行政院所屬各機關因公出國人員出國報告書

（出國類別：國際會議）

赴美參加 2018 美國地球物理協會秋季年度會議

服務機關：行政院環境保護署

姓名職稱：陳彥君環境監測技術師、黃健瑋環境監測技術師

派赴國家：美國

出國時間：107 年 12 月 9 至 17 日

報告日期：108 年 2 月

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摘要

本次參加 2018 年美國地球物理協會第 51 屆秋季年度會議，除為瞭解國外衛星遙測對環境應用與細懸浮微粒監測新知外，亦積極投稿發表論文—「應用衛星火點觀測資料進行露天燃燒稽查 An Application of Satellite Data on Fires for Environmental Inspection of Open Burning」，以展現我國衛星資料應用成果。

透過本次會議可知衛星產品眾多，亦有許多可作為環境監測及預測相關使用，本署將持續參與國際上相關研討會或如美國太空總署(NASA)、美國海洋暨大氣總署(NOAA)所辦專題討論會(Workshop)，以瞭解不同衛星發展之產品，進而找尋更適合且方便用於環境治理之衛星產品。

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壹、 會議目的及背景

一、 美國地球物理協會簡介

美國地球物理協會(American Geophysical Union (AGU))是一個國際非營利性的科學協會，由國家研究委員會(National Research Council)於西元 1919 年成立。

2018 年 AGU 秋季會議是第 51 屆，也是有史以來規模最大的會議，與會人員總計超過 2 萬 8,500 人，共有 101 個國家的人員出席，有 8,000 多個口頭報告及 1 萬 7,000 個海報展示。

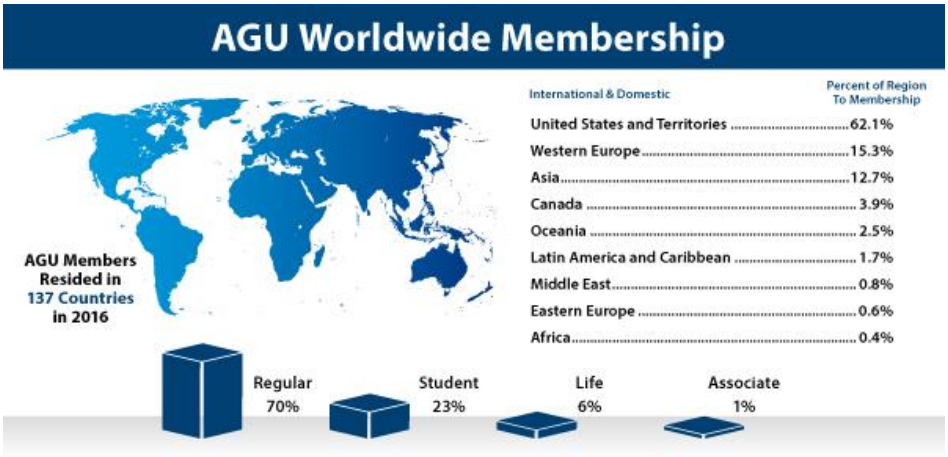


圖 1、AGU 會員分布圖(資料取自 AGU 官網)

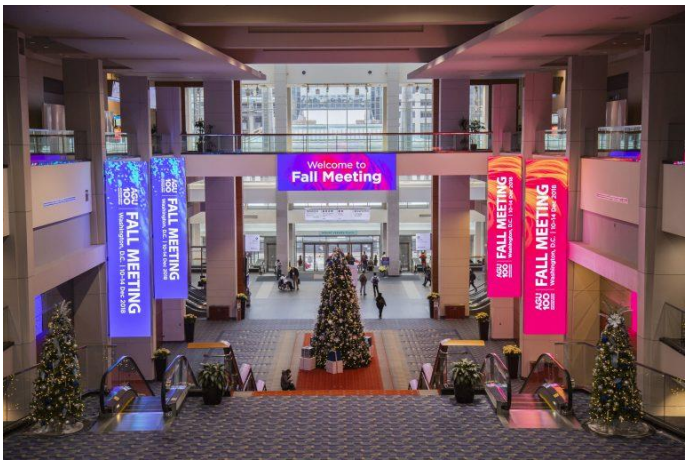


圖 2、會場照片(取自 AGU 官網)

二、 會議目的

本署自 1996 年開始與中央氣象局簽訂合作協議，由該局提供衛星影像產品，輔助本署執行中國大陸沙塵監測及預報作業，即透過衛星影像追蹤沙塵動態，研判可能影響我國空氣品質的時間及範圍。後陸續應用於中國霾害監測及火點資料反演，加強非傳統的污染監控功能。

AGU 秋季會議與衛星遙測技術對環境監測之應用自提包括：「地球同步衛星對於空氣品質運算及研究應用」、「美國國家海洋暨大氣總署(NOAA)衛星數據產品之應用」、「利用美國航空暨太空總署(NASA)衛星數據對健康及空氣品質之應用」、「衛星數據對健康、空氣品質、環境管理方面之應用」等，本次參加 2018 年美國地球物理協會第 51 屆秋季年度會議，除為瞭解國外衛星遙測對環境應用與細懸浮微粒監測新知，學習世界各國利用衛星數據對空氣品質相關之應用，以供本署加強非傳統污染監控功能，亦積極投稿發表論文—「應用衛星火點觀測資料進行露天燃燒稽查 An Application of Satellite Data on Fires for Environmental Inspection of Open Burning」，展現我國衛星資料應用成果，有效提升我國在國際上之能見度。

貳、 出國人員與行程

一、 出國人員：

監資處陳彥君環境監測技術師及黃健瑋環境監測技術師

二、 出國日期：107 年 12 月 9 日至 107 年 12 月 17 日

三、 出國行程紀要

日期	工作內容概要
12月9日	啟程，臺北前往美國加州舊金山
12月10日	加州舊金山轉機前往華盛頓DC
12月11日	參加2018美國地球物理學會秋季年度會議 Workshop：Exploring and Using MISR Aerosol, Cloud, and Plume Data Oral：Air Pollution, Aerosol, and Climate Interactions in Asia III Oral：Air Pollution, Aerosol, and Climate Interactions in Asia IV
12月12日	參加2018美國地球物理學會秋季年度會議 Oral：Extreme Wildfires and Smoke Plumes：Past, Present, and Future II
12月13日	參加2018美國地球物理學會秋季年度會議 Oral：Dust, Black Carbon , and Other Aerosols in the Cryosphere I Oral：Urban and Regional Air Quality： Emissions, Land Surface Forcing, and Meteorological Impacts II Oral：Urban and Regional Air Quality： Emissions, Land Surface Forcing, and Meteorological Impacts III
12月14日	參加2018美國地球物理學會秋季年度會議 Oral：Atmospheric Chemistry in Highly Polluted Environments I

