CHAPTER 5

ABL CHARACTERISTICS OVER KAASHIDHOO THROUGH OBSERVATIONS AND SIMULATIONS
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5.1 GENERAL INTRODUCTION

The field of micrometeorology, which essentially deals with various small-scale phenomena in the atmosphere, has always relied heavily on the field experiments to learn more about the ABL. Unfortunately, the large variety of scales involved and the tremendous variability in the vertical require a large array of sensors including airborne platforms and remote sensors. The relatively large costs of such instruments have limited the scope of many field experiments. Some of the early field experiments focused on surface layer data over flat uniform terrain or ocean. In the later part, experiments probed higher in the boundary layer with specified goals (See Table 10.1, pg. 418-49, Stull, 1988). As an alternative, numerical simulations using digital computers have become very popular since the 1960’s. Although actual measurements taken during field experiments represent the real picture of the atmosphere, a desire to forecast the weather objectively (future atmospheric states) has always attracted attention of many investigators and simulation studies of the atmosphere remain one of the very interesting topics of the research (Anthes, 1976; 1983; Arya, 1982; Pielke, 1984 and the references cited therein). Except in trivial steady state situations, long range forecasting of future developments, whether in science, technology, consumer demand, or operational methods, is difficult and uncertain. Simulation studies over the land surface as well as oceanic surface essentially requires proper understanding of the ABL processes and its associated dynamics. Though, a considerable amount of work has gone towards improving our understanding of the ABL structure and the turbulent processes which govern the ABL dynamics over land and ocean, a very little is known about the mesoscale influence of small islands on the vertical structure of the ABL.
In this chapter of the thesis, we provide some important observational features of the ABL over a tiny island of Kaashidhoo (4.96°N, 73.47°E) in the Republic of Maldives. As part of INDOEX campaign, GLASS Sondes were launched regularly from Kaashidhoo at a frequency of 3 Sondes per day during February 11 – March 29, 1999. With a view to testing mesoscale model performance over Kaashidhoo and to see how the model simulation supports the observations, two mesoscale models were used to simulate the lower atmosphere circulation over the tiny island of Kaashidhoo: (1) Oregon State University – One dimensional Planetary Boundary Layer (OSU 1-D PBL) model, also known as Coupled Atmospheric boundary layer Plant Soil (CAPS) model and (2) Advanced Regional Prediction System (ARPS) model. Model simulations were carried out for 24 hours in vertical column mode configuration with similar input parameters to both the models for obtaining the profiles of winds, potential temperature and specific humidity and to understand its diurnal evolution. In brief, this chapter describes the following three aspects of the ABL studies over Kaashidhoo: (1) Observational features of the ABL over Kaashidhoo from the surface layer measurements and GLASS Sonde profiles, (2) Description of the mesoscale models – OSU 1-D PBL and ARPS model and (3) Comparison of simulations with the observations. Various aspects of the model like model sensitivity and error analysis are also presented in this chapter.

5.1.1 KAASHIDHOO: SITE DESCRIPTION

With a view to studying the aerosols and radiation parameters and global influence of the sub-continent on them, the Center for Clouds, Chemistry and Climate (C3) established the Kaashidhoo Climate Observatory (KCO) on the island of Kaashidhoo (4.96°N, 73.46°E; encircled in Figure 5.1) in the Republic of Maldives in the year 1998. Maldives consists of a group of almost 1200 small islands forming a long, narrow belt spread over the Indian Ocean extending along the latitudinal region between 7°N to 1°S (Figure 5.1). The islands of Maldives are sufficiently far from India and Sri Lanka to be truly representative of the remote marine environment of the northern Indian Ocean, yet they are strongly influenced by the northeast monsoon.
Kaashidhoo is an isolated, small and falcate shaped island, roughly 2.9 km by 1 km in the Republic of Maldives, approximately 550 km southwest of the southern tip of the India. The nearest largest city is 85 km south, and the nearest neighbouring island is 20 km distant. The population of the island is about 1600 and is free from anthropogenic activities such as industries or automobile transport. Located on the island of Kaashidhoo, one of the largest islands in the Maldives, KCO is equipped with a suite of instruments to gather round-the-clock data on such things as solar flux under clear and cloudy conditions, aerosol chemical composition and radiative properties and trace gases tied to man-made emissions (Conant, 2000; Eck et al., 2001; Guazzotti et al., 2001; Lobert and Harris, 2001; Moorthy an Satheesh, 2001; Podgorny et al., 2000; Satheesh et al., 1999). With availability of aerosols and radiation measurements over the tropical Indian Ocean, KCO located on the tiny island of Kaashidhoo becomes an ideal site for estimating the global influence of the subcontinent (Krishnamurti et al., 1998). KCO also provide the facilities to record standard meteorological readings such as wind speed and direction, dry air temperature, relative humidity, barometric pressure and rainfall.

![Figure 5.1. Location of Kaashidhoo island in the Republic of Maldives.](image)

5.2 METEOROLOGICAL OBSERVATIONS OVER KAASHIDHOO DURING INDOEX, IFP-99

In this section, we describe the meteorological conditions that prevailed over the island of Kaashidhoo during INDOEX, IFP-99 campaign. The climate over the
islands of Maldives, which is determined by two monsoons, is warm and humid. The rainy Southwest monsoon begins during April and continues until October, while the Northeast monsoon prevails from the month of December to March. Continuous measurements of air temperature, relative humidity, wind speed, wind direction, barometric pressure and rainfall were taken at KCO through tower based meteorological instrumentation at KCO during the campaign. Detailed description of tower based meteorological instrumentation at KCO is given in Section 2.3 of this thesis. Further details on these measurements are also available in Lobert et al. (2001). Figure 5.2 shows the time series of hourly mean values of surface layer meteorological parameters obtained from various sensors mounted on the tower at an altitude of 14 m above the mean sea level during February 11 - March 31, 1999. Five panels (a) to (e) shown in Figure 5.2 gives the temporal variation of air temperature (AT), relative humidity (RH), pressure (Pres), wind speed (WS) and wind direction (WD) respectively. During the entire campaign period, AT shows variation within a range 25.0°C to 30.0°C with an average value of about 28.6°C (Figure 5.2a). From Figure 5.2a, it can be seen that the diurnal variability of AT over Kaashidhoo during the campaign lie between 2°C to 3°C, which is almost similar to the diurnal variability over the oceanic surface. From Figure 5.2b, it can be seen that RH during the campaign period varied between 67% to 93% with a mean value of about 80%. Temporal variation in pressure during the study period is shown in Figure 5.2c. On an average, pressure varied from 1002 mb to 1013 mb with a mean of about 1007 mb. Figure 5.2d gives the temporal variation of surface WS. In general, wind speeds were low in magnitude and varied within a range 1 ms⁻¹ to 9 ms⁻¹ with a mean value of about 4 ms⁻¹. Figure 5.2e shows the surface wind direction observed at KCO. Throughout the campaign period, northerly winds were observed. First half of the campaign before 10th March 1999 (Julian day number 69) experienced northeasterly winds, whereas northwesterly winds were observed after 11th March 1999. It has to be noted that INDOEX, IFP-99 campaign was conducted during Northern Hemispheric winter season, when the prevailing winds over the Indian sub-continent are north-easterly, as were seen over the island of Kaashidhoo.
Figure 5.2. Temporal variation of (a) air temperature, (b) relative humidity, (c) pressure, (d) wind speed and (e) wind direction respectively at KCO.
5.3 GLASS SONDE OBSERVATIONS OVER KAASHIDHOO DURING INDOEX, IFP-99

