Single Station Climatology of Central European Fronts: Number, Time and Precipitation Statistics

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Abstract:
A single station time series of fronts and occlusions passing Berlin is evaluated to provide number, duration and precipitation statistics. The results refer to the basic synoptic episodes of occlusions, warmsector and fronts, warm and cold fronts, which lead to a single station composite cyclone. This composite cyclone is related to standard circulation analyses of midlatitude disturbances representative for the central European climate. About half of the wet composite cyclones (14 in summer, 17 in winter) producing more than 2 mm water yield per occurrence contribute about 70 % of the total seasonal precipitation; i.e. about 10 mm per summer and 5 mm per winter cyclone. The related distributions are comparable with tropical rain systems forced by midlatitude troughs.

Zusammenfassung: Eine Stationsklimatologie mitteleuropäischer Fronten: Anzahl, Dauer und Niederschlagsstatistiken.
Aus einer Berliner Zeitreihe der Fronten und Okklusionen werden Statistiken von ihrer Anzahl und Dauer sowie vom Niederschlag erstellt. Die Ergebnisse werden zu den synoptischen Episoden Okklusionen, Warmsektor und Fronten, Warm- und Kaltfronten zusammengefaßt, um eine stationsbezogene „composite"-Zyklone zu definieren. Die Ergebnisse für diese Zyklone werden verglichen mit der Zirkulationsstatistik von Störungen in den mittleren Breiten, die repräsentativ für das Klima von Mitteleuropa sind. Etwa die Hälfte der „composite"-Zyklonen mit Niederschlag (14 im Sommer, 17 im Winter) bringen mehr als 2 mm pro Ereignis; sie liefern etwa 70 % des gesamten Niederschlags einer Jahreszeit (d. h. ca. 10 mm pro Zyklone im Sommer, 5 mm im Winter). Die dazugehörigen statistischen Verteilungen sind vergleichbar mit tropischen Niederschlagssystemen, die von den Trögen der mittleren Breiten ausgelöst werden.

Résumé: Climatologie des fronts d'Europe Centrale à partir d'une seule station: statistique du nombre, de la durée et des précipitations.
On analyse une série temporelle de fronts et d'occlusions en la seule station de Berlin pour obtenir une statistique de leur nombre, de leur durée et des précipitations. Les résultats se rapportent aux épisodes synoptiques fondamantaux d'un cyclone: occlusion, front et secteur chauds, fronts chaud et froid tels qu'ils peuvent être identifiés en une seule station. Ce cyclone composite est rattaché aux analyses standard des perturbations des latitudes moyennes représentatives du climat d'Europe Centrale. Environ la motié des cyclones précipitants, produisant plus de 2 mm d'eau, contribuent pour 70 % des précipitations totales saisonnières soit, par cyclone, approximativement 10 mm en été et 5 mm en hiver. Les distributions associées sont comparables à celles des pluies tropicales engendrées par des creux des latitudes moyennes.

1 Introduction

Standard atmospheric circulation statistics provide information of means, covariances and, occasionally, space-time filtered or cross-spectral properties of the basic physical state variables: mean temperatures, eddy heat fluxes, energy conversions in appropriate space-time or wavenumber frequency

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domains, etc.. In this sense bulk properties of the underlying weather processes define climate. Another type of circulation statistics is more closely related to the real weather phenomena: storm tracks of tropical and extratropical cyclones, regional cyclone frequency distributions depending on their life cycle, the number distribution of storms contributing to the rainfall, etc.. This leads to a phenomenological circulation statistics which accounts for the individual weather processes and leads also to the observed climate of a particular area. The phenomenological circulation analysis in this note contributes to a description of the climate of the central European continent. A single station climatology of fronts and frontal cyclones at Berlin is evaluated in terms of their seasonal number, duration, and precipitation statistics.

2 Data, analysis and climatological setting

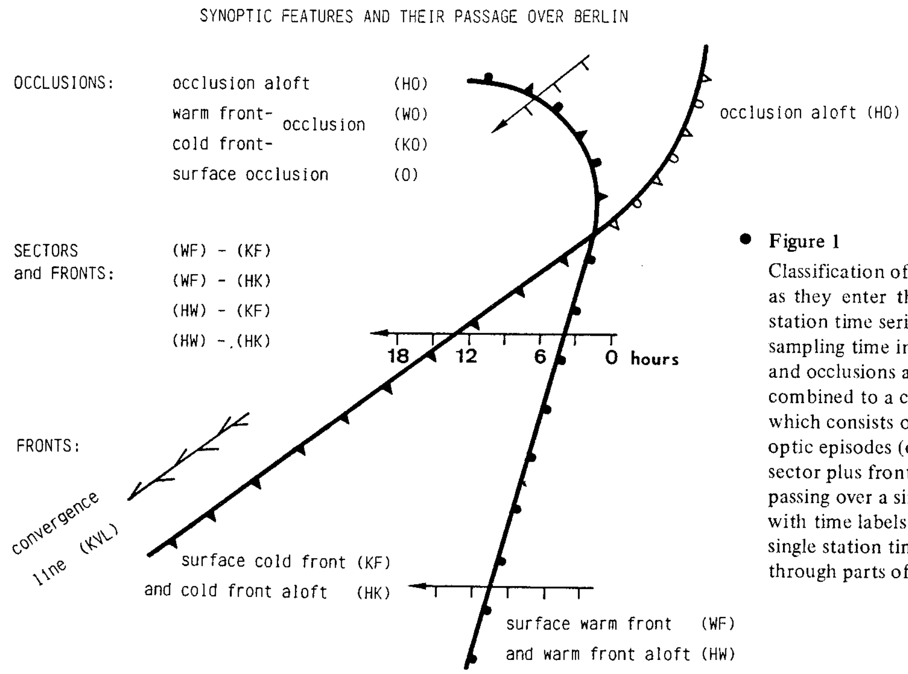
Since 1953 frontal passages and airmasses over Berlin are classified in real time by eight daily observations of three-hourly periods (Berliner Wetterkarte 1953). Since 1969 this data set has been checked (a posteriori) and is available on tape: the present analysis is confined to the period 1969 to 1982. The fundamental definitions of fronts and airmasses, which form the basis of this observational record, can be found elsewhere (SCHERHAG,1948; GEB, 1971). They include both the temperature and motion fields to account for the relevant temperature advection. Characteristic properties of fronts are a cross-sectional length-scale of 50–200 km, a temperature gradient $\geqslant 3$ K/100 km and a pseudopotential temperature gradient $\geqslant 5$ K/100 km deduced from regional weather maps. In the following only a brief review of the underlying and applied concepts is given, which are based on both local observations and the analyses of regional weather maps.

