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Comparative Analysis of Suspended Load Transport Function for Vaitarna River

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Abstract — the present paper discusses the outcome of the comparative analysis of the applicability of Bagnold (1966), Wiuff (1985) and Celik & Rodi (1991) Suspended load transport functions for Vaitarna River. Statistical parameters such as Root Mean Square Error (RMSE), Discrepancy Ratio (DR) and Inequality Coefficient (U) have been computed for evaluating the performance of the selected formulas. Graphical comparisons are done to demonstrate the performance and variations for different data sets. Score in terms of percentage of discrepancy ratio within the range 0.5 to 2.0 are calculated for comparison. Analytical evaluation reveals that Bagnold (1966) Suspended load transport formula holds good for Vaitarna River with score of 98.90% while Wuiff and Celik & Rodi Suspended Transport formula are incapable in predicting the Suspended Load for Vaitarna River to a satisfactory level.

Keywords- Suspended Load; Stream Power Approach; RMSE; Inequality coefficient; Statistical Analysis.

I. INTRODUCTION

Suspended-sediment transport relates with either particles or grains of sediment which moves within a river and is supported wholly by the flow. Sediment grains remain in suspension unless the upward-directed forces associated with turbulence in the flow is stronger than the downward gravity force acting on the grains.

Bagnold (1966) defined stream power as the time rate of potential energy spend for the fluid flow. This energy is partially used for transporting suspended load particles. Bagnold (1966) further developed model that relates the rate of bed load and suspended load transport with the stream power. Celik and Rodi (1984, 1988) proposed that the turbulence is generated in upward direction at the boundary of channel is most intense, Suspended sediment have higher concentrations and involve coarser material near the boundary and both sediment size and concentration reduces as we move up through the water column towards the surface of the flow away from boundary.

The various approaches which are used to predict suspended load transport rate includes approaches of Lane Kalinske (1941), Einstein (1950), Brooks (1963), Yalin (1963), Bagnold (1966), Chang Simons Richardson (1967), Van Rijn (1984b), Wiuff (1985), Samaga et al (1986), Celik & Rodi (1991), Habibi & Sivakumar (1992) and Saleh (2014). The present study includes a comparative analysis of Bagnold (1966), Wuiff (1985) and Ceilk & Rodi (1991) Suspended load transport formulae for the chosen study area.

II. STUDY AREA

For the present study, the Vaitarna River which is located in north of the city of Mumbai, India, near its border with Gujarat is chosen as the study area. The river Vaitarna is one of the west flowing rivers in the region North of Mumbai and South of the Tapi River. The river rises in the Sahyadri hill range at Trimbak in the Nasik district of Maharashtra State and after traversing a distance of about 120 km in Maharashtra towards west, it joins the Arabian Sea.
The Vaitarna basin lies between East longitude of 72° 45’ to 73° 35’ and North latitude of 19° 25’to 20° 20’. The main tributaries of Vaitarna River are Pinjal, Ganjai, Surya, Daharji, Tansa. The catchment area of Vaitarna basin completely lies in Thane and Nasik districts of Maharashtra. The Vaitarna drains an area of 2019 sq km before it falls in Gulf of Khambhat. Suspend sediment load of Vaitarna River are measured by Central Water Commission at hydrological observation site, Durvesh, which is situated at the upstream of confluence of Surya and Tansa tributaries. Vaitarna River basin with sediment gauging site, Dhruvesh is shown in Fig.1.

