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A five-year record of temperature, mixing, and stability for a tropical lake (Lake Valencia, Venezuela)

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With 4 figures and 1 table in the text

Abstract

Temperature and chemical data were taken for Lake Valencia, Venezuela, over a five-year period. The data show that Lake Valencia is always stratified between April and November, and that seasonal mixing always begins in November or December. Variation between years in date of overturn, maximum stability of stratification, and duration of stratification are slight. Variations between years in rate of heat uptake, time of maximum heat, and heat budget are large.

Introduction

Lakes often vary considerably between years, even in such fundamental respects as the timing and degree of seasonal mixing. Degree of variation between years has been studied for a number of temperate lakes but is virtually unstudied for tropical lakes. Early generalizations about tropical lakes, which were made without the benefit of geographically extensive data or long-term records, stressed the probable irregularity and unpredictability of the key physical processes of stratification and mixing in the tropics (RUTTNER 1937; HUTCHINSON & LÖFFLER 1956; HUTCHINSON 1957). More recent information supports the notion that the great majority of tropical lakes, even very near the equator, show definite and predictable seasonality in mixing and stratification (TALLING 1969; LEWIS 1973), even though non-seasonal variation is probably more significant than at temperate latitudes. The data which support the concept of limnological seasonality in the tropics principally consist of short-term records. Long-term records for individual tropical lakes will be required to produce a more definite understanding of the degree of variation to be expected between years.

The purpose of the present paper is to show the degree of variation between years in Lake Valencia, Venezuela, for certain important physical variables, including temperature, mixing, stratification, heat content, and stability. The data were collected between January 1977 and August 1981. A detailed analysis has already been made of the first two years with emphasis on short-term variation (LEWIS 1983). The present paper will therefore focus specifically on the differences between years over the entire five-year period.

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Methods and Study Site

Lake Valencia is situated in the Aragua Valley of Venezuela at an elevation of 420 m asl. The lake occupies a tectonically-formed basin of great age. The basin is presently endorheic (LEWIS & WEIBEZAHN 1981), thus the lake level varies somewhat from year to year. During the period of study, the maximum depth of the lake averaged near 39 m and mean depth was near 19 m. The area of the lake varied between 350 and 360 km^2 depending on lake level. Advective terms in the heat budget are obviously of minor importance under endorheic conditions. The temperature and mixing properties of the lake are thus determined almost entirely by meteorological conditions.

Measurements were made routinely at an index station in the deepest part of the lake over the five-year period of study. During the first two years of the study the measurements were made at weekly intervals, and during the last three years of the study they were made at bi-weekly intervals. Despite occasional interruptions caused by equipment failure, the record is complete enough to support interpretation for all five years.

Temperatures were measured at 1-m intervals to the nearest .02 °C between the surface and bottom of the lake. Although temperature is the principal variable of interest here, chemical data are also used in determining the extent of mixing. Chemical samples were taken at the same time as the temperature profiles at 5 m intervals from the surface to the bottom of the lake. Oxygen data, which are the most useful in determining the degree of mixing, were made by the WINKLER method (azide modification) during the first two years of the study and thereafter by an oxygen probe. Profiles of nitrite and soluble reactive phosphorus are also useful in determining the degree of mixing. Nitrite was determined by the method of BENDSCHNEIDER & ROBINSON (1952) and soluble reactive phosphorus was determined by an ascorbic acid-molybdate method (MURPHY & RILEY 1962).

Results

Fig. 1 shows the range of temperature variation over the five-year period at 5 m and 35 m in the water column. The variation across the five-year interval ranges from 1 °C to 2 °C, depending partly on the season. Definite seasonal trends are evident. Water temperatures at the surface declined steadily from November through the middle or end of February, and climbed between the middle or end of February and the end of May. In years with rapid warming, there is a temperature plateau at the end of May, while in other years, warming is slower and may continue beyond the end of May, in some years as long as the end of September. The degree of variation is considerably less at 35 m than at 5 m. At 35 m there is a steady warming between May and October as heat is transferred by turbulence from the upper water column. In some years, a brief plateau occurs in October and November, while in others deep heating continues unabated until the end of November. The lower water column cools between the end of November and the first of March. The range of variation in bottom temperatures over the five-year period is between 0.5 and 1.5 °C, depending on the month. Although this range is not very large in absolute terms, it is surprisingly high for a tropical lake. It

