Comparative Impact Assessment of Wet-Bulb Potential Temperature and Equivalent Potential Temperature on Precipitable Water in Nigeria

Udo, I. A[1], Okujagu, C. U[2]

[1]Department of Physics, College of Science, University of Port Harcourt, Nigeria
[2]Department of Physics, College of Science, University of Port Harcourt, Nigeria

Abstract: ***Mean annual surface temperatures were determined using a ten year surface maximum and minimum temperatures for twenty eight locations in Nigeria. The results were then used to read off the values of wet-bulb potential temperature, equivalent potential temperature and mixing ratio by following pseudo-adiabatic chart from condensation level, 500mb to 1000mb level. Two of the aforementioned read off parameters: wet-bulb potential temperature and equivalent potential temperature were then used to estimate precipitable water values respectively while one of the parameters, mixing ratio was used to calculate for precipitable water. With reference to calculated precipitable water, the impact of wet-bulb potential temperature and equivalent potential temperature on precipitable water was compared. The comparison shows that wet-bulb potential temperature gives excellent impact on precipitable water than equivalent potential temperature in many locations.***

Keywords: Condensation, Equivalent Potential Temperature, Mixing Ratio, Precipitable Water, Wet bulb Potential Temperature

1. Introduction

Wet-bulb potential temperature is defined as the temperature attained by a mass of air brought adiabatically to saturation and then carried pseudo-adiabatically to a pressure of 1000mb. On the other hand, equivalent potential temperature (also known as pseudo-equivalent potential temperature) according to [1] is defined as the final temperature which a parcel of air attains when it is lifted dry adiabatically to its lifting condensation level, then pseudo-adiabatically (with respect to water saturation) to height (dropping out condensed water as it is formed) then finally brought down dry adiabatically to 1000mb. Both wet-bulb potential temperature and equivalent potential temperature have been regularly employed in air mass analysis as an identification invariant for air undergoing pseudo-adiabatic changes [2].

In West Africa equivalent potential temperature has been widely used for the prediction or estimation of precipitable water or precipitable water related events such as the use of instability indices [3],[4] the reasons are that equivalent potential temperature is capable of predicting convective instability which is most prevalent in West Africa [3][5] Besides, equivalent potential temperature represents total static energy of the tropical atmosphere which isresponsible for generating buoyancy [3] added. Others used other surface meteorological data in their estimation of precipitable water. These include: Monthly average atmospheric perceptible water vapour in Sokoto and its relationship with the horizontal global solar-radiation [6], Empirical determination of the monthly average atmospheric precipitable water distribution for nine Nigeria locations [7]. [8], also worked on the estimation of precipitable water. However the relevance of a particular parameter may be different in a particular location due to the physical complexity of precipitable water forming mechanisms and the availability of their appearance at a particular location, hence global applicability of the experience at a particular location may be inexpedient. In the light of this, this work would extensively assess in comparison the relevance of both parameters:wet-bulb potential temperature and equivalent potential temperature in the estimation of precipitable water formation in twenty eight locations in Nigeria.

2. Data Collection / Method of Analysis

2.1 Data collection

Monthly meteorological data (surface maximum and minimum temperatures) in degree Celsius were collected for ten years (1989-1998) from Nigeria Meteorological (NiMet) Agency, Abuja for twenty eight locations. The locations and their coordinates given in table 1 below are arranged according to latitudinal order of arrangement.

Table 1: Locations and their coordinates

Location	*Lat. (^oN)*	*Longitude (^oE)*
P/H	04.47	06.59
Calabar	04.71	08.55
Uyo	05.00	07.50
Umuahia	05.25	07.30
Owerri	05.29	07.20
Asaba	06.11	06.45
Benin	06.12	05.36
Lokoja	06.12	07.50
Enugu	06.47	07.55
Ikeja	06.58	03.33
Akure	07.18	05.51
Ibadan	07.43	03.90
Makurdi	07.43	08.32
Osogbo	07.46	04.95
Abeokuta	07.95	03.21
Illorin	08.30	04.42
Jalingo	08.50	11.22
Abuja	09.00	07.32
Yola	09.12	12.29
Minna	09.39	06.32
Jos	09.87	04.97
Kaduna	10.00	07.45
Bauchi	10.37	09.80
Damaturu	11.44	11.57

