Kevin W Bowman

JPL Engineering and Science Directorate Principal

Research

My research interests are centered on understanding the processes controlling the trajectory of atmospheric composition and quantifying their impact on climate, environmental quality, and human health. To that end, I lead teams of scientists to construct end-to-end systems that produce advanced global observational products and integrate them with Earth system modeling through state-of-the-art data assimilation and inverse modeling techniques. We've applied these systems to critical questions in atmospheric chemistry such as the balance of local and non-local emissions on air quality, attribution of radiative forcing from short-lived climate pollutants (SLCP), and climate model evaluation for the IPCC. The NASA Carbon Monitoring System (CMS-Flux) has been used to quantify the carbon cycle response to climate variability such as El Niños, partition the role of direct and indirect effects on carbon dynamics, and provide critical information for assessments such as the Global Stocktake. Taken together, these systems provide a framework for linking climate forcing from short and long-lived greenhouse gases to Earth system responses and societal benefits.

Experience

2016–Present **Engineering and Science Directorate Principal**, *Jet Propulsion Laboratory, California Institute of Technology*, Pasadena.

2014–Present **Principal Investigator, Tropospheric Emission Spectrometer (TES)**, *Jet Propulsion Laboratory, California Institute of Technology*, Pasadena.

2010–Present **Principal Investigator, Carbon Monitoring System Flux Pilot Project**, *Jet Propulsion Laboratory, California Institute of Technology*, Pasadena.

2010–2014 **Deputy Principal Investigator, Tropospheric Emission Spectrometer (TES)**, *Jet Propulsion Laboratory, California Institute of Technology*, Pasadena.

2009–Present **Visiting Associate Researcher**, *Joint-Institute for Regional Earth System Science and Engineering (JIFRESSE)*, University of California, Los Angeles.

1997 **NASA Graduate Student Researcher's Program Fellow**, *Georgia Institute of Technology*, Atlanta, Georgia.

Education

1997 **Phd in Electrical Engineering**, *Georgia Institute of Technology*, Altanta, Georgia.

1993 **Masters of Science in Electrical Engineering**, *Georgia Institute of Technology*, Atlanta, Georgia.

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1992 **Diplôme de Spécialisation en Traitement et Transmission des Informations**, *Ecole Supérieure d'Electricité (SUPELEC)*, Metz, France.

1991 **Bachelor of Electrical Engineering**, *Auburn University*, Auburn, Alabama.

Awards

2019 NASA Exceptional Public Service Medal

2015 NASA JPL Voyager Award

2015 NASA Langley, Henry J. Reid Award

2015 NASA Group Achievement Award-Observations for Climate Model Intercomparison

2014 NASA Group Achievement Award-Aura Tropospheric Emission Spectrometer Team

2013 NASA Group Achievement Award-Carbon Monitoring System Flux Project

2009 NASA Group Achievement Award-Aura Science Team Proposal Group

2007 NASA Group Achievement Award-TES Level 2 Algorithm Team

2005 NASA Group Achievement Award-Aura Project

2005 NASA Group Achievement Award–Aura Tropospheric Emission Spectrometer instrument team and the ground data system development teams

2005 Goddard Space Flight Center Group Achievement Award as a member of the Aura Team

Field Campaigns

2019 FIREX-AQ (NOAA/NASA) satellite team member

2016 KORUS-AQ (NASA/Korea) satellite team member

2016 ACT-America (NASA) science team member

2006 INTEX-B/MILAGRO (NASA/NSF) satellite team member

2006 TexAQS/GoMACCS (Texas Air Quality Study/Gulf of Mexico Atmospheric Composition and Climate Study) (NOAA/NASA/Texas) Rapid Science Synthesis (RSS) panel member

Professional Activities

2017–Present External Experts Group European Union–CO2 Human Emissions (CHE) Project

2017–Present Atmospheric Composition Constellation–Committee on Earth Observing Systems, AQ/Carbon Synergies Session Chair