Fronts and occlusions: The time series consists of successive sampling time intervals of fixed duration of $\Delta t = 3$ hours. Each interval Δ t is classified by one of the following synoptic patterns: fronts, occlusions and airmass. The classification of these basic synoptic features is extended, but airmasses will not be investigated in this note: Besides surface warm and cold fronts (WF, KF) and occlusions (O) there are warm and cold fronts in upper levels (HW, HK), warm and cold front occlusions (WO, KO), and upper level occlusions (HO) which are realized by surface convergence and temperature changes in upper levels. Convergence lines (KVL) are also treated; they characterize minor instabilities or mesoscale systems of the surface weather map and cover only a single three-hourly time interval embedded in airmass properties. A three-hourly time interval is labelled front or occlusion period, if the significant and often sharp temperature change (which is related to the arrival or passage of a front or occlusion) falls into the fixed $\Delta t = 3$ h sampling time interval, although the meteorological process may be of shorter duration. Furthermore, there are 3 hourly time intervals labelled front or occlusion layers; they precede (e.g. warm fronts), follow (e.g. cold fronts) or even appear without connection to the 3 hourly front or occlusion period. These layer periods are characterized by slow or gradual changes of temperature (and other relevant weather variables, e.g. precipitation) in time; they may not necessarily be connected with a sharp local change, but with slowly moving systems.

An *event* or synoptic episode is defined by a sequence of 3 hourly time intervals occupied by a front or occlusion period plus the related layer periods; or by a sequence of layer periods alone, if a sharp local change does not occur. One event is separated from another by airmass properties occupying at least one time interval of $\Delta t = 3$ h. Its *duration* is the sum of all connected frontal and/or frontal layer periods. Its *water yield* is the precipitation accumulated during the whole event (or synoptic episode) plus the preceding and following 3 hourly time intervals (labelled airmass) to include all forerunning or following cloud systems.

Sectors and fronts: Sectors also belong to frontal cyclones; they occur between an advancing warm front and the following cold front before an occlusion process sets in. Episodes "sector and fronts" are defined by the airmass properties of the warm sector and the related adjacent frontal and frontal layer periods of warm and cold fronts. This episode "sector and fronts" includes suitable combinations of fronts, which consist of warm fronts or warm fronts aloft followed by cold fronts or cold fronts aloft. As only sector and fronts of the same frontal cyclone are admitted, the single station data set needs careful control by observations documented in the regional weather maps (Berliner Wetterkarte). This check allows exclusion of the occasional direct transition from the warm front of one cyclone to the cold front of the preceeding one. In such cases frontal episodes are distinguished and counted separately deleting the sector properties. Again, for precipitation (but not duration) statistics of the event "sector and fronts" we add the two adjacent three-hourly airmass periods ahead of the warm front and following the cold front.

Composite cyclone: Fronts and occlusions can be suitably combined to a single station composite cyclone, which is representative for the area of Berlin. Its dominant features are the occlusion, the warm sector with its fronts, the warm or the cold front (Figure 1). Single stations realize the passage of frontal cyclones by traverses through different regions of the system and by their various stages of development; i.e. local realizations depend on the direction of the passing system, its distance from Berlin and its life cycle. Particularly the state of maturity effects the number statistic of composite cyclones. Thus the total number of composite cyclones effecting Central Europe is the sum over the three basic synoptic episodes: front, occlusion, and warm sector plus fronts. However, the full amount of the locally observed occlusions may not necessarily add completely to the total number of composite cyclones representative for the Berlin area, but leads to an estimate of the upper limit. This is due to "bent back occlusions" following cold and warm fronts which belong to the same system; i.e. occlusions are incorporated into the fast rotating center of the maturing cyclonic vortex and, occasionally, reappear on the rear side of the system. **Summarizing:** This composite cyclone is a single station process and may not be mistaken with the classical Norwegian cyclone. It combines all synoptic episodes in time



