# BERICHTE UND MITTEILUNGEN

## CONTINENTALITY INDICES METHODOLOGICAL REVISION AND PROPOSITION

With 9 figures and 1 table

JUAN L. MINETTI

*Zusammenfassung:* Kontinentalitätsindizes: Methodologische Revisionen und Vorschläge

Kontinentalitätsindizes wurden schon in der Vergangenheit eingehend behandelt, aber die mathematische Behandlung der jahreszeitlich bedingten thermischen Wellen hat in der Gegenwart eine neue Bewertung der Indizes erlaubt.

Die jährliche thermische Welle irgendeiner im außertropischen Gebiet liegenden Station weist einen Amplitudeneffekt auf, der dem Kontinentalitätsgrad zuzuschreiben ist, aber sie zeigt auch eine Verschiebung und Asymmetrie in Beziehung zur Sonneneinstrahlung an der Obergrenze der Atmosphäre.

In dieser Arbeit wird dargestellt, daß der Phasenwinkel der ersten Harmonischen einer Fourierschen Reihe der Temperatur-Monatsmittel nicht nur in Verbindung mit der Verzögerung von Maxima und Minima einer Welle steht, sondern daß er auch einen Index der Asymmetrie darstellt. Abschließend wird gezeigt, daß dieser Phasenwinkel als Indikator des Kontinentalitäts- oder Maritimitätsgrades eines Ortes zu interpretieren ist, und es wird eine Qualifikationsskala vorgeschlagen.

### *1. Introduction*

The effects of continents and oceans upon the climate of a region are well known in climatological literature. GORCZYNSKI (1920), BRUNT (1924), JOHANSSON (1926), BERG (mentioned by BERRY et al. 1945), CONRAD (1946) and BARRY and CHORLEY (1972) suggested some indices to quantify those effects.

Due to the dependence between temperature and latitude, GORCZYNSKI suggested to estimate the continentality of a region by taking into account the amplitude of the annual temperature oscillation and the latitude of the place. Later on, JOHANSSON proposed to modify these variables and CONRAD mapped them (CONRAD and POLLAK 1950).

CONRAD and POLLAK carried on the methodological study of the proposed indices. They regard BRUNT's index as a promising one, because it worked according to the average radiation amplitude coming into the atmosphere for a given latitude and the annual amplitude of the monthly average of temperature. Latitude is included in BRUNT's index in the radiation coming into the atmosphere. The mathematical algorithm has a physical meaning now.

BERG used a new concept of continentality: the prevailing continental air masses in a region in relation to the total mass present during a year.

Because of the difficulty to identify the types of air masses as they come out from their sources and the lack of information concerning the altitude for a three-dimensional study in these regions, BERG's methodology is not easily to apply.

The previous indices, which are based on thermal amplitude and latitude, are difficult to apply in low latitudes (CONRAD and POLLAK 1950) due to the low temperature amplitudes of tropical humid continental climates. RATISBONA (1976) says that with these indices the basin of Amazonas River seems to be a large ocean. This disturbing effect caused by the mentioned variable spreads from the humid Tucumano-Oranense forest, in the northwest of Argentine, to the Sierras de Córdoba and the Sierras de San Luis.

Oceanic masses not only regulate the annual temperature of a region but also the wave phase and asymmetry with regard to the external radiative wave which force the land-ocean atmosphere system.

JOHANSSON (1926) introduced an index which takes into account the asymmetry of the seasonal thermal wave, the thermal amplitude and the latitude of a place. Afterwards, PROHASKA (1976) discussing the seasonal change of the temperature in extratropical South America, introduced a continentality or oceanity classification based upon the difference between the average temperatures of autumn and spring (asymmetry synonym).

This paper will show that some of the indices which are used to identify continental or maritime effects in an extratropical place are not effective, and therefore suggests an improved classification based upon the phase and asymmetry of the seasonal thermal wave.

## 2. *Materials and Methods*

Monthly means of 30-year temperature records in 356 places of the Southern Hemisphere (176 belong to Argentine) were computed in this analysis. The sources were the Climatological Statistics published by the *Servicio Meteorológico Nacional* (1944, 1958, 1969, 1974, 1981), the USA *Department of Commerce* (1959, 1966) and Prohaska (1976).

