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The General Circulation of the atmosphere in the light of more recent investigations

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Abstract

Extensive synoptic studies carried out by the author at the International Institute of Meteorology in Stockholm [7] to [11] for selected periods in midwinter 1956 and based on a total careful check of all the radiosonde ascents of the Northern Hemisphere (temperature and wind) allowed to specify the following important basic phenomena inside the General Circulation of the Atmosphere:

1) A threefold subdivision of the tropopause-level by means of two hemispheric tropopause breaks. One interrelated with the position of the Polarfront Jetstream and another one connected with the position of the Subtropical Jetstream (Tropopause-overlap near 30°N in winter).

2) Relative to the main outline of the atmospheric field of flow a classification of the radiosonde ascents has been obtained giving important information about the baroclinic structure of the atmosphere.

3) By means of several characteristics Polarfront Jetstream and Subtropical Jetstream have to be clearly distinguished from each other.

4) Meandering behaviour of the Subtropical Jetstream in form of suddenly occurring and rapid northward advances of it (<u>subtropical impulses</u>) towards higher latitudes with simultaneous formation of strong and extensive blocking-anticyclones over mid-latitudes. The effect of these on the Polarfront Jet circulation has been demonstrated.

These phenomena are discussed in this article. All statements refer strictly to the <u>midwinter of the Northern Hemisphere</u>. Similar studies for summer are at the time in progress.

1) Introduction

The General Circulation of the atmosphere may possibly be defined as that state of motion of the air in the three-dimensional atmospheric space which tends to establish an equalisation of existing heat differences inside this space. The General Circulation, however, certainly includes much more than only the simply basics of a thermodynamic heat engine. The latter could be described by a uniform medium with only one heat and cold source and such a simple system simulates the actual facts in the atmosphere, of course, only very little. The complicated vertical structure of the atmosphere deviates strongly from a uniform medium in many respects (f.i. the subdivision into tropo- and stratosphere with a differentiated vertical stratification in each and others). Thereby heat and cold sources are in a rather complicated way distributed in space and this more so, as the total system earth - atmosphere forms a non-separable unity and therefore the non-uniform underlying surface of the atmospheric space (distribution of continents and oceans) takes important influence on the distribution of the heat and cold sources. This non-uniform topography of the earth surface has in addition also other essential effects acting as a feed-back on the atmosphere. Furthermore for the continental areas the differences in the topography add, which are an additional factor, influencing the atmospheric motions in an important way.

And finally the total system of earth and atmosphere is in a state of constant rotation, whereby the apparent forces caused by the rotation (Coriolis forces) depend on the latitude.

As the only energy source taking influence on the system of earth and atmosphere solely the sun radiation must be considered and one knows from preliminary calculations of the atmospheric heat budget that lower latitudes receive more heat as they give off again to the free space while for higher latitudes the opposite is the case. Such calculations indicate that even if for the atmosphere as a whole a nearly equalized heat budget exists, still differences in the heat budget in zonal as well as meridional direction remain but the atmospheric temperature distribution still remains almost stationary (at least for individual seasons). This can only be the case if atmospheric and oceanic, permanent and turbulent mass transports lead to an equalisation of the existing differences in the heat budget, whereby the transport of condensation heat, of course, plays a rather important role.

Differences in the sun radiation together with differences in the heat budget cause a more or less strong meridional temperature gradient as the main phenomenon of the heat distribution in the lower atmospheric layers (troposphere). The observed two-fold subdivision of the atmosphere in vertical direction into a tropo- and stratosphere is certainly only partly an effect of an approach to the state of a radiational equilibrium, but also the flow conditions, turbulence as well as condensation of water vapour will contribute in order to establish a certain spacial position of the boundary surface between tropo- and stratosphere (the tropopause).

This tendency to approach a state of radiational equilibrium inside the atmosphere leads by means of meridional heat transports to thermal instabilities in the stratification which cause in connection with the action of the Coriolis force zonal atmospheric movements (following latitude circles). These, however, sometimes will become for themselves unstable if a certain critical value depending mainly on the wind shear along the vertical is surpassed. Such instabilities lead to transformations of potential into kinetic energy and cause on the one hand "disturbances" in the pressure field with increasing amplitudes, on the other hand they give rise to an increasing meridional exchange.

In this way the different circumstances interact without making it possible for the individual basic phenomena to reach an equilibrium; since radiational equilibrium and dynamic equilibrium can never exist side by side at the same time but they rather exclude each other.

It is therefore in general not too surprising that until now no generally accepted and all the observed facts covering theory or a so-called general model of the General Atmospheric Circulation has been derived and this more so as the knowledge of the exact three-dimensional structure of the atmosphere especially with respect to the upper troposphere and in particular also with respect to the stratosphere remained for a long time a rather poor one due to the lack of sufficient observational material.

It appears therefore of special importance to select out from the rather disturbing variety of phenomena occurring in the vertical stratification of the atmosphere of all latitudes and in the field of motion only those which can be defined as the characteristic and dynamic - thermodynamic important ones. Such a selection should especially stress those phenomena which are present all the time as dominant phenomena and which are at the same time also of a world wide extent (hemispheric phenomena). From these such ones with a more local character and with a restricted appearance in time have to be separated.

The purpose of this paper shall be to discuss some of these characteristic phenomena inside the total atmospheric mass field and field of motion. On the basis of more recent synoptic - aerological investigations, which I have carried out at the International Meteorological Institute in Stockholm, new light shall be drawn to the three-dimensional structure of the atmosphere and the characteristic flow patterns in it. [7 to 11]

In most of the synoptic - aerological investigations of the General Atmospheric Circulations mean values of individual meteorological elements taken along the individual latitude circles for different atmospheric levels play the main role for an investigation of the three-dimensional atmospheric structure. Many of these investigations are based in a characteristic way on an evaluation of the observational data with respect to latitude. All the available mean charts of atmospheric pressure (dynamic height), of the temperature, of the density and partly also of the wind are based entirely on an averaging process with respect to latitude circles. It is in the first place obvious that this kind of working scheme as a consequence of the meandering structure of the field of motion or what is the same, as a consequence of the interaction of fundamentally different stratified parts of the atmosphere smoothes the existing important contrasts drastically and partly even eliminates completely the interesting phenomena. One may therefore by justified to warn synopticians not to draw hasty conclusions from the results of such investigations about the existence or non-existence of atmospheric phenomena.

