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NUMERICAL MODELLING OF COASTAL CIRCULATIONS NEAR COMPLEX TOPOGRAPHY

HASNAH HASSAN AND SETHU RAMAN

Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University Raleigh, NC 27695-8208 (USA)

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Brunei Darussalam has an equatorial climate. Sea breezes occur almost everyday. The elevated topography of the neighboring countries leads to complex wind flow patterns when combined with the coastal circulations. Transport of pollutants under these circumstances in turn becomes complex. To study the role of the coastal circulation on the long-range transport of pollutants in Brunei region, a non-hydrostatic mesoscale model (MM5) was used to simulate the flow conditions over Brunei using one-way, double nested domain. The period chosen was during the ENSO year when haze conditions were prevalent in the region. The simulated wind fields from the model were used to determine trajectories of air parcels. Observations and numerical results show that, due to strong solar heating over land, sea breeze develops along the coastline coupled with stable offshore flow aloft induced by the topography. Onshore flow persists into early night, possibly due to the larger island-induced circulation. It is replaced by offshore katabatic flow as the night advances.

Key Words: Air Pollution; Coastal Circulation; Katabatic Winds; Mesoscale Circulation; Mesoscale Modelling; Sea Breeze

1 Introduction

Brunei Darussalam is at 4°N, 114°E on the northwest coast of Borneo Island where it faces the South China Sea. It has an area of 5765 square kilometers with a coastline of 161 km. More than 85% of the Brunei's population live in the coastal area. Air quality in Brunei is generally good except during El Nino years when long-range transport of pollutants causes haze and associated health problems. The haze has a diurnal variation with the minimum during day and maximum early morning.

Coastal circulations, especially the sea breeze – land breeze circulations have been studied extensively. Thermodynamic forcing that drives the circulation and its characteristics, including its initiation, inland penetration of the sea breeze front, the compensating return flow aloft and the broad scale of subsidence over the water, as well as the formation of mixed layer over land have been studied in the past at several locations mostly through numerical simulation[1-6]. In tropical regions such as Brunei, where the large-scale pressure gradient is weak, sea breeze occurs at the coast everyday at about the same time.

Air pollution as a result of industrial activities or mineral resource development (e.g. oil production) in a coastal area is one example that is influenced by the diurnal cycle of the land-sea breeze circulation. The significance of sea and land breezes in air pollution is that they tend to have fairly and steady wind direction within the zone of circulation, but will vary dramatically beyond . Also, they tend to be shallow flow so that the pollutants are trapped and do not mix well with the air above. Katabatic winds over a complex terrain are caused by the cooling of surface air at night. As this air becomes more dense it flows downhill to converge in valleys. They are often regular and quite shallow, so again pollutants tend to be pushed in one direction. In katabatic flow, they do not get mixed well resulting in large concentrations.

Main objective of the numerical study reported in this paper is to understand the pattern of the coastal circulation in Brunei and its effects on the long-range transport of air pollutants from neighbouring countries taking into account the effect of complex topography of the region. For this purpose, a high resolution Fifth-Generation Mesoscale Model (MM5) is used to simulate the coastal circulation over Brunei from April 11-13, 1998. This period was selected because of the observations of high concentrations of aerosols in Brunei related to the forest fires in the region caused by the dry conditions prevalent during the 1997-98 ENSO period.

2 The Model

The Fifth-Generation Penn State/NCAR Mesoscale Model Version 5 or MM5[7] originated from a mesoscale model developed by Richard Anthes at Penn State University, documented in Anthes and Warner[8]. It is best described as a non-hydrostatic, sigma-coordinate model designed to simulate and predict mesoscale and regional-scale atmosphere.

The Blackadar High-resolution PBL scheme[8] with non-local mixing is used to forecast the vertical mixing of horizontal wind, potential temperature, mixing ratio, cloud water, and ice. The vertical mixing is parameterized as taking place between the lowest layer and each layer in the mixed layer, instead of between adjacent layers as in K-theory. An explicit moisture scheme is used which handles resolved (grid scale) precipitation physics. Dudhia's explicit simple ice scheme is used in this parameterization. No implicit cumulus parameterization is used in this study to avoid double counting of cloud processes as the grid size is small (less than 10 km).

2.1 Domain and Initial Conditions

In this study, the Mercator projection was used primarily because it is appropriate for lower latitudes. The coarse grid for this study was centered over Borneo Island (Fig. 1). Even though the principle study region was Brunei Darussalam, the outer coarse grid (9 km) was taken to be the whole island of Borneo and the surrounding ocean to capture the dynamics that might influence the circulation in Brunei, and to simulate the transport of air pollutants from Kalimantan. The inner finer grid (3 km) within this coarse grid comprised of Brunei, South China Sea, eastern part of Sarawak, western part of Sabah and northern part of Kalimantan. The coarse domain has the size of 174 x 149 grid points while the finer one has 151 x 151 grid points. The model was run with 31 sigma levels with 14 levels below 850 hPa (about 1.5 km). Topography data has a resolution of 30 seconds (0.925 km) for both the domains. The vegetation and landuse data are from the USGS global 30 seconds data consisting of 25 categories.

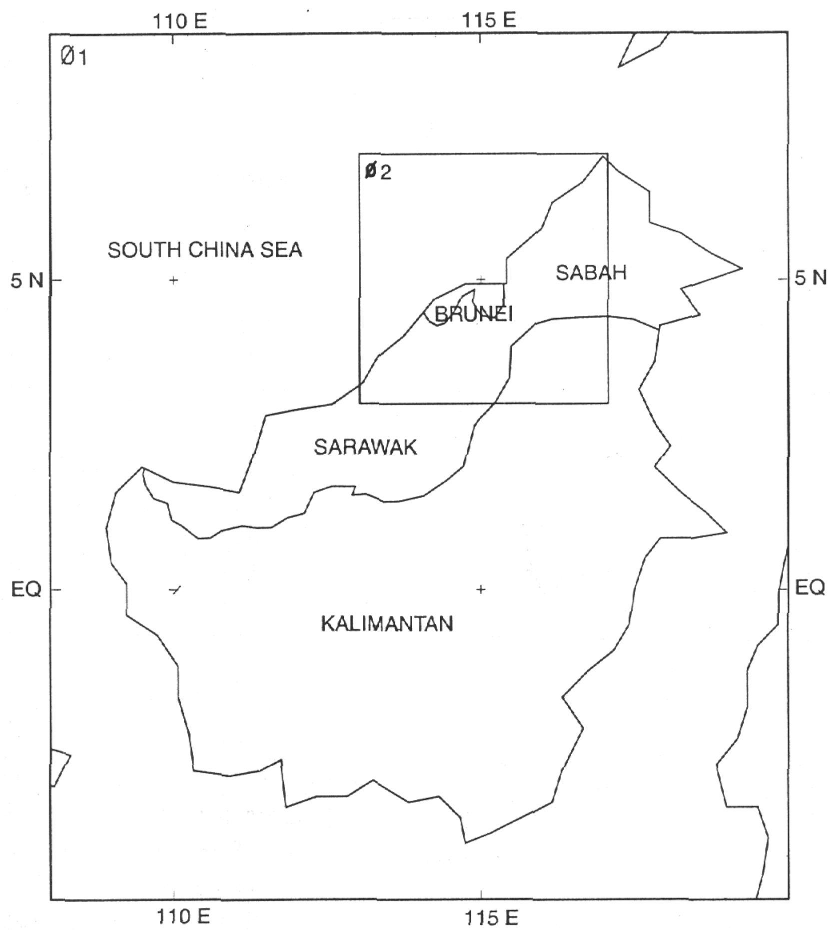

Fig. 1 Model domains used in PSU/MM5 model. Outer domain (#1) is coarse with a resolution of 9 km and the inner domain (#2) is finer with a resolution of 3 km

Initial and lateral boundary conditions were obtained from 2.5 x 2.5 degrees NCEP analyses as pressure level input. NCEP global sea-surface temperatures are used for the initial condition. This information was updated daily from 00Z April 11 to 00Z April 13, 1998. Reference sea-level pressure and sea-level temperature used are 1000 hPa and 298 K respectively. Pressure level at the top of the domain is selected as 100 hPa.

3 Observations

The onset of the sea breeze is usually marked by an increase in wind speed, a fall in temperature and a rise in humidity. Observations of near surface (2 m) mean wind speed, air temperature, and relative humidity for the period, April 11-13, 1998 are shown in Figs. 2, 3 and 4 respectively. They were obtained at the Brunei International Airport located at a distance of about 5 km from the coast. Increases in wind speed and humidity and decreases in air temperature in these plots show the regular occurrence of sea breeze in this region. Onset of the sea breeze occurs approximately at the same time at least for this period, April 11-13, 1998 between 11 a.m. and 12 noon local time (LT). Fig. 5 shows the diurnal variation of wind direction for this time period. Wind direction during the sea breeze initiation is north-northwest with the night time offshore flow occurring from a southerly direction. Large-scale prevailing winds over the region are northeasterly.

4 Numerical Simulations

The pattern of the simulated coastal circulation is first analyzed using the horizontal wind vectors at 975 hPa for the inner domain (Domain 2). Fig. 6 shows the terrain heights for this domain to help us better understand and analyze the coastal circulations. Terrain heights in this domain range from 0 m to 3300 m. Highest elevations in Brunei are only in the rural areas to the south. The lines A and B represent the locations of vertical cross-sections analyzed in this study. Section A is located near the capital city, Bandar Seri Begawan (BSB), and B is located near the oil-producing district, Belait. Most populated district, Brunei–Muara consists