The following indicators of continentality were used in the analysis:

a) Index of Johansson (1926), used by Conrad (1946). Sometimes it is mentioned as Conrad's index.

$$K = \frac{a A}{\sin(\varphi + 10)} - b \qquad (1)$$

with:

K: index of continentality (%)

A: range of annual temperature

a and b: constants, ($a = 1.7$; $b = 14$)

$\varphi$: latitude

b) Prohaska (1976, p. 43) classifies extratropical South American places into continental and maritime ones, on the base of the asymmetry of the seasonal change of temperature (difference between the average temperatures of autumn and spring). The criteria are:

Continental climates:

May average temperature - September average temperature $<0$

Maritime climates:

May average temperature - September average temperature $>0$

In this case the limit between continental and maritime climates is given by the same temperature reached in autumn and spring.

c) This work is based upon the following hypothesis. It is supposed that the phase angle as well as the asymmetry of the seasonal thermal wave could be properly represented by the phase of the first harmonic, from a Fourier's analysis for discrete series according to $N = 12$, so that the wave for the most part of the variability may be represented as:

$$\overline{T}_t = \overline{T} + A_1 \sin\left(\frac{360°}{P} t\right) + B_1 \cos\left(\frac{360°}{P} t\right) \qquad (2)$$

with $\overline{T}_t$ = monthy average temperature, $\overline{T}$ = annual average temperature and

$$\begin{aligned} A_1 &= 2/N \sum_{t=1}^{12} \overline{T}_t \sin\left(\frac{360°}{P} t\right) \qquad N = P = 12 \\ B_1 &= 2/N \sum_{t=1}^{12} \overline{T}_t \cos\left(\frac{360°}{P} t\right) \qquad N = P = 12 \end{aligned} \qquad (3)$$

$\Phi = \operatorname{arc\,tg} B_1/A_1$, called *phase angle.*

Later on, some adjustments between variables (containing simple or logarithmically transformed values) are made, using the least square method (Brooks and Carruthers 1953).

## 3. *Results and Discussion*

In this paper the ocean is regarded as a reservoir of energy, large enough to regulate the amplitude of annual temperature, to delay and change the seasonal thermal wave in large regions.

It is useful to remember that the local variation of temperature T° may be represented by the model:

$$\frac{\partial T°}{\partial t} = \frac{d T°}{d t} - \vec{v}_H \cdot \nabla_H T° \qquad (4)$$

with:

$\frac{\partial T°}{\partial t}$ = local variation of temperature (in a fixed geographical station)

$\frac{d T°}{d t}$ = individual variation of temperature (movable according to the parcel)

$\vec{v}_H \cdot \nabla_H T°$ = horizontal temperature advection

Moreover,

$$\frac{d T°}{d t} = \frac{1}{Cp} \cdot \frac{dW}{dt} - \vec{w} g \varrho \qquad (5)$$

with:

$Cp$ = specific heat of air at constant pressure

$\frac{dW}{dt}$ = variation of the received and emitted energy

$\vec{w}$ = vertical velocity of air

$g$ = gravity acceleration

$\varrho$ = air density

$\vec{w} g \varrho$ - air compression or expansion term (it represents the adiabatic variations of parcel temperature)

The variation of energy with time is a function of the energy balance. The balance of energy may be represented by:

$$W = (Q + q)(1 - a) + I\!\downarrow - I\!\uparrow \qquad (6)$$

$$W = H + LE + \triangle F \qquad (7)$$

where the three terms of (6) show the balance of short and long wave radiation or net radiation (Rn), and (7) shows the flow of sensible and latent heat and the balance surface net energy. The last one only acts over the ocean (Sellers 1972). Afterwards:

$$\frac{dW}{dt} = \frac{\partial W}{\partial t} + \vec{v}_H \cdot \nabla W \qquad (8)$$

It is supposed by the aforesaid that the variation of temperature of a place is a function of energy balance fluctuation, adiabatic processes and energy advection. This situation may be represented by the model:

$$\frac{\partial T°}{\partial t} = f\left(\frac{dW}{dt}, \vec{v}_H \cdot \nabla_H W, \vec{w} g \varrho\right) \qquad (9)$$

Land and sea features give different answers to the balance of local energy because of their different specific heats. Fig. 1 shows an example of "Q" for two places of South America. So it is easily seen that the

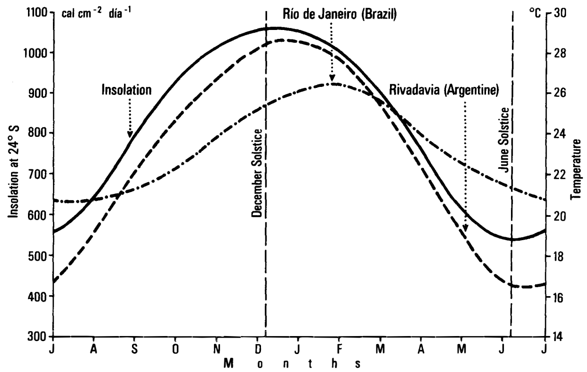

*Fig. 1:* Annual distributions of temperature for a maritime city (Rio de Janeiro - Brazil) and a continental city (Rivadavia - Argentine). Quantities (by cal/cm² day) of received energy are indicated by uninterrupted line. Delays of temperatures with respect to the insolation curve are represented by arrows