2018–Present GEOS-Chem Steering Committee: Carbon Cycle Co-Chair

2010–2018 Carbon Monitoring System Science-Frameworks Working Group Team Leader

2011 NASA Science Community Workshop on Polar Orbiting IR and MW Sounders Co-Chair

2009–2018 GEOS-Chem Steering Committee: Adjoint Model and Data Assimilation Co-Chair

2007–2008 JPL Earth system assimilation working group lead (ESAWG)

Pedagogy

2008-2017 **Guest Lecturer**, *Inverse Methods*, ESE/GE 152 ATMOSPHERIC RADIATION, Division of Geological and Planetary Sciences, California Institute of Technology.

2016 **Lecturer**, *Global Carbon Cycle*, JPL Summer Climate School.

2011 **Lecturer**, *Inverse Methods and Data Assimilation*, JPL Summer Climate School.

Mentorship

Postdoctoral Advisor **Paul Hamer, Adetutu Aghedo, Min Huang, Nicolas Parazoo, Thomas Walker**.

Thesis Committee **Edwin Sarkission (CalState LA), Kumaresh Singh (Virginia Tech), Amir Souri (University of Houston)**.

Intern **Nadia Colombi (UCLA), Oscar Nazarett (UCLA)**.

Media

2018 A tale of three continents: record carbon dioxide growth during the 2015 El Niño

2016 ACT-America Science

2015 Pollution transport seen from TES

Selected Invited Seminars and Presentations

Invited K. Bowman, "The carbon cycle and the global stocktake: Prospects and challenges", *Carnegie Institute for Global Ecology*, Stanford, 2019

Invited K. Bowman, "The changing landscape of emissions and their impact on air quality and climate", *National Center for Atmospheric Research*, Boulder, 2019

K. Bowman, "The global stocktake: A top-down view", *Atmospheric Composition Constellation, Committee on Earth Observing Satellites (CEOS)*, Tokyo, 2019

Invited K. Bowman, "Unweaving the webs of carbon", *EU Carbon Human Emissions Project, Reading, UK,* 2019

K. Bowman, "On the information content of OCO-2", *OCO-2 Science Team Meeting, Boulder, CO,* 2019

Invited K. Bowman, "A global view: the carbon cycle from space", *RECCAP2, Global Carbon Project, Gotemba, Japan*, 2019

Invited K. Bowman et al., "Attribution of Ozone and Methane Radiative Forcing in the Last Decade: A Tale of the Tiger and the Dragon", *Asia Oceania Geosciences Society, Honolulu, Hawaii*, 2018

K. Bowman et al, "A hierarchical framework for emergent constraints: applications to Earth System Forcings and Feedback", *AGU, Washington, D.C.*, 2018

Invited K. Bowman et al, "A New Fast Randomized Optimal Approach for Diagnostic and Optimization (FRODO) Carbon Dioxide Fluxes Inferred from the NASA CMS-Flux", *AGU, Washington D.C.,* 2018

Invited K. Bowman, "Tropospheric Emission Spectrometer: From Mission of Discovery to Earth System Sounder", *Fourier Transform Spectroscopy, Optical Society of America, Singapore,* 2018.

K. Bowman et al, "Detection of fossil fuel emission trends across the globe: Challenge of natural variability" *Integrated Carbon Observingy System (ICOS), Prague, Czech Republic,* 2018

K. Bowman and M. Lee, "Impact of Local and Non-local Sources of Pollution on Background US ozone: Potential of the LEO and GEO Sounders Composition Constellation", *GEO-CAPE final science team meeting, College Park, MD*, 2018

Dynamic Publications

Google Scholar

Publons

Publications

David Schimel, Fabian D. Schneider, and JPL Carbon and Ecosystem Participants. Flux towers in the sky: global ecology from space. *New Phytologist*, 07 2019.

K. Miyazaki, K. W. Bowman, K. Yumimoto, T. Walker, and K. Sudo. Evaluation of a multi-model, multi-constituent assimilation framework for tropospheric chemical reanalysis. *Atmos. Chem. Phys. Discuss.*, 2019:1–63, 08 2019.