Maiduguri	11.85	13.05
Kano	12.00	08.31
Katsina	12.15	07.30
Sokoto	13.01	05.25

The monthly average surface temperatures were computed from the maximum and minimum surface temperatures using the formula:

$$T_{av} = \left(T_{\max} + T_{\min}\right) \quad (1)$$

T_{av} = average surface temperature
$T_{\max}$ = maximum surface temperature
$T_{\min}$ = minimum surface temperature

This was then used to read off mixing ratio, m by following pseudo-adiabatic chart from condensation level, 500mb to 1000mb level. From the values of mixing ratio, values of precipitable water for each month at each station were computed using the formula:

$$W = m\,(P_{1000} - P_{500})/1000g \quad (2)$$

Where:

W = Calculated precipitable water (mm)
m = mixing ratio (g/kg)

P_{1000}= Pressure level at 1000mb
P_{500} = Pressure level at 500mb
g = acceleration due to gravity.

The choice of these two pressure levels was based on the fact that (1000 and 500) mb pressure levels are standard levels hence conventional data are available for utilization and the energy required to generate buoyancy is found near the earth surface at 1000mb, [3], [5] Monthly average values of precipitable water for each station were computed and used to compute for the annual mean values.

3. Method of Analysis

(i) Simple Linear Regression

The read off values of wet-bulb potential temperature, θ_w, equivalent potential temperature, θ_e; and calculated precipitate water W were regressed as follows:

$$\theta_w = \theta_w - \overline{\theta_w} \quad (3)$$

θ_w= regressed wet-bulb potential temperature
θ_w = monthly wet-bulb potential temperature
$\overline{\theta_w}$ = average wet-bulb potential temperature

$$\theta_e = \theta_e - \overline{\theta_e} \quad (4)$$

θ_e = regressed equivalent potential temperature,
θ_e= monthly equivalent potential temperature,
$\overline{\theta_e}$ = average equivalent potential temperature;

$$w = W - \overline{W} \quad (5)$$

w = regressedprecipitable water,
W = monthly calculated precipitable water
$\overline{W}$ = Average calculated precipitable water

The sum of the square of the regressed wet-bulb potential temperature, θ_w and that of equivalent potential temperature, θ_e as well as calculated precipitable water, w for mean annual values were obtained thus:

$$\sum \overline{\theta_w}^2 = \sum \overline{\theta_w}^2 - \left[\sum (\theta_w)^2\right]/n \quad (6)$$

$$\sum \overline{\theta_e}^2 = \sum \overline{\theta_e}^2 - \left[\sum (\theta_e)^2\right]/n \quad (7)$$

$$\text{and } \sum \overline{W}^2 = \sum \overline{W}^2 - \left[\sum (W)^2\right]/n \quad (8)$$

Where n = number of months (12 months).

Also, the mean annual values of the sum of the product of regression parameters for wet-bulb potential temperature, equivalent potential temperature and precipitable water were obtained as:

$$\sum \overline{\theta_w W} = \sum \overline{\theta_w} \overline{W} - \left[\sum \left(\overline{\theta_w}\right)\left(\sum \overline{W}\right)\right]/n \quad (9)$$

$$\sum \overline{\theta e W} = \sum \overline{\theta_e} \overline{W} - \left[\sum \left(\overline{\theta e}\right)\left(\sum \overline{W}\right)\right]/n \quad (10)$$

(ii) Using the Linear Regression Model for Estimation of Precipitable Water.

First, point estimate of slope, b for both parameters were calculated as:

$$b_{\theta w} = \sum \overline{\theta_w W} / \sum \overline{\theta_w}^2 \quad (11)$$

$$b_{\theta e} = \sum \overline{\theta_e W} / \sum \overline{\theta_e}^2 \quad (12)$$

From the values of point estimate of slopes point estimate of intercepts, a for the two parameters were also calculated respectively, using the formula:

$$a_{\theta w} = \overline{W} - b_{\theta w}\overline{\theta_w} \quad (13)$$

$$a_{\theta e} = \overline{W} - b_{\theta e}\overline{\theta_e} \quad (14)$$

(iii) Estimation of Precipitable Water

From the results obtained above, the values of precipitable water were estimated using the equations:

$$\hat{W}_{\theta w} = a_{\theta w} + b_{\theta w}\overline{\theta_w} \quad (15)$$

$$\hat{W}_{\theta e} = a_{\theta e} + b_{\theta e}\overline{\theta_e} \quad (16)$$

$\hat{W}_{\theta w}$ = estimated precipitablewater from wet-bulb potential temperature