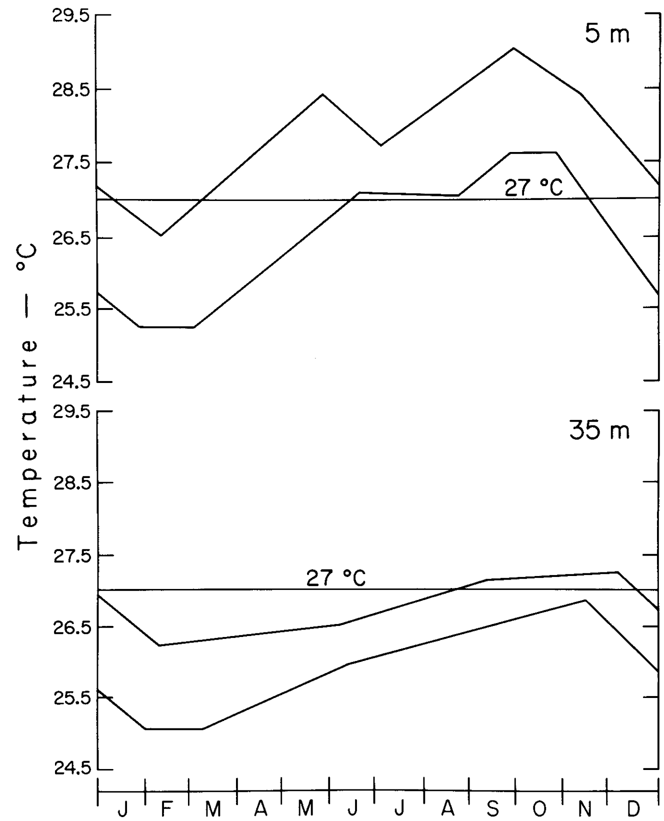

Fig. 1. Boundary lines enclosing temperatures of Lake Valencia at 5 m and 35 m over the five-year study period.

is not difficult to find examples of temperate lakes, especially deep ones, whose range of bottom temperatures across a number of years is narrower than this.

Fig. 2 shows in more detail the variation in uptake and loss of heat in different years. Minimum heat content can occur at any time between the beginning of January and the end of March. Heat uptake was rapid in some years (1978) and slow in others (1977). In all years, maximum heat content occurred between September and November. The onset of significant heat loss, which occurs about the end of November, appears to be one of the most reliable aspects of heat flux.

Table 1 shows the annual heat budget for 1977 through 1981 as determined from the data in Fig. 2. As expected, the total heat budget is relatively small, and it varies between years according to the variation of seasonal cooling and heat uptake among years.