Balloon borne GLASS Sonde launches provide vertical variation of meteorological parameters, such as air temperature, relative humidity, wind speed, wind direction and pressure to an altitude of about 25 km. Further details on the sensors and data acquisition system through GLASS Sonde launches are already being described in Section 2.5 of the thesis (Further details on GLASS Sonde are also available at: http://www.atd.ucar.edu/sslff/facilities/gllass/).

Table 4.1 described in Chapter 4 of this thesis summarizes different moisture variables relevant for the study of vertical structure of the ABL. In this section, we present the estimates of moisture variables obtained from individual GLASS Sonde profiles over Kaashidhoo. The methodology of data processing and analysis of the vertical profiles of meteorological parameters obtained from GLASS Sonde profiles remain similar to that described in Section 4.2 of this thesis. During INDOEX, IFP-99 campaign period, three GLASS Sondes launches, typically at 0000, 0600 and 1200 UTC (corresponding to 0500, 1100 and 1700 LT, Kaashidhoo LT = GMT + 5 hrs.) were launched per day from the KCO to study the vertical structure of the lower atmosphere. On certain days, GLASS Sondes were also launched at 1800 UTC (2300 LT). Overall 143 launches were conducted during the entire campaign (February 11 – March 29, 1999).

5.3.1 DEGREE OF CONVECTION PREVAILING OVER KAASHIDHOO

For studying the degree of convection and thermodynamic structure of the ABL over Kaashidhoo in terms of vertical profiles of moisture variables, we have chosen seven different altitude levels (namely 50, 500, 1000, 1500, 2000, 3000 and 5000 m; hereafter these levels are referred to as seven standard levels), and the estimates of specific humidity (q), equivalent potential temperature (θ_e) and saturation equivalent potential temperature (θ_{es}) at these levels obtained from the individual profiles during the entire campaign are shown as a function of Julian day number (Figures 5.3 and 5.4).
**Figure 5.3.** Vertical variation of $q$ at seven standard altitude levels as a function of Julian day number.
Profiles of specific humidity essentially quantify the amount of water vapour present in the atmosphere as a function of height (Figure 5.3). On the other hand, the magnitudes of $\theta_e$ and $\theta_{es}$ can be linked with the latent heat release (Figure 5.4). In general, the specific humidity remains almost constant within the mixed layer. Above the top of the mixed layer, it decreases with increasing altitude. From figure 5.3, we notice that the magnitudes of $q$ do not show drastic variation in relation to Julian day numbers at an altitude of 50 m, whereas significant variations can be seen at an altitude of 2000 m and above. Large peaks in $q$ at an altitude of 2000 m and above (for instance, during Julian days 52-53, 60-62, 71-72, 76-77, 82-83 and 87) are due to enhanced convection during those days, which in turn can lead to the formation of convective clouds. In case of cloud topped boundary layers, the base of the cloud is often considered as the mixed layer top. Hence the vertical distribution of moisture is one of the critical parameters in describing the thermodynamic structure of the ABL.

Figure 5.4 gives variation of $\theta_e$ and $\theta_{es}$ at seven standard altitude levels as a function of Julian day number. Profiles of $\theta_e$ and $\theta_{es}$ are often used for the determination of various sub-layers of the ABL, such as cloud base, capping layer, inversion base and inversion top. In general, the altitude corresponding to minimum of $\theta_e$ and maximum of $\theta_{es}$ in an individual profile is taken as the inversion top. During enhanced convection, the magnitude of $\theta_e$ becomes larger and the difference between $\theta_{es}$ and $\theta_e$ comes down. Vertical slices of $q$ and $\theta_e$ (and $\theta_{es}$) shown in Figure 5.3 and 5.4 are used for identifying days with enhanced and suppressed convection during the campaign. With the help of vertical slices of $q$ and $\theta_e$ (and $\theta_{es}$) shown in Figure 5.3 and 5.4, Julian days 52-53, 60-62, 71-72, 76-77, 82-83 and 87 are considered to be cloudy and convective, where moisture is transported vertically up to higher altitudes due to active convection. On the other hand, Julian days 46, 56, 66-68, 74-75, 78-79 and 84-85 are taken as clear sky days with suppressed convection.
Figure 5.4. Same as Figure 5.3, but for $\theta_E$ (continuous line) and $\theta_{ES}$ (dashed line).
5.3.2 **Mixed Layer Height Variability over Kaashidhoo**

Profiles of virtual potential temperature ($\theta_v$) and specific humidity ($q$) are often used for determination of convective mixed layer heights (Garratt, 1992; Holt and Raman, 1985; 1986; 1987; Lambert and Durand, 1999; Lambert et al., 1999; Manghanani et al., 2000; Parasnis and Morwal, 1993). Mixed layer height variability along the cruise track of INDOEX, IFP-99 campaign is detailed in Section 4.5 of this thesis. In this section, we describe the mixed layer height variability over the tiny island of Kaashidhoo during INDOEX, IFP-99 campaign. To avoid the diurnal variability of the ABL, we show the convective mixed layer heights corresponding to 0600 UTC (1100 LT) profiles. Figure 5.5 shows the profiles of $\theta_v$ and $q$ obtained from the GLASS Sonde launches over Kaashidhoo corresponding to 0600 UTC (1100 LT). Profiles of $q$ are biased by 300 g kg$^{-1}$ so as to enable display of $q$ along with $\theta_v$ profiles. Profiles of $\theta_v$ and $q$ shown in Figure 5.5 are used for the identification of the top of the mixed layer. It has to be noted that during cloudy days (52-53, 60-62, 71-72, 76-77, 82-83 and 87), when enhanced convective activities help in the transportation of moisture to greater altitudes, accurate determination of the mixed layer top becomes difficult. Profiles of $\theta_v$ and $q$ during these days do not show sharp and significant gradients at the top of mixed layer. On the other hand, during cloud free and suppressed convective days (46, 56, 66-68, 74-75, 78-79 and 84-85), the top of the mixed layer is well defined.