$\hat{W}_{\theta w}$ = estimated precipitablewater from equivalent potential temperature

3.1 Test for the Models' Performance

Correlation coefficient, $r_{\theta w}$ and $r_{\theta e}$ for wet-bulb potential temperature and equivalent potential temperature given by equations (17) and (18) respectively were used alongside with their respective sample deviation from the least square lines equations (19) and (20) respectively for the test of how fit the models are

$$r_{\theta w} = \sqrt{\frac{1 - SS_{\theta w \text{Residual}}}{SS_{\theta w Total}}} \quad (17)$$

$$r_{\theta e} = \sqrt{\frac{1 - SS_{\theta e \text{Residual}}}{SS_{\theta e Total}}} \quad (18)$$

and sample deviation from the least-square lines, S_e given as

$$S_e(\theta w) = \sqrt{\frac{SS_{\theta w \text{Residual}}}{n-2}} \quad (19)$$

$$S_e(\theta e) = \sqrt{\frac{SS_{\theta e \text{Residual}}}{n-2}} \quad (20)$$

Where, n = 12 (number of months) where used for the test of how fit the models are.

4. Result and Discussion

4.1 Measured Parameters' Distribution

In this work the measured parameters: wet- bulb potential temperature, precipitable water estimated from wet-bulb potential temperature, equivalent potential temperature, and precipitable water estimated from equivalent potential temperature and calculated precipitable water as presented in table 2 are arranged according to latitudinal order of arrangement. The table shows that Sokoto has the highest values of all the parameters: wet-bulb potential temperature (20.31^{o}C) precipitable water estimated from wet-bulb potential temperature (21.34mm), equivalent potential temperature (51.37^{o}C), precipitable water estimated from equivalent potential temperature (21.35mm) and; calculated precipitable water (21.36mm). While Jos has the lowest values of all the parameters: wet-bulb potential temperature (13.38^{o}C), precipitable water estimated from wet-bulb potential temperature (12.84mm), equivalent potential temperature (36.03l^{o}C), precipitable water estimated from equivalent potential temperature (12.86mm) and , calculated precipitable water (12.84mm). Yola, Lokoja, Minna, Damaturu, Abeokuta, Makurdi, Maiduguri, Owerri, Asaba, Ikeja, Jalingo, Bauchi, Benue, Ibadan, Illorin, Umuahia, Enugu, Uyo, Katsina, Calabar, Port Harcourt, Abuja, Akure, Kano, Kaduna and Osogbo fall between the two extremes in that order, (table 2). The result shows that the parameters' indices do not follow latitudinal patternrather the pattern is complex. The complex pattern of the parameters' indices could be factored by first, oceanic influence: in-homogeneity of ocean current intrusion with its air mass characteristics to different locations has strong force to break up latitudinal influence on the measured parameters. Second, topography: for example low indices of measured parameters in Jos and Osogbo suggest the effects of orographic uplift; as the sun heats the surface of the earth. It causes air parcels to rise up, as the rising parcel meets orographic barrier it then be forced to ascend. As the parcel ascends the barrier most of its potential temperature is used for work, the result causes reduction in adiabatic lapse rate as compared to environmental lapse rate. Reduction in adiabatic lapse rate leads to low level condensation, hence cloud formation. As the cloud forms, it shades the ground from the sun thereby cutting off the surface from further heating by the sun hence more parcel uplift is impeded except the parcels that were ascended before the shading of the surface by the cloud would be lifted aloft. The resultant effect of this process is low indices of measured parameter. This confirms the assertion, by [9] that the orographic convective activities are strongly affected by convective instability in lower troposphere. On the other hand, locations with large land mass and with plain terrain such as Sokoto, Damaturu, Maiduguri and Yola, have strong surface heating, this causes buoyant lifting of the surface air. In the absence of orographic barrier, parcels do no work hence; adiabatic lapse rate would remain unaffected and high. The effect therefore is more parcels uplift viaparcels high potential temperature. Hence, high indices of measured parameters in the locations.

4.2 Comparison of Impact Assessment

In this work, precipitable water is got from three approaches: (i) precipitable water estimated from wet-bulb potential temperature, (ii) precipitable water estimated from equivalent potential temperature and (iii) calculated precipitable water from mixing ratio-pressure levels, Table 2.

