# A permanent free-tropospheric observatory at Pico summit in the Azores Islands? Past measurements (2001–2005) and future plans

A51D -0108


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## 1 Overview

The PICO-NARE station was established in July 2001. Measurements to date have demonstrated that the station frequently samples the free troposphere (FT) and captures:

- lower FT North American anthropogenic pollution, aged ~4–6 days (frequently);
- hemispheric-scale impacts of boreal forest fires on CO, $O_3$, nitrogen oxides, and other species (frequently in high-fire years);
- aged European pollution (occasionally); and
- African dust (occasionally).

**Transition to a long-term station.**
Over the next ~3 years, the station will be transferred to the Azores Regional Government and the Portuguese Meteorological Institute, who plan to operate it as a permanent Global Atmosphere Watch (GAW) station. The goal is to provide a long-term atmospheric record and a base for research intensives.

**Summary of main findings to date.**

- Large $d[O_3]/d[CO]$ slopes (~1.0) in summertime lower-FT U.S. outflow [1].
- Significant impact of boreal wildfires in Siberia and North America on CO, $O_3$, and nitrogen oxides (poster A51D-109 [2], pres. A41D-02 [3], [1]).
- U.S. pollution events are the result of low-altitude transport governed by the locations of the Azores/Bermuda high and transient northerly lows [4]. This type of event is significant in the total U.S. pollution export budget, and similar events can reach Europe.
- African dust events can be separated from black carbon events and are observed occasionally [5].

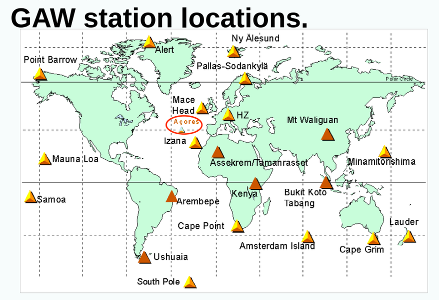
**The rest of this poster** presents

- information on the station (top row: sections 2–5);
- seasonal cycles and interannual variation of $O_3$, CO, black carbon, NMHCs, and nitrogen oxides (2nd row: section 6); and
- Examples of time series observed during pollution transport events in summer, winter, and spring (bottom row: section 7).

## 2 Station Location

Pico mountain is the only location where ground-based free troposphere measurements can be made in the marine region of westerly winds downwind of North America. A permanent Pico station would complement the Mace Head station (in the MBL) and the Izaña station (in the easterly trade wind region).

**GAW station locations.**



Pico island is located in the **Azores central island group.**

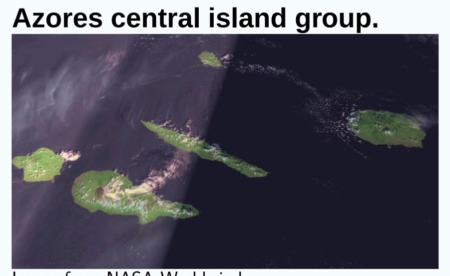
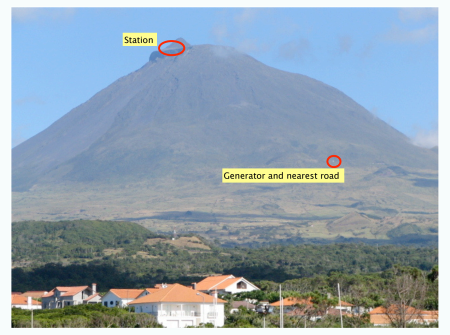


Image from NASA Worldwind.

Pico island is small and dominated by Pico mountain.

Image from NASA Worldwind.

The station is located on the summit caldera (2225 m altitude, circled). It is powered by a generator at 1200 m altitude (circled).



**The PICO-NARE station.**

View of MBL-capping clouds behind the station. The FAAM (ITOP) aircraft is visible behind–see section 3.

