangi

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Contents

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IG^{3}IS: An Integrated Global Greenhouse Gas Information System

Jocelyn Turnbull[1,2*], Phil DeCola[3], Oksana Tarasova[4], Mario Peiro Espi[4] and the IG^{3}IS Steering Committee[5]

Extended Abstract

Implementation of the Paris Agreement, and in particular its transparency mechanism adopted at the Conference of the Parties in 2021, requires all nations to report their greenhouse gas emissions on a regular basis. This information should be timely and accurate to be able to track progress towards climate goals. The Integrated Global Greenhouse Gas Information System (IG^{3}IS) is a World Meteorological Organisation – Global Atmosphere Watch initiative that aims to expand the greenhouse gas (GHG) observational capacity, extend it to regional and urban domains, and develop the information systems and modelling frameworks to provide GHG emissions information to society[1]. Information provided within the IG^{3}IS framework will be consistent across policy relevant scales from facility to national and across the portfolio of gases and sectors that are included in climate mitigation.

IG^{3}IS views the science through the lens of stakeholder requirements, and success is measured by the extent to which GHG information is being used to support decisions. The ultimate success criteria are that the IG^{3}IS information is "used" and guides valuable and additional emission reduction actions, building confidence in the role of atmospheric composition measurements as an essential part of the climate change mitigation tool kit. To achieve these goals, IG^{3}IS endorses and supports research projects around the world. Such projects will be the basis for longer-term operational services.

IG^{3}IS endorsed projects at the national scale include ongoing efforts to improve methane emissions estimation (United Kingdom, Switzerland), and other non-CO_2 GHGs (Australia, United Kingdom). In all three countries, emission estimates obtained from atmospheric observations and modelling of these gases are compared with the National Inventory Report. The atmospheric information is used to develop country-specific emission factors that are then used to revise those reports to obtain a better match with the observations[2]-[4].

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National-scale efforts to evaluate CO_2 emission rates are being carried out in New Zealand and Korea and endorsed by IG^{3}IS. Initial work in New Zealand has demonstrated a discrepancy in land carbon uptake (LULUCF) between the National Inventory Report and atmospheric observations[5]. This discrepancy remains even after accounting for differences in methodology, and it is likely that such differences between reported emissions and atmospheric observations are not limited to New Zealand. This result implies that improved data, as well as strengthened quantification and reporting mechanisms, will be needed to ensure that nationally reported emissions are consistent with the impact on the Earth's atmosphere[6].

California's regional emissions work is perhaps unique in that the atmospheric observations and modelling have been developed in direct response to policy initiatives, and in many instances are an integral part of policy evaluation[7], [8].

Facility scale emissions information (that may include different economic sectors) endorsed by IG^{3}IS has so far largely focussed on oil and gas industry emissions, from drilling, distribution and delivery[9]-[12]. This work aligns directly with the recently announced Global Methane Pledge led by the European Union and United States of America and supported by 103 countries (https://ec.europa.eu/commission/presscorner/detail/en/statement_21_5766), aiming to reduce methane emissions by 30% by 2030 versus 2020 levels.

There is also increasing recognition of the role of non-state stakeholders in addressing the challenge of emission reductions and in this respect cities are the front runners. City-scale GHG emissions estimation is ongoing in numerous cities around the world, including Beijing, Seoul, Tokyo, Los Angeles, Salt Lake City, Indianapolis, Boston, Washington DC/Baltimore, Toronto, Mexico City, Sao Paolo, Auckland, Melbourne, Paris, Munich, and many more. A wide variety of methodologies are being employed in these urban studies. The combination of tower observations of GHGs with meso-scale inversion modelling and prior emission estimates from fine scale inventories, conceptually similar to the national scale efforts, is widely used[13]-[15]. Determination of city-wide emissions using a mass balance technique driven by aircraft observations is also widespread[16]. Other techniques include ground-based mobile surveys[17], urban eddy covariance[18], tracer:tracer ratios[19], sector partitioning with isotopes and ancillary trace gases[20], ground-based remote sensing[21], dense networks[22], and satellite GHG observations[23]. Each method has advantages and disadvantages, depending on the type of emission information required, ranging from determining a baseline of whole city emissions, tracking changes through time, attributing the emissions by sector, identifying and quantifying individual sources, quantifying sources and spatial patterns throughout a city, or ultimately understanding the processes and drivers of every emission source in a city (Figure 1).

As urban GHG measurement techniques evolve, IG^{3}IS has brought the research community together to produce the IG^{3}IS Urban Greenhouse Gas Emission Observation

and Monitoring Best Research Practices. These best research practice guidelines lay out the range of available methodologies for determining urban GHG emissions. They are intended to provide stakeholders with a metric by which they can assess the quality of proposed urban GHG emission information and services, and conversely, and allow the providers of this information including the research community to demonstrate the quality of their information products to stakeholders and funding agencies. An overview of each method is given, along with annexes that consolidate detailed information on how each method can be implemented. These best research practice guidelines are available on the IG^{3}IS website (ig3is.wmo.int) in draft form for public comment until January 31st, 2022, following which the final version will be released in mid-2022. As the research practices are refined through research and implementation of the IG^{3}IS pilot and demonstration projects over the next few years, these guidelines are anticipated to be the first step towards documentary standards. IG^{3}IS is currently working towards a similar set of good practices for national-scale emissions information.

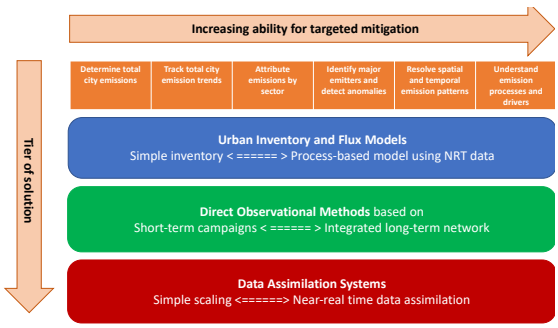

Figure 1. Solutions for targeted mitigation action for urban greenhouse gas emissions.

To facilitate the interaction between the providers of the information including research community and users of this information, IG^{3}IS hosts regular Stakeholder Symposiums and user consultations. Ongoing projects highlight the pathways that have been successful in linking policy and reporting changes to enhanced emissions information, as well as the challenges faced in doing so. At the same time, new relationships are forged between scientists, inventory builders and policymakers. IG^{3}IS partners with the UNFCCC to connect the IG^{3}IS methodologies and advances to international reporting frameworks, including updates to the Subsidiary Body for Scientific and Technological Advice[24] and recognition of atmospheric observations and modelling in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (TFI)[25].

In summary, the best indicator of the success and vitality of the Paris Agreement are the very measurements of atmospheric concentrations of CO_2 and other GHGs that stimulated action on climate change. Continuous, consistent, and accurate GHG concentration measurements at local, national, and global scales have value beyond their original role as the harbinger calling attention to the climate change challenge. Measured GHG concentrations are the ultimate indicators of emission reduction policy successes. Regardless of the GHG emission reduction policies and measures applied, effective implementation, both in the short- and long-term, will require consistent, reliable and timely information on the magnitude of GHG concentrations, their sources and sinks, and their trends over time.

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Introduction of the WMO endorsed IG^{3}IS project INVERSE-KOREA

Sangwon Joo[1], Haeyoung Lee[1], Jinkyu Hong[2], Jeongsik Lim[3], Hochan Lee[4], Eunsook Kim[4] and Yeon-Hee Kim[1]

Background

South Korea declared a policy to achieve carbon neutrality by 2050. As a part of the efforts for meeting the national goal, the National Institute of Meteorological Sciences/Korea Meteorological Administration (NIMS/KMA) proposes to develop a system INVERSE-KOREA (INverse modeling for Validating and Evaluating of the Reduction of Sectoral greenhouse gas Emissions in KOREA) to monitor the greenhouse gas (GHG) inventory in the country.

NIMS has a long history and extensive specialties in measuring atmospheric GHGs and has contributed to the World Meteorological Organization/Global Atmospheric Watch (WMO/GAW) GHG measurements[1,2]. Furthermore, recently Korean Integrated Model (KIM) is in operation to simulate weather flows better in Korea with extremely dense meteorological observations in the Korean peninsula[3].

With the success of GHG observations and numerical modelling efforts, NIMS has a strong potential to contribute the WMO IG^{3}IS (Integrated Global Greenhouse Gas Information System) and can support the national GHG reduction policy by reducing the uncertainty in the national emission inventory.

The observations and modelling is described in section 2 and followed by the implementation plan in section 3. No results are included in this article as the project starts now, but we hope this article help to share the IG^{3}IS activities in Korea with other countries and encourage collaborations for the success of the project.

Method

1. Observations

In-situ observations are shown in Figure 1. Since 1999, NIMS/KMA has been monitoring the atmospheric CO_2, CH_4, N_2O, SF_6, and CFCs mole fractions at Anmyeon-do. In 2012, the monitoring network is expanded towards the southwest (Jeju Gosan) and the east (Ulleung-do). In-situ observation at the Lotte world tower will start (550m Above Ground Level (AGL)) in 2022 to monitor GHGs from the north. A tall tower at Boseoung located in southwest Korea samples GHGs at 150 and

1 National Institute of Meteorological Sciences/Korea Meteorological Administration, 2Yonsei University, 3Korea Research Institute of Standard and Service, 4 Seoul Metropolitan Government Research Institute of Public Health and Environment

300 m AGL. The five in-situ observations are in operation to be assimilated in the INVERSE-KOREA modeling framework for a better understanding of GHG inflow and outflow at the Korean Peninsula. CRDS is also installed on the NIMS research vessel to analyze CO_2 and CH_4 to assimilate continuously GHG observations over the ocean around the peninsula.

For a better understanding of upper level GHGs from distant sources, airborne in-situ observations and ground-based Fourier Transform Spectrometer (FTS) at AMY will be assimilated. To monitor GHGs in high resolution, we are developing a low-cost-medium-accuracy optical equipment (column) sensor mainly focusing on CO_2, CH_4, and SF_6. It will help to improve the accuracy of the inversion results with dense observations in future.

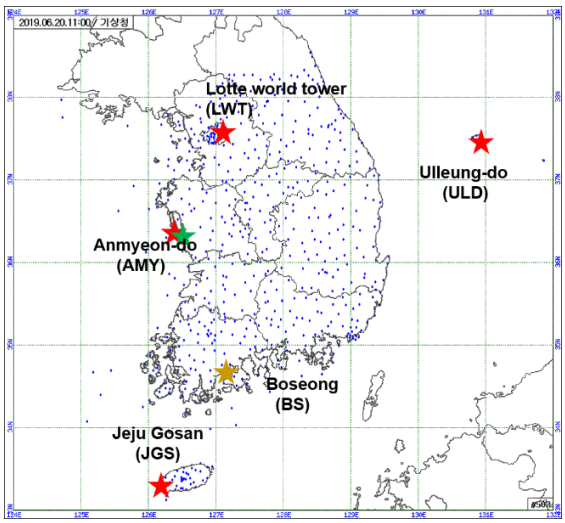

Figure 1. Horizontal distribution of automatic weather stations (AWS) and in-situ GHG observation sites. AWS are in blue dot, surface in-situ, tall tower, and FTS site are marked in red, blue and green star, respectively.

For identifying sector specific emissions, isotopes and trace gas ratios are being developed. The isotope data have been collected since 2013 with NOAA flasks at AMY and will be expanded to CH_4 in 2022. More quasi-continuous measurements for halocarbons and isotopes will be made from 2021.

South Korea is covered with about 600 surface observation stations in 13 km resolution (Figure 1). 26 upper air observation stations (8 radiosonde observations, 9 wind profiler, 15 doppler weather radars, 22 doppler Lidars and 95 ceilometer backscatter data will be used to retrieve PBL winds and heights. The PBL observations are used to evaluate the weather model performance and will be assimilated in the inversion framework.

2. Inversion

KMA has operated a state-of-the-art NWP model, KIM, in 12-km resolution since 2020 with initial conditions from the hybrid four-dimensional ensemble variational data assimilation [3]. The advantage of the KIM is that it incorporates all of the local weather observations over South Korea including AWS, local Aircraft Meteorological Data Relay, ground Global Navigation Satellite System data, wind profiler, and so on. The KIM analyses are used as the initial and boundary weather conditions in the inversion system to depict the atmospheric flow better over the Korean Peninsula.

Main inversion system is WRF/DART (Weather Research and Forecasting/Data Assimilation Research Testbed) with advanced physics (i.e. YSU TKE PBL, YSL surface layer, etc.)[4], and ensemble adjustment Kalman filter[5] The domain and resolution of the system is shown in Figure 2. WRF Vegetation Photosynthesis and Respiration Model (VPRM) is used to estimate regional-scale CO_2 and CH_4 emissions from the anthropogenic, , terrestrial, and oceanic emissions sources[6].

Prior emissions will include Regional Emission inventory in ASia (REAS) v3 for anthropogenic emissions[7], Carbon Tracker Asia for terrestrial biosphere flux, and Estimating the Circulation[8] and Climate of the Ocean, Phase II (ECCO2)-Darwin available at an 18-km horizontal grid spacing for ocean flux[9]. For CH_4 emissions, we will use Emission Database for Global Atmospheric Research (EDGAR) v5 gridded emissions, combined with a new dataset on fuel exploitation dataset[10]. Wetland and termite emissions will be modeled in VPRM. For both CO_2 and CH_4 emissions, we will use Fire INventory from NCAR (FINN) emissions for wildfire[11]. Once the WRF-VPRM/DART framework is well tested for both CO_2 and CH_4, we will also include SF_6 into the framework.

The global Carbon Tracker is going to be used to generate boundary concentration for the WRF-VPRM at the beginning but the GEOS-Chem (Goddard Earth Observing System-Chemistry) is going to be installed to generate multiple boundary conditions and their impact in the inversion will be compared to estimate the uncertainty of the boundary conditions.

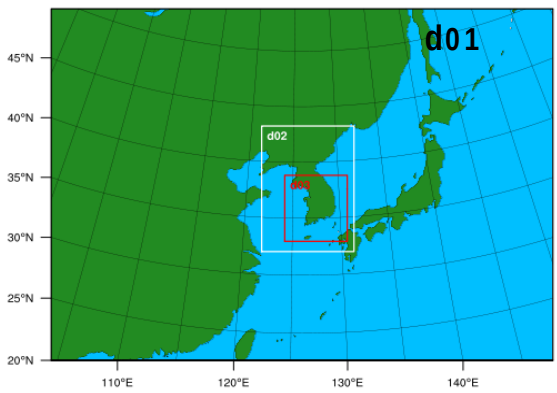

Figure 2. The WRF domain size for the INVERSE-KOREA. The inner-most domain is 3km over south Korea, middle domain is 9km over the Korean peninsula, and outer domain is 27km over the East Asia.

Implementation Plan

The first phase takes 3 years from 2021 to 2023 and consists of 3 steps as follows:

1) Installing the inversions system, mainly the WRF-DART based system. Footprint simulation with STILT and WRF, and GEOSchem based inversion system will be installed to reduce the uncertainty of the WRF-DART inversion.

2) Testing and evaluating the installed inversion systems and compare with the bottom-up national inventory reports.

3) Starting the service of near-real-time top-down emission products for inventory communities and public.

