Nowcasting of Thunderstorm using Integrated Precipitable Water Vapor Contents measured by ground based GPS over Guwahati Airport of India

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Abstract:

International Airport of Guwahati is located in Assam Valley and due to its typical geographical position is highly prone from moderate to severe thunderstorms during the pre-monsoon season (March –May). These events are often known as Norwesters. Recording of real time Integrated Precipitable Water Vapor (IPWV) contents at each hour by ground based GPS which has been recently introduced have advantages over the traditional methods to nowcast thunderstorm episode.

The study utilizes IPWV data recorded by GPS thunderstorm during pre-monsoon 2007 2008 and 2009.Total 25 events were analyzed. A skewed normal curve was identified in each matured thunderstorm. It is also observed that the peak of curve and commencement of rainfall generally coincides. Considering this observed fact authors has made an attempt to nowcast this event before two hours. For this eight hours or observations from initial value of polynomial curve to peak is considered. Three types of pattern were observed on the basis of initial value of polynomial curve. Equations of these three polynomial curves were worked out and limits of +1 and -1 are assigned which will enable to track consecutive six observations. For this a suitable computer program is developed which will pick the minimum value of 25 mm of first pattern and continuously monitor all the hourly values. The warning will be issued after consecutive six values lying in any one of pattern two hours before.

Key words: GPS, IPWV, Thunderstorm, polynomial curve, profile, nowcasting.

Introduction:

International Airport of Guwahati is located in the Assam Valley (Fig -1) and due to its typical geographical position it is highly prone to moderate to severe thunderstorms and occasionally with hailstorms during Pre-monsoon season (March –May). These events are often known as Nor'westers. Considering its destructive potential in short duration, nowcasting of occurrences of this event has been always been seen as a forbidden challenge to Meteorologists. In the past many authors had analyzed the events using conventional methods. In India Koteswaram and Srinivasan (1958) initiated the work of thunderstorm events over Gangetic West Bengal and discussed the synoptic conditions favorable for development of thunderstorm and infer that the simultaneous presence of low level convergence and upper air divergence is the key factor.

An attempt made by Choudhury (1961) on development of thunderstorm in over northeast region had drawn attention towards low level convergence and lifting mechanism. Mukherjee (1964) has significantly contributed on different aspects of this event. He showed that the frequency of this event is maximum in pre-monsoon season (March – May) particularly during night in Assam valley. He also observed that about 6 'Squalls' had been occurred over Guwahati during pre-monsoon season from 1955-61.

Recently climatologically aspects of thunderstorm and squall over Guwahati airport was studied by *Gajendrakumar and Mohapatra (2006).* They showed that average 5.4 'Squalls' had been occurred during pre-monsoon for the period 1991-2000, mostly from North-Westerly direction. Further they showed that on an average fall of temperature was noticed as 2.2°C and rise in mean sea level pressure as 1.6 hpa. The average maximum and minimum wind speed noted as 39 and 70 knots respectively. Sutapa Choudhury (2006) has studied Ampliative reasoning to view the prevalence of this event over northeast region of India and concluded that for genesis of this event minimization of convective inhibition energy is fundamental whereas neither maximization nor minimization of convective available potential energy is of significance. Huge amount of work on climatology of thunderstorm of all the seasons of for Indian using data of 450 stations has been done by *Tyagi (2007).* The study shows that Guwahati airport is having a very high frequency in the pre-monsoon season. *Chakrabarti et al (2008)* analyzed these events for Assam and adjoining region during April and May 2006 under a pilot project entitled ‘Severe Thunderstorm Observation and Regional Modeling’(STORM). The study included multiple observational systems such as radiosonde observations in addition to radar, satellite and synoptic situations. The conclusions drawn generally confirm results of earlier studies and also brought some new results such as maximum frequency observed was along Brahmputra river. The key factor of its occurrence is due to lower level cyclonic circulation over Sub-Himalayan West Bengal and adjoining west Assam which moves towards east under influence of trough in westerly and finally struck over Guwahati and other region of Assam. Thus the systems are of migratory in nature. One of an important lacuna in these systems of weather prediction is the time lag between the observations and analysis and the issue of forecast. In India the estimation of IPWV using GPS has been initiated by *Giri et al (2006)* for winter season during 2003. *Giri et al (2007)* has also done the comparative study of GPS derived IPWV data with MODIS, NCEP and Radisonde data. Nowcasting of thunderstorm using this technique has been studied conducting field experiments by many authors in other countries. *S.de Haan et al (2008)* studied two cases of this event using construction of real time IPWV maps fro GPS surface network and showed that the location of development of thunderstorms cab be identified a couple of hours. *Chan et al (2009)* made a field experiment of a multiwavelengh ground based microwave radiometer for the nowcasting of heavy rain and thunderstorms and concluded that it is useful to measure increase in RH at all altitudes and the accumulation of water vapor in lower troposphere for nowcasting purpose.

In recent years generalized GPS scheme is in operation at a few stations in India. This innovation provides a unique devise which are of immense use for instantaneously issue of weather forecast. As such a ground based GPS system was also installed at Regional Meteorological Center Guwahati airport for measurement of Integrated Precipitable Water Vapor (IPWV). As the thermo dynamical properties of tropical troposphere changes rapidly application of T-∅' gram is having limitations on account of only two daily observations viz.0000 GMT and 1200 GMT. Conventional radar installed at present has technological constraints and also on dependency on manual tracking. Since synoptic observations are based totally on manual observational systems thunderstorm events can only be recorded as a routine observations. Under such circumstances recording of real time IPWV contents at each hour by ground based GPS is having advantages over all these methods to nowcast thunderstorm events.

2.0 Computation of IPWV from ZTD

Ground based GPS systems are used for the estimation of Integrated Precipitable water vapor (IPWV). The main sources of delay in GPS dual frequency radio signals (L1=1575 MHz, L2=1225 MHz) are Ionosphere and Troposphere. The Ionosphere delay or error is removed by the linear combination of L1 and L2 frequencies. But Troposphere delay cannot be removed easily. The total delay in the Zenith direction is estimated with the help of GPS observational data. The total delay in zenith direction (ZTD) is the sum of two parts; dry delay in zenith direction called zenith hydrostatic delay (ZHD) and wet delay, which is known as zenith wet delay (ZWD). ZTD values are estimated from the observation file getting from the GPS receiver of each site by measuring the pseudo range or phase delay methods .The brief computation procedure of estimation of Integrated Precipitable Water Vapor (IPWV) is given below:

ZTD=ZHD+ZWD

ZHD values are more sensitive to station level pressure and temperature and calculated by the following formula:

ZHD=0.00278* Ps*{1+0.0026*COS(2 Ø)+0.00000028*Hs}

Where,

Ps =Station level pressure in milibar

Hs = Surface height above geoid in Km

ϕ = Latitude of the station

IPWV=K*ZWD

Where,

$$K = \{10^{-6}(\frac{k_3}{T_m} + k'_2)R_v\rho\}^{-1}$$

Where,

ρ = Density of water in Kg/m³

$k'_2 = (17 \pm 10)Kmb^{-1}, k_3 = (3.776 \pm 0.004)10^5 K^2 mb^{-1}$

RV = water vapour gas constant

Tm = weighed mean temperature of the atmosphere is given by

$$T_m = 55.8(^0K) + 0.77 * T_s(^0K)$$

Ts = Surface temperature in degree C.

ZHD values can be modeled properly and ZWD values cannot be modeled properly due to its in homogeneity in space and time. The final output product of precipitable water will be in mm. Its estimation from GPS is more precise and timely which is very useful in assimilating it into numerical models to modify the moisture fields.

3.0 Data and Method of analyses

The main objective of this study is to reveal the efficacy of IPWV data (mm) received at each hour through GPS installed at Meteorological Center, Guwahati Airport to nowcast the convective activities like thunderstorm, squall, and hailstorms and to have a water vapor channel of the region. Total 25 events of thunderstorm during pre-monsoon season of 2007, 2008 and 2009 were observed and analyzed for nowcasting purpose using IPWV data. This data has been supplied by Satellite Meteorological Division, New Delhi which is receiving data for six stations in India. The amount and duration of rainfall during of theses events are collected from autographic records available at Meteorological Center, Guwahati Airport. It is well known fact that the convective activity initiates with sudden rise in moisture under favorable instability conditions reaches to its peak and resulting with heavy downpour. IPWV vs Time of all the 25 events were plotted and observed the skewed normal curve in each thunderstorm (Fig- 2 to 26). All these curves furnishes following information (Table-1) which provides guideline to nowcast the event.

i) Peak value of skewed normal curve(saturation)

ii) Lowest value or initial value

iii) Number observations considered for nowcasting

iv) Rise in IPWV/hour = Difference between lowest value and peak value / No. of Obs.

v) Average IPWV = Total of IPWV values of 8 observations (i.e. from initial value to peak / No. of Obs.(i.e.8)

In view of the fact that generally convective activity takes few hours to develop a matured thunderstorm and also to keep uniformity in the data total number of observations (hours) was chosen as eight from initial to peak value for analysis.. As such all the 25 contours from initial to peak were plotted (Fig -29) for analysis. The contours show three different patterns from initial value up to peak. All these three patterns are plotted separately and shown in Fig -30, 31 and 32. Thus three identical patterns are identified and intervals on the basis of initial value are made as follows.

