

# Dr. John R Worden

JPL Principal Scientist  
Job Family: Research  
Discipline: Research Management  
Career Level: 2

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## Current Responsibilities

**Current:** Section Manager for JPL Earth Sciences (329)

**2014-2015:** Deputy Section Manager for JPL Earth Sciences (329)

## Previous Responsibilities

**2010 – 2014:** Principal Investigator (PI) for the NASA Aura TES project

**2007 – 2010:** Deputy PI for the Aura TES project

**2007 – 2014 :** Group Supervisor for the Section 329 Tropospheric Sounding, Assimilation and Modeling Group

**2002 – 2007:** Research Scientist, JPL

**2000 – 2002:** Scientist, Raytheon ITSS: Pasadena

**1999 – 2000:** Scientist, Atmospheric Environmental Research

**1997 – 1999:** Postdoc, National Solar Observatory

## Areas of Expertise

Remote sensing of atmospheric composition, Carbon and Water cycle science, Atmospheric Chemistry and Dynamics, Radiative Transfer and Spectroscopy

## Education

**Ph.D.** in Physics, University of Colorado 1996

**B.S.** in Physics, University of California at Santa Cruz 1990

### Research Interests

My background is in the remote sensing of atmospheric trace gases and the use of these data for investigating the role of natural and anthropogenic perturbations to the global water, carbon, and nitrogen cycles and its effects on atmospheric chemistry and surface pollution.

I have authored or co-authored over 100 publications on new approaches for using satellite thermal infrared (IR), near IR, and Ultraviolet radiance measurements for quantifying the distribution of water vapor isotopes, methane, CO<sub>2</sub>, ozone, CO, Carbonyl Sulfide, ammonia, and methanol in the Troposphere and then use of these data for investigating the process controls on tropical convection, carbon and water cycle feedbacks, fire emissions of ozone pre-cursors, methane, and CO<sub>2</sub>, and the dynamics and chemistry of the North American and Asian monsoons.

### Postdocs Mentored

**Dr. Zhe Jiang (2013 – Present):** Emissions, Chemistry, and Dynamics of the Asian Monsoon

**Dr. Anthony Bloom (2013 – Present)** Carbon and Water cycling in the tropics and high-latitudes

**Dr. Le Kuai (2011 – Present):** Remote sensing of CO<sub>2</sub> profiles and tropospheric carbonyl sulfide.

**Dr. Richard Dupont (2008 – 2011):** Ozone production in boreal fires

**Dr. Jeonghoon Lee (2008 – 2011):** Quantifying tropospheric moisture processes using water vapor isotope measurements

**Dr. Sunita Verma (2008 – 2009):** Ozone production in boreal fires

Awards

**July 2008:** NASA Team Award, TES tiger team

**April 2008:** JPL Spot Award, OCO tiger team

**Sep. 2007:** JPL Ranger Award, For development of the TES water vapor isotope product

**March 2007:** JPL Team Award, For reducing L2 processing time in order to meet project processing requirements

**June 2006:** JPL Spot Award, TES animation

**April 2005:** JPL Team Award, Production of first TES data sets

**Sep. 2004:** JPL Bonus Award, Outstanding accomplishment for L2 algorithm development

**Sep. 2004:** JPL Team Bonus Award, TES

**Sep. 2001:** Raytheon ITSS, Employee of the year

### **Proposals Won (PI)**

NASA Roses Aura / ACMAP (2017) **Decadal record of lower tropospheric methane**

NASA ROSES IDSL (2017) **Atmospheric methane budget and trends**

NASA Roses (2013): **CH<sub>4</sub> emissions estimates from tropical and subtropical fires using Aura TES CH<sub>4</sub> and Terra MOPITT CO profiles**

NASA ROSES (2010) **Quantifying the Tropospheric Ozone budget During the Summertime Asian Monsoon**

NASA ROSES (2007) **TES and RAQMS support of ARCTAS Campaign: Impact of Boreal Fires on Arctic Ozone**

JPL DRDF (2005) **Applications of TES Satellite Measurements to Southern California Air Quality: Comparisons with SMOG Air Pollution Model Simulations**

### **Proposals Won (Co-I)**

**NASA Aura Senior Review (2013)**

NASA ROSES (2013): **Tropospheric Ozone Profiles Using Multispectral Measurements from OMI, MLS, and AIRS**

