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On the occurrence of "Großwetterlagen" in winter related to anomalies in North Atlantic sea temperature

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Summary. In this article, the main results of an investigation concerning the relation between deviating Atlantic sea temperatures and the frequency of occurrence of "Großwetterlagen" in winter are presented. It appeared that blocking systems over North-west Europe more frequently occur if in the northern part of the North Atlantic sea temperatures are higher than normal and in the southern part lower than normal. A positive sea temperature anomaly in the western part of the Atlantic seems to be a favourite condition for the occurrence of atmospheric circulation systems with a trough over Europe.

A tentative interpretation of the obtained results is given. It is concluded that the direct effect of an anomalous heat transfer to the atmosphere, namely an anomalous increase of the vertically averaged air temperature, may account for the results.

Furthermore, as an example, the circulation during the last quarter of 1974 related to the sea temperature anomaly pattern is shortly discussed.

Zusammenfassung. Es wird der Einfluß von Temperaturänderungen des Wassers im Atlantischen Ozean auf die Großwetterlagen im Winter untersucht. Wenn die Wassertemperaturen im nördlichen Teil des atlantischen Ozeans über normal, im südlichen Teil unter normal sind, treten über Nordwesteuropa häufig Blockierungen auf. Positive Abweichungen der Wassertemperatur im westlichen Teil des Atlantiks scheinen die Voraussetzung für Troglagen über Europa zu sein. Es wird der Versuch unternommen, die Ergebnisse unmittelbar aus den Wärmetransport in die Atmosphäre zu erklären, nämlich durch die Änderung der mittleren vertikalen Temperaturverteilung in der Atmosphäre. Zum Abschluß wird die atmosphärische Zirkulation im letzten Vierteljahr 1974 mit den Änderungen der Wassertemperatur besprochen.

1. Introduction

In the atmospheric circulation variations with very different characteristic time-scales, regardless of seasonal influences, occur. In this paper scales of one month or longer will only be dealt with. The investigation concerns the possible effects of Atlantic Sea-surface Temperature Anomalies (STAs) on the atmospheric circulation, mainly in terms of the occurrence of the well-known "Großwetterlagen" (GWLs).

From estimation of the total kinetic energy in the atmosphere, made by several authors, Sawyer [1] concludes that anomalies in the atmospheric circulation, acting on the above-mentioned time-scales, can hardly be explained by the inertial dynamics of the streampattern. Therefore probably other factors, the so-called external factors (like anomalous sensible and latent heat transfer to the atmosphere), play an important role. Changes in heat supply can be caused, for example, by changes in snow cover, variations in the extension of sea ice and deviating soil- and sea-surface temperatures.

Sawyer points out that STAs, covering an area of at least 1000 km across and causing an anomalous heat transport of at least 45 cal cm^{-2} day^{-1} (this is one tenth of the normally out-going long wave radiation), are likely to be the most important external factor.

Namias [2, 3, 4] has written many articles concerning the ocean-atmosphere interaction. One of his important conclusions is that a deviating sea-surface temperature gradient seems to have a steering control on cyclone tracks. It appears that an adjustment of the atmospheric circulation to the sea temperature pattern exists in such a way that the direction of the jetstream is tending to be perpendicular to the sea temperature gradient. He also gives some ideas about possible feed-back mechanisms.

Bjerknes [5, 6] has already devoted a series of articles to the large-scale ocean-atmosphere problem, many of them containing case studies. Bjerknes states that the sea-surface temperature anomalies in the equatorial regions are the most important ones and extend their influence to the westerlies by means of the Hadley-circulation. It seems that a positive sea temperature anomaly in the equatorial region of the Pacific causes a change to more vigorous westerlies over the North Pacific and to a weaker zonal circulation over the North Atlantic.

