出國報告（出國類別：會議）

第18屆空氣品質模式發展研討會

服務機關：行政院環境保護署

姓名職稱：蔡宜君技士

派赴國家：美國

出國期間：民國108年10 月20日至10 月26 日

報告日期：民國 109 年 1 月 17 日

摘要

本署全年度每日 3 次發布全臺七大空品區未來 3 日及離島隔日空氣品質預報，提供民眾外出活動及相關應變單位決策參考。而無論氣象觀測或是環境品質監測之技術，以及預報模式發展，皆隨科技發展日益進步，為提升空氣品質預報模擬技術及預報作業流程，並了解國際空氣品質預報及遙測環境品質發展情形，爰規劃至美國參加第 18 屆空氣品質模式研討會(The 18th Annual Community Modeling and Analysis System Conference，簡稱 CMAS)。

本次研討會從 2019 年 10 月 21 日至 23 日為期三天，計有 17 國環境部門代表、民間單位及學術研究人員與會，共有 270 多位專家、學者參與，總計有 82 篇學術演講以及 66 篇論文海報。本次研討會討論議題包含模式發展、環境品質監測、排放清單建立機制、空品模式如何耦合氣象模式、探討遙測環境品質技術、空氣品質對於健康之風險評估、經濟影響及物聯網感測器數據比較等等。藉由參加本次研討會了解國際專家、學者於環境品質相關研究及監測技術最新研究成果。本署與國立中央大學大氣科學學系鄭芳怡副教授亦共同以「Assessment of a weather pattern-dependent bias correction method to the $PM_{2.5}$ prediction in Taiwan」（利用天氣型態校正臺灣 $PM_{2.5}$ 預報誤差之結果評估）為主題發表，將本署空氣品質預報偏差校正成果展現於國際研討會，並吸取與會國際專家、學者意見及建議。

美國環保署作業用空氣品質模式(CMAQ)已發展至第 5.3 版，針對污染物模擬的化學機制更臻完善，並預計將預報長度從 48 小時延長至 72 小時，另美國國家太空總署(NASA)發展全球尺度模式結合衛星監測資料，針對臭氧、二氧化氮等氣體之三維分布(GEOS-CF)發布 5 天預報。國際間環保相關部門為提升預報能力，皆投入許多資源及研究人力於預報模式的精進。除邁向長天期預報，亦納入高解析度衛星資料輔助空氣品質預報，值得我國精進空品預報相關業務參考。

目錄

壹、目的及背景說明

本署全年度每日 3 次發布全臺七大空品區未來 3 日及離島隔日空氣品質預報，提供民眾外出活動及相關應變單位決策參考。本署預報作業人員檢視氣象觀測資料（如降雨、衛星 AOD 產品等）及空氣監測資料，判斷空氣品質受氣象條件影響關係，並參考人為排放分布輔助了解污染分布狀況，再以氣象預報及空氣品質預報模式推估未來 1 至 3 日空氣品質變化情形，製作空氣品質預報後於本署空氣品質監測網發布。而無論氣象觀測或是環境品質監測之技術，以及預報模式發展，皆隨科技發展日益進步，為提升空氣品質預報模擬技術及預報作業流程，並了解國際空氣品質預報及遙測環境品質發展情形，爰規劃至美國參加第 18 屆空氣品質模式研討會(The 18th Annual Community Modeling and Analysis System Conference，簡稱 CMAS)。

CMAS 由美國環保署與北卡羅萊納大學主辦，自 2000 年舉辦第一屆以來，至 2019 年共辦理 18 屆研討會，舉辦地點皆在北卡羅來納大學教堂山分校，此研討會為全球空氣品質模式研發者及使用者提供交流討論的平台。來自全球各地的空氣品質模式的專家、學者藉此機會交流意見，討論議題多為模式發展、環境品質監測、排放清單建立機制、空品模式如何耦合氣象模式等，近年亦加入探討遙測環境品質技術、空氣品質對於健康之風險評估、經濟影響及物聯網感測器數據比較等等應用性議題。本次研討會從 2019 年 10 月 21 日至 23 日為期三天，共有來自 17 個國家、270 多位專家、學者參與，總計有 82 篇學術演講以及 66 篇論文海報。

此次參加研討會目的除前述所言，本署與國立中央大學大氣科學學系鄭芳怡副教授亦共同以「Assessment of a weather pattern-dependent bias correction method to the $PM_{2.5}$ prediction in Taiwan」（利用天氣型態校正臺灣 $PM_{2.5}$ 預報誤差之結果評估）為主題發表，將本署空氣品質預報偏差校正成果展現於國際研討會，並吸取與會國際專家、學者意見及建議。

貳、研習過程

日期	工作內容概要
108.10.20	啟程，出發至美國北卡羅萊納州教堂山。
108.10.21	第 18 屆空氣品質模式研討會於美國北卡羅萊納州教堂山星期五會議中心(Friday Center)舉行，由北卡羅萊納大學教堂山分校副校長 Terry Magnuson 教授進行開幕致詞拉開序幕。本次研討會共有 3 個主題演講，首先為哈佛-史密松天體物理中心 Kelly Chance 教授介紹利用地球同步衛星量測大氣中各種空氣污染物並解析污染物長程傳輸及污染物與氣候交互影響，接著由美國環保署 Wayne Cascio 博士說明空氣品質模式研發對於人體健康及經濟的重要性，最後為美國環保署 Sherri Hunt 博士介紹空氣品質預報模式研發所遭遇的問題及挑戰。本日議程主題分別為空氣品質預報模式(Community Multiscale Air Quality, CMAQ)最新研究發展趨勢及利用空品模式探討人體曝露對健康的風險等 20 篇演講，另於論文海報解說階段共 32 篇論文海報參加。
108.10.22	研討會第 2 天議程主題為排放量估計及多尺度模式應用及評估，共有 32 篇演講。美國太空總署全球模式與同化辦公室 Emma Knowland 博士介紹全球觀測系統成分預報模式(Global Earth Observing System Composition Forecast model, GEOS-CF)發展現況。下午時段為論文海報解說，共 34 篇論文海報參加，其中本署與國立中央大學鄭芳怡老師共同投稿「利用天氣分類偏差校正方法修正臺灣 $PM_{2.5}$ 預報結果評估」。
108.10.23	研討會第 3 天議程主題為空氣品質與氣候或能源應用之關係、模式個案診斷分析與敏感度分析、污染物遙測/感測技術研究等 3

項，共有 30 篇演講，其中美國太空總署 Laura Judd 博士報告於紐約長島地區進行機載遙測實驗，量測地面高空間解析度臭氧及 NO2 ，解析污染物時空分布。

108.10.24 返程，至美國舊金山轉機

108.10.25-26 返程，回到臺北。

參、心得與建議事項

（一）本次會議旨在空氣品質預報模式研發成果及其在各領域的應用，藉由持續更新的空氣品質預報模式探討空氣品質預報的精進、污染物管制策略制定、增加衛星資料提高模式解析度以及應用於人體曝露之健康風險、經濟影響等等。參訪重點主要國外空氣品質預報模式及遙測/感測技術發展趨勢，成果評估如下：

本次投稿主題為「Assessment of a weather pattern-dependent bias correction method to the $PM_{2.5}$ prediction in Taiwan」，由主辦單位安排以論文海報方式進行展示，為了改善空氣品質預報模式結果，利用風場及海平面氣壓做群集分析，計算出 6 種天氣型態，並歸納各種天氣型態分別於 $PM_{2.5}$ 預報誤差的特徵藉此進行偏差校正，對比原有利用統計模型的系統性偏差校正等模式後處理，準確度有明顯提升，於會場亦得到熱烈討論。

美國國家氣象局所發展的國家空氣品質格點預報系統(The National Air Quality Forecasting Capability , NAQFC)所使用的空氣品質預報模式(Community Modeling Air Quality, CMAQ)已發展至 5.3 版本，並且預計將預報長度從 48 小時延長至 72 小時。

美國近年積極發展衛星遙測技術並將其資料加入全球預報模式，例如全球觀測系統成分預報模式(Global Earth Observing System

Composition Forecast model, GEOS-CF)，此模式可合成三維的大氣成分結構如臭氧、氮氧化物、有機化合物等，解析度為 25 公里，預報長度可達 5 天，除有利掌握大範圍的長程傳輸，亦用於大範圍的能源開發評估。

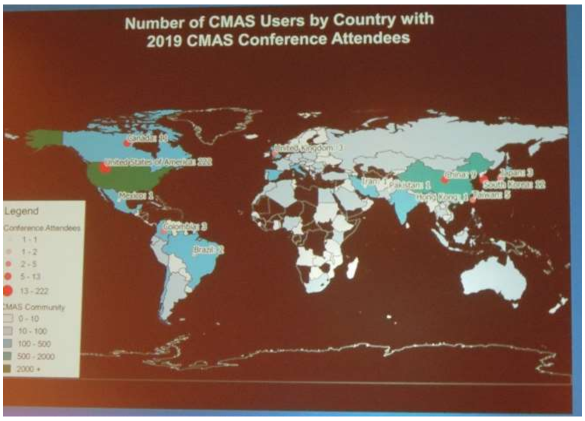
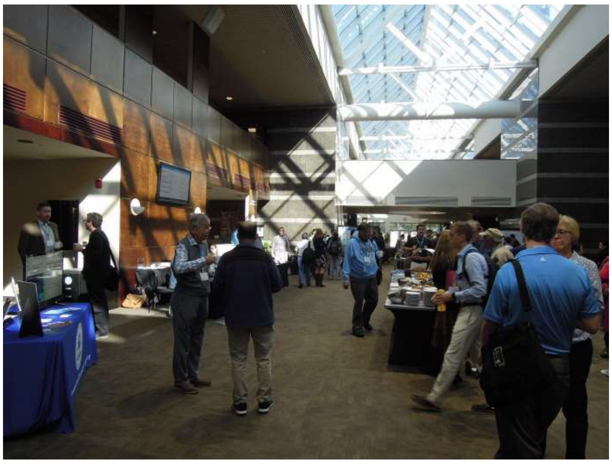
本次會議安排數個有關感測器研究的演講，顯示感測器數據研究亦為未來空氣品質預報模式研究趨勢。北卡羅萊納大學夏洛特分校 Brian Magi 助理教授進行感測器(PurpleAir PA-II)與 FEM 標準方法(BAM 1022)測值、濕度及溫度做多線性回歸校正,結果發現在中、高濕度時有更明顯的改善，顯示濕度越高越容易造成感測器數值偏差，此與國內感測器數據表現類似，但此研究目前僅計算低濃度表現(約 20 微克/立方公尺以下)，未來將持續研究較高濃度誤差之校正。同時亦顯示感測器數據研究為未來精進空氣品質預報模式研究趨勢。

（二）心得與建議：

考量 CMAQ 第 5 版以後針對污染物模擬的化學機制更臻完善,建議將本署空氣品質預報系統更新至 CMAQv5.0 以上版本並介接氣象局作業化 WRF 之氣象預報資料。另本署空氣品質預報模式系統預報長度為 72 小時，建議改善模式能力的同時可評估延長預報時段，以利本署未來提供較長天期預報產品。

本署與交通部中央氣象局合作,介接該局衛星資料及相關氣溶膠產品,並於 2018 年新增日本向日葵衛星 8 號資料產品。建議持續發展衛星產品推估空氣污染物濃度技術，除了透過衛星遙測技術具有大範圍的環境監測量能，更可作為未來評估使用衛星資料改善模式排放量或精進空氣品質預報模式參考，提升本署空氣品質預報能力。

附錄一、研討會相關照片

	
圖 1、研討會情形	圖 2、本次研討會參與國家分布圖
	
圖 3、研討會中場休息時間學者討論情形(1)	圖 4、研討會中場休息時間學者討論情形(2)

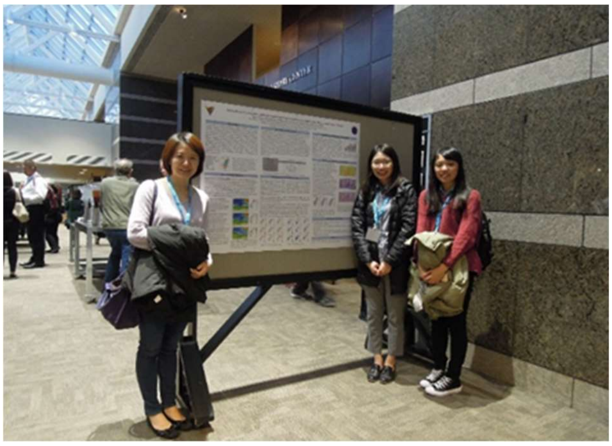
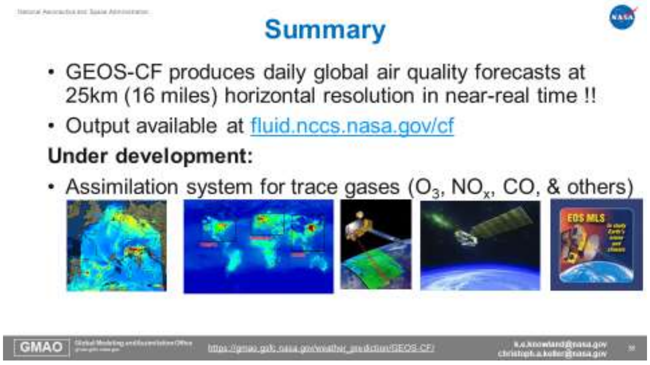

	

圖 5、與國立中央大學鄭芳怡老師（左 1）及李怡茹博士生（右 1）於投稿海報前留影	圖 6、GEOS-CF 發展現況

附錄二、研討會議程

October 21, 2019		
	Grumman Auditorium	
7:30 AM	Registration and Continental Breakfast	
8:00 AM	A/V Upload	
	Opening Remarks	
8:30 AM	Dr. Terry Magnuson, Vice Chancellor for Research, UNC Chapel Hill "State of the CMAS Center - 18 years Serving the CMAS Community"	
8:40 AM	Sarav Arunachalam, Acting Director, CMAS Center "The TEMPO Green Paper: Applications in air quality and health, agriculture, forestry, and economics"	
8:50 AM	Dr. Kelly Chance, Harvard-Smithsonian Center for Astrophysics "New Insights into the Health Effects of Air Pollution and Persistent Knowledge Gaps: Why is CMAS more important now than ever?"	
9:20 AM	Wayne E. Cascio, M.D., Director, National Health and Environmental Effects Research Laboratory, U.S. EPA "Challenges in Atmospheric Science and Air Pollution: Directions and Questions for Modelers"	
9:50 AM	Dr. Sherri W. Hunt, National Center for Environmental Research, U.S. EPA "How to Enjoy the CMAS Conference"	
10:20 AM	BH Baek, UNC Institute for the Environment	
10:25 AM	Break	
	Grumman Auditorium Model Development Chaired by Ben Murphy (US EPA) and Talat Odman (Georgia Tech)	Dogwood Room Modeling to Support Exposure, Health Studies, and Community-scale Applications Chaired by Vlad Isakov (US EPA) and Amir Hakami (Carleton University)
10:40 AM	NOAAs National Air Quality Forecast Capability operational and experimental updates Jose Tirado	Air quality and health benefits of Chinas emission control policies on coal-fired power plants 2005-2020 Ruili Wu
11:00 AM	Implementation of new satellite-based source maps in the FENGSHA dust module and initial application with the CMAQ-based NAQFC system Daniel Tong	Comparing Projected and Modeled Health Benefits of Alternative Energy Futures Kristen E Brown
11:20 AM	Exploring the Vertical distribution of Wildland Fire Smoke in CMAQ Joseph L. Wilkins	Air Quality and Human Health Impacts of Prescribed Fire: Links to $PM_{2.5}$ and Asthma in Georgia, USA Talat Odman
11:40 AM	Impact of renoxification on air quality over Northern Hemisphere Golam Sarwar	Health and Economic Impacts of Air Pollution Induced by Weather Extremes over the Continental U.S. Yang Zhang
12:00 PM	Lunch in Trillium	
	Model Development, cont.	Modeling to Support Exposure, Health Studies, and Community-scale Applications, cont.
1:00 PM	Predicting the phase state and phase separation of atmospherically relevant aerosols and its impact on multiphase chemistry in a	Impacts of Medium-Range Transport of Biomass Burning Aerosols on Air Quality and Public Health in Colombia

	regionalscale atmospheric model (CMAQ) Quazi Ziaur Rasool	Karen Ballesteros-González
1:20 PM	CAMQ-AI: A computationally efficient deep learning model to improve CMAQ performance over the United States Ebrahim Eslami, Yunsoo Choi	Source Attribution of Global $PM_{2.5}$ Mortality Using the Adjoint of Hemispheric CMAQ Amir Hakami
1:40 PM	An efficient way in quantifying the nonlinear response of air pollution to emission changes using the indicator-based response surface model Song Liu	Traffic-Related $PM_{2.5}$ and NO_2 Health Risk Assessment in the United States: A Fine Scale Hybrid Modeling Approach Alejandro Valencia
2:00 PM	Estimating damages from climate change and air pollution for subnational incentives for green onroad freight Rebecca Kaarina Saari	Hybrid Air Quality Modeling in West Oakland, California, to Support the Development of an Emissions Reduction Program Stephen Reid
2:20 PM	Improving SCICHEM Pre- and Post-Processing Setup Speed Using Cloud Computing Amy McVey	Using mobile phone data to quantify the impact of spatiotemporal human mobility on air pollution exposure estimation Haofei Yu
2:40 PM	CMAQ 5.3b PARALLEL PERFORMANCE WITH MPI AND OPENMP George Delic	HyADS: A tool for estimating nationwide exposures to emissions from large numbers of sources Lucas Henneman
3:00 PM	Break	
3:30 PM	Lightning Poster Talks: Day 1	
4:00 PM	Poster Session: Day 1	
October 22, 2019		
	Grumman Auditorium	Dogwood Room
7:30 AM	Registration and Continental Breakfast	
8:00 AM	A/V Upload	
	Multi-scale Model Applications and Evaluations Chaired by Christian Hogrefe (US EPA) and Marina Astitha (University of Connecticut)	Emissions Inventories, Models, and Processes Chaired by Jeff Vukovich (US EPA) and Mike Moran (Environment and Climate Change Canada)
8:30 AM	Global Sources of North American Ozone Barron Henderson	Version 1.0 of the National Emissions Inventory Collaborative 2016 Emissions Modeling Platform Alison Eyth
8:50 AM	Local to Global Air Quality Simulations using the NASA GEOS Composition Forecast Model GEOS-CF Emma Knowland	Updates and Improvements to 2023 and 2028 Emission Inventory Projections Caroline Farkas
9:10 AM	CAMx Ozone Source Apportionment Application over the Northern Hemisphere Pradeepa Vennam	Development of a Year 2016 fire inventory for United States through a multi-agency inventory collaboration effort Jeff Vukovich
9:30 AM	Quantifying Economic Damages from Crop Productivity Loss Due to Ozone Precursor Emissions via Hemispheric Adjoint Analysis Yasar Burak Oztaner	Estimating Emissions from Wildland Fires for Air Quality Modeling: Status Update George Pouliot
9:50 AM	Incorporation of Volcanic SO2 Emissions in H-CMAQ Modeling System and its Impacts on Sulfate Aerosol Concentration across the Northern Hemisphere	Evaluating Updated Tools for the Estimation of Wildland Fire Emissions James Beidler

	Syuichi Itahashi	
10:10 AM	Break	
10:40 AM	Evaluation of the Community Multiscale Air Quality (CMAQ) model version 5.3 K. Wyat Appel	Development of a Fast Fire Emission Processor and Its application with HMS-Bluesky and GBBEPx Inventories Youhua Tang
11:00 AM	Evaluation of CMAQ Estimated NOx from 2002 to 2016 Kristen Foley	Impacts of a National Survey on the Development of the 2017 National Emissions Inventory Rich Mason
11:20 AM	Improved estimation of background ozone and emission impacts using chemical transport modeling and data fusion Nash Skipper	EPA's 2018 Emissions & Generation Resource Integrated Database (eGRID): Updates and Improvements Jonathan Dorn or David Cooley
11:40 AM	Evaluating Seasonality and Trends in Modeled $PM_{2.5}$ Concentrations Using Empirical Mode Decomposition Marina Astitha	Improvements to EPA's SPECIATE database: SPECIATE 5.0 Madeleine Strum
12:00 PM	Lunch in Trillium	
	Multi-scale Model Applications and Evaluations, cont.	Emissions Inventories, Models, and Processes, cont.
1:00 PM	A Novel Ensemble Design for $PM_{2.5}$ Probabilistic Predictions and Quantification of Their Uncertainty Rajesh Kumar	Expansion of a Size Distribution Profile Library for Particulate Matter (PM) Emissions Processing from Three to 30 Source Categories Junhua Zhang
1:20 PM	Lightning Assimilation in WRF4.0.2: Impact of Parameter Options and Introduction of New Lightning Data Daiwen Kang	The estimated impacts of volatile chemical products on particulate matter and ozone criteria pollutants in an urban atmosphere Havala Pye
1:40 PM	Comparing Extreme Weather Events Generated by 36-km and 12-km WRF Simulations Tanya Spero	Initial Development of a NOAA Emissions and eXchange Unified System (NEXUS) Patrick C Campbell
2:00 PM	Particulate matter sensitivity to local emissions and meteorology over a Latin American megacity for source apportionment and uncertainty analysis James East	Towards Refining Estimates of Ammonia Emissions: Modeling Framework Preparations Shannon Capps
2:20 PM	Break	
2:50 PM	Model-Measurement Comparison of Ozone and Precursors Along Land-Water Interfaces during the 2017 LMOS Field Campaign Liljegren, J	Inter-comparison of Mobile Source Emissions from the CARS and CAPSS in Seoul Metropolitan Area, South Korea Minwoo Park
3:10 PM	Application of ozone source apportionment using CMAQISAM during LISTOS Qian Shu	Impact of anthropogenic emissions on urban air quality over the East African big conurbations of Addis Ababa, Kampala and Nairobi. Andrea Mazzeo
3:30 PM	Ramboll Shair: Integrating real-time sensor measurements and regional/local-scale models in Richmond, California Justin Bandoro	Incorporating Isotope into Atmospheric Chemistry Models Huan Fang
3:50 PM	Break	

4:15 PM	Lightning Poster Talks: Day 2	
5:00 - 7:00 PM	Poster Session: Day 2 and Reception with Research-Discussion Tables	
October 22, 2019		
	Grumman Auditorium	Dogwood Room
7:30 AM	Registration and Continental Breakfast	
8:00 AM	A/V Upload	
8:30 AM	Analysis of Recent Ozone Exceedances in Atlanta, GA Byeong-Uk Kim	Air Quality Impacts of Oil and Gas Emissions in the United States Srinivas Reka
8:50 AM	Source Apportionment Modeling to Investigate Local and Non-Local Contributions to Ground-Level Ozone in Albuquerque, New Mexico Garnet Erdakos	Examining the air pollutant emission implications of electric vehicle market penetration scenarios Dan Loughlin
9:10 AM	Mutual comparison of source sensitivities and apportionments obtained by BFM, DDM, and ISAM on $PM_{2.5}$ and ozone concentrations over Japan Satoru Chatani	Impact of future electrification of passenger cars on air quality within the United States Huizhong Shen
9:30 AM	Assessing the Impacts of Emissions from Oil and Gas Extraction on Urban Ozone and Associated Health Risks Congmeng Lyu	Optimal use of grid-connected energy storage to reduce human health impacts Qian Luo
9:50 AM	Assessing Air Quality Impact on Non-attainment Regions in Ohio Resulting From Power Plant Closures and Shale Gas Activity Saikat Ghosh	Impact of using the updated detailed-level marine emissions on Canadian Air Qualit Rabab Mashayekhi
10:10 AM	Break	
10:40 AM	Vehicle Emission Regulations Save Lives in California Shupeng Zhu	Relaxing energy policies on top of climate change will significantly undermine states efforts to attain U.S. ozone standards Huizhong Shen
11:00 AM	Exploring air emissions of per- and polyfluoroalkyl substances (PFAS): emission rates, chemical and depositional fate, and transport E.L. D'Ambro	Air pollution control strategies directly limiting national health damages in the U.S. Yang Ou
11:20 AM	Assessing $PM_{2.5}$ Model Performance for the Conterminous U.S. with Comparison to Model Performance Statistics from 2007-2015 James T. Kelly	The Fast Air Quality Responses from the Fine Particle Reduction Measures of South Korea Jinseok Kim
11:40 AM	Modeling of U.S. and International Contributions to Visibility Impairment at Class I Areas Brian Timin	Dynamical downscaling of a global chemistry-climate model to study the influence of climate change on mid-21st century $PM_{2.5}$ and Ozone distributions in the Continental US Surendra Kunwar
12:00 PM	Air Quality Modeling of a Typical Wintertime $PM_{2.5}$ Pollution Event in Cache Valley, Utah: Implications for Emission Control Strategies. Nancy Daher	Urban-Scale Source Attribution of Greenhouse Gases Using an Air Quality Model Mike Moran

12:20 PM	Lunch in Trillium	
	Remote Sensing/Sensor Technology and Measurements Studies Chaired by Daniel Tong (George Mason University) and Matthew Alvarado (AER)	Air Quality, Climate, and Energy, cont.
1:20 PM	Estimation of Surface NO_2 Using Airborne Remote Sensing Data and CMAQ Model Output from DISCOVER-AQ Campaigns Kenneth E. Pickering	
1:40 PM	A Retrieval Closure Study to Determine the Best Metrics for Evaluating the CMAQ Model with CrIS NH3 Retrievals Matthew J. Alvarado (AER)	The impact of the direct effect of aerosols on meteorology and air quality using aerosol optical depth assimilation during the KORUS-AQ campaign Jia Jung
2:00 PM	High-spatial resolution airborne mapping of NO_2 column densities of New York City and Long Island Sound Laura Judd	Understanding the Impacts of Land Use and Land Cover Change on Regional Climate in Sub-Saharan Africa: A Cautionary Tale for Regional Climate Modeling Timothy Glotfelty
2:20 PM	Overview of measurements and preliminary findings from the Long Island Sound Tropospheric Ozone Study 2018 (LISTOS) Luke Valin	Intensification of Extreme Precipitation in Eastern North Carolina Projected in Dynamically Downscaled CESM and CM3 Models Under Future Scenarios (2025-2100) Using WRF. Anna Jalowska
2:40 PM	Improving Mexico Emissions Inventory Using Satellite Data Tejas Shah	Quantifying the air quality and human health benefits of GHG mitigation Pathways in California Shupeng Zhu
3:00 PM	Comparison of $PM_{2.5}$ measured in urban North Carolina settings using a low-cost optical particle counter and Federal Equivalent Methods Brian Magi	Estimation of nose-level NO_2 in the Houston-Galveston area using airborne remote sensing data from DISCOVER-AQ and output from a 4-km resolution simulation with CMAQ D. Allen (Dale Allen)
3:30 PM	The CMAS Job and Career Fair!	
Poster Session 1: Monday at 4:00 PM		

Air Quality, Climate and Energy

Modeling the Contribution of Long Range Transport to Nitrogen Deposition in U.S. Hydrological Regions
Sharmin Akter

Modelling the impact of aromatics on secondary pollutants over eastern China
Xiaoyang Chen

Greater contribution from land-use related sources to reactive nitrogen deposition under future climate change
Yilin Chen

Improving Air Quality Simulation for 2016 Summer Ozone Episode by Assimilating Geostationary Satellite Observations
Peiyang Cheng

Projected Wildfire Impacts on Regional Air Quality in The Western United States
XINYI DONG

Impact of dust emission on particulate matter in spring of 2018 in China
Song Liu

Future ozone concentrations in the state of Delaware under climate change scenarios
Mojtaba Moghani

A multi-scale model analysis of ozone formation in the Bangkok Metropolitan Region, Thailand
Pornpan Uttamang

Air Quality Impacts of Energy Transitions: Analysis of Alternative Pathways Through 2050 Using the National Energy

Modeling System and Emissions Downscaling Mr. Shen Wang, Ph.D. Student, Johns Hopkins University
Model Development Imputing air quality estimates for alternative meteorological years using relative response values from a single meteorological year. G.E. Bowker What's New with the I/O API Carlie J. Coats, Jr. Investigating aqueous production pathways of particulate sulfur in CMAQ with AQCHEM-KMT (version 2) and the sulfur tracking method Kathleen Fahey Assessment of Environmental Variables that Affect Dissolved Oxygen Concentrations in Lake Erie Using Multi-media Modeling and Machine Learning Christina Feng Chang Development of PM2.5 short-term prediction model using Artificial Intelligence. JeongBeom Lee, Geon-Woo Yun Modelling high-resolution NO2 concentrations over the United Kingdom using RapidAIR Nicola Masey The Effect of Source-Resolved Primary Size Distributions on Particle Concentrations and Size predicted CMAQ Ben Murphy Improvements to the Integrated Source Apportionment Method (ISAM) for CMAQv5.3 release. S.L.Napelenok Development of a Visibility Forecasting Product using Canada's Wildfire Smoke Prediction System (FireWork) Rita So Kalman Filter Bias Correction for Improving Wildfire Smoke 24-hr Average PM2.5 Forecasting for AIRPACT5 Joseph K Vaughan
Modeling to Support Exposure and Health Studies and Community-scale Applications Evaluating the air quality impacts of an operational prescribed burning program Sadia Afrin Development of Smartphone Application for Modeling Personal Exposures to Ambient PM2.5 and Ozone Sarav Arunachalam Fusing CMAQ with Surface Observations to Improve Estimates of Air Quality & Health Impacts of Oct. 2017 California Wildfires Stephanie Cleland Mapping Global Surface Ozone Concentrations through the Statistical Fusion of Observations and Models Marissa DeLang and Jacob Becker CMAQ-Enhanced Estimates of Personal Exposure to Diesel Particulates Cesunica Ivey Fixed point versus time-activity based personal air pollution exposure assessment: Does the number of days of assessment matter? Xiangyu Jiang A comparison of land management modeling tools as used for estimating prescribed fire smoke impacts Megan Johnson Modeling Air Quality and Health Impacts of the 2017 California Wildfires Bonyoung Koo
The Impacts of Prescribed Burning on PM2.5 Air Quality and Human Health: Application to Georgia, USA Talat Odman A Comparative Study of Two-way and Offline Coupled WRF and CMAQ over the continental U.S.: Performance Evaluation and Impacts of Chemistry-Meteorology Feedbacks on Air Quality Kai Wang Effects of grid resolution on the global mortality burden of fine particulate matter and ozone Tammy Ruozhang Xu
Poster Session 2: Tuesday at 5:00 PM
Emissions Inventories, Models, and Processes Using WRF-STILT to Determine the Relative Contributions of US and Mexican Emissions to High Ozone Events in El

Paso, Texas Matthew Alvarado A Quantitative Assessment of Vehicle-class and Precursor-specific Contribution from Onroad Emissions to $PM_{2.5}$ and O_3 Formation in the Northeast and Mid-Atlantic U.S. Calvin Arter Implementation of a dynamical NH_3 emissions parameterization in CMAQ for improving PM2.5 simulation in Taiwan Fang-Yi Cheng EPA's National Emissions Inventory for Nonpoint Sources: Process and Improvements for the 2017 NEI Hannah Derrick or Jonathan Dorn U.S. Residential Wood Combustion (RWC) Survey: Results and Use in Improving RWC Emissions in the 2017 National Emissions Inventory David Cooley or Jonathan Dorn Chemical Speciation of $PM_{2.5}$ in Bogot, Colombia: Experimental Determination and Simulation with the Chemical Transport Model WRF-Chem Sebastian Orlando Espitia Cano Emissions of PCDD/Fs from 1960 to 2014 in China Ye Huang Hamilton Airshed Modelling System Janya Kelly Practical Application of Python for Emissions Data Processing, QA/QC, and Documentation Byeong-Uk Kim Improving Spatial Resolution of EDGAR Emissions for Mexico Amy McVey Using 15N in NO_x emissions for source identification Greg Michalski Modeling and Evaluation of Quebecs Air Quality due to an Increase in the Electric Vehicle Fleet Combined with Off-Road Emission Reductions Jessica Miville
Multiscale Model Applications and Evaluations Modeling SOA Formation over Eastern China: Impacts of Updates in CMAQ v5.3b2 relative to CMAQ v5.1 Xiaoyang Chen Assessment of a weather pattern-dependent bias correction method to the PM2.5 prediction in Taiwan Fang-Yi Cheng Performance evaluation of the updated and developed air quality forecasting system for South Korea. Dae-Ryun Choi Puget Sound Ports Air Quality Health Impacts Study Mahshid Etesamifard Fine-scale meteorological modeling of the land-sea breeze circulation of Long Island Sound and surrounding coastal areas Robert Gilliam and Ana Torres-Vazquez Evaluation and Intercomparison of Modeled Atmospheric Deposition over North America and Europe An Overview of Phase 4 of the Air Quality Model Evaluation International Initiative Christian Hogrefe Evaluation of GFS-driven CMAQ predictions of PM2.5 and O3 at NOAA Jianping Huang Organic mass predictions during PM2.5 high pollution episodes in China and Korea: high resolution model experiments Hyeon-Kook Kim Changes in ozone production chemistry across the U.S. between 2007 and 2016: An integrated modeling assessment Shannon Koplitz Apportioning Emission Source-group Impacts among Individual Sources: Application to Prescribed Fires Talat Odman Long-range transport of air pollutants over Brazilian Southeastern: Interaction between metropolitan areas Rizzieri Pedruzzi Numerical evaluation of the impacts of emission and meteorological characteristics on air pollution in the Seto Inland Sea region, Japan

Hikari Shimadera EPA-State 2016 Model Evaluation Forum Heather Simon The Benefits of Using High-Resolution Sea Surface Temperatures for Simulating Historical and Future Climate Extremes Tanya Spero Regulatory Modeling and SIP Applications Projecting Future Ground-Level Ozone Concentrations in Albuquerque, New Mexico Shih Ying Chang Particulate Matter Emissions from Building Destruction in Armed Conflict Regions Daniel Han Influence of the emission sources on O3 and PM2.5 concentrations in Taiwan using CMAQ-HDDM Yi-Ju Lee SCICHEM model performance evaluations for near-field regulatory applications Ryan Cleary and Chris Owen
Remote Sensing/Sensor Technology and Measurements Studies Atmospheric Monitoring of Methane Leaks from Shale Oil and Gas Production using Airborne Near-Infrared Spectrometer Saikat Ghosh Community Participatory Mapping Crowdsourced Platform for Monitoring Air Pollution Wansoo Im, Ph.D. Ambient measurements of biogenic VOCs near Cannabis facilities in Denver, CO Chi-tsan Wang

附錄三、"NOAA' s National Air Quality Forecast Capability operational and experimental updates"

NOAA's National Air Quality Forecast Capability operational and experimental updates

Dorothy Koch[1], Ivanka Stajner[2], Jeff McQueen[2], Pius Lee[3], Jianping Huang[2,5], Ho-Chun Huang[2,5], Li Pan[2,5], Youhua Tang[3,6], Daniel Tong[3,6], Patrick Campbell[3,6], Ariel Stein[3], James Wilczak[4], Irina Djalalova[4,8], Dave Allured[4,8], Phil Dickerson[7], Jose Tirado[1,9]

(1) NOAA NWS/STI
(2) NOAA NWS/NCEP
(3) NOAA ARL
(4) NOAA ESRL
(5) IMSG
(6) Cooperative Institute for Satellite Earth System Studies (CISESS)
(7) EPA
(8) CIRES, University of Colorado
(9) ERG

with contributions from the entire NAQFC Implementation Team

CMAS Conference, Chapel Hill, NC October, 2019

NAQFC related presentations

- Implementation of new satellite-based source maps in the FENGSHA dust module and initial application with the CMAQ-based NAQFC system, Daniel Tong (next speaker).
- Development of a Fast Fire Emission Processor and Its application with HMS-Bluesky and GBBEPx Inventories, Youhua Tang (Tue, Oct 22, 10:40 AM - 11:00 AM, Dogwood Room).
- Evaluation of GFS-driven CMAQ predictions of PM2.5 and O3 at NOAA, Jianping Huang (poster session, Tue, Oct 22, 05:00 PM - 07:45 PM, Main Atrium).

NWS context

The Office of Science and Technology Integration (OSTI) Modeling Division (about $29M/yr) Includes:

- NGGPS (Next Generation Global Prediction System)
- HFIP (Hurricane Forecast Improvement Program)
- “Weeks 3-4”
- Air Quality
- COASTAL Act

❑ We are moving towards “unification”, reducing the number of model component versions, for example using the FV3 dynamical core for all atmospheric applications, including AQ

❑ We are collaborating closely with the Research office (OAR) and community, to bring “Research to Operations” and vice versa.

❑ The Unified Forecast System (UFS) is becoming a central effort, started from our office, now also supported by OAR/OWAQ, and we are planning to extend the collaboration to other NOAA Offices and beyond: http://ufscommunity.org

❑ The UFS has 8 “applications”, including air quality, and an atmospheric chemistry working group

❑ Most of our air quality development work will now be supported under the UFS project, and we are in the project and proposal development stage now.

National Air Quality Forecast Capability

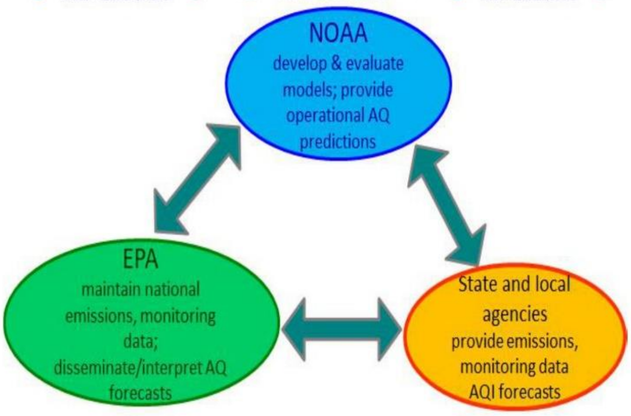
We improve the basis of air quality alerts and provide air quality information to people at risk to further NWS mission of protecting life and property and the enhancement of the national economy.

National Air Quality Forecast Capability (NAQFC) develops and implements operational air quality forecast guidance for the United States.

Current operational Prediction Capabilities are:

- Ozone nationwide
- Smoke nationwide
- Dust over CONUS
- Fine particulate matter (PM2.5) nationwide

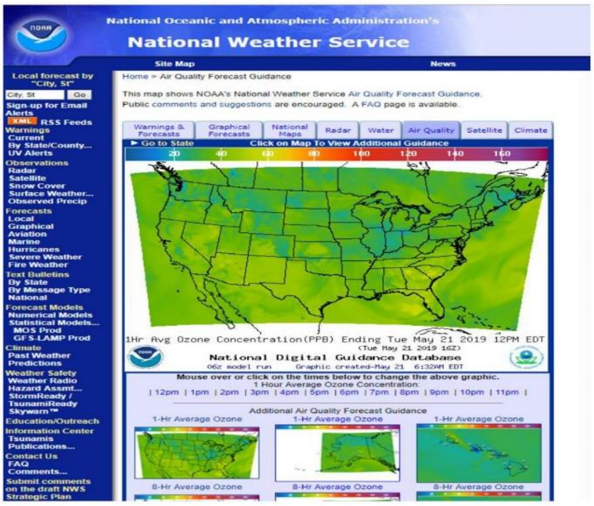
These capabilities rely on a strategic partnership with the Environmental Protection Agency (EPA) and state and local air quality forecasters.