NASA ROSES (2012) **Use of GOSAT, TES, and suborbital observations to constrain North American methane emissions in the Carbon Monitoring System**

**NASA Aura Senior Review (2011)**

NASA ROSES (2010) **Atmospheric Composition and Air Quality Science Using Data From the European Metop Infrared Atmospheric Sounding Interferometer (IASI)**

NASA ROSES (2010) **Estimation and attribution of global CO<sub>2</sub> surface fluxes using satellite observations of CO<sub>2</sub> and CO from TES, GOSAT, and MOPITT**

NASA ROSES (2010) **Panchromatic Fourier Transform Spectrometer Engineering Model (PanFTS EM) Instrument for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission**

JPL SURP (2009) **Estimating Sources of Arctic moisture using ground and space based measurements of water vapor and its isotopes**

NASA ROSES (2008) **Satellite and model constraints on water cycling responses to ENSO and tropical storms using water isotopes**

NASA ROSES (2006) **Convective Scale Transport of Trace Gases Assessed with Models and Satellite**

**Invited Talks**

**Dec 2015: American Geophysical Union, San Francisco CA**

"Remote sensing of water vapor isotopes and their scientific application"

**April 2015: Composition of Earth Observing Satellites Workshop, Frascati Italy**

"Distinguishing Local from Non-Local sources of pollution: The role of LEO sounders in the air-quality constellation."

**Oct 2014: EUMETSAT Conference, Geneva Switzerland**

"Global Changes In Ozone Pre-Cursor Emissions And The Intercontinental Transport Of Pollution"

**May 2014: Utrecht University, Netherlands**

"Tropospheric Ozone, Composition, and Climate from the Aura Tropospheric emission Spectrometer"

**April 2014: NASA HQ, Washington D.C.**

"Tropospheric Ozone, Composition, and Climate from the Aura Tropospheric emission Spectrometer"

**May 2012: ASSFTS, Madison Wisconsin**

"Overview of TES project and science"

**May 2011: BASIN Isotope Conference, Keystone Colorado**

"Aura TES water vapor isotope measurements"

**April 2010: Water Isotope Workshop, Paris France**

"Aura TES water vapor isotope measurements"

**February 2009: Seminar, U. of Toronto**

"TES Water Vapor Isotopes, Measurement And Science"

**September 2009: Caltech Keck Water Cycle Conference**

"Remote Sensing Of Water Vapor And Its Isotopes"