International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Table 2: Location and their measured parameters

Location	*Wet-bulb Potential Temperature (^oC)*	*Precipitable water estimated from wet bulb potential temperature (mm)*	*Equivalent Potential Temperature (^oC)*	*Precipitable water estimated from equivalent potential temperature (mm)*	*Calculated precipitable water (mm)*
P/H	18.17	17.56	46.58	16.70	17.52
Calabar	18.07	17.51	46.87	17.54	17.52
Uyo	17.60	17.81	47.03	17.81	17.81
Umuahia	18.45	18.05	47.38	18.05	18.05
Owerri	18.49	18.51	47.73	18.52	18.51
Asaba	18.55	18.38	48.25	18.27	18.38
Benin	18.13	18.16	47.16	18.17	18.16
Lokoja	19.10	19.53	49.12	19.53	19.53
Enugu	18.43	17.93	47.40	17.95	17.93
Ikeja	18.70	18.32	48.03	18.43	18.33
Akure	17.30	16.81	44.80	16.00	16.82
Ibadan	18.32	18.17	47.23	18.15	18.16
Makurdi	18.80	18.90	48.35	18.88	19.88
Osogbo	14.55	13.51	38.81	13.57	13.57
Abeokuta	19.12	18.91	48.78	18.94	18.91
Illorin	18.22	18.09	46.69	18.07	18.08
Jalingo	18.66	18.30	47.45	18.30	18.30
Abuja	18.82	17.53	44.82	17.52	17.52
Minna	19.85	19.53	49.90	19.53	19.53
Jos	13.38	12.84	36.03	12.86	12.84
Yola	19.56	19.65	94.38	19.67	19.64
Kaduna	16.92	16.25	44.04	16.26	16.25
Bauchi	18.72	18.21	46.19	18.21	18.21
Damaturu	18.98	19.08	48.68	19.08	19.08
Maiduguri	16.88	18.75	48.23	18.78	18.97
Kano	17.51	16.51	44.37	16.51	16.52
Katsina	17.79	17.72	45.62	17.71	17.72
Sokoto	20.31	21.34	51.37	21.35	21.36

In the comparison, calculated precipitable water is taken as the reference measurement. The result would be categorized: (i) when the difference between the estimated precipitable water and the calculated precipitable water is 0.00mm the parameter gives excellent estimate; (ii) when the difference is 0.01mm the parameter gives better estimate; when the difference is 0.02mm the parameter gives good estimate and when the difference is above 0.02mm the parameter gives fair estimate. Table3. The analysis shows that precipitable water estimated from wet-bulb potential temperature, precipitable water estimated from equivalent potential temperature and the precipitable water calculated are the same in Osogbo, Uyo, Umuahia, Lokoja, Minna, Jalingo, Bauchi and Damaturu i.e. the difference between the calculated precipitable water and estimated precipitable water from both parameters each is zero. This means that wet-bulb potential temperature and equivalent potential temperature give excellent estimate of precipitable water in these locations as shown in table 3.Locations such as Ikeja, Ibadan, Illorin and Kano have 0.01mm difference between calculated precipitable water and estimated precipitable water from both wet-bulb potential temperature and equivalent potential temperature respectively. Thus in these locations both wet-bulb potential temperature and equivalent potential temperature give a better estimate of precipitable water. On the other hand, in Makurdi and Abuja, the calculated precipitable water has the same value with the estimated precipitable water from equivalent potential temperature i.e. the difference between them is zero. This means that in Makurdi and Abuja equivalent potential temperature gives an excellent estimate of precipitable water.

Also in Benin, Abeokuta, Asaba, Owerri, Enugu, Jos, Kaduna and Katsina calculated precipitable water has the same value with the estimated precipitable water from wet-bulb potential temperature, i.e. the difference between them is zero hence, in the locations, and wet-bulb potential temperature gives an excellent estimate of precipitable water.

Locations such as Benin, Akure, Owerri, Kaduna, Katsina, Sokoto and Maiduguri have 0.01mm difference between calculated precipitable water and estimated precipitable water from equivalent potential temperature hence;equivalent potential temperature gives better estimate of precipitable water in these locations. Calabar, Abuja and Yola have 0.01mm difference between calculated precipitable water and estimated one from wet-bulb potential temperature, thus in Calabar, Abuja and Yola wet-bulb potential temperature is a better option for the estimation of precipitable water. In Calabar, Enugu and Jos the difference between calculated precipitable water and the estimated one from equivalent potential temperature is 0.02mm each, thus one can say that equivalent potential temperature gives good estimate in those locations. While in Makurdi and Sokoto, the difference between the calculated precipitable water and the estimated one from wet-bulb potential temperature is 0.02mm hence, wet-bulb potential temperature gives good estimate of precipitable water in Makurdi and Sokoto. On the contrary, locations such as Port Harcourt, Abeokuta, Asaba, Yola, and Akure their respective differences are 0.73mm, 0.03mm, 0.11mm and 0.03mm between the calculated precipitable water and the estimated precipitable water from equivalent potential temperature. In these locations equivalent potential temperature gives fair estimate while wet-bulb potential temperature gives fair estimate in locations such as Akure, and Maiduguri of 0.82mm, and 0.04mm differences respectively. The results also show that both parameters performed fairly too in Port Harcourt table 3.