A – Initial value range 25 to 30 mm with 7 events

B - Initial value range 31 to 35 with 11 events

C- Initial value range more than 35 with 7 events

The average values of eight hours of each of these three sets are utilized to find out fourth degree polynomial equations. Thus the three equations obtained are used as a tool for now casting thunderstorm event. For this a computer programme is developed which satisfies following conditions.

i) Monitoring IPWV values continuously during pre –monsoon season of Guwahati Airport with the minimum value as 25 mm and greater.

ii) The values if initiating from each group with an interval of +1 & - 1 (randomly taken) is taken by computer programme.

iii) Up to six values if it follows the polynomial curve with the limits of +1 & - 1 through out then now casting or warning of 8th value or peak of the curve or commencement of rainfall will be issued.

3.0 Results and Discussions

3.1 Analysis of IPWV values of all 25 events

Table –1 shows peak, lowest, average and rise per hour of IPWV values of all events. The number of observations considered for calculating average and rainfall amount during each event is also furnished for analysis. Rise per hour in IPWV values indicate the fast growth of convective clouds whereas the average value shows the comparison of level of moisture among the 25 events. The highest value of rise in per hour is found to be 5.3 on 18th April 2009 with an average IPWV as 28.5 only. The rainfall amount observed was 11.0 mm. On the contrary the lowest value of rise per hour is found to be 0.8mm on 19th March 2009 with average value as 29.4 mm. The rainfall observed was 18.3 mm. The highest rainfall recorded was 28.9 mm on 19th May 2008 with an average and rise per hour in IPWV as 31.6 mm and 1.4 mm. whereas the lowest rainfall of 5 mm observed on 13th April 2009 and 3rd May 2009 shows the average and rise per hour as 36.0 mm and 3.0 and 40. 6mm and1.5. The analysis indicates that the correlation among all these parameters with respect to rainfall or the severity of thunderstorm events is poor. Thus to utilize these values for nowcasting the event it is necessary to have an identical profiles. As mentioned in data and methodology considering the initial value as reference of all the skewed normal curves identical profiles are worked out.

3.2 Innovation of coincidence of peak IPWV of skewed normal curve and commencement of Rainfall

Fig -27 is a classic example of typical matured thunderstorm structure in which the areas of development of thunderstorm and down fall is shown. Fig -28 shows the time of commencement of rainfall which coincides with peak. This kind of picture well represents the skewed normal curve and provides the input to analyze IPWV value before reaches to its peak for nowcasting the commencement of rainfall. It is to mention that on 24^{th} April 2007 a squall line was observed at Guwahati airport in the evening with sudden heavy rainfall and other typical characteristics of squall. Being a rare phenomenon a case study was undertaken by meteorologists and a part of analysis IPWV data was utilized. The IPWV data was plotted with time and a skewed normal curve (Fig-27) was observed. As discussed above surprisingly it was noticed that the time of commencement of rainfall and the peak of IPWV coincides, which is verified by self recording rain gauge data (Fig-28). This innovation encouraged the authors to analyze 24 more events and a methodology for nowcasting was developed considering eight continuous observations from initial to peak for nowcasting thunderstorm events which show its significant occurrence along with thunder, lightining and strong surface wind.

3.3 Now casting on the basis of polynomial equation of profiles of different groups

Fig- 33, 34, and 35 shows three polynomial curves of fourth degree for eight observations under consideration. For this average values of each group is worked out and then curve is plotted. The regression equation of each curve shows very high correlation coefficient of the order of 0.99. Utilizing these three equations values of eight observations are obtained as shown in Table -2. In order to keep margin in variation of values the limits of +1 and -1 are assigned randomly. Thus the three sets of profiles with limits are provided as basic input to computer. For this a suitable program is developed to track the real time data. The computer will follow six continues values which falls in any of three profiles of groups. Thus the warning will be issued before two hours in anticipation that it will reach to its peak.

Conclusions:

Forecasting thunderstorms is quite tricky because of their small signatures in time and space and their complex dynamics and physics. Recording of real time Integrated Precipitable Water Vapor (IPWV) contents at each hour by ground based GPS provides a valuable input to nowcast thunderstorm event. A skewed normal curve was observed in each matured thunderstorm event when plotted IPWV data with time. It is identified that the peak of skewed normal curve and commencement of rainfall generally coincides. The recording of real time Integrated Precipitable Water Vapor (IPWV) contents at each hour by ground based GPS can be compared with three type of derived polynomial curves of fourth degree for six continuous values which follow any of these patterns by keeping margin of variation of values in the limit +1 to -1 mm for International Airport of Guwahati (India) through a computer programme, will be used for now-casting the thunder storm event. The warning then will be issued two hours before about probable commencement of rainfall with the other characteristics of this event. Being a preliminary study the conclusions drawn are purely of tentative in nature and the technique suggested to nowcast the event may be useful as an additional tool. However the updating of data during each pre-monsoon may help to stabilize the model. Prediction and forewarning the population about the natural hazards well in time is becoming more and more significant each day. The population pressure is such that in the eventuality of being caught unaware the loss of life becomes more. A forewarned population can therefore hope to avoid the loss of life. However, the loss of agriculture or even property at times is inevitable.

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TABLE- 1 SHOWS THE DETAILS OF 25 EVENTS OF THUNDERSTORM

SN	DATE	RF (MM)	PEAK PWVC (MM)	LOWEST PWVC (MM)	AVERAGE PWVC (MM)	RISE IN PWVC PER HOUR	DIFF IN HRS FROM PEAK TO LOWEST
1	24.04.07	18.0	47.0	39.2	37.2	1.1	7
2	04.03.08	13.7	30.1	23.9	23.2	1.6	4
3	17.03.08	15.2	35.4	25.7	27.6	1.6	6
4	19.03.08	18.3	35.8	29.9	29.4	0.8	7
5	21.03.08	26.9	44.4	27.6	29.8	2.4	7
6	29.03.08	17.2	38.5	27.7	28.4	2.7	4
7	02.04.08	6.2	39.2	29.5	30.7	1.6	6
8	03.04.08	12.8	44.3	30.9	32.1	2.7	5
9	12.0408	19.0	45.4	37.8	36.9	1.5	5
10	13.04.08	12.7	48.0	32.9	34.0	2.2	7
11	15.04.08	5.8	50.5	39.3	39.8	3.7	3
12	28.04.08	26.2	49.5	38.3	38.7	1.9	6
13	29.04.08	9.6	44.9	34.0	36.3	1.6	7
14	30.04.08	17.0	53.1	43.6	43.7	1.9	5
15	18.05.08	11.0	44.0	26.5	30.8	2.5	7
16	19.05.08	28.9	39.8	30.0	31.6	1.4	7
17	29.03.09	9.0	39.5	31.6	34.2	1.1	7
18	31.03.09	27.0	41.3	34.5	35.0	1.0	7
19	08.04.09	28.0	44.0	29.9	33.6	2.4	6
20	13.04.09	5.0	52.8	32.1	36.0	3.0	7
21	15.04.09	8.0	49.8	32.2	36.6	2.9	6
22	18.04.09	11.0	40.6	24.6	28.5	5.3	3
23	23.04.09	6.0	38.2	28.8	31.4	3.1	3
24	24.04.09	8.0	38.4	23.3	29.9	2.2	7
25	03.05.09	5.0	48.5	40.8	40.6	1.5	5

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TABLE -2 SHOWS THE IPWV VALUES DERIVED FROM EQUATION(X) AND THE VALUES WITH THE LIMITS OF X+1 AND X-1

Range of groups	X-1	X	X+1
25-30	26.1	**27.1**	28.1
	26.5	**27.5**	28.5
	27.6	**28.6**	29.6
	28.9	**29.9**	30.9
	30.3	**31.3**	32.2
	31.9	**32.9**	33.9
	34	**35.0**	36.0
	37.1	**38.1**	39.1
31 -35	X-1	X	X+1
	31.2	**32.2**	33.2
	31.7	**32.7**	33.7
	31.9	**32.9**	33.9
	32.1	**33.1**	34.1
	32.5	**33.5**	34.5
	33.7	**34.7**	35.7
	36.4	**37.4**	38.4
	41.1	**42.1**	43.1
>35			
	X-1	X	X+1
	39.6	**40.6**	41.6
	38.5	**39.5**	40.5
	38.6	**39.6**	40.6
	39.2	**40.2**	41.2
	40.3	**41.3**	42.3
	41.9	**42.9**	43.9
	44.3	**45.3**	46.3
	48.2	**49.2**	50.2

