MODELS OF THE SOUTHERN OSCILLATION IN THE 300-100 mb LAYER AND THE BASIS OF SEASONAL FORECASTING

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Summary — The geometry of the principal Upper High (near the Indian Ocean) in the 300-100 mb layer appears to account for the Southern Oscillation (S.O.), and models of its behaviour are presented. Significant features of these models include the equatorial points of upper convergence (C) and divergence (D), a pressure discontinuity (CNDS) forming « arcs » and an « enclosure » around the high, and, lastly, encircling « crescents » both outside and inside the enclosure. The geography of the seasonal succession can thus — in a qualitative manner — be interpreted in the light of known wind and contour patterns near the tropopause. With a few general principles, the established empirical rules of long-range forecasting then follow by deduction. The models and the terminology are useful likewise in the interpretation of solar-terrestrial relations and of climatic fluctuations.

1. *Introduction.*

The barometric see-saw between the Pacific and Indian Oceans — the Southern Oscillation (S.O.) — is associated with numerous empirical correlations (WALKER 1923-37, BERLAGE 1957, SCHOVE & BERLAGE in progress) useful in seasonal forecasting. No satisfactory explanations for the Oscillation itself or for the lag-correlations have been given. Meanwhile, computer-analysis has enabled WILLETT & PROHASKA (1962) to find further unexplained relationships at the 700/500 mb level, and BERLAGE (1961, p. 355) has emphasised that the upper air must play an important though unknown part in the oscillation. The present paper is an attempt to fill these gaps in a qualitative sense.

2. *The S. O. and the Upper High.*

The primary hypothesis of this paper identifies the negative area of the Southern Oscillation with the regions traversed by the main Upper High at 300 - 100 mb. (HEASTIE & STEPHENSON 1961, abbreviated in this paper as H & S, p. 47 and 101). With surface pressure higher over the Pacific than the Indian Ocean, the positive sign was used by WALKER (1928 p. 99), the circulation of the equatorial winds then being more vigorous at the *surface*. However, the S. O. is negatively correlated

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with temperature in both areas, so that the pressure anomalies over the Pacific diminish and those over the Indian Ocean become greater with height. Our first diagram (Fig. 1) shows the way this works at about 700-500 mb, when the S. O. is negative, the sign implicit in many other diagrams of the present paper.

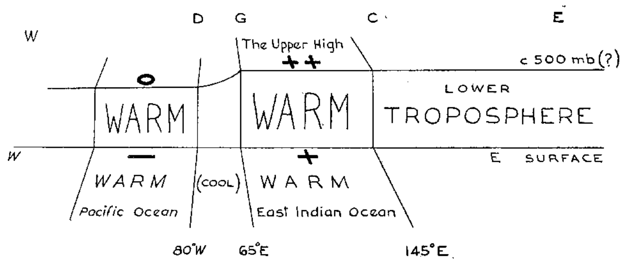

Fig. 1 - *The signs* (0, —, +, ++) *of equatorial pressure anomalies at the surface and in the middle troposphere* (500 mb) *corresponding to a negative S.O.* (cf. WALKER, 1932, Charts 8, 9, 11, 12 and 1937, Charts 11, 12, 14, 15).

The lack of persistent meridional tropospheric temperature gradients in low latitudes means moreover that seasonal pressure anomalies at the surface are a guide to the seasonal anomalies of the contour surfaces in the upper troposphere. In short, it is plausible to assume that in a particular season a *negative* S. O. corresponds to *above*-normal tropical pressure at 200 mb.

Since this paper was submitted tropical 200 mb data for the period 1950/60 have been obtained and analysed; they confirm this statement provided that the « nor- mal » is a *short*-period mean of the neighbouring 3 or 4 years. The sign of deviations from 10-year means depends also upon another factor, not discussed here, but presumably the solar cycle and perhaps the associated pressure parameter (SCHOVE 1961 b).

Certainly the most marked negative S.O. area on the equator lies in the same longitudes (65° — 145° E) as the highest contours at 300-100 mb, the region of the principal upper high.