- **Figure 1**

Classification of synoptic patterns as they enter the Berlin single station time series of Δt = 3 hours sampling time intervals. The fronts and occlusions are schematically combined to a composite cyclone which consists of three basic synoptic episodes (occlusions, warm sector plus fronts, and fronts) passing over a single station. Arrows with time labels are examples of single station time trajectories through parts of the system.

and thus defines a probability process for a single station providing probability estimates for the occurrence and preferred traverse of various synoptic episodes: fronts, warm sectors plus fronts, and occlusions. The related number, duration and precipitation statistics quantify the weather processes (in terms of a composite cyclone), which contribute one part to the climate time-statistics of the station. The other part consists of those remaining time intervals ($\Delta t = 3$ h), which are classified as airmasses (the warm sectors are excepted because they are considered as part of the composite cyclone). In this sense the composite cyclone appears as a stochastic point process (e.g. COX and ISHAM, 1980) which defines the climatological setting of the Berlin and Central European frontal weather in terms of a phenomenological circulation statistic. The composite cyclone is introduced to allow a comparison between phenomenological and standard circulation statistics (see following subsection and sections).

Climatological setting from standard circulation statistics: The western part of the European continent in mid-latitudes lies downstream from the major jet core over the Atlantic. Berlin (52 °N, 13 °E) appears to be representative for this region as revealed by the atmospheric dynamical structures deduced from cross-spectral rawinsonde analyses (FRAEDRICH et al., 1979). The zonal flow and its shear is weaker than in the corresponding eastern parts of continents. The upper troposphere is characterized by a southward eddy flux of sensible heat, whereas the eddy heat transport in the lower troposphere (and stratosphere) is poleward; but the eddy flux of geopotential energy is equatorward throughout the troposphere. The atmospheric processes leading to these (variations and) eddy transports are well represented in the frequency domain by three spectral peaks at short (< 5 days), long (5 to 10 days), and ultra-long (> 10 days) periods. They arrange themselves in an index-cycle (ultra-long period) of an active and inactive phase; the period of synoptic activity is locally realized by slowly progressive long period waves steering ensembles of short period disturbances (i.e. frontal cyclones), which are more mature in the western part of the continents than over the oceans, where they originate. Thus, the observed flux patterns of sensible heat represent an indirect (energy consuming) eddy circulation over the western parts of the continents, which is produced by mature cyclones; i.e. short period disturbances or frontal cyclones which, like clouds, undergo a life cycle, are the basic elements producing the observed eddy transport structures. A synoptically more quiet or inactive phase follows the period of activity of the ultra-long index cycle.

In the following sections an essentially phenomenological circulation statistic is deduced for frontal cyclones which fulfill the required eddy transports at Berlin. It is based on the conventional summer and winter seasons (1 May to 31 August, 1 December to 28 February) of the period 1969 to 1982. As diurnal variations have been discussed elsewhere (DRONIA, 1965; FREUER, 1981), they are not considered here.

3 Number statistics

The statistics is deduced from a total of 740 (665) fronts, occlusions, and convergence lines at Berlin, which occurred during 13 summer (12 winter) seasons. The number of synoptic episodes, $RR \geqslant 0$, is determined (as schematically defined in Section 2, Figure 1) separating dry, $RR = 0$, from precipitating events, $RR > 0$. Furthermore, rainfall efficient episodes $RR \geqslant 2.0$, cumulating more than 2 mm are also counted. Results are presented in terms of seasonal means, standard deviations, and extrema; wet and dry categories are also distinguished (Table 1).

Composite cyclone: From the synoptic features (see Table 1, but convergence lines, KVL, are excluded) one can estimate the mean total number, $N(RR \geqslant 0)$, of the composite cyclones (defined in Section 2, Figure 1) and the contribution from dry, $N(RR = 0)$, and wet, $N(RR > 0)$, events; symbolically written as $N(RR \geqslant 0) = N(RR = 0) + N(RR > 0)$: There are forty to fifty composite cyclones in both summer ($46.7 = 20.2 + 26.5$) and winter seasons ($47.7 = 14.6 + 33.1$); i.e. alsmost one every second to third day. But only 27 in summer (33 in winter) precipitate; i.e. one every third day. Even less, 14 in

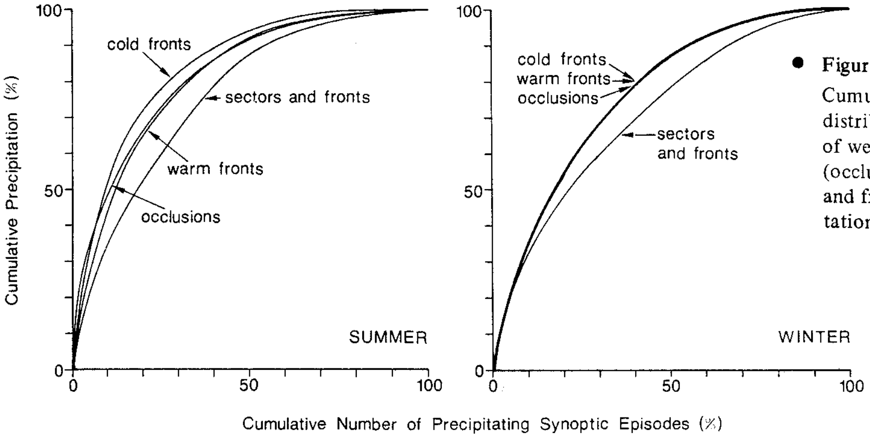
■ **Table 1** **Number of synoptic episodes** in summer and winter: their average number, the seasonal standard deviations, the extrema, and a separation of dry and wet events. The basic synoptic episodes subsume all four to five features shown in Figure 1. Note that the synoptic episode (3) "fronts" includes warm and cold fronts at the surface and aloft, and convergence lines (which contribute 4 in SU, 2 in WI). Surface cold and warm fronts (KF, WF) are also analysed as distinct classes.

