Abnormal modulation of atmospheric parameters during the tsunami of 2004

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This paper discusses the abnormal changes in weather elements observed at a tropical mountain location and a coastal station in India. Abnormal changes were noticed in the atmospheric parameters at a time close to the occurrence of tsunami on the Indian coasts due to high magnitude earthquakes in the Sumatra region on 26 December 2004. Close to the time of this earthquake occurrence, uncharacteristic and large magnitude changes in weather elements were recorded at Braemore (8°45′N, 77°05′E, 360 m amsl), a mountain field station at Western Ghats. Abnormal changes were also recorded at Minambakkam (13°N, 80°18′E, 16 m SLP), close to eastern coastal belts. In the Braemore field station, simultaneous changes were observed in the atmospheric parameters; decrease in pressure by 0.6 hPa, increase in relative humidity by 30% and a prominent reduction in air temperature by more than 3°C on the day of tsunami. Also, unusually the relative humidity did not reach 100% on the previous night. However, in the Minambakkam station, the relative humidity increased by 10% associated with a sharp decrease in temperature by about 2.5°C. The changes in both the stations occurred almost at the same time and duration. Therefore, it may be concluded that these changes are associated with the high magnitude earthquake and subsequent tsunami.

Keywords: Air temperature, earthquake, relative humidity, tsunami.

TSUNAMI is the result of an underwater earthquake that is a geological phenomenon. Earthquakes are not known to produce predictable changes in weather elements or in atmospheric circulation. In other words, there are no hypotheses on the specific relationship between earthquakes and atmospheric phenomena. However, Dunajecka and Pulinets[1] have reported changes in air humidity and air temperature few days before strong earthquakes ($M \geq 7$) in Mexico. Singh *et al.*[2] reported abnormal changes in surface and atmospheric parameters prior to the main earthquake event in Gujarat on 26 January 2001. Anomalous changes in water vapour content were also observed after the Gujarat earthquake[3]. Studies were conducted to understand the impact of earthquakes on aerosols[4] and gaseous pollutants in the atmosphere[5] and these were found to vary significantly. Matsuda and Ikeya[6] reported an enhancement in nitric oxide mixing ratio ten times larger than the average peak level on normal days before the Kobe earthquake on 17 January 1995. Singh *et al.*[2] noticed anomalous changes in CO concentrations prior to the main earthquake event in Gujarat on 26 January 2001. The present communication primarily discusses a set of distinct changes in atmospheric parameters recorded by an automatic weather station (AWS) in South India on the day of tsunami, i.e. 26 December 2004. The tsunami was experienced along most of the coastlines of India, and was generated by an earthquake of magnitude between 9.1 and 9.3 on the Richter scale at 3°24′N, 95°42′E, off the coast of Sumatra at 06 : 29 h IST. The tsunami hit the Indian coast at Chennai and Visakhapatnam at 09 : 05 h IST. Inundation occurred at several parts of the east and west coasts of South India. This earthquake had the longest duration of faulting ever observed, lasting between 8.3 and 10 min.

The AWS has been operational at a mountain field station, namely Braemore (8°45′N, 77°05′E, 360 m amsl) since 2003. Figure 1 shows the location of Braemore station. The station is at a radial distance of about 40 km from the west coast of South India. The station is being maintained for studying the formation of thunderclouds and their characteristics. The weather parameters monitored at the station are air temperature (AT), atmospheric pressure (P), relative humidity (RH), wind direction (WD), wind speed (WS), rainfall (RF) and sun duration (SD).

The reliability of the weather station at this location was proven by detecting known atmospheric phenomena[7]. Table 1 gives the weather elements monitored, the sensor types, their output sensitivity/resolution and range of measurements. The AWS data logger was programmed for collecting data every 10 min.

In addition to the Braemore data, the surface boundary layer parameters over the Minambakkam station (13°N, 80°18′E, 16 m slp) were also collected. Minambakkam is close to the coastal belt of the Bay of Bengal. The data were downloaded from the website http://weather.uwyo.edu/surface/meteogram/. In comparison with the Braemore dataset, the temporal resolution of the Minambakkam dataset was low (hourly) and therefore, it may not have captured the minute changes in the surface parameters during the tsunami period. The dataset used here for discussing the abnormal characteristics of atmospheric parameters during the tsunami event is from the Braemore and Minambakkam weather stations.

