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Severe cyclonic storm JAL, air-sea interaction perspectives and floods along Andhra Pradesh-Tamilnadu coast

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ABSTRACT

Severe cyclonic storm **JAL** that devastated many Asian countries including southern east coast of India during 4-8 November 2010, evolved from a low pressure area in the South China Sea, near the eastern coast of Borneo, on 28 October 2010. Moving northwestward, the low pressure area emerged in the Bay of Bengal and concentrated in to a tropical depression on 4th November and into a severe cyclonic storm in the early morning of 6th. It produced very heavy rains causing severe floods and damage to life and property over parts of Malaysia, Thailand,Sri Lanka and India. It crossed the east-coast of India on November 7 north of Chennai, 13.3°N and 80.3°E and landfall near Nellore. The system attained a maximum intensity of T3.5. Coupled ocean-atmospheric processes have been examined to understand the unusually long track of the system and impact of floods on landfall along Andhra Pradesh- Tamil Nadu coast. Analysis of daily high resolution reanalysis data in the domain, 0-25°N, 60-130°E, during 1-8 November 2010 has revealed variation of Sea Surface Temperature (SST) between 27- 31°C, cooler SST to the left of the cyclone track and wind speed between 16 to 24 ms^{-1}. Satellite derived 3-hourly daily accumulated precipitation varied between 36 to 90 mm. Heavy rainfall was confined to the coastal hilly regions and rainfall was very low over the open ocean along the cyclone track. This had resulted in only a marginal cooling of SST, which had helped in the maintenance of sensible and latent heat fluxes. Significantly warm SST had provided continuous supply of moisture for the sustenance and unusually long travel of the system over sea.

Key words: Severe cyclonic storm JAL, Air- sea interactions, floods, damage.

INTRODUCTION

Tropical systems with maximum sustained surface winds of less than 17 ms^{-1} are called tropical depressions. Once the surface wind speed in a tropical depression reaches the strength of at least 17 ms^{-1} it is typically called a tropical storm or a tropical cyclone and assigned a name. When the surface winds attain the speed of 33 ms^{-1}, the storm is called a typhoon over (North Atlantic Ocean and the Northeast Pacific Oceans) and it is referred as a severe tropical cyclone in the southwest Pacific Ocean and southeast Indian Ocean (Neumann et al., 1993). Severe intensity tropical cyclones form during south-west post–monsoon period of October and November over the Bay of Bengal.Tropical cyclones (TCs) developing over the southern and central Bay of Bengal and Andaman Sea move northwestward towards the east coast of India and sometimes recurve between 15° and 18°N affecting the Bangladesh coast. Remnants of northwest Pacific typhoons moving westward develop into a low pressure system over the Andaman Sea and intensify further over the Bay of Bengal during the post–monsoon season. The life span of a severe cyclonic storm over the north Indian Ocean averages about 4 days on a yearly basis (IMD, 1979). The number of cyclones over the Bay of Bengal is 3–4 times more than those over the Arabian Sea (Obasi, 1997). The information about the ocean response to storm forcing is one of the important factors in tropical cyclone track prediction. Monitoring of surface weather parameters and the upper ocean thermal structure from moored buoys has become a key element in the studies of tropical cyclones (Premkumar et al., 2000). Several studies have been carried out to document the ocean's response to the tropical cyclones and to understand the associated air-sea interaction processes (Stramma et al., 1986).In the case of the tropical cyclones in north Indian Ocean, earlier investigators (Gopala krishna et al., 1993; Chinthalu et al., 2001) had reported cooling of the SST after the passage of cyclones. They had noted that in the regions of weaker upper ocean stratification (southern and western Bay of Bengal) the magnitude of the SST decreases by around 2°C, due to the passage of cyclone. Tropical cyclones are more likely to intensify than weaken after an interaction with an upper-level trough when cyclones are moving over warm waters, as they continue to derive energy (Hanley et al., 2001). Emanuel (1986) had suggested that the energy from the ocean is through the transfer of moisture from the ocean to the atmosphere, which is dependent on wind speed and the difference of moisture content between the air and the saturation mixing ratio at the sea surface. The response of the upper ocean plays a major role in controlling the storm intensity through associated variability in the upper ocean conditions such

Figure 1. Track of the severe cyclonic storm JAL

Table 1. The Saffir–Simpson scale has been followed and color codes denote the wind speed of JAL.

