The sensitivity of simulations of air pollution events at Cape Grim to the modelled meteorology

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(Manuscript received February 2003; revised November 2003)

Pollution originating from Melbourne is commonly observed at Cape Grim Baseline Air Pollution Station (northwestern Tasmania) in isolated events. These pollution events are known to advect to Cape Grim in the pre-frontal air masses with the surface concentrations being sensitive to the frontal dynamics. These pollution events are also observed to undergo a strong annual cycle with peak concentrations present over the winter. Numerical simulations of these pollution events have been made in an effort to examine their sensitivity to the simulation of the underlying frontal dynamics. A relatively primitive set of simulations is made in which the meteorology is nudged to a uniform background state, which effectively weakens the strength of the front. These simulations are found to diffuse the Melbourne plume and actually enhance the simulated concentrations over the summer months. During the winter, the pollution plume is found to be far enough ahead of the front so that it is only weakly sensitive to the frontal passage. More advanced simulations in which the front is not artificially diffused are found to be more accurate in simulating the annual cycle of pollution events. These simulations suggest that pollution events are not commonly observed at Cape Grim over the summer due to the seasonality of the fronts. The summertime front, while more intense, is often not sustained long enough for pollution to reach Cape Grim. Even when the pre-frontal advection is sufficiently maintained during the summer, the simulations suggest that pollution events reach Tasmania to the east of Cape Grim.

Introduction

Observations of atmospheric composition from the Cape Grim Baseline Air Pollution Station (CGBAPS) provide an ideal record for testing regional air pollution models for southeastern Australia. The greater Melbourne region, located approximately 300 km to the north, is the single dominant source of many chemical species. Bass Strait lies between any such emissions and Cape Grim and ensures that there are

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no intermediate sources to confuse observations. Moreover, emissions commonly arrive at CGBAPS as clear, isolated events due to the local meteorology. The duration of these pollution events is typically on the order of hours, and the time between them is on the order of days, which allows them to be readily defined.

A number of recent papers have taken advantage of this unique meteorology and the quality of the CGBAPS record. Tory et al. (2004) used the carbon monoxide (CO) records from Cape Grim to examine the accuracy of the Australian Air Quality Forecasting System (AAQFS). Similarly, both Dunse (2002) and Cox et al. (2000) used these CGBAPS CO records while employing The Air Pollution Model (TAPM, Hurley (1999)). In these studies, CO emissions from the greater Melbourne region, provided by the Environmental Protection Authority of Victoria (1998, 1999), were used to initialise the numerical models. The models simulated the evolution of the CO as the air flowed over Bass Strait to Cape Grim. Given the confidence in the emissions inventory, it was possible to directly compare the simulated concentrations to observations for individual pollution events.

For any given pollution event, however, it’s not possible to isolate and quantify the error due strictly to the underlying simulation of the meteorology. Moreover, it is not uncommon for relatively small errors in the meteorology to lead to ‘absolute errors’ in the simulated concentrations arriving at Cape Grim; i.e. a simulated pollution event might simply miss Cape Grim at a time when pollution is being observed or vice versa.

Over long periods of time, however, one might hope that errors in the meteorological trajectory are unbiased and will average out in some sense. Thus the cumulative concentrations for simulations and observations would be similar, further assuming that there was no significant error in the chemical transport. These cumulative concentrations could then ideally be used to estimate or verify the strength and location of emissions. Cox et al. (2003a) undertook this exercise over the period of one year for dichloromethane and suggested that the estimated regional sources were roughly a factor of two too low. Central to this work was the assumption that any meteorological errors were unbiased and thus averaged out over time. This paper examines the sensitivity of year-long cumulative concentrations to the simulation of the underlying meteorology as defined by the boundary conditions. We find that a more primitive choice of boundary conditions leads not only to a weaker immediate simulation of the meteorology, but also a systematic error in the cumulative concentration distribution over the course of a year. Two case studies, a winter and a summer, are then presented to provide insight into how this systemic bias comes about.

Meteorology

The Cape Grim Baseline Air Pollution Station is located at the northwest tip of Tasmania (40°41'S, 144°41'E) with Bass Strait and the Australian mainland lying to the north and the Southern Ocean to the west (Fig. 1). The Australian Bureau of Meteorology and CSIRO Atmospheric Research (CAR) jointly run the facility in liaison with the Global Atmosphere Watch program of the World Meteorological Organization. The primary purpose of CGBAPS is to monitor background, or ‘baseline’, air that has been travelling over the Southern Ocean and is thus free of anthropogenic influence for periods of days to weeks. CGBAPS also maintains records of common air pollutants, which allows the station to serve in assessing the regional air quality. Carbon monoxide, the species used in this study, has been measured at CGBAPS since 1993 as part of the Advanced Global Atmospheric Gas Experiment (AGAGE) project (Langenfelds et al. 2001). CO measurements are obtained every 40 minutes from air samples taken alternately at 10 m and 70 m altitudes. These CO concentrations are reported in ppb, which is defined as the mixing ratio in units of nmol/mol.

