Chapter 7

Summary and Scope of the future work

Summary

To improve the current knowledge of the aerosol properties, seasonal trends and climate implications over Hyderabad, this thesis mainly focused on three specific topics 1) Seasonal and temporal variation of aerosol characteristics, 2) Classification of aerosol types and their modification processes and 3) Spatial and vertical aerosol characteristics. These studies were further supplemented by observations carried out over surrounding hotspot regions including Bay of Bengal (BoB), Arabian Sea (AS), Northern Indian Ocean (NIO) and the Indo Gangetic Plain (IGP) which have profound impact on observed aerosol properties at Hyderabad. The important findings and results obtained from this study are summarized in the following:

The daily averaged values of aerosol optical depth (AOD_{500}) and Ångström exponent ($\alpha_{440-870}$) during the period of April 2009-March 2010 over Hyderabad showed significant day-to-day variability in both AOD_{500} and $\alpha_{440-870}$, which indicates the influence of meteorology, variety of aerosol types and sources. The large daily variations in $\alpha_{440-870}$ suggests significant daily variations in particle size distributions ranging from fine mode dominated events ($\alpha_{440-870} > 1.5$) during postmonsoon and winter to coarse mode dust events ($\alpha_{440-870} < 0.17$) during monsoon and the mixed aerosol size and type particularly during pre-monsoon season. The magnitude of the AOD values during winter and post-monsoon seasons is much lower compared to the pre-monsoon season but exhibits higher spectral dependence. The seasonal variation in the spectral dependence is mainly caused by the presence of aerosols of different origin and characteristics. The spectral variation of Ångström exponent (i.e. curtature effect, α_2) showed negative curvature associated with the fine mode particles for post monsoon and winter while positive curvature for coarse mode abundance in the pre-monsoon and monsoon season. The fine-mode aerosols in post-monsoon and winter seasons appear to be associated with airmasses from continental India, while the coarse-mode particles during pre-monsoon and monsoon seasons seem to be arriving from the west Asia and western India. The aerosol columnar size distribution (CSD) retrieved from the spectral AOD data over Hyderabad during the period of January 2008 to December 2009, showed bimodal size distributions for all the seasons except for monsoon, with an accumulation mode radius of 0.12-0.25 µm and a coarse-mode aerosol of 0.86-1.30 µm. The CSD during monsoon follows the power law functional form for fine-mode and the unimodal distribution for coarse mode aerosol.

The classification of aerosol types and the modification processes were studied using three techniques i) Ångström exponent (α) vs AOD correlation, ii) α vs dα variations as a function of AOD and iii) aerosol number size distribution using King's inversion algorithm. The analysis show the presence of fine-mode aerosols under turbid atmospheres in winter and post-monsoon, the concurrent presence of fine and coarse aerosol types in pre-monsoon and the significant influence of marine mixed with dust air masses in monsoon season. The occurrence of several aerosol modification processes such as coagulation and condensation in winter and post-monsoon, gas to particle conversion and hydration process seems to be more effective in pre-monsoon and humidification of aerosols was observed during monsoon season. A comparison of the results and drived parameters obtained from different methods were found to be consistent with each other.

The temporal variation of Black Carbon (BC) aerosols over different timescales including daily and annual changes were studied using extensive round-the-clock measurements during the period of 2009 to 2010 over Hyderabad. The BC values were highest during winter season (December to January) ~ 6.67 ± 0.22 µg m^{-3} and lowest during summer (June to August) ~ 2.36 ± 0.09 µg m^{-3}, which establishes that there is a large seasonal variation. In addition to seasonal variation, BC mass concentration also showed strong well defined diurnal variations with a morning peak and minimum at afternoon. The absorption Ångström exponent (α_{abs}) estimated from the spectral values of absorption coefficients (σ_{abs}) are found to vary from 0.9 to 1.1, indicating high BC/OC ratio typical of fossil fuel origin. The most potential source regions contributing to BC mass concentrations in Hyderabad are the eastern coastal India, central India, western IGP and Pakistan. Air masses originating from Arabian Peninsula and Persian Gulf traversing the northern AS can also contribute to BC mass concentrations.