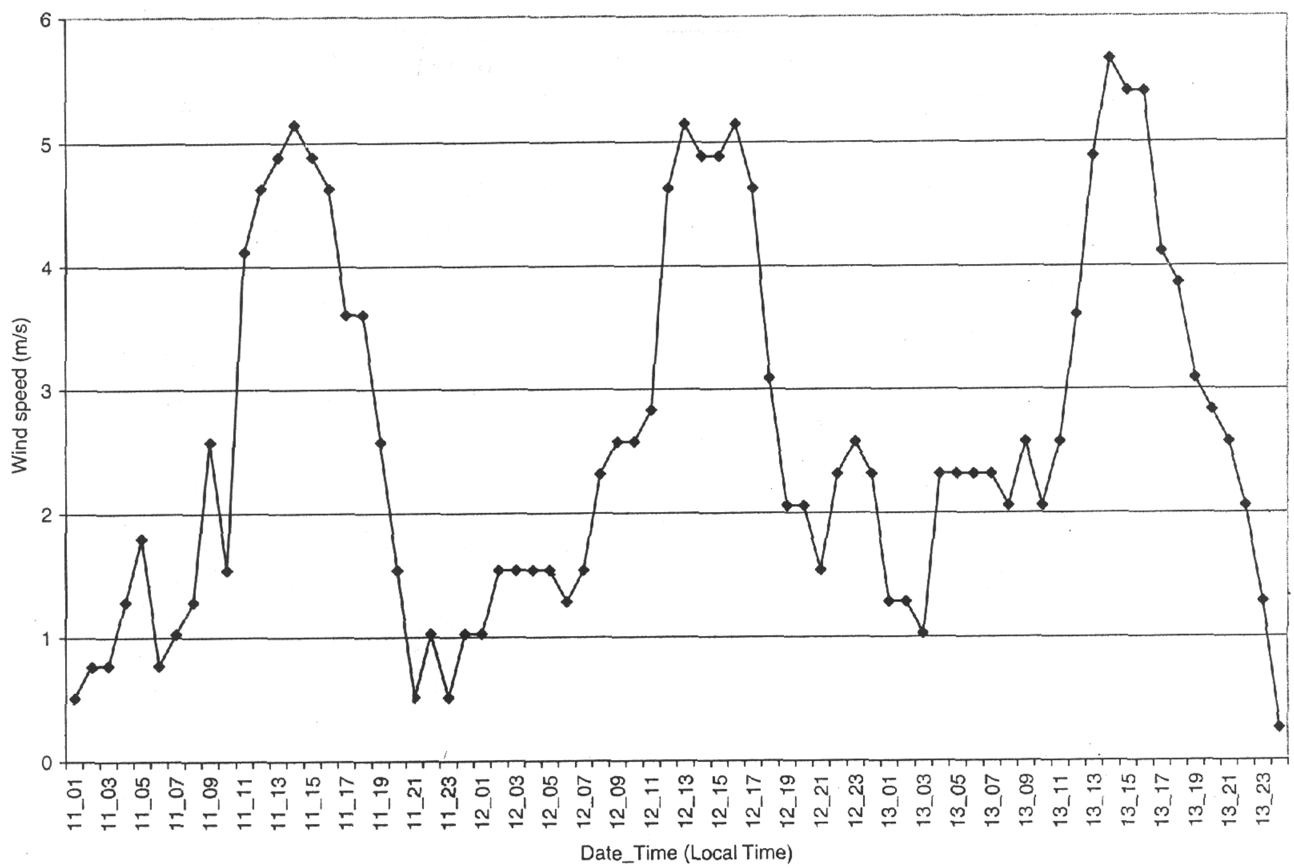

Fig. 2 Surface wind speed (10 m) recorded by the Meteorological Services at Brunei International Airport for April 11-13, 1998. The onset of sea breeze is shown by the increase in wind speed around noon

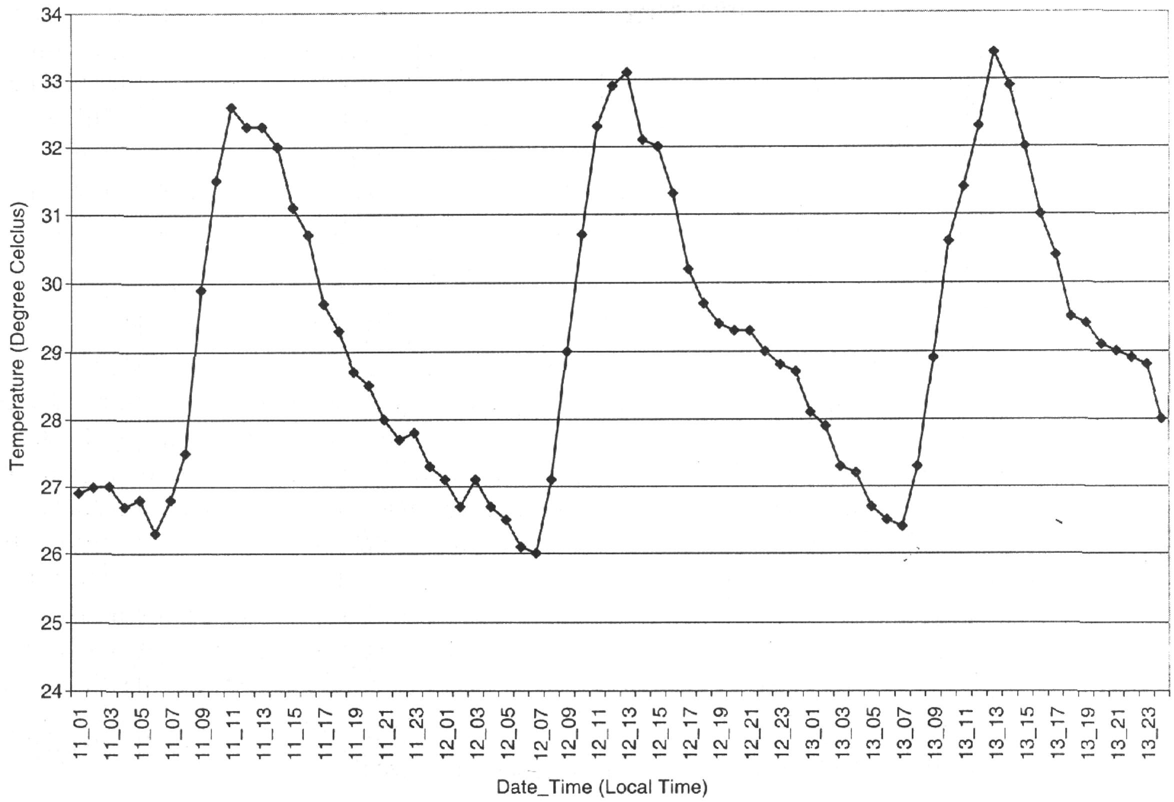

Fig. 3 Surface temperatures recorded by the Meteorological Services at Brunei International Airport for April 11-13, 1998. The onset of sea breeze is shown by a sharp decrease in temperature around noon

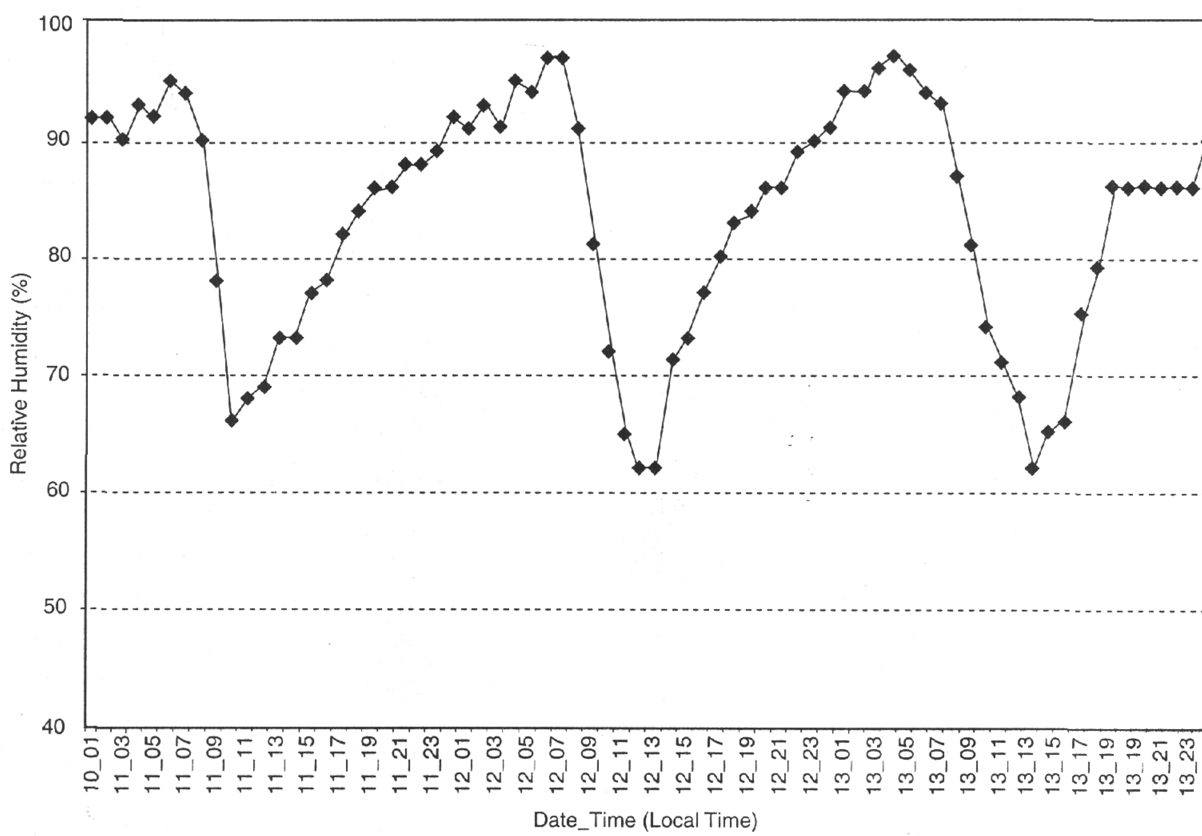

Fig. 4 Relative humidity recorded at the Meteorological Services at Brunei International Airport for April 11-13, 1998. The onset of sea breeze is indicated by a sharp increase in relative humidity around noon

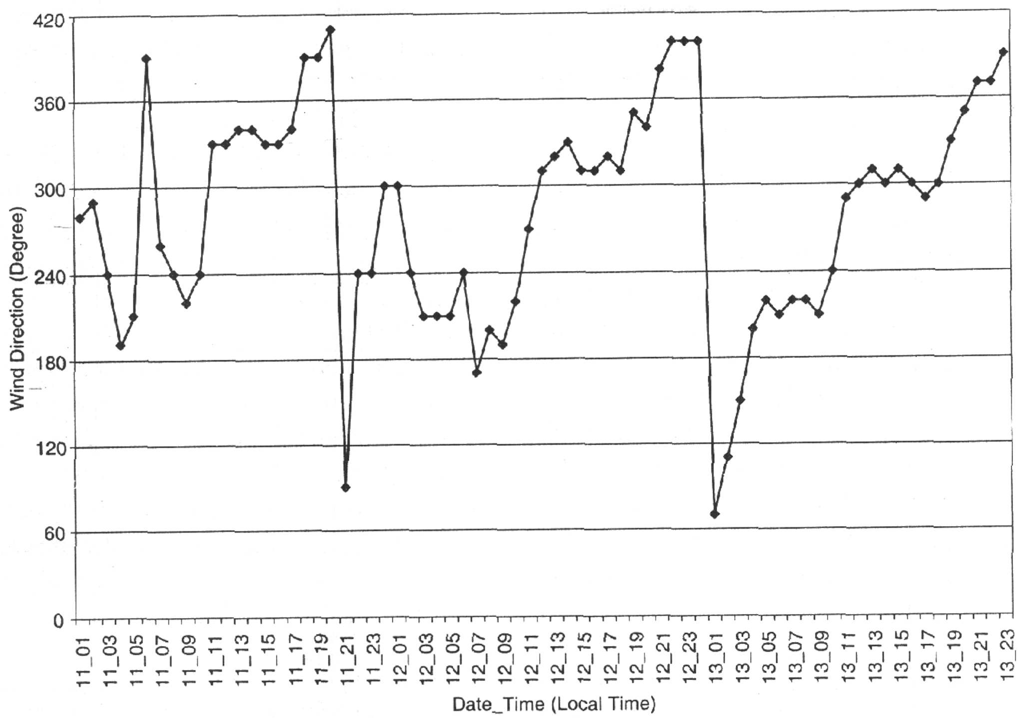

Fig. 5 Surface wind directions recorded by the Meteorological Services at Brunei International Airport for April 11-13, 1998. The onset of sea breeze is shown by the shift in wind direction from offshore to onshore

