9999

Manual: Measurement of Evapotranspiration by the Bowen Ratio Energy Balance Method

Joon Kim
University of Nebraska - Lincoln

Shashi B. Verma
University of Nebraska - Lincoln

Kim, Joon and Verma, Shashi B., "Manual: Measurement of Evapotranspiration by the Bowen Ratio Energy Balance Method" (9999). *Papers in Natural Resources*. 1411.
https://digitalcommons.unl.edu/natrespapers/1411

3

MANUAL

MEASUREMENT OF EVAPOTRANSPIRATION BY THE BOWEN RATIO ENERGY BALANCE METHOD

Joon Kim and Shashi B. Verma

Center for Agricultural Meteorology and Climatology,
University of Nebraska-Lincoln

1. Theoretical Consideration:

The Bowen ratio energy balance method has been widely used by many researchers to estimate the fluxes of water vapor and sensible heat between crops and atmosphere. The energy balance for the crop canopy can be expressed as

$$Rn + G + H + LE + PS + M = 0 \tag{1}$$

where Rn is net radiation, G is soil surface heat flux, H is sensible heat flux and LE is latent heat flux. Energy stored in a crop canopy (M) or used in photosynthesis (PS) can be assumed negligible because of their small size (1-2 % of the total). The sign convention is such that fluxes toward the surface are positive and those away from the surface are negative. Both Rn and G can be measured using net radiometers and soil heat transducers, respectively.

The flux of sensible heat can be expressed as

$$H = K_h \rho C_p (\partial T/\partial z) \tag{2}$$

where K_h is the turbulent exchange coefficient for sensible heat flux, ρ is the air density and C_p the specific heat of ambient air and $(\partial T/\partial z)$ is the mean gradient of air temperature.

The flux of latent heat can be expressed as

$$LE = K_w (L\epsilon\rho/P) (\partial e/\partial z) \tag{3}$$

where K_w is the turbulent exchange coefficient for latent heat, ϵ is the ratio of the molecular weight of water to the molecular weight of dry air (equal to 0.622), P is the atmospheric pressure, and $(\partial e/\partial z)$ is the mean vapor pressure gradient.

By assuming similarity between the turbulent exchange coefficients $(K_h = K_w)$ and by using Equations 1, 2 and 3 the following relationship is derived:

$$K = \frac{-\ (Rn + G\ )}{(L\epsilon\rho/P)(\partial e/\partial z)\ +\ \rho C_p(\partial T/\partial z)} \tag{4}$$

Values of K $(= K_h = K_w)$ can then be substituted into Equations 2 and 3 to evaluate the fluxes of sensible heat and latent heat. Equation 1 can be rearranged to give

$$LE = -(Rn + G)/(1 + \beta) \tag{5}$$

where β is the Bowen ratio (= H/LE). By assuming $K_h = K_w$ and by using Equations 2 and 3 the following solution for LE is also derived:

$$LE = -(Rn + G)/[1 + \gamma\ (\Delta T/\Delta e)] \tag{6}$$

where $\gamma = PC_p/L\epsilon$. Equation 6 is the so-called "Bowen Ratio Energy Balance" (BREB) method of estimating LE.

2. Net Radiation:

A. General aspect:

Net radiometers are divided into two types: those with thin domes and those that have thick domes.

a. Thin wall radiometers: The commonly used types are the hemispheric polyethylene dome (or Funk type), which consists of an epoxy wafer containing an embedded thermopile to detect the temperature difference across the wafer. The surfaces are painted flat black to absorb about 98 % of the short and long wavelength radiation that impinges on the surface. Thin wall (about 0.05 mm) polyethlene hemispheric windows protect the upper and lower surfaces from convective heat loss. These thin windows require a small positive pressure of dry air to maintain their shape and prevent condensation. The dry air may be supplied by bottled gas, an air pump, or by periodic manual purging. Examples of these thin wall radiometers are Swissteco and C. W. Thornthwaite Associates.

b. Thick wall radiometers: Dr. Leo Fritschen of University of Washington several years ago introduced a thick single dome net radiometer which is designed with a self-supporting dome about 0.25 mm thick. Fritschen subsequently introduced a double dome net radiometer with a second self supporting window, smaller in diameter and thinner (0.05 mm), to further reduce the convective heat loss from the sensing surface. Both of these net radiometers are manufactured by Radiation Energy Balance System (REBS). These Fritschen type of radiometers maintain a dry atmosphere inside the polyethylene domes by arranging the instrument to "breathe" through desiccant material contained in the radiometer support bar.