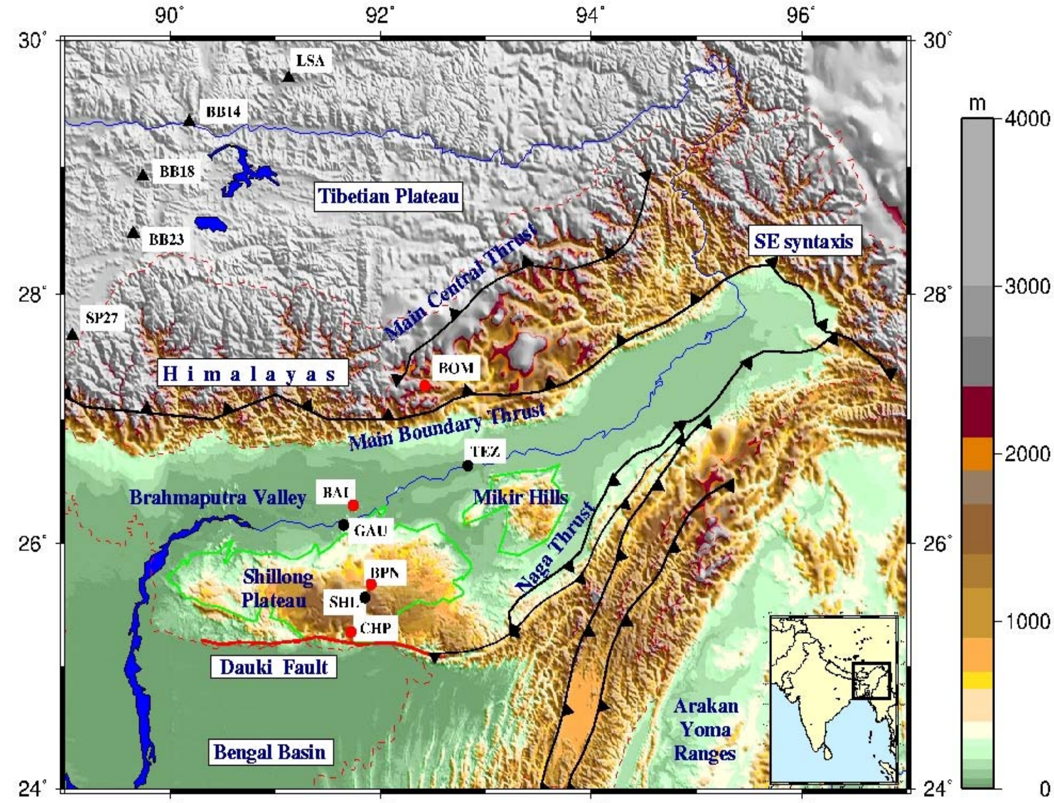


FIG -1

SHOWING ASSAM AND MEGHALAYA SUB-DIVISION

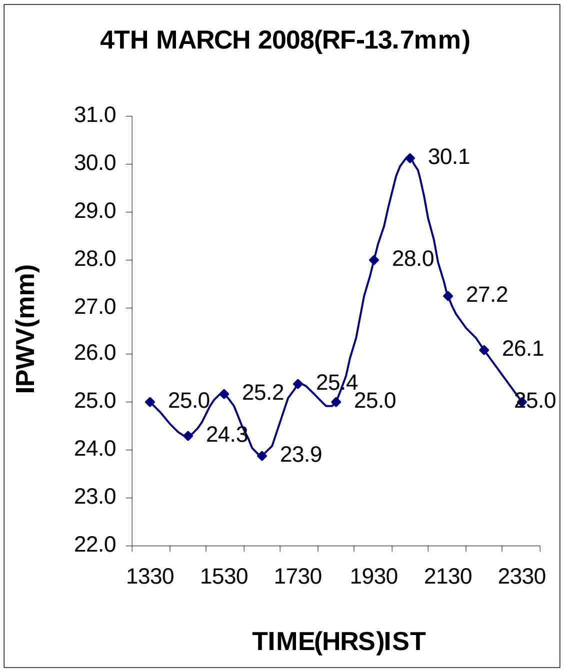


FIG-2 (Group-A)

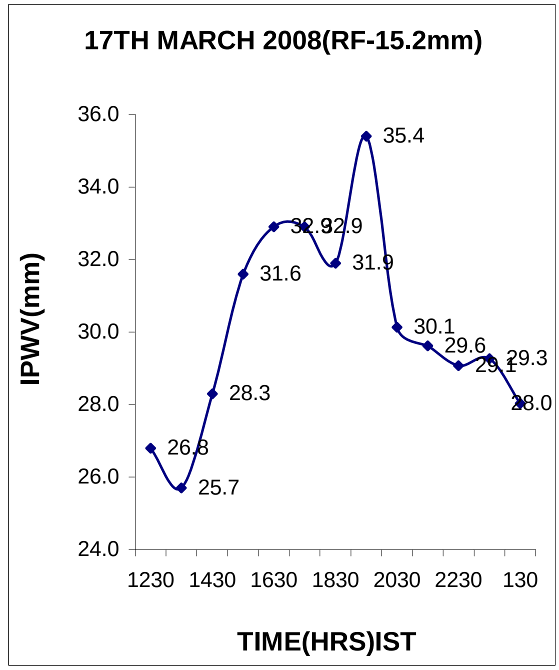


FIG-3 (Group-A)

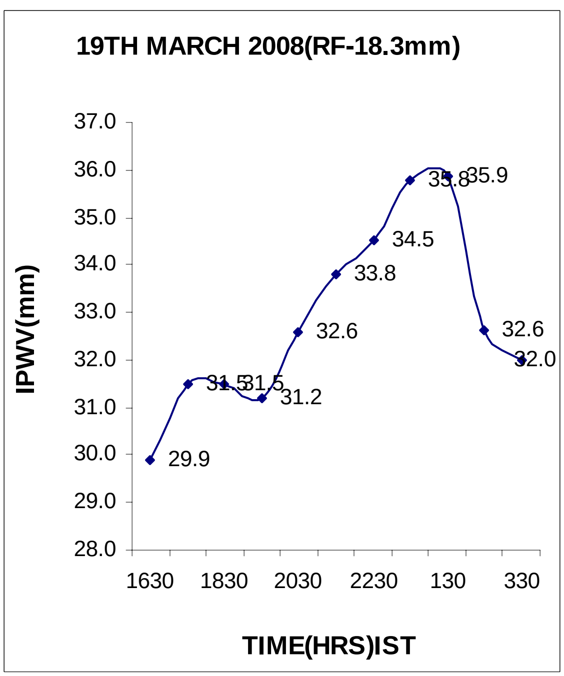


FIG-4 (Group-A)

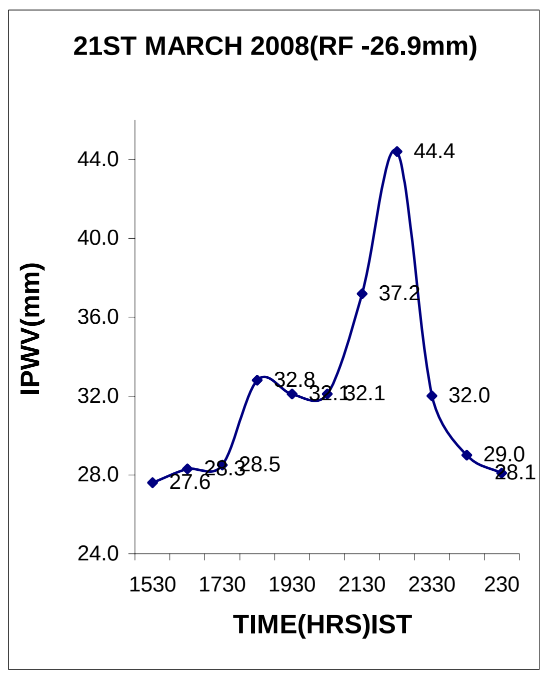


FIG-5(Group-A)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

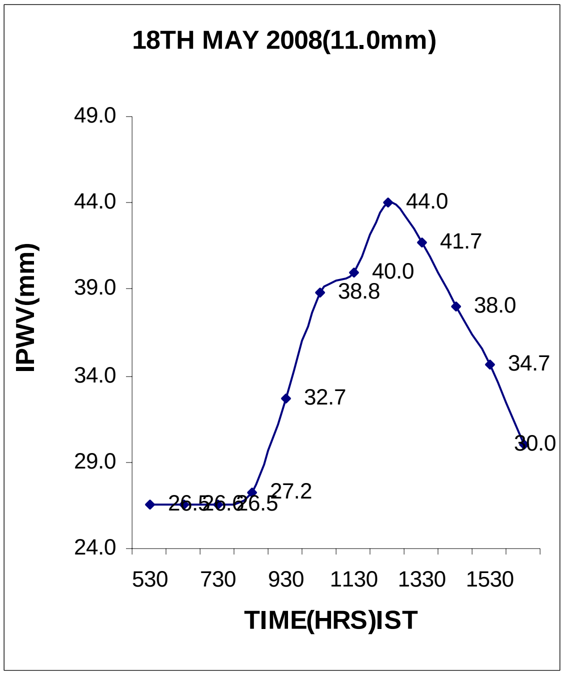


FIG-6 (Group-A)

