

INTRODUCTION

- Among the fundamental aims of the North Atlantic Regional Experiment (NARE) are:
 - to determine the relative importance of natural and anthropogenic ozone (O_3) sources
 - to quantify the principal mechanisms for the transport of O_3 and its precursors from the continental boundary layer to the remote marine troposphere
- An important natural process that contributes to the budget and variability of tropospheric O_3 is stratosphere-troposphere exchange (STE)
- One possible agent for STE is the cut-off low, a number of which were encountered during the 1996 NARE intensive
- Cut-off lows are also venues for the export of continental boundary layer air to the free troposphere
- A case study is presented here in which the NOAA Aeronomy Laboratory three-dimensional regional air quality model is used in an attempt to elucidate signatures of STE and mixing of anthropogenically- and stratospherically-influenced air that were observed in association with a cut-off low during a flight of the NOAA WP-3 Orion on March 20, 1996

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- The study is a tracer study, using both O_3 and carbon monoxide (CO)

- Results from two different horizontal grid resolutions for the model are presented, to demonstrate the effect of each on reproducing the aircraft measurements
- The relationships between O_3 and CO are examined, to amass an indication of air-mass mixing
- Model results are additionally compared with ozonesonde measurements, to further quantify the model's ability

SYNOPTIC SITUATION

- During the second half of March 1996, the synoptic situation over the extratropical North Atlantic was dominated by upper-level pressure anomalies and intense surface fronts
- On March 20, 1996 the prominent feature was a developing trough over the North Atlantic, whose base was located over Pennsylvania at 1200 UTC and which had by that time developed a cut-off circulation