Jährliche Temperaturverteilung für eine maritime Stadt (Rio de Janeiro - Brasilien) und eine kontinentale Stadt (Rivadavia - Argentinien). Die Energiemengen der Insolation (in cal/cm² und Tag) sind mit einer durchgezogenen Linie dargestellt. Verzögerungen der Temperatur in Bezug zur Insolationskurve sind durch Pfeile gekennzeichnet

oceanic effect not only controls the amplitude of the average temperature but causes a shift of the thermal wave according to the radiation coming into the upper boundary of the atmosphere (Q) and the asymmetry of the wave, changing the sine-shaped type.

On the whole, the thermal wave shifts from 15 days to one month in the continental regions and from 15 days to two months in the oceanic ones with respect to the incoming radiation wave. In order to delimit how effective the advection of the "inland" sea energy is to accurate thermal control, a quantification of the "phase angle $\Phi$" is necessary. This horizontal zonal movement takes place from the sea to continent and vice versa.

Fig. 2 shows the seasonal variation of average temperature for some places in Australia and South America (continental and oceanic zones and western and eastern coasts).

In order to compare thermal waves with regard to phase and distortion and to eliminate amplitude, Fig. 3 shows the same graphics in terms of the relative temperature with respect to the annual thermal amplitude.

According to PROHASKA's criteria, temperatures are higher in autumn than in spring in places located in the oceans and on the coasts; the seasonal wave delay on the Southeastern Pacific Ocean is lower than on the Southwestern one; there is a three month mild winter maximum in South America compared with a short minimum in Australia.

It was intended to improve the criterion of asymmetry and shift of the seasonal wave considering the phase angle of the first harmonic. The phase angle is equal to 1.5708 for a sine-shaped simple wave (maximum in January and minimum in July).

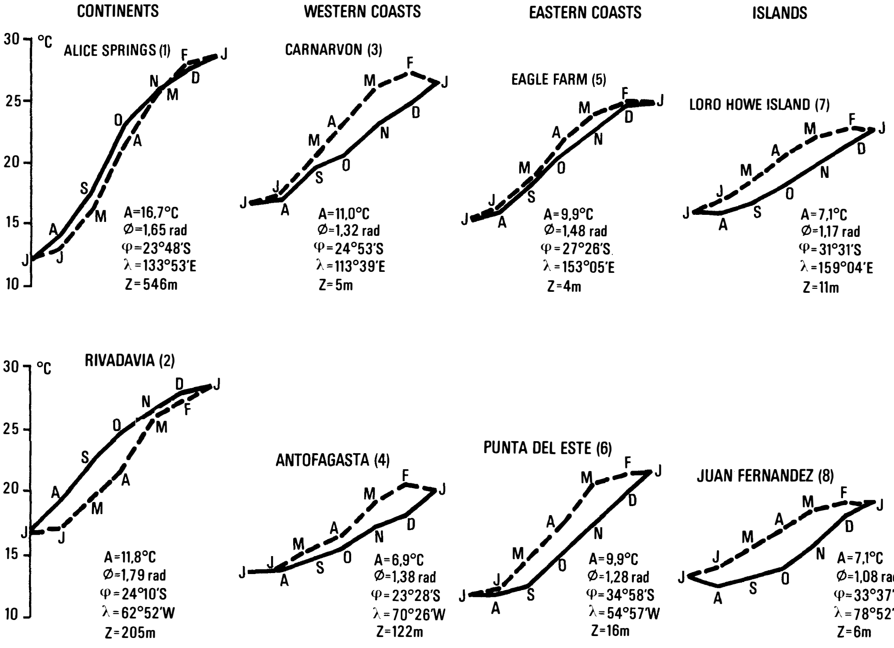

*Fig. 2:* Seasonal changes of average temperature in continental, coastal, and oceanic regions

Saisonale Veränderungen der Durchschnittstemperatur in kontinentalen, küstennahen und ozeanischen Regionen

