

Determination of Kelvin Radii and Bulk Hygroscopicity of Volume Based Hygroscopicity for Atmospheric Aerosols

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Abstract

In this study, a volume based hygroscopicity (k_v) model was applied to the data obtained from Optical Properties of Aerosol and Clouds (OPAC), the properties obtained were the radii of arctic, continental clean, continental polluted, maritime clean, maritime polluted, Sahara and urban at eight relative humidity of 0%, 50%, 70%, 80%, 90%, 95%, 98%, and 99%. The Kelvin radii (A) and bulk hygroscopicity (B) were determined using regression analysis, the result shows that B is more dominant than A for maritime clean and maritime polluted, also discovered that maritime clean and maritime polluted has higher value of k_v while Saharan has lowest. We also discovered that R^2 is greater than 90%, p-value and significance are less than 0.05, therefore the parameter k_v is good for atmospheric modeling.

Keywords: Volume based hygroscopicity; OPAC; Kelvin radii; Bulk hygroscopicity; Relative humidity

Introduction

Atmospheric aerosols interact with water vapour which is one of the central issues of current research in atmospheric and climate. The atmospheric RH in equilibrium with the aqueous solutions of atmospheric aerosols at a given temperature depends on the hygroscopic nature of the solutes, their compositions, concentrations and the effective sizes of these aerosols [1]. The effect of aerosols on the atmosphere climate and public health also among the central topics in current environmental research.

Aerosols particle scatter and absorb solar and terrestrial radiation and also involved in the formation of clouds and precipitation as cloud condensation nuclei (CCN). The efficiency of particles as CCN also affects both aerosol particle and cloud droplet lifetimes [2]. It is well recognized that these effects represent one of the largest uncertainties in assessing the changes in radiative forcing from pre-industrial times to the present [3]. As such, understanding the hygroscopic properties of aerosols and the processes that govern cloud droplet activation are important. Kohler theory has been used to predict the CCN-activity of inorganic compounds for many years [1].

This paper focus on volume based hygroscopicity (k_v) model were it is applied to the data extracted from optical properties of aerosols and clouds (OPAC) to determine the Kelvin radii and bulk hygroscopicity of the aerosols.

Methodology

Where water soluble components (WASO, consists of scattering aerosols), water insoluble (INSO), soot (SOOT) not soluble in water, *ssam* and *sscm* are Sea-salt accumulation and coarse modes particles that consist of the various kinds of salt contained in seawater [4-11]. The *mitr* are Mineral transported, is used to describe desert dust that is transported. The Mineral (nucleation mode) *MINM*, Mineral (accumulation mode) *MIAM*, and Mineral (coarse mode) *MICM*, are mineral aerosols or desert dusts that are produced in arid regions (Table 1) [12-26].

The kohler theory that will describe the equilibrium water vapor saturation ratio S is given by

$$S = a_w k_e \quad (1)$$

Where a_w represent the water activity and k_e is the Kelvin effect. The relationship between

Droplet radius and RH at equilibrium can also be given as:

$$s_w = a_w \exp\left(\frac{4\sigma_w v_w}{RTD}\right) \quad (2)$$

Where R is the universal gas constant and T is the temperature. According to ref. [13], eqn (2) can be written as:

$$s_w \approx a_w \exp\left(\frac{4\sigma_w M_w}{RT\rho_w D}\right) \quad (3)$$

$$= \left[\frac{k_v}{g^3 - 1} + 1\right]^{-1} \exp\left(\frac{4\sigma_w M_w}{RT\rho_w D}\right) \quad (4)$$

The aerosol's hygroscopicity growth factor $g(S)$, [13,14] is defined as:

$$\ln S = \frac{A}{r(S)} + \frac{B}{1 - (g(S))^3} \quad (5)$$

Where S can be set for eight values, substituting eqn (5) in to eqn (4) we get

$$\ln S = \frac{A}{r(S)} + \frac{B}{1 - (g(S))^3} \quad (6)$$

Where $r_k = \frac{2\sigma_w v_w}{RT} = A$ and $B = v\varnothing \frac{v_w}{v_s}$ are assumed to be constants.