Lying in the mid-latitudes of the southern hemisphere, the meteorology of CGBAPS is dominated by the procession of mid-latitude cyclones and anticyclones. The cores of the cyclones normally lie to the south of Tasmania with cold fronts extending north towards the equator, sometimes extending deep into the Australian continent (Reeder et al. 2000.) Ideally, one would envision these fronts to be sharp boundaries between two air masses in the free troposphere; immediately before the passage of the front, the warm prefrontal air mass has a northerly or northwesterly origin and the clean, postfrontal air mass has a southwesterly, or baseline, origin. It is under these prefrontal conditions that pollution from Melbourne is normally delivered to Cape Grim. The prefrontal air mass is a classic example of warm air advection as the warm continental air flows poleward. Typically as the air flows over colder water, the boundary layer will become stably stratified and form numerous internal stable layers (Garratt 1988; Russell et al. 1998.) In winter, the passage of fronts is quite common, on average about twice a week. In summer, the mid-latitude cyclones and fronts are normally pushed further poleward and frontal passages are less frequent over Cape Grim.

Fig 1 A map of southeastern Australia and Tasmania, showing the location of the Cape Grim Baseline Air Pollution Station (CGBAPS).

Numerical simulations

A PC-based, three-dimensional, prognostic model (TAPM, Hurley (1999)) has been used to simulate the transport and evolution of the carbon monoxide released in the greater Melbourne area. The outer domain for TAPM is nested within an archive of analyses from the Australian Bureau of Meteorology's LAPS model (Puri et al. 1998), which provides the initial meteorological conditions for TAPM. The TAPM model is weakly relaxed or 'nudged' towards the LAPS analyses at subsequent time steps. TAPM predicts the mesoscale flows important to local and regional air pollution studies, as well as the concentration of pollutants at ground level.

The meteorological component of the model solves the incompressible, non-hydrostatic, primitive equations with a terrain-following vertical coordinate. The model solves the momentum equations for horizontal wind components, the incompressible continuity equation for vertical velocity, and scalar equations for potential virtual temperature and specific humidity of water vapour, cloud water and rain water. Terrain height data are taken from a United States Geological Survey 30-second resolution dataset (approximately 0.9 km), supplied by the Australian Land Information Group. A vegetative canopy and soil scheme is used at the surface, while radiation both at the surface and at upper levels is also included. CSIRO Wildlife and Ecology provided vegetation and soil type data on a longitude/latitude grid at three-minute spacing (approximately 5 km), while the US National Center for Atmospheric Research supplied sea surface temperature data.

For this work simulations were configured with a 100×100 outer grid of 10 km horizontal resolution, centred at 39°25′S and 144°46′E in Bass Strait. A 100×100 nested inner grid of 5 km horizontal resolution, that encompasses northern Tasmania and southern Victoria, was also centred at the same location. TAPM was run with 20 levels in the vertical with the lowest five layers ranging from approximately 5 to 200 m. The LAPS analysis was defined at 0.75° resolution to provide the base meteorology from which the prognostic meteorology was determined.

As with many of the previous studies, carbon monoxide has been chosen for this work. Its properties are well understood, its regional source is well established and its observations at Cape Grim are readily available. Given that the lifetime of CO is far in excess of 10 days (Holloway et al. 2000) and that the transit time from Melbourne to Cape Grim is less than a day (Cox et al. 2003b), CO is effectively a passive tracer for our purposes. The Environmental Protection Authority (EPA) of Victoria has been monitoring air quality and the concentrations of atmospheric pollutants around the greater Melbourne region for over 20 years (Environmental Protection Authority 2000). As the single greatest source of CO is motor vehicle emissions, a high level of confidence is placed in the inventory. The inventory accounts not only for motor vehicles, but also other domestic, rural and mobile source emissions, which contribute roughly 17 per cent of the gross emissions. TAPM produces the concentration of CO at Cape Grim at hourly intervals.

The current version of TAPM (V2.0) (Hurley 2002; Hurley et al. 2002) contains a number of improvements over the earlier version (V1.0) used by Cox et al. (2003a) and Dunse (2002). Most notably, the use of the synoptic analyses provided by LAPS is more consistent. In V1.0, the boundary conditions for the synoptic meteorology imposed a zero gradient at the outer grid. Also, only the horizontal winds varied with space and time. Temperature and humidity only varied in height and time, not horizontally. This effectively meant that synoptic temperature and humidity across the entire domain were relaxed to the value at the central grid-point. Since a front represents a discontinuity in air mass characteristics, the V1.0 treatment of the synoptic inputs had weakened the transition between the two air masses and weakened the frontal dynamics. TAPM simulations that have been run with this set of boundary conditions are referred to as TAPM1 throughout the rest of this paper.

TAPM (V2.0) allows for synoptic temperature and moisture, as well as winds, to vary in 3D space and time and for the boundary conditions on the outer grid to come directly from the synoptic inputs at six-hourly intervals. This option also includes the horizontal variation of sea-surface temperature. These features allow for a better representation of synoptic-scale weather patterns, in particular fronts. Simulations run with this set of boundary conditions will be hereafter referred to as TAPM2.

Hurley et al. (2002) compared TAPM V1.0 and V2.0 at the Cape Grim site for the period December 1997 – February 1998, and showed that the results improved with the latest release of the model. This can be seen when examining the root mean square error (RMSE) and Index of Agreement (IOA) values from the various model versions – the IOA is a measure of how well predicted variations about the observed mean are represented, with a value greater than about 0.50 considered to be good, as judged by several other published prognostic modelling studies (Hurley 2000). For winds at 50 m (averaged over wind speed and the wind components), the

- RMSE values for V1.0 and V2.0 were 3.7 and 3.1 m s^{-1} respectively;
- IOA values for V1.0 and V2.0 were 0.83 and 0.89 respectively.