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RESULTS AND DISCUSSION

Figure 2

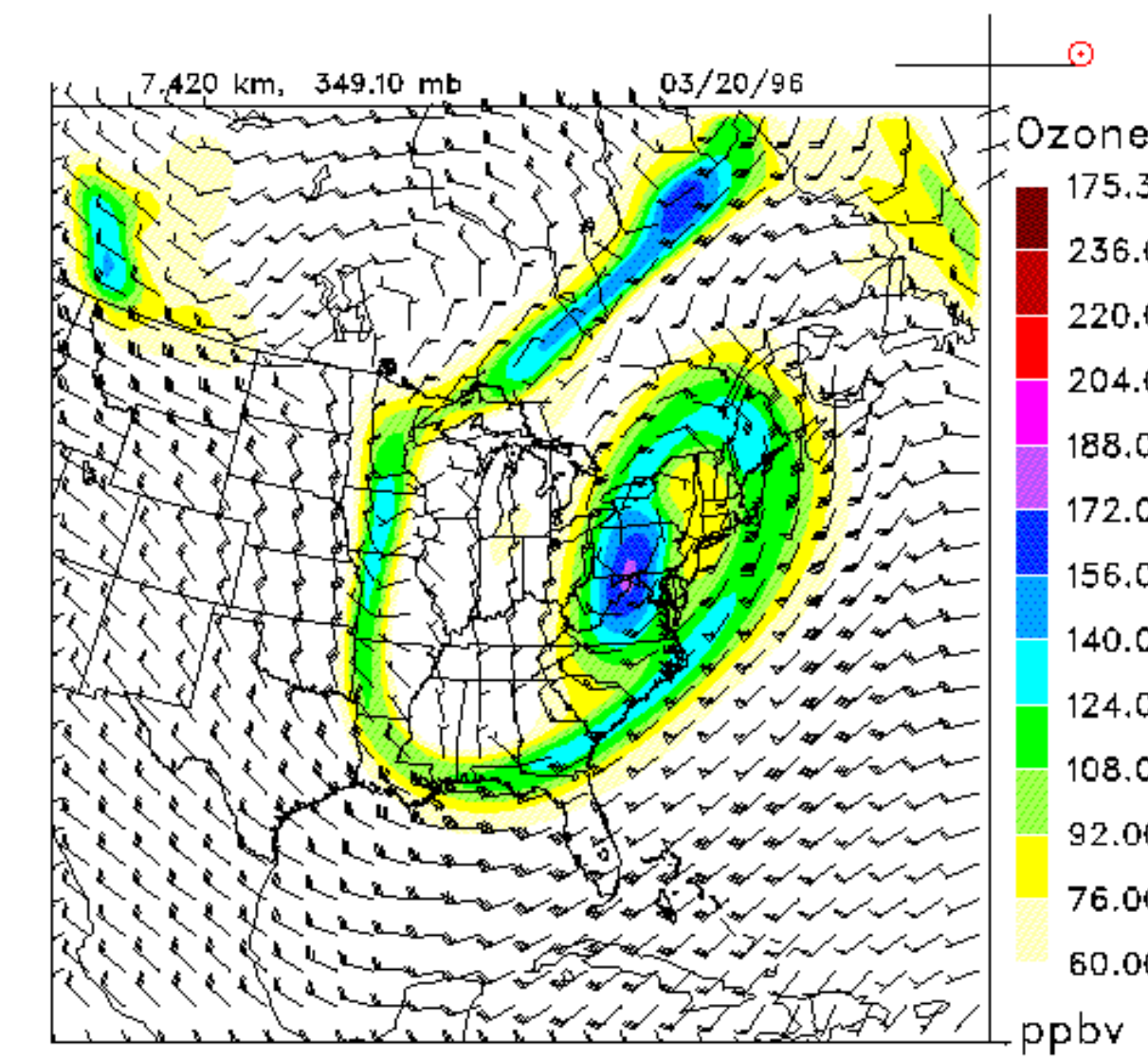


Figure 2: Horizontal distribution of O_3 , in parts per billion by volume (ppbv), produced by the NOAA Aeronomy Laboratory three-dimensional regional air quality model at 7.4 km (349 mb) and at 2230 UTC on March 20, 1996. The horizontal grid resolution is 60km x 60km.

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Figure 3

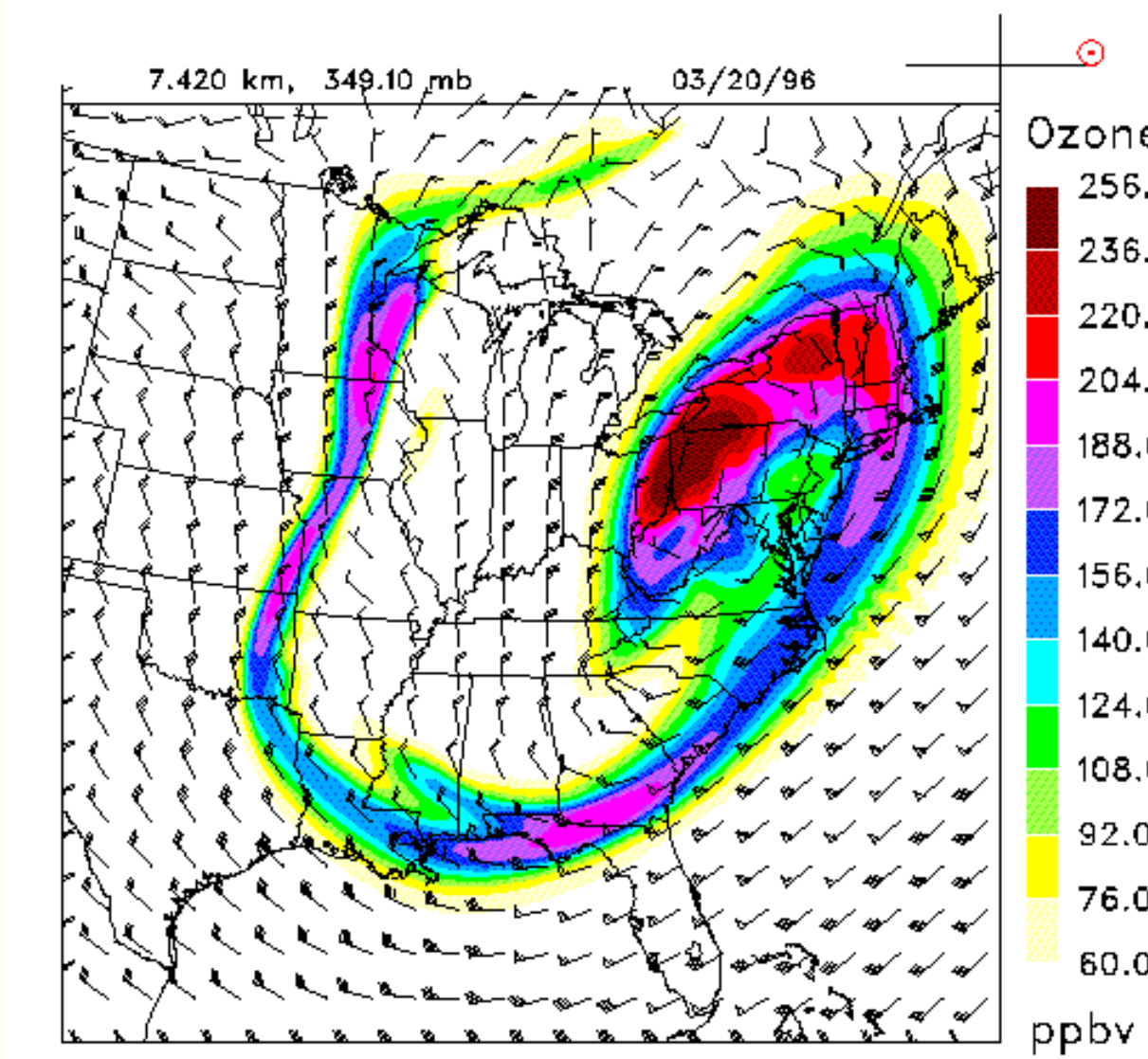


Figure 3: Horizontal distribution of O_3 , in parts per billion by volume (ppbv), produced by the NOAA Aeronomy Laboratory three-dimensional regional air quality model at 7.4 km (349 mb) and at 2230 UTC on March 20, 1996. The horizontal grid resolution is 20km x 20km.