Mixed layer heights corresponding to 1100 LT inferred from the profiles of $\theta_v$ and $q$ shown in Figure 5.5 are shown as a function of Julian day number in Figure 5.6. In general, mixed layer heights are low for cloud-topped boundary layers as observed during Julian day numbers 52-53, 60-62, 71-72, 76-77, 82-83 and 87. However, during cloud free clear sky days (as observed during Julian day numbers 46, 56, 66-68, 74-75, 78-79 and 84-85), a well-defined convective mixed layer is seen. To summarize, the mixed layer heights varied within a range of 255 m to 880 m, with a mean value of about 600 m during the entire campaign.
Figure 5.5. Profiles of $\lambda$ and $q$ corresponding to the GLASS Sonde launches at 0600 UTC (1100 LT) over Kaashidhoo during INDOEX, IFP-99 campaign.

On top of each profile, the Julian day numbers are marked.
5.4 MESOSCALE MODELLING OVER KAASHIDHOO

The main impetus for the study of atmospheric sciences in relation to meteorology has been the desire to forecast the weather objectively (predict future atmospheric states). Bjerknes (1911) described forecasting as an ultimate problem in meteorology and outlined forecasting as an initial-value problem, which involved solving of already known basic set of equations. However, the system of highly non-linear partial differential equations does not possess closed solutions. Mohanty and Madan (2001) reviewed the essential components of a numerical model for deterministic weather prediction. In brief, the essential components of a numerical model for determination of weather prediction can be described under the following points:

- Identification and understanding of physical processes
- Mathematical representation of atmospheric processes: Dynamical framework (Laws of conservation of mass, momentum and energy)
- Mathematical representation of physical processes: Parameterization of physical processes (Convection, turbulent transfer, radiation, land-ocean-air interaction)
- Description of initial conditions: Conventional and non-conventional observations, Analysis and Initialization
- Numerical Techniques: Computer solutions
- Post processing and validation of forecast
The spectrum of atmospheric motion extends from the mean free path of molecules at the lower end to the circumference of the earth at the upper end. Table 5.1 gives a detailed classification scheme for meteorological phenomena as a function of their time and space scales (adopted from Stull, 1988). It has to be noted that phenomena with very large time scales and spatial scales are not included in Table 5.1. Within such a wide range of motion, meteorologists have attempted to classify atmospheric flow according to the physical scale of the apparently coherent structures that appears generally or intermittently in an atmospheric flow (Tyagi, 2000). Mesoscale can be descriptively defined as having a horizontal scale of the order of few kilometers to several hundred kilometers or so, with a time scale of about 1 to 12 h. The vertical scale extends from tens of meters to the depth of the troposphere. Mesoscale can also be applied to those atmospheric systems that have a horizontal extent large enough for the hydrostatic approximation to the vertical pressure distribution to be valid, yet small enough for the geostrophic and gradient winds to be inappropriate as approximation to the actual wind circulation above the ABL (Pielke, 1984).
### Table 5.1. Typical Time Space Orders of Magnitudes for Micro and Meso Scales. (After Stull, 1988)

<table>
<thead>
<tr>
<th>Horizontal Spatial Scale</th>
<th>1 month</th>
<th>1 day</th>
<th>1 hour</th>
<th>1 minute</th>
<th>1 second</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 km</td>
<td>Hurricanes Fronts</td>
<td>20 km</td>
<td>Low level jet etc.</td>
<td>Meso α Scale</td>
<td></td>
</tr>
<tr>
<td>2 km</td>
<td>Thunderstorm etc.</td>
<td>Meso β Scales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200 m</td>
<td>Boundary layer Cu clouds etc.</td>
<td>Meso γ Scales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 m</td>
<td>Dust devils Thermals wakes</td>
<td>Micro α Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 m</td>
<td>Surface layer plumes</td>
<td>Micro β Scales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2 m</td>
<td>Mechanical turbulence</td>
<td>Micro γ Scales</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 cm</td>
<td>Isotropic turbulence</td>
<td>Micro δ Scale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5.4.1 **MESOSCALE MODELS**

Knowledge of meteorology forms the basis of scientific weather forecasting. The evolution of operational numerical weather prediction (NWP) from larger to smaller scales partially reflects the increased computer power that has allowed global models to resolve more details of atmospheric flow fields. Availability of high-power computers has led to the development of a variety of mesoscale models both in research and operational mode. Mesoscale meteorology has immensely benefited from major developments in observational techniques. Mesoscale analysis is an important pre-requisite for mesoscale research and modelling work. Operational mesoscale numerical weather prediction is now taking place in USA, UK, France, Japan, Australia, Poland, Austria, Rumania, Hungary and other European countries (Tyagi, 2000). These models fall primarily into three categories: (a) mesoscale non-hydrostatic models; (b) mesoscale hydrostatic models and (c) convective cloud models. In the present study, we have made use of two mesoscale models: (1) OSU One-dimensional PBL model and (2) ARPS model. In the following sections, we describe the inner details of both the models.

5.4.2 **OSU 1-D PBL (CAPS) MODEL.**

The Oregon State University One-Dimensional Planetary Boundary Layer model (hereafter referred to as OSU Model) simulates the atmosphere, soil and vegetated surface (Ek and Mahrt, 1991; Mahrt et al., 1984; 1987; 1991; Mahrt and Pan, 1984; Pan and Mahrt, 1987; Troen and Mahrt, 1986). The equations used in this composite model are comprehensive enough to approximate the important physical processes. The model is also robust with respect to atmospheric stability and has been run for long integrations under a variety of diverse conditions for many different locations around the globe (Ek and Mahrt, 1991; and the references cited therein).