Papers Published: 121 H-Index of 35

1. Jiang, Z. *et al.* A 15-year record of CO emissions constrained by MOPITT CO observations. *Atmospheric Chemistry and Physics* **17**, 4565–4583 (2017).
2. Kuai, L. *et al.* Characterization of anthropogenic methane plumes with the Hyperspectral Thermal Emission Spectrometer (HyTES): a retrieval method and error analysis. *Atmos. Meas. Tech.* **9**, 3165–3173 (2016).
3. Hulley, G. C. *et al.* High spatial resolution imaging of methane and other trace gases with the airborne Hyperspectral Thermal Emission Spectrometer (HyTES). *Atmos. Meas. Tech.* **9**, 2393–2408 (2016).
4. Fu, D. *et al.* High-resolution tropospheric carbon monoxide profiles retrieved from CrIS and TROPOMI. *Atmos. Meas. Tech.* **9**, 2567–2579 (2016).
5. Oetjen, H. *et al.* A joint data record of tropospheric ozone from Aura-TES and MetOp-IASI. *Atmospheric Chemistry and Physics* **16**, 10229–10239 (2016).
6. Jiang, Z. *et al.* Impacts of anthropogenic and natural sources on free tropospheric ozone over the Middle East. *Atmospheric Chemistry and Physics* **16**, 6537–6546 (2016).
7. Bousserrez, N. *et al.* Constraints on methane emissions in North America from future geostationary remote sensing measurements. *Atmospheric Chemistry and Physics* (2016). doi:10.5194/acp-16-6175-2016
8. Bloom, A. A. *et al.* What are the greenhouse gas observing system requirements for reducing fundamental biogeochemical process uncertainty? Amazon wetland CH<sub>4</sub> emissions as a case study. *Atmospheric Chemistry and Physics* **16**, 15199–15218 (2016).
9. Jiang, Z. *et al.* Ozone export from East Asia: The role of PAN. *Journal of Geophysical Research-Atmospheres* (2016). doi:10.1002/2016JD024952
10. Field, R. D. *et al.* Simulating the Black Saturday 2009 smoke plume with an interactive composition-climate model: Sensitivity to emissions amount, timing, and injection height. *Journal of Geophysical Research-Atmospheres* (2016). doi:10.1002/(ISSN)2169-8996
11. Galewsky, J. *et al.* Stable isotopes in atmospheric water vapor and applications to the hydrologic cycle. *Rev. Geophys.* (2016). doi:10.1002/2015RG000512
12. Bloom, A. A. *et al.* Remote-sensing constraints on South American fire traits by Bayesian fusion of atmospheric and surface data. *Geophys. Res. Lett* **41**, 1329–1335 (2015).
13. Verstraeten, W. W. *et al.* Rapid increases in tropospheric ozone production and export from China. *Nature Geoscience* (2015). doi:10.1038/ngeo2493
14. Lee, J., Worden, J., Noone, D., Chae, J. H. & Frankenberg, C. Isotopic changes due to convective moistening of the lower troposphere associated with variations in the ENSO and IOD from 2005 to 2006. *Tellus B* **67**, 1147 (2015).
15. Worden, J. R. *et al.* Quantifying lower tropospheric methane concentrations using GOSAT near-IR and TES thermal IR measurements. *Atmos. Meas. Tech.* **8**, 3433–3445 (2015).
16. Sutanto, S. J. *et al.* Global-scale remote sensing of water isotopologues in the troposphere: representation of first-order isotope effects. *Atmos. Meas. Tech.* **8**, 999–1019 (2015).
17. Lacour, J. L. *et al.* Cross-validation of IASI/MetOp derived tropospheric  $\delta D$  with TES and ground-based FTIR observations. *Atmos. Meas. Tech.* **8**, 1447–1466 (2015).
18. Alvarado, M. J. *et al.* Impacts of updated spectroscopy on thermal infrared retrievals of methane evaluated with HIPPO data. *Atmos. Meas. Tech.* **8**, 965–985 (2015).

19. Jiang, Z. *et al.* Regional data assimilation of multi-spectral MOPITT observations of CO over North America. *Atmospheric Chemistry and Physics* **15**, 6801–6814 (2015).
20. Jiang, Z. *et al.* Constraints on Asian ozone using Aura TES, OMI and Terra MOPITT. *Atmospheric Chemistry and Physics* **15**, 99–112 (2015).
21. Zhu, L., Fischer, E. V., Payne, V. H., Worden, J. R. & Jiang, Z. TES Observations of the Interannual Variability of PAN over Northern Eurasia and the Relationship to Springtime Fires. *Geophys. Res. Lett* **42**, 1–8 (2015).
22. Parazoo, N. C. *et al.* Influence of ENSO and the NAO on terrestrial carbon uptake in the Texas-northern Mexico region. *Global Biogeochemical Cycles* (2015). doi:10.1002/2015GB005125
23. Field, R. D. *et al.* Sensitivity of simulated tropospheric CO to subgrid physics parameterization: a case study of Indonesian biomass burning emissions in 2006. *Journal of Geophysical Research - Atmospheres* **120**, (2015).
24. Tuinenburg, O. A. *et al.* Moist processes during MJO events as diagnosed from water isotopic measurements from the IASI satellite. *Journal of Geophysical Research-Atmospheres* **120**, 10619–10636 (2015).
25. Sutanto, S. J. *et al.* Atmospheric processes governing the changes in water isotopologues during ENSO events from model and satellite measurements. *Journal of Geophysical Research-Atmospheres* 6712 (2015). doi:10.1002/(ISSN)2169-8996
26. Kuai, L. *et al.* Estimate of carbonyl sulfide tropical oceanic surface fluxes using Aura Tropospheric Emission Spectrometer observations. *Journal of Geophysical Research-Atmospheres* **120**, 11012–11023 (2015).
27. He, Y. *et al.* Impact of atmospheric convection on south Tibet summer precipitation isotopologue composition using a combination of in situ measurements, satellite data, and .... *Journal of Geophysical Research-Atmospheres* (2015). doi:10.1002/2014JD022180
28. Field, R. D. *et al.* Evaluating climate model performance in the tropics with retrievals of water isotopic composition from Aura TES. *Geophys. Res. Lett* n/a–n/a (2014). doi:10.1002/2014GL060572
29. Neu, J. L. *et al.* Tropospheric ozone variations governed by changes in stratospheric circulation. *Nature Geoscience* (2014). doi:10.1038/ngeo2138
30. Payne, V. H. *et al.* Satellite observations of peroxyacetyl nitrate from the Aura Tropospheric Emission Spectrometer. *Atmos. Meas. Tech.* **7**, 3737–3749 (2014).
31. Oetjen, H. *et al.* Extending the satellite data record of tropospheric ozone profiles from Aura-TES to MetOp-IASI: characterisation of optimal estimation retrievals. *Atmos. Meas. Tech.* **7**, 4223–4236 (2014).
32. Kuai, L., Worden, J., Kulawik, S. S., Montzka, S. A. & Liu, J. Characterization of Aura TES carbonyl sulfide retrievals over ocean. *Atmos. Meas. Tech.* **7**, 163–172 (2014).
33. Herman, R. L. *et al.* Aircraft validation of Aura Tropospheric Emission Spectrometer retrievals of HDO / H<sub>2</sub>O, Atmospheric Measurement Techniques (2014)
34. Wecht, K. J., Jacob, D. J. & Sulprizio, M. P. Spatially resolving methane emissions in California: constraints from the CalNex aircraft campaign and from present (GOSAT, TES) and future (TROPOMI, .... *Atmospheric Chemistry and Physics* (2014). doi:10.5194/acp-14-8173-2014
35. Kahn, B. H. *et al.* The Atmospheric Infrared Sounder version 6 cloud products. *Atmospheric Chemistry and Physics* **14**, 399–426 (2014).