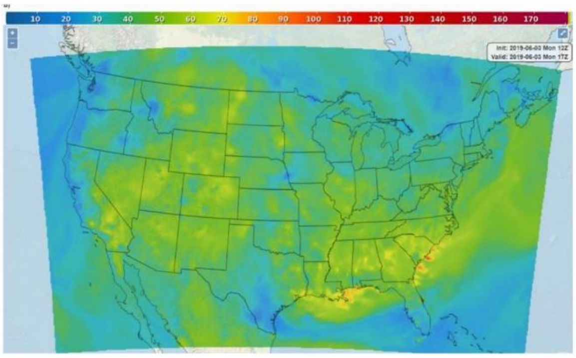
附錄三、" NOAA’ s National Air Quality Forecast Capability operational and experimental updates"

Our products are available @

Realtime images @ airquality.weather.gov and as GRIB files from ftp://tgftp.nws.noaa.gov/SL.us008001/ST.opnl/DF.gr2/DC.ndgd/GT.aq/AR.conus/



In GIS format @ https://idpgis.ncep.noaa.gov/arcgis/rest/services/NWS_Forecasts_Guidance_Warnings

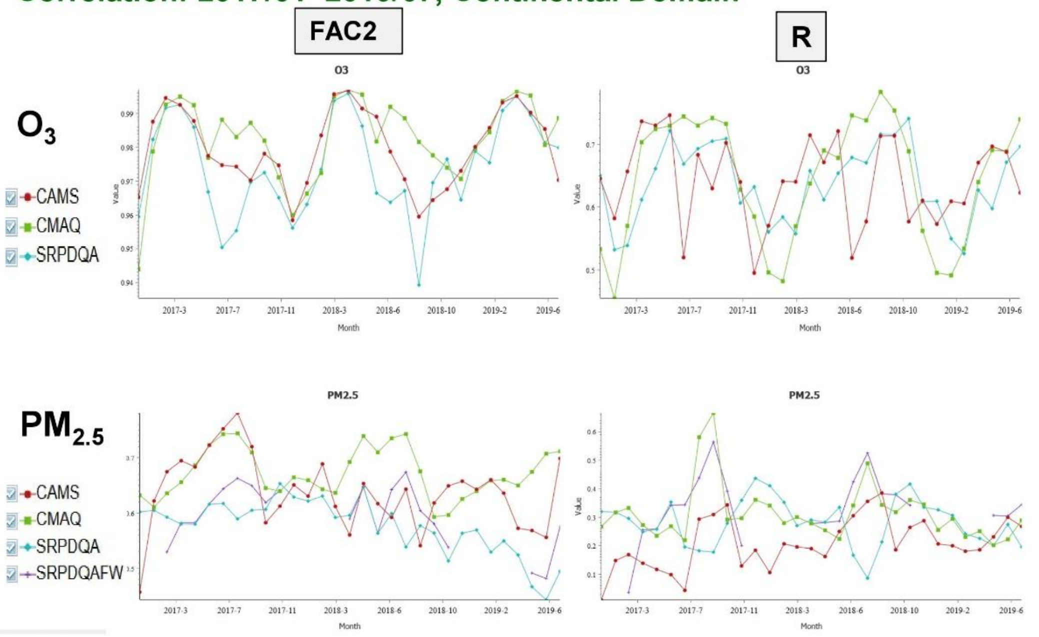


Historical database available from the National Digital Guidance Database@ https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/national-digital-guidance-database-ndgd

Operational centers Forecast performance analysis

- NAQFC/CMAQ has the best performance based on several metrics against other operational centers models, ECCC (Regional AQ Deterministic Prediction system) Canada and ECMWF (CAMS-IFS)
- NAQFC/CMAQ has best overall Factor of 2 fraction (FAC2) scores for O3 and PM2.5.
- For ozone in the summertime, NAQFC/CMAQ has the best correlations.
- NAQFC/CMAQ has best (closest to 0) Mean Fractional Bias for daily max O3 and PM2.5
- NAQFC/CMAQ has best overall performance (AQPI) for summertime daily max O3
- NAQFC/CMAQ has best overall performance (AQPI) for daily max PM2.5
- All comparison statistics based on CMAQ raw output

Time Series of O_3 and $PM_{2.5}$ Mean Monthly Values for Factor-of-2 and Correlation: 2017/01–2019/07, Continental Domain



Moran, et al

*Statistics are calculated using **daily MAX** observed and forecasted concentrations*

Operational updates implemented last December

Updated fine particulate matter (PM2.5) bias correction system to use:

- Consistent model predictions for training of the unified KFAN bias correction system
- Increased number of observation sites for model bias correction to over 900 monitors
- Improvements to forecast extreme events by adding the difference between the current raw model forecast and historical analogs’ mean to the KFAN bias-corrected predictions

New ozone bias correction with the same unified codes and configuration

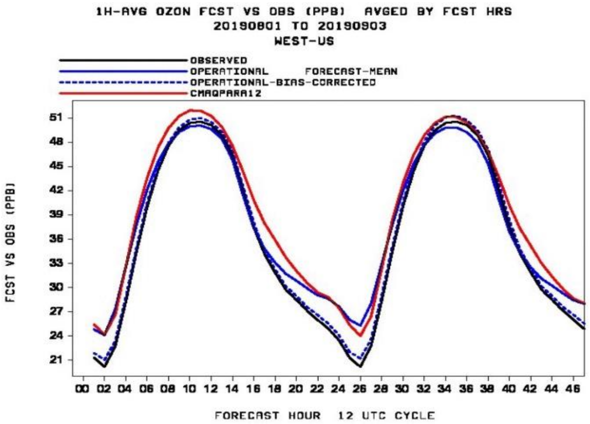
- Uses ozone, wind direction, wind speed, temperature, solar radiation, NOx, NOy and PBL height as parameters to identify analogs
- airquality.weather.gov display bias corrected ozone instead of raw ozone

Updated anthropogenic emissions (NEI2014v2)

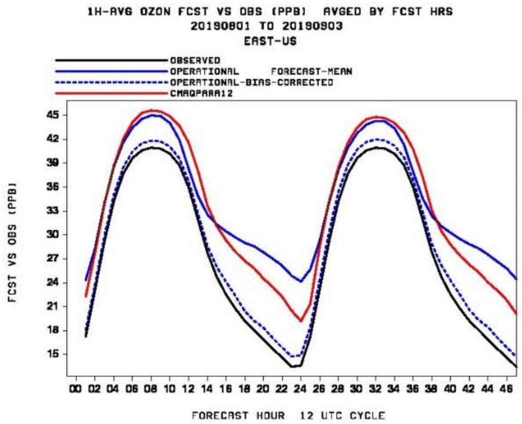
Update Alaska and Hawaii domain CMAQ code to the same version used for CONUS:

- CB05 gas-phase and aero6 aerosol chemistry (155 species)
- Improved heterogeneous, aqueous, winter-time reactions
- Improved SOA and coarse mode PM

Performance of Ozone predictions:
Observed Vs predicted 1 hr averaged Diurnal variability, August 2019

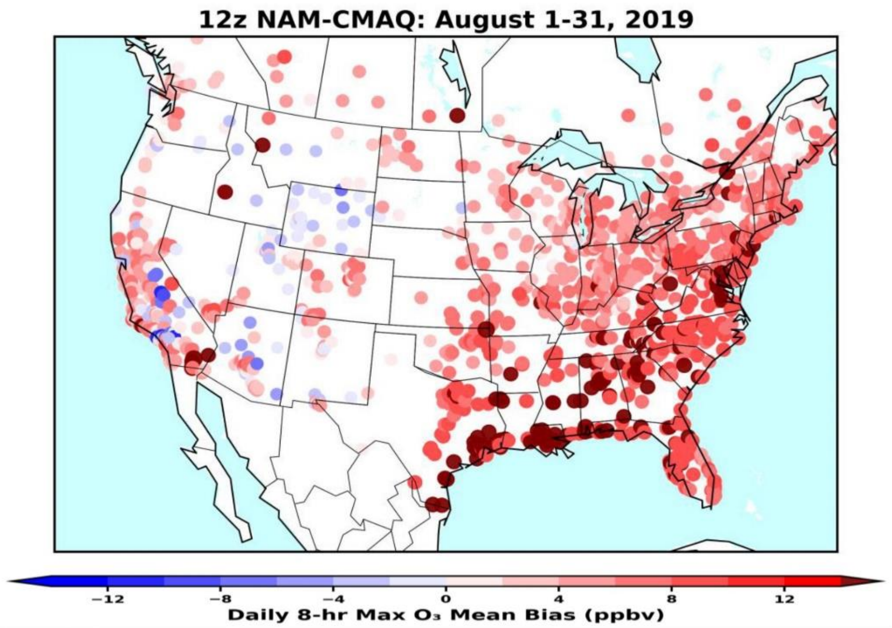


Western U.S.

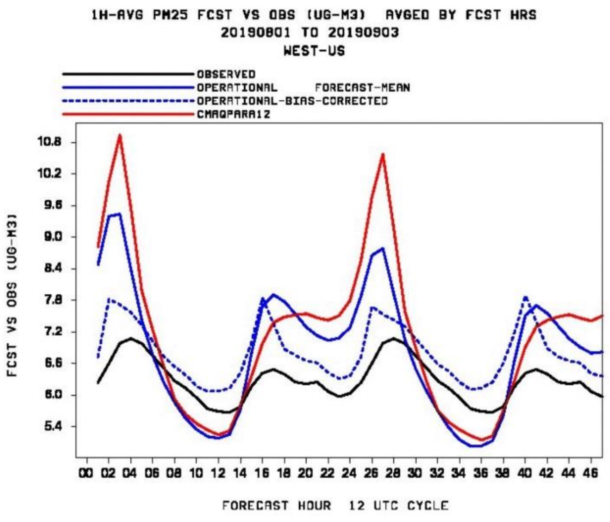


Eastern U.S.

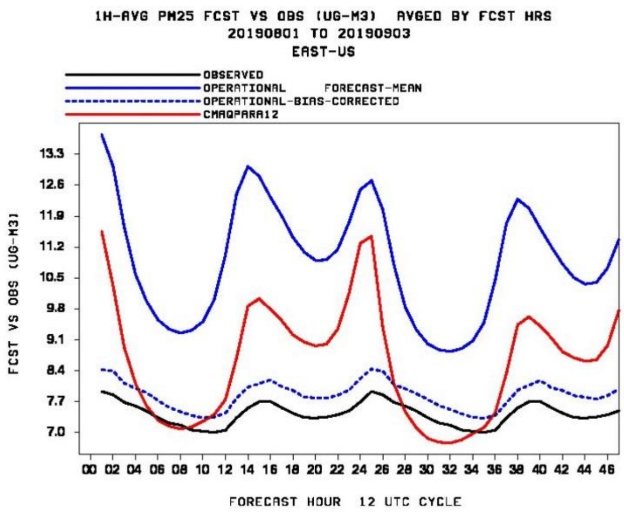
Performance of Ozone predictions:
Daily 8 hr max mean bias, August 2019



Performance of PM predictions:
Observed Vs predicted 1 hr averaged Diurnal variability, August 2019

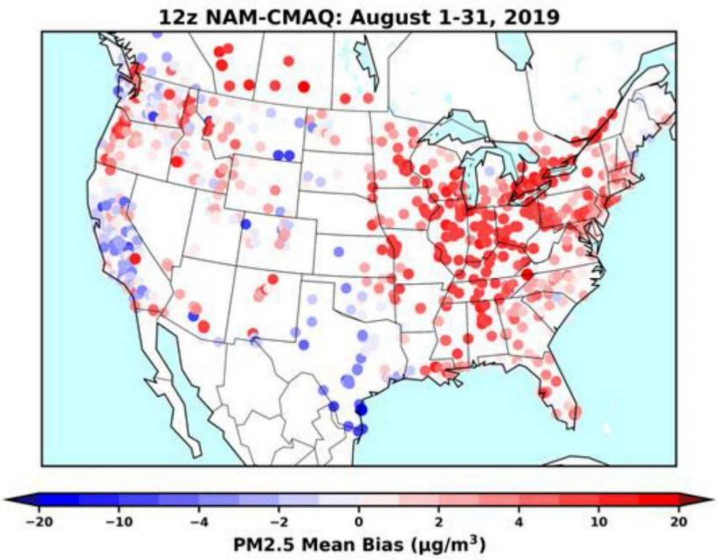


Western U.S.



Eastern U.S.

Performance of PM predictions:
1 hr daily max PM2.5 August 2019 Monthly Average Bias

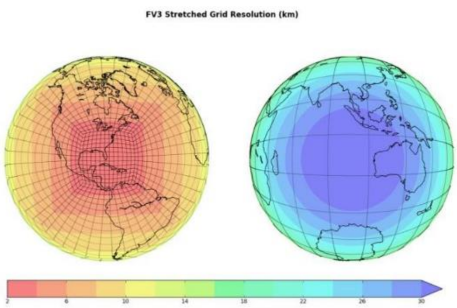


NAQFC Future updates and work in progress

- Couple and drive CMAQ with FV3GFS, NOAA’s Next Generation Global Prediction System.
- Extend the range of CMAQ predictions from 48 hours to 72 hours
  - Including the KFAN/Bias corrected products
- Updates to fire emission scheme (Global Biomass Burning Emissions Product eXtended (GBBEPx)
- Use of GEFS-Aerosols for lateral boundary conditions
- Develop new probabilistic forecast product for ozone and PM2.5
- Working on initiating display of operational PM 2.5 products on NWS websites and ozone bias correction on GIS web services

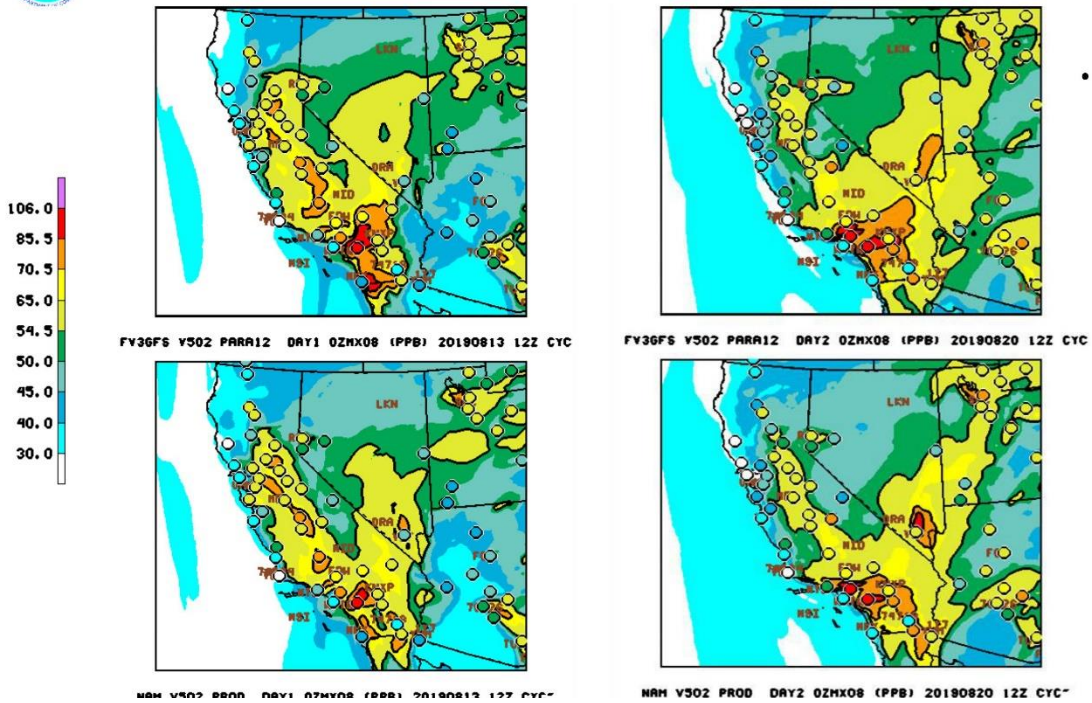
Transitioning to FV3GFS-CMAQ

- The new dynamic core, Finite-Volume on a Cubed-Sphere (FV3)
- NOAA next generation global prediction system
- Allows for higher resolution and extension of weather forecast through 14 days
- Implemented last June



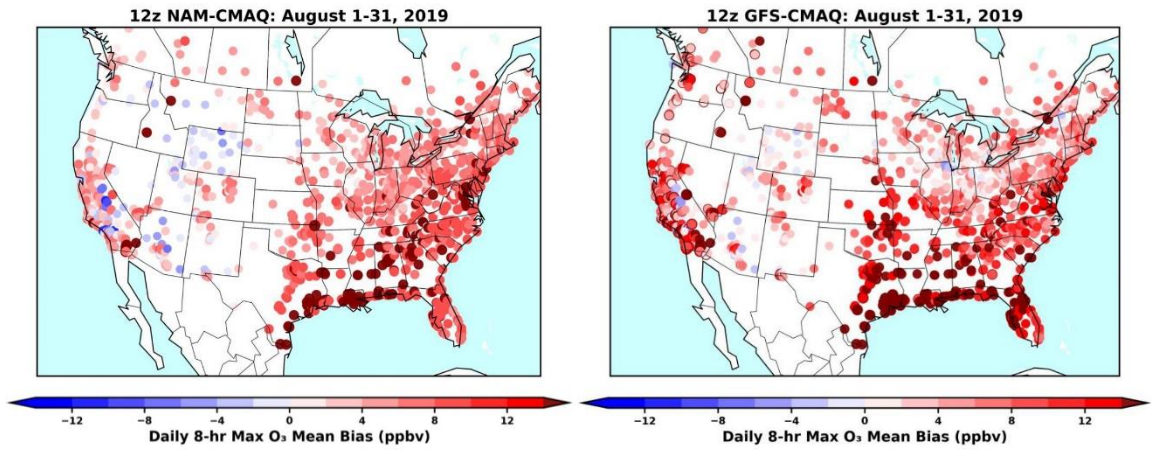
noaa.gov

CMAQ Ozone driven by FV3GFS 13 km



- FV3 and operational predictions are similar

8 hr daily max Ozone (day 1) August 2019 Monthly Average Bias



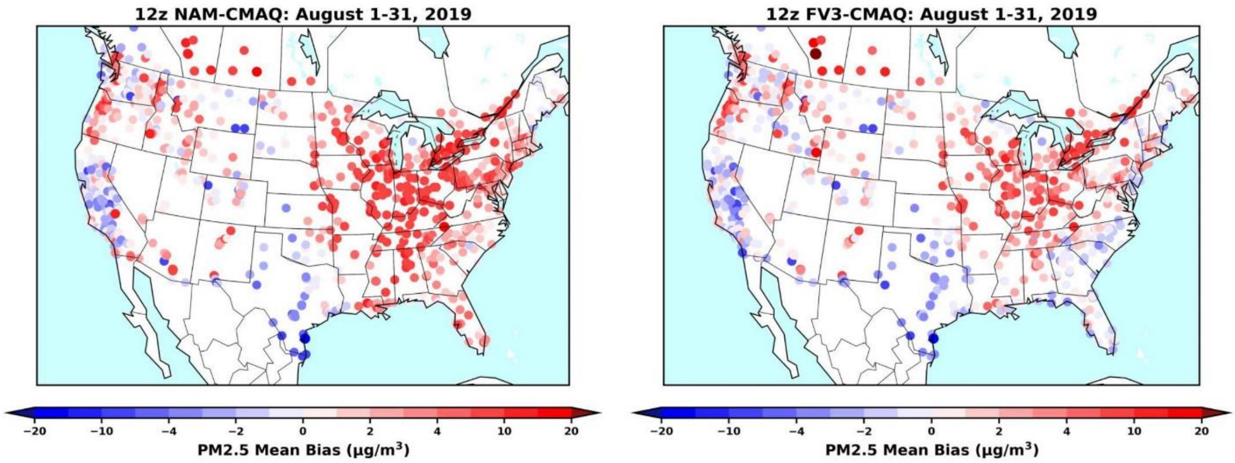
NAM driven **FV3GFS driven**

Both models over predict Ozone, for FV3-CMAQ in SE and Mid-Atlantic slightly larger over prediction

Jianping Huang, EMC
Benjamin Yang, PSU

附錄三、" NOAA’ s National Air Quality Forecast Capability operational and experimental updates"

1 hr daily max PM2.5 August 2019 Monthly Average Bias



Both models over predict PM over north
FV3-CMAQ: under prediction over south

Jianping Huang, EMC
Benjamin Yang, PSU

Global Biomass Burning Emissions Product eXtended (GBBEPx)

- Currently also testing a new fire emissions scheme with FV3GFS-CMAQ
- GBBEPx calculates biomass burning emissions from wildfires using the Fire Radiative Power (FRP) derived from satellites.
- Uses observations from MODIS, VIIRS and Geostationary satellites like GOES
- Developed by NOAA, NESDIS and scientist from NASA and South Dakota State University
- Currently testing 2 configurations in near real time and a retrospective run from last year’s Camp fire event in California
- We also participated in this year multiagency Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) field campaign and will be using the data to evaluate our system

Case study
GBBEPx Mean Fire Radiative Power

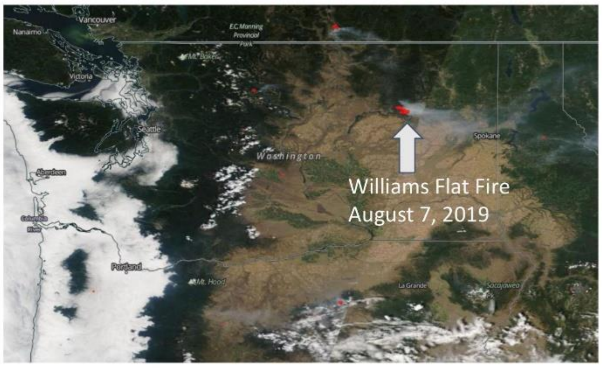
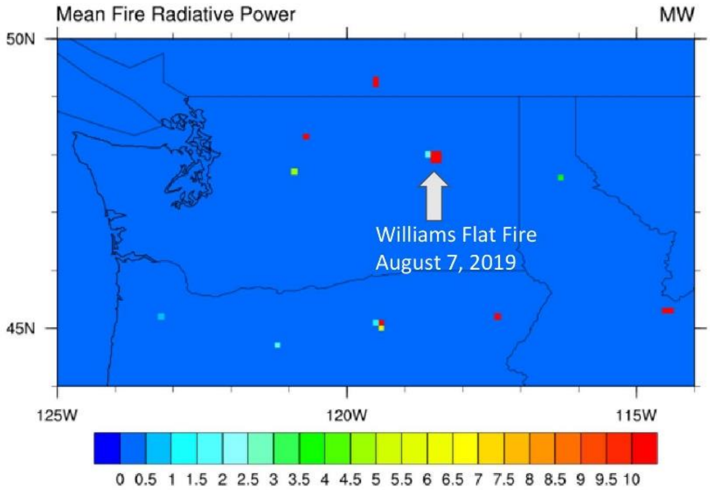
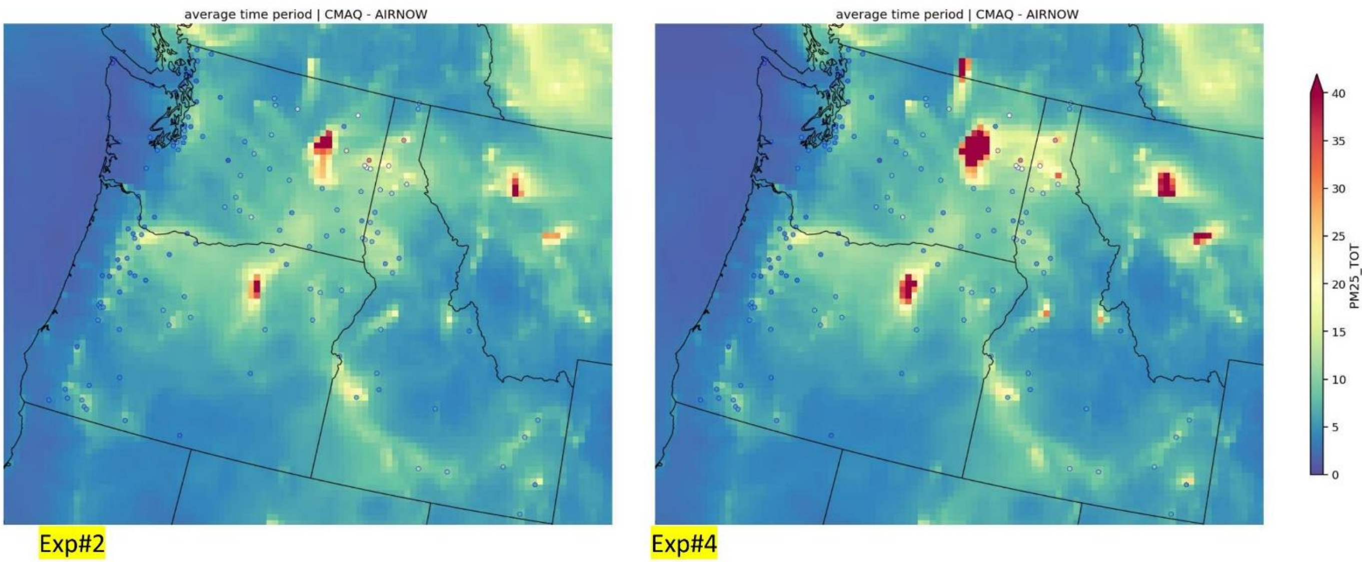


Image credit: NASA



Suomi NPP satellite natural-color image using the VIIRS (Visible Infrared Imaging Radiometer Suite)

CMAQ-AIRNOW $PM_{2.5}$ Evaluation - Region 10

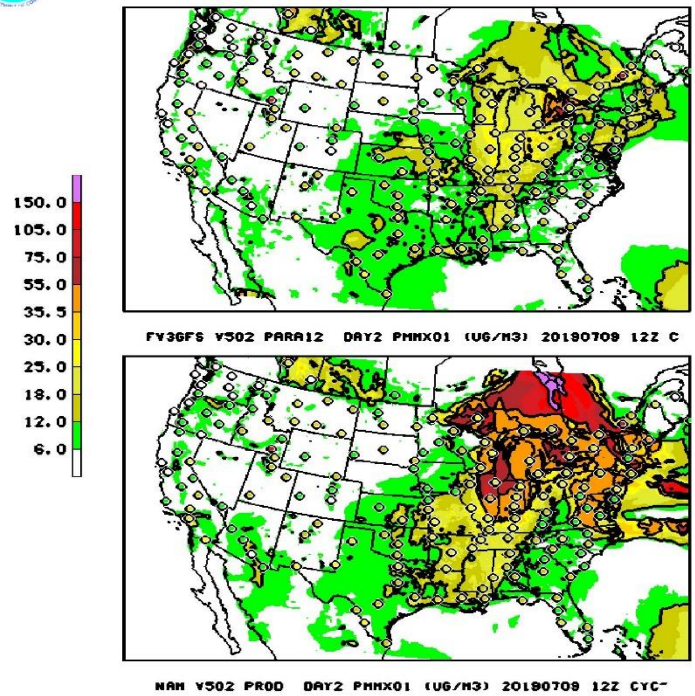


MONET AIR RESOURCES LABORATORY

Average of 24-hr forecasts for 2019-08-06_13 to 2019-08-08_12

ARL AQ team, Experimental product

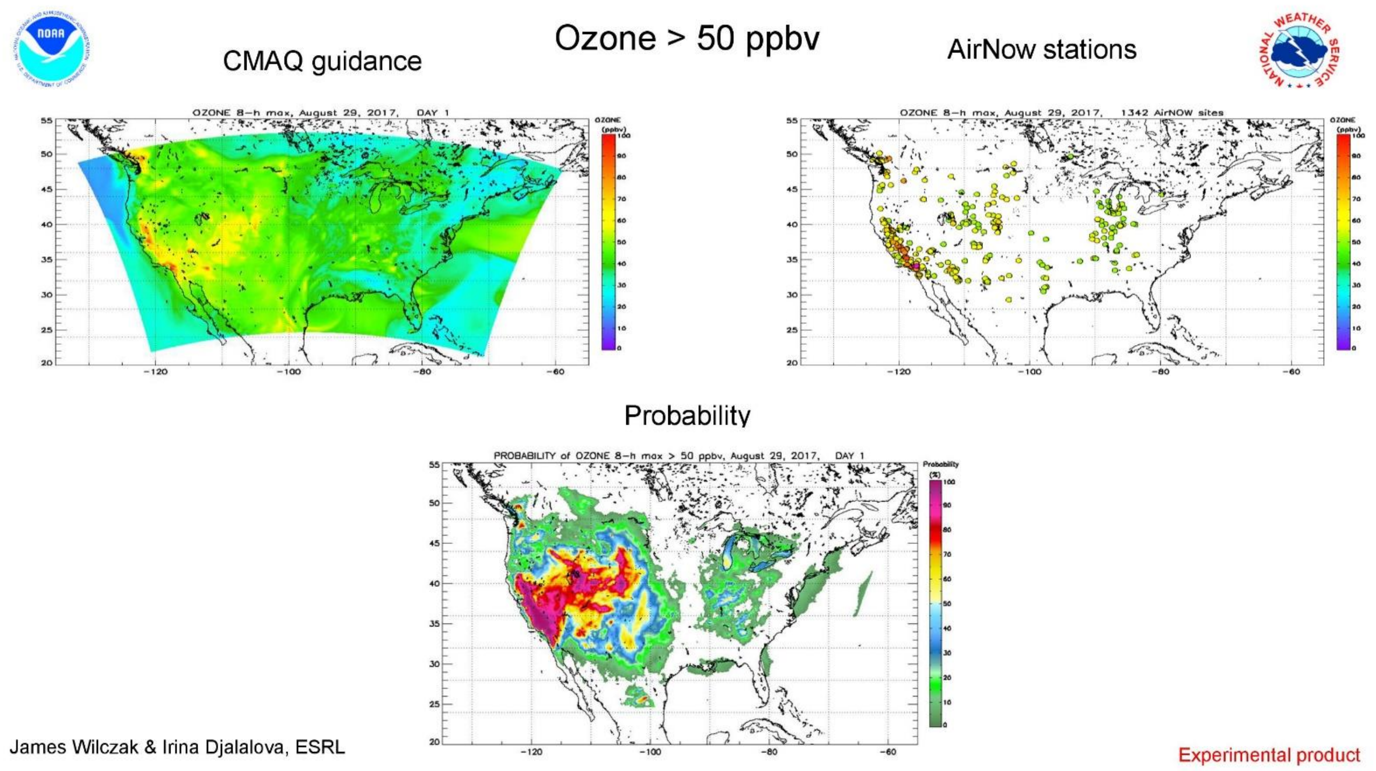
NAM vs FV3 fire cases

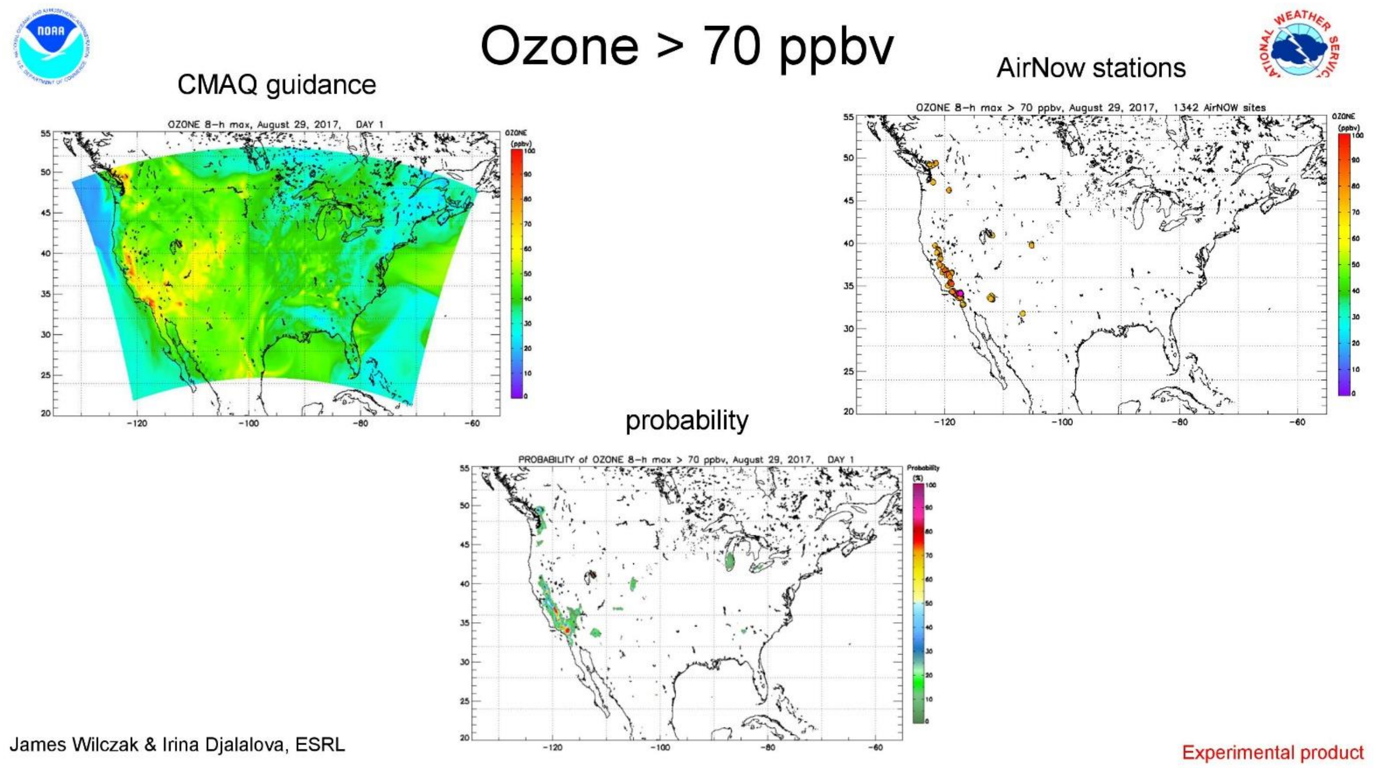


- Para12 GBx run performs best especially during fire events
- FV3 runs under predict over SE away from fires

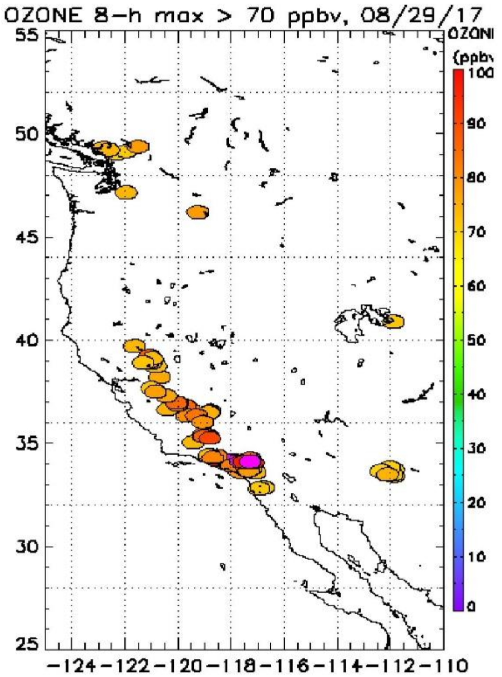
Probabilistic forecast

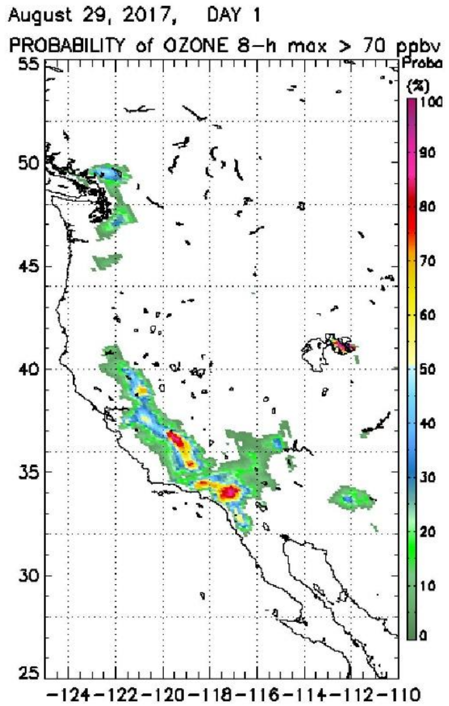
- In collaboration with partners from NOAA Earth System Research Laboratory probabilistic forecast for Ozone and PM2.5 is being developed
- The probabilities are calculated from a climatology first guess of previous CMAQ predictions and computed analogs from AirNOW observation sites around the nation.
- The following are examples for Ozone > 50 ppbv and Ozone > 70 ppbv respectively


Ozone > 50 ppbv
CMAQ guidance
AirNow stations
OZONE 8-h max, August 29, 2017, DAY 1
OZONE 8-h max, August 29, 2017, 1342 AirNOW sites
Probability
PROBABILITY of OZONE 8-h max > 50 ppbv, August 29, 2017, DAY 1
James Wilczak & Irina Djalalova, ESRL
Experimental product


Ozone > 70 ppbv
CMAQ guidance
AirNow stations
OZONE 8-h max, August 29, 2017, DAY 1
OZONE 8-h max > 70 ppbv, August 29, 2017, 1342 AirNOW sites
probability
PROBABILITY of OZONE 8-h max > 70 ppbv, August 29, 2017, DAY 1
James Wilczak & Irina Djalalova, ESRL
Experimental product

附錄三、" NOAA’ s National Air Quality Forecast Capability operational and experimental updates"





Summary

- We provide real time hourly predictions of ozone, particulate matter, smoke and dust to the nation
- Our work relies on a strategic partnership with the Environmental Protection Agency (EPA) and state and local air quality forecasters.
- Our products are freely available online (airquality.weather.gov, others)

December 18 implementation:

- New bias-corrected ozone predictions
- Updated fine particulate matter (PM2.5) bias correction
- Updated anthropogenic emissions from NEI2014v2
- Updated Alaska and Hawaii domain CMAQ code to the same version used for CONUS

Work in progress:

- Future improvements will include coupling of CMAQ with FV3GFS, extension to 72 hour predictions and new fire emissions processing

Thank you for your attention

Questions?

