

Supplementary Figure 1 | NO, CO, and ozone profiles in the TWP. Sample profiles of 10 sec averaged O₃ (red), CO (grey), and NO (green) from four flights during CONTRAST (panels a, b, and d) and CAST (panel c). These are the same profiles as shown in Figure 2. Vertical profiles have a characteristic horizontal length of approximately 300 km.



Supplementary Figure 2 | Chemical regimes of the TWP determined by CO and NO composition. 10 sec averaged O₃ regressed against CO observations, colored by NO. (a) Data from all CAST and CONTRAST flights. (b) Data analyzed in the trajectory analysis. CAST data are for the 17 flights that provided observations between 300 and 700 hPa and CONTRAST data are for RF03-05 and RF07-14.



Supplementary Figure 3 | Correlation of CO with the biomass burning tracer CH₃CN. Regression of CO against acetonitrile (CH₃CN) for all observations where O₃>40 ppbv and RH<20%. The dashed red line is the best fit via orthogonal linear regression. The Δ CH₃CN/ Δ CO enhancement ratio and r² values are also shown. The Δ CH₃CN/ Δ CO ratio is consistent with emissions from burning of a tropical forest. Using a linear, least squares regression the Δ CH₃CN/ Δ CO enhancement ratio is 1.1 pptv/ppbv.



Supplementary Figure 4 | Fraction of modeled CO attributed to African and Southeast Asian biomass burning. Fraction of CO produced from biomass burning on 11 Feb 2014 from Africa (a-c) and 25 Feb 2014 from Southeast Asia (d-f) at 300 (a & d), 500 (b & e), and 700 (c & f) hPa found using tagged CO in CAM-Chem. The CAST/CONTRAST study region is shown by the rectangle and Hawaii is shown by the orange star to provide perspective in interpretation of these model results.



Supplementary Figure 5 | Measured and modeled ozone over Southeast Asia. (a) Vertical distribution of CAM-Chem O₃ in the Southeast Asian biomass burning region (i.e. black box Fig. 4); 5^{th} , 25^{th} , median, 75^{th} , and 95^{th} percentiles are shown. (b) Mean $\pm 1\sigma$ of SHADOZ ozonesonde observations over Hanoi, Vietnam for January and February 2014 (red). Mean $\pm 1\sigma$ CAM-Chem O₃ modeled over Hanoi, sampled on the same days as the ozonesondes (blue).



Supplementary Figure 6 | Median ozone over Africa and Southeast Asia. Median of SHADOZ ozonesonde observations for January and February 2014 (red) and CAM-Chem O₃ sampled on the same days as the ozonesondes (blue) over Nairobi, Kenya (a) and Hanoi, Vietnam (b). Error bars represent the 25th and 75th percentiles.



Supplementary Figure 7 | Photochemical ozone production from three CONTRAST profiles. Vertical profiles of observed O₃, H₂O, CO, and NO_x (red) from the CONTRAST flights in Figure 2 used as input for the DSMACC photochemical box model. Model outputs (blue) are 24-hour averaged NO, gross O₃ production $(P(O_3)=k_1[NO][HO_2]+k_2[NO][CH_3O_2])$, and net O₃ production $(P(O_3)^{Net}=P(O_3)-k_3[O_3][OH]-k_4[O_3][HO_2]-k_5[O^1D][H_2O])$. Panels show data from (**a**) 19 Jan 2014 (**b**) 13 Feb 2014 (**c**) 19 Feb 2014.



Supplementary Figure 8 | Comparison of AIRS water vapour to *in situ* observations. (a) Vertical profile of H₂O mixing ratio from CONTRAST RF11 conducted at 7.1°N and 143°E on 13 Feb 2014. Grey dots are *in situ* observations, red, open circles are *in situ* observations averaged over the AIRS layers, and cyan, closed squares are AIRS observations. AIRS data have been bilinearly interpolated to the profile coordinates. (b) *In situ* H₂O from one profile from every CONTRAST flight, averaged to the AIRS layers, regressed against AIRS H₂O interpolated to the respective profile location.





TWP. Normalized distribution of the change in water vapour mixing ratio along the back trajectories for the HOLW structures. The change in water vapour is defined as the difference between the H₂O mixing ratios at the trajectory starting point (*i.e.* the trajectory initialization point along the flight track) and the trajectory end point (*i.e.* 10 days prior to observation or the point of last precipitating convection). Water vapour was calculated from the RH output by the HYSPLIT model, which is based on GDAS meteorology (see methods). Positive values indicate the water vapour mixing ratio has increased during transit to the TWP.