**(A) MODEL EQUATIONS AND NUMERICAL METHODS:**

In order to close the system of equations and determine the turbulent mixing, the boundary conditions near the earth's surface must be provided. In order to obtain these initial conditions, an atmospheric surface layer parameterization is used.
BOUNDARY LAYER MODEL

The model forecasts the tendencies due to turbulent mixing of the potential temperature ($\theta$), specific humidity ($q$), and horizontal components of the wind ($V_h$, or $u$ and $v$). The set of prognostic equations is:

\[
\frac{\partial V_h}{\partial t} = \frac{\partial}{\partial z} \left( K_m \frac{\partial V_h}{\partial z} \right) - w \left( \frac{\partial V_h}{\partial z} \right) \quad (5.1)
\]

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K_h \left( \frac{\partial \theta}{\partial z} - \gamma_\theta \right) \right] - w \left( \frac{\partial \theta}{\partial z} \right) \quad (5.2)
\]

\[
\frac{\partial q}{\partial t} = \frac{\partial}{\partial z} \left( K_h \frac{\partial q}{\partial z} \right) - w \left( \frac{\partial q}{\partial z} \right) \quad (5.3)
\]

In equation (5.2) $\gamma_\theta$ is the counter gradient correction term for potential temperature (Troen and Mahrt, 1986). In the above equations, $K_m$ and $K_h$ (both in m$^2$s$^{-1}$) represent the coefficient of diffusivity for momentum and heat respectively. These coefficients are defined as:

\[
K_m = \frac{u_h h_k z}{h (1 - \frac{z}{h})} \quad (5.4)
\]

\[
K_h = K_m Pr \quad (5.5)
\]

In equation (5.4), $h$ is the boundary layer depth; $p$ is set equal to 2 and $u$ $\phi_m^{-1}$ ($z/L$) replacing $w$, in the stable case. $w$, represents the velocity scale (ms$^{-1}$) of the boundary layer defined as:

\[
w = u_s \phi_m^{-1} \left( \frac{z}{L} \right) \quad (5.6)
\]

where $u_s$ is the surface friction velocity, $z$ is the top of the surface layer (currently 0.4 $h$ in the model), and $L$ is the Monin-Obukhov length. In equation (5.5) $Pr$ is the turbulent Prandtl number (Ek and Mahrt, 1991).

\[
Pr = \begin{bmatrix} \frac{\phi_h(z)}{L} \\ -\frac{1}{L} \frac{\phi_m(z)}{h} \end{bmatrix} + \left( \frac{1}{Pr} \right) \begin{bmatrix} \frac{z}{L} \\ \frac{z}{h} \end{bmatrix} \quad (5.7)
\]
The term $\phi_m$ and $\phi_h$ used in equation (5.6) and (5.7) are the nondimensional profile function for the shear and temperature gradient (Businger et al., 1971). Further details on the set of equations may also be found in Troen and Mahrt (1986).

**SURFACE LAYER MODEL**

The surface layer fluxes are calculated and parameterized following Mahrt (1987) for the stable case and following Louis et al., (1982) for the unstable case with modification suggested by Holtslag and Beljaars (1989):

\[
\begin{align*}
\frac{u^2}{\sqrt{V_h}} & = C_m \frac{V_h}{\sqrt{V_h}} & \text{---(5.7)} \\
\frac{(w^2)}{\sqrt{V_h}} & = C_h (\theta_i - \theta_h) & \text{---(5.8)} \\
\frac{(w q)}{\sqrt{V_h}} & = C_h (q_i - q_h) & \text{---(5.9)}
\end{align*}
\]

where $C_m$ and $C_h$ are the surface exchange coefficients for momentum and heat respectively and they are defined so that the wind speed factor is absorbed in them. $|V_h|$ is the wind speed evaluated at the first model level above the surface. The potential temperature ($\theta_h$) and specific humidity ($q_h$) are taken at the first model level above the surface while the surface potential temperature ($\theta_i$) and specific humidity ($q_i$) are obtained from the surface energy balance. Further details on the surface exchange coefficients are described in Ek and Mahrt (1991). The soil model incorporated in OSU model has been described by Mahrt and Pan (1984) and Pan and Mahrt (1987).

**SURFACE ENERGY BALANCE**

Surface temperature is calculated from surface energy balance method:

\[
(1 - \alpha) S \downarrow + L \downarrow - \sigma T^4 = G + H + L.E \text{---(5.8)}
\]

where each term is expressed in W m\(^{-2}\). The first term on the Left Hand Side (LHS) is the downward solar radiation. The nondimensional coefficient $\alpha$ is the surface albedo and is a function of surface characteristics. The second term on the LHS is the downward atmospheric radiation. The third term on the LHS is the upward terrestrial radiation: the coefficient $\sigma$ is the Stefan-Boltzmann constant. The first term on the Right Hand Side (RHS) is the soil heat flux, the second term on the RHS is sensible heat flux and the last term on the RHS is latent heat flux.
**BOUNDARY LAYER CLOUDS**

Calculation of fractional cloud cover in the boundary layer is based on *Ek and Mahrt* (1991). The model predicts cloud cover using the following generalized equation:

\[ CLC = f(RH, \sigma_{RH}) \]  

---(5.9)

where \( CLC \) is the fractional cloud cover, \( RH(bar) \) is the maximum relative humidity in the boundary layer, and \( \sigma_{RH} \) is the standard deviation of relative humidity which accounts for the turbulent and mesoscale variations in relative humidity.

**DOWNWARD RADIATION**

The OSU model includes a simple radiation package for estimation of total downward radiation (*Collier and Lockwood*, 1974). In this package, the incoming solar radiation is calculated as:

\[ S_\downarrow = \left[ 1 - \left(1 - t\right)CLC^n \right]S_{cs\downarrow} \]  

---(5.10)

where \( S_\downarrow \) is the net incoming solar radiation (below clouds but above the ground), \( t \) is a fraction dependent on the solar radiation transmitted through the clouds which depends on sun angle, \( n \) is empirically derived coefficient (\( = 1.0 \) in the model), and \( S_{cs\downarrow} \) is the clear sky solar radiation adjusted for solar elevation. Atmospheric (downward longwave) radiation is parameterized as (*Ek and Mahrt*, 1991):

\[ L_\downarrow = \varepsilon \sigma T_{ref}^4 + c_2 CLC \]  

---(5.11)

where \( L_\downarrow \) is the downward atmospheric radiation; \( \varepsilon \) is the emissivity of the atmosphere; \( T_{ref} \) is the temperature at the reference height (200 m in the model) and \( c_2 \) is an empirically derived constant (\( = 60 \text{ Wm}^{-2} \)).