	Oral：New Directions for Open-Source Air Quality Data：Applications in Health, Air Quality, Environmental Management, and Public Outreach I Oral：A New Era for Aerosol Products from Geostationary Satellites for Air Quality Operational and Research Applications I
12月15日	參加2018美國地球物理學會秋季年度會議 Oral：Advances in an Integrated Global Oberving System for Air Quality I Oral：Advances in an Integrated Global Oberving System for Air Quality II Post：An Application of Satellite Data on Fires for Environmental Inspection of Open Burning
12月16日	返程，前往加州舊金山
12月17日	返程，抵達臺北

參、 會議內容及成果說明

一、 Workshop：Exploring and Using MISR Aerosol, Cloud, and Plume Data

本次會議除各主題演講及海報展示外，另有辦理數場專題討論會，其中「探討及利用多角度成像光譜儀（Multi-angle Imaging SpectroRadiometer, MISR）之氣膠、雲與煙流資料」即與本次出國主題相關。

本 workshop 是由美國航空暨太空總署(NASA)的 Jet Propulsion Laboratory 的 Abigail Nastan 主持，主要是多角度成像光譜儀(Multi-angle Imaging SpectroRadiometer, 後簡稱 MISR)的基本介紹、運用及資料使用解說。

NASA 的 Terra 衛星於 1999 年 成功發射， 2000 年 開始觀測地球並收集有關輻射、氣溶膠、雲、風等相關資料，而 Terra 衛星上配備了許多儀器，除了一般大家最熟知的中解析度成像光譜儀(Moderate Resolution Imaging Spectroradiometer，MODIS)外，還有先進太空熱輻射暨反射輻射計(Advanced Spaceborne Thermal Emission and Reflection Radiometer，ASTER)、對流層內污染量測儀(Measure of Pollution in the Troposphere，MOPPIT)、雲層與地球輻射能量系統(Clouds and Earth’s Radiant Energy System，CERES)，以及本 workshop 的主題—MISR。

要進行全球氣溶膠觀測並不容易，最經濟實惠的方式就是透過衛星觀測，也因此使用衛星遙測氣溶膠的研究在近年來一直相當活躍。MISR 總共有 9 個不同角度的攝影機可同時觀測地球，提供較高的空間解析，其圖像經過校準，藉由拍攝角度造成反射率的變化，可區分不同類型的氣溶膠及其表面結構，提供不同型態大氣顆粒和雲對區域氣候的影響，在全球氣溶膠觀測部分，MISR 可以多角度收集多光譜數據，收集全球微粒組成即數量之數據，以作為地球氣候模擬相關模式之用，目前本署已有應用在火點資料、衛星影像研判沙塵位置等空氣

品質監測上。

MISR 的衛星產品分為 Level 1 的輻射數據；Level 2 的雲/立體的數據、氣膠數據、地表數據、大氣層頂/反照率數據；Level 2.5 的煙流高度項目；Level 3 的輻射、氣膠和地表資料及雲運動向量。要使用 MISR 數據可利用 MINX (MISR INteractive eXplorer)這套軟體，其是在 2005 年美國環保署（US EPA）及美國太空總署（NASA）為了研究森林火災、氣候變化及空氣品質所資助開發，因氣膠在不同高度的大氣對煙霧的散佈有很大的影響，是氣膠傳輸模式的重要輸入關鍵，而 MINX 即為利用立體方法檢索氣膠煙流和雲的高度和運動。討論會中有提供 MISR 各軌道雲/風和氣膠產品及 MISR 煙流高度數據，可供空氣品質、火山及火災科學等研究，唯因第一次接觸該資料，故無相關程式工具可開啟檔案資料，未能於現場實際操作。

圖 3、MISR 剖視圖(圖片取自 Jet Propulsion Laboratory 網頁)

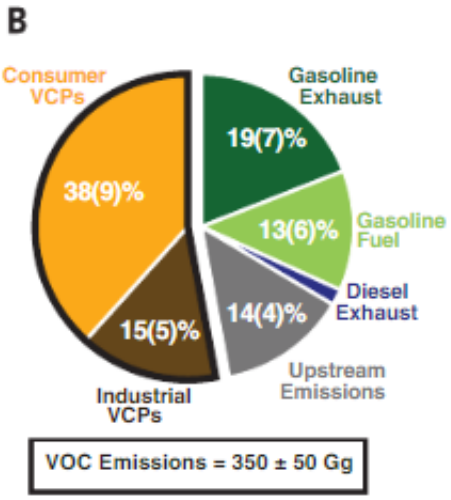
表 1：MISR 的數據產品

Level	Name	Example uses
1	Radiance data	Images
2	Cloud /strero data	Cloud-top height, cloud motion vectors
2	Aerosol data	Aerosol climatologies, PM studies
2	Land surface data	Vegetation health
2	TOA/albedo data	Climate studies
2.5	Plume height project	Global wildfire plume heights
3	Radiance, aerosol, and surface	Global-scale, long-term studies
3	Aerosol joint	Global-scale, coarse-resolution particle properties
3	Cloud motion vector	Wind climatologies

二、 揮發性有機化合物：

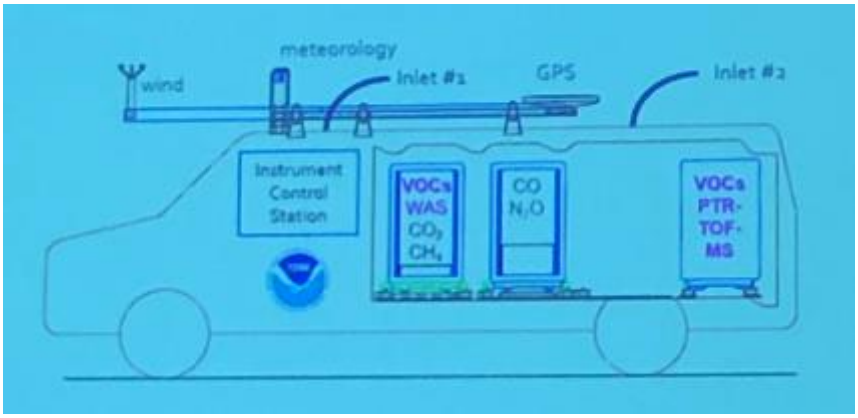
(一)、韓國國家環境研究所(NIER)於 2016 年與美國太空總署(NASA)合作，執行韓國-美國空氣品質研究計畫(KORUS-AQ)，在韓國實際利用飛機載具進行空氣監測，並與衛星觀測資料比對建模，以有效瞭解空氣污染狀況。而由研究指出，首爾的揮發性有機物來源組成為：生物來源 6%、天然氣/有機溶劑/CNG 32%、有機溶劑(非塗料)18%、長程傳輸 24%。首爾在春季主要的揮發性有機化合物(VOCs)為乙烷、丙烷、甲苯等，而異戊二烯，甲苯，二甲苯及乙烯等 VOCs 會影響首爾的臭氧生成，並建議有效減排 VOCs 的策略為管制有機溶劑（甲苯，二甲苯，乙苯）及車輛排放（乙烯，丙烯）。