System/Category	Wind speed
Tropical Depression	≤ 17 m/s ▲
Tropical storm	18-32 m/s •
Category one	33-42 m/s •
Category two	43-49 m/s •

as SST, surface salinity, mixed layer depth, currents in the mixed layer, etc. and atmospheric conditions such as winds, atmospheric pressure, and precipitation. Recent studies indicate that generally cyclones originating from the Bay of Bengal cross the east coast of India and cause floods due to heavy rainfall.In a case study of September 1997 Andhra cyclone (Chintalu et al., 2012), the persistent southward movement of 500 hPa ridge on the eastern wedge of the system along with the steering current at 200 hPa level, has helped in maintaining the movement of the system parallel to the east coast of India. Such cyclones give rise to copious rainfall and often cause major floods, causing damage to life and property in the eastern states of India.

Track of the system

The Severe cyclonic storm JAL, 4-8 November 2010, evolved from a low pressure area in the South China Sea, near the eastern coast of Borneo on 28 October 2010. Moving northwestward the low pressure area picked up strength and emerged in the Bay of Bengal. Figure 1 shows the track of the severe cyclonic storm JAL. The wind speed criterion refers to the Saffir–Simpson scale. Different wind speeds given by color codes and symbols are shown in Table 1. IMD upgraded the system to a Depression at 0000UTC of 4 November and to a Severe Cyclonic Storm at 2100 UTC of 5th November.

JAL lay centered over southwest Bay of Bengal at 0000 UTC of 6th November 2010 near 10.0°N, 85.5°E about 450 km east-northeast of Trincomalee (Sri Lanka). The cyclone was about 600 km east-southeast of Chennai and about 750 km southeast of Nellore before landfall. The JAL cyclone was tracked by INSAT Kalpana-1 satellite imagery from 0600 UTC of 2 November till the time of landfall. The maximum estimated intensity of T 3.5 was reported by IMD from 2100 UTC of 5th to 0500 UTC of 7th November. The estimated lowest central pressure was 988 hPa. The estimated maximum wind speed was 30 ms^{-1}. As per Doppler Weather Radars (DWR) at Chennai and SHAR, the system started weakening from 0300 UTC of 7th November. Continuing its northwesterly track JAL crossed the coast as a deep depression between Puducherry and Nellore and very close to SHAR around1800 UTC of 7th. The system weakened into a low pressure area over Rayalaseema and adjoining south interior Karnataka. The cloud heights were ~ 5 to 6 Km and the maximum reflectivity in the wall cloud region was about 35-45 dBz. The DWR at Chennai tracked the maximum wind, which was about 23 ms^{-1} from 0400 to 1800 UTC on 7th November. Rainfall occurred at most places with heavy to very heavy falls at a few places over north Tamil Nadu, Puducherry, coastal Andhra Pradesh, Rayalaseema, south Interior and coastal Karnataka. JAL crossed the east-coast of India on November 7 north of Chennai near Nellore. Figure 2 shows the INSAT (Kalpana-1) satellite cloud imagery during landfall near Nellore on 7th November, at the time of land fall. The maximum intensity attained by the severe cyclonic storm JAL was T 3.5. The satellite imagery on 7th November also shows the thick and dense spiral cloud bands and overcast conditions, which has covered the major parts of the states of Andhra Pradesh and Tamil Nadu. It is further noticed that another band