Contact me @ jose.tirado-delgado@noaa.gov

Acknowledgments:
AQF implementation team members

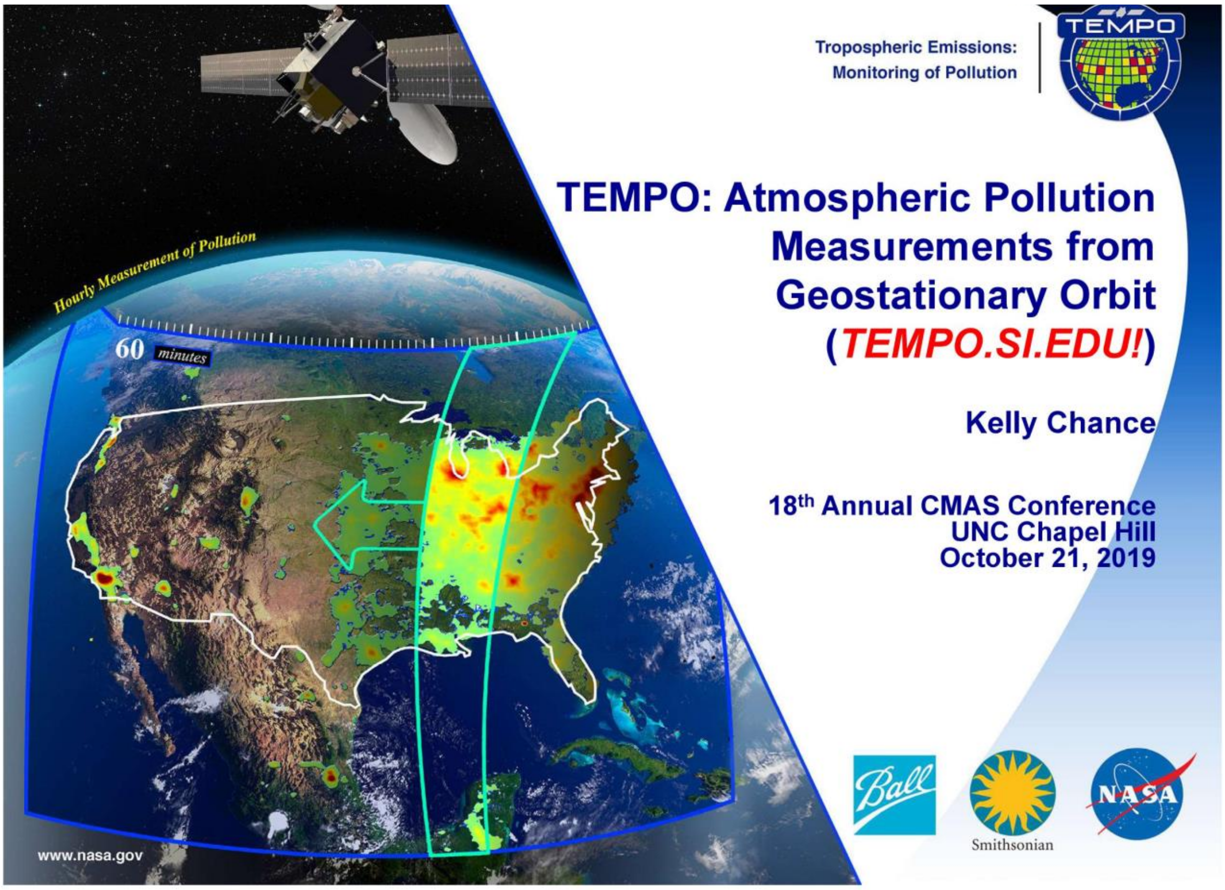
Special thanks to new and previous NOAA and EPA team members who contributed to the system development

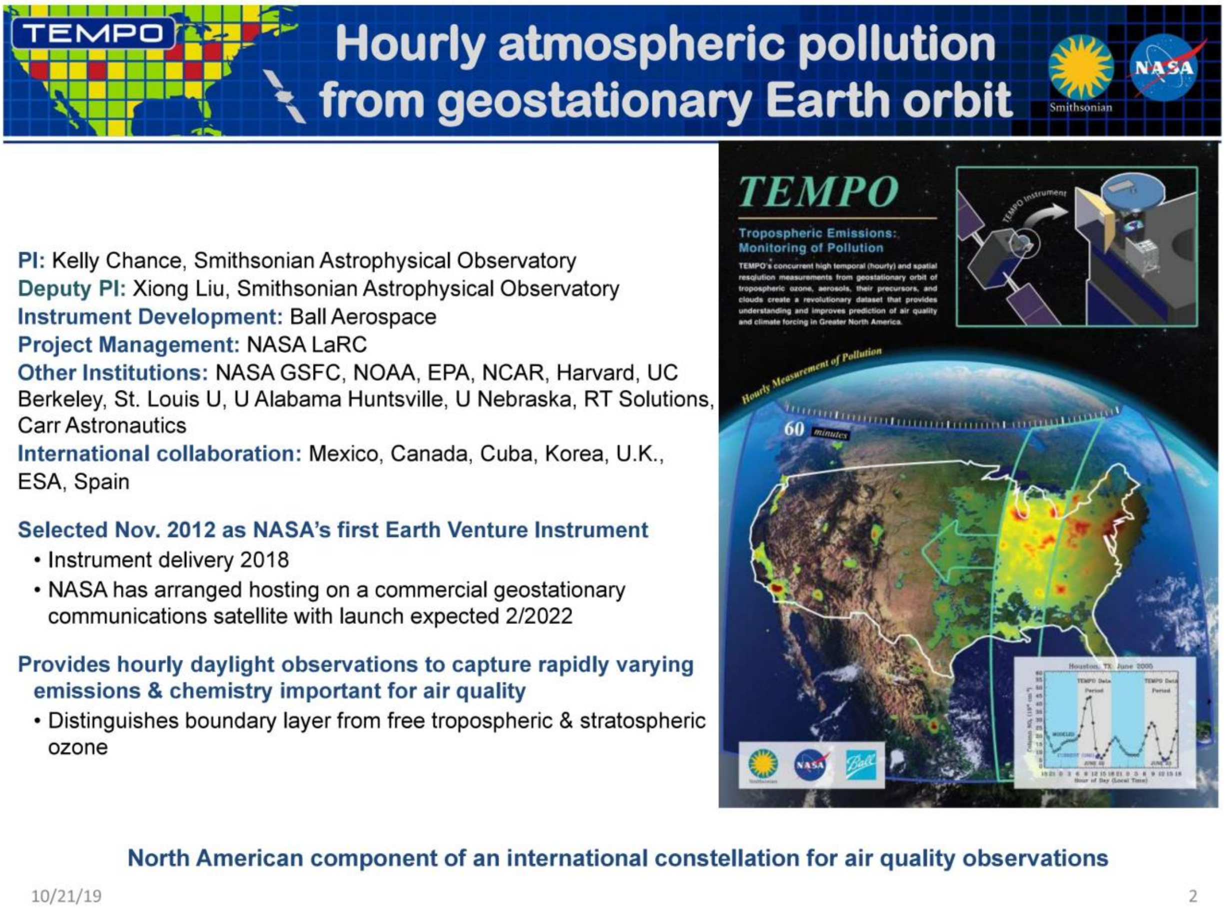
NOAA/NWS/STI	***Dorothy Koch***	***STI modeling program lead***
NWS/OD	***Cynthia Jones***	***Data Communications***
NWS/OSTI/MDL	***David Miller, Dave Ruth***	***Dev. Verification, NDGD Product Development***
NWS/STI	***Jose Tirado-Delgado***	***Program Support***
NESDIS/NCDC	***Alan Hall***	***Product Archiving***
NWS/NCEP		
	Ivanka Stajner, Jeff McQueen, Jianping Huang, Ho-Chun Huang	**AQF model interface development, testing, & integration**
	Jun Wang, Li Pan, *Sarah Lu	**Global dust aerosol and feedback testing**
	***Brad Ferrier, *Eric Rogers,**	**NAM coordination**
	***Hui-Ya Chuang, Perry Shafran, Boi Voung**	
	Geoff Manikin	**Smoke and dust product testing and integration**
	Rebecca Cosgrove, Steven Earle, Chris Magee	**NCO transition and systems testing**
	Mike Bodner, Andrew Orrison	**HPC coordination and AQF webdrawer**
ESRL/PSD		
Jim Wilczak, Irina, Djalalova, Dave Allerud,		***bias correction development***
NOAA/OAR/ARL		
	Pius Lee, Daniel Tong, Youhua Tang	**CMAQ development, adaptation of AQ simulations for AQF**
	Barry Baker, Patrick Campbell	
	Ariel Stein	**HYSPLIT adaptations**
NESDIS/STAR	***Shobha Kondragunta***	***Smoke and dust verification product development***
NESDIS/OSDPD	***Liqun Ma***	***Production of smoke and dust verification products***
EPA/OAQPS	***partners:***	
Chet Wayland, Phil Dickerson, Brad Johns, John White		***AIRNow development, coordination with NAQFC***

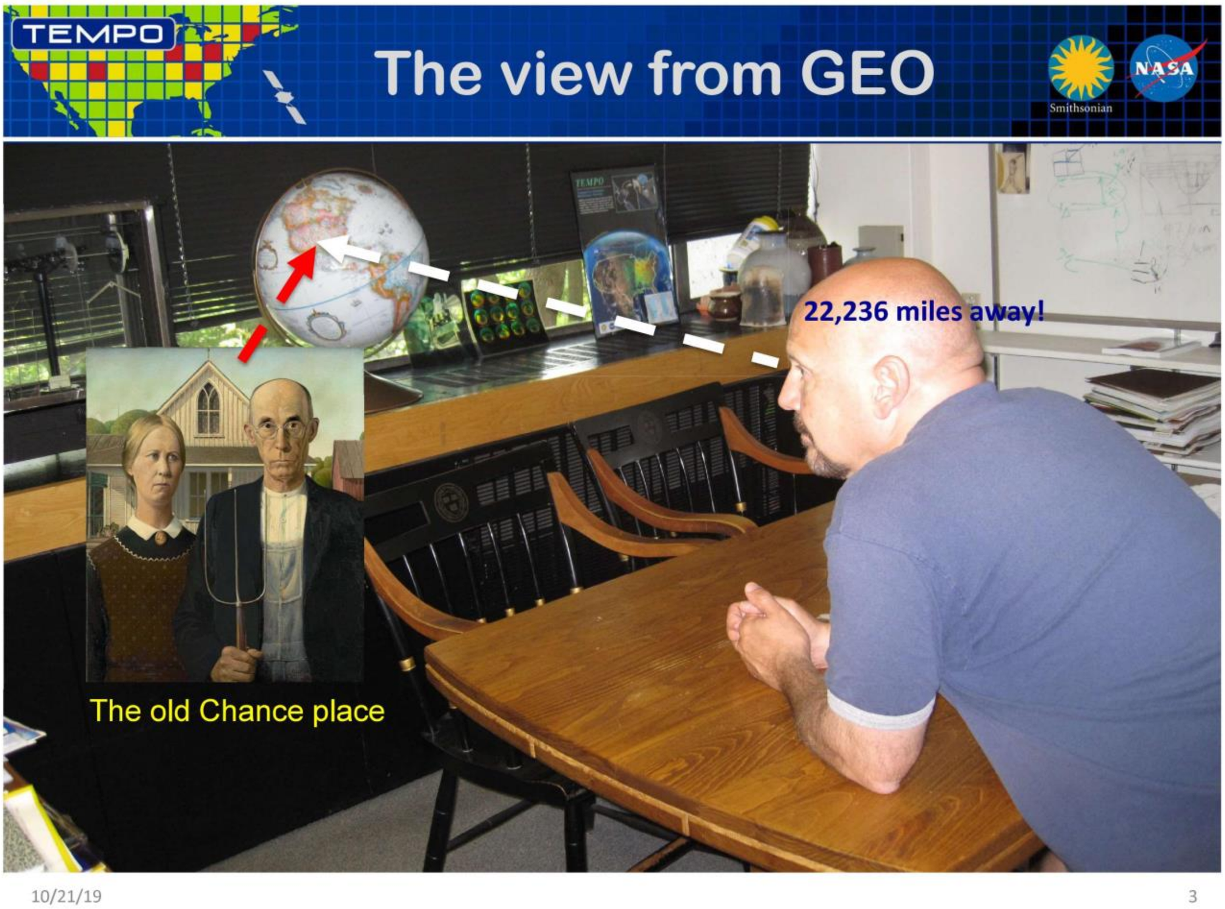
* Guest Contributors

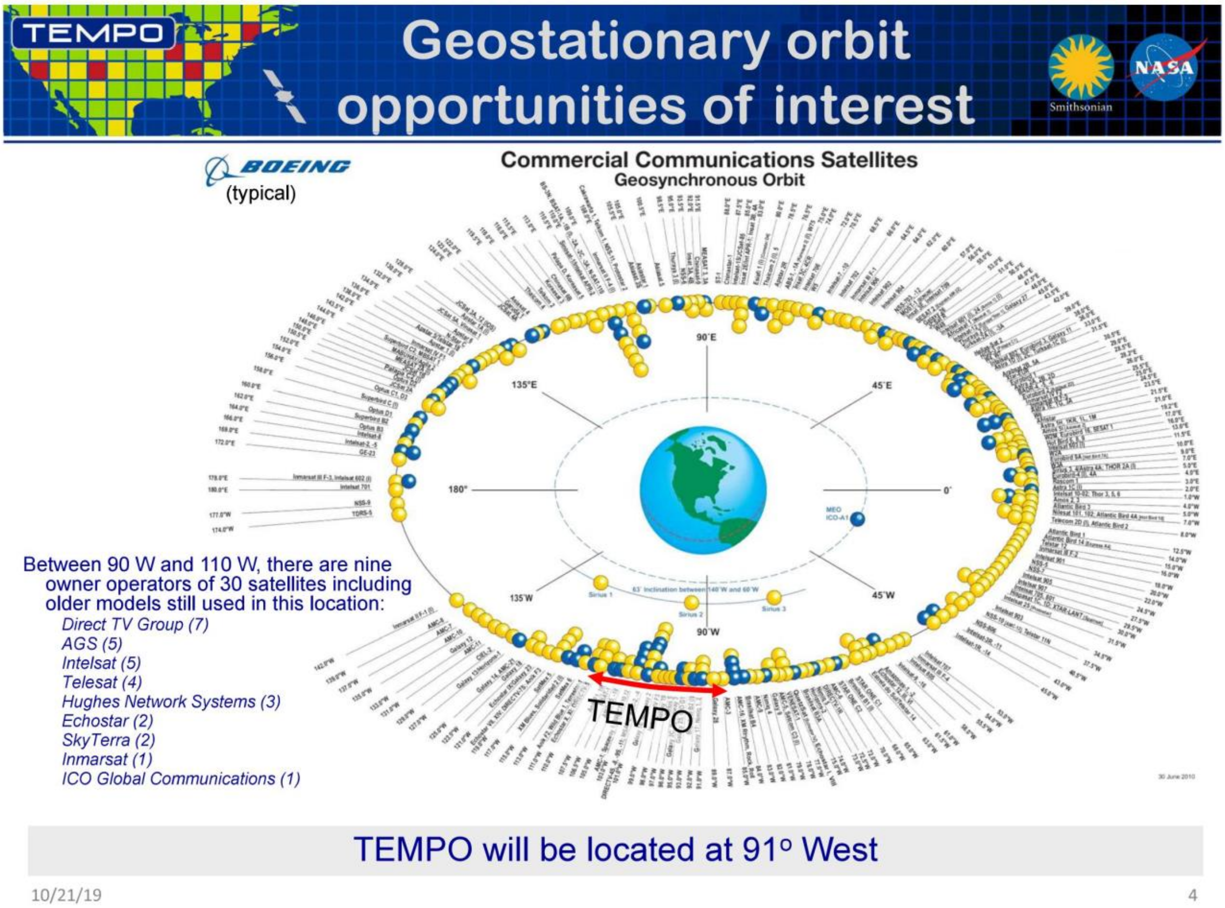
28

附錄四、"New Insights into the Health Effects of Air Pollution and Persistent Knowledge Gaps: Why is CMAS more important now than ever?"






TEMPO
The view from GEO
Smithsonian
NASA
22,236 miles away!
The old Chance place
10/21/19
3


TEMPO
Geostationary orbit opportunities of interest
Smithsonian
NASA
BOEING
(typical)
Commercial Communications Satellites
Geosynchronous Orbit
90°E
135°E
45°E
180°
0°
135°W
45°W
90°W
Between 90 W and 110 W, there are nine owner operators of 30 satellites including older models still used in this location:
Direct TV Group (7)
AGS (5)
Intelsat (5)
Telesat (4)
Hughes Network Systems (3)
Echostar (2)
SkyTerra (2)
Inmarsat (1)
ICO Global Communications (1)
TEMPO
TEMPO will be located at 91° West
10/21/19
4

TEMPO status

- **Instrument completed, accepted, delivered, now in storage**
- **Commercial geostationary satellite host selected for launch in February 2022 to 91^{o}W**

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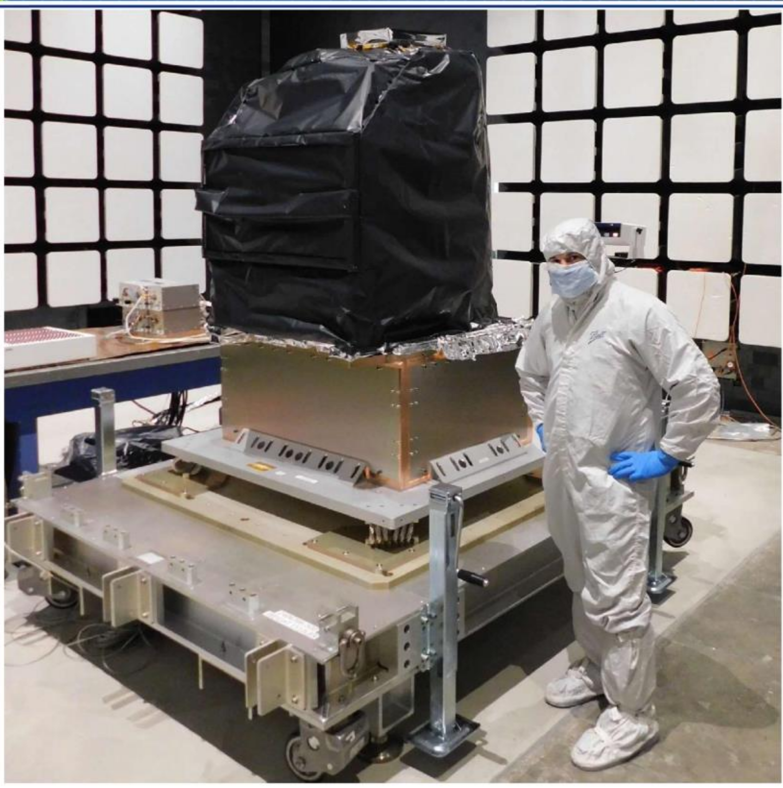
Ready for storage



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TEMPO

TEMPO instrument concept

Smithsonian NASA

- **Measurement technique**
  - Imaging grating spectrometer measuring solar backscattered Earth radiance
  - Spectral band & resolution: 290-490 + 540-740 nm @ 0.6 nm FWHM, 0.2 nm sampling
  - 2 2-D, 2k × 1k, detectors image the full spectral range for each geospatial scene
- **Field of Regard (FOR) and duty cycle**
  - Mexico City/Yucatan, Cuba to the Canadian oil sands, Atlantic to Pacific
  - Instrument slit aligned N/S and swept across the FOR in the E/W direction, producing a radiance map of Greater North America in one hour
- **Spatial resolution**
  - 2.1 km N/S × 4.7 km E/W native pixel resolution (9.8 km^2)
  - Co-add/cloud clear as needed for specific data products
- **Standard data products and sampling rates**
  - Most sampled hourly, including eXceL O_3 (troposphere, PBL)
  - NO_2, H_2CO, $C_2H_2O_2$, SO_2 sampled hourly (average results for ≥ 3/day if needed)
  - Measurement requirements met up to 50° for SO_2, 70° SZA for other products

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TEMPO

TEMPO science questions

Smithsonian NASA

1. What are the temporal and spatial variations of **emissions of gases and aerosols important for air quality** and climate?
2. What are the physical, chemical, and dynamical **processes that transform tropospheric composition and air quality** over scales ranging from urban to continental, diurnally to seasonally?
3. How does air pollution drive **climate forcing** and how does climate change affect **air quality** on a continental scale?
4. How can observations from space **improve air quality forecasts and assessments** for societal benefit?
5. How does **intercontinental transport** affect air quality?
6. How do **episodic events**, such as wild fires, dust outbreaks, and volcanic eruptions, affect atmospheric composition and air quality?

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附錄四、"New Insights into the Health Effects of Air Pollution and Persistent Knowledge Gaps: Why is CMAS more important now than ever?"

TEMPO Science Team, U.S.

Team Member	Institution	Role	Responsibility
K. Chance	SAO	PI	Overall science development; **Level 1b, H_2CO, $C_2H_2O_2$**
X. Liu	SAO	Deputy PI	Science development, data processing; **O_3 profile, tropospheric O_3**
J. Al-Saadi	LaRC	Deputy PS	Project science development
J. Carr	Carr Astronautics	Co-I	**INR Modeling and algorithm**
M. Chin	GSFC	Co-I	Aerosol science
R. Cohen	U.C. Berkeley	Co-I	NO_2 validation, atmospheric chemistry modeling, process studies
D. Edwards	NCAR	Co-I	VOC science, synergy with carbon monoxide measurements
J. Fishman	St. Louis U.	Co-I	AQ impact on agriculture and the biosphere
D. Flittner	LaRC	Project Scientist	Overall project development; STM; instrument cal./char.
J. Herman	UMBC	Co-I	Validation (PANDORA measurements)
D. Jacob	Harvard	Co-I	Science requirements, atmospheric modeling, process studies
S. Janz	GSFC	Co-I	Instrument calibration and characterization
J. Joiner	GSFC	Co-I	**Cloud, total O_3, TOA shortwave flux research product**
N. Krotkov	GSFC	Co-I	**NO_2, SO_2, UVB**
M. Newchurch	U. Alabama Huntsville	Co-I	Validation (O_3 sondes, O_3 lidar)
R.B. Pierce	NOAA/NESDIS	Co-I	AQ modeling, data assimilation
R. Spurr	RT Solutions, Inc.	Co-I	**Radiative transfer modeling for algorithm development**
R. Suleiman	SAO	Co-I, Data Mgr.	Managing science data processing, **BrO, H_2O, and L3 products**
J. Szykman	EPA	Co-I	AIRNow AQI development, validation (PANDORA measurements)
O. Torres	GSFC	Co-I	**UV aerosol product, AI**
J. Wang	U. Iowa	Co-I	Synergy w/GOES-R ABI, **aerosol research products**
J. Leitch	Ball Aerospace	Collaborator	Aircraft validation, instrument calibration and characterization
D. Neil	LaRC	Collaborator	GEO-CAPE mission design team member

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TEMPO Science Team, non-U.S.

Team Member	Institution	Role	Responsibility
Randall Martin	Dalhousie U.	Collaborator	Atmospheric modeling, air mass factors, AQI development
Chris McLinden	Environment Canada	Collaborator	Canadian air quality coordination
Michel Grutter de la Mora	UNAM, Mexico	Collaborator	Mexican air quality coordination
Gabriel Vazquez	UNAM, Mexico	Collaborator	Mexican air quality, algorithm physics
Amparo Martinez	INECC, Mexico	Collaborator	Mexican environmental pollution and health
J. Victor Hugo Paramo Figeuroa	INECC, Mexico	Collaborator	Mexican environmental pollution and health
Brian Kerridge	Rutherford Appleton Laboratory, UK	Collaborator	Ozone profiling studies, algorithm development
Paul Palmer	Edinburgh U., UK	Collaborator	Atmospheric modeling, process studies
Alfonso Saiz-Lopez	CSIC, Spain	Collaborator	Atmospheric modeling, process studies
Juan Carlos Antuña Marrero	GOAC, Cuba	Collaborator	Cuban Science team lead, Cuban air quality
Osvaldo Cuesta	GOAC, Cuba	Collaborator	TEMPO validation, Cuban air quality
René Estevan Arredondo	GOAC, Cuba	Collaborator	TEMPO validation, Cuban air quality
J. Kim	Yonsei U.	Collaborators, Science Advisory Panel	Korean GEMS, CEOS constellation of GEO pollution monitoring
C.T. McElroy	York U. Canada		CSA PHEOS, CEOS constellation of GEO pollution monitoring
B. Veihelmann	ESA		ESA Sentinel-4, CEOS constellation of GEO pollution monitoring
J.P. Veefkind	KNMI		ESA Sentinel-5P (TROPOMI)

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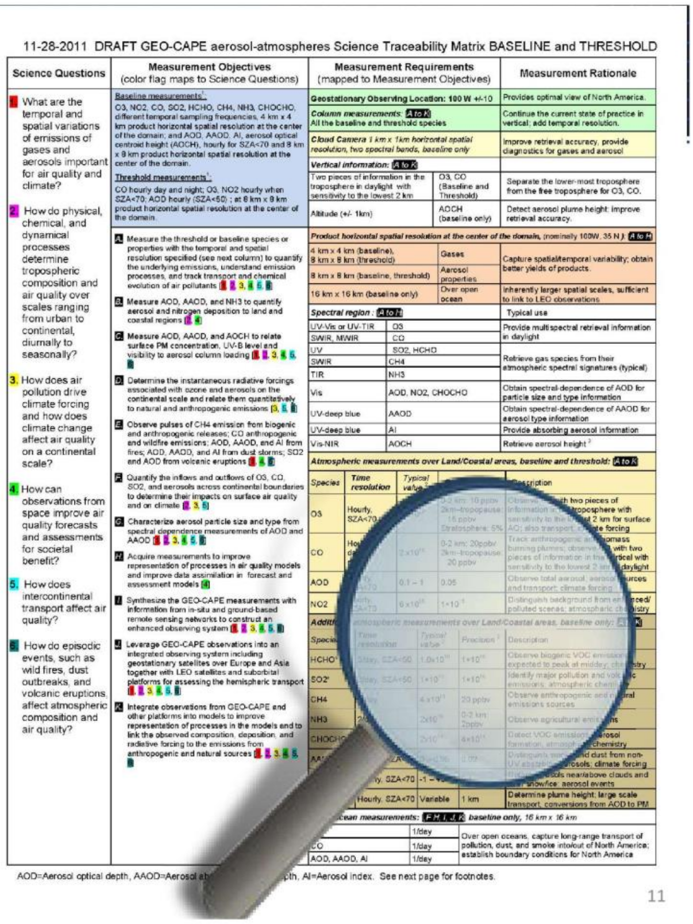
TEMPO

Air quality requirements from the GEO-CAPE Science Traceability Matrix



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Ultraviolet/ visible species (GOME, SCIA, OMI, OMPS, TEMPO, etc.)

Atmospheric measurements over Land/Coastal areas, baseline and threshold: **A to K**				
Species	*Time resolution*	*Typical value* [2]	*Precision* [2]	Description
O3	Hourly, SZA<70	9×10^{18}	0-2 km: 10 ppbv 2km–tropopause: 15 ppbv Stratosphere: 5%	Observe O3 with two pieces of information in the troposphere with sensitivity to the lowest 2 km for surface AQ; also transport, climate forcing
CO	Hourly, day and night	2×10^{18}	0-2 km: 20ppbv 2km–tropopause: 20 ppbv	Track anthropogenic and biomass burning plumes; observe CO with two pieces of information in the vertical with sensitivity to the lowest 2 km in daylight
AOD	Hourly, SZA<70	0.1 – 1	0.05	Observe total aerosol; aerosol sources and transport; climate forcing
NO2	Hourly, SZA<70	6×10^{15}	1×10^{15}	Distinguish background from enhanced/ polluted scenes; atmospheric chemistry

Additional atmospheric measurements over Land/Coastal areas, baseline only: **A to K**				
Species	*Time resolution*	*Typical value* [2]	*Precision* [2]	Description
HCHO*	3/day, SZA<50	1.0×10^{16}	1×10^{16}	Observe biogenic VOC emissions, expected to peak at midday; chemistry
SO2+	3/day, SZA<50	1×10^{16}	1×10^{16}	Identify major pollution and volcanic emissions; atmospheric chemistry
CH4	2/day	4×10^{19}	20 ppbv	Observe anthropogenic and natural emissions sources
NH3	2/day	2×10^{16}	0-2 km: 2ppbv	Observe agricultural emissions
CHOCHO*	2/day	2×10^{14}	4×10^{14}	Detect VOC emissions, aerosol formation, atmospheric chemistry
AAOD	Hourly, SZA<70	0 – 0.05	0.02	Distinguish smoke and dust from non-UV absorbing aerosols; climate forcing
AI	Hourly, SZA<70	-1 – +5	0.1	Detect aerosols near/above clouds and over snow/ice; aerosol events
AOCH	Hourly, SZA<70	Variable	1 km	Determine plume height; large scale transport, conversions from AOD to PM

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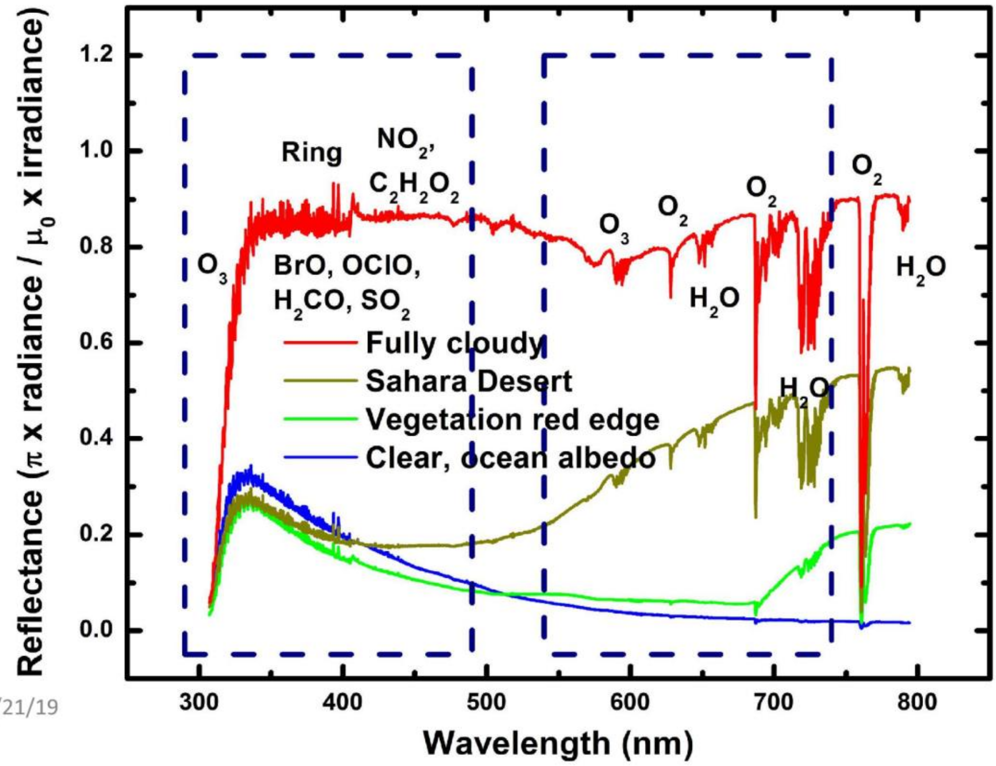
Typical TEMPO-range spectra (from ESA GOME-1)



Low Earth orbit: Sun-synchronous nadir heritage

Instrument	Detectors	Spectral Coverage [nm]	Spectral Res. [nm]	Ground Pixel Size [km²]	Global Coverage
GOME-1 (1995-2011)	Linear Arrays	240-790	0.2-0.4	40 × 320 (40 × 80 zoom)	3 days
SCIAMACHY (2002-2012)	Linear Arrays	240-2380	0.2-1.5	30 × 30/60/90 30 × 120/240	6 days
OMI (2004)	2-D CCD	270-500	0.42-0.63	13 × 24 - 42 × 162	daily
GOME-2a,b (2006, 2012)	Linear Arrays	240-790	0.24-0.53	40 × 80 (40 × 10 zoom)	near-daily
OMPS-1 (2011)	2-D CCDs	250-380	0.42-1.0	50 × 50	daily

More than 10 billion measurements of spectra!

Previous experience (since 1985 at SAO and MPI)

Scientific and operational measurements of pollutants O_3, NO_2, SO_2, H_2CO, $C_2H_2O_2$ (& CO, CH_4, BrO, OClO, ClO, IO, H_2O, O_2-O_2, Raman, aerosol, ….)

TEMPO LEO measurement capability

A full, minimally-redundant, set of polluting gases, plus aerosols and clouds is now measured to very high precision from satellites. Ultraviolet and visible spectroscopy of backscattered radiation provides O_3 (including profiles and tropospheric O_3), NO_2 (for NO_x), H_2CO and $C_2H_2O_2$ (for VOCs), SO_2, H_2O, O_2, O_2-O_2, N_2 and O_2 Raman scattering, and halogen oxides (BrO, ClO, IO, OClO). Satellite spectrometers we planned since 1985 began making these measurements in 1995.

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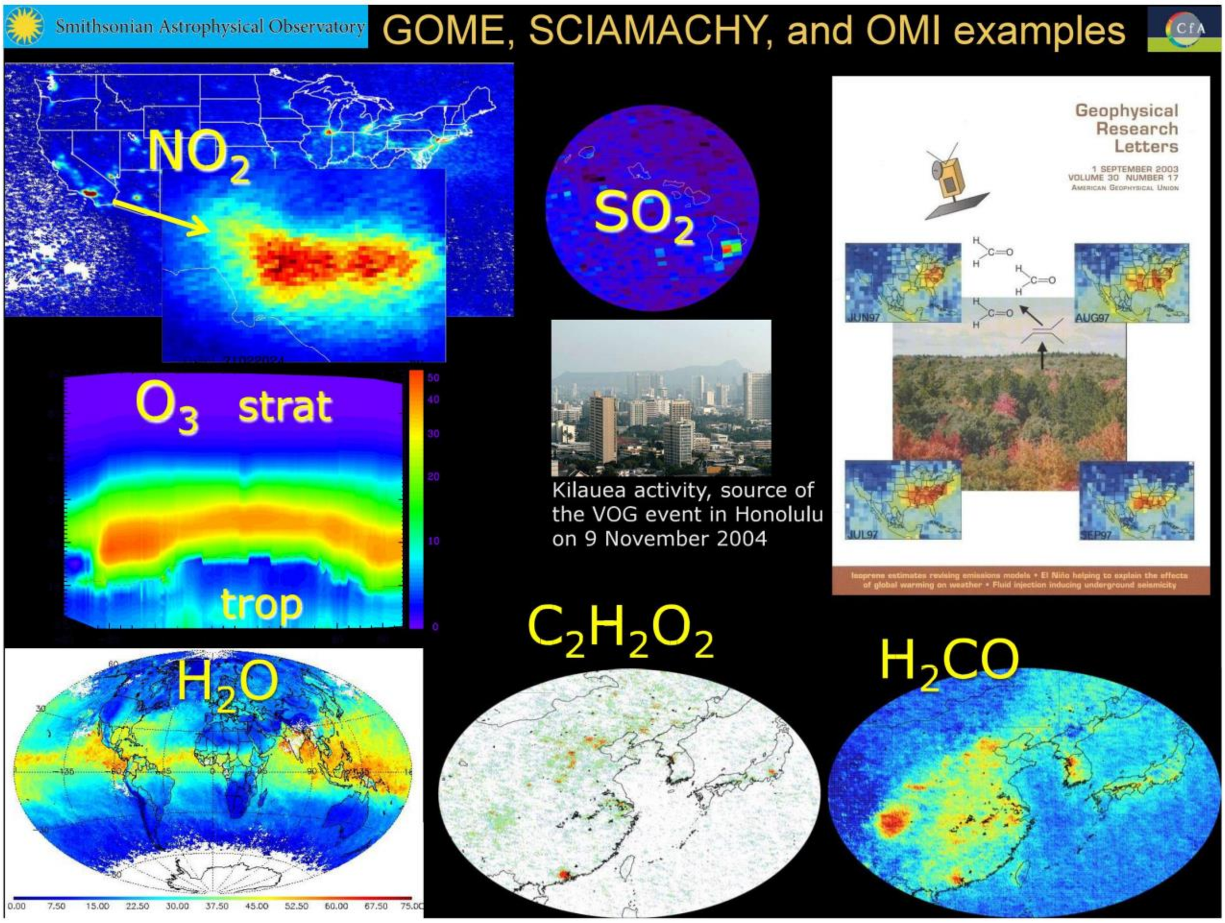

TEMPO

Baseline and threshold data products

Smithsonian NASA

Species/Products	Required Precision	Temporal Revisit
0-2 km O_3 (Selected Scenes) Baseline only	10 ppbv	2 hour
Tropospheric O_3	10 ppbv	1 hour
Total O_3	3%	1 hour
Tropospheric NO_2	1.0×10^{15} molecules cm^{-2}	1 hour
Tropospheric H_2CO	1.0×10^{16} molecules cm^{-2}	3 hour
Tropospheric SO_2	1.0×10^{16} molecules cm^{-2}	3 hour
Tropospheric $C_2H_2O_2$	4.0×10^{14} molecules cm^{-2}	3 hour
Aerosol Optical Depth	0.10	1 hour

- **Minimal set of products sufficient for constraining air quality**
- **Across Greater North America (GNA): 18°N to 58°N near 100°W, 67°W to 125°W near 42°N**
- **Data products at urban-regional spatial scales**
  - **Baseline ≤ 60 km^2 at center of Field Of Regard (FOR)**
  - **Threshold ≤ 300 km^2 at center of FOR**
- **Temporal scales to resolve diurnal changes in pollutant distributions**
- **Geolocation uncertainty of less than 4 km**
- **Mission duration, subject to instrument availability**
  - **Baseline 20 months**
  - **Threshold 12 months**

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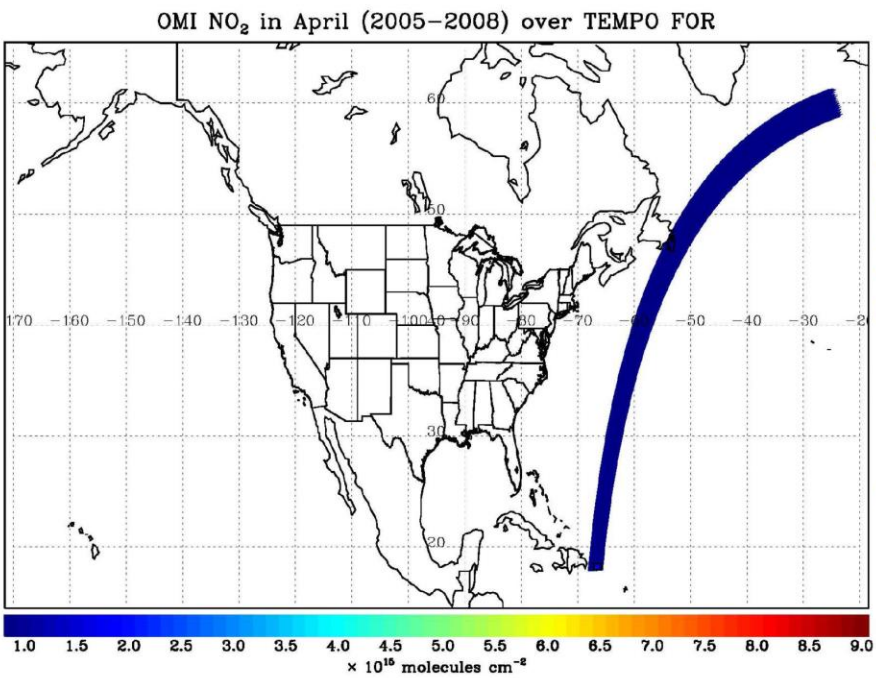
TEMPO

TEMPO hourly NO_2 sweep (GEO @92.85W)

Smithsonian NASA



Boresight: 34N, 91W ~ 2034 good N/S pixels

- **~ 1282 scans/hr**
- **~ 2.6 M pixels/hr**
- **Data rate: ~31.2 Mbs (~20 times of OMI data, comparable to TROPOMI)**
- **Scanning partial FOV at ≤ 10 min allowed up to 25% of time**

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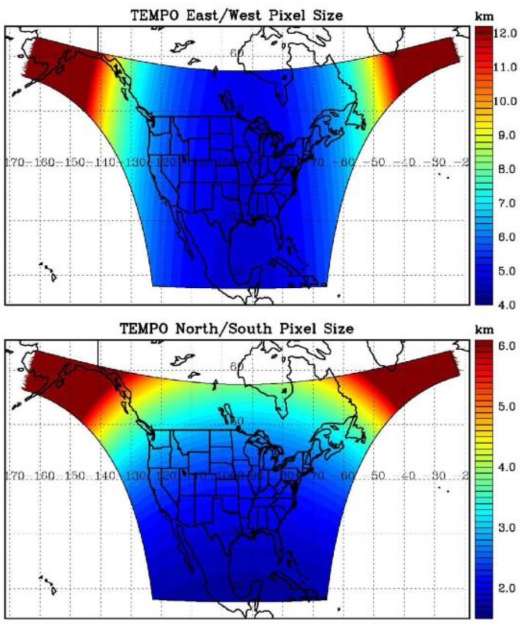
TEMPO footprint (GEO @91° W)