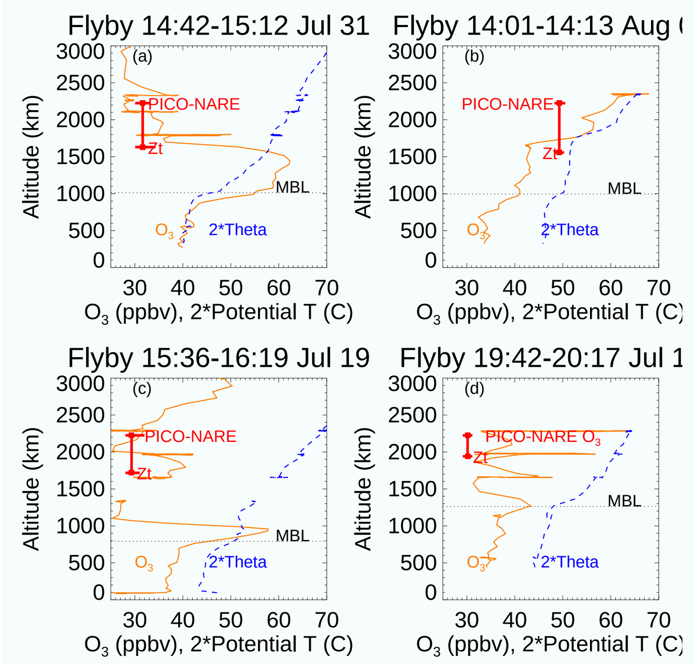
## 3 Flow Characterization: Upslope Flow

Detailed analyses of upslope flow on Pico mountain are provided in poster A51D-110 and [6]. We find that:

- Buoyant uplift occurs on Pico mountain about $1/3$ of the summer days.
  - Impacts of marine boundary layer air are detectable on only a fraction of the buoyant upslope flow days, and free tropospheric air is sampled throughout the day on most other summer days.
- Wind-driven uplift may bring MBL air to the summit on about $1/3$ of the days during fall–spring, but does so only rarely during summer.

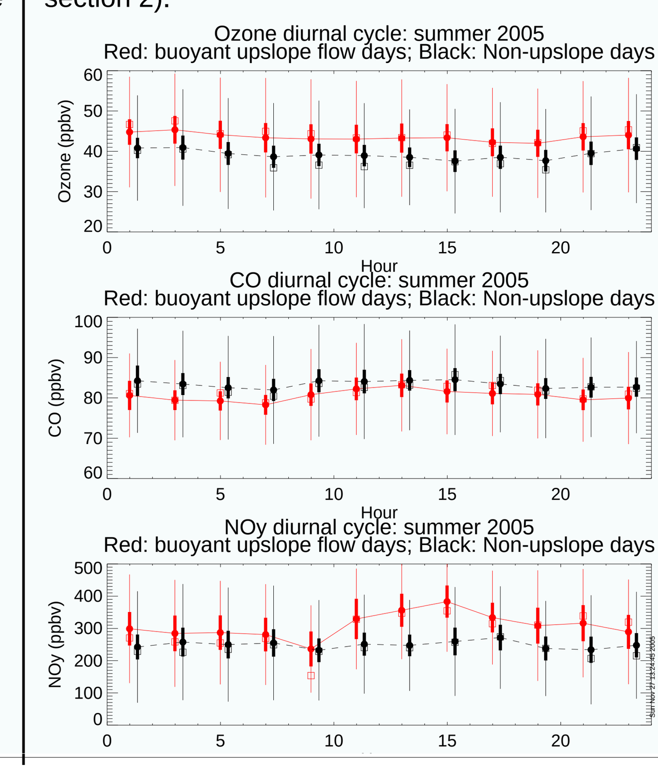
**Comparison to aircraft vertical soundings**
During summer 2004, the U.K. FAAM aircraft flew soundings near Pico on several days. The plots below compare $O_3$ at the PICO-NARE station to soundings within 35 km of the station. The PICO-NARE $O_3$ is plotted from station altitude to the estimated minimum upwind height of air travelling over the mountain ($Z_l$). (Dashed blue line: potential temperature.)