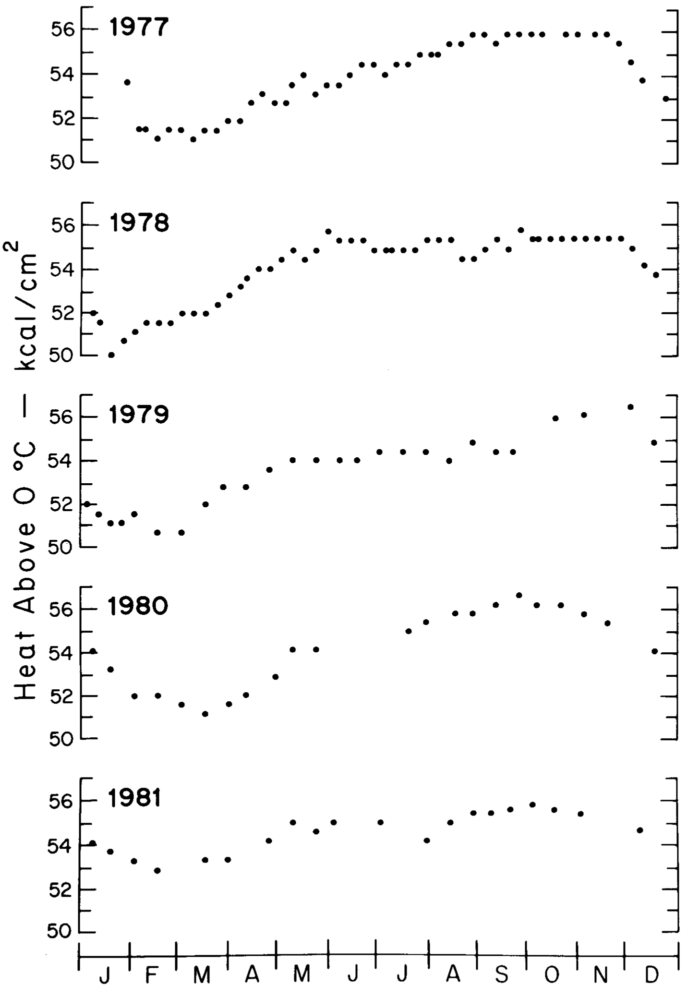

Fig. 2. Birgean heat content of Lake Valencia.

Table 1. Summary statistics for Lake Valencia between 1977 and 1981.

	Date of Overturn	Heat Budget cal/cm^2	Maximum Stability g · cm/cm^2	Work of Wind g · cm/cm^2	Minimum Temperature C°
1977	Nov. 25±3	4755	345	2639	25.55
1978	Dec. 1±3	5766	352	3156	24.95
1979	Nov. 27±7	6059	373	3313	25.35
1980	Nov. 15±7	5294	410	2882	25.63
1981	Dec. 10±7	3045	368	1921	26.10

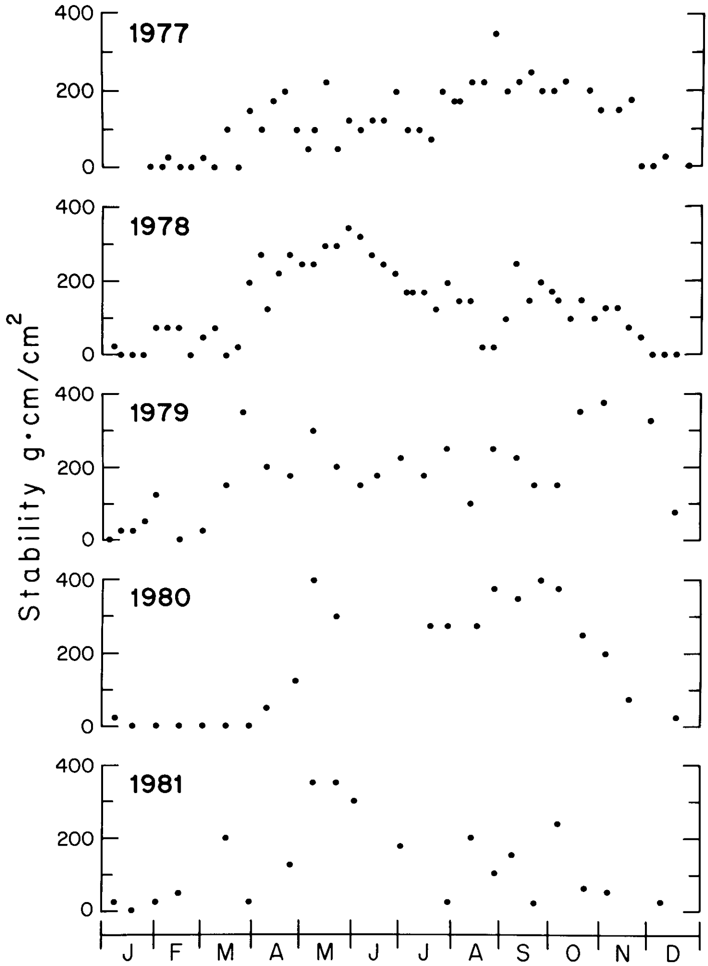

Fig. 3. Stability of stratification for Lake Valencia.