B. Sensor location:

Net radiometers should be located over the vegetation canopy of interest if the information is to be obtained for use in the Bowen ratio energy balance method. The mounting apparatus for supporting the net radiometer should be chosen as to present a minimum of obstruction to radiant fluxes due to shadows. Over surfaces such as grass or alfalfa the height of the instrument is not very critical (we suggest 1 m above the canopy). However, with row crop spaced at 1 m intervals, the instrument should be located at least 1 m above the canopy to be representative of a large area. For widely scattered type vegetation, a higher elevation is desirable. However, the sensor should be readily accessible for inspection and maintenance.

C. Calibration:

Net radiometers can be calibrated by the shading technique (see Fritschen and Gay, 1979) and require an additional check of symmetry. If the difference between the top and bottom readings exceed 2 or 3 %, the instrument should be corrected. A net radiometer may also be calibrated by comparing it to the output of another net radiometer (standard) over the same surface. The standard net radiometer should be used only for calibration.

3. Soil Heat Flux:

A. General aspect:

Proper evaluation of the soil heat flux at the surface is necessary for the evaluation of the fluxes of sensible and latent heat. The soil heat flux not only reduces the amount of energy available during the day for partitioning into the other fluxes but also alters the phase relation of the fluxes.

Soil heat transducers should not be located close to the soil surface because the transducers could impede root development and will resist the natural flow of moisture that may result in an unnaturally dry layer above to the transducer. In addition, soil above the transducer may crack exposing it to direct insolation. Tanner (1960) suggested that the transducer be located 5-10 cm below the soil surface. The change in energy storage of the layer of soil above the transducer is estimated from the heat capacity equation and supplementary measurements in temperature within the layer. When the soil heat transducer is located at a depth Δz (for example, 5 cm) the energy flow at the surface is given by

$$G_0 = G_5 - C\ \Delta z\ (\Delta T/\Delta t) \qquad (7)$$

The first term, G_5 is the soil heat flux at a 5 cm in this case, and is measured with a heat flow transducer. The second term is the change in energy storage above the transducer where T is the average soil temperature of the layer and C is the heat capacity of the layer. The average soil temperature can be measured with a set of thermocouples installed at several depths below the soil surface (i.e., 1, 10, 20, 30, 40, 50 mm) or with a set of platinum resistance thermometers (0.2 m long) buried at an angle of about 15 degree at several locations.

The heat capacity of the soil can be estimated from

$$C = C_m X_m + C_o X_o + C_w X_w \tag{8}$$

where X is the volume fraction and C the heat capacity (MJ m^{-3} K^{-1}) of mineral (m), organic matter (o), and water (w). Alternatively, Equation 8 can be rewritten as follows:

$$C = \rho_b \; (C_m' X_m' + C_o' X_o' + C_w' X_w') \tag{9}$$

where ρ_b (g cm^{-3}) is the bulk density of the soil layer, X' is the weight fraction and C' is the specific heat capacity (J g^{-1} K^{-1}).

Since the thermal conductivity of the transducer is not the same as that of the soil, the measured soil heat flux must be corrected. The correction used is based on the theory developed by Philip (1961) where he related the ratio of the heat flow through the transducer to the heat flow in the soil to the ratio of the thermal conductivity of the transducer, k_T, to thermal conductivity of the soil, k_S. The heat transducers are usually calibrated in a media (usually sand or wetted glass beads) having a thermal conductivity, k_M, different from either the transducer or soil. Therefore, the measured soil heat flux, G_S, is corrected using a ratio of the expressions as follows:

$$G_S^{corrected} = G_S \; \frac{[1 - 1.70(d/L)(1-k_S/k_T)]}{[1 - 1.70(d/L)(1-k_M/k_T)]} \tag{10}$$

where 1.70 is the constant shape factor for square transducer

(1.92 for circular transducer) and L is the side length of the transducer, and d is the thickness of the transducer. The final equation to calculate surface soil heat flux is, therefore,

$$G_0 = G_S^{corrected} - C\ \Delta z\ (\Delta T/\Delta t) \qquad (11)$$

The thermal conductivity of the soil, k_S, is related to soil water content and can be calculated, for example, by an expression developed by McInnis (1981)

$$k_S = 0.64 + 1.63\ \theta_m - 0.505\ \exp(-17\theta_m^2) \qquad (12)$$

where θ_m is the gravimetric soil water percentage and the coefficients were found for loam soils in Eastern Washington.