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Figures 2 and 3

- The distribution of O_3 in each of figures 2 and 3 spirals around the cut-off low that existed on March 20, 1996
- For figures 2 and 3, the maximum values of O_3 are 175 ppbv and 256 ppbv, respectively
- Qualitatively, figures 2 and 3 indicate that changing the horizontal grid resolution does not have a large effect
- Quantitatively, the maximum value of O_3 for a horizontal grid resolution of 20 km x 20 km is almost half as much again as that for a horizontal grid resolution of 60 km x 60 km
- To investigate whether O_3 is higher at other altitudes for a horizontal grid resolution of 20 km x 20 km than of 60 km x 60 km, figure 4 was plotted for all twenty-three of the vertical model levels

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Figure 4

- As defined by the boundary conditions, the average values of O_3 at the highest vertical model level are the same for the two different horizontal grid resolutions
- With decreasing altitude, for the third to the ninth vertical model levels the average O_3 value for a horizontal grid resolution of 20 km x 20 km is higher than that for a horizontal grid resolution of 60 km x 60 km. For the remaining lower-altitude vertical model levels, the average O_3 values for the two horizontal grid resolutions are almost the same
- A possible reason for the higher O_3 values for the 20 km x 20 km horizontal grid resolution is that with finer horizontal grid resolution, the magnitude of the vertical wind component increases significantly, as calculated by MMS. The extent of vertical transport in the model is thereby increased. A second reason could be the influence of the boundary conditions
- It should also be noted that the initially-defined correlation between O_3 and PV in the model deteriorates much more rapidly with decreasing height for the 20 km x 20 km horizontal grid resolution than the 60 km x 60 km