The variation in the values of precipitable water in each location could be attributed to the assumption of constant heat capacity throughout the reading off of parameters from pseudo-adiabatic chart, which contradict assertion that heat capacity at lifting condensation level is no more constant, [10].Thus the neglect of variation of heat capacity at various levels of condensation in this work could introduce error into the values of precipitable water not only from its condensation level to a great height, but also from initial condensation level and most importantly as it returns from great height to the surface [1].

Table 3: Comparison of the Impact of Equivalent Potential Temperature and Wet-bulb Potential Temperature for the Estimation of Precipitable Water across the Zones

Locations	*Difference between calculated precipitable water and estimated one with respect to equivalent potential temperature(mm)*	*Difference between calculated precipitable water and estimated one with respect to wet-bulb potential temperature (mm)*	*Remark*
Osogbo	0.00	0.00	Both equivalent potential temperature and wet-bulb potential temperature give excellent estimate for precipitable water
Uyo	0.00	0.00	
Umuahia	0.00	0.00	
Lokoja	0.00	0.00	
Minna	0.00	0.00	
Jalingo	0.00	0.00	
Bauchi	0.00	0.00	
Damaturu	0.00	0.00	
Makurdi	0.00		Equivalent potential temperature gives excellent estimate
Abuja	0.00		
Benin		0.00	Wet-bulb potential temperature gives excellent estimate
Abeokuta		0.00	
Asaba		0.00	
Owerri		0.00	
Enugu		0.00	
Jos		0.00	
Kaduna		0.00	
Katsina		0.00	
Ikeja	0.01	0.01	Both equivalent and wet-bulb potential temperature gives better estimate
Ibadan	0.01	0.01	
Illorin	0.01	0.01	
Kano	0.01	0.01	
Benin	0.01		Equivalent potential temperature gives better estimate
Akure	0.01		
Owerri	0.01		
Kaduna	0.01		
Katsina	0.01		
Sokoto	0.01		
Maiduguri	0.01		
Calabar		0.01	Only wet-bulb potential temperature gives better estimate
Abuja		0.01	
Yola		0.01	
Calabar	0.02		Only equivalent potential temperature gives better estimate
Enugu	0.02		
Jos	0.02		
Sokoto		0.02	Only wet-bulb gives good estimate
Makurdi		0.02	
Port Harcourt	0.82	0.04	Both give fair estimate
Abeokuta	0.03		Only equivalent potential temperature gives fair estimate
Asaba	0.11		
Yola	0.03		

Akure		0.82	Only wet-bulb potential temperature gives fair estimate
Maiduguri		0.04	

4.3 Models' Performance

High values of correlation coefficients and lower values of sample deviation from the least-square lines as compared to precipitable water values (table 4) are clear indications that the models could be used for the estimation of precipitable water.

Table 4: Locations and their correlation coefficient (r_θw)for wet-bulb potential temperature (WPT) and its sample deviation(S_e θ_w) and correlation coefficient (r_θe)for equivalent potential temperature (EPT) and its sample deviation(S_eθ_e)