Alternatively, the thermal conductivity of the soil, k_S, can be obtained by calculating the thermal diffusivity of the soil, D, from the measurement of soil temperature profile:

$$D = k_S/C \quad \text{or} \quad k_S = DC \qquad (13)$$

where C ($J\ m^{-3}\ K^{-1}$) is the volumetric specific heat of the soil. D can be evaluated as follows:

$$(\partial T/\partial t) = D\ (\partial^2 T/\partial Z^2)\text{: Governing Equation} \qquad (14)$$

with boundary conditions: 1) $T(0,t) = T + T_0 \sin wt$ and 2) $T(\infty,t) = T$.

$$T(Z,t) = T + T_0 \exp(-Z\sqrt{w/2D})\ \sin\ (wt - Z\sqrt{w/2D}) \qquad (15)$$

From Equations 13 and 14:

$$D = (w/2)\ [(Z_2 - Z_1)/\ln(A_1/A_2)]^2\ ;\ (m^2\ sec^{-1}) \qquad (16)$$

where A_1 and A_2 are the amplitudes at soil depth Z_1 and Z_2, respectively, $w = 2\pi/P$, and P is the period of the fundamental cycle of soil temperature.

B. Sampling requirements:

The number of sampling locations required varies with the experimental conditions. Fewer locations are required under bare soil, uniform dense grass, or other uniform dense vegetation. No general rules are available on the number of samples required. However, at least three sample locations would be reasonalble number under reasonably homogeneous conditions.

Installation of heat transducer is briefly described in Figure 1. One can prepare a squre hole (10 x 10 x 6 cm) next to the location where the transducer is placed. Make a slit very carefully from the side at a depth (at which you want to place the transducer), say 5 cm, so that the transducer can be inserted from the side with minimum disturbance of the soil layer and plant cover above the transducer. The signal leads can be arranged to form S-shape to prevent the possible penetration of water along the leads. Refill the hole carefully and make sure that the soil is as compact as before.

C. Calibration:

The heat transducers are usually calibrated at the manufacturing factory. There are various methods used to calibrate heat flow transducers (i.e., conduction method, radiometric method). Readers may refer Fritschen and Gay (1979) for detailed information.

4. Gradients of Air Temperature and Vapor pressure:

A. General aspect:

To measure gradients of dry bulb and wet bulb air temperatures, ceramic wick psychrometers (Hartman and Gay, 1981) are widely used. A psychrometer is illustrated in Figure 2A. The psychrometer consists of two ventilated thermometers (dry and wet bulbs) and can be disassembled down to the basic 4-way cross that contains the water distribution tee and the fitting that holds the wet bulb. Dry bulb measures air temperature directly, while wet bulb, covered with a ceramic wick saturated in distilled water, measures a temperature lowered by an amount determined by the evaporative cooling caused by the sample air. Water is evaporated into the humid air flowing past the wet blub until equilibrium is reached. The temperature of the wet bulb at this point is T_W, the wet bulb temperature. At equilibrium

$$e_A = e_S - AP(T-T_W) \qquad (17)$$

where T and T_W are the dry and wet bulb temperatures (C), P is the air pressure, e_A is the actual vapor pressure, and e_S is the saturation vapor pressure at T_W. A is a constant of proportionality and is slightly dependent on T. A, according to Harrison (1965), has a value of

$$A = 6.6 \times 10^{-4} (1 + 1.15 \times 10^{-3} T_W) \qquad (18)$$

when the aspiration rate is sufficiently high.

The sensitivity of the temperature sensors is quite important in Bowen ratio energy balance method. The temperature sensors are made of tiny nickle resistance thermometers encapsulated in stainless steel tubes of 3.175 mm diameter with thin walls of 0.152 mm thickness. These nickle-iron resistance elements (RTD: Resistance Thermometer Device) have an output of about 2.7 mV C^{-1}. The wet bulb RTD is covered with a porous ceramic tube operating under a water supply with a positive head. Two precisely calibrated ceramic wick psychrometers are mounted on one mast. The vertical separation between the psychrometers is adjustable (usually 0.9 or 1.0 m). Each pair of psychrometers is interchanged every 5 minutes to minimize the effect of instrument bias. The exchange mechanism used here has been described in detail by Gay and Fritschen (1979).