3. *The Geometry of the Upper High.*

The wind-pattern of any equatorial upper high is indicated in Fig. 2. By the geometry of the situation, air is transferred around the high from a *Div*-point of

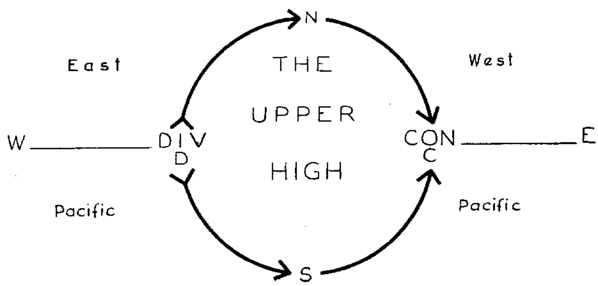

Fig. 2 - *The « Enclosure » of the equatorial upper high at* 300-100 *mb, showing the points of upper divergence* (*D*) *and convergence* (*C*).

upper divergence (*D* in our Figs.) to a *Con*-point of upper convergence (*C*). In practice, the most important divergence is over South America, and convergence occurs over Indonesia; as far as the models are concerned the positions can be regarded as points rather than lines. Indeed, ageostrophic wind components at this level for straight isopleths are usually directed across the contours from low to high pressure and the air around the high becomes trapped in an « Enclosure » (Fig. 2) or a pressure discontinuity. The contour pattern of the Upper High is thus raised above the surrounding slopes; its geographical analogue would be a « volcanic plug ».

The principle illustrated in Fig. 2 can be termed the principle of equatorial inflation, which is significant inasmuch as it operates through a considerable depth of the troposphere. In a season when surface pressure anomalies over the Indian Ocean are positive, the tropical contour anomalies at 200 mb are likewise positive, and the Indonesian equatorial easterlies at the same level are stronger. The absolute topography of the 200 mb contours on account of equatorial inflation imprints itself on the anomaly pattern at the surface.

4. « *Simple* » *and* « *Dynamic* » *patterns.*

The simple pattern of Fig. 2 might seem to be particularly appropriate in April and October when the Upper High straddles the equator. Whenever this high is more powerful than usual we expect air to be transferred from the « Western Arc » (*SDN*) to the « Eastern Arc » (*NCS*). Although this does happen, the accumu-

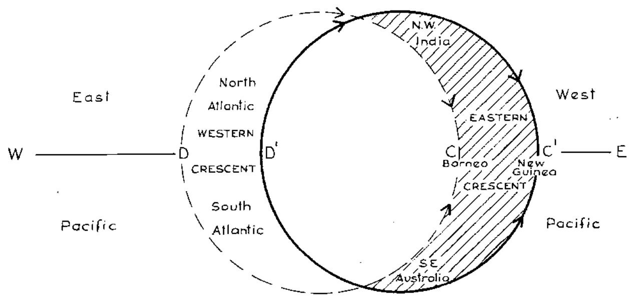

Fig. 3 - *The dynamic pattern.* The external Eastern Crescent (shaded) of rising pressure caused by accumulation at the Indonesian point of upper convergence.

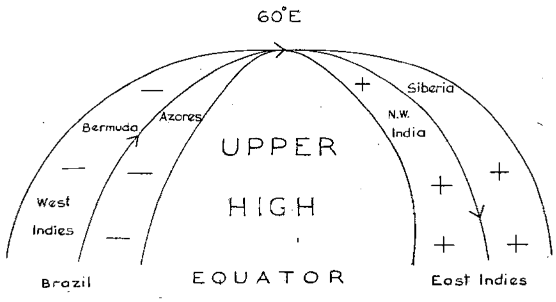

Fig. 4 - *The cusps.* The western (—) and eastern (+) crescent in the northern hemisphere.

lation of air on the eastern sector causes the Upper High to move eastwards as a whole, the *Con* points in these two months being displaced from Borneo (*C*) to near New Guinea (*C'*). This « dynamic pattern », together with the « western crescent » and « eastern crescent », is illustrated in Fig. 3. The situation in higher latitudes, where air leaves the cusp of the western crescent to enter the eastern crescent, is illustrated in Fig. 4. In this figure a loose geographical distinction has been indicated between an internal and an external crescent.