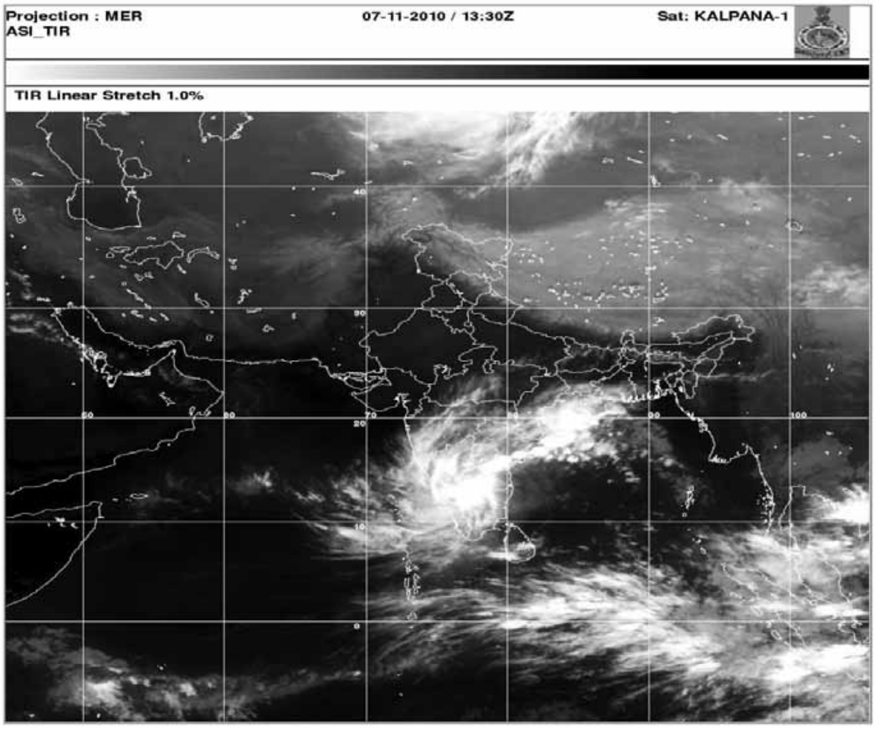

Figure 2. INSAT Kalpana-1 satellite cloud imagery of JAL during landfall on 7 November 2010.

of dense convective clouds that lay near 5° N and 82° E has crossed the Andhra Pradesh and Tamil Nadu coast in the morning hours of 8th November resulting in very heavy rainfall. This was reported by India Meteorological Department, as discussed below. The above mentioned states had suffered heavy losses in terms of life and property due to devastating floods caused by heavy rainfall.

Data and methodology

Analyses of various parameters are presented below for the period 1-8 November. The data used in the present study consist of NCEP-NCAR reanalysis and Tropical Rainfall Measuring Mission (TRMM) data products such as daily SST, winds, pressure, Outgoing Longwave Radiation (OLR), sensible and latent heat fluxes, Vertical Wind Shear (VWS) daily data with resolution of 1°lat. x 1°long and sensible and latent heat fluxes and TRMM 3 hourly accumulated precipitation. Daily composite maps have been prepared in the domain of 0-25°N, 60-130°E. These maps have been analyzed to understand the features in air-sea interaction, which helped JAL to survive for a comparatively longer period of time.

Atmospheric pressure

Figure 3 (a-h) shows the day to day sea level pressure distribution during 1-8 November 2010. Values of atmospheric pressure, to the right of the track, varied between 1008-1018 hPa. Falling pressure to the left of the track was an indication of gradual intensification of cyclone. The sea level pressure that initially fell slowly towards the centre of the system and later rapidly to its minimum value indicated the severity of the cyclone, with lowest pressure of 998 hPa during 5-7 November. A comparison of mean sea level pressure values with TRMM derived rainfall (Figure 9) indicates that the centre of low pressure has been associated with enhanced convective activity and heavy rainfall. There has been an increase of sea-level pressure of about 10 hPa (Fig. 3h) within a span of 2 to 6 hours after landfall. The heavy orographic rainfall has been confined to low level hills located within the cyclone track zones. They are also the potential areas of flash floods and large scale disaster. This shows that the topography along the path of the cyclone has resulted in a drastic reduction in the intensity of the system.

Sea Surface Temperature

The Sea Surface Temperature (SST) distribution is the single most important parameter in the development of tropical systems and the track followed by them (Goldernberg et al., 2001). Several studies have indicated higher SST inducing strong convection (Yu and Wang., 2009). Figure 4(a-h) depicts the daily variation of SST and 850 hPa wind field composite during 1-8 November 2010. SST was cooler (26-28°C) to the right as compared to the left of the cyclone track in the domain of 14-25°N and 110-130°E. The higher SST (~ 29-30°C) was observed to