B. **Field setup:**

Before carrying the psychrometer from the lab to the field location, install the insulated shields on the reservoir and the aspiration tube (see Fig. 2A) to avoid damage. Use care when sliding the sunshield on/off the aspiration tube so as not to damage the external leads of the dry bulb RTD. The psychrometers are screwed to the slider blocks on the exchange mast with a bolt. To connect the leads, note that the retractable cords terminate in a 4-pin connector attatched to signal leads. Each RTD has a 2-pin connector; the pair of 2-pin RTD connectors from the psychrometers plug into the 4-pin connector on the cord, using the red and black color codes. The connector on the dry bulb element (the hotter one) is coded red, and the wet bulb element (the cooler one) is coded black. The fan (or vacuum sweeper) should start to draw whenever power is supplied to the controller board. The small push-pin connectors are not waterproof. In field use, the psychrometer connectors are tucked into the short length of 3/4" PVC tubing that serves as a rainshield at the rear of the psychrometer (Fig. 2A).

a. Positioning the RTD's: The dry bulb RTD is supported by its leads, which should be bent as necessary to center the element in the tube. The wet bulb RTD inside the ceramic wick is also supported by its leads which extend for a short distance beyond 1/8" stainless steel support tube (see Fig. 2B). Although this wet bulb design minimizes heat conduction down the leads within the support tube, the design is very fragile, and care must be used whenever the wet bulb RTD is removed or replaced.

b. Wet bulb maintenance: The ceramic wick is attatched to the water distribution tee by a short length of Tygon tubing. This ceramic wick is aerodynamically uniform and has consistent porosity. The wick can be removed (or replaced) by rotating and pulling (or pushing), using a tissue for cleanliness. The water supply in the reservoir is usually adequate for one week of field operation without refilling. Impurities in the water tend to cause the indicated wet bulb to be higher than the true wet bulb. For example, a saturated solution of NaCl at 20 C on the wet bulb would lower the vapor pressure of water by 25 %. Ceramic wicks should be prepared by cleaning (and brushing, if necessary) in a soap solution and then boiled in a solution containing nitric acid, and then stored in clean distilled water (in the refrigerator, if possible) to insure adequate cleanliness. If it is necessary to remove the wet bulb element, first review the components pictured in Fig. 2B. Then unscrew the clamp nut on the rear of the psychrometer and gently withdraw the stainless steel support tube with clamp nut, washer and rubber gasket. To replace, gently rotate and insert the element into the psychrometer, taking care that the RTD element does not jam against the edge of the tee or the ceramic wick. The clamp nut normally needs to be only finger tight to keep water from leaking. Be careful during disassemble not to apply lateral force to the ceramic wick; this could damage the wick or the tube inside that supports the wet bulb RTD. To prevent accidents, leave the aspiration tube on for protection whenever the wet bulb RTD is in place.

c. Freezing weather:

One difficulty that ceramic wicks have is that break under freezing weather. This problem is solved by using a mixture of ethanol and water. Since ethanol and water have different saturation vapors and different heat of vaporization, one would anticipate that the psychrometric relation would have to be modified. A test was conducted to determine the difference in wet bulb temperatures of two precision psychrometers, one with water and the other with ethanol-water. The results indicated a wet bulb temperature increase of

0.071 C with a 10 % mixture of ethanol-water and 0.162 C with a 20 % mixture. This resulted in calculated vapor pressure increases of 0.011 and 0.20 kPa, respectively. The freezing point of a 10 % ethanol-water mixture is -5 C and of a 20 % ethanol-water mixture is -11 C. Using the standard psychrometric equation, the calculated vapor pressures were increased by 1.6 % and 3.7 % above that of pure water. It appears, that for most uses, the standard psychrometric equation can be used with ethanol-water mixtures without appreciable erroros. The small errors would not effect gradient measurements. Field test show no adverse effects when a 10 % mixture was used. The ceramic wick did not break when air temperature reached -9 C with a 10 % ethanol-water mixture.