- **Boresight at 33.76°N, 92.85°W**

Location	N/S (km)	E/W (km)	GSA (km^2)	VZA (°)
Boresight	2.0	4.8	9.5	39.3
36.5°N, 100°W	2.1	4.8	10.1	42.4
Washington, DC	2.3	5.1	11.3	48.0
Seattle	3.2	6.2	16.8	61.7
Los Angeles	2.1	5.6	11.3	48.0
Boston	2.5	5.5	13.0	53.7
Miami	1.8	4.9	8.6	33.2
San Juan	1.7	5.6	9.2	37.4
Mexico City	1.6	4.7	7.7	23.9
Can. tar sands	4.1	5.6	20.8	67.0
Juneau	6.1	9.1	33.3	75.3

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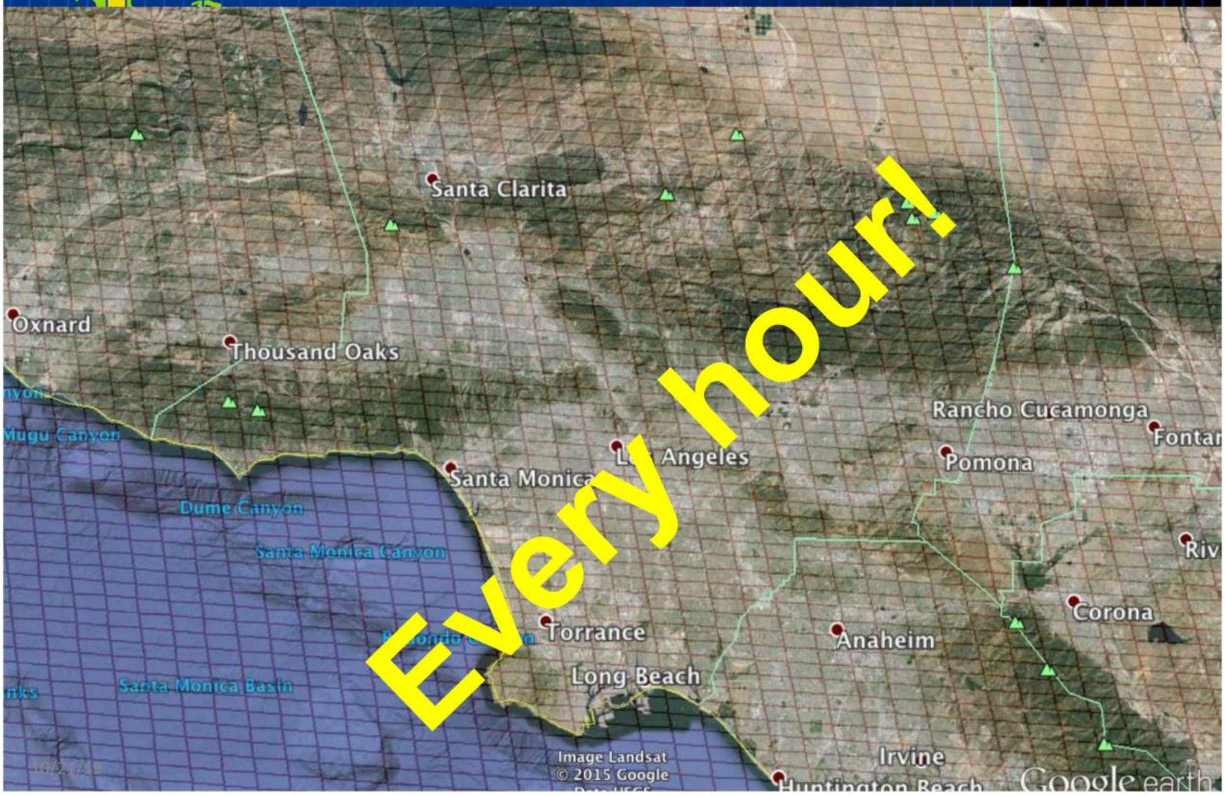
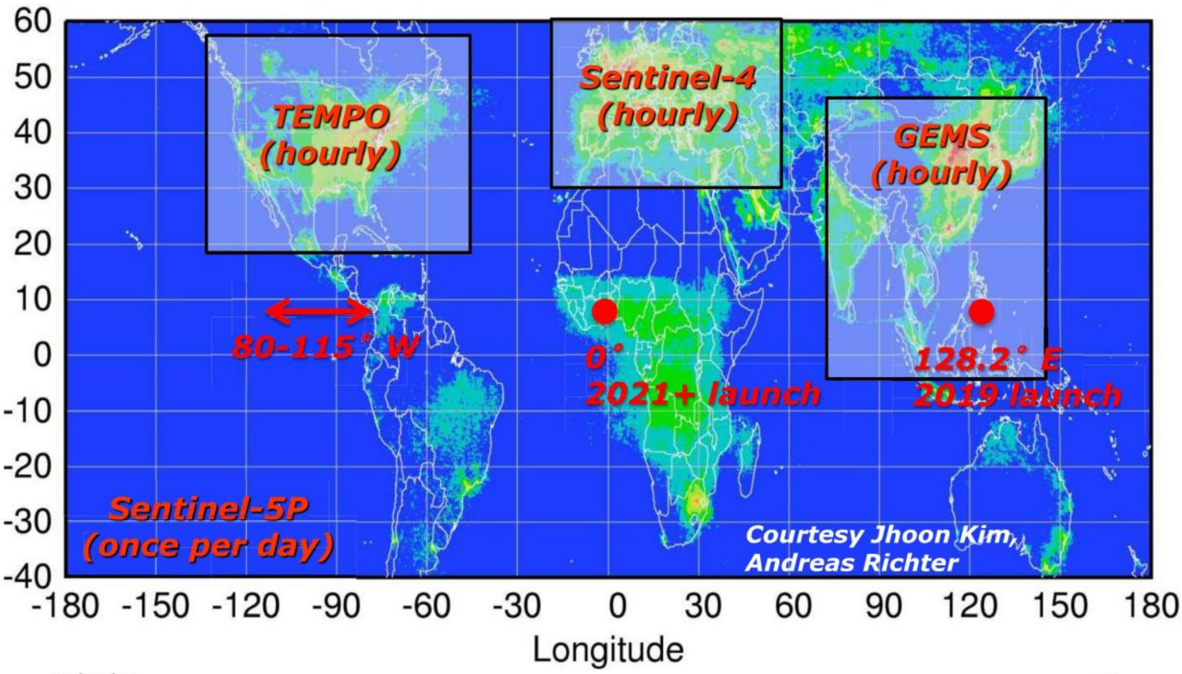
Los Angeles coverage



Global pollution monitoring constellation



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The TEMPO Green Paper

Chemistry, physics, and meteorology experiments with the Tropospheric Emissions: Monitoring of Pollution instrument

Now at: https://www.cfa.harvard.edu/atmosphere/publications.html

K. Chance[a], X. Liu[a], C. Chan Miller[a], G. González Abad[a], G. Huang[b], C. Nowlan[a], A. Souri[a], R. Suleiman[a], K. Sun[c], H. Wang[a], L. Zhu[a], P. Zoogman[a], J. Al-Saadi[d], J.-C. Antuña-Marrero[e], J. Carr[f], R. Chatfield[g], M. Chin[h], R. Cohen[i], D. Edwards[j], J. Fishman[k], D. Flittner[d], J. Geddes[l], M. Grutter[m], J.R. Herman[n], D.J. Jacob[o], S. Janz[h] J. Joiner[h], J. Kim[p], N.A. Krotkov[h], B. Lefer[q], R.V. Martin,[a,r,s], O.L. Mayol-Bracero[t], A. Naeger[u], M. Newchurch[u], G.G. Pfister[j], K. Pickering[v], R.B. Pierce[w], C. Rivera Cárdenas[m], A. Saiz-Lopez[x], W. Simpson[y], E. Spinei[z], R.J.D. Spurr[aa], J.J. Szykman[bb], O. Torres[h], J. Wang[cc]

NORMAL TIME RESOLUTION STUDIES	**Volcanoes**
Air quality and health	**Socio-economic studies**
Ultraviolet exposure	**National pollution inventories**
Biomass burning	**Regional and local transport of pollutants**
Synergistic GOES-16/17 Products	**Sea breeze studies for Florida and Cuba**
Advanced aerosol products	**Transboundary pollution gradients**
Soil NO_x after fertilizer application and after rainfall	**Transatlantic dust transport**
Solar-induced fluorescence from chlorophyll	**HIGH TIME RESOLUTION EXPERIMENTS**
Foliage studies	**Lightning NO_x**
Mapping NO_2 and SO_2 dry deposition at high resolution	**Morning and evening higher-frequency scans**
Crop and forest damage from ground-level ozone	**Dwell-time studies and temporal selection to improve detection limits**
Halogen oxide studies in coastal and lake regions	**Exploring the value of TEMPO in assessing pollution transport during upslope flows**
Air pollution from oil and gas fields	**Tidal effects on estuarine circulation and outflow plumes**
Night light measurements resolving lighting type	**Air quality responses to sudden changes in emissions**
Ship tracks, drilling platform plumes, and other concentrated sources.	**Cloud field correlation with pollution**
Water vapor studies	**Agricultural soil NO_x emissions and air quality**

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TEMPO The TEMPO Green Paper

Chemistry, physics, and meteorology experiments with the Tropospheric Emissions: Monitoring of Pollution instrument

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K. Chance[a], X. Liu[a], C. Chan Miller[a], G. González Abad[a], G. Huang[b], C. Nowlan[a], A. Souri[a], R. Suleiman[a], K. Sun[c], H. Wang[a], L. Zhu[a], P. Zoogman[a], J. Al-Saadi[d], J.-C. Antuña-Marrero[e], J. Carr[f], R. Chatfield[g], M. Chin[h], R. Cohen[i], D. Edwards[j], J. Fishman[k], D. Flittner[d], J. Geddes[l], M. Grutter[m], J.R. Herman[n], D.J. Jacob[o], S. Janz[h] J. Joiner[h], J. Kim[p], N.A. Krotkov[h], B. Lefer[q], R.V. Martin,[a,r,s], O.L. Mayol-Bracero[t], A. Naeger[u], M. Newchurch[u], G.G. Pfister[j], K. Pickering[v], R.B. Pierce[w], C. Rivera Cárdenas[m], A. Saiz-Lopez[x], W. Simpson[y], E. Spinei[z], R.J.D. Spurr[aa], J.J. Szykman[bb], O. Torres[h], J. Wang[cc]

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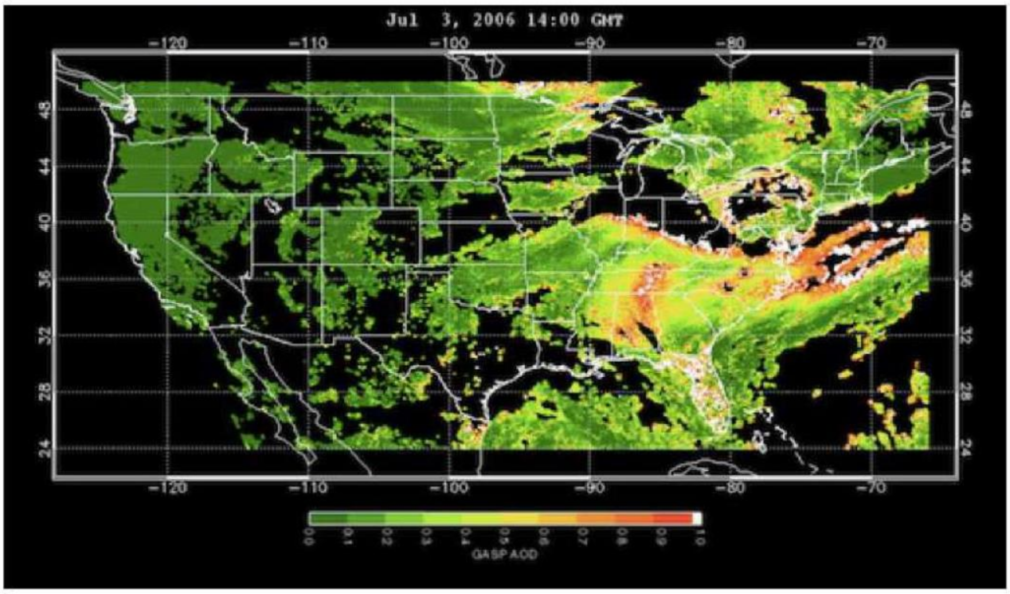
Water vapor studies	Agricultural soil NO_x emissions and air quality

TEMPO www.epa.gov/rsig

TEMPO will use the EPA's Remote Sensing Information Gateway (RSIG) for subsetting, visualization, and product distribution – *to make TEMPO YOUR instrument*



TEMPO

Air quality and health

Smithsonian NASA

TEMPO's hourly measurements allow better understanding of the complex chemistry and dynamics that drive **air quality on short timescales**. The density of TEMPO data is ideally suited for data assimilation into chemical models for both air quality forecasting and for better constraints on emissions that lead to air quality exceedances. Planning is underway to combine TEMPO with regional air quality models to **improve EPA air quality indices and to directly supply the public with near real time pollution reports and forecasts through website and mobile applications**. As a case study, an OSSE for the Intermountain West was performed to explore the potential of geostationary ozone measurements from TEMPO to improve monitoring of ozone exceedances and the role of background ozone in causing these exceedances (Zoogman *et al*. 2014).

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TEMPO

Experimental opportunities

Smithsonian NASA

The TEMPO Green Paper living document is at http://tempo.si.edu/publications. Please feel free to contribute

1. **Up to 25% of observing time can be devoted to non-standard operations: Time resolution higher, E/W spatial coverage less**
2. **Two types of studies under regular or non-standard operations**
   1. **Events (*e.g.*, eruptions, fires, dust storms, etc.)**
   2. **Experiments (*e.g.*, agriculture, forestry, NO_x, ….)**
3. **TEMPO team will work with experimenters concerning Image Navigation and Registration (*i.e.*, pointing resolution and accuracy)**
4. **Experiments could occur during commissioning phase**
5. **Hope to include SO_2, aerosol, H_2O, and $C_2H_2O_2$ as operational products**
6. **Can initiate a non-standard, pre-loaded scan pattern within several hours**
7. **Send your ideas into a TEMPO team member**

10 October, 2019

TEMPO — Traffic, biomass burning

Morning and evening higher-frequency scans The optimized data collection scan pattern during mornings and evenings provides multiple advantages for addressing TEMPO science questions. The increased frequency of scans coincides with peaks in vehicle miles traveled on each coast.

Biomass burning The unexplained variability in ozone production from fires is of particular interest. The suite of NO_2, H_2CO, $C_2H_2O_2$, H_2O, O_3, and aerosol measurements from TEMPO is well suited to investigating how the chemical processing of primary fire emissions effects the secondary formation of VOCs and ozone. For particularly important fires it is possible to command special TEMPO observations at even shorter than hourly revisit time, as short as 10 minutes.

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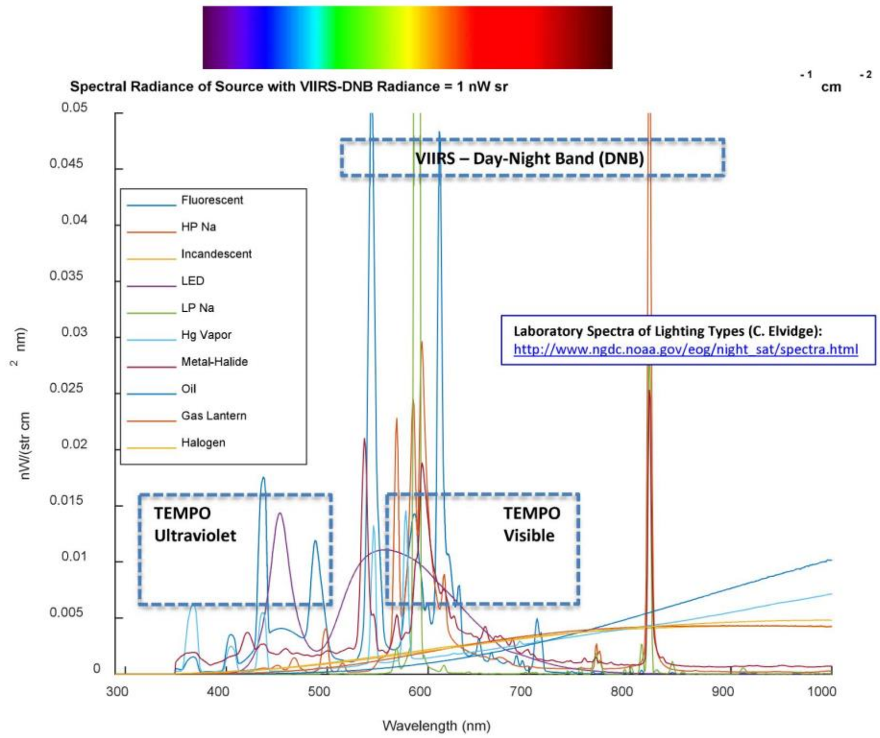
TEMPO — City lights spectroscopic signatures



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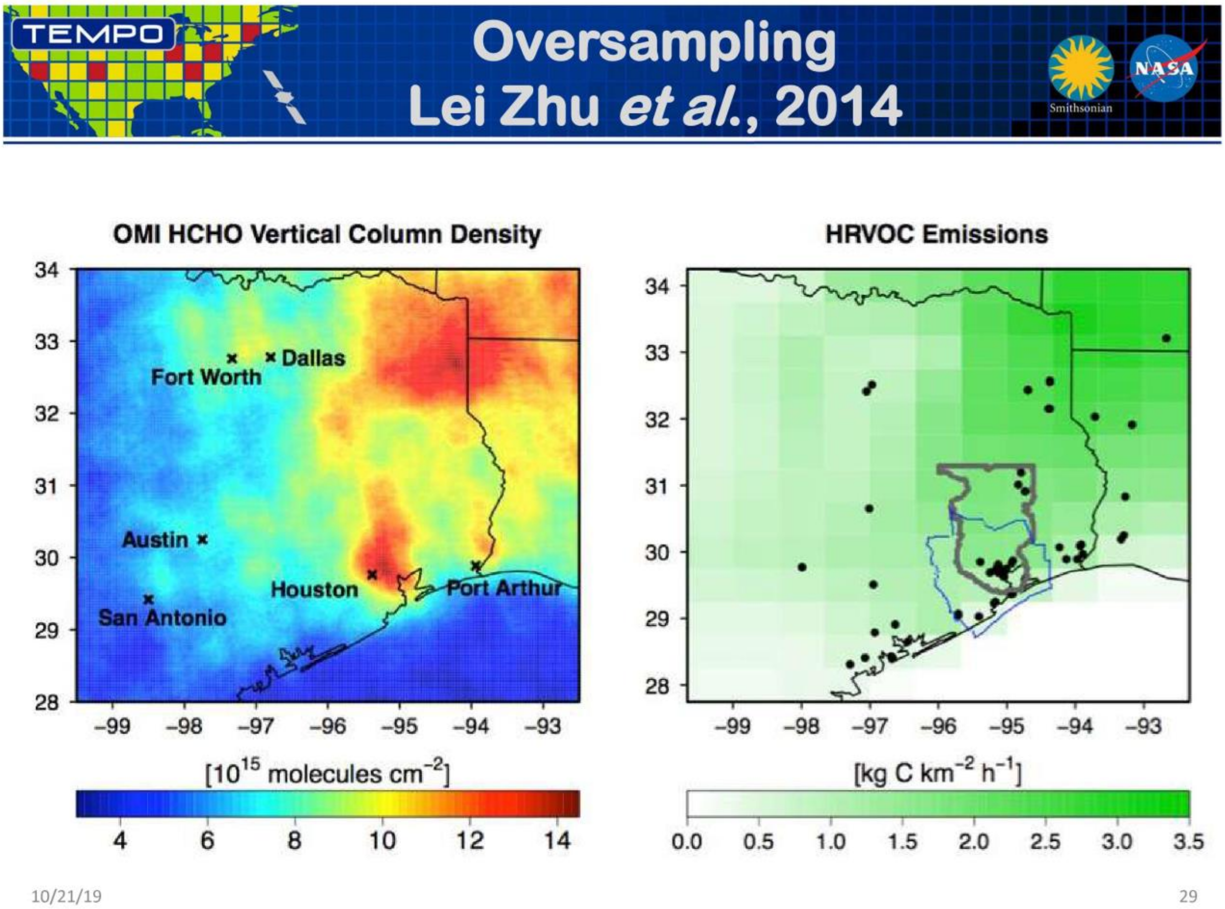
TEMPO
Oversampling
Lei Zhu *et al.*, 2014
Smithsonian
NASA
OMI HCHO Vertical Column Density
Fort Worth
Dallas
Austin
Houston
Port Arthur
San Antonio
[10^{15} molecules cm^{-2}]
HRVOC Emissions
[kg C km^{-2} h^{-1}]
10/21/19
29


TEMPO
The end!
Thanks to NASA, ESA, Maxar, Ball
Aerospace & Technologies Corp., ESA
Smithsonian
NASA
INECC
INSTITUTO NACIONAL DE ECOLOGÍA Y CAMBIO CLIMÁTICO
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CSIC
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FINNISH METEOROLOGICAL INSTITUTE
CARR ASTRONAUTICS
NCAR
KNMI
Environment and Climate Change Canada
Environnement et Changement climatique Canada
10/21/19
30

TEMPO

Backups

Smithsonian NASA

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TEMPO

NO_x studies

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Lightning NO_x Interpretation of satellite measurements of tropospheric NO_2 and O_3, and upper tropospheric HNO_3 lead to an overall estimate of 6 ± 2 Tg N y-1 from lightning [Martin et al., 2007]. TEMPO measurements, including tropospheric NO_2 and O_3, can be made for time periods and longitudinal bands selected to coincide with large thunderstorm activity, including outflow regions, with fairly short notice.

Soil NO_x Jaeglé et al. [2005] estimate 2.5 - 4.5 TgN y^{-1} are emitted globally from nitrogen-fertilized soils, still highly uncertain. The US a posteriori estimate for 2000 is 0.86 ± 1.7 TgN y^{-1}. For Central America it is 1.5 ± 1.6 TgN y^{-1}. They note an underestimate of NO release by nitrogen-fertilized croplands as well as an underestimate of rain-induced emissions from semiarid soils.

TEMPO is able to follow the temporal evolution of emissions from croplands after **fertilizer application** and from rain-induced emissions from semi-arid soils. Higher than hourly time resolution over selected regions may be accomplished by special observations. Improved constraints on soil NO_x emissions may also improve estimated of lightning NO_x emissions [Martin *et al.* 2000].

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TEMPO Spectral indicators

Fluorescence and other spectral indicators Solar-induced fluorescence (SIF) from chlorophyll over both land and ocean will be measured. In terrestrial vegetation, chlorophyll fluorescence is emitted at red to far-red wavelengths (~650-800 nm) with two broad peaks near 685 and 740 nm, known as the red and far-red emission features. Oceanic SIF is emitted exclusively in the red feature. SIF measurements have been used for studies of tropical dynamics, primary productivity, the length of carbon uptake period, and drought responses, while ocean measurements have been used to detect red tides and to conduct studies on the physiology, phenology, and productivity of phytoplankton. TEMPO can retrieve both red and far-red SIF by utilizing the property that SIF fills in solar Fraunhofer and atmospheric absorption lines in backscattered spectra normalized by a reference (*e.g.*, the solar spectrum) that does not contain SIF.

TEMPO will also be capable of measuring **spectral indices developed for estimating foliage pigment contents and concentrations**. Spectral approaches for estimating pigment contents apply generally to leaves and not the full canopy. A single spectrally invariant parameter, the Directional Area Scattering Factor (DASF), relates canopy-measured spectral indices to pigment concentrations at the leaf scale.

UVB TEMPO measurements of daily UV exposures build upon heritage from OMI and TROPOMI measurements. Hourly cloud measurements from TEMPO allow taking into account diurnal cloud variability, which has not been previously possible. The OMI UV algorithm is based on the TOMS UV algorithm. The specific product is the downward spectral irradiance at the ground (in $W\ m^{-2}\ nm^{-1}$) and the erythemally weighted irradiance (in $W\ m^{-2}$).

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TEMPO Aerosols and clouds

Aerosols TEMPO's launch algorithm for retrieving aerosols will be based upon the OMI aerosol algorithm that uses the sensitivity of near-UV observations to particle absorption to retrieve **absorbing aerosol index** (AAI), **aerosol optical depth** (AOD) and **single scattering albedo** (SSA). TEMPO will derive its pointing from one of the **GOES-16** or **GOES-17** satellites and is thus automatically co-registered. TEMPO may be used together with the advanced baseline imager (ABI) instrument, particularly the 1.37μm bands, for aerosol retrievals, reducing AOD and fine mode AOD uncertainties from 30% to 10% and from 40% to 20%.

Clouds The launch cloud algorithm is be based on the rotational Raman scattering (RRS) cloud algorithm that was developed for OMI by NASA GSFC. Retrieved cloud pressures from OMCLDRR are not at the geometrical center of the cloud, but rather at the optical centroid pressure (OCP) of the cloud. **Additional** cloud products are possible using the O_2-O_2 collision complex and/or the O_2 *B* band.

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TEMPO

Halogens

Smithsonian NASA

BrO will be produced at launch, assuming stratospheric AMFs. Scientific studies will correct retrievals for tropospheric content. **IO** was first measured from space by SAO using SCIAMACHY spectra [Saiz-Lopez *et al.*, 2007]. It will be produced as a scientific product, particularly for coastal studies, assuming AMFs appropriate to lower tropospheric loading.

The atmospheric chemistry of halogen oxides over the ocean, and in particular in coastal regions, can play important roles in ozone destruction, oxidizing capacity, and dimethylsulfide oxidation to form cloud-condensation nuclei [Saiz-Lopez and von Glasow, 2012]. The budgets and distribution of reactive halogens along the coastal areas of North America are poorly known. Therefore, providing a measure of the budgets and diurnal evolution of coastal halogen oxides is necessary to understand their role in atmospheric photochemistry of coastal regions. Previous ground-based observations have shown enhanced levels (at a few pptv) of halogen oxides over coastal locations with respect to their background concentrations over the remote marine boundary layer [Simpson et al., 2015]. Previous global satellite instruments lacked the sensitivity and spatial resolution to detect the presence of active halogen chemistry over mid-latitude coastal areas. TEMPO observations together with atmospheric models will allow examination of the processes linking ocean halogen emissions and their potential impact on the oxidizing capacity of coastal environments of North America.

TEMPO also performs **hourly measurements one of the world's largest salt lakes: the Great Salt Lake in Utah**. Measurements over Salt Lake City show the highest concentrations of BrO over the globe. Hourly measurement at a high spatial resolution can improve understanding of BrO production in salt lakes.

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TEMPO

TEMPO mission concept

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- **Geostationary orbit, operating on a commercial telecom satellite**
    - NASA will arrange launch and hosting services (per Earth Venture Instrument scope)
        - 80-115^{o} W acceptable latitude
        - Specifying satellite environment, accommodation
    - Hourly measurement and telemetry duty cycle for at least ≤70^{o} SZA
- **TEMPO is low risk with significant space heritage**
    - We proposed SCIAMACHY in 1985, as suggested by the late Dr. Dieter Perner
    - All proposed TEMPO measurements except eXceL O_3 have been made from low Earth orbit satellite instruments to the required precisions by SAO and Science Team members
    - All TEMPO launch algorithms are implementations of currently operational algorithms
        - NASA TOMS-type O_3
        - SO_2, NO_2, H_2CO, $C_2H_2O_2$ from fitting with AMF-weighted cross sections
        - Absorbing Aerosol Index, UV aerosol, Rotational Raman scattering cloud
        - SAO eXceL profile/tropospheric/PBL O_3 for selected geographic targets
- **Example higher-level products: Near-real-time pollution/AQ indices, UV index**
- **TEMPO research products will greatly extend science and applications**
    - **Example research products:** BrO and IO from AMF-normalized cross sections; height-resolved SO_2; additional cloud/aerosol products; vegetation products; additional gases; city lights

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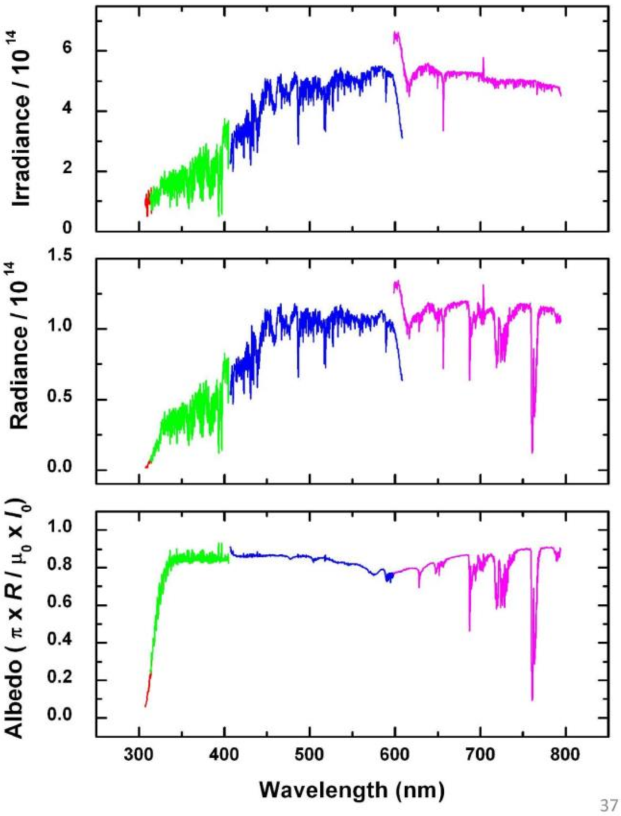
TEMPO

What do we measure?

GOME irradiance, radiance, and reflectance spectrum for high-albedo (fully cloudy) ground pixel



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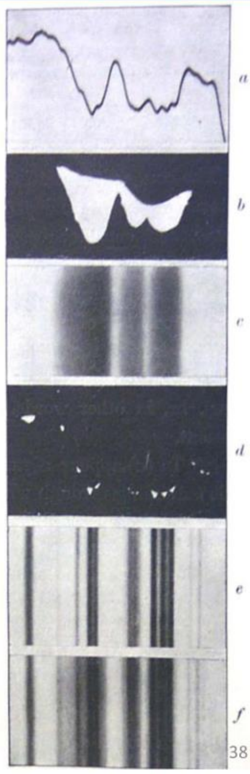
TEMPO

Why the Smithsonian?

Langley, S.P., and C.G. Abbot, ***Annals of the Astrophysical Observatory of the Smithsonian Institution, Volume 1*** **(1900).**

Langley's recently invented bolometer was used to make measurements from the infrared through the near ultraviolet in order to determine the mean value of the solar constant and its variation. Langley and Abbot also developed substantial new experimental techniques (such as an early chart recorder) and various analysis techniques (*e.g.*, the "Langley plot"), including photographic techniques for high and low pass filtering to produce line spectra from "bolographs" (spectra), illustrated, foreshadowing the high pass filtering used today by researchers employing the DOAS technique for analyzing atmospheric spectra.



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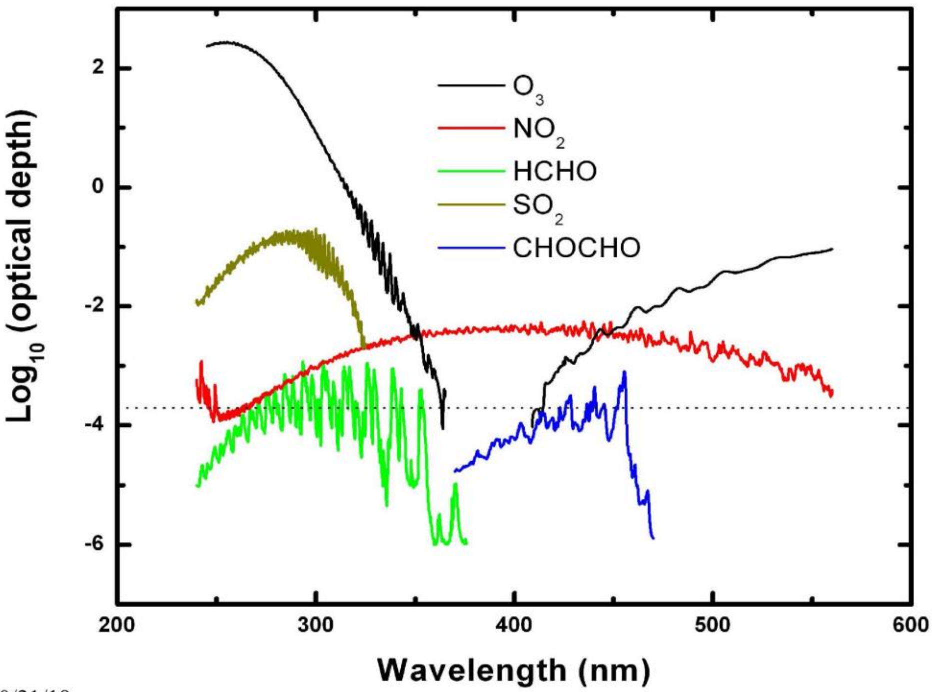
Smithsonian Astrophysical Observatory

Optical Depths for Typical GEO Measurement Geometry



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Puerto Rico coverage

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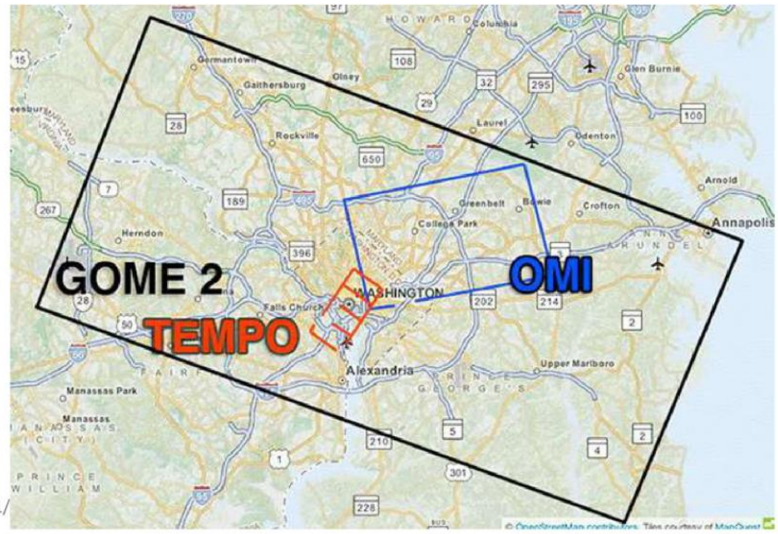
TEMPO

Coverage comparisons

Smithsonian NASA

- **Spatial resolution: allows tracking pollution at sub-urban scale**
  - GEO at 100°W: 2.1 km N/S × 4.7 km E/W = 9.8 km^2 (native) at center of FOR (36.5°N, 100°W)
  - Full resolution for NO_2, HCHO, total O_3 products
  - Co-add 4 N/S pixels for O_3 profile product: 8.4 km N/S × 4.7 km E/W



~ 1/300 of GOME-2

~ 1/30 of OMI

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Why geostationary? High temporal and spatial resolution

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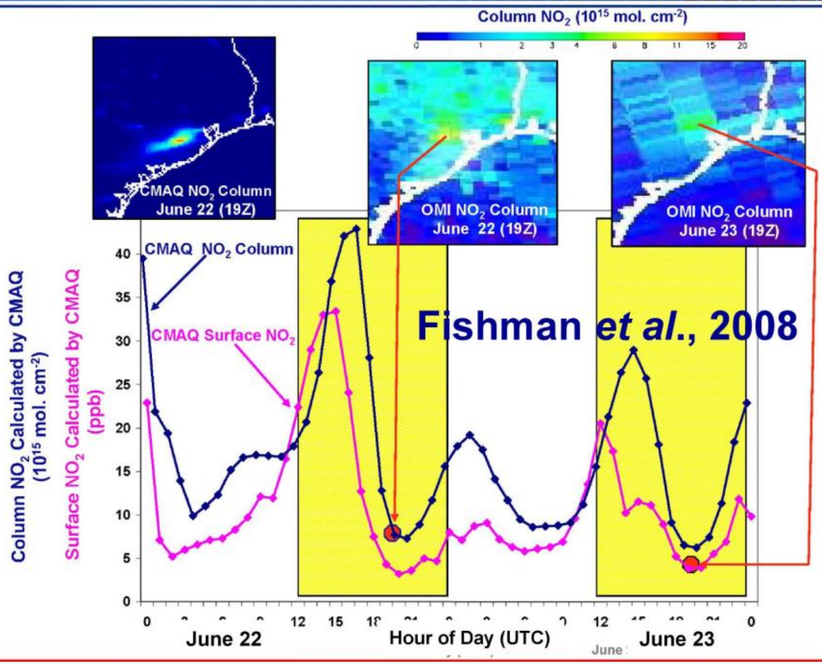
Hourly NO_2 surface concentration and integrated column calculated by CMAQ air quality model: Houston, TX, June 22-23, 2005



LEO observations provide limited information on rapidly varying emissions, chemistry, & transport

GEO will provide observations at temporal and spatial scales highly relevant to air quality processes