synoptic episode	average		standard deviation		minimum		maximum		without precipitation RR = 0		with precipitation RR > 0		above threshhold RR > 2.0 mm	
	SU	WI	SU	WI	SU	WI	SU	WI	SU	WI	SU	WI	SU	WI
1. occlusions	21.4	23.3	7.0	8.0	10	9	35	35	7.6	5.3	13.8	18.0	7.1	9.2
2. sectors & fronts	6.2	5.6	2.8	2.9	2	2	12	12	1.6	0.5	4.6	5.1	3.1	3.3
3. fronts	23.1	20.8	4.3	4.9	16	14	31	32	13.5	9.9	9.6	10.9	4.0	5.3
KF	12.3	6.7	2.8	2.6	8	2	16	12	7.1	3.8	5.2	2.9	2.1	2.1
WF	5.7	8.7	2.0	2.7	3	4	10	14	3.1	3.0	2.6	5.7	1.2	2.6
all fronts, occlusions	56.9	55.4	11.2	10.9	42	34	76	62	24.4	16.4	32.5	39.0	17.3	21.1

summer (17 in winter) cumulate more than 2 mm precipitation which amounts to one episode per week. For each individual synoptic episode the variability of their occurrence (standard deviation and extrema) from season to season is rather large, with extrema varying about the mean with almost 3/2 standard deviations. The average number of dry and wet composite cyclones shows hardly any seasonal difference, because the major storm tracks, originating over the North Atlantic and ending over north and central Europe, reveal also only minor changes (WHITAKER and HORN, 1984); wet systems, however, occur more often in winter.

The total number of dry and wet composite disturbances in the vicinity of the single station is rather large. But spectral analyses of three-hourly pressure records and daily rawinsonde observations reveal broad spectral density maxima at periods less than five days (FRAEDRICH et al., 1979, see also climatological setting). It is the frequency of short period disturbances (wavenumber 7 to 9 and larger), ensembles of which are attached to the major troughs. This peak coincides with the occurrence of wet synoptic episodes (one every third day) whereas the additional dry frontal events should be regarded as less weather efficient relicts of dissipating frontal cyclones passing the station. Another spectral peak is found between 5 and 12 days related to the midlatitude troughs of the slowly propagating major waves (BÖTTGER and FRAEDRICH, 1980) passing Berlin about once a week. This corresponds to the frequency of wet episodes which cumulate more than 2 mm precipitation.

A detailed evaluation of five years of frontal analyses (from Seewetteramt Hamburg; ERIKSON, 1963, Figure 2) documents summer and winter averages for the area of interest; this agrees with our number of precipitating composite cyclones at Berlin. Another relevant analysis depends on nine years of frontal observations from various weather services (Italy, Greece, European Centre; FLOCAS, 1984, Figure 1) showing an average of 14 fronts and occlusions in summer (15 in winter); this corresponds with the number of our more heavily precipitating synoptic systems (RR $\geqslant$ 2 mm). These two studies on frontal statistics exhibit the principal problems in evaluating frontal analyses of different sources. They are, to a certain degree, subjective and also guided by the regional interests of the weather services. The subjectivity depends on the definition of frontal features, however weak they may be. There is certainly general agreement on strong and weather efficient episodes. But weak remnants of dissipating frontal systems are often discarded by weather services. The presently analysed record, however, has been designed to include even the weakest frontal episodes. Thus, many forms of dissipative stages of



● **Figure 2**
Cumulative percent distribution of the number of wet synoptic episodes (occlusions, fronts, sector and fronts) versus precipitation due to such episodes.

fronts and frontal cyclones, which preferably tend to occlude over the central part of the European continent, are incorporated in this single station statistic, leading to the observed large number of fronts, occlusions etc.

Warm and cold changes: Another kind of composition of fronts is based on the value for prediction; local changes to warm (cold) temperatures are due to passing warm fronts at the surface and aloft, WF and HW, and warm front occlusions, WO (cold fronts, KF and HK, and cold front occlusions, KO). Occluded systems at the surface and aloft, OK und HO, and airmasses remain separate groups. In contrast to the number of frontal episodes and/or cyclones passing Berlin this composition shows a notable seasonal difference between summer and winter. From the data leading to Table 1, one can extract the mean total number of warm or cold changes, N $(RR \geqslant 0)$, and the contribution of dry, N $(RR = 0)$, and wet, N $(RR > 0)$ events; N $(RR \geqslant 0)$ = N $(RR = 0)$ + N $(RR > 0)$:

There are almost twice as many warm changes (WF, HW, WO) in winter $(24.7 = 7.4 + 17.3)$ as in summer $(14.0 = 8.0 + 6.0)$. Vice versa, the cold changes (KF, HK, KO) in winter $(19.0 = 8.1 + 10.9)$ are significantly reduced compared with the summer $(26.2 = 12.8 + 13.4)$. Finally, there occur less occlusions (O, HO) in winter $(9.6 = 2.6 + 7.0)$ than in summer $(12.9 = 4.3 + 8.6)$. Estimates of standard deviations and extrema may be inferred from Table 1. This is a significant seasonal difference of warm and cold weather changes which is evident from basic climatological structures: During winter (summer) relatively warm (cold) sea surface temperatures and cold (warm) surface temperatures of the continent enhance the number for warm (cold) temperature changes, which are realized over the European continent by frontal cyclones.