L. Kuai, K. W. Bowman, H. Worden, K. Miyazaki, S. Kulawik, A. Conley, J.-F. Lamarque, F. Paulot, D. Paynter, L. D. Oman, S. Strode, E. Rozanov, A. Stenke, L. Revell, D. A. Plummer, M. Deushi, P. Jöckel, and M. Kunze. Attribution of Chemistry-Climate Model Initiative (CCMI) ozone radiative flux bias from satellites. *Atmospheric Chemistry and Physics Discussions*, 2019:1–33, 2019.

K. Miyazaki, T. Sekiya, D. Fu, K. W. Bowman, S. S. Kulawik, K. Sudo, T. Walker, Y. Kanaya, M. Takigawa, K. Ogochi, H. Eskes, K. F. Boersma, A. M. Thompson, B. Gaubert, J. Barre, and L. K. Emmons. Balance of Emission and Dynamical Controls on Ozone During the Korea-United States Air Quality Campaign From Multiconstituent Satellite Data Assimilation. *Journal of Geophysical Research: Atmospheres*, 124(1):387–413, 04 2019.

Andrew E. Schuh, Andrew R. Jacobson, Sourish Basu, Brad Weir, David Baker, Kevin Bowman, Frédéric Chevallier, Sean Crowell, Kenneth J. Davis, Feng Deng, Scott Denning, Liang Feng, Dylan Jones, Junjie Liu, and Paul I. Palmer. Quantifying the Impact of Atmospheric Transport Uncertainty on CO2 Surface Flux Estimates. *Global Biogeochemical Cycles*, 04 2019.

A. G. Konings, A. A. Bloom, J. Liu, N. C. Parazoo, D. S. Schimel, and K. W. Bowman. Global satellite-driven estimates of heterotrophic respiration. *Biogeosciences*, 16(11):2269–2284, 2019.

J. D. Maasakkers, D. J. Jacob, M. P. Sulprizio, T. R. Scarpelli, H. Nesser, J.-X. Sheng, Y. Zhang, M. Hersher, A. A. Bloom, K. W. Bowman, J. R. Worden, G. Janssens-Maenhout, and R. J. Parker. Global distribution of methane emissions, emission trends, and OH concentrations and trends inferred from an inversion of GOSAT satellite data for 2010–2015. *Atmospheric Chemistry and Physics*, 19(11):7859–7881, 2019.

J. R. Worden, S. S. Kulawik, D. Fu, V. H. Payne, A. E. Lipton, I. Polonsky, Y. He, K. Cady-Pereira, J.-L. Moncet, R. L. Herman, F. W. Irion, and K. W. Bowman. Characterization and evaluation of AIRS-based estimates of the deuterium content of water vapor. *Atmospheric Measurement Techniques*, 12(4):2331–2339, 2019.

Yi Yin, Kevin W. Bowman, A. Anthony Bloom, and John Worden. Detection of fossil fuel emission trends in the presence of natural carbon cycle variability. *Environmental Research Letters*, 2019.

D. Fu, S. S. Kulawik, K. Miyazaki, K. W. Bowman, J. R. Worden, A. Eldering, N. J. Livesey, J. Teixeira, F. W. Irion, R. L. Herman, G. B. Osterman, X. Liu, P. F. Levelt, A. M.

Thompson, and M. Luo. Retrievals of tropospheric ozone profiles from the synergism of AIRS and OMI: methodology and validation. *Atmos. Meas. Tech.*, 11(10):5587–5605, 10 2018.

Kevin W. Bowman, Noel Cressie, Xin Qu, and Alex Hall. A hierarchical statistical framework for emergent constraints: Application to snow-albedo feedback. *Geophysical Research Letters*, 45(23):13,050–13,059, 2018.

