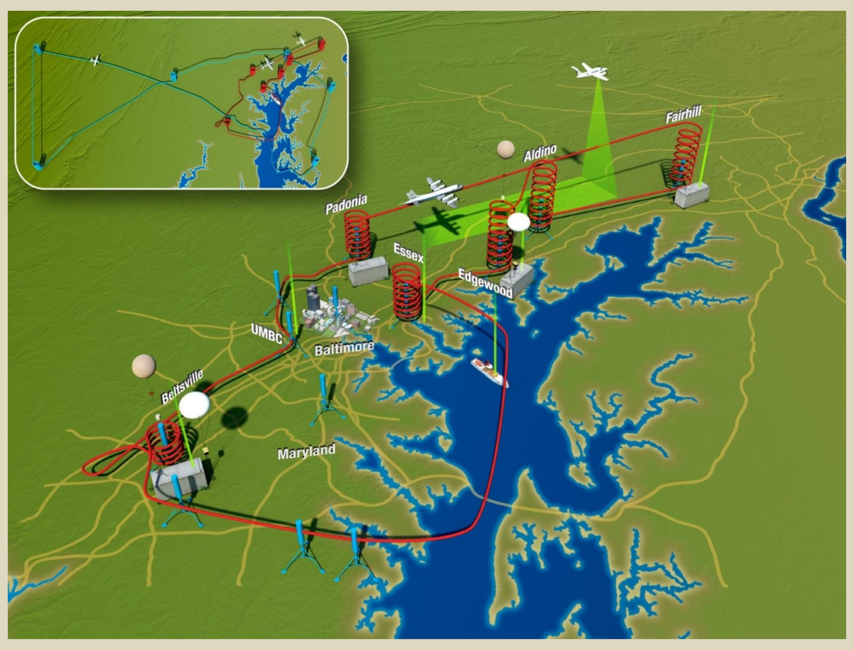
Improving the view of air quality from space: Current findings and future directions for analysis of DISCOVER-AQ observations

Jim Crawford, Ken Pickering, and the DISCOVER-AQ Science Team

Background

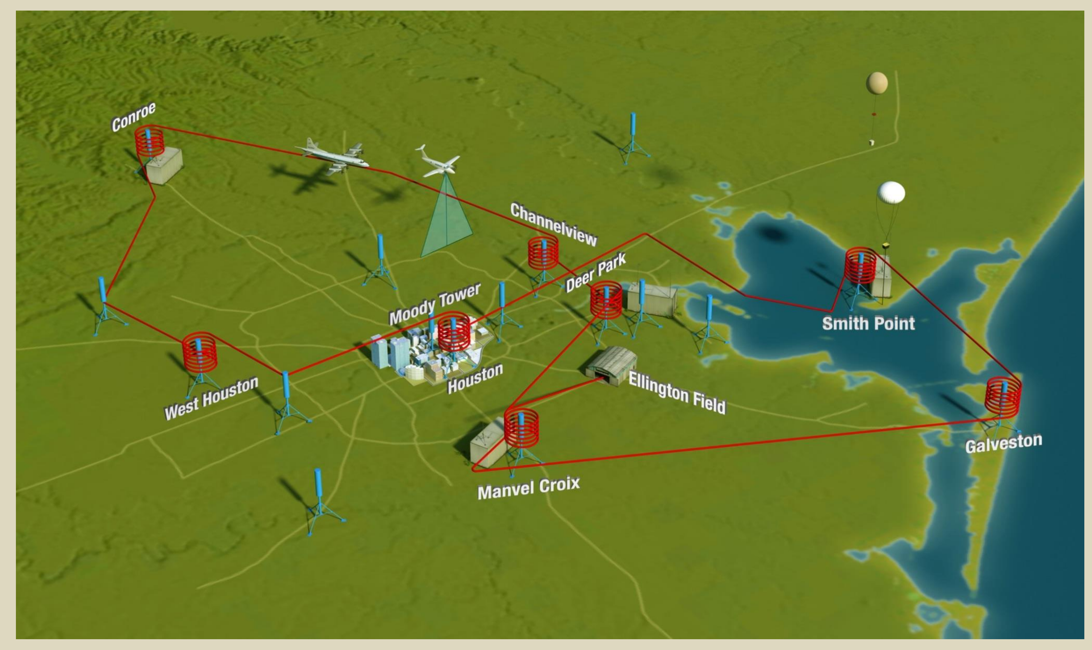
Through a series of four field studies, DISCOVER-AQ (Deriving Information on Surface conditions from COlumn and VERtically resolved observations relevant to Air Quality) has aimed to study the distribution of gaseous and particulate pollution in the lower atmosphere over contrasting regions of the U.S. that are currently in violation of National Ambient Air Quality Standards. At each study location, a detailed observing system comprised of two aircraft and a ground network have collected detailed in situ and remote sensing observations intended to improve the interpretation of current and future satellite observations to diagnose near-surface conditions relating to air quality. Each study was designed and conducted in partnership with state and local air quality agencies having long-term experience and understanding of the conditions and factors controlling air quality for each specific region. Observations were expanded through partnerships with EPA, NSF, NOAA, and numerous universities. More complete information on the experimental details as well as data from each of the campaigns can be obtained from the project website (http://discover-aq.larc.nasa.gov). The examples presented below offer only a small sampling of the insights provided by these observations and the broad research being pursued by the DISCOVER-AQ Science Team and its partners.