This result is also reflected by the mean first passage times from warm to cold frontal weather changes (and vice versa) and recurrence times between either cold or warm events (Table 2, top). Starting from any synoptic episode, including airmass, it takes almost twice as long (i.e. 8 to 10 days) in summer (compared with the winter) to realize a change to fronts with relatively warmer weather. And it takes longer in winter (3 to 5 days) than in summer to realize colder synoptic episodes. The time between these frontal weather changes is mainly occupied by airmass properties (Table 2, bottom). An example: The average time passing from any cold frontal system to the next (first) warm front is the average first passage time lasting 209 hours in summer (110 hours in winter). Table 2 top shows values of these and a selection of other first passage times, and reccurrence times between the same events. The first passage time of 209 hours in summer is occupied by 198.3 hours of airmass properties, 3.1 hours of occluded systems and 7.9 hours of cold fronts (105.4 hours, 1.0 hour, 4.1 hours in winter, respectively). Table 2 bottom presents these results and a selection of other occupation times.

■ **Table 2a Average first passage and recurrence times** in hours (with standard deviations) of cold, warm, and occluded frontal episodes; see example given at the end of Section 3.

to from	cold KF, HK, KO		warm WF, HW, WO		occluded OK, HO		airmass	
	SU	WI	SU	WI	SU	WI	SU	WI
cold KF, HK, KO	87 (77)	125 (123)	209 (220)	110 (111)	223 (200)	279 (281)	3.0 (0.5)	3.0 (0.3)
warm WF, HW, WO	35 (48)	78 (94)	217 (230)	109 (105)	253 (213)	272 (296)	3.3 (1.0)	3.2 (0.8)
occluded OK, HO	75 (75)	93 (78)	202 (178)	118 (107)	184 (187)	194 (200)	3.1 (0.6)	3.1 (0.5)
airmass	82 (74)	124 (124)	230 (227)	104 (103)	197 (195)	263 (273)	3.2 (1.5)	3.2 (0.8)

■ **Table 2b Average occupation times** in hours (with standard deviations) between selected first passages and recurrences; see example given at the end of Section 3.

from	occupation time							
	warm WF, HW, HO		cold KF, HK, KO		occluded OK, HO		airmass	
	SU	WI	SU	WI	SU	WI	SU	WI
cold to warm	0	0	7.9 (6.5)	4.1 (1.9)	3.1 (4.8)	1.0 (2.1)	198.3 (212.1)	105.4 (109.7)
warm to cold	3.0 (0.5)	4.6 (2.3)	0	0	0.4 (1.1)	1.2 (2.4)	31.6 (48.1)	71.8 (91.5)
cold to cold	1.1 (1.5)	3.3 (3.1)	3.0 (0)	3.0 (0)	1.3 (2.5)	1.5 (2.6)	82.0 (76.0)	117.7 (120.5)
warm to warm	3.0 (0)	3.0 (0)	7.3 (6.4)	2.5 (2.7)	3.0 (4.8)	1.2 (2.4)	204.0 (223.0)	102.0 (102.1)

■ **Table 3 Period length of synoptic episodes:** cumulative duration in percent of total hours (13 summers or 28704 hours, 12 winters or 25920 hours), average duration with standard deviation, maximum and modal values. The synoptic episode (3) "fronts" includes convergence lines; surface cold and warm fronts (KF, WF) have been analysed as distinct classes.

synoptic episodes	relative total (%)		average (h)		standard deviation (h)		max/mode (h)	
	SU	WI	SU	WI	SU	WI	SU	WI
1. occlusion	11.6	13.4	12.0	12.4	6.7	6.1	45/9	54/9
2. sectors & fronts	9.6	7.5	33.9	28.7	16.0	12.4	84/30	60/9
3. fronts	8.7	8.5	8.3	8.9	7.7	6.3	39/6	42/9
KF	5.2	2.5	9.3	8.1	7.2	4.5	33/9	24/6
WF	2.9	4.5	10.2	11.2	7.7	7.8	39/9	42/9
sum (1+2+3)	29.9	29.4	11.6	11.5	12.1	10.3	84/9	60/9
airmasses	70.1	70.6	50.5	40.7	45.5	44.7	336/60	339/60
total	100.0	100.0	23.2	23.1	33.5	33.1	336/9	339/9

4 Duration

The record of 13 summers (28704 hours) and 12 winters (25920 hours) is occupied by synoptic episodes and airmass properties. They need a certain time for their passage over the station, which is measured in discrete three-hourly intervals. Long period lengths indicate both slowly moving or nearly stationary episodes and/or large systems; they cannot be separated by single station time statistics (Table 3).