Many atmospheric and oceanic parameters change prior to an earthquake[8], due to the release of large amount of latent heat[9]. The variation of trace gases such as CO has been recently reported by Retnamayi *et al.*[10]. They reported coherent modulation of atmospheric CO monitored at Jaduguda, an inland station, about 75 km away from the coastal belt and attributed the variation to the tsunami event on 26 December 2004. However, the simultaneous

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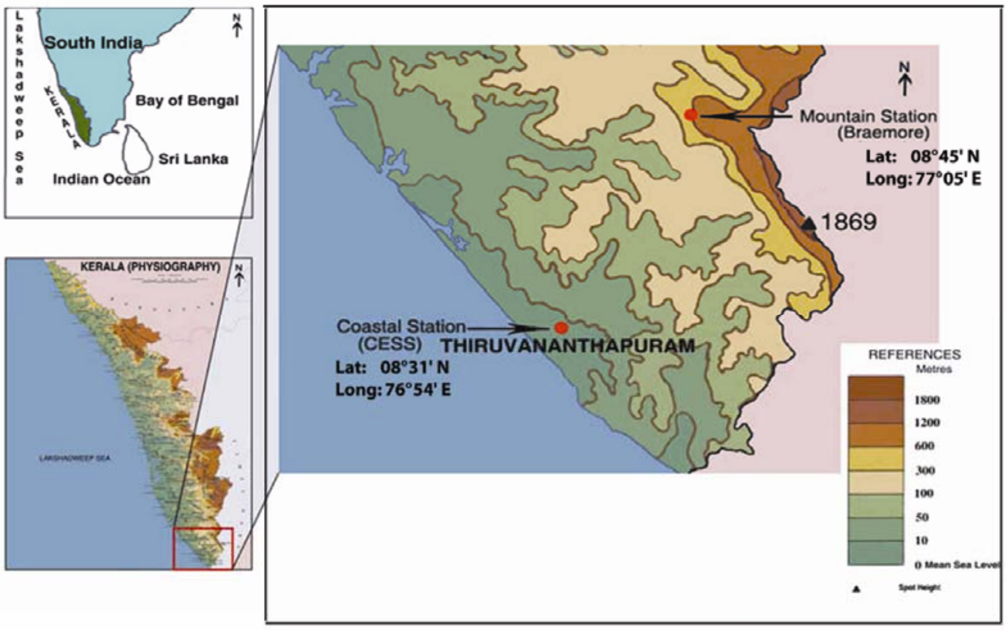

Figure 1. Map showing the location of the mountain station at Braemore.

Table 1. Specifications of sensors used for the measurement of weather elements

Weather element	Sensor	Output	Sensitivity/resolution	Range	Accuracy
Air temperature	Platinum resistance (PT100)	0–2.5 V	0.1°C	0°–50°C	< 0.5°C
Wind speed	Three-cup rotor	Frequency–reed switch	0.1 m/s, 0.3 m/s as threshold	0–50 m/s	± 2%
Wind direction	Potentiometer	Resistance	1°	0–360°	± 2.25%
Relative humidity	Thin film capacitance	Frequency	1% RH	0–100%	± 5% (10–90%)
Pressure	Strain gauge bridge	Analogue voltage	0.1 m hPa	800–1100 hPa	–

changes in atmospheric parameters associated with a tsunami event are yet to be reported. We report here the changes observed in the atmospheric parameters such as RH, AT, P, WS and WD associated with the tsunami event of 2004. On the day of tsunami, significant changes in the atmospheric parameters were observed at Braemore and Minambakkam stations. The significant changes observed in the surface parameters are described below.