Fig. 3 shows the stability of Lake Valencia according to the concept of Schmidt (1928: see Idso 1973). The stability of stratification in a lake of given size and shape is affected by the base temperature and by the heat distribution. Since the base temperature of Lake Valencia changes very little from one time of the year to the next, the stability is almost entirely determined by heat distribution. At times of uniform heat distribution, the stability is zero. Stability may even become slightly negative (as low as -10 g · cm/cm^2) during the cooling season when rapid loss of heat from the top causes a density inversion.

Uneven distribution of heat results in high stability. The stability of the water column is low during the cooling season and begins to increase as the lake warms. Significant stability is maintained typically between April and November, even though the value increases and decreases irregularly under the influence of changes in average wind strength or temperature and insolation. The period of sustained positive stability is the seasonal stratification period and can also be identified from the individual thermal profiles for this interval, which show persistent thermal stratification. On only three occasions between April and November did the stability of the lake reach very low values indicating minimal resistance to complete mixing. In none of these instances (August 1978, July 1981, September 1981) did the lake actually reach zero stability and mix completely. Thus for the entire five-year study period, stratification was sustained on a seasonal basis between April and November.

Complete mixing of the water column begins in November or December each year. This is suggested in Fig. 2 by the decline of stability in these months. The first date of complete mixing can be determined with precision only by careful examination of the individual thermal and chemical profiles. The dates of mixing indicated by such data are given in Table 1. Complete mixing is accompanied by uniformity in the distribution of oxygen and appearance of nitrite and large amounts of soluble reactive phosphorus at the surface. During overturn the sediment surface temperatures, and possibly the temperature of the water just over the sediment, lag behind the water temperature, producing a temperature profile that appears anomalous but is probably stabilized by dissolved solids (cf LEWIS 1973, 1976; MARMORTNO 1978). However, as mixing becomes more vigorous and the thermal difference becomes greater, the lake mixes completely (Fig. 4).

The regularity in complete mixing is impressive and is scarcely more variable in its timing than would be expected in most temperate-zone lakes. The division of the year into a stratification season and a predictable period of complete mixing obviously qualifies Lake Valencia as a warm monomictic lake. Variations in the thickness of the mixing zone during stratification are

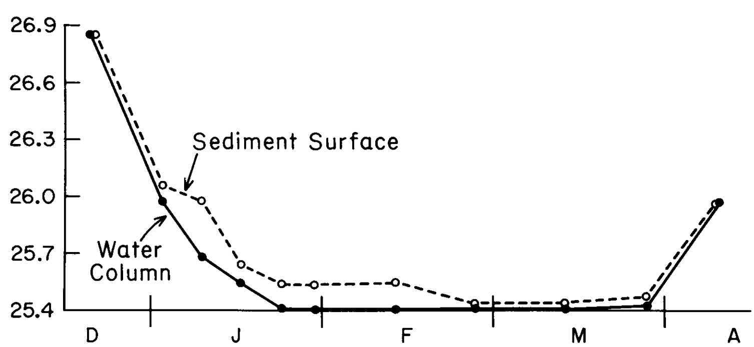

Fig. 4. Bottom temperatures of Lake Valencia near the time of overturn.

probably greater than would be expected in most temperate lakes, but the seasonal cycle of complete mixing and stratification is predictable.

Acknowledgements

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Zusammenfassung

Temperatur- und Chemiedaten für Lago de Valencia, Venezuela wurden über eine Zeitspanne von fünf Jahren gesammelt. Die Daten beweisen, daß der See zwischen April und November immer geschichtet ist, und daß jahreszeitliche Vermischung immer im November oder Dezember anfängt. Jährliche Schwankungen des Datums der Vollzirkulation, der maximalen Schichtungsstabilität und der Schichtungsdauer sind gering. Dagegen sind jährliche Unterschiede in der Wärmeaufnahmerate, des Zeitpunktes des maximalen Wärme-Inhaltes oder des Wärmehaushaltes beträchtlich.

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