Spring O_3 at Mount Washington Observatory: Implications for Stratospheric Intrusions

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1. Introduction

It is well known that tropospheric O_3 peaks in late spring in most remote regions of northern mid- and high-latitudes, which has been attributed to: (1) meteorological process: mass transfer from the stratosphere to the troposphere peaks in spring and; (2) photochemical activity after accumulation of O_3 and its precursors in winter and early spring. However, determining the relative contribution of chemical versus meteorological processes has been a research focus for over two decades.

The multi-year (2002-2006) record of O_3 observations at Mount Washington Observatory (MWO, 44.3N, 71.3W, 1910m asl) from the AIRMAP program at the University of New Hampshire provides an opportunity to examine the anthropogenic and stratospheric contributions to springtime O_3. In this work, we integrate the meteorological and chemical data to identify the synoptic conditions, which are favorable for stratospheric influence at MWO, and examine the frequency of stratospheric air masses affecting MWO among such synoptic conditions. Case studies of stratospheric intrusions at MWO are discussed here. We further quantify the contributions of stratosphere and photochemistry to O_3 in the Northeastern U.S. using a global 3-D chemistry transport model (CTM).

2. Objectives and Approach

(1)

To identify the weather conditions favorable for stratospheric influence at Mount Washington Observatory (MWO) ⇦ **Data analysis** — integrating meteorological and chemical data

- Map typing
- O_3-CO correlation

(2)

To quantify the relative contributions of the stratosphere and photochemistry to springtime O_3 in the Northeastern U.S. ⇦ **Model analysis (GEOS-Chem)**

- Annual cycle
- Synoptic-scale variability
- Vertical profile

GEOS-Chem model :

- Driven by NASA/GMAO assimilated meteorological data (GEOS4 2002)
- Horizontal resolution 2°x2.5°, 30 vertical levels
- Coupled ozone-NOx-CO-Hydrocarbons simulations
- Transport of O_3 from the stratosphere: Synoz method of McLinden et al. [2000]
- Extensive evaluation with U.S. observations for ozone [Fiore et al., 2002, 2003ab; Li et al., 2002]

3. Observations

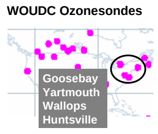
Chemical dataset (March-May, 2002-2006)

Mount Washington Observatory (MWO, 44.3N, 71.3W, 1910m asl)

- Representative of regional O_3 in lower free troposphere over the Northeast
- AIRMAP network: Hourly O_3, CO, NO_x, and NO_y observations

EPA AIRNOW (rural sites)

WOUDC Ozonesondes



Meteorological dataset

- NCEP global final analysis (1˚ lat x 1˚ lon)
- HYSPLIT transport and dispersion model (NOAA/ARL)
- Unisys surface maps
- Sounding observations from NOAA/NWS

9. References

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Fischer, E. V., R. W. Talbot, J. E. Dibb, J. L. Moody, and G. L. Murray (2004), Summertime ozone at Mount Washington: Meteorological controls at the highest peak in the northeast, *J. Geophys. Res.*, *109*, D24303, doi:10.1029/2004JD004841.

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Acknowledgements

Financial support for this work was provided through NOAA AIRMAP program. We thank Jack Dibb, Shannon Davis for helpful comments and Tod Hagan for technical support at University of New Hampshire. We thank Thomas M. Seidel for providing meteorological data at Mount Washington Observatory. We thank Rynda Hudman at Harvard University for help with model simulations. The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for the provision of the HYSPLIT transport and dispersion model and Mark Serreze from the Cooperative Institute for Research in Environmental Sciences at the University of Colorado for providing the storm track data. The Ozonesonde data are obtained from the World Ozone and Ultraviolet Data Center (WOUDC) at http://www.woudc.org/.

4. Major weather patterns in the Northeastern U.S.

Map typing approach

$$r_{xy} = \frac{\sum_{i=1}^{n}[(x_i-\bar{x})(y_i-\bar{y})]}{[\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2]^{1/2}}$$

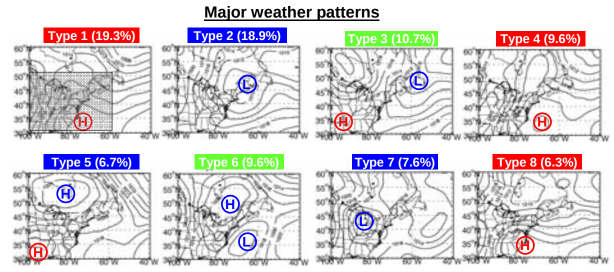
, Where ***x*** and ***y*** are corresponding pressures or heights on different maps at grid location ***i***, and ***n*** is the number of grid points per map.

[Lund, 1963; Hegarty et al., 2007]

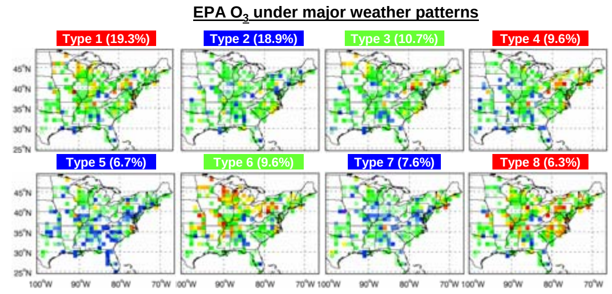
R=0.6; 8 major types, 72% classified; totally 23 types, 449/460 classified

- NCEP Global Final Analysis: daily 12UTC sea level pressure (1˚ lat x 1˚ lon)
- Time window: March 1st – May 31st during 2002-2006
- Geographical domain: [30N, 50N], [100W, 60W]

Major weather patterns



EPA O_3 under major weather patterns



Category 1, 4, 8: subtropical high → Northeast U.S.: southwesterly flow, high ozone