Such critical remarks refer, of course, not to the detailed and careful investigations of the synoptic aerology, for which the classical working scheme of the Norwegian school during the investigations of the extratropical disturbances of temperate latitudes and the aerological studies carried out especially by Palmén, Bergeron, J. Bjerknes and others are examples. On the contrary it have been exactly these investigations using a most careful three-dimensional technique of analysis which gave the best information about the three-dimensional structure of these special atmospheric phenomena. But the time and thereby also the quality, density and vertical extent of atmospheric radiosonde ascents has made its progress. This what has been impossible to explore in previous synoptic - aerological investigations due to the lack of data or due to incomplete data, can at present already be touched by the investigating hand of the aerologist. This concerns especially the upper atmospheric layers (higher parts of the troposphere, tropopause, total stratosphere as far as direct observational evidence goes). Since hemispheric data in comprehensive publication are now available, the road is open for the strenuous work of a global synoptic research which only will allow to clear up questions about the fundaments of the world wide three-dimensional structure of the atmosphere.

But one of the most essential difficulties, with which synopticians have been confronted up to 1950, namely the lack of sufficient, and high reaching wind data, which are completely available at each of the twice daily radiosonde termines, slowly is removed. At elder times one has always been forced to conclude from the more or less well known pressure- or temperature field on the field of motion by means of theoretical relations (geostrophic or gradient wind, thermal wind equation a.o.). Each meteorologist is familiar with the difficulties, which thereby stand in question. But when measured actual winds are available, which is increasingly the case, these difficulties are also removed in an increasing way. Here I am not going to touch questions concerning the quality and correctness of actual upper air winds, it may only be stressed, that the most detailed wind structure in atmospheric ascents is of such an outstanding importance for meteorology, that utmost attention should be paid to marked features in the wind distribution as maximum wind speed, sharp wind shear a.o. and should especially be indicated in the synoptic code. It seems to me that it would also be rather economic to make a proper and total use of the wind measurement for scientific purpose and in practical meteorology since it is only to obtain with appreciable costs.

The kind of view point to conclude from the pressure or temperature field (density field) on the field of motion seems especially for world wide meteorological investigations at present already inappropriate. With the availability of numerous actual wind observations it seems to be rather suitable to start with the field of motion of the atmosphere. Such a methodical approach seems also dynamically better founded and this more so, as the field of flow possesses certain characteristic properties (jetstream-bands) in preferred heights as well as also over preferred latitudes and the temperature field, pressure field resp. adjusts relative to these patterns of the field of flow with characteristic contrasts.

These should, however, not mean that I attempt here to discuss the possibly unsolvable question what field occurs primary and causes an adjustment of the other (field of flow and mass field and the reverse).

Similar to the view point already taken long ago in oceanography it appears now also in meteorology appropriate for a study of the field of mass of the total atmosphere to take an orientation relative to the form and outline of the field of motion and to chose this field as a reference system or basis for further studies of the mass field. The advantage of such a methodical approach as compared with a purely geographical orientation (with respect to latitude circles) will be shown to the reader lateron in section 3.

2) The three-dimensional atmospheric field of motion

If one deals with the atmospheric field of flow one must at first be aware of the fact that the atmospheric space (from the pole to the equator and from the earth surface up to about 25 - 30 km) in which the three-dimensional movements of the air occur, is a space of extraordinarily large horizontal extent (40.000 x 10^3 m) and is only of comparatively little vertical extent (20 to 30 x 10^3 m). Correspondingly the horizontal flow components (u = zonal and directed positive eastward and v = meridional and directed positive northward) are of much larger magnitude (1 - 150 m/sec) than the vertical ones (w = positive towards the zenith; in general 1 - 10 cm/sec, rarely of the order of m/sec). The quasi-horizontal atmospheric motion is, however, extremely sensible for weak upward motion, downward motion resp. and interconnected current phenomena will be cut arbitrarily on horizontal maps of different levels, which are used for a study of the large-scale atmospheric movements, and the connected form of these phenomena will be masked. This refers especially to higher levels near to the appearance of maximum wind speed, where strong positive wind shear below the maximum wind (wind increase with height) and strong negative shear above it (wind decrease with height) occurs. Utmost care is therefore needed if isotachs (lines of equal wind velocity) are drawn on horizontal maps and if one attempts then even to follow the resulting areas with maximum wind intensity from day to day as individual phenomena.

Vertical cross sections taken normal to the main current direction appear most suitable to investigate the atmospheric field of flow in the vertical. But only the full use of all the data available (not only those f.i. from the main isobaric surfaces) allows it to perform a micro-analysis of the atmospheric wind field in the vertical which comes close to the actual truth. A rather deeply penetrating study c' the total radiosonde material with respect to the vertical wind distribution (lateron I will also deal in detail with the temperature distribution in section 3) made it possible to mention the following marked phenomena inside the field of motion of the atmosphere:

As well from a purely formal view point of synoptic facts as also according to dynamical considerations concerning the theory of the General Circulation of the atmosphere it seems to me appropriate to subdivide the atmospheric field of flow into two rather different regimes. Correspondingly a three-fold subdivision of the three-dimensional atmospheric space will be made lateron.

A) The regime of the Westwinddrift of temperate and higher latitudes.

a) General remarks about the Westwinddrift

We may chose as one of the two principle wind regimes of the atmospheric circulation the <u>general Westwinddrift (Westerlies) of temperate and higher</u> latitudes (between about 65 and 30^0 latitude), which is characterized by a special flow character consisting of long waves throughout all atmospheric levels, if one disregards the lowest one or two kilometres, in which the turbulent current patterns, however, still allow to visualize this upper more large-scale wave type. Towards 30^0 N the wave-form character gets slowly lost and a more zonal Westwinddrift dominates. Typical for this regime is the general increase of the wind with height (in correspondence with the thermal wind relationship) upwards to <u>just below</u> the boundary surface between tropo- and stratosphere (the tropopause) where the maximum wind intensity is reached. Above inside the stratosphere at first a more rapid then a rather variable decrease of the wind with height is to observe. Although the intensity of the wind increases inside this regime to just below the tropopause and decreases above, the general wave character in the flow pattern is conserved throughout all levels if one disregards parttime and vortex-form cut-offs northward (anticyclonic), southward (cyclonic) resp. .

But inside the general flow of wave-form character and of a wind increase with height the wind-velocities are not at all uniform in meridional direction (variance of the zonal wind with latitude), but two narrow bands with remarkably high wind speeds stand clearly out. However, they can be distinguished from each other besides other characteristics by the special circumstance that <u>the height in which the maximum wind occurs is rather different for both jetstreams</u>. Here it shall thus be mentioned beforehand that a single level is not appropriate to picture both current cores of maximum wind intensity.

b) The polarfront jetstream.

