Surface Ozone Differences Between Appledore Island and Thompson Farm: Local-Scale vs. Synoptic Scale

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Sea breeze | Appalachian Lee Trough | Post-frontal flow

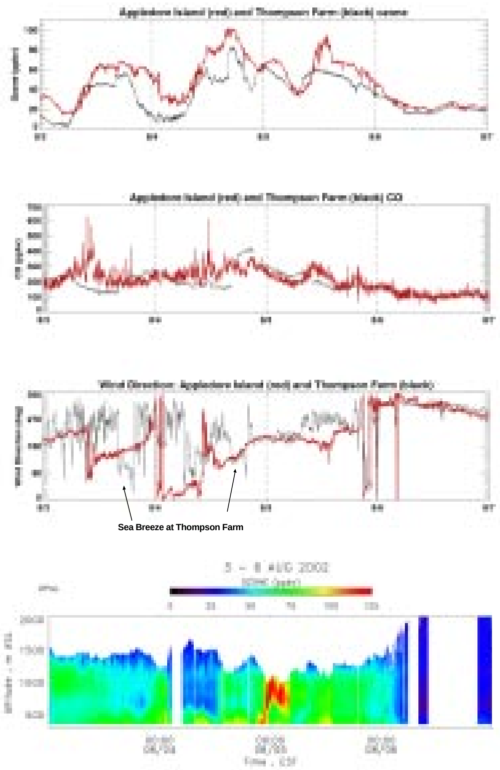

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Fig. 3: Time series for 3 – 6 Aug. 2002. In all line plots, red is Appledore Island and black is Thompson Farm. From top to bottom: Ozone, Carbon Monoxide, Wind Direction, Ozone profiles from the Ron Brown. The color bar above the ozone profiles represents ozone in ppbv. All times are LST.

Introduction

During the New England Air Quality Study (NEAQS) 2002, the surface ozone observation network included stations at Thompson Farm (TF), near Durham, NH, and Appledore Island (AI), just off the coast of NH (Fig. 1). The stations were only ~30 km apart, yet the differences in the ozone measured at the two sites could be as low as 5 ppbv or as high as 50 ppbv. This study focuses on meteorological processes that contribute to the ozone differences at the two sites, particularly during the afternoon hours.

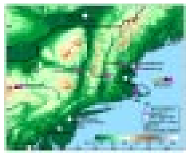


Fig. 1: Map showing locations of instrumented sites for NEAQS (courtesy of Allen White, ETL).

Sea Breeze

3 Aug
_Stationary front hugging the New England coast (Fig. 2)
_TF and AI in two different air masses

_Appeldore Island
East of the stationary front
Southerly component winds
CO measurements > 200 ppbv
Transport of pollutants from the Boston area
Higher ozone than at TF (Fig. 3)

_Thompson Farm
West of the stationary front
Westerly flow
1600 LST, the sea breeze reached TF, as indicated by the wind shift from westerly to southeasterly
Coincident rise in ozone and CO (see Fig. 3)

_Sea breeze negated the separation effect of the stationary front

_Intrusion of marine air reduced the difference in ozone between the two sites (Fig. 3)

Fig. 2: Synoptic weather map for 1800 UTC (1300 LST), 3 Aug. 2002.

Sea Breeze

4 Aug
_Appalachian Lee Trough formed in the afternoon (Fig. 4)
_Sea breeze played a similar role as on Aug. 3
_During sea breeze period at Appledore Island
CO concentrations consistently above 200 ppbv
Southerly-component winds
Transport of pollutants from Boston
Higher ozone than at TF(Fig. 3)
_At1600 LST, the sea breeze front reached TF
Ozone increased by more than 20 ppbv; CO concentrations also increased
_Intrusion of marine air reduced the difference in ozone between the two sites (Fig. 3)

_Ozone profiles: reservoir of ozone to the southeast of the New Hampshire coast available for advection to both sites (Fig. 3).

Fig. 4: Synoptic weather map for 1800 UTC (1300 LST), 4 Aug. 2002.

For both of the sea breeze days, it appears that pollutants were transported to northern coastal regions by large-scale southerly-component winds. The sea breeze then acted to 'nudge' the pollutants toward the coast, further enhancing pollution levels at Appledore Island, and later, at Thompson Farm. Figure 5 shows a conceptual model of this.

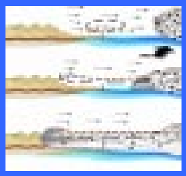


Fig. 5: Conceptual model of transport of pollution inland by the sea breeze (Graphics by Robert Banta and Al Romero).

