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Contents

30 Years of Global Atmosphere Watch Activities in Korea

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Activities related to the Global Atmosphere Watch (GAW) program of World Meteorological Organization (WMO) in Korea began in 1980s. Many institutes in Korea including the Korea Meteorological Administration (KMA) have focused on measurements of atmospheric chemical composition and its long-term variations, providing reliable scientific data and information on the chemical composition of the atmosphere, its natural and anthropogenic change, helping improve the understanding on climate change. Besides the measurements, they are recently expanding their contribution to the GAW program in various fields of activities, e.g. running the GAW central facilities and training and education course, participating in intercomparison campaigns, and acting as members in scientific advisory groups. Here we introduce the brief history of the GAW related activities carried out in Korea, in particular measurements and other activities.

Measurement activities

The first GAW-related activity got officially started with establishment of an ozone station as one of the world ozone network by the Yonsei University, Seoul in May 1984.[1] This station was the only one in the Korean Peninsula and monitors daily total ozone values in addition to Umkehr observations for the vertical distribution of ozone, using Dobson spectrometer (Beck No. 124). Within the framework of the WMO Global Ozone Observing System (WMO/GO_3OS), the Global Environment Laboratory of the Yonsei University has carried out ozone layer research and monitoring program as Station No. 252 (GAW ID: SEO) over Korea in Seoul since May 1984, using Brewer spectropho-

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tometer and other atmospheric radiation observation instruments as well.

In 1987, KMA established an atmospheric observatory at Mt. Sobaek for atmospheric composition watch, which was located in the middle of the Korean Peninsula, collecting observational data of reactive gases. It moved to Anmyeondo (GAW ID: AMY) in 1997.

Currently KMA has the three main stations for the atmosphere watch, which are located in the west (at Anmyeondo, Chungnam Province), south (at Gosan, Jeju), and east (at Ulleung, Gyungbook Province) of the Korean Peninsula, in aim of monitoring of transportation of the atmospheric substances and variation in the atmospheric composition over the Korean Peninsula. In collaboration with institutes in Korea, they collect the observational data from six auxiliary stations which are run by universities or research institutes in Korea. For the detail information, see reference.[2]

There are six GAW regional stations in the Korean Pheninsula, Seoul (GAW ID: SEO), Gosan (GAW ID: GSN), Taeahn (GAW ID: TAP), Pohang (GAW ID: POH), Jeju Gosan (GAW ID: JGS), and Anmyeondo (GAW ID: AMY), and one GAW station in Antarctica, King Sejong (GAW ID: KSG). KMA established the four stations, GSN in 1990, POH in 1993, AMY in 1996, and JGS in 2009. The TAP station has been established and managed by the Korea Center for Atmospheric Environment Research (KCAR) and jointly the National Oceanic and Atmospheric Administration (NOAA) in U.S. since 1990. The KSG station has been established and operated by the Korea Polar Research Institute since 1988.

Greenhouse gases

KMA got started with greenhouse gas (GHG) measurements at Gosan, Jeju (GSN) using a flask sampling method in 1990 in collaboration with Seoul National University. Real-time in-situ continuous monitoring of GHGs began at the Muan meteorological station in 1995, which was located at the south-western of the Korean Peninsula. The Anmyeondo station, one of the GAW regional stations in Korea, was established in 1996. The measurements of the Sobaek observatory and Muan station were integrated into the AMY station in 1997. GHGs including CO_2, CH_4, N_2O, CFC-11, 12, 113, and SF_6 have been measured using various methodologies, e.g. Cavity Ring Down Spectroscopy (CRDS), Off-Axis Integrated Cavity Output Spectroscopy (OAICOS), and Gas Chromatography (GC) since 1998 at AMY, 2009 at JGS, and 2014 at Ulleungdo (ULL, not designated as a GAW station yet).

The KSG station in Antarctica has collected the GHG measurement data using a CRDS method as well as a weekly-based flask sampling method. The data are available since 1988. It also collects data of stratospheric ozone, reactive gases, and ultraviolet

radiations. The TAP station has produced the GHGs data, e.g., CO_2, CH_4, C_2H_6, and C_3H_8, using weekly-based flask sampling method, which has been a part of the NOAA GHG reference network since 1990.

Aerosols

Physical, chemical, and optical characteristics of aerosols, widely acknowledged as one of the most significant and uncertain aspects of climate change projections, have been measured with in-situ instruments or ground-based remote sensing instruments, including their vertical profiles retrieved using a ground-based LIDAR at AMY, and GSN in collaboration with universities in Korea. In physical parameters, we collect atmospheric observation data of mass concentrations (PM1, PM2.5, PM10) with ß-ray absorption and/or laser scattering methods, and size distributions in the ranges of 0.01 − 20 μm using Scanning Mobility Particle Sizer and Aerodynamic Particle Sizer. For the optical properties, it measures scattering and absorption coefficients by Nephelometer and Aethalometer, aerosol optical depth by sun-photometer and precision filter radiometer, vertical profiles of back-scattering coefficients, depolarization ratio, and color ratio from a LIDAR instrument with wavelengths of 1064 and 532 nm. The aerosols ($PM_{2.5}$, PM_{10}) were sampled for 24 hours once a week for analysis of the chemical components and metals.

Stratospheric ozone, ultraviolet radiation, and others

In addition to the SEO station, total column of ozone and ultraviolet radiation began at the Pohang station in January 1994, located in the south-eastern coast of Korea. Ozone sonde measurements have been carried out at Pohang station, since 1994. Sookmyeong Women's University, designated as an auxiliary station of KMA in 2015, got started with measurement of vertical profiles of water vapor and ozone in the stratosphere and mesosphere using passive microwave radiometers since 2006. In general, total column ozone is measured using the Brewer spectrometers, together with collocated ultraviolet and solar/terrestrial radiations.

The reactive gases such as carbon monoxide (CO), surface ozone (O_3), nitrogen oxides (NO_x), and sulfur dioxide (SO_2) have also been measured since 1998 at AMY and 2009 at GSN, because these compounds play a role in the chemistry of the atmosphere and the formation of aerosols. It used instruments using gas-phase chemiluminescence for NO_x, UV fluorescence for SO_2, UV photometry for O_3, nondispersive infrared photometry for CO, which is changing to CRDS for the better maintenance. Precipitation chemistry observations as a part of total atmospheric deposition began at 4 sites (Anmyeondo, Gosan, Ulleungdo, and Pohang) in 1997, focusing on measurements of the acidity,

conductivity, and major 9 ions (F^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}).

To enhance the effectiveness and application of the long-term measurements under the umbrella of GAW, KMA cooperates with the atmospheric measurement networks domestic and worldwide along with focusing on the quality assurance and control.

Participation in inter-comparison experiments and audits

To maintain traceability and compatibility and secure the level of measurements, we have taken part in the inter-comparison campaigns under the auspices of Quality Assurance and Scientific Activity Centers (QA/SAC), in particular on greenhouse gases and precipitation chemistry, and taken audit World Calibration Centres.

We have taken part in the sixth round-robin comparisons organized by the WMO GAW Central Calibration Laboratory (CCL) in NOAA since 2004, and methane reference gas inter-comparisons organized by the World Calibration Centre for CH_4 (WCC-CH_4) in Japan Meteorological Agency (JMA) since 2001. Recently we participated in the sixth round-robin comparison (RR6) and 5th methane reference gas inter-comparison. In terms of precipitation chemistry, we taken participated in the GAW annual laboratory inter-comparison studies organized by the World Data Centre for Precipitation Chemistry (WDCPC) since 1990, once a year for 1990-2000 and twice a year since 2001.

In agreement with the WMO/GAW quality assurance system, we took a system and performance audits for the AMY station in 2006 on aerosols by World Calibration Centre for Aerosol Physics (WCC-AP) in Libniz Institute for Tropospheric Research in Germany, and 2014 for CO_2 and CH_4 by WCC-Empa, which is run by Federal Laboratories for Materials Sciences and Technology in Switzerland. The report of the audit by WCC-Empa, available on the WMO/ GAW webpage, describes "The Regional GAW station Anmyeon-do comprises a very comprehensive set of measurements. The AMY station a very important contribution to the GAW programme. The assessed greenhouse gas measurements were of high quality. To date, not all of the parameters measured at AMY are considered as being part of the GAW programme by KMA, but KMA is working towards the integration of all measurements under the umbrella of GAW. WCC-Empa strongly encourages this process, since the available data would be a very valuable contribution to GAW. The continuation of the AMY measurement series as well as the inclusion of the reactive gases measurement programme as GAW parameters is highly recommended."[3]

Integration of the GAW activities in Korea

KMA is going to integrate the Korean domestic GAW-related activities and share their observational data with universities and research institutes. Its first step is integration of the GAW activities conducted at Gosan, Jeju, and construction of the Korea aerosol LIDAR observation network.

Integration of the GAW related activities at Gosan, Jeju

There are two regional GAW stations at the Gosan area in Jeju island, Korea, Jeju Gosan station (JGS) and Gosan station (GSN). The JGS station, which is all run by the KMA, comprises a comprehensive set of measurements under the umbrella of the GAW program. The JGS station produces data of greenhouse gases, reactive gases, aerosols, stratospheric ozone and ultraviolet radiation, atmospheric radiation, and atmospheric chemistry (see Table 2). The GSN station is known as a supersite where the International Global Atmospheric Chemistry Program (IGAC) has conducted the Aerosol Characterization Experiment (ACE-Asia) in March to May in 2001.[3] There are many institutes that conduct the atmospheric composition measurements in the supersite, e.g. KMA, SNU, Kyungpook National University (KNU), Yonsei University (YU), Korea University (KU), and Jeju National Universities (JNU) (see Table 1). The greenhouse gas measurement system operated by KNU is a part of the Advanced Global Atmospheric Gases Experiment (AGAGE) network.

We are integrating the two stations, GSN and JGS, into one station and share their output, which is resulting in enhancing usage of the data. To fulfill the integration, we are renovating infrastructure of the site and install new inlets for greenhouse gases and aerosols in accordance with the GAW recommendations. New parameters and methodologies are also secured and applied, e.g. greenhouse gas isotopes. KMA has a strong scientific supporting program with appropriate data analysis and interpretation in cooperation with research institutes and universities involved in the integration of the site. To enhance the effectiveness and application of the long-term measurements within GAW, we also cooperate with the atmospheric measurement networks worldwide along with focusing on the quality assurance and control.

The station is well-suited to become a global GAW program given the long-term measurements of a large number of parameters carried out there, and the location of the site. We hope the intergated station to be a global station in the GAW network.

Korea Aerosol LIDAR Observation Network (KALION)

In 2015, we constructed KALION to cope with aerosol-related atmospheric environ-

mental issues, e.g., Asian dust, smog, haze, volcanic ashes, and fire plumes, originating both from the Asian Continent and in the Korean Peninsula.

An aerosol LIDAR (Light Detection and Ranging) instrument retrieves vertical profiles of information on aerosols so that it has advantages in monitoring of transport of aerosols, unlike conventional in-situ instruments. The KALION, which consists of twelve LIDAR measurement sites to monitor transport of aerosols over the Korean Peninsula, is run by ten institutes in Korea; National Institute of Meteorological Sciences (NIMS), National Institute of Environmental Research (NIER), Seoul Research Institute of Public Health and Environment (SRIPHE), Seoul National University (SNU), Mokwon University (MU), Hanbat University (HU), Gwangju Institute of Science and Technology (GIST), Ulsan National Institute of Science and Technology (UNIST), and Gangneung-Wonju National University (GWNU). In KALION, continuous observations are carried out at six sites and event observations in the other six sites. There are also two intensive observation campaigns a year, during March to May and September to November. KALION members run the elastic-backscatter or inelastic-backscatter (Raman) LIDAR instruments with at least two wavelengths.

They basically share the range-corrected raw data and the vertical information on aerosols in real time using a unified signal processing algorithm via; i) aerosol optical properties, e.g., backscattering coefficients, depolarization ratios, and color ratios, ii) aerosol classification, e.g. Asian dust, pollutants, and clouds, and iii) aerosol mass concentrations. These data are shared through a webpage, www.kalion.kr.

Integration of aerosol remote sensing networks

There are monitoring networks for aerosols over the Korean Peninsula, ground-based LIDAR network (KALION) consisting of 12 sites, ceilometer network consisting of 92 sites, and satellite-based observations (geostationary and polar-orbit satellites). We have a plan to construct a monitoring system to be producing three-dimensional map of aerosols through integrating these three networks, which is resulting in watching transport of aerosols over the Korean Peninsula.

Asia-Pacific GAW workshop on Greenhouse gases (APGG)

The Asia-Pacific GAW Workshop on Greenhouse Gases (APGG) has annually been held by KMA since 2009. The APGG has become a venue for cooperation on the greenhouse gases (GHGs) activities. The APGG has been designed to introduce the measurement technologies, quality control/assurance methodologies, and new monitoring stations as well as to share major research findings. It provides a good opportunity to share our

knowledge on greenhouse gas measurements. The APGG-2016, in which ~60 peoples from 12 countries take part, is in tandem with the technical training/education course in part of the WCC-SF_6 activities.