The northern one of both wind bands inside the general Westwinddrift can be found always in variable latitude between 65 and 30° N and shows its maximum velocity (up to 200 knots and more) near to the 300 mb-surface (ca. 9 km). This special jetstream shows a close relation to the polarfront (defined as that boundary layer, which separates pure polar air masses in the north or on its left side from much warmer masses in its south or on its right side). This relationship is such that the wind maximum of the polarfront jetstream occurs just south of the upper part of the polarfront, which in the upper troposphere mostly takes on a rather steep slope (quasi-vertical). Therefore this special current core of the Westwinddrift ("Strahlstrom" or jetstream) has been denoted the "polarfront jetstream" (<u>Palmén</u> [22]). <u>Rossby</u> and his Chicago co-workers have devoted much of their theoretical interest to this jet phenomenon of the atmospheric field of motion. Thereby also the wave-form character of the Westwinddrift which finds its special expression in the meandering behaviour of this special current core, has been dealt with theoretically (long waves, instability of the polarfront jet, cut-off process north- and southward, energy considerations and dispersion). [34] , [28 - 33]

c) The subtropical jetstream.

With the further progress in our synoptic knowledge and with the further extension of the world wide network and the increase of the upper air stations it became, however, apparent, that besides the polarfront jetstream inside the general Westwinddrift another current core of high wind intensity is in existence (Palmén [22] and others). It can be markedly distinguished from the polarfront jetstream not only due to its preferred latitudinal occurrence (mostly near to the 30° parallel in winter and near to about the 45° parallel in summer) but also with reference to the height of occurrence of maximum wind (mostly near the 200 mb-surface or about 12 km). For these reasons it has been taken more and more as a wind phenomenon different from that of the polarfront jet and it has been denoted "the subtropical jetstream". Investigations carried out by the author (Fr. Defant [2 - 5] , [8] , [9]) have, however, shown that its more or less permanent character (quasi-zonal current near 30° N in winter) at times is lost and also this current core starts to meander. However, these meanderings do not show a well pronounced wave-character but can rather be described as rapid northward displacements of the current taking on in time an anticyclonic curvature (subtropical impulses). It may be mentioned that such rapidly occurring northward displacements of the total current band are rare phenomena and weaker developments of this kind more frequently occur for which only a side branch of the subtropical jetstream executes such a northward displacement, the main current core, however, remains near to 30° N. It can easily be understood that under these circumstances a parttime approach of both jet phenomena of the general Westwinddrift occurs (as well in the south, but also in northern latitudes) the consequence and special importance of which will be discussed lateron more in detail.

d) The lower layers of the Westwinddrift with variable wind conditions.

Starting out from the higher atmospheric levels in which the maximum wind intensity is found (say approx. the 200 mb-surface) and going down to lower and lower levels, then one realizes soon, that the wind phenomenon of subtropical jetstream is lost entirely in the flow patterns and from the 300 mb-level down to 500 mb (about from 9 to 5.5 km) only the polarfront jetstream can be visualized, in 500 mb already with a strongly decrease of its core velocity. The intensity of the general westerlies still weakens if decending further down to the 700 mb-surface (ca. 3 km). Down to this altitude, however, the large-scale wave character (long planetary waves) of the upper flow is still retained and at first in the height-interval from the 700 to the 850 mb-level (ca. 3 down to 1.5 km) and further down to the earth surface the general allover wave pattern breaks up into a series of in themselves closed vortical disturbances of cyclonic or anticyclonic character (extratropical disturbances of temperate latitudes). The general dominant wave train of upper atmospheric levels then only is reflected by the course of individual frontal trains each of which belongs to a single cyclone family (mostly at the eastern or south-eastern side of the upper long wave troughs). The lower atmospheric layers are therefore governed by variable wind conditions, whereby in the climatological average of the wind directions and speeds for most stations the westerly winds (from SW over W to NW) stand out with larger intensity (if we disregard orographically influenced stations). For a closer detail about extratropical disturbances see meteorological text books and it seems of no use here to deal further with this.

Summarizing the foregoing discussion, the general Westwinddrift as one of the wind regimes of the atmospheric field of flow contains two dominating wind bands which can be followed all around the earth and possess jet-character, the polarfront jetstream and the subtropical jetstream, which as hemispheric phenomena must be distinguished by the following characteristics:

	Polarfront Jetstream	Subtropical Jetstream
Vertical wind profile:	a) gradual vertical wind increase until the polarfront	a) gradual increase of the wind mostly without essential discontinuities
	b) inside the polarfront layer rapid wind increase	b) just below the wind maximum most rapid wind increase
	c) further but slower wind increase until jet maximum	c) narrow jet peak
	d) above jet maximum more rapid, then gradually slower wind decrease, however, always still relative strong westerly winds in the upper stratosphere	d) above the jet maximum at first rapid, then slower wind decrease to small intensities, partly also change into easterly winds in the higher parts of the stratosphere
	e) (note combination with the upper part of the polarfront)	
Height of maximum wind:	about the 300 mb-level (9 km)	about the 200 mb-level (12 km) or somewhat higher
Latitudinal position and characteristics:	strong meandering behaviour in meridional direction, long Rossby-waves, cut-off processes towards north and south	more permanent position near to the 30° latitude circle, sometimes rapid displacements towards north (subtropical impulses)

B) The tropic-subtropical circulation regime.

The second wind regime of the atmospheric three-dimensional field of flow occurs in the atmospheric space south of 30° N until the equator. The movements occurring in this space are of an essentially different kind as those occurring in the previously subdivided wind regime (Westwinddrift of temperate and higher latitudes).

As the space between the equator and the 30° latitude circle possesses about the same underlying area as the 60 latitudinal degrees covering space between 30° and the pole, it is understandable that the first space must be of much importance. This tropic-subtropical space obtains also much more direct sun radiation (about 62% of the total incoming radiation). But our knowledge about the flow conditions in this space is completely insufficient primarily due to the lack of high reaching wind measurements but also due to the rather meagre density of the station network. Only in more recent times slowly a better insight has been gained, however, this is restricted to special regions where the network has locally been increased for other purposes. Therefore synoptic day-to-day patterns of the flow in this space remain still rather poor and are by no means of a world wide extent. So we have to restrict ourselves for a description to more or less average summations of the flow conditions. [24], [Palmén 23]

a) The zonal wind components.

One fact can in general be mentioned, that the velocity of the westerly wind from the 30° parallel towards south and beginning with the more zonally oriented subtropical jetstream decreases in all heights in the direction towards the equator, the maximum wind, however, shifts gradually to a higher elevation from the 200 mb-level (12 km) towards the 100 mb-level (16km). In the shallow bottom layers, however, a zonal east-component appears just south of 30° latitude in winter and already in 35° latitude in summer and the height of this layer with a zonal E-component increases equatorward at first slowly [in 15° lat. in winter and in the mean for the total earth in ca. 3.5 km (650 mb)] and then more rapidly so that in winter already south of about 10° latitude (in summer south of about 20° latitude) the zonal W-components are lost, and we observe throughout the total atmosphere in the zone near to the equator solely zonal E-components. The air flow in the zone south of 30° latitude is therefore <u>preferrably zonal</u> either from west or east, which applies especially to the latitudes just south of 30° north and to the region just north of the equator (0° to 10° N in winter, 0° to 20° N in summer).

b) The meridional wind components.