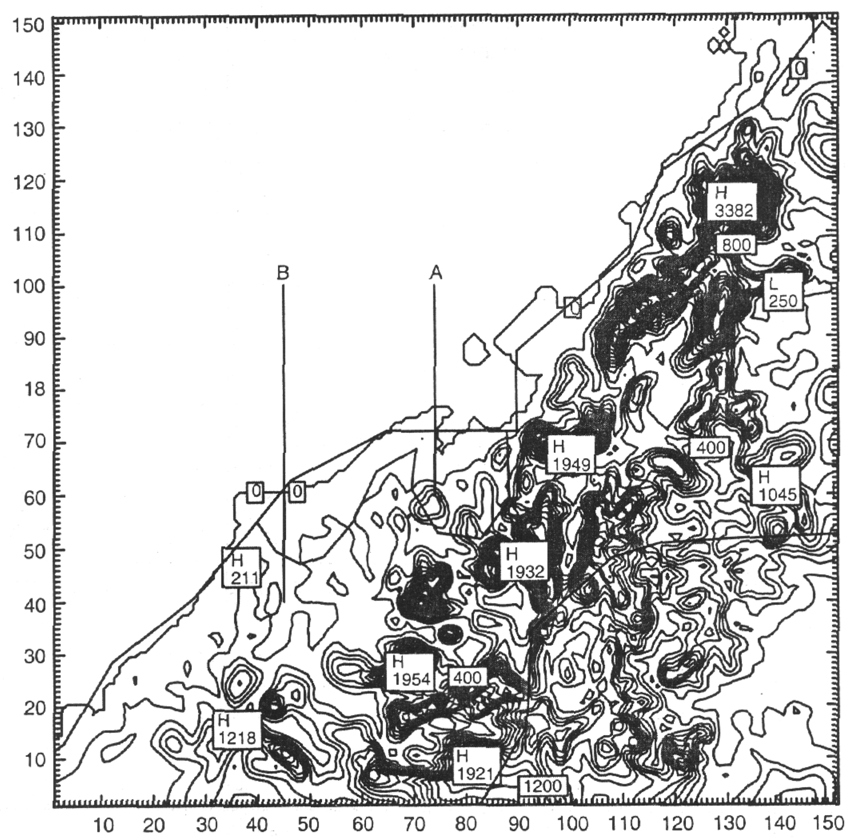

Fig. 6 Terrain heights for the innermost domain, Domain 2 with a range from 0 m to 3300 m. Lines A and B show the locations of the two vertical cross-sections. A is located near the capital city, Bandar Seri Begawan (BSB) whereas B is at the oil-producing district, Belait

of the capital city Bandar Seri Begawan (BSB) and most non-oil industries. The numbers on the left vertical axis and bottom horizontal axis give the grid point numbers.

4.1 Coastal Circulation Development

Simulated horizontal wind vectors at 975 hPa on April 11 at 11LT after three hours of model integration are shown in Fig. 7. Values of the maximum vectors indicated in the figure pertain to the whole domain, but maximum wind speeds for the Brunei area were obtained from the model simulations and are included in the discussions. During this time, a rotor type of circulation is present in the northern part of the domain possibly due to the influence of high terrain near the coastline of the neighbouring state, Sabah. Flow over and around the mountain range (about 3300 m) in that region is believed to have caused this feature. Thus, the topography appears to affect the mesoscale circulations in this region. However, the main objective of this thesis is to study coastal circulations caused by sea and land breezes.

Simulated sea breeze starts to develop around 11LT as shown in Fig. 7 as a result of the increase in surface temperature gradient across the coastline. At this time, it is limited only to the coastline with a maximum onshore speed of about 2 ms^{-1}. These values of maximum wind speeds over the Brunei area are obtained from simulated winds over this region and are different from the domain maximums. At 14LT (not shown), simulated sea breeze penetrates more inland and the maximum wind increases to about 5 ms^{-1} over Brunei. An acceleration of the simulated wind is seen, particularly over the western Brunei. Penetration of the sea breeze is already beyond the country's boundary at this time.

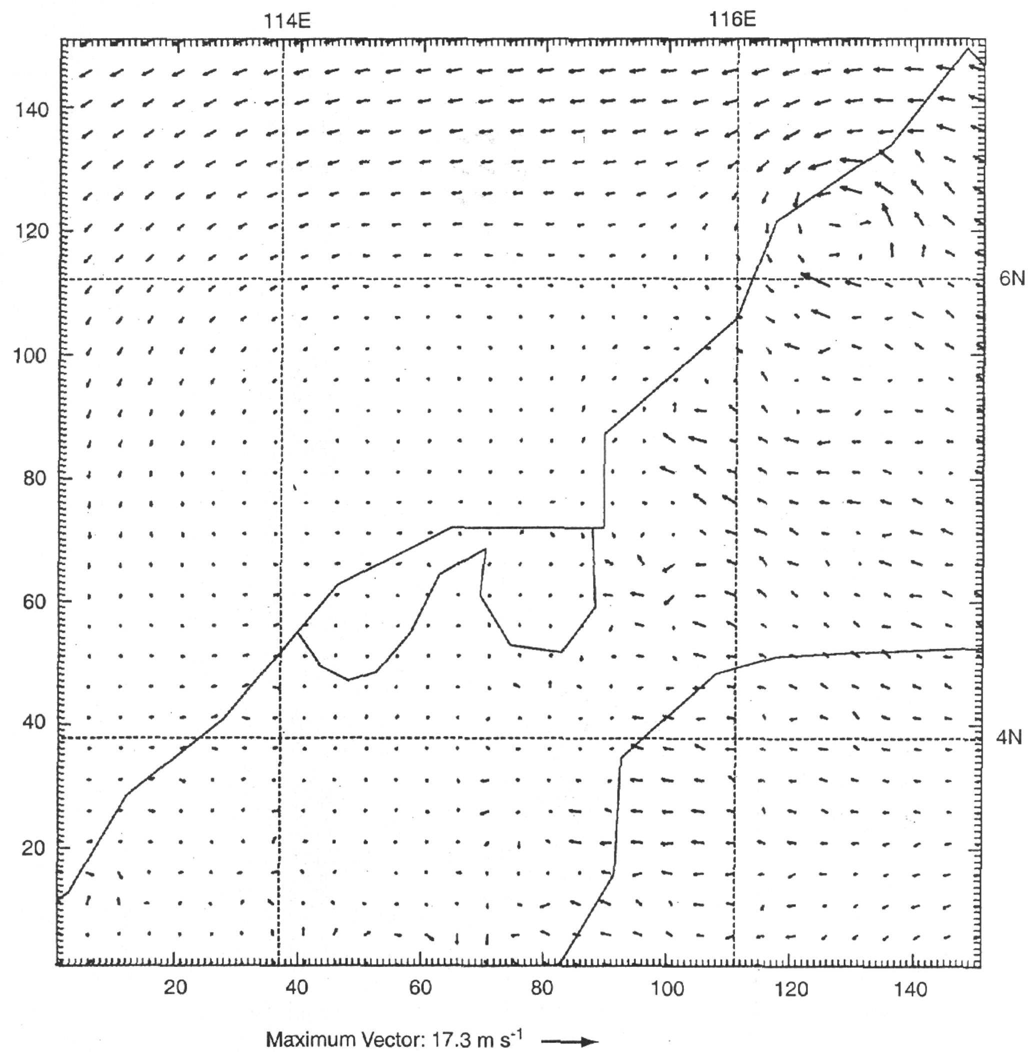

Fig. 7 Horizontal wind vectors at 975 hPa for Domain 2 on April 11 at 11LT. Sea breeze develops near the coast

The flow pattern at 17LT is shown in Fig. 8. Near surface flow induced by the sea breeze is northerly over most of the domain and almost perpendicular to the coastline of Brunei with winds accelerating over the entire country. Wind speeds over the sea are relatively weaker but uniform as compared to the accelerated flow over land. A backing of the wind occurs as the sea breeze penetrates inland. At 20LT (not shown), wind speeds over the southern part of Brunei weaken to about 4 ms^{-1} compared to about 7 ms^{-1} over the coast. Winds over the sea become more northeasterly as the land-sea surface temperature contrast decreases. Thus the simulated sea breeze induced flow accelerates during the afternoon with the direction perpendicular to the coastline and reaches a maximum value of about 7 ms^{-1}. As the solar insolation decreases, the sea breeze gets weaker.