Baltimore-Washington (July 2011)

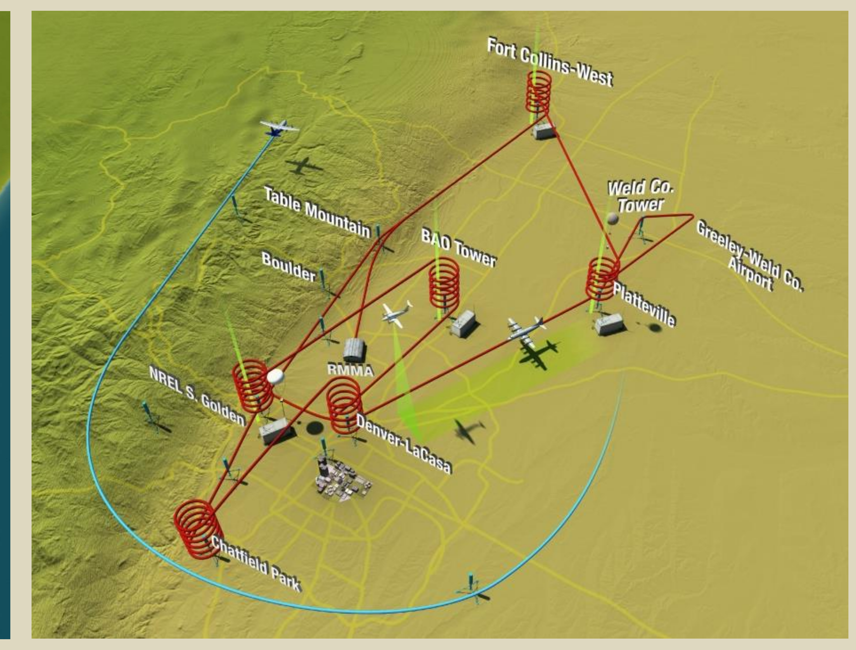


San Joaquin Valley (Jan-Feb 2013)

Houston, Texas (September 2013)



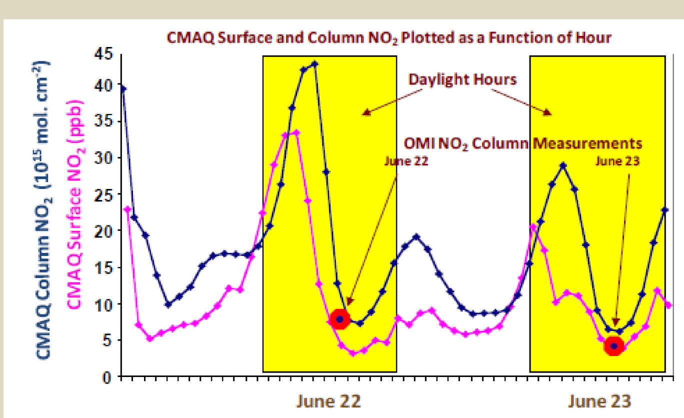
Denver, Colorado (July-August 2014)