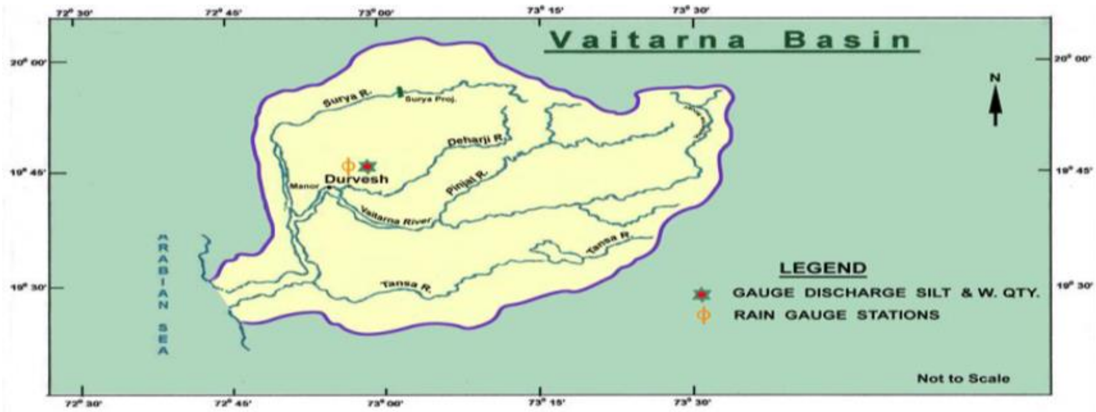

Figure. 1. Vaitarna River Basin

III. DATA COLLECTION

Data for the present study were collected from Central Water Commission, Surat. Range of Hydraulics Parameter used in the present study is given below in table 1.

Data set	Flow Discharge Q (m3/s)	Width of Flow B (m)	Flow velocity (m/s)	Energy slope (m/m)x 10^3	Depth of Flow D (m)
Vaitrana	0.68 to 5080.00	56 to 156	0.08 to 2.75	0.0001 to 0.0006	1.11 to 12.05

Table 1. Range of Hydraulic Data

IV. METHODOLOGY

Various statistical parameters describing the deviation and divergence of the predicted values from the line of equality has been defined. The selected sediment transport load predictor is tested against large data sets for natural rivers. Limitations, deficiencies and drawback of the existing transport formulae were analyzed by the following process. The discrepancy (ratio of calculated value to measured value) for each set of data is considered for comparison of performance. The percentage of data coverage between accepted lower and upper limits of the discrepancy ratio and their statistical properties is taken as the criteria of the goodness of fit. In addition, the calculated values are plotted against the observed values for the same data set, so that the distribution (scatter) about the perfect agreement line can also be evaluated.
For the present study following formula were selected based on the suitability and characteristics of available data sets to predict the suspended load transport rate.

Bagnold Suspended load transport formula (1966)

According to Bagnold (1966), a particle is suspended when the bed shear velocity, u* exceeds its fall velocity ω and the general expression to compute suspended load transport rate can be described as:

$$q_s = \frac{0.01}{\frac{\rho_s - \rho}{\rho}\omega} \tau o V^2$$

Where τ_o is Shear stress, ρs is Sediment density (kg/m^3), ρ is Fluid density (kg/m^3), ω is fall velocity (m/s), V is Average Velocity (m/s).

Wiuff Suspended load transport formula (1985)

Wuiff (1985) used simple formula based on energy exchange in alluvial streams for estimation of suspended load. Wuiff (1985) related the suspended load discharge to a particular dimensionless efficiency formula which was defined as a ratio of gain in potential energy of the suspended materials to the dissipation of turbulence energy. Wuiff (1985) efficiency formula is basically same as a suspended load efficiency factor in Bagnold's (1966) theory. Using the experimental results of Guy et al (1966), Wuiff (1985) showed that despite assumption of Bagnold (1966), the suspended load efficiency is not constant but varies linearly with Shields dimensionless shear stress parameter.
Unlike Bagnold (1966), Wuiff (1985) argued that the use of a constant value for modified suspended load efficiency η_s is not sufficient. Using linear regression analysis Wuiff (1985) concluded that Shields parameter τ* is the best dominant variable. The correlation obtained was

$$\eta s = 0.016\tau *$$

Where in τ* is expressed by

$$\tau * = \tau_o / [\rho s - \rho\ gds]$$

Where τ_o =ρgDS and ds representing sediment diameter.
Suspended load transport per unit time and unit width in volumetric ratio can be written as:

$$q_s = 0.016\,\frac{(VDS)^2}{\Delta 2ds\omega}$$

Where V is Average Velocity (m/s), d_s is Median grain size (m), S is Slope, ω is fall velocity (m/s), and D is Depth of water (m).