(二)、過去都市大氣中揮發性有機物濃度通常是與交通運輸有關，但研究發現現在卻轉向與揮發性有學產品為主，白天人為排放的D-檸烯(D-Limonene)可能導致臭氧及二次有機氣膠(Secondary organic aerosols，SOA)的形成。洛杉磯的 VOCs 排放，以 VCPs 的占比最高，達 38%。



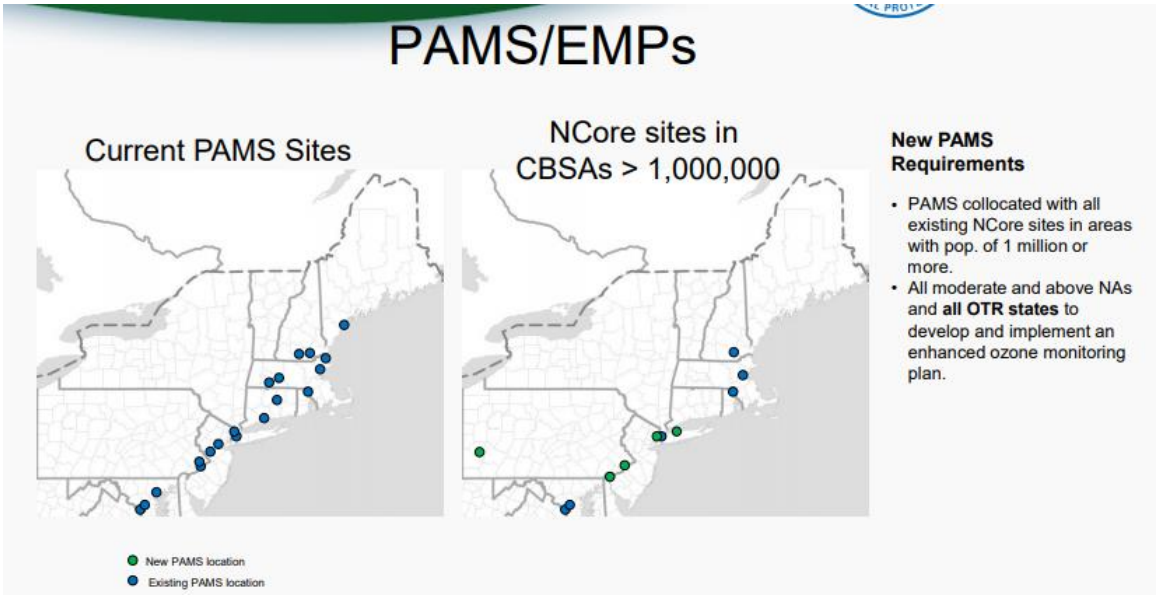
(三)、根據美國國家海洋暨大氣總署(NOAA)的研究發現，一般在都市地區，能源使用及運輸是相對重要的 VOC 來源，而如今車輛的排放已相對較低，應該更加注意 VCPs(含揮發性有機物的化學產品)的貢獻。Brian C. Mcdonald 等人 2018 年在 science 發表了“Volatile chemical products emerging as largest petrochemical source of urban organic emissions”，文章中提到美國和歐洲的交通排放迅速下降，使得都市揮發性有機物來源與排放清冊差距加大。VCPs(包含農藥、塗料、印刷油墨、黏著劑、清潔劑及個人護理產品)現已占工業化城市化石燃料 VOC 排放量的一半，且這個排放比例和實際監測所得到的量測值是一致的(包含室內和戶外監測)，顯示人類所接觸到的化石來源碳質氣溶膠(carbonaceous aerosols of fossil origin)已由交通轉為 VCPs。2018 年 NOAA 使用車載 WAS/GC-MS 及 PTR-TOF-MS 於紐約執行監測，通常都市大氣中揮發性有機物濃度是與交通運輸有關，但現卻轉向與揮發性有學產品為主，結果顯示在白天，

人為排放的 D-檸烯(D-Limonene)可能導致臭氧及 SOA 的形成。



三、 光化學評估監測站

美國環保署目前針對臭氧不合格區域及臭氧傳輸區域除原有的光化學評估監測站(PAMS)，另執行加強監測計畫(EMP)，並增加高空監測，例如藉由 NASA Pandonia Global Network 的 Pandora 計畫獲取相關數據產品，包括：(1) 總臭氧 column 和對流層臭氧 column、(2) 總 NO_2column 和對流層 NO_2column、(3) AOD(光譜在紫外光和可見光範圍內的)及(4) SO_2、甲醛、水蒸氣 column 等。



四、 邊界層

由於氣溶膠的散射和吸收都會減少太陽輻射抵達地表的量，造成溫度反轉，大氣穩定度增加，因此抑制了邊界層的發展，而造成空氣污染現象惡化，因此了解邊界層的日變化以及他與氣溶膠的相互作用是很重要的。邊界層的發產涉及到許多化學、物理的動態過程，並與氣溶膠存在複雜的相互作用，共同影響著空氣品質，兩者間的相互作用加上氣象條件，使得空氣品質的預測是相當複雜且困難的。此研究可顯著改善邊界層建模的工作，並改善空氣品質預測，需要進一步了解氣溶膠吸收性質及其垂直分布，並增加邊界層測量。

邊界層高度的觀測可透過探空氣球或是無線電探空儀(radiosonde)，目前全球有超過 2,700 測點，其中中國有 120 個(稱為 CRN)，每天進行兩次量測(北京時間上午及下午 8 時)，而夏季大多數地點每天發布四次(8、14、20、2)。夏季的時候邊界層的日夜變化非常顯著，下午的時候最高，夜間較低，根據陸方研究，邊界層與 $PM_{2.5}$ 間是存在負相關，但相關性不強，而黑碳與臭氧在冬季呈現負相關，但 $PM_{2.5}$ 與臭氧則不顯著。