RH: This is a measure of water vapour in the atmosphere and is represented in percentage. The diurnal variation of RH during the tsunami day with the monthly mean is presented in Figure 2 *a*. The diurnal pattern of RH in December is unimodal, with a minimum during the noon hours (~ 50%). High values of RH are observed during the night hours from 20 : 00 to 08 : 00 h IST. During this period, the average value is more than 80%. However, during the tsunami event, the magnitude of RH did not reach the usual maximum on the previous night. Instead it was continuously decreasing till the sudden increase occurred. Thereafter, RH increased from the ambient value and reached a maximum of 100%, indicating that the atmosphere reached saturation. The atmosphere becomes saturated either by adding more moisture to it or by advecting the moist air from the surrounding, or with the both. As seen from Figure 2 *a*, RH shows an increase from 05 : 50 to 07 : 20 h to reach the saturation value of 100% by increasing about 30% from the base value. An increase of such a large magnitude in RH before sunrise is an uncharacteristic change. It is to be noted that as the increase in RH began before sunrise, it is clear that this was not due to a low insolation regime. Another unusual variation that can be observed in the data is the magnitude and change of RH before 05 : 50 h. Normally RH goes to a maximum during early hours of the day and remains unaltered till sunrise. It is abnormal to see RH decreasing before sunrise. On this day it decreased continuously in the previous night to reach a value of 70% before 05 : 50 h (Figure 2 *b*). On most of the days at the same time of the year, the station has recorded 80–85% RH before dawn. The 70% magnitude of RH recorded on the previous night of the tsunami day is unusual.

Air temperature and pressure: Figure 3 *a* shows a comparison of AT variation during the tsunami day with the same on two other normal days. This illustrates that during the tsunami hours, AT fell significantly below the normal values. Such a drastic reduction in AT may be

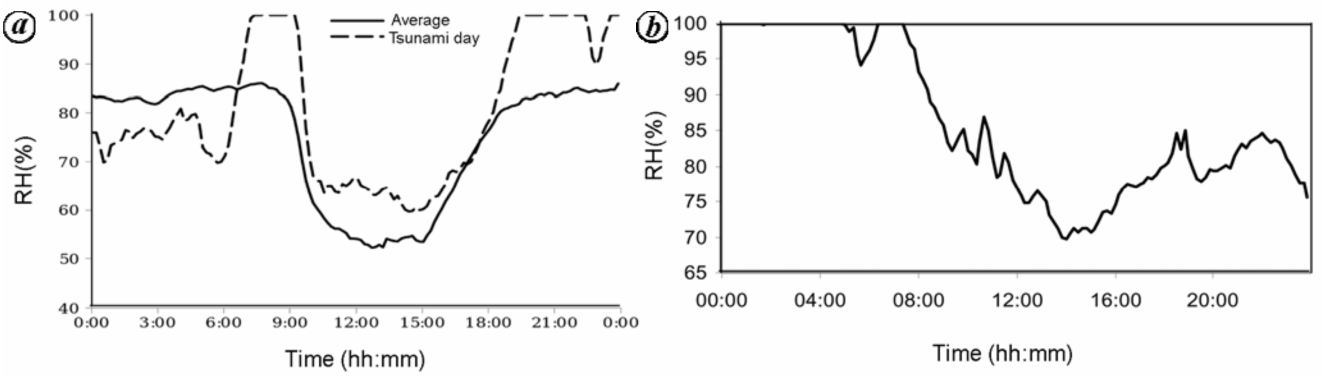

Figure 2. ***a***, Diurnal variation of relative humidity (RH) during the tsunami day, i.e. 26 December 2004 (shown as dashed line). The solid line is the average diurnal variation of the same parameter during the clear-sky days. ***b***, Variation of RH recorded at Braemore station on the previous day, i.e. 25 December 2004.