The lidar measurements were also carried out during the period of April 2009 to March 2010 over Hyderabad and the results reveal considerable variations of the vertical distribution and concentration of aerosols within the boundary layer and in the free troposphere. The majority of aerosols were found in the boundary layer below 2 km and in some cases they reached higher altitudes (~4 km) during pre-monsoon. The data show that the boundary layer aerosols originate mainly from local sources during winter, while a mix of local and those arriving from long-range transport during pre-monsoon season. The extinction and backscatter vertical profiles revealed that the aerosol properties get significantly modified depending on season, atmospheric boundary layer variations, local aerosol emissions and long-range transport. The vertical profiles of extinction coefficient revealed the presence of multiple elevated aerosol layers on certain days during monsoon season refered as "Monsoon Layers". The contribution of atmospheric boundary layer AOD to the total AOD was found to be 92.5±6.9%, 68.5±13.4%, 88.2±8.1% and 93.6±4.4% for the pre-monsoon, monsoon, post-monsoon and winter, respectively. This seasonal variation is similar to the one that was observed for BC mass fraction indicating that the BC aerosols play an important role in the determination of columnar aerosol loading (i.e. AOD) in the urban environment.

The composite aerosol radiative forcing (ARF) calculated using SBDART shows pronounced monthly variability at surface, top of the atmosphere (TOA) and within the atmosphere due to large variations in AOD and SSA. In general, larger negative ARF values at surface (-65 to –80 Wm^{-2}) and TOA (~-17 Wm^{-2}) are observed in pre-monsoon and early monsoon. The atmospheric heating is higher (~50-70 Wm^{-2}) during January-April resulting in heating rates of ~1.6-2.0 $Kday^{-1}$. The radiative forcing at the atmosphere due to BC component alone shows strong seasonal dependency, higher in winter (33.49 ±7.01 Wm^{-2}) and pre-monsoon (31.78±12.89 Wm^{-2}) and moderate in postmonsoon (19.54±9.38 Wm^{-2}) and monsoon (14.68 ±2.90 Wm^{-2}). The annual average BC mass fraction was found to be 10±3 % and contributing to the atmospheric forcing by 55 ± 10 %. The BC ARF at TOA is positive for all months, thus suggesting an overall heating of the regional climate.

The ship-borne measurements of the aerosol physical and optical properties over the BoB were carried out during the period of 27 December 2008 to 30 January 2009. The results show a large spatial and temporal heterogeneity in aerosols characteristics such as the total aerosol number concetraion (N_T), AOD_{500}, $\alpha_{380\text{-}870}$ and α_2 over the entire study region. The classification of the aerosols using aerosol load (AOD_{500}) and $\alpha_{380\text{-}870}$ indicated an extremely large fraction of fine-mode aerosols in turbid atmospheres, even larger than 90% in the western part of BoB and approaches 100% over eastern BoB. Furthermore, there is also an evidence of aerosol-size growth under more turbid conditions, which is indicative of coagulation and/or humidification over specific BoB regions. The aerosol number size distribution showed a bi-modal distribution over BoB for 72% of the cases and for the rest of the cases the distribution can be parametrized by uni-modal or by a combination of both power law and uni-modal distributions. The mode radius for accumulation and coarse mode particles ranges from ~0.13±0.01 μm and ~0.72±0.10μm respectively. In the northern BoB and along the Indian coast, the aerosols are mainly of sub-micron size with effective radius (R_{eff}) ranging between 0.25 μm and 0.3 μm highlighting the strong anthropogenic influence, while in the open oceanic areas these have much higher effective radius (0.4-0.6 μm). The altitude variation of aerosol number density over BoB studied for the first time during W-ICARB compaign was found to be steady in the convective boundary layer of upto ~ 400 m at all locations and above 400m the aerosol concentration is found to decrease, except for far eastern BoB. Over far eastern BoB, the altitude distribution of aerosol number concentration showed an increase at ~ 600 m. The simultaneous air mass back trajectories computed at respective locations indicated that the air masses arriving over central and northern BoB, mainly originated from the IGP, while those reaching over eastern/far eastern BoB and coastal AS were originating from the East Asian regions. This along with the observations of effective radius (R_{eff}) and mode radius of the size distribution (r_{m2}), indicated that the aerosols advected from IGP have an important natural component (i.e. coarse mode aerosols) while, those from the East-Asia region are in general of accumulation mode aerosols.