Ratcliffe and Murray [7] made a very interesting study of sea-level pressure anomalies in relation to STAs occurring in the preceding month. For this purpose they used the STA classification of Ratcliffe [8]. In principle this classification is a monthly one and consists of mainly two classes. The region south and east of New Foundland, bounded by the 40 °N and 50 °N parallels and the 40 °W and 60 °W meridians, is the key area for the first class. If in this region a positive or negative anomaly of at least 1 °C is present, the STA is classified as WP (Warm

Pool) or CP (Cold Pool) respectively. On the other hand, if a positive anomaly in the northern part of the North Atlantic exists (say at latitudes higher than 50 °N) and in the southern part a negative one, the STA is called DZ (Decreased Zonality) in contrast with EZ (Enhanced Zonality), which describes the reverse situation. For several months Ratcliffe and Murray computed sea-level pressures averaged over the cases in which in the preceding month the same STA (WP or CP) had occurred. The investigated period was 1888—1968, except for some years when no maps were available. The most interesting results were:

a) In the case of WP, over North Russia a positive pressure anomaly is present and over western Europe a negative one.

b) In the case of CP, over the "Azores region" a negative pressure anomaly is present and over North-west-Europe a positive one.

c) The maximum anomalies range from 2 to 9 mb and are often significant at the 5%-level. The positions of the anomaly centers are somewhat different in different months.

In an article written by Lamb and Ratcliffe [9] interesting results of Vinogradov and Semenov are mentioned. Vinogradov studied the relation between the occurrence of STAs in May and the character of the following summers over the period 1890—1960. Warmer-than-normal summers in northern Europe have often been associated with a positive STA north of 50 °N. Summers with temperatures below average tended to follow Mays with subnormal sea temperatures in the northern and higher-than-normal sea temperatures in the southern part of the North Atlantic. Semenov found that in years with an increased sea temperature gradient in meridional direction the region of strong cyclonic activity over the North Atlantic was displaced to the north. This result was based on data for the period 1889—1939. Reference to the original articles (in Russian) can be found in [9].

A monthly mean sea-level pressure anomaly can be caused by very different series of GWLs. Furthermore, each GWL can be associated with a characteristic 500 mb streampattern, as is demonstrated by Van Dijk et al. [10]. With this in mind, the relation between STAs and the occurrence of GWLs in winter was investigated, as will be described in the third section.

2. The origin of the STAs

In general, STAs in the North Atlantic show a great persistence (of the order of three months) and represent a great anomaly in heat content. In winter they are better defined than in summer. Due to the radiation, received by the sea-surface, in the warm season a thin surface layer of warm water can be built up in a relative short time. In fall, when surface winds get stronger, a (nearly isothermal) mixed-layer develops. In spring the STA pattern becomes often more chaotic.

The features creating STAs are mainly anomalies in the mass transport in the Ekman-layer of the ocean, in upwelling due to a changed divergence field of the horizontal mass transport, in heat transfer to the atmosphere, in the thickness of the mixed-layer and in the net radiation received by the sea-surface. Since, in the Ekman-layer of the ocean, the mass transport is directed to the right of the wind stress vector, a positive vorticity of the wind stress field will cause a divergent flow (and, as a consequence, upwelling) and a negative vorticity convergent flow.

The relative importance of the mentioned different causes depends on the local climatological situation. In winter, over the North Atlantic variations in the net radiation are comparative small. As indicated by Sawyer [1] and Namias [3], deviating heat transfer to the atmosphere is not very effective in creating STAs. Some evidence exists that anomalous upwelling (or "downwelling") and advection in the Ekman-layer are the most important factors. Maximov et al. [11] have shown that in the North Atlantic a correlation between long-term planetary (tidal) forces and the occurrence of STAs exists.

All the mentioned processes are closely related to the circulation in the atmosphere. Every STA affecting this circulation will therefore induce feed-back mechanisms, which make a theoretical approach of the long-term air-sea interaction very difficult. Anyway, it can be stated that the response of the ocean acts on a much greater time-scale than the response of the atmosphere does.

3. Method and results

Concerning the STAs, the above-described classification of Ratcliffe [8] has been used. Furthermore, use has been made of 500 mb topographies related to the GWLs of Van Dijk et al. [10] and the classification of the daily circulation types by Hess and Brezowsky [12]. As has been done in [7], a time-lag of one month has been assumed. The investigated period was 1881—1972.