At 23LT (Fig. 9), southerly offshore flow from land starts to develop over the eastern part of Brunei. Channeling of offshore flow induced by the topography is also simulated. Three hours later, at 02LT, on the next day (not shown), the offshore flow over Brunei is still weak (about 1-2 ms^{-1}) at this height. Wind speeds in this region are at a maximum of about 3 ms^{-1} near the coast. Strong southeasterly flow associated with the down slope winds north of Brunei has a maximum wind speed of about 8 ms^{-1}. Both these flows are obviously caused by high terrain regions and stable stratification of the atmosphere over them during the night. However, the simulated offshore flows near Brunei coast in the east increase in intensity up at 05LT (Fig. 10) with a wind speed between 2 and 7 ms^{-1} in the east and 1 to 2 ms^{-1} in the west. This figure also shows a maximum horizontal wind vector of 16.4 ms^{-1} for the entire domain, occurring due to the down slope flow from the hills with an elevation of about 2000 m east of Brunei. At 08LT (not shown), the offshore flow is prevalent over the entire Brunei region. Strongest simulated wind in the east coast is 6 ms^{-1}, but is only 3 ms^{-1} near the west coast. This offshore flow continues

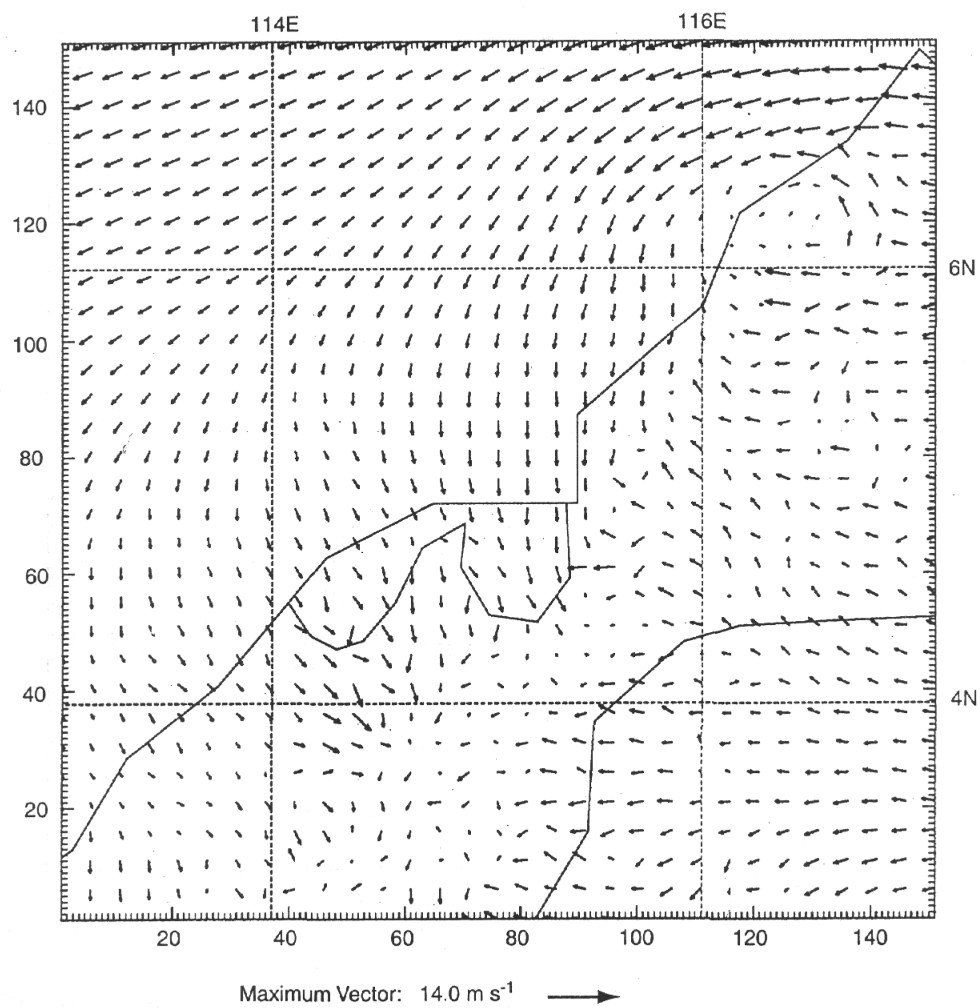

Fig. 8 As in Fig. 7 except at 17LT. Sea breeze has penetrated far inland

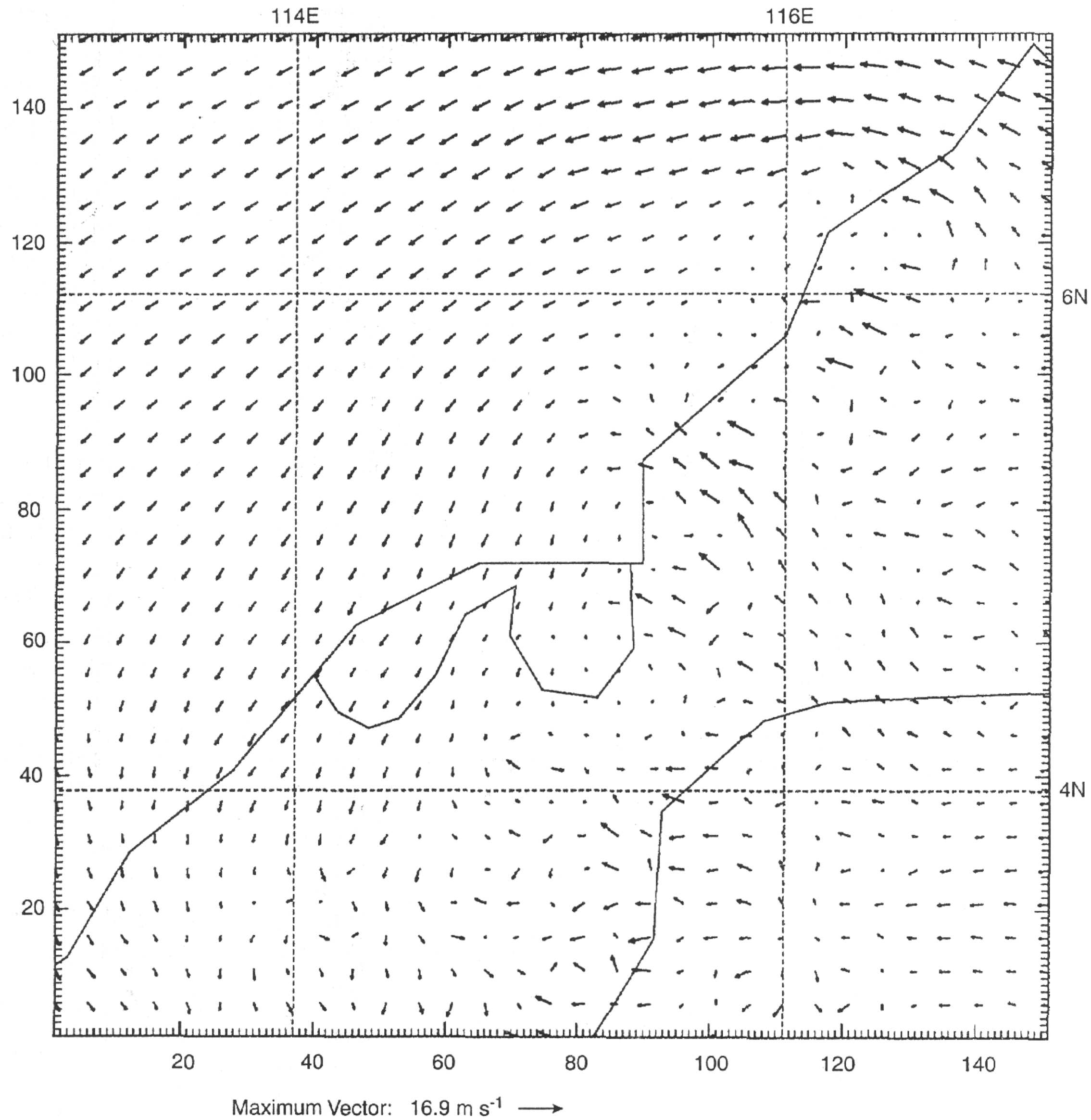

Fig. 9 As in Fig. 7 except at 23LT. Southerly offshore flow is simulated over the eastern part of Brunei

during the early morning hours (not shown). By 11LT, of the second day of forecast, sea breeze begins to develop again at about the same time as the previous day (Fig. 11). Again, the coast in the west experiences sea breeze first as compared to the east. Maximum simulated wind speed of the flow over the sea near the northern part of Brunei is 3.5 ms^{-1}.

From the simulations of the horizontal winds discussed above, there appears to be a significant effect of the topography from the east and to the south of Brunei on the coastal circulation pattern in the country. Sea breeze induced convergence is strongest along the entire coast except in the northern region of the island where mountain induced flow dominates. This katabatic flow is strongest in the night, but still persists during early morning hours.

In summary, for the first few hours of the simulation, from morning to noon, the flow near the coast is generally weak. Sea breeze starts to develop over Brunei around 11 A.M. local time when it intensifies and penetrates inland progressively with time until night. The simulated starting time is consistent with the observations shown in Figs. 2, 3 and 4. As mentioned earlier, wind flow in the eastern part of Brunei is affected by the topography which also contributes to the strong offshore flow during early morning hours until the sea breeze starts later during the day from the opposite direction. However, the wind

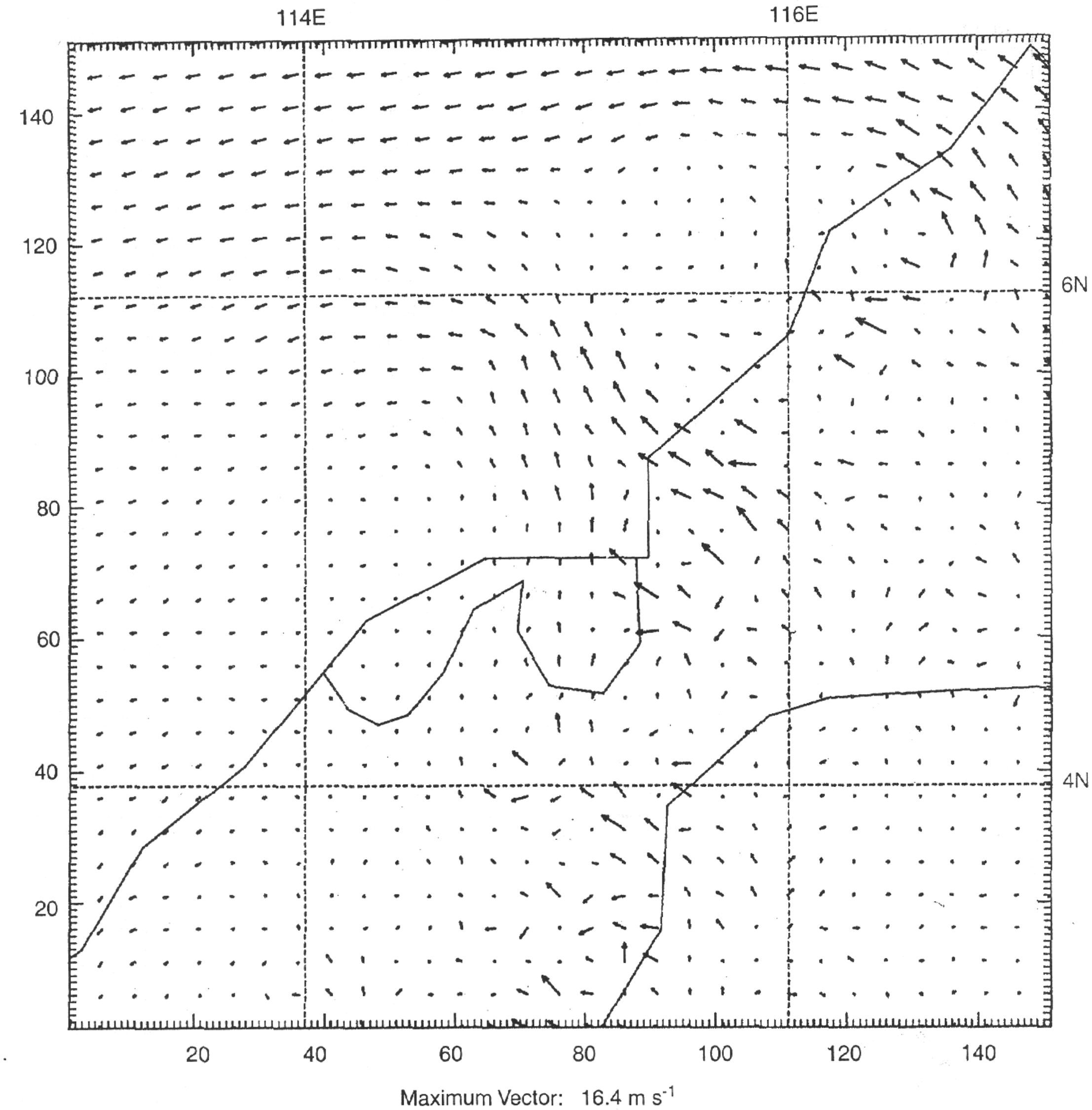

Fig. 10 As in Fig. 7 except on April 12 at 05LT

flow over the western part of Brunei is not affected much by the complex topography.