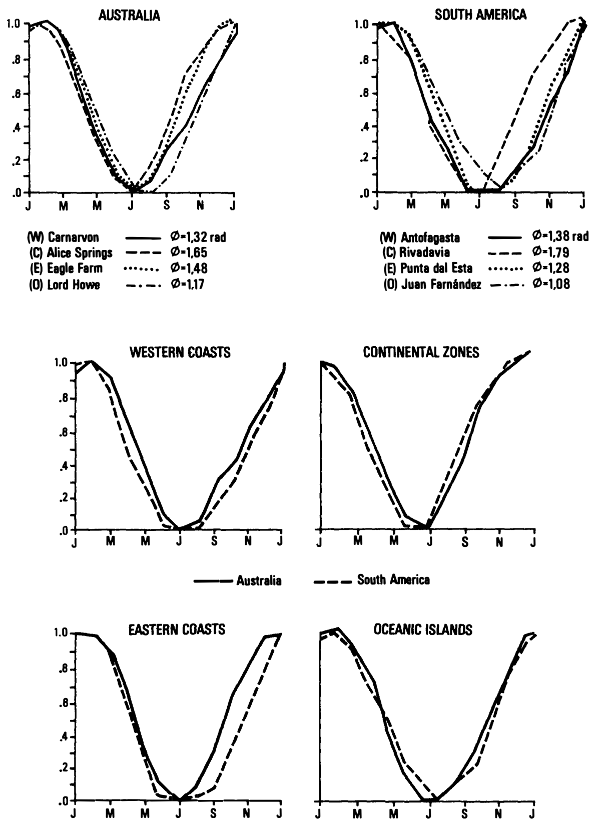

*Fig. 3:* Comparison between seasonal changes of average temperatures in different regions. Values indicate relative temperatures reduced to the same annual amplitude

Vergleich zwischen den saisonalen Veränderungen der Durchschnittstemperaturen in verschiedenen Regionen. Dargestellt sind relative Temperaturwerte, die auf die gleiche Jahresamplitude reduziert sind

Any shifting of the maximum towards February or December and of the minimum towards June or August should be detected by itself. Fig. 4a shows the linear relationship between the average temperature difference during April and October and angle $\Phi$. It is possible to deduce that angle $\Phi$ (which takes the 12 monthly values) is representative not only for the wave phase but also for the asymmetry caused by the difference between the temperature of autumn and spring. Fig. 4b represents the same linear association as in Fig. 4a, but applied to the places present in Fig. 2. To get these lines, data were taken from 80 Argentine places and Western and Eastern Pacific islands (7 and 8).

In Fig. 4a, it is possible to see a slight difference of temperature (– 0,3 °C) between April and October regarding that for the limit suggested by PROHASKA between continental and maritime climates $\Phi$ is equal to 1.5403, and for a perfectly symmetrical sine-shaped wave (according to a maximum of average temperature in January and a minimum in July) $\Phi$ is equal to 1.5708.

Fig. 5 shows the correlation between the phase angle $\Phi$ and the thermal amplitude in 191 places of the Southern Hemisphere, with $X = \log A$, A being the annual thermal oscillation. The correlation is statistically significant (at the 99.9% level). The dots tend to form an asymptote for $\Phi = 1.6$ including a wide range of annual thermal amplitudes (A). In this paper it is intended to show that if $\Phi$ is representative of the continentality degree, it is not necessary to add the thermal amplitude because it is included, although not linearly. The stated limit between continental and maritime climates set by the difference between autumn and spring temperature seems to be exchangeable. So the rate of the observed $\Phi$ (from $\Phi = 1.81$ to $\Phi = 1.03$) had been divided into three equal parts:

| | |
|---|---|
| $\Phi$ higher than 1.55 | continental climates |
| $\Phi$ between 1.29 and 1.55 | coastal and transitional climates |
| $\Phi$ lesser than 1.29 | maritime climates |

As thermal amplitude (A) for high values is not distinguished by function $\Phi = f(A)$, it can be used to feature continentality including continental humid and arid climates in the identification.

Fig. 6 shows the regional distribution of $\Phi$, Fig. 7 the distribution of the limit used by CONRAD (1946). Table 1 shows the rainfall values and indices used by CONRAD and the phase angle $\Phi$ in an east-west direction in the Argentinean Northwest (NOA), from Santiago del Estero to Villa Nougués; the former in xerophytic Chaco, the latter in the Tucumano-Oranense forest.

In this table CONRAD continentality varies inversely according to precipitation. Fig. 7 shows the similarity between the spatial field of CONRAD and the Argentinean Northwestern and San Luis Sierras and Córdoba Sierras rainfall fields (HOFFMANN 1975). Cloudiness and rainfall in this region are produced by the advection of energy carried as latent heat from the ocean, diminishing the thermal amplitude. It is thought that the index given by CONRAD for Villa Nougués (13,5%), located within the continent (value similar to the ones obtained for the Southeastern coast of Buenos Aires), and showing a great difference with the values calculated for San Miguel de Tucumán is not relevant. RATISBONA (1976) shows that the Amazonean basin resembles a large ocean with little thermal amplitude.