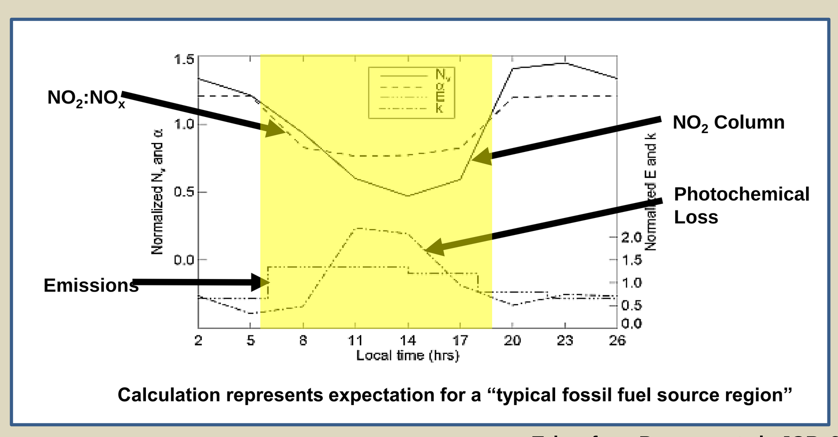
Observing strategies for each study are shown above. Red lines trace the P-3B flight paths for in situ measurements with recurring spirals over local air quality monitoring sites. The flight paths were repeated three times on each flight day. Actual flight paths for remote sensing from the higher flying King Air are not shown but closely follow that of the P-3B. Tripod sensors represent locations of Pandora spectrometer and AERONET sunphotometer pairs (30 additional AERONET locations as part of the DRAGON network in Baltimore-Washington are not shown). Balloons represent tethered balloon and ozonesonde operations. Trailers are shown at sites where additional in situ measurements were added to a monitoring location. Lidar observations are shown as vertical traces in light green. The inset view for Baltimore-Washington shows upwind and downwind sampling by the UMD Cessna. In Colorado, the third aircraft is the NCAR C-130 collaborating as part of the Front Range Air Pollution and Photochemistry Experiment (FRAPPE). Collaborative ship cruises took place in the Baltimore-Washington and Houston studies. (Images courtesy of Timothy Marvel)

Predicted NO_2 Column Behavior

The two figures below depict published diurnal trends in NO_2 taken from model studies using CMAQ (left) and GEOS-Chem (right). They represent the best information available prior to the DISCOVER-AQ field observations. While they are not identical in their behavior, both show a minimum in NO_2 column density in the afternoon and changes during daylight hours that are greater than a factor of 2. These trends are specific to urban areas influenced by fossil fuel combustion and should not be viewed as the expected behavior across the globe.