4.2 Structure of the Circulation

Structure of the coastal circulation over Brunei is further analyzed using the cross-sections of the circulation vectors, potential temperature gradients and vertical velocity distributions. Flow patterns across two cross-sections over Brunei will be discussed in this section. Locations of the cross-sections were shown earlier in Fig. 2 as A and B. Section A is situated through an urban area which includes the capital, Bandar Seri Begawan, BSB. It is the most populated district (Brunei-Muara) where most of the industries other than oil are located. Section B is in the oil-producing district, Belait where the industry's premises are located mostly near the coast. Population is more concentrated along the coast.

4.2.1 Circulation Over the Urban Area

A north-south cross-section is shown in Fig. 12 starting from a location 70 km over the sea to a location 50 km over land. The boundary between sea and land is indicated by the number 0 on a horizontal axis. Negative numbers represent distance over the sea from the coastline and positive numbers represent distance over land. Vertical cross-sections of potential temperature and circulation vectors are overlaid with the corresponding plots of vertical velocities to study the development of the coastal circulation. The values

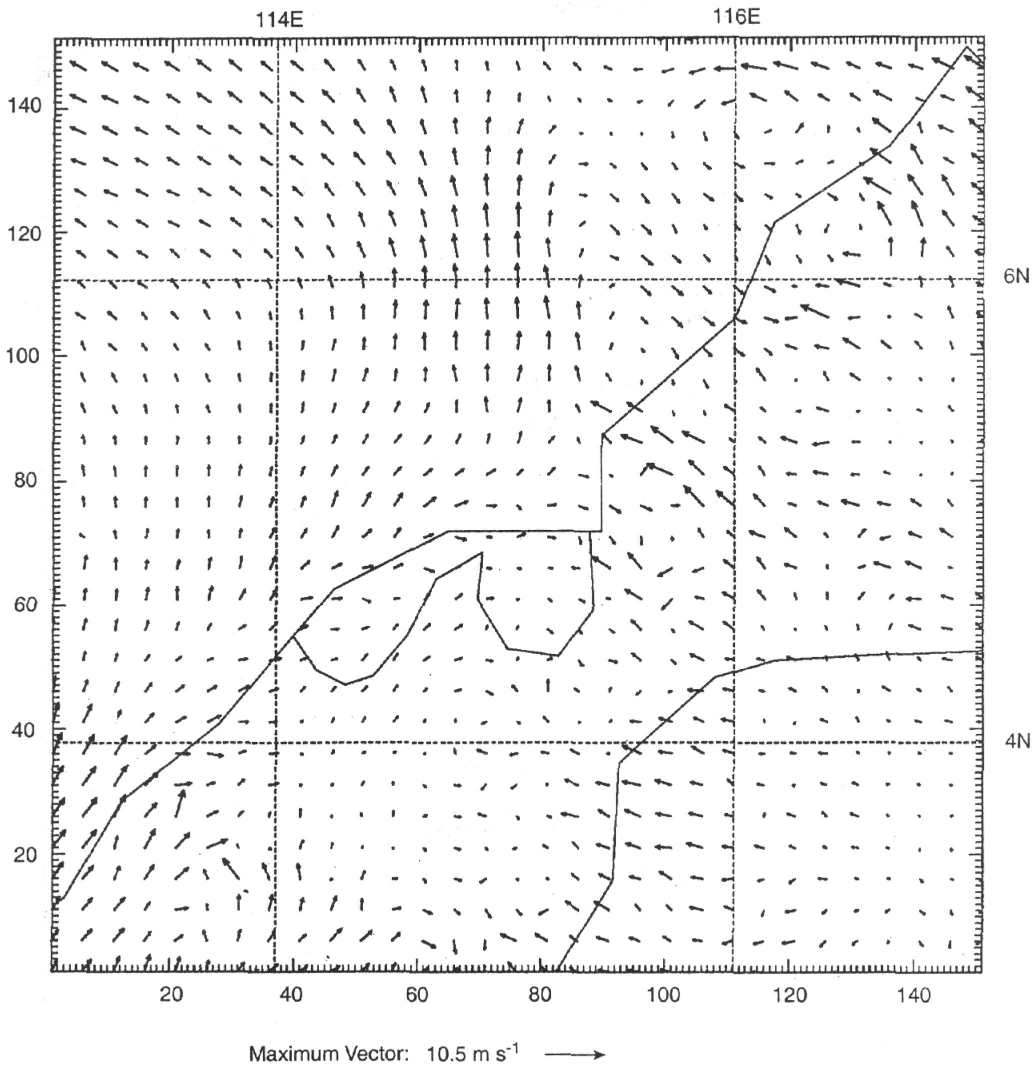

Fig. 11 As in Fig. 7 except on April 12 at 11LT

at the bottom of the vector plots show the maximum vector for the whole cross-section. The minimum and maximum values of the potential temperature are also indicated. Lowest and highest values of vertical velocities are also indicated in the figures.

The simulated vertical cross-section at 11LT is shown in Fig. 12. Coastal circulation is apparent at about 40 km from the shore over the sea as shown by the divergence region indicative of the return flow aloft. The onshore flow is still weak and limited to lower levels, approximately up to 200 m. The return flow starts at about 400 m. The simulated sea breeze front is located inland at about 8 km from the coast as can be seen from the strong convergence indicated by the presence of significant vertical velocity. At the sea breeze front, the vertical velocity is at a maximum of 11 cms^{-1} (not shown). Rapid growth of the mixed layer is also simulated over land close to the shore due to the warming of sea breeze air mass by the land surface. A thermal internal boundary layer (TIBL) grows by entraining warmer air from the overlying stable layer. There appears to be an interaction between the sea breeze circulation and the katabatic flow aloft. The offshore katabatic flow in the stable layer occurs over the sea breeze front forming a wave as indicated by a negative vertical velocity of 8 cms^{-1} north of the sea breeze front. This elevated offshore flow is strong and has a depth of about 400 m above the sea breeze circulation.

At 12LT (not shown), the land surface gets warmer as shown by an increase in near surface air temperature. The front is almost at the same position as an hour back with a vertical velocity of about 7 cms^{-1}. However, the extent of the sea breeze is now about 60 km over the sea from the shore. The onshore flow increases and the return flow is simulated at about 300 m. The down

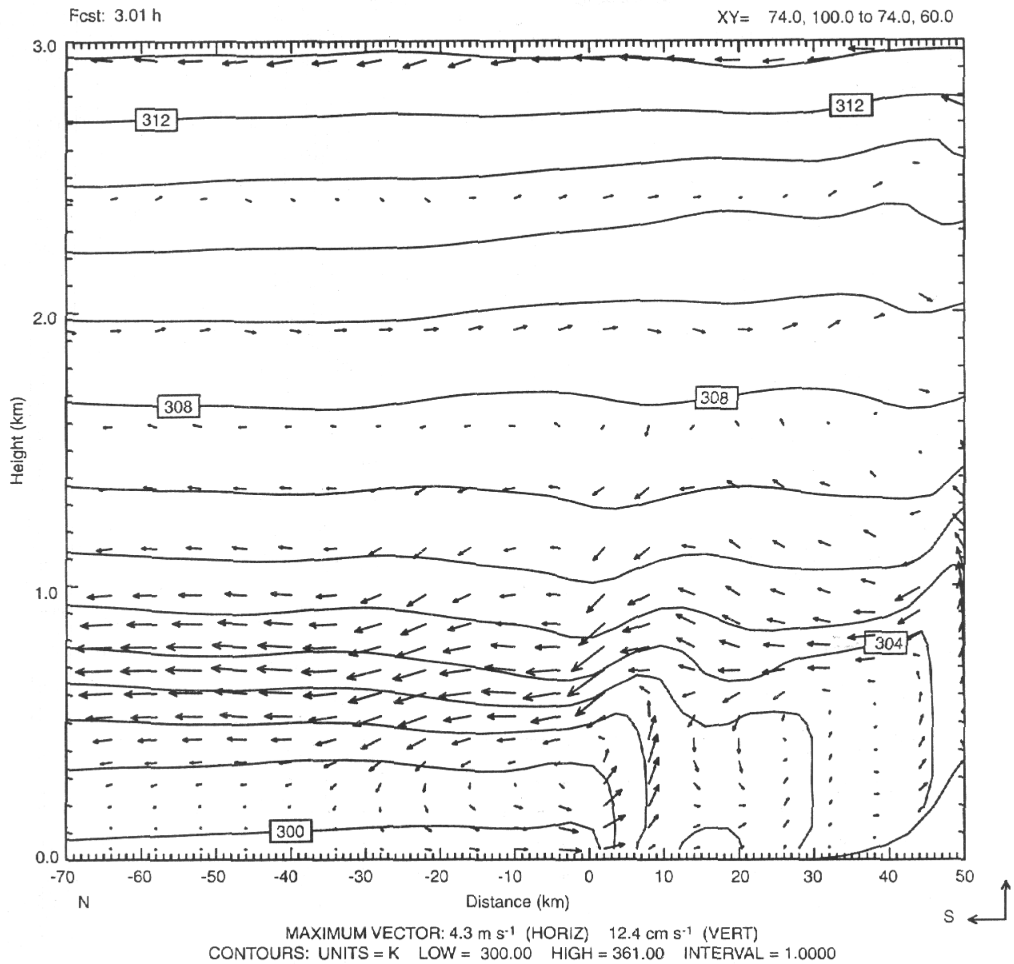

Fig. 12 Vertical cross-section showing circulation vectors (ms^{-1}) and potential temperature (K) with height (in km) on April 11 at 11LT for cross-section A

slope flow is still present over the sea breeze circulation. The simulated front appears to produce internal gravity waves at higher altitudes due to penetrative convection into the stable layer. At 13LT (not shown), the simulated front is located at 35 km inland. The temperature over land increases causing an increase in the mixed layer (or TIBL) height. The onshore flow is still shallow with a depth of 400 m. At the sea breeze front, the vertical velocity is about 11 cms^{-1}. Due to the interaction with the topography, a circulation is produced behind the sea breeze front at 500 m, but the frontal convergence zone is still very distinct at a distance of 105 km from the coastline.