Index $\Phi$ could be used for the identification of the Argentinean continental region, including Cuyo and Northwest, and proves the existence of humid and dry continental climates. On the other hand, the limits used to separate the three climatic regions show

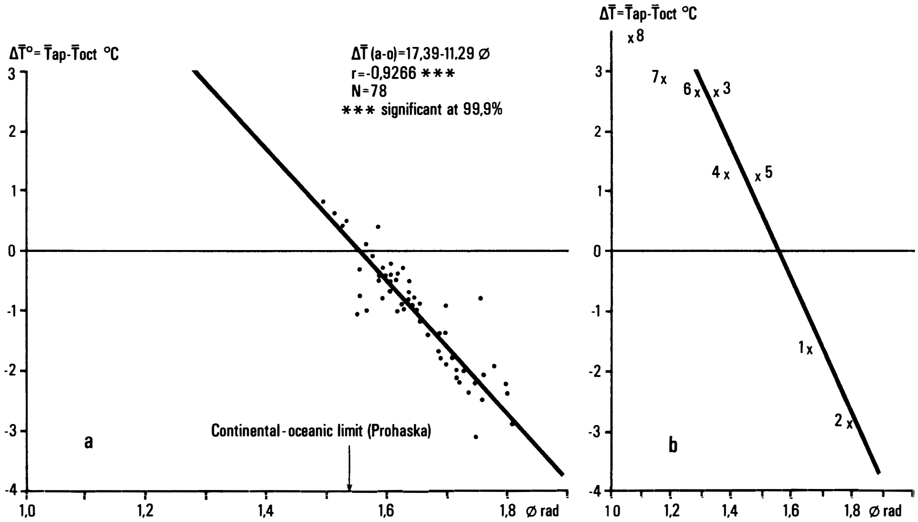

*Fig. 4:* (a) Relationship and fitted line between phase angle $\Phi$ and difference of average temperature of April and October in the Argentine Republic. (b) Idem for South Hemispheric places indicated in figure 2

(a) Streuungsdiagramm und Regressionslinie zwischen dem Phasenwinkel $\Phi$ und der Differenz von April- und Oktobertemperatur in der Republik Argentinien. (b) Gleiche Darstellung für die Standorte der südlichen Hemisphäre aus Abb. 2

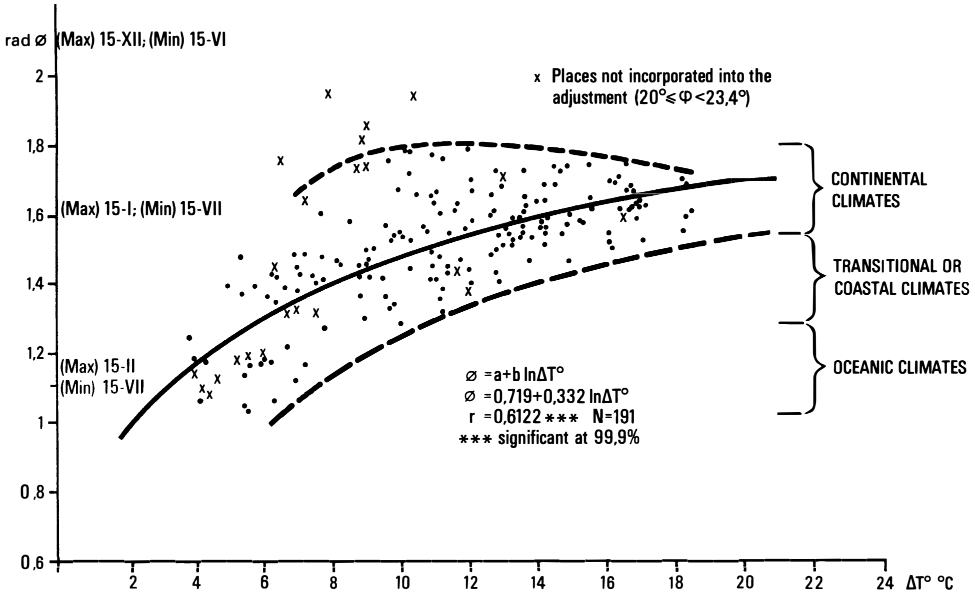

*Fig. 5:* Relationship and logarithmic fitted curve between annual thermic amplitude and phase angle $\Phi$. Proposed climatic limits

Streuungsdiagramm und logarithmisch angepaßte Kurve zwischen der thermischen Jahresamplitude und dem Phasenwinkel $\Phi$. Vorschlag für Klimagrenzen

the different South American extra-tropical regions. Juan Fernández Island, Guafo Island and Evangelista Island, Punta del Este and Rio de Janeiro are considered as oceanic or maritime regions. Cristo Redentor is now considered as a transitional region, whereas it was included among maritime regions by PROHASKA. The most humid region of the mountain range (western slope and ridges) is regarded as a

*Tab. 1: Annual precipitation, index of* CONRAD *and phase angle Φ for places in the Argentinean North-west*

Jahresniederschlag, Index von CONRAD und Phasenwinkel Φ für Stationen im argentinischen Nordwesten

| Places | Annual Rainfall (mm) | CONRAD's Index (%) | Angle Φ (rad) |
|---|---|---|---|
| Santiago del Estero | 518.4 | 25.8 | 1.72 |
| La Cocha | 740.3 | 23.2 | 1.73 |
| San Miguel de Tucumán | 976.2 | 22.3 | 1.68 |
| Villa Nougués | 1474.0 | 13.5 | 1.68 |

transitional one, too. The limit between the transitional region and the continental one is set between Puente del Inca and Uspallata (latitude of Mendoza).