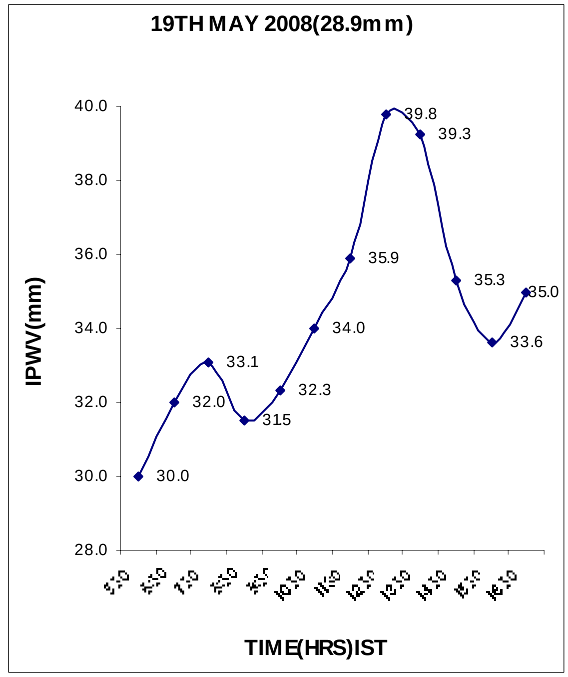


FIG-7 (Group-A)

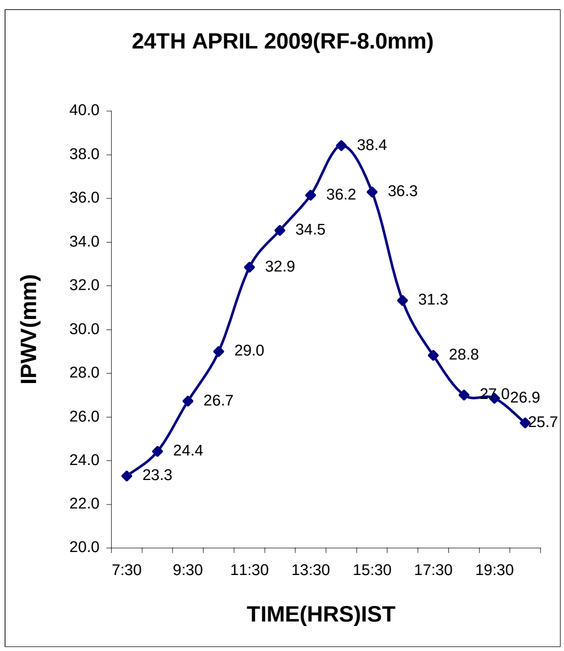
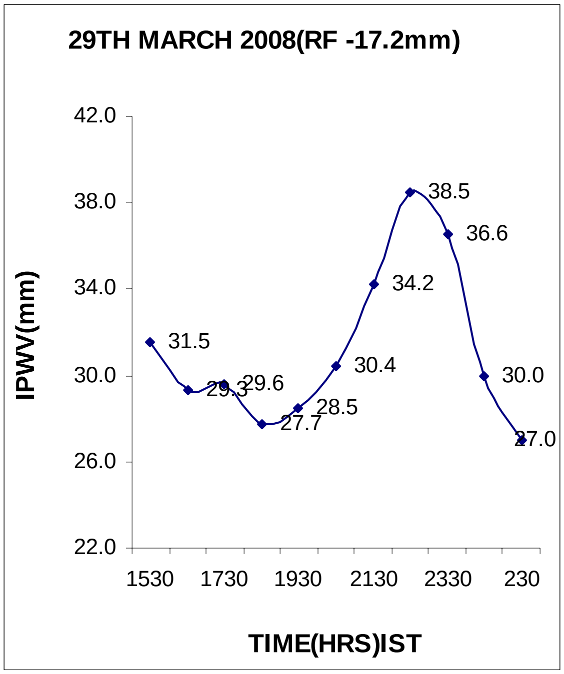


FIG-8 (Group-A)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS



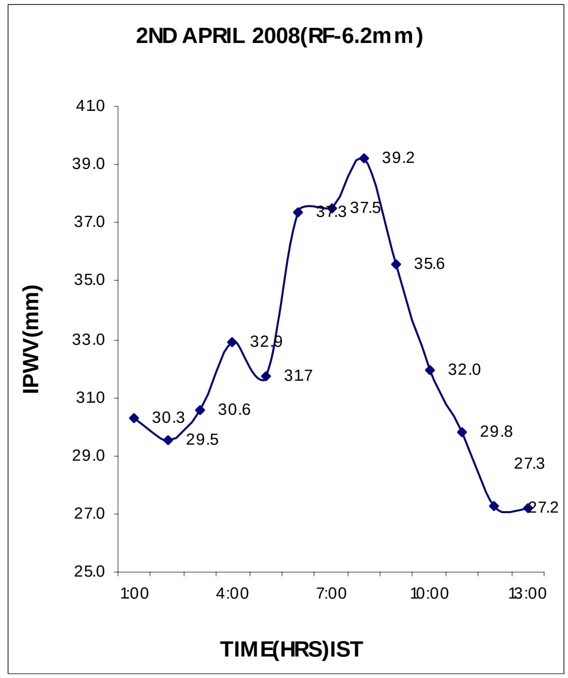
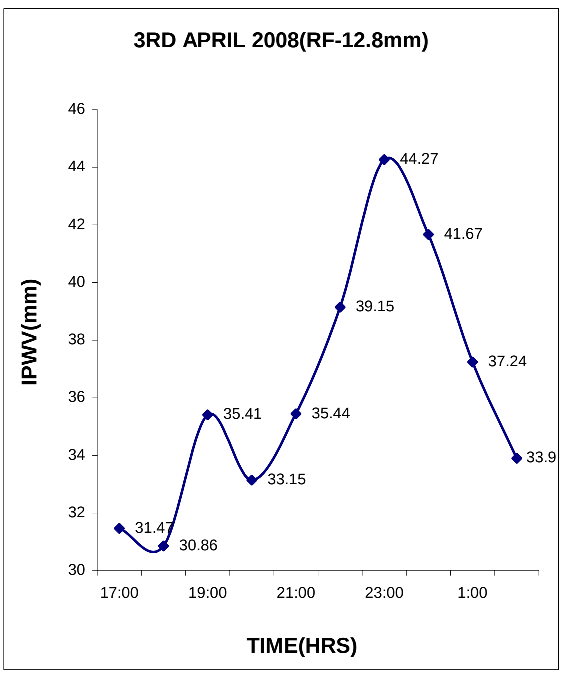


FIG-9(Group-B)

FIG-10 (Group-B)



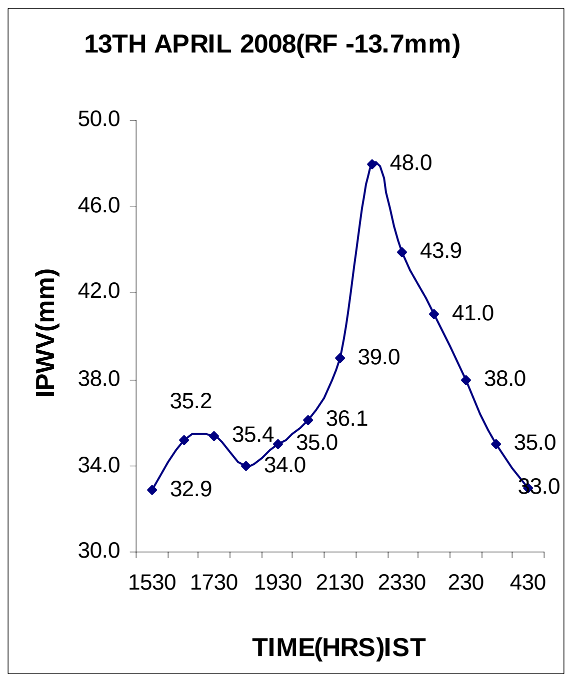


FIG-11(Group-B)

FIG-12(Group-B)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

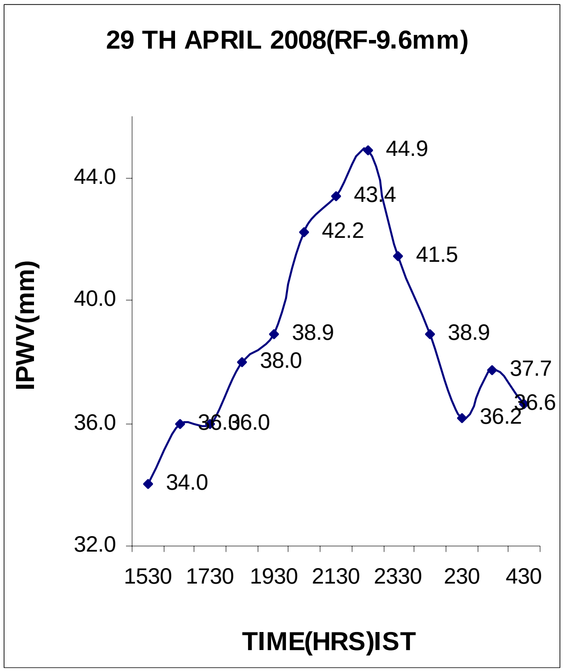


FIG- 13 (Group-B)