At 14LT (not shown), the land as well as the atmosphere become warmest. The sea breeze intensifies in depth and reaches its maximum penetration inland. Height of the mixed layer reaches to about 1000 m at 50 km inland. The sea breeze flow has deepened to about 800 m. Return flow occurs at a height 1000 m. These values are about twice as compared to simulations two hours before. This rapid growth and sharp increase in vertical velocities are believed to be due to the interaction of the sea breeze circulation with the topography. Maximum horizontal wind speed of 5.5 ms^{-1}occurs near the surface. By this time, the front has reached foothills and becomes ill defined. The katabatic flow aloft weakens considerably by this time. Wind speed over the sea is weaker as compared to that inland. The offshore extent of the sea breeze over the sea is now 25 km from the shore.

Sea breeze is still active inland with a frontal vertical velocity of about 32 cms^{-1} at 17LT as shown in Fig. 13. Gravity wave induced by the sea breeze front and associated convection can be seen aloft with negative vertical velocities on either side. Sea breeze induced flow is still very strong with a maximum wind speed of about 8.6 ms^{-1}. By 20LT (not shown), land surface temperature gradually decreases. At this time, the near surface air temperature is constant at 300 K. The sea breeze induced onshore flow is still strong.

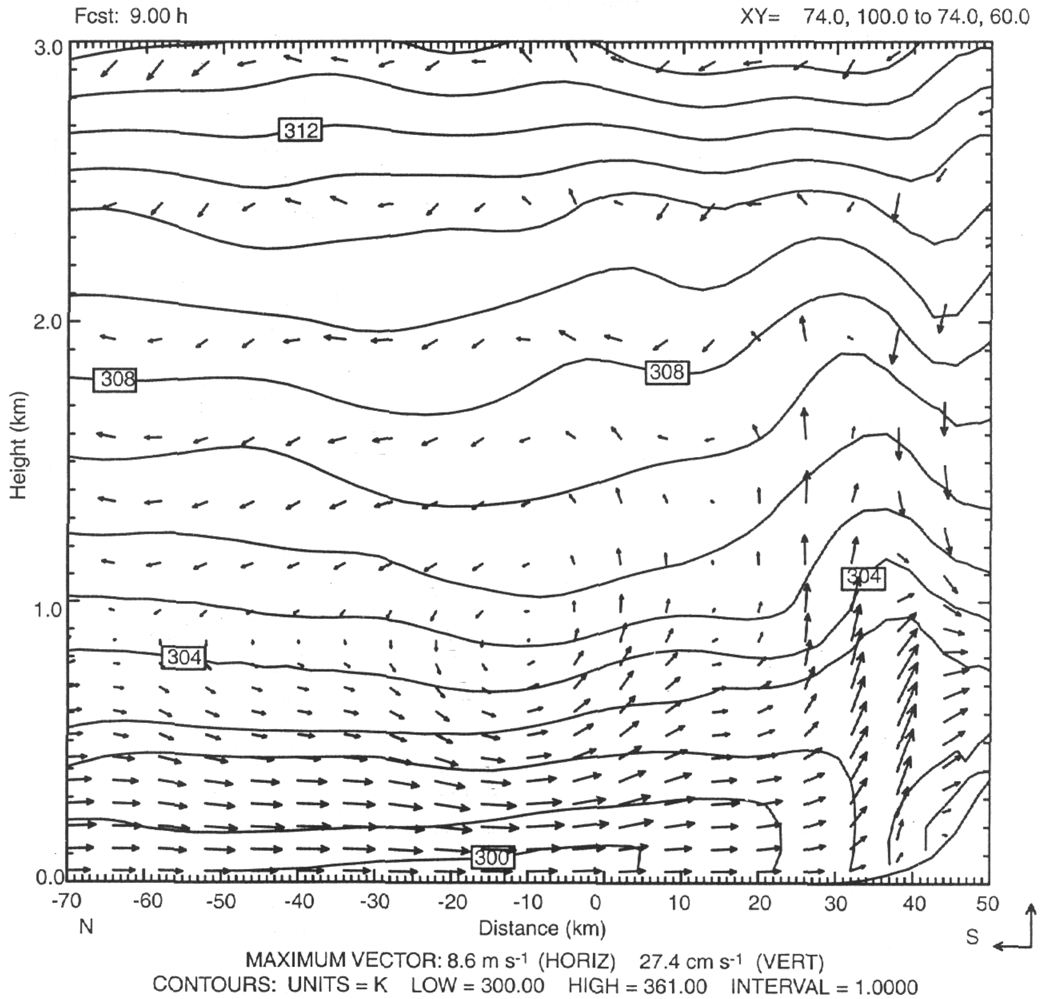

Fig. 13 As in Fig. 12 except at 17LT

The front recedes close to the coast with a maximum vertical velocity of about 13 cms^{-1}.

By 23LT (Fig. 14), the simulated onshore flow is getting shallower (400 m) and the flow over land gets weaker. The sea breeze circulation continues to break into smaller cells, one near the coast and the other offshore. Winds aloft at above 1 km, are getting stronger. At 02LT next day (not shown), simulated down slope winds caused by the topography become strong between the altitudes of 500 m and 1000 m.

At 05LT (Fig. 15), winds are completely offshore with stronger winds aloft. The down slope flow accelerates as it flows offshore over water with less friction. Land is slightly cooler than water as can be inferred from temperature plots. Southerly offshore flow is simulated throughout the lower troposphere. Vertical velocity contours (not shown) indicate two distinct flows, one of shallow land breeze type and the other katabatic flow type over running it. At 08 LT (not shown), there is still a strong offshore wind with the same distribution as was simulated for 05 LT. By 11 LT, as the land gets warmer, the sea breeze is simulated by the model as before with its front near the coastline to a height of 800 m as shown in Fig. 16. A maximum vertical velocity of 16.2 cms^{-1} is simulated near the front located at 7 km inland from the coastline.

4.2.2 Circulation over the Rural Area

This vertical cross-section "B" is north to south, 115 km over the sea and 65 km over land located near the oil town of Belait District. From here on, only significantly distinct characteristics will be discussed for brevity. Fig. 17 shows that at 11LT, sea breeze has already formed at about 10 km onshore extending to about 35 km offshore. Mixed layer over land is well developed. The front has winds with a maximum vertical velocity of 12.8 cms^{-1}. As in the cross-section A, upper-level winds from the south in the stable layer are offshore and a convection induced gravity wave forms as before.