Zonal gradients are well defined on the western Andes Range as compared to the oriental one, showing that the sea-effect spreads inland through the Brazilian coast, Uruguay and the Argentinean Pampa easier than through the rest of South America. This is due to the fact that the geographical factor supports the advection of energy. This effect is not present along the Patagonian coast where the continental limit reaches the coast. In this case, this phenomenon is due to the presence of the Patagonian plateau and the western flow (PROHASKA 1976).

The greatest anomalies in the regional distribution of index Φ are present in the central and northern Chilean region (mostly continental region identifying the longitudinal valleys isolated from the sea by the coastal range) and in La Plata basin in Argentina (transitional or coastal climate over River Plate and Mesopotamia). The first anomaly is identified according to the thermal amplitude and CONRAD's Index. The Rio de la Plata influence on the temperature shows the isopleths $\Phi = 1.5$ which run along the Buenos Aires northeastern coast and then through Entre Rios and Uruguay (Fig. 6).

The degree of continentality according to Φ is placed in the Argentinean Northwest with an axis of

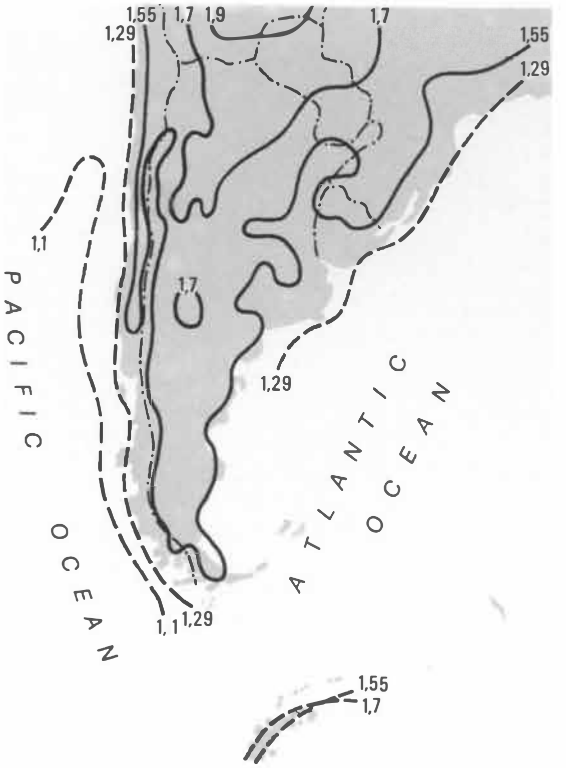

*Fig. 6:* Spatial field of phase angle Φ in meridional South America

Räumliche Verteilung des Phasenwinkels Φ im meridionalen Südamerika

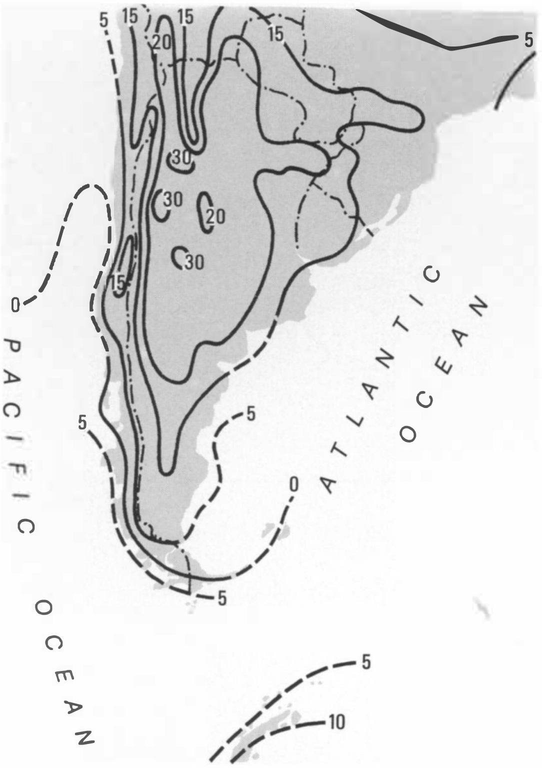

*Fig. 7:* Spatial field of CONRAD's Index in meridional South America

Räumliche Verteilung des Index von CONRAD im meridionalen Südamerika

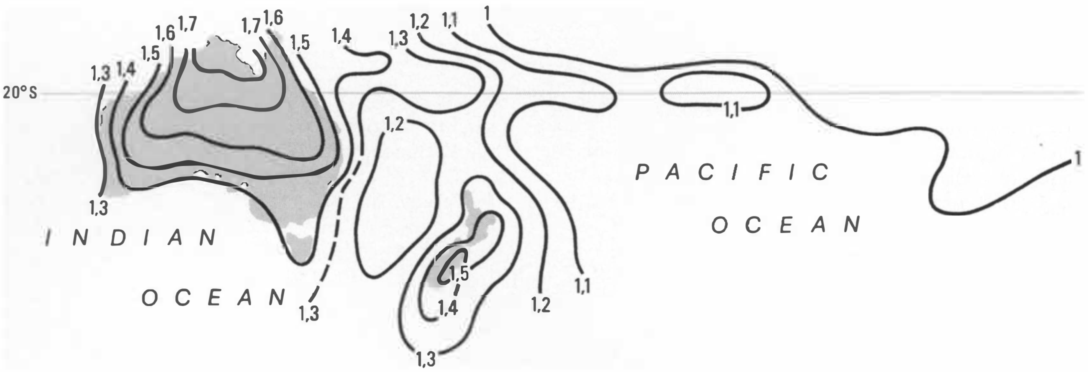

*Fig. 8:* Spatial field of phase angle $\Phi$ in Australia and the South Pacific Ocean
Räumliche Verteilung des Phasenwinkels $\Phi$ in Australien und im Südpazifik

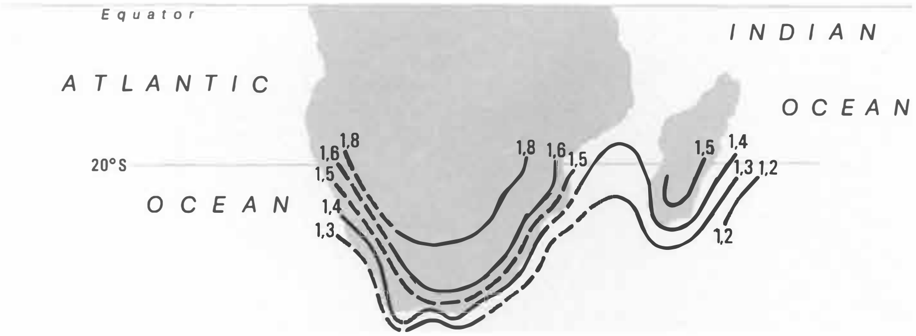

*Fig. 9:* Spatial field of phase angle $\Phi$ in South Africa
Räumliche Verteilung des Phasenwinkels $\Phi$ in Südafrika