Taken from Fishman et al., BAMS, 2008



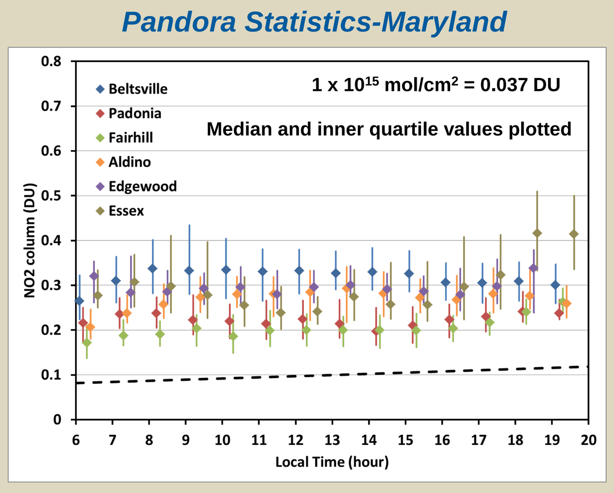
Taken from Boersma et al., JGR, 2008

Observed NO_2 Column Behavior

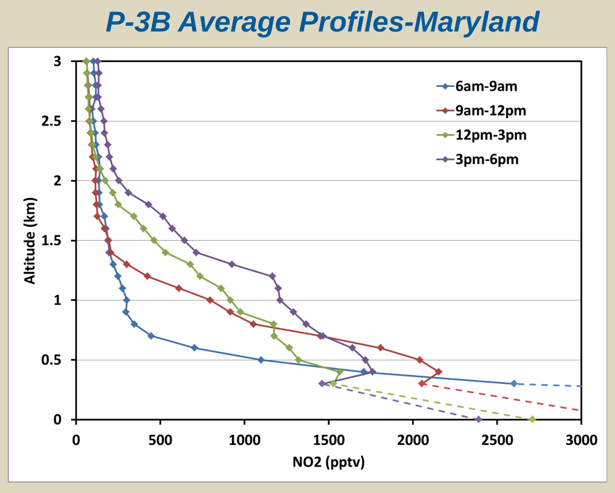
Pandora spectrometer observations of NO2 column behavior presented in the panels below differ considerably from what was expected based on the model studies. (Note: the dashed line on the upper left panel indicates the expected stratospheric contribution to the total NO2 column)

Additional data on the detailed vertical profiles from the P-3B aircraft qualitatively corroborate the Pandora observations. These observations suggest that satellite retrievals from geostationary orbit will rely heavily on accurately representing the change in vertical profiles throughout the day. It also suggest that Pandora spectrometers could play a key validation role since their direct sun observations provide column observations that are insensitive to the vertical distribution. Thus, comparison of diurnal behavior in column observations from the ground and space will be critical in revealing where assumptions regarding boundary layer growth and impacts on column densities are most in need of improvement.