各國各單位包含 NOAA 等，都積極的在改進現有的模式，例如空氣品質模式、邊界層預測模式、HYSPLIT(Hybrid Single Particle Lagrangian Integrated Trajectory)、Ammonia 模式、GEOS forecast system 等等，在會議中發表各種模式改善結果，可提供我國空氣品質動力模式版本升級及偏差修正等參考，使空氣品質預報作業自動化得以更加精進。

而在韓國的研究中發現，以激光雷達的觀測值與空氣品質模式相比，模式中的邊界層在夜間太弱，而在白天太高導致 PM 濃度低估，由於氣溶膠的存在會影響邊界層高度，在白天降低邊界層高度，在晚間升高邊界層高度，顯示氣象和化學間的相互作用對於東亞空氣品質模式有很大的影響。

五、 加州大火

由於在研討會前發生了加州大火事件，因此相關議題在會議中出現頻繁。野火的預測最難的在於他的起始以及他會如何發展，空氣品質預報模式也很難去估算野火的排放量，但可以使用衛星觀測客觀估計。雲-氣溶膠激光雷達和紅外探測器衛星觀測（Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, CALIPSO）是 NASA 與法國航天局 CNES 的聯合任務，為雲和大氣氣溶膠（空氣傳播顆粒）在調節地球天氣，氣候和空氣質量方面的作用提供了新的見解。CALIPSO 的數據可以提供隨機時間及空間的煙羽流數據，不限定特定的火災類型或是一天中的時間。也可以藉由 CALIPSO 的氣溶膠數據、NOAA HMS、NASA LaTM 和 MODIS 火災探測數據來辨識煙羽流高度，但 CALIPSO 也不是每一個煙羽流都有辦法捕獲到。

六、 FORMALDEHYDE(HCHO)甲醛

野火造成的氣體和氣溶膠顯著的影響著地球的氣候，甲醛就是其中之一。衛星數據(例如 CO、NO_2、氣膠 INDEX(AI))已被用來估算野火排放的影響以及用來估算野火羽流。目前僅有少數研究利用衛星來觀測全球甲醛。NOAA/NWS 根據美國環保署 CMAQ 模式系統建立了美國國家氣象局空氣品質格點預報系統(NAQFC)，提供 $PM_{2.5}$ 和臭氧預報，而 NAQFC 中的野火排放量即是取自 NOAA 環境衛星。

肆、 心得與建議

一、 心得：

(一)、本署目前透過中央氣象局所接收的向日葵 8 號衛星（Himawari-8）資料，有增加包含火點資料、氣膠光學厚度等衛星反演產品，而現在日本氣象廳氣象研究所（JMA/MSI）為進行沙塵預報，已在進行利用 Himawari-8 資料開發二維變分法（2D-Var）氣膠數據同化系統，目前準確性經統計結果評估，與目前常用的預測系統（全球氣膠預測模型，MASINGAR mk-2）能更有效的預測沙塵分布，該系統目前正在測試中，預計將於 2019 年開始運行。而日本相關空氣品質模式資料對本署助益很大，後續將密切注意日本發布情況，作為未來預報相關參考。

(二)、本署為了加強空氣品質防制，利用先進衛星遙測技術提供相關火點資訊，製作查詢系統，即時發布火點通報，包括熱區分析、農廢生質燃燒監測及空污固定污染源燃燒塔的異常查核等，協助地方環保局露天焚燒稽查工作之執行。經統計火點出現並經稽查查獲露天燃燒，時間、地區多發生在春季（3-5 月）及臺灣中南部，主要原因為農廢、棄置垃圾焚燒及清明節掃墓之墓地焚燒。火點偵測主要利用衛星所搭載多光譜感測器，解析中紅外(Middle-Infrared)與熱紅外(Thermal Infrared)頻譜，評估地表較高溫區域，並解算合理座標及亮度溫度。目前解析之火點除了露天焚燒外，亦可能把工廠煙囪、森林火災、建物失火等造成高亮溫之案件納入紀錄，無法精準確認該火點為露天燃燒之人為活動。經分析稽查查獲案件與亮度(BRIGHTNESS)、火輻射功率(FRP)、信心指數(CONFIDENCE)之相關性，可發現亮溫或信心指數高（前 40%高值區域內）時，查獲的準確度也會有提升。目前經 1 年實際上線使用經驗，衛星遙測提供的火點資料及系統的通報功能確實能提升地方環保局稽查之效率，加強其對轄區露天燃燒情形的掌握，達改善當地空氣品質之目的。

二、 建議事項：

(一)、透過本次會議可知衛星產品眾多,亦有許多可作為環境監測及預測相關使用,但目前本署所知或應用的衛星資料僅限少數,主要為 Terra & Aqua MODIS 及 Himawari-8 衛星資料，且多為影像產品,在監測及預報上所提供資訊仍屬有限,建議能持續參與國際上相關研討會或如美國太空總署(NASA)、美國海洋暨大氣總署(NOAA)所辦專題討論會(Workshop)，以瞭解不同衛星發展之產品，進而找尋更適合且方便用於環境治理之衛星產品。

(二)、本署與中央氣象局合作接收衛星火點資料,提供地方環保局執行環境稽查相關工作,目前已有初步成果,惟衛星資料應用仍有許多限制,如雲遮蔽或火點發生時非衛星所通過時間等情況,稽查情況仍屬有限,如何精進模式資料之應用或再找尋其他適用的衛星資料互補,都是未來可研究的方向,以有效提升環境執法及相關管制作為。

附件1、 投稿海報

An Application of Satellite Data on Fires for Environmental Inspection of Open Burning

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Environmental Protection Administration Executive Yuan, R.O.C.(Taiwan)

Introduction

- Open burning of waste significantly affects air quality in Taiwan, but the times and places of its occurrence are uncertain, presenting major challenges to the carrying out of inspections by environmental protection units.
- The Taiwan Environmental Protection Administration is using fire-related data from satellite remote sensing technology to develop an inquiry system, provide real-time notification of fires and strengthen the capabilities of non-traditional pollution monitoring. This includes hot zone analysis, monitoring of agricultural waste biomass burning, and irregularities detected in fixed sources of air pollution such as combustion towers, etc..
- The purpose of this study is to examine the distribution of fires and periods they are prone to occur by using satellite data on fires in Taiwan. In addition, statistics from actual site checks, brightness temperature, and fire radiative power are collected to determine correlations and data reliability.