C. Calibration of psychrometer:

A schematic circuit diagram for psychrometer calibration is shown in Figure 3. The circuit consists of platinum RTD (to estimate temperature), RTD #1 (dry bulb RTD for head #1), RTD #2 (wet bulb RTD for head #1), RTD #3 (dry bulb RTD for head #2), RTD #4 (wet bulb RTD for head #2), a reference resistance, and a current source. We want to measure the resistance of each RTD (which is a variable resistance depending on temperature) and relate it to temperature. Since we can measure only the voltage with the data acquisition system, current source of 1 mA is connected in the circuit so that the measured output voltage is equivalent to output resistance. However, it is technically difficult to maintain the current precisely at 1 mA. Therefore, a reference resistance (R_{REF}, which is always constant and not affected by temperature) is added to accurately calculate the changing current in the circuit. We now can calculate resistance of each RTD (R_{RTD}) from Ohm's law (V [voltage] = I [current] x R [resistance]):

$$R_{RTD} = V_{RTD}/I_{RTD}; \quad I_{RTD} = I_{REF} = V_{REF}/R_{REF} \qquad (19)$$

The relationship between RTD resistance and temperature is slightly non-linear, and nicely described by a 3rd order polynomial. Unique equations, each containing four coefficients, define the relationship for each RTD.

$$T = A + B\, R_{RTD} + C\, R_{RTD}^2 + D\, R_{RTD}^3 \qquad (20)$$

where T is the temperature, A, B, C and D are coefficients. Typical values of coefficients are tabulated in Table 1.

Each nickel-iron RTD is calibrated in a stirred, thermoregulated temperature bath against a platinum resistance thermometer. The RTD's are read with the Net-Pac data acquisition system, using the same constant current source with 4-wire circuit used for reading psychrometer RTD's in the field. The platinum resistance thermometer is also read (as it varies over a range of about 470 to 550 ohms) to calculate precise temperature. The relationship between temperature and platinum RTD is provided by the factory. Four RTD's (one psychrometer at a time) are calibrated at a time against the platinum RTD. After the bath stabilizes at the desired temperature, the user start sampling the data in or der voltages from RTD #1, RTD #2, RTD #3, RTD #4, reference (current source) voltage, and the voltage of platinum resistance thermometer. Data are taken for 5 minutes after the stabilization, and this minimizes the effects of temperature drift in the bath during the period required for the data acquisition system to scan through the sensors. The bath temperature is then increased, and the sampling is repeated. Data are collected at approximately 5 C increments between 0 and 50 C. Two samples are made at each end of the scale, so that a total of 13 samples are used to define the coefficients of each calibration equation, using the polynomial regression. Although the precision of the calibration is excellent, as indicated by the high R^2 and low mean square error (MSE) terms in Table 1, accuracy depends on the calibration of the platinum RTD. Therefore, the platinum RTD should be periodically checked (or calibrated).

D. Field operation:

Each psychrometer consists of two heads and, thus, 4 RTDs (1 RTD for dry bulb and 1 RTD for wet bulb for each head). Therefore, one psychrometer uses up to six channels: 4 channels for 4 RTDs, 1 channel for reference voltage, and 1 channel for the position.

a. Voltage output: voltage output from each RTD slightly varies with each RTD and, in general, ranges from 650 to 700 mV (± 25 mV). This range is a very rough estimation and the output can go beyond this rage in case of extreme weather condition. Usually the outputs from the dry bulb RTDs are higher than those from wet bulb RTDs (higher voltage output means higher temperature (roughly 3 mV = 1 C). However, there will be small difference between dry and wet bulb RTDs when the humidity is very high (usually early in the morning). Voltage output from the reference channel is similar but should be fairly constant. If the reference voltage changes more than ± 2 mV every 5 minutes, current source electronics is not operating properly. Especially, after the heavy rain, electronic box of psychrometer can be easily wet and the circuit is shorted out. This causes abnormally high or low voltage outputs or fluctuations. If this happens, open the electronic box and let it dry. Voltage output from the position channel is either close to zero or 800 mV (± 50 mV) depending on the locations of two heads. Every 5 minutes, psychrometer receives a signal from the computer and exchanges the levels. This can be checked by just looking at the psychrometer every 5 minutes, or by inspecting 5 minute computer outputs.

b. Test run with known resistance: The performance of the psychrometer circuit can be precisely checked in the field using 4 known temperature-independent resistors. Two known resistors are connected to a 4-pin connector attatched to signal leads for each head. Since the resistances are known, one can check not only the output from each channel, but also the computer software for the calculations of temperature, vapor pressure, sensible heat flux, and latent heat flux.