For screen-level temperature, the

- RMSE values for V1.0 and V2.0 were 1.4 and 1.3ºC respectively;
- IOA values for V1.0 and V2.0 were 0.84 and 0.92 respectively.

The results showed that the statistical error had decreased and the index of agreement had increased for TAPM V2.0. Note that while these statistical measures are appropriate to measure the performance of meteorological variables that vary in a relatively smooth and continuous nature, they are not appropriate for highly intermittent variables such as pollution concentrations (e.g. CO) – a more meaningful measure of pollution model performance is to look at the extreme (high) concentrations over a significant period of time (e.g. in regulatory modelling, a suitable, and generally used period, is one year).

For this study both TAPM1 and TAPM2 simulations were made for 1998 in monthly intervals. The CO concentrations, as well as all meteorological variables, are produced at hourly intervals, with concentrations being the one-hour averages. The concentrations for the grid containing Cape Grim are compared with the observations taken at CGBAPS. Note that the instrument measuring the CO concentration at Cape Grim samples the air over only a 40-second period during which time the concentration could be significantly different to the hourly average. To correct for this, the observations were adjusted from a 40-second sampling to an hourly average according to

$$c_{\max,2} = c_{\max,1}\left(\frac{t_2}{t_1}\right)^p$$

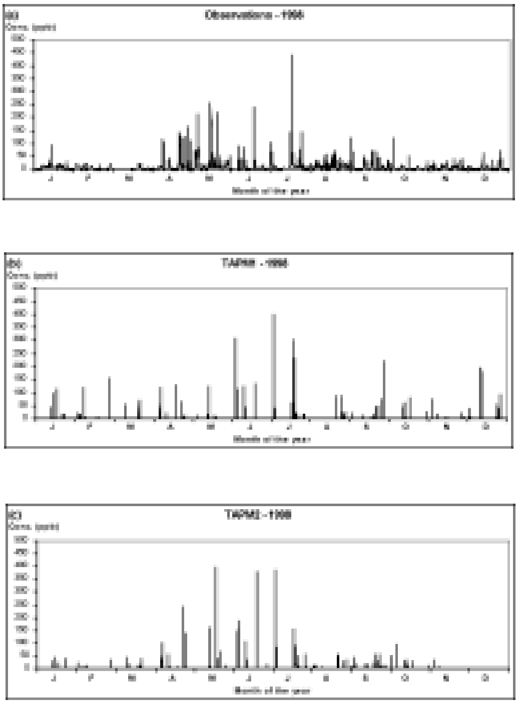
where t_1 and t_2 are the two different averaging periods for data with maximum concentration $c_{\max,1}$ and $c_{\max,2}$ respectively and p is a value between –0.1 and –0.5 that is dependant upon the distance from the source ($p \rightarrow 0$ as the distance increases) (Hibberd (1998) cited in Cox (2001)). Using this equation it is observed that model output must be multiplied by a factor ranging from 1.6 to 9.5 in order to accurately compare with observations. Since the transport distance to Cape Grim from Melbourne is very large the correction factor would be closer to 1.6 and this value will be used when comparing results for this study.

Year-long cumulative distributions

Figure 2(a) is a time series of the observations of CO taken at CGBAPS for 1998. These data have been adjusted to remove the background concentration. This was achieved by first creating individual plots of observations for each month of the year, with those observations known to be due to pollution events removed. Using Microsoft Excel linear trendlines were fitted to each of the 12 baseline plots. These trendlines were then subtracted from the overall observed measurements to produce the plot shown. It should be pointed out that there is occasional missing data in the CO record at Cape Grim. In particular there were two extended periods where no observations were recorded – February 26 to March 12, and June 1 to June 6. For the majority of the time the concentration of CO is well below 10 ppb. A number of spikes occur throughout the year indicating the arrival of pollution events from Melbourne. Dunse (2002) used numerical back trajectories to directly link the vast majority of these events to Melbourne sources. Both the magnitude and frequency of events display a seasonal cycle, with events being more common and more severe during the winter months. As the CO emissions inventory does not have a similar seasonal cycle, this cycle in the observed and simulated concentrations must in some way be in response to the meteorology.

Figure 2(b) shows the simulated concentrations of CO at Cape Grim when TAPM employs the more primitive set of boundary conditions (TAPM1). The events show a similar seasonal cycle, although the frequency and magnitude of events appears to be too great over the summer months. In particular, TAPM1

Fig. 2 **The concentration of CO (a) observed at CGBAPS for 1998, and the simulated concentrations using (b) the primitive boundary conditions, TAPM1, and (c) the more advanced boundary conditions, TAPM2.**



simulations produce a number of events with magnitudes over 100 ppb that are not observed at CGBAPS. From April to August the problem is perhaps reversed with TAPM1 simulating events with magnitudes between 100 and 200 ppb, while the observations are often greater than 200 ppb.

The figures also show that CGBAPS often records weak events (< 50 ppb) throughout the year that are not evident in the TAPM1 simulations. As the source inventory for the TAPM simulations was restricted to the Melbourne vicinity, other regional sources (e.g. Tasmania, rural Victoria or even Adelaide) have not been included and are likely to contribute to this difference. Similarly, the duration of events is usually shorter in the TAPM1 simulations than in observations.

The simulations were undertaken again (Fig. 2(c)) using the more sophisticated boundary conditions available (TAPM2). The figure suggests that this upgrade in the boundary conditions has led to the simulated pollution events behaving more closely to the observations, especially during the late spring/summer months of November-March. These plots have been examined on a much finer resolution to more clearly show their duration and magnitude. Individual case studies are presented in the next section.