We target CO_2 from 2021 and will apply this inversion system to CH_4 and SF_6 successively. In 2023, we expect to have a campaign in Seoul, to expand the inversion system to a city scale. This campaign can be linked to the second phase of the project targeting Seoul. Isotope measurements also will be deployed for this project so that the isotope ratio of $^{13}C/^{12}C$ in CO_2 will be installed at AMY in 2021 and CH_4 in 2022.

Acknowledgement

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JMA's activities for GHGs observation and recent topics

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Introduction

The Japan Meteorological Agency (JMA) has been observing greenhouse gases (GHGs) at three ground stations and by using an aircraft and observation vessels (Fig.1), and serves as the World Calibration Centre (WCC, hereinafter WCC-JMA) for methane (CH_4) in Asia and the South-West Pacific within the framework of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO).

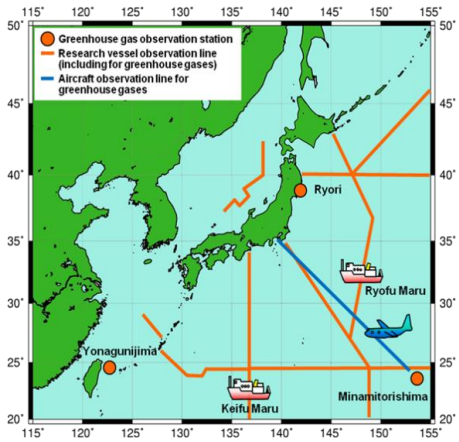

Figure 1. The schematic diagram of JMA's observation network.

In this 10th Asia-Pacific GAW Workshop on Greenhouse Gases, we introduce JMA's new activities for GHGs observation and recent topics.

HFCs (Hydrofluorocarbons) observation at Minamitorishima GAW global station

In 2020, JMA started the observation of the Hydrofluorocarbons (HFCs) at the Minamitorishima GAW Global Station, one of the 30 GAW global stations in the world (Fig.2), as it relates to the Kigali amendment to Montreal protocol that restricts the production and emission of HFCs. HFCs are known as potent greenhouse gases and we observe the eight species that have the biggest contribution in the total HFCs to global warming (Fig.3).

Figure 2. Minamitorishima (red circle) is one of the 30 GAW global stations in the world.

1. Japan Meteorological Agency (JMA), Tokyo, Japan
2. Meteorological Research Institute (MRI), Tsukuba, Japan

The air sample is taken from the top of the tower, 20 m above ground level. It is filtered, dehumidified before the preconcentration in the cryogenic chamber with two traps (Fig.4). Then it is analyzed with GC/MS (GCMS-5977 system model, Agilent Technologies Inc.). The sampling interval is 1 hour.

We use one working standard in a 48L cylinder which includes eight species of HFCs and synthetic air as matrix gas. The mole fraction of the working standard is assigned based on the gravimetrically prepared JMA-Primary in a 9.4L cylinder and target gas is measured periodically to check the condition of the system and the stability of the mole fraction of the working standard.

The results of HFCs observation are presented to the public in the JMA homepage (https://www.data.jma.go.jp/ghg/kanshi/ghgp/cfcs_e.html) and the data is available from WMO/GAW World Data Centre for Greenhouse Gases (WDCGG) (https://gaw.kishou.go.jp).

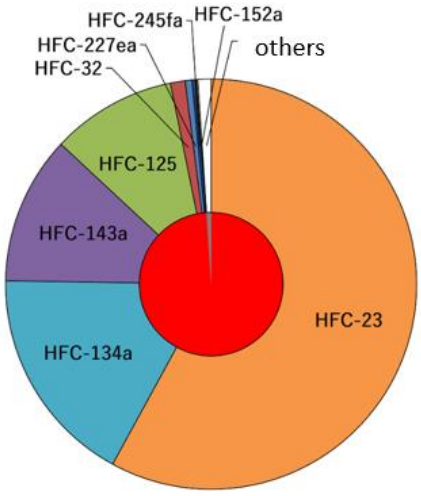

Figure 3. The contribution (%) of each HFC in the total HFCs to global warming, estimated from the global warming potential (GWP) in IPCC AR5 reports and AGAGE data.

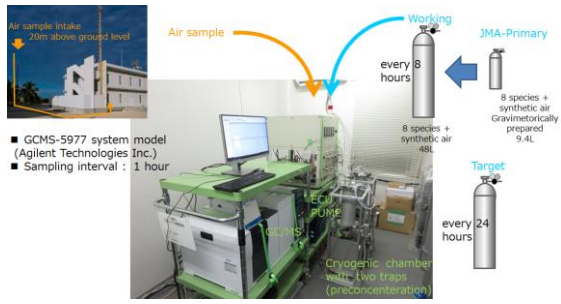

Figure 4. The schematic diagram of JMA's HFCs observation system and the calibration.

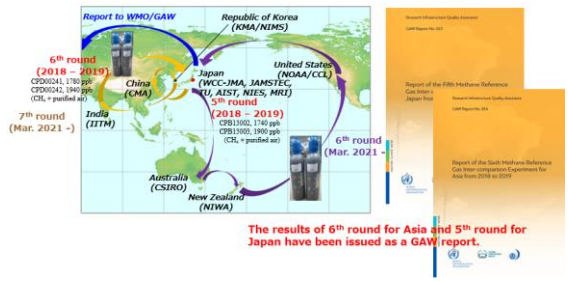

Figure 5. The overview of the reference gas inter-comparison and the reports of the recent results of CH_4 reference gas inter-comparison experiments published as GAW Report No. 263 and 264.

The recent results of CH_4 reference gas inter-comparison experiments

1. The back ground

The WCC-JMA has so far carried out five rounds of inter-comparison experiments of CH_4 reference gases from 2001 to 2019 as well as ongoing the sixth and the seventh rounds as one of the WCC activities in co-operation with NOAA/ESRL (WMO/CCL, USA), CSIRO (Australia), NIWA (New Zealand), CMA (China), KMA/NIMS, KRISS (Republic of Korea), IITM (India), and several Japanese laboratories.

We circulate two 9.4L cylinders around each region and each participant measures them with their measurement system and their Primary standard, and we compare the measurement results submitted from each laboratory.

The purpose of the inter-comparisons is to understand the differences between the participants' CH_4 standard scales as well as to monitor the long-term stability of standard gases in Asia and the South-West Pacific regions.

The direct corrective action to the observation of each laboratory by using the results of the inter-comparisons to satisfy the GAW network compatibility goal would be difficult because we could understand just two relationships in the two cylinders between measurements of CH_4 by each laboratory and the WCC-JMA at a certain point in time. Despite the difficulty, each laboratory has strived to search for the reasons of the differences derived from the inter-comparisons; it improves the compatibility to the WMO scale. Also, the Primary standard maintained by the WCC-JMA serves as de-facto additional long-term "surveillance cylinders" providing information on the stability of the WMO mole fraction scales maintained by the CCL (GAW, 2019). In that way, the inter-comparisons activity meets the purposes mentioned above.

Previously the results were issued as "Other GAW related publications" on the former GAW homepage. However, WMO proposed to publish them as a GAW Report, so the recent results of the fifth in Japan and the sixth in Asia were issued as GAW Reports (GAW Report No. 263 and 264, respectively) in the WMO Library, online.

2. The recent results

Table 1 and 2 provide details of the CH_4 analytical methods used by each laboratory. WCC-JMA, Japan Agency for Marine-earth Science and TEChnology (JAMSTEC), China Meteorological Administration (CMA), Korea Meteorological Administration/National Institute of Meteorological Sciences (KMA/NIMS), and Indian Institute of Tropical Meteorology (IITM) reported their measurements on the WMO CH_4 X2004A scale or X2004 scale. Tohoku University (TU), The National Institute of Advanced Industrial Science and Technology (AIST), National Institute for Environmental Studies (NIES) and Meteorological Research Institute (MRI) adopt their own scales. Figure 6 shows differences between measurements of CH_4 by each laboratory and the WCC-JMA. Results from some laboratories agree within the GAW network compatibility goal of ±2 ppb represented by green lines, and the others have some differences because of their CH_4 calibration scales or other reasons.

Table 1. Methods, instruments, and calibration scales used by each laboratory (the fifth round in Japan, GAW Report No. 263)

Laboratory	Method	Instrument	Calibration Scale	Range of calibration gases (ppb)
WCC-JMA	CRDS	Picarro G2301	WMO CH_4 X2004A	1611.38 ~ 2164.63
JAMSTEC	CRDS	LGR GGA-30r-EP	WMO CH_4 X2004A*	1611.05 ~ 2119.54
TU	GC/FID	Agilent 6890	TU 1987 Scale	896.1 ~ 2500.4
AIST	GC/FID	GC-14BPF (SHIMADZU)	AIST Scale	1006.5 ~ 2534.0
NIES	GC/FID	Agilent 7890A	NIES 94 CH_4 scale	1310.62 ~ 2486.92
MRI	CRDS	Picarro G1301	MRI Scale	1598.7 ~ 2102.1

* Calibrated by JMA primary standards

Table 2. Methods, instruments, and calibration scales used by each laboratory (the sixth round in Asia, GAW Report No. 264)

Laboratory	Method	Instrument	Calibration scale	Range of calibration gases (ppb)
WCC-JMA	CRDS	Picarro G2301	WMO CH_4 X2004A	1 611.38 ~ 2 164.63
CMA (CRDS)	CRDS	Picarro G2301	WMO CH_4 X2004A	1 645.11 ~ 2 376.29
CMA (GC/FID)	GC/FID	Agilent 6890N	WMO CH_4 X2004A	1 721.92 ~ 2 579.0
KMA/NIMS	CRDS	Picarro G2301	WMO CH_4 X2004A	1 674.25 ~ 2 329.67
IITM	CRDS	Picarro G2201-I	WMO CH4 X2004	1 652.22 ~ 1994.48

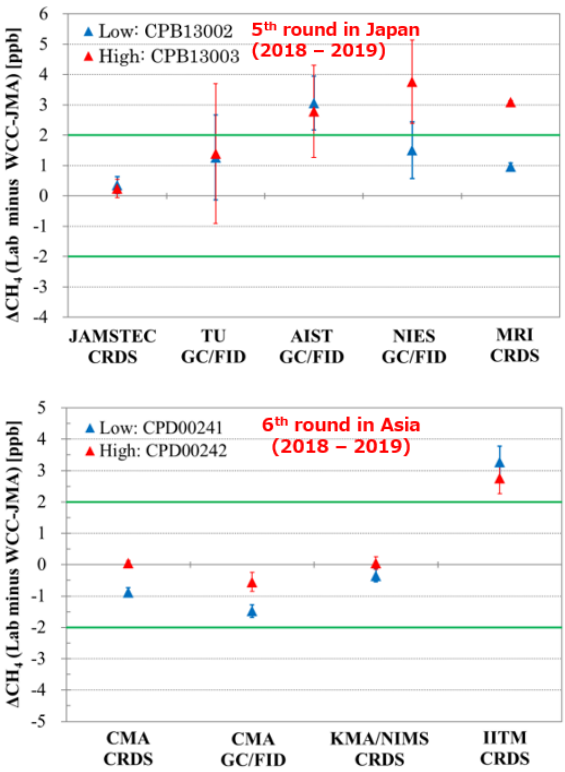

Figure 6. CH_4 differences (Laboratory X minus WCC-JMA) for each cylinder. The mean value of WCC-JMA measurements at the beginning and end of the experiment was used as WCC-JMA results. The two green lines identify the WMO recommended network compatibility goal (±2ppb) for atmospheric CH_4 measurements. The measurement uncertainty (σ) in this experiment indicated by the error bars is defined as the square root of the sum of squares of the two standard deviations reported by WCC-JMA and the other laboratory.

Summary

In 2020, JMA started the observation of the HFCs at the Minamitorishima GAW Global Station. The data is available from WMO/GAW World Data Centre for Greenhouse Gases (WDCGG) (https://gaw.kishou.go.jp).

JMA serves as the World Calibration Centre (WCC-JMA) for methane in Asia and the South-West Pacific within the framework of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO).

The results of the experiments in the two regions (the fifth round in Japan, the sixth round in Asia) were published as GAW Reports (GAW Report No. 263 and 264, respectively). The seventh round in Asia and the sixth round in South-West Pacific are on-going.

Acknowledgements

We thank all of the participating laboratories for their contribution to the WCC inter-comparison experiments.

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Recent activities of World Data Centre for Greenhouse Gases (WDCGG)

SAWA Yousuke, KINOSHITA Atsuya, OHKUBO Saki, OWAKI Mika, NAGAI Yasuyuki, OGI Akinori, TONOZAKI Hiroki

Introduction

The World Data Centre for Greenhouse Gases (WDCGG) is one of the World Data Centres operated by the Japan Meteorological Agency (JMA) under the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO). WDCGG was established in October 1990 and it celebrated its 30th anniversary in 2020. The function of the WDCGG is to gather, archive and provide data on greenhouse gases (CO_2, CH_4, CFCs, N_2O, etc.) and related gases (CO, H_2, etc.). The number of reporting stations and submitted gas species has significantly increased during WDCGG's 30-year activity period. We updated WDCGG website (https://gaw.kishou.go.jp/) and relevant protocol in August 2018 to respond to the changing needs of users/contributors such as detailed metadata, improved findability and selection of the data, improved submission process, download information as reported in the previous Newsletter.[1] Here we report on the major progresses at the WDCGG after the update in 2018.

Current status of the reported data, contributors and registered users at the WDCGG

Reported data to the WDCGG has largely increased in 30 years as shown in Figure 1. WDCGG now archives and provides the data of 59 species of greenhouse gases. Data on 178 stations and 33 mobile platforms in more than 50 countries are available at the WDCGG. The number of contributors and collaborators has reached 132 as of October 2021 (Table 1). After the renewal of the WDCGG website, user registration became mandatory for data downloads. When registering and downloading

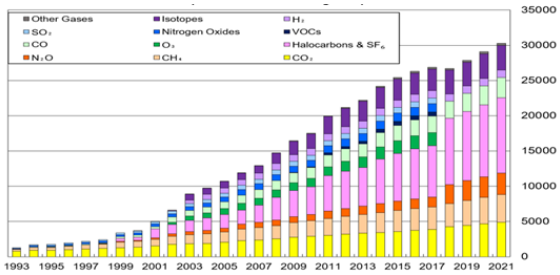

Figure 1. Data amount archived at the WDCGG. Reactive gases such as O_3, SO_2, nitrogen oxides and VOCs data were migrated to World Data Centre for Reactive Gases in 2018.

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the data, confirmation is needed to follow GAW data policy and WDCGG privacy policy. According to the WDCGG privacy policy, information on each user (name/email address/organization) is provided to the contributors when a user downloads data. Users are requested to contact contributors and make offer appropriate co-authorships or acknowledgment in their papers or presentations following GAW data policy. Feedback to the data providers encourages and supports long-term monitoring activities and data submissions to the data centres. As of October 2021, 1703 users are registered at the WDCGG.

Data submitted to the WDCGG	Total
Contributors and Collaborators	132
Station	178
Mobile	33
Gas species (data available)	59
Country/territory (data available)	56

Table 1. Statistics of the WDCGG as of October 2021.

Current status of the reported data, contributors and registered users at the WDCGG

After the 9th Asia-Pacific GAW workshop on Greenhouse Gases in 2018, we started several new services.