c. Checking flow (aspiration) rate: The wet bulb temperature is affected by wind movement, especially at lower velocities. It also depends on the size and geometry of the wet bulb element. The ventilation requirement decreases with decreasing size of wet bulb, but the maximum depression is achieved at flow rates in excess of 3 m sec^{-1}. The WMO (1971) specifies flow rates must between 4 and 11 m sec^{-1}. The flow rate can be checked with a hot-wire anemometer or any other appropriate flow probe, inserted in front of the dry bulb RTD of each head while the psychrometer is operating. In relation to this, strong wind (say, greater than 10 m sec^{-1}), which is blowing directly toward the psychrometer, may affect the flow rate (water in the wick may not be able to keep up with evaporation). In this case, you may want to rotate the mast about 45 to 90 degrees away from the wind direction. Also one should be careful not to have direct sunlight on the dry or wet bulb RTDs inside the inlet tube especially in the morning and in the evening.

5. Reference

Gay, L. W., and L. J. Fritschen. 1979. An exchange system for precise measurements of temperature and humidity gradients in the air near the ground. Proc. Hyd. Water Res. Ariz. and SW. 9:37-42.

Fritschen, L. J., and L. W. Gay. 1979. Environmental Instrumentation. Springer-Verlag, New York. 216 pp.

Harrison, L. D. 1965. Fundamental concepts and definitions relating to humidity. Humidity and Moisture (A. Wexler, ed.), Meas. Contr. Sci. Ind. 3:3-70.

Hartman, R. K., and L. W. Gay. 1981. Improvements in the design and the calibration of temperature measurement systems. Proc., 15th Conf. Agric. For. Meteorol. 210 pp.

McInnis, K. 1981. Thermal conductivities of soils from dryland wheat regions in eastern Washington. M. S. Dissertation. Washington State University, Pullman, Wa.

Philip, J. R. 1961. The theory of heat flux meters. J. Geophys. Res. 66:571-579.

Tanner, C. B. 1960. Energy balance approach to evapotranspiration from crops. Soil. Sci. Soc. Am. Proc. 24:1-9.