Celik & Rodi Suspended load transport formula (1991)

Celik & Rodi (1991) proposed a simple formula to estimate suspended load under equilibrium condition. They defined the suspended sediment transport capacity of a certain flow as the maximum amount of sediment carried in suspension when the flow is uniform.
Celik & Rodi (1991) assumed that "Suspended load work rate" is equivalent to the work that turbulent energy has to perform on the suspended material to keep them in suspension & hence should appear as a sink term in budget equation for the turbulent kinetic energy. Adding this term to k- equation and integrating over the depth, Celik & Rodi (1991) arrived at

$$\frac{\alpha_1 \tau_O V}{D} = (\rho_S - \rho) g C_D \omega$$

Where $\tau_o V/D$ = total turbulent energy production rate per unit of fluid volume, τ_o=ρgDS is the overall bed shear stress, V is the mean flow velocity, D is the total flow depth and S denotes the energy or water surface slope. α_1 is used to represent Celik & Rodi (1991) assumption that a constant portion of total turbulent kinetic energy is used to keep suspended particles in suspension.
According to Celik and Rodi, q_s leads to

$$q_s = \alpha_1 \frac{\tau_O V}{(\rho_S - \rho)\, g\omega}$$

Where, α is calibration factor, V is velocity, ρ_S is Sediment Density, ρ is Water Density, τ_O is bed shear stress, ω is fall velocity (m/s).

V. RESULT & RESULT ANALYSIS

1. Analysis

Various statistical parameters such as root mean square error (RMSE), Inequality coefficient (U) and discrepancy ratios (D.R) are used to evaluate the performance of sediment transport approach. Score in terms of % of DR within the range of 0.5-2.0 is also calculated.
Comparative summary of discrepancy ratio and root mean square error (RMSE) using selected different suspended transport rate formulas is given in Table 2.

Sr no.	Suspended Load Equation	DR	RMSE	U	Score (% D R within range of .5-2)
1	Bagnold	1.000296	24.40992	0.152541	98.90%
2	Wuiff	0.168834	449.2278	0.9931	2.50%
3	Celik and Rodi	0.421579	318.5123	0.695258	20%

Table 2. Comparative summary of discrepancy ratio and root mean square error (RMSE)

2. Statistical Analysis

Discrepancy ratio (r): It is the ratio of the predicted to the observed bed load discharge. If this ratio is one, the equation exactly predicts the measured rate. If the ratio is less than one or greater than one the equation under or over predicts measured data respectively.

r = q (predicted)/q (observed)

Root Mean Square Error (RMSE): It measures the deviation between the trend of the predicted and observed values.

$$Rmse = \left[\sum_{i=1}^{n} \frac{(Q_{bo} - Q_{bp})_i^2}{n}\right]^{1/2}$$

A zero value of RMSE indicates a perfect fit between measured and predicted values.

Inequality coefficient (U): It refers to a simulation statistics related to the RMSE, defined as under,

$$U = \frac{Rmse}{\left[\frac{1}{n}\sum_{i=1}^{n} (Q_{bo})_i^2\right]^{1/2} + \left[\frac{1}{n}\sum_{i=1}^{n}(Q_{bp})_i^2\right]^{1/2}}$$

Where, Q_{bo}=observed suspended load rate, Q_{bp}=Predicted suspended load rate

From the Comparison and detailed analysis, followings can be concluded regarding the suitability of suspended load transport functions.

- Bagnold Suspended load transport formula based on stream approach predicts best results with score of 98.90%, with an average error of 0.029%.
- As shown in Fig.2, Most of the value of D.R. computed using Bagnold's approach lies in between .5 and 2.
- As shown in Fig.3, Bagnold (1966) suspended sediment transport approach over predicts as well as under predicts. The percentage error between the observed and predicted transport rate is in the range of -25% to 20%.