The change of sign of pressure anomalies (Fig. 4) as air passes round the Upper Ridge is a familiar feature of pressure anomaly maps, notably in Spring and Summer in the USSR when this upper ridge lies about 60° E. The anomaly map (unpublished) for 1940 for instance, in relation to 1941-50 means, shows a partial crescent of low pressure extending from South America to Europe and a crescent of high pressure extending from N.W. India to S.E. Australia. A mean anomaly map for all those years since 1841 in which there were famines in N.E. Brazil showed precisely those features of Fig. 3, with a crescent of low pressure extending from South America via the West Indies to Northern Italy.

5. *The Valve Model.*

Upper easterlies prevail in the 300-100 mb layer over Indonesia in months other than April and October, and normally, therefore, these winds force into the enclosure the air accumulating at the *Con*-point. In this way, the eastward motion of the dynamic pattern (Fig. 3) is inhibited and the simple pattern (Fig. 2) preserved. In order to introduce these easterly winds into our model, *C* and *D* can be regarded as valves, and a « valve-model » is shown (in three-dimensions) in Fig. 5.

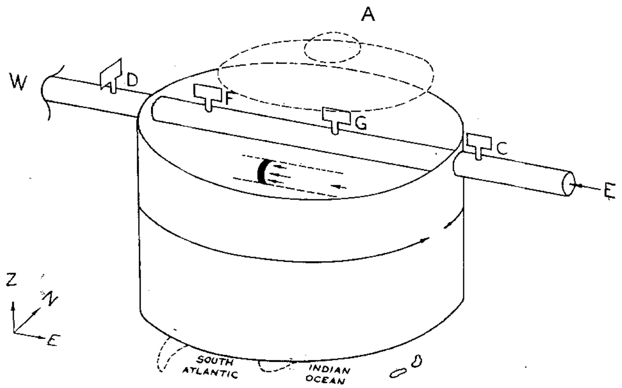

Fig. 5 - *The valve-model: a three-dimensional view.*
A = The contours of the upper high.
E = The equatorial easterlies at 300-100 mb.
C = The *Con*-point over S. America.
D = The *Div*-point over Indonesia.
F, *G* = Other points off W. and E. Africa.

The positions of *C* and *D*, the *Con*- and *Div*- points, can be determined from the intersections of the upper contours with the equator. In January, for instance, the *Con*-point *C* is thus located (110 °E) between Singapore and Borneo not only on the 300 mb map but also on the 200 mb and the 150 mb maps (H & S, pp. 45, 47, 49).

In April again, a *Con*-point (*C'* in Fig. 3) is identically sited N.E. of Borneo (155 °E) on four separate maps (300-100 mb), corresponding to a genuine discontinuity around the Upper High.

In the model the Indonesian *Con*-point *C* (or *C'*) is regarded as an entry-valve. The entry-valve is normally open. The exit-valve is normally shut, as easterly winds in Ecuador appear to be effective only in July and August.

6. *Deformation of the Enclosure.*

The Upper High and the « Enclosure » have so far been regarded as coinciding circles. This is true as a first approximation, but the discontinuity does not everywhere coincide with the same isopleth; the circular shape of Fig. 2 is distorted by the winds of the 300-100 mb layer.

The equatorial easterlies deform the simple « Enclosure » within a few degrees of the equator itself and produce *V*-kinks. In the sub-tropics the upper westerlies likewise produce *U*-bends directed in the opposite sense (cf. Fig. 6).

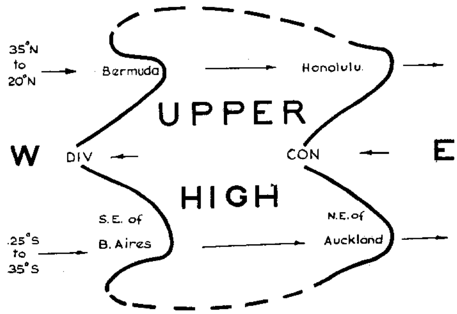

Fig. 6 - V-*kinks and* U-*bends: Deformation of the boundaries of the enclosure by upper easterlies near the equator and by upper westerlies in the sub-tropics.*
(Places named are included in the *U*-bends in winter but not in summer. The criterion here is a correlation coefficient of 0.25 in WALKER 1932, Charts 11, 8; cf. also Fig. 7 in this paper).