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Figure 4

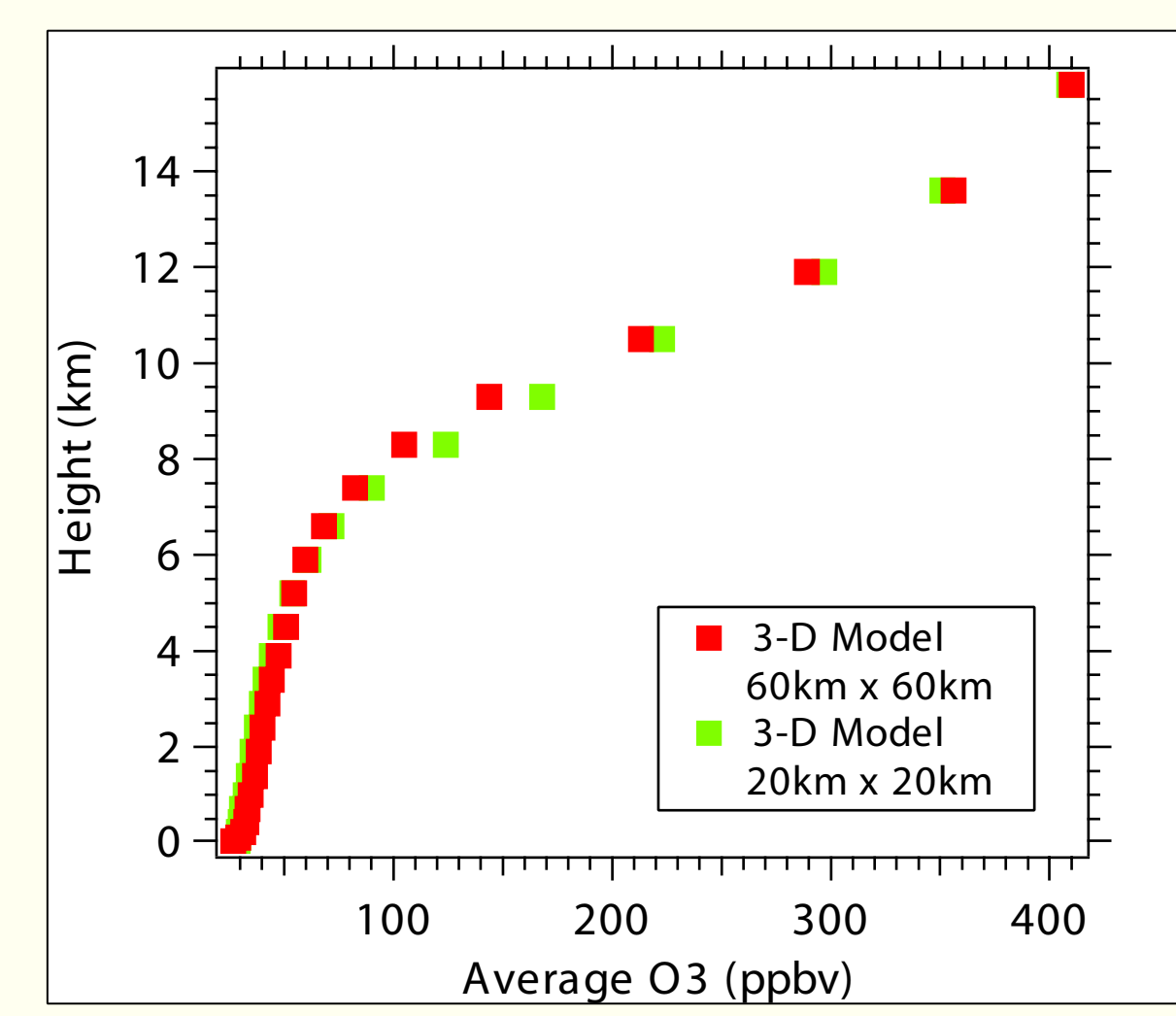


Figure 4: Correlations of altitude (km) versus O_3 (ppbv) produced by the NOAA Aeronomy Laboratory three-dimensional regional air quality model at 2230 UTC on March 20, 1996. Each red circle represents the value of O_3 , at a given vertical model level, averaged over the area between latitudes 30°N and 50°N and longitudes 70°W and 90°W, for a horizontal grid resolution of 60km x 60km. Similarly for each green circle, except that the horizontal grid resolution is 20km x 20km.

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Figure 5

- On comparing figures 5(a) and 5(b), an anti-correlation between O_3 and CO is apparent
- The values of O_3 and CO generally increase and decrease, respectively, with increasing aircraft altitude
- Figures 5(a) and 5(b) demonstrate that, overall, the model represents the aircraft observations reasonably well for both O_3 and CO
- The aircraft observations indicate STE encounters between 2015 UTC and 2045 UTC and between 2215 UTC and 2245 UTC, as the aircraft peaked in altitude both times during the flight
- From figures 5(a) and 5(b), the model represents the first of the STE encounters well, especially for the 20 km x 20 km horizontal grid resolution.

- For the second STE encounter, the model does less well: the encounter is captured but not to its full extent. Again the results for the 20 km x 20 km horizontal grid resolution are more favorable than those for the 60 km x 60 km horizontal grid resolution