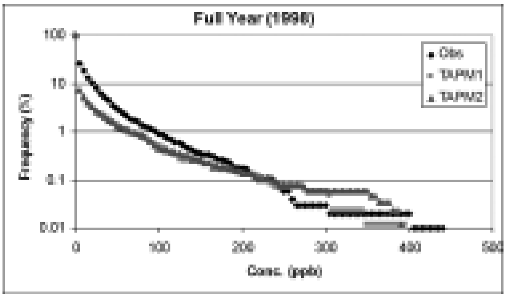
In an effort to quantify these time series, year long, cumulative distributions for the CGBAPS observations and the TAPM1 and TAPM2 simulations are presented in Fig. 3. The CGBAPS observations have cumulative concentrations of 20 ppb or higher roughly ten per cent of the time and reflect the wide variety of sources including Tasmania and rural Victoria. The percentage of time that Cape Grim is influenced by relatively heavy pollution levels, say concentrations of 100 ppb or higher, is limited to roughly one per cent of the time. Extreme events are seen to be quite rare with concentrations greater than 230 ppb present only 0.1 per cent of the time.

Consistent with Fig. 2, the simulated concentrations of both TAPM1 and TAPM2 do not capture nearly as many weak (<50 ppb) events. Again, the simulations excluded all Tasmanian and rural Victorian sources that are likely to account for some of these weak events. Only three per cent of the simulated concentrations are above 20 ppb. This difference between the simulated and observed cumulative concentrations is visible up to ~200 ppb. This suggests that major CO pollution events (>200 ppb) predominantly originate from Melbourne and that both TAPM1 and TAPM2 are capable of capturing such events. Considerable differences exist between the curves at this level as the cumulative distributions essentially come down to only a handful of major pollution events. The difference between TAPM1 and TAPM2 at these high concentrations reflects the sensitivity of the simulations to the imposed boundary conditions.

Returning to Fig. 3, it is perhaps surprising that it is difficult to distinguish between the TAPM1 and TAPM2 yearlong cumulative distributions. The time series indicates a strong difference in simulated events over the summer, yet Fig. 3 shows only a very weak difference between these curves occurs at ~100 ppb. This difference is actually much more visible in the summer seasonal plot (Figure 4(a)); the concentrations at this level are dominated by the winter pollution events in which there is not a great difference between TAPM1 and TAPM2. At higher concentrations, the curves differ more strongly. Again though, this is in response to only a handful of major pollution events. Thus, while Fig. 2 demonstrates differences between these simulations, it is largely averaged out in time.

Figure 4 breaks down the cumulative plots into the four seasons. Overall we see that on a seasonal basis,

Fig. 3 **The full-year, cumulative distribution of observed and simulated (TAPM1 and TAPM2) CO concentrations.**



TAPM2 simulations outperform TAPM1, especially in summer (December - February). Consistent with Fig. 2, the TAPM1 simulations greatly overpredict the number of events over 50 ppb. For the spring months (March-May) the TAPM1 simulations perform nearly as well as the TAPM2. In winter (June-August) all three curves are relatively similar once above 50 ppb. In autumn (September-November) neither TAPM1 nor TAPM2 bear a strong resemblance to the observed concentrations although TAPM2 does record a larger number of events. We note that since the concentrations are greatest in winter, these events dominate the yearlong plot as well, i.e. there is a strong similarity between Fig. 3 and Fig. 4(c).

Case studies

As described previously, the boundary conditions enforced in TAPM1 are believed to effectively weaken the strength of the front in the numerical simulations. Still, it is not clear precisely why this would lead to a systematic underestimation of pollution events in the winter and an overestimation in the summer. We have examined a number of individual pollution events through the year in an effort to better understand this bias. Two case studies are considered to further explore this: a summer case study (7-8 Feb), and a winter case study (19-20 June).

Figure 5(a) displays the time series of the observed and simulated concentrations of CO arriving at CGBAPS for the summer case study. TAPM1 registered a peak concentration of 120 ppb just after midday (AEDT) on 7 February, roughly a factor of five greater than the observed peak of ~25 ppb. The TAPM2 simulation underestimated the observed concentrations throughout the day, often at levels around

Fig. 4 **The seasonal, cumulative distribution of observed and simulated (TAPM1 and TAPM2) CO concentrations. The horizontal axis denotes the CO concentration in parts per billion, and the vertical axis denotes the percentage of time that concentrations were at or above this level.**