The first term on the RHS of eqn (6) is the Kelvin effect given as

$$\ln K_e = \frac{2\sigma_w v_w}{RT r(S)} = \frac{A}{r(S)} = g_\sigma(r(S)) \quad (7)$$

The Second term on the RHS of eqn (3.6) is the water activity given as:

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Model number	Aerosols model types	Aerosols components	Number concentrations (cm ³)	Rmin	Rmax	Sigma	Rmod
				(μm)	(μm)	σ	(μm)
1	Arctic	Inso	0.01	0.005	20	2.51	0.471
		Waso	1,300.00	0.005	20	2.24	0.0212
		Soot	5,300.00	0.005	20	2	0.0118
		Ssam	1.9	0.005	20	2.03	0.209
2	Continental clean	Waso	2,600.00	0.005	20	2.24	0.0212
		Inso	0.15	0.005	20	2.51	0.471
3	Continental Polluted	Inso	0.6	0.005	20	2.51	0.471
		Waso	15,700.00	0.005	20	2.24	0.0212
		Soot	34,300.00	0.005	20	2	0.0118
4	Desert	Waso	2,000.00	2.24	0.0212	0.0212	0.005
		Minm	269.5	1.95	0.07	0.07	0.005
		Miam	30.5	2	0.39	0.39	0.005
		Micm	0.142	2.15	1.9	1.9	0.005
5	Maritime Clean	Waso	1,500.00	0.005	20	2.24	0.0212
		Ssam	20	0.005	20	2.03	0.209
		Sscm	0.0032	0.005	60	2.03	1.75
6	Maritime Polluted	Waso	3,800.00	0.005	20	2.24	0.0212
		Soot	5,180.00	0.005	20	2	0.0118
		Ssam	20	0.005	20	2.03	0.209
		Sscm	0.0032	0.005	60	2.03	1.75
7	Urban	Waso	28,000.00	0.005	20	2.24	0.0212
		Inso	1.5	0.005	20	2.51	0.471
		Soot	130,000.00	0.005	20	2	0.0118

Table 1: The models extracted from OPAC at 0 RHs.

$$\ln a_w = \frac{B}{1 - (g(S))^3} \quad (8)$$

But atmospheric aerosols usually comprised mixtures of soluble components, therefore an effective hygroscopic growth factor of the mixture, $g_{eff}(S)$ representative for the entire aerosols particle population is giving from the previous study as:

$$g_{eff}(S) = \left(\sum_k x_k g_k^3(S) \right)^{1/3} \quad (9)$$

The effective or volume equivalent radius of the mixture was determined using the relation

$$r_{eff}(S) = \left(\sum_k x_k r_k^3 \right)^{1/3} \quad (10)$$

Where x_k denote the volume fractions, using the Zdanovskii-Stokes-Robinson relation (ZSR relation) [15-18].

For many components eqn (6) can be written to represent the property of the bulk components using eqns (9) and (10) as:

$$\ln S = \frac{A}{r_{eff}(S)} + \frac{B}{1 - g_{eff}^3(S)} \quad (11)$$

By using regression analysis with SPSS 16, the constants A and B were determined.

Therefore eqn (7) can be written as

$$k_e = \exp\left(\frac{A}{1 - g^3}\right) \quad (12)$$

The hygroscopicity parameter κ_v relates the volume of the dry aerosol particle (V_d) to the volume of water (V_w) and the activity of water (a_w) in the aqueous droplet:

$$\frac{1}{a_w} = 1 + k_v \frac{V_d}{V_w} \quad (13)$$

Result and Discussion

From Table 2, we can observe that, based on the values of R^2 , the data fitted the equation very well and by looking at the table, we can observe that B is more dominant than A for maritime clean and maritime polluted due to their p-values and from the values of Kelvin radii, it observed that, only Saharan aerosols is negative which means that the Kelvin radii apart from positive (Figure 1 and Table 2) [26].

