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Supplement of "Quantifying the contribution of long-range transport to Particulate Matter (PM) mass loadings at a suburban site in the North-Western Indo Gangetic Plain (IGP)"

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SUPPLEMENT

1 Spatial and dynamic patterns of the air flow associated with the clusters

The *local cluster* accounts for 40.1, 35.7, 31.1 and 51.3 % of the air mass trajectories during winter (December to February), summer (March to June), monsoon (July to September) and post-monsoon (October and November) season respectively. This air mass transport corresponds to times when weak northerlies or north-westerlies and a weak, low-level anti-cyclonic circulation prevail in the NW-IGP during winter, summer and post monsoon season. The predominant locally measured wind direction for this cluster during winter, summer and post monsoon season is west to north-west (47 % of the time) with katabatic winds (320–120° wind sector) accounting for most of the remainder (31 %). South easterly winds (8 %) and south westerly winds (14 %) account only for a minor fraction of the locally observed wind direction each. During summer season and monsoon season convective activity above the site is also attributed to this cluster. Strong squalls leading to "Aandhi" type convective dust storms (Joseph, 1982) are observed occasionally, both in late summer and early in the monsoon season. During monsoon season, locally observed wind direction associated with this cluster is variable (35 % north west, 29 % south east, 18 % south west, 18 % katabatic flow). The local cluster is associated with average temperatures and wind speeds at the lower end of those observed for the different clusters both during day and night in all seasons. The absolute humidity is higher than the absolute humidity observed for medium and fast westerly flows and lower than the absolute humidity observed for south easterly and south westerly flow during all seasons. Occasionally rain events occur in all seasons, however, the total number of rain events associated with the local cluster is low except during monsoon season.

The *slow westerly* cluster is associated with the same general meteorology (weak northerlies or north-westerlies and a weak, low-level anti-cyclonic circulation) as the local cluster and most of the locally observed parameters are also similar to those of the local cluster. However, the fetch region of the air masses is larger. The predominant local wind di-

rection for this cluster is west to northwest during all seasons including monsoon (50 %) and katabatic winds from the north-northwest to east-southeast sector (28 %) account for most of the remainder. South easterly winds (10 %) and south westerly winds (12 %) account only for a minor fraction of the locally observed wind direction each. The main differences between air masses associated with the local cluster and air masses associated with the slow westerly cluster are as follows: slightly higher temperatures and wind speeds are observed for the slow westerly cluster during most seasons and both relative and absolute humidity are lower for air masses associated with the slow westerly cluster due to the recent descend of the air masses from the free troposphere. Air masses associated with the slow westerly cluster have a shorter residence time in the convective boundary layer over the irrigated fields in the IGP and consequently contain less moisture. The slow westerly cluster accounts for 17.4, 26.6, 10.7 and 28.4 % of the air mass transport to the site during winter, summer, monsoon and post-monsoon season respectively. Rain events are associated with this cluster only rarely.

The *medium westerly* cluster is observed only during winter, summer and post monsoon seasons and accounts for 7.7, 8.5 and 4.5 % of the air masses respectively. The clusters are associated with a strong subtropical jet stream poised over westerly troughs and shows higher than average wind speeds. The predominant local wind direction for this cluster is west to northwest during all seasons (44 %) and katabatic winds from the north-northwest to east-southeast sector (38 %) account for most of the remainder of the flow. South westerly (13 %) and south easterly winds (6 %) account for only a minor fraction of the locally observed wind direction each. Air masses associated with this cluster descended from the free troposphere less than 30 h prior to their arrival at the receptor site and had significant residence time over arid regions west of India. Consequently, they are associated with low relative and absolute humidity and do not bring rain. The medium westerly cluster is typically observed shortly before the arrival of a western disturbance.

The *fast westerly* cluster is observed only during winter, summer and post monsoon seasons and accounts for 7.7, 6.4 and 6.4 % of the air masses respectively. The cluster is associated with a strong subtropical jet stream poised over westerly troughs and shows

higher than average wind speeds. The predominant local wind direction for this cluster is West to Northwest during all seasons (60 %) and katabatic winds from the north-northwest to east-southeast sector (30 %) account for most of the remainder. South westerly (6 %) and south easterly winds (4 %) account only for a minor fraction of the locally observed wind direction each. Due to the fact that air masses associated with this cluster descended from the free troposphere less than 30 h prior to their arrival at the receptor site and had significant residence time over arid regions west of India, they are associated with low relative and absolute humidity and do not bring rain. The fast westerly cluster is most frequently observed during winter and early summer season 2–3 days prior to the arrival of a western disturbance.