World Calibration Centre for SF_6

World Calibration Centre (WCC), one of the GAW central facilities, maintain calibration standards and provide instrument calibrations and training to the stations, that is, link observations to World Reference Standards and ensure networks comparability and compatibility through inter-comparison campaign and regular audits. World Calibration Centre for SF_6 (WCC-SF_6) was designated to be established in KMA in 2012, and has been operated since 2013. WCC-SF_6 conducts the missions for the traceability and compatibility of the SF_6 measurement in the GAW network.

We developed the standard operating procedure for atmospheric SF_6 measurements and published it as a WMO/GAW report (No. 222) in 2015. Through its technical support, we give help build up and improve methodologies for Indian Institute of Tropical meteorology in 2015, and conduct an audit the Cape Point station in South Africa in 2016. The first SF_6 intercomparison experiment started in May 2016.

We have annually held the training and education course since 2014. In total, fifteen from fourteen countries have participated in the course for 2014-2016. We hope to get a regional training and education centre for atmospheric SF_6 measurements established in KMA

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The evaluation of JMA's standard gas scale for measurements of atmospheric methane

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Introduction

The Japan Meteorological Agency (JMA) operates the GAW World Calibration Centre (WCC) for methane (CH_4) in Asia and the South-West Pacific under the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO). In order to ensure the traceability to the GAW international standard scale and maintain the accuracy of the measurements, the long-term stability of the JMA primary standards gases have been examined. We also have carried out CH_4 intercomparisons around Asia and the South-West Pacific since 2002 under the JMA/WCC program. In addition, the JMA plans to replace our current flame-ionization-detector gas chromatograph (GC/FID) with a wavelength-scanned cavity ring-down spectroscopy (WS-CRDS) analyzer as a new CH_4 calibration system, so that we started to preliminarily compare these methods.

JMA standard

JMA has used two sets of CH_4 standard gases (first generation (1G) and second generation (2G)) whose mole fractions were assigned by the NOAA04 scale (Table 1). To ensure the traceability of these standard gas sets, the 2G standards were measured by the 1G standards regularly (Figure 1). All of the five cylinder measurements showed small differences (measured − assigned) of less than 1 ppb, indicating a consistency of the assigned mole fractions between 1G and 2G. To evaluate the long term stability of standard gases, we have regularly compared JMA's standard

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Table 1. JMA primary standard gases of the 1G and 2G sets

	Cylinder ID	Cylinder Volume(L)	Preparation Data	CH_4 NOAA04 Scale(ppb)	Sdev (ppb)	Measurement Date
JMA 1G Primary	CQB11442	48	NOV15, 1999	1621.94	0.38	SEP 19-OCT 3, 2006
	CQB11443	48	NOV15, 1999	1749.77	0.51	SEP 13-25, 2006
	CQB11444	48	NOV15, 1999	1867.19	0.19	SEP 13-28, 2006
	CQB11446	48	NOV15, 1999	1982.57	0.43	SEP 13-28, 2006
	CQB11447	48	NOV15, 1999	2108.48	0.28	SEP 19-OCT 2, 2006
JMA 2G Primary	CQB18737	48	APR-JUN, 2011	1611.65	0.20	NOV 17-28, 2011
	CQB18738	48	APR-JUN, 2011	1760.51	0.16	OCT 27-NOV 14, 2011
	CQB18739	48	APR-JUN, 2011	1898.07	0.91	OCT 27-NOV 14, 2011
	CQB18740	48	APR-JUN, 2011	2030.35	0.10	OCT 27-NOV 14, 2011
	CQB18741	48	APR-JUN, 2011	2165.00	0.30	NOV 17-28, 2011

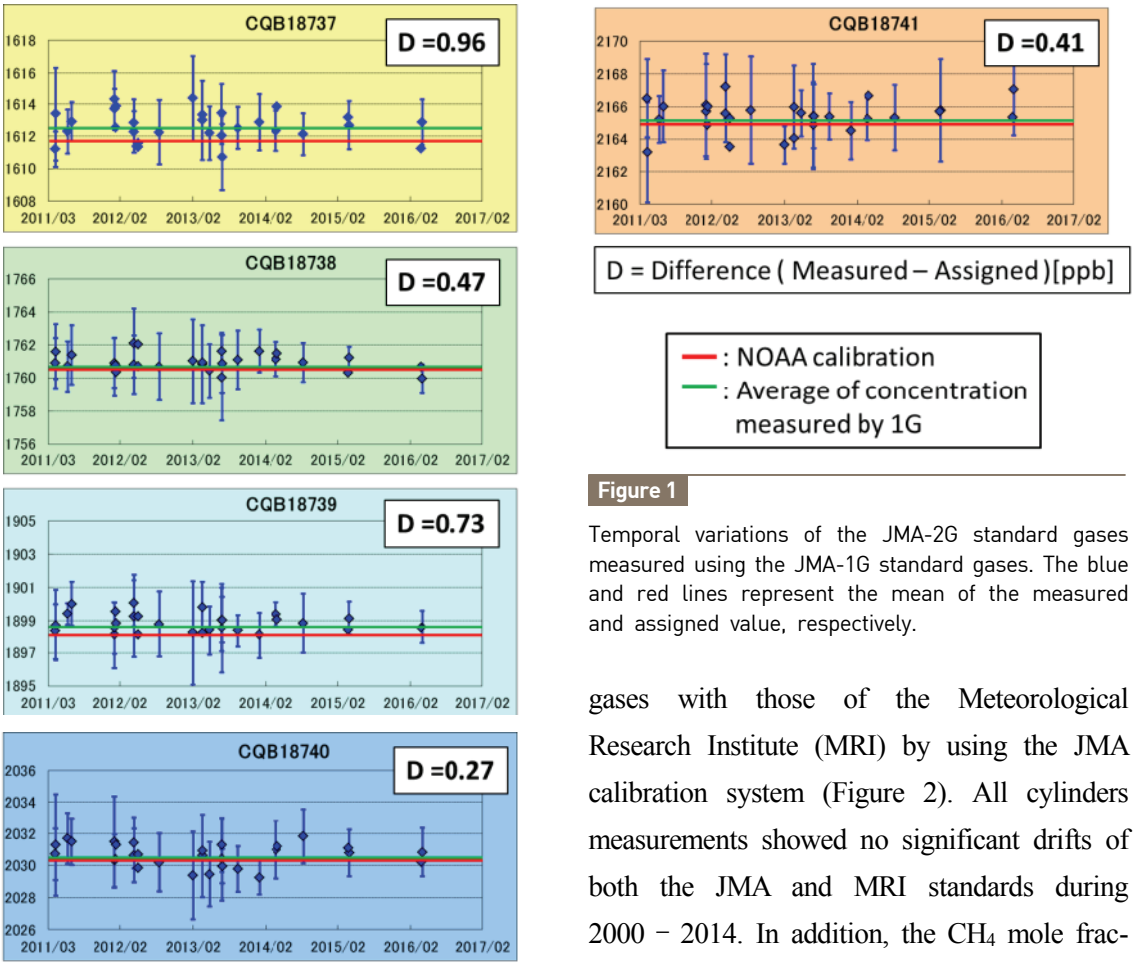

Figure 1

Temporal variations of the JMA-2G standard gases measured using the JMA-1G standard gases. The blue and red lines represent the mean of the measured and assigned value, respectively.

gases with those of the Meteorological Research Institute (MRI) by using the JMA calibration system (Figure 2). All cylinders measurements showed no significant drifts of both the JMA and MRI standards during 2000 – 2014. In addition, the CH_4 mole fractions of each standard gas for the JMA 1G

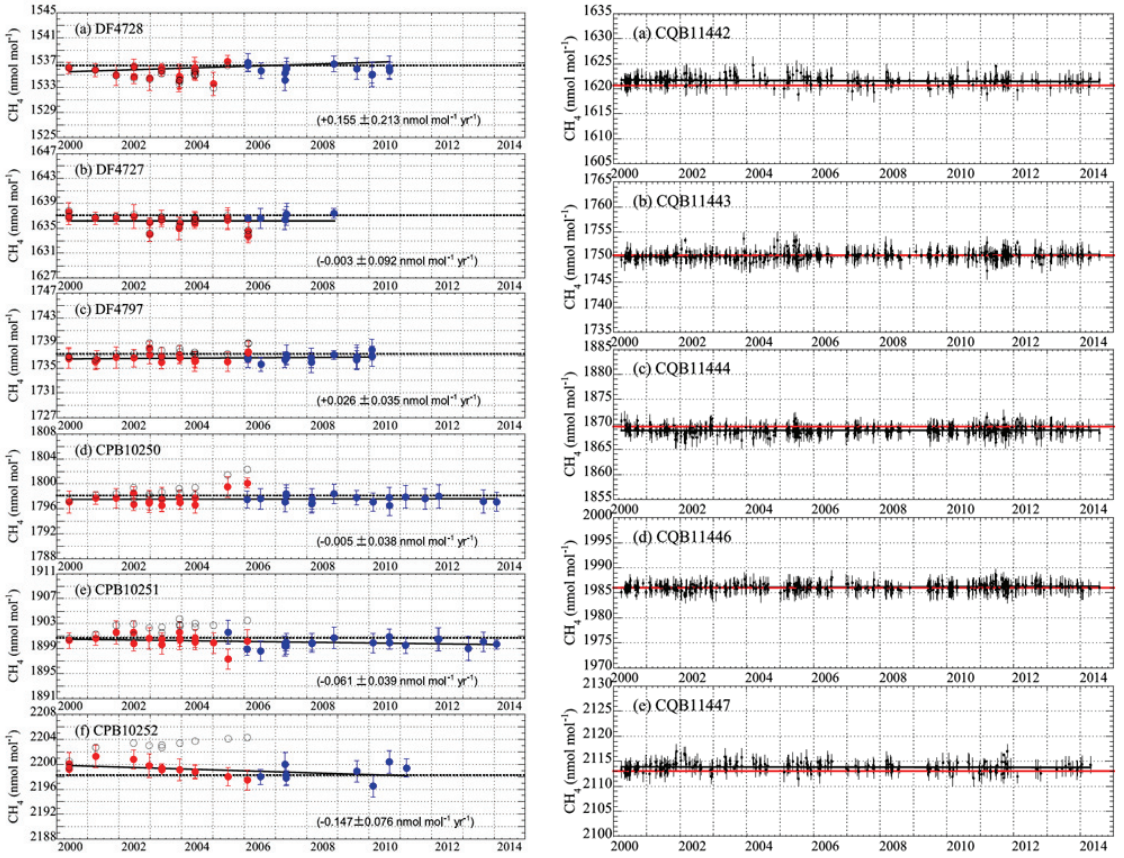

Figure 2

Temporal variations of the MRI standard gases measured using the JMA standard gases (left panels), and internal consistency tests of the JMA-1G standard gases (right panels).

set were re-calculated based on the measurements of the other four standard gases within the same 1G set (Figure 2). It enables us to find out the internal consistency and no significant drift of 1G set for a long period of time. These results indicate that the mole fractions of all standard gases were stable and the JMA CH_4 calibration system has been well maintained over the past 14 years (Matsueda et al., 2004; Tsuboi et al., 2016). Thus, it is confirmed that the JMA standard gases are suitable as the reference for the JMA/WCC intercomparison experiments.

Intercomparison experiments

To pursue more accuracy of CH_4 measurements, we carried out two intercomparison experiments of the JMA/WCC and the InterComparison Experiments of Greenhouse Gases Observations (iceGGO) (Table 2). Since 2002, JMA/WCC has carried out round-robin

Table 2. The history of CH_4 intercomparisons for the JMA/WCC and iceGGO programs

WCC round robbin for CH_4			
Round	Period	Participant	Cylinders [ppb]
1st	2001.04 - 2005.03	CMA, KMA, CSIRO, NIWA, TU, NIES	1800, 1950
2nd	2005.07 - 2010.01	CMA, KMA, KRISS, CSIRO, NIWA, NIES, TU,	1700, 1875
3rd	2008.05 - 2013.02	KRISS, KMA, CMA, CSIRO, NIWA, NIPR, AIST, MRI, NIES, TU	1665, 1850
4th	2011.06 - 2012.05	CMA, KMA	1740, 1880
	2013.06 - 2014.02	CSIRO, NIWA, NOAA/ESRL	
	2015.12 - 2016.08	AIST, MRI, NIES, TU	
5th	2015.02 - 2016.10	KMA, IITM	1740, 1900
	In the planning	CSIRO, NIWA, NOAA	
iceGGO for CH_4			
Round	Period	Participant	Cylinders [ppb]
1st	2012.10 - 2012.12	JMA, NIPR, AIST, MRI, NIES, TU, NMIJ	1664.2, 1779.6, 1811.2, 1844.8, 1918.8, 2234.6
2nd	2016.2 - 2016.8	JMA, AIST, MRI, NIES, TU, NMIJ	1740.1, 1797.3, 1878.6, 2198.3

intercomparisons for CH_4 around Asia and the South-West Pacific (http://ds.data.jma.go.jp/gmd/wcc/wcc.html).