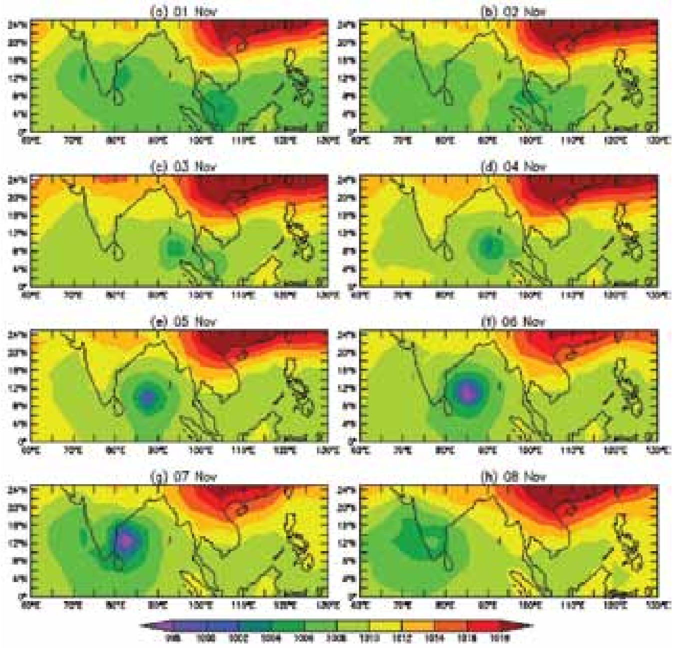

Figure 3. (a-h) Mean sea level pressure (hPa)

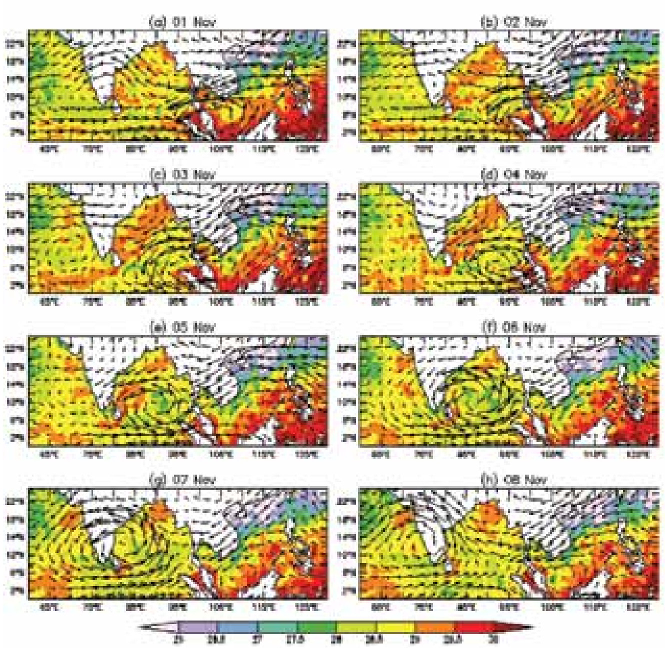

Figure 4. (a-h) Daily mean time series wind speed and direction.

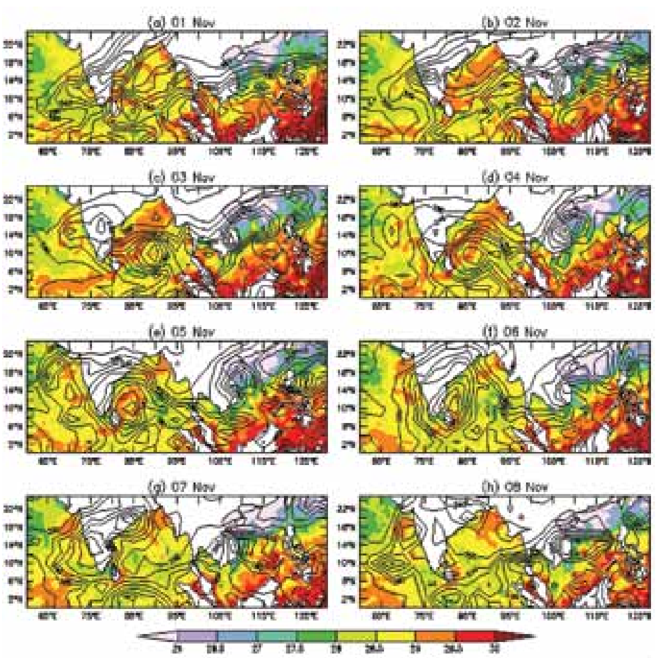

Figure 5. (a-h) Daily mean SST and OLR.