The *south easterly* cluster is associated with the passage of a western disturbance in winter and summer and with active spells of the monsoon during monsoon season and accounts for 19.3, 13.1 and 42.6 % of the flow respectively. It is generally not observed during post monsoon season. The western disturbance is responsible for most of the wintertime and summer time rain events (Table 1 of main paper). During winter and summer season, the predominant local wind direction for this cluster is south easterly (38 %). Katabatic winds from the north-northwest to east-southeast sector account for 27 %, south westerly winds for 17 % and north westerly winds for 18 % of the locally observed wind direction. Temperatures and wind speeds associated with this cluster are above average in winter and below average in summer. The relative and absolute humidity of air masses associated with this cluster are always high during both seasons. During monsoon season, the "Bay of Bengal branch" of the monsoon circulation brings warm and moist air masses to the receptor site. The absolute humidity is high and the highest total amount of rainfall is observed for this cluster. The predominant local wind direction for this cluster is south east (53 %). Katabatic winds from the north-northwest to east-southeast sector account for 24 %, south westerly winds for 12 % and north westerly winds for 11 % of the locally observed wind direction.

The *south westerly* cluster is associated with the passage of a western disturbance in winter and summer and with "break" spells of the monsoon during monsoon season and accounts for 3.4, 7.3 and 10.4 % of the flow respectively. It is not observed during post

monsoon season. During winter and summer, the south westerly cluster is usually observed in association with a weakening western disturbance or at times when the centre of the low pressure system is above or close to the receptor site. The predominant local wind directions are west to northwest (42 %) and southeast (35 %). South westerly winds (13 %) and katabatic flow (10 %) account only for a minor fraction of the locally observed wind direction. During monsoon this cluster is associated with "break" spells. "Break" spells occur when the monsoon trough is located over the foothills of the Himalayas and the low level jet originating off the coast of Somalia enters the IGP through the Indus valley. The local wind direction is variable: 46 % south east, 21 % north west 21 % katabatic flow and 11 % south westerly winds. The absolute humidity of air masses associated with this cluster is high although rainfall events occur only rarely. However, extreme rainfall events are associated more frequently with this cluster.

Calm conditions (WS $< 1\,\mathrm{m\,s^{-1}}$) account for only 4.5, 2.5, 5.2 and 8.7 % of the total time during winter, summer, monsoon, post-monsoon season respectively. They occur more frequently at night (60 %) and less frequently during the day (40 %). The local wind direction during periods with low wind speed is variable: 36 % south west, 33 % katabatic flow, 19 % south east and 12 % north west.