The long term trends in aerosol characterstics in the Southeast Asian region derived from MODIS observations of AOD_{550} during the last decade (2000–2009) show considerable spatio-temporal variations in AOD_{550} as well as its decadal changes with a general increasing trend by 10.17% over the whole South Asia. This increasing trend was found to be more intense during winter season. A pronounced decrease in AOD_{550} trend was observed over IGP during late pre-monsoon and monsoon months (April to September) and interestingly higher in the western IGP. This decrease in AOD may be closely related to the attenuation of dust activity. The GOCART simulations also showed considerable reduction of dust-AOD and its contribution to the total AOD over south Asia during 2000–2007, which is in agreement with the MODIS observations of decreasing AOD trend over IGP.

Scope of the future work

It is seen that the spatial and temporal inhomogeneities in surface, columnar and vertical aerosol characteristics due to the variety of the aerosol sources and sinks, the influence of dynamic and synoptic meteorology and the mixing processes, coagulation, humidification, are the key determinant of aerosol characterstics in a given location. Over Southeast Asia these parameters have large uncertainties in the global climate system. To reduce the uncertainty associated with climate model due to aforementioned components, the comprehensive study of the microphysical and optical properties of aerosol and their interactions with cloud over entire Southeast Asia are necessary for developing the accurate model and society benefits. Results from several field campaigns (e.g. INDOEX, ACE-Asia, ICARB/W-ICARB) have shown that large amounts of wind-blown dust particles and other anthropogenically produced aerosols get transported from the Asian landmass over oceanic regions, thousands of kilometers away from their sources and result in the frequent occurrence of elevated aerosol layers (e.g. Ramanathan et al., 2001, Moorthy et al., 2009, Kaskaoutis et al., 2011). Radiative forcing studies show a large negative forcing at the surface and comparably large atmospheric heating over Southeast Asia (Ramanathan et al., 2001, Huebert et al., 2003). The absorbing haze over Northern Indian Ocean has decreased the surface solar radiation by an amount of about 50% of the total ocean heat flux and nearly doubled the lower tropospheric solar heating (Ramanathan et al., 2001). This tropospheric solar heating can evaporate lower level clouds and decrease the cloud cover and albdeo and affect the Earth's radiation budget (Ackerman et al., 2000). More recently, Lau et al. (2006) reported that an elevated BC aerosol mixed with dust particles over Southeast Asia can impact the stability of the atmosphere and consequently the monsoon circulation and so called Elevated Heat Pump effect. Despite the great progress that has been made in understanding of atmospheric aerosols from the systematic ground-based measurements and satellite remote sensing, the uncertainties in their direct and particularly indirect effects still persist, mainly due to the short life time (~ 5-7 day) of aerosols, spatial and temporal variabilities of aerosol properties and their mixing state. Therefore, for better understanding of aerosols and their climate implications, the evolution and characteristics of aerosol particles and their interaction with clouds need to be further examined on regional and global scales. The goals of the proposed research are:

1. Extensive measurements of size resolved chemical, micro-physical and optical properties of aerosols as a function of altitude and interrelationship between these properties and their controlling factors during anthropogenic pollution, biomass burning, dust and marine aerosol transportation.

2. Assess the mixing state (internal/external) of aerosol as a function of altitude and estimate the impact of aerosol mixing state on temporal evolution of aerosol size distribution and optical properties and their radiation budget as a function of altitude.

3. Estimate the radiative impact of size-segregated (fine/anthropogenic and coarse/natural) aerosols, relative contributions of fine and coarse mode aerosols to the composite aerosol forcing and their spatial and temporal trends as well as their impact on regional precipitation.

4. Investigate the vertical profile of aerosol and cloud properties acquired from the concurrent measurements during different episodes of biomass burning, dust transportation and their impact on the Earth's radiation budget.

5. Evaluate to what extent an absorbing aerosol can impact the cloud properties and cloud development.

6. An assessment of radiative forcing and their heating rates of various trace gases.