Fig.1. Schematic diagram of satellite data inversion process for fires

Methods

- The Taiwan Environmental Protection Administration's satellite data on fires mainly comes from three NASA satellites that provide data to the Taiwan Central Weather Bureau, which are named Terra, Aqua and Suomi NPP. Terra and Aqua are equipped with a Moderate Resolution Imaging Spectroradiometer (MODIS), while Suomi NPP is equipped with a Visible Infrared Imaging Radiometer Suite (VIIRS).
- Multi-spectral sensors mounted on satellites exploit the strong emission of mid-infrared and thermal infrared radiation from fires, allowing assessment of areas with higher surface temperatures, and enabling reasonable calculation of coordinates and brightness temperature values (Fig.1). With current fire analysis tools, in addition to open burning, it is also possible to incorporate into records cases of high brightness caused by factory chimneys, forest fires, building fires, etc., but it is impossible to accurately confirm whether a fire is an open-air burning activity.
- Because polar-orbiting satellites orbit Earth in the north-south trajectory, an observation point will be passed only once per day. The sensors used at present are for the mid-infrared and thermal infrared spectrum, which are susceptible to the influence of the cloud layer. If there are clouds above an observation area, the system may be unable to recognize the fire point. Moreover, the maximum error of sensors installed on the satellites is about 1 km, so the observed fire point may be slightly deviated from the actual position.

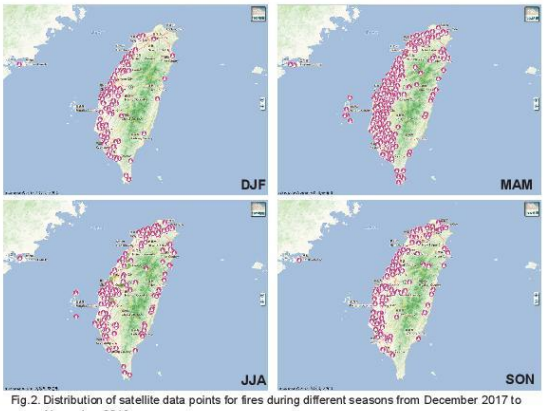

Fig.2. Distribution of satellite data points for fires during different seasons from December 2017 to November 2018

Results & Discussion

- This study used satellite data on fires from December 2017 to November 2018. The time and region of the occurrence of most fires were in the spring (March-May) and in south-central Taiwan (Fig.2). The main economic activities in these regions are agricultural. During the harvest period, it is customary to burn agricultural waste on the spot. Also, the Qing Ming Festival in the spring sees widespread practice of traditional folk customs to worship ancestors by burning incense and ritual paper money.
- After determining fire points of statistically high occurrence, local environmental protection bureau were notified to conduct follow-up inspections. A majority of the points did not undergo any investigation, possibly due to the deviation of the observed fire position from the actual position, or because the satellite data inversion method causes misjudgments (reduced confidence). Further analysis revealed that the causes of the observed combustion included the burning of agricultural waste, garbage incineration, and Qingmin Festival grave sweeping activities (Fig.3).
- In addition, statistics from local fire protection inspections of local environmental protection bureau were analyzed. After fire spots were reported, the proportion of inspections conducted in the central and southern regions was relatively high, as were the number of related investigations cases(Fig.4). The highest proportion of investigation cases occurred in Chiayi and Tainan, where open air combustion cases were a major factor impacting local air quality.
- In order to understand whether the satellite inversion products are helpful for inspection, the brightness temperature, fire radiative power and confidence index were divided into 10 levels. Comparing the different levels of each product with the success rate of identifying open burning, judgment can be made as to when the brightness the brightness temperature or confidence index is high (in the top 40% high value area), and the accuracy rate for the actual investigations will also increase (Fig.5).

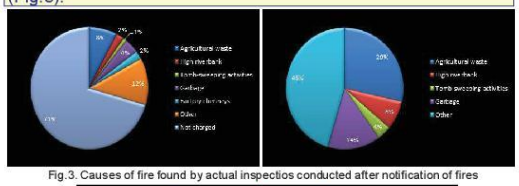

Fig.3. Causes of fire found by actual inspectios conducted after notification of fires

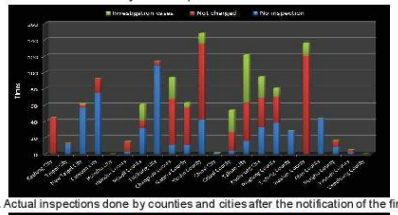

Fig.4. Actual inspections done by counties and cities after the notification of the fires

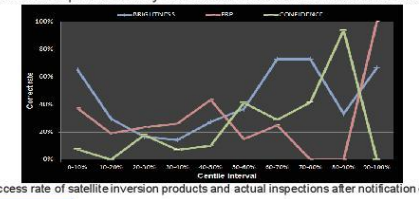

Fig.5. The success rate of satellite inversion products and actual inspections after notification of the fires

Conclusion

After gaining one year of actual experience, the Taiwan Environmental Protection Administration has found that fire data provided by satellite remote sensing along with notifications through the system can truly improve the efficiency of local Environmental Protection Bureau inspections, helping to strengthen control of open burning activities in specific areas, and to achieve the objective of improving local air quality.

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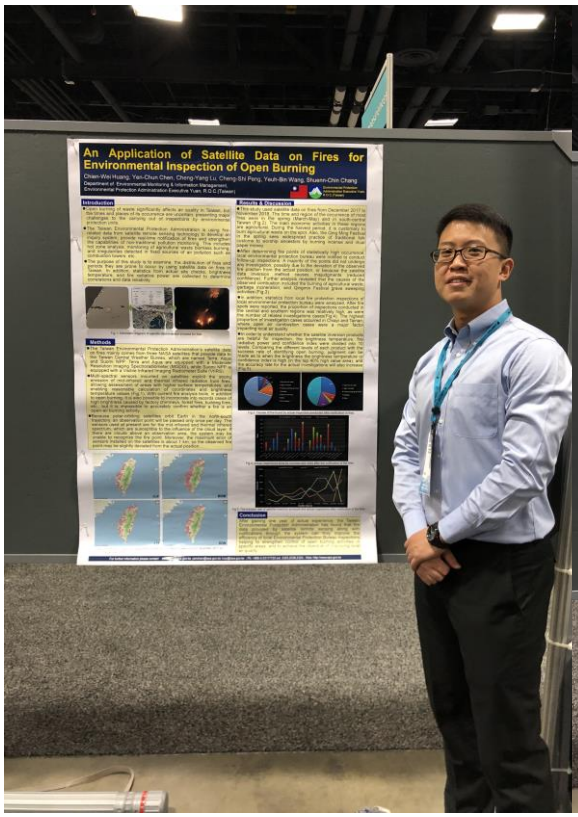
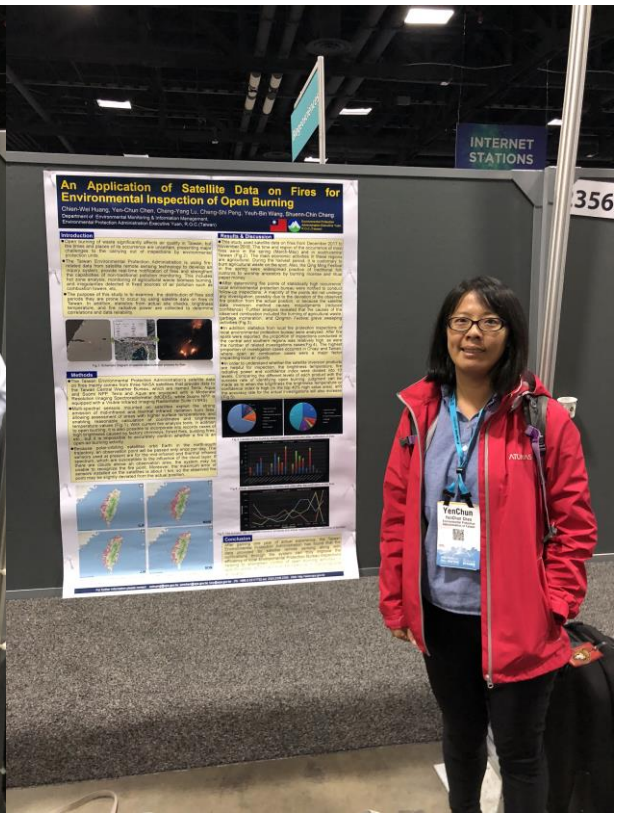
附件2、出國期間相關照片