**PICO $O_3$ measurements (thick red vertical line) are consistent with the aircraft soundings (orange line) and indicate FT air was sampled.**




**Summertime Diurnal Cycles (2005)**
The diurnal cycles of $O_3$, CO, and $NO_y$ for days identified as buoyant upslope flow days (red solid line) and non-upslope flow days (black dashed line).

Day/night differences are insignificant for $O_3$ and CO—see poster A51D-110 for more information. The daytime increase in $NO_y$ on upslope-flow days may reflect generator emissions (location shown in section 2).

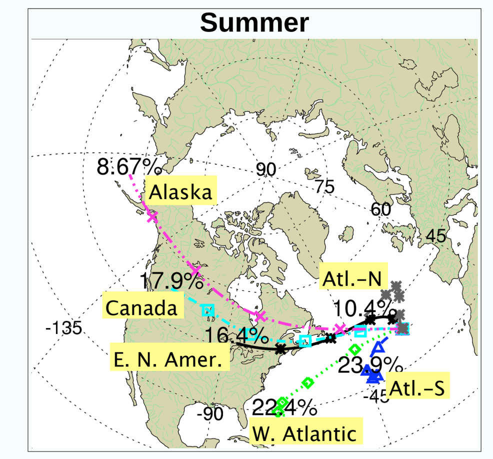



## 4 Flow Characterization: Transport Pathways

We have conducted cluster analyses of 10-day backward trajectories ending at the station over a 45-year period.

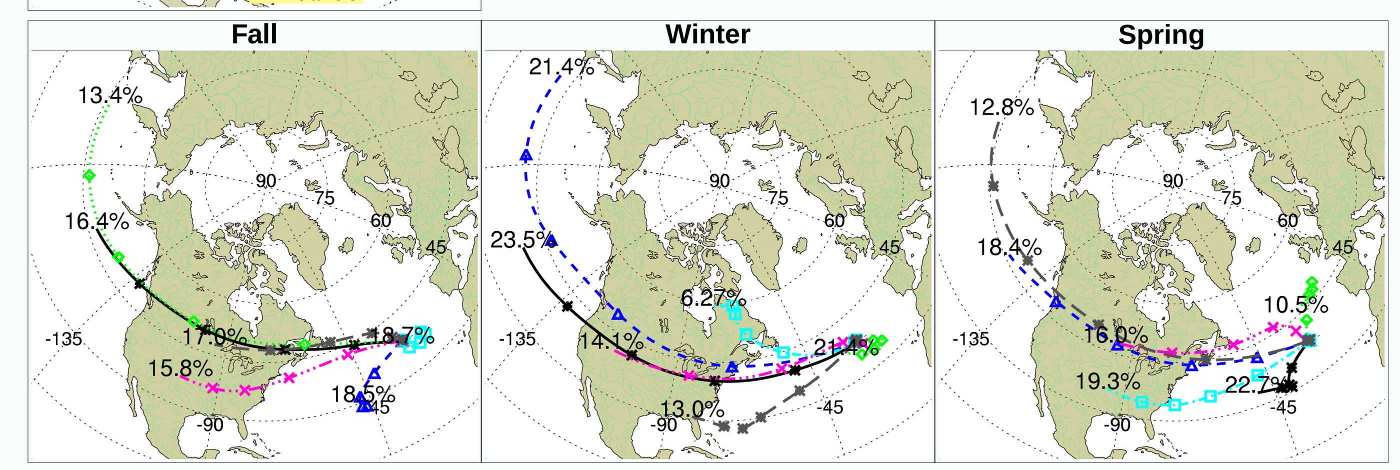
**Figures: Cluster means by season.**
These emphasize the stronger zonal flow during fall–spring and more frequent sampling of Atlantic air during summer, due to the Azores/Bermuda high.

**Table: Summertime interannual variability.**
Large enhancements in CO were observed in 2003 and 2004 (see section 6). Large boreal fires occurred in Siberia and North America, respectively, during those summers (see poster A51D-109.) The frequency of trajectories in the "Alaska" and "Canada" clusters was only moderately enhanced during these years (+37% and +15%). The long-term values and those during the ICARTT summer of 2004 are highlighted below.