**FINITE DIFFERENCING TECHNIQUES**

The OSU model employs different schemes for the numerical simulation of each of the different physical processes depending on the stability and other characteristics of the terms being approximated. These schemes are: (1) the Leap-frog method used for time stepping in the boundary layer, (2) the fully implicit Crank-Nicholson time integration scheme with the Galerkin technique for atmospheric diffusion, (3) the
Crank-Nicholson scheme used for time integration in the soil and plant canopy, and (4) the Euler forward differencing scheme used for diffusion in the soil. Further details on the entire set of equations can be found in OSU Model User’s Guide (Ek and Mahrt, 1991).

(B) BOUNDARY LAYER PROCESSES IN OSU MODEL

In this section, we present a schematic diagram representing the boundary layer processes simulated in the OSU model. Figure 5.7 shows some important interactions between surface evapotranspiration and boundary layer development for conditions of daytime surface heating. In Figure 5.7, solid arrows indicate the direction of those feedbacks, which are normally positive (leading to increases of the recipient variable). Dashed arrows indicate negative feedbacks. Two consecutive negative feedbacks make a positive one. Depending on conditions, cloud cover can lead to positive or negative feedbacks.

[Diagram of Boundary Layer Processes]

*Figure 5.7. Suspected important interaction between surface evapotranspiration and boundary layer development for conditions of daytime surface heating.*
5.4.2 ARPS MODEL

The Atmospheric Regional Prediction Systems (ARPS) model has been developed by the Center for Advanced Prediction of Storms, Norman, Oklahoma, USA (Xue et al., 1995).

(A) MODEL DESCRIPTION

It is a general purpose, non-hydrostatic, compressible model designed for storm and mesoscale atmospheric simulation and real time prediction on computers. The model is three dimensional, non-hydrostatic and fully compressible. It is a primitive equation model based on compressible Navier-Stokes equations describing the atmospheric flow. It uses a generalized terrain following co-ordinate system with equal spacing in x and y directions and grid stretching in the vertical. The model has 1-D, 2-D and 3-D configurations. In the present study, 1-D configuration has been used.

The prognostic variables are cartesian wind components, perturbation potential temperature and pressure, sub grid scale Turbulent Kinetic Energy (TKE), mixing ratios for water vapour, cloud water, rain water, cloud ice, snow and hail. The spatial discretization is achieved by second order quadratically conservative and fourth quadratically conservative finite differences for advection and second order differencing for other terms. The A-akawa C-grid is used with a terrain following co-ordinate system. For temporal discretization a second order leap-frog scheme is used is used for large time steps with Asselin time filter option. A first order forward-backward explicit scheme with second order centered implicit scheme is used for small time steps. The solution technique is a split-explicit (mode-splitting) scheme with a vertically implicit option. A single sounding initializes the model. The vertical grid stretch option is used to increase the resolution in the lower layers. The model also provides options for isotropic and an-isotropic turbulence treatments. The options for sub-grid scale parameterization include the Smagorinsky-Lilly diagnostic first order scheme and 1.5 order TKE scheme. The model incorporates a Kuo cumulus parameterization scheme. Surface parameterization is achieved using the bulk aerodynamic laws as well as stability dependent formulations for surface wind stress, heat and moisture fluxes. The ARPS model used in the present study has a capability of forecasting mesoscale phenomena at a
horizontal scale of 5-15 km, that is for location of events to within 50 km of a
domain center. It also can give storm scale forecasts up to 6 hours for location of
events to within 10 km and a timing of events to within 15 minutes.

**THE PRIMITIVE EQUATIONS**

Primitive form of dynamic and thermodynamic equations, i.e., derived from
conservation principles of the basic physical variables such as momentum,
thermodynamic energy and mass, in Eulerian formulation forms the basis of the
numerical model. In ARPS, these equations are represented in a curvilinear
coordinate system, which is orthogonal in the horizontal. These equations are solved
in a rectangular computational space. In this system vertical grid stretching and a
lower grid surface that is conformal to the terrain are accommodated by vertical
transformations.

**PARAMETERIZATION**

Since resolution, i.e., size or scales of motion that can be properly described by the
model is limited by the model's grid spacing, effects of smaller scale motions must
be included in an 'average' or 'statistical' sense. For example, terms representing
the transport of quantities by moist or dry convective elements are inherently too
small to be resolved by the model. Their effects are parameterized. These
techniques are also employed to include the effects of surface fluxes and turbulent
transport, to name a few.

**(B) ARPS FEATURES**

**PROGNOSTIC VARIABLES**

Cartesian wind components, perturbation potential temperature and pressure, sub-
grid scale turbulent kinetic energy, mixing ratios for water vapour, cloud water, rain
water etc.

**INITIAL STATE**

Options for horizontally homogeneous initialization using a single sounding, analytic
functions, or three-dimensional horizontally inhomogeneous state.
**Top and Bottom Boundary Conditions**

Options for rigid, zero-gradient, perio dic, Raleigh sponge layer etc.

**Lateral Boundary Conditions**

Options for periodic, rigid, zero-gradient, wave radiating, externally forced and user specified conditions. All can be mixed and matched.

**Sub-Grid Scale Turbulence**

Options include a Smagorinsky-Lilly diagnostic first order closure, 1.5 order turbulent kinetic energy formulation etc. The model also provides options for isotropic and anisotropic turbulence based upon grid-aspect ratio.

**Surface Layer Parameterization**

Surface momentum, heat and moisture fluxes based on bulk aerodynamic drag laws as well as stability dependent formulations.

**History Dumps**

The ARPS supports several formats like HDF, NetCDF, GrADS, GRIB, packed binary, SavI3D etc.

**Restart Option**

Full restart capability is available at intervals selected by the user.

**Graphical Post Processing and Analysis**

A vector graphics package similar to NCAR Graphics, ZXPL OT, supports a variety of graphic functions and supports X-windows, GKS and post-script functionality. It is available for generating colour plots, 3D wire frames, and profiles of basic and derived fields using model generated history data.

Other significant features, no less important, include Divergence damping, spatial computational mixing, cloud microphysics, cumulus parameterization, soil model, etc. The new version of ARPS (version 4.5.0.1) has an option to incorporate
radiation physics parameters. These include an option to choose transmission functions in the long wave band.

**A Typical Forecast Algorithm**

1) Starting from an initial state in which all variables are known at all grid locations, tendencies for \( u, v, T, q \) (humidity), \( c \) (cloud water) and \( r \) (precipitation) are calculated by using their respective conservation equations.
2) New values of these dependent variables are calculated or stepped forward by using their initial values and their calculated tendencies.
3) New values of \( p_{\text{top}} \) are calculated from the top boundary conditions.
4) New values of \( p \) are diagnosed by integrating the hydrostatic equations down from the model top.
5) New values of \( p \) are diagnosed by substituting the already calculated new values of \( p \) and \( T \) into the ideal gas law.
6) Finally, new values of \( w \) are diagnosed by integrating the conservation of mass equation up from the surface.
7) Steps 1 through 6 are repeated as often as required.