Category 2, 5, 7: cyclone, polar anticyclone → Northeast U.S.: cold frontal passage, northerly flow, low ozone

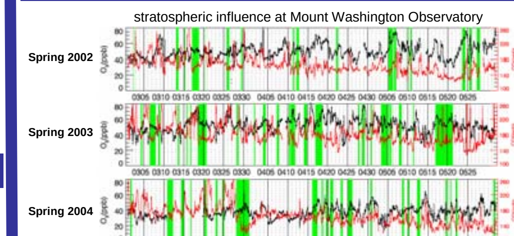
Category 3, 6: not clearly classified

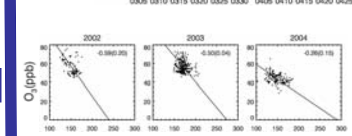
MWO O_3 (ppb):

36.7(1)	39.1(4)	39.8(8)
35.3(2)	35.5(5)	38.7(7)
38.4(3)	37.9(6)	

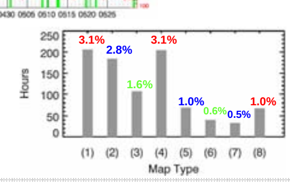
5. Stratospheric influence: favorable synoptic conditions

stratospheric influence at Mount Washington Observatory





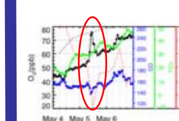
As compared to the O_3-CO slope of: -1.4 (mid-troposphere) and -2.5(upper troposphere) in dry air masses during NARE aircraft campaign [Cooper et al.,2004]



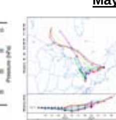
Dry events at Mount Washington Observatory, an indicator of stratospheric influence, occur more often under the dominance of southwesterly flow around subtropical anticyclone, which are also favorable for photochemical production.

6. Case studies: stratospheric influence

May 5, 2002

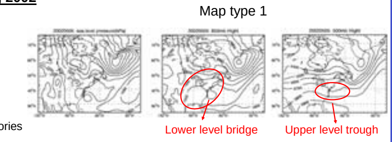


O_3-CO negatively correlated (slope=-0.88, r^2=0.36)

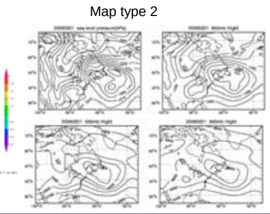


May 5, 2002, back trajectories every 3 hours

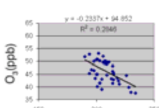
Map type 1



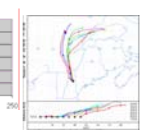
Map type 2

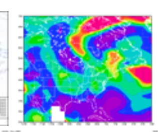


Mar 21, 2006



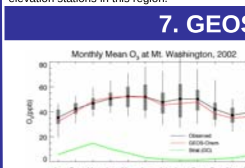
O_3-CO slopes are -0.13 (r^2=0.27) at Castle Spring and -0.09(r^2=0.29) at Thompson Farm, two low elevation stations in this region.



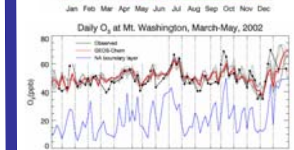


IPV on 12UTC Mar. 21, 2006

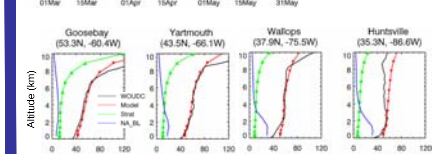
7. GEOS-Chem model simulations



- GEOS-Chem reproduces the observed seasonal cycle of O_3 at MWO: broad maximum from April to September
- Stratospheric O_3 accounts for 25% of total modeled O_3 in Feb.-Apr.

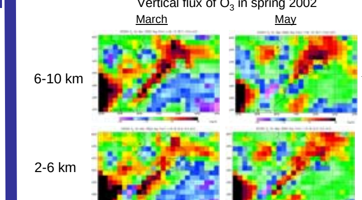


- GEOS-Chem reproduces the observed synoptic scale O_3 variability at MWO, as driven by pollution events
- North American boundary layer: major contributor to total modeled O_3 in spring: 43% (all days)
  51% (model daily O_3 > 50 ppb)
  62% (model daily O_3 > 55 ppb)



GEOS-Chem reproduces the vertical profiles of O_3 in eastern U.S. In the model, stratosphere contributes more to total simulated O_3 above 3-4km, while photochemistry from North American boundary layer more below 3-4 km.

Vertical flux of O_3 in spring 2002



Consistent with the storm tracks

8. Conclusions

- A correlation-based classification algorithm (map typing method) was used to identify the major synoptic-scale patterns modulating the spatial and temporal variations of springtime O_3 in the lower troposphere in the Northeastern U.S. The major factor driving high O_3 episodes in Northeast U.S. in spring is subtropical anticyclone.
- By integrating the meteorological and chemical data, we estimate that dry events at Mount Washington Observatory (MWO), an indicator of stratospheric influence, occur more often (2/3 of them, with a frequency of 8% of springtime) under the dominance of southwesterly flow to the Northeast under the subtropical anticyclone, a synoptic pattern which are also favorable for photochemical production. Only 1/3 of these events (occurrence frequency of 5%) are associated with northerly flow associated with air mass sinking behind a cold front.
- The model reproduces the observed seasonal cycle, day-to-day variability of spring O_3 at MWO, and the vertical O_3 profiles determined from ozonesondes in eastern U.S. in spring. Stratospheric O_3 accounts for 25% of total simulated O_3 in Feb.-Apr. Photochemical production in the North American boundary layer is a major component of total simulated O_3 in spring (50-60% in high O_3 episodes).