TABLE 1. THE COEFFICIENTS FOR THE CALIBRATION OF RTDs

NIFe #	A	B	C	RTDCOEF D	DF	R**2	MSE	DATE
9 RTD0888	-318.5062	0.748897	-4.60201e-04	1.52644e-07	9	0.99999993	0.00003251	26-NOV-86
10 RTD0898	-322.0007	0.763531	-4.81581e-04	1.63080e-07	9	0.99999996	0.00001960	26-NOV-86
11 RTD0908	-327.9859	0.791323	-5.23966e-04	1.84644e-07	9	0.99999996	0.00001649	26-NOV-86
12 RTD0918	-333.3378	0.815159	-5.58345e-04	2.00926e-07	9	0.99999998	0.00000914	26-NOV-86
13 RTD0928	-341.0229	0.849498	-6.08931e-04	2.25938e-07	9	0.99999993	0.00003091	26-NOV-86
14 RTD0938	-346.5653	0.872502	-6.42047e-04	2.41844e-07	9	0.99999995	0.00001992	26-NOV-86
15 RTD0948	-343.6843	0.860237	-6.24709e-04	2.33735e-07	9	0.99999988	0.00005186	26-NOV-86
16 RTD0958	-332.4248	0.812802	-5.55660e-04	1.99883e-07	9	0.99999999	0.00000506	26-NOV-86
17 RTD096	-312.7833	0.724349	-4.25892e-04	1.36002e-07	9	0.99999992	0.00003564	28-NOV-86
18 RTD097	-325.4607	0.777197	-5.01120e-04	1.71499e-07	9	0.99999996	0.00001764	28-NOV-86
19 RTD098	-322.7206	0.769369	-4.89610e-04	1.66535e-07	9	0.99999998	0.00001087	28-NOV-86
20 RTD099	-327.4695	0.789030	-5.17732e-04	1.79464e-07	9	0.99999998	0.00000848	28-NOV-86
21 RTD100	-322.2932	0.765803	-4.85436e-04	1.64054e-07	9	0.99999987	0.00005804	28-NOV-86
22 RTD101	-319.6109	0.751455	-4.61834e-04	1.51476e-07	9	0.99999987	0.00005915	28-NOV-86
23 RTD102	-320.4455	0.754464	-4.66475e-04	1.54045e-07	9	0.99999983	0.00007497	28-NOV-86
24 RTD103	-324.4394	0.773446	-4.95197e-04	1.67888e-07	9	0.99999995	0.00002081	28-NOV-86
25 RTD104	-315.6969	0.738515	-4.47281e-04	1.47168e-07	10	0.99999996	0.00001579	29-NOV-86
26 RTD105	-326.2998	0.782226	-5.09679e-04	1.77422e-07	10	0.99999996	0.00001563	29-NOV-86
27 RTD106	-323.0752	0.769781	-4.92513e-04	1.69545e-07	10	0.99999994	0.00002433	29-NOV-86
28 RTD107	-333.6761	0.813923	-5.54609e-04	1.97610e-07	10	0.99999997	0.00001194	29-NOV-86
29 RTD108	-329.6182	0.798141	-5.34371e-04	1.90175e-07	10	0.99999987	0.00005156	29-NOV-86
30 RTD109	-324.3754	0.774688	-4.98337e-04	1.71454e-07	10	0.99999994	0.00002244	29-NOV-86
31 RTD110	-316.5582	0.742281	-4.51315e-04	1.48545e-07	10	0.99999994	0.00002621	29-NOV-86
32 RTD111	-327.3211	0.789350	-5.20580e-04	1.82646e-07	10	0.99999998	0.00000992	29-NOV-86
33 RTD112	-318.4099	0.752669	-4.67041e-04	1.55353e-07	11	0.99999997	0.00001431	11-FEB-87
34 RTD113	-328.6147	0.793208	-5.24647e-04	1.83344e-07	9	0.99999997	0.00001316	10-FEB-87
35 RTD114	-340.5339	0.843679	-5.96561e-04	2.17621e-07	9	0.99999994	0.00002795	10-FEB-87
36 RTD115	-330.6860	0.802590	-5.37824e-04	1.89797e-07	9	0.99999996	0.00001972	10-FEB-87
37 RTD116	-326.5829	0.783068	-5.08699e-04	1.75782e-07	9	0.99999998	0.00000999	10-FEB-87
38 RTD117	-332.0617	0.807960	-5.46522e-04	1.94454e-07	9	0.99999998	0.00000786	10-FEB-87
39 RTD118	-320.4791	0.763059	-4.83204e-04	1.64200e-07	9	0.99999999	0.00000379	10-FEB-87
40 RTD119	-336.9118	0.829469	-5.79310e-04	2.11617e-07	9	0.99999998	0.00000837	10-FEB-87
41 RTD120	-314.3646	0.732800	-4.37687e-04	1.41767e-07	11	0.99999996	0.00001902	11-FEB-87
42 RTD121	-323.7964	0.774452	-4.99248e-04	1.71990e-07	11	0.99999998	0.00000960	11-FEB-87
43 RTD122	-319.3721	0.754802	-4.70385e-04	1.57837e-07	11	0.99999998	0.00000758	11-FEB-87
44 RTD123	-329.2566	0.797934	-5.32537e-04	1.87962e-07	11	0.99999998	0.00001073	11-FEB-87
45 RTD124	-325.2813	0.779324	-5.05983e-04	1.75384e-07	11	0.99999995	0.00002289	11-FEB-87
46 RTD125	-326.4060	0.786514	-5.16431e-04	1.80182e-07	11	0.99999997	0.00001317	11-FEB-87
47 RTD126								
48 RTD127	-320.6796	0.759425	-4.76331e-04	1.60423e-07	11	0.99999992	0.00003473	11-FEB-87
49 RTD128	-335.1796	0.821112	-5.64697e-04	2.03042e-07	8	0.99999998	0.00000792	4-APR-87
50 RTD129	-335.1219	0.822376	-5.65934e-04	2.03256e-07	8	0.99999998	0.00000786	4-APR-87
51 RTD130	-326.6795	0.786091	-5.14727e-04	1.79042e-07	8	0.99999999	0.00000341	4-APR-87
52 RTD131	-329.2956	0.795476	-5.26662e-04	1.83683e-07	8	0.99999999	0.00000454	4-APR-87
53 RTD132	-330.5404	0.799642	-5.33210e-04	1.87692e-07	8	0.99999999	0.00000227	4-APR-87
54 RTD133	-327.5500	0.788612	-5.16265e-04	1.78605e-07	8	0.99999996	0.00001414	4-APR-87
55 RTD134	-316.0920	0.735785	-4.38460e-04	1.41287e-07	8	0.99999997	0.00001100	4-APR-87
56 RTD135	-324.4766	0.775753	-4.97149e-04	1.68757e-07	8	0.99999996	0.00001371	4-APR-87