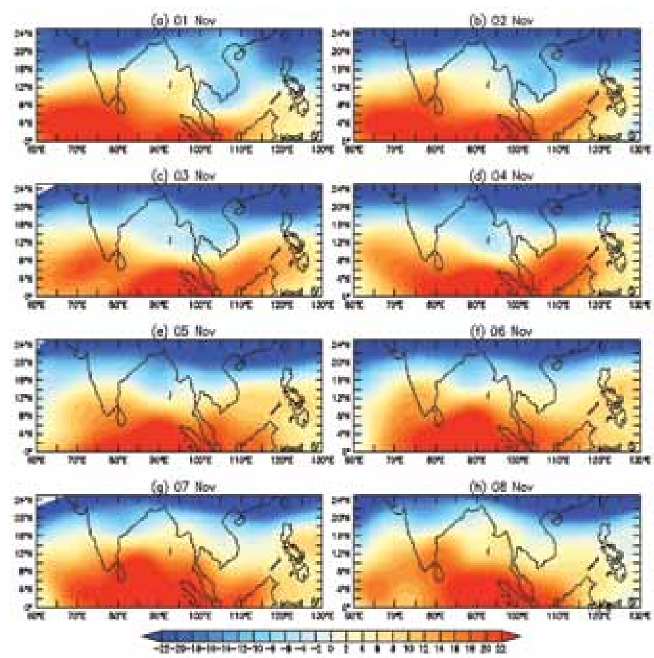

Figure 6. (a-h) Vertical Wind shear.

the left of the cyclone track. The SST was warmer by 2-4 °C to the left of the cyclone track. Fairly long survival and westward travel of the JAL could be the direct response of prevailing high SST along the track of cyclone.

Wind field

Figure 4(a-h) gives the composite of SST and wind field. The wind speed varied between 10-20 ms^{-1} in the central Bay of Bengal and it increased on 6th and 7th November before landfall. Similarly, the analysis of SST and wind field for 700 hPa level has shown prominent cyclonic circulation extending up to 700 hPa level during 4-7 November and system's improved organization on 5th, 6th, and 7th November. Further, analysis of wind field at 500 and 200 hPa (figures not shown) indicated that the cyclonic circulation had lost its organization above 700 hPa level, while it was still over the ocean.

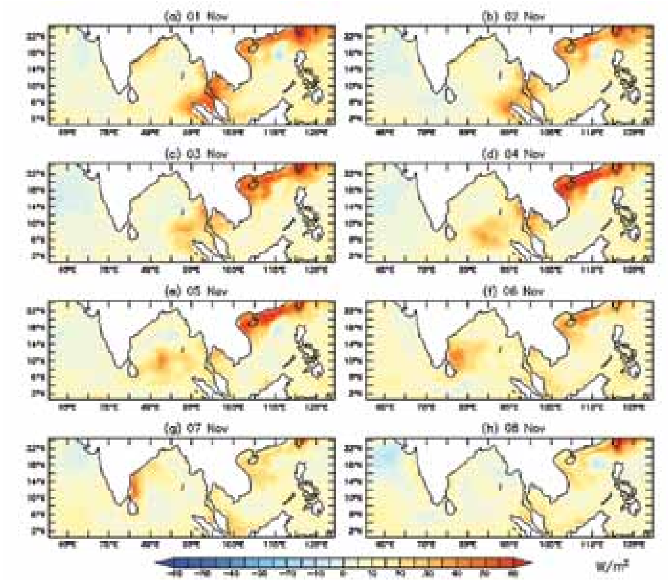

Figure 7. Sensible heat flux during 1-8 November 2010.

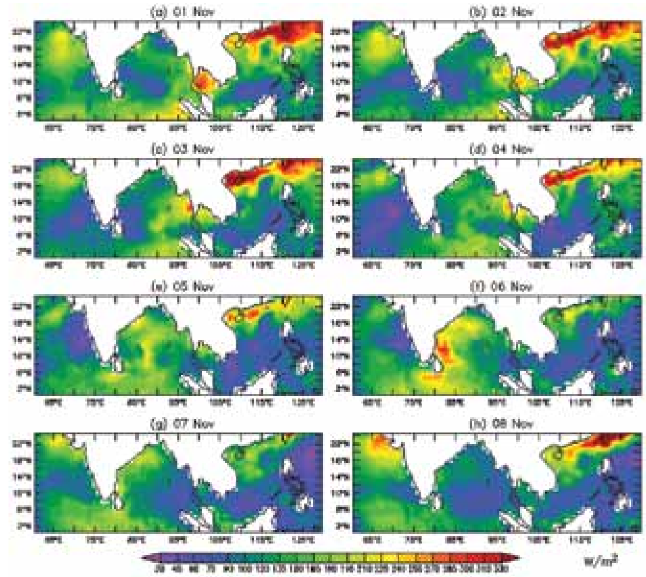

Figure 8. Latent heat flux during 1-8 November 2010.