The *V*-kinks and *U*-bends in BERLAGE's maps of the correlation with Jakarta pressure can now be interpreted. The persistent boundaries of the « enclosure » – i.e. the pressure discontinuities – are indicated by narrow belts where BERLAGE's isopleths are close together; his zero isopleth represents an average position through the five-month period in question.

7. *Seasonally changing axes.*

The same two maps define very clearly the changing orientation of the axis of the Enclosure. The axis of the Upper high shows a similar but smaller swing. In general, the axis extends from WSW to ENE in northern winter and from WNW to ESE in northern summer. This is explained by the eastward displacement of that half of the enclosure affected by the sub-tropical upper westerlies, a process illustrated in Fig. 7. In northern winter the north-eastern edge of the enclosure is thus pushed beyond China into the North Pacific, whereas in the southern winter the south-east edge is carried east of Australia and north of New Zealand into the South Pacific.

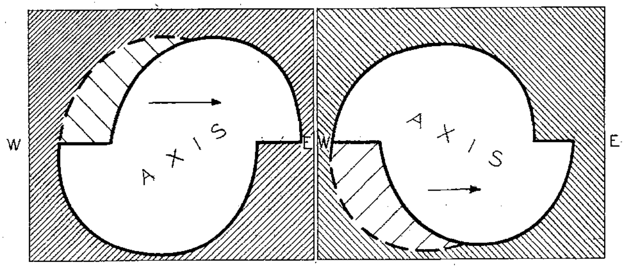

Fig. 7 - *The effect of winter westerlies on the axes of the enclosure* (Idealized): *i*) Oct. - Feb., *ii*) Apr. - Sep.

8. *The « Internal Valves ».*

In the valve model of Fig. 5 two additional valves, *F* and *G*, are shown inside the enclosure. Although the complications so introduced will be largely ignored in the present paper, the significance of these valves must be mentioned.

At specific periods of the year secondary points of upper convergence or divergence or divergence arise along the equator, especially at positions about a thousand miles from the coasts of West and East Africa respectively. The nature and positions of these points can again be estimated from intersections, or near intersections, of contours with the equator on the 300-100 mb maps in H & S.

Thus, in the northern winter both these positions (*F* and *G*) are often points of divergence usurping the functions of the exit-valve *D*; in that season, therefore, we would expect pockets of « positive » correlation with the S.O. to the westward. Certainly the irregularities in BERLAGE's map near Ascension and Mauritius-Zanzibar respectively (cf. also WALKER 1932, Fig. 11, p. 65) are partly consistent with this interpretation.

The domain of the Upper High can once again be subdivided geometrically (Fig. 8). The main « Indian Ocean » chamber includes the Cape, India, Indonesia, and Australia. The reversed surface pressure in this area has already (SCHOVE 1961 b) been referred to as *PP*, a « first approximation to the Pressure Parameter ». The Pressure Parameter is an attempt to measure the extent of the transfer of air from the region of the Upper High to the regions of the Upper Troughs; it explains thereby the major difference between one five-year period and the next. The *PP* reflects – again in inverted form – the strength of the Upper High. Its January value, as we shall see, corresponds closely to the January value of the Southern Oscillation.

9. *The Piston Model.*

With the entry valve open and the exit-valve shut, we should expect the pressure to rise inside the enclosure during the first half of the year. The continued « pumping » at the eastern end does indeed « inflate » the 200 mb surface. The level of the highest isopleth (H & S) – 1245 geopotential decametres in January and April – rises to over 1255 in July, collapsing to only 1240 by October. This suggests the piston model of Fig. 8, in which the movable valves *F* and *G* are replaced by a single piston. This piston is located at the most effective Div-point and is pushed westwards by the pressure from the « compression » chamber. The accumulated air near the eastern arc pushes it from near Singapore in October to East Africa by January, until about July the piston discharges its compressed air – to be rarified by divergence as it leaves the enclosure at *D* – across the Andes into the Pacific.

This time-table explains many of WALKER's findings. It may explain the 6-8 months lag between the pressure in Indonesia and the reversed pressure at Juan Fernandez off Western Chile (BERLAGE 1957, Table 9, p. 34).