### Summertime interannual variability

| Cluster name | 1960–2005 | 2001 | 2002 | 2003 | 2004 | 2005 |
|---|---|---|---|---|---|---|
| Eastern North America | 16.4 | 8 | 20 | 12 | 19 | 22 |
| Western Atlantic | 22.4 | 35 | 17 | 32 | 23 | 7 |
| Canada | 17.9 | 15 | 14 | 23 | 23 | 16 |
| Alaska | 8.67 | 9 | 7 | 14 | 8 | 7 |
| Atlantic south of Azores | 23.9 | 26 | 30 | 15 | 20 | 30 |
| Atlantic north of Azores | 10.4 | 7 | 12 | 4 | 7 | 19 |




## 5 Measurements and Data Availability

- **Current measurements.**

| Species | Method | Start date |
|---|---|---|
| CO | NDIR [1] | July 2001 |
| $O_3$ | UV abs. [1] | July 2001 |
| NO, $NO_2$, $NO_y$ | Chemilum. | August 2002 |
| $C_2$–$C_6$ NMHCs | GC-FID [7] | July 2004 |
| black carbon, | | July 2001 |
| absorbing dust | Multi-λ Aethalometer | July 2001 |

- **Data status**

| Species | Data status | Contact |
|---|---|---|
| CO | Final to 8/2004 | Honrath |
| | Prelim. to 8/2005 | |
| $O_3$ | Final to 8/2005 | Honrath |
| black carbon, | | |
| absorbing dust | Prelim. to 12/2004 | Fialho |
| NO, $NO_2$, $NO_y$ | Final 5–9/2004 | Honrath |
| | Prelim. 8/2003 to 8/2005 | |
| $C_2$–$C_6$ NMHCs | Prelim. to 8/2005 | Helmig |

Information on data availability is posted at `http://www.cee.mtu.edu/~reh/pico/data_exchange/`

- **Planned future measurements**

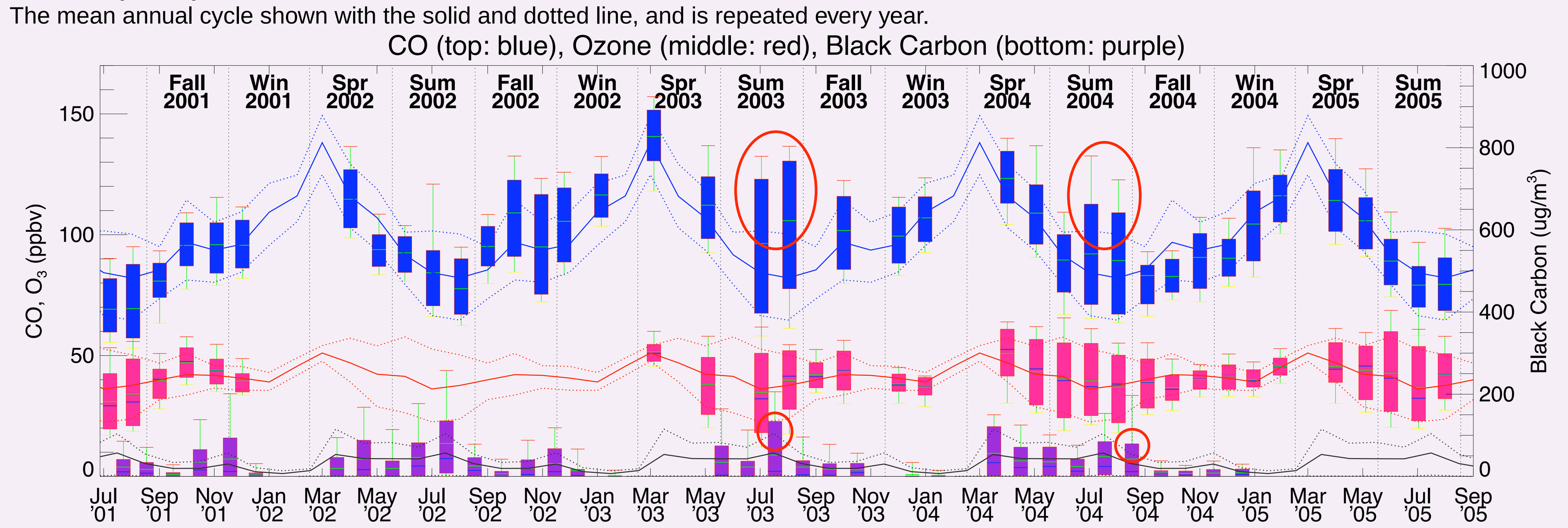
The station is currently shut down for the 2005–2006 winter. Station status during 2006 is dependent upon NOAA and NSF funding.