In the intermediate zone in which the previously described change from a zonal E-component close to the earth surface into an upper W-component can be observed and a line of separation indicates the change in direction of the zonal component (axis of the subtropical anticyclone, rising equatorward) the zonal motion in the mean for the total earth is superimposed by a systematic mean meridional motion or mean meridional circulation. The latter one is such that in the lower layers meridional N-components, in the upper ones, however, meridional S-components have been determined which are extraordinarily weak near to the 30° latitude circle, in the middle of the space (near 15° N) at their maximum and in the equatorial zone again rather weak.

It may be stated, however, in general that even the intensity of the maximum meridional components amounts only to about 1/10 of the zonal ones and therefore our statement about an essentially zonal tropic-subtropical air flow seems to be justified.

The interplay of zonal E- and meridional N-components gives rise to the phenomenon of the trades in the lower layers and the interplay of the zonal W- with the meridional S-components to the anti-trades of the upper layers.

This more or less schematic circulation picture gained by an averaging process over all longitudes can only partly be looked upon to be realized in actuality in the tropic-subtropical atmospheric space; it seems to be especially applicable in the ocean areas (southern Atlantic and Pacific). However, also there important and characteristic differences from this kind of mean circulation model between the western and eastern sides of the oceans must exist. This can be seen and understood already from the position of the subtropical high pressure cells, which is asymmetric to the middle part of the oceans in the bottom layers and by the displacement of the center with height. The surface of separation between west- and east winds must therefore be assumed as an inclined surface in the space which slopes not only from north to south but also from west to east.

More recent synoptic investigation of flow conditions present in partial areas of the Pacific as well as in the Atlantic Ocean in addition seem to indicate the existence of a variety of wave- and vortex-formations not only inside the Easterlies but also inside the Westerlies of the tropic-subtropical space. The more regular picture of the vertical distribution of the meridional flow components (in lower layers from N, in the upper ones from S) seems therefore only a fictive average result, while in actuality the directional sense of the flow components is rather variable corresponding to the wave- and vortex disturbances. [24]

It remains to point out that the seasonally different monsoon systems strongly change the model-like picture in certain parts, especially in the middle and lower layers. In addition one knows little about the continental regions where the trades are missing. Referring to the zonal components the model picture seems to be well in the Pacific, less well expressed in the Atlantic and least verified in the Indian Ocean. From the African continental region it is known that here the model is approximately justified but little winds are available from levels higher than 6 km.

Summarizing the analysis of the total atmospheric field of flow then two wind regimes have been distinguished: the general Westwinddrift of temperate and higher latitudes with its dominating two main current cores (polarfront jetstream and subtropical jetstream) and secondly the regime of the tropic-subtropical circulation with its more complicated conditions of a superposition of a western or eastern zonal motion to which is added in the average a slower systematic meridional circulatory movement.

Further wind phenomena in the considered total atmospheric space are f.i. the so-called "Berson Westerlies" near to 50 mb above the equator and a possible winterly jet occurring in the higher polar stratosphere. None of these seems to be a world wide and dominating phenomenon, and we may therefore not include them into our discussion; this more so, as further proof by observation seems to be necessary and the existence as hemispheric phenomena seems not to be sufficiently clarified. see [24], Lee-Godson [13]

Also the variable wind conditions north of the 65^0 parallel into the polar cap (small region, about 0.1 of the total area of the Northern Hemisphere) seems to allow no systematic description and also here there is still a lack of high reaching winds.

3) The vertical temperature stratification and position, as well as form of the tropopause in the light of more recent investigations.

A) Subdivision of the three-dimensional space and method for investigation of the temperature distribution.

For an investigation of the three-dimensional temperature field basically the usual way of an orientation according to latitude circles has been left aside and another approach has been made to carry out this investigation relative to the characteristic properties of the atmospheric field of motion.

It is sufficiently known in synoptics that the temperature contrasts adjust to the momentary current patterns and therefore the above mentioned current cores limit in a rather plausible way the following three atmospheric spaces:

1) the inner polar calotte (about $70 - 90^0$ lat.)
   the polar space limited towards south by the position of the polarfront jetstream and the sloping polarfront
2) a middle space taken between the position of the polarfront jet and the polarfront southward to the position of the subtropical jet (mostly near to 30^0 N in winter)
3) tropic-subtropical space south of the position of the subtropical jetstream.

In each of these three spaces a rather careful check of the total, tropo- and stratospheric vertical temperature distribution of all the radiosonde ascents of the Northern Hemisphere has been made for a winterly time-interval (about half a month). Special attention has been devoted thereby to the height and special form of the tropopause.

The position of the main current cores has been fixed as exact as possible at first by means of several detailed horizontal maps (surface, 700, 500, 300, 200 mb-level). According to the above described spatial subdivision of the atmospheric space a selection of radiosonde ascents out of each of the spaces has been made separately for each day of the period under consideration and soon it showed that a rather remarkable agreement in the type of all the radiosondes in each of the spaces was present. Especially the vertical temperature distribution in the middle and upper troposphere and in the stratosphere were rather similar in each space. In addition in all the radiosondes of each space a characteristic form of the tropopause but also in particular a characteristic tropopause height was found or a small height interval in which the tropopauses of all the radiosondes of each space occurred. And all this was observed to be almost independent on the latitude, in spite of the fact that the soundings selected out from each of the spaces had a rather different latitudinal position.

This rather remarkable conservative character in the radiosonde type of each space which already during the check became rather apparent has been investigated more extensively. For each of the spaces a characteristic <u>mean</u> vertical temperature distribution has been computed for each day and finally also for the total time-interval of half a month. When this had been completed, standard deviations of the vertical temperature distribution of all the individual ascents from that of the mean distribution were computed (separately for each height from the ground up to 30 mb). Although it was already clear by the careful inspection that a conservative character of the radiosondes in each space appeared this conservative tendency unmistakably was shown to exist by the relatively small standard deviations, as a correct statistical measure. *)

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*) We remind the reader that the mean fixes the center of a given distribution and the standard deviation σ indicates the spread or the variation of the individual measurements. In the present case the individual measurements

are the temperatures in different heights of the individual radiosondes in each space and the mean is the mean temperature in the corresponding height. The concentration of the temperature measurements towards the mean value is expressed by the circumstance that over 2/3 of the observations (66,7%) lie in the interval $m \pm \sigma$ while 95% are situated in the interval $m \pm 2\sigma$

But finally after a careful re-check of the total radiosonde material in certain cases there was still a difficulty for a clear-cut selection into one of the three main spaces or groups (polar, middle, subtropic-tropical radiosondes). This concerns on the one hand those ascents which in their vertical flight exactly cross the main axis of the polarfront jetstream or at least come very close to. Then special conditions resulted in the vertical temperature structure, and it has been difficult to decide clearly about the tropopause because additional kinks in the vertical temperature gradient (frontal intersection) appear. Or there was no tropopause to observe at all since the temperature decreased in those cases continuously with height from the tropo- into the stratosphere.