On the basis of the 500 mb topographies (which extend from 100 °W to 60 °E), the GWLs were divided into ten groups G_i, $i = 1, \ldots, 10$. The groups have been chosen in such a way that the locations of the ridge(s) and trough(s) of the GWLs within one group approximately coincide. The groups are:

G_1 : TRW, TRM, TM, Nz.	G_6 : HFz/a, SEa, WW.
G_2 : NWz, NE, Na.	G_7 : Sz/a, SEz.
G_3 : TB, SWz.	G_8 : HM, SWa.
G_4 : HNFz/a, HNz/a.	G_9 : WS, Wz.
G_5 : NWa, HB.	G_{10}: BM, Wa.

As an example, Fig. 1a, b, c, d shows the mean 500 mb topographies (winter) of the GWLs forming G_1. The through-ridge-trough system with the ridge over the North Atlantic is typical for the GWLs of this group. Then for every G_i a criterion C_i was fixed. A month satisfies C_i if the total number of days, classified with a

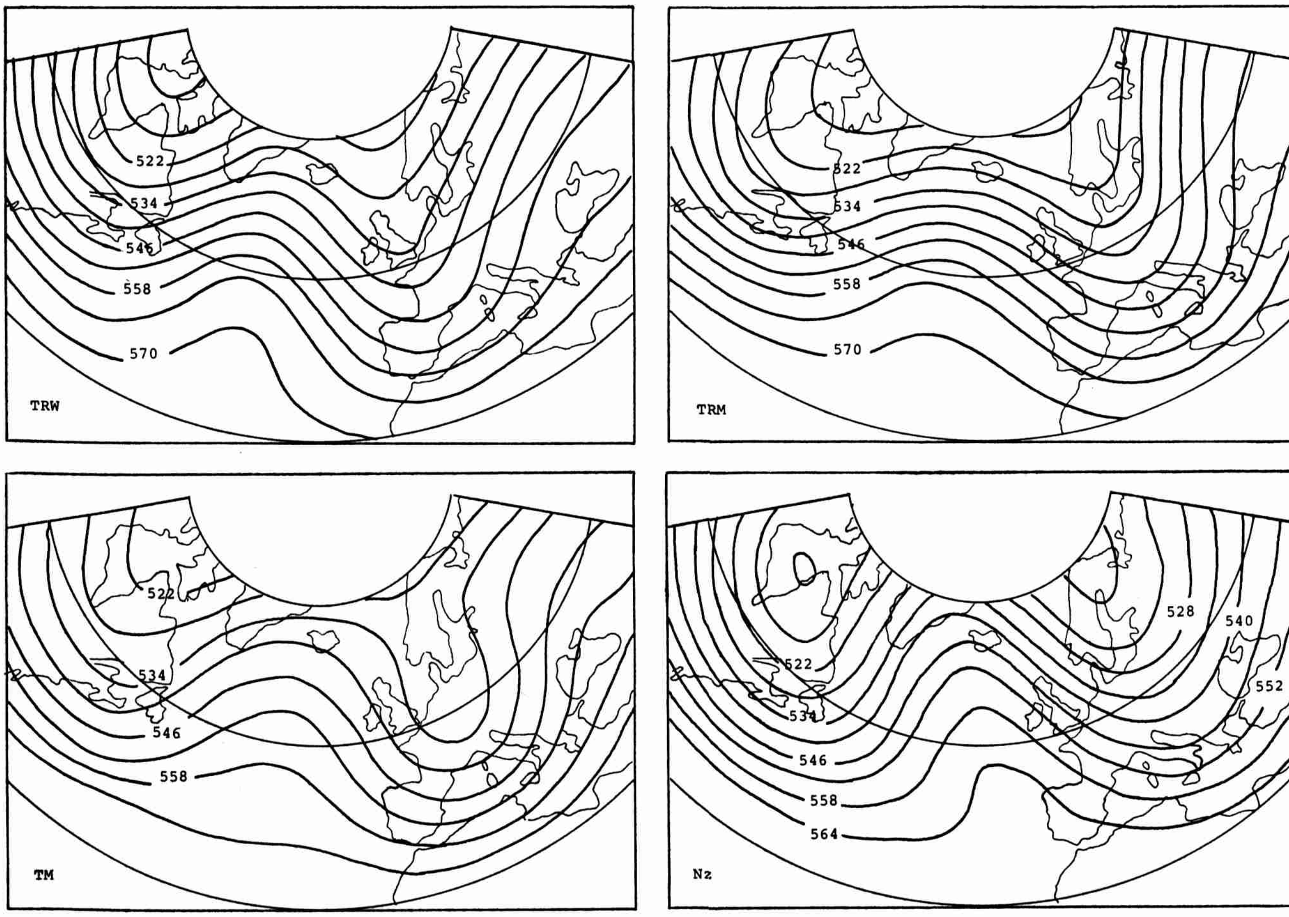

Fig. 1. Mean topographies of the 500 mb level in geopot. decametres for the GWLs TRW, TRM, TM and Nz (winter), forming G_1 (after Van Dijk et al. [10]).

GWL from G_i, is equal to or greater than some c_i; c_i was chosen in such a way that not more than one third of all months fulfils C_i.

In the following, an underlined variable is considered to be stochastic. The same character without bar denotes a realization of that stochastic variable.

Let the number of times that C_i was satisfied be denoted by n_i, the "climatological chance" on Q (a STA) in the preceding month by P(Q) and the number of times that in the preceding month a STA Q was found out of the n_i cases by $\underline{N}_i$ (Q).

Then it can be written:

$$E(\underline{N}_i(Q)) = n_i \cdot P(Q)$$

where E denotes the expectation under the hypothesis that no correlation between the appearance of Q and the fulfilment of C_i exists. The deviation $\underline{A}_i(Q)$ from the expected value of $\underline{N}_i(Q)$ is:

$$\underline{A}_i(Q) = \underline{N}_i(Q) - n_i \cdot P(Q)$$