## 6 Seasonal Distributions

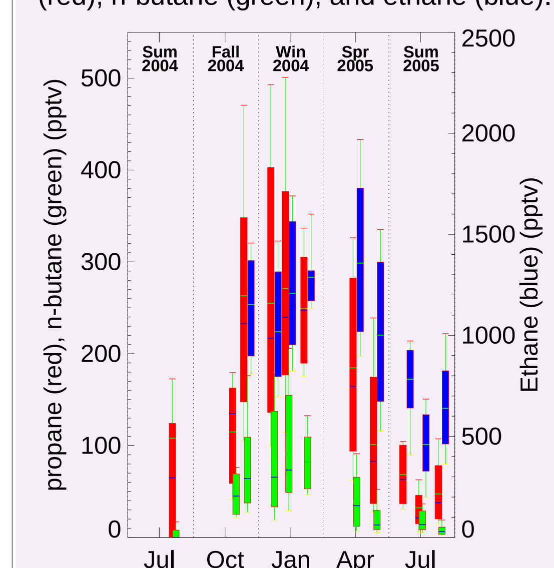
Seasonal distributions during non-upslope flow periods are shown in the three plots to the right. The monthly box-plots show the middle $2/3$ (colored box) and middle 90% (error bars), with lines at the means and medians. (In the CO/$O_3$/black carbon plot, the mean and middle $2/3$ for the mean annual cycle is also plotted over each year for comparison.)

- **CO and black carbon:** Note the large enhancements in CO during the summers of 2003 and 2004. Extreme boreal fire years in Siberia and North America were responsible. Black carbon was also enhanced.
- **$O_3$:** Mean $O_3$ peaks during spring—but note the much larger range of $O_3$ during summer. This is the result of increased $O_3$ in anthropogenic and biomass-burning plumes contrasting with reduced $O_3$ in background Atlantic air.
- **NMHCs:** a strong seasonal cycle is apparent, driven by enhanced loss during summer, when [OH] is high.
- **$NO_y$ and $NO_x$:** High $NO_x$ levels were observed during summer 2004 in boreal fire plumes (Val Martin presentation A41D-02, [3]).

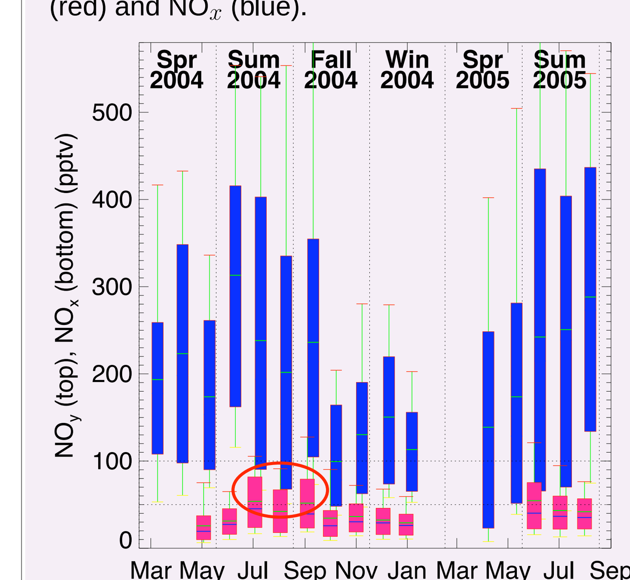
**Ozone, CO, and black carbon.** Box-plots show the distributions of observations each month. The mean annual cycle shown with the solid and dotted line, and is repeated every year.