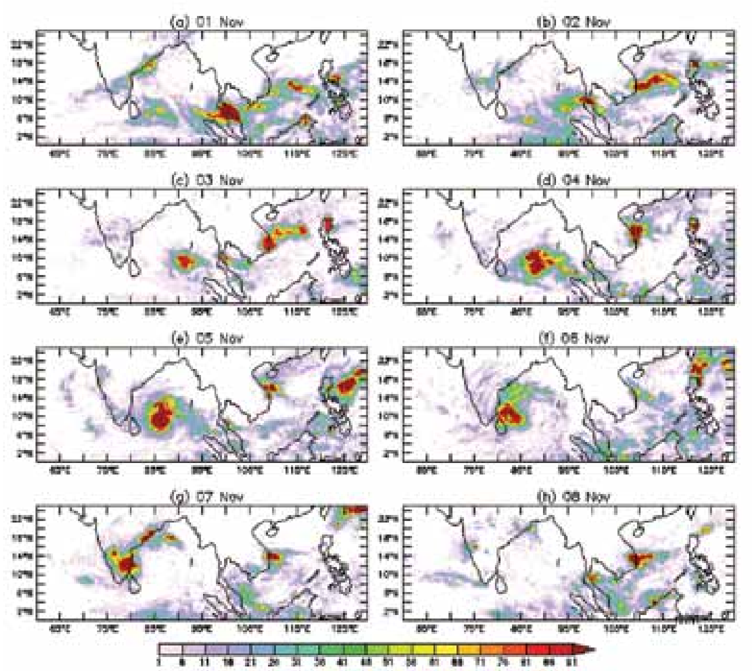

Figure 9. TRMM derived daily mean rainfall (mm).

SST and OLR

Figure 5 shows the SST and OLR composite during 1-8 November. OLR is used to locate the areas of deep tropical convection as a proxy for precipitation (Arkin and Ardanuy, 1989). The OLR values below 240 Wm^{-2} are considered to represent the convective area (Richards and Arkin, 1981). Over the land and cloud free zones (14°-25°N, 80° -100°E), the OLR varied between 200-240 Wm^{-2}. In the active convection zone along the track of JAL (5°-10°N, 80-100°E), OLR varied between 140-180 Wm^{-2}. It is seen that during the cyclone's active days, as shown in Figure (4d-f), the low values of OLR varying between 120-180 Wm^{-2} were co-located with warmer SST (~ 28-30°C) in the central Bay of Bengal. The large fall in OLR values indicated enhanced convective activity when JAL was approaching the east coast of India. After the landfall on 8th November, OLR values increased to 260-280 Wm^{-2}.

Table 2. 24 hrs accumulated rainfall (≥7 cm) between 0300 UTC of 7 to 0300 UTC of 8th November 2010, along Andhra Pradesh coast.

Stations	Rainfall (cm)	Stations	Rainfall (cm)
Palasa	27	Vempalli	8
Sompeta	14	Bhimunipatnam	8
Itchhapuram	12	Thambalapalli	7
Puttur	11	Madakasira	7
Kalingapatnam	10	Nellore	7
Rayacholi	10	Anakapalli	7
Kuppam	10	Mandasa	7
Tekkali	9	Kandukur	7

Table 3. Same as Table 2 but for Tamil Nadu-Puducherry coast**.**

Stations	Rainfall (cm)	Stations	Rainfall (cm)
Gingee	16	Vanu	9
Panruti	15	Thali	9
Ambur	13	Chengalpattu	8
Vaniyambadi	12	Polur	8
Tiruvannamalai	11	Krishnagiri	8
Alangayam	11	Dharmapuri	7
Tindivanam	10	Palacode	7
Villupuram	10	Sholingu	7
Puducherry A.P	10	Gudiyatham	7
Cuddalore	10	Vellore	7

Vertical wind shear

Figure 6(a-h) shows Vertical Wind Shear (VWS) field between 200 and 850 hPa levels during 1-8 November 2010.The VWS is an important dynamical factor affecting tropical cyclones intensity and precipitation pattern (Yu and Wang, 2009). The VWS has long been recognized to have a strong influence on the development, structure and intensity of tropical cyclones (Tang and Emanuel 2010). When VWS is low, it accelerates genesis of a system and when it increases the genesis is hampered. The low values of VWS was observed to the north of the track of JAL suggesting existence of favorable conditions for maintaining the cyclone for a relatively longer period of time.