36. Gryazin, V. *et al.* To what extent could water isotopic measurements help us understand model biases in the water cycle over Western Siberia. *Atmospheric Chemistry and Physics Discussions* **14**, 9807–9830 (2014).
37. Neu, J. L. *et al.* The SPARC Data Initiative: Comparison of upper troposphere/lower stratosphere ozone climatologies from limb-viewing instruments and the nadir-viewing .... *Journal of Geophysical Research - Atmospheres* **119**, 6971–6990 (2014).
38. Samuels Crow, K. E. *et al.* Upwind convective influences on the isotopic composition of atmospheric water vapor over the tropical Andes. *Journal of Geophysical Research-Atmospheres* (2014).
39. Huang, M. *et al.* Changes in nitrogen oxides emissions in California during 2005–2010 indicated from top-down and bottom-up emission estimates. *Journal of Geophysical Research-Atmospheres* **119**, (2014).
40. Luo, M. *et al.* Carbon monoxide (CO) vertical profiles derived from joined TES and MLS measurements. *Journal of Geophysical Research-Atmospheres* **118**, 10,601–10,613 (2013).
41. Worden, J. *et al.* El Nino, the 2006 Indonesian Peat Fires, and the distribution of atmospheric methane. *Geophys. Res. Lett* **40**, 1 (2013).
42. Risi, C., Noone, D., Frankenberg, C. & Worden, J. Role of continental recycling in intraseasonal variations of continental moisture as deduced from model simulations and water vapor isotopic measurements. *Water Resour. Res.* **49**, 4136–4156 (2013).
43. Parazoo, N. C. *et al.* Interpreting seasonal changes in the carbon balance of southern Amazonia using measurements of XCO<sub>2</sub> and chlorophyll fluorescence from GOSAT. *Geophys. Res. Lett* **40**, 2829–2833 (2013).
44. Li, K.-F. *et al.* A link between tropical intraseasonal variability and Arctic stratospheric ozone. *Journal of Geophysical Research-Atmospheres* **118**, 4280–4289 (2013).
45. Lee, J.-E. *et al.* Forest productivity and water stress in Amazonia: observations from GOSAT chlorophyll fluorescence. *Proceedings of the Royal Society B: Biological Sciences* **280**, 20130171–20130171 (2013).
46. Jiang, Z. *et al.* Impact of model errors in convective transport on CO source estimates inferred from MOPITT CO retrievals. *Journal of Geophysical Research-Atmospheres* **118**, 2073–2083 (2013).
47. Lee, J., Worden, J., Koh, D.-C., Yoshimura, K. & Lee, J.-E. A seasonality of  $\delta D$  of water vapor (850–500 hPa) observed from space over Jeju Island, Korea. *Geosci J* **17**, 87–95 (2013).
48. Worden, H. M. *et al.* Averaging kernel prediction from atmospheric and surface state parameters based on multiple regression for nadir-viewing satellite measurements of carbon monoxide and ozone. *Atmos. Meas. Tech.* **6**, 1633–1646 (2013).
49. Verstraeten, W. W. *et al.* Validation of six years of TES tropospheric ozone retrievals with ozonesonde measurements: implications for spatial patterns and temporal stability in the bias. *Atmos. Meas. Tech.* **6**, 1413–1423 (2013).
50. Kuai, L. *et al.* Profiling CO<sub>2</sub>, *Atm. Meas. Tech.* **6**, 63–79 (2013).
51. Frankenberg, C. *et al.* Water vapor isotopologue retrievals from high-resolution GOSAT shortwave infrared spectra. *Atmos. Meas. Tech.* **6**, 263–274 (2013).
52. Worden observed by the Aura TES satellite instrument and modeled by GEOS-Chem. *Atmospheric Chemistry and Physics* **13**, 3679–3692 (2013).