**NMHCs.** Monthly boxplots: propane (red), n-butane (green), and ethane (blue).




**$NO_x$ and $NO_y$.** Monthly boxplots for $NO_y$ (red) and $NO_x$ (blue).




## 8 Final Remarks

- Pico summit is well suited for studies of aged N. American anthropogenic emissions exported in the lower troposphere. Pico station is unique in providing FT measurements in the lower troposphere downwind of N. America. Pico observations of significant enhancements in $O_3$ and $O_3$ precursors indicate that the fate of lower-FT export is significantly different from that of MBL export.
- The location is also well suited for studies of the large-scale impacts of boreal wildfires. FT measurements well downwind are necessary to capture the full magnitude of $O_3$ impacts resulting from fire emissions; Pico measurements indicate these impacts are significant.
- A long-term Pico station would provide a valuable base for such studies and would observe trends resulting from changes in boreal fires (expected due to climate change [9]), from changes in U.S. emissions, and from hemispheric changes in background tropospheric composition.

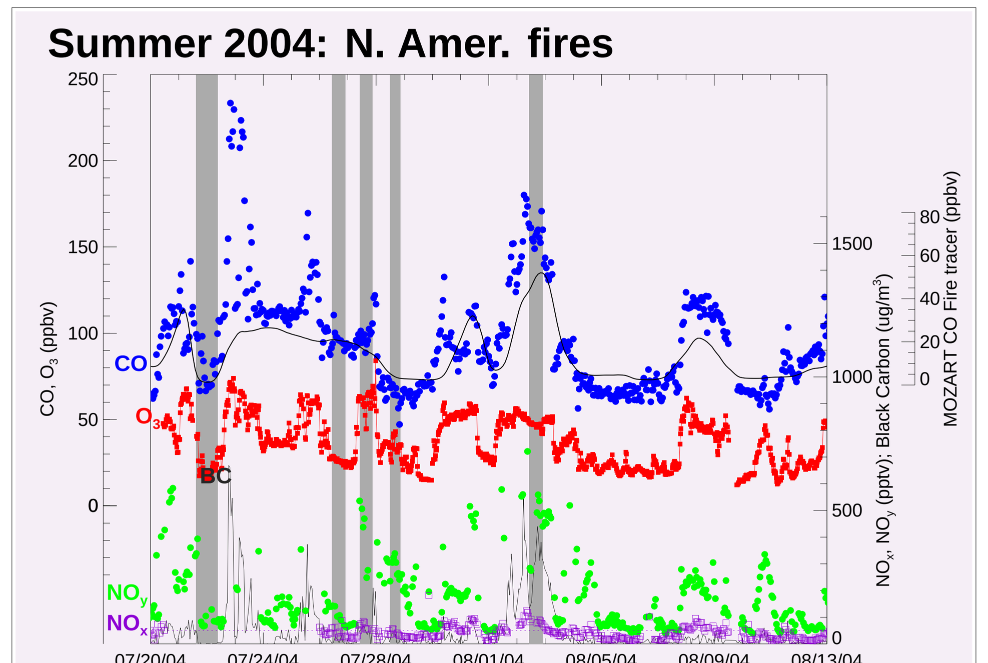
If you would like to receive updates on the status of a long-term Pico station, please sign up below.