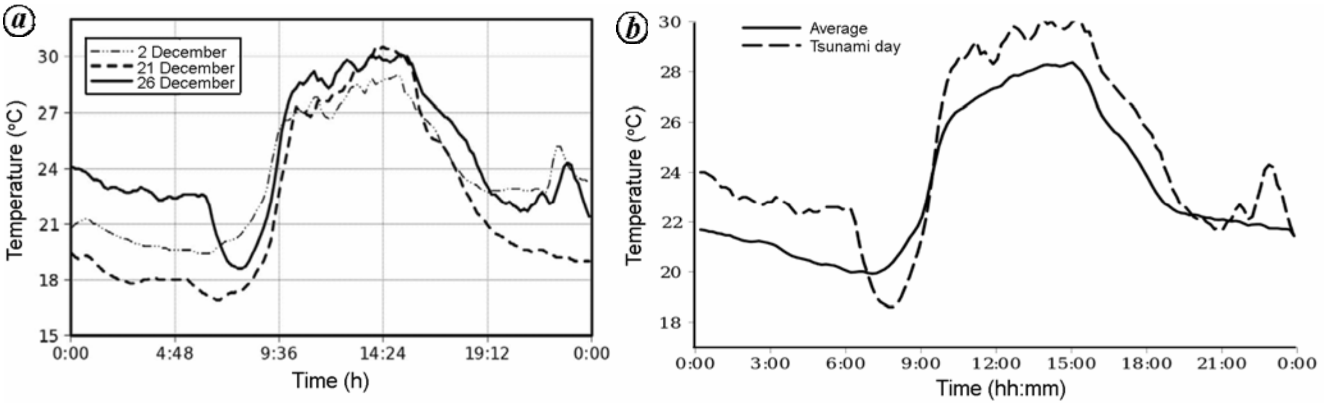

Figure 3. ***a***, Comparison of diurnal variation of air temperature (AT) during the tsunami day (26 December 2004) and two other normal days to indicate the abnormal variation. ***b***, Diurnal variation of AT during the tsunami day. The solid line is the average diurnal variation of the same parameter during the clear-sky days.

associated with the atmospheric disturbances caused by the tsunami event over the coastal belts. Normally, a change in AT is caused due to the heating by insolation. In fact, the rate of change of AT caused by changes in the insolation is not as fast as the present observed change.

Figure 3 *b* shows the variation of AT recorded on the tsunami day with the monthly mean. As mentioned earlier, the RH shows saturation value from 07:20 to 09:30 h in the morning. During the saturation period, AT shows a decrease from the average value during the month of December. However, AT increases after 09:30 h and consequently, RH decreases from the saturation value. Decrease in the RH value with the increase in AT is due to the increase in the water-holding capacity. In general, maximum AT observed during December is 29°C at about 15:00 h, but on the tsunami day, the maximum AT was 30.5°C recorded at the same time. The minimum temperature observed on the tsunami day at about 08:00 h was 18.8°C, which was less by 1.5°C compared to the same observed during December. This can be attributed to the occurrence of tsunami over the Kerala coast.

Using the satellite and other surface observations, it has been proved that the latent heat flux increases abnormally during an earthquake[9]. Therefore, in the present study, an attempt was also made to understand the variation of latent heat flux due to the earthquake on 26 December 2004 using the TropFlux dataset. This daily dataset has a spatial resolution of $1° \times 1°$ latitude–longitude grid over the entire tropics[11]. Figure 4 *a–c* shows the spatial structure of the latent heat flux during a normal day, tsunami day and difference between tsunami day and normal day respectively. It is evident that in most of areas of the Arabian Sea and Bay of Bengal, the latent heat flux is more. Over the south of the west coast stations, the value of latent heat is higher by about 30 W m^{-2} from the normal day. However, over south of east coastal stations, the value of latent heat is more by about 90 W m^{-2}. In general, the latent heat flux is more during the tsunami day due to the release of latent heat prior to an earthquake. This may enhance the rise in the rate of energy exchange between sea surface and atmosphere[9].

Figure 5 shows the diurnal pattern of the surface pressure during the tsunami day with the monthly mean. The diurnal pattern during the tsunami day shows significant changes from the average diurnal pattern. The surface pressure shows a decrease with a maximum reduction of about 0.6 hPa at the same time interval and same duration as that of RH. The reduction is coherent with the increase of RH and decrease of AT. After saturation of the atmosphere, P starts increasing with the diurnal pattern. However, the magnitude of the diurnal pattern significantly differs from the average magnitude of the diurnal pattern in December. At every point, the value of surface pressure is lower by about 0.6–1.5 hPa.

Wind speed and direction: Similar to the above-said parameters, WS and WD were also abnormally different from the rest of the days (Figure 6). High WS was observed before the occurrence of the earthquake in the Sumatra region and subsequent tsunami along the coastal belts of the Indian subcontinent. However, during the tsunami period WS was zero, indicating the absence of horizontal wind. This can also be noticed in the values of RH. During the saturated condition of the atmosphere, WS is very low or zero. Prior to the earthquake, strong wind was observed at the surface and it was 2–3 times more than the average wind speed (Figure 6 *a*). This may be due to the large amount of latent heat released prior to the earthquake and latent heat is related to wind speed[12].

Abnormal behaviour was also noticed in WD (Figure 6 *b*). General pattern of WD during the month is northwesterly in the night and morning hours; it turns clockwise to northerly in the daytime and this starts from around 09 : 30 h. The turning of WD is due to the mountain effect and the wind is called anabatic wind. The wind seemed to be anabatic from WD in the early morning hours during the tsunami day. However, this anticlockwise turning of wind may not be considered because the prevailing wind speed is zero.