JMA and other 11 laboratories from 6 countries participated in the 1st - 4th round-robins, and the 5th round-robin is ongoing. On the other hand, JMA and other 5 major laboratories in Japan, including the National Metrology Institute of Japan (NMIJ), established a domestic alliance to compare the standard gas scales under the iceGGO program. Figure 3 plots all results of JMA/WCC round-robins and iceGGO experiments. Since several participants of iceGGO are not using NOAA04 scale, we adjusted their data based on the NOAA04 scale by using conversion factors (Kawasaki et al., 2016, Dlugokencky et al., 2005), except for KRISS whose conversion factor is unknown. The result shows that although several data on the different scales are largely deviated, their adjusted data well agreed within±5ppb with all other measurements on the same NOAA04 scale (Kawasaki et al., 2016).

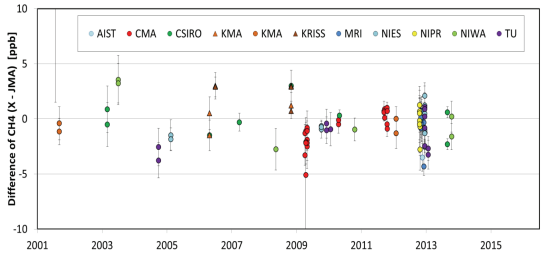

Figure 3

Differences of CH_4 measurements (Laboratory X – JMA) from the JMA/WMO round-robins and ice GGO experiments. All data converted to the same NOAA04 scale are shown.

New calibration system

JMA plans to replace a gas chromatograph (GC/FID) with a wavelength-scanned cavity ring-down spectroscopy (WS-CRDS) analyzer as a new CH_4 calibration system. To check the difference between GC/FID and WS-CRDS which is used for gas sampling measurements in JMA, we have preliminarily measured several CH_4 reference gases by using both the analyzers (Figure 4). It shows a good agreement within the WMO compatibility goal of ± 2 ppb. When we will replace a new calibration system using a WS-CRDS, we will again test the comparison in detail to confirm no gaps between the old and new calibration systems.

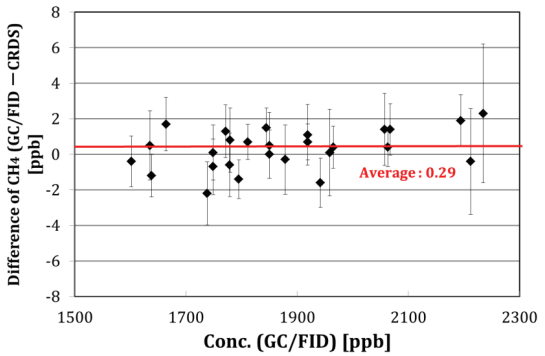

Figure 4

Differences of CH_4 measurements between GC/FID and WS-CRDS.

Summary

The stability and traceability of JMA's CH_4 standard gases have been ensured by several long-term tests. The JMA/WCC round-robins and iceGGO experiments provided good opportunities to examine the traceability and stability of standard gases maintained by different laboratories. And we continuously carry out further and more accurate tests for replacing the CH_4 calibration system from GC/FID to WS-CRDS. Finally, we gratefully acknowledge all participating laboratories for their co-operations of the JMA/WCC and iceGGO intercomparisons.

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Recent Progress on Greenhouse Gas Measurements at Mt. Lulin and Dongsha Island, Taiwan

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Background

The island of Taiwan is situated in a unique position in Western Pacific in terms of observing polluted outflows from Indochinese Peninsula and the East Asian continent. Regional meteorological conditions are favorable for the transport of air pollutants, such as dusts, acidic pollutants, and biomass burning emissions, from upwind source regions to Taiwan. Thus, a high-elevation baseline station, Lulin Atmospheric Background Station (LABS; 23.47°N, 120.87°E; 2,862 m a.s.l., Figure 1), was established to measure baseline air pollutants and to study the atmospheric transport patterns.[1] Official operation of LABS began on April 13, 2006. This station offers a great deal of opportunities to investigate the atmospheric chemistry of trace gases, aerosols, precipitation, mercury, and radiations, providing a distinctive contrast of atmospheric changes and impacts by a variety of air masses originated from relatively clean to emission source regions. In March 2010, as part of NOAA/ESRL/GMD's Cooperative Air Sampling Network, flask air sampling at Dongsha Island (DSI; 20.70°N, 116.73°E; 3 m a.s.l., Figure 2) was launched to measure surface greenhouse gases (GHGs) in the northern South China Sea.[2]

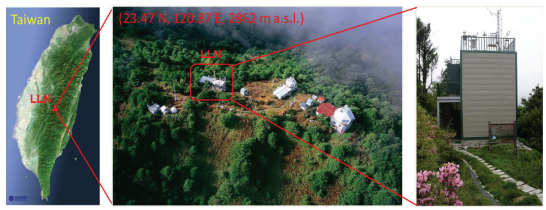

Figure 1

Lulin Atmospheric Background Station (LABS).

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3. Environmental Protection Administration, Taipei, Taiwan
4. NOAA/ESRL/GMD, Boulder, CO.

Figure 2

Air sampling at Dongsha Island (DSI).

Preliminary Results and Discussion

As reported by IPCC in 2013, CO_2 is the largest contributor of the atmospheric well-mixed greenhouse gases, accounting for 64.3% of the total global radiative forcing from 1750 to 2011. During the past decade of greenhouse gas measurements at the two sites, the annual mean CO_2 mixing ratio reached the milestone of 400 ppm at LABS (402.61±3.11 ppm) in 2015 and at DSI (401.67±4.65 ppm) in 2014. Springtime vegetation growth dramatically drew down the CO_2 mixing ratios at both sites in summer (Figure 3). The annual mean mixing ratios of CO_2 in 2015 are calculated to be 402.61±3.11 ppm and 404.60±5.28 ppm at LABS and DSI, respectively. In the same year, the annual mean mixing ratios of CH_4 are calculated to be 1877.2±36.7 ppb and 1894.4±55.0 ppb at LABS and DSI, respectively. The CO_2 increased at average rates of +2.69±2.30 ppm at LABS and +2.10±1.32 ppm at DSI during the observation period, whereas the CH_4 mixing ratio increased at average rates of +6.9±9.2 ppb at LABS and +6.4±9.2 ppb at DSI (Figure 4). During the same period, N_2O were also increasing at average rates of +0.9±0.3 ppb and +1.1±0.2 ppb at LABS and DSI, respectively (Figure 5). In addition, the annual mean mixing ratios of N_2O are almost the same at the two sites in 2015, which are calculated to be 329.2±0.6 ppb and 329.3±0.6 ppb at LABS and DSI, respectively.

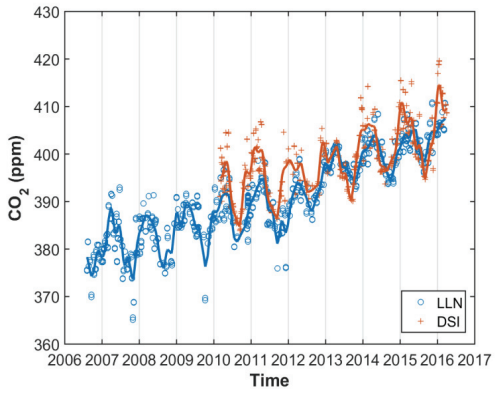

Figure 3

Preliminary results of CO_2 at LABS (LLN) and Dongsha Island (DSI).

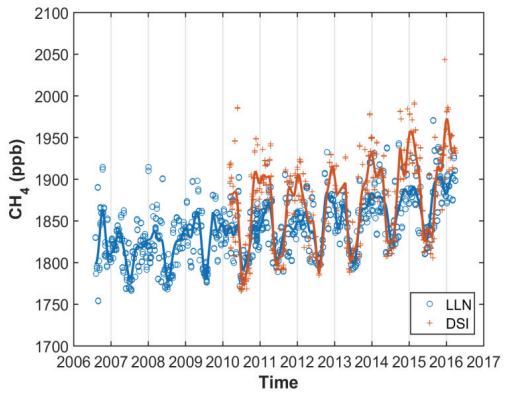

Figure 4

Preliminary results of CH_4 at LABS (LLN) and Dongsha Island (DSI).

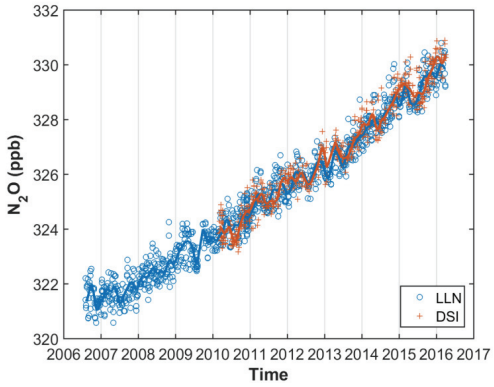

Figure 5

Preliminary results of N_2O at LABS (LLN) and Dongsha Island (DSI).

Future Work

Four new stations are proposed to be incorporated with LABS and DSI to form a greenhouse gas network in the near future (Figure 6). The observation locations are listed as follows: Taiping Island (10.37°N, 114.37°E; 3 m a.s.l.), Mt. Yushan (23.49°N, 120.96°E; 3845 m a.s.l.), Lanyu Island (22.04°N, 121.55°E; 324 m a.s.l.), and Mt. Bamboo (25.19°N, 121.55°E; 1103 m a.s.l.). Besides the measurements of greenhouse gases, each of the four new stations has its own particular functionality. Taiping Island is located in the southern South China Sea close to the active biomass burning region as the maritime Southeast Asia. Mt. Yushan is the highest mountain in the western Pacific, which is situated in the free troposphere at a distance of approximately 9.2 km away and ~1 km higher than LABS, measuring the background air that is less affected by the local vegetation. Lanyu Island lies on the southeast side of Taiwan, which has observed CO_2 by Taiwan Central Weather Bureau since 1995. Mt. Bamboo station sits just above the boundary level in the northern Taiwan, which in the meantime can also be considered as the outpost station of Taiwan for monitoring the long-term transport of air pollutants along with the Asian continental outflow.

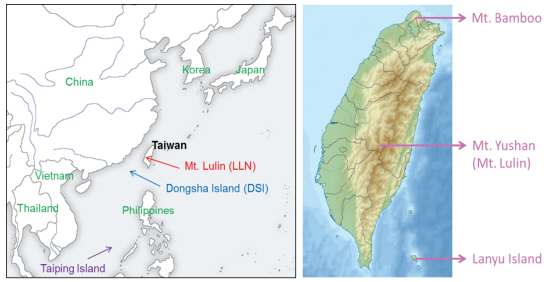

Figure 6

Proposed greenhouse gas network.

Reference

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Trace Gas Monitoring at Cape Point Global Atmosphere Watch (GAW) Station: South Africa

Thumeka Mkololo, Casper Labuschagne, Ernst-Günther Brunke and Lynwill G Martin*

Introduction

As part of the World Meteorological Organization Global Atmosphere Watch (WMO_GAW) mandate, Cape Point (CPT) Global Atmosphere Watch (GAW) station monitors trace gases in clean background air for the assessment of short and long term trends. Over the past years, the CPT monitoring program has grown tremendously from the initial two parameters (CO and Freon-11) in 1978 to exceed 10 parameters in 2015. In addition, there are currently nine local and international collaboration programs which serves as a mutual benefit between CPT and its collaborators. In addition, standard meteorological parameters such as humidity, pressure, temperature, wind direction and wind speed are also measured at the station.

The CPT GAW station is primarily exposed to air from the South Atlantic Ocean which provide background levels of trace gases as per CPT measurements. However, the station can be affected by non-background air, especially from the Cape Town urban region.[1] Non-background air results from a number of factors such as traffic, industrial emissions, domestic fuel burning and biomass burning. Biomass burning is one of the known sources of CO_2, CH_4, CO and other hydrocarbons. These trace gases are emitted during different fire stages e.g. the highest quantity of CO_2 and H_2O is emitted during flaming phase, whereas, CO, CH_4, and other hydrocarbons are emitted during smoldering phase.[2], [3] During March 2015, CPT was affected by such a biomass burning event, which started in Muizenberg Mountains, approximately 40 km to the north of the CPT GAW station. Windy conditions resulted in difficulties in

South African Weather Service, Stellenbosch, South Africa

controlling and extinguishing the wild fire within a short period of time. As a result, the massive wild fire quickly spread to the surrounding suburbs such as Chapman's Peak, Hout bay and Cape Point. During this fire episode, elevated levels of CO, CO_2, CH_4 and O_3 were measured at CPT GAW station whilst the CFCs mixing ratios remained at ambient levels. Similar observations were reported by Brunke et al, (2001) when studying trace gas variations at CPT during a 1997 regional biomass burning event.