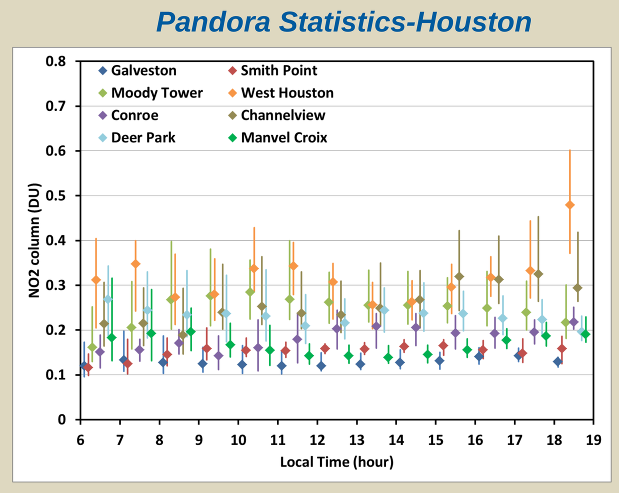
Pandora Statistics-Maryland



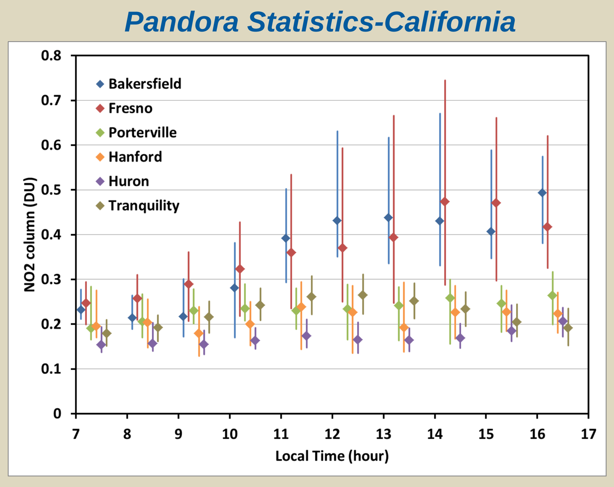
P-3B Average Profiles-Maryland



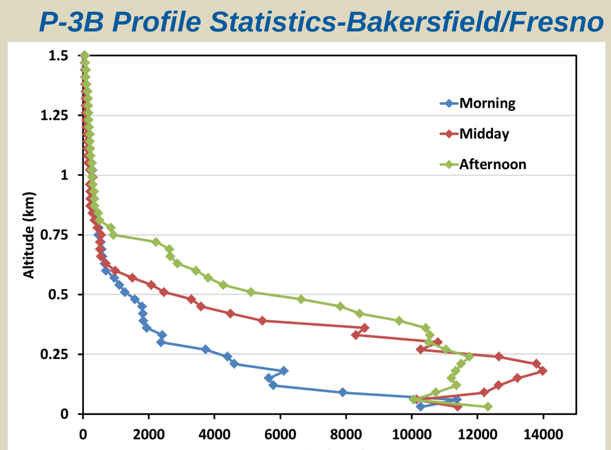
Pandora Statistics-Houston



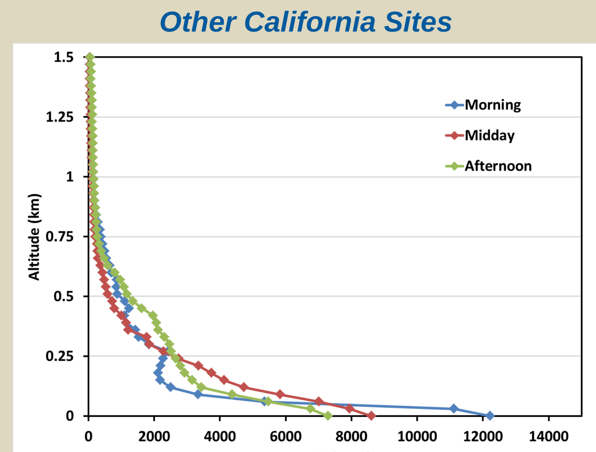
Pandora Statistics-California



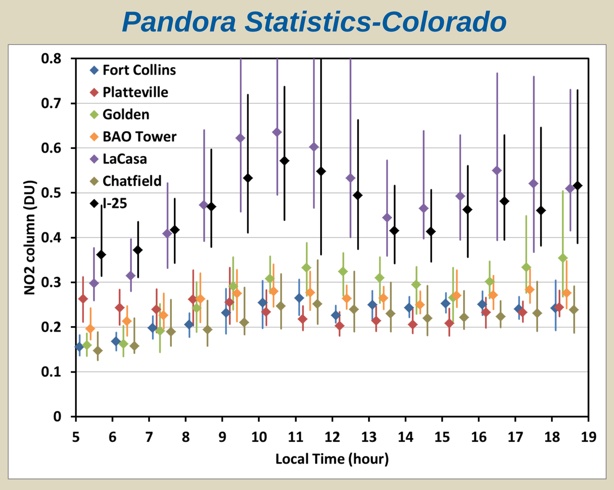
P-3B Profile Statistics-Bakersfield/Fresno