10. *The Models through the Seasons.*

a) *Introduction* — The contemporary correlations established by WALKER (1932 Charts 8, 11 and 1937, Charts 11 and 14), viewed side by side with the

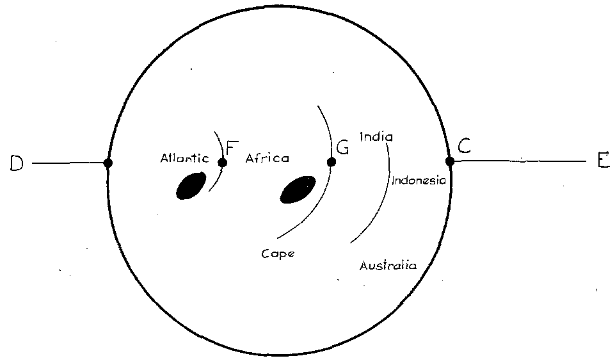

Fig. 8 - *The sub-division of the enclosure in January.* Positive islands shown in black.

contour and wind charts in H & S, enable us to interpret the seasonal succession in the light of our models. The piston-model and the valve-model are both idealized conceptions. The piston-model explains the normal seasonal succession and the valves the irregularities, and a piston has therefore been included in the three-dimensional model of Fig. 5. Neither model must be taken too literally. In particular, the discontinuity or boundary of the enclosure is not necessarily narrow, and different boundaries can be selected corresponding to differing degrees of pressure correlation with the Upper High (cf. Fig. 6, above).

The intensity of the Upper High in a particular summer — using terms appropriate to the *northern* hemisphere — is the most important factor determining the excess of air available for the « compression chamber » — say the Pressure Parameter area — six-months ahead. Hence the well-known persistence of the S.O. between northern Summer and the following « Winter », a persistence characteristic also of the tropical contour anomalies at the 200 mb level. The value of the S.O. — or the *PP* for a given winter is thus — if we may use yet another metaphor — conceived in the « summer » although it is born in the « autumn ». It is convenient therefore to begin our survey with the month of October.

b) *October: The Eastern Arc.* — The main Upper High in October lies over south-east Asia and (120 °) Indonesia, with a subsidiary centre (15 °E) over Africa and an extension westwards to Brazil. The most significant area of the S.O. was placed by WALKER (1937, Chart 11) between the Ganges and north-east Australia crossing the equator at 120 °E; this is the eastern arc (*NCS*) of our Fig. 2.

With a negative S.O. we would expect a tongue of colder air, associated with air advected northwards from higher latitudes, between New Zealand and northern Australia, and this is confirmed by WALKER's temperature correlations (1937, Chart 15). Once inside the enclosure, especially under the Upper High as at nearby Jakarta, the temperature is particularly warm.

The subsidiary high has significant correlations of its own (cf. SCHOVE, in progress), but between the Seychelles (*G*) and Brazil (*D*) most of the effect of the preceding S.O. has been neutralised through divergence in the Indian Ocean and by the disappearance of the easterlies.

c) *January: The* PP *Area.* — The main Upper High in January extends from a *Con*-point near Borneo to a Div-point (*F'*) in Africa and this situation corresponds to that shown in Fig. 15 of the BERLAGE's (1957) paper. The « piston » in this month has reached East Africa. Strong upper easterlies in Indonesia are still pumping air into the « compression chamber » which, as shown in Figs. 14 and 15 of the BERLAGE's paper, now coincides with the area associated with the pressure parameter (cf. SCHOVE 1961 b).