Method and data

The CPT GAW station uses a number of different analytical instruments and techniques for continuous greenhouse gas measurements. Detailed analytical techniques have been previously described by [4], [5]. An O_3 calibrator (primary standard) (TEI 49i-PS), is being used to validate the O_3 instruments every three months. The calibrator in use is referenced to the GAW World Calibration Centre (WCC)-Empa (Switzerland) standard, which happens at the station in regular intervals of 3-4 years. In addition, daily zeros and sensitivity (span) checks are conducted automatically on O_3 instruments. For the greenhouse gas parameters, target gases are regularly used to check the CO, CO_2, CH_4, CFC's and N_2O-SF_6 instrument sensitivities and accuracies. In addition, every gas species is verified against sets of working gases which are prepared at the laboratory and calibrated against the National Oceanic and Atmospheric Administration (NOAA) laboratory standards. Instrumental calibration frequencies vary according to measurement technique that is being used. The station's data, in the form of 30-min. averages, are subsequently filtered via a statistical filter to provide "all" and "background" data sub-sets, described in Brunke et al, (2004). Quality checked background data is submitted to the World Data Centre for Greenhouse Gases (WDCGG) and the South African Air Quality Information System (SAAQIS) on yearly basis. On the other hand, non-background data is used to study regional pollution and transport episodes.

Results and Discussion

Figure 1 shows the Cape Point (CPT) carbon dioxide (CO_2) monthly mean mole fraction, based on filtered monthly means from 1993-2015. As a result of the statistical filtering technique applied, the Cape Point background CO_2 levels largely represent the greater southern ocean region.[6] Since the inception of measurements, a continuous increase of CO_2 mole fractions has been observed at CPT GAW station.

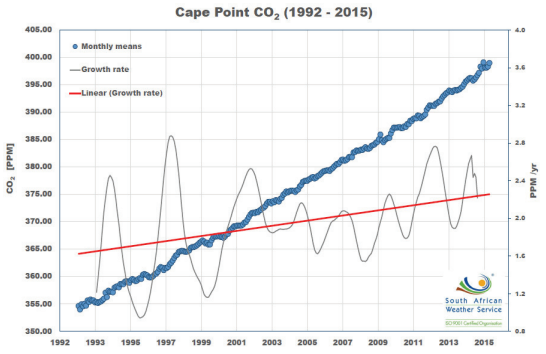

Figure 1

Cape Point CO_2 background filtered monthly means.

The CO_2 filtered annual mean mole fractions have increased by over 40 ppm from 355 ppm in 1994 to 398 ppm in 2015. In May 2016 the CPT background CO_2 monthly mean passed 400 ppm for the first time.

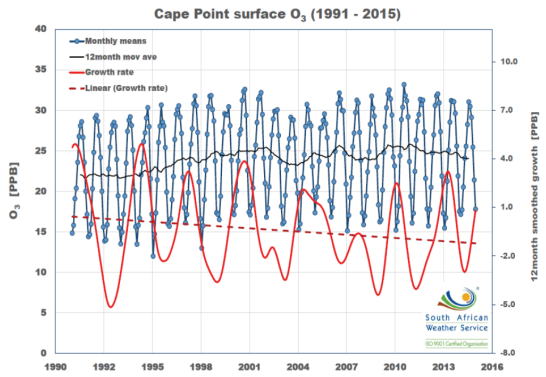

Figure 2

Cape Point surface ozone (O_3) background filtered monthly means.

Figure 2 shows CPT surface ozone (O_3) filtered monthly mean mole fractions from 1983–2015. The distinct seasonal cycle for CPT O_3 monthly mean mole fractions show winter maxima and summer minima. During winter months, the photochemical breakdown of O_3 is at its minimum due to a lower solar intensity, while in summer, the photochemical breakdown of O_3 is at its maximum because of higher solar intensity.[7]

The CPT data set confirms an increasing trend which was observed in the Southern Hemisphere surface O_3 measurements since 1992 by [8]. Figure 3 shows CPT carbon monoxide (CO) filtered monthly mean mole fractions from 1979–2015. The CPT CO seasonal cycle is characterised by summer minima and winter maxima. CO mixing ratios as observed for the southern oceans remained fairly constant during the period 1979–2000, however, showed inter-annual variations which are ascribed to changes in biomass burning and inter-hemispheric transport.[5] Since 2000 a declining trend was observed from both surface based (this work) as well as satellite measurements.[9], [10]

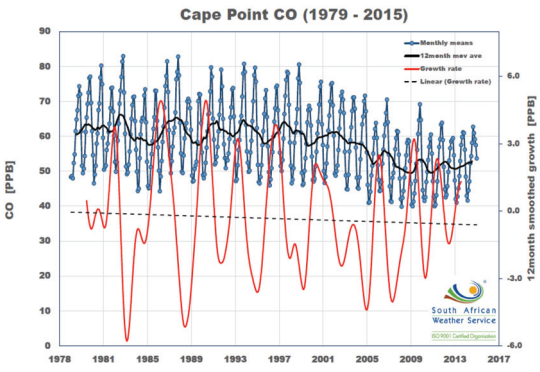

Figure 3

Cape Point carbon monoxide background filtered monthly means.

Cape Point short-term observations: Biomass burning event

A massive biomass burning episode occurred in the Western Cape close the Cape Point GAW Station from the 1st till 5th March 2015 in the Muizenberg Mountains, circa 40 km to the north of CPT.

Figure 4

Map showing the location of the fire (Muizenberg) to Cape Point GAW Station.

During this episode, NOAA HYSPLIT backward trajectories showed that air masses have originated from the greater Cape Town region (Figure 5). Such air masses reached the CPT GAW station two days later resulting in elevated levels of CO, CO_2, CH_4 and O_3. Mole fractions for these gases exceeded the background levels observed for March by 480 ppb (CO), 29 ppm (CO_2), 292 ppb (CH_4) and 53 ppb (O_3) yielding delta values of 474 ppb, 19 ppm, 260 ppb and 54 ppb for CO, CO_2, CH_4 and O_3 respectively.

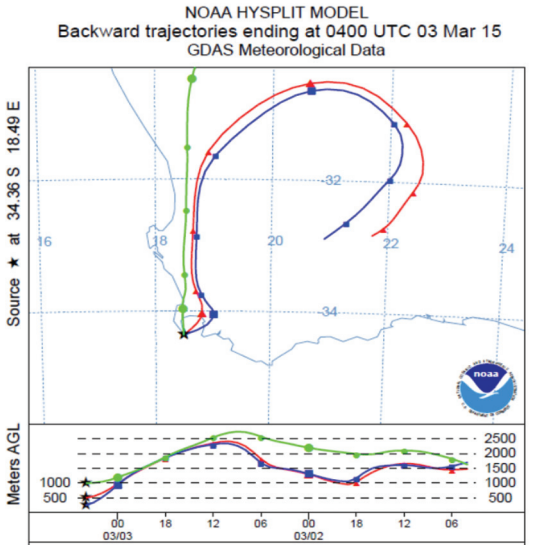

Figure 5

NOAA HYSPLIT backward trajectories observed on the 3rd of March 2015.

However, CFCs mole fractions remained at ambient levels, as would be expected. Table 1 summarizes the CO, CO_2, CH_4, O_3 and chlorofluorocarbons (CFCs) [Freon-11(F-11), Freon-12 (F-12), Freon-113 (F-113) and carbon tetrachloride (CCl4)] mole fractions during the biomass burning episode when the air masses reached the station.

The x-y plots in figure 6 illustrate trace gas variations measured at CPT GAW station during biomass burning episode. The calculated regression slopes are 0.043 and 0.0042 for $\triangle CO/\triangle CO_2$ and $\triangle CH_4/\triangle CO_2$ respectively. These values are in good agreement with those reported by Brunke et al., (2001) for Fynbos emission ratios. This gives validity to the reported statement that these emission ratios are typical of Fynbos biomass burning episodes in the region. Brunke et al.,

Table 1. Trace gas measurements during biomass burning observed on the 3rd to the 4th of March 2015

	O_3 [ppb]	CO [ppb]	CH_4 [ppb]	CO_2 [ppm]	F-11 [ppt]	F-12 [ppt]	F-113 [ppt]	CCl_4 [ppt]
Event Minimum	13.4	65.1	1759.5	396.2	230.1	507.0	70.6	82.1
Event Maximum	73.5	515.8	2031.5	415.7	235.1	512.8	75.5	84.3
Background monthly Average	20.1	35.9	1740.0	397.1	232.8	509.7	73.3	83.0
Standard deviation	13.2	137.4	53.6	3.7	1.3	1.5	1.1	0.6
Deviation from calculated average	54.0	474.0	260.4	19.4	5.0	5.8	4.9	2.2

(2001) reported regression slopes of 0.042 and 0.040 for $\triangle CO/\triangle CO_2$ and $\triangle CH_4/\triangle CO_2$ studying the effect of a 1997 regional biomass burning event on the trace gas levels observed at CPT.

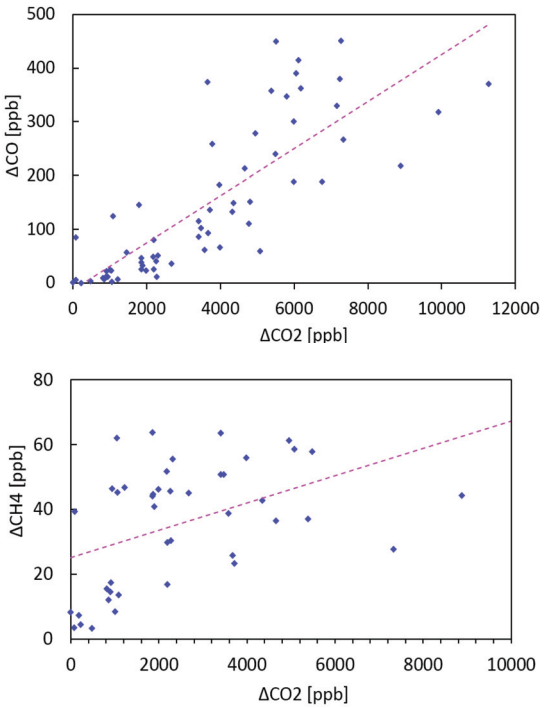

Figure 6

ΔCO versus ΔCO_2 and ΔCH_4 versus ΔCO_2 for 3-4 March 2015. Top plot: slope regression = 0.043, N = 64, r^2 = 0.66. Bottom plot: slope regression = 0.0042, N = 43, r^2 = 0.20.

The current results are in good agreement with those reported by [11] for Fynbos emission ratios. This gives validity to the reported statement that these emission ratios are typical of Fynbos biomass burning episodes in the region.

Conclusions

The CPT background trends are in good agreement with other background observations reported by the Southern Hemisphere mid-latitude stations. Consequently, the CPT data filtering techniques currently applied, are effective in separating 'all data' into background and non-background data. Furthermore, the station's non-background data is an indication of regional pollution as shown by the use of back trajectory analyses. Opportunistic studies on the effect of Cape Town regional biomass burning episodes on CPT trace gas measurements show that air masses from the regional biomass burning sources reaches CPT several hours later and can lead to observed elevated levels of trace

gases despite a dilution effect. The recently calculated regression slopes of 0.043 for $\triangle CO/\triangle CO_2$ and 0.0042 for $\triangle CH_4/\triangle CO_2$ are in good agreement with values reported in literature for a 1997 regional biomass burning study. This gives validity to the earlier reported statement that these emission ratios are typical of Fynbos biomass burning episodes from within the region. Following that these emission ratios fall within the reported range of SAFARI-92 trace gas emission ratios and is also much closer to Savannah-type biomass burning emission ratios.

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The Ozone Monitoring Activities and Its Trends Analysis in Malaysia during El Nino and La Nina Phenomena

Maznorizan Mohamad*, Mohd Firdaus Jahaya, Hanashriah Hassan and Zamuna Zainal

Introduction

The ozone monitoring activities in Malaysian has started since October 1992, after realizing the importance of developing countries in the tropics to play a more prominent role in the global initiative to achieve a better understanding of the inadvertent atmospheric changes and their effects on the ecosystem and life on earth, that links to the ozone depletion. Even though ozone is only a minor constituent, its role is important in the photochemical process in the atmosphere. At stratospheric level, its strong absorption of the solar radiation in the UV wavelength provides the shield that protects life on the earth surface from the harmful UV radiation.