Location	*Corr. coeff. for WPT* ($r_{\theta w}$)	*Sample deviation for wet-bulb potential temperature* ($S_e\theta_w$)	*Corr. coeff. for EPT*($r_{\theta e}$)	*Sample deviation for wet-bulb potential temperature* ($S_e\theta_e$)
P/H	0.9931	0.92	0.9835	1.34
Calabar	0.9639	0.18	0.9090	0.41
Uyo	0.9652	2.82	0.9519	3.76
Umuahia	0.9004	2.10	0.9707	0.99
Owerri	0.9561	1.28	0.9389	1.04
Asaba	0.8660	3.85	0.8694	1.11
Benin	0.9579	4.88	0.8602	1.45
Lokoja	0.8970	1.49	0.9422	1.47
Enugu	0.9346	0.98	0.9216	1.15
Ikeja	0.9729	1.61	0.9779	1.53
Akure	0.6425	3.83	0.9997	2.96
Ibadan	0.9320	0.92	0.9149	0.86
Makurdi	0.9625	2.68	0.9645	0.68
Osogbo	0.9179	2.96	0.7173	3.17
Abeokuta	0.8253	2.12	0.7387	1.77
Illorin	0.9124	2.62	0.8473	2.11
Jalingo	0.9049	2.25	0.6994	1.17
Abuja	0.6410	2.36	0.6038	2.75
Yola	0.9954	0.37	0.9615	0.96
Minna	0.8499	4.64	0.9055	3.14
Jos	0.8661	0.08	0.9380	0.06
Kaduna	0.9606	3.19	0.9246	1.23
Bauchi	0.9625	3.12	0.9653	2.79
Damaturu	0.9487	2.65	0.9616	1.16
Maiduguri	0.9805	1.28	0.8274	3.91
Kano	0.9307	2.19	0.8227	2.57
Katsina	0.9049	3.86	0.6994	2.40
Sokoto	0.9914	2.90	0.9748	1.26

5. Conclusion

This work gives comparative analysis of the effectiveness between wet-bulb potential temperature and equivalent potential temperature for the estimation of precipitable water in twenty eight locations in Nigeria in which meteorological parameters are available with calculated precipitable water as a bench mark. Form the analysis, wet-bulb potential temperature performed excellently in the following sixteen locations: Osogbo, Uyo, Umuahia, Lokoja, Minna, Jalingo, Bauchi, Damaturu, Benin, Abeokuta, Asaba, Owerri, Enugu, Jos, Kaduna and Katsina and better in seven (7) locations, these include Ikeja, Ibadan, Illorin, Kano, Calabar, Abuja and Yola and fairly in three locations: Port Harcourt, Akure and Maiduguri. Equivalent potential temperature on the other hand gives an excellent estimation in ten (10) locations namely: Osogbo, Uyo, Umuahia, Lokoja, Minna, Jalingo, Bauchi, Damaturu, Makurdi and Abuja. The parameter also gives better estimation in eleven (11) locations. These include: Ikeja, Ibadan, Illorin, Kano, Benin, Akure, Owerri, Kaduna, Katsina, Sokoto and Maiduguri while in four (4) locations namely Port Harcourt, Abeokuta, Asaba and Yola equivalent potential temperature performed fairly.

References

[1] D. Bolton, "The computation of equivalent potential temperature," Atmos. Phy. Grup. Imperial college London, 1980

[2] H. H. Bindon, "Relationship between equivalent potential temperature and wet-bulb potential temperature," Meteorology Division, 1939, Canada

[3] K. Oduro-Afriyie, "On the mean monthly equivalent potential temperature and rainfall in west Africa,"Theor. Appl. Climatol, XXXIX, 1989, 188 – 193.

[4] A.B Udoimuk and I. O Akpan, "The use of instability indices to predict the amount of rainfall in some Northern Nigerian Towns," Calabar, II (1), 2004, 16 -22

[5] J. A. A. Adedokun, "On a relationship for estimating preicipitable water vapour a loft from surface humidity over West Africa,"J Climatol XXIV (6), pp. 5 -10, 1986

A. A. L Maduekwe and A. Ogunmela, "Estimation of the monthly water vapour in Sokoto and its relationship with the horizontal global radiation," Nig Journal of physics, IX, pp. 25 – 29,1997.

[6] A.A. Maduekwe and E.E Iheonu, "Emperical determination of the monthly average atmospheric precipitable water distribution for nine Nigeria locations,"Nig. Journal of Renewable Energy VII,pp. 26 -31, 1999.

[7] G. O Idemudia and T.O Aro, "Measurement of atmospheric precipitable water vapour at micrometer wave length over tropical stations,"Nig. Journal of physics,IX, pp. 100 – 105, 1997.

[8] T. Santo and F. Kimura, "The relationship between precipitable water and static stability around central mountains in Japan during warm season" Tandem Accelerator Centre, University of Tsukuba, Tsukuba, Japan, 2003.

[9] Nelson – common, W. John and K. Daniel, "Effective Stratification for pseudo adiabatic ascent,"Mon. Wea. RevCXXVIII,pp. 3007 – 3010,2000