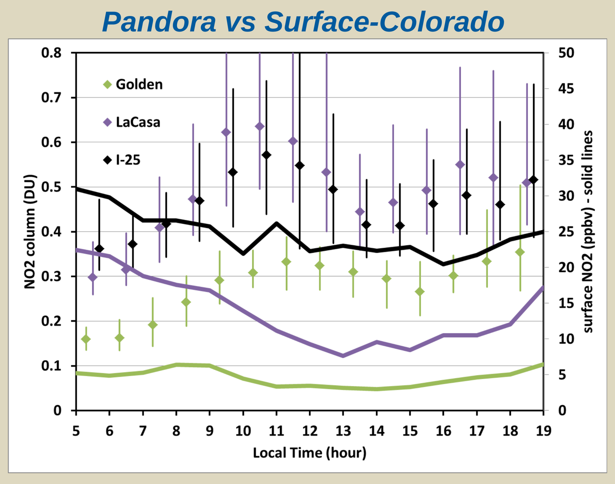
Other California Sites

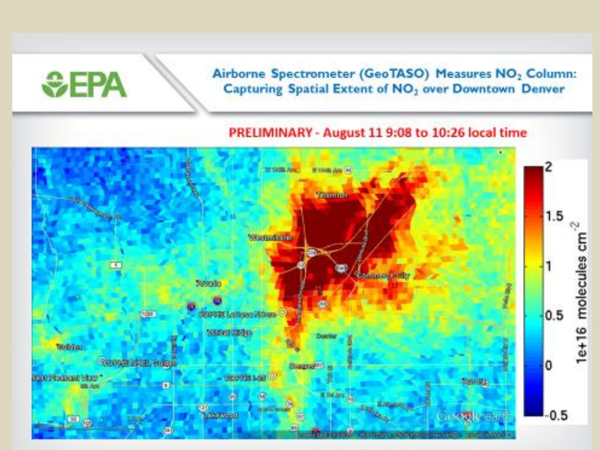


Pandora Statistics-Colorado

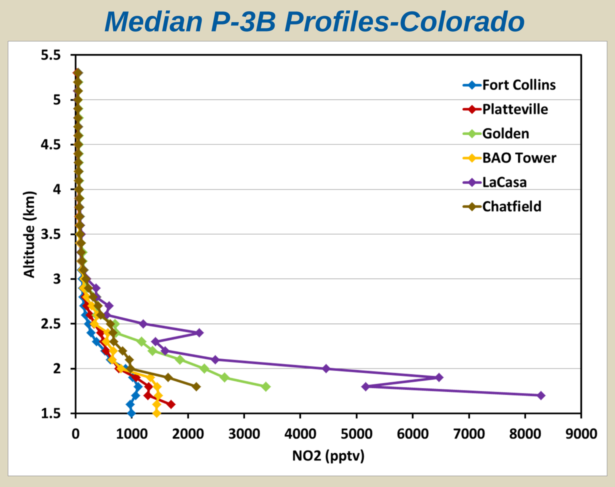


Pandora vs Surface-Colorado

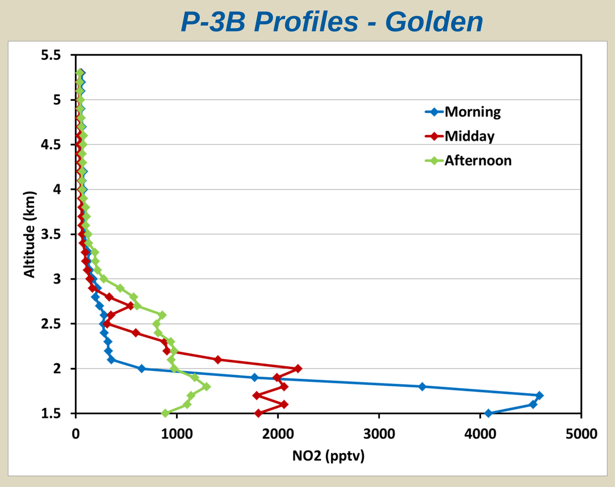




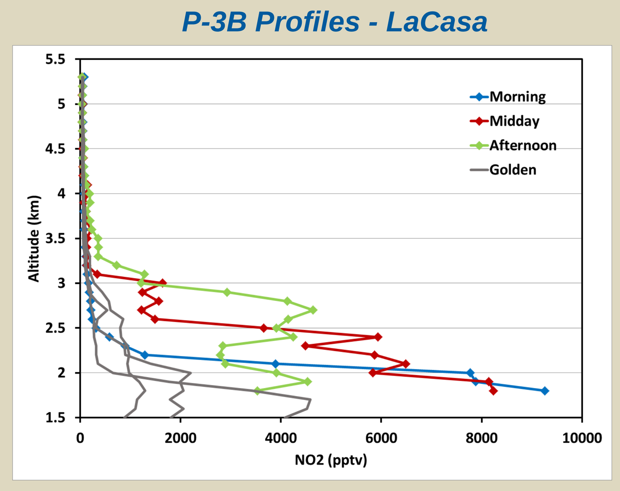
Median P-3B Profiles-Colorado



P-3B Profiles - Golden

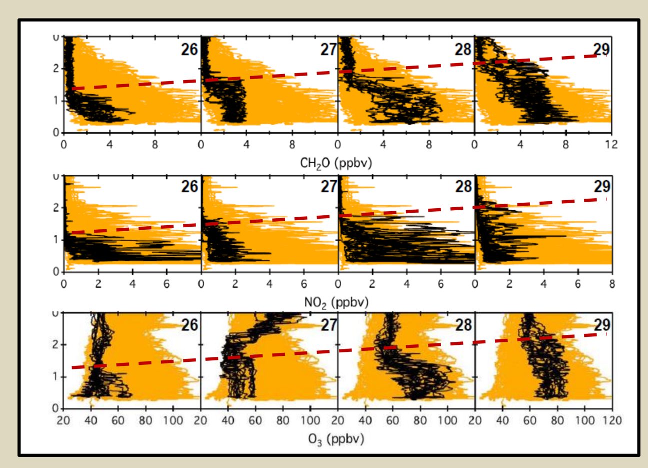


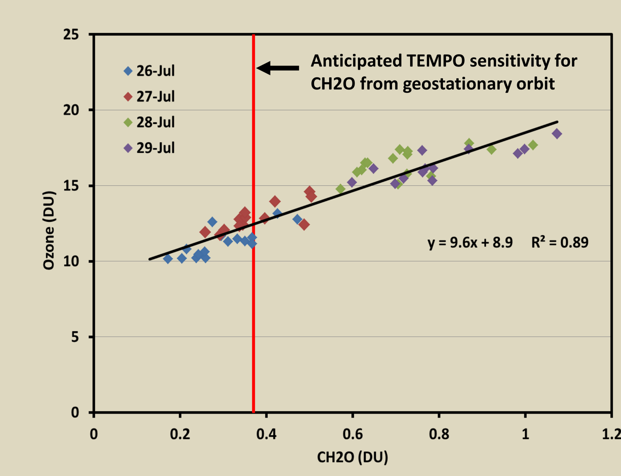
P-3B Profiles - LaCasa



Signatures of Biogenic Influence on Ozone and CO

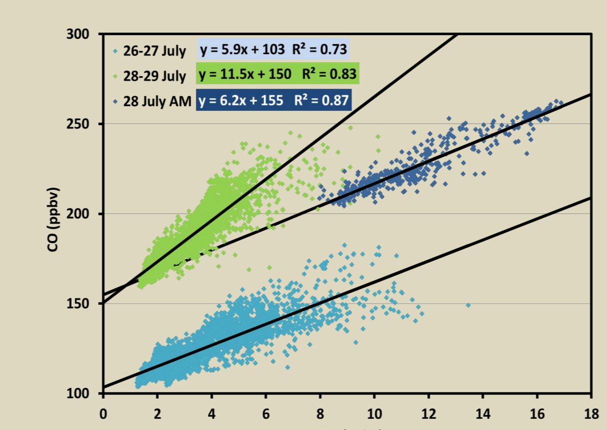
In situ profiles of CH_2O and O_3 exhibit an increasing trend during 26-29 June 2011 over Baltimore-Washington (left panel). Increasing temperatures and relative humidity contributed to both deeper mixing of emissions and increased biogenic emissions (e.g., isoprene). During this period, column amounts for CH_2O and O_3 exhibit a striking correlation (right panel). CH_2O has a very short lifetime, changing rapidly with photochemical activity. The large dynamic range can be traced to the trends in relative humidity and isoprene emissions, both being sensitive to temperature. This suggests that satellite measurements of CH_2O might have utility for inferring O_3 (at least in this environment). Given the large dynamic range in CH_2O along with its short lifetime, production rates ranging from 10-45 ppbv CO/day have been calculated from the observations. In the bottom panel, data collected at 1000 feet along the I-95 traffic corridor has been segregated to assess mobile emissions on 26-27 July (low biogenic activity) and 28-29 July (high biogenic activity). Under high biogenic activity, the CO:NOy slope doubles, although the slope reverts to the expected value when fresh emissions are observed on the morning of the 28th. This behavior raises some concern regarding the practice of normalizing trace gas measurements with CO to determine emission factors or dilution effects on downwind evolution.