Composite cyclone: An average occlusion spends more time (10 to 14 hours) over Berlin than an average front; cold fronts last 6 to 7 hours, whereas warm fronts tend to effect single station weather for a longer period: 10 to 11 hours for warm fronts; warm front occlusions have the longest period length: 13 to 14 hours. A mean sector and fronts episode needs a passage time from 29 to 34 hours, where front and sector durations are of comparable magnitude. Statistically and practically more relevant are the modal values: the most frequently observed durations of frontal or occlusion episodes are short, 6 to 9 hours (i.e. two to three three-hourly intervals) and 30 hours for sector plus fronts. The time which synoptic episodes and their weather spend over a station is another climatologically relevant information. Related to the observation period (100 % refer to 13 summers, 12 winters), Berlin and its region realize – in a cumulative sense – synoptic events during 30 % of the time. The largest contributions come from occlusions; although they occur almost as frequently as frontal episodes (Section 3), they spend a longer time over the area due to their longer period length.

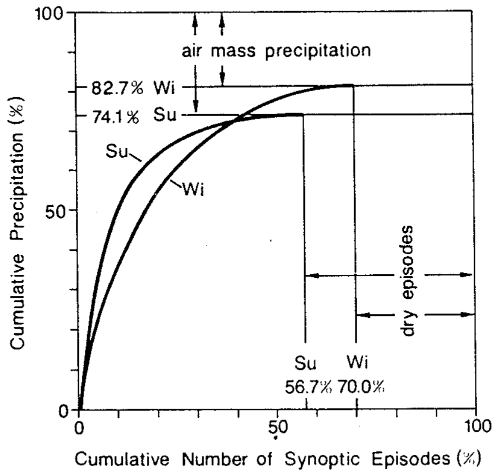
5 Precipitation

The total precipitation of the 13 summer (12 winter) seasons yields 2515.0 mm or 193.5 mm per average summer (1457.7 mm or 121.5 mm per winter), to which both synoptic episodes and airmass events contribute. Airmass precipitation from three-hourly intervals is assumed to add to those synoptic episodes, to which it is adjacent, because the frontal rainfall process may (partly though) continue or advance into the neighbouring three hours of an otherwise dry airmass period (see Section 2).

Composite cyclone: The average precipitation from wet synoptic episodes is presented in Table 4, which also contains standard deviations and maxima. Not unexpected are the following results: Occlusions produce more precipitation than the fronts, cold fronts more than warm fronts, summer more than the winter events; additionally, the precipitation variability (standard deviation) of wet summer

■ **Table 4 Precipitation of synoptic episodes:** averages, standard deviations, maxima, and the cumulative percent precipitation without and with the adjacent three-hourly time intervals. Note that the synoptic episode (3) "fronts" contains convergence lines (adding 3.3 % to summer and 0.8 % to winter precipitation).

synoptic episodes	mean precipitation (mm)		standard deviation (mm)		max (mm)		relative accumulated precipitation (%)		plus 3 h adjacent airmass	
	SU	WI	SU	WI	SU	WI	SU	WI	SU	WI
1. occlusions	5.5	2.9	7.7	2.1	97.5	11.3	34.9	39.3	39.3	43.1
2. sectors & fronts	6.7	4.9	10.1	5.0	42.0	21.7	15.7	19.9	16.1	20.6
3. fronts	3.8	2.4	3.2	2.5	30.2	11.3	15.4	14.3	18.7	19.0
KF	4.2	3.5	3.7	1.9	30.2	11.3	9.7	6.6	11.3	8.2
WF	2.9	1.6	2.3	1.8	15.6	9.7	3.5	5.8	3.9	7.3
sum (1+2+3)	4.4	3.7	6.5	3.8	97.5	21.7	66.0	73.5	74.1	82.7
airmasses							34.0	26.5	25.9	17.3



- **Figure 3**
Cumulative percent distribution of all wet and dry synoptic episodes (composite cyclones) versus total precipitation (including airmass): 70 % of the winter (56.7 % of summer) episodes produce 82.7 % (74.1 %) of the total rainfall; the remaining episodes (30 % in winter, 43.4 % in summer) are dry, the remaining precipitation (17.3 % in winter, 25.9 % in summer) is due to convective processes in airmasses (see also Section 5).