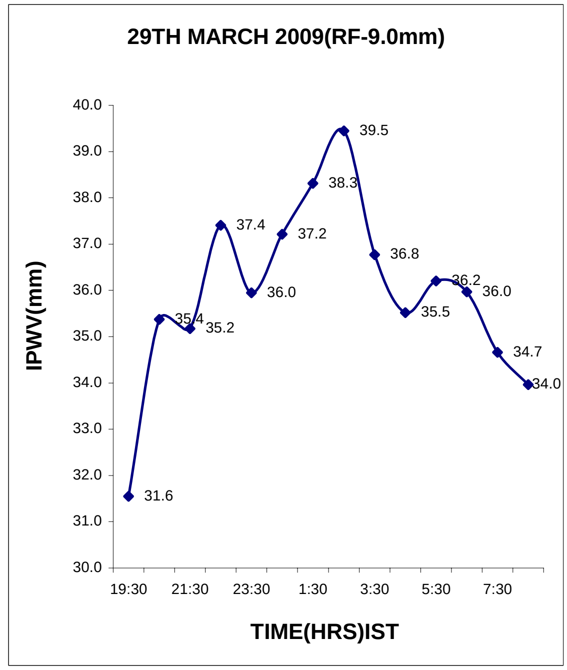


FIG-14(Group-B)

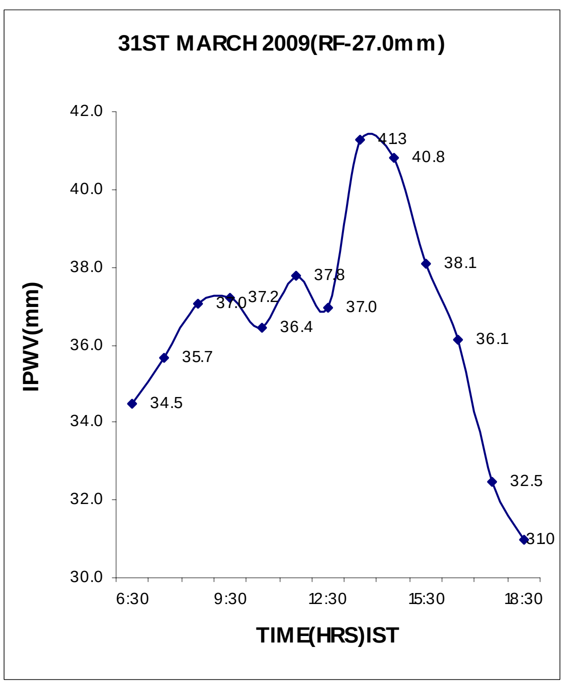


FIG-15(Group-B)

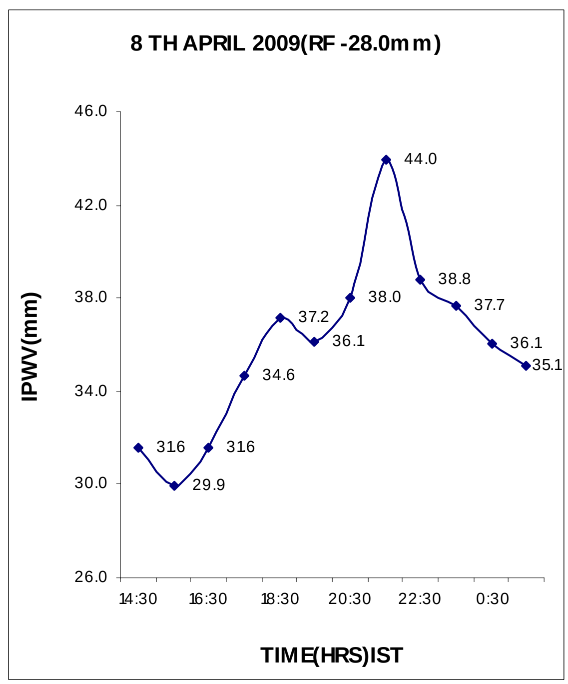


FIG-16(Group-B)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

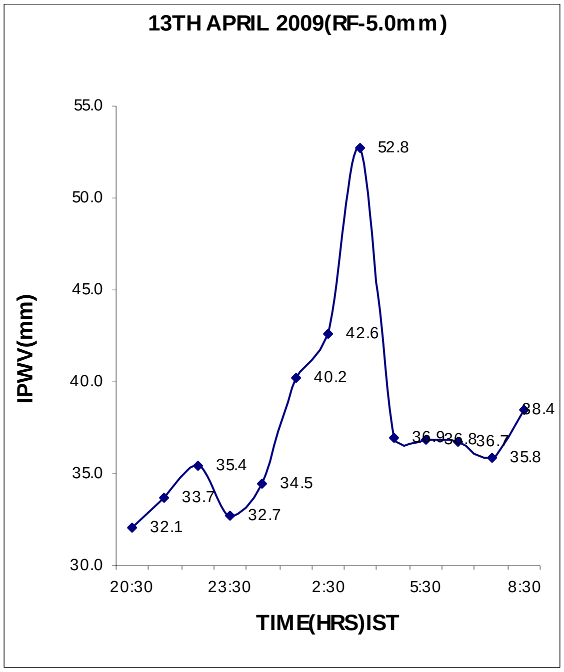


FIG- 17(Group-B)

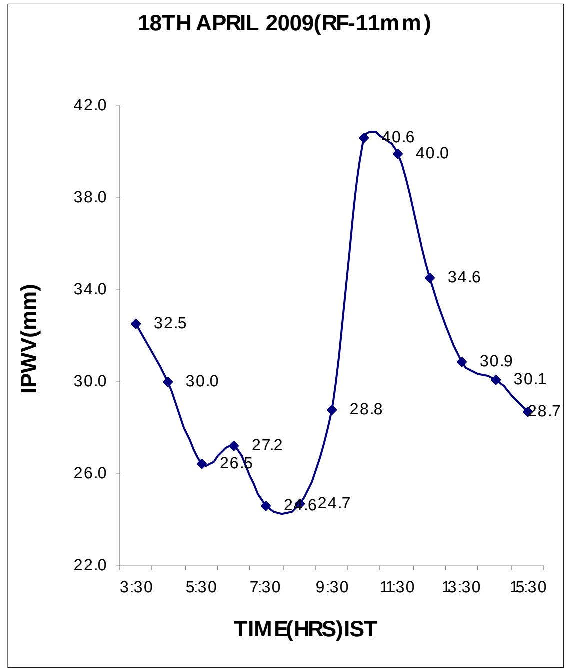


FIG-18(Group-B)

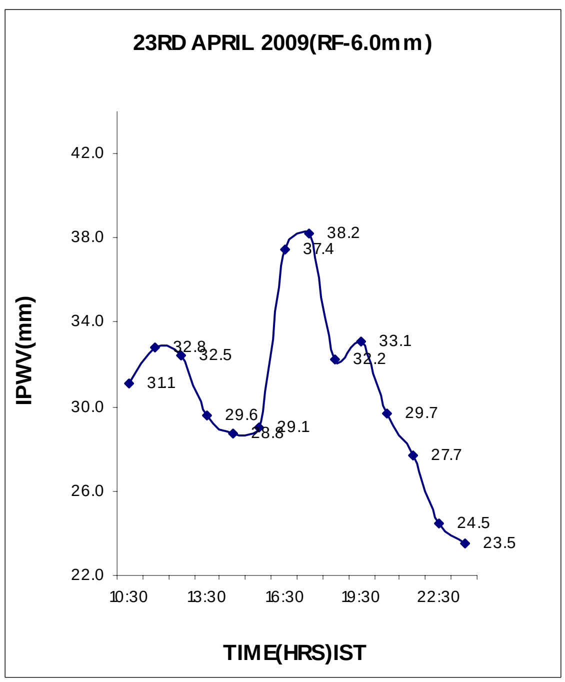


FIG-19(Group-B)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

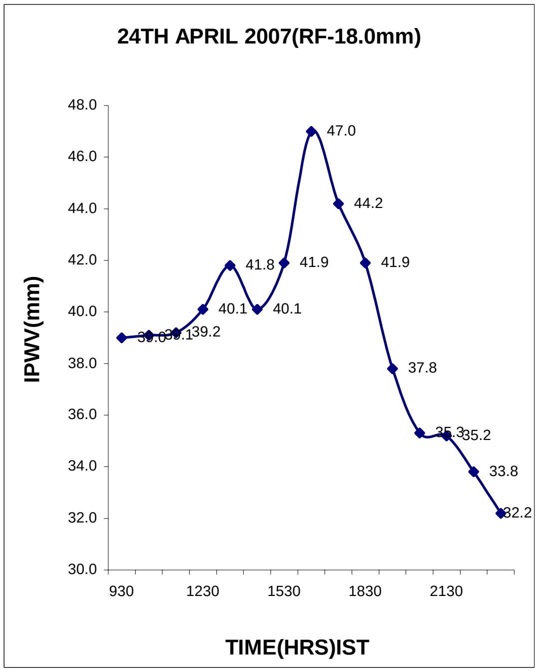


FIG-20(Group-C)

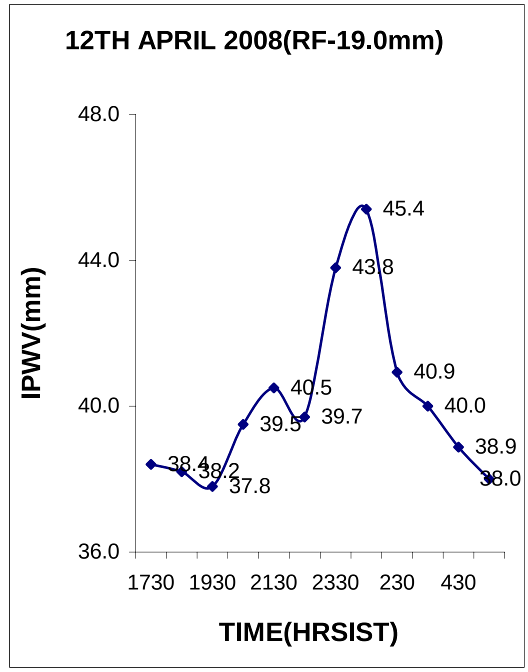


FIG-21(Group-C)