From Figure 1, It can be seen that volume based Kelvin effect on the Saharan, is linear and is while Urban, Continental polluted, continental clean are independent of RH and are greater than one. The Maritime polluted and Arctic have the same type of pattern, that is why they increase with the increase in RH and is more sensitive at higher RHs (90-99%). Lastly the Maritime clean is more sensitive to RH and is non-linear (Table 3).

Table 3 show that, the data fitted the equation very excellent by considering the values of R^2 . By observing the result it can be seen that maritime clean and maritime polluted has high values of k_v due to dominant of sea salt while it is moderate for arctic aerosols and is less for Saharan due to sufficient mineral at the region.

Figure 2 represents bulk hygroscopicity and Kelvin radii of the aerosols where it shows linearity for both bulk hygroscopicity and Kelvin radii except that of Sahara due to its compositions.

From Figure 3, it shows a linear relationship between bulk hygroscopicity and volume based Hygroscopicity where the continental average, continental clean, Sahara and urban falls between 0-0.5, arctic falls between 1.5-2 and lastly maritime clean and maritime polluted falls between 2-2.5 (Figure 4).

Aerosol model	Kelvin radii (A)	p-value	Bulk hygroscopicity (B)	p-value	R ²	Significance
Arctic	0.0268	0.0272	1.5819	1.16E-05	0.9957	1.20E-05
Cont. Av.	0.0062	0.0336	0.4005	3.09E-07	0.9973	4.72E-06
Cont clean	0.0066	0.0350	0.4125	4.02E-07	0.9970	5.87E-06
M. clean	0.0512	0.0802	2.1480	3.37E-05	0.9893	7.39E-05
M. polluted	0.0481	0.0793	1.9964	2.81E-05	0.9902	6.23E-05
Sahara	-0.0186	0.0283	0.0194	4.27E-08	0.9990	6.15E-07
Urban	0.0054	0.0304	0.3727	1.60E-07	0.9979	2.74E-06

Table 2: The results of Kelvin radii and bulk hygroscopicity using eqn (11).

Aerosol model	kv	p-value	R2	Significance
Arctic	1.602744	4.05E-12	0.999765	1.82E-10
Continental clean	0.421407	1.90E-11	0.999607	6.59E-10
Continental polluted	0.454286	8.10E-09	0.999107	1.92E-07
Maritime clean	2.180441	7.62E-12	0.99971	3.08E-10
Maritime polluted	2.025402	6.31E-12	0.999728	2.64E-10
Sahara	0.019433	6.27E-15	0.999973	8.29E-13
Urban	0.38008	1.25E-11	0.999658	4.66E-10

Table 3: The results of volume based hygroscopicity using eqn (12).

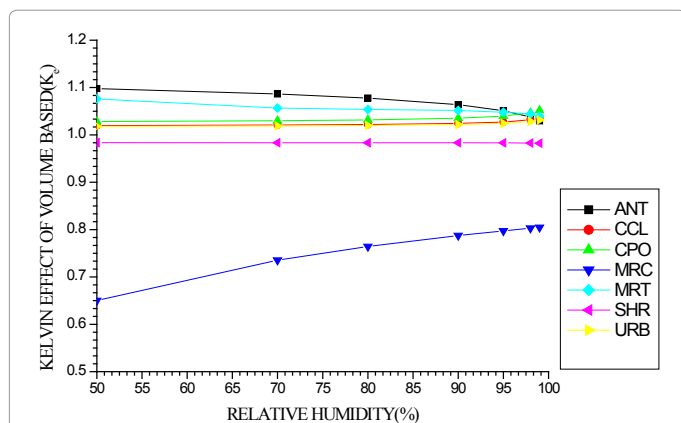


Figure 1: A volume based Kelvin effect plotted against relative humidity using eqn (12).