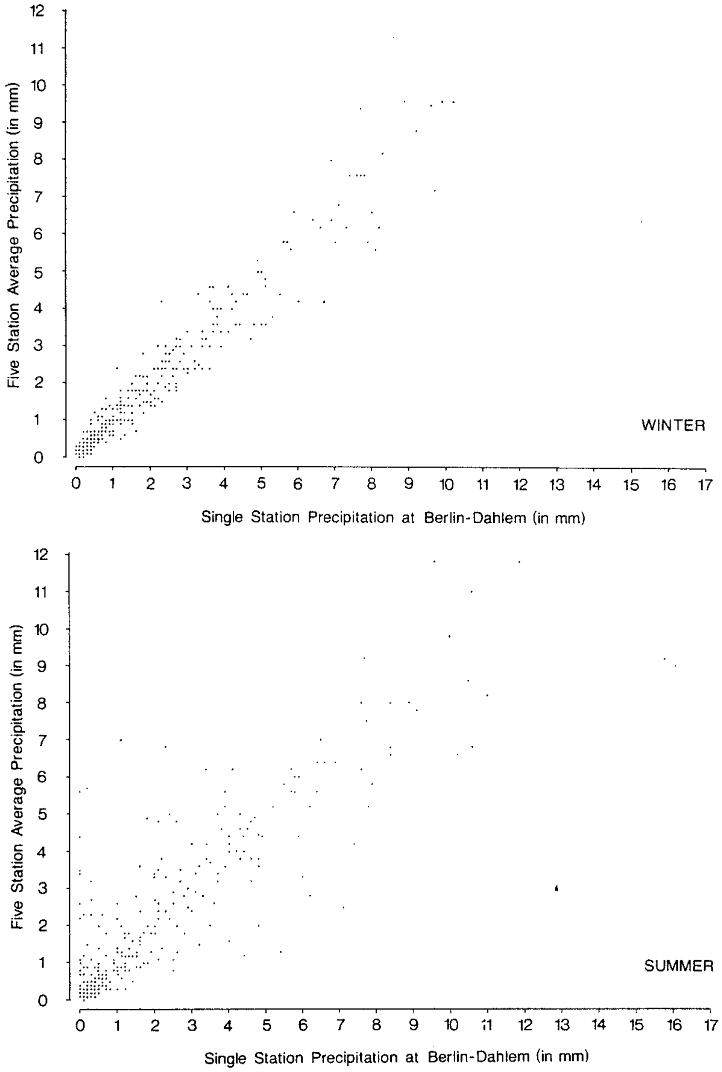
systems is high compared with the winter situations, which is also reflected by the extrema. During an average season one may expect between 2 to 5 mm rainfall from one of the 10 wet fronts or 14 to 18 occlusions, and 5 to 7 mm precipitation from one of the five wet sector plus front episodes.

The relative number (in percent) of wet synoptic episodes contributing to their related total precipitation is presented in Figure 2. Occlusions, warm and cold fronts show similar cumulative distribution functions and almost no seasonal difference. It should be noted that only a few potent wet events (10 % in summer, 20 % in winter) produce about half of the total precipitation of the related episodes; 50 % of the wet events contribute 80 to 90 % of the water yield. The remaining 10 %, say, are due to a certain background number of weak wet episodes, which always occur (i.e. the other 50 % of the wet systems). The rainfall distribution of the larger sector and fronts episodes deviates from the other ones. It shows less skewness, because there are less events of heavy precipitation.

Midlatitude and tropical rain systems: All synoptic episodes and airmass periods combined give 100 % of the precipitation. Most of it is produced by the precipitating frontal cyclones (74.1 % or 143.4 mm for the average summer; 82.7 % or 100.5 mm for the average winter). The largest amount is due to occlusions (39.3 % in summer, 43.1 % in winter), whereas fronts, sector and fronts, and airmasses contribute between 16 and 25 % to the seasonal precipitation (Table 4). The cumulative frequency distribution of water yield versus percent of all synoptic episodes (Figure 3) corroborates the main results: It shows greater skewness in summer than in winter, since rainfall events are more efficient in summer. For both seasons one observes that about half of the raining synoptic episodes (i.e. 35 % or 17 in winter, 28.4 % or 14 in summer) produces about 70 % of the total. This is almost identical with the number of synoptic episodes cumulating more than 2 mm per occurrence (Table 1, sum of occlusions, sector and fronts, and fronts with RR $\geqslant$ 2 mm); i.e. the seasonally independent threshold precipitation of 2 mm per event is now climatologically justified. The remaining background number of the weaker wet and dry synoptic episodes (i.e. 71.6 % or 36 of the summer disturbances, 65 % or 25 of the winter episodes) and of the airmass events is always present generating nearly 36.4 mm of the winter and 58.0 mm of the summer precipitation (i.e. the remaining 30 % of the seasonal average). Thus, the occurrence of a few strongly precipitating synoptic episodes (exceeding about 2 mm per occurrence) determines whether a season will be wetter or drier.

This is comparable with results of two single station tropical experiments in Venezuela (RIEHL et al., 1973; RIEHL, 1977). The tropical rainy season of the Caribbean is forced by extratropical troughs intruding into the tropics from the north. The upper 75 % of its average precipitation is contributed by about 15 rain systems which occur during 90 to 100 days; i.e. one per week. They are embedded in almost the same number of synoptic scale areas forced by corresponding midlatitude troughs of wave-number 5 to 7 and periods 5 to 12 days, as they are observed along the latitude circle at 50 °N (BÖTTGER and FRAEDRICH, 1980). Half of the rain systems produce about 70 to 80 % of their rainfall (RIEHL, 1977, Figure 2; and this section, Figure 2) with rain yields exceeding 1 cm per occurrence. This, of course, is above the threshold value (2 mm per event) of Berlin or central European synoptic episodes, which contribute about 70 % of the total (including the background rainfall) and 80 to 90 % of the wet episode precipitation.