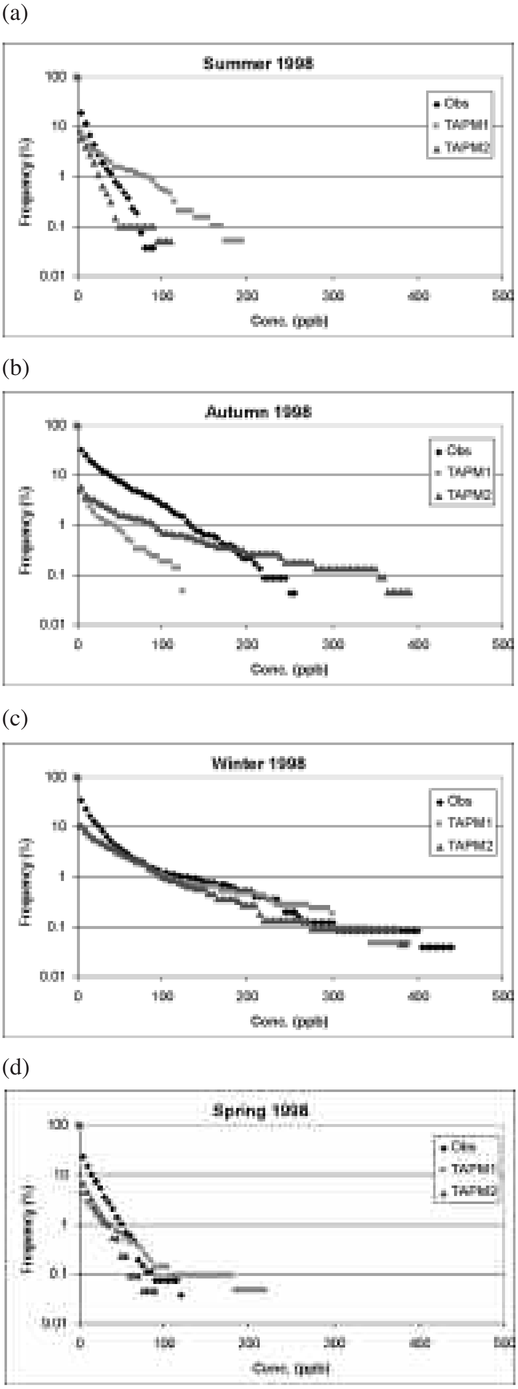
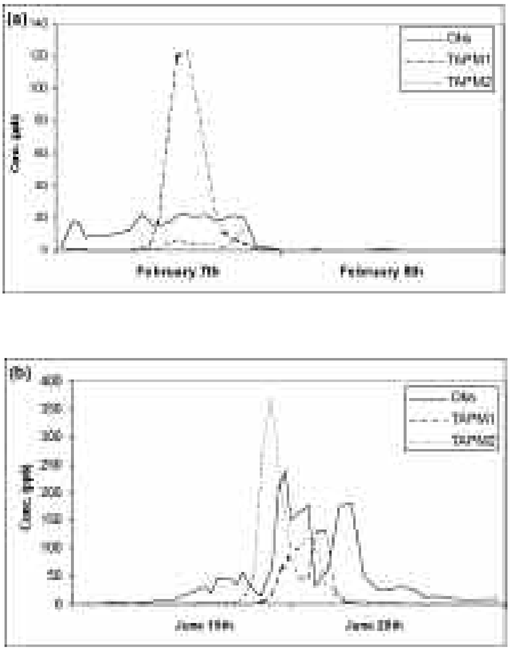


Fig. 5 **The concentration of CO observed at CGBAPS and the simulated concentrations TAPM1 and TAPM2 for (a) the summer case study, 7-8 February and (b) the winter case study, 19-20 June.**



5 ppb. Qualitatively, the TAPM1 time series shows a strong, short peak, whereas the TAPM2 simulation shows a more uniform concentration similar to the observations.

The simulated surface concentration for TAPM1 (Fig. 6(a)) at 1300 Australian Eastern Daylight Savings Time (AEDT) (+11 UTC) on 7 February reveals a high CO pollution event over Bass Strait, just reaching Cape Grim. From the wind direction it appears as if the southerly advance of the CO air mass has been halted, with weak westerly winds reaching the peak of the pollution event. The winds shift sometime thereafter and by 2000 AEDT (Fig. 6(b)) the polluted air mass is being blown away from Cape Grim to the northeast. The surface winds suggest that Cape Grim is within the post-frontal southwesterly air mass at this time. At either point in time, it is difficult to define a sharp front based on the surface winds and potential temperature (Figs 6(c), (d)). Nevertheless, the winds along the boundaries indicate that the front is passing through Bass Strait at this time, and that the polluted air mass is tied in with this transition.

Similar to the TAPM1 simulation, the TAPM2 simulation of 7 February reveals a pollution event south of Melbourne en route to Cape Grim at 1300 AEDT (Fig. 7(a)). The peak magnitude of this event is more than a factor of two greater than the peak in the TAPM1 simulation, but it has not travelled far enough south to reach Cape Grim. Again, the winds shift sometime before 2000 AEDT, and the pollution event moves off to the northeast. The surface winds show a much stronger gradient, especially at 2000 AEDT. It is interesting to note the difference in the winds along the eastern boundary between the TAPM1 and TAPM2 simulations.

Returning to the question of specifically why does the TAPM1 simulation tend to overestimate summer pollution events, it is not possible to draw any conclusions from a single case study. Nevertheless, this case study suggests that the TAPM1 CO air mass is more diffuse allowing it to reach Cape Grim whereas the TAPM2 CO air mass largely remains more concentrated. It also suggests that the pollution events arrive only a few hours before a frontal passage and are thus highly sensitive to their simulation.