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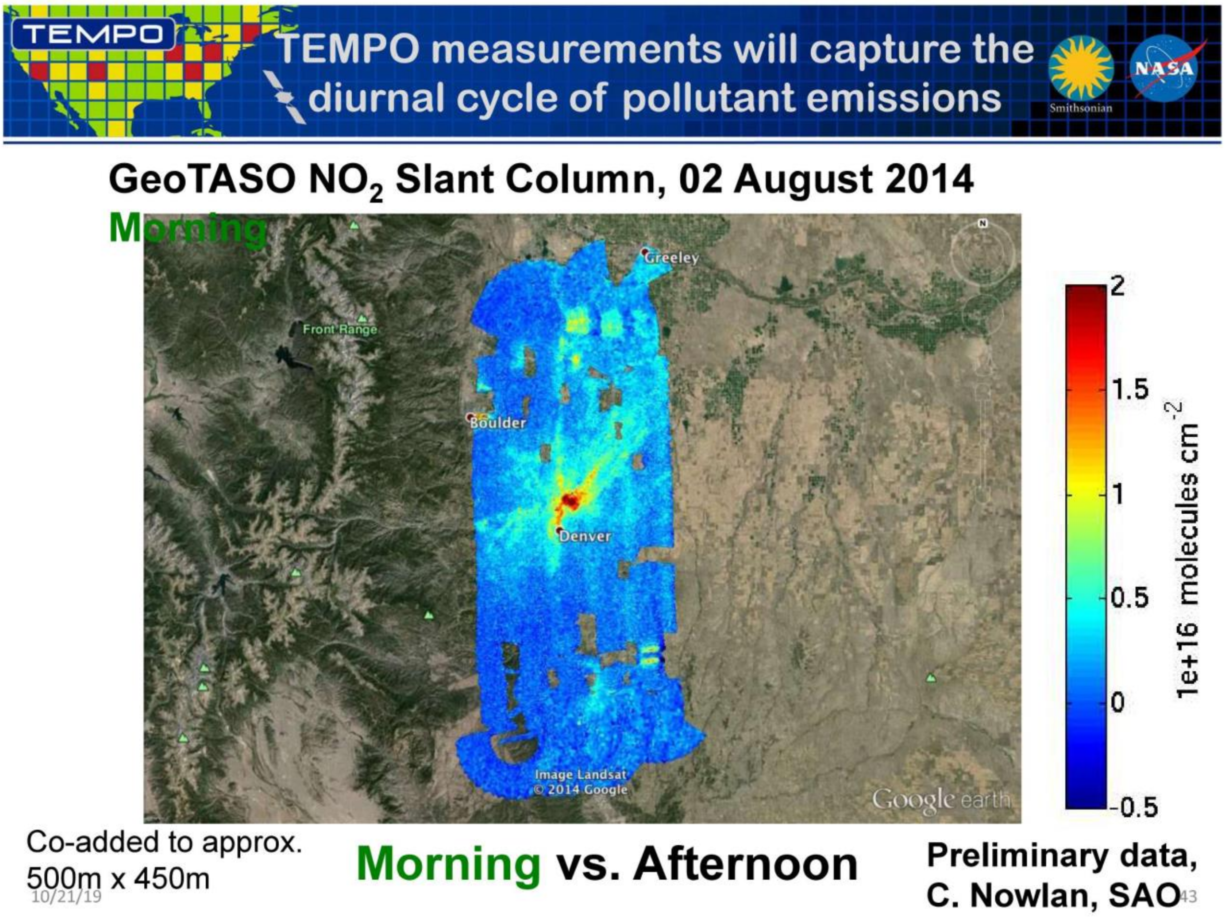
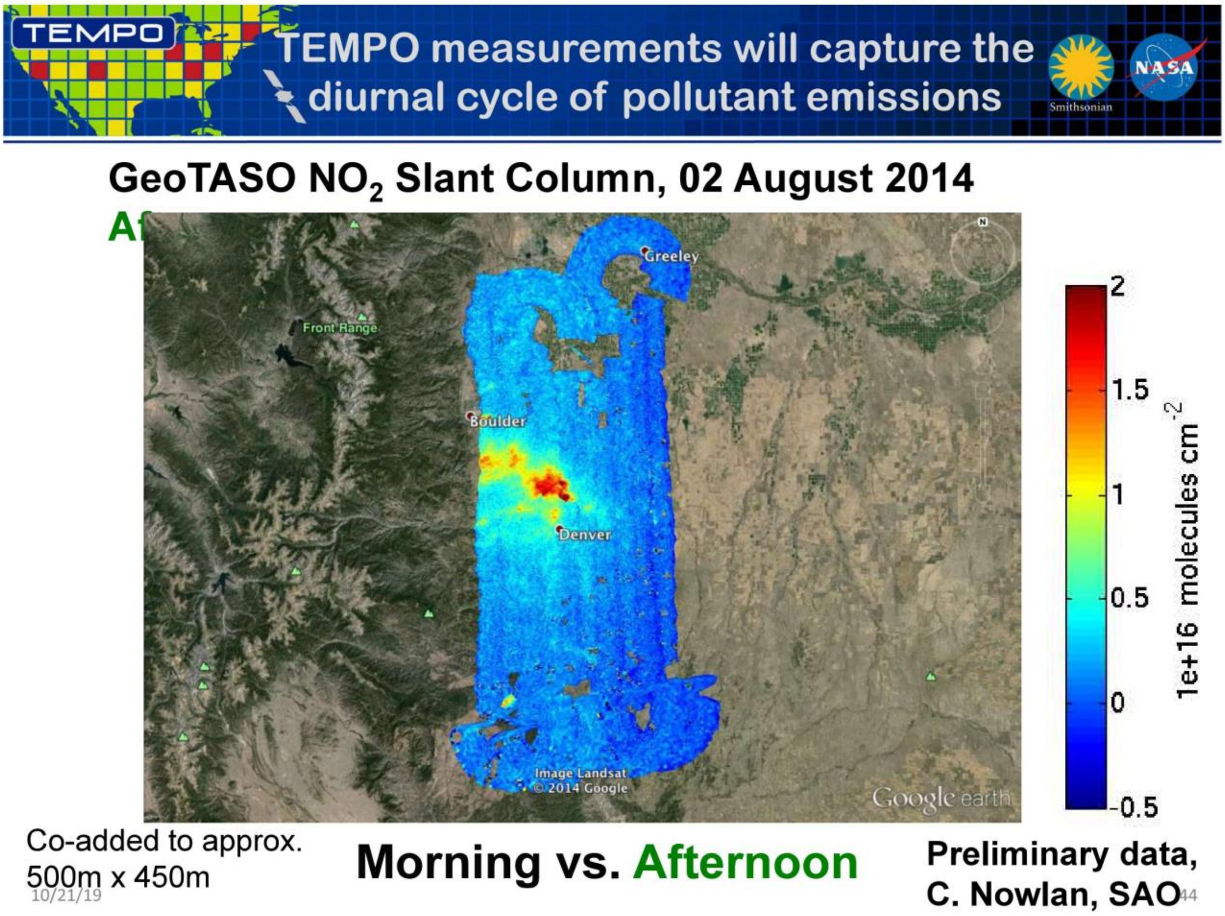

TEMPO
TEMPO measurements will capture the diurnal cycle of pollutant emissions
Smithsonian
NASA
GeoTASO NO2 Slant Column, 02 August 2014
Morning
Greeley
Front Range
Boulder
Denver
Image Landsat
© 2014 Google
Google earth
2
1.5
1
0.5
0
-0.5
1e+16 molecules cm-2
Co-added to approx. 500m x 450m
Morning vs. Afternoon
Preliminary data, C. Nowlan, SAO
10/21/19
43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NASA
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Image Landsat
© 2014 Google
Google earth
2
1.5
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1e+16 molecules cm-2
Co-added to approx. 500m x 450m
Morning vs. Afternoon
Preliminary data, C. Nowlan, SAO
10/21/19
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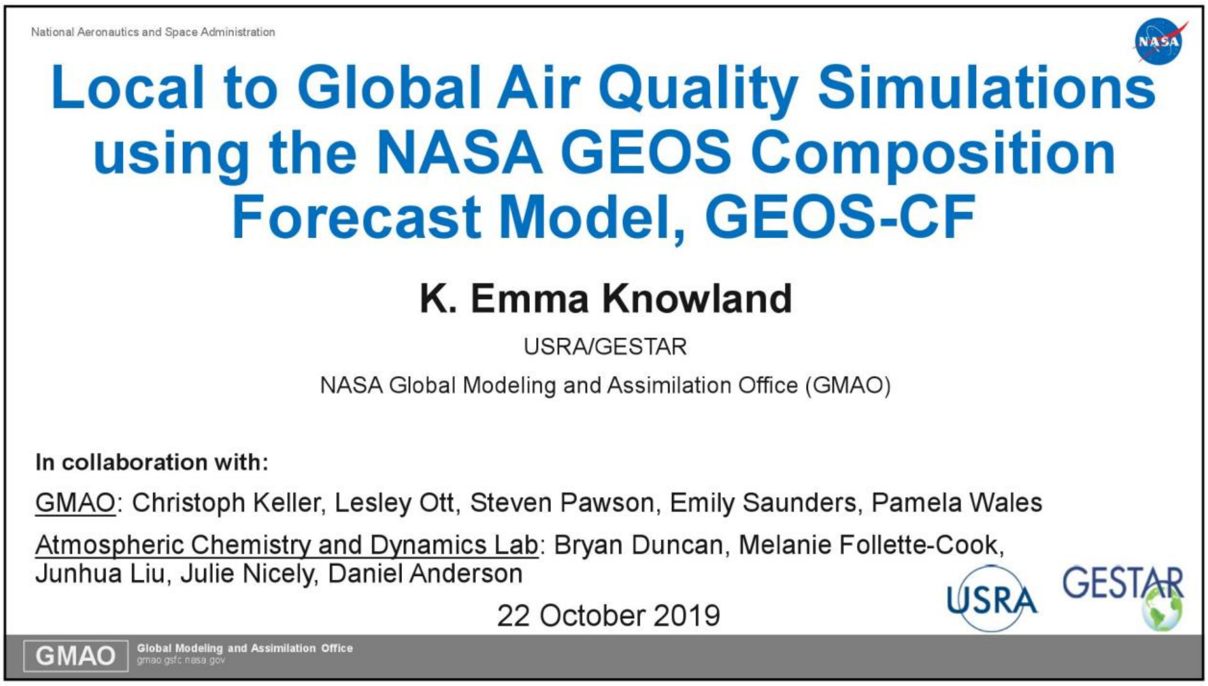
附錄五、" Local to Global Air Quality Simulations using the NASA GEOS Composition Forecast Model GEOS-CF"



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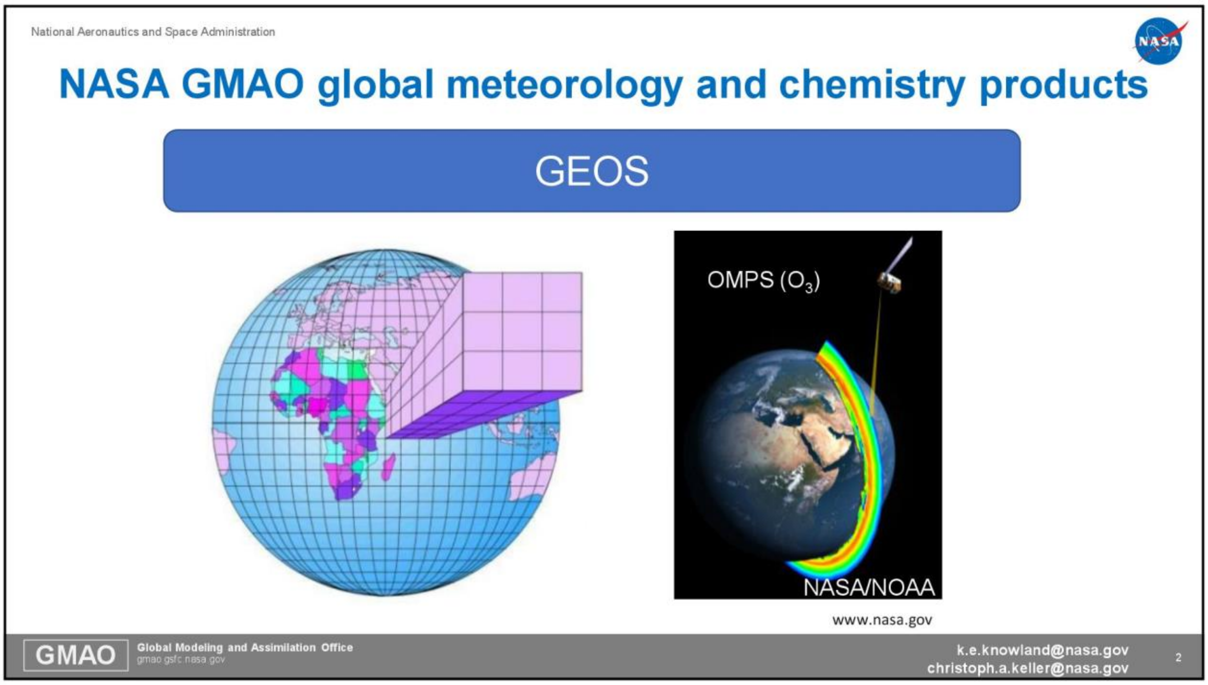

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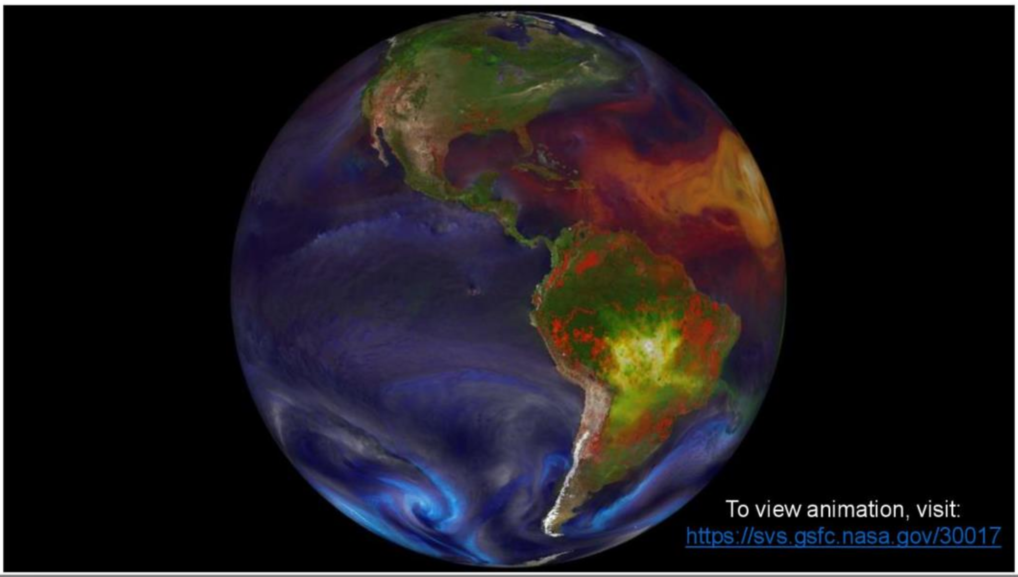
National Aeronautics and Space Administration



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gmao.gsfc.nasa.gov 3

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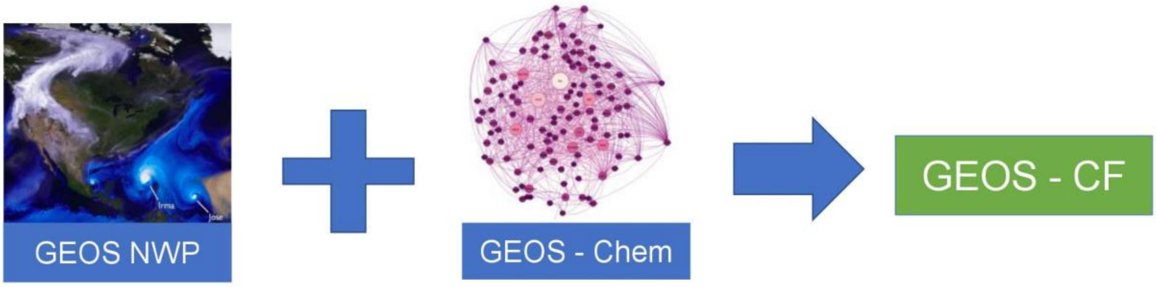
NASA GMAO's Composition Forecast



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https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/

k.e.knowland@nasa.gov
christoph.a.keller@nasa.gov 4

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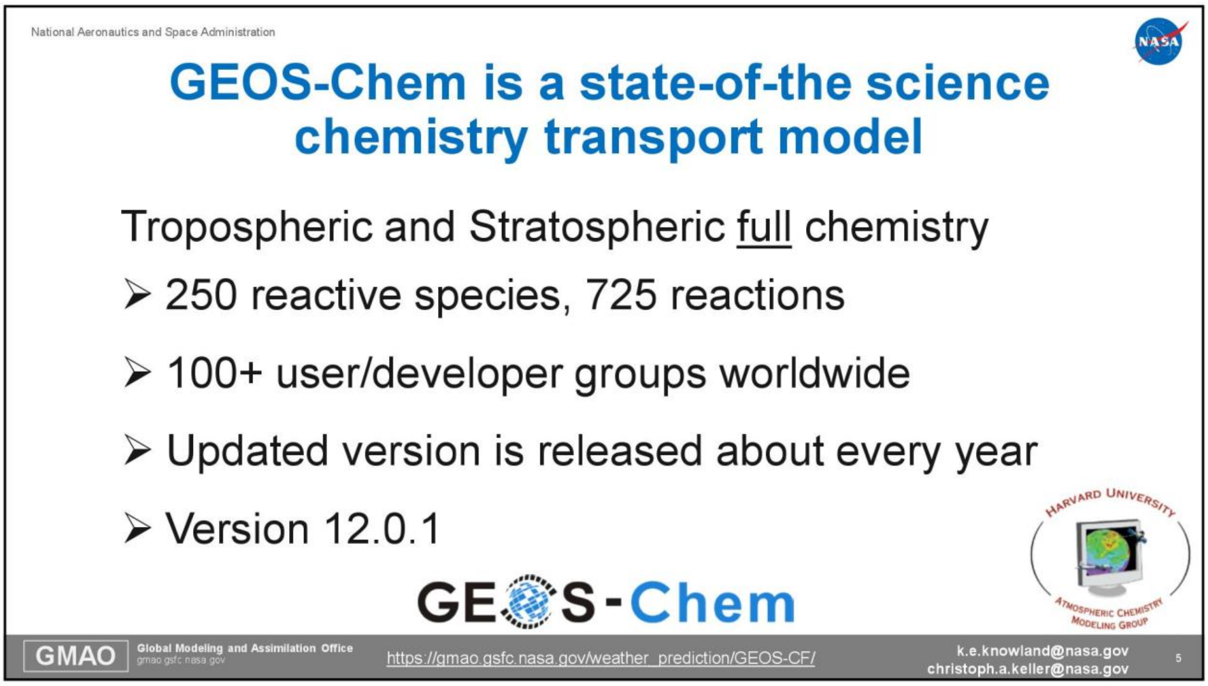
National Aeronautics and Space Administration
GEOS-Chem is a state-of-the science chemistry transport model
Tropospheric and Stratospheric full chemistry
➤ 250 reactive species, 725 reactions
➤ 100+ user/developer groups worldwide
➤ Updated version is released about every year
➤ Version 12.0.1
GEOS-Chem
HARVARD UNIVERSITY
ATMOSPHERIC CHEMISTRY MODELING GROUP
GMAO
Global Modeling and Assimilation Office
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
k.e.knowland@nasa.gov
christoph.a.keller@nasa.gov
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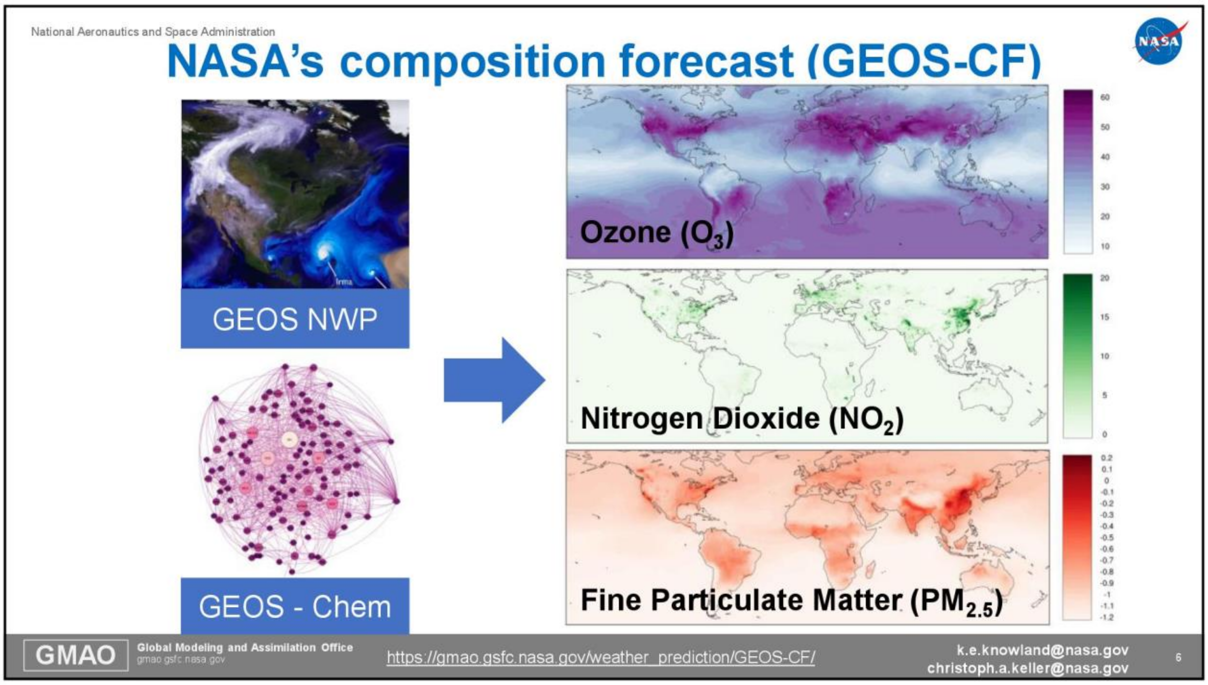
National Aeronautics and Space Administration
NASA's composition forecast (GEOS-CF)
GEOS NWP
GEOS - Chem
Ozone (O3)
Nitrogen Dioxide (NO2)
Fine Particulate Matter (PM2.5)
GMAO
Global Modeling and Assimilation Office
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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6

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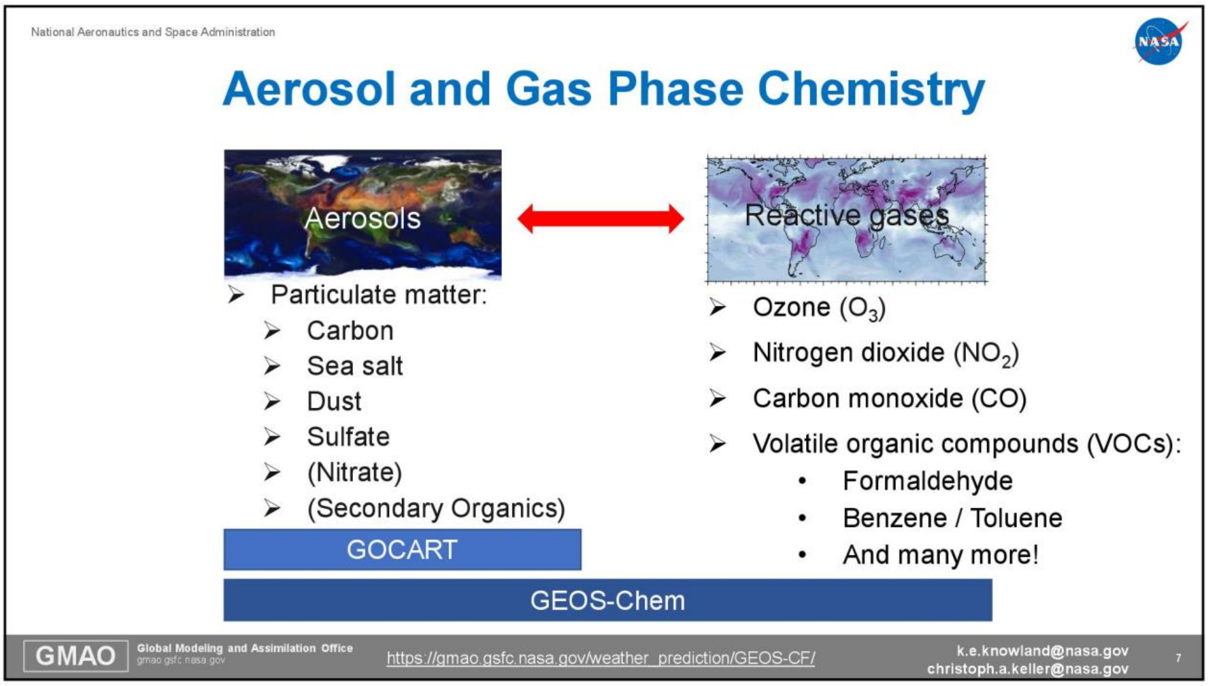
National Aeronautics and Space Administration
Aerosol and Gas Phase Chemistry
Aerosols
Reactive gases
➢ Particulate matter:
➢ Carbon
➢ Sea salt
➢ Dust
➢ Sulfate
➢ (Nitrate)
➢ (Secondary Organics)
➢ Ozone (O_3)
➢ Nitrogen dioxide (NO_2)
➢ Carbon monoxide (CO)
➢ Volatile organic compounds (VOCs):
• Formaldehyde
• Benzene / Toluene
• And many more!
GOCART
GEOS-Chem
GMAO Global Modeling and Assimilation Office gmao.gsfc.nasa.gov
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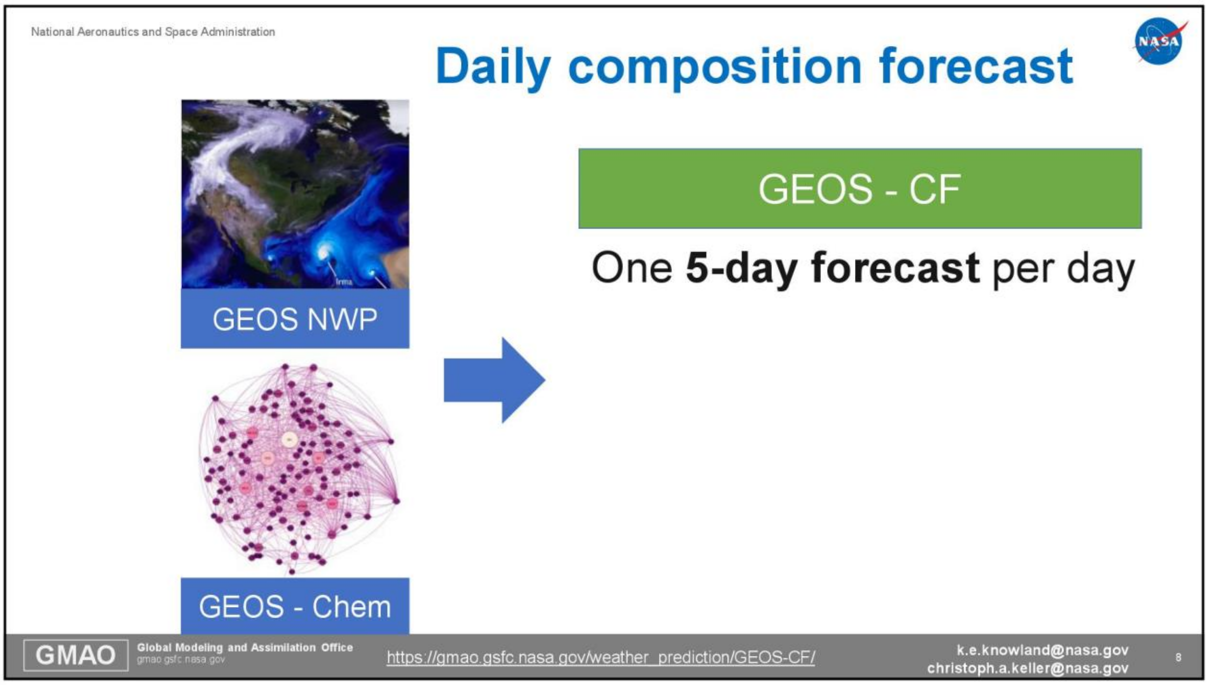
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One **5-day forecast** per day
GMAO Global Modeling and Assimilation Office gmao.gsfc.nasa.gov
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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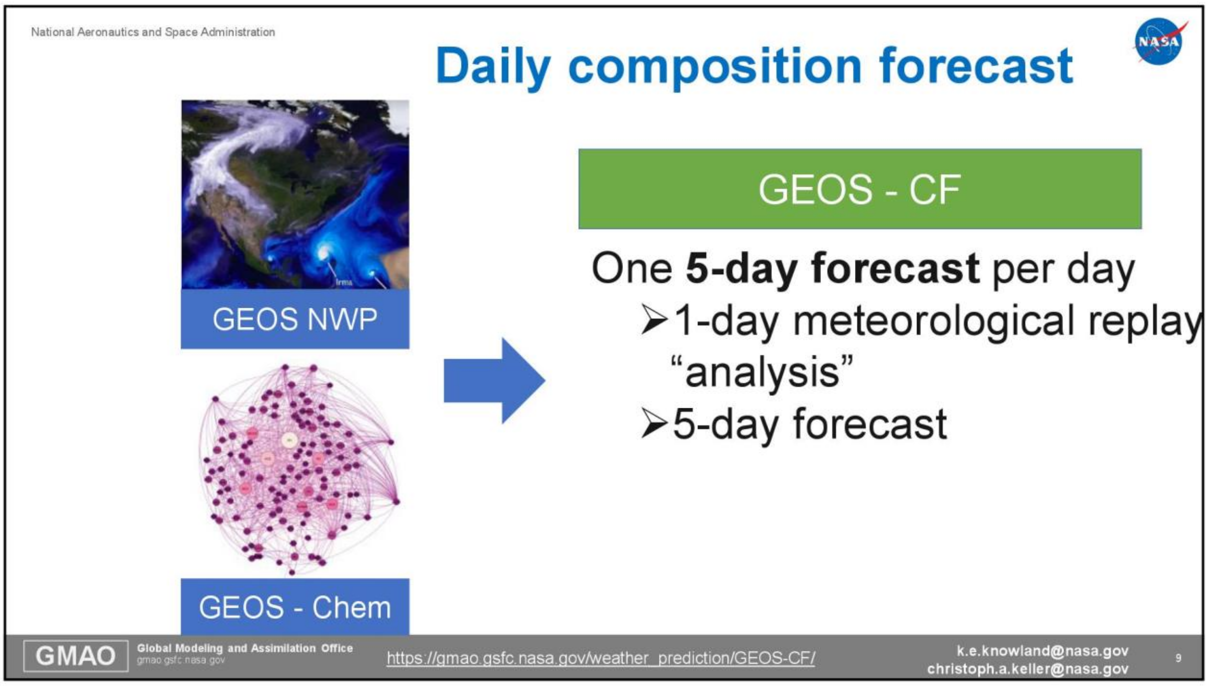
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One **5-day forecast** per day
➢1-day meteorological replay "analysis"
➢5-day forecast
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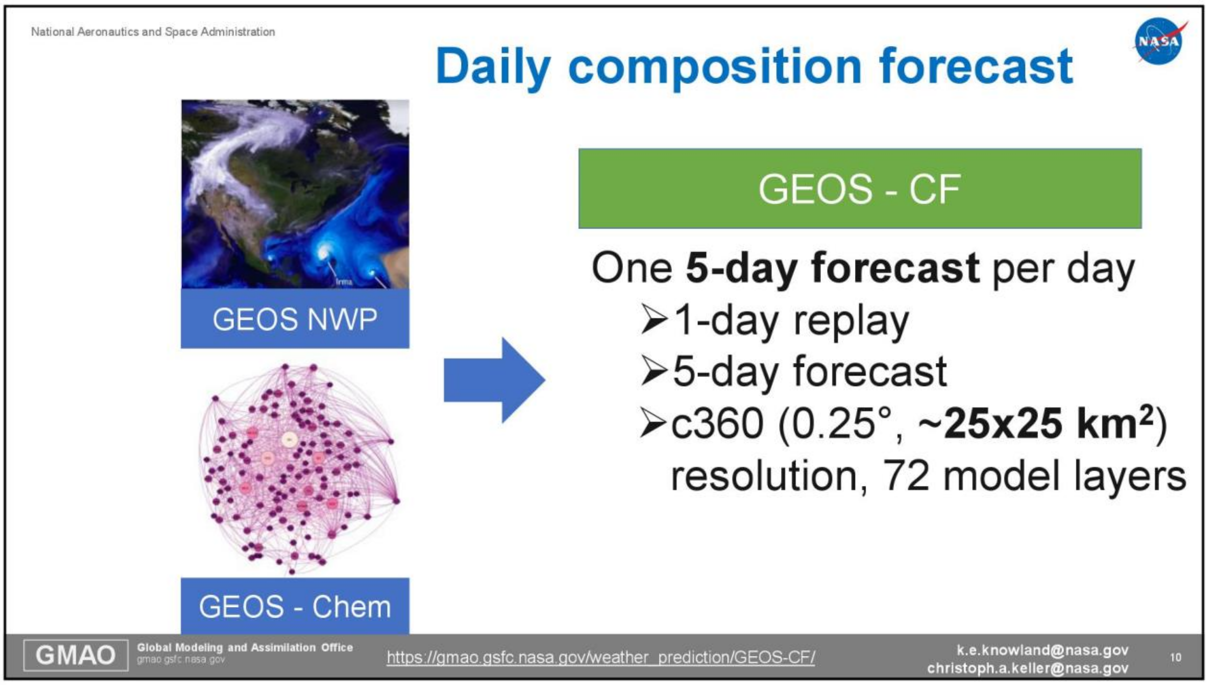
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One **5-day forecast** per day
➢1-day replay
➢5-day forecast
➢c360 (0.25°, **~25x25 km^2**) resolution, 72 model layers
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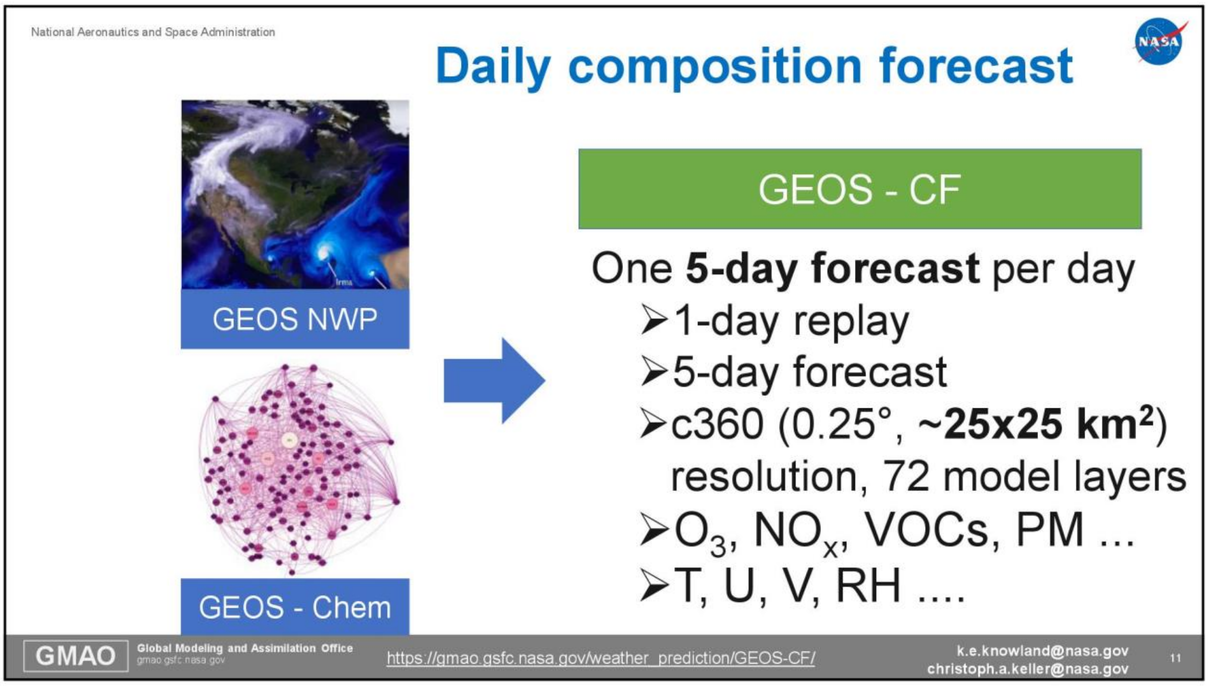
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One **5-day forecast** per day
➢1-day replay
➢5-day forecast
➢c360 (0.25°, **~25x25 km²**) resolution, 72 model layers
➢O3, NOx, VOCs, PM ...
➢T, U, V, RH ....
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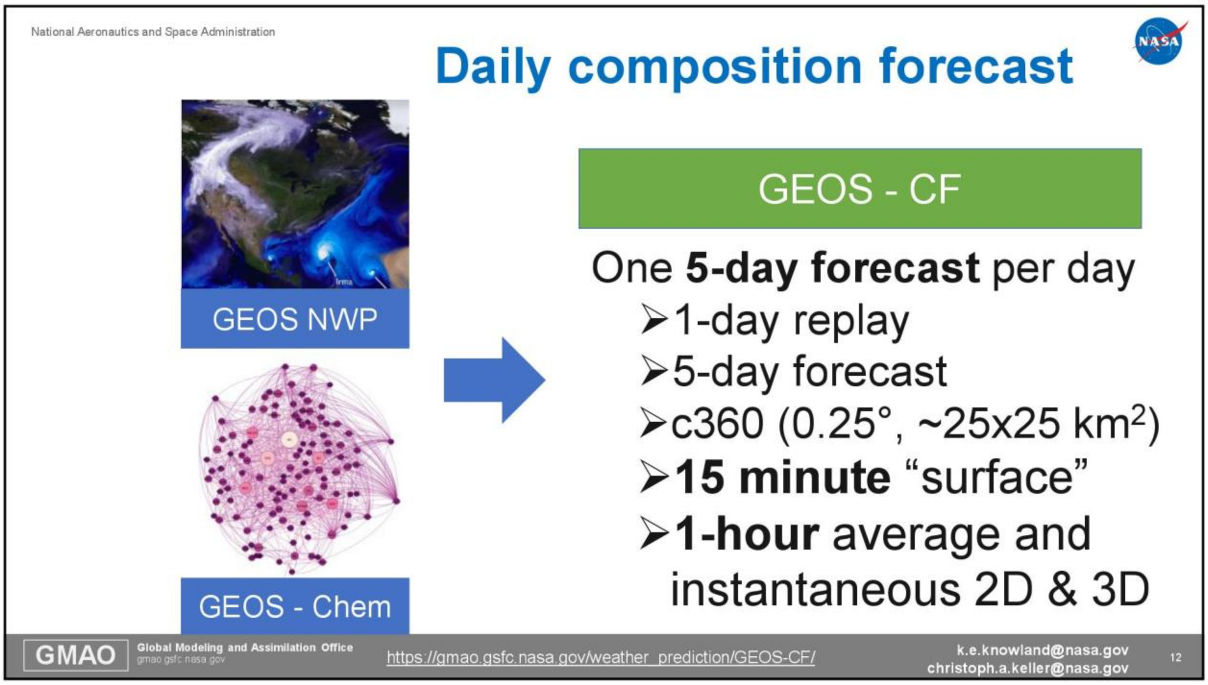
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One **5-day forecast** per day
➢1-day replay
➢5-day forecast
➢c360 (0.25°, ~25x25 km²)
➢**15 minute** "surface"
➢**1-hour** average and instantaneous 2D & 3D
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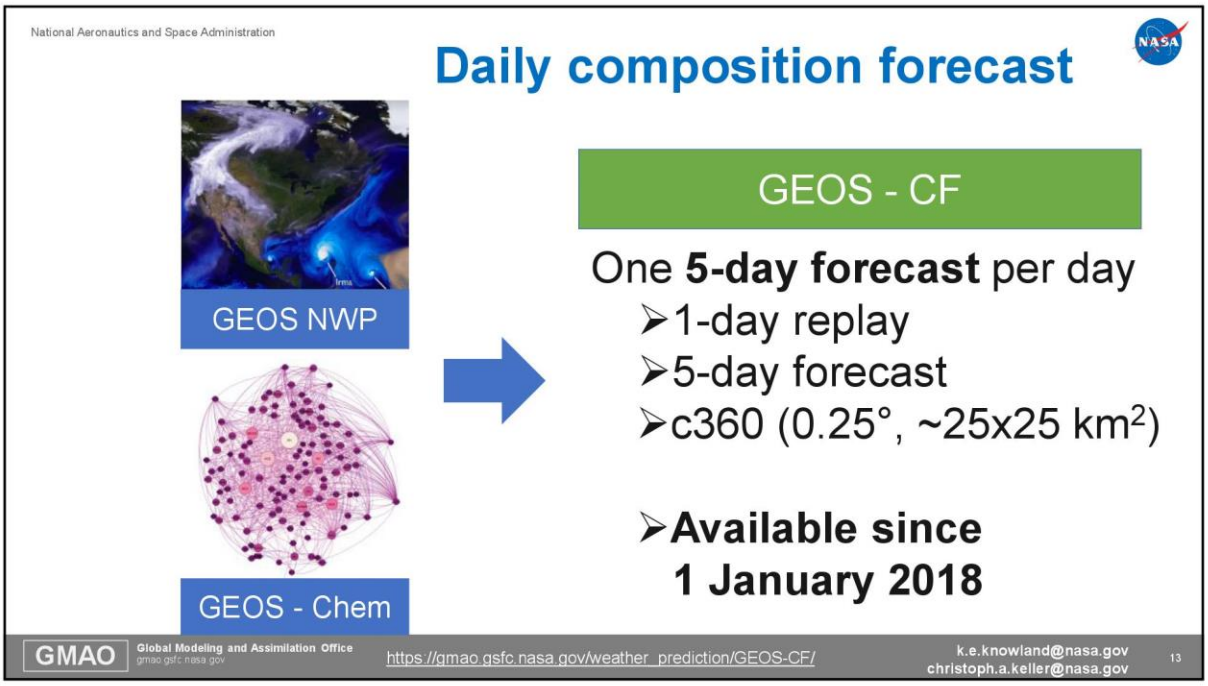
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
One 5-day forecast per day
➢1-day replay
➢5-day forecast
➢c360 (0.25°, ~25x25 km2)
➢Available since 1 January 2018
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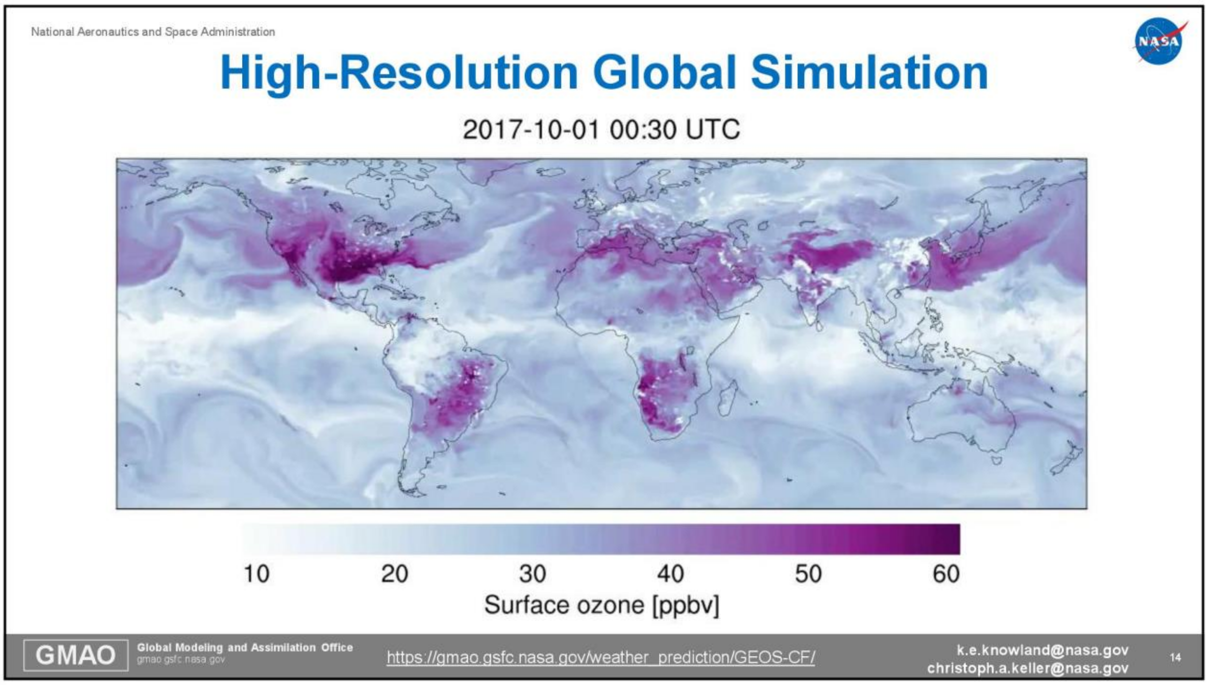
National Aeronautics and Space Administration
High-Resolution Global Simulation
2017-10-01 00:30 UTC
10 20 30 40 50 60
Surface ozone [ppbv]
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Global Modeling and Assimilation Office
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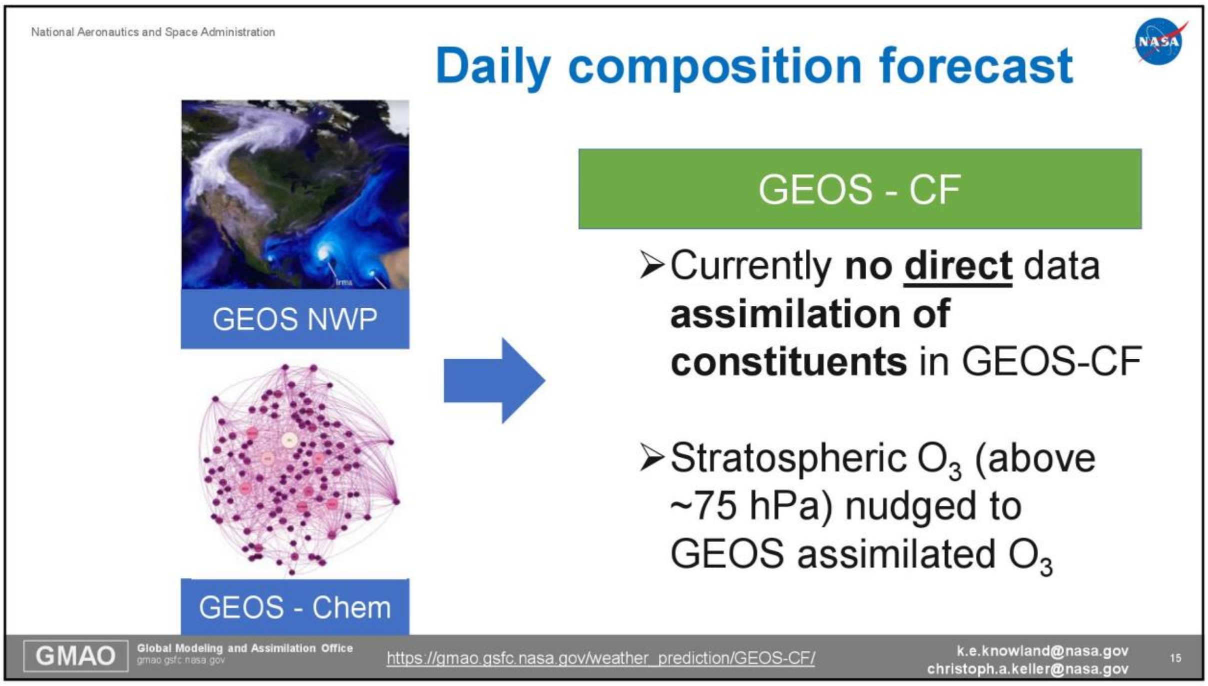
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
➢Currently **no direct** data **assimilation of constituents** in GEOS-CF
➢Stratospheric O_3 (above ~75 hPa) nudged to GEOS assimilated O_3
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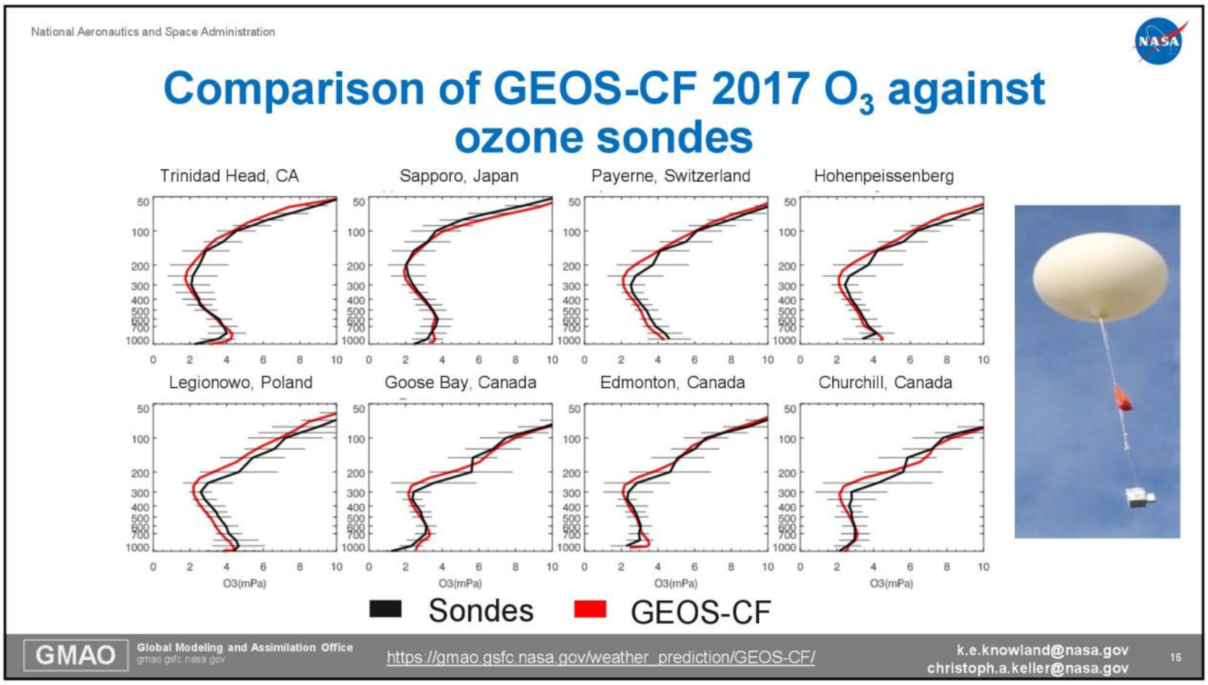
National Aeronautics and Space Administration
Comparison of GEOS-CF 2017 O_3 against ozone sondes
Trinidad Head, CA
Sapporo, Japan
Payerne, Switzerland
Hohenpeissenberg
Legionowo, Poland
Goose Bay, Canada
Edmonton, Canada
Churchill, Canada
O3(mPa)
Sondes
GEOS-CF
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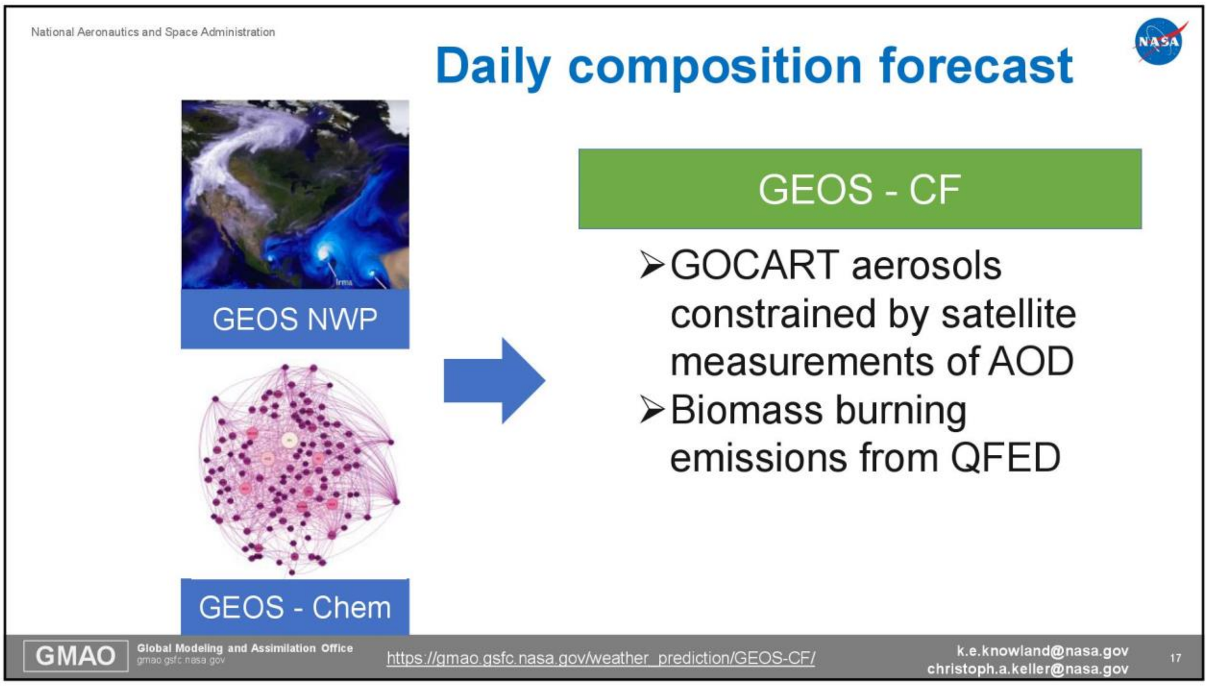
National Aeronautics and Space Administration
Daily composition forecast
GEOS NWP
GEOS - Chem
GEOS - CF
➢GOCART aerosols constrained by satellite measurements of AOD
➢Biomass burning emissions from QFED
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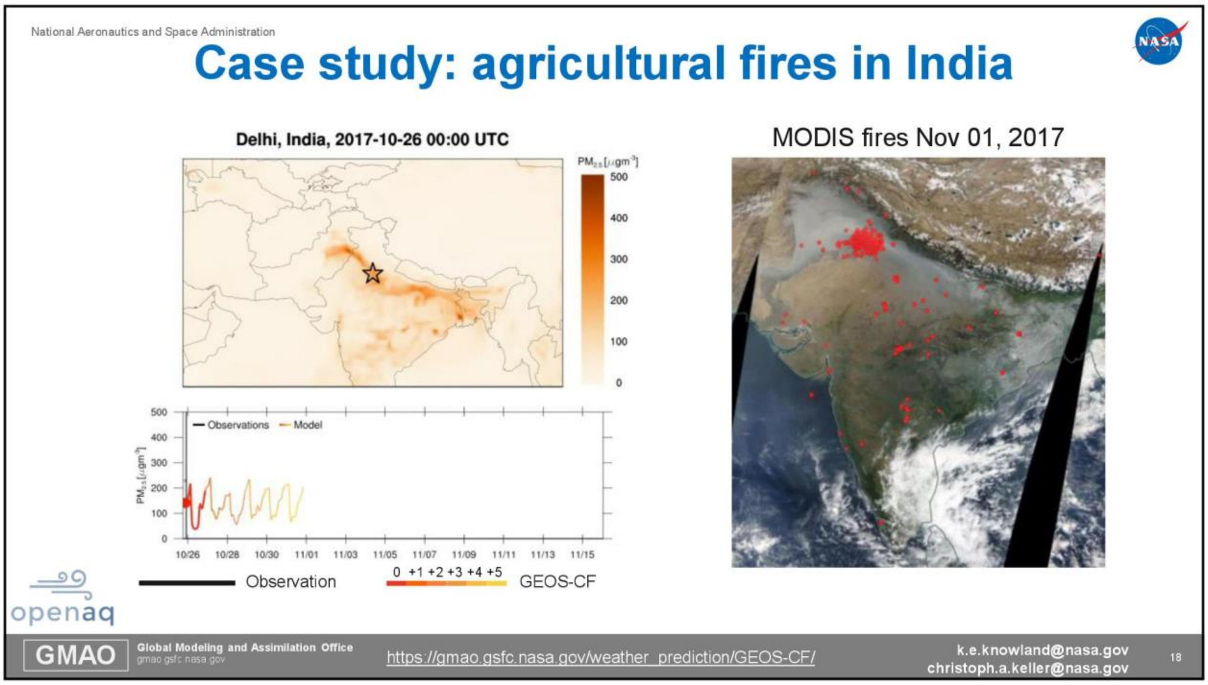
National Aeronautics and Space Administration
Case study: agricultural fires in India
Delhi, India, 2017-10-26 00:00 UTC
MODIS fires Nov 01, 2017
Observations
Model
Observation
0 +1 +2 +3 +4 +5
GEOS-CF
openaq
GMAO
Global Modeling and Assimilation Office
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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christoph.a.keller@nasa.gov
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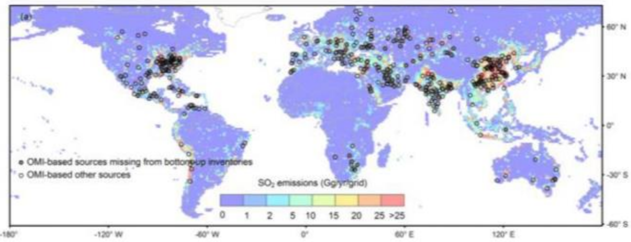
Daily composition forecast