**5.4.4 Model Run Configuration**

In addition to a numerical model, a complete system that includes pre-and post-model analysis techniques is necessary. Prior to running a model, the initial data must go through the following steps:

- **Data validation**: Data checked for errors and consistencies.
- **Objective Analysis**: Data interpolated and analyzed onto a regular grid.
- **Initialization**: Data prepared for the numerical model equations.

After the model has been run, results must be processed to provide diagnostic information and graphical displays before they can be interpreted. In this analysis presented in this chapter of the thesis, OSU and ARPS model includes the pre- and post-processing software. All the simulations are done for duration of 24 hours, and the models are initialized with vertical profiles of meteorological parameters corresponding to 0600 UTC GLASS Sonde sounding.
In this section, we describe some important parameters that are set in the input control files prior to running the model. Tables 5.2 and 5.3 show the model run configuration of OSU and ARPS model indicating some important parameters to the model:

**Table 5.2 OSU 1-D PBL Model Run Configuration**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model domain center</td>
<td>Kaashidhoo (04.96°N, 73.46°E)</td>
</tr>
<tr>
<td>Time step</td>
<td>6 seconds</td>
</tr>
<tr>
<td>Duration of the model run</td>
<td>24 hours</td>
</tr>
<tr>
<td>Roughness length for momentum</td>
<td>0.001 m</td>
</tr>
<tr>
<td>Roughness length for heat</td>
<td>0.001 m</td>
</tr>
<tr>
<td>Displacement height for vegetation</td>
<td>0.0 m</td>
</tr>
<tr>
<td>Albedo</td>
<td>0.25</td>
</tr>
<tr>
<td>Fractional cloud cover</td>
<td>as per manual observations</td>
</tr>
<tr>
<td>Soil type</td>
<td>3 (sandy loam)</td>
</tr>
<tr>
<td>No. of input levels</td>
<td>98 (50-m resolution)</td>
</tr>
<tr>
<td>No. of grid points in the vertical</td>
<td>38 levels (vertical stretching)</td>
</tr>
<tr>
<td>No. of output levels (to be printed)</td>
<td>60 (vertical stretching)</td>
</tr>
</tbody>
</table>

**Table 5.3 ARPS Model Run Configuration**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model domain center</td>
<td>Kaashidhoo (04.96°N, 73.46°E)</td>
</tr>
<tr>
<td>Model Configuration</td>
<td>1-D vertical column mode</td>
</tr>
<tr>
<td>Time step</td>
<td>60 seconds</td>
</tr>
<tr>
<td>Terrain Option</td>
<td>No terrain, flat ground</td>
</tr>
<tr>
<td>Mean sea level</td>
<td>5.0 m</td>
</tr>
<tr>
<td>Model grid set up</td>
<td>vertical grid stretching</td>
</tr>
<tr>
<td>Soil type</td>
<td>3 (sandy loam)</td>
</tr>
<tr>
<td>Roughness length for momentum</td>
<td>0.001 m</td>
</tr>
<tr>
<td>Roughness length for heat</td>
<td>0.001 m</td>
</tr>
<tr>
<td>No. of input levels</td>
<td>25 (~ 200-m resolution)</td>
</tr>
<tr>
<td>No. of grid points in the vertical</td>
<td>33 levels (vertical stretching)</td>
</tr>
<tr>
<td>No. of output levels (to be printed)</td>
<td>78 (100-m resolution)</td>
</tr>
</tbody>
</table>
OSU model is essentially one-dimensional PBL model and it has been run in the vertical column mode. ARPS model also has been run in one-dimensional vertical column mode and the simulations are compared with the observations. Both the models provide flexible control over many parameters that can be used to configure the model. Most of these parameters can be set at run time without modifying or recompiling the model code.

5.5 SENSITIVITY OF MODEL TO INPUT PARAMETERS

As described in the previous section (Table 5.2 and 5.3), simulation of ABL parameters from OSU and ARPS model requires certain input control parameters, which are fed to the model through control files. These input control parameters include albedo, roughness lengths for momentum and temperature, soil structure, vegetation type, cloud cover and some other factors (Please see Table 5.2 and 5.3 for details). Depending on the location of the experimental site, prevailing meteorological conditions and many other factors, these parameters are assigned to the models. Some of these parameters are very sensitive and can change the model output drastically; hence one should be very careful in assigning these parameters to the model prior to simulations. In this section, we show the sensitivity of model output fields to some of the input control parameters. Basically, we shall consider two output fields: (1) simulated surface layer parameters, such as surface temperature, air temperature, soil heat flux, sensible heat flux, latent heat flux and ABL height and (2) simulated profiles of winds, potential temperature and specific humidity.

5.5.1 OSU MODEL SENSITIVITY

(A) ALBEDO \( \alpha \)

The planetary albedo \( \alpha \) is defined as the ratio of the reflected (scattered) solar radiation to the incident solar radiation measured above the atmosphere. As this reflected radiation is lost immediately from the earth-atmosphere system, the accurate determination of planetary albedo is important in the calculation of the amount of solar radiation absorbed by the system, and therefore the climate of the earth. On average, the global albedo is 30\% \( \pm 2\% \). This value has been determined
from a number of satellite measurements over a period of a few years (Wells, 1997). However, it is not constant but varies on both seasonal and interannual time scales by approximately 2%. The latitudinal variation in albedo is determined by the elevation of the Sun, distribution and type of the cloud and some other factors. At latitudes less than 30° (either side of the hemisphere), the planetary albedo is relatively constant at about 25% (Wells, 1997). In the present study also, we have assigned a value of 0.25 for the albedo at Kaashidhoo.