Sensible and latent heat fluxes

Figure 7(a-h) shows the sensible heat flux during 1-8 November 2010. Warming and moistening of the boundary layer, through the sensible and latent-heat fluxes from underlying warm sea, is an efficient mechanism for convective destabilization and production of heavy precipitation. In particular, the effect of moistening the low levels is two-fold: it favors the conditional destabilization of the boundary layer, facilitating the release of convection, and it allows a continuous replenishment of the buoyant energy, favoring the maintenance of convection. Once a favorable environment was produced, and convection developed, the latent heat released from convection further induces cyclo-genesis through diabatic heating over a deep column. This enhances the cyclone intensity and the associated surface winds, leading to greater latent-heat flux, and resulting in a hurricane-like energy engine via air–sea interaction instability. Sensible heat flux of the order of 30 - 40 Wm^{-2} was located over Thailand and adjoining sea along the track on 1st November 2010. It fell and rose as JAL approached the east coast of India. It varied between 20-30 Wm^{-2} as the system reached Andhra Pradesh-Tamil Nadu coast. It rose sharply to 30-40 Wm^{-2} on 6th and 7th November. After land fall, the sensible heat flux fell sharply to 0 to -10 Wm^{-2}. Figure 8 (a-h) shows the latent heat flux during 1-8 November. The latent heat flux was of the order of ~270-300 Wm^{-2} on 1st November and was located along the track near and adjoining the Thailand sea. It varied between 75 &180 Wm^{-2} during 2-5 November. On 6th November, there was a significant rise in latent heat flux about 100 Km away and along the Andhra Pradesh-Tamil Nadu coast. As the system approached the coast, the latent heat flux fell sharply to a low value of 120-150 Wm^{-2}.

Figure 10. Photograph showing damage and floods caused by the severe cyclonic storm JAL in the state of Andhra Pradesh (Source: Babu/Reuters)

Satellite derived rainfall

Figure 9(a-h) shows the Tropical Rainfall Measuring Mission (TRMM) derived rainfall data during the period 1-8 November 2010. On 1st November, heavy rainfall of the order of 90 mm/day was confined to a small area located around 6°N, 100°E. During 3-7 November, the system intensified and produced heavy rainfall of the order of 40-60 mm/day. These spells of heavy rainfall was for a small duration and on a smaller area. Tables 2 and 3 show the rainfall along Andhra Pradesh coast and Tamilnadu –Puducherry coast, respectively on 8th November 2010.

Damage

The severe cyclonic storm JAL caused heavy down pour in Thailand resulting in extensive flooding, which led to the demise of 59 people. The cyclone claimed four lives in Malaysia. Due to timely warnings, 70,000 people were evacuated from the villages of Andhra Pradesh where damage was expected to be the highest. Figure 10 shows the flooding and damage in Andhra Pradesh. On 9th November, the state declared that 54 people died due to the storm. The total damage estimated by the government was of the order of Rs.363 crore.

DISCUSSIONS

Cyclonic storms striking east coast of India during the south-west post-monsoon season (October-December), generally develop in the southeast Bay of Bengal. However, some of the remnants of typhoons in west Pacific Ocean/ south China Sea move westward and emerge in east Bay of Bengal as a low pressure area, intensify into a cyclonic storm and cross east coast of India. JAL was one such cyclone. It formed as a weak system in South China sea on 28th October 2010 and moved across Thailand, Myanmar. Then it emerged in the Bay of Bengal and concentrated into a Depression at 0000 UTC on 4th November 2010 over southeast Bay of Bengal near lat.8.0°N and 92.0°E. The lowest value of atmospheric pressure of 998 hPa was observed during 5-7 November. The SST was cooler to the right as compared to the left of the cyclone track in the latitude belt of 14-25°N and long. 110-130°E.The higher SST was observed to the left of the cyclone track. The wind speed varied between 10-20 ms^{-1}.Wind field showed prominent cyclonic circulation during 4-7 November in the central Bay of Bengal and increased on 6th and 7th November before making landfall on Tamilnadu-Andhra coast. The SST and wind field level shows the formation of prominent cyclonic circulation during 4-7 November, extending up to 700 hPa level. It is seen that during cyclonic active days viz. 4-7 November, the low values of OLR were co-located with warmer SST in the central Bay of Bengal. The large fall in OLR indicated enhanced convective activity as the **JAL** cyclone approached the east coast of India. Sensible heat flux fell and rose as the JAL cyclone approached the east coast of India and it varied between 20-30 Wm^{-2}; as the system approached Andhra Pradesh - Tamilnadu coast. The sensible heat flux rose sharply to 30-40 Wm^{-2} on 6th and 7th November. The latent heat flux was fluctuating between 75 and 180 Wm^{-2} during 2-5 November. On 6th November there was a significant increase in the latent heat flux along the Andhra Pradesh -Tamilnadu coast and as the system approached the east coast, the latent heat flux fell sharply. Heavy rainfall occurred in the domain 110°E, 5-6°N, but it was confined to a very small area. On 2nd November, the Jal cyclone produced comparatively less rainfall. This may be attributed to the slight weakening of the cyclone. On 7th November the cyclone made land fall and caused considerable damage to life and property due to heavy rainfall. Subsequent to landfall the convective clouds dissipated and OLR rose sharply indicating dry and fair weather conditions.