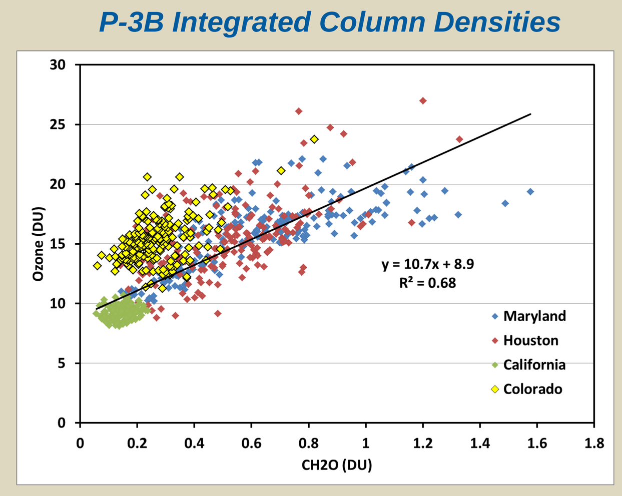


Further Examination of Ozone and Formaldehyde Relationships

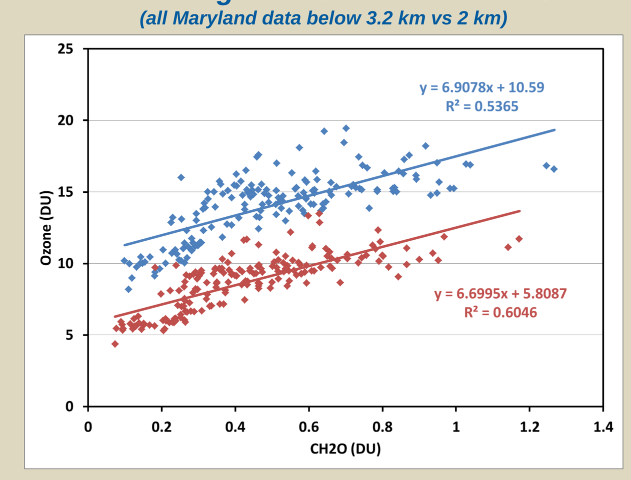
The figures below shows that is some evidence for a broader applicability of formaldehyde as an indicator of ozone production. While California (winter) and Colorado (low CH2O) are not encouraging, both Texas and Maryland demonstrate the same general relationship shown in the regression (upper left panel). The upper right panel demonstrates that the relationship may be driven partially by the depth over which the column is integrated. The bottom panels show two consecutive days over Houston. On the 25th, the relationship may be degraded by primary CH2O emissions in stagnant air over source regions, while the 26th is characterized by steady flow to the northwest, diluting primary production and allowing the photochemical relationship between O3 and CH2O to emerge.



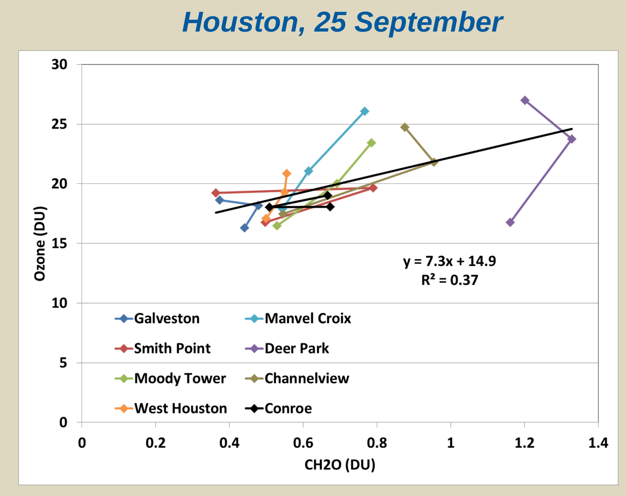
P-3B Integrated Column Densities



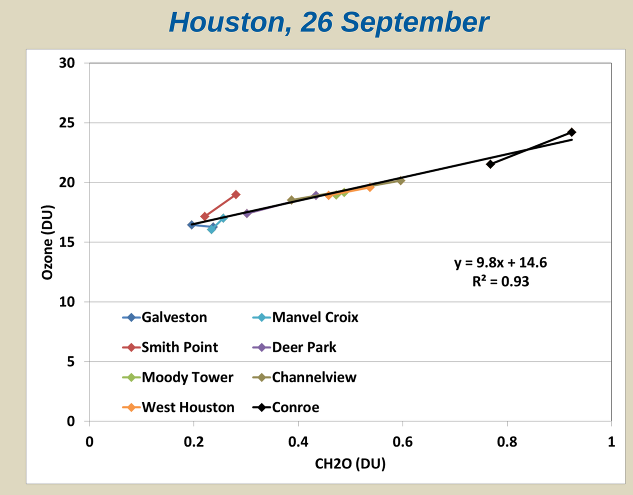
P-3B Integrated Column Densities
(all Maryland data below 3.2 km vs 2 km)



Houston, 25 September



Houston, 26 September



Future Work

The examples shown here draw heavily on the detailed atmospheric structure provided by in situ observations to demonstrate interesting features, some of which may be possible for satellites to diagnose. A critical next step will be to conduct a fully integrated analysis of the remote sensing observations and in situ data to determine how well they agree and to what extent the DISCOVER-AQ observing system supports improved interpretation of remote sensing observations. These results will inform the development of satellite retrievals, improvement of air quality models, and the optimization of ground-based networks to determine the best set of measurements to connect with satellites as part of future air quality observing systems.

http://discover-aq.larc.nasa.gov/