附件 3、會議資料

A11F-2271 Construction of Black Carbon emission inverse system for east Asia

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(1)Meteorological Research Institute, Tsukuba, Japan, (2) Asia Center for Air Pollution Research (3) Kyusyu University (4) National Institute of Environmental Studies

AGU 100 FALL MEETING Washington, D.C. | 10-14 Dec 2018

Table 1: The outline of our BC emission inverse system.

BC emission analysis system	
Analysis Target	Monthly BC emission in East Asia
Aerosol model	MASINGAR mk-2 (Tanaka et al)
Spatial resolution	TL159L80
Meteorology	Nudging towards JRA-55
Analysis Period	2011 – 2014
Number of regions	33 (see figure 1)
Observation data	5 sites (see figure 2)
Observation error	20%
Prior BC emission	REAS Ver. 2.11 (Kurokawa et al)
Prior flux error	20%

Inverse model

The BC emission analysis system is based upon the Bayesian synthesis inversion (Tarantola, 1987). This technique assumes that the observations maybe explained by linear combinations of dust fluxes and that the transport itself is a linear operation as well. We analyzed the dust-emission flux x to minimize the cost function S(x) using singular value decomposition.

Observation data

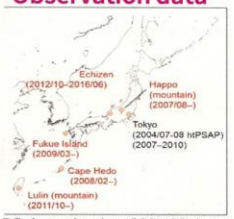


Figure 1: BC observation sites (COSMOS) in East Asia.

Inversion Area

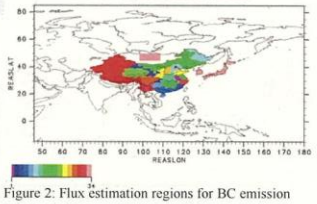
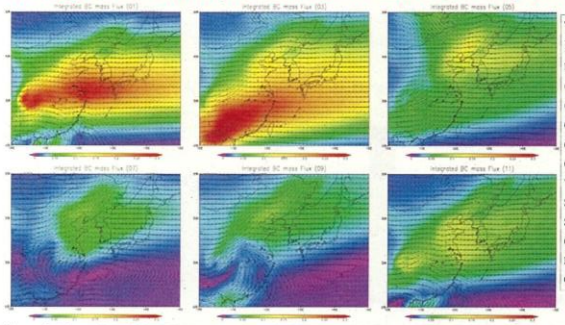


Figure 2: Flux estimation regions for BC emission inverse system. We allocated 31 areas to China, 1 area to Korea and Japan respectively.

Averaged BC transport route in East Asia (by MASINGAR mk-2)



The vertically integrated BC mass flux suggests that the observation network could approximately constrain BC emission at east Asia. However, it is difficult to constrain BC emission in southern and western part of China in summer season. So, we still need more observation data to obtain more reliable BC emission by our inverse model system.

Figure 3: 10 year's (2007 - 2016) averaged vertical integrated BC mass flux by MASINGAR-mk2.

Acknowledgement

The authors are grateful to K. Gurney, R. Law, and P. Rayner for providing the inversion code. The observation data were provided by Prof. M. Koike and Dr. Y. Kanaya. This work is supported by the Environment Research and Technology Development Fund (S-12) of the Environmental Restoration and Conservation Agency, Japan.

Forward simulation results

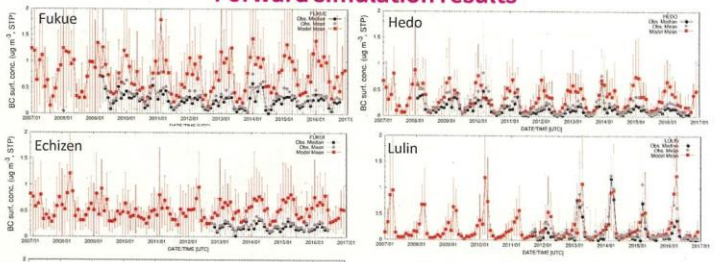


Figure 4: Comparison between model simulation (BC emission year is 2010) and COSMOS observation.

The overestimation trend of BC in the model against observations suggests that BC emissions in East Asia are beginning to decline

Inverse model results

We estimated the BC emissions in East Asia from 2011 to 2014, using BC emissions in 2010 as a priori. In this case, we attempted a method of using the observation data as it is and a method of subtracting the difference between the model and the observation in 2010 in advance from the observation data in order to remove the bias of the model. The table shows 2014 BC emission rate against 2010 in each region.

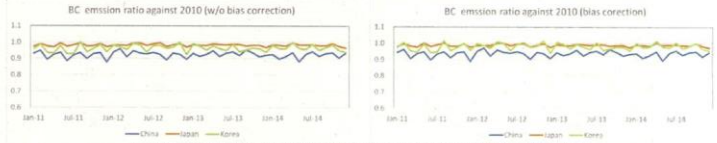


Figure 5: The monthly BC emission rate against a priori (2010) in each country.

