Atmospheric Environment 149 (2017) 55–69

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Use of tethersonde and aircraft profiles to study the impact of mesoscale and microscale meteorology on air quality

Gina M. Mazzuca [a, *], Kenneth E. Pickering [a, b], Richard D. Clark [c], Christopher P. Loughner [g, h], Alan Fried [e], Deborah C. Stein Zweers [d], Andrew J. Weinheimer [f], Russell R. Dickerson [a]

[a] Department of Atmospheric and Oceanic Science, University of Maryland, College Park, MD 20742, USA
[b] NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[c] Department of Earth Sciences, Millersville University, Millersville, PA 17551, USA
[d] KNMI-Royal Netherlands Meteorological Institute, De Bilt, The Netherlands
[e] Institute for Arctic & Alpine Research, The University of Colorado Boulder, CO 80309, USA
[f] National Center for Atmospheric Research, Boulder, CO 80307, USA
[g] Air Resources Laboratory, National Oceanic and Atmospheric Administration, College Park, MD 20740, USA
[h] Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD 20740, USA

HIGHLIGHTS

- Thermally direct circulations can strongly alter air quality near bodies of water.
- Large ozone concentration gradients could exist between water and its adjacent land.
- Bay/gulf breeze circulations of varying magnitudes have profound impacts on ozone.

ARTICLE INFO

Article history:
Received 2 June 2016
Received in revised form
10 October 2016
Accepted 14 October 2016
Available online 14 October 2016

Keywords:
Ozone
Bay breeze
Gulf breeze
DISCOVER-AQ campaign
Pollution

ABSTRACT

Highly-resolved vertical profiles of ozone and reactive nitrogen in the lower troposphere were obtained using Millersville University's tethered balloon system and NASA's P-3B aircraft during the July 2011 Baltimore, MD/Washington DC and the September 2013 Houston, TX deployments of the NASA DISCOVER-AQ air quality field mission. The tethered balloon and surface measurement sites were located at Edgewood, MD and Smith Point, TX. The balloon profiles are used to connect aircraft data from the lowest portion of NASA's P-3B spirals (300 m AGL) to the surface thus creating complete profiles from the surface to 3–5 km AGL. The highest concentrations of surface ozone at these coastal sites resulted from mean flow transport of polluted air over an adjacent body of water followed by advection back over land several hours later, due to a bay or gulf breeze. Several meteorological processes including horizontal advection, vertical mixing, thermally direct circulation (i.e., bay, gulf, and, sea breezes) combined with chemical processes like photochemical production and deposition played a role in the local ozone maxima. Several small-scale, but highly polluted layers from the Chesapeake Bay advected landward over Edgewood, MD. The Houston Metro area was subject to large-scale recirculation of emissions from petrochemical sources by the Gulf of Mexico and Galveston Bay breezes.

1. Introduction

Boundary-layer ozone is a secondary photochemical pollutant formed by a reaction mechanism involving nitrogen oxides ($NO_x = NO + NO_2$), volatile organic compounds (VOCs), carbon monoxide (CO), and sunlight (UV radiation). Since ozone is harmful to both the human respiratory system and the photosynthetic processes of vegetation, the United States Environmental Protection Agency (EPA) has implemented air quality standards for ozone as a criteria pollutant (Krupa and Manning, 1988; Burnett et al.,

* Corresponding author. Department of Atmospheric and Oceanic Science, University of Maryland, College Park, 4254 Stadium Dr., College Park, MD 20742-2425, USA.
E-mail address: gmazzuca@umd.edu (G.M. Mazzuca).

http://dx.doi.org/10.1016/j.atmosenv.2016.10.025
1352-2310/

1997). Surface ozone is regulated according to the current primary National Ambient Air Quality Standard (NAAQS) of 70 parts per billion by volume (ppbv), calculated as the daily maximum of an 8-h running mean.

The concentration of ozone at or near the surface is also contingent upon meteorological conditions such as the synoptic-scale circulation, boundary-layer height and turbulence, advection, incoming solar radiation, temperature, and humidity (Seaman and Michelson, 2000; Hegarty et al., 2007). Areas most commonly affected by high ozone concentrations are downwind of metropolitan centers. Additionally, coastal regions are frequently subject to poor air quality due to bay or sea breezes that can effectively recirculate pollution in the lower boundary layer (Banta et al., 2005; Loughner et al., 2011, 2014).

The same meteorological conditions that yield thermally direct circulations can also lead to ozone events in the right chemical regime: weak winds, warm temperatures, intense solar radiation, and subsidence inversions. Under these atmospheric conditions pollutants accumulate leading to ozone formation as well as allow these mesoscale circulations to compete with synoptic forcing. With pressure gradients in place, air near the surface moves from water to land during the day due to differential heating. The reversal of this occurs at night when the land cools much more quickly than water and causes a pressure gradient force in the opposite direction. This sequence forces early morning emissions over land to be transported over the adjacent body of water, and then re-circulated back to the land in the afternoon (Jacob, 2000; Wang et al., 2001).