The forward edge of the « compression chamber » near South-East Africa is most significant in seasonal forcasting, but there is also the western Div-point (*D*) near Ecuador, and correlation coefficients with the *PP* or the S.O. reveal that some portion of the new S.O. does now reach as far west as the Andes. Indeed,

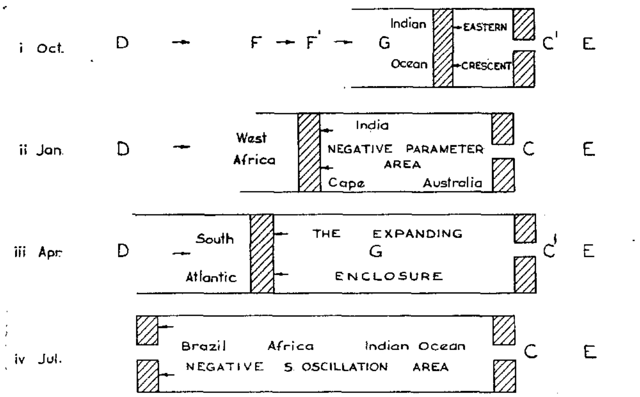

Fig. 9 - *The Piston Model.*
i) October *iii*) April *iv*) July.
(Arrows refer to Upper Winds.: cf. H & S, pp. 116-176)

correlations with the *PP* indicate the enclosure there as a sharp boundary between positive and negative regions, commencing near Ecuador itself.

Deformation of the boundaries of the enclosure in the northern winter is caused by the upper westerlies, following the patterns of Fig. 6 and 7. In January itself, the jet near Tokyo carries the negative area in a *U*-bend as far east as Honolulu (cf. WALKER 1932, Chart II). In the South Pacific the negative area extends into the Tasman Sea, with the lesser *U*-bend evident about 25 °S in BERLAGE's map, and this roughly corresponds once again to the latitude of the westerlies of the 300-100 mb layer (25 °S in H & S, p. 194).

Advection of air towards and away from the equator near the pressure discontinuity again explains the tongues of warmth and cold associated with a negative S.O. In January the positions of these tongues lie near Chile and New Zealand respectively (cf. WALKER 1932, Chart 12); in particular, the temperature at Arequipa (a high- level station in the Andes), reflects very closely (correlation coefficient of 0. 8) in this season (cf. WALKER 1937, Chart 19, curves 2 and 3) the inverted southern oscillation, and it is no doubt an equally close reflection of the strength of the Upper High. Inside the enclosure under the Upper High in latitudes 80° -110° E the surface temperature is particularly warm.

The *U*-bend in the northern hemisphere helps the North Pacific high to develop in this season in sympathy (correlation coefficient of 0.5, WALKER 1932, p. 62) with the main Upper High. This in turn induces low pressure near Alaska setting up a North Pacific Oscillation. Meanwhile the primary positive are an the Pacific extends north-eastwards through Florida (cf. WALKER 1932, p. 65) into the North Atlantic in the position of the western external crescent of Fig. 4.

The 700-500 mb level in the same season presumably responds in a similar manner. Correlation coefficients (WILLETT & PROHASKA 1962, Table VI, cols.1 and 5. Their S.O. in *this* season has the opposite sign to that of WALKER) might be interpreted in the light of the 700 mb chart (H & S, pp. 40-41) as follows:

i. The *U*-bend extends to a point off the West Coast of the U.S.A. with a N-wind component at 40 °N in the North Pacific;
ii. The Alaskan ridge weakens;
iii. The trough near Japan weakens;
iv. The upper high in the Gulf of Mexico weakens;
v. The belt of reduced pressure (the W. external crescent) extends NE to the Eastern North Atlantic at 60 °N;
vi. The upper trough in N.E. Canada fills.

Surface pressure information for the last two regions was not available to WALKER, but even these interpretations are not inconsistent with the surface conditions indicated in WALKER's (1932) Chart II; the remaining correlations correspond.

d) *April: The Western Crescent.* — The position of the Upper High in April — Indonesia to south of Ghana — corresponds generally with the compression chamber in our piston diagram (Fig. 9, iii). The discontinuity in pressure at the *Con*-point (140 °-180 °E) is clearly evident. The isopleths in H & S (pp. 62, 64 and 66) suggest that the main divergence in our figures is at *F*, which point is temporarily usurping, much of the function of the exit-valve *D*. This is thus the « forward edge » and special significance may therefore be attached to pressure in the « Western Internal Crescent » (cf. Fig. 3) between Ascension and the Azores, which feeds (WALKER 1937, p. 124) the « positive » region of the North Atlantic Oscillation. WALKER's map of the N.A.O., (1937, Chart 2) with signs reversed, shows a curious resemblance to the pattern of Fig. 3 or 4, with the anomalies changing signs east of the Upper Ridge at 60 °East. There are reasons for this, but the N.A.O. is, nevertheless, neutral as far as the S.O. or the Upper High as a whole is concerned.