First, two satellite CO_2 products became available on the WDCGG website. GOSAT L2 products by National Institute for Environmental Studies were published in March 2019 and OCO-2 L2 products by NASA Jet Propulsion Laboratory/California Institute of Technology became available in March 2020. We prepare and show quick look maps for users to help understanding distributions of the CO_2 data (Figure 2).

Second, meteorological data were republished in June 2020 after checking and quality control by contributors and the WDCGG. They are served as auxiliary information for gas data in the common new data format regardless of platform types.

We also started providing data files in Network Common Data Form (NetCDF) format as well as text format in March 2021. NetCDF is a widely used format for exchanging or distributing scientific data. Files are self-describing and easy to be analyzed and visualized with many kinds of software. We hope that these would be further assistance to users' studies.

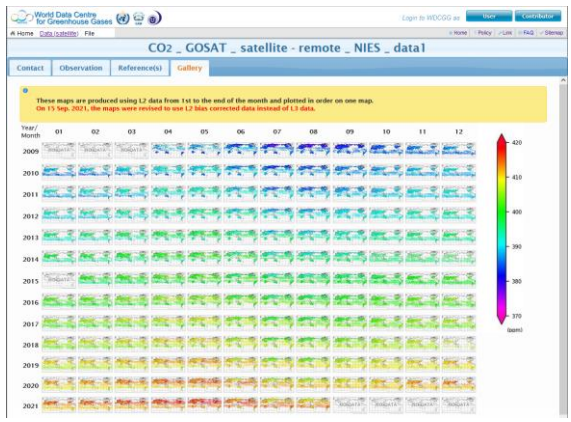

Figure 2. Quick-look maps for GOSAT CO_2 data. These maps are produced using L2 bias corrected data from 1st to the end of the month. The data are retrieved by National Institute for Environmental Studies, Japan.

Third, we began to issue Digital Object Identifiers (DOIs) in March 2021. Use of DOIs are promoted in GAW community to facilitate proper recognition of the data contributors in scientific analyses and reports and it will also allow for better monitoring of the actual data use. [2] As of October 2021, we have already issued 178 DOIs for individual datasets

as requested by contributors. Please note that the dataset for each station is available only for the latest version on the WDCGG and DOIs is kept same even it is updated. If a dataset already has an original identifier (DOI) issued by the contributor, it is posted on the WDCGG website as is.

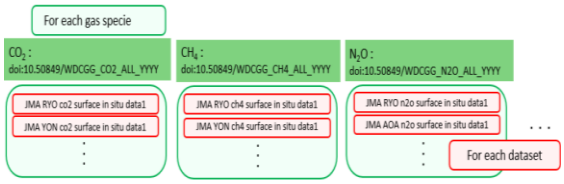

Figure 3. Digital Object Identifiers (DOIs) at the WDCGG. WDCGG registers DOIs for archived individual datasets and yearly fixed datasets for individual gas species.

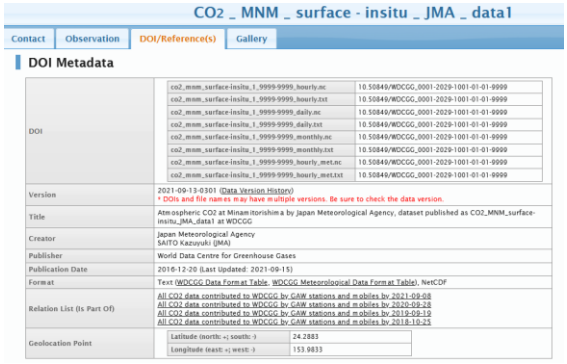

Figure 3 (continued) Example for metadata information at the WDCGG. Relation list for DOIs is shown for individual datasets at the WDCGG. Unique DOIs are issued for yearly fixed datasets (individual gas species datasets) used for WMO Greenhouse Gas Bulletins and WDCGG Data Summaries every year while DOIs for individual datasets issued by WDCGG kept same even if they are updated.

Fourth, the WDCGG began rolling out of "yearly fixed datasets". They are datasets used for WMO Greenhouse Gas Bulletin and WDCGG Data Summary, containing all data contributed by fixed and mobile stations regardless of DOI status. The reason for the launch of the yearly fixed datasets is that the WDCGG was often requested to provide older versions of datasets because they are useful to retest the results of previous studies. For the yearly fixed datasets, new DOIs are issued when a new WMO Greenhouse Gas Bulletin is published usually in autumn (Figure 3). See details at https://gaw.kishou.go.jp/policy/doi.

Global analysis by the WDCGG in WMO Greenhouse Gas Bulletin

The data submitted to the WDCGG are used for global analysis in the WMO Greenhouse Gas Bulletin, which is usually published before the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). Detailed data and analyses are also provided in WMO WDCGG Data Summary. The calculation method is described in GAW report No.184.[3] Global averaged mixing ratios have continuously increased and reached 413.2 ppm for CO_2, 1889 ppb for CH_4, and 333.2 ppb for N_2O in 2020 as shown in GHG Bulletin No. 17.[4] Analyzed global annual mean mixing ratios for CO_2, CH_4 and N_2O were referred as values of WMO/GAW in chapter 2 of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Working Group I – The Physical Science Basis.[5] We believe that these publications/activities would support continuous development in the observational and research activities about greenhouse gases.

Acknowledgements

We would like to thank for strong contributions to the activities of the WDCGG from all the users, data providers and experts in the GAW community. Your continuing support is really appreciated.

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High precision measurement of greenhouse gases and ozone depletion substances at background stations in China and national emission estimates

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Introduction

China Meteorological Administrations (CMA) has conducted high precision in-situ measurement of CO_2 and CH_4 since 1994 at Mount Waliguan, a global background station in Qinghai-Tibet Plateau by means of non-dispersive infrared (NDIR) and gas chromatography-flame ionization detector (GC-FID)[1]. With the development of greenhouse gases (GHG) measurement techniques, high frequency in-situ systems using cavity ring-down spectroscopy (CRDS) technique were installed since 2009 at 7 CMA stations, including Mt. Waliguan Shangdianzi, Lin'an, Longfengshan, Shangri-La, Jinsha, and Akedala[2]. Gas chromatography-electron capture detector (GC-ECD) was applied to measure N_2O and SF_6 at 5 CMA stations since 2009, and also applied to measure ozone depletion substances (ODS), e.g. CH_3CCl_3, CCl_4 and HCFCs at Shangdianzi since 2006.

In 2010, Medusa-GC/MS, a state-of-art system, was installed at the Shangdianzi station to measurement HFCs, PFCs, NF_3 as well as ODS[3]. Besides, weekly samples were collected at CMA stations, and GHG and ODS mixing ratios were analyzed at CMA GHG lab[4]. The data was combined with inverse models to estimate Chinese national emission, which help to understand the trends and geographic distributions of the sources or sinks, and to support the national GHG and ODS inventory.

Mixing ratios of major greenhouses of CMA stations

The averaged background mixing ratios of CO_2, CH_4 and N_2O at the Waliguan Global Background Station through 2019 reached 411.4 ± 0.2 ppm for CO_2, 1931 ± 0.3 ppb for CH_4 and 332.6 ± 0.1 ppb for N_2O[5]. They are roughly equivalent to the averaged mixing ratios in the northern mid-latitudes,

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but are slightly higher than the global averages in all these components over the same period. Global mixing ratios in atmospheric CO_2, CH_4 and N_2O increased by 2.6 ppm, 8 ppb and 0.9 ppb in absolute terms, from 2018 to 2019[6], while those at Waliguan by 2.0 ppm, 8 ppb and 1.2 ppb. Global annual averages in atmospheric CO_2, CH_4 and N_2O over the past 10 years increased by 2.37 ppm, 7.3 ppb and 0.96 ppb per year in absolute terms[6], while those at Waliguan by 2.40 ppm, 7.7 ppb and 0.95 ppb per year[5].

In 2019, valid monthly atmospheric CO_2, CH_4 and N_2O mixing ratios at the 6 regional stations (Shangdianzi, Lin'an, Longfengshan, Shangri-La, Jinsha and Akedala) are mostly higher than those in 2018. The annually averaged CO_2 mixing ratios at the Shangdianzi, Lin'an, Longfengshan, Shangri-La, Jinsha, and Akedala station in background conditions were 420.2±0.3ppm, 426.2±0.4ppm, 416.2±0.5ppm, 411.0±0.2ppm, 416.9±2.3ppm and 412.9±2.9ppm, respectively. The atmospheric SF_6 mixing ratios during background conditions observed at Waliguan and Shangdianzi reached 10.11 ± 0.14 ppt and 10.21 ± 0.13 ppt in 2019, the highest ever records since the observation [5].

Large Chinese land carbon sink estimated from CMA data

China is the largest emitter of CO_2, accounting for approximately 27 per cent of global fossil fuel emissions in 2017. By using the atmospheric mixing ratio of CO_2, measured from six sites across China during 2009 to 2016, we estimate a mean Chinese land biosphere sink of −1.11±0.38 petagrams of carbon per year during 2010 to 2016, equivalent to about 45 per cent of our estimate of annual Chinese anthropogenic emissions over that period[7].

Our estimate reflects a previously underestimated land carbon sink over southwest China (Yunnan, Guizhou and Guangxi provinces) throughout the year, and over northeast China (especially Heilongjiang and Jilin provinces) during summer months. These provinces have established a pattern of rapid afforestation of progressively larger regions, with provincial forest areas increasing by between 0.04 million and 0.44 million hectares per year over the past 10 to 15 years. These large-scale changes reflect the expansion of fast-growing plantation forests that contribute to timber exports and the domestic production of paper. Space-borne observations of vegetation greenness show a large increase with time over this study period, supporting the timing and increase in the land carbon sink over these afforestation regions [7] .

Decreasing trend of Chinese CH_3CCl_3 mixing ratios and emissions

CH_3CCl_3 is an important ozone-depleting substance regulated by the Montreal Protocol and its Amendments. Long-term in-situ measurements by GC-ECD have been conducted at the Shangdianzi Station in northern China since October 2006. In addition, air samples have been collected daily/weekly at seven stations and analyzed by GC/MS system since 2010. The two methods show comparable precisions at around 1% and all the measurements were calibrated by standards linked to the Advanced Global Atmospheric Gases Experiment (AGAGE) reference scale Scripps Institution of Oceanography (SIO)-05. The atmospheric CH_3CCl_3 mixing ratios during background conditions showed a significant and consistent decreasing trend with a decline rate from 1.9 ppt/yr (October 2006 to December 2007) to 0.3 ppt/yr (November 2015 to December 2017) at the Shangdianzi Station.

Measured background mixing ratios increased from 41% in 2007 to 95% in 2017.

The mean mixing ratios and their enhancement of polluted conditions have decreased from 15.1 and 2.0 ppt in 2007 to 2.7 and 0.3 ppt in 2017 at Shangdianzi. The mixing ratios in air at background conditions at the seven stations in China agree well with each other and all decrease gradually. The percentage of pollution events to the total number of measurements (POL/SUM) at Lin'an has decreased significantly from 2010 to 2017, especially after 2013. In 2017, POL/SUMs of all stations were < 8% and the enhancements above background were < 0.7 ppt. Both mixing ratios and enhancements have decreased by one or two orders of magnitude when comparing the results from previous studies, in the early 2000s, with the results in 2017 from this study. Chinese emissions of CH_3CCl_3, which were estimated by a tracer-ratio method, have decreased from 1.6 kt/yr in 2007 to 0.3 kt/yr in 2013, indicating that CH_3CCl_3 has been phased-out in China in accordance with the Montreal Protocol[8].

Chinese HCFC emissions reached peaks before 2015

HCFCs is the main substitutes of CFCs, are regulated by the Montreal Protocol. Chinese HCFC emissions increased fast from the beginning of this century. However, limit reports based on atmospheric measurement are available for years after 2011, an important period when significant changes are expected. Combining atmospheric observations at seven sites across China with a FLEXPART dispersion model-based Bayesian inversion technique, we estimate emission magnitudes and changes of four major HCFCs in China during 2011–2017.

As in Figure 1, the emissions of all major HCFCs (HCFC-22, HCFC-141b, HCFC-142b, HCFC-124) reached peaks before 2015. Our results agreed well with the reported bottom-up inventories. The Chinese ozone depletion potential (ODP)-weighted emission of the three most abundant HCFCs (HCFC-22, HCFC-141b and HCFC-142b) accounted for 37% of global totals from 2011 to 2016. The total emission of HCFC-22 from China, the European Union, and the United States accounted approximately a half of the global totals, suggesting large HCFC emission emitted from the rest of the world[9].

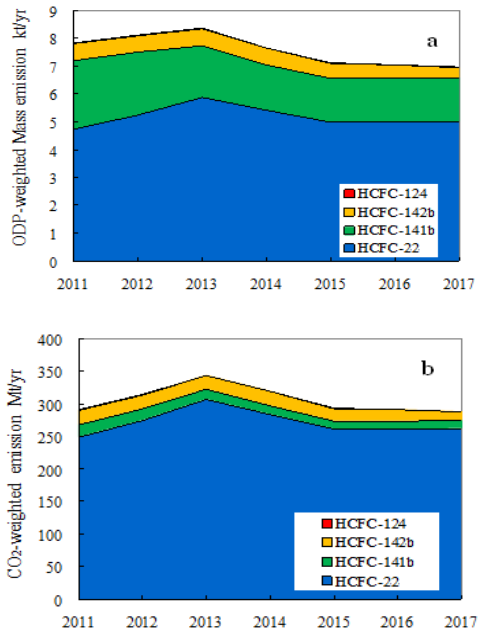

Figure 1. HCFC emission in terms of ODP-weighted (right) and CO_2-eq (right) emission in China during 2011 to 2017[9]

China's HFCs emissions increased rapidly from 2011 to 2017

HFCs have been widely used in China to replace ODSs that are required to be phased out under the Montreal Protocol regime. We used flask and

in situ measurements for nine HFCs from seven sites across China over the period 2011−2017, and FLEXPART-model-based Bayesian inverse modeling, to estimate HFC emission magnitudes and changes in China. As in Figure 2, we found that emissions of HFC-32, HFC-125, HFC-134a, HFC-227ea, and HFC-245fa have been increasing fast over this period, while emissions of HFC-143a, HFC-152a, HFC-236fa, and HFC-365mfc were relatively stable. Total CO_2-equivalent emissions of the nine HFCs increased from ~60 Tg yr^{-1} in 2011 to ~100 Tg yr^{-1} in 2017. Among these nine HFCs, HFC-134a (39%) and HFC-125 (35%) are the biggest contributors to the national total HFC CO_2-equivalent emissions. Cumulative contributions from China's HFC emissions to the global total HFC mixing ratios and their related radiative forcing increased from 1.0% in 2005 to 10.7% in 2017. When comparing global emissions with the sum of emissions from China and the developed countries, an increasing difference is observed over recent years, which points to substantial additional HFC emissions from other developing countries under the Kyoto Protocol[10].