If $A_i(Q)$ is positive it is likely that the occurrence of Q favours the appearance of GWLs belonging to G_i. Negative values of $A_i(Q)$ indicate that the frequency of occurrence of these GWLs tends to be smaller than normal after the presence of Q.

In order to avoid that very extreme months should have too much influence on the final results, a method with a criterion as described above was applied.

For the months December, January and February A_i (Q) was computed for Q = WP, CP, EZ, DZ and i = 1, . . ., 10. The influence of WP appeared to be approximately the reverse of the influence of CP. The same was concluded for EZ and DZ. The results were suggesting that the effects of a STA on the atmospheric circulation are roughly the same in the individual winter months. Accepting this to be true, the months were put together, forming one collection. Now the following relations can be defined:

$$\underline{X}_i = \underline{N}_i(WP) - \underline{N}_i(CP) - n_i \cdot (P(WP) - P(CP))$$

$$\underline{Y}_i = \underline{N}_i(DZ) - \underline{N}_i(EZ) - n_i \cdot (P(DZ) - P(EZ))$$

P, n_i and $N_i(Q)$ referring to the whole collection of 276 months. A positive value of X_i indicates that after the occurrence of WP the probability of occurrence of GWLs belonging to G_i is greater than after CP. For negative values of X_i the reverse holds. In the same way, Y_i is a measure of the influence of DZ compared with that of EZ. Table 1 shows the results; $K_i = N_i(WP) + N_i(CP)$ and $L_i = N_i(DZ) + N_i(EZ)$. The probabilities for the occurrence of the various anomalies in sea temperatures are: P(WP) = 72/276, P(CP) = 63/276, P(DZ) = 39/276

Table 1. *Main results (see text).*

	c_i	n_i	X_i	K_i	Y_i	L_i
G_1 (TRW, TRM, TM, Nz)	5	71	*+14.8*	39	+1.5	11
G_2 (NWz, NE, Na)	5	56	+5.3	33	+3.7	12
G_3 (TB, SWz)	2	60	+4.2	30	+1.3	14
G_4 (HNFz/a, HNz/a)	2	71	+4.8	35	*+8.5*	14
G_5 (NWa, HB)	3	86	—4.6	40	+0.3	17
G_6 (HFz/a, SEa, WW)	5	74	*—11.2*	35	*+7.4*	19
G_7 (Sz/a, SEz)	4	66	+3.0	35	—2.1	17
G_8 (HM, SWa)	8	66	*—12.0*	32	—1.1	12
G_9 (WS, Wz)	10	71	+5.8	36	*—9.5*	8
G_{10} (BM, Wa)	5	80	+0.6	35	—1.2	15

and P(EZ) = 19/276.