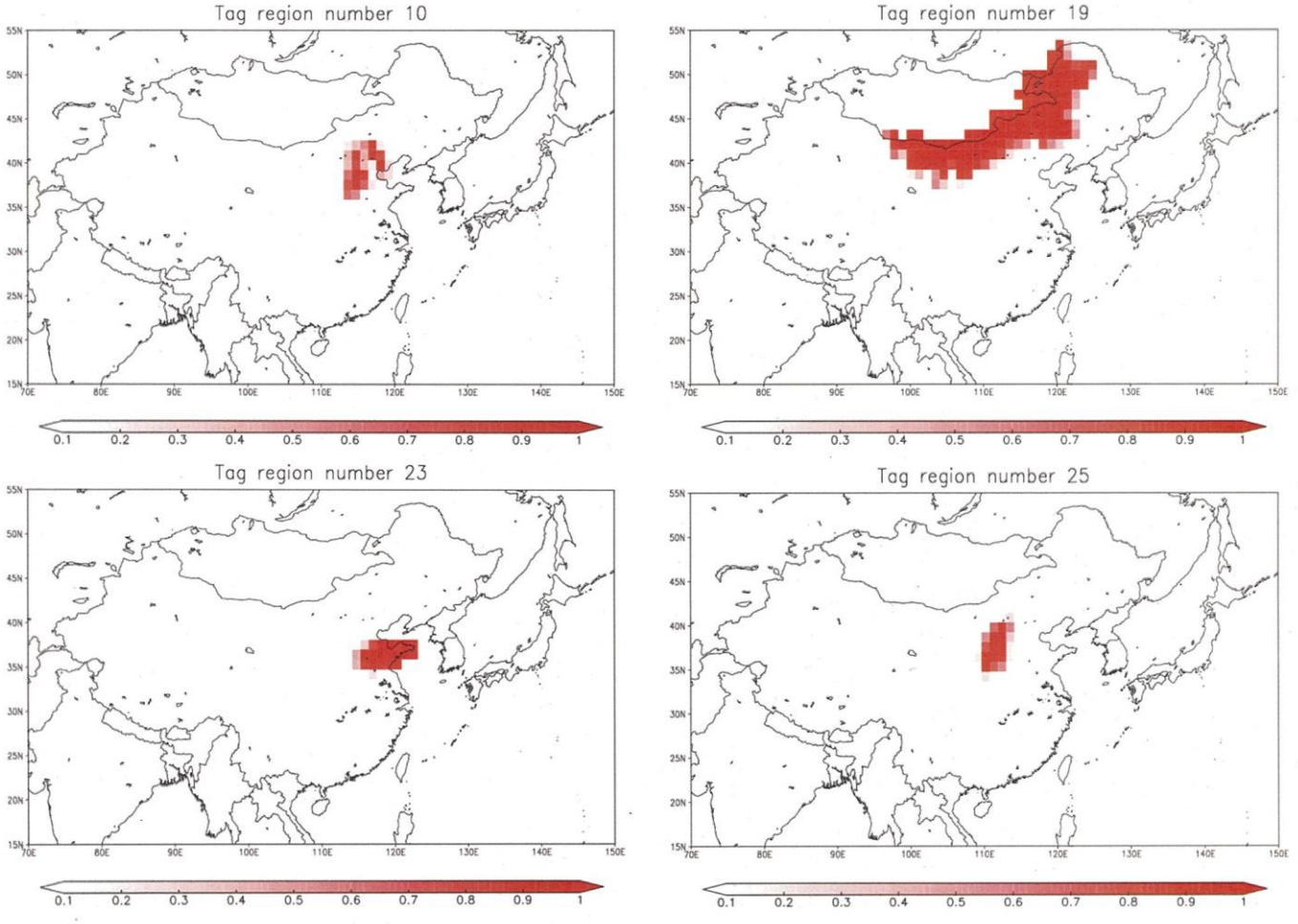
Table 2: The 2014 BC emission rate against a priori (2010) in each region (bias corrected results).

Reg_01	Reg_02	Reg_03	Reg_04	Reg_05	Reg_06	Reg_07	Reg_08	Reg_09	Reg_10	Reg_11
-3.8%	-6.7%	-0.7%	-0.2%	-2.1%	-0.2%	-0.3%	-1.2%	0.0%	-18.4%	-2.1%
Reg_12	Reg_13	Reg_14	Reg_15	Reg_16	Reg_17	Reg_18	Reg_19	Reg_20	Reg_21	Reg_22
-7.7%	-2.1%	-0.5%	-9.8%	-0.2%	-3.1%	-7.5%	-19.7%	-1.2%	-0.3%	-3.1%
Reg_23	Reg_24	Reg_25	Reg_26	Reg_27	Reg_28	Reg_29	Reg_30	Reg_31	Korea	Japan
-11.3%	-3.8%	-10.8%	-2.2%	-8.4%	-0.1%	-3.1%	-0.9%	-3.5%	-1.2%	-2.0%

Summary and conclusion

- We constructed the BC emission estimating system that uses a global aerosol model (MASINGAR mk-2), a Bayesian synthesis inversion and BC observation data.
- Our model simulation overestimated BC concentrations against observations especially from 2011.
- We found that BC emissions in East Asia between 2011 and 2014 are decreasing especially in China, compared to the 2010 emissions. We need more observation data to constrain BC emission amount.

The area where BC emissions decrease was large



A 0.56°-resolution global data assimilation of multi-constituent satellite measurements for tropospheric chemistry analysis

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Kengo Sudo (Nagoya Univ./JAMSTEC), Masayuki Takigawa (JAMSTEC), Henk Eskes (KNMI), K. Folker Boersma (KNMI)

1. Introduction

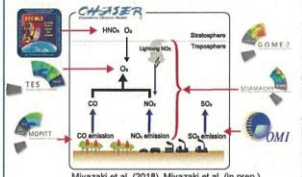
- Chemical compositions of the atmospehre such as ozone are controlled by the tropospheric chemistry system.
- The combined use of satellite retrievals of ozone and its precursors has great potential to provide comprehensive information on the tropospheric chemisty system.
- Previous studies have demonstrated the capability of advanced multi-species satellite data assimilation to simultaneously optimize the concentrations and emissions at relatively low resolutions (1-4°) on regional to global scales.
- A 0.56° resolution, which is comparable to typical area of mega cities, is expected to improve analyses of data assimilation on mega city scale. Therefore, we conduct a 0.56°-resolution global data assimilation using an ensemble Kalman filter approach (Miyazaki et al., 2015) and high-resolution global chemical transport model (Sekiya et al., 2018).

Sekiya et al. (paper in preparation)

2. Data assimilation sytem

- We performed an assimilation of multi-constituent satellite measurements at 0.56° resolution for 30 days (June 22-July 21 2008).