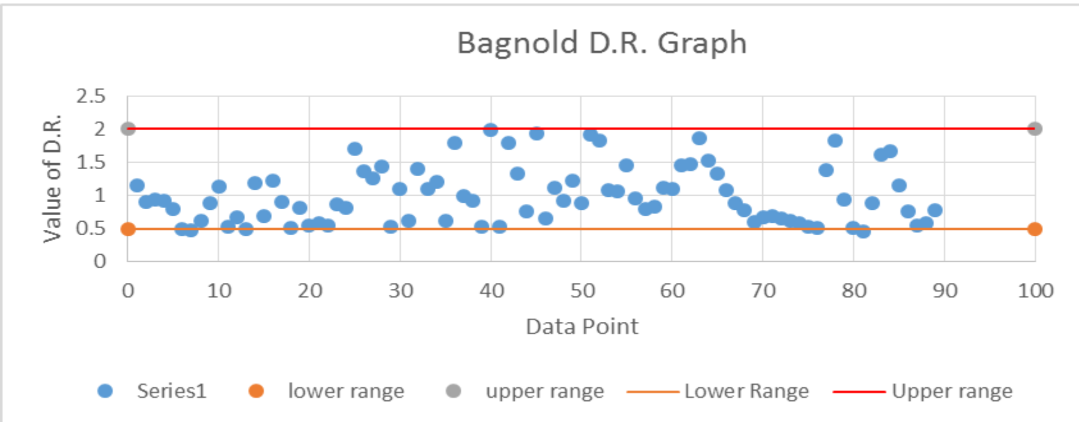

Figure 2. Range of D. R.

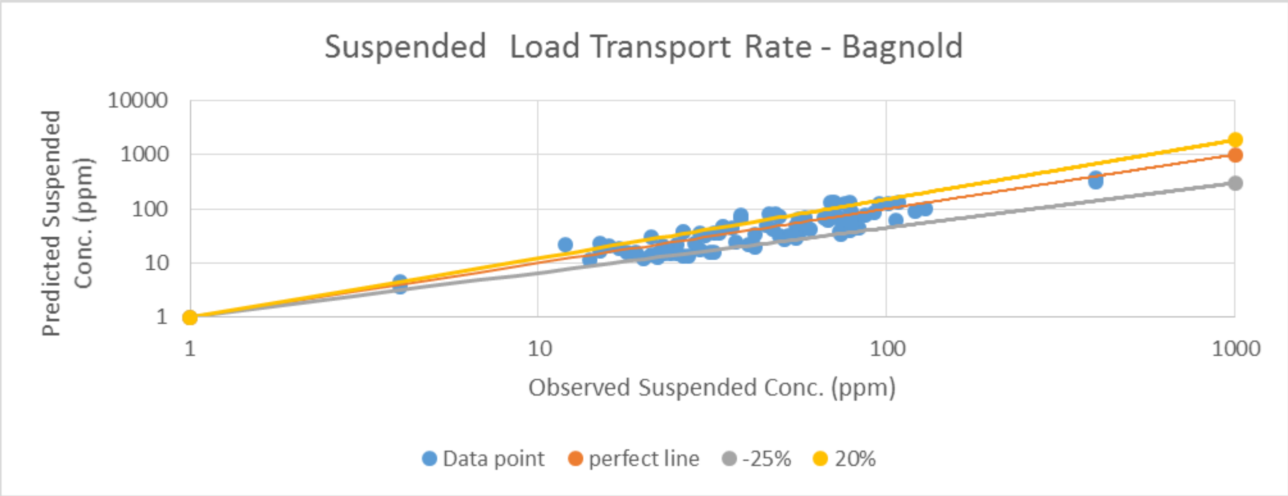

Figure 3. Predicted q_s v/s Observed q_s using Bagnold Suspended Load Transport Formula

- While Celik and Rodi suspended load transport formula fails to predict the suspended load for Vaitrana River.
- Ceilk and Rodi shows poor results with score of 20% with an average error of -57.84%.
- As shown in Fig.4, Ceilk and Rodi suspended sediment transport approach over predicts as well as under predicts. The percentage error between the observed and predicted transport rate is in the range of -99% to 50%.
- Wuiff Suspended load transport formula fails to predict the suspended load for Vaitrana River.
- Wuiff shows poor results with least score of 2.50% with an average error of -94.185%.
- As shown in Fig.5, Wuiff suspended sediment transport approach over predicts as well as under predicts. The percentage error between the observed and predicted transport rate is in the range of -99% to 50%.
- Thus it was concluded that Bagnold's approach is better, compared to other approaches in predicting the suspended load for Vaitrana River Basin.