Similar difficult circumstances have been found in ascents passing vertically through the subtropical jet core or at least close to it. Here a double tropopause was always to observe whereby between the two marked tropopause levels a vertical distance of about 5 km remained. Already due to these regularly returning phenomena I have been guided to the opinion that the tropopause is not a continuous surface between equator and pole but rather shows breaklines in connection with the position of the main current cores of the general Westwinddrift.

B) Grouping of the radiosonde ascents and the differentiated position of the tropopause.

According to the careful selection I could distinguish thus between the following 6 radiosonde types (Fig. 1 shows for the time interval from Jan. 8 to 13 the mean vertical temperature structure averaged out from each group and for each day):

Group 1 : Radiosonde ascents of the polar cap (ca. 70 - 90° lat.).

These ascents are on the one hand of the marked polar type, which will be defined in the following group 2, on the other hand as it was the case in the period Jan. 8 - 13, 1956 these ascents may be clearly distinguished from the polar type insofar as no sharp tropopause which could definitely be fixed was found and no isothermal structure was present in the stratosphere but rather a further temperature decrease with height so that in the very high stratospheric layers (100 - 30 mb) temperatures lower than -70° C appeared. A continuous transition in the vertical temperature gradient shows somewhat above the 300 mb-level a kind of separation between tropo- and stratosphere. Strong surface inversions or rather high reaching isothermy characterizes the temperature distribution in the lowermost layers. The latter phenomena occur especially with anticyclonic conditions in the polar region, while for cyclonic situations the type described in the following group 2 is present in the polar region (then of course we need not to distinguish these polar cap soundings from the ones in group 2).

Group 2 : Polar ascents north of the position of the polarfront jet until the pole or until about 70° N. In these ascents a clear-cut and two-fold subdivision of the atmosphere in vertical direction is always present; in the troposphere with a vertical temperature decrease, a marked tropopause always lower than 300 mb (about 9 km) and above it an almost isothermal stratosphere. The tropopause height in this space or group is, however, rather variable (it can go down to 500 mb), either in deep polar depressions or above vortices, which are cut-off from the polar space towards south. The mean tropopause height in this group is 320 mb, the mean temperature at the tropopause has a value of - 53.8° ± 5°.

Group 3 : This group contains the so-called middle soundings selected from the space between the position of the polarfront jetstream and that of the subtropical one. This type possesses again a pronounced two-fold structure; however, the tropospheric temperature distribution indicates in all layers a temperature which is about 10° warmer than the corresponding polar one. There is a uniform temperature decrease with height to observe in the troposphere, a well marked tropopause with an average height of about 240 mb (ca. 10.5 km) and a quasi-isothermal stratosphere above. The characteristic average tropopause temperature is $-57.4^{\circ} \pm 4^{\circ}$.

The tropospheric temperature difference between group 2 and 3 indicates in a clear manner that the polarfront (as the main baroclinic zone inside the troposphere) separates these groups and the selection of the ascents north of the polar jetstream, resp. south of it, gives a proof that this meandering wind core of the Westwinddrift goes parallel with a break or a breakline in the tropopause level (see in this connection Fig. 4 and Tab. I, polar tropopause breakline). Stratospheric temperature differences (higher temperature in the north, reversed meridional temperature gradient) between both groups remain in limits of 2 - 3° C; this circumstance will be discussed lateron more in detail.

Group 4 : This group contains sounding types which are sometimes present in the space otherwise occupied by the middle soundings. This special type occurs when the subtropic-tropical system advances towards middle and higher latitudes with a simultaneous meandering behaviour of the subtropical jetstream or at least of a branch of it. These important northward advances will be discussed lateron. This special sounding type has therefore been denoted as subtropical impulse soundings. They are characterized again by a sharp two-fold subdivision in the vertical temperature distribution, however, they show in the total troposphere again higher temperatures as compared with those of the middle group (ca. 4 - 5^0 C). The tropopause in this group is found much higher up near to the 200 mb-level (ca. 12 km) and the typical mean tropopause temperature was computed to - $65.4^0 \pm 3^0$. Also with reference to the stratospheric temperature distribution they differ from the middle ones insofar as in the height interval from 200 - 150 mb appreciably colder temperatures appear (7 - 10^0 C colder, very pronounced temperature gradient directed from north to south). In the higher stratosphere above these ascents are mostly only little colder than the ascents of the middle group. A secondary tropopause break between group 3 and group 4 (between 240 mb and 200 mb) should therefore occur always combined with the existence of a branch of the subtropical jet.

Thus one may immediately understand that inside the troposphere between the spaces containing ascents of group 3 and 4 (middle soundings and subtropical impulse soundings) a further frontal zone should exist which contains, however, a much weaker tropospheric temperature contrast than the polarfront but separates warmer air masses of a mixed type from the pure subtropical warm air. The existence of two kinds of warm air south of the polarfront appears to me essential and the proof of their existence is of fundamental importance.

Since, if an approach of group 4 and the pure polar group 2 occurs and the intermediate group 3 is eliminated, an especially baroclinic polarfront is consequently generated (with about 15^0 temperature difference between the cold and warm side). At the same time in the stratosphere above a sharp baroclinic zone is formed (however, the cold temperature of the upper subtropical troposphere is in the south and relative warm air of the polar stratosphere is in the north) and the steeply inclined tropopause (with an opposite inclination to that of the polarfront) possesses the character of an upper frontal zone. Then a strong jet current with two cores of maximum intensity occurring in different heights (polarfront jetstream and branch of subtropical jet) is concentrated in the angle between both boundary surfaces of opposite inclination. The importance of such transitory generated atmospheric systems will be discussed lateron.

Group 5 : This group contains the so-called <u>subtropical jet soundings</u>, which near to the 30° latitude circle during their vertical flight cross the main current core of the subtropical jetstream or at least close to it. Two marked tropopause levels can be found in these soundings (a lower one near to the 200 mb level (ca. 12 km) and an upper one near to the 100 mb-level (ca. 16 km). In this way the vertical temperature structure in the region near to 30° N falls into three parts:

(a) the troposphere
(b) the 5 km-layer between the two tropopauses and
(c) an upper stratosphere.

The troposphere shows a stratification which is almost similar to that of group 4 and this indicates that in the tropospheric space of such subtropical impulses pure subtropical air moves northward. After the lower tropopause is passed one observes in the intermediate part a weak temperature increase with height and then again a decrease until the second upper tropopause is reached. The stratospheric space above shows definitely a gradual temperature increase with height (no isothermy). The characteristic two-fold tropopause was found in all individual soundings of this group. <u>Just below</u> the lower one in each case an enormously sharp jet peak with a strong positive wind shear below and an even sharper negative one above it was found when the subtropical jet axis was exactly met by the ascent. This form of the subtropical jet stream is characteristic. But also in horizontal direction the subtropical jetstream is a narrow concentrated current, a fact which can often not be concluded from horizontal maps because of the sharpness of the wind maximum in vertical direction.