We should expect a warm tongue (cf. again Fig. 2) in this crescent, and there is some evidence for this in WALKER's chart (1937, chart 13) from Spain via Brazil — possibly — to Tristan da Cunha. The evidence for the cold tongue in New Zealand is definite and this again is evidently associated with the northward advection of colder air towards the Div-point. Once again, inside the enclosure directly under the high (120 °E) warmth is especially evident.

e) *July*: *The Valves.* — The main Upper High is now centred over south-east Iran (almost over the Monsoon Low) and there is a subsidiary with a centre near the Texas-Mexico border. Their equatorial attachments — and it is these that matter most — lie well to the south-east, and the set-up is essentially that of the valve-model, with secondary points of upper convergence (*F*) and divergence (*G*) respectively (cf. H & S, pp. 84-85).

The piston-diagram (Fig. 9) ignores the secondary points and suggests an enclosure extending from Brazil to Indonesia. However, the southern westerlies (cf. Fig. 7) add a clockwise rotation, and the axis of the enclosure actually lies from the south-east Mediterranean to beyond Australia. The features suggested by Fig. 6 develop in the southern hemisphere where strong upper westerlies in the Pacific (H & S, p. 207) at 25 °-30 °S push the western boundary in a *U*-bend east of Buenos Aires and (cf. H & S, p. 202) the eastern boundary into another *U*-bend (20 °S) north-east of New Zealand. In the northern hemisphere on the other hand, strong upper easterlies (cf. H & S, p. 211, 202 and 87) produce a *V*-kink extending into north-east India beyond Calcutta. These winds convey the anomalies of the equatorial part of the Upper High via S. India and Egypt (cf. BERLAGE 1957, Fig. 20) into eastern Europe clockwise round the Upper High. The Easterly winds at 15 °N (H & S pp. 204-205) convey the influence across North Africa to produce a *V*-kink in the North Atlantic (cf. also the annual maps in BERLAGE 1961, Figs. 6 and 7).

The temperature effects follow the usual pattern. A cold tongue extends from New Zealand into N. Australia (WALKER 1932, Chart 9) and there is a secondary cold tongue near the *Con*-point in the Gulf of Guinea, affecting sea as well as air temperatures (WALKER 1937, Table VIII, 5 °S, 5 °W.)

The 700-500 mb correlation coefficients of WILLETT & PROHASKA (1962, Table VI, cols. 3,7) show few clear-cut features. The dominant influence of the high in the North Pacific and of a low in North America are more evident than in WALKER'S surface map (1932, Chart 8), where the zero isopleth in the N. Pacific and N. Atlantic is probably in need of adjustment.

11. *The basis of seasonal forecasting.*

Most of the concepts needed for seasonal forecasting have now been introduced in the study of contemporary correlations. The following general principles enable the empirical rules of WALKER to be deduced in a qualitative sense:

i. The winds of the equatorial Upper High at 300-100 mb create a pressure discontinuity around it;

ii. The movement and rotation of the Upper High are reflected in a somewhat similar movement or rotation of the « Enclosure » (bounded by the discontinuities);

iii. Seasonal pressure anomalies within this mobile « Enclosure » show a persistence from season to season. This is essentially what was recognized and measured by WALKER'S correlation coefficients of the Southern Oscillation;

iv. Seasonal pressure anomalies in low latitudes reflect the anomalous pressures of the higher layers;
v. Seasonal anomalies are propagated with the winds of the 300-100 mb layer. Equatorial anomalies thus travel from East to West and Subtropical anomalies (except in S. Asia in summer) from West to East;
vi. The sign of the anomalies reverses as the air enters or leaves the « Enclosure » along the equator;
vii. Especially when easterlies at the entry-point are ineffective, anomalies near the boundary of the Enclosure may travel around the Upper High from west to east, moving first away from and later towards the equator, changing signs as they pass round the ridge;
viii. The raised surface pressure of the Sub-tropical Highs over the Oceans induces lowered surface pressure in higher latitudes. The N.P.O. and N.A.O. are stimulated by induction in this way.