In addition to the variations observed in surface boundary layer parameters prior to and during the tsunami, we made similar analysis on RH, AT and surface pressure over the east coastal station, Minambakkam. The observations were hourly and therefore sharp peaks may not have been registered in this station due to lack of high-resolution dataset. It was observed that the variations in RH, AT and surface pressure were almost similar at both Braemore and Minambakkam stations. The tsunami reached the station at almost the same time as that of the western coastal stations. Change in RH was observed during and prior to the tsunami; the value increased by 10% from the previous value (Figure 7 *a*). In general, the average value of RH over this region was higher than that on the tsunami day. However, the RH value exceeded the average value due to greater availability of moisture during noontime. In the case of AT, an abnormal decrease was observed (Figure 7 *b*) during the same time as in the Braemore station. The reduction in AT was about 2.5°C from the previous value. The average value of AT during December is generally above the tsunami day temperature. However, during the afternoon hours the AT value increased till midnight. In the case of surface pressure, it was below the normal pressure (Figure 7 *c*) as observed in the case of Braemore station. In general, abnormal changes in the surface parameters were also present in the Minambakkam data, associated with the earthquake and subsequent tsunami over the west and east coastal regions.

Changes in oceanic and atmospheric parameters prior to or after an earthquake are reported in many places. However, the simultaneous changes on diurnal pattern are yet to be reported. Therefore, the present communication reports changes in the surface atmospheric parameters such as AT, RH, surface pressure and surface wind. Abnormal changes in weather parameters were observed at two different locations. The changes were seen to have occurred close to the time of occurrence of the Sumatra earthquake and the tsunami on 26 December 2004. The

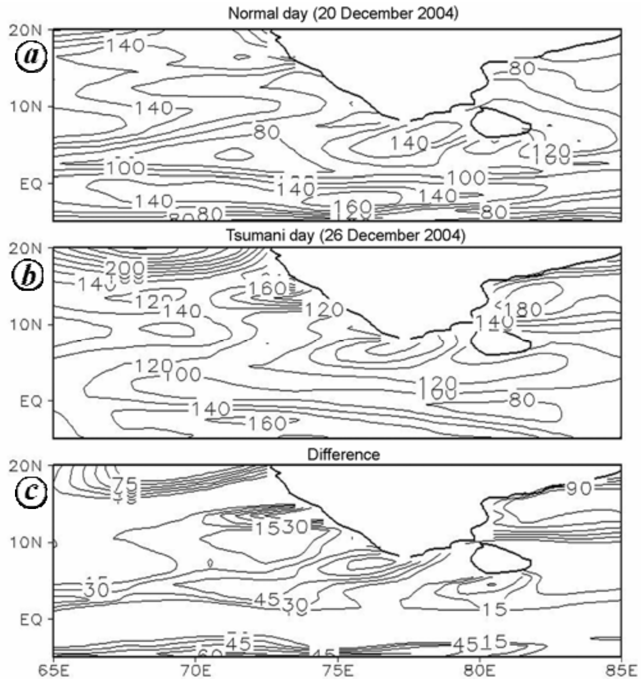

Figure 4. Spatial structure of latent heat flux during (***a***) normal day (20 December 2004), (***b***) tsunami day and (***c***) tsunami–normal day, i.e. the difference.

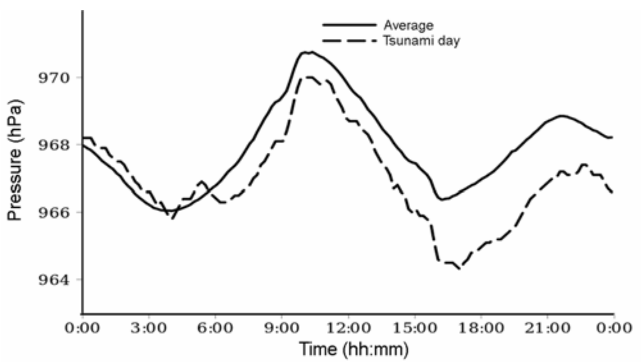

Figure 5. Diurnal variation of surface pressure during the tsunami day (26 December 2004). The sold line is the average diurnal variation of the same parameter during the clear-sky days.