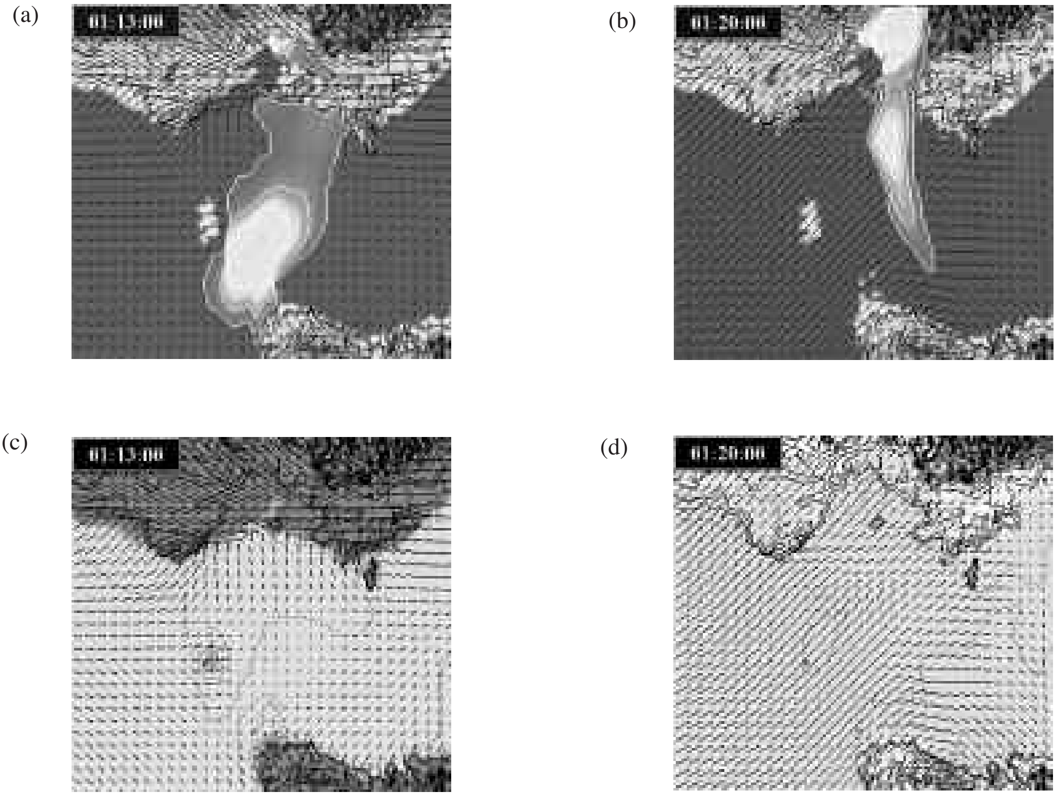
The TAPM simulations may also provide insight into why there are fewer summertime pollution events observed at Cape Grim than during the winter. The simulations of surface concentrations over the course of the summer (not shown) suggest that the summertime frontal passages are often simply not sustained long enough to transport a polluted air mass from Melbourne to Tasmania. This was the nature of the 7 February case study. It is also common for the simulated plume to reach Tasmania east of Cape Grim.

This may pertain to the placement of the front in relation to the parent mid-latitude cyclone. During the summer, the cyclones are pushed further poleward. Fronts that pass over Bass Strait have less of a north-south orientation and more of a northwest-southeast orientation. Thus pollution events from Melbourne pass over the eastern part of Tasmania rather than Cape Grim.

Turning to the winter case study (19-20 June), one sees that the time series of the TAPM1 simulated concentrations at Cape Grim (Fig. 5(b)) shows a peak concentration of around 150 ppb, compared to observations of 250 ppb. The TAPM2 simulation records a peak reading at Cape Grim of over 350 ppb.

The TAPM1 simulations again show a large pollution event en route to Cape Grim at 2200 Australian Eastern Standard Time (AEST) (+10 UTC) on the 19 June (Fig. 8(a)). Four hours later, the pollution has passed over Cape Grim (Fig. 8(b)). The surface winds and the potential temperature (Figs 8(c), (d)) suggest that the front has yet to arrive, with the winds along the western boundary shifting slightly from a northerly heading to a northwesterly heading.

Fig. 6 **February 1998 TAPM1 case study. CO concentration and winds at (a) 1300 and (b) 2000 on 7 February and shading shows potential temperature at (c) 1300 and (d) 2000. Time stamp refers to the hour (in local time) and the day number of the simulation.**