In Figure 5.8, we show the variations in simulated parameters for a typical day (surface temperature, air temperature, soil heat flux, sensible heat flux, latent heat flux and PBL height) with change in albedo values. For testing the sensitivity of simulated parameters, three typical values of albedo (arbitrarily chosen as 0.25, 0.50 and 0.75) are assigned to OSU model for obtaining the corresponding outputs. We notice that, for higher values of albedo (0.50 and 0.75), diurnal variations of simulated parameters are affected. It also shows that for highly reflecting surface (with higher albedo), the ABL heights will be reduced in the magnitude. Figure 5.9 shows simulated profiles of $u$, $v$, $\theta$ and $q$ for three typical values of $\alpha$ ($= 0.25, 0.50$ and 0.75). We notice that the simulated profiles of $u$, $v$, $\theta$ and $q$ do not show large deviations for different values of $\alpha$, particularly above an altitude of about 1000 m, whereas a considerable variation can be seen below 1000 m (Figure 5.9), thereby indicating that simulations in lower altitudes are quite sensitive to albedo values.
Figure 5.8. OSU Model Sensitivity of simulated parameters to 'albedo':
(a) Surface temperature (°C), (b) Air temperature (°C), (c) Soil Heat Flux (Wm⁻²),
(d) Sensible heat flux (Wm⁻²), (e) Latent heat flux (Wm⁻²)
and (f) Planetary boundary layer height (m).
In this section, we describe the sensitivity of model output fields for different values of $z_0$. We have assigned two typical values of $z_0$ (0.001 m and 0.05 m) for obtaining the corresponding outputs. A typical value of 0.001 m for $z_0$ corresponds to open sea, whereas a value of about 0.05 m for $z_0$ corresponds to partly vegetated surface with few trees (Arya, 1988). Our aim is to study the variations in the model simulated fields due to change in surface roughness. Figure 5.10 and 5.11 show the variation in the output field for two typical values of $z_0$. Analogous to Figures 5.8 and 5.9, the plots shown in Figure 5.10 and 5.11 correspond to surface parameters and profiles respectively. From Figure 5.10, we notice that the magnitudes of all the parameters except latent heat flux show larger values for $z_0 = 0.05$ m compared to those for $z_0 = 0.001$ m. Larger values of latent heat flux for $z_0 = 0.05$ m can be attributed to partly vegetated surface which in turn can produce moisture through transpiration. In contrast to Figure 5.10, we do not see any drastic changes in the output fields in terms of profiles, as shown in Figure 5.11. Simulated profiles of $u$, $v$, $\theta$ and $q$ almost retrace the same values for both the values of $z_0$, thereby indicating that the simulated profiles of these parameters are less sensitive to the values of roughness lengths initially assigned to the model.
Simulations for 57th Julian day
Initial time: 1100 LT (57th Jday) End time: 1100 LT (58th Jday)
--- (z_0 = 0.001 m); --- (z_0 = 0.05 m)

Figure 5.10. OSU Model Sensitivity of simulated parameters to 'roughness length':
(a) Surface temperature (°C), (b) Air temperature (°C), (c) Soil Heat Flux (Wm⁻²),
(d) Sensible heat flux (Wm⁻²), (e) Latent heat flux (Wm⁻²)
and (f) Planetary boundary layer height (m).
Simulated Profiles (+12 hr run)

- \( z_0 = 0.001 \text{ m} \);
- \( z_0 = 0.05 \text{ m} \)

Figure 5.11. OSU Model Sensitivity of vertical profiles to 'roughness length':
(a) Zonal winds \( u, \text{ ms}^{-1} \), (b) Meridional winds \( u, \text{ ms}^{-1} \),
(c) Potential temperature \( \theta, \text{ K} \) and (d) Specific humidity \( q, \text{ g.kg}^{-1} \).

5.5.2 ARPS Model Sensitivity

In Space Physics Laboratory, ARPS model has been in use in operational mode for predicting winds, wind shears and thunderstorm activity over Sriharikota (13.1°N, 80.3°E), a site on the east coast of India and in parallel as a specific research activity with similar goals to understand and improve the capabilities of the model in a tropical environment (Dolas et al., 2001; Radhika, 2001; Radhika and Dolas, 2001a; 2001b; 2000; Radhika et al., 2002). The sensitivity studies conducted using ARPS model shows that a 15% error in the input wind value causes a change in the 12-hour forecast that is well within the model prediction error margins. For 2-D and 3-D configuration runs using ARPS, topography, soil and vegetation data with fine resolution and near real time are essential for forecast studies. Accurate lateral boundary conditions from global regional model are most essential. A suitable choice of moist processes, soil model and surface layer parameterization for the tropics is vital (Radhika, 2001; 1999; Radhika and Raman, 1997). However, it must be noted that ARPS was run in -D vertical column mode configuration in order to maintain similarity with OSU model. Moreover, 2-D and 3-D runs require lateral boundary conditions, fine topography details, which at present are not available for
the experimental site. Since, we do not have the actual observations and estimates of surface layer parameters (e.g., surface layer fluxes and soil heat flux), the study had to be restricted towards simulation of profiles of winds, temperature and humidity, so that the simulated output can be compared with the actual observations.

5.5 SIMULATION OF $u$, $v$, $\theta$ AND $q$
PROFILES OVER KAASHIDHOO

In this section, we present model simulations of winds (zonal winds `$u$' and meridional winds `$v$'), potential temperature ($\theta$) and specific humidity ($q$) for +6 hr, +12 hr, +18 hr and +24 hrs. For capturing the diurnal evolution of vertical structure of the ABL over Kaashidhoo, simulations were carried out for duration of 24 hours each for an individual run. Simulations were done from 06 UTC to 06 UTC (next day). Both the model's are initialized with the input sounding file corresponding to 06 UTC and the simulated profiles of $u$, $v$, $\theta$ and $q$ corresponding to 12, 18, 24 and 06 UTC (+6, -12, +18 and +24 hrs) are compared with the observations.

Two extreme cases are chosen for comparisons: one during enhanced convective and cloudy days (Julian day numbers 60 and 83) and other one during clear sky cloud free days (Julian day numbers 56 and 85). The main aim of the simulations is to study the diurnal evolution of the vertical profiles of $u$, $v$, $\theta$ and $q$ over a tiny island for different stability conditions and study the model performance. Figures 5.12 to 5.19 show the simulations of $u$, $v$, $\theta$ and $q$ profiles for Julian day number 60, 83, 56 and 85 respectively.