Schematic diagram of data assimilation system



Miyazaki et al. (2018), Miyazaki et al. (in prep.)
Sekiya et al. (in prep.)

Settings of assimilation

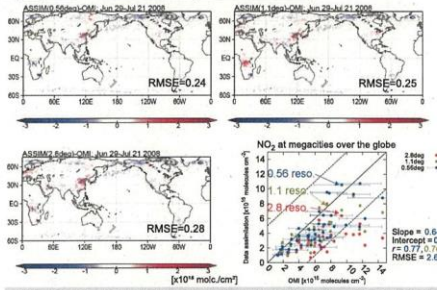
Assimilation scheme	Ensemble Kalman filter, 32 and 64 members
Forecast model	CHASER V4.0 (Sekiya et al., 2018) 92 species & 262 reactions
State vector	NO_x, CO, and SO_2 emissions, lightning NO_x, 35 chemical species
A priori emissions	HTAP_v2.2 (anth.), GFED4s (BB), GEIA (soil)
Period	Boreal summer (Jun. 22-Jul. 21) 2008
Resolution	Horizontal: 2.8, 1.1, and 0.56° Vertical: 32 layers (to 4 hPa)

Assimilated observations

OMI, GOME-2, SCIAMACHY QA4ECV v1.1 Trop. NO_2 column	Boersma et al. (2017)
TES v7 O_3 profile	Herman and Kulawik (2013)
MLS v4.2 O_3 and HNO_3 profiles	Livesey et al. (2011)
MOPITT v7 NIR/TIR CO column	Deeter et al. (2017)
OMI v3 PCA SO_2 PBL column	Li et al. (2013)

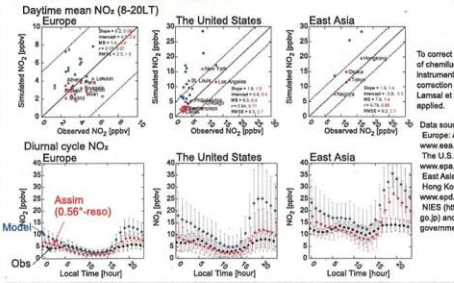
3. Evaluation of 0.56°-resolution data assimilation

Tropospheric NO_2 column: comparisons with OMI



- By increasing horizontal resolution from 2.8° to 0.56° resolution, the global RMSE against OMI NO_2 was reduced by 14% because of error reduction near strong local sources.
- The improvements at 0.56° resolution were substantial over mega cities for the globe (-36%).

Validation using surface NO_2 observations



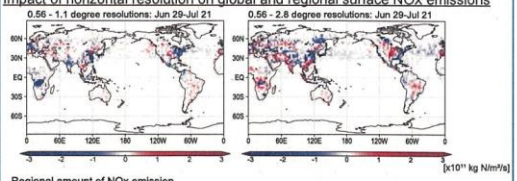
To correct interference of chemiluminescence instruments from NO_y, correction factor (e.g., Lamsal et al. 2008) was applied.

Data source:
Europe: AirBase (http://www.eea.europa.eu)
The U.S.: AQS (http://www.epa.gov/airdata)
East Asia:
Hong Kong EPD (http://www.epd.gov.hk/epd/)
NIES (https://www.nies.go.jp) and local governments

- The 0.56° resolution data assimilation was effective to improve surface NO_2 concentrations over large cities: by 33% at European large cities, by 67% at U.S. large cities, and by 75% at East Asian cities.
- The model overestimation in diurnal NO_2 cycle amplitude was also reduced by 49% at European large cities, by 69% at U.S. large cities, and by 22% at East Asian cities in the data assimilation.

4. NOx emission estimation and its impact on O_3

Impact of horizontal resolution on global and regional surface NOx emissions



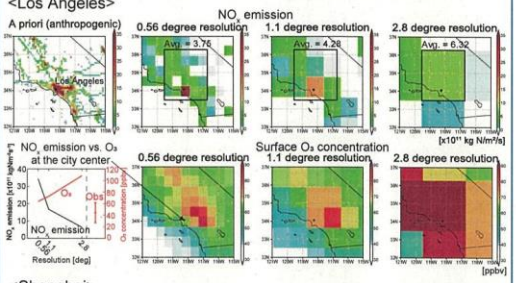
Regional amount of NOx emission during June 29-July 21 2008 [Tg N/yr]

Resolution	A priori	0.56°	2.8°
Global	49.9	51.5	56.8
Europe	4.6	4.7	4.9
U.S.	6.4	5.3	5.9
China	9.6	7.7	8.8
India	3.3	2.6	2.7

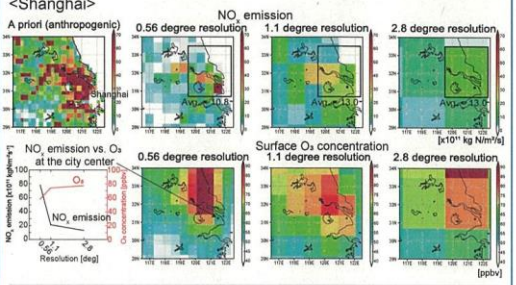
- The posteriori NO_x emissions were decreased when using 0.56° resolution instead of 2.8° resolution by 6% over Europe, by 12% over the U.S., by 10% over China, and by 4% over India because of reductions of resolution-dependent negative model bias over polluted regions.

Impact of horizontal resolution on megacity surface NOx emission and O_3

<Los Angeles>



<Shanghai>



- The NO_x emission contrasts between strong local sources and their surrounding areas were clearly represented by the 0.56°-resolution data assimilation.
- The mega city emission became higher at 0.56° resolution by a factors of 4.4 and 5 at Los Angeles and Shanghai, respectively, whereas large-scale (at 2.8°; black rectangles) total emission became lower by 41% around Los Angeles and by 17% around Shanghai because of resolving the emission contrasts and different chemical regimes.
- The emission adjustments resulted in reductions of the surface O_3 concentrations by 41% at Los Angeles and by 25% at Shanghai and improved the agreements with insitu observations.

5. Summary

- The use of 0.56°-resolution data assimilation system helped us (1) improve the agreements with remote-sensing and insitu observations over mega cities, (2) estimate surface NO_x emission on the scale from mega city (4-5 times higher than 2.8° resolution) to global (10% lower than 2.8° resolution) in a consistent way, and (3) capture mega city-scale pollutions of O_3 for the globe.
- These results suggest the potentials of using the high-resolution global data assimilation for making better use of new high-resolution satellite retrievals such as TROPOMI and geostationary satellites (GEMS, Sentinel-4, and TEMPO) and for studying air pollution on mega city scale for the globe including emerging mega cities over developing regions in the future.