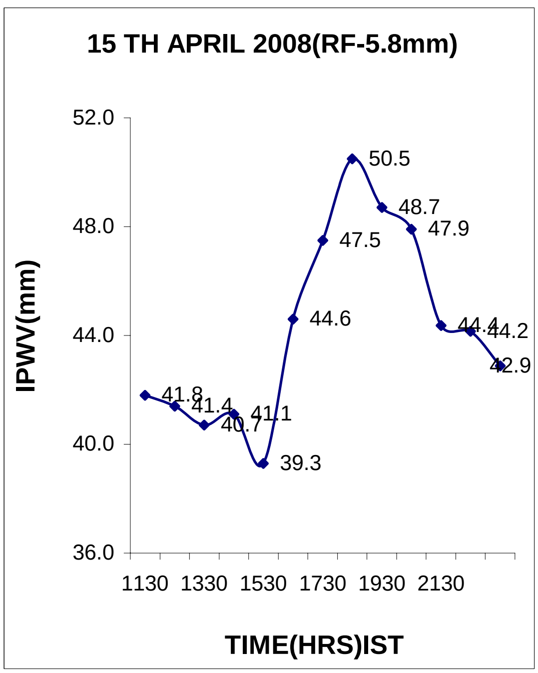


FIG-22(Group-C)

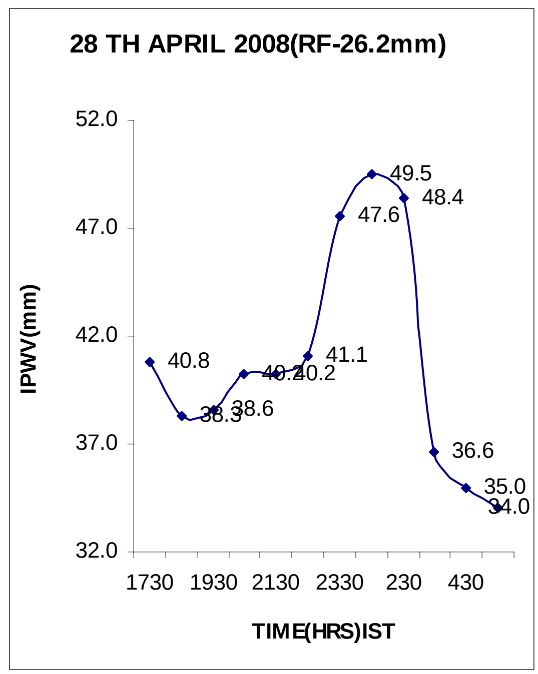


FIG-23(Group-C)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

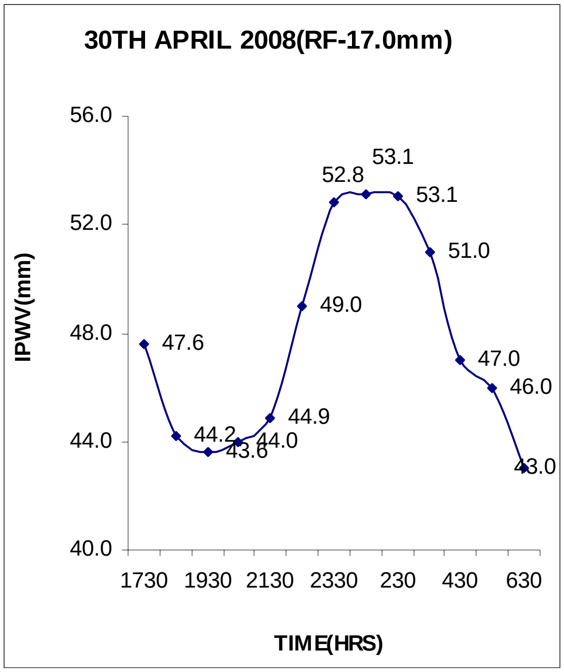


FIG-24(Group-C)

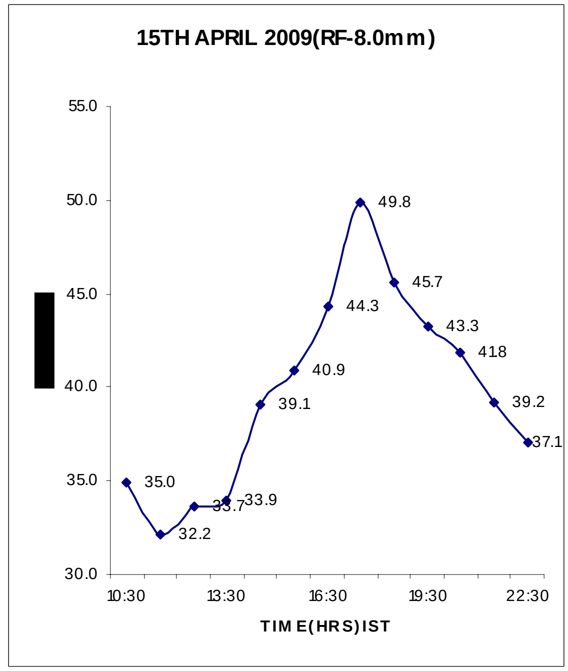


FIG-25(Group-C)

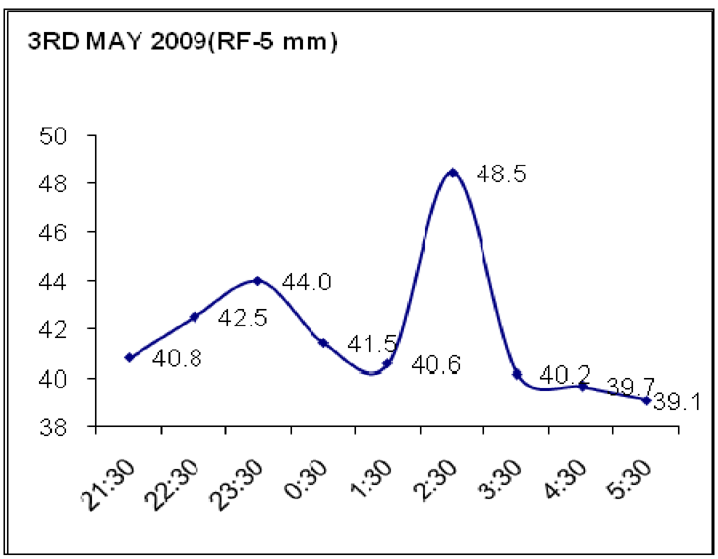


FIG-26(Group-C)