Since El Niño and La Niña is one of the significant and complex weather phenomena that occur within 2 to 7 years cycle, and its effect is widespread over the globe, therefore it is important to look into the effect of either El Niño or La Niña has on the ozone data concentration over the region especially over Malaysia. Observation and analysis of ozone provide important information with regard to the trend of ozone composition in the atmosphere which is beneficial to the policy makers who are dealing with the environmental issues, planning and policy.

The Ozone Monitoring Activities

Malaysian Meteorological Department (MetMalaysia) has established the ozone monitoring activities in the western and central part

Atmospheric Science Division, Malaysian Meteorological Department

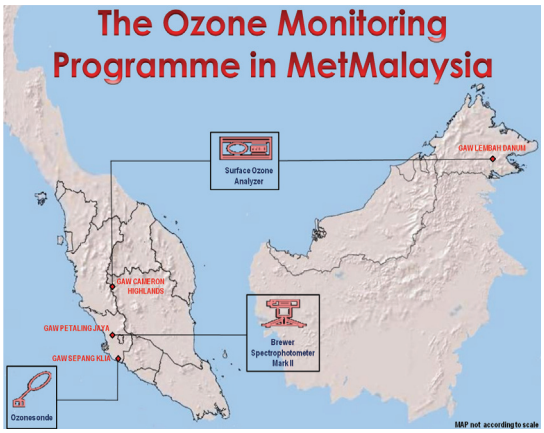

Figure 1

The ozone monitoring programme in MetMalaysia.

of Peninsular Malaysia as well as in the eastern part of Sabah. The locality of the monitoring sites represent the station in the equatorial tropical region (Figure 1), where in general, the climate is influenced by the drier period during the Southwest Monsoon (summer monsoon) and wetter period during Northeast Monsoon (winter monsoon). The study is conducted to investigate the O_3 distribution from 1995 - 2015 in several locations in Malaysia. The surface ozone is monitored using Surface Ozone Analyzer at Cameron Highlands GAW Regional Station since 1997 and Danum Valley GAW Global Station since 2007 but for this paper, only the surface ozone from Cameron Highlands station is discussed. The total amount of ozone in a vertical column from the surface to the edge of the atmosphere (total column) is observed using Brewer Ozone Spectrophotometer in Petaling Jaya GAW Regional Station since 1992. Finally, the vertical ozone profile is recorded by releasing the ECC type ozonesonde twice a month to probe the atmosphere in Petaling Jaya (1991 - 98) and Sepang Kuala Lumpur International Airport (KLIA) Station (since 1998). For this paper, only the vertical ozone profile from Sepang KLIA station is discussed.

Analysis, Result and Discussion

Surface Ozone

The time series analysis of surface O_3 data in Peninsular Malaysia (Cameron Highlands) was analyzed with reference to the O_3 data recorded in Mauna Loa, Hawaii. It is observed in Figure 2, that the monthly average concentration of surface O_3 in Cameron Highlands (1995-2015) is generally lower than the monthly average concentration of surface O_3 in Mauna Loa. For Cameron Highlands, the concentration fluctuated between 1 - 40 ppb, while for Mauna Loa, the concentration recorded are higher with values fluctuated between 20 - 60 ppb. Surface ozone data was also analyzed to study the fluctuation pattern during El Niño / La Niña phenomena (refer to Ocean Nino Index (ONI)), and whether the O_3 concentration will be influenced by this phenomena. The monthly average of surface ozone at Cameron Highlands also shows a higher concentration especially during the strong El Niño in 1997/98 and 2015/16. The two highest monthly average of surface ozone at Cameron Highlands were

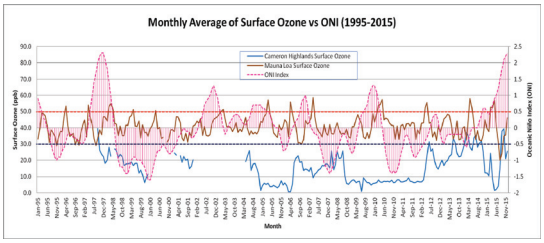

Figure 2

The monthly average of surface ozone and ocean Nino Index (ONI) at Carmeron Highlands and Mauna Loa (1995-2015).

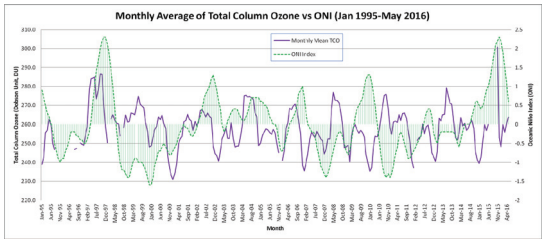

Figure 3

The monthly average of total column ozone and ONI at Petaling Jaya (1995-2016).

39.69 ppb and 39.45 ppb and were observed in September 1997 and October 2015 respectively and this coincides with the period of strong El Niño event experienced in the tropical region. Whereas during extensive La Niña phase (from June 1998 to April 2001), it can be identified that the trend of Surface ozone is proportionally correlated with the ONI values. On the other hand, during short period of La Niña event and neutral phase, no significant correlation can be detected. From the analysis, it can also be concluded that for the past 20 years (1995 – 2015), both stations in Cameron Highlands and Mauna Loa were not showing any significant changes of the surface ozone trend.

Total Column Ozone (TCO)

The total column ozone (TCO) is described as a total amount of ozone in a vertical column from the surface to the edge of the atmosphere (NOAA, 2005). The annual average of total column ozone for more than 20 years (1995-May 2016) was collected at the Petaling Jaya station using the Brewer Ozone Spectrophotometer. From Figure 3, the analysis shows that generally, the total column ozone was fluctuated in irregular cycle from Jan 1995 to May 2016 especially during weak El Niño/La Niña and Neutral phase, except during strong El Niño (1997 & 2015) where the changing patterns corresponded to the strength of the El Niño. The analysis also shows that for the long term record of nearly 20 years, the overall trend line was showing a slight decrease for the TCO over the area.

One of the strongest El Niño phase of the century was recorded in 1997/1998, which is comparable to the 2015/2016 and 1982/83 episode.[1] The observed monthly average of total column ozone in Petaling Jaya indicates the two highest readings were recorded in September 1997 (286.5 DU) and November 2015 (300.7 DU). During strong El Niño and extensive La Niña event, the reading recorded clearly identified which well suggested that there was a good correlation of the TCO and ONI, in which TCO increases as ONI increases and vice versa. In addition, a study has claimed that the highest amount of tropospheric column ozone (up to 25 DU increase)

has been registered in the tropic during the 1997/98 El Niño event.[2] [3] also reported the significant increases of total column ozone during the El Niño event in 1997.

Figure 4 shows that during the Northeast Monsoon, the highest TCO recorded is 265 DU while the lowest is 231 DU, whereas, during the Southwest Monsoon (Figure 5), the highest TCO recorded is 285 DU and the lowest value recorded is 247 DU. It is clearly indicated that the TCO increases during dry period (SW monsoon) and decreases during the wet period (NE monsoon). As observed during inter monsoon l, the value of TCO ranged from 250-285 DU (Figure 6), and during inter monsoon II, it ranged from 244-286 DU (Figure 7). It can be concluded that for both inter monsoon, the value of TCO is quite consistent and almost within the same range.

During the dry period, where the region experiences many days with cloudless sky and receive very intense solar radiation, it will subsequently influence the production of surface ozone by the photochemical reaction between radiation and the emission of oxide of nitrogen (NOx) and VOCs produced by the motor vehicles, industries, electricity utilities, etc. On the other hand, during rainy season when the atmosphere experiences many cloudy days, less radiation will be able to penetrate the atmosphere and less photochemical reaction will take place, resulting in less amount of ozone being produced.

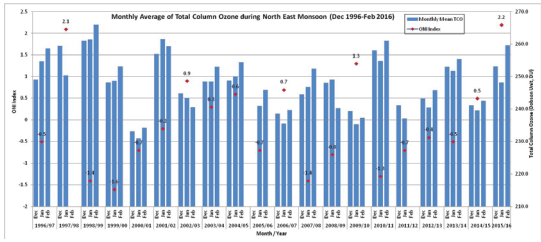

Figure 4

The Monthly Average of Total Column Ozone and ONI at Petaling Jaya during Northeast Monsoon (1996 – 2016).

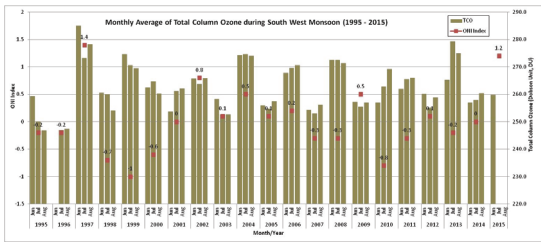

Figure 5

The Monthly Average of Total Column Ozone and ONI at Petaling Jaya during Southwest Monsoon (1995 – 2016).

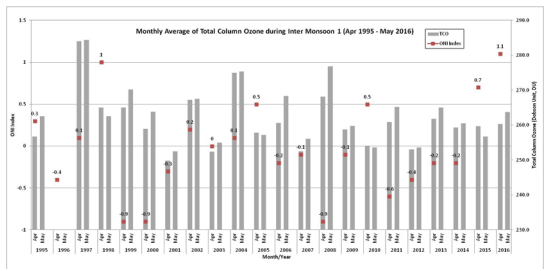

Figure 6

The Monthly Average of Total Column Ozone and ONI at Petaling Jaya during Inter Monsoon I (April-May) (1995 – 2016).

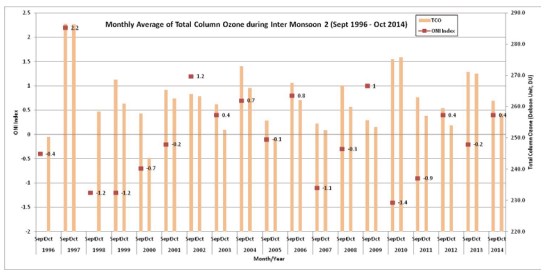

Figure 7

The Monthly Average of Total Column Ozone and ONI at Petaling Jaya during Inter Monsoon II (Sept-Oct) (1996–2016).

Vertical Ozone Profile

The vertical ozone profile monitoring activities are conducted at the Sepang KLIA station. This station is also one of the contributing station for the South Hemispheric Additional Ozonesondes (SHADOZ) network (Figure 8). The analysis is done using 18 years of observation data from 1998 to 2015. Operationally, the ozonesondes are launched twice a month, during the early and middle of the month. In total, there were 396 profiles collected, with the average of 22 launches per year. Only ozone profiles collected during significant El Niño and La Niña years from 1998 to 2016 are selected for analysis.

Figure 8

The SHADOZ Network.

The vertical ozone profiles are showing the mean ozone concentration at all altitudes for all the launches during the respective events. It is observed that the general pattern of ozone profiles did not vary significantly during the selected El Niño and La Niña event, as well as during neutral years (Figure 9). The profiles follow and agreeable with the pattern of the standard global ozone vertical profiles which clearly determined the maximum ozone concentration are within the stratospheric levels.

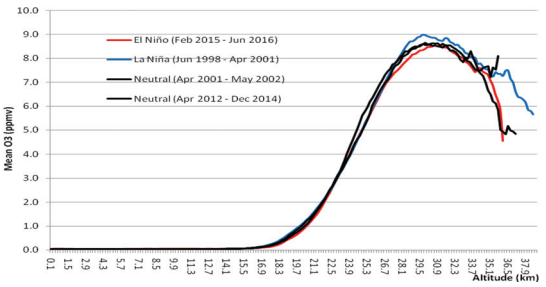

Figure 9

Vertical ozone profiles during the strong El Niño (Feb.2015 – June 2016), moderate La Niña (June 1998 – April 2001) two neutral periods (April 2001 – May 2002) & (April 2012 – Dec 2014).

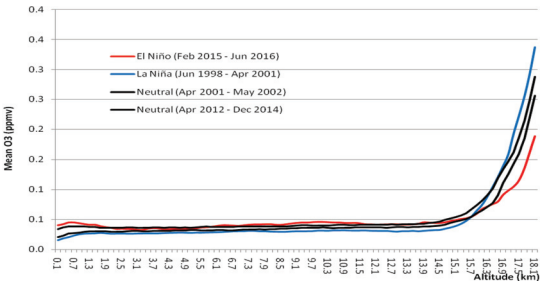

Figure 10

Vertical ozone profiles during the strong El Niño (Feb.2015 – June 2016), moderate La Niña (June 1998 – April 2001) two neutral periods (April 2001 – May 2002) & (April 2012 – Dec 2014), extracted from the surface up until 18 km.