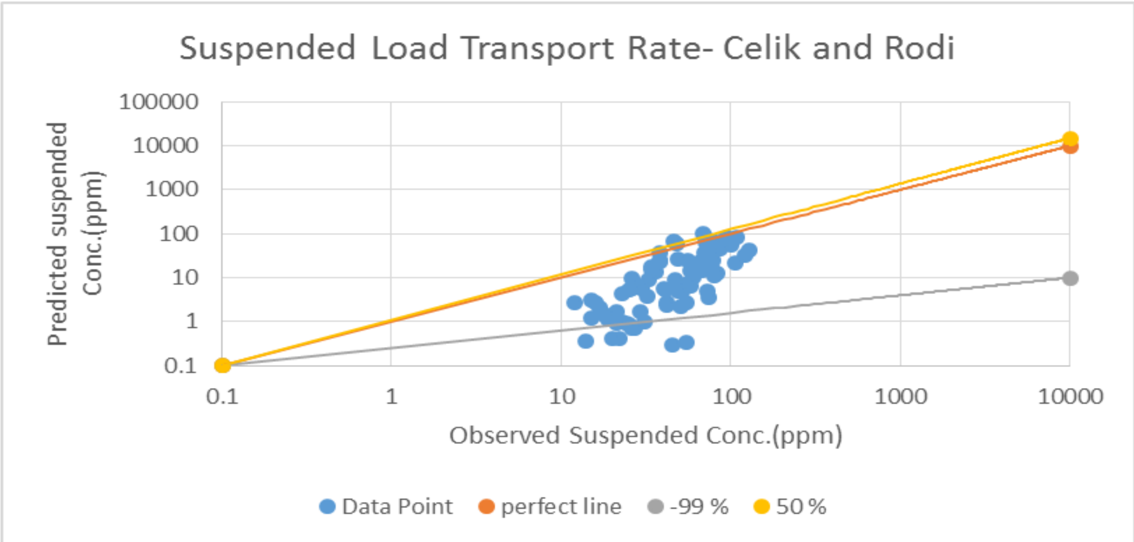

Figure 4. Predicted q_s v/s Observed q_s using Celik and Rodi Suspended Load Transport Formula

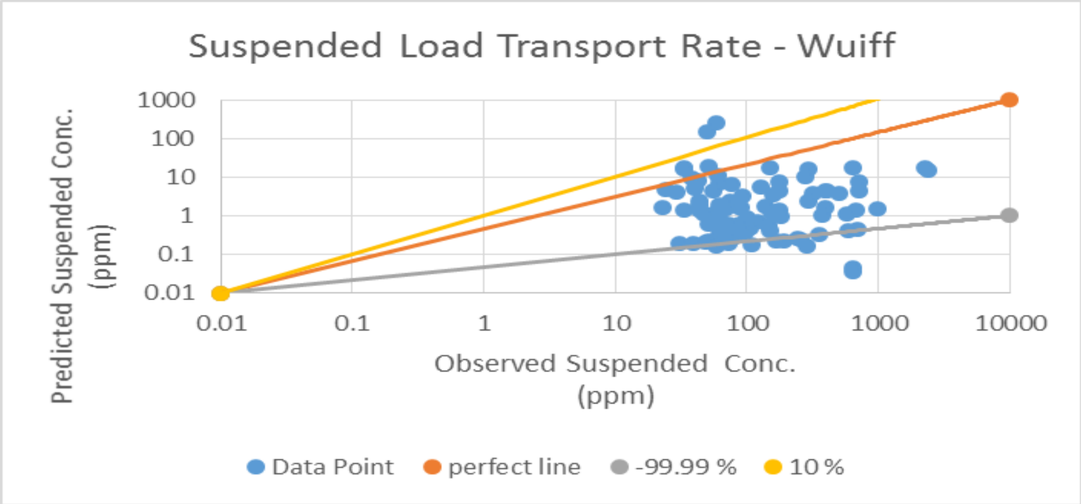

Figure 5. Predicted q_s v/s Observed q_s using Wuiff Suspended Load Transport Formula

VI. CONCLUSIONS

- It is also observed that Bagnold's transport functions predicts better for sediment diameter ranges from 0.0040375 to 0.002610 mm with less discrepancy as compare to other sediment mixture of lesser diameter of sediment size.
- While Wuiff's and Celik & Rodi's approach fails to predict for given datasets with large scattering values as compared to Bagnold's approach.