Junjie Liu, Kevin W. Bowman, David Schimel, Nicolas C. Parazoo, Zhe Jiang, Meemong Lee, A. Anthony Bloom, Debra Wunch, Christian Frankenberg, Ying Sun, Christopher W. O'Dell, Kevin R. Gurney, Dimitris Menemenlis, Michelle Gierach, David Crisp, and Annmarie Eldering. Response to comment on "contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño". *Science*, 362(6418), 2018.

Junjie Liu, Kevin Bowman, Nicholas C Parazoo, A Anthony Bloom, Debra Wunch, Zhe Jiang, Kevin R Gurney, and Dave Schimel. Detecting drought impact on terrestrial biosphere carbon fluxes over contiguous us with satellite observations. *Environmental Research Letters*, 13(9):095003, 2018.

Junjie Liu, Kevin W. Bowman, David S. Schimel, Nicolas C. Parazoo, Zhe Jiang, Meemong Lee, A. Anthony Bloom, Debra Wunch, Christian Frankenberg, Ying Sun, Christopher W. O'Dell, Kevin R. Gurney, Dimitris Menemenlis, Michelle Gierach, David Crisp, and Annmarie Eldering. Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño. *Science*, 358(6360), 10 2017.

K. E. Cady-Pereira, V. H. Payne, J. L. Neu, K. W. Bowman, K. Miyazaki, E. A. Marais, S. Kulawik, Z. A. Tzompa-Sosa, and J. D. Hegarty. Seasonal and spatial changes in trace gases over megacities from Aura TES observations: two case studies. *Atmos. Chem. Phys.*, 17(15):9379–9398, 08 2017.

K. Miyazaki and K. Bowman. Evaluation of ACCMIP ozone simulations and ozonesonde sampling biases using a satellite-based multi-constituent chemical reanalysis. *Atmos. Chem. Phys.*, 17(13):8285–8312, 07 2017.

J. R. Worden, G. Doran, S. Kulawik, A. Eldering, D. Crisp, C. Frankenberg, C. O'Dell, and K. Bowman. Evaluation and attribution of OCO-2 XCO2 uncertainties. *Atmos. Meas. Tech.*, 10(7):2759–2771, 07 2017.

A. A. Bloom, K. W. Bowman, M. Lee, A. J. Turner, R. Schroeder, J. R. Worden, R. Weidner, K. C. McDonald, and D. J. Jacob. A global wetland methane emissions and uncertainty dataset for atmospheric chemical transport models (WetCHARTs version 1.0). *Geosci. Model Dev.*, 10(6):2141–2156, 06 2017.

M. Huang, G. R. Carmichael, R. B. Pierce, D. S. Jo, R. J. Park, J. Flemming, L. K. Emmons, K. W. Bowman, D. K. Henze, Y. Davila, K. Sudo, J. E. Jonson, M. Tronstad Lund, G. Janssens-Maenhout, F. J. Dentener, T. J. Keating, H. Oetjen, and V. H. Payne. Impact of intercontinental pollution transport on North American ozone air pollution: an HTAP phase 2 multi-model study. *Atmos. Chem. Phys.*, 17(9):5721–5750, 05 2017.

K. W. Bowman, J. Liu, A. A. Bloom, N. C. Parazoo, M. Lee, Z. Jiang, D. Menemenlis, M. M. Gierach, G. J. Collatz, K. R. Gurney, and D. Wunch. Global and Brazilian carbon response to El Niño Modoki 2011-2010. *Earth and Space Science*, 4, 2017.

Le Kuai, Kevin W. Bowman, Helen Worden, Robert Herman, and Susan Kulawik. Hydrological controls on the tropospheric ozone greenhouse gas effect. *Elementa*, 5(10), 2017.

K. Miyazaki, H. Eskes, K. Sudo, K. F. Boersma, K. Bowman, and Y. Kanaya. Decadal changes in global surface NO_x emissions from multi-constituent satellite data assimilation. *Atmos. Chem. Phys.*, 17(2):807–837, 01 2017.