## 7 Example Time Series

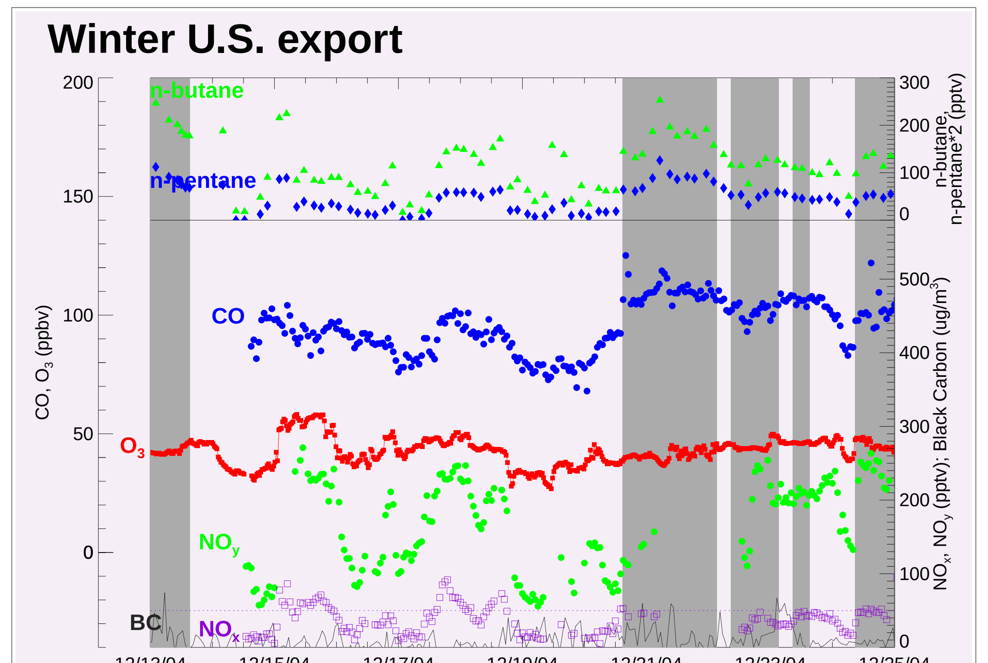
The plots to the right show examples of measurements during periods impacted by pollution transport during summer, winter, and spring.
Greyed out periods indicate when upslope flow may have brought MBL air to the station.

- **Summer 2004: N. American boreal fires.** Large CO enhancements (including the highest CO yet observed) coincided with peaks in fire-CO simulated by MOZART [8]. Corresponding enhancements in $O_3$, $NO_x$, and black carbon were observed.
- **December 2004 U.S. export.** Backward trajectories during 12/14–20/2004 travelled from the southeast U.S. Enhancements of $NO_x$, $NO_y$, $O_3$, and CO and NMHCs occurred intermittently.
- **Spring 2005 U.S. export.** Trajectories arriving 4/18 and 4/22–23/05 travelled from the southwest and northeast U.S.