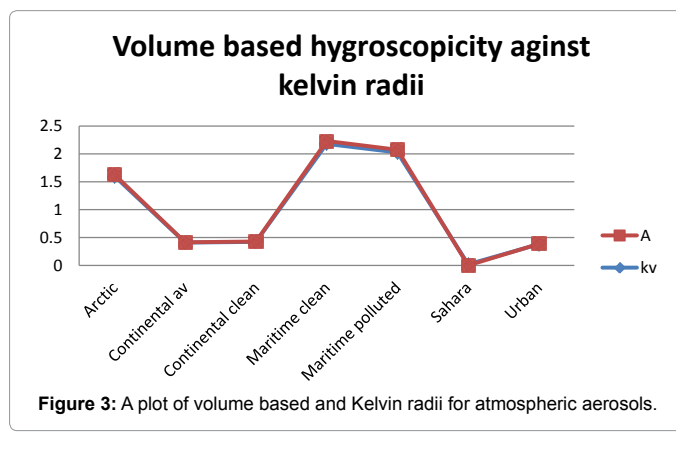


Figure 3: A plot of volume based and Kelvin radii for atmospheric aerosols.

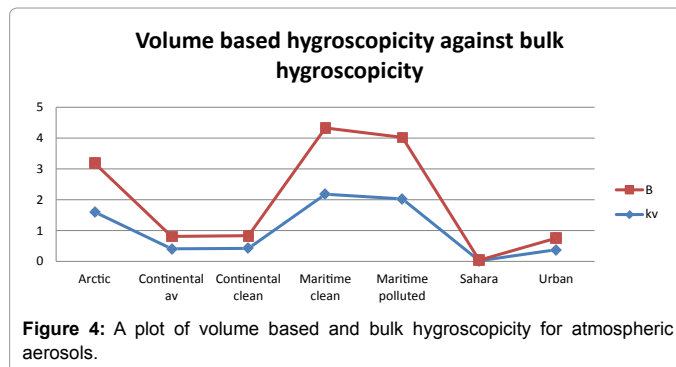


Figure 4: A plot of volume based and bulk hygroscopicity for atmospheric aerosols.

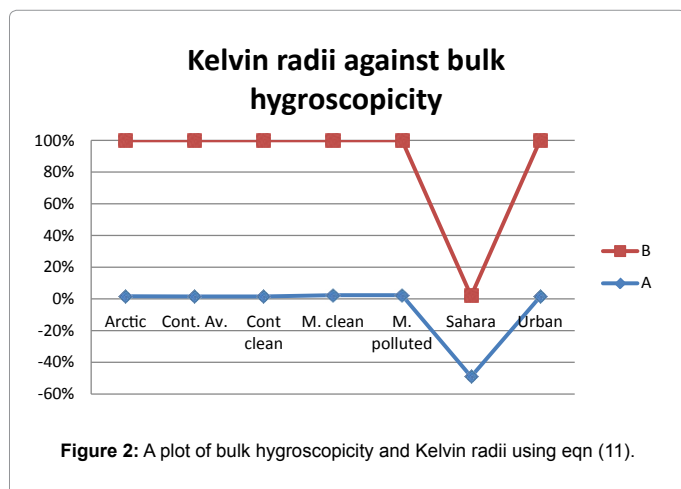


Figure 2: A plot of bulk hygroscopicity and Kelvin radii using eqn (11).

From Figure 4, it can be seen that only Sahara aerosol has a good agreement between volumes based hygroscopicity and bulk hygroscopicity.

Conclusion

From the results obtained, we observed that bulk hygroscopicity (A) dominates the Kelvin radii (B) for maritime clean and maritime polluted and also as RH increase, the Kelvin effect increases. This implies that, they are more sensitive at deliquescence point (90-99%). By observing the volume based hygroscopicity parameter k_v , it can be seen that, it has higher value for maritime clean and maritime polluted and less for Saharan and Figure 2 shows a good agreement between Kelvin radii and bulk hygroscopicity except for Saharan due to its compositions.

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