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Figure 5

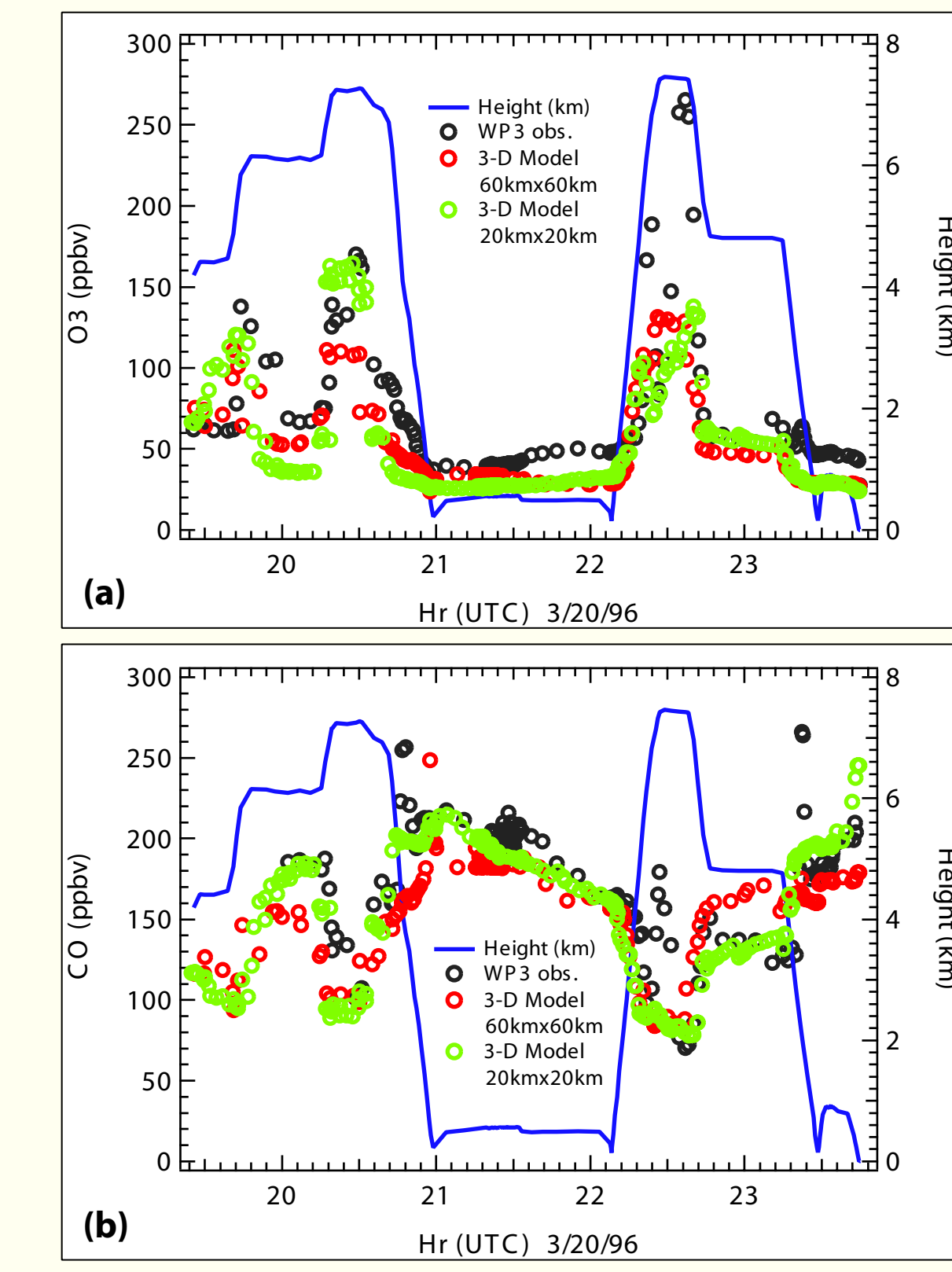


Figure 5: Time series, in UTC, of (a) O_3 (ppbv) and (b) CO (ppbv) on March 20, 1996. The blue line represents the altitude, in km, of the NOAA WP-3 Orion aircraft; the black circles are the aircraft observations, averaged over the model grid cells; and the red and green circles are the results, for horizontal grid resolutions of 60km x 60km and 20 km x 20 km, respectively, from the NOAA Aeronomy Laboratory three-dimensional regional air quality model. The blue line is to be read with the right vertical axis, while the different-colored circles are to be read with the left.

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AIRCRAFT DATA

- Name: NOAA WP-3 Orion
- Flight path: Tampa, FL to Providence, RI
- Flight times: ~1900 UTC to 2400 UTC
- Average flight speed: ~100 m/s
- Maximum altitude reached: 7.5 km above sea level
- O_3 measurement: NO chemiluminescence instrument with 1 s temporal resolution
- CO measurement: vacuum UV fluorescence instrument with 1 s temporal resolution

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MODEL DESCRIPTION

- Name: NOAA Aeronomy Laboratory three-dimensional regional air quality model
- Meteorological input source: Penn State/National Center for Atmospheric Research (NCAR) mesoscale model system, MMS
- Emissions input source: National Acid Precitation Assessment Program (NAPAP)
- Initial conditions source: NOAA WP-3 Orion aircraft data
- O_3 boundary conditions: corrected by potential vorticity (PV)
- CO boundary conditions: corrected by a stratospheric, O_3 -dependent source
- Advection algorithm: Leonard upstream finite-difference
- Horizontal grid resolution: 60km x 60km and 20km x 20km, in turn
- Vertical grid resolution: 23 unevenly-spaced levels
- Pressure at top of model domain: 50 mb