Figure 10 is showing the profiles with more focus on the tropospheric level until 18 km in altitude. From both figures, it is observed that the ozone concentration fluctuate slightly at the stratospheric level as compared to the tropospheric level, but the general pattern of the vertical profiles still persist. The stratospheric ozone concentration during moderate La Niña event reached the maximum mean

value of 9.0 ppm at the height of 29 – 30 km. While, the stratospheric ozone concentration during strong El Niño event reached the maximum mean value of 8.5 ppm at the height of 30 – 31 km. During the two neutral periods, the mean maximum values were around 8.6 ppm at altitudes between 29.9 – 30.9 km. It is also observed that the tropospheric ozone concentration during strong El Niño event is slightly higher than in moderate La Niña event at the tropospheric layer (up until 15 – 16 km) and the situation is reversed once entering the stratospheric layer. In general, it can be summarized that over Peninsular Malaysia, the maximum stratospheric ozone is ranged between 8.5 – 9.0 ppm at the stratospheric layer of between 29 km – 31 km and the ozone concentration at this stratospheric layer is not so much influenced by the El Niño or La Niña phenomena.

Conclusion

It is observed that the monthly average concentration of surface O_3 in Cameron Highlands (1995-2015) is generally less than the monthly average concentration of surface O_3 in Mauna Loa, Hawaii (global reference). Surface O_3 concentration is also observed to be influenced by the strong El Niño phenomena where the highest surface concentration were recorded during these events, while during weak El Niño, La Niña and neutral phase, the values fluctuate within the monthly average range. The observed monthly average of total column ozone in Petaling Jaya recorded highest reading in September 1997 (286.5 DU) and November 2015 (300.7 DU) which were during strong El Niño events. The significant increasing trend of TCO were clearly suggested that there is a good correlation of the TCO and ONI, in which TCO increases as ONI increases and vice versa. This study also concludes that during dry period which is during southwest monsoon, the TCO increased, while during the wet period (northeast monsoon), the value of TCO decreased significantly. On the other hand, during inter monsoon I and II, the value of TCO is quite consistent and almost within the same range. Finally, from the analysis, it is observed that the maximum stratospheric ozone is within the range of 8.5 to 9 ppm and is found at the stratospheric layer ranged from 29 to 31 km above ground.

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Greenhouse gases seasonal variability over India

Yogesh K. Tiwari*, Vinu Valsala, K. Ravi Kumar and Tania Guha

Monitoring and analyzing the greenhouse gases concentrations (mainly CO_2 and CH_4) collected by the ground based observation network is ultimately important in regions like India because the satellite measurements are not capable of seeing the column concentrations through the clouds during the monsoon season. Because of this, during the Indian summer monsoon period (June to September, JJAS hereinafter), the Indian subcontinent has huge data gaps in the observed CO_2 from satellite.[1] The same is the case for chlorophyll measurements as well.[2] The ground based observations of CO_2 CH_4 are also lacking at present except at a few key stations in operation for multiple years, for example, [3] and [4] reported the continuous monitoring of atmospheric CO_2 & CH_4 from a station close to the western peninsular India and is providing atmospheric CO_2 & CH_4 in the boundary layer at weekly resolutions for past four years. In this study we use surface observations and model simulations[5], [6] to understand CO_2 & CH_4 seasonal variability over India.

Surface observations of atmospheric CO_2 & CH_4 over a station close to the western peninsular India (Sinhagad, SNG hereafter) has been operational since Oct 2010.[3] Weekly samples in the afternoon are collected systematically, analyzed and calibrated against the World Meteorological Organization (WMO) standards and archived for the past 3 annual cycles from 2011 to 2013.[3] Routine air samples at SNG are collected from a 10 m meteorological tower. However after quality control, we have chosen data from 2011 to 2013 for this study. The air sampling methodology at SNG is described in detail by [3]. We also utilized the ground based observations from Cape Rama (CRI) located at 400 km southwest to SNG which was in operation since 1999 but discontinued after 2012. After 2012, SNG is the sole ongoing systematic ground-

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based CO_2 measurement from western peninsula of India. Another observation used in this study is from Seychelles (SEY) located in the Indian ocean. SEY site was operated and run by the NOAA/ESRL Boulder USA.

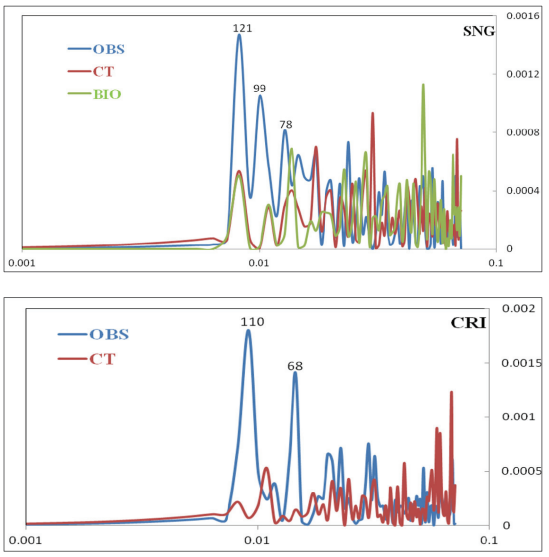

Figure 1

Power spectrum of de-trended and de-seasonalized observed (OBS) surface atmospheric CO_2 concentrations at Sinhagad (SNG) and Cape Rama (CRI) are shown together with correspondingly calculated power spectrum from the CarbonTracker (CT). Biospheric (BIO) NEE from CarbonTracker are shown over the SNG grid. SNG observations span from the period 2011 to 2013. CT data are from 2000 to 2011. The power spectrum of biospheric fluxes (NEE) is for SNG. The x-axis is in logarithmic units of power and y-axis is the variance preserving spectra. The periods (in days) of selected spectral peaks are marked.

The power spectrum of the de-trended and de-seasonalized atmospheric CO_2 at SNG shows distinct peaks of variability notably at 121 days, 99 days and 78 days (Figure 1). The quality control of data from this station has been reported elsewhere.[3] The corresponding spectrum of surface CO_2 concentrations from the CarbonTracker (CT) shows a peak at 121 and 99 days consistent with the SNG data. However, the CT data has another peak at ~75 days which is slightly different from that seen in SNG. The comparison of power spectrum of the biospheric NEE from CarbonTracker over the SNG grid location shows similar peaks indicating that the NEE in the CT causes corresponding scale variability in the atmospheric concentrations of CO_2, with the caveat that the period under consideration is relatively short. Nonetheless, this consistent overlapping of reanalysis and SNG observed CO_2 variability adds to the confidence in our conclusions. A similar analysis from Cape Rama station (CR) shows that the distinct peaks of atmospheric CO_2 are at 110 days and 68 days (Figure 1b). Such subtle changes in the spectral peaks between SNG and CRI can be expected considering the differences in vegetation types and rainfall variability surrounding these two stations[3], [7] although the limited length of the time-series should be again kept in mind.

In order to back the hypothesis that during the active phase, the relatively cold air-temperature and reduced Photosynthetically active radiation lead to a reduction in the Net Primary Productivity and thereby a positive anomaly of terrestrial biospheric CO_2 fluxes, we have performed an active and break composite analysis on CT atmospheric

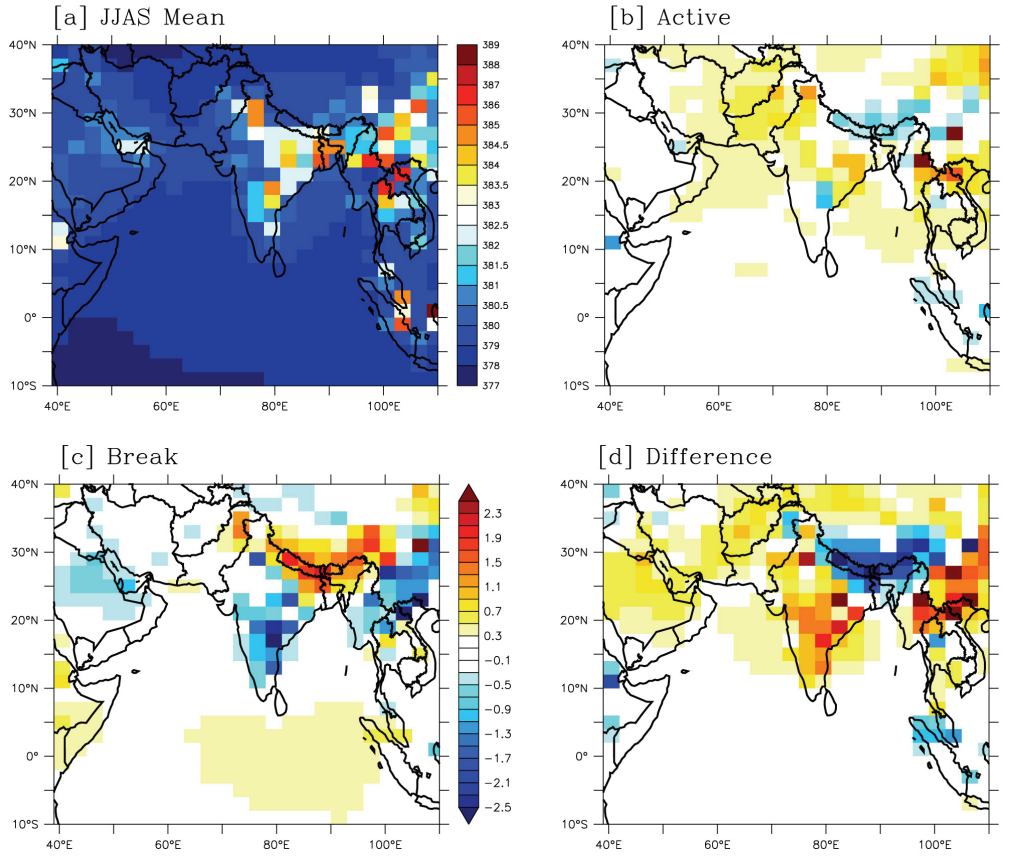

Figure 2

[a] June to September (JJAS) mean surface CO_2 concentrations from CT (average of 2000 to 2011). [b] Composite of surface CO_2 concentration anomalies during JJAS active days. [c] Same as b, but for break days. [d] Difference between b and c. Anomalies are calculated by de-trend and then de-seasonalized by removing first two harmonics of individual years. Units are in ppm.

CO_2 concen- trations. The CT atmospheric CO_2 concentrations from 2001-2010 are band-pass filtered (after removing the first two harmonics from data of individual years) in order to include only the 20-90 days of variability. The group of active and break days from June to September during individual years are obtained from the work of [8]. The filtered CO_2 concentration anomalies are averaged separately for active and break days.

The JJAS mean of surface level CO_2 concentrations over the Indian region is between 377 and 399 ppm according to the CT data (Figure 2). The composite mean of CO_2 concentration anomalies in the CT data during 'active' days are generally positive over the domain of our analysis (Figure 2b) except for a small number of grid cells with negative values. The range of anomalies is between ±2.5 ppm. The anomalies are strongly negative during the break period (Figure 2c) with

some notable exceptions over the northeastern part of India. The positive (negative) atmospheric CO_2 anomalies visible in the CT data, however, are not much of a surprise because the corresponding NEE biospheric fluxes also display positive (negative) anomalies during active (break) phase of monsoon, respectively.[8] Figure 2d shows the difference between active and break composites of CO_2 concentration anomalies illustrating the positive atmospheric CO_2 anomalies during active phase with a peak to peak amplitude from active to break of about 3 ppm.

On the other hand, atmospheric CH_4 at SNG and CRI has a moderate seasonality of ~200 ppb (Figure 3a, b). CH_4 concentration reaches its minima during the summer monsoon (i.e. during JJAS); whereas it reaches its maxima during the winter monsoon (i.e. during DJF). During JJAS the CH_4 concentrations at SNG was minimum about 1821± 21 ppb and 1818±21 ppb for years 2012 and 2013, respectively; whereas at CRI the minimum is about 1781±18 ppb, 1792±11 ppb and 1795±22 ppb years 2010, 2011 and 2012, respectively. On the other hand during DJF at SNG a maximum is observed about 1882±54 ppb and 2015±32 ppb for years 2012 and 2013, respectively; whereas at CRI the maximum is about 1910±30 ppb, 1922± 28 ppb and 1927±20 ppb for years 2010, 2011 and 2012, respectively. Here the uncertainty depicts the standard deviation of daily CH_4 with respect to the monthly seasonal average. In comparison to SNG the CRI is located at the coast and the site is comparably free from vegetation and local anthropogenic influences. Thus CRI captures lower magnitude of CH_4 concentration in comparison with SNG.[3]

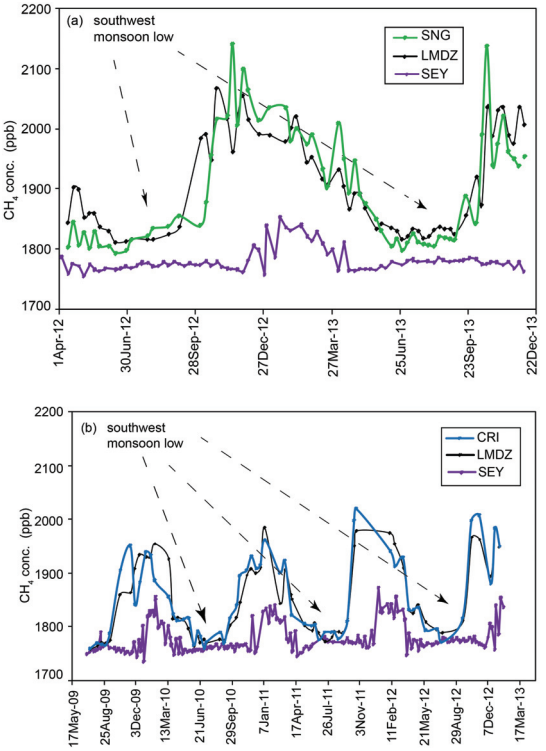

Figure 3

Measured and LMDz model simulated CH_4 concentration at a) SNG (Sinhagad) and SEY (Seychelles), and b) CRI (Cape Rama) and SEY (Seychelles).