53. Worden, H. M. *et al.* Decadal record of satellite carbon monoxide observations. *Atmospheric Chemistry and Physics* **13**, 837–850 (2013).
54. Kulawik, S. S. *et al.* Comparison of improved Aura Tropospheric Emission Spectrometer 3205–3225 (2013).
55. Fu, D. *et al.* Characterization of ozone profiles derived from Aura TES and OMI radiances. *Atmospheric Chemistry and Physics* **13**, 3445–3462 (2013).
56. Bowman, K. W. *et al.* Evaluation of ACCMIP outgoing longwave radiation from tropospheric ozone using TES satellite observations. *Atmospheric Chemistry and Physics* **13**, 4057–4072 (2013).
57. Brown, D., Worden, J. & Noone, D. Characteristics of tropical and subtropical atmospheric moistening derived from Lagrangian mass balance constrained by measurements of HDO and H<sub>2</sub>O. *Journal of Geophysical Research-Atmospheres* **118**, (2013).
58. Hurley, J. V., Galewsky, J., Worden, J. & Noone, D. A test of the advection-condensation model for subtropical water vapor using stable isotopologue observations from Mauna Loa Observatory, Hawaii. *J. Geophys. Res* **117**, D19118 (2012).
59. Lee, J.-E. *et al.* Reduction of tropical land region precipitation variability via transpiration. *Geophys. Res. Lett* **39**, L19704 (2012).
60. Lee, J.-E. *et al.* Asian monsoon hydrometeorology from TES and SCIAMACHY water vapor isotope measurements and LMDZ simulations: Implications for speleothem climate record interpretation. *J. Geophys. Res* **117**, D15112 (2012).
61. Worden, H. M. *et al.* Satellite-based estimates of reduced CO and CO<sub>2</sub> emissions due to traffic restrictions during the 2008 Beijing Olympics. *Geophys. Res. Lett* **39**, L14802 (2012).
62. Natarajan, M. *et al.* Radiative forcing due to enhancements in tropospheric ozone and carbonaceous aerosols caused by Asian fires during spring 2008. *J. Geophys. Res* **117**, D06307 (2012).
63. Risi, C. *et al.* Process-evaluation of tropospheric humidity simulated by general circulation models using water vapor isotopologues: 1. Comparison between models and observations. *J. Geophys. Res* **117**, D05303 (2012).
64. Risi, C. *et al.* Process-evaluation of tropospheric humidity simulated by general circulation models using water vapor isotopic observations: 2. Using isotopic diagnostics to understand the mid and upper tropospheric moist bias in the tropics and subtropics. *J. Geophys. Res* **117**, D05304 (2012).
65. Worden, J. *et al.* Profiles of vertical resolution from Aura TES radiances. *Atmos. Meas. Tech.* **5**, 397–411 (2012).
66. Wecht, K. J. *et al.* Validation of TES methane with HIPPO aircraft observations: implications for inverse modeling of methane sources. *Atmospheric Chemistry and Physics* **12**, 1823–1832 (2012).
67. Walker, T. W. *et al.* Impacts of midlatitude precursor emissions and local photochemistry on ozone abundances in the Arctic. *J. Geophys. Res* **117**, D01305 (2012).
68. Li, K.-F. *et al.* Vertical structure of MJO-related subtropical ozone variations from MLS, TES, and SHADOZ data. *Atmospheric Chemistry and Physics* **12**, 425–436 (2012).
69. Frankenberg, C. *et al.* Aerosol information content analysis of multi-angle high spectral resolution measurements and its benefit for high accuracy greenhouse gas retrievals. *Atmos. Meas. Tech.* **5**, 1809–1821 (2012).