How representative is single station precipitation? Two half daily precipitation cumulants (from 6 to 18 and from 18 to 6 GMT) are deduced from the eight three-hourly observations per day at Berlin-Dahlem to make the single station record comparable with observations of four neighbouring stations. They form an almost equilateral triangle of about 15 km sidelength surrounding Dahlem as a centre;



- **Figure 4**
Twelve-hourly Berlin-Dahlem single station precipitation versus five station average (Potsdam, Schönefeld, Tegel, Tempelhof, and Dahlem) for wet synoptic episodes.

two corners are in the south, Potsdam and Schönefeld; Tegel defines the northern corner, and Tempelhof is situated near the eastern leg. Precipitation averages of all 5 stations (including Dahlem, available from BRÜGGEMANN , 1982) and the related 12-hourly values of Dahlem are selected for all occlusions, warm and cold fronts at the surface and aloft, which fall into the 12-hourly intervals. The Dahlem precipitation is plotted versus the 5 stations average in Figure 4; dry cases for all five stations (RR $<$ 0.05 mm) are not included. One obtains a cloud of points aligning along the diagonal showing good correlation; a regression analysis reveals a slope near one (0.976 in summer, 0.924 in winter) and an almost vanishing additive term. Thus, we may conclude that the single station statistic of synoptic episode precipitation (e.g. Figure 3) is characteristic for a mesoscale environment and may also be representative for the climate of the whole region.

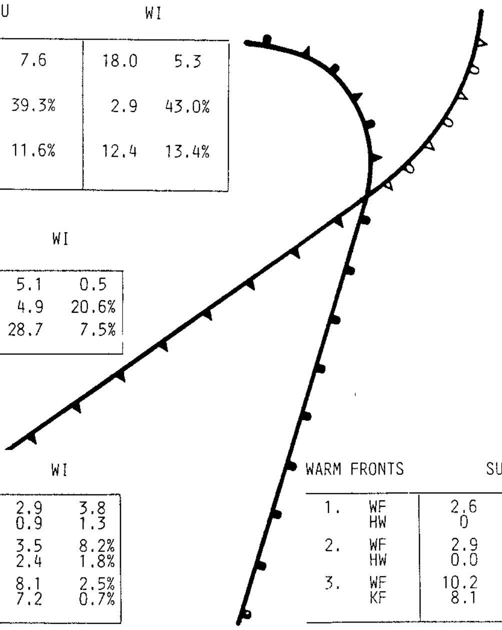
6 Conclusion

The main results of the number, time, and precipitation statistic of Berlin or central European frontal episodes are summarized in Figure 5, where seasonal averages are presented. It shows the dominant role played by the occluded part of the frontal cyclones in central Europe. They contribute most of the precipitation, and most of the time local weather is affected by them. In addition, new

SUMMARY OF NUMBER, TIME AND PRECIPITATION STATISTICS AT BERLIN
1969-81

OCCLUSIONS	SU		WI	
1. # per season RR > 0 RR = 0	13.8	7.6	18.0	5.3
2. precipitation mm in %	5.5	39.3%	2.9	43.0%
3. duration hours in %	12.0	11.6%	12.4	13.4%

SECTORS & FRONTS	SU		WI	
1.	4.6	1.6	5.1	0.5
2.	6.7	16.1%	4.9	20.6%
3.	33.9	9.6%	28.7	7.5%



COLD FRONTS		SU		WI	
1.	KF	5.2	7.1	2.9	3.8
	HK	0.3	0.3	0.9	1.3
2.	KF	4.2	11.3%	3.5	8.2%
	HK	1.6	0.2%	2.4	1.8%
3.	KF	9.3	5.2%	8.1	2.5%
	HK	6.4	0.2%	7.2	0.7%

WARM FRONTS		SU		WI	
1.	WF	2.6	3.1	5.7	3.0
	HW	0	0.5	0.4	0.7
2.	WF	2.9	3.9%	1.6	7.3%
	HW	0.0	0.0%	2.5	1.0%
3.	WF	10.2	2.9%	11.2	4.5%
	KF	8.1	0.2%	9.0	0.5%

- **Figure 5** Summary of number, duration and precipitation statistics of synoptic episodes at Berlin: occlusions, warm sector plus fronts, and fronts separated into cold and warm fronts at the surface (KF, WF) and in upper levels (HK, HW) for summer and winter (left and right column). The rows present (1) the average number per season with and without precipitation, (2) the average precipitation of all episodes (in mm) and their relative contribution (in %) to the season's total precipitation, (3) the average durations (in hours) of the episodes effecting the single station Berlin and their relative contribution (in %) to the total time of a season.

frontal disturbances evolve along the old. This leads to the synoptic episodes of warm sector and fronts which are also observed over Europe. Their occurrence indicates a cascade of new frontal developments during the dissipative stage of the mature cyclones. The existence of warm and cold fronts often depends on the distance and direction of the cyclone centres passing the single station. That there are more warm fronts observed in winter than in summer, and more cold fronts in summer than in winter, is due to the seasonally varying ocean-continent temperature contrast. The frequency of wet synoptic episodes (i.e. one every third day) can be related to frontal cyclones which are represented by a spectral peak at wavenumbers 7 to 9 and periods below 5 days in the wavenumer-frequency domain of standard midlatitude circulation statistics. The events cumulating more than 2 mm precipitation (occurring once per week) correspond to the major troughs at wavenumber 5 to 7 and periods between 5 and 12 days. The dry synoptic episodes may be related to the less efficient remnants of dissipating cyclones.

The climatological value of the synoptic episodes can be assessed by their contribution to the seasonal precipitation. Not unlike the tropical rainy season affected by intruding midlatitude troughs, there are about 15 (or half of the) wet episodes with more than 2 mm water yield necessary to contribute about 70 % of the total rainfall of a season and 80 to 90 % of the wet episode precipitation. In summarizing, the phenomenological statistic supports the interpretation of standard circulation analyses and may serve as another independent data set for controlling numerical simulations.

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