Joannes D. Maasakkers, Daniel J. Jacob, Melissa P. Sulprizio, Alexander J. Turner, Melissa Weitz, Tom Wirth, Cate Hight, Mark DeFigueiredo, Mausami Desai, Rachel Schmeltz, Leif Hockstad, Anthony A. Bloom, Kevin W. Bowman, Seongeun Jeong, and Marc L. Fischer. Gridded National Inventory of U.S. Methane Emissions. *Environmental Science & Technology*, 11 2016.

Wayana Dolan, Vivienne H. Payne, Susan S. Kualwik, and Kevin W. Bowman. Satellite observations of ethylene (C2H4) from the Aura Tropospheric Emission Spectrometer: A scoping study. *Atmospheric Environment*, 141:388–393, 9 2016.

D. Fu, K. W. Bowman, H. M. Worden, V. Natraj, J. R. Worden, S. Yu, P. Veefkind, I. Aben, J. Landgraf, L. Strow, and Y. Han. High-resolution tropospheric carbon monoxide profiles retrieved from CrIS and TROPOMI. *Atmos. Meas. Tech.*, 9(6):2567–2579, 06 2016.

Junjie Liu and Kevin Bowman. A method for independent validation of surface fluxes from atmospheric inversion: Application to CO2. *Geophysical Research Letters*, 43(7):3502–3508, 2016.

Junjie Liu, Kevin W. Bowman, and Meemong Lee. Comparison between the Local Ensemble Transform Kalman Filter (LETKF) and 4D-Var in atmospheric CO2 flux inversion with the Goddard Earth Observing System-Chem model and the observation impact diagnostics from the LETKF. *J. Geophys. Res. Atmos.*, 121(21):13,066–13,087, 2016.

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S. Doniki, D. Hurtmans, L. Clarisse, C. Clerbaux, H. M. Worden, K. W. Bowman, and P. F. Coheur. Instantaneous longwave radiative impact of ozone: an application on IASI/MetOp observations. *Atmos. Chem. Phys.*, 15(22):12971–12987, 11 2015.

F. Deng, D. B. A. Jones, T. W. Walker, M. Keller, K. W. Bowman, D. K. Henze, R. Nassar, E. A. Kort, S. C. Wofsy, K. A. Walker, A. E. Bourassa, and D. A. Degenstein. Sensitivity analysis of the potential impact of discrepancies in stratosphere-troposphere exchange on inferred sources and sinks of CO2. *Atmos. Chem. Phys.*, 15(20):11773–11788, 10 2015.

P. D. Hamer, K. W. Bowman, D. K. Henze, J. L. Attié, and V. Marécal. The impact of observing characteristics on the ability to predict ozone under varying polluted photochemical regimes. *Atmos. Chem. Phys.*, 15(18):10645–10667, 09 2015.

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J. R. Worden, A. J. Turner, A. Bloom, S. S. Kulawik, J. Liu, M. Lee, R. Weidner, K. Bowman, C. Frankenberg, R. Parker, and V. H. Payne. Quantifying lower tropospheric methane concentrations using GOSAT near-IR and TES thermal IR measurements. *Atmos. Meas. Tech.*, 8(8):3433–3445, 08 2015.

N. Bousserez, D. K. Henze, A. Perkins, K. W. Bowman, M. Lee, J. Liu, F. Deng, and D. B. A. Jones. Improved analysis-error covariance matrix for high-dimensional variational inversions: application to source estimation using a 3D atmospheric transport model. *Quarterly Journal of the Royal Meteorological Society*, 141(690):1906–1921, 2015.

Min Huang, Kevin W. Bowman, Gregory R. Carmichael, Meemong Lee, Tianfeng Chai, Scott N. Spak, Daven K. Henze, Anton S. Darmenov, and Arlindo M. da Silva. Improved western U.S. background ozone estimates via constraining nonlocal and local source contributions using Aura TES and OMI observations. *Journal of Geophysical Research: Atmospheres*, 120(8):3572–3592, 2015.