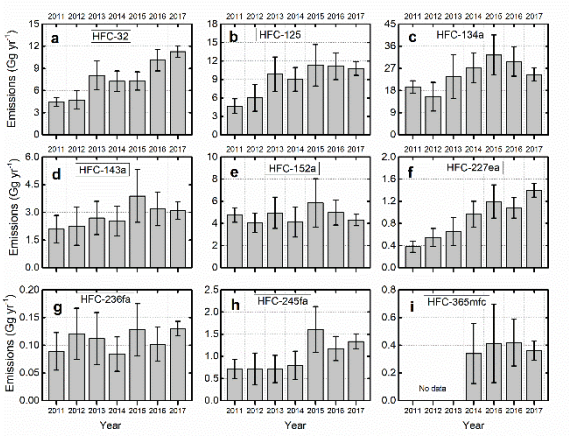

Figure 2. Annual emissions of HFCs in China derived from inverse modeling using atmospheric observations at seven sites.[10]

Summary

High precision measurement of greenhouse gases (GHGs) including CO_2, CH_4, N_2O, HFC, PFC, SF_6 and NF_3 as we all as ozone depletion substances (ODSs) including CFCs, HCFC, Halons, CCl_4, CH_3CCl_3 and CH_3Br were conducted at seven background stations of CMA by the means of in-situ measurement and flask sampling. The results shows Chinese land biosphere sink was underestimated significantly during 2010 to 2016 by using atmospheric mixing ratios of CO_2 from six CMA sites. Decreasing Chinese emissions were found for the first generation of ODS, such as CH_3CCl_3, while the emissions of HCFCs, the second generation of ODS, reached peaks before 2015. However, HFCs emissions showed rapid growth trends due to their increasing productions and consumptions.

Acknowledgement

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Measurement and modeling of GHGs in India

Yogesh K. Tiwari*, Santanu Halder, Smrati Gupta, Pramit Kumar Deb Burman

Introduction

Despite the global efforts to curb the menace of increasing anthropogenic greenhouse gases (GHG) emissions, observed atmospheric GHG concentrations have broken all the records and reported the highest ever values in the recent past. Some of these emissions get compensated by vegetation and oceanic uptake (~50%). Quantifying the carbon balance between the emissions of industry and transport and the ecosystem uptake in India is an important step towards designing effective greenhouse gas mitigation strategies in this subcontinent. The only land station for greenhouse gases (GHG) monitoring in India is Cape Rama (CRI) Goa, which operated for more than ten years and was discontinued in 2012. There was no GHG monitoring in India other than CRI. LSCE France, in collaboration with CMMACS and IIA Bangalore, started a few monitoring sites in 2007, which were mainly centered over the far eastern island, east coast, or extreme northern part of India [1].

IITM has initiated various Greenhouse gases/carbon flux monitoring and modeling projects in India to fill the gap. We established a Gas Chromatograph (GC) lab at the IITM Pune in 2009. We started the first surface site at Sinhagad (SNG) Pune in November 2009 where we collect glass flask samples at a weekly interval and analyze them at the GC lab. SNG is currently the only operational GHG monitoring site in western India. We use NOAA standards to calibrate all these observations [2] with appropriate precision and accuracy. GC lab is part of an inter-calibration program among the WMO/GAW laboratories in Asia (JMA, KMA, etc.). For upper atmospheric GHGs monitoring, we used airplane campaigns during 2014, 2015, 2018 (under the CAIPEEX airplane campaign project), where we monitored horizontal and vertical profiles GHGs in different parts of India. Additionally, a tall tower project at the Atmospheric Research Testbed (ART) in central India (outside Bhopal) will significantly help in constraining Indian emissions.

Indian Institute of Tropical Meteorology (IITM), Ministry of Earth Sciences, Pune, India

We have initiated a GHG transport modeling framework at the IITM Pune, where we used an offline global atmospheric tracer transport model NIES-TM to simulate atmospheric CO2 in India and the globe [3][4].

This study presents GHGs observation and modeling outputs and discusses transport processes and emissions variability over India.

Sampling site and method

Air samples are collected at the top of a 10-meter tower with a 2-meter external boom at a remote site called Singahad located near Pune city India. Sinhagad is a hill station on a mountain top approx 40 Km southwest of Pune city (73^{o} 45`E, $18^{o}$ 21`N, 1400 m a.s.l.). Its top is flat with an area of about 0.5 km^2. The site is free of any major vegetation over a scale of 500 m from one side (southeast) where the inlet of the sampling tube is installed [1]. On the other side's sparse and short (less than 3 meters) vegetation is available in the vicinity of 20 meters of the tower. Meteorological data at the Sinhagad site show that zonal wind direction is south and south-east during afternoon hrs. Wind speed during the afternoon is very calm and the temperature varies between 25-30^{o} C. The mean wind speed at the time of sampling is about 0.5 to 1 ms^{-1} both during the summer and winter months. Therefore samples mostly represent a vast area free from any vegetation. On a larger scale, the site receives maritime as well as continental air masses during the year. During the Indian summer monsoon months (JJAS) it is mostly dominated by maritime air masses and during winter months (DJF) it receives continental air masses (Fig.2b).

Samples are collected at a weekly interval every Friday, in the afternoon. It is assumed that air masses are well mixed in the afternoon hours and the site is not biassed towards any particular local signal. Chemical drying agent 'magnesium perchlorate' is used as a moister drier in the air sampler system. Magnesium perchlorate is changed every week before sampling starts. To detect sample contamination, flasks are sampled in pairs. When the concentration in the pair of flasks differs by more than a certain threshold, the measurement is rejected. Sampling starts with the fitting of the flasks to the air sampler. Once flasks are fitted tightly leak test is done on the flasks. Any leak may contaminate air samples in the glass flasks. Leak-proof fitting undergoes glass flask flushing for 10 minutes. Finally, samples are collected by pressurizing flasks. We leave the air sampler unattended and move around 20 meters far and while closing the air sampler after the filling process we stop breathing until flasks knobs are closed. Human breathing may contaminate to air filling the flasks. All precautions are taken to avoid any contamination in glass flasks. After air sampling, flasks are detached and sent to the Gas Chromatograph lab for air sample analysis.

Cavity Ring-Down Spectroscopy (CRDS) analyzer G-2401m from Picarro Inc USA was used for GHG monitoring onboard research aircraft during the summer months of 2014 and 2015 in India. The campaign was conducted under the CAIPEEX project coordinated by the IITM Pune. A reverse-facing inlet tube was used for transporting the air sample to the analyzer. The analyzer was calibrated using NOAA standards.

Further, we have set up an offline tracer transport model from NIES Japan to simulate atmospheric CO2 and CH4 over India and the Globe. We used surface observations from India and estimates CO2 sources and sinks.

Results

1. Observations and model simulation

Model outputs were compared with available

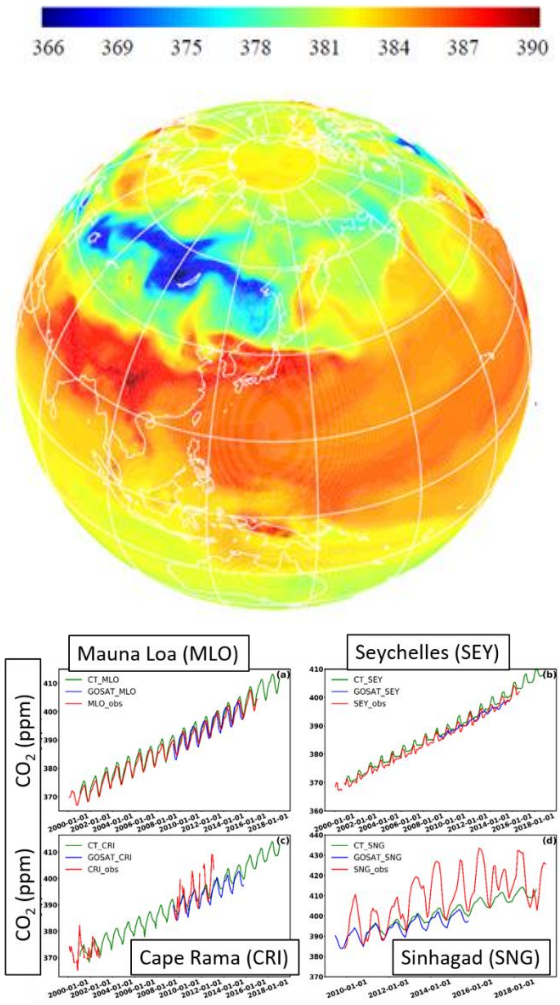

Figure 1. A snapshot of surface CO_2 (ppm) from model NIES-TM (top panel) [5][6][7]. Comparison of model simulations with surface observations (bottom panel)

long-term observations (Fig.1). Seasonal amplitude (**5-6** ppm) and growth rate of CO_2 (~**2.5** ppm $year^{-1}$) at Mauna Loa (MLO) is well simulated by NIES-TM. The seasonal amplitudes at Seychelles (SEY) is also well reproduced by NIES-TM. At CRI, the growth rate is reproduced but failed to reproduce seasonality because of the weak biosphere [8]. SNG observations failed to reproduce in the implied fluxes except during the biospheric growing season.

We have set up a National Institute of Environment Studies – Transport Model (NIES-TM), a global offline atmospheric tracer transport model at IITM Pune [8]. NIES-TM uses the three hourly Meteorology from JRA-25-JCDAS. 3-hourly varying PBL height is taken from ECMWF. The resolution of the model is 2.5°×2.5° and 17 vertical sigma coordinate levels. The model calculates the vertical distribution of tracers with the help of a Kuo-type scheme [9]. The boundary layer height is prescribed by 3-hourly varying PBL height from ECMWF.

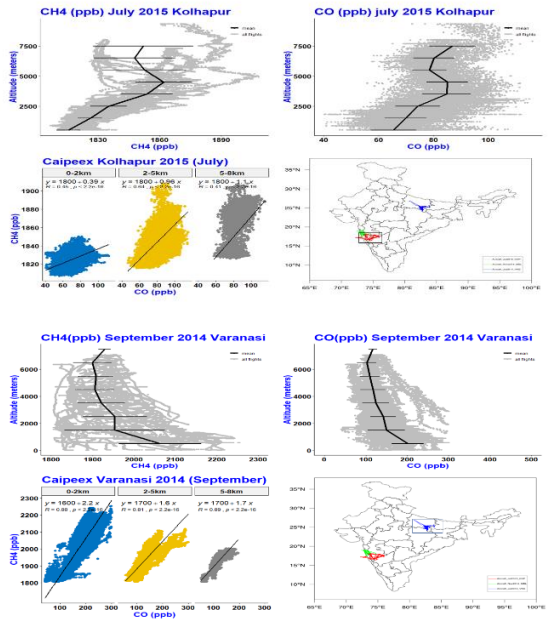

Figure 2. Atmospheric CH_4 (ppb) and CO (ppb) concentration observations onboard CAIPEEX research aircraft in India during July 2015 (top panel) and September 2014 (bottom panel).

We used CRDS analyzer G-2401m from Picarro Inc USA to monitor GHGs concentration observations over India during July 2015 and Sept. 2014 (Fig.2). Meteorological parameters wind speed, wind direction, relative humidity were observed from Aircraft Integrated Meteorological Measurement System (AIMMS). Both AIIMS and CRDS were synchronized in the centralized data logger onboard aircraft. Fig.2 represents CH_4 (ppb) and CO (ppb) concentration profiles observed by the aircraft during July 2015 (upper panel) and Sept 2014 (lower panel) over Kolhapur and Varanasi respectively. A black solid line represents the mean profile with standard deviation as a horizontal bar. And grey solid lines represent observed profiles on different days. CH4 and CO concentrations gradually increase (decreases) with altitude over Kolhapur (Varanasi) region (Fig.2). Varanasi's densely populated area over the Ganga river basin significantly contributes GHG emissions to the atmosphere. Slopes of CH_4 and CO indicate sources of these gases are possibly coupled at the surface (upper atmosphere) over the Ganga basin (Kolhapur).

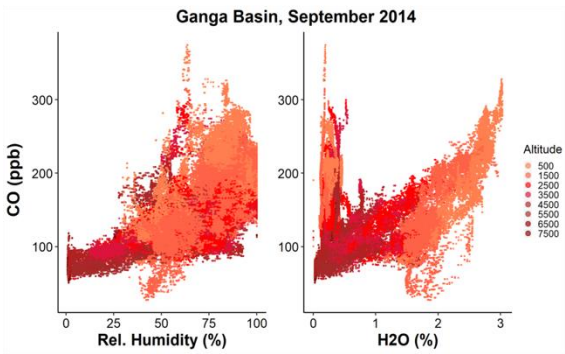

Figure 3. CO concentration variability at different altitudes over Ganga basin during Sept 2014

Relative Humidity (RH) is close to 100% below 3.5 Km (Fig.3). CO (ppb) concentration values at this altitude are in the polluted range (200-250 ppb). The water vapor content (H_2O) of the atmosphere varies from near zero to about 4%, depending on the moisture at the surface beneath and the air temperature. Water vapor is a strong greenhouse gas and is naturally available in the atmosphere.

Summary

In this study, we present greenhouse gases (GHGs) observations and modeling activities over India. GHGs observations at the Sinhagad site, located over the western boundary of India, started in late 2009. Air samples collected at the weekly interval were analyzed at the Gas Chromatograph lab at the IITM Pune. GHGs observations were conducted using research aircraft over Varanasi and Kolhapur India during Sept 2014 and July 2015. We have set up NIES-TM model in a forward mode for CO2 and CH4 simulations over India and the Globe and inverse modeling to estimate the GHGs surface fluxes over India and its adjacent regions.

Acknowledgment

The authors would like to thank Director IITM and the Ministry of Earth Sciences, Govt of India for supporting this work.

Reference

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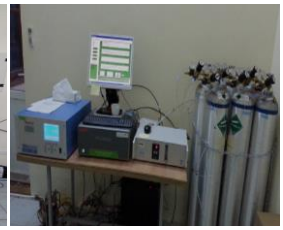
Initial assessment of greenhouse gas monitoring at Pha Din GAW station and development trend of climate change monitoring network in Vietnam

Tran Thi Thanh Hai

Initial assessment of operation of Pha Din GAW Station

The implementation of the Pha Din Global Atmosphere Watch (GAW) station was strongly supported by the Swiss Government on the basis of a cooperation between the Viet Nam Meteorological and Hydrological Administration (VNMHA) and the Federal Office of Meteorology and Climatology MeteoSwiss

*Pha Din is considered the first official greenhouse gas monitoring station in Vietnam.
*The station started basic meteorological observations in January 2012.
* Continuous observations of greenhouse gases CO_2, CO, CH_4, O_3 and aerosol optical properties were launched in March 2014.



*Since then, the station has maintained relatively stable operation with the fruitful support of Swiss experts, including Paul Scherrer Institute (PSI) and Swiss Federal Laboratories for Materials Science and Technology(Empa);

* Operators are present on-site every day for basic operation control.
* In addition, advanced maintenance and trouble-shooting is performed by skilled technicians, about 2 times/year.

* In July 2014, Pha Din was accepted by WMO as a regional GAW station.

* Greenhouse gas and aerosols measurements are ongoing and are continuously processed in accordance with WMO's annual requirements and guidelines.

* Having these results must include the cooperation and help of Swiss experts (Empa and PSI).