REFERENCES

1. Einstein H.A "The Bed-Load Function for sediment transportation in open channel", USDA, Tech. Bull no. 1026,September, (1950).
2. Sutherland "Entrainment Of Fine Sediments By Turbulent Flows" Division of Engineering and Applied Science California Institute of Technology Pasadena, California (1967)
3. R. A. Bagnold "An approach to the sediment transport problem from general physics" U. S. Geol. Surv., Prof. Pap. 422-1, (1966)
4. Leo C. Van Rijn "sediment transport, part ii: suspended load transport" J. Hydraul. Eng., ASCE, Vol. 110, No. 11, Paper No. 19277, (1984)
5. Belle R,Samaga,1 Kittur G. Ranga Raju, and Ramchandra J. Garde "SUSPENDED LOAD TRANSPORT OF SEDIMENT MIXTURES" , ASCE Journal of Hydraulic Engineering, Vol. 112, No. 1 (1984)
6. Rasmus Wiuff "Transport of suspended material in open and submerged streams" J. Hydraul. Eng., ASCE, Vol. III , No. 5, Paper No.19713, (1985)
7. Ismail Celik and Wolfgang Rodi "suspended sediment-transport capacity for open channel flow" J. Hydraul. Eng., ASCE, Vol. 117, No. 2, Paper No. 25520 (1991).
8. Prabhata K. Swamee and Chandra Shekhar P. Ojha "bed-load and suspended-load transport of no uniform sediments" J. Hydraul. Eng., ASCE, Engineering, Vol. 117, No. 6, Paper No. 25868, (1991)
9. M. Habibi "Sediment transport estimation in river system" university of Wollongong, 1994
10. Kireet kumar, m. S. Miral, v. Joshi & y. S. Panda "discharge and suspended sediment in the meltwater of gangotri glacier, garhwal himalaya, india" hydrological sciences-journal-des sciences hydrologiques, 47(4) august 2002
11. Camenen, B. And Larson, M.,A general formula for no cohesive suspended sediment transport. Journal Of Coastal Research, 24(3), 615–627 2008.
12. Asli Ulke; Gokmen Tayfur; and Sevinc Ozkul "Predicting Suspended Sediment Loads and Missing Data for Gediz River, Turkey" Journal of Hydrologic Engineering, ASCE Vol. 14, No. 9, (2009).
13. H. Md. Azamathulla & Yong Chong Cuan & Aminuddin Ab. Ghani & Chun Kiat Chang(2011) "Suspended sediment load prediction of river systems: GEP approach" Saudi Society for Geosciences
14. Huijuan cui "Estimation of velocity distribution and suspended sediment discharge in open channels using entropy." Graduate Studies of Texas A&M University (2011)
15. Kazumasa Mizumura "Prediction of Sediment Concentration in Rivers by Recursive Least-Squares and Linear Minimum Variance Estimators", Journal of Hydrologic Engineering, Vol. 17, No. 8, ASCE, (2012)

16. Brooks, S., and Miloradov, V. "Calculation of sedimentation in backwater affected rivers with particular attention to the Danube upstream of the Djerdap High Dam." Symp. on current problems in river trainings and sediment movement, Budapest, Hungary (1968).
17. Yalin, M. S. Mechanics of sediment transport. 2nd Ed., Pergamon Press, Toronto, Canada (1977).
18. Shields, A. , "Anwendung der Aehnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung ", Mitt. Der Preuss. Versuchsanstalt fur Wasserbau und Schiffbau, Berlin, (1936).
19. Simons and Daryl B."Sediment Transport Technology" Water Resources Pub., 1977.
20. Prof. Dr. Saleh I. Khassaf, Ayman A. Hassan "Suspended Sediment Transport Formula for the Upstream of Al-Amarah Barrage" International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 (2014)
21. Huijuan Cui1 and Vijay P. Singh, F.ASCE "Suspended Sediment Concentration in Open Channels Using Tsallis Entropy" J. Hydrol. Eng. 2014.19:966-977 (2014).
22. N. Sravanthia, R. Ramakrishnanb, A. S. Rajawatb, and A.C. Narayanaa "Application of Numerical Model in Suspended Sediment Transport Studies along the Central Kerala, West-coast of India" Aquatic Procedia 4 (2015) 109 – 116
23. Lane, E. W, and Kalinske A.A., "Engineering Calculation of Suspended Sediment Transport", American Geophy. Union, 1941, Vol. 20 Pt.3, pp. 603-607