70. Parrington, M. *et al.* The influence of boreal biomass burning emissions on the distribution of tropospheric ozone over North America and the North Atlantic during 2010. *Atmospheric Chemistry and Physics* **12**, 2077–2098 (2012).
71. Field, R. D. *et al.* A Tropospheric Emission Spectrometer for climate models. *Atmospheric Chemistry and Physics* **12**, 10485–10504 (2012).
72. Dupont, R. *et al.* Attribution and evolution of ozone from Asian wild fires using satellite and aircraft measurements during the ARCTAS campaign. *Atmospheric Chemistry and Physics* **12**, 169–188 (2012).
73. Cady-Pereira, K. E. *et al.* Methanol from TES global observations: retrieval algorithm and seasonal and spatial variability. *Atmospheric Chemistry and Physics* **12**, 8189–8203 (2012).
74. Barth, M. C. *et al.* Thunderstorms and upper troposphere chemistry during the early stages of the 2006 North American Monsoon. *Atmospheric Chemistry and Physics* **12**, 11003–11026 (2012).
75. Noone, D. *et al.* Properties of air mass mixing and humidity in the subtropics from measurements of the D/H isotope ratio of water vapor at the Mauna Loa Observatory. *J. Geophys. Res* **116**, D22113 (2011).
76. Yoshimura, K. *et al.* Comparison of an isotopic atmospheric general circulation model with new quasi-global satellite measurements of water vapor isotopologues. *J. Geophys. Res* **116**, D19118 (2011).
77. Frankenberg, C. *et al.* New global observations of the terrestrial carbon cycle from GOSAT: Patterns of plant fluorescence with gross primary productivity. *Geophys. Res. Lett* **38**, L17706 (2011).
78. Worden, J. *et al.*: Estimate of Bias in TES HDO And H<sub>2</sub>O Measurements. *Atmospheric Chemistry and Physics* **11**, 4491–4503 (2011).
79. Nassar, R., *et al.*: Inverse Modeling of CO<sub>2</sub> sources and Sinks, *Atmospheric Chemistry and Physics*, 6047 (2011).
80. Lee, J. *et al.* Relating tropical ocean clouds to moist processes using water vapor isotope measurements. *Atmospheric Chemistry and Physics* **11**, 741–752 (2011).
81. Risi, C. *et al.* Understanding the Sahelian water budget through the isotopic composition of water vapor and precipitation. *J. Geophys. Res* **115**, D24110 (2010).
82. *Dev.* **3**, 689–716 (2010).
83. Boxe, C. S. *et al.* Validation of northern latitude Tropospheric Emission Spectrometer stare ozone profiles with ARC-IONS sondes during ARCTAS: sensitivity, bias and error analysis. *Atmospheric Chemistry and Physics* **10**, 9901–9914 (2010).
84. *for carbon cycle science. Atmospheric Chemistry and Physics* **10**, 5601–5623 (2010).
85. Jourdain, L. *et al.* Lightning NO<sub>x</sub> emissions over the USA constrained by TES ozone observations and the GEOS-Chem model. *Atmos. Chem. Phys* **10**, 107–119 (2010).
86. Worden, J. *et al.* Observed vertical distribution of tropospheric ozone during the Asian summertime monsoon. *J. Geophys. Res* **114**, D13304 (2009).
87. Liu, J. J. *et al.* Analysis of the summertime buildup of tropospheric ozone abundances over the Middle East and North Africa as observed by the Tropospheric Emission Spectrometer instrument. *J. Geophys. Res* **114**, D05304 (2009).
88. Shim, C. *et al.* Satellite observations of Mexico City pollution outflow from the Tropospheric Emissions Spectrometer (TES). *Atmospheric Environment* **43**, 1540–1547 (2009).