SO$_2$ emissions in the OMI-HTAP inventory



A new emission inventory, OMI-HTAP, combines OMI-based SO$_2$ emissions for large sources and the bottom-up inventory, HTAP, for smaller sources. Liu, F., et al., *Atmos. Chem. Phys., 18*, 2018

GEOS - CF

- Annual gridded scale factors based on satellite data are applied to the emissions of CO (Oda et al., 2017) and SO$_2$ (Liu et al., 2018).

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19

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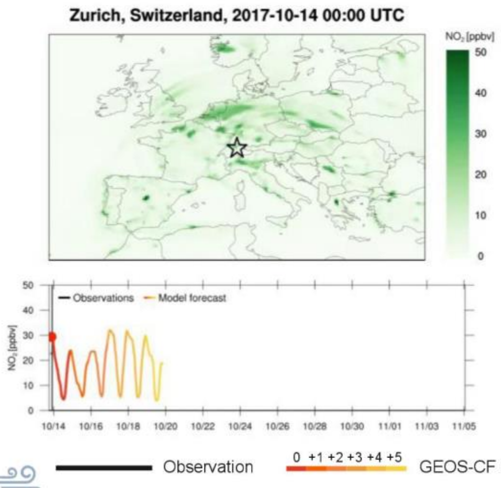
Daily composition forecast



openaq

GEOS - CF

- Scale factors applied to emissions for diurnal and weekly variations

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20

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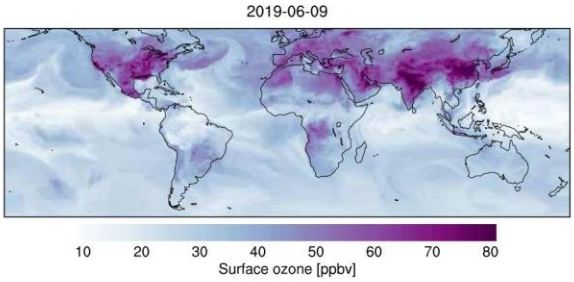
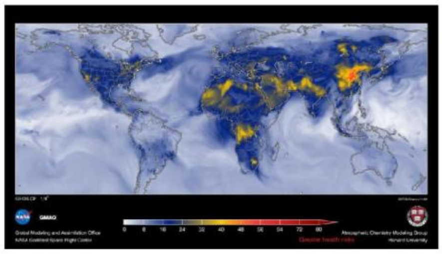
Air quality and health applications

➤ **How good is the model?**

➤ **How bad is the air pollution?**





Optimize model predictions

Global exposure assessment

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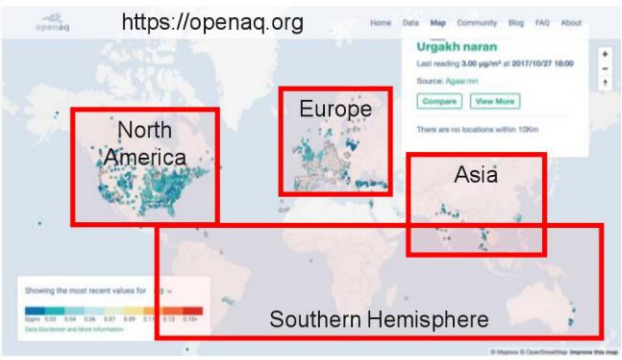
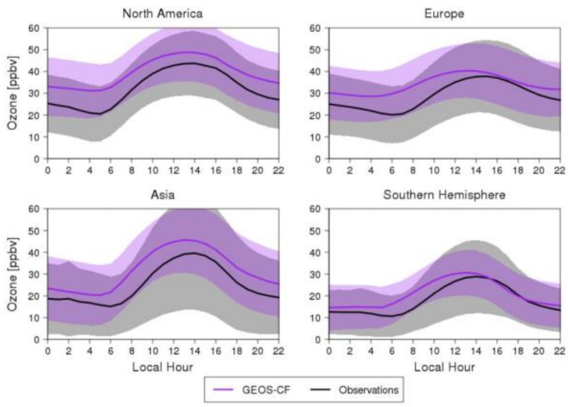
Surface evaluation





OpenAQ is a non-profit compiling publicly available air quality data in near-real time into an open-source data base

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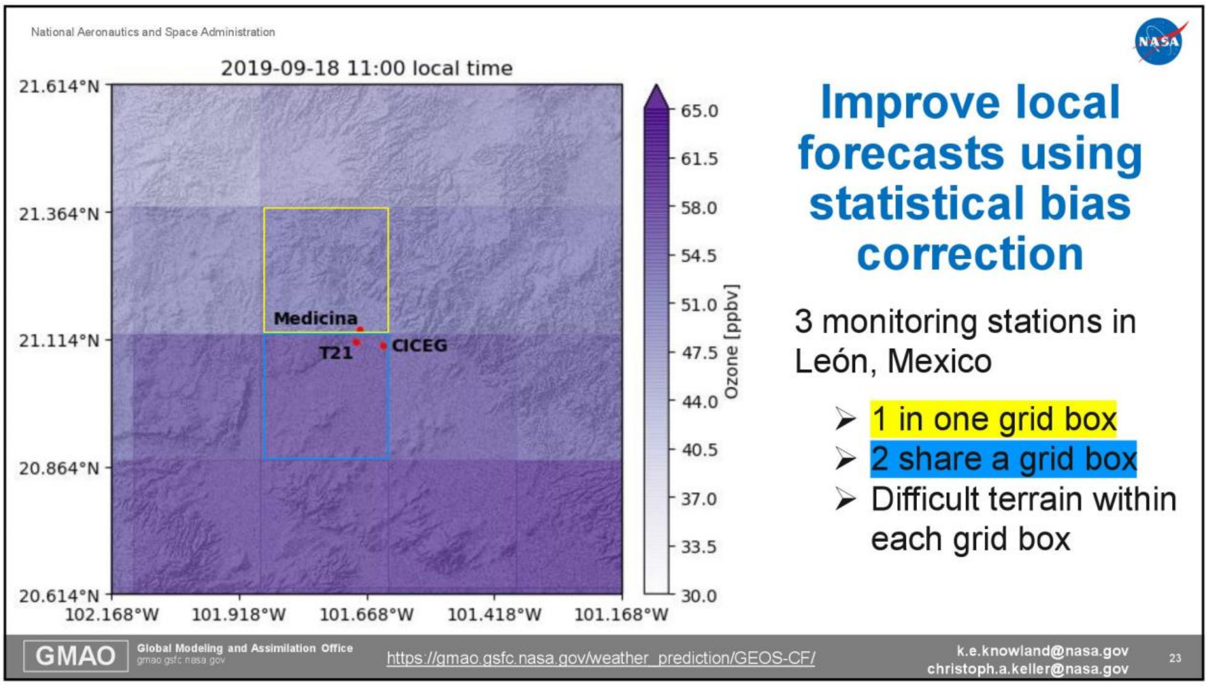
22

11


National Aeronautics and Space Administration
2019-09-18 11:00 local time
21.614°N
21.364°N
21.114°N
20.864°N
20.614°N
102.168°W
101.918°W
101.668°W
101.418°W
101.168°W
Medicina
T21
CICEG
65.0
61.5
58.0
54.5
51.0
47.5
44.0
40.5
37.0
33.5
30.0
Ozone [ppbv]
Improve local forecasts using statistical bias correction
3 monitoring stations in León, Mexico
1 in one grid box
2 share a grid box
Difficult terrain within each grid box
GMAO
Global Modeling and Assimilation Office
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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christoph.a.keller@nasa.gov
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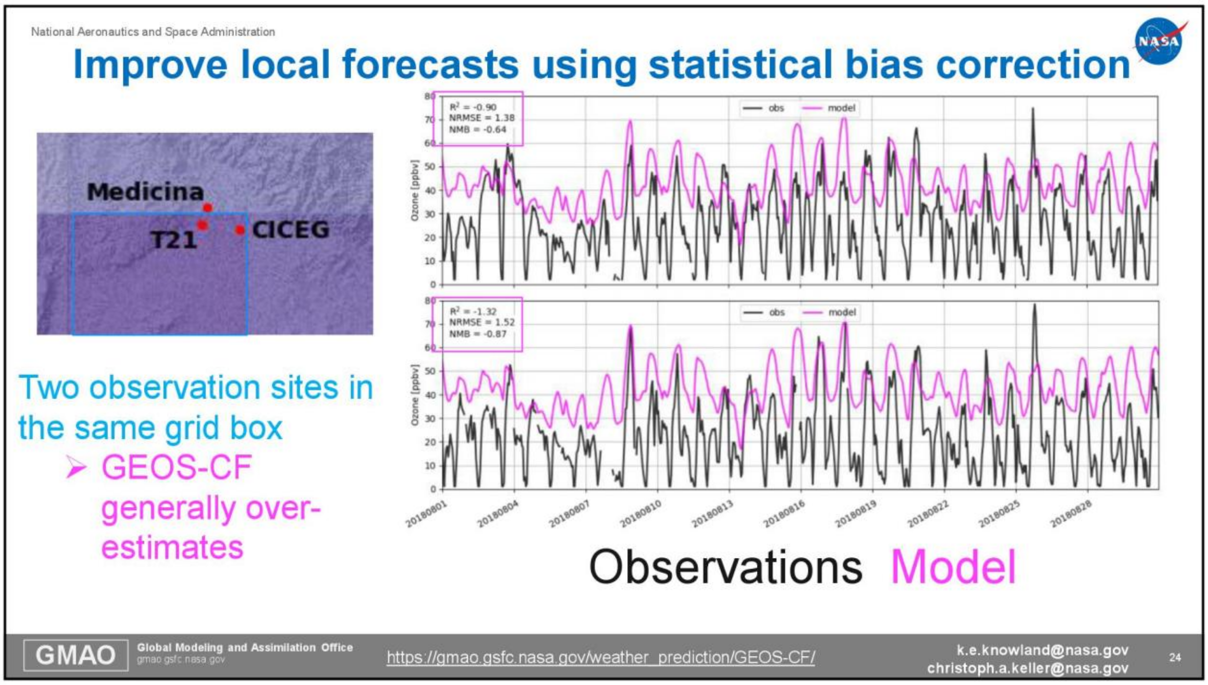
National Aeronautics and Space Administration
Improve local forecasts using statistical bias correction
Medicina
T21
CICEG
Two observation sites in the same grid box
GEOS-CF generally over-estimates
obs
model
Ozone [ppbv]
Observations
Model
GMAO
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Use machine learning to correct for small scale variability and/or model biases

Inputs
- Meteorology (10 vars)
- Chemistry (42 vars)
- Emissions (not yet used)
- Geography (not yet used)

ML →

Output
- Local concentration adjustment

- Algorithm: gradient boosted decision trees (XGBoost)
- Train separate algorithm for each site

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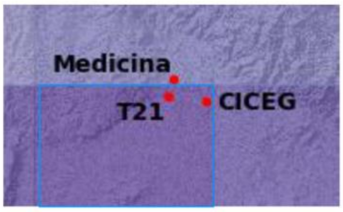
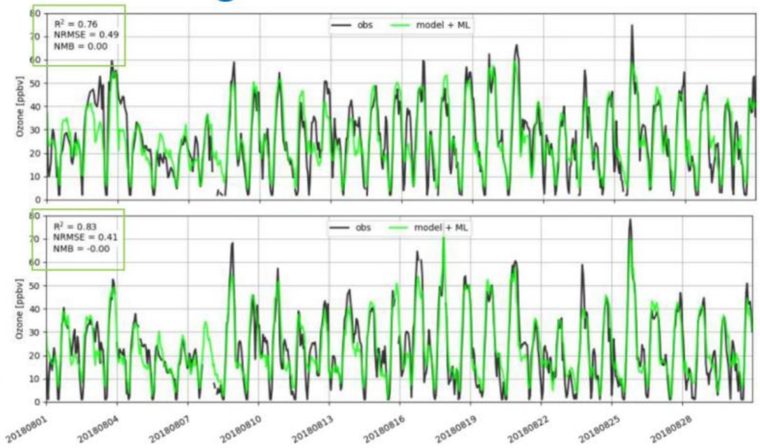
Improve local forecasts using statistical bias correction





Two observation sites in the same grid box
- GEOS-CF+AI captures diurnal variability at sub-grid scale

Observations Model + AI

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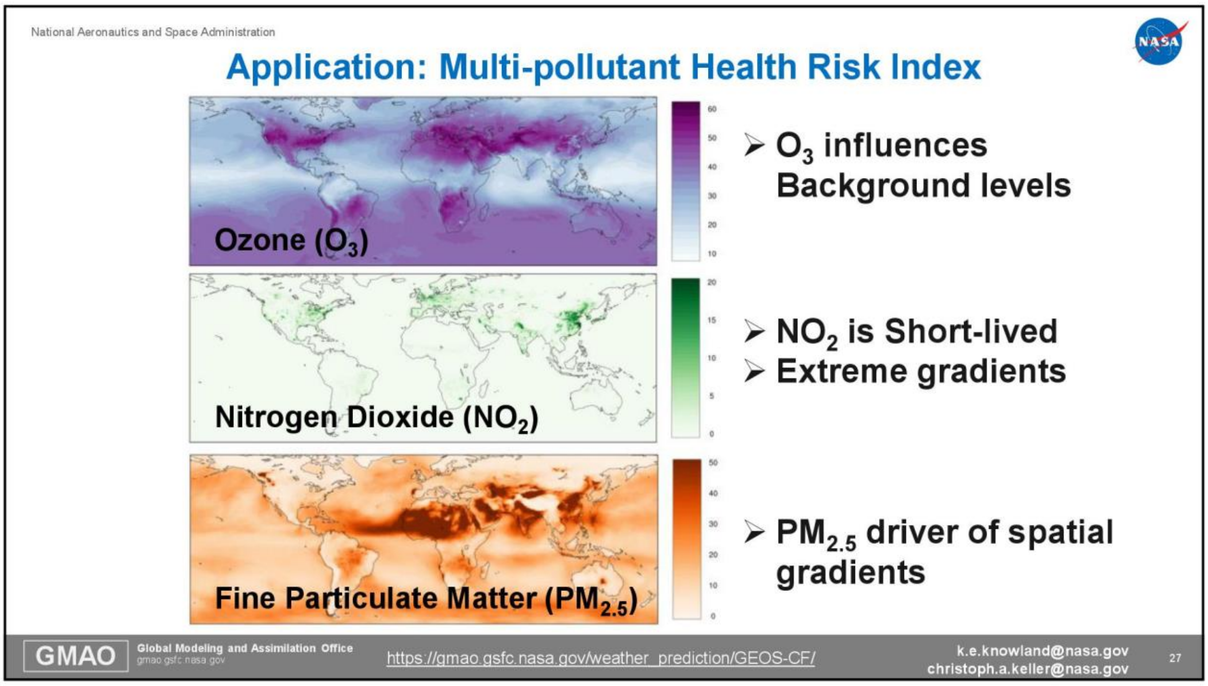
26


National Aeronautics and Space Administration
Application: Multi-pollutant Health Risk Index
Ozone (O_3)
Nitrogen Dioxide (NO_2)
Fine Particulate Matter ($PM_{2.5}$)
➢ O_3 influences Background levels
➢ NO_2 is Short-lived
➢ Extreme gradients
➢ $PM_{2.5}$ driver of spatial gradients
GMAO
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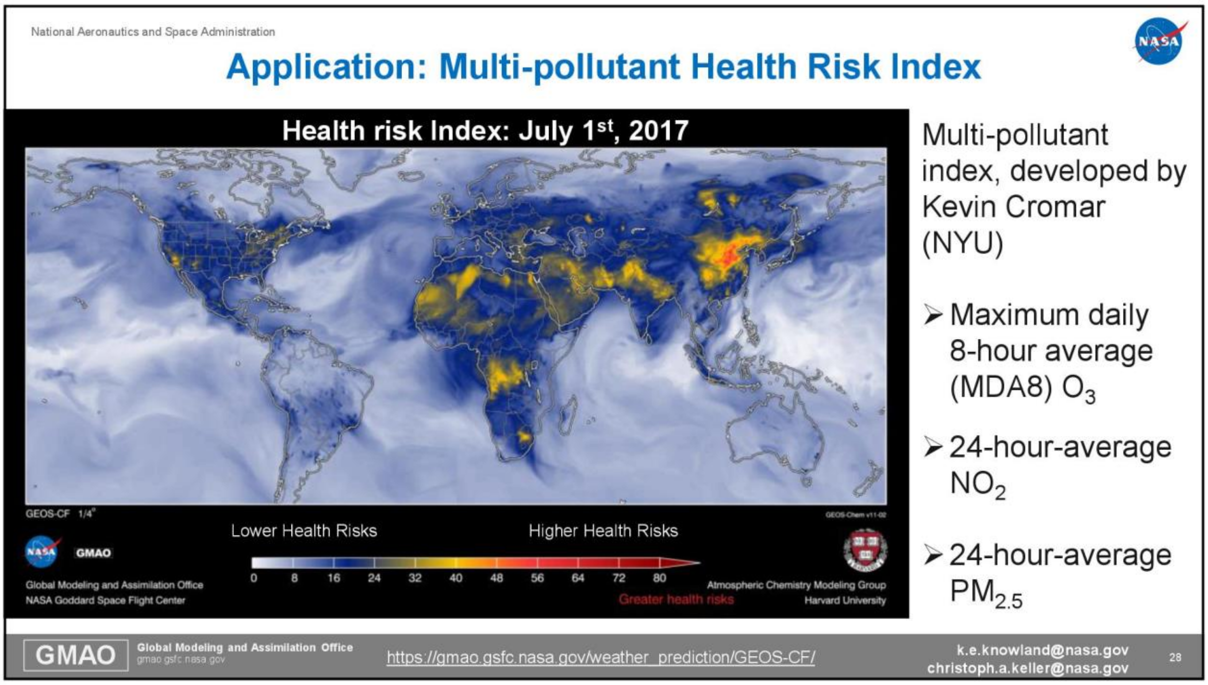
National Aeronautics and Space Administration
Application: Multi-pollutant Health Risk Index
Health risk Index: July 1st, 2017
Lower Health Risks
Higher Health Risks
0 8 16 24 32 40 48 56 64 72 80
Greater health risks
Global Modeling and Assimilation Office
NASA Goddard Space Flight Center
Atmospheric Chemistry Modeling Group
Harvard University
Multi-pollutant index, developed by Kevin Cromar (NYU)
➢ Maximum daily 8-hour average (MDA8) O_3
➢ 24-hour-average NO_2
➢ 24-hour-average $PM_{2.5}$
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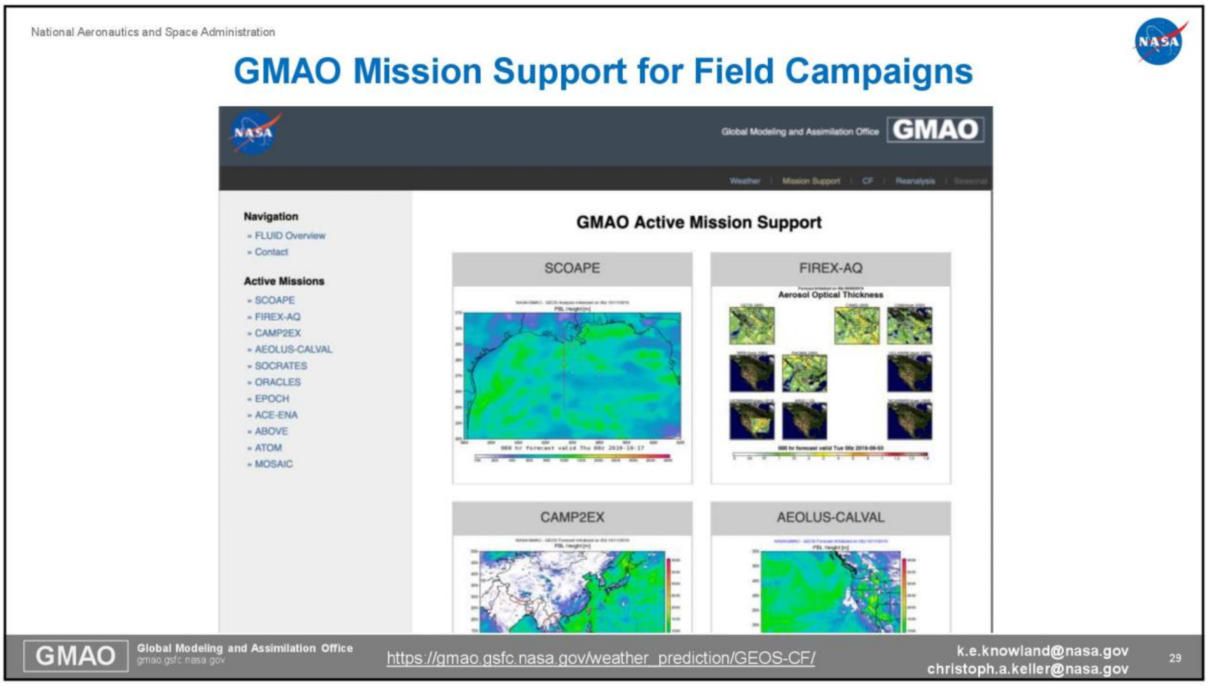
附錄五、" Local to Global Air Quality Simulations using the
NASA GEOS Composition Forecast Model GEOS-CF"



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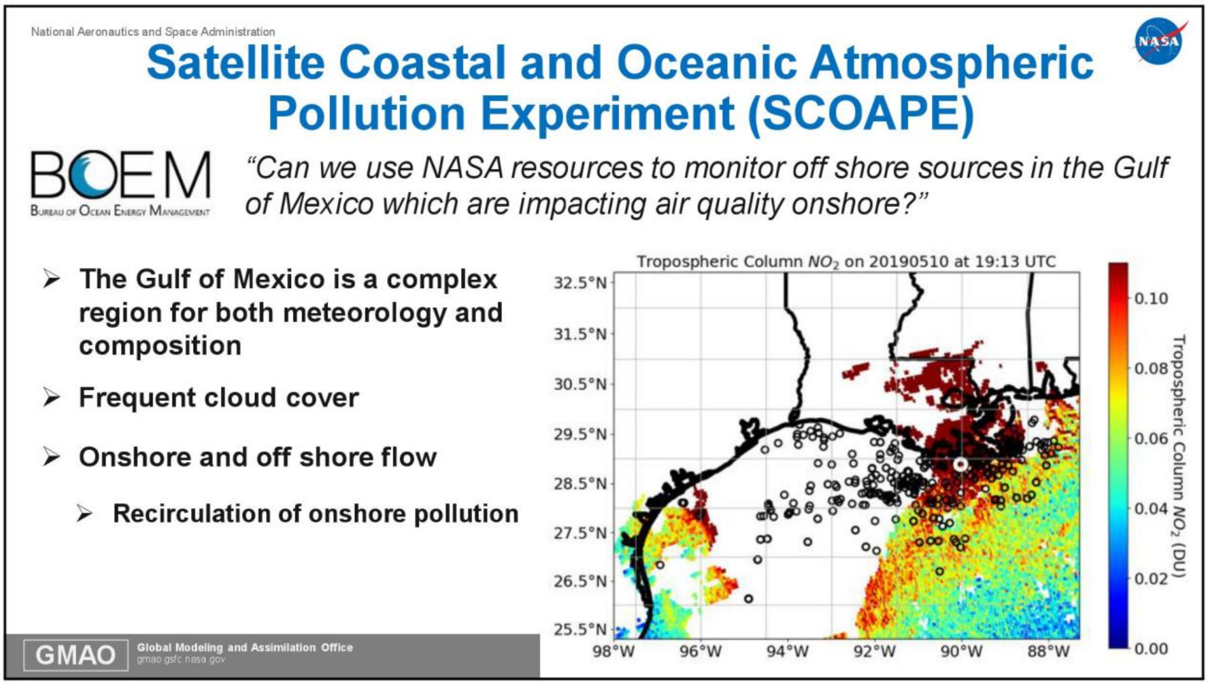