Considering the occurrence of the STAs of one class to be mutually independent and assuming that the appearance of a STA does not depend on the preceding STAs of the same kind (since the period between the occurrence of two STAs of the same kind in the series is mostly about a year or longer), the hypothesis $E(\overline{X_i}) = 0$ or $E(\overline{Y_i}) = 0$ can be tested against $E(\overline{X_i}) \neq 0$ or $E(\overline{Y_i}) \neq 0$ respectively. In Table 1, values of $\overline{X_i}$ and $\overline{Y_i}$ rejecting $E(\overline{X_i}) = 0$ or $E(\overline{Y_i}) = 0$ with a confidence coefficient greater than 0.95 are in italics. Since in computing the climatological probability of a STA all months have been used (so also the months which fulfilled C_i), the significance of the final results will have been suppressed.

4. Discussion of the results

In the following, ridges and troughs refer to the 500 mb level.

A ridge over the North Atlantic is typical for the groups G_1, G_2, G_3 and G_4. GWLs belonging to G_1 show a ridge south of Greenland. Up to G_4 this ridge is gradually shifted to the east. In the case of G_4 the ridge is already situated over the Norwegian Sea and Scandinavia. Table 1 shows that after WP and DZ these groups occur more often than after CP and EZ. When the ridge is situated more eastward, the influence of CP and WP is tending to decrease and the effect of DZ and EZ to increase. After CP and DZ, GWLs characterized by a ridge over Scandinavia and a trough south of Greenland (G_6) more often occur.

The just-mentioned results suggest the following conclusion: *a region with a positive or negative STA favours the occurrence of a ridge or trough respectively, situated east of the STA region.*

In the case of G_8 a wide trough over the Atlantic is present, while over western Europe a ridge has been built up. CP appears to be the favourite condition for the occurrence of HM and SWa. This agrees with the abovemade suggestion. Compared with the groups 1 to 6, the ridge has been shifted to the south. As a consequence, the influence of EZ and DZ on G_8 is small.

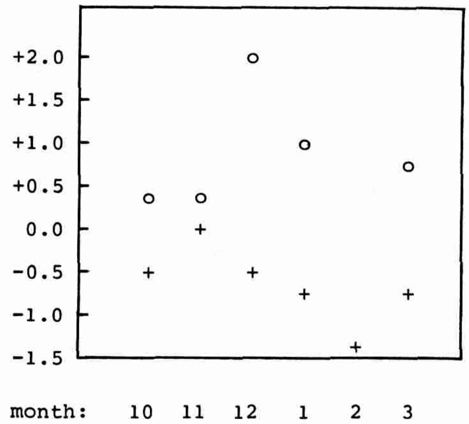

Fig. 2. Monthly air temperature anomalies at De Bilt in °C after EZ (0) and DZ (+) in the preceding month. In January, no EZ occurred.

After EZ, atmospheric circulations of the westerly type (G_9) occur more frequently than after DZ. However, since $L_9 = 8$ and $E(L_9) = 15$, it cannot be concluded that the existence of EZ is a better condition for the occurrence of westerly types than situations without an anomaly in the "zonality" of the Atlantic sea temperatures.

From Table 1 it follows that in winter after DZ the chance on a blocking system over North-west Europe is considerably greater than after EZ.

In addition it should be noted that after the 39 cases in which DZ occurred G_4 was fulfilled 14 times, after the 19 cases with EZ not one time. Since in winter these blocking highs cause low temperatures in western Europe, the effects of EZ and DZ can be demonstrated by air temperatures at De Bilt. Fig. 2 shows anomalies of the monthly temperatures, averaged over the cases with DZ or EZ in the preceding month. Clearly, DZ is associated with temperatures below and EZ with temperatures above normal.

A striking example is February 1956. At the end of December 1955 a DZ situation started to develop and lasted for several months. In consequence of the persistent occurrence of circulation types from G_4 and G_6, in the Netherlands this February became the coldest month of the century till now.

5. Physical interpretation of the results

In spite of the complexity of the ocean-atmosphere interaction, the results obtained in this investigation can be made plausible in a rather easy way.