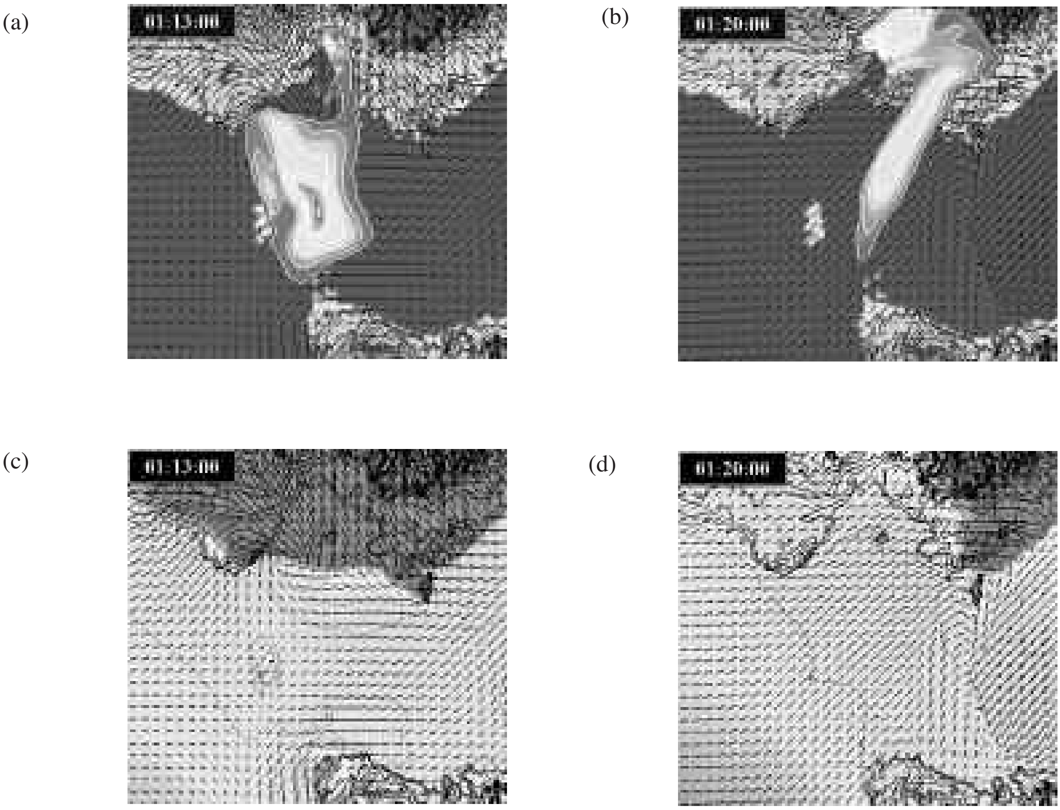


The TAPM2 simulations are qualitatively similar to the TAPM1 concentrations. At 2200 AEST on 19 June the pollution event has travelled further south with a peak almost directly over Cape Grim (Fig. 9(a)). Four hours later this peak has advected further south with a trail of CO pollution still flowing out of Melbourne (Fig. 9(b)). There is fundamentally little difference between the TAPM1 and TAPM2 simulations of surface winds and potential temperature. This is not surprising as the front has yet to enter into the domain. Ultimately this is consistent with the cumulative concentration distribution for winter (Fig. 4(c)) that found little difference between the TAPM1 and TAPM2 simulations. Here the polluted air mass arrives at Cape Grim relatively far ahead of the actual front. The choice of boundary conditions will have minimal impact on the simulated frontal dynamics.

Conclusions

In an effort to better appreciate the sensitivity of numerical simulations of air pollution to the underlying meteorology, two sets of year-long simulations of CO emissions from Melbourne have been simulated with the TAPM air quality model. The first set of simulations, TAPM1, employs zero-gradient boundary conditions and uniform background fields for temperature and humidity. The second set of simulations, TAPM2, employs direct boundary conditions from the synoptic-scale analysis and fully varying temperature and humidity fields for the background state. Effectively, the more primitive TAPM1 simulations weaken the strength of a front by relaxing the two separate air masses across the front to a uniform background state.

Fig. 7 Same as Fig. 6 for TAPM2 simulations.

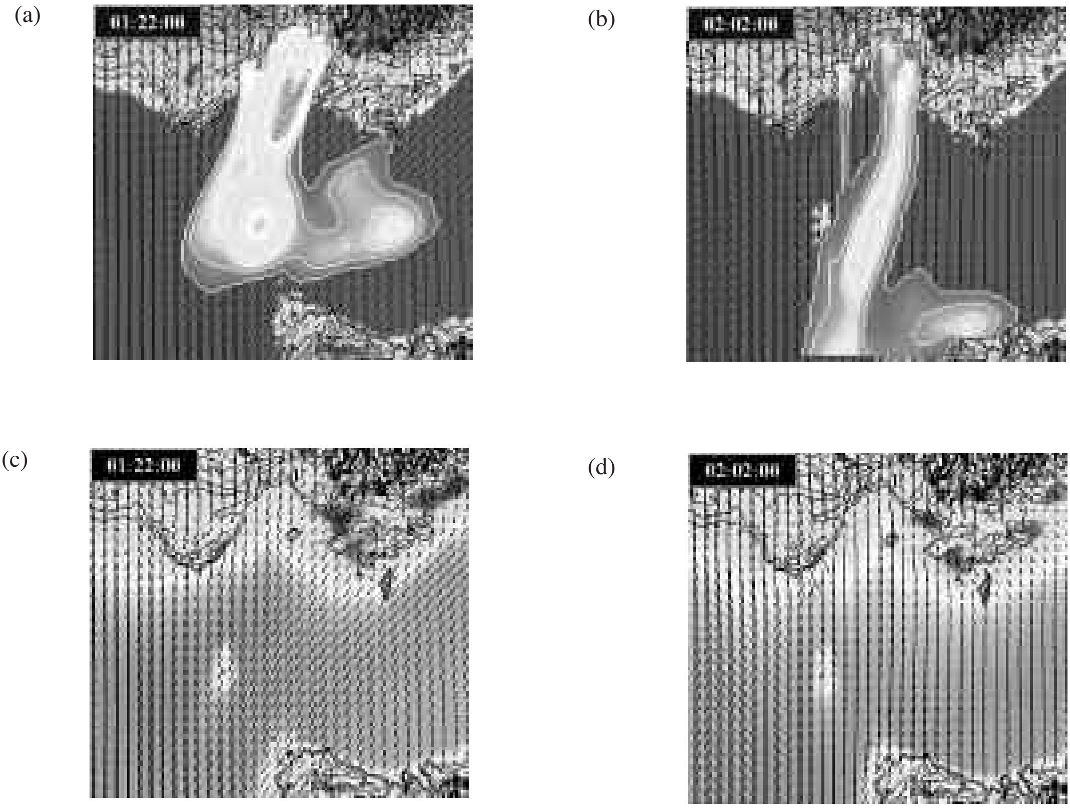


Both sets of simulations were compared with the actual observations of CO taken at the Cape Grim Baseline Air Pollution Station over the course of one year. The simulations of surface concentrations underestimate the weak day-to-day observations, which was anticipated given that no emissions of CO from Tasmania or rural Victoria were modelled. The observations and both sets of simulations reveal a large seasonal cycle in the peak CO concentrations arriving at Cape Grim. These peak concentrations represent major pollution events arriving from Melbourne, and they are greatest during the winter and relatively weak events over the summer. While both sets of simulations demonstrate an ability to capture these large pollution events that have originated from Melbourne, the TAPM2 simulations are found to be more accurate than the more primitive TAPM1 simulations, especially over the summer months.