During enhanced convective and cloudy conditions (Julian day number 60 and 83, Figure 5.12 - 5.15), we notice that model performance is quite good for +6 hr and +12 hr simulations, whereas winds do not show good agreement beyond that. Both the models show similar features in the vertical profiles of zonal and meridional wind components for all the four simulations (i.e., +6, +12, +18 and +24 hr). Observed profiles of $\theta$ and $q$ for both the days show suppressed mixed layer heights with a stable layer on top of the mixed layer. In such situations, accurate definition of the top of the mixed layer is difficult. However, in contrast to
actual observations, simulated profiles of $\theta$ and $q$ from OSU model show a well
defined mixed layer, which is not true as can be seen from the observations. On the
other hand, simulated profiles of $\theta$ and $q$ from ARPS model seem to be in better
agreement with observations in comparison with OSU simulations. However, in both
the model simulations, the magnitudes of $\theta$ and $q$ differ significantly from the
observations. During clear sky and cloud free days (as seen on Julian day number 56
and 85, Figures 5.16 - 5.19) also, we see similar features in simulations. Overall,
we notice that simulation of meridional wind component does not match the
observations for a 24 hr run. When the winds are low in magnitude, simulations
seem to be in good agreement with observations, as against the high windy
conditions.
**56th Julian Day (Cloud Free Clear Sky)**

Figure 5.12. Simulation of $u$ (top panel) and $v$ (bottom panel) components for $+6, +12, +18$ and $+24$ hrs. (56th Julian day)

Figure 5.13. Simulation of $\theta$ (top panel) and $q$ (bottom panel) for $+6, +12, +18$ and $+24$ hrs (56th Julian day).
Figure 5.14. Similar to Figure 5.12, but for 85th Julian day.

Figure 5.15. Similar to Figure 5.13, but for 85th Julian day.
Figure 5.16. Similar to Figure 5.12, but for 60th Julian day.

Figure 5.17. Similar to Figure 5.13, but for 60th Julian day.
Figure 5.18. Similar to Figure 5.12, but for 83rd Julian day.

Figure 5.19. Similar to Figure 5.13, but for 83rd Julian day.
For studying the quantitative estimates in the errors in simulations, we have estimated Root Mean Square Errors (RMSE) for OSU and ARPS simulations separately for each set of the plots (Figure 5.12 - 5.19). RMS errors are defined as:

\[ \text{RMSE} = \frac{1}{N} \left[ \sum_{i=1}^{N} (\text{Observed}_i - \text{Simulated}_i)^2 \right]^{1/2} \]

where \( N \) is the number of observations in vertical.

RMSE estimates corresponding Figures 5.12 - 5.19 are tabulated in Table 5.4. From the Figures 5.12 - 5.19 and Table 5.4, we see that the model performance for different convective conditions is quite reasonable for both the models for simulations of \( u, v, \theta \text{ and } q \) up to +12 hrs. Simulated profiles of \( \theta \text{ and } q \) from both the models show good match with the observations with RMSE estimates less than 3°C for \( \theta \) and less than 2 g kg\(^{-1}\) for \( q \). However simulation for +18 and +24 hrs are not in good agreement. In general, the RMS error increases for +18 and +24 hr simulation as against for +6 and +12 hrs. Most of the times, simulation of meridional wind component does not show good agreement with the observations. Such a mismatch between simulations and observations can be due to the fact that both the models are run in 1-D configuration and hence the dynamical features associated with horizontal advection of winds are not capture satisfactorily.
<table>
<thead>
<tr>
<th>Degree of Convection</th>
<th>Julian Day No.</th>
<th>Model</th>
<th>Parameter</th>
<th>Simulation Period (in hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+ 06</td>
</tr>
<tr>
<td>Clear Sky</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>56 (Figure 5.12 &amp; 5.13)</td>
<td>OSU</td>
<td>u (ms⁻¹)</td>
<td>1.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>v (ms⁻¹)</td>
<td>2.32</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>θ (K)</td>
<td>1.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>q (g.kg⁻¹)</td>
<td>2.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ARPS</td>
<td>u (ms⁻¹)</td>
<td>3.95</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>v (ms⁻¹)</td>
<td>2.93</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>θ (K)</td>
<td>2.69</td>
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<td></td>
<td>q (g.kg⁻¹)</td>
<td>4.72</td>
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<td>85 (Figure 5.14 &amp; 5.15)</td>
<td>OSU</td>
<td>u (ms⁻¹)</td>
<td>1.76</td>
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<tr>
<td></td>
<td></td>
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<td>v (ms⁻¹)</td>
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<td></td>
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<td>q (g.kg⁻¹)</td>
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<tr>
<td></td>
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<td>ARPS</td>
<td>u (ms⁻¹)</td>
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<td>θ (K)</td>
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<td>q (g.kg⁻¹)</td>
<td>1.62</td>
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<td>60 (Figure 5.16 &amp; 5.17)</td>
<td>OSU</td>
<td>u (ms⁻¹)</td>
<td>2.03</td>
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<tr>
<td></td>
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<td>v (ms⁻¹)</td>
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<td>θ (K)</td>
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<td>θ (K)</td>
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<td></td>
<td>q (g.kg⁻¹)</td>
<td>1.55</td>
</tr>
<tr>
<td>Cloudy Days</td>
<td>83 (Figure 5.18 &amp; 5.19)</td>
<td>OSU</td>
<td>u (ms⁻¹)</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>v (ms⁻¹)</td>
<td>-</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>θ (K)</td>
<td>1.38</td>
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<td>q (g.kg⁻¹)</td>
<td>1.34</td>
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<td></td>
<td>θ (K)</td>
<td>1.55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>q (g.kg⁻¹)</td>
<td>1.86</td>
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</table>
5.7 CONCLUDING REMARKS

In this chapter of the thesis, some of the interesting features of the ABL observed over Kaashidhoo during INDOEX 1999 campaign are described. Kaashidhoo, being a tiny island, surface layer meteorological observations at KCO suggest weak diurnal variability in air temperature and relative humidity. This suggests the overwhelming influence of the surrounding ocean that engulfs this tiny island. Mixed layer heights inferred from the daytime profiles of thermodynamic variables corresponding to 1100 LT show a variation within a range of 255 m to 880 m with a mean value of about 600 m. During cloud free and clear sky days, well-defined mixed layer is observed, whereas mixed layer structure was not well defined during enhanced convection.

With a view to testing mesoscale model performance over Kaashidhoo and to see how the model simulation supports the observations, OSU and ARPS models were used in 1-D vertical column mode to simulate the lower atmosphere circulation over Kaashidhoo. Model simulations for varying convective conditions show good agreement for + 6 hr to + 12 hr duration, whereas it is not so beyond +12 hr. This could be because the simulations are done in 1-D configuration. Perhaps a 2-D/3-D simulation with realistic lateral boundary conditions would be able to provide a better picture. Also one needs to conduct the simulations in a small domain with high-resolution land use and terrain data. This is presently not available for the Kaashidhoo region. However, these mesoscale models can serve as important tools to study the diurnal variability of the ABL parameters over places where routine observations are not available.

# - # - # - # - # - #