Group 6 : Subtropical-tropical soundings, south of the position of the subtropical jetstream. In this group again a two-fold subdivision of the vertical temperature distribution can be found, only the separation of tropo- and stratosphere occurs at a high-situated tropopause near 85 mb (ca. 17.5 km). The temperature distribution of the high upward extending troposphere is not uniform but shows near to about 230 mb a change in the vertical temperature gradient which can be taken as some kind of continuation of the lower tropopause described in group 5 towards the south. However, one should not call this phenomenon a tropopause, since the temperature decreases further with height and at first near to 85 mb the pronounced and only tropopause occurs which has an average temperature of $-73.4^{0} \pm 4.5^{0}$. In the stratosphere of this group the temperature above the tropopause increases even more with height as has been the case in group 5.

The structures of the radiosonde ascents contained in group 5 and 6 leave no doubt that in about 30^{0} N an overlaping of two tropopause levels occurs and the continuously assumed decrease of the tropopause level over these latitudes according to elder viewpoints does not exist. Therefore one may define the high situated tropopause level (near to 17 km) as the "tropical tropopause", which lifts its level from the 30^{0} latitude circle gradually towards north and finally disappears. Towards the equator it also lifts somewhat and the tropopause temperature decreases thereby to about -85^{0} C near to the equator. The lower tropopause level which I have denoted as the "middle tropopause" which disappears south of 30^{0} N but can still be found in the vertical temperature gradient of the subtropic-tropical ascents by a kink in the lapse rate, seems to lower therefore its level towards south. The Fig. 1 immediately shows that due to these facts a direct connection exists between the upper part of the tropical troposphere and the stratospheric space of mid-latitudes, which allows a horizontal exchange of air between tropo- and stratospheric spaces. The same also applies to the polar breakline in the tropopause level which occurs parallel with the polarfront jet, however, this is of much less vertical extent than the subtropical break and is also especially of quite another character.

C) Tropopause statistic.

From the total radiosonde material of half a month the tropopause height (in mb) and the tropopause temperature (in ^{o}C) has been taken for each individual sounding and the diagram (Fig. 2) possesses the first one as the vertical and the latter one as the horizontal coordinate. Each radiosonde ascent therefore supplies one point in the diagram, each ascent with a double tropopause two separate points. Five points in the same position are indicated by a small square in the diagram. The point-cloud shows, although the material of about 2500 soundings can not be called a rather extensive material for the purpose of statistics, that in the height interval between 180 and 100 mb only very little points occur. This minimum proves the existence of the subtropical tropopause break and it separates the total point-cloud clearly into two parts (see also the diagram on the right hand side of Fig. 2 which shows a frequency-curve after a horizontal summation of the points for 5 mb-height intervals, 10 mb-intervals resp.). The upper point cloud concerns the tropical tropopause with two preferred heights (85 mb and 100 mb, south of 30^{o} latitude and at 30^{o} lat.). The lower part of the point-cloud concerns the middle and polar tropopause. In this part three preferred heighcs stand out (at 200 mb due to the impulse soundings and the lower tropopause of the subtropical jet soundings, at 240 mb due to the middle soundings and at 320 mb due to the polar ones). A strong reduction in the frequency at about 290 mb indicates the existence of the polar breakline in the tropopause level.

In general the point-cloud of Fig. 2 makes it clear that the tropical tropopause seems to be little dependent on the height, while in the lower part of the point-cloud the compensation principle seems to be well fulfilled (greater heights combined with lower temperature opposite to lower height combined with warm temperature).

Summarizing the results it may also be pointed out that such kind of preparation throws light on the character of the radiosonde ascents, unfolds existing meridional contrasts in temperature at all heights of the tropo- and stratosphere in a rather marked way and finally shows a characteristic and primarily three-fold subdivision of the tropopause level as well also of the sounding type. Especially important, however, appears the proof of a conservative character of the vertical temperature distribution in each of the spaces subdivided naturally by the field of flow and the secondary importance of the dependence of the temperature on the latitude in each of the spaces. Thereby, of course, the general temperature gradient in meridional direction still remains in existence, however, the transitions from one into the other atmospheric space occur much sharper. Such an insight into the complicated three-dimensional structure of the atmospheric temperature field could never have been obtained by means of the so far usually applied method (statistical averaging of the material with respect to latitude). On the contrary, such a working method smoothes the existing important contrasts completely and thereby leads to misinterpretations. The fundamental character of the results obtained by these investigations can be of utmost importance for correct investigations of the General Atmospheric Circulation and for a deeper understanding of it; a circumstance, which I attempt to show in some respect in the following sections. Also for a more realistic formulation of mathematic numerical models of the atmosphere the results appear fundamental.

4) <u>The normal state of the General Atmospheric Circulation in the Northern Hemisphere winter.</u>

Corresponding to the discussion carried on in section 2 about the form of the atmospheric field of flow in the Northern Hemisphere certain types in the form of the polar jetstream may be distinguished concerning the number and the amplitude of the long waves and also the general character of the hemispheric polarfront jetstream. The form of this jet, which can best be investigated by means of horizontal maps of the height interval from 500 to 300 mb shows normally during the winter a generous large-scale meandering character most of the time with three to six long waves of relatively strong amplitude (meridional circulation type). The relatively slow eastward progressing wave patterns (parttime also stationary or even retrograde) cause for an individual meridian such a great variability of the latitudinal position of the polarfront jetstream that it appears impossible to gain an average hemispheric position of this jet. In the long yearly average of upper air charts, of course, mean trough and ridge positions are contained in the average contour lines, however, they fix only statistically preferred regions and the actual position of troughs and ridges of the long waves is still so variable from day to day that they differ widely from the average picture.

With reference to the position of the subtropical jetstream due to its much larger constancy a more permanent form near to 30° latitude all around the earth can be defined as its normal position in winter.

This kind of normal structure of the atmospheric field of motion was first described by <u>Palmén</u> [22] and lateron was pointed to also by the author [5] .