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Figure 1

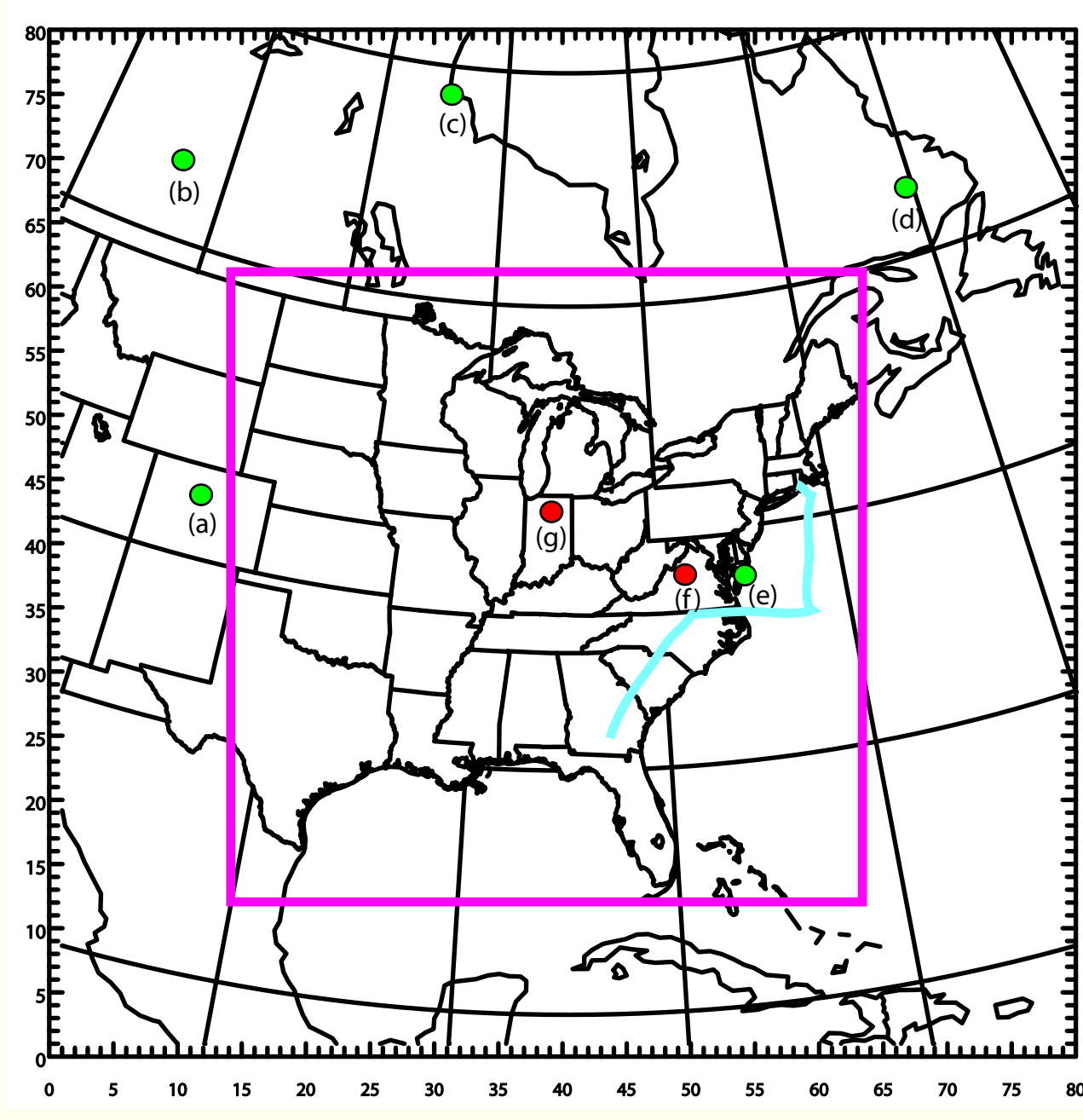


Figure 1: NOAA Aeronomy Laboratory three-dimensional regional air quality model domain used in the March 20, 1996 NARE case study with 60km x 60km horizontal grid resolution. The numbers along the axes refer to the number of grid cells, counted from the bottom left-hand corner; the magenta box indicates the reduced domain employed with 20km x 20km horizontal grid resolution; the blue line traces the flight path; and the colored circles represent ozonesonde stations. Green circles denote sites of weekly- or semi-weekly-launched ozonesondes, whereas red circles denote sites where ozonesondes were launched only for the duration of the 1996 Atmosphere/Ocean Chemistry Experiment (AEROCE). The names of the indicated ozonesonde sites are as follows: (a) Boulder, (b) Edmonton, (c) Churchill, (d) Goosebay, (e) Wallops Island, (f) Charlottesville, and (g) Indianapolis.