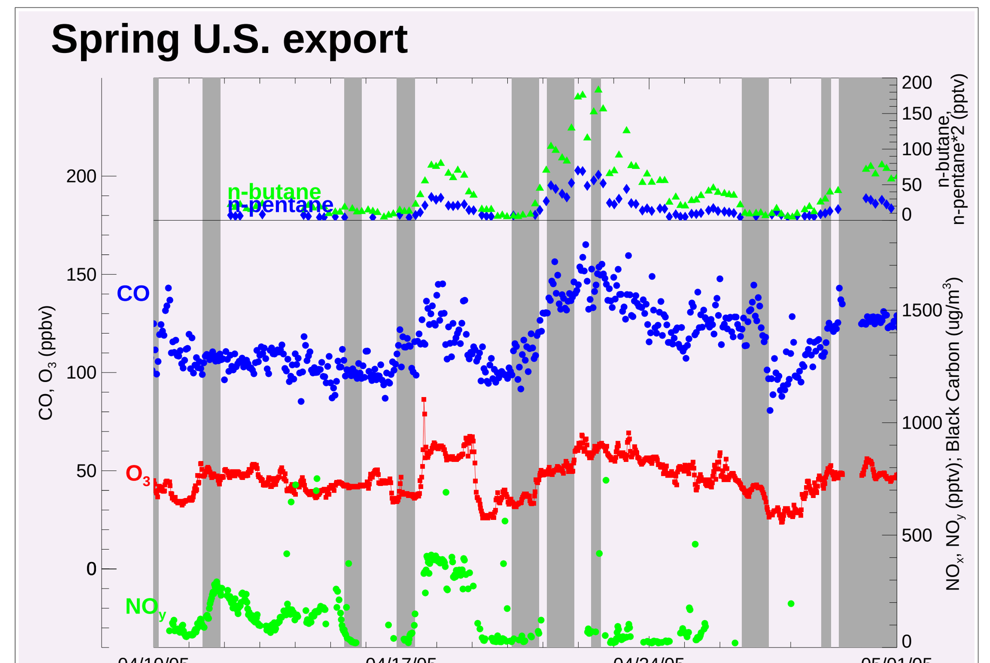
**Summer 2004: N. Amer. fires**




**Winter U.S. export**




**Spring U.S. export**





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**Notes.** To receive preprints of bold-faced manuscripts, leave your name on the list below.


[1] **Regional and hemispheric impacts of anthropogenic and biomass burning emissions on summertime CO and $O_3$ in the North Atlantic lower free troposphere, R. E. Honrath, R. C. Owen, M. Val Martin, J. S. Reid, K. Lapina, P. Fialho, M. P. Dziobak, J. Kleissl, and D. L. Westphal, J. Geophys. Res., 109, D25310, doi:10.1029/2004JD005147, 2004.**

[2] **Evidence of significant impacts of large-scale boreal fires on ozone levels in the midlatitude Northern Hemisphere free troposphere, K. Lapina, R. E. Honrath, R. C. Owen, and M. Val Martin, for submission to GRL Jan. 2006.**

[3] **Observations of large enhancements of nitrogen oxides in the North Atlantic lower free troposphere resulting from boreal wildfires, M. Val Martín, R. E. Honrath, R. C. Owen, J. Kleissl, P. Fialho, G. Pfister, and K. Lapina, for submission to JGR, Mar. 2006.**

[4] **An analysis of transport mechanisms of North American emissions to the central North Atlantic, R. C. Owen, O. Cooper, A. Stohl, and R. E. Honrath, J. Geophys. Res., for submission to JGR Jan. 2006.**

[5] **Aethalometer calibration and determination of iron concentration in dust aerosols, P. Fialho, M. C. Freitas, F. Barata, B. Vieira, A. D. A. Hansen, and R. E. Honrath, J. Aerosol Sci., submitted October 2005; Absorption coefficients by aerosols in remote areas: a new approach to decouple dust and black carbon absorption coefficients using seven-wavelength Aethalometer data, P. Fialho, A. D. A. Hansen, and R. E. Honrath, J. Aerosol Sci. (in press), 2005.**

[6] **Analysis and application of Sheppard's airflow model to predict mechanical orographic lifting and the occurrence of mountain clouds, J. Kleissl and R. E. Honrath, J. Appl. Met., in review, 2005; The occurrence of upslope flows at the Pico mountain observatory: a case study of orographic flows on small, volcanic islands, J. Kleissl, R. E. Honrath, R. C. Owen, M. Val Martin, and M. P. Dziobak, for submission to JGR Jan. 2006.**

[7] **A Gas Chromatography System for the Automated, Unattended, and Cryogen-Free Monitoring of $C_2$ to $C_6$ Non-Methane Hydrocarbons in the Remote Troposphere, David Tanner, Detlev Helmig, Jacques Hueber, and Paul Goldan, J. Chromatography A, submitted November 2005.**

[8] Presentation A21B-0847; Quantifying CO emissions from the 2004 Alaskan wildfires using MOPITT CO data, G. Pfister and P. G. Hess and L. K. Emmons and J.-F. Lamarque and C. Wiedinmyer and D. P. Edwards and G. Pétron and J. C. Gille and G. W. Sachse, *Geophys. Res. Lett.*, doi:10.1029/2005GL022995, 2005.

[9] Climate change and forest fire potential in Russian and Canadian boreal forests, B.J. Stocks and M.A. Fosberg and T.J. Lynham and L. Mearns and B.M. Wotton and Q. Yang and J-Z. Jin and K. Lawrence and G.R. Hartley and J.A. Mason and D.W. McKenney, *Clim. Change*, *38*, 1–13, 1998.