Le Kuai, John R. Worden, J. Elliott Campbell, Susan S. Kulawik, King-Fai Li, Meemong Lee, Richard J. Weidner, Stephen A. Montzka, Fred L. Moore, Joe A. Berry, Ian Baker, A. Scott Denning, Huisheng Bian, Kevin W. Bowman, Junjie Liu, and Yuk L. Yung. Estimate of carbonyl sulfide tropical oceanic surface fluxes using Aura Tropospheric Emission Spectrometer observations. *Journal of Geophysical Research: Atmospheres*, 120(20):11,012–11,023, 2015.

Junjie Liu, Kevin W. Bowman, and Daven K. Henze. Source-receptor relationships of column-average CO2 and implications for the impact of observations on flux inversions. *Journal of Geophysical Research: Atmospheres*, 120(10):5214–5236, 2015.

Georgios Matheou and Kevin W. Bowman. A recycling method for the large-eddy simulation of plumes in the atmospheric boundary layer. *Environmental Fluid Mechanics*, pages 1–17, 2015.

Lesley E. Ott, Steven Pawson, George J. Collatz, Watson W. Gregg, Dimitris Menemenlis, Holger Brix, Cecile S. Rousseaux, Kevin W. Bowman, Junjie Liu, Annmarie Eldering, Michael R. Gunson, and Stephan R. Kawa. Assessing the magnitude of CO2 flux uncertainty in atmospheric CO2 records using products from NASA's Carbon Monitoring Flux Pilot Project. *Journal of Geophysical Research: Atmospheres*, 120(2):734–765, 2015. 2014JD022411.

Nicholas C. Parazoo, Elizabeth Barnes, John Worden, Anna B. Harper, Kevin B. Bowman, Christian Frankenberg, Sebastian Wolf, Marcy Litvak, and Trevor F. Keenan. Influence of ENSO and the NAO on terrestrial carbon uptake in the Texas-northern Mexico region. *Global Biogeochemical Cycles*, 29(8):1247–1265, 2015.

Christopher R. Schwalm, Deborah N. Huntzinger, Joshua B. Fisher, Anna M. Michalak, Kevin Bowman, Philippe Ciais, Robert Cook, Bassil El-Masri, Daniel Hayes, Maoyi Huang, Akihiko Ito, Atul Jain, Anthony W. King, Huimin Lei, Junjie Liu, Chaoqun Lu, Jiafu Mao, Shushi Peng, Benjamin Poulter, Daniel Ricciuto, Kevin Schaefer, Xiaoying Shi, Bo Tao, Hanqin Tian, Weile Wang, Yaxing Wei, Jia Yang, and Ning Zeng. Toward "optimal" integration of terrestrial biosphere models. *Geophysical Research Letters*, 42(11):2015GL064002, 2015.

F. Deng, D. B. A. Jones, D. K. Henze, N. Bousserez, K. W. Bowman, J. B. Fisher, R. Nassar, C. O'Dell, D. Wunch, P. O. Wennberg, E. A. Kort, S. C. Wofsy, T. Blumenstock, N. M.

Deutscher, D. W. T. Griffith, F. Hase, P. Heikkinen, V. Sherlock, K. Strong, R. Sussmann, and T. Warneke. Inferring regional sources and sinks of atmospheric CO2 from GOSAT XCO2 data. *Atmos. Chem. Phys.*, 14(7):3703–3727, 04 2014.

Min Huang, Kevin W. Bowman, Gregory R. Carmichael, Tianfeng Chai, R. Bradley Pierce, John R. Worden, Ming Luo, Ilana B. Pollack, Thomas B. Ryerson, John B. Nowak, J. Andrew Neuman, James M. Roberts, Elliot L. Atlas, and Donald R. Blake. Changes in nitrogen oxides emissions in California during 2005–2010 indicated from top-down and bottom-up emission estimates. *Journal of Geophysical Research: Atmospheres*, page 2014JD022268, 2014.