high values from La Rioja to San Juan, and an isolated region in Rio Negro. Joaquin V. González and El Cadillal (Jujuy) show the maximum values, and Mar del Plata (Buenos Aires) and Punta Delgada (Chubut) show the minimum ones.

Figures 8 and 9 show the index $\Phi$ in Australia, New Zealand, the Pacific Ocean and South Africa. The extreme values are located in Pretoria (25.8° S) in South Africa ($\Phi = 1.81$) and Pitcairn Island (25.1° S) in the middle of the Pacific Ocean ($\Phi = 1.03$). Based on the observation of the regional distribution of $\Phi$, it is possible to infer the validity of the proposed criterion.

## 4. Conclusions

It has been shown that the phase angle of the first harmonic of the seasonal wave of temperature is a good climatic indicator of continental and oceanic effects. It shows the different types of climates (transitional-coastal and maritime ones) and sets the limit of the influence of the sea on the regulation of the phase and the asymmetry of the seasonal wave of temperature, both probably produced by the effect of the horizontal transport of energy from the ocean to the continent.

The proposed index is related to the annual thermal amplitude and allows the elimination of undesirable effects from the classification of humid continental climates. Because of this, a large region in the Argentinean Northwest should be identified as a continental one. The index-anomalies show the disturbing regional effects, i.e. the many rivers belonging to the La Plata System in the Argentinean Mesopotamia.

## Acknowledgements

The author would like to express his gratitude to Dr. Arturo E. Corte for his generous encouragement in the preparation of this paper, to Professors Alberto Flores and Susana Bishoff for their comments and to Miss Janina Arturo for the typing work.

## *References*

Barry, G. R. and Chorley R. J.: Atmósfera, Tiempo y Clima. Barcelona 1972.

Berry, E., Bollay, E. and Beers, N. R.: Handbook of Meteorology. New York 1945.