World Meteorological Organization
Organisation météorologique mondiale

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Weather • Climate • Water
Temps • Climat • Eau

Our ref.: 5549-14/RES/AER/Viet Nam

Mr Duong Hoang Long
National Hydro-Meteorological Service
No.3 Dang Thai Than street
100000 HANOI
Viet Nam

GENEVA, 25 July 2014

Subject: Acceptance of the Pha Din station, Viet Nam, as a GAW Regional station

Dear Mr Long,

I wish to acknowledge receipt of your official application for inclusion of the Pha Din station, Viet Nam, as a Regional station in the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO). As you are aware, GAW is the only existing long-

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
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wmo@wmo.int – public.wmo.int

Our ref.: 07179/2021-SI/AER

GENEVA, 24 March 2021

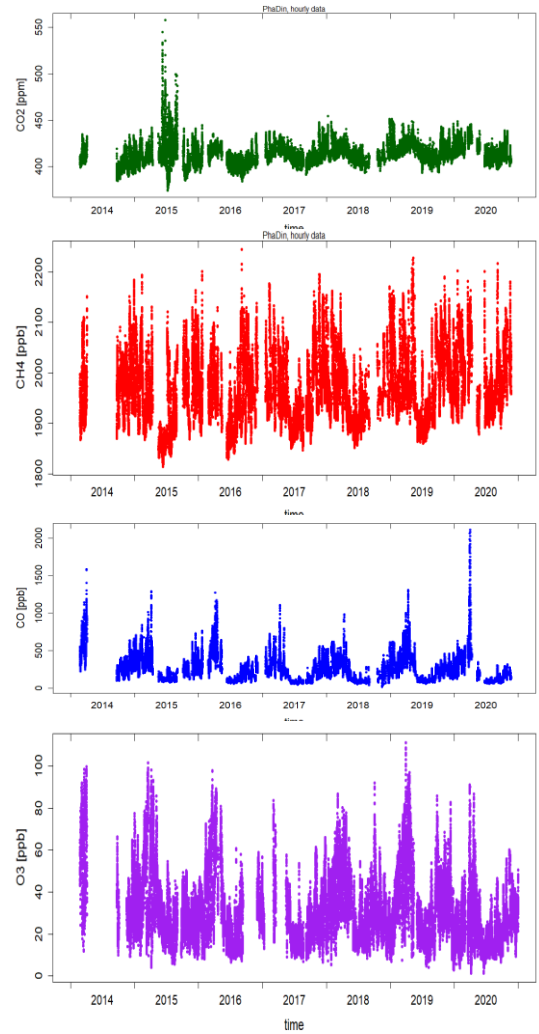
Subject: **Request for greenhouse gas data submission by 30 June 2021**

Dear Contributors of greenhouse gas data,

We hope that you and your families stay safe and healthy during the on-going health crisis. We appreciate your continuous support of the activities of the World Meteorological Organization (WMO).

We also thank you for your previous contributions of greenhouse gas measurement data and metadata to the World Data Centre for Greenhouse Gases (WDCGG), located at the Japan

* Last data submission to WDCGG (CO_2, CH_4, CO) and WDCRG (O_3) was in July 2021. All data (till end of 2020) were reprocessed and submitted on the most recent WMO scales (WMO X2019 for CO_2, WMO X2004A for CH_4, WMO X2014A for CO).



* However, during the operation of station, there are many difficulties, including:

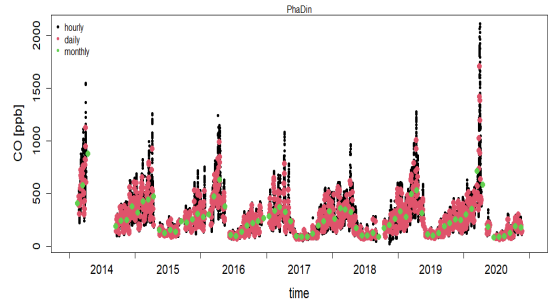
-Instruments are easily damaged due to hot & humid and tropical rain weather conditions.

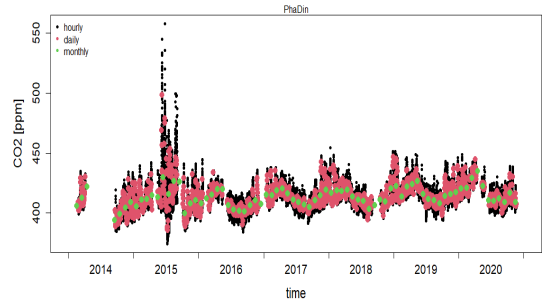
-The location in rural Vietnam, limited experience and the difficult supply of spare parts make it challenging to quickly fix instrumental failures.

-Due to the complicated situation of the Covid-19 pandemic, from April 2021 to now, we have not been able to fix the power-supply outage of the station as well as some damaged equipment.
-The station operators are mostly hydro-meteorological observers, with no training on environment and climate change monitoring fields. Therefore, the operation of modern monitoring equipment faces many limitations and difficulties.

Continued outcome of GHGs measurement at Pha Din Station

*After evaluating preliminary monitoring results from 2014 to 2017 presented at the APGG in 2018, we have continued to follow and assess the greenhouse gases variation at the station until the end of 2020.
*Most of the monitoring results have continued to show the regular variation of the previous years.
*Highest CO_2 and CO concentrations are usually observed in spring. This is the time of the dry season of the year which large scale fires in Northwest Vietnam and the surrounding countries.

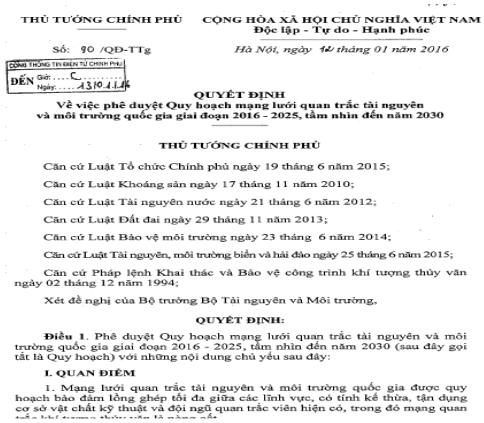




*Fires on the Indochinese Peninsula are a yearly recurrent phenomenon which clearly manifests in the observations at Pha Din.
*Time series of CH_4 seems to be very stable like every year and has not changed much. The maximum concentration still occurs in winter
*O_3 maxima are also observed during the dry season in spring.

Trend of climate change monitoring network in Viet Nam

*Over the years, climate change issues has received a great concern of the Government of Vietnam. This has been concretized in Vietnam's development policies and strategies. One of them is the Planning of Vietnam's National Environmental and Natural Resources Monitoring Network period 2016 - 2020, vision to 2030.



THỦ TƯỚNG CHÍNH PHỦ — CỘNG HÒA XÃ HỘI CHỦ NGHĨA VIỆT NAM
Độc lập - Tự do - Hạnh phúc

Số: 90 /QĐ-TTg — *Hà Nội, ngày 14 tháng 01 năm 2016*

CỔNG THÔNG TIN ĐIỆN TỬ CHÍNH PHỦ ĐẾN Giờ: ... Ngày: 13/01/16

QUYẾT ĐỊNH
Về việc phê duyệt Quy hoạch mạng lưới quan trắc tài nguyên và môi trường quốc gia giai đoạn 2016 - 2025, tầm nhìn đến năm 2030

THỦ TƯỚNG CHÍNH PHỦ

Căn cứ Luật Tổ chức Chính phủ ngày 19 tháng 6 năm 2015;

Căn cứ Luật Khoáng sản ngày 17 tháng 11 năm 2010;

Căn cứ Luật Tài nguyên nước ngày 21 tháng 6 năm 2012;

Căn cứ Luật Đất đai ngày 29 tháng 11 năm 2013;

Căn cứ Luật Bảo vệ môi trường ngày 23 tháng 6 năm 2014;

Căn cứ Luật Tài nguyên, môi trường biển và hải đảo ngày 25 tháng 6 năm 2015;

Căn cứ Pháp lệnh Khai thác và Bảo vệ công trình khí tượng thủy văn ngày 02 tháng 12 năm 1994;

Xét đề nghị của Bộ trưởng Bộ Tài nguyên và Môi trường,

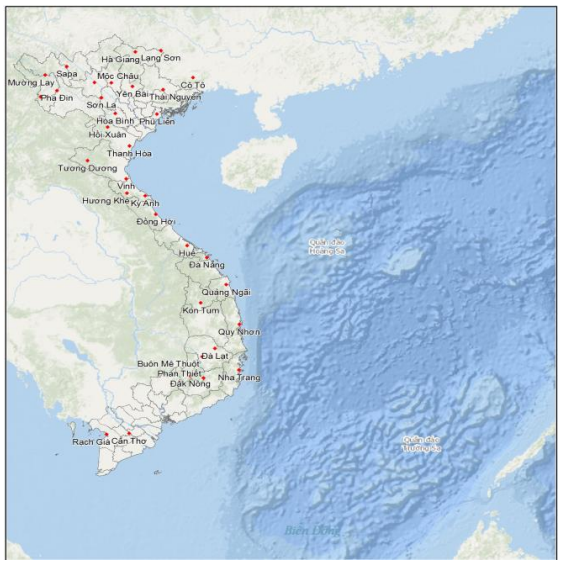
QUYẾT ĐỊNH:

Điều 1. Phê duyệt Quy hoạch mạng lưới quan trắc tài nguyên và môi trường quốc gia giai đoạn 2016 - 2025, tầm nhìn đến năm 2030 (sau đây gọi tắt là Quy hoạch) với những nội dung chủ yếu sau đây:

I. QUAN ĐIỂM

1. Mạng lưới quan trắc tài nguyên và môi trường quốc gia được quy hoạch bảo đảm lồng ghép tối đa giữa các lĩnh vực, có tính kế thừa, tận dụng cơ sở vật chất kỹ thuật và đội ngũ quan trắc viên hiện có, trong đó mạng quan

*According to the above plan, by 2030, Vietnam will have a system of 35 climate change monitoring stations. These stations monitor the same GHGs parameters of Pha Din GAW station.



*The objective of this system is to gradually strengthen the capacity of the monitoring network, serving forecasting, warning, prevention and mitigation of damage caused by natural disasters and response to climate change in Vietnam in future.

*Simultaneously, this monitoring network will contribute to the construction of a national natural resources and environmental monitoring system which is appropriate, uniform and modern, reaching the top level in South East Asia and the advanced level in Asia.

*In 2021, implementing the above network of climate change stations, VNMHA has invested and developed 7 of 35 stations located (Son La, Tuyen Quang, Lang Son, Thai Binh, Ky Anh, Hue, Can Tho) in 7 provinces across the country

*These stations are measuring the same trace gases like at Pha Din (CO_2, CO, CH_4 and O_3).

*In general, the stations basically have stable data and are suitable with the characteristics of the area.

Conclusion and Suggestion

*Pha Din station is considered the first GAW station in Vietnam. The station's data has actively contributed to the assessment of climate change globally.

*In the management and operation of Pha Din station, there are still many difficulties that need to be fixed

*Vietnam has also developed a national climate change monitoring network with initial results 7 stations were invested. The objective of this system is to serve warning, forecasting, disaster prevention, and climate change adaptation.

*Need to strengthen support and sharing on technology and training of human resources to operate and manage the climate change monitoring stations.

*Support and share experiences in assessing climate change using software or artificial intelligence.

*Viet Nam is looking forward to the coordination and support to keep developing and completing 35 climate change monitoring stations in the future. And toward meeting the demands for using climate change monitoring data in Vietnam.

Reference

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Advancing the New Zealand atmospheric greenhouse gas observation network

Gordon Brailsford [1*], Mark Murphy [1], Sylvia Nichol [1], Tony Bromley [1], Lucas Gatti Domingues [2], Sally Gray [1], Ross Martin [1], John McGregor [1], Sara Mikaloff Fletcher [1], Rowena Moss [1], Harrison O'Sullivan-Moffat [2], Jeremy Parry-Thompson [2], Rahul Peethambaran [1] , Peter Sperlich [1] , Kararaina Te Puni [1] , Jocelyn Turnbull [2] ,Hayden Young [2].

Introduction

The greenhouse gas observation network in New Zealand was initially developed to observe baseline air arriving off the ocean that was representative of large areas of the mid-latitude southern hemisphere. In more recent years the focus has shifted to include observations of air that has interacted across the country. This has allowed us to utilize inverse modelling techniques at a national scale [1] for both carbon dioxide and methane to identify sources and sinks of these species.

This approach has seen the development of our CarbonWatch - NZ programme a multi-institute, partnering programme that provides a better national coverage and allows for specific sectors to be studied more closely. An expanded network has been developed that provides observation in key areas and support various modelling approaches. Urban areas are being investigated with a focus on the Auckland area, Grasslands are another focus in a range of types, while forest both indigenous and planted are an important third sector under investigation.

Supporting the in situ observations we utilise a number of tracer species that assist in interpreting the processes involved in production and removal of greenhouse gases. Tracer techniques can provide insight into fossil fuel contributions, chemistry and the role of photosynthesis. The network flask collections provide air for laboratory studies of isotopic composition, and related species like carbonyl sulfide that are unable to be performed in the field.

Systems

When a new observation site is developed the requirements for the site are assessed in terms of the gas species being observed, the environment being assessed and infrastructure like power. Based on this an analyser is selected and flask collections included if laboratory analyses are required to answer the research questions.

An on-site Pi platform is used to gather, filter and send data back to NIWA in a standard format. A bespoke interface PCB expands the functionality of the computer to enable the reading of digital pressure and flow sensors,

1. NIWA, National Institute of Water and Atmospheric Research, New Zealand
2. GNS Science, Lower Hutt, New Zealand

system voltages and to be able to control the switching of solenoid valves and solid-state relays to isolate sub-system power. Meteorological data is sampled from a sonic anemometer. The gas analyser can be connected via USB, RS232 or ethernet, depending in the instrument (G2401, G2301, LI-7000, LI-7810 or LI-7815), and the software is able to modify the gas control accordingly. Analyser data are gathered into 30-minute blocks and filtered to remove unnecessary information and then merged with data from sensors and valve positions. This is compressed, then stored locally and sent via SFTP over a cellular connection. Power consumption is less than 10 W so the platform can be powered either via a mains connection with UPS, or a combined solar and wind turbine charging system. Both the UPS and solar controller are monitored and logged by the computing platform and that data is returned to NIWA each night.

Auckland Urban network

Auckland is New Zealand's largest city with a population of nearly 1.5 million and a land area of 607 km2. Auckland is in a sub-tropical environment, located on an isthmus with the Tasman Sea to the west and the Pacific Ocean to the east, and is a relatively low-density city.

An initial study in Auckland utilized flask samples collected from 26 sites around Auckland in campaigns every three months (Figure 1). Samples were collected from 10 m above local ground height. Sites included tall buildings, hilltops and neighbourhood parks. This campaign allowed identification of suitable sites for installation of a long-term in situ network.

The network currently includes three sites located across the Auckland isthmus. Manukau Heads (MKH) is southwest of the main urban area, with Auckland University of Technology (AUT) in the central area and Pourewa (NWO) in partnership with Ngāti Whātua Ōrākei, to the east of the urban area. A fourth station is under development in the Devonport area to the northeast of the urban area (Figure 1).

Each site has the same type of instrument (Picarro G2401) to allow for inter site comparison of CO_2, CO and CH_4. Weekly flask samples are collected at each site, for later laboratory analysis. CO_2, CO, and CH_4 are measured in the flasks to provide an additional inter-site calibration check. The radiocarbon content of CO_2 ($^{14}CO_2$) is measured from the flasks to evaluate the fossil fuel CO_2 (CO_2ff) component of the air. Stable isotopes in CO_2 and COS are also measured.

The dominant wind regime in Auckland is either a SW or NE wind. The isthmus location means that characterizing the incoming background air is straightforward compared to many cities, allowing Manukau Heads to be used as a background site during SW winds, and the proposed Devonport site will be the background site during NE winds.