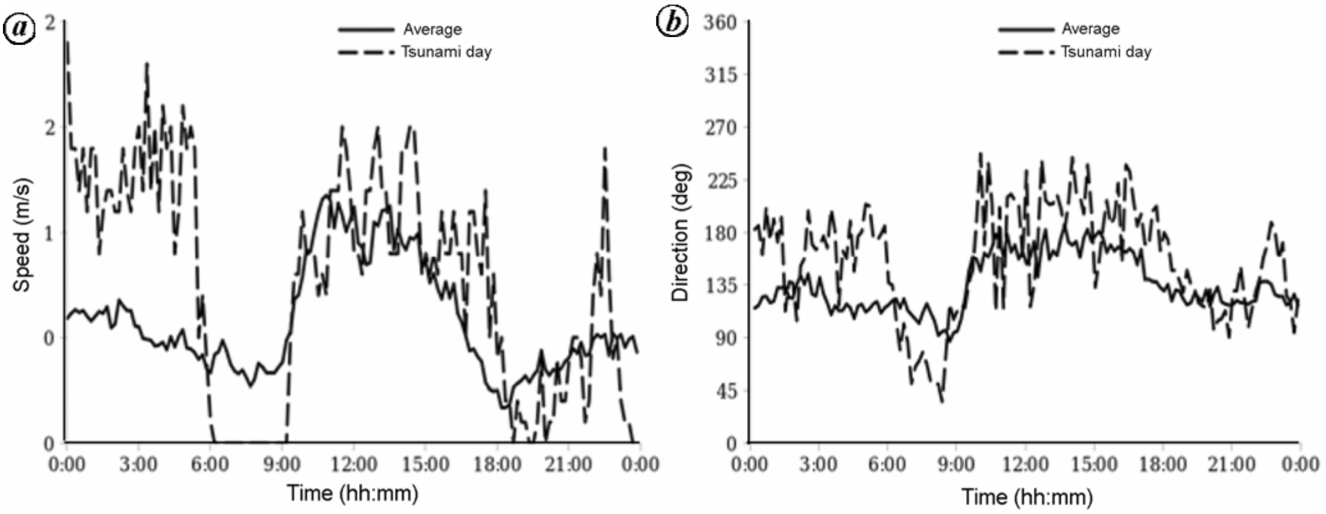

Figure 6. Diurnal variation of (***a***) wind speed (m/s) and (***b***) wind direction during the tsunami day (26 December 2004). The solid line is the average diurnal variation of the same parameter during the clear-sky days.

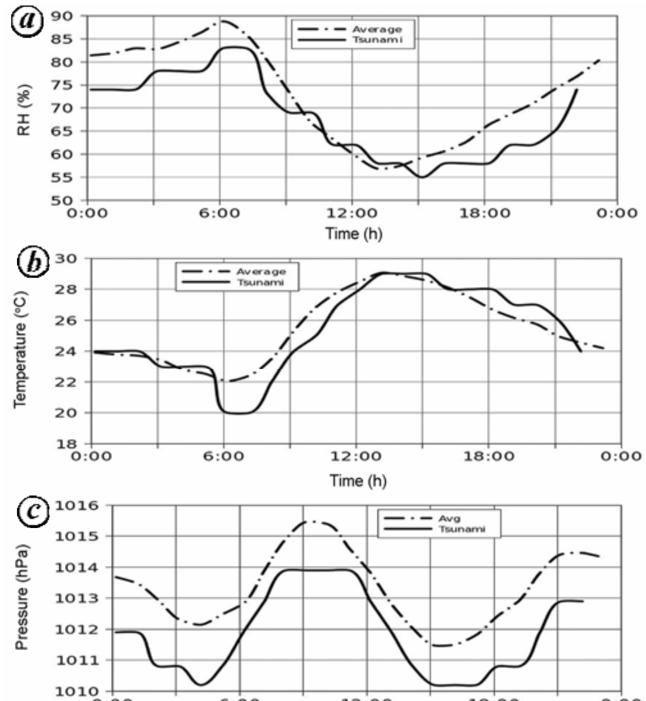

Figure 7. Diurnal variation of (***a***) relative humidity (%), (***b***) air temperature (°C) and (***c***) surface pressure (hPa) during the tsunami day (26 December 2004). The dotted line is the average diurnal variation of the same parameters during the month of December.

coherent variations observed at both the stations are irrefutable evidences. The possibility of any other natural phenomenon causing the observed uncharacteristic changes in weather elements is remote. The earthquake has been classified as one of the strongest earthquakes. As on today there is no proven hypothesis or theory to link the abnormal changes recorded and the earthquake. So a cause–effect relationship could not be established. If we consider the possibility of a lithosphere atmosphere coupling as suggested by Singh *et al.*[13], it is possible that the effects of coupling are seen in the present earthquake because of the very high magnitude. Analysis of high-resolution data of stable air constituents and weather elements before and after earthquakes should throw more light into the mechanism of linkage.