Apart from surface GHGs observations in India we are monitoring using aircraft campaigns as well. More surface sites are planned for future. All these observations will be very helpful in understanding carbon variability over India as well as sources sink estimations over the region.

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The GAW Training and Education Centre (GAWTEC) and German GAW activities and monitoring

Mirella Glor

The Global Atmosphere Watch (GAW) program is a worldwide network of measurement stations and related facilities coordinated by the World Meteorological Organization (WMO). The purpose of GAW is to measure the background level of atmospheric pollutants and other trace substances to determine their trends and to analyze the relationship between environment and climate. The goal of GAW is to supply the scientific community with the means to predict future atmospheric states as well as to provide reliable scientific data and information for national and international policy makers.

The GAW community has set up high data quality objectives (DQOs) that should be met by all participating stations. Training and Education for GAW station personnel are therefore an integral part of the GAW program and critical to the long-term success of the GAW program. As a part of the WMO's capacity building strategy, the German Quality Assurance/ Science Activity Centre (QA/SAC Germany) has established in 2001 the GAW Training and Education Centre. Courses are offered twice a year and cover measurement technique, lab courses, theoretical background of atmospheric physics and chemistry and data handling and interpretation. Each course deals with two or three major topics, covering all relevant parameters in the GAW measurement program: Physical Properties of Aerosols and Aerosol Optical Depth, UV radiation, Reactive Gases, Precipitation chemistry, Greenhouse Gases and Data evaluation and Quality Control.

The objectives of GAWTEC are the improvement of personal skills in chemical, physical and meteorological measurement techniques and data handling. Additionally to provide a platform for GAW station personnel for the exchange of measurement related

Environmental Research Station Schneefernerhaus, Zugspitze, Germany

experiences and the discussion of problems. On top of that broadening the understanding of atmospheric processes to increase the ability for data interpretation. Another objective is to enhance the ability to identify measurement errors to increase data quality within the GAW station network.

GAWTEC courses are held exclusively in English. Trainees must therefore have good English language skills to follow lectures, instrument instructions and discussions. GAWTEC offers its courses only to technicians and junior scientists who work at stations with instruments and data and is not meant for senior scientists. Applications should be made via the GAWTEC webpage at www.gawtec.de Upcoming courses will also be announced on this webpage.

There are no costs for trainees, air fares are paid by the WMO, all other expenses are covered by the German Environment Agency and the Bavarian State Ministry of the Environment and Consumer Protection. Lecturers are funded by their scientific organizations.

Lessons are given by experts of the German Weather Service, the German Environment Agency, the GAW World Calibration Centres (WCC) for NO_2, VOC and Physical Aerosols and the Swiss EMPA. For special topics, lecturers from national and international Universities and other institutes are invited.

Since the first training course in summer 2001, 31 GAWTEC courses took place with 352 participants from 64 different countries. 49% of them came from institutes in (predominantly eastern) Europe, 18% from Asia and Africa, 13% from the Southwest Pacific region, 8% from South America and only a few from North- and Central America and the Caribbean. Approximately 30% worked at Global Stations, Regional Stations or central facilities (associated with several stations), 14% were from other institutes.

Currently (2016) the GAW network consists of 31 Global Stations, more than 400 Regional Stations and 100 Contributing stations. Germany operates two Global Stations (Zugspitze/Hohenpeißenberg and the Antarctic Station Neumayer) and three Regional stations (Neuglobsow, Schauinsland and Gartow). The German contribution is covering GAWTEC and four World Calibration Centres (WCCs): Aerosol Physics, Volatile Organic Compounds (VOCs), Nitrous oxide (N_2O) and Ozone Sondes (OS). Furthermore the In-service Aircraft for a Global Observing System (IAGOS), the Regional Dobson Calibration Centre Europe (RDCC-E), the Central Calibration Laboratory for molecular hydrogen in air (CCL H_2) and the Center for Remote Satellite Data (WDC- RSAT) contribute to the GAW activities.

The monitoring program at the platform Zugspitze started in 1999. The Environmental Agency built up the platform Zugspitze at the site Schneefernerhaus situated at 2650 m asl at the northern rim of the alps, on the south-

ern slope of Zugspitze summit. They are looking for climate atmospheric gases, reactive gases, aerosols and meteorology. The Hohenpeißenberg station is situated in an observatory in the pre-alpine area about 40 km north of Zugspitze, on a mountain top at 985 m asl. The observatory was founded in 1781 and is the oldest in the network. Since that year, meteorological data have been continuously recorded. The station is operated by the German Weather Service and is part of the GAW network since 1995. The measurement program also consists of reactive gases, aerosols, precipitation chemistry, solar radiation and meteorology. The Neumayer station in the Antarctic is operated by the Alfred Wegener Institute (AWI) in Bremerhaven. In 1981 AWI started to run permanently manned Neumayer station next to the Atka Iceport on the Ekström Ice Shelf. The measuring program contains the same parameters like Zugspitze/ Hohenpeißenberg except reactive gases and precipitation chemistry.

In Germany are three Regional stations. The oldest one, Schauinsland, is operated by the UBA since 1988. The measuring program consists if reactive gases, greenhouse gases, aerosols and radiation. The Neuglobsow station is also operated by the UBA and exists since 1991. The measurement program is the same with additionally precipitation chemistry and meteorology. The third and newest station is Gartow (since September 2016). It is operated by the DWD and they measure greenhouse gases, meteorology and the radiation.

Greenhouse Gases Measurement at Pha Din station, Viet Nam

Tong Thi Van Anh

History of Pha Din Station

Greenhouse gases (GHG) and aerosols in the atmosphere are very closely linked to global warming and climate change, where it is carefully monitored to ensure that GHG emissions are always low. In view of the global GHG concentrations they showed an increase in pattern, and one of them is because of human activities. However, in large regions of Africa, South-East Asia and South America, observations of atmospheric variables are not available.The project Capacity Building and Twinning for Climate Observing Systems (CATCOS) establishes measurement of these essential climate variables at selected stations in four countries. These are Chile, Indonesia, Kenya and Vietnam. In close collaboration, Swiss and international partner instituations make the measured data traceable, quality-controlled and available at the International Data Centers for aerosols or GHGs, respectively.

The CATCOS project will be divided into two phases. The phase 1 is implemented between 12 September 2011 and 31 December 2013. The phase 2 is implemented between 01 April 2014 to 30 September 2016. The project is supported by the Swiss Agency for Development and Cooperation (SDC) with the Federal Office of Meteorology and Climatory MeteoSwiss as the coordinating partner on the part of Switzerland.

Within the CATCOS Project, the National Hydro-Meteorological Service of Vietnam (NHMS) together with the Paul Scherrer Institute (PSI) and the Swiss Federal Laboratories for Materials Science and Technology (Empa) established aerosol and greenhouse gas observations at Pha Din station. Subsequent to the successful implementation of the measuring equipment, joint efforts concentrate on training and twinning activities.

Hydro-Meteorological and Environmental Station Networks Center (HYMENET), National Hydro-Meteorological Service of Viet Nam (NHMS)

Figure 1

The stations of CATCOS project.

A first meeting of CATCOS project took place at NHMS on 13 June, 2012. The meeting was chaired by Deputy Director General of NHMS Mr. Nguyen Van Tue, who also introduced NHMS. Dr. Jörg Klausen then introduced MeteoSwiss, the Global Atmosphere Watch. On 27 may 2013, Memorandum of Understanding (MOU) between Federal Office of Meteorology and Climatology MeteoSwiss and National Hydro-Meteorological Service of Viet Nam (NHMS) with reference to the project CATCOS has been signed. On 09 September 2013, the project is approved in the Decision No. 1692/QĐ-BTNMT by the Minister of Ministry of Natural Resources and Environment (MONRE, Viet Nam). The instrument is packed and shipped to Viet Nam in 4 December 2013. According to the announce ment of Swiss Embassy, the instrument expected to Viet Nam in 22 December 2013. Installation works scheduled for February 2014. The Vietnamese side will transport equipment to Pha Din and collaboration with Swiss specialist to install the equipment.

The Pha Din Global Atmospheric monitoring station went into operation in March 2014.

Pha Din station has been recently officially nominated for a Global Atmospheric Watch (GAW) regional station by the World Meteorological Organization (WMO) since July, 2014.

The Pha Din GAW station was inaugurated in 01 July 2016.

Informations of Pha Din station

Pha Din station is a rural site in a hilly, forested area in Northern Vietnam (Figure 2). It is located at 21.57°N, 103.52°E, 1466 m.a.s.l. Pha Din has been a Level 3 NHMS meteorological station. The station has been moved from a nearby site to this site in April 2012, because a radar tower is planned to be operational at the same site. Within the CATCOS project in 2014 can be enable the continuous in-situ ground-based observation of carbon dioxide, methane, carbon monoxide and ozone next to the new monitoring of optical properties of aerosols.

Figure 2

Overview of Pha Din station.

Pha Din station (see Figure 3) is located in a region where GHG measurements are sparse. The station is located on the top of a hill. The sample inlet is at 12m above ground, which is above the canopy - this is important for the CO_2 measurements, which would otherwise be influenced by uptake and respiration by the nearby vegetation.

Figure 3

Pha Din Station.

Pha Din station is the first of its kind in Viet Nam, recording greenhouse gases, surface ozone and aerosol properties in a rural setting.

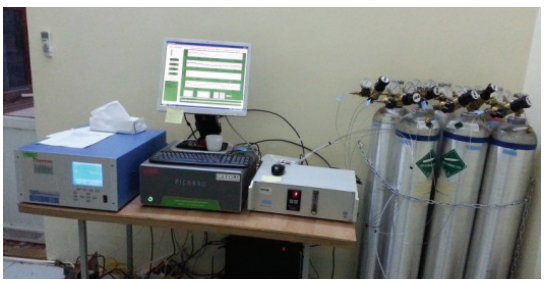

Figure 4

The GHG equipment at Pha Din station.

The GHG equipment at Pha Din station is (Figure 4):

- Cavity ring-down spectrometer Picarro 2401 for measuring carbon dioxide (CO_2), methane (CH_4), carbon monoxide (CO) and water vapor (H_2O);
- Calibration unit for spectrometer;
- UV absorption analyzer Thermo Model 49i for measuring ozone (O_3) and O_3 zero air unit;
- Computer with data acquisition software;
- Six cylinders with calibration gases from NOAA, Boulder (USA);
- Two pumps;

Observations at Pha Din station in 2015

1. CH_4

The data of CH_4 observations at Pha Din station changes hourly, daily and monthly in 2015 is illustrated in Figure 5, 6 and 7.

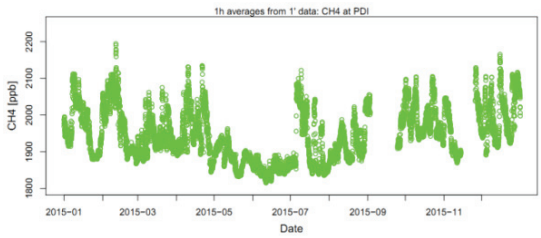

Figure 5

CH_4 concentration changes hourly in 2015.

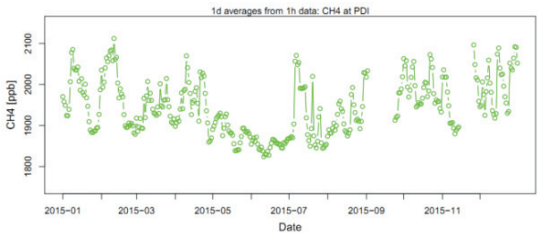

Figure 6

CH_4 concentration changes daily in 2015.

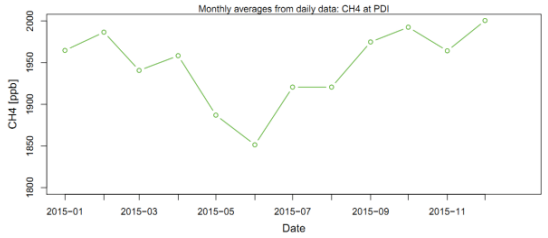

Figure 7

CH4 concentration changes monthly in 2015.