If the air above the sea-surface is in nearly neutral equilibrium, the fluxes of sensible heat (S) and latent heat (L) can be given by (see e.g. Kraus [13]):

$$S = C_1 \cdot U \cdot (T_s - T_a) \text{ and } L = C_2 \cdot U \cdot (q_s - q_a)$$

where U is wind speed, T_s and T_a are the temperatures of the water and the air respectively, q_s and q_a are the specific humidities at the sea-surface and of the air. C_1 and C_2 are constants depending on the height at which

U, T_a and q_a are measured. A positive STA causes a greater-than-normal heat transfer to the atmosphere resulting in an anomalous increase of the vertically averaged temperature of an overlying air-mass, as long as this air-mass stays over the STA region. Is should be noted that an anomalous latent heat flux will only affect the mean temperature of an air-mass in regions where condensation takes place. These regions may be (far) behind the STA region (in downstream direction). Anyway, it can be stated that in general the total anomalous thickness increase will reach a maximum somewhere behind the STA region. Therefore, a positive STA favours the occurrence of circulation types with an upper ridge situated east of the STA region. In the same way, a negative STA will cause a tendency to a more frequently occurrence of types with an upper trough east of the STA region.

Rapidly moving air-masses are exposed only for a short time to the anomalous heat flux. However, since in such cases surface winds often are strong, this anomalous heat flux will be large. Stated in another way: due to the correlation between the wind speed at the sea-surface and the displacement of the associated air-mass, the "U-dependency" of the total heat transfer during some period will be reduced. Therefore, the total anomalous amount of heat, gained by an air-mass just leaving the STA region, is more affected by the air sea temperature difference than by the wind speed U.

In winter, the heat flux to the atmosphere is negative over the northern part of the North American continent. Over the northern Atlantic (say at latitudes higher than 40 °N), however, the climatological value of T_s—T_a is positive and decreases rapidly towards the east. This implies that in the eastern part of the North Atlantic the relative effect of a STA (of constant magnitude) on the upward heat flux is much greater than in the western part. In spite of the fact that deviating sea temperatures seem to have an influence on the development of cyclones, regions with strong cyclogenesis (like the New Foundland region) are not necessarily key areas for the influence of STAs on the large-scale atmospheric circulation.

As already discussed, the large-scale thickness pattern over the North Atlantic will be related to the occurrence of STAs. Of course, this indirectly affects the development of cyclones. More important, however, is the resulting steering control on the tracks of the cyclones.

The reasoning, presented above, is very crude. In fact it is too simple to consider the circulation over the North Atlantic as consisting of air-masses which just travel eastward. A detailed study, however, seems to require the aid of advanced numerical models.

6. A recent example

The circulation during the last quarter of 1974, exceptional as it was over many areas of Europe, provides a fair example.

Fig. 3 shows the anomalies of the 500—1000 mb thickness for October and the sea temperature anomalies for the period 23/9 to 17/10. Relative low sea temperatures are found in the central and eastern part of the North Atlantic while over Europe a pronounced negative thickness anomaly is present. East of the warmer-than-normal sea at the American east-coast a positive thickness anomaly appears.

During November the negative STA was displaced to the north-west, while in the south-eastern part of the North Atlantic a relative warming took place. Fig. 4 shows that for December in the whole region bounded by 50 °N and 30 °N and the continental coast-lines sea temperatures were above normal. In agreement with the remarks, made in section 5, over Europe a positive thickness anomaly appeared. During December and January a positive pressure anomaly was often present over South-west Europe, causing severe drought in Spain and high temperatures in North-west Europe.