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Variation in wood anatomical properties and specific gravity in relation to sexual dimorphism in *Populus deltoides* Bartr. ex Marsh

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This study deals with intra- and inter-ramet, and inter-clonal variation in dimensions of wood elements and specific gravity of 6-year-old *Populus deltoides* based on sexual dimorphism of a female clone (G48) and male clone (G3). The origin of both the clones is USA. The trial used uniform spacing (5 m × 5 m). Variance ratio (*F*) test revealed that both clones differ significantly in fibre length and diameter, wall thickness, vessel element length and diameter, and specific gravity. The G48 clone showed higher fibre and vessel element dimensions but lower specific gravity than G3 clone, suggesting better fibre dimensions for G48 and specific gravity for G3. It showed female dominance on wood anatomical properties. Fibre length and specific gravity increased with height. Dimensions of wood element and specific gravity also increased from pith to periphery. Non-significant intra-ramet variations for both the clones indicated that homogeneous wood properties could be achieved from the single bole. Intra-clonal variations in G48 revealed non-significant differences, suggesting stable wood properties in the clone.

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Keywords: Fibre dimensions, *Populus deltoides*, ramet, specific gravity, wood elements.

DIFFERENT forestry programmes have used *Populus deltoides* Bartr. ex Marsh. extensively as clonal plantations to ensure its genetic superiority, better growth and wood quality. Most of them were propagated through shoot-cuttings. The wood is used in plywood, wood composite and paper industry.

Tree performance assessment usually used two important parameters: wood quality (structure and dimensions of wood elements) and growth. Wood specific gravity and dimensions of fibre are reliable indicators of wood quality[1]. Variation in the dimension of wood elements for different species was studied in India for *Eucalyptus tereticornis*[2–4]. Similar studies were also carried out on *Pinus roxburghii*[1], *Dalbergia sissoo*[4], *Pinus caribaea*[5] and *Populus deltoides*[6]. *P. deltoides* is a dioecious tree species. Some studies reported variation in wood quality parameters in *Populus* clones elsewhere[7–9]. The variability patterns in wood traits in the natural population and clonal plantation of *P. deltoides* in relation to sex however remain unknown. Hybridization is one of the important aspects in tree improvement programmes for gaining superior wood traits. The present communication deals with two aspects, viz. (1) the intra-ramet, intra- and inter-clonal variation in selected wood anatomical properties and specific gravity having technological applications, and (2) the influence of sex on wood traits (female and male clones). Consequently, this study aimed to determine the intra-, inter-ramet and inter-clonal variations in dimensions of wood elements and specific gravity for female (G48) and male (G3) clones of *P. deltoides*. The study also attempted to compare female and male clones based on wood traits.

The study site located in Rampur District, Uttar Pradesh, India lies between lat. 28°N and long. 78°E. The experimental trial was conducted at the foothills of Uttarakhand, at an altitude of 200 m amsl, which shares a border with Rudrapur District, Uttarakhand. The area receives annual rainfall of about 1200 mm, mean maximum summer temperature (April–June) of 36.7°C and mean minimum temperature (December–February) of 7.5°C (2005–06). The topography is almost flat, with loam soil (sand 61.4%, silt 14.1% and clay 14.1%). The following criteria were used for the selection of these clones: (i) they are diploid and (ii) both the clones are original and their origin is USA.

The material was collected from plantations of the G48 (female) and G3 (male) clones of *P. deltoids* of harvesting age (6 years), raised by WIMCO Plantations Ltd, Rudrapur. Plantation of the selected clones was propagated by macro-propagation and was planted under similar climatic and soil conditions. The plantation was raised in randomized block design. The spacing was 5 m × 5 m. The layout was four-way factorial design.