A winter case study suggests that the pollution events from Melbourne arrive at Cape Grim sufficiently far in advance of the front so that the boundary conditions were not a first order factor in simulating these events. Both the TAPM1 and TAPM2 simulations showed similar skill in simulating wintertime pollution events.

A summer case study suggests that the pollution events from Melbourne are tightly tied to the frontal passage and are therefore highly sensitive to the simulation of the underlying meteorology. Weakening the strength of the front, as is effectively done in the TAPM1 model formulation, leads to a more diffuse pollution event, though higher-than-observed concentrations at Cape Grim. The TAPM2 case study suggests that pre-frontal advection may not be maintained for a long enough period of time for the air mass to reach Cape Grim. The edge of the diffuse

Fig. 8 June 1998 TAPM1 case study. CO concentration and winds at (a) 2200 on 19 June and (b) 0200 on 20 June and shading shows potential temperature at (c) 2200 on 19 June and (d) 0200 on 20 June. Time stamp refers to the hour (in local time) and the day number of the simulation.



TAPM1 plume, however, does reach Cape Grim. Other summertime simulations suggest that pollution events may actually reach Tasmania to the east of Cape Grim and are thus not observed.

Both the short duration of summertime pollution events and their arrival to the east of Cape Grim can be explained by the meteorology of the fronts. In the summer, the parent cyclone has typically advanced further poleward and away from Cape Grim; the wind shift and temperature change at Cape Grim are normally more pronounced and occur over a short period of time. The front also has more of a northwest-southeast alignment rather than a north-south alignment. Thus pollution events advect further to the east. During the winter the parent cyclone lies further to the north and closer to Cape Grim, and the pre-frontal air mass is much broader and will flow more directly to Cape Grim.

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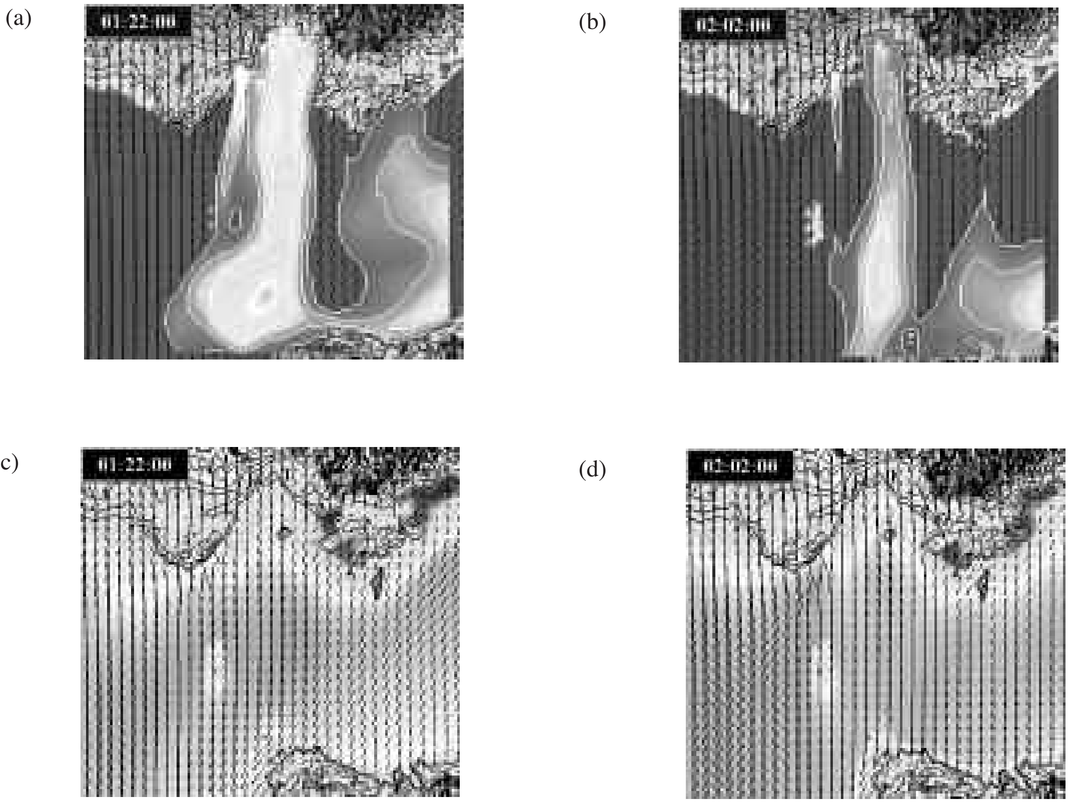
Fig. 9 Same as Fig. 8 for TAPM2 simulations.



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