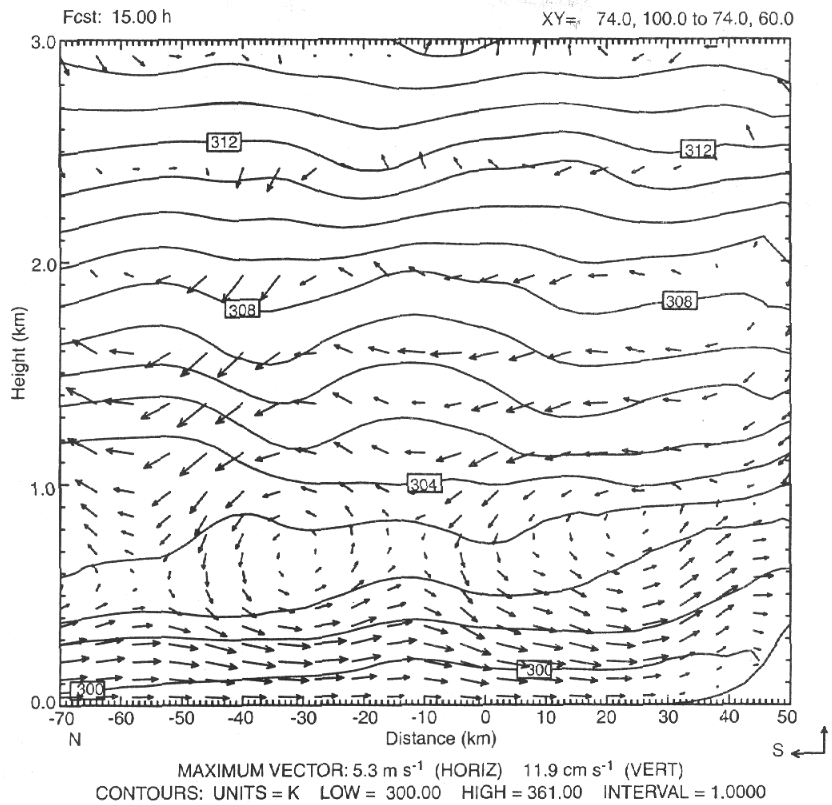

Fig. 14 As in Fig. 12 except at 23LT

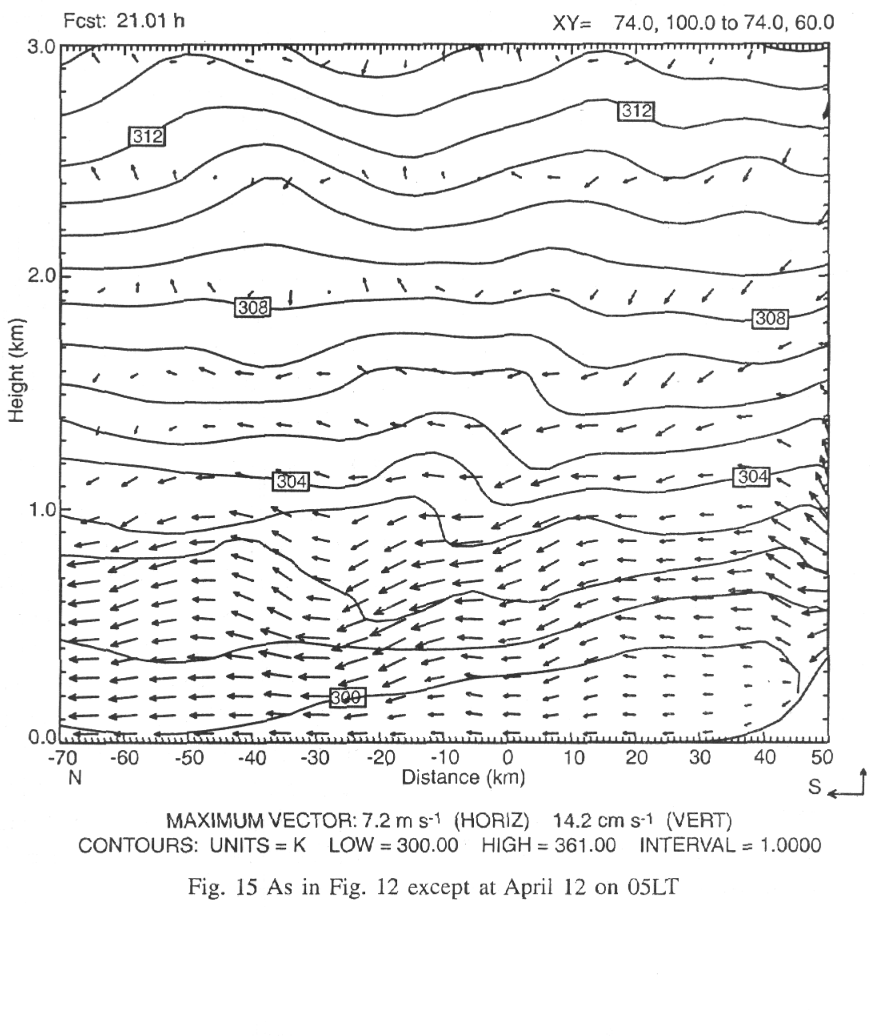

Fig. 15 As in Fig. 12 except at April 12 on 05LT

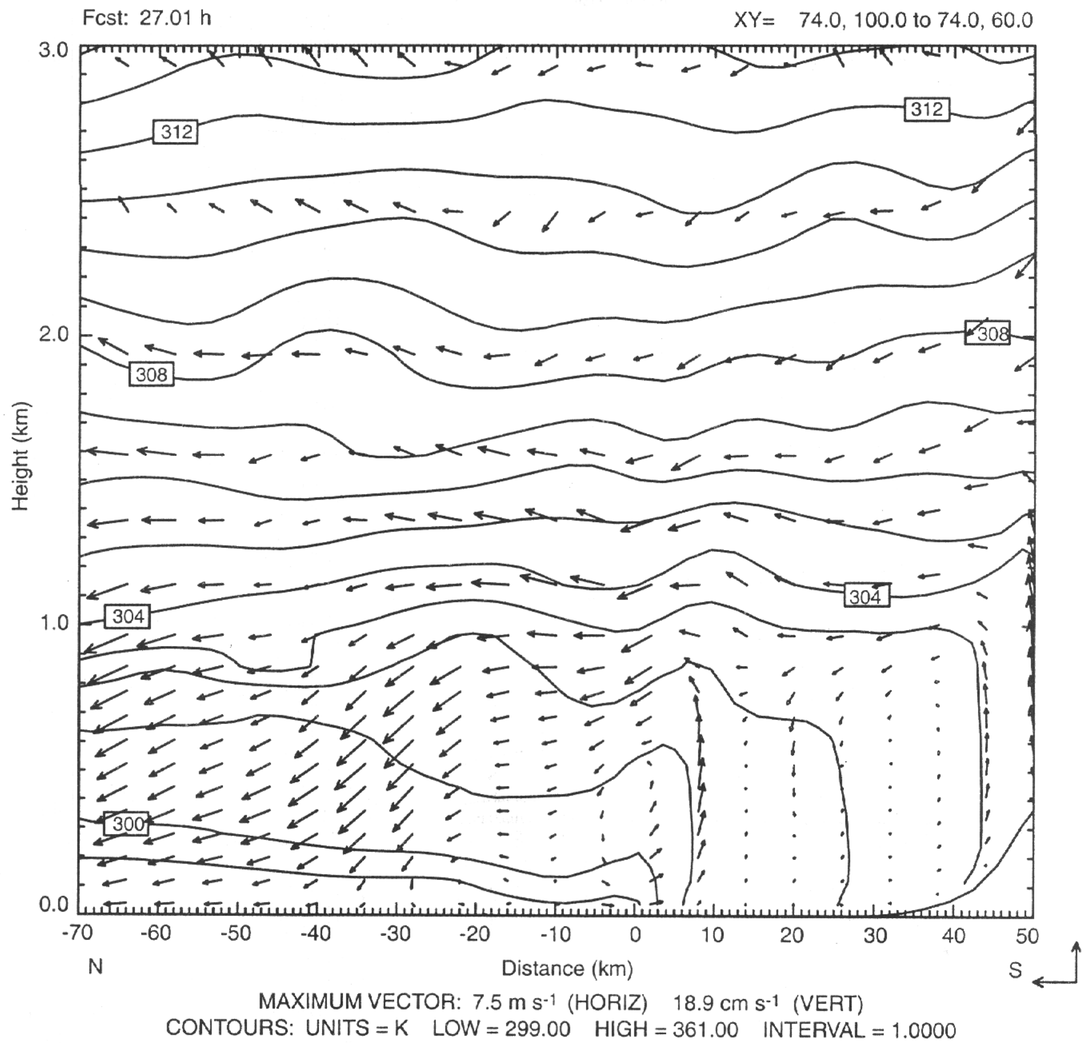

Fig. 16 As in Fig. 12 except on April 12 at 11LT

At 12LT (not shown), the sea breeze front is at about 15 km onshore. The sea breeze is further developed at this time extending to about 34 km offshore. Maximum vertical velocity at the front is about 20 cms^{-1} (not shown). There is still divergence caused by the wave formation over the sea breeze front in the stable offshore flow.

At 13LT (not shown), as the land gets much warmer, the sea breeze penetrates more inland. The land intrusion increases to 30 km, about two-fold the distance an hour ago. Extent of the sea breeze is about 45 km offshore. The effect of the katabatic flow aloft is still present. The sea breeze front has grown deeper to about 1200 m with a maximum vertical velocity of about 22 cms^{-1}.

By 14LT (not shown), the simulated sea breeze strengthens, deepens and penetrates further. It has penetrated 50 km inland. There is a strong divergence of 35 cms^{-1} due to gravity waves aloft. Fig. 18 shows that the sea breeze circulation is deeper at 17LT. There is a break in the contours of the potential temperature near the foot hills where a band of convergence is also seen. The simulated sea breeze front has winds with a maximum vertical velocity of 34 cms^{-1} inducing gravity waves aloft.

The simulated diurnal variations in coastal circulation are essentially similar as before including the onset of the sea breeze next day.

4.2.3 Mean Air Mass Transport during the 1998 Forest Fires in Borneo Island

Monitoring of the 1997/98 forest fires episode in southeast Asia using satellite images gave in formation regarding the locations and the intensity of the fires. It would be of interest to study the effect of different meteorological processes on the transport of pollutants, in this case, particulates and smoke associated with the forest fires.

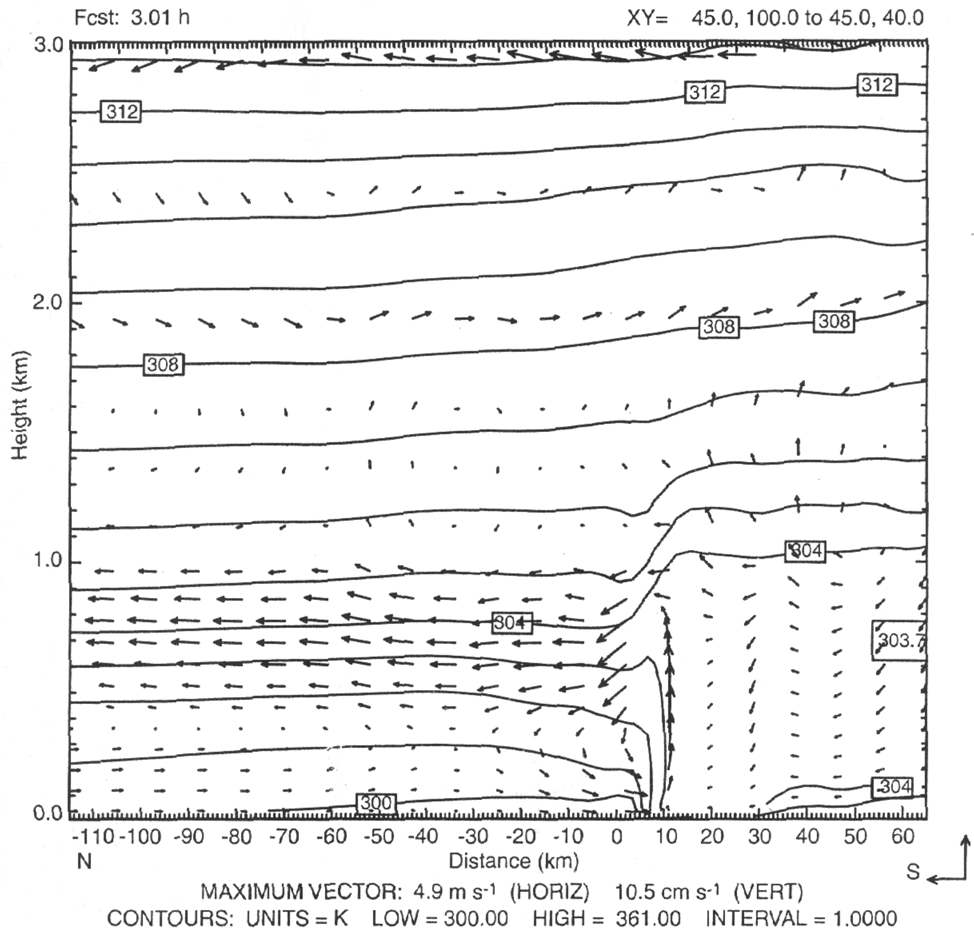

Fig. 17 As in Fig. 12 except for cross-section B on April 11 at 11LT

Brunei experienced high intensity of haze during the period April 11-13, 1998 making the visibility as low as 150 m at the capital. One of the objectives of this study is to study the role of the coastal circulations on the mean transport of smoke during the 1998 ENSO-related forest fire.

The coarser domain (Domain 1), is used for simulating smoke trajectories. The meteorological fields used are the hourly simulated 48-hour (April 11-13, 1998) forecasts from PSU/NCAR MM5 model. Backward trajectories are calculated using the three-dimensional simulations. Backward trajectories enable us to position a receptor, in this case Brunei in investigating the location of pollutant sources that affect the country. Since pollutants spread out horizontally and vertically due to dispersion, a realistic representation of the mean transport can be obtained from an ensemble of various trajectory pathways. Trajectories are examined at 950 hPa (about 0.5 km altitude). This altitude is chosen to represent average plume rise and to examine the coupling of flows in the lower boundary layer with flows at higher altitudes.