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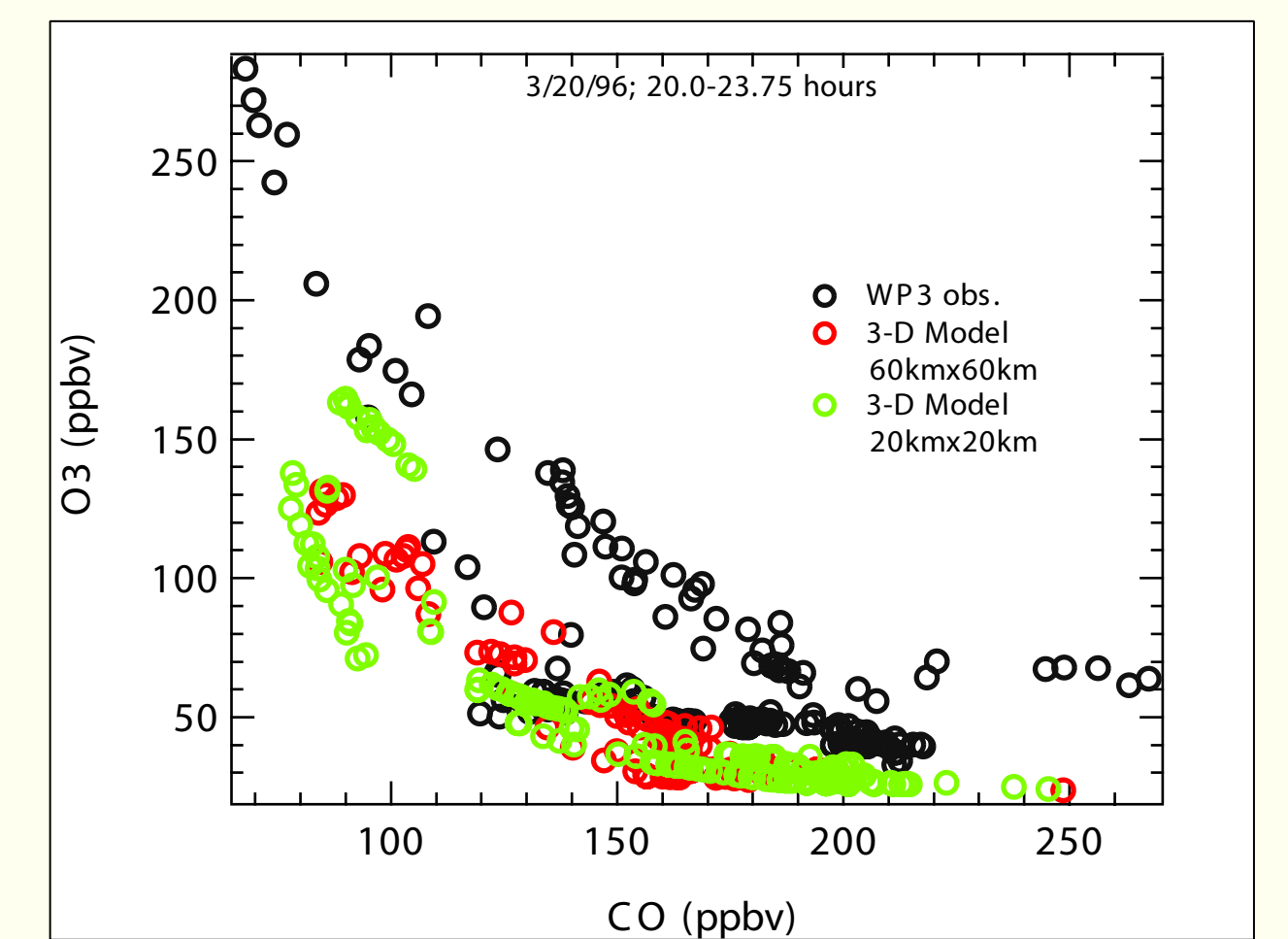
Figure 6

- Considering background levels of O_3 and CO to be around 40 ppbv and 120 ppbv, respectively, the aircraft and model data in figure 6 suggest an extent of mixing of two types of air masses:
 - anthropogenically-influenced (CO increasing)
 - stratospherically-influenced (O_3 increasing and CO decreasing)
- Mixing of stratospherically-influenced air takes place to a lesser extent in the model than the aircraft data, in accordance with figures 5(a) and 5(b)

Figure 6: Correlations of O_3 (ppbv) vs CO (ppbv) on March 20, 1996, between 2000 UTC and 2375 UTC. As for figure 5, the black circles are the NOAA WP-3 Orion aircraft observations, averaged over the model grid cells; and the red and green circles are the results, for horizontal grid resolutions of 60km x 60km and 20 km x 20 km, respectively, from the NOAA Aeronomy Laboratory three-dimensional regional air quality model

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Figure 6



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Figure 7

- The agreement between the model and ozonesonde data associated with a cut-off low that occurred during a NARE flight of the NOAA WP-3 Orion aircraft on March 20, 1996