CONCLUSIONS

The persistent high sea surface temperature (> 26°C) along the track enabled continuous supply of moisture for long travel of JAL.

Marginal cooling of SST along the track, which had helped in the maintenance of sensible and latent heat fluxes, has aided in the longer survival of JAL.

Significant increase in latent heat, sensible heat flux and incursion of moisture, before land fall, were responsible for enhanced convective activity leading to heavy floods along Andhra Pradesh-Tamilnadu coast.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

Arkin and Ardanuy, 1989. Estimating Climatic-Scale Precipitation from space: A review, Journal of Climate, v.2, pp: 1229-1238.

Chinthalu, G.R., Seetaramayya, P., Ravichandran, M., and Mahajan, P.N., 2001. Current Science, v.81, no.3, 10 August.

Chinthalu, G.R., Dharmaraj, T., Dhakate, A.R., and Devara, P.C.S., 2012. Salient features of Andhra Pradesh cyclonic storm in the Bay of Bengal during September 1997 Nat Hazards 62:613–633 DOI 10.1007/s11069-012-0097-5.

Cyclonic disturbances over north Indian Ocean during 2010. A Report, Cyclone warning division New Delhi, report No. 5/2011, India Meteorological Department, January 2011.

Emanuel, K.A., 1986. An air–sea interaction theory for tropical cyclones. Part I: Steady-state maintenance. J. Atmos. Sci., v.43, pp: 585–604.

Gopala krishna Murty, V.V.V.S. N., Sarma, M.S.S., and Sastry, J.S., 1993. Thermal response of upper layers of Bay of Bengal to forcing of a severe cyclonic storm: A case study, Indian J. Mar. Sci., v.22, pp: 8–11.

Hanley, D., Molinari, J., and Keyser, D., 2001. A composite study of the interactions between tropical cyclones and upper-tropospheric troughs. Mon. Wea. Rev., v.129, pp: 2570-2584.

India Meteorological Department, 1979. Tracks of storms and depressions in the Bay of Bengal and the Arabian sea, 1877–1970, 186 maps, pp: 26.

Neumann, C.J., Jarvinen, B.R., McAdie, C.J., and Elms, J.D., 1993. Tropical cyclones of the North Atlantic Ocean, 1871-1992. NOAA Historical Climatology Series 6-2, Asheville, pp: 193.

Obasi, G.O.P., 1997. WMO's programme on tropical cyclone, Mausam, v.48, pp: 103–112.

Premkumar, K., Ravichandran, M., Kalsi, S.R., Sengupta, D., and Gadgil, S., 2000. First results from a new observational system over the Indian seas, Curr. Sci. v.78, no.3, p: 323–330.

Richards, F., Arkin, P.A., 1981. On the relationship between satellite-observed cloud and precipitation. Mon. Wea. Rev. v.109, pp: 1081-1093.

Stramma, L., Cornillon, P., and Price, J.F., 1986. Satellite observations of sea surface cooling by hurricanes. Journal of Geophysical Research, v.91, no.C4, pp: 5031-5035.

Tang, B., Emanuel, K., 2010. Midlevel ventilation's constraint on tropical cyclone intensity. J. Atmos. Sci., v.67, pp: 1817-1830.

Jinhua, Y., and Yuqing Wang., 2009. Response of tropical cyclone potential intensity over the north Indian Ocean to global warming Geophysical Research Letters, v.36, L03709, doi:10.1029/2008GL036742,

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