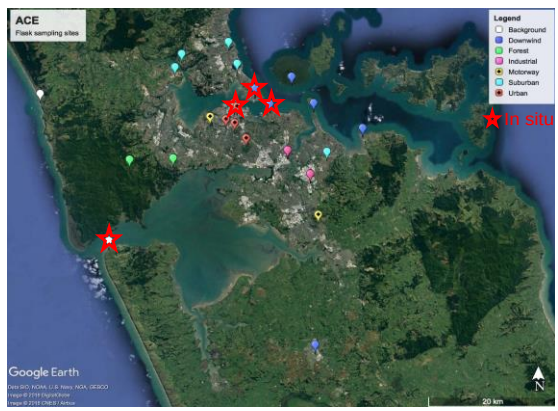

Figure 1. Auckland and sampling site locations. Red stars show the four in situ measurement sites. Coloured symbols indicate sampling sites used during the flask campaigns from 2017-2020.

Carbonyl Sulfide

The potential use of the trace gas carbonyl sulfide (COS) to assess forest gross primary production is currently being investigated within the group, the annual seasonal cycle of COS is 40 to 50 ppt in the mid latitude of the southern hemisphere. Analysis of COS concentrations are favourable as, generally, the gas is taken on by plants during photosynthesis (alongside CO_2) but is not released in respiration [2].

A Los Gatos high performance (OCS-914) COS instrument designed for in situ flux measurements has been modified to allow flask sample measurements within the lab. This instrument utilises Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) and allows the simultaneous measurement of COS, CO_2 and CO, with a constant flow of 70 ml/min.

Using air from high pressure cylinders with constant mole fractions, we varied the inlet pressure to the COS instrument under otherwise constant conditions, to test for the effect of inlet pressure variations on measured mole fractions, as is observed during flask measurements. This defined the cell pressure correction, which is applied to every measurement.

We installed a two-stage regulator (Beswick Engineering Co, part# PRD3-2N7-0-3VIK) upstream of the analyser to stabilise the pressure within the instrument and account for the fluctuating sample pressures, particularly as flask pressures dropped. This reduces the cell pressure variation to less than 0.5 Torr within a typical run. The instrument was further stabilised by utilising two multi-position VICI valves for an integrated platform to introduce air from flasks or tanks and providing a continuous flow of dry air through the analyser during idle time when no measurements were being made. Sample inlet control and data acquisition are performed via custom-built LabView environment.

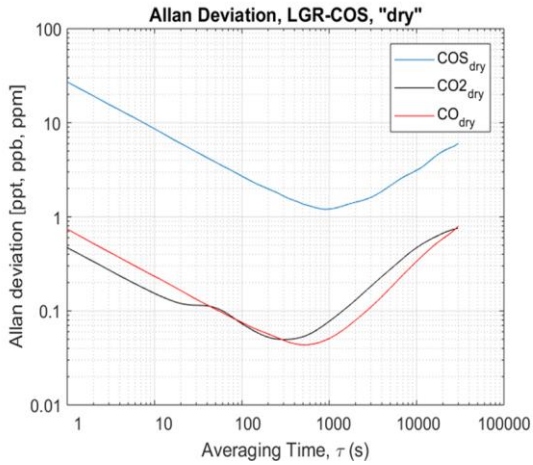

Fig 2. Allan deviations for COS, CO_2 and CO.

Various tests were performed to assess the stability of the instrument. An Allan deviation test was run on the instrument with the same gas flowing through for 24 hours to determine the optimum response. From this test, both CO_2 and CO showed an optimal response after 200 to 500 seconds of run time; The COS required longer, recording its optimal response after 1000 seconds. From this, we were able to establish a nine-minute run time of data collected with the first two minutes discarded for "flushing".

Variability was noted when observing reference gases over periods of days, and pressure regulator instability was identified as the cause of increased COS variability. While high purity Tescom regulators (Tescom model # 64-3440KA412) had been selected these exhibited increases in COS when not used for several days. Calgaz regulators (Calgaz model # 1002) where found to stabilise quickly and repeatably.

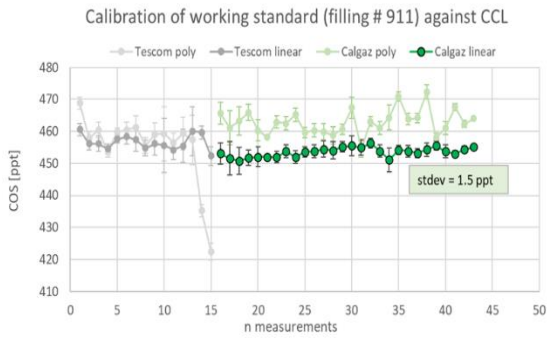

Figure 3. Repeatability of COS determination in working tank using 3 primary reference gases from the CCL.

Further assessment is planned to determine if the Tescom regulators can be conditioned in a way to make them more stable.

The reproducibility of the instrument was then assessed by repeated measurements of primary reference gas tanks calibrated at NOAA [2] with known dry mole fractions (220 to 680 ppt) against a suite of three working standards with a range of COS (all between 350 and 500 ppt). Multiple observations of the CCL demonstrated a very linear response and repeated analysis of the working tanks shows a typical repeatability around 2 ppt for COS (1 σ, n = 28).

LI-COR instruments

To enable the operation of observation sites off-grid low power instruments are preferred. The LI-COR LI-7800 series instruments utilise Optical Feedback – Cavity Enhanced Absorption Spectroscopy (OF-CEAS) and under normal operation consume only 22 W of power. In assessing these instruments for our observation network we have reduced the flow through the instrument from 250 ml/min to 70 ml/min by installing the available low flow kit, which conserves reference gas and allows for better drying.

Allan Deviation tests to date, where gas is flowed through two instruments in parallel over a 24 hour period, have demonstrated that the LI-7810 which is primarily a methane instrument reaches a minimum deviation of 0.02 ppb in 500 seconds, while the CO_2 on that instrument reaches 0.05 ppm in 300 seconds. The LI-7815 instrument which is CO_2 specific reaches a minimum deviation in 300 seconds of 0.005 ppm. These two instruments exhibited a small drift in the observed concentration over the 24 hour period which can be compensated for through measurement of known working tanks.

Summary

The CarbonWatch NZ programme, which aims to guide New Zealand's carbon mitigation strategies through an expanded and focused observation network and modelling program, has progressed the development of observation sites and analytical tools for this purpose.

The Auckland Urban observation sites are now in place with both in situ analysers and complimentary flask collections enabling other tracers to be measured in the laboratory. These provide insight into the CO_2 fossil fuel component using radiocarbon and the biogenic effects through analysis of carbonyl sulfide.

A unified platform for control and communication has been developed that simplifies operations at observation sites. A carbonyl sulfide flux instrument has been demonstrated as both stable and sensitive enough for flask observations. Progress with low power Cavity Enhanced Absorption Spectroscopy instruments demonstrates that these analysers are capable of meeting the GAW compatability goals for both CO_2 and CH_4

Acknowledgements

We gratefully acknowledge the support from CarbonWatch NZ partners in this work, also Steve Montzka at NOAA for advice and measurements of COS, Bradley Hall and Duane Kitzis at NOAA for providing scale transfer gases to enable the international NOAA scale realisation for COS at NIWA.

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Integrated greenhouse gas observation system of KMA/NIMS

Haeyoung Lee, Sangwon Joo, Young-Suk Oh, Sunran Lee, Samuel Takele Kenea, Soo Jeong Lee, Chu-yong Chung, Yeon-Hee Kim

Introduction

Observed increases in well-mixed greenhouse gas (GHG) mole fractions since around 1750 are obviously caused by human activities [1]. To understand their source and sink, various platforms such as through a surface, aircraft, vessel and tall tower, etc. are used to monitor atmospheric GHG. This integrated observation is also necessary to support the development of services with a high societal impact that relies on information on atmospheric composition and related parameters. This will be accomplished through enhanced modelling efforts and improved information management infrastructure [2]. Korea Meteorological Administration/National Institute of Meteorological Science (KMA/NIMS) has launched the INverse modeling for Validating and Evaluating of the Reduction of Sectoral GHG Emission in KOREA (INVERSE-KOREA) which was endorsed by World Meteorological Organization/Integrated Global Greenhouse Gases Information System (WMO/IG^{3}IS) in May 2021. To implement INVERSE-KOREA, atmospheric measurement data became more important

KMA/NIMS integrated observation system in national scale

There are various platforms to monitor atmospheric GHG such as in situ surface stations, a remote sensing measurement, a flight, a tall tower, and a vessel operated by KMA/NIMS (Table 1). KMA/NIMS started to observe atmospheric GHG at Anmyeon-do (AMY) regional Global Atmospheric Watch (GAW) station which is located western part of Korea as a first station to monitor GHG and expanded its observations at Jeju Gosan Suwolbong station (JGS) in the South and Ulleungdo stations in the East (ULD) since 2012 [3]. For ULD, official observation data has been published from 2014 (Table 1). In 2014, Fourier Transform Spectroscopy (FTS) was installed at AMY and started to act as one of the total carbon column observing network (TCCON) stations [4]. Airborne GHG observation has been started in 2018 [5].

Through the climate monitoring (CM) and environmental monitoring (EM) missions, the observation is implemented over 50 times per year on a regular basis. From this year, 2021, the measurement from a vessel and tall tower measurement is started. The vessel measurement was conducted for the Yellow-sea air quality (YES-AQ) campaign from

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March to May with cavity ring down spectroscopy (CRDS 2301, Picarro, USA). A tall tower with 300 m locates at Boseong station, south-western part of Korea. The intake was mounted at two different levels, 300 m and 150 m to compare the characteristics of GHG according to the atmospheric boundary layer.

AMY monitors 7 different species such as CO_2, CH_4, N_2O, SF_6, and CFCs and collects air with weekly flasks for isotopes in a collaboration with National Oceanic and Atmospheric Administration (NOAA). JGS and ULD monitor CO_2, CH_4, N_2O, and SF_6 with quasi-continuous measurement. CO_2 and CH_4 are mainly observed by aircraft, vessel, tall-tower, and FTS.

Table 1. Observation platform in KMA/NIMS and the accumulated data year

Platform/Year	99	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21
AMY-in situ																							
AMY-TCCON (total column)																							
JGS-in situ																							
ULD-in situ																							
Nara (Flight)																							
Gisang (Vessel)																							
BS (tall-tower)																							

The efforts to fill the gap of measurement

Even though we monitor atmospheric GHG on a national scale, its source and sink cannot be fully explained without mega cities which occupy 70% of total GHG emissions. In this regard, we have cooperated with Seoul Metropolitan Government Research Institute of Public Health and Environment to monitor GHG mole fractions observed by three stations in Seoul. We are going to install a new instrument on Lotte world tower which is the highest tower (around 555 m) in Seoul from December, 2021 to get the representative background level for GHG.

Low cost sensor is under development with high precision for a total carbon column of the GHG in the atmosphere by using a novel material (graphene based 3D structure). This sensor has the purposes of establishing a high density GHG monitoring network and supporting the scientific monitoring of GHG not only in cities but also in the places which still remain as a gap. Now we have a prototype of the sensor and test its precision for CO_2, CH_4, and SF_6.

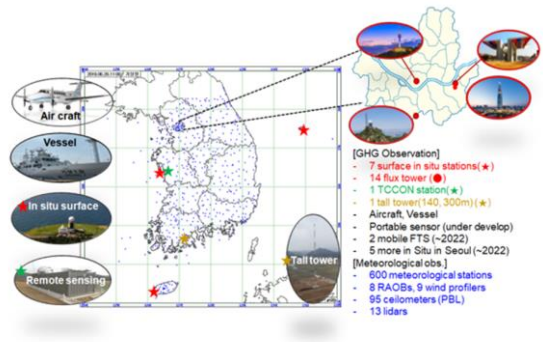

Figure 1. Korea network in national scale (map) and in Seoul mega city (upper right map).

Two mobile version of FTS will be operated from 2022 with existed FTS at AMY. This will be used to cover the column information in downwind and upwind area. The continuous data for isotopes in CO_2 and CH_4 can be accumulated from this year in a cooperation with Korea Research Institute of Standards and Science (KRISS). To analyze the proxies of major GHG such as HFCs and PFCs will be monitored after developing the pre-concentrator with KRISS.

Science for service

The measurement data have been accumulated from 1999 while those data are very limited for users. Therefore, as part of INVERSE-KOREA, we will provide the integrated GHG observation data through one portal to the public from 2022. This portal includes the data from surface, aircraft, vessel, tall tower, and FTS. From 2023, the integrated data can be displayed 3-D system to compare those data from different platforms. In 2024 we will install the QA/QC system for city observation and share the high-quality data with the public.

We expect this portal can support carbon neutral policy in 2050 as part of INVERSE-KOREA in the future not only for South Korea but also the countries or scientists who are willing to verify the inventories.

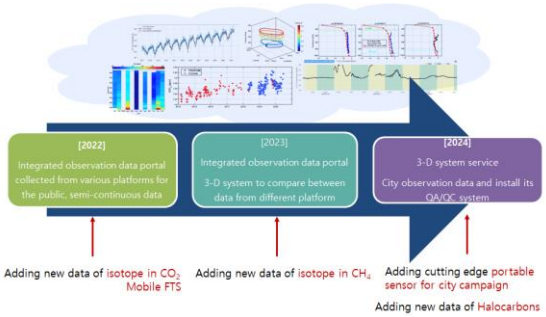

Figure 2. The plan for data service from integrated greenhouse gas observation in each year.

Acknowledgement

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Aircraft-based in-situ monitoring of CO_2 and CH_4 over South Korea with high-resolutions

Sunran Lee, Haeyoung Lee, Chu-Yong Chung, and Yeon-Hee Kim

Introduction

Aircraft measurements are less frequent but allow comparisons between a variety of locations and provide precise information regarding the vertical/horizontal distributions of main GHGs (CO_2, CH_4). Those observations are also essential for observations in the free troposphere and lower stratosphere covering regional to continental scales. Despite the importance of aircraft monitoring [1-2], regular aircraft monitoring of GHGs are sparse in the Korean region. The intensive aircraft campaign were conducted over South Korea during May-June 2016, Korea-United States Air Quality (KORUS-AQ) filed campaign, which was performed based on an international collaboration between the republic of Korea and United States, led by the National Institute of Environmental Research of Korean and the National Aeronautics and Space Administrations (NASA), respectively[3]. The Observations obtained from KORUS-AQ were utilized to quantify the contribution towards understanding air quality and factors controlling air quality in the South Korea[3]. Korean Meteorological Administration (KMA)/National Institute of Meteorological Sciences (NIMS) firstly established the King Air 350 aircraft platform for regular GHGs monitoring since 2018 using the layer-based cavity ring-down spectroscopy (CRDS) instruments under the KMA-atmospheric Research Aircraft Program.

In this study, we evaluated the measurements systems including uncertainty analysis related to instrumentation precision, cavity pressure sensitivity test in simulated flight condition, and error test of water vapor correction in laboratory. Also we presented the spatial and seasonal variations in western South Korea where large clusters of CO_2 and CH_4 emission sources are presented

Aircraft analyzer set up

1. GHGs' analyzer set up

We used a KMA research aircraft based on the Beechcraft King Air 350 (Figure 1a,b) modified by Weather Modification Incorporated (Fargo, ND, USA). It has a ceiling of 9.6 km, speed range of 70-120 m/s, with a maximum flight time of 5.5 hours with the maximum payload. There are 24 instrumentations and one air inlet installed in the aircraft.