B. H. Kahn, F. W. Irion, V. T. Dang, E. M. Manning, S. L. Nasiri, C. M. Naud, J. M. Blaisdell, M. M. Schreier, Q. Yue, K. W. Bowman, E. J. Fetzer, G. C. Hulley, K. N. Liou, D. Lubin, S. C. Ou, J. Susskind, Y. Takano, B. Tian, and J. R. Worden. The Atmospheric Infrared Sounder version 6 cloud products. *Atmos. Chem. Phys.*, 14(1):399–426, 01 2014.

Kateryna Lapina, Daven K. Henze, Jana B. Milford, Min Huang, Meiyun Lin, Arlene M. Fiore, Greg Carmichael, Gabriele G. Pfister, and Kevin Bowman. Assessment of source contributions to seasonal vegetative exposure to ozone in the U.S. *Journal of Geophysical Research: Atmospheres*, 119(1):324–340, 2014.

Junjie Liu, Kevin Bowman, Meemong Lee, Daven Henze, Nicolas Bousserez, Holger Brix, G. James Collatz, Dimitris Menemenlis, Lesley Ott, Steven Pawson, Dylan Jones, and Ray Nassar. Carbon monitoring system flux estimation and attribution: impact of ACOS-GOSAT XCO2 sampling on the inference of terrestrial biospheric sources and sinks. *Tellus B*, 66(0), 2014.

Nicholas C. Parazoo, Kevin Bowman, Joshua B. Fisher, Christian Frankenberg, Dylan B. A. Jones, Alessandro Cescatti, Óscar Pérez-Priego, Georg Wohlfahrt, and Leonardo Montagnani. Terrestrial gross primary production inferred from satellite fluorescence and vegetation models. *Global Change Biology*, 20(10):3103–3121, 2014.

Kevin W. Bowman. Toward the next generation of air quality monitoring: Ozone. *Atmos. Environ.*, 80(0):571–583, 12 2013.

K. Singh, A. Sandu, M. Jardak, K. Bowman, and M. Lee. A practical method to estimate information content in the context of 4d-var data assimilation. *SIAM/ASA Journal on Uncertainty Quantification*, 1(1):106–138, Sept. 2013.

Bruce A. Wielicki, D. F. Young, M. G. Mlynczak, K. J. Thome, S. Leroy, J. Corliss, J. G. Anderson, C. O. Ao, R. Bantges, F. Best, K. Bowman, H. Brindley, J. J. Butler, W. Collins, J. A. Dykema, D. R. Doelling, D. R. Feldman, N. Fox, X. Huang, R. Holz, Y. Huang, Z. Jin, D. Jennings, D. G. Johnson, K. Jucks, S. Kato, D. B. Kirk-Davidoff, R. Knuteson, G. Kopp, D. P. Kratz, X. Liu, C. Lukashin, A. J. Mannucci, N. Phojanamongkolkij, P. Pilewskie, V. Ramaswamy, H. Revercomb, J. Rice, Y. Roberts, C. M. Roithmayr, F. Rose, S. Sandford, E. L. Shirley, W. L. Smith, B. Soden, P. W. Speth, W. Sun, P. C. Taylor, D. Tobin, and X. Xiong. Achieving climate change absolute accuracy in orbit. *Bulletin of the American Meteorological Society*, 94(10):1519–1539, 2013/11/12 2013.

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K. W. Bowman, D. T. Shindell, H. M. Worden, J. F. Lamarque, P. J. Young, D. S. Stevenson, Z. Qu, M. de la Torre, D. Bergmann, P. J. Cameron-Smith, W. J. Collins, R. Doherty, S. B. Dalsøren, G. Faluvegi, G. Folberth, L. W. Horowitz, B. M. Josse, Y. H. Lee, I. A. MacKenzie, G. Myhre, T. Nagashima, V. Naik, D. A. Plummer, S. T. Rumbold, R. B. Skeie, S. A. Strode, K. Sudo, S. Szopa, A. Voulgarakis, G. Zeng, S. S. Kulawik, A. M. Aghedo, and J. R. Worden. Evaluation of ACCMIP outgoing longwave radiation from tropospheric ozone using TES satellite observations. *Atmos. Chem. Phys.*, 13(8):4057–4072, 04 2013.

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