SKWED POLYNOMIAL CURVE OF IPWV UPTO PEAK VALUE OF 25 EVENTS

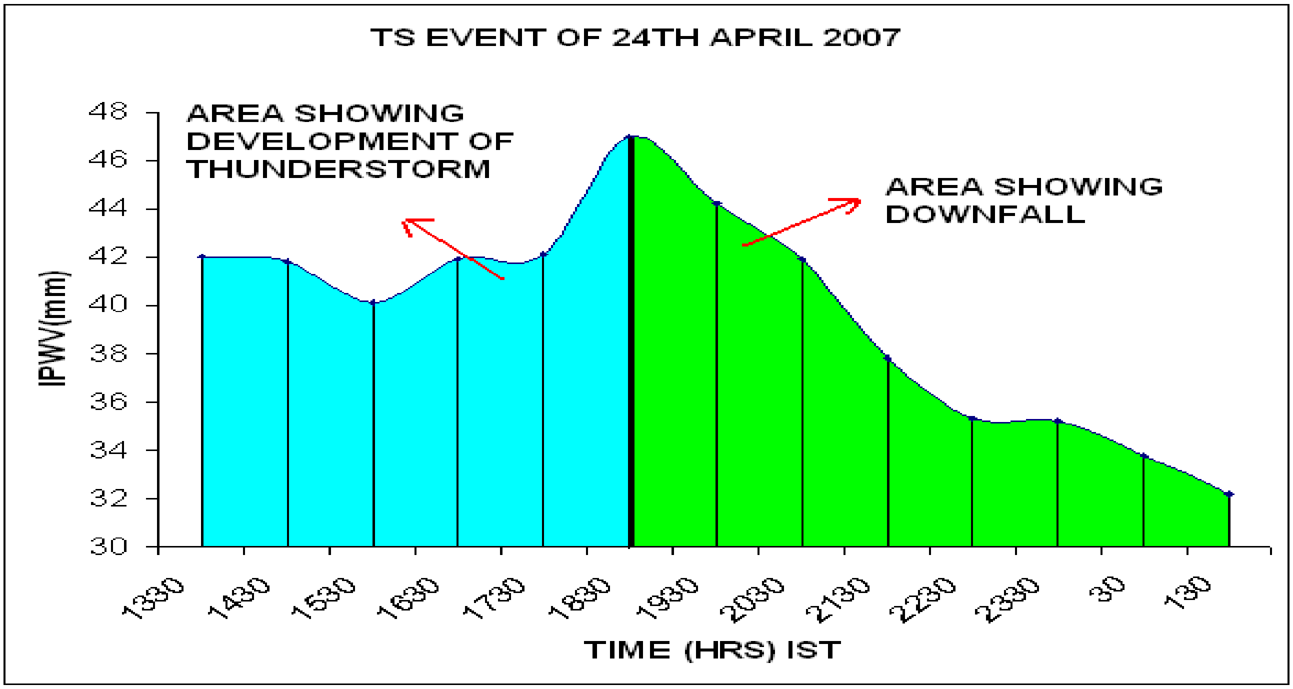


FIG -27

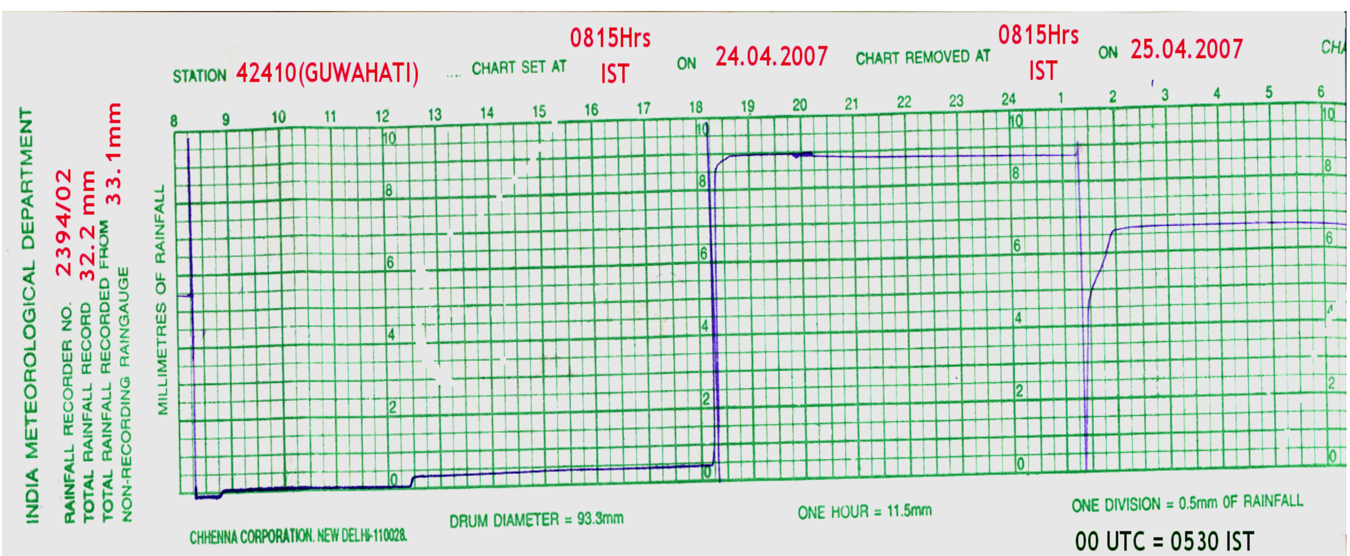


FIG -28

COMMENCEMENT OF RAINFALL TIME (HRS IST)