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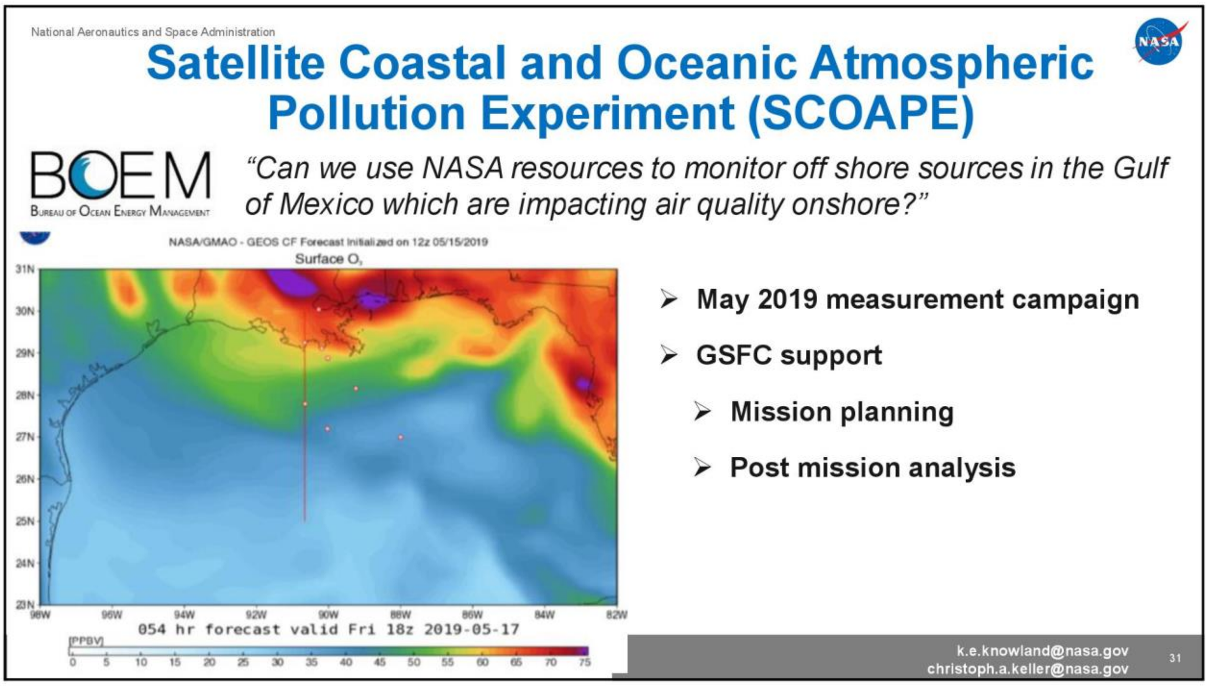
National Aeronautics and Space Administration
Satellite Coastal and Oceanic Atmospheric Pollution Experiment (SCOAPE)
BOEM
Bureau of Ocean Energy Management
"Can we use NASA resources to monitor off shore sources in the Gulf of Mexico which are impacting air quality onshore?"
NASA/GMAO - GEOS CF Forecast Initialized on 12z 05/15/2019
Surface O₃
054 hr forecast valid Fri 18z 2019-05-17
May 2019 measurement campaign
GSFC support
Mission planning
Post mission analysis
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christoph.a.keller@nasa.gov
31

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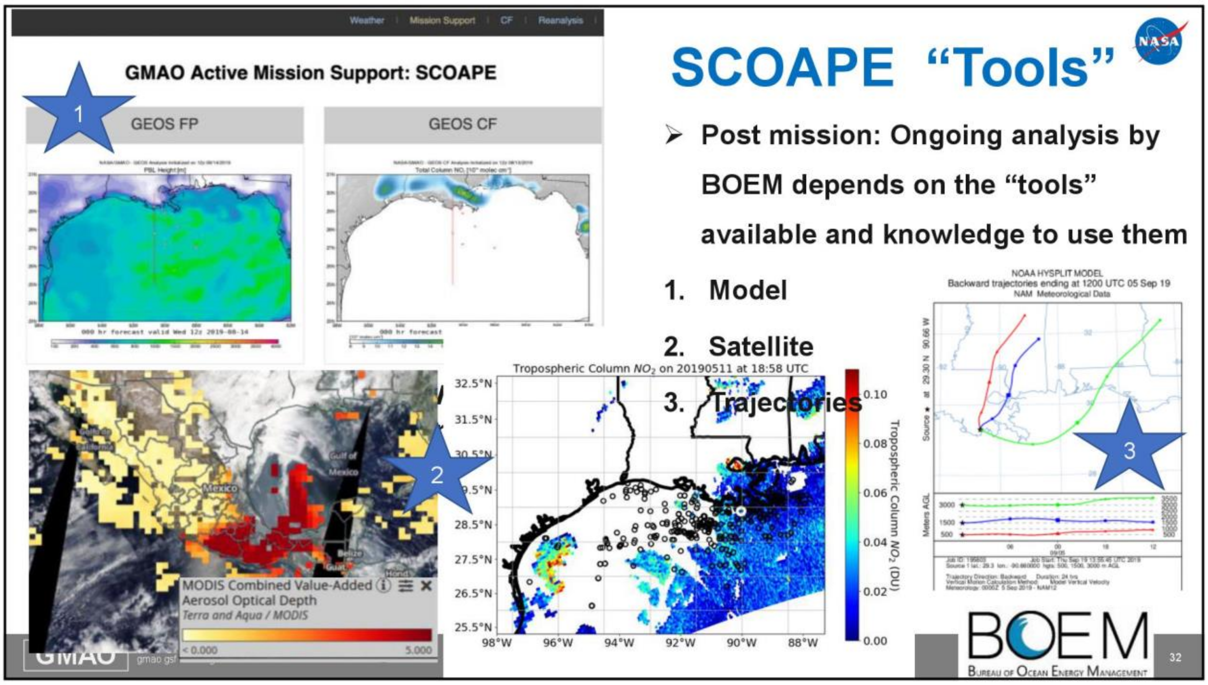
GMAO Active Mission Support: SCOAPE
GEOS FP
GEOS CF
1
2
3
SCOAPE "Tools"
Post mission: Ongoing analysis by BOEM depends on the "tools" available and knowledge to use them
1. Model
2. Satellite
3. Trajectories
MODIS Combined Value-Added Aerosol Optical Depth
Terra and Aqua / MODIS
Tropospheric Column NO₂ on 20190511 at 18:58 UTC
Tropospheric Column NO₂ (DU)
NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 05 Sep 19
NAM Meteorological Data
BOEM
Bureau of Ocean Energy Management
32

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UNIVERSITY of York
NYU
Airlabs
IIEC
HAQAST
developmentSEED
openaq
unicef
HARVARD
QUITO ALCALDÍA
NOAA
CDC CENTERS FOR DISEASE CONTROL AND PREVENTION
JAYA RAYA
BMKG
C40 CITIES
CLIMATE & CLEAN AIR COALITION
HawaDawa
APHC ARMY PUBLIC HEALTH CENTER
SCOAPE
KNMI
JOHNS HOPKINS BLOOMBERG SCHOOL of PUBLIC HEALTH
ECMWF
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
GOVERNO DO Rio de Janeiro
IBM
Swiss Re
WORLD RESOURCES INSTITUTE
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https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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christoph.a.keller@nasa.gov
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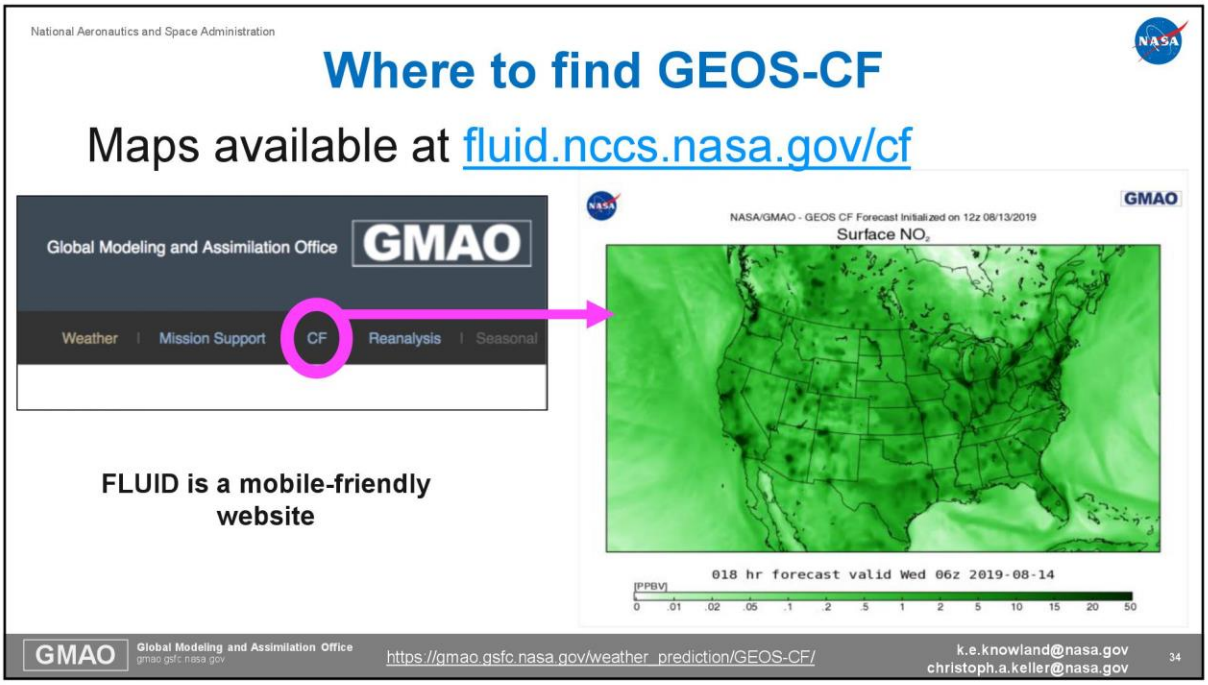
National Aeronautics and Space Administration
Where to find GEOS-CF
Maps available at fluid.nccs.nasa.gov/cf
Global Modeling and Assimilation Office GMAO
Weather | Mission Support | CF | Reanalysis | Seasonal
FLUID is a mobile-friendly website
GMAO
NASA/GMAO - GEOS CF Forecast Initialized on 12z 08/13/2019
Surface NO2
018 hr forecast valid Wed 06z 2019-08-14
[PPBV]
0 .01 .02 .05 .1 .2 .5 1 2 5 10 15 20 50
GMAO Global Modeling and Assimilation Office gmao.gsfc.nasa.gov
https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
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Where to find GEOS-CF

GEOS-CF 3D and 2D data since 1 January 2018:

1) Download from the NASA Data Portal

   https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/

2) Remote access through OPeNDAP

   https://opendap.nccs.nasa.gov/dods/gmao/geos-cf

GMAO Global Modeling and Assimilation Office gmao.gsfc.nasa.gov https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/ k.e.knowland@nasa.gov christoph.a.keller@nasa.gov 35

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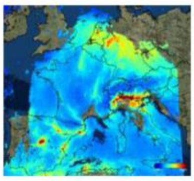
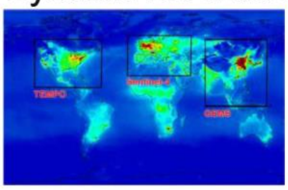
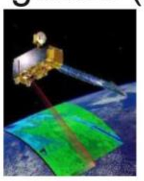
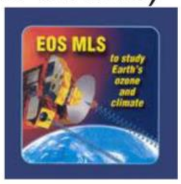
Summary

- GEOS-CF produces daily global air quality forecasts at 25km (16 miles) horizontal resolution in near-real time !!
- Output available at fluid.nccs.nasa.gov/cf

Under development:

- Assimilation system for trace gases (O_3, NO_x, CO, & others)



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Thank you!
https://svs.gsfc.nasa.gov/
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https://gmao.gsfc.nasa.gov/weather_prediction/GEOS-CF/
k.e.knowland@nasa.gov
christoph.a.keller@nasa.gov
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附錄六、"Ramboll Shair: Integrating real-time sensor measurements and regional/local-scale models in Richmond, California"

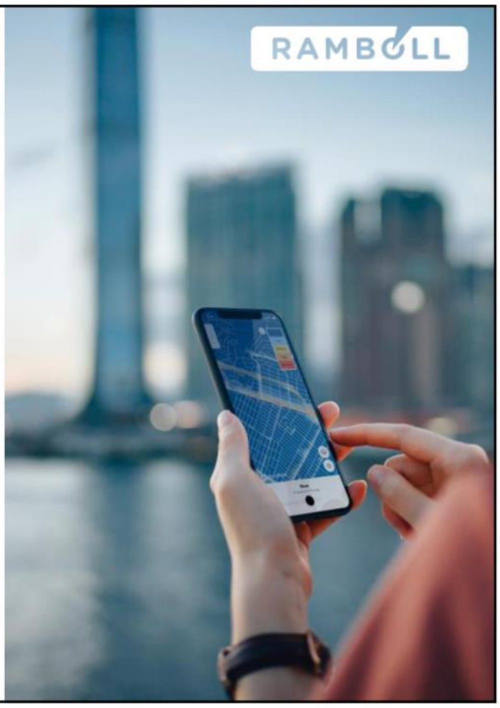
Ramboll Shair: Integrating realtime sensor measurements and regional/local-scale models in Richmond, California

Justin Bandoro, Julia Luongo, Mike Dvorak, Drew Hill, Tasko Olevski, Kurt Richman, Chris Emery, Greg Yarwood, Shari Libicki

18th CMAS Conference

October 22nd, 2019

Ramboll Shair
Make sense of your air quality data

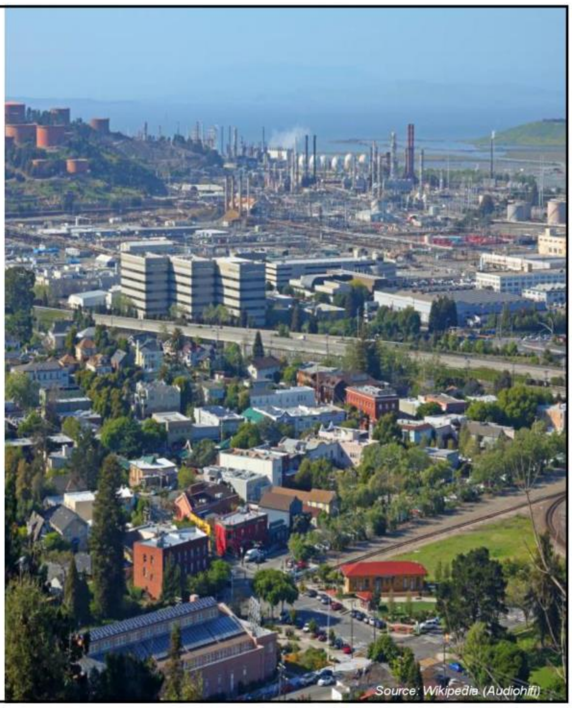


1

Outline

- **Background**
  - AB617 overview
  - Air Rangers Community Air Protection
- **Ramboll Shair Model**
  - Emission estimates with near-realtime traffic emissions
  - CAMx regional and Shairstreet roadway models
  - Sensor integration
- **Feedback and Next Steps**
  - Communicating results to the Richmond community

Ramboll Shair
Make sense of your air quality data



2

1

附錄六、"Ramboll Shair: Integrating real-time sensor measurements and regional/local-scale models in Richmond, California"

Background

AB617

- California Assembly bill
- Funds community level air measurement, education, and emissions reductions
- Targets disadvantaged communities

AB617 Funded Project in Richmond, CA ("Air Rangers")

- Fill PM and NO_2 monitoring gaps
- Attribute hotspots to sources
- Communicate actionable data to the public in **near-realtime**
- Facilitate healthy outdoor recreation
- Local work force development for disadvantaged youth

Ramboll Shair
Make sense of your air quality data

3

Air Rangers Community Air Protection Grant

Action Plan

Converge strategic partners

Site **50** PM & NO_2 sensors; take **70** toxic metals samples

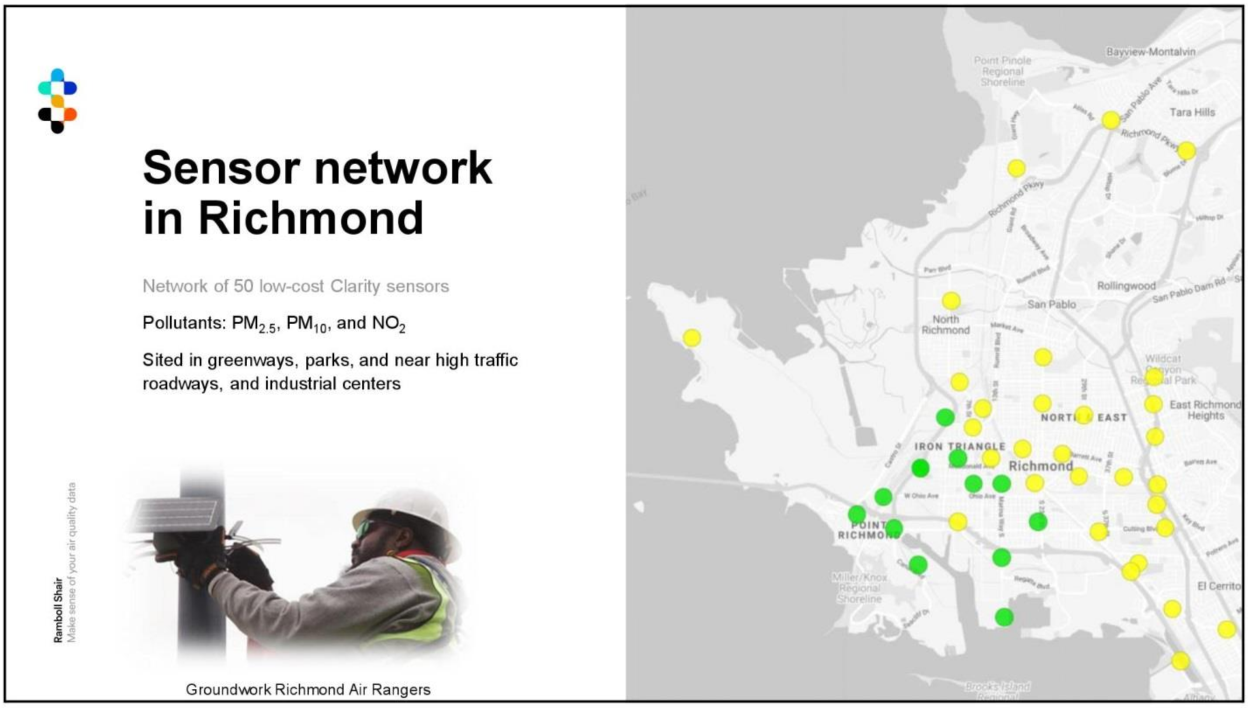
Communicate hyper-local air quality to the public, hourly

Hourly hotspot identification and source attribution

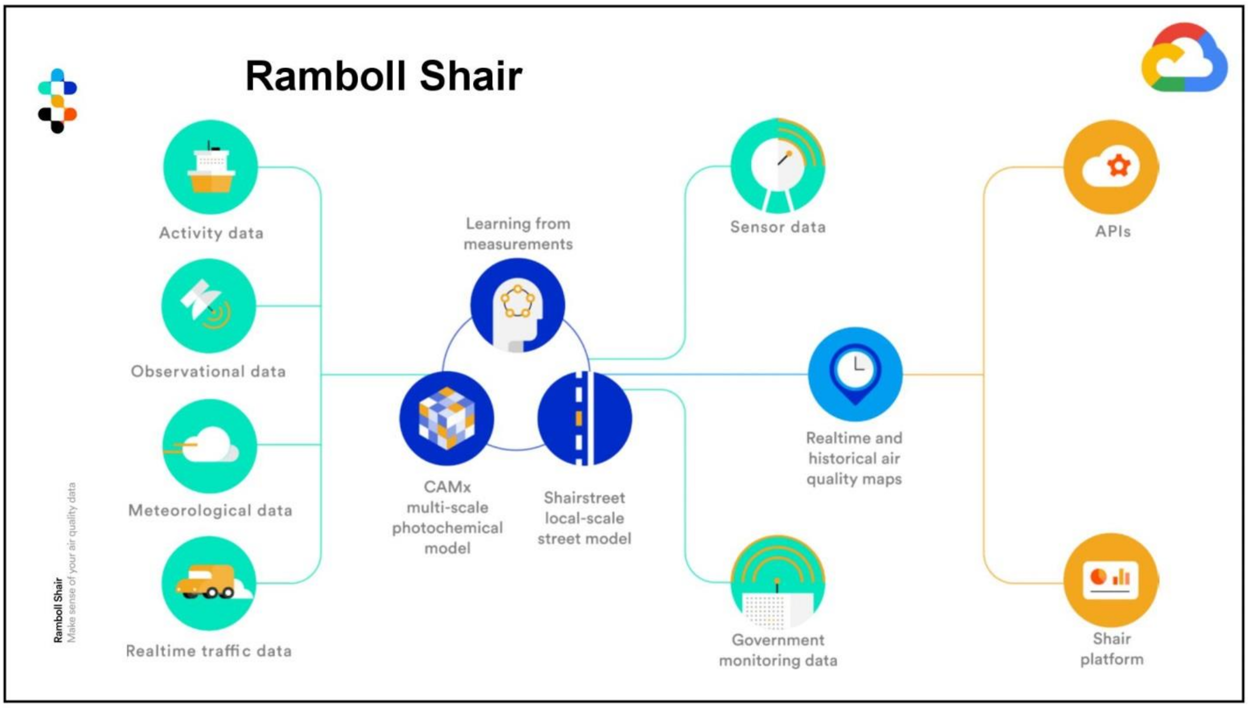
Ramboll Shair
Make sense of your air quality data

4

2


Sensor network in Richmond
Network of 50 low-cost Clarity sensors
Pollutants: $PM_{2.5}$, PM_{10}, and NO_2
Sited in greenways, parks, and near high traffic roadways, and industrial centers
Groundwork Richmond Air Rangers
Ramboll Shair
Make sense of your air quality data
Tara Hills
North Richmond
San Pablo
Rollingwood
IRON TRIANGLE
Richmond
POINT RICHMOND
East Richmond Heights
El Cerrito

5


Ramboll Shair
Activity data
Observational data
Meteorological data
Realtime traffic data
Learning from measurements
CAMx multi-scale photochemical model
Shairstreet local-scale street model
Sensor data
Realtime and historical air quality maps
Government monitoring data
APIs
Shair platform
Ramboll Shair
Make sense of your air quality data

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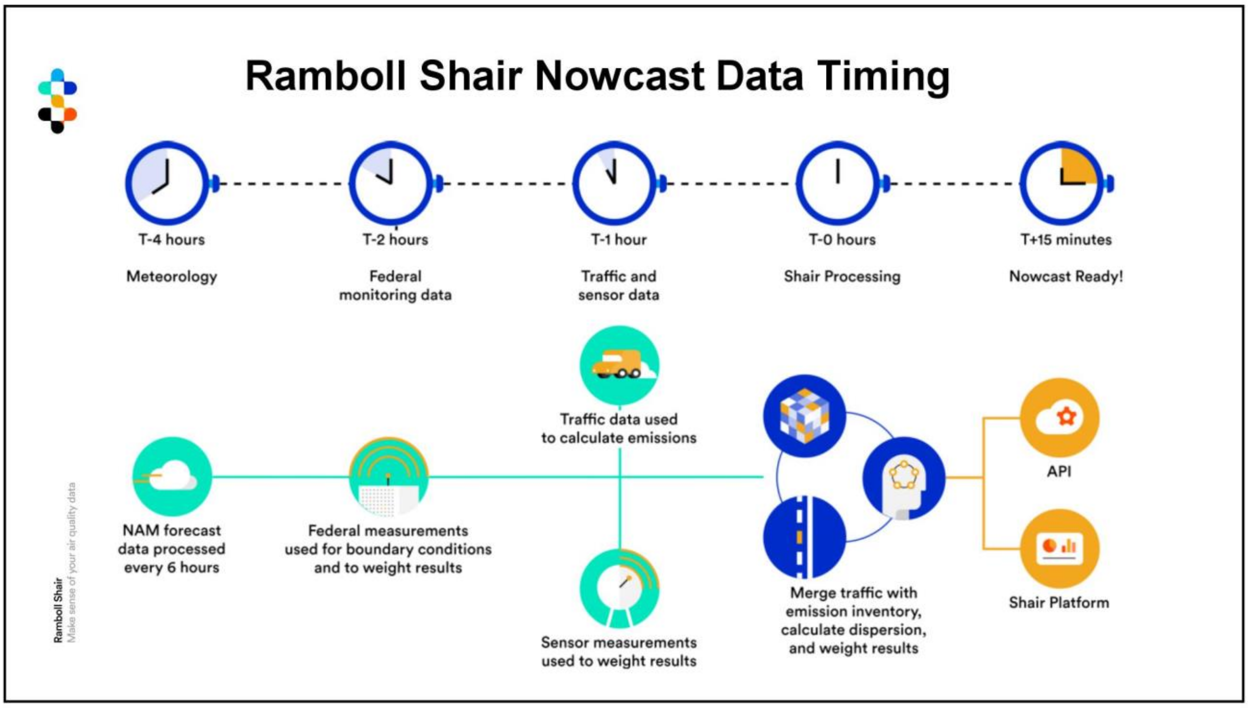
附錄六、"Ramboll Shair: Integrating real-time sensor measurements and regional/local-scale models in Richmond, California"



7

CAMx Modeling

- **Meteorology**
  - WRF NAM forecast refreshed every 6 hours
  - Nested grids: 9km, 3km, and 1km resolution
- **CAMx Grids**
  - 1km and 200m resolution
  - Captures region's most influential sources
- **Chemistry and Deposition**
  - Fast chemical scheme for O3-NO-NO2
  - Wet and dry deposition with ZHANG03 model
- **Source Attribution**
  - Tag emissions by source category for source apportionment
- **Modeled every hour**
  - Latest emissions combined with previous hour dispersion results

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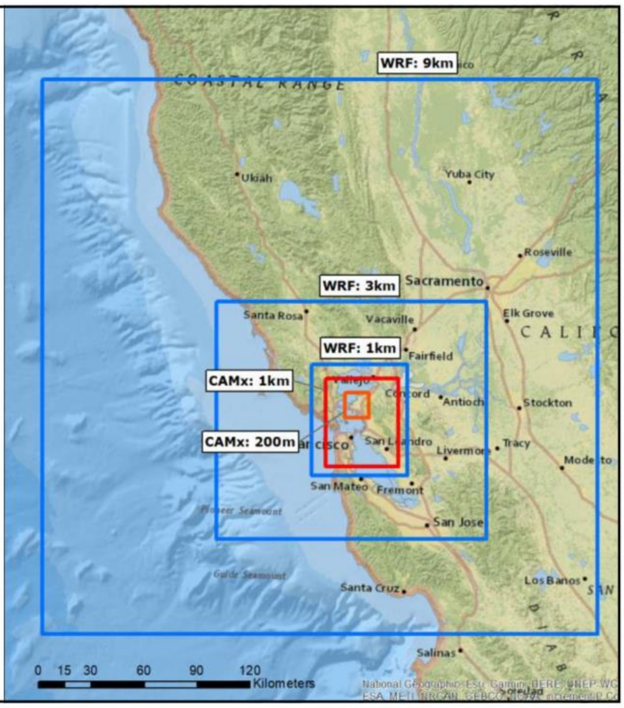
Make sense of your air quality data



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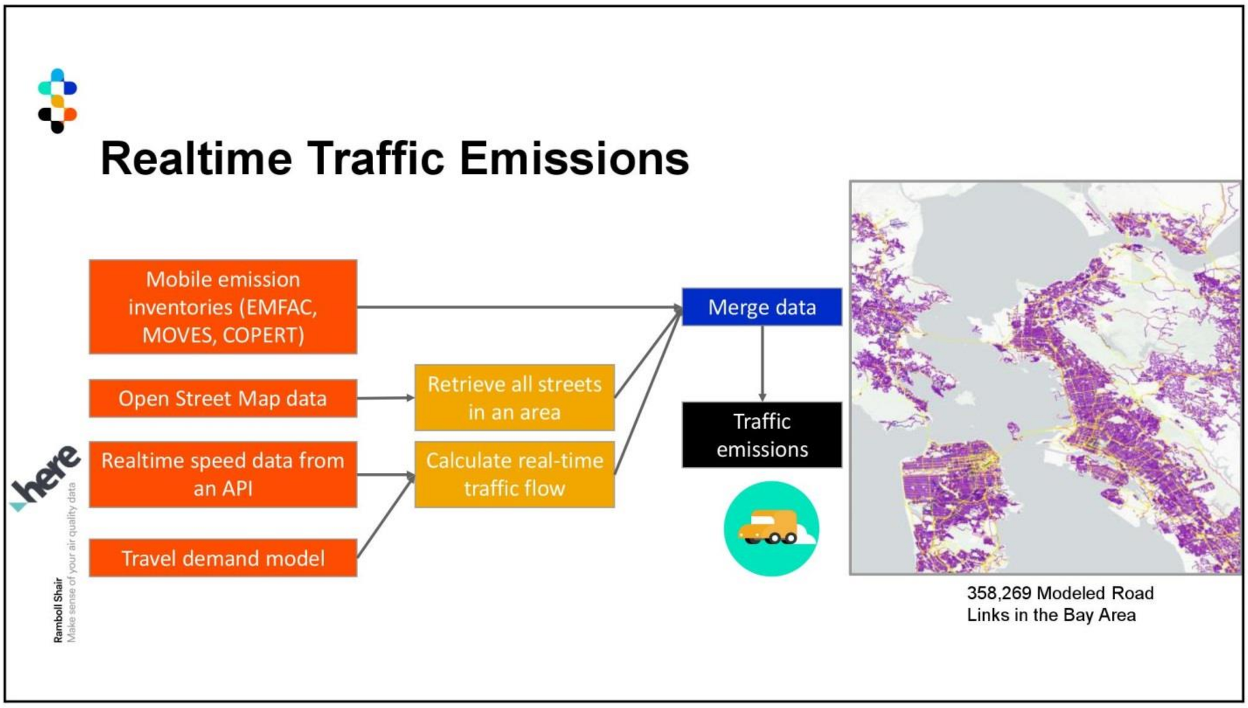
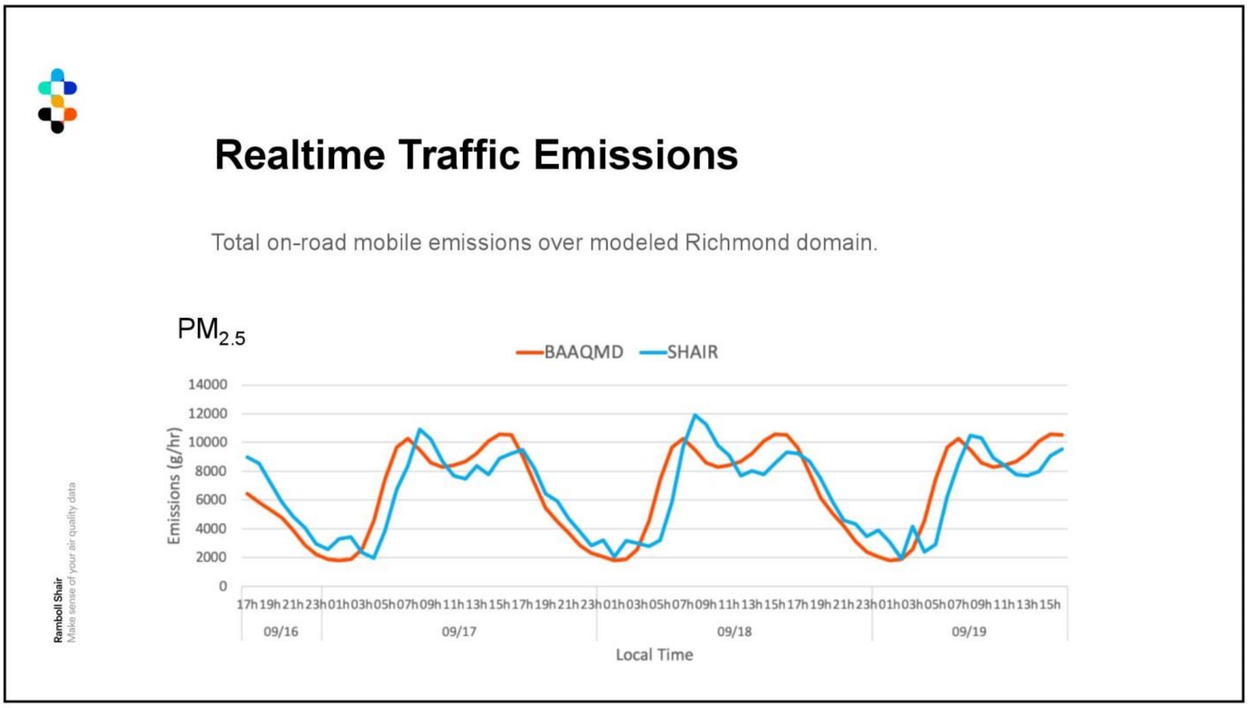

Realtime Traffic Emissions
Mobile emission inventories (EMFAC, MOVES, COPERT)
Open Street Map data
Realtime speed data from an API
Travel demand model
Retrieve all streets in an area
Calculate real-time traffic flow
Merge data
Traffic emissions
here
Ramboll Shair
Make sense of your air quality data
358,269 Modeled Road Links in the Bay Area

9


Realtime Traffic Emissions
Total on-road mobile emissions over modeled Richmond domain.
PM2.5
BAAQMD
SHAIR
Emissions (g/hr)
14000
12000
10000
8000
6000
4000
2000
0
17h 19h 21h 23h 01h 03h 05h 07h 09h 11h 13h 15h 17h 19h 21h 23h 01h 03h 05h 07h 09h 11h 13h 15h 17h 19h 21h 23h 01h 03h 05h 07h 09h 11h 13h 15h
09/16
09/17
09/18
09/19
Local Time
Ramboll Shair
Make sense of your air quality data

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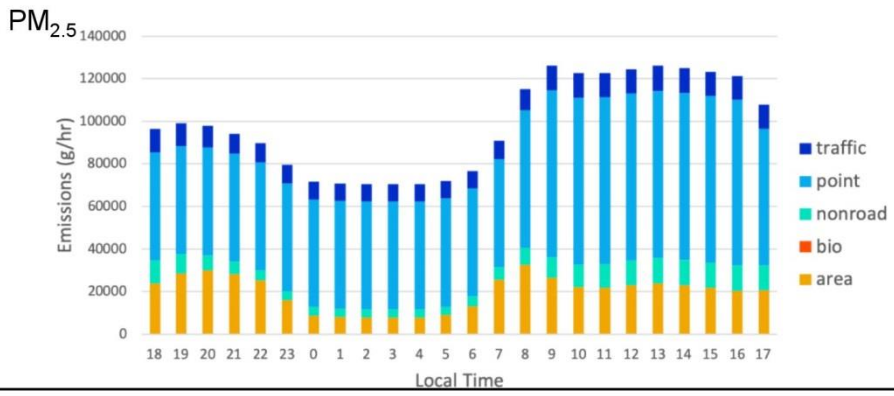
Additional Source Emissions

2016 BAAQMD 1km emissions inventory used for non-mobile sources.

Total emissions over modeled Richmond domain.



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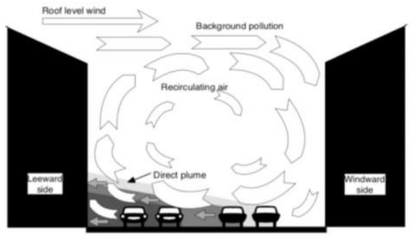
11

Shairstreet Modeling

Fine scale resolution of road emissions

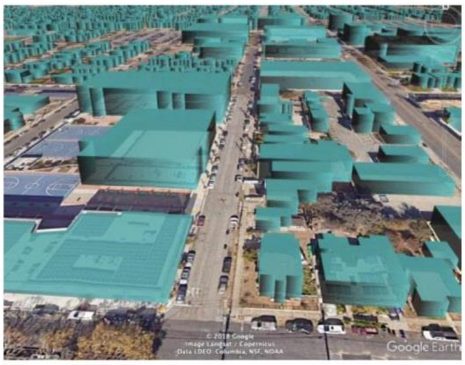
1. Street canyon model

Calculates additional recirculation contribution for road links that have street canyon-like geometry, using wind speed and direction at top of the canyons. Takes into account vehicle generated mechanical turbulence.



Source: Berkowicz 1997.

Modeled buildings in Richmond (view from Chanslor Ave and 9th St)



Ramboll Shair
Make sense of your air quality data

12

Shairstreet Modeling

Fine scale resolution of road emissions

1. Street canyon model

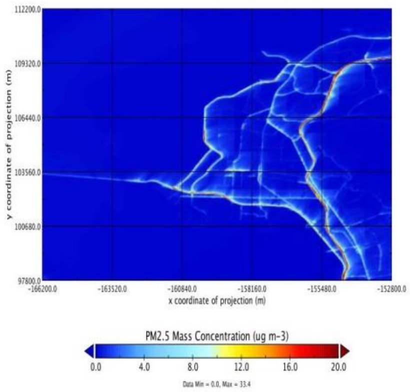
Calculates additional recirculation contribution for road links that have street canyon-like geometry, using wind speed and direction at top of the canyons. Takes into account vehicle generated mechanical turbulence.

2. Line source dispersion model

Road links are modeled as line sources based on Venkatram and Horst 2006 approximate Gaussian dispersion solution at **10x10m resolution**.

3. NOx chemistry model

Simplified NO-NO_2-O_3 model based on During et al. 2011, with parameterized mixing times based on street-canyon geometry.