Fig. 19 shows 48-hour backward trajectories ending in Brunei at 08LT on April 13, 1998 from five different locations at an altitude corresponding to 900 hPa. Generally, smoke plume and the haze that arrive in Brunei originate from the east (beyond the simulated domain) and are transported by upper level winds. This simulation illustrates that the long-range transport involves the whole depth of the troposphere. It shows that polluted air parcels or smoke plumes go down from higher altitudes possibly due to large-scale subsidence and relatively dry atmosphere associated with the ongoing ENSO event at that time.

Other simulations (not shown), confirm that within the 48 hours, there is no effect of the haze from Kalimantan's raging forest fires in Brunei, at least for this case study. The hazy condition experienced during that period appears to be the result of the local sources and those located over the nearest Malaysian states. The simulations are in agreement with available satellite pictures. However, circulations at the Brunei coastline do influence the transport of air pollutants.

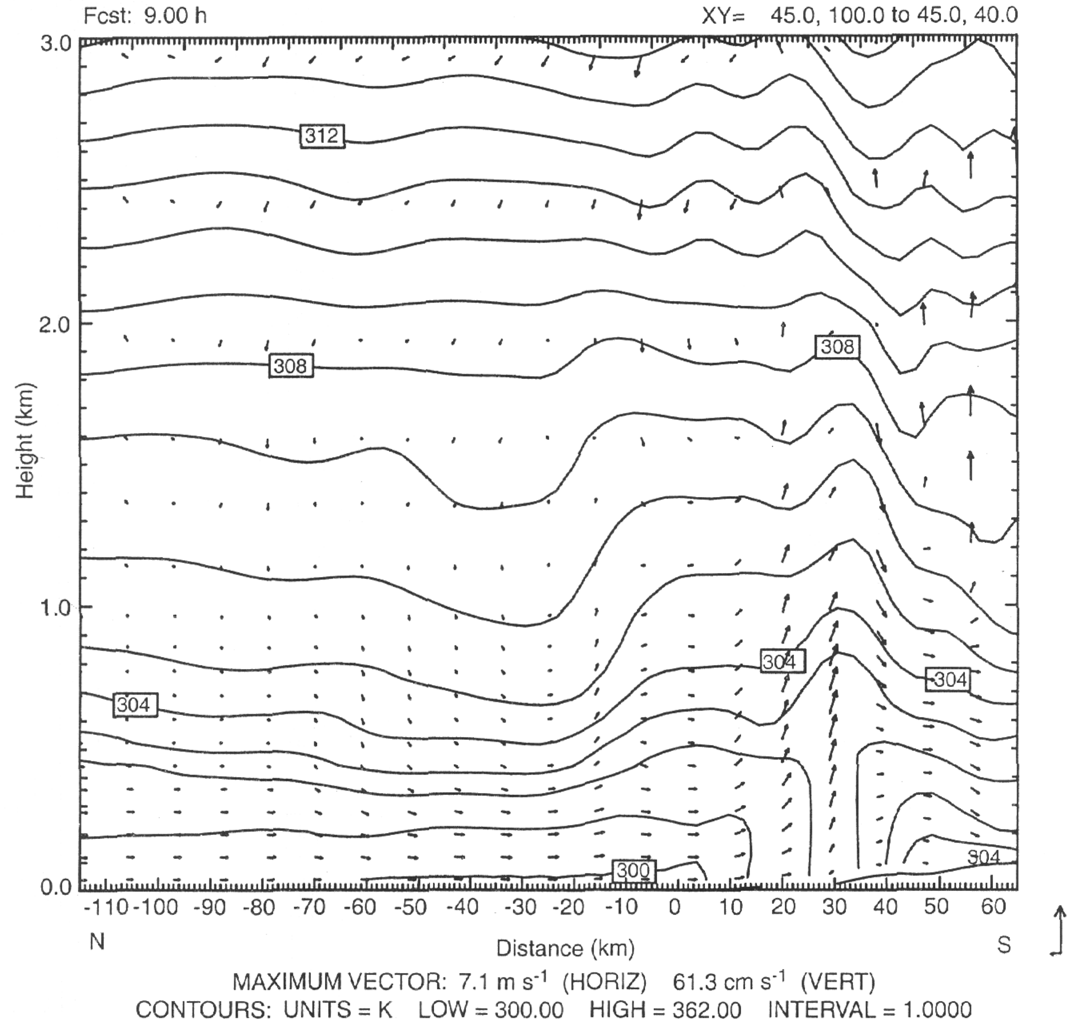

Fig. 18 As in Fig. 17 except at 17LT

5 Conclusions

Sea and land breezes are important components of coastal circulation. Diurnal variation of the land temperatures, and the associated heat transfer in the lower atmosphere play an important role in generating these thermally forced circulations. Circulations along the coast of Brunei were studied using a high-resolution mesoscale weather prediction model.

The model used is the Fifth-Generation PSU/NCAR Mesoscale Model (MM5). A one-way, double-nested domain configuration was used for the simulation presented in this study with all the nest locations held fixed throughout the simulation. For this study the model was integrated with a horizontal resolution of 9 km for the outer domain and 3 km for the inner one. However, only simulations from the innermost domain are discussed since the main objective is to study the coastal circulation patterns over Brunei. The model was integrated for 48 hours from 00Z on April 11 to 00Z on April 13, 1998. The planetary boundary layer physics consisted of a high resolution Blackadar PBL parameterization while the precipitation physics used is the explicit Dudhia simple ice scheme.

Simulated coastal circulation over Brunei is characterized by the sea breeze induced onshore flow during daytime. The model shows a fully developed sea breeze over Brunei at 11 LT. This agrees with the observations at the Brunei airport. Wind direction during the sea breeze initiation is north-northwest. Maximum wind speeds of the simulated sea breeze is about 7 ms^{-1} along the coast. Sea breeze develops with an onshore low-level flow penetrating inland and growth of mixed layer over land. The sea breeze front characterized by low-level convergence and strong vertical motion advances inland with time. The sea breeze front reaches more than 50 km inland by the evening.

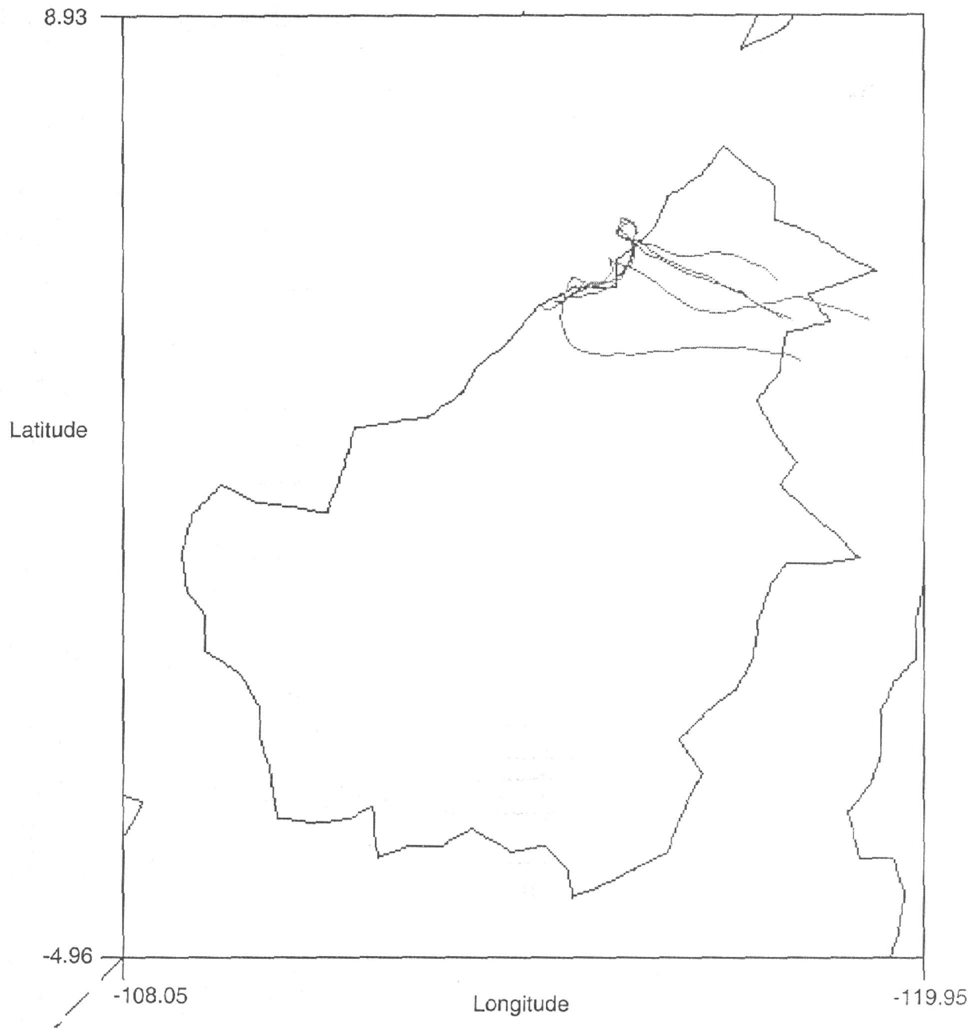

Fig. 19 Backward trajectories (48 hours) starting 08LT April 15, 1998 ending 08LT April 13, 1998 at 5 different locations in Brunei at 950 hPa showing air mass coming from the Eastern part of Borneo Island

As the sea breeze propagates inland it is affected by the topography in the south. Interaction with the topography causes strong vertical motion. Simulated sea breeze circulation is capped by a strong stable layer about 500 m thick where down slope katabatic winds dominate. The model is able to simulate the formation of internal waves in this stable layer triggered by the penetrative convection along the sea breeze front.

The wind pattern in Brunei is affected by the presence of topography of its neighbouring countries from the east and to the south. A rotor-like circulation is simulated, probably caused by the topography to the east. Due to the presence of significant offshore katabatic flow over the region during nights, land breeze is not prominent.

Trajectory simulations of air parcel, treated as polluted air were conducted in this study using the predicted wind fields from the model. It is shown that during the period of this study, haze over Brunei, is caused by the pollution originating from the eastern part of Borneo Island. Locally emitted contaminants near the shore are generally blown offshore. The trajectory pathways are affected by the coastal circulation. Aerosol transport during the simulated period appears to originate from local sources and the nearby Malaysian states and not from the forest fires in South Kalimantan, Indonesia. However, more case studies are needed to study the long-range transport of air pollution in this region.

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