89. Verma, S. *et al.* Ozone production in boreal fire smoke plumes using observations from the Tropospheric Emission Spectrometer and the Ozone Monitoring Instrument. *J. Geophys. Res* **114**, D02303 (2009).
90. Jones, D. *et al.* The zonal structure of tropical O<sub>3</sub> and CO as observed by the Tropospheric Emission Spectrometer in November 2004—Part 1: Inverse modeling of CO emissions. *Atmos. Chem. Phys* **9**, 3547–3562 (2009).
91. Bowman, K. *et al.* The zonal structure of tropical O<sub>3</sub> and CO as observed by the Tropospheric Emission Spectrometer in November 2004—Part 2: Impact of surface emissions on O<sub>3</sub> and its precursors. *Atmos. Chem. Phys* **9**, 3563–3582 (2009).
92. Zhang, L. *et al.* Transpacific transport of ozone pollution and the effect of recent Asian emission increases on air quality in North America: an integrated analysis using satellite, aircraft, ozonesonde, and surface observations. *Atmospheric Chemistry and Physics* **8**, 6117–6136 (2008).
93. Brown, D., Worden, J. & Noone, D. Comparison of atmospheric hydrology over convective continental regions using water vapor isotope measurements from space. *J. Geophys. Res* **113**, D15124 (2008).
94. Shephard, M. W. *et al.* Comparison of Tropospheric Emission Spectrometer nadir water vapor retrievals with in situ measurements. *J. Geophys. Res* **113**, D15S24 (2008).
95. Beer, R. *et al.* First satellite observations of lower tropospheric ammonia and methanol. *Geophys. Res. Lett* **35**, L09801 (2008).
96. Worden, H. M., Bowman, K. W., Worden, J. R., Eldering, A. & Beer, R. Satellite measurements of the clear-sky greenhouse effect from tropospheric ozone. *Nature Geoscience* **1**, 305–308 (2008).
97. Eldering, A., Kulawik, S. S., Worden, J., Bowman, K. & Osterman, G. Implementation of cloud retrievals for TES atmospheric retrievals: 2. Characterization of cloud top pressure and effective optical depth retrievals. *J. Geophys. Res* **113**, D16S37 (2008).
98. Jourdain, L. *et al.* Tropospheric vertical distribution of tropical Atlantic ozone observed by TES during the northern African biomass burning season. *Geophys. Res. Lett* **34**, (2007).
99. Worden, H. M. *et al.* Comparisons of Tropospheric Emission Spectrometer (TES) ozone profiles to ozonesondes: Methods and initial results. *J. Geophys. Res* **112**, (2007).
100. Worden, J. *et al.* Improved tropospheric ozone profile retrievals using OMI and TES radiances. *Geophys. Res. Lett* **34**, L01809 (2007).
101. Worden, J. *et al.* Importance of rain evaporation and continental convection in the tropical water cycle. *Nature* **445**, 528–532 (2007).
102. Kulawik, S. S. *et al.* TES atmospheric profile retrieval characterization: an orbit of simulated observations. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING* **44**, 1324–1333 (2006).
103. Zhang, L. *et al.* Ozone-CO correlations determined by the TES satellite instrument in continental outflow regions. *Geophys. Res. Lett* **33**, (2006).
104. Clough, S. A. *et al.* Forward model and Jacobians for tropospheric emission spectrometer retrievals. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING* **44**, 1308–1323 (2006).
105. Bowman, K. W. *et al.* Tropospheric emission spectrometer: Retrieval method and error analysis. *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING* **44**, 1297–1307 (2006).

106. Worden, J. *et al.* Tropospheric Emission Spectrometer observations of the tropospheric HDO/H<sub>2</sub>O ratio: Estimation approach and characterization. *J. Geophys. Res* **111**, (2006).
107. Kulawik, S. S. *et al.* Implementation of cloud retrievals for Tropospheric Emission Spectrometer (TES) atmospheric retrievals: part 1. Description and characterization of errors on trace gas retrievals. *J. Geophys. Res* **111**, D24204 (2006).
108. Worden, J. *et al.* Predicted errors of tropospheric emission spectrometer nadir retrievals from spectral window selection. *J. Geophys. Res* **109**, D09308 (2004).
109. Worden, J. R., Bowman, K. W. & Jones, D. B. Two-dimensional characterization of atmospheric profile retrievals from limb sounding observations. *Journal of Quantitative Spectroscopy and Radiative Transfer* **86**, 45–71 (2004).
110. Jones, D. B. A. *et al.* Potential of observations from the Tropospheric Emission Spectrometer to constrain continental sources of carbon monoxide. *J. Geophys. Res* **108**, 4789 (2003).
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