Our models also suggest new seasonal forecasting rules (especially for the southern hemisphere) not noted by WALKER. Certain further principles involving and accounting for non-persistence of the S.O., seem to be implied (e.g. the closure of valve C) by our models, and some of these appear to be valid in practice.

12. *The S.O. in the Stratosphere.*

The influence of the « Southern » Oscillation or Upper High Oscillation as we should now term it — extends well above 200 mb.

The temperature, at the 50-20 mb level, over the globe as a whole, using the estimates of C. WARNECKE, appears to behave in the same sense as the tropical surface temperature in relation to the S.O. In the years 1951-52 and 1957-9 when the surface pressure in the Indian Ocean and the 200 mb pressure in the tropics was high this temperature was much higher than in 1954-6 or 1960, in which years the S.O. was positive.

13. *Solar Fluctuations.*

The effects of an increase in solar activity is to convert the peak of the Upper High into a crater. In the case of minor fluctuations from month to month the air erupts from the region within the central isopleth (cf. Fig. 5) and falls on the slopes, thus remaining inside the enclosure. In the case of a moderately developed solar cycle, the debris falls — from a much larger crater — outside the enclosure, and then the pressure falls in the negative area of the Southern Oscillation as a whole. In the case of a well-developed cycle, the still greater negative area of the pressure parameter acts as the crater. This happened in the past decade, where the surface pressure fell between 1951/5 and 1956/60 as far north-west as the British Isles. The 200 mb contours in the same period fell in the Indian Ocean area and rose at Canton Island in the equatorial Pacific.

Individual solar cycles vary in their reaction. Thus TROUP's (1962) Fig. 1 shows (for Dec/Feb) that sunspots were associated in the 1910's with increased tropical pressure and temperature (and easterlies) at 130 °E and in the 1920's with decreased pressure and temperature at exactly the same longitude.

14. *Climatic Fluctuations.*

Over five-year periods the geography of the Southern Oscillation is transformed into that of the Pressure Parameter. The debris from the expanded crater then not only falls onto the Pacific col but accumulates in the several upper troughs from where the air flows polewards as if the troughs were rivers.

The pressure lost in regions around the Indian Ocean is thus gained by the main Upper lows in the Antarctic and off north-east Canada. This is the parameter oscillation, reflected, as noted elsewhere, in the (simultaneous) opposition of surface pressure changes by five-year periods between the Indian Ocean and Greenland (SCHOVE 1961b, in progress).

The concept of the enclosure is again useful. The discontinuity in pressure-changes by five-year periods is sharply defined and its equatorial positions in South America and Indonesia correspond again to *D* and *C* in our models. The discontinuity extends north-west from Brazil into North America, including, in this case, most of the interior states of the U.S.A. It is hoped that wind changes in Argentina, New Zealand and elsewhere measured by the author's method (SCHOVE 1962) will enable its precise position to be specified. It is at least clear that the main differences between one five-year period and the next depend on the change in the parameter — approximately the (reversed) surface pressure change inside the enclosure. The simple model of Fig.2 thus provides the key to climatic fluctuations by five-year periods.

Barometric changes by 30-year periods were discussed in the author's previous (1961g) paper in this journal. It is clear from the maps presented then that the most important changes(except in high latitudes) since 1880 are explained, not by the conventional methods but by a « superoscillation » comparable with the Southern Oscillation. It seems probable therefore that this major pressure oscillation, as it was then termed, has an equatorial origin after the pattern of Fig.3. Indeed, although the topic has not yet been investigated in the United States itself, the boundary of the enclosure between the states with a pressure maximum about *1920/24* (i.e. 1905/34 to 1909/38) and those with a pressure minimum in the same period is probably even closer than was suggested by the author's previous figures (SCHOVE 1961 g, Figs. 1, 2). However, the barometric evidence is not sufficiently reliable to determine whether *D* in South America or *F* and *G* near Africa is the effective point of upper divergence.

Tree-ring data (SCHOVE 1961b, 1961g) promise to throw light over the past two thousand years on fluctuations which in low and middle latitudes appear to be associated primarily with oscillations of the enclosure of the Upper High.

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