$NO + O_3 \rightarrow NO_2 + O_2\ (k)$
$NO_2 \rightarrow NO + O_3\ (J)$

Reaction and photolysis rates, k and J, taken from CAMx 200m grid along with background NO_x and O_3

Ramboll Shair
Make sense of your air quality data

13

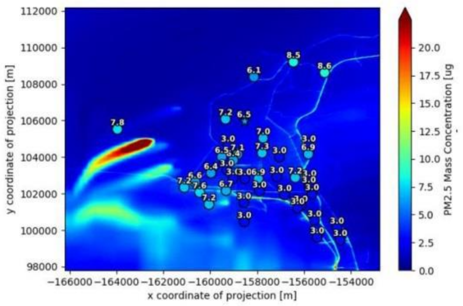
Sensor Integration

- Latest Clarity sensor and BAAQMD monitor data pulled
- Measurement data undergoes internal quality control checks and adjustment
- Objective analysis via Barnes interpolation is used to assimilate sensor measurements

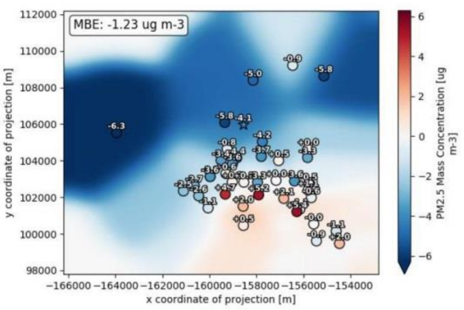
$$\varphi(\vec{x}) = \sum_{i=1}^{N_d} w_i d_i \quad , w_i = e^{-\frac{r_i^2}{2R^2}} / \sum_i e^{-\frac{r_i^2}{2R^2}}$$

October 12th 2019, 7:00pm PDT

Raw model + sensors



Interpolated model error



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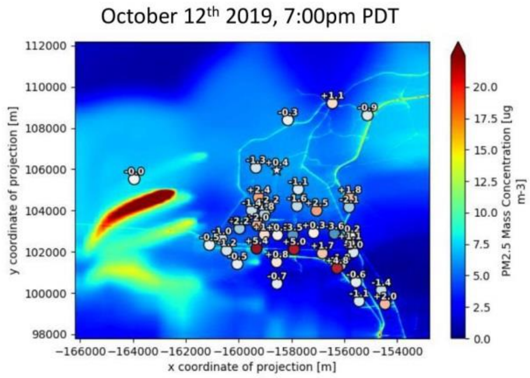
7

Sensor Integration

- Latest Clarity sensor and BAAQMD monitor data pulled
- Measurement data undergoes internal quality control checks and adjustment
- Error between model and observations are calculated
- Objective analysis via Barnes interpolation is used to assimilate sensor measurements

$$\varphi(\vec{x}) = \sum_{i=1}^{N_d} w_i d_i \quad , w_i = e^{-\frac{r_i^2}{2R^2}} / \sum_i e^{-\frac{r_i^2}{2R^2}}$$

Assimilated map



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Communicating Results

Web/phone app for Richmond is being developed

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Next Steps

In the coming months, Shair output will be put to use by stakeholders

Groundwork Richmond
- Targeted tree planting as an air pollution intervention

City of Richmond
- Integrate hourly Shair output into the City's web data dashboard
- Investigate air quality data-driven land use planning activities
- Communicate information to the public

Richmond citizens
- Engage with their environment
- Plan healthier outdoor activities
- Take precautionary actions during localized pollution events

Richmond-San Pablo Community Air Monitoring Steering Committee
- Identify major emissions sources
- Inform their official Community Emissions Reduction Plan (December 2020)

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“

We're excited to partner with Ramboll Shair to better understand air quality on a community scale. We need more information to better direct our resources and achieve our climate action goals.

- Adam Lenz, Environmental Services Manager, City of Richmond

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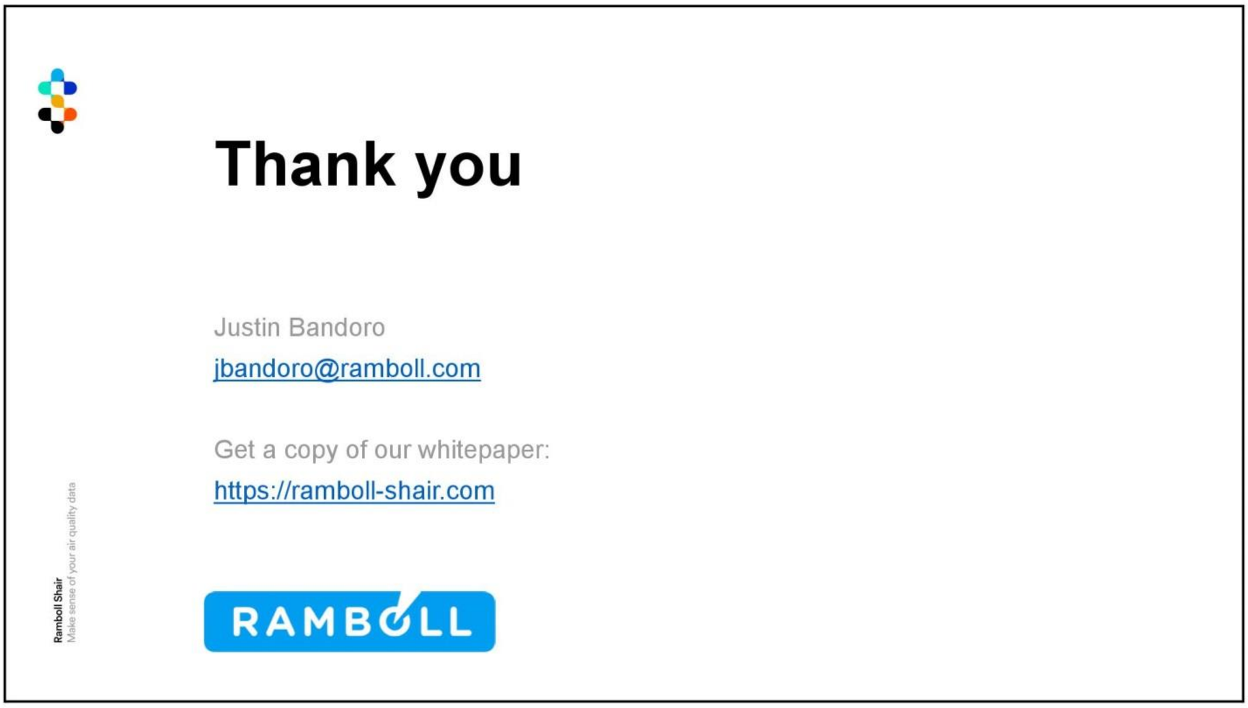
Thank you
Justin Bandoro
jbandoro@ramboll.com
Get a copy of our whitepaper:
https://ramboll-shair.com
RAMBOLL
Ramboll Shair
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附錄七、"Comparison of $PM_{2.5}$ measured in urban North Carolina settings using a low-cost optical particle counter and Federal Equivalent Methods"

Comparison of PM2.5 measured in urban North Carolina settings using a low-cost optical particle counter and Federal Equivalent Methods

Brian Magi
Associate Professor of Atmospheric Sciences
UNC Charlotte (Charlotte, North Carolina)

Calvin Cupini
Citizen Science Program Manager
Clean Air Carolina (Charlotte, North Carolina)

Presentation at CMAS Conference
23 October 2019

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1

Collaborations and input from

Mecklenburg County AQ (Charlotte, North Carolina)
Forsyth County AQ (Winston-Salem, North Carolina)
EPA National Exposure Research Lab
EPA National Health and Environmental Effects Lab
Students at UNC Charlotte

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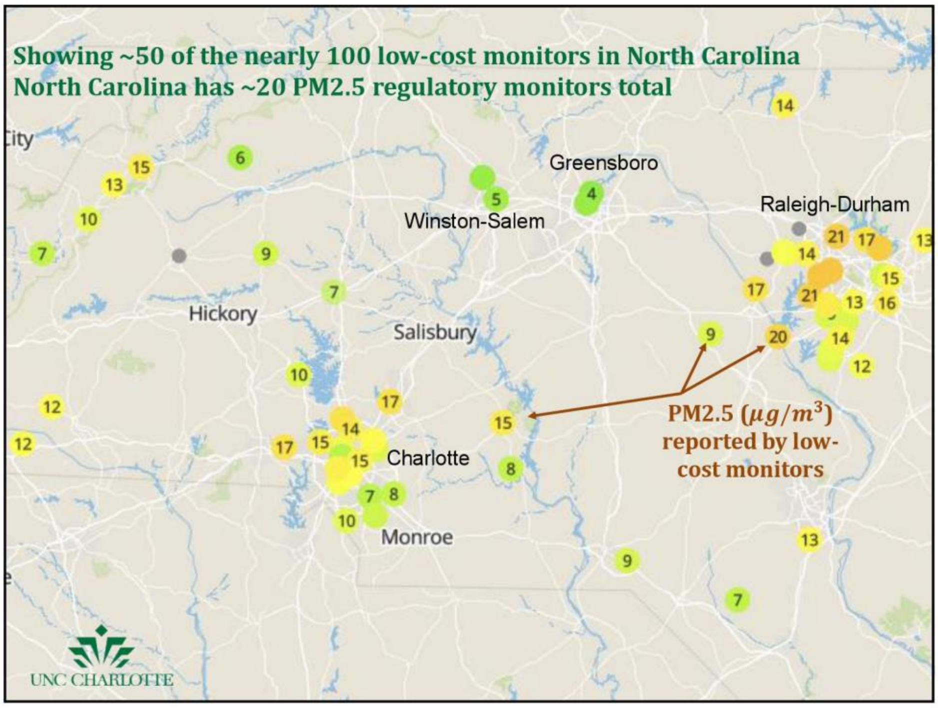
2


Showing ~50 of the nearly 100 low-cost monitors in North Carolina
North Carolina has ~20 PM2.5 regulatory monitors total
Greensboro
Winston-Salem
Raleigh-Durham
Hickory
Salisbury
Charlotte
Monroe
PM2.5 ($\mu g/m^3$)
reported by low-cost monitors
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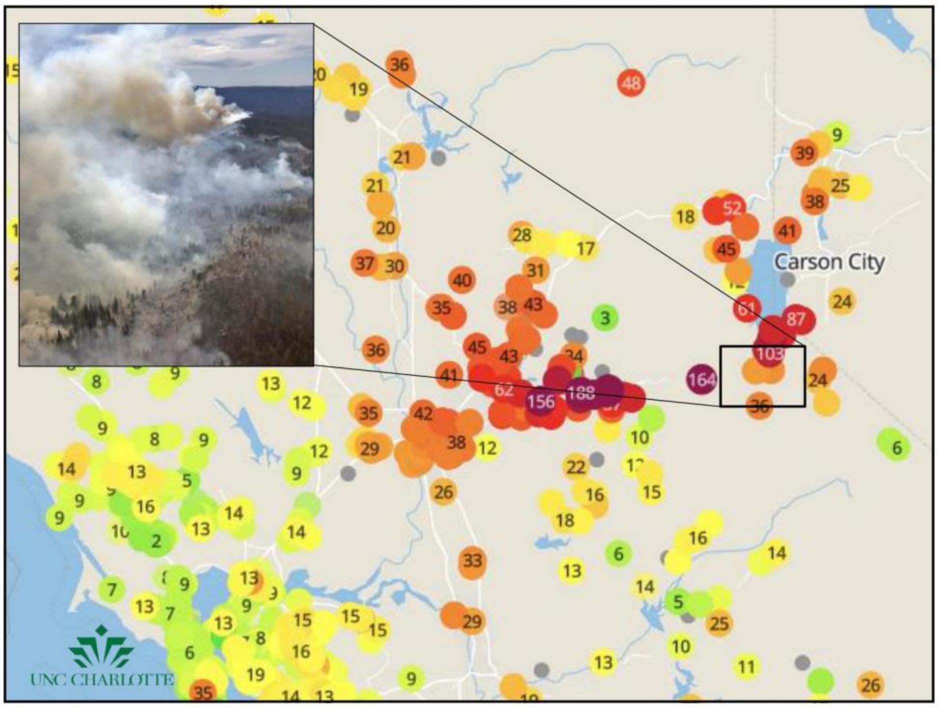
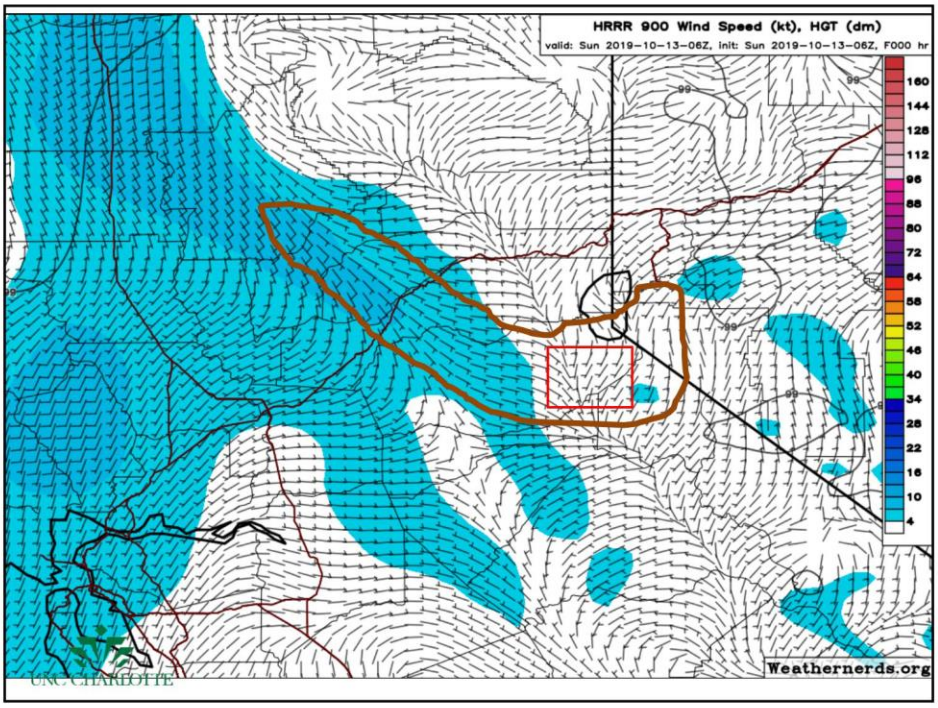
3


Carson City
UNC CHARLOTTE

4


HRRR 900 Wind Speed (kt), HGT (dm)
valid: Sun 2019-10-13-06Z, init: Sun 2019-10-13-06Z, F000 hr
Weathernerds.org
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5


Purple Air PA-II
sensor package
Measures number concentration using 2 Plantower PMS5003 sensors. Reports number and mass concentrations.
Also measures temperature and relative humidity
Good description at https://www.aqmd.gov/aq-spec/product/purpleair-pa-ii but also at Zamora et al 2019 Environmental Science & Technology https://doi.org/10.1021/acs.est.8b05174
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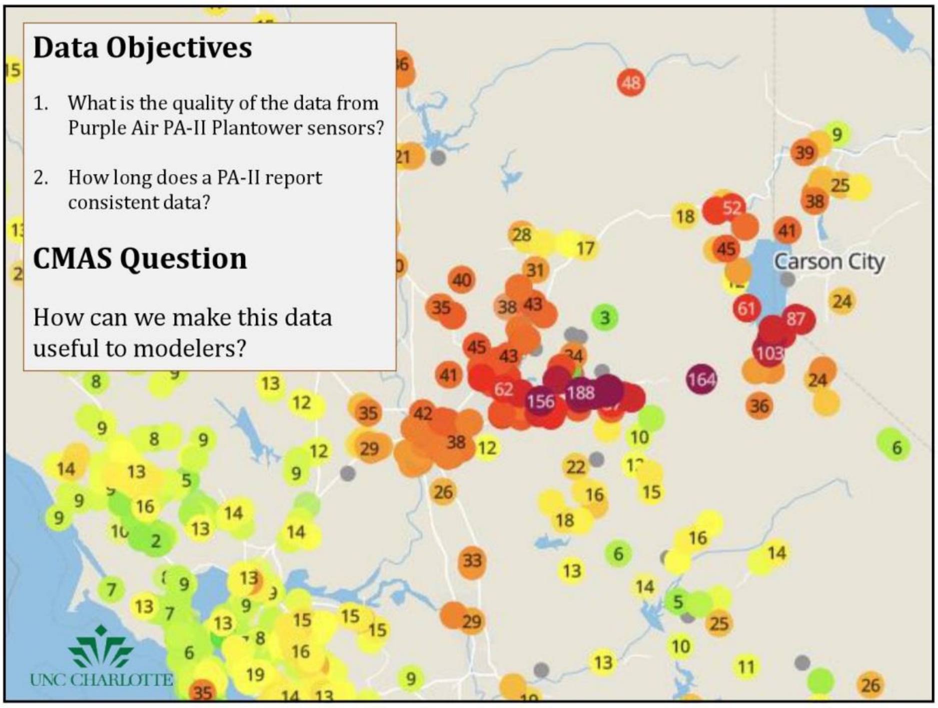
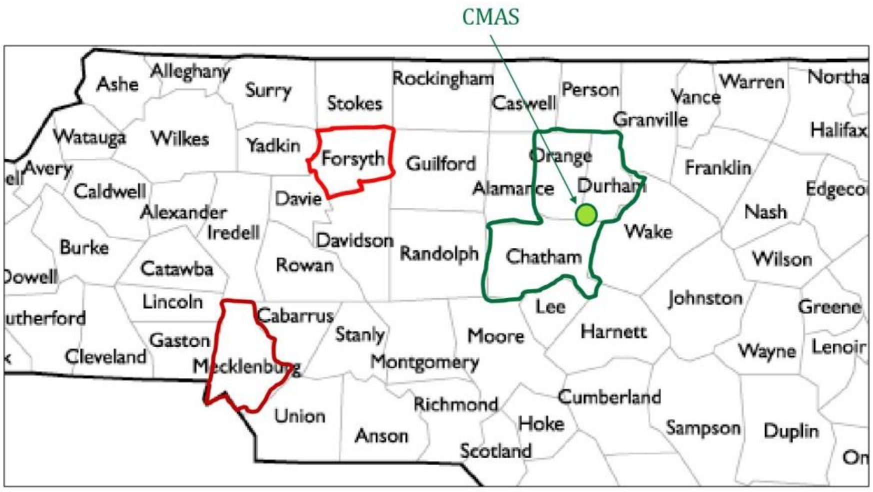


7



Co-location study sites

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Co-location
PA-II and FEM BAM 1020
Since June 2019

Co-location
PA-II and FEM T640X
Since March 2018

Co-location
PA-II and FEM BAM 1022
Since March 2017

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Field Work in North Carolina

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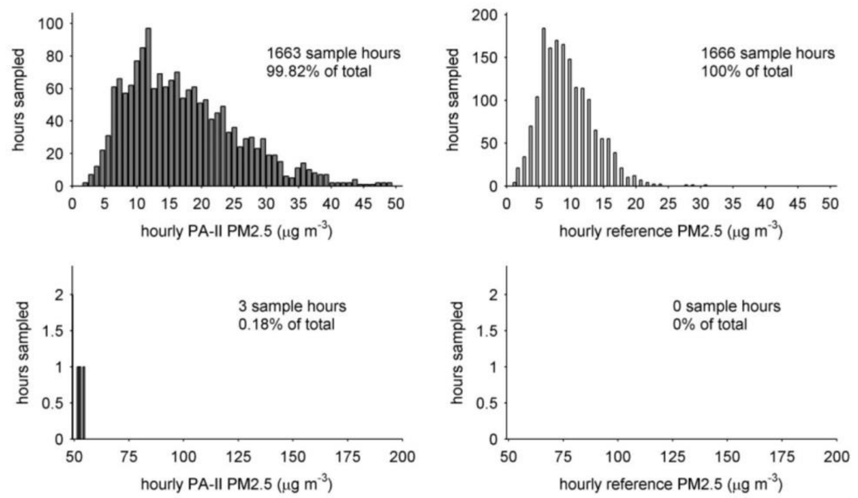

Histograms of quality controlled hourly-averaged PM2.5 reported at 3 sites

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Quality control and data processing

1. Collect raw sub-hourly data
2. QC Step 1 (non-physical reporting)
3. QC Step 2 (repeating artifact)
4. Hourly average the sub-hourly
5. Discard values less than limit of detection
6. Discard values greater than limit of sampling
7. Use remaining "uncorrected" PA-II data as input to a linear regression

~5% of raw data discarded

~20% of remaining data discarded

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Correction of PA-II PM2.5 data using a linear regression

bias correction / RH correction / T correction

$$PM2.5_{PAII} = a_0 + a_1 PM2.5_{ref} + a_2 RH + a_3 T$$

bias correction

$$PM2.5_{PAII} = b_0 + b_1 PM2.5_{ref}$$

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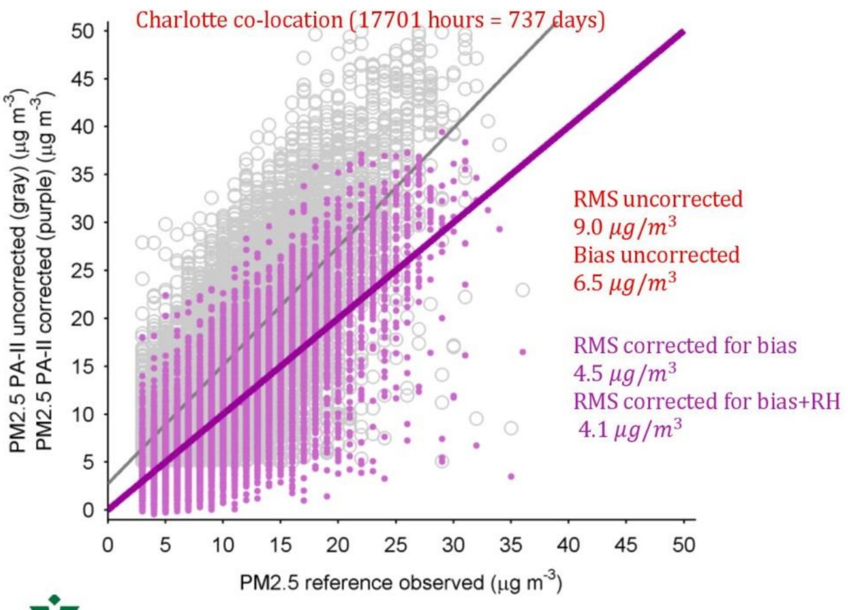

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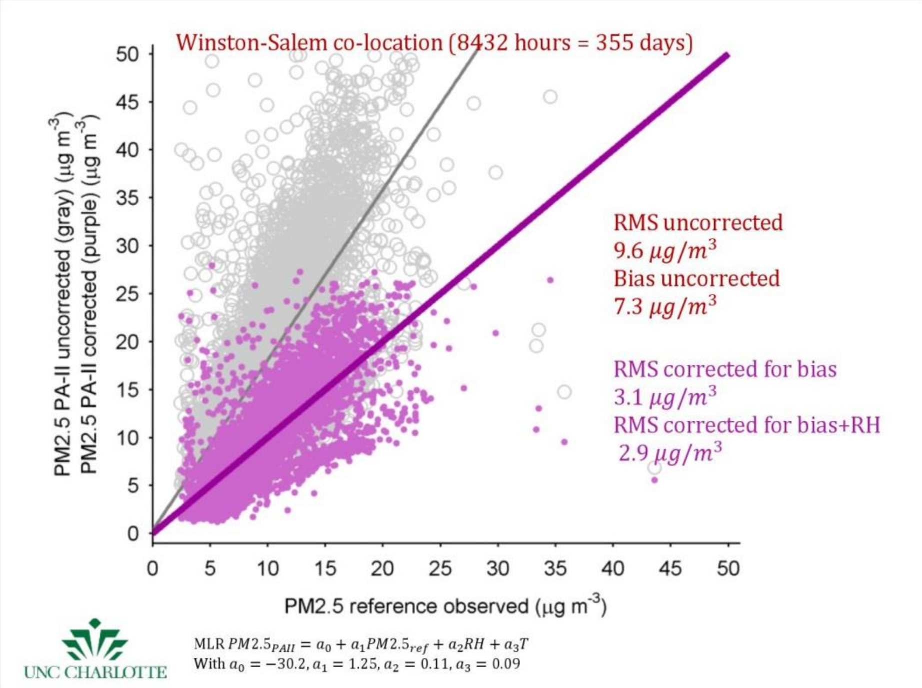
MLR $PM2.5_{PAII} = a_0 + a_1 PM2.5_{ref} + a_2 RH + a_3 T$

With $a_0 = -30.2$, $a_1 = 1.25$, $a_2 = 0.11$, $a_3 = 0.09$

14



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Comparison of all FEM co-location hourly-averaged results

Site Sensor A	N (hours)	Bias before ($\mu g/m^3$)	RMS before ($\mu g/m^3$)	RMS after ($\mu g/m^3$)
Remount1	13964	5.3	7.8	4.2
Remount2	2892	9.8	12	4.5
Forsyth	8432	7.3	9.6	2.9
Garinger1	1593	8.1	10	3.1
Garinger2	1435	7.1	9.5	3.2
Site Sensor B	**N (hours)**	**Bias before ($\mu g/m^3$)**	**RMS before ($\mu g/m^3$)**	**RMS after ($\mu g/m^3$)**
Remount1	17701	6.5	9	4.1
Remount2	2882	8.2	11	3.9
Forsyth	8312	6.8	8.9	2.6
Garinger1	1611	7.8	9.9	3.1
Garinger2	1446	7.8	9.9	3.2

Average bias $7.5 \pm 1.2\ \mu g/m^3$

Average RMS before $9.8 \pm 1.2\ \mu g/m^3$

Average RMS after $3.5 \pm 0.6\ \mu g/m^3$

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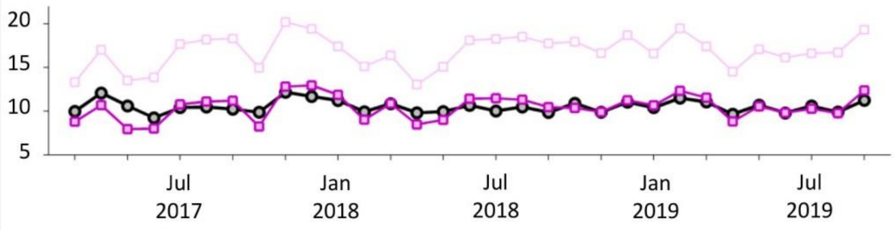

Apply the FEM correction to the PA-II data from Charlotte, NC

Black shows monthly-averaged PM2.5 from BAM1022 (FEM)
Lighter purple is uncorrected PA-II PM2.5 (RMS 6.5 $\mu g/m^3$)
Darker purple is the corrected PA-II PM2.5 (RMS 0.97 $\mu g/m^3$)

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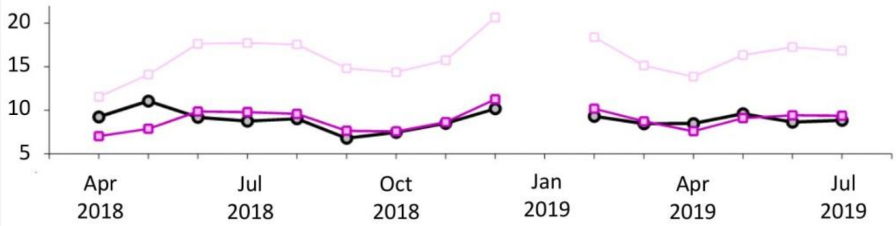

Apply the FEM correction to the PA-II data from Winston-Salem, NC

Black shows monthly-averaged PM2.5 from T640X (FEM)
Lighter purple is uncorrected PA-II PM2.5 (RMS 7.5 $\mu g/m^3$)
Darker purple is the corrected PA-II PM2.5 (RMS 1.2 $\mu g/m^3$)

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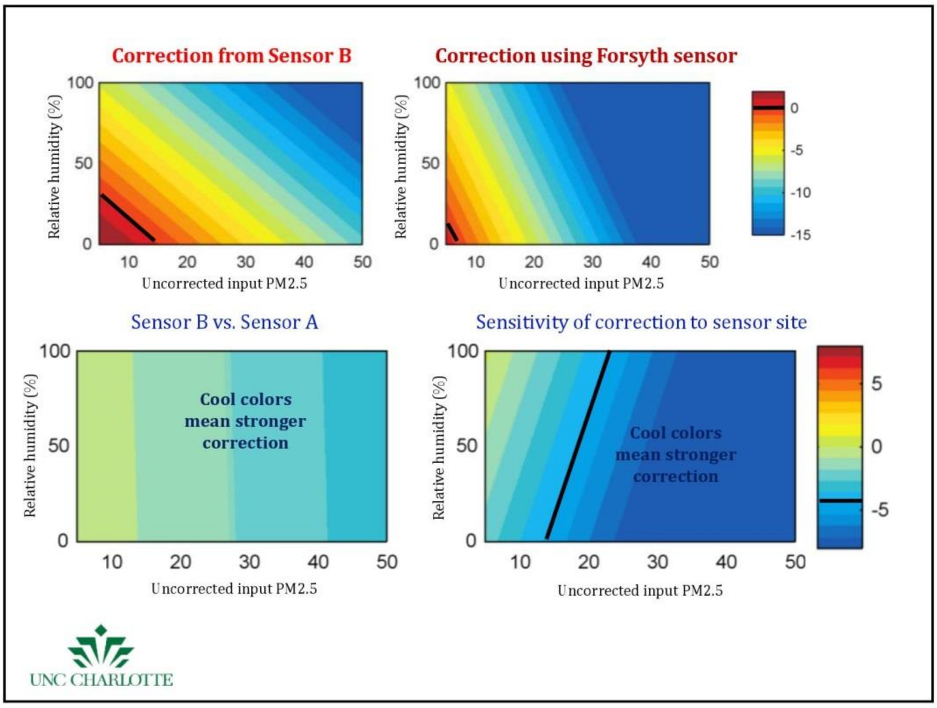
Correction from Sensor B
Correction using Forsyth sensor
Relative humidity (%)
Uncorrected input PM2.5
Sensor B vs. Sensor A
Sensitivity of correction to sensor site
Cool colors mean stronger correction
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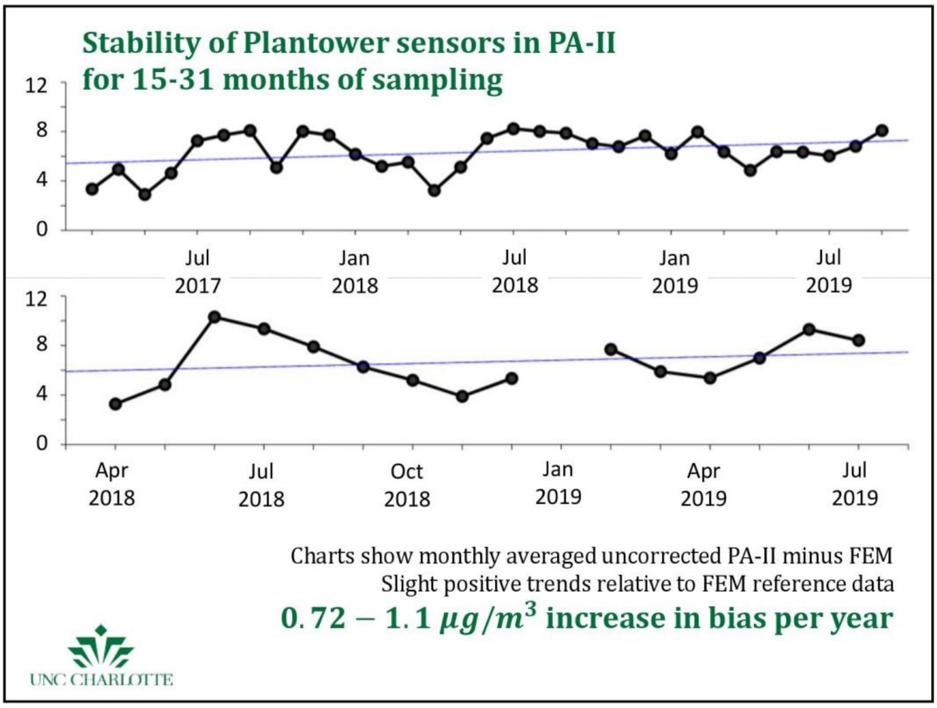
Stability of Plantower sensors in PA-II
for 15-31 months of sampling
Jul 2017
Jan 2018
Jul 2018
Jan 2019
Jul 2019
Apr 2018
Jul 2018
Oct 2018
Jan 2019
Apr 2019
Jul 2019
Charts show monthly averaged uncorrected PA-II minus FEM
Slight positive trends relative to FEM reference data
0.72 – 1.1 μg/m³ increase in bias per year
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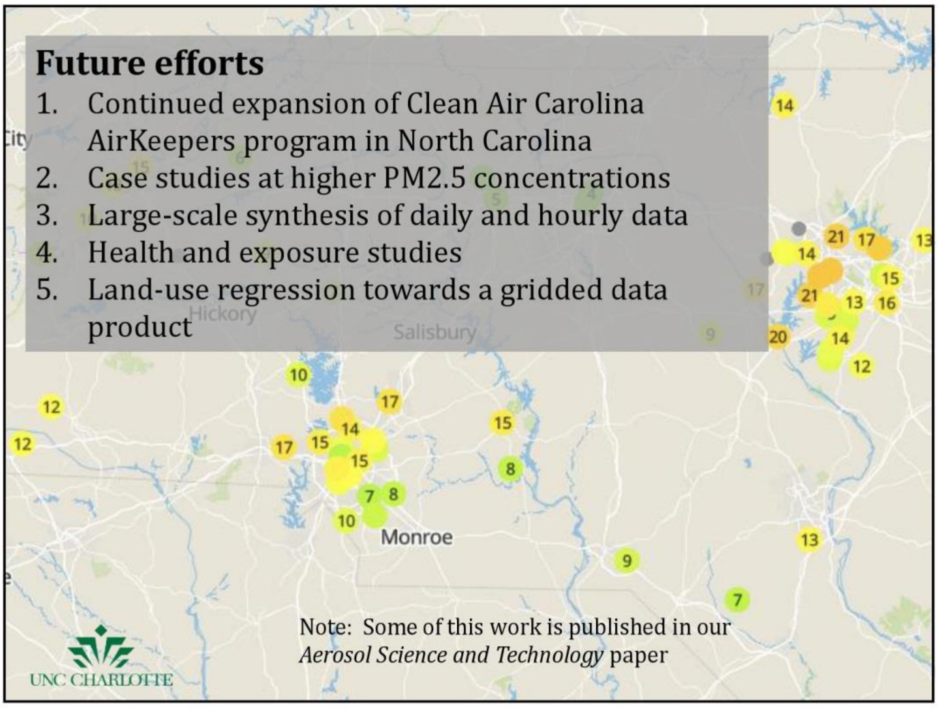
Future efforts
1. Continued expansion of Clean Air Carolina AirKeepers program in North Carolina
2. Case studies at higher PM2.5 concentrations
3. Large-scale synthesis of daily and hourly data
4. Health and exposure studies
5. Land-use regression towards a gridded data product
Hickory
Salisbury
Monroe
Note: Some of this work is published in our *Aerosol Science and Technology* paper
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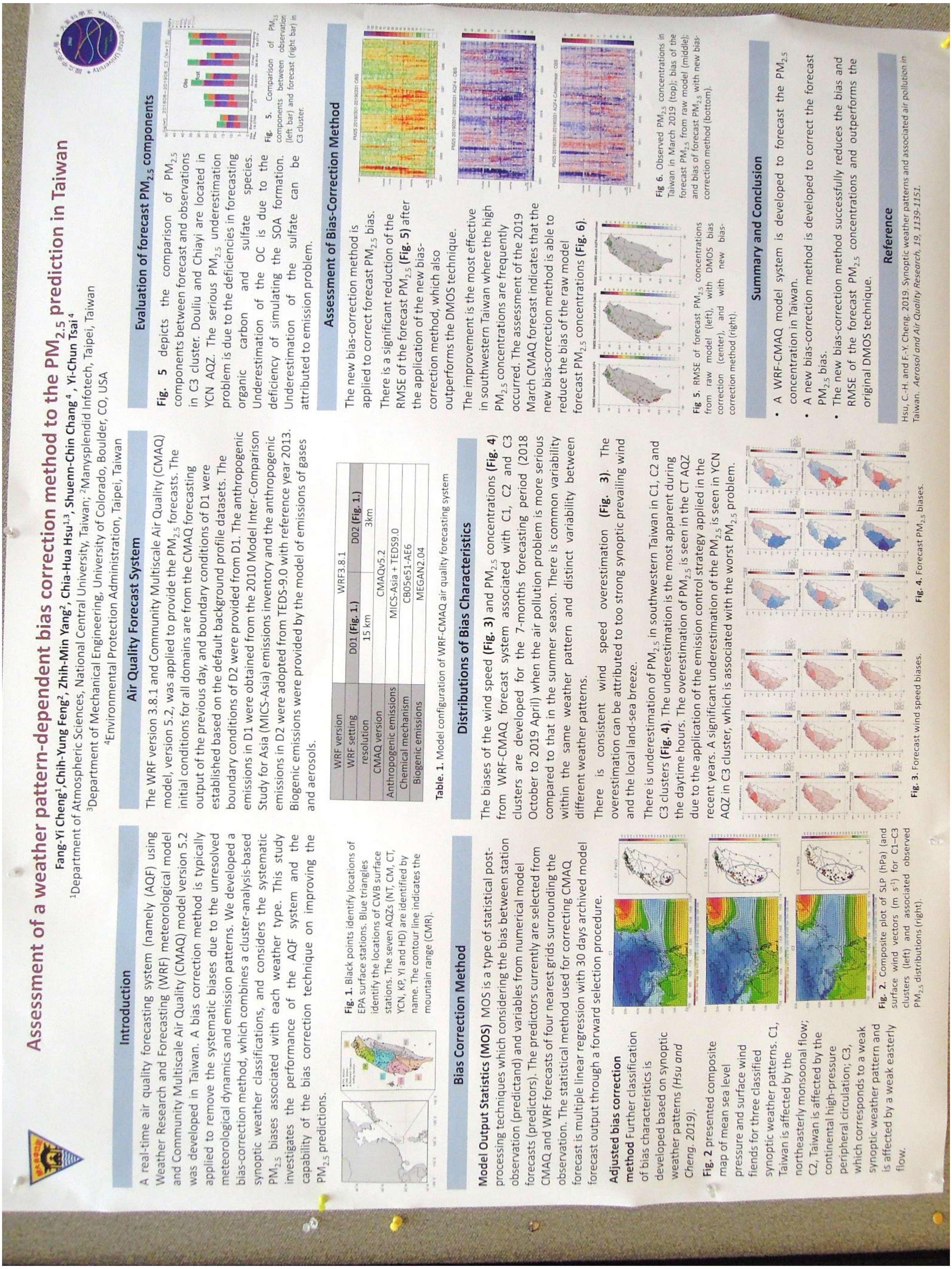
附錄八、" Assessment of a weather pattern-dependent bias correction method to the PM2.5 prediction in Taiwan "



Assessment of a weather pattern-dependent bias correction method to the $PM_{2.5}$ prediction in Taiwan

Fang-Yi Cheng[1], Chih-Yung Feng[2], Zhih-Min Yang[2], Chia-Hua Hsu[1,3], Shuenn-Chin Chang[4], Yi-Chun Tsai[4]

[1]Department of Atmospheric Sciences, National Central University, Taiwan
[2]Manysplendid Infotech, Taipei, Taiwan
[3]Department of Mechanical Engineering, University of Colorado, Boulder, CO, USA
[4]Environmental Protection Administration, Taipei, Taiwan

Abstract

A real-time air quality forecasting (AQF) system using Weather Research and Forecasting (WRF) meteorological model and Community Multiscale Air Quality (CMAQ) model version 5.2 was developed in Taiwan. There is a systematic over-prediction of the wind speed in western Taiwan. The too strong wind can be attributed to both synoptic prevailing wind and the local sea breeze. The sulfate and organic carbon are under-predicted in western Taiwan while the nitrate is over-predicted in northern Taiwan and under-predicted in southern Taiwan.

To improve the $PM_{2.5}$ forecast, a bias correction method based on the dynamic model output statistics (DMOS) is developed to reduce the predicted $PM_{2.5}$ bias. It was found that under the influence of the strong northeasterly monsoonal flow, AQF tends to underestimate the $PM_{2.5}$ concentration in southwestern Taiwan. On the other hand, when the synoptic weather condition is weak, there is systematic $PM_{2.5}$ over-prediction in northern Taiwan and under-prediction in southern Taiwan. As the $PM_{2.5}$ biases vary with the synoptic weather patterns, an alternative bias correction method to account for the influence of the synoptic weather types was developed (namely DMOS_W). A certain number of synoptic weather patterns were identified using the cluster analysis method. The bias correction method considers the systematic $PM_{2.5}$ biases associated with each weather type.

The performance of the $PM_{2.5}$ prediction is further improved with the approach using the synoptic weather pattern based method (DMOS_W) compared to that from the original DMOS method. More details will be introduced during the workshop.

Keywords: $PM_{2.5}$ forecast, bias correction, dynamic model output statistics, synoptic weather patterns.