Several studies have shown that sea, bay, and gulf breezes can contribute to poor air quality (Banta et al., 2005; Evtyugina et al., 2006; Darby et al., 2007; Loughner et al., 2011). The 2011 DISCOVER-AQ (Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality) campaign yielded data demonstrating the influence of the Chesapeake Bay breeze as it enhanced pollution inland of the coastline (Stauffer et al., 2015; Stauffer and Thompson, 2015; Loughner et al., 2014). During the July 2011 DISCOVER-AQ campaign, the 2008 8-h ozone standard of 75 ppbv was violated at Edgewood, MD on ten days, and a bay breeze was observed on eight of these days (Stauffer et al., 2015). Studies during the 2011 DISCOVER-AQ campaign showed that concentrations of surface ozone tended to be higher over the Chesapeake Bay than upwind land areas due to a shallower boundary layer, ship emissions, lower deposition rates, higher photolysis rates, and decreased boundary-layer venting due to a decrease in cloud cover compared to the nearby land (Goldberg et al., 2014).

Concentrations of background ozone in eastern Texas tend to be higher in late summer and early fall due to the synoptic circulations of northerly and easterly flow transporting continental high ozone air to the area. Higher background concentrations could contribute to the frequency and magnitude of ozone episodes (Langford et al., 2009). The Texas Commission on Environmental Quality (TCEQ) uses the background ozone concentration to estimate the local contribution of ozone as the difference between the 8-h maximum background ozone and the 8-h maximum measured ozone (Nielsen-Gammon et al., 2005). High ozone in the Houston area is often a result of small-scale circulations with advection of pollutants from the Houston Ship Channel to the southwestern part of the Houston Metro area (Ngan and Byun, 2011) and in many cases is the result of wind shifts in a postfrontal environment (Rappenglück et al., 2008). When a gulf or Galveston bay breeze sets up after these pollutants are advected over the water behind the front, the Houston Metro area can experience a second dose of pollution.

Studies performed in Houston, TX, showed that ozone episodes begin when the synoptic-scale winds transport pollutants from the land to water before a bay or gulf breeze sets up (Darby, 2005). As the bay or gulf breeze develops, pollutants are recirculated over the adjacent land adding to the pollution generated locally in these areas. Banta et al. (2005) discussed an ozone episode where the gulf/bay breeze contributed to surface hourly ozone concentrations of 200 ppbv.

Similarly in this paper, we focus on the effects of thermally direct circulations and local meteorology on air quality in Edgewood, MD and Smith Point, TX, as measured during DISCOVER-AQ.

2. The DISCOVER-AQ field project

It remains a challenge to accurately detect and resolve near-surface pollution with Earth observations from space (Liu et al., 2005; Fishman et al., 2008; Martin, 2008; Chatfield and Esswein, 2012). DISCOVER-AQ, a five-year NASA Earth Venture campaign, was designed to advance satellite observation capabilities by investigating the relationship between column-integrated trace gas quantities and pollution in the near-surface environment (http://discover-aq.larc.nasa.gov). Goals of DISCOVER-AQ include assessing uncertainties in column, surface trace gas, and aerosol observation correlations, characterizing the diurnal variation of the column and surface observations, and to investigate how much horizontal variability can be captured in satellite retrievals and model calculations. The P-3B aircraft provided profiling of meteorological, trace gas, and aerosol variables centered over surface air quality sites.

The ability to understand and predict air pollution events has been limited in part by the lack of vertical meteorological and chemical profile observations. With this unprecedented DISCOVER-AQ data set in terms of horizontal, vertical and temporal coverage, the spatial-temporal variability of air pollution can be better addressed.

2.1. P-3B aircraft measurements

NASA's P-3B aircraft typically spiraled over each ground site three to four times within an operational day at altitudes from 300 to >3000 m AGL, and did not measure air pollutants near the surface. However in some DISCOVER-AQ deployments, missed approaches were used to fill this gap between 300 m and the surface. In the Maryland deployment, the tethered balloon at Edgewood is used in this study. In the Houston deployment, the Millersville University tethered balloon was used at Smith Point. Onboard the P-3B there was continuous ozone, NO, NO_2, and NO_y measurements made using the National Center for Atmospheric Research (NCAR) 4-Channel Chemiluminescence Instrument with 1-s averages with 5% uncertainty for ozone and NO, 10% for NO_2, and 20% for NO_y. CH_2O measurements were made on the P-3B using the Difference Frequency Generation Absorption Spectrometer (DFGAS) with 30 s averaging and 13% uncertainty (Weibring et al., 2007).

Some differences were observed between the P-3B measurements and those of the tethersonde. These differences are likely due to the horizontal distance between the aircraft and the balloon along a convoluted coastline near the Edgewood site, and/or the timing between the flyover and the tethered balloon position. Based on inter-comparisons between the P-3B and the tethersonde, differences due to representativeness (timing and exact location) are likely greater than differences associated with instrument errors or operations. The timing between the flyover and when the tethered balloon reached the aircraft altitude was sometimes as different as 30 min.