Brooks, C. E. P. and Carruthers, N.: Handbook of Statistical Methods in Meteorology. London 1953.

Brunt, D.: Climatic continentality and oceanity. In: Geogr. J. 44, 1924, 43ff.

Conrad, V.: Usual formulas of continentality and their limits of validity. In: Trans. Am. Geophys. Union 27, 1946, 663ff.

Conrad, V. and Pollak, L. W.: Methods in Climatology. Cambridge, Massachussets 1950.

*Department of Commerce.* Weather Bureau: World Weather Records 1941-50. Washington 1959.

*Department of Commerce.* Weather Bureau: World Weather Records 1951-60. Washington 1966.

Goczynski, L.: Sur le calcul du degré du continentalisme et son application dans la climatologie. In: Geografiska Annaler 2, 1920, 324-331.

Hoffmann, J. A. J.: Atlas Climático de América del Sur. OMM-UNESCO. Budapest 1975.

Johansson, O. V.: Über die Asymmetrie der meteorologischen Schwankungen. In: Soc. Sci. Fennica, Commentationes Phys. Math. 3, 1926, 1ff.

Prohaska, F.: The climate of Argentina, Paraguay and Uruguay. In: Schwerdtfeger, W. (Ed.): Climates of Central and South America. World Survey of Climatology, Vol. 12. Amsterdam, Oxford, New York 1976, 13-112.

Ratisbona, L. R.: The climate of Brazil. In: Schwerdtfeger, W. (Ed.): Climates of Central and South America. World Survey of Climatology, Vol. 12. Amsterdam, Oxford, New York 1976, 219-293.

Sellers, W. D.: Physical Climatology. Chicago 1972.

*Servicio Meteorológico Nacional:* Estadísticas Climatológicas 1928-37. Publicación N°1, Serie B. Buenos Aires 1944.

*Servicio Meteorológico Nacional:* Estadísticas Climatológicas 1941-50. Publicación N°3, Serie Bl. Buenos Aires 1958.

*Servicio Meteorológico Nacional:* Estadísticas Climatológicas 1951-60. Publicación N°6, Serie Bl. Buenos Aires 1969.

*Servicio Meteorológico Nacional:* Normales Climatológicas 1931-60. Publicación N°7, Serie B. Buenos Aires 1974.

*Servicio Meteorológico Nacional:* Estadísticas Climatológicas 1961-70. Publicación N°35, Serie B. Buenos Aires 1981.

---

# BEZIEHUNGEN ZWISCHEN ABFLUSS UND IONENGEHALT IN KLEINEN EINZUGSGEBIETEN DES SÜDNIEDERSÄCHSISCHEN BERGLANDES

Mit 5 Abbildungen und 4 Tabellen

Karl-Heinz Pörtge und Ingolf Rienäcker

*Summary:* Ion content/run-off relations in small catchments in the southern Lower Saxony mountain region

The relations between material concentration and run-off were investigated in 12 catchments in the southern Leine-Weser-mountain region. The 12 catchments were free of settlements and differently used. The data obtained were compared.

The dissolved material of the run-off consists of alkaline-earth, mostly hydrogenic-carbonatic, and sometimes of sulphatic constituents. The rate of mineralization runs from 1.7 up to 20.5 mmol/l (eq), depending on the lithogenous situation of the catchment. The mostly geogenic substances, such as Ca, Mg, $HCO_3$, and in part $SO_4$, have minimum variability and are subject to the so-called dilution effect at increasing run-off rates. Species such as K, $PO_4$, $NH_4$, $NO_3$, and the atmogenic $SO_4$ show bigger fluctuations in the flow regime and their content usually correlates positively with the run-off. The relation between ion content and run-off is to be evaluated specifically in each area because the dilution effect of the element concentration during increasing run-off was not observed in all cases.

## 1. *Einleitung*

Zahlreiche Untersuchungen in kleinen hydrologischen Einzugsgebieten befassen sich mit der Ermittlung von Stoffkonzentrations-/Abflußbeziehungen, dem Ursache-Wirkungsgefüge von Konzentrationsschwankungen im Verlauf von Abflußwellen und der damit verbundenen Berechnung von Frachtraten (z. B. Pörtge 1979, Rausch 1982, Rienäcker 1985, Agster 1986). Wegen des vermehrten atmosphärischen Protoneneintrages gilt das besondere Augenmerk Lösungsprozessen und Lösungsausträgen. Der Lösungsaustrag hat lithogene, pedogene und anthropogene Quellen und ist, bezogen auf den lithogenen Teil, auch als „Innerer Abtrag“ bezeichnet worden (Rohdenburg und Meyer 1963).

Eine Differenzierung des Lösungsaustrags in die genannten Komponenten ist problematisch, weil Migration und Mobilität der einzelnen Wasser-