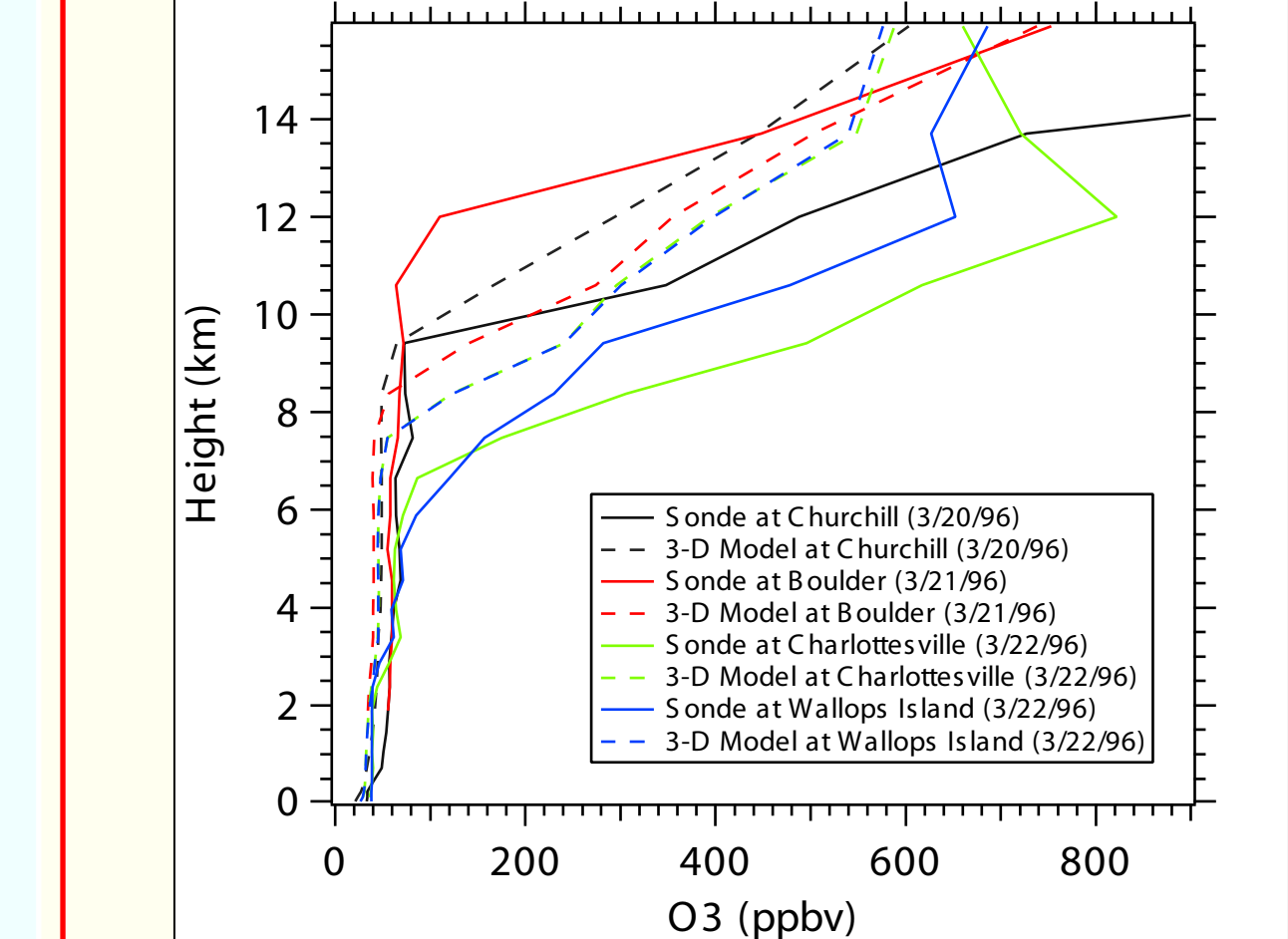


Figure 7: Correlations of altitude (km) versus O_3 (ppbv) above four ozonesonde stations. The solid lines represent the ozonesonde data, and the dashed lines data produced by the NOAA Aeronomy Laboratory three-dimensional regional air quality model with a horizontal grid resolution of 60km x 60km.

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CONCLUSIONS

- A case study has been presented here of the O_3 transport associated with a cut-off low that occurred during a NARE flight of the NOAA WP-3 Orion aircraft on March 20, 1996
- The NOAA Aeronomy Laboratory three-dimensional regional air quality model was employed with two different horizontal grid resolutions, namely 60 km x 60 km and 20 km x 20 km, and at higher altitudes the latter was found to produce significantly higher O_3 values than the former. Possible reasons include increased vertical transport rates and boundary condition effects
- Overall, the model provides a reasonable representation of the NOAA WP-3 Orion aircraft observations of O_3 and CO, and captures the aircraft-recorded STE encounters, the 20 km x 20 km horizontal grid resolution providing closer agreements than the 60 km x 60 km
- Both aircraft and model data suggest mixing of anthropogenically- and stratospherically-influenced air, though less so for the model than the aircraft data
- The model also compares fairly well with ozonesonde data at lower altitudes

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