Figure 5, 6 and 7 showed the pattern of CH_4 concentrations at Pha Din station in 2015. The monthly concentration is range between around 1900 - 2000 ppb. However, by mid-year, the monthly concentration of CH_4 has tended to go down to about 1850 ppb.

2. CO

The data of CO observations at Pha Din station changes hourly, daily and monthly in 2015 is illustrated in Figure 8, 9 and 10.

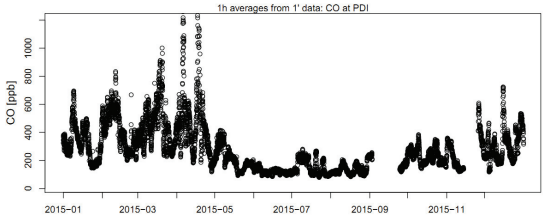

Figure 8

CO concentration changes hourly in 2015.

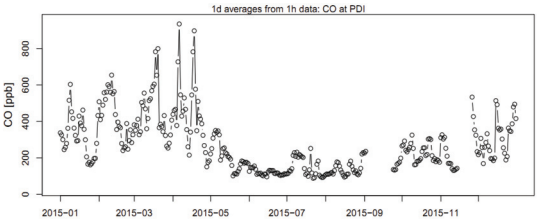

Figure 9

CO concentration changes daily in 2015.

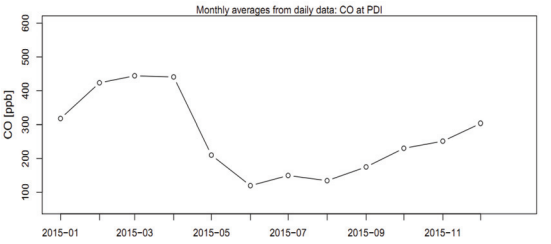

Figure 10

CO concentration changes monthly in 2015.

Earlier of year, the monthly concentration of CO is high, around 300-450 ppb. By mid-year, the monthly concentration decreased to 100 ppb, and return to increase slightly the following months (Figure 8, 9 and 10).

3. CO_2

The data of CO_2 observations at Pha Din station changes hourly, daily and monthly in 2015 is illustrated in figure 11, 12 and 13.

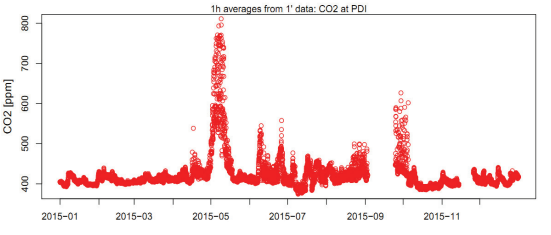

Figure 11

CO_2 concentration changes hourly in 2015.

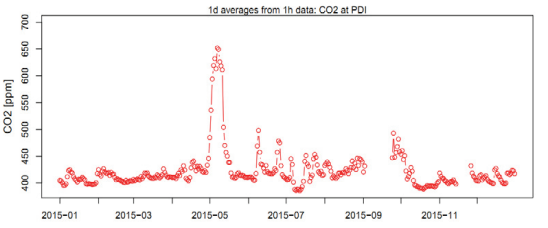

Figure 12

CO_2 concentration changes daily in 2015.

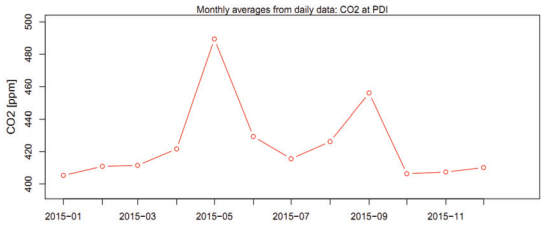

Figure 13

CO_2 concentration changes monthly in 2015.

Figure 11, 12, and 13 showed the pattern of CO_2 concentrations at Pha Din station in 2015. The monthly concentration is range between 400 - 430 ppm, without much change in concentration between the months of the year. However, in May and September, CO_2 levels spike, the average monthly concentration of CO_2 in May and September increases to around 490 and 450 ppm.

4. O_3

The data of O_3 observations at Pha Din station changes hourly, daily and monthly in 2015 is illustrated in figure 14, 15 and 16.

Earlier of year, the monthly average O_3 concentrations fluctuated in the range of 40 - 50 ppb and descending into the middle of the year to the end of the year, the average levels of the last months about 20 - 30 ppb.

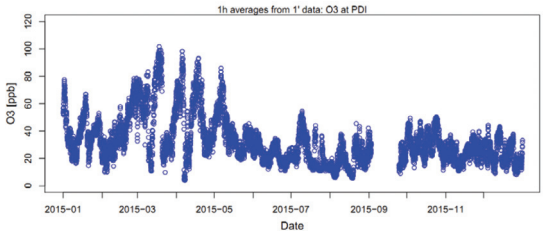

Figure 14

O_3 concentration changes hourly in 2015.

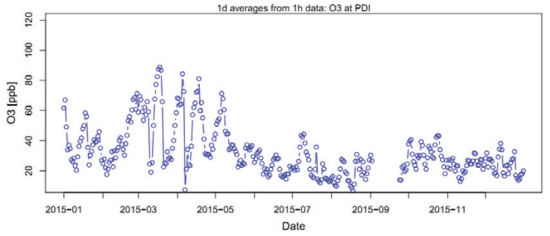

Figure 15

O_3 concentration changes daily in 2015.

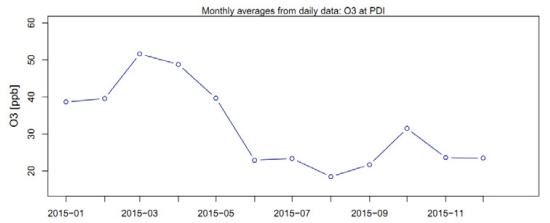

Figure 16

O_3 concentration changes monthly in 2015.

Conclusion

Continuous monitoring and measurement of GHG is important to observe the fluctuation and the general pattern of GHG emissions as well as providing information for the early warning. It also important to provide the information on the changes in atmospheric composition in the forest that may affect the flora and fauna. Besides, the information will provide a better understanding in regard to the patterns of absorption and emission of GHG in tropical forests.

Reference

[1] The Project CATCOS (Capacity Building and Twinning for Climate Observing System);

[2] Memorandum of Understanding (MOU) between Federal Office of Meteorology and climatology (MeteoSwiss) and National Hydro-Meteorological Service of Viet Nam (NHMS) with reference to the project CATCOS signed in May 27, 2013;

[3] MOU between MeteoSwiss and NHMS with reference to the project CATCOS, phase 2 signed in March 16, 2015;

[4] Duong Hoang Long, NHMS (2013). Establishment of Continuous Greenhouse Gas Observation Capacity in Northern Viet Nam through a Swiss-Vietnamese Collaboration. Asia-Pacific GAW Greenhouse Gases Newsletter Volume 4 December, 2013

[5] Trinh Lan Phuong, NHMS (2014). Greenhouse gases measurements in Viet Nam. Asia-Pacific GAW Greenhouse Gases Newsletter Volume 5 December, 2014

Observations and modelling combine to inform network developments

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The New Zealand greenhouse gas in situ observation network consists three stations Baring Head (BHD),[1] Lauder (LAU) and Rainbow Mountain (RBM).

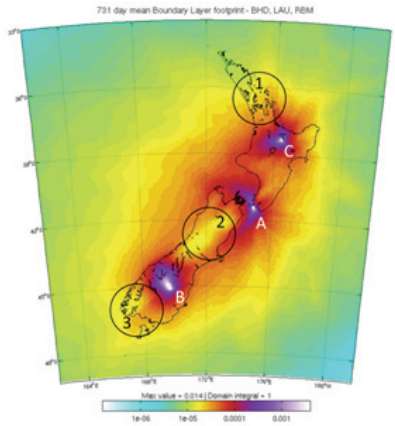

Figure 1

The network stations are indicated by A = Baring Head, B = Lauder, C = Rainbow Mountain. The circles indicated with numbers represent the areas not captured by the current network.

These stations provide continuous CO_2 data that are used to determine trends and growth rates. Recently we have developed an inverse modelling capability and consequently reassessed the goals for our regional network. Our goals are to establish a CO_2 and CH_4 emissions and uptake verification system, underpinned by the high precision greenhouse gas data from a network of atmospheric observing stations and utilising an atmospheric transport model.

Inverse Model

Data from our CO_2 observation sites are used alongside winds output from the New Zealand Limited Area Model[2] at ~ 12 km resolution (NZLAM-12) with 70 vertical levels in an inverse Lagrangian model NAME[3] from the UK Met Office. Daily at each

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observation station during a 1 hour period of stability 10,000 particles are released in the model and allowed to run backwards in time for 4 days. These model data are plotted in fig 1. The purple colours indicate a higher number of particles have passed through an area while the light blues indicate a much lower number of back trajectories passing through that area. The inverse modelling approach allows for the contribution of source regions to be determined for the observation of CO_2 made at a station.

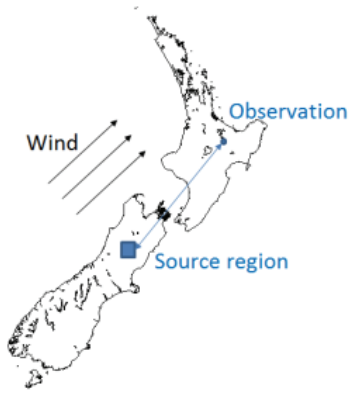

Figure 2

By making observation at a monitoring site the model allows us to determine the influence of a source region on the observation.

Current Network

When we assess the current network with the NAME model runs we find that we capture a significant portion of the country. There are areas that the footprints from the three stations overlap giving more confidence in the contributions for the regional inversion. There are though three areas that are not currently visible to the network (Figure 1). To enhance our modelling capability we intend to add observing stations within these three zones, these are 1 = Upper North Island, 2 = Canterbury and 3 = Southland

New Station assessments

In the process of assessing the ideal location for siting future observation stations, within the three areas lacking in coverage, we investigated the local topography to ensure air flows would not be modified dramatically making modelling difficult. Next the air arriving at the site should be representative of the wider region, so we would not want exposure to significant local sources. If we look at the Auckland region for a potential site we proposed four sites (A-D) in figure 3, that would meet these criteria, however when we look at the site winds and exposure we find that some (B and D) are not as exposed to flows from the southwest which are important to inform the model of incoming air. The proposed site at A appears to be sheltered by a mountain range to the southeast of it, this would limit our option to see the Auckland urban area. For this reason we propose to investigate more fully the site at C, Manukau Heads as a potential site. The wind speeds are high at this location, and the initial modelling would suggest that observations at this location would provide a data set of air com-

ing off the Tasman Sea and periods from the wider region including the Auckland metropolitan area, which has the largest population in the country at around 1.4 million people.

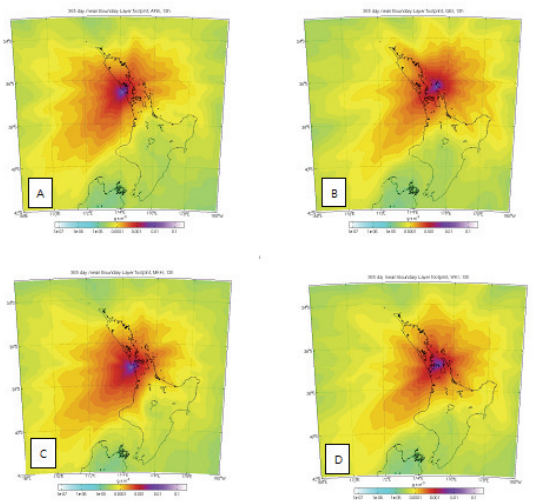

Figure 3

Composite of one year of NAME four day back trajectories for potential observation sites in Auckland region.

Conclusions

The use of an inverse model along with quality observation data can provide a top down version of the carbon inventory for New Zealand that compliments the bottom up approach currently in usage. While the established network of CO_2 observations provide significant coverage for the country there are assessments underway utilizing observations and modelling to enhance the coverage to be more representative of the whole country. The inclusion of a station in Auckland region, potentially at Manukau Heads would allow for the addition of both Southwest air flows off the Tasman Sea and the Auckland metropolitan area.

Acknowledgements

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[2] Davies, T., et al. (2005): A new dynamical core for the Met Office's global and regional modelling of the atmosphere, Quarterly Journal of the Royal Meteorological Society, 131, 1759-1782.

[3] Jones, A. et al (2007).: The UK Met Office's next-generation atmospheric dispersion model, NAME III, Air Pollution Modeling and its Application XVII, 580-589.

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