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The aircraft in-situ measurements and laboratory calibration scheme were shown in Figure 1c. The CRDS-2401m analyzer developed by Picarro was employed for CO_2, CH_4, and CO simultaneous measurements with high-precision using the aircraft. A water/dust filter trap (5 μm) for removing water droplets and dust, and a three-way valve for pre-deployment calibrations were installed upstream of the CRDS. A purge gas-free Nafion membrane dryer was installed as well to remove water vapor included in the air sample. Picarro CRDS was calibrated every two-month in laboratory, with a series of three World Meteorological Organizations (WMO) scale standard sample tanks for CO_2 (374.06, 419.45, and 467.78 ppm), CH_4 (1756.7, 1901.4, and 2325.8 ppb), two for CO (311.1 and 89.7 ppb) from NOAA/ESRL, with full coverage of the ambient air range.

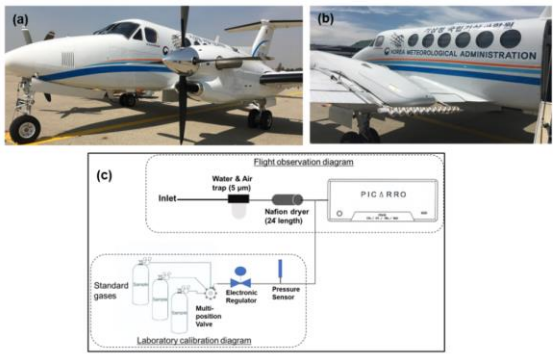

Figure 1. The external view of Korean Meteorological Administration (KMA) (a) King air 350, (b) inlet plate, and (c) Cavity Ring Down Spectroscopy (CRDS) greenhouse gas airborne measurement and laboratory calibration scheme.

2. Scientific aim and flight design

There are four missions under the KMA-Atmospheric Research Aircraft Program: precedent observations for Severe Weather (SW) such as heavy rain, heavy snow, typhoons, etc.; Cloud Physical (CP) processes monitoring for research of cloud micro-physical processes, precipitation systems, and weather modification (cloud seeding); air quality missions for Environmental Monitoring (EM)focused on observations of aerosols and reactive gases; and Climate change Monitoring (CM) mainly focused on observing major GHGs (CO_2, CH_4, and H_2O) and an indirect GHG (CO). All scientific missions are usually conducted in different routes and periods, however, all measurements are expected to be combined for interpretations.

GHGs measurements (CM mission) have been conducted with two scientific aims. First, the vertical profiles are measured for altitude range between 0.6 km and 9.0 km over the AMY station (36.53˚N, 126.32˚E) (Figure 2a), a GAW regional background station[4], to coincided with overpasses of the Greenhouse Gases Observing Satellite (GOSAT). Second, the horizontal profiles are measured over Western Korea and the route of the CM mission was as follows: the research aircraft was flown from the aircraft's home base at Gimpo airport near Seoul megacity to conduct a low-altitude (about 1 km AMSL, mostly within the boundary layer) survey on a south-north path between about 34°N and 37°N over the western South Korean land region that include a metropolitan, urban and rural regions (Figure 2b). The primary scientific goal of this mission is to investigate the distribution of CO_2 and CH_4 within the boundary layer over South Korea for all seasons. The high resolution data can provide information on various sources and sinks of particulates and trace gases in the region and can be utilized in inversion simulations coupled with an atmospheric transport model to quantify the GHGs budgets in South Korea.

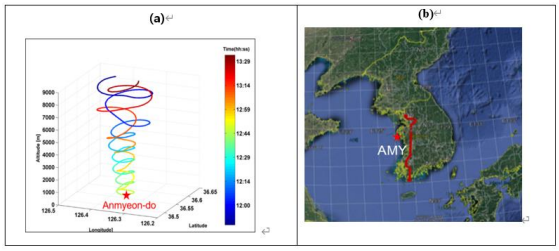

Figure 2. The typical flight route for greenhouse gas monitoring missions (Climate change Monitoring, CM) that covered the western Korean inland with red line (a) and spiral observations over Anmyeon-do stations (b).

3. Total uncertainties analysis

The total measurement uncertainty in this study was calculated by the combination of the CRDS instrumentation precision, water vapour correction errors, and the errors in the cavity pressure sensitivity test. We performed pressure sensitivity experiments in the laboratory to simulate flight conditions over the pressure range of 320 -1000 hPa and calculated the average one-sigma standard deviation during 3 hours of NOAA standard gas sampling. We obtained 0.03 ppm for CO_2, 0.5 ppb for CH_4. Overall, the uncertainties in the CRDS instrument were 0.28 ppm, 2.7 ppb for CO_2, and CH_4 respectively, by propagating all uncertainty terms (Table 1). Larger uncertainties are primarily attributed to the water vapour corrections in the summer season, making the Nafion dryer necessary.

Table 1 Total uncertainty of CO_2 and CH_4 measurement observed using KMA aircraft

	CO_2 (ppm)	CH_4 (ppb)
Instrument Precision	0.03	0.1
Water correction	0.28	2.7
※Repeatability (simulated flight condition)	0.03	0.5
Total uncertainty (KMA Aircraft CRDS)	0.28	2.7

The laboratory tests were performed to assess the water vapour correction error for the manufacturer-supplied correction factors by adding water vapour to dry standard gases from tanks at mole fractions of 467 ppm for CO_2 and 2325.4 ppb for CH_4. The method described by Karion[5] used a standard gas flowing through chamber mounted with an ME membrane tube and a small humidifier of distilled water, then, the water vapour is delivered to the gas stream which results in a smother water vapour transition across a range of approximately 0.3–2.3% (Figure 3). The residuals between NOAA standard gas mole fraction and those that responded to CRDS as changing water vapour concentrations are depicted in Figure 3. Residuals increased sharply at water vapour concentrations < 1%, then more gradually for water vapour concentrations > 1%. Also, the CO_2 and CH_4 dry mole fractions changed by more than 0.2 ppm and 2 ppb (compatibility goals of WMO/GWA), respectively, for H_2O values over 1%.

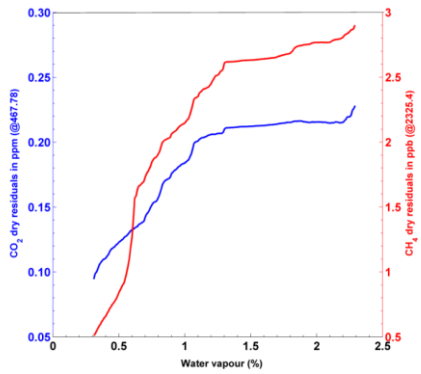

Figure 3. The residuals of CO_2 and CH_4 dry mole fractions corrected by Picarro manufacture provided water correction parameter corresponding to NOAA standard gas at mole fraction of 467.78 ppm for CO_2 and 2325.4 ppb for CH_4 with gradually increasing water vapour from 0.3 to 2.3%.

4. Spatio-temporal variations

The horizontal distributions of atmospheric CO_2 and CH_4 for 2019 over western South Korea within the latitude range of 34–37°N are shown in Figure 4. We integrated the observations along the western inland transitions as shown in Figure 2b. The studies are currently in progress using the aircraft AMY spiral mission data and this will be discussed in future studies. The CO_2 show clearly the zonal and seasonal distribution characteristics, with high CO_2 levels in the northern part of Korea which includes densely populated urban and industrial regions such as Seoul, Gyeonggi-do, and Chungcheong-do, and low levels in the southern part near Jeolla-do which includes large agricultural lands and forests (Figure 4a). Conversely, CH_4 showed high levels in the southern region in the vicinity of Jeolla-do from June to August, followed by Gyeonggi-do and Chungcheong-do in May and August (Figure 4b). According to national bottom-up inventory reports, > 40% of Korean CH_4 emission was emitted from agriculture, followed by landfill (31%) and energy consumption (22.9%) [6]. Rice paddies are the largest CH_4 source in the agriculture sector, and 54% of total agriculture land is used for rice paddies in South Korea [7]. Thus, CM missions clearly captured the seasonal and spatial gradients using the in situ aircraft measurements.

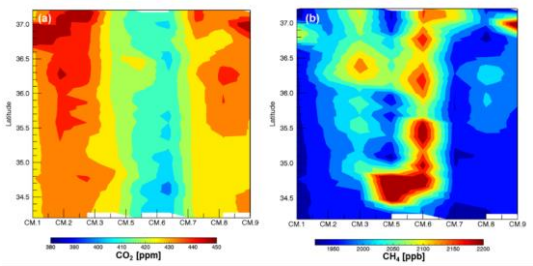

Figure 4. Spatiotemporal distributions of (a) CO_2 and (b) CH_4 for whole Climate change Monitoring (CM) missions for 2019 year. This figure displayed with the 0.075° latitude averaged values (approximately 5-km spatial resolutions) and interpolated with aircraft sampled time. CM.4 mission's data are not included because aircraft sampled above boundary layer height (BLH) in northern Korea.

Summary

A new KMA aircraft measurement platform allows regular observations over South Korea since 2018 for scientific purposes. A CRDS G-2401m analyzer mounted on the platform was used to measure in situ CO_2, CH_4, and CO dry mole fraction. We operated high frequency (i.e., 2-month interval) NOAA/ESRL standard sample gas calibrations in the laboratory with precise pressure controller. The total uncertainty based on a combination of instrument precision, a cavity pressure sensitivity test, and water vapour correction errors was estimated to be 0.28 ppm, 2.7 ppb for CO_2, and CH_4, respectively. In this study, we clearly identified the CO_2 and CH4 hot-spots, and showed that CO_2 emissions hot-spots were located in the northwest part of South Korea which are densely populated by urban and industry emission sources. In contrast to CO_2, the main CH_4 sources were identified in southwest part of South Korea from rice paddy emissions in summer.

Using the research aircraft, we continue to conduct in situ CO_2, CH_4 and CO measurements at least once per month as a long-term operational monitoring program. Thus, the aircraft observations can provide a useful high-density dataset over western part of South Korea to better understand the CO_2 and CH_4 emissions source characteristics. Next scientific objective is that the CO_2 aircraft

Acknowledgement

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Interannual Variability of Atmospheric CH_4 and Its Driver Over South Korea Captured by Integrated Data in 2019

Samuel Takele Kenea[1*], Haeyoung Lee[1], Sangwon Joo [1], Shanlan Li[1], Lev D. Labzovskii[2], Chu-Yong Chung[1] and Yeon-Hee Kim[1]

Introduction

Methane (CH_4) is the second most effective greenhouse gas after carbon dioxide (CO_2), and therefore a substantial contributor to global warming. CH_4 has multiple sources, including natural sources such as wetlands, oceans, and termites, that account for 35%–50% of total emissions, and the rest from anthropogenic sources such as agricultural soils, landfill, rice paddies, ruminants, biomass burning, and energy utilization[1]. However, the geographical distribution and sectorial attribution of methane emissions, and the interannual variations of the sources, are uncertain[2][3]. This gap hampers the effective formulation of emission-mitigation strategies.

Between 2007 and 2013, global CH_4 has annual growth rates of about 6 ppb yr−1[4], and has accelerated to 10 ppb yr−1 between 2014 and 2018[5]. The drivers of this increase are partly addressed and may embrace enhanced emissions and a possible decline in the destruction of methane in the air[5]. Especially, it is known that the growth rate is related to ENSO, e.g.,[5,6], while the growth rate increased in 2019 without the presence of clear ENSO signal over Korea, which was the interest of this work and attempted to address the cause for high growth of CH_4.

To understand the increase of CH_4 in 2019 over South Korea, integrated data comprising of near-surface CH_4 observations from the surface in situ and column-averaged CH4 (XCH_4) retrievals from space-borne instruments (e.g., Greenhouse Gases Observing SATellite (GOSAT)[7], TROPOspheric Monitoring Instrument (TROPOMI)[8] were utilized.

Data and method

The Anmyeondo (AMY) station is located at the west coast of South Korea at 36.54° N, 126.33° E, and 46 m above sea level (Figure 1). It is a WMO/GAW regional station. Several GHGs have been regularly monitored, of

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which atmospheric mole fractions of CH_4 from 40 m tower has been continuously measured using Cavity Ring Down Spectroscopy (CRDS 2401, Picarro, CA, USA) based on 5 s intervals from 2016. Before the CRDS, we monitored CH4 with a Gas Chromatography–Flame Ionization Detector (GC-FID) based on 30 min intervals. This instrument is calibrated against the WMO-X2004A scale with 4 reference tanks every 2 weeks while the GC-FID with 1 reference gas every 6 h. To highlight the source signatures of CH_4, flask-air measurements of $^{13}C/^{12}C$ in CH_4 ($\delta^{13}C$-CH_4)[9](ftp://aftp.cmdl.noaa.gov/data/trace_gases) were analyzed. We also utilized satellite XCH4 data such as GOSAT (2014-2019) and TROPOMI (April 2018–December 2020) to explore spatio-temporal variations.

To understand the soil associated drivers for interannual variability and spatial characteristics of atmospheric CH4 anomalies captured by the instruments, soil temperature and soil moisture content at 10 cm depth with a spatial resolution of 0.1-degree of latitude–longitude and monthly temporal resolution from the Famine Early Warning Systems Network (FEWS NET), the Land Data Assimilation System (FLDAS) and Noah Land Surface Model (LSM) L4 (https://disc.gsfc.nasa.gov/datasets/FLDAS_NOAH01_C_GL_M_001) were used. To analyze the seasonal variability, long-term trend, and yearly growth rate from the surface and satellites data, we applied Thoning's method[10] to extract those informations.

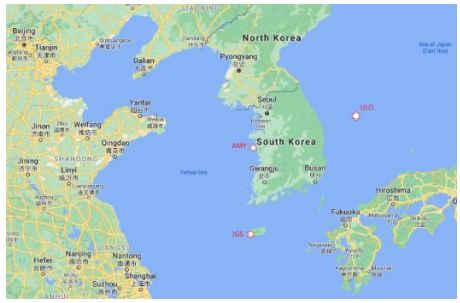

Figure 1. Map of South Korea in situ stations marked by red stars, Anmyeondo (AMY: 36.54° N, 126.33° E, 46 m), Jeju-Gosan (JGS, 33.3° N,126.16° E, 71.47 m), and Ulleungdo (ULD, 37.48° N,130.9° E, 220.9 m). Taken from Google Maps.

Result

1. Interannual Variability of CH4 Growth Rate in Korea

The annual increase was calculated from the trend line (Figure 3a) as the increase from January 1 in 1 year to January 1 in the next year, after removing the seasonal cycle. The successive annual differences of CH_4 at AMY were determined in the range of -16.8 ppb yr^{-1}-31.3 ppb yr^{-1} by in situ and 3.9 ppb yr^{-1}-16.4 ppb yr^{-1} by GOSAT (Table 1). The annual averages CH_4 estimated from in situ and GOSAT were 7.55 ± 23.59 ppb yr^{-1} and 8.92 ± 6.87 ppb yr^{-1}, respectively (Table 1). The large growth rates dramatically increased in 2016 (31.3 ppb yr^{-1} and 13.4, ppb yr^{-1} as seen by in situ and GOSAT, respectively) and 2019 (27.4 ppb yr^{-1} and 16.4, ppb yr^{-1}, in situ and GOSAT, respectively). The long-term trend revealed that the increase from 2014 to 2016 corresponding with the cold-to-warm transition from weak La Niña started in the earlier period of 2014 to a strong El Niño event in 2016. After 2016, the trend has shown to be oscillated, with minimum and maximum growth in 2018 and 2019, respectively.