Wind profiler SNR indicates that afternoon small-scale mixing is suppressed in the marine environment (bottom) relative to the continental environment (top).

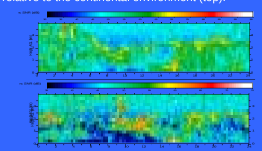


Fig. 6: Signal-to-noise ratio (SNR) for two 915-MHz radar wind profilers. Top is Concord, N.H. and bottom is Appledore Island.

Appalachian Lee Trough

5 Aug
_Appalachian Lee Trough
_Dynamically-driven
Extends NNE to SSW along the east coast
Mechanism for long-range transport
_5 Aug. 2002 is an excellent example of this meteorological feature, (Fig. 7)

_Ozone profiles: reservoir of ozone to the southeast of the New Hampshire coast available for advection to both sites (Fig. 3).

Fig. 7: Synoptic weather map for 1800 UTC (1300 LST), 5 Aug. 2002.

_Appledore Island
East of trough axis
Southerly flow and CO > 200 ppbv
Significantly higher ozone than at TF (1100 and 1500 LST)
Indicates transport of pollution from Boston
_Thompson Farm
West of trough axis
Westerly flow kept ozone relatively low (Fig. 3)
No sea breeze to transport ozone inland

The position of the Appalachian Lee Trough axis affected wind direction and long-range transport for each site. The station within the southwest flow, AI, had enhanced ozone concentrations, while TF, behind the trough axis, had westerly flow and lower ozone concentrations.

Post-frontal flow

6 Aug
_Cold front passage before midnight (LST) of 6 Aug (Fig. 8)
_Large-scale northwesterly flow to New England
_Nice contrast to 3 – 5 Aug.
_Transport of pollution from south shut down by NW winds
_No sea breeze
_Uniform winds, ozone, and CO at both TF and AI
_Ozone and CO were lower than the previous 3 days

After the cold front passage, when large-scale winds dominated, northwest winds from a region with fewer emissions lowered the CO and ozone at both the TF and AI sites.

Fig. 8: Synoptic weather map for 1800 UTC (1300 LST), 6 Aug. 2002.

How did MM5 and WRF-Chem perform over this time period?

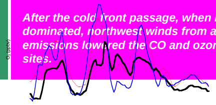
3 Aug Fig. 9a
_Both models were several hours late in predicting the sea breeze at the shore (but, two hours early when compared to TF)
_Timing difference is probably a function of the 27-km grid spacing

4 Aug Fig. 9b
_Structure of the sea-breeze flow at 1200 LST and later was fairly well-simulated
_Better job of simulating the winds above 500 m.

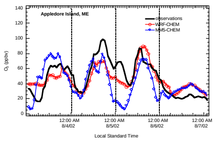
5 Aug Fig. 9c
_Better model performance early in the morning
_Both models missed the low-level westerly flow after 1000 LST
_ MM5 winds too southerly during day

6 Aug Fig. 9d
_Both models - fairly good job of predicting the wind direction for 6 Aug.
_MM5 overpredicted wind speeds

Fig. 9: Wind profiles from a Doppler lidar stationed at the coast of New Hampshire (top), WRF-Chem output (middle), and MM5 output (bottom). Doppler lidar data has been binned to match the heights of the WRF-Chem model. Only model times and heights with corresponding Doppler lidar data are shown. Long barbs are 10 m/s, short barbs are 5 m/s.



Ozone forecast results



3 Aug *During the day…*
_ WRF-Chem underpredicted the ozone
_ MM5 overpredicted the ozone
_ Missed timing of the Sea-breeze flow may play a role
_ Something other than poor wind forecast at play (e.g., MM5 has northerly flow and overpredicted ozone: northerly flow should have lower ozone)

4 Aug *During the day…*
_ WRF-Chem and MM5 underpredicted the ozone
_ Ozone forecast worse than anticipated given that the wind forecasts were fairly good on this day

5 Aug *During the day…*
_ WRF-Chem was in agreement with obs for many hours, but overpredicted ozone for a few hours
_ MM5 underpredicted the ozone
_ MM5 winds too southerly, probably not transporting the Boston plume

6 Aug *During the day…*
_ WRF-Chem and MM5 overpredicted the ozone, but
_ Captured drop in ozone associated with the front passage

The Doppler lidar/model wind profile comparisons reveal problems in the models that will impact the accuracy of the ozone forecasts. However, even when the winds do well, there are other model issues that affect ozone forecasts. Boundary layer height is one of the more important issues under investigation.

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