Already preliminary attemps to type the polarfront jet circulation by means of lower level charts (<u>Willett</u> [35]), and also by means of upper air charts (500 - 300 mb, <u>Riehl</u> and coll. [26, 27], <u>Fr. Defant</u> [2 - 5]) have shown that parttime deviations from such a normal state (index changes) occur in such a way that the polarfront jetstream looses at times almost its wave character and takes on a latitudinal position shifted towards the pole having a quasi-zonal flow character. In this way the polarfront jetstream not only performs meandering motions, but rather undergoes as a whole latitudinal displacements. This latter state can then be looked upon as an extreme one (zonal circulation type with reference to the polarfront jetstream). Already in some of my earlier works (Fr. Defant [2 - 4]. I have pointed out that a connection between such index changes of the polarfront jet circulation and the activity at the southern boundary of the Westwind - drift (30° lat.) exists. According to the more recent investigations this viewpoint was strengthened since it could be shown that the subtropical jetstream during such a change of the polarfront jet circulation does not hold its quasi-permanent average position but rather shifts extremely far northward in form of rapid northward displacements (meanders with anticyclonic curvature).

In this way for the meridional circulation type a strongly meandering polarfront jet is combined with a quasi-zonal subtropical jetstream while for a zonal circulation type the opposite characteristics apply to both jet phenomena.

Often, however, the atmospheric circulation is in a transitory phase of change from one into the other circulation type and it is a goal of synoptic meteorology to reveal the complicated machinery of such disturbances of the normal atmospheric state of flow in order to find lateron also reasons of a theoretical nature for this kind of operative mechanism. However, this can only be done when the observational facts are fixed without doubt. With these changes in circulation I will now deal furtheron.

5) The disturbances of the normal state of the General Atmospheric Circulation.

A) Subtropical impulses.

Two of such disturbance periods of the General Circulation have been investigated in detail one of which covers the period from Jan. 1 - 7, 1956 the other one that from Jan. 8 - 13, 1956.

Especially for this purpose constructed hemispheric maps of the tropopause level served thereby as a rather effective means for the diagnosis of the atmospheric state besides the normal preparation of main isobaric surfaces.

Especially with help of a rather deeply penetrating study of tropopause conditions it has been possible to clarify certain important allover atmospheric processes and to picture the hemispheric development of them.

Starting with Jan. 1, 1956 on which day a meridional circulation type in the polarfront jetstream with five long waves was present, I have been able to show that the subtropical jetstream in large parts of the Northern Hemisphere possesses its normal zonal form corresponding to the meandering polarfront jet but over the Atlantic Ocean undergoes an unusual northward displacement (from the Bermuda Islands northward until Iceland). The tropopause map (Fig. 3 A) indicates this fact in a clear manner. Such disturbances in the zonal form of the subtropical jetstream occur preferrably at the boundaries between the continents and oceans (especially south-east coasts of North America and Asia). However, they may also appear elsewhere but then the possibility for their further development seems not to be that favourable (due to mountain barriers, or development over continents instead of oceans a.o.). Such phenomena show first as small deviations from the initially zonal form of the subtropical jet or as corresponding small northward displacements of the subtropical tropopause break. At the same time an increasing warm air advection occurs in the troposphere (pure subtropical air) but in the higher layers the opposite is the case, namely an advection of extremely cold air towards northern latitudes. With the further displacement of the subtropical jet and with a growth of the meander strong anticyclogenesis takes place in the bottom layers a well pronounced ridge of high pressure is formed. The total phenomenon in the following time of development includes more and more space and finally a large part of the subtropical atmosphere looses its connection with its source region and occupies a wide space over middle and higher latitudes (see Fig. 3 B , Westatlantic and Europe). Thereby the subtropical jetstream or a branch of it surrounds the large anticyclonic air body, which in the surface layer shows excessively high pressure values and now reaches upward with closed isobars into the upper atmosphere. The whole anticyclonic space is filled with rather warm air of subtropical type and only near to the high-situated tropopause a layer with extraordinary cold air as some kind of upper cover can be found. The total phenomenon is nothing else as the already in other works often described phenomenon of a "blocking" high which has been interpreted as an instability phenomenon of the polarfront jetstream [1],[25]. I have come to quite another view and the generation and vertical stratification of such a blocking anticyclone indicate without doubt a connection with the subtropical jetstream and its parttime meandering behaviour and can only be related to instability in this current core of the Westwinddrift. It seems to have no relation, whatsoever, to the polarfront jetstream. However, this should not mean that ultimately it has no effect on the form of the polarfront jetstream. On the contrary the formation of such anticyclonic blocks of which in the time interval between Jan. 1 - 7, 1956 several appeared (over the Western Atlantic, over the southern North American Continent, over the Aleuten-Alaska region), had a rather strong effect on the form and structure of the polarfront jetstream, which slowly during the time of generation of these blocks over mid-latitudes lost its normal meandering form, was concentrated towards higher latitudes and took on a more zonal character (zonal circulation type of Jan. 7, 1956). (See Fig. 3 C)

While on Jan. 1, 1956 a clear-cut three-fold subdivision in the atmospheric space in the sense of the foregoing discussion presented in the previous sections was present, (with the exception of the Atlantic region), the space having a middle tropopause has been nearly eliminated on Jan. 7, 1956 and in several regions of the world pure polar air masses stand opposite to pure subtropical ones in small regions over higher latitudes. While previously the polarfront separated spaces with a middle and a polar vertical temperature structure, and since due to the weak meridional contrasts in temperature inside the stratosphere, a stronger disturbance activity did not occur because the subtropical system did not take part in the generation of such disturbances, there are now formed situations in many parts of the world which we have observed as "especially baroclinic" ones inside tropo- and stratosphere by means of the radiosonde material (strongest baroclinicity at the polarfront, double structure of the jets, excessive wind intensity, strong wind shear, steeply inclined tropopause with frontal character oppositely inclined to the polarfront, reversed meridional temperature gradient (from north to south) in the stratosphere).

As I have shown in previous papers (Fr. Defant, [6]) and in more recent ones (Fr. Defant [11]) such vertical structures in the atmosphere according to theoretical ideas (van Mieghem [14], [15]) are by no means in a hydrodynamic equilibrium, and it is very likely that vertical overturning of such atmospheric systems takes place. The existing extreme accumulation of potential energy can be set free during such overturning and after critical conditions in the hydrodynamic equilibrium in isentropic surfaces and also in the static equilibrium are surpassed, the available potential energy is transformed into kinetic energy. The latter one serves then again for an onset of especially strong cyclogenesis and as a consequence motions occure which change the character of the existing zonal circulation type in the polarfront jetstream in large areas drastically. A decisive role will thereby be played by the anticyclonic character of such subtropical impulses since this character favours the occurrence of hydrodynamic instability, especially at the north-eastern edge of the blocking anticyclone.