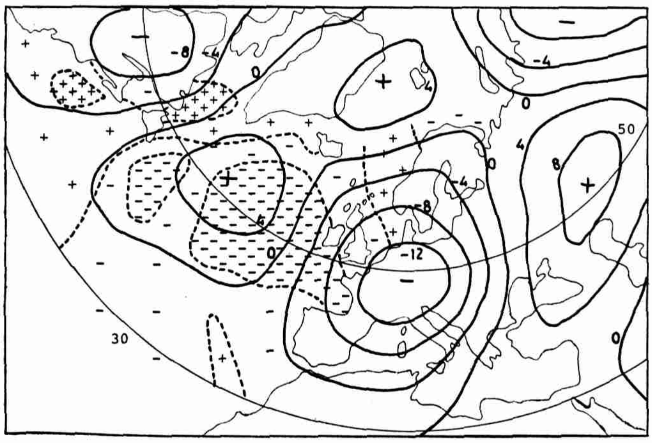

Fig. 3. Deviations from normal of the 500—1000 mb thickness for October 1974 in geopot. decametres (full lines). Sign of the sea temperature anomalies for the period 23/9 to 17/10 1974 (after Ratcliffe). Anomalies exceeding 1 °C are indicated by closely filled up areas.

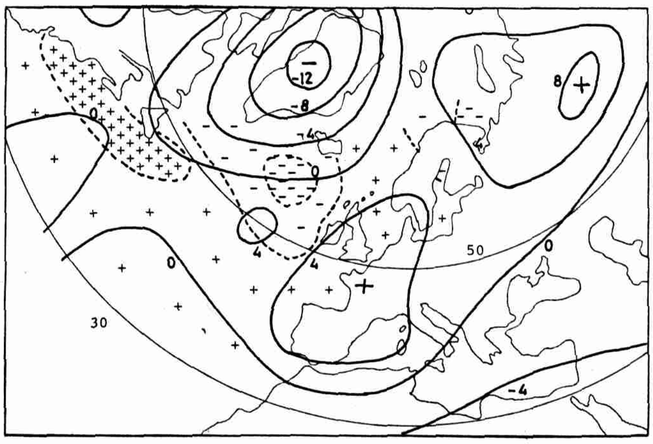

Fig. 4. Deviations from normal of the 500—1000 mb thickness for Dec. 1974 in geopot. decametres (full lines). Sign of the sea temperature anomalies for Dec. 1974 (after Ratcliffe). Anomalies exceeding 1 °C are indicated by closely filled up areas.

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Mittlere, wetterlagenabhängige Z/R-Beziehungen für Hohenpeißenberg

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Hohenpeißenberg

Zusammenfassung. Das 3jährige (Sommer 1972 bis 1974) Meßmaterial von Regentropfenspektren (rund 58000 1-Minuten-Spektren) wird zunächst kritisch überprüft. Für die Niederschläge von einigen, für Hohenpeißenberg charakteristischen Wetterlagentypen werden dann mittlere Z/R-Beziehungen berechnet und ihre Unterschiede diskutiert.

Abstract. The measured quantity of raindrop size distributions during the summerperiods 1972—1974 (about 58000 one-minute spectra) is checked critically. Average Z/R relations are evaluated for precipitations of some different, for Hohenpeissenberg characteristic weather types and their deviations discussed.

1. Einleitung

Bei der praktischen Durchführung der quantitativen Flächenniederschlagsmessung mittels Radar (z.B. [1]) ist zur Umrechnung der gemessenen Radarechostärke in Niederschlag mit der sog. Radargleichung u.a. die Kenntnis der Radarreflektivität(Z) -Niederschlag(R) -Beziehung für jedes Niederschlagsereignis von wesentlicher Bedeutung. In Deutschland hat Diem [2] als erster auf den großen Schwankungsbereich dieser Z/R-Beziehung sowohl in zeitlicher als auch in räumlicher Hinsicht hingewiesen. Zusammen mit seinen Mitarbeitern (z.B. [3]) konnte gezeigt werden, daß die häufig verwendete Marshall-Palmer-Formel [4] zur Beschreibung von Regentropfenspektren keine Verallgemeinerung für alle Regenarten zuläßt. Der direkte Rückgriff auf unmittelbar gemessene Tropfenspektren ist zwar bei Radarmessungen im Forschungsbetrieb möglich, erscheint jedoch im praktischen Routinebetrieb schwer realisierbar zu sein. Ein relativ neues, automatisch arbeitendes System, Distrometer RD 69 nach Joss und Waldvogel [5], erlaubt seit wenigen Jahren die kontinuierliche Messung und Auswertung von Tropfenspektren und damit die Verarbeitung eines sehr umfangreichen Materials. Die Auf-