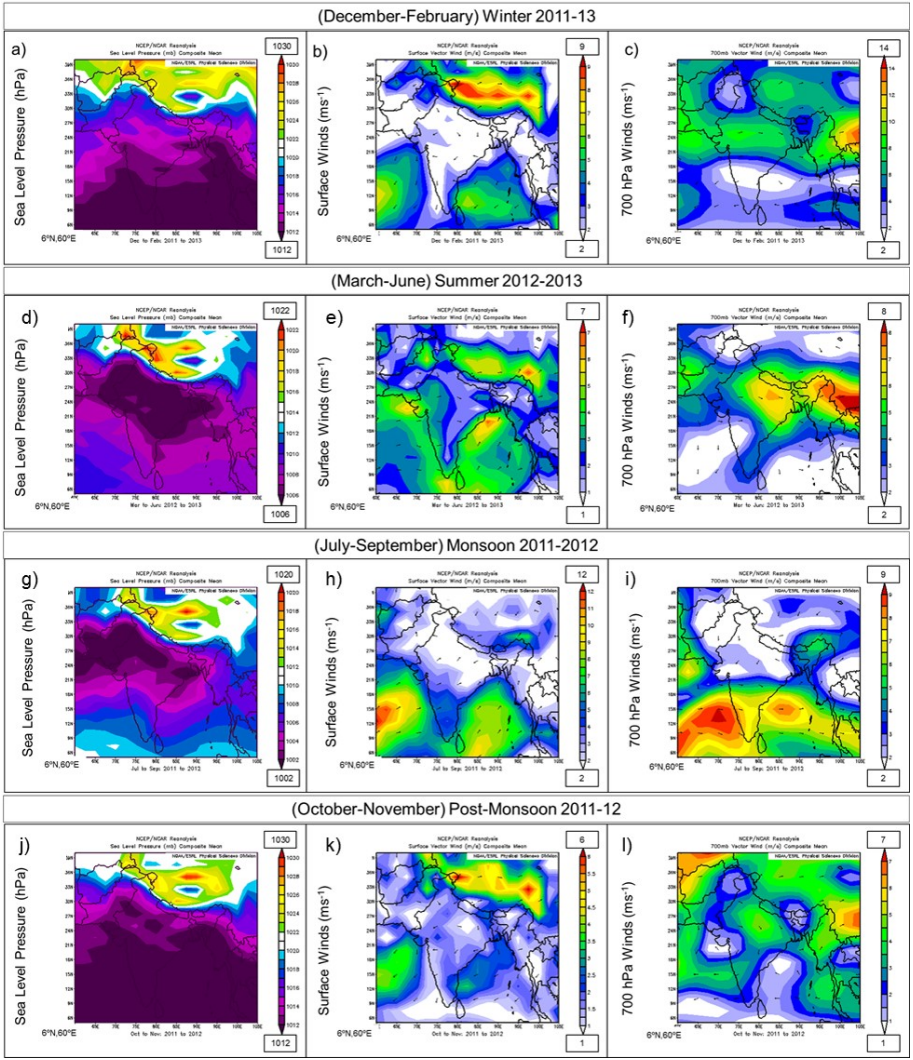
(December-February) Winter 2011-13
a)
b)
c)
Sea Level Pressure (hPa)
Surface Winds (ms-1)
700 hPa Winds (ms-1)
6°N,60°E
(March-June) Summer 2012-2013
d)
e)
f)
(July-September) Monsoon 2011-2012
g)
h)
i)
(October-November) Post-Monsoon 2011-12
j)
k)
l)

Figure 1. Seasonal composites of sea level pressure, surface winds and 700hPa winds. The values on the top and bottom of the legend in each figure shows the maximum and minimum respectively.(Images provided by the NOAA-ESRL Physical Sciences Division, Boulder Colorado from their Web site at http://www.esrl.noaa.gov/psd/)

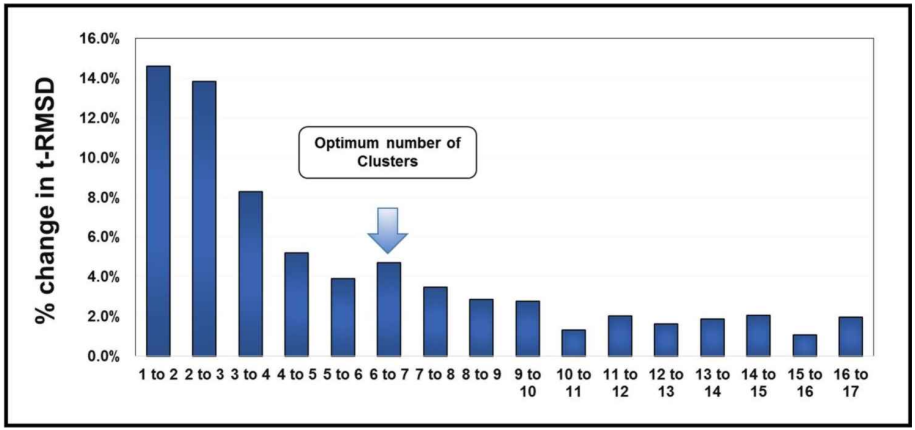

Figure 2. Percentage change in t-RMSD with increase in cluster number.

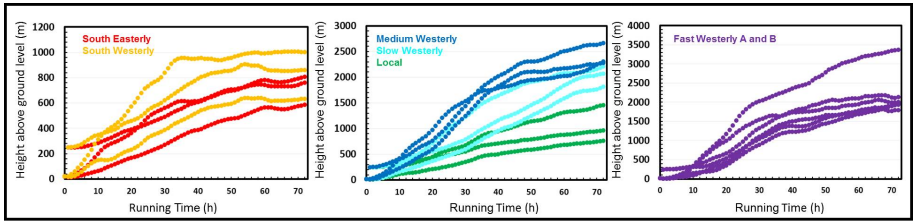

Figure 3. Mean height (a.g.l.) of all trajectories in an individual cluster as a function of trajectory running time (72 h) for trajectories arriving at 09:00 and 23:00 UTC.

References

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