A higher temperature in 2019 was observed in Korea, which could be caused by the presence of atmospheric instability in the region.

Table 1. Annual means (ppb) and yearly growth rates (ppb yr^{-1}) of in situ CH_4 and GOSAT XCH_4 at AMY derived using curve-fitting method [10] after being deseasonalized. Annual mean is derived from the trend curve, after removing the seasonal cycle, and then yearly growth rate is computed as a difference of successive annual means (i.e., 1 January in that year to 1 January of the next year), and relative increase is given in percentage in open bracket. Growth rate is denoted as GR and relative increase as RI (%).

	In situ CH_4		GOSAT XCH_4	
Year	mean	GR (RI%)	mean	GR(RI%)
2014	1989.5	-	1836.1	7.3 (0.4)
2015	1998.6	9.1 (0.5)	1841.1	5.0 (0.3)
2016	2029.9	31.3 (1.6)	1854.5	13.4 (0.7)
2017	2013.1	-16.8 (-0.8)	1858.4	3.9 (0.2)
2018	2001.6	-11.5 (-0.6)	1864.2	5.8 (0.3)
2019	2029.0	27.4 (1.4)	1880.6	16.4 (0.9)
2020	2031.5	2.5 (0.1)	-	-
Average	2013.3 ± 17.2	7.0 ± 19.7	1855.8 ± 16.1	8.6 ± 5.1

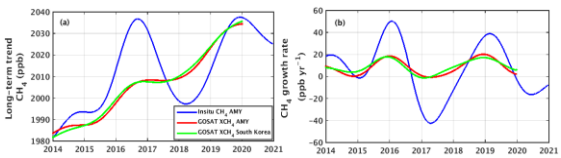

Figure 2. The plot demonstrates deseasonalized long-term trend (**a**) and instantaneous growth rates (**b**) of in situ CH_4 (blue line), GOSAT XCH_4 AMY (red line), and GOSAT XCH_4 South Korea domain (green line), mole fractions 2014-2020. Noted that GOSAT XCH_4 in panel (**a**) is scaled by adding 150 ppb (GOSAT XCH_4 + 150 ppb), which is just used to zoom in the plot.

2. CH_4 growth rate related to isotopic ratios, soil temperature and moisture in 2019

The isotopic composition of atmospheric methane $^{13}C/^{12}C$ (expressed as $\boldsymbol{\delta}^{13}$C-CH_4) collected by flask-air sampling weekly at AMY was used to understand the source signatures.

Figure 3a depicts the time series of monthly and yearly means of atmospheric observations of δ^{13}C-CH_4 (‰) during 2014–2019. The monthly result fluctuated within −47.96‰ to −47.17‰, with an annual average of −47.59 ± 0.19‰, and strong depletion fell in August–September. We also computed the intercept of the Keeling plot to infer the isotopic signature of the source responsible for enhancements in CH_4, and the intercept values for summer and autumn were found to be −53.3‰ and −52.9‰, respectively (Figure 3b), which is consistent with biogenic emissions. The enhanced depletions found in 2016 and 2019 accounts for enhanced biogenic CH_4 signals that coincided with the high growth rates of CH_4 in those respective years. This change apparently responded to the variations of soil temperature and soil moisture. Quantitatively, the spatial Pearson correlation of XCH_4 interannual variability with the soil temperature and soil moisture was determined between 0.5 and 0.8 and statistically significant ($p < 0.05$) (Figure 4).

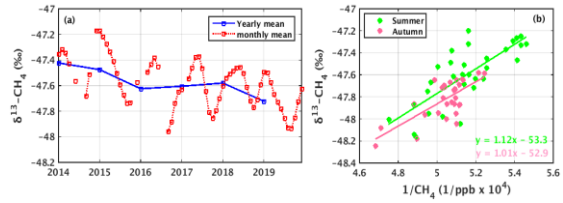

Figure 3. Panel (a) shows the time series of monthly and yearly means of atmospheric observations of δ^{13}C-CH_4 (‰) collected by flask-air sampling at AMY during 2014-2019. Panel (b) depicts δ^{13}C-CH_4 (‰) versus inverse CH_4 mole fractions at AMY for summer (green) and autumn (pink) seasons.

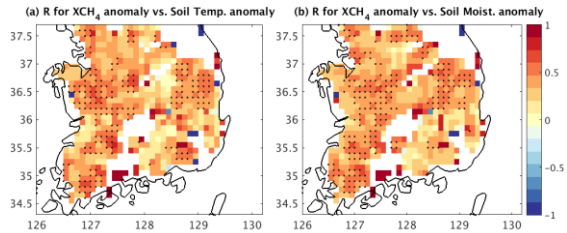

Figure 4. The correlation of TROPOMI XCH_4 anomaly versus soil temperature (a) and soil moisture anomalies (b) during April 2018-December 2020. Anomaly is calculated by subtracting annual mean from monthly means. Overlay plots marked by dots denote a statistical significance of $p < 0.05$.

Conclusions

At AMY, the average growth rates computed from in situ and GOSAT were 7.0 ± 19.7 ppb yr^{-1} and 8.6 ± 5.1 ppb yr^{-1}, for 2014–2020 and 2014–2019, respectively. The high growth rates were detected in 2016 and 2019, resulting in 27.4–31.4 ppb yr^{-1} from in situ and 13–16 ppb yr^{-1} from GOSAT.

The isotopic composition of CH_4 (δ^{13}-CH_4) collected by flask-air sampling at AMY was analyzed to infer the source signatures, and the result was varied within −47.96‰ to −47.17‰, with an annual average of −47.59 ± 0.19‰. Enhanced depletions appeared in 2016 and 2019 that matched the large growth of CH_4.

These elevated depletions were driven by the summer and autumn seasons. The intercepts of the Keeling plot for summer and autumn were found to be −53.3‰, and −52.9‰, respectively, which is consistent with biogenic emissions that are accountable for the enhancements in CH_4. We investigated that the change of soil temperature and moisture have contributed for the variations of CH_4, and the correlation between interannual variability of XCH_4 and those attributes were determined within 0.5-0.8 with the statistical significance of a 95% confidence interval. We can infer that biogenic-related CH_4 with associated drivers such as soil temperature and moisture is relevant in understanding the interannual variability of the growth rate over our domain.

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Inter-comparison activities for high quality atmospheric measurement

Soo Jeong Lee and Haeyong Lee

Introduction

The Global Atmospheric Watch (GAW) Programme operated by World Meteorological Organization (WMO) inaugurated in 1989 and has coordinated measurement data from more than 500 stations worldwide. To harmonize the measurement data within the global GAW network, it sets the standard scales by each greenhouse gas species[1][2]. For the stability of long-term measurement data, the standard scales should be maintained constantly from past to present within the same network[1].

It is needed to establish scientifically determined maximum bias between data from different stations, called the compatibility goal, to minimize the measurement uncertainty within the network of the same standard scale[1],[2]. The current WMO/GAW compatibility goal range is ±0.1 ppm for CO_2, ±2 ppb for CH_4, and ± 0.1 ppb for N_2O[1]. If the data between the stations exceeds the compatibility range, biases can significantly affect scientific interpretations of combined datasets and influence fluxes inferred from observations with models[1]. In this regard, an inter-comparison experiment is an approved way to examine the compatibility of the data among laboratories within the network. Here we introduce the domestic inter-comparison experiment conducted in 2016 and 2020 within the greenhouse gas monitoring network of Korea Meteorological Administration/ National Institute of Meteorological Sciences (KMA/NIMS) for data quality management and verification of measurement precision.

Method

For the domestic inter-comparison experiments, three greenhouse gas monitoring stations of KMA/NIMS, Anmyeondo (AMY), JGS (Jeju Gosan Suwolbong), and Ulleungdo (ULD), participated(Fig 1). Each station sequentially analyzed the mole fraction of the traveling standard cylinders provided by NOAA, the central calibration laboratory (CCL) of WMO/GAW. Then each measured value was compared with the certified value by CCL to examine whether the difference was within the WMO/GAW network compatibility goal range.

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The certified mole fraction of the prepared traveling standard gases was arranged based on the background mole fraction of Korea Peninsula of each period, thus that of 2nd round is a bit higher than the 1st round(Table 1).

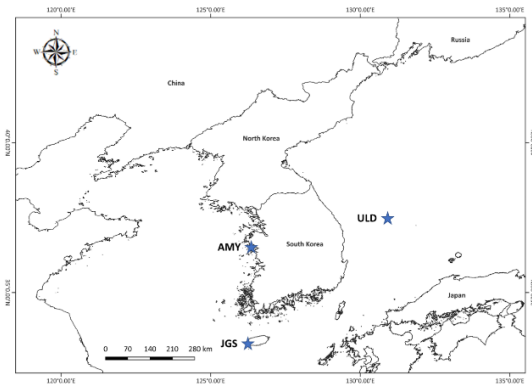

Figure 1. Greenhouse gas monitoring network of National Institute of Meteorological Sciences of Korea Meteorological Administration in Republic of Korea: Anmyeondo (AMY), Jeju Gosan Suwolbong (JGS) and Ulleungdo (ULD)

Table 1. Certified mole fraction of the traveling standard gases for the inter-comparison experiment

Certified mole fraction	1st round (2016)	2nd round (2020)
CO_2 (ppm)	406.05 ±0.01	415.2 ±0.01
CH_4 (ppb)	1,898.84 ±0.10	1,950.5 ±0.10
N_2O (ppb)	329.05 ±0.11	332.1 ±0.11

Result

1. CO_2 and CH_4

For CO_2 and CH_4, all stations presented the difference to the certified value within the network compatibility range in both rounds(Fig 2 and Fig 3). And most of them showed better precision in the 2nd round than the 1st round.

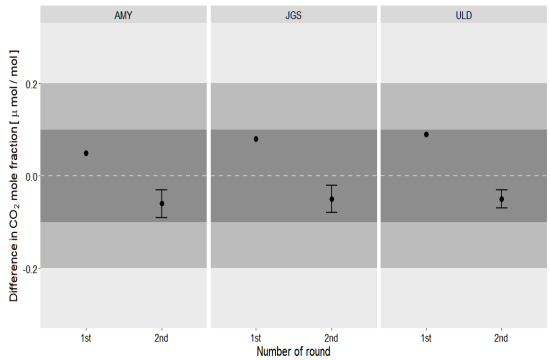

Figure 2. CO_2 difference (each station-CCL) in the 1st and 2nd round of the inter-comparison experiment. (Dark grey area: WMO/GAW network compatibility goal, light grey area: WMO/GAW extended network compatibility goal)

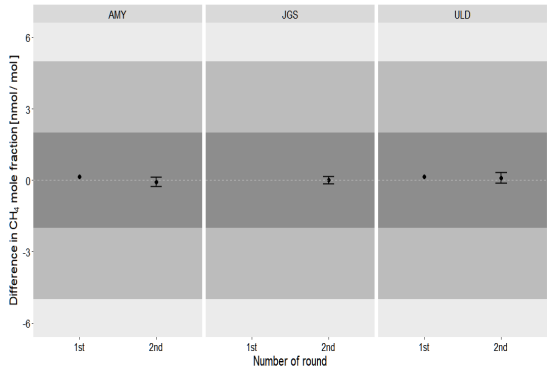

Figure 3. CH_4 difference (each station-CCL) in the 1st and 2nd round of the inter-comparison experiment. CH_4 value of JGS at 1st round was excluded due to the error from experiment procedure (Dark grey area: WMO/GAW network compatibility goal, light grey area: WMO/GAW extended network compatibility goal)

The high precise result of the CO_2 and CH_4 both in two experiments is mainly due to the advantage of the latest measuring instrument, Cavity Ring-Down Spectroscopy (CRDS). It presents better linearity and stability and needs fewer efforts for calibration than the traditional measuring instrument such as Non-dispersive infrared (NDIR) spectroscopy for CO_2 or Gas Chromatograph- Flame Ionization Detector (GC-FID) for CH_4[3],[4],[5].

According to the result of the IAEA/WMO round-robin inter-comparison experiment, this can be reinforced. KMA/NIMS submitted the values out of compatibility range at a low level during the 4th and 5th rounds which were measured by Non-Dispersive Infrared (NDIR) spectroscopy spectroscopy. However, after changing to CRDS, its measured values were within the network compatibility range at both low and high level, which appears on the result of the 6th round[6].

Another reason of reduced uncertainty for CO_2 and CH_4 is the change to multi-point calibration from 2-point calibration at JGS and ULD. According to the research of KMA/NIMS, 4-point calibration allows more precise results of CO_2 and CH_4 measurement than 2- or 3-point calibration despite the linearity of CRDS[7].

At last, on the 2nd round, all monitoring stations have sufficient injection time for measurement around 50-60 minutes. Picarro G2401 used in the stations shows the most stable at around 60 minutes from the injection[8].

2. N_2O

For nitrous oxide, all stations showed exceeding values on the 1st round, while on the 2nd round, JGS and ULD presented the values within the network compatibility and the extended network compatibility goal,

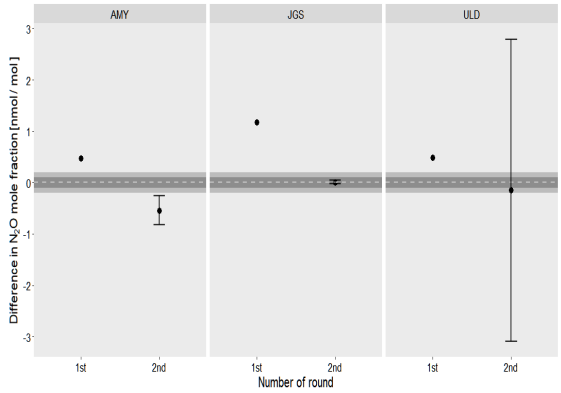

Figure 4. N_2O difference (each station-CCL) in the 1st and 2nd round of the inter-comparison experiment. (Dark grey area: WMO/GAW network compatibility goal, light grey area: WMO/GAW extended network compatibility goal)

In the case of N_2O, the high uncertainty result might be linked to the characteristics of Gas Chromatograph-micro Electron Capture Detector (GC- μ ECD). It represents non-linearity and high drift, so that it needs frequent calibration to correct the non-linearity and drift of the measurement data[9]. However, the latest N_2O measurement instrument, Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) shows better linearity, repeatability, and reproducibility compared to GC-μECD. As JGS station has changed instrument from GC-μECD to OA-ICOS on the 2nd experiment, it is the only station who gets the stable values within the network compatibility range. So, it is recommended by WMO to checkup the linearity range of each instrument for setting the number and the range of the mole fraction of standard gases every year[10],[11].

Summary

According to the result of the domestic inter-comparison experiments, the latest measurement instruments affect the quality of the measurement data, though the latest does not guarantee the quality of the data. Thus, developing and applying the proper calibration method is necessary for each instrument and condition. Also, repeatability, reproducibility, and linearity checkups before the operation of the instruments are indispensable. Finally, continuous endeavor to develop and operate site-specific calibration method is necessary.

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