Such cyclogenesis of especially strong character took place on Jan. 8 and 9 south-west of Iceland with a pressure fall of 62 mb in 24 hours and similar developments occurred in the space between the Aleuten Islands and Alaska in the Northern Pacific. A detailed determination of the places of possible hydrodynamic instability in a vertical cross section oriented in southwestward direction from Iceland just before the onset of the strong cyclogenesis showed that first of all the instability is a consequence mainly of the strong vertical wind shear inside and just above the polarfront surface; secondly a small region in vertical and horizontal direction just south of the polarfront jet core showed critical conditions mainly as a consequence of almost fulfilled inertial instability, in spite of the small baroclinicity there. Both of these places have often been described as the hydrodynamically critical ones. ([18] , [29] , [34] , [22] , [14], [15])

But new and extremely important a third possibility resulted out from these calculations, which is a consequence of the existing upper baroclinicity in such atmospheric systems (cold temperature in the south below the high situated tropical tropopause opposite to relatively warm air of the polar stratosphere in the north). The latter one causes in combination with the srong vertical stability above the tropopause an excessive wind decrease with height. Here in a small height interval between the position of the maximum wind and that of the tropopause a third possibility for strong hydrodynamic instability exists. (It might be stressed in this connection that the maximum wind according to the observations never occurs at the tropopause but rather somewhat below). These three in the vertical one above the other occurring places with hydrodynamic instability in the vicinity of the polarfront jetstream can possibly be looked upon as the cause for the onset of a vertical overturning whereby nearly at the same time the static stability is offset in vertical direction.

Following this development cold polar air spreads out in all heights in the rear of the strongly developing cyclone from the Arctic region southward. Slowly the meandering form of the polarfront jet is reestablished and according to the theory of planetary waves the number and amplitude of the long waves increases with the increase in meridional motion and the simultaneous decrease in the zonal one. The anticyclonic areas (blocks) are slowly destroyed over the mid-latitude belt, the subtropical jetstream takes on again its normal and zonal form near the 30^0 latitude circle and the three-fold subdivision of the atmospheric space is reestablished. It can be understood that strong lateral mixing occurs during this transformation-time in the mid-latitude space and causes a mixed type of air to be formed again between the spaces occupied with pure polar air and that with pure subtropical air. On Jan. 13, 1956 such a normal meridional circulation type similar to that present on Jan. 1 has been reestablished and the subtropical jetstream shows its normal form near 30° lat. (See Fig. 3 D)

A detailed description of both transformation periods must be left to the individual publications (Fr. Defant [8], [10]) ; here only the basic features can be mentioned.

6) Possible explanations of the disturbances of the normal state of the General Atmospheric Circulation.

Laboratory experiments (Fultz [12]) of fluid motions in a rotating dish pan have shown that two entirely different circulation types occur which, as it seems, are generated in the first place by a variation in the meridional temperature difference on the one hand and by variations in the rotational velocity on the other. The first type corresponds to a meridional circulation cell which is superimposed on the general rotation and is strongly influenced by it. It reaches from the center of the dish pan (pole) until the outer rim (equator) (Hadley regime). The second type shows a general meandering zonal flow with a marked jet concentration, whereby the wave number for the total circumference of the dish pan varies with the rotational velocity (Rossby regime). It appears that either the one or the other type occurs according to the experimental conditions present.

Looking again at the above described normal state of the General Atmospheric Circulation then one is guided to similarity considerations in the sense that the flow regime south of about 30° latitude simulates the Hadley regime, most so over the oceans. Only it does not cover as in the experiment the total space equator - pole. On the other hand the flow regime of the general Westwinddrift simulates a Rossby regime with its long waves and its uniformity with height, as well as the polarfront jet concentration. But also here this regime is limited only to the region north of 30^0 lat.

This extraordinary subdivision in regimes in the actual atmosphere can then only be understood if the intensity of rotation (expressed by the Coriolis parameter depending on latitude) is considered. Then it becomes obvious that in the subtropics and tropics with a much smaller effect of the Coriolis force a thermally forced and Hadley regime-form circulation system develops, while in higher latitudes with the much stronger action of the Coriolis force a circulation dominates related to the Rossby regime.

It seems therefore as if the normal state of the atmospheric circulation is in a rather critical and combined circulatory state and small disturbances in the parameters controlling both regimes may possibly cause an extension of the one regime into the region governed by the other and the opposite. The general progress of such disturbances will show a cycle-like character, the duration and intensity of which depends on the parttime intensity of such extensions into the other regime.

Possibly the following processes are fundamental:

(a) If due to instabilities in the polarfront jetstream cyclonic and cold vertical disturbances are cut-off in medium and upper layers or if shallow outflow of polar air occurs towards the low latitudes (breakes in a continuous polarfront around the earth in lower layers), then inside the trade regions the winds will be strengthened together with their turbulent components. As a consequence an increased transport of angular momentum over the northern boundary of the subtropic-tropical circulation cell in the higher layers should occur (see mean considerations of Palmén [21],[23]). [19] Riehl [27].
This is in accordance then with a strengthening of the intensity of the zonal subtropical jet near latitude 30^0 N.

(b) If the wind shear in the vertical wind profile of the so strengthened subtropical jetstream reaches excessive values, then the subtropical jetstream may become hydrodynamically unstable in the region between

(Fr.Defant [11])

the wind maximum and the tropopause (in heights of about 180 mb) due to the strong negative vertical wind shear and inertial oscillation may appear in isentropic surfaces, which for sufficient instability lead to poleward directed and rapidly progressing northward displacements (hyperbolic type) of the subtropical jet (subtropical impulses). In this way then the Hadley regime extends locally its influence into the space of the Rossby regime (preferrably over the southwestern and western parts of the oceans) and leads to considerable disturbances in the regular character of the Rossby regime (transformation of a meridional into a zonal circulation type in the polarfront jetstream). After several such impulses have been active, the Hadley regime will loose its parttime intensification and will then favour an opposite extension of the Rossby regime into the lower latitude space.

(c) The approach of the polarfront jetstream and the subtropical jet over northern latitudes together with the thermal contrasts of the spaces separated by the jet cores and the sloping polarfront surface lead in the following to hydrodynamic instabilities in the flow but now at the polarfront inside the troposphere over northern latitudes as well as just south of the polarfront jet core, and in addition in the tropopause level above. The latter region seems to be especially important (Fr.Defant [11]). A vertical overturning of the unstable stratified atmosphere causes in time especially intensive cyclogenesis and leads to strong southward directed cold outbreaks from the polar region with a simultaneously developing long wave motion in the polarfront jetstream. The latter one looses increasingly its zonal character and the Rossby regime expands in form of a strongly meridional circulation type far towards south. Soon the amplitude in the long waves increases to a stage where the polarfront jet flow itself becomes unstable and then the cycle seems to be closed and leads again back to point (a).

Even if these ideas are only of an approximate and quasi-speculative nature, they seem yet to describe the main features of the complicated three-dimensional mechanism of such oscillatory cycles of the General Atmospheric Circulation. It shall, however, not be forgotten that firstly a possible interaction of the circulation of both hemispheres across the equator can not be excluded and secondly extraterrestrial influences seem to be possible. However, if at all a parttime intensification of the sun radiation has an effect inside the atmospheric space, we have no knowledge where and in what manner such an influence will take its action.

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