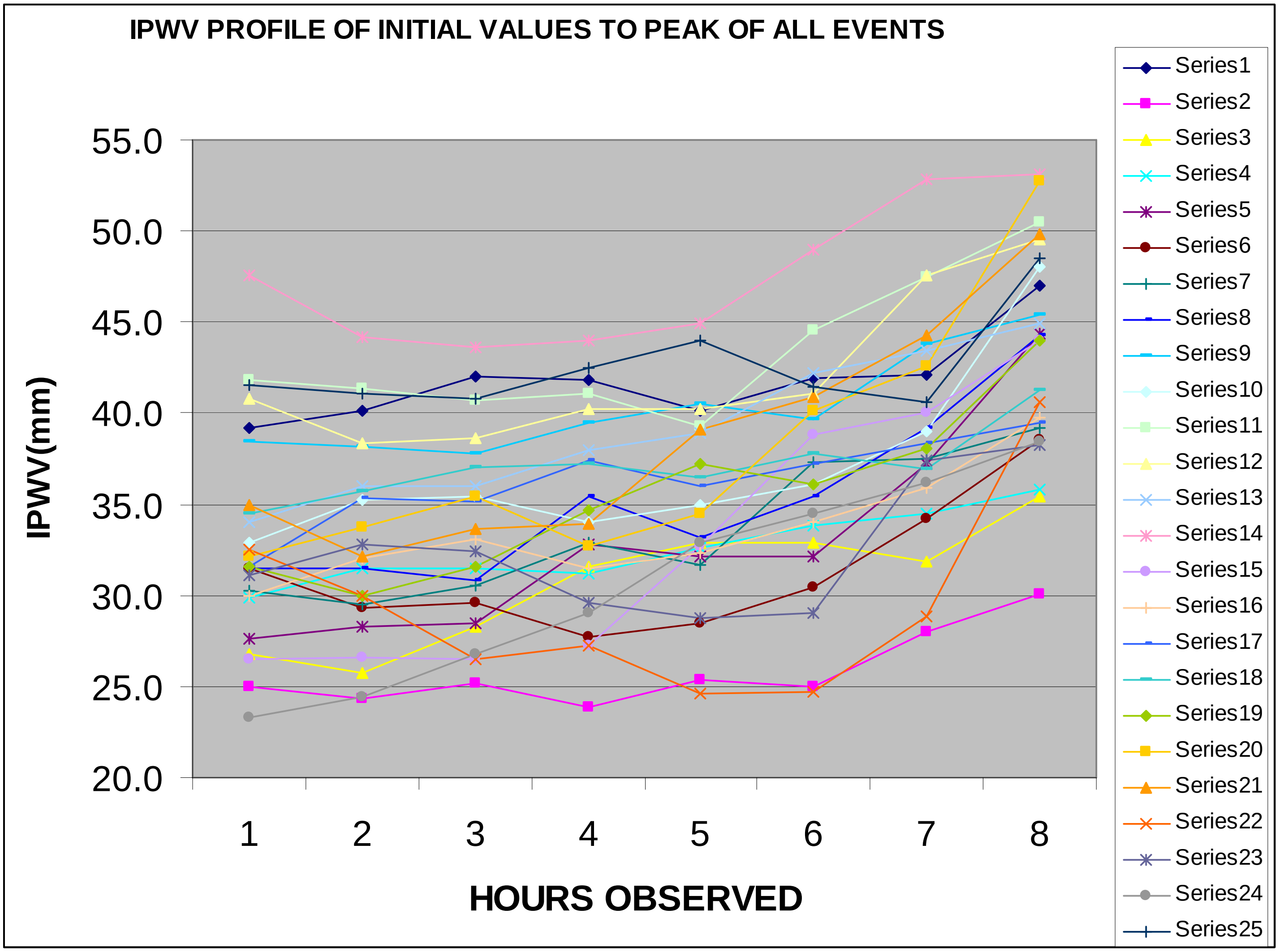


FIG -29

GRAPHS INDICATING IDENTIFICATION OF INTERVALS OF INITIAL VALUE OF IPWV (mm) FOR ALL 25 EVENTS OF TS

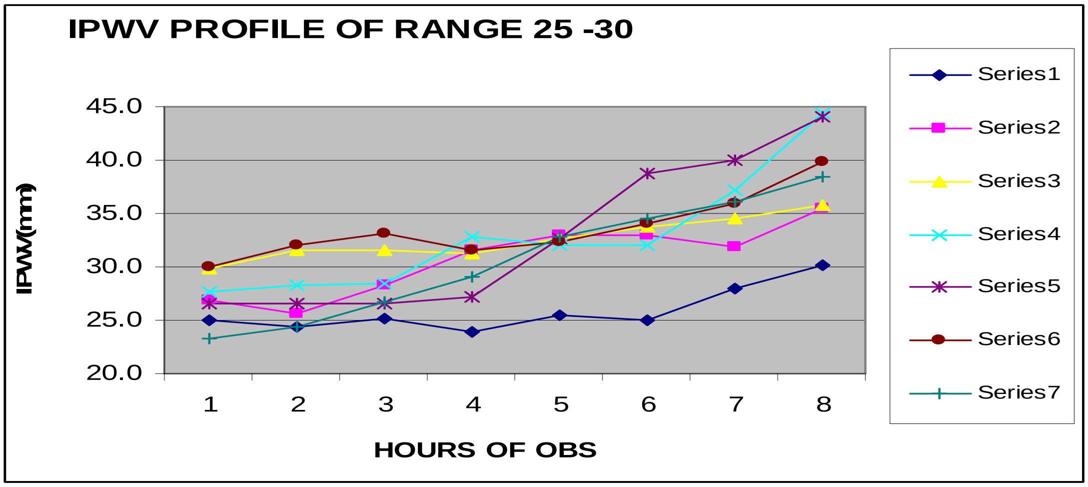


FIG -30

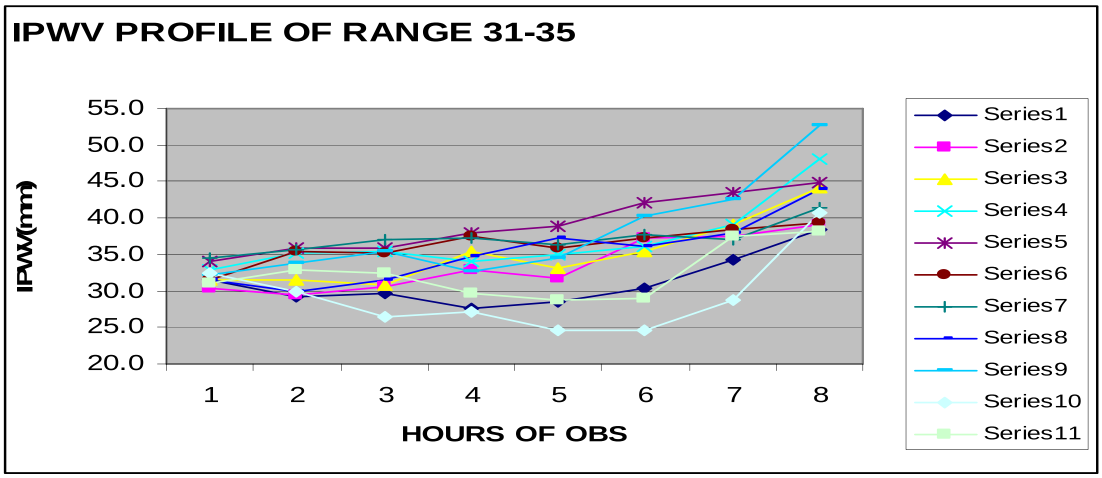


FIG -31

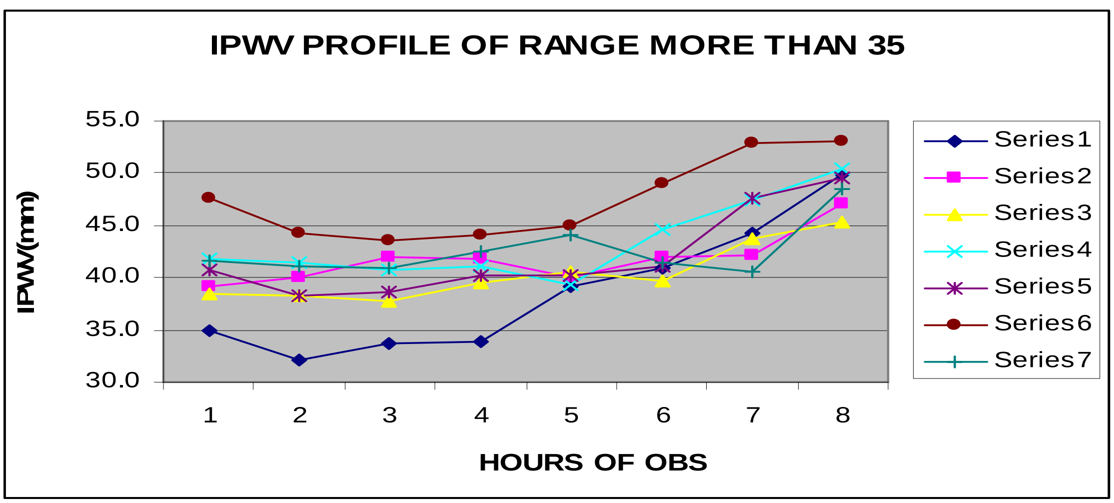


FIG -32

GRAPHS SHOWING DIFFERENT INTERVALS OF INITIAL VALUE OF IPWV

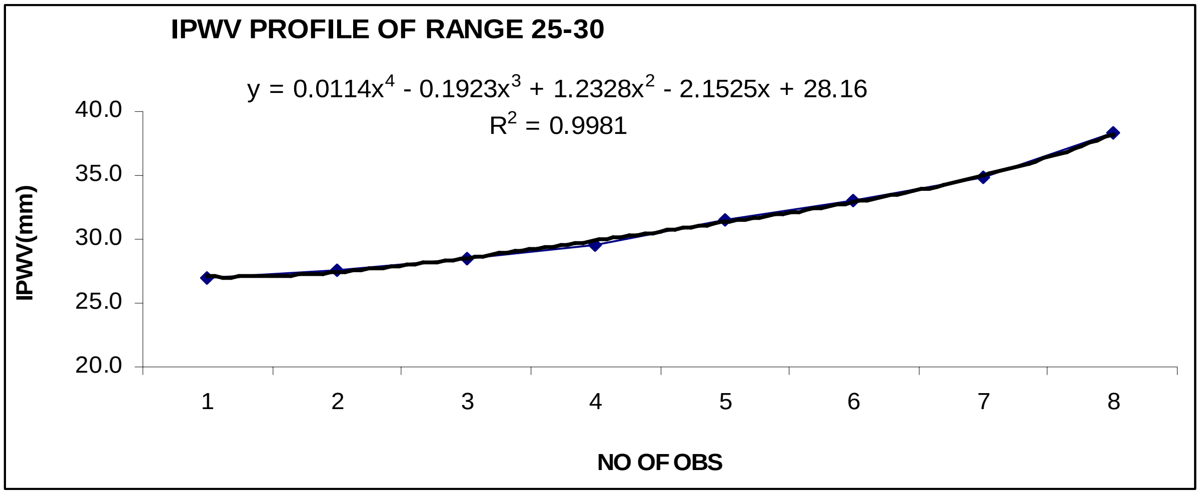


FIG -33

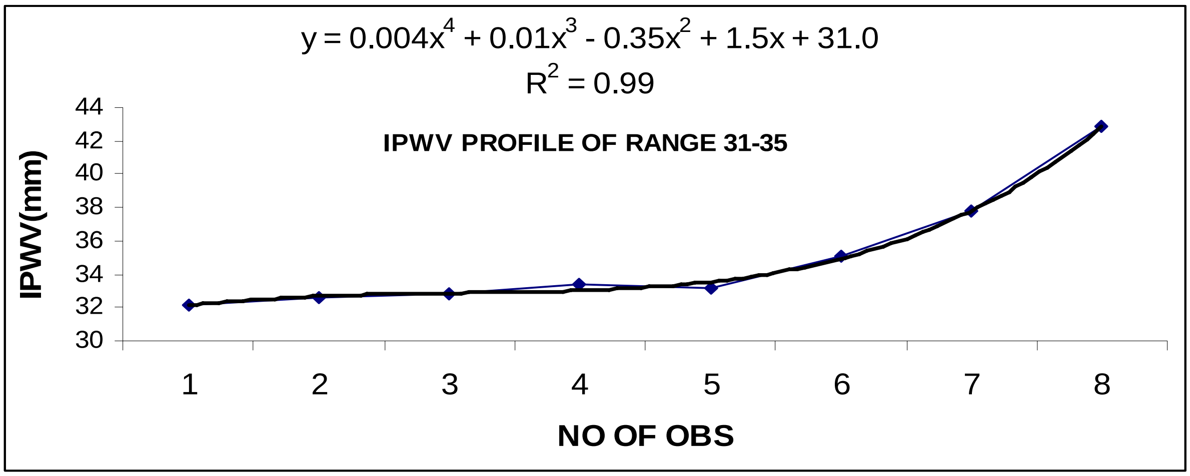


FIG -34

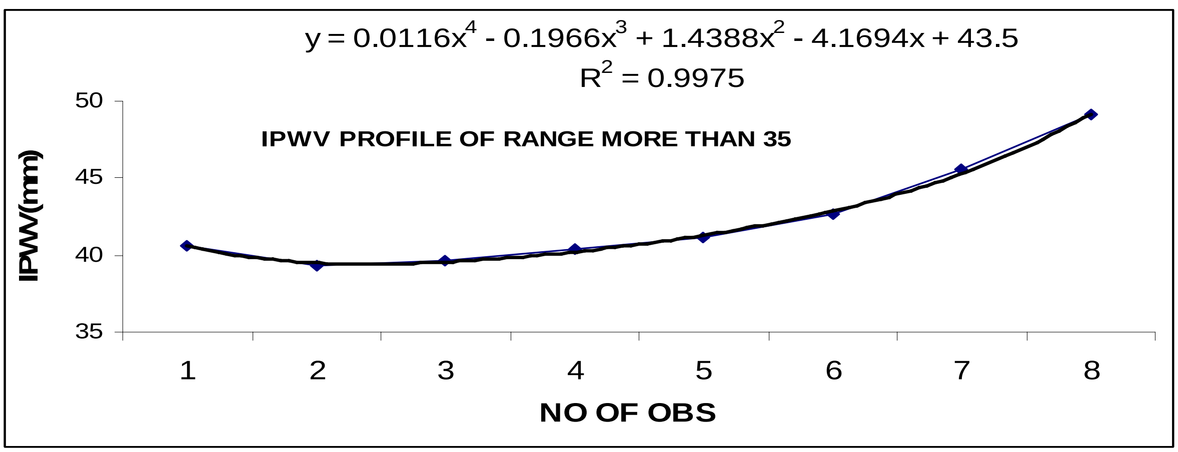


FIG -35

POLYNOMIAL CURVE DRAWN ON AVERAGE OF EVENTS OF DIFFERENT INTERVALS OF INITIAL VALUE OF IPWV INDICATING AN EQUATION FOR NOWCASTING OF TS