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Publication de la Société canadienne de météorologie et d'océanographie, le Bulletin climatologique offre un moyen d'information sur la climatologie. Le comité de rédaction encourage en particulier la soumission de manuscrits sur la climatologie appliquée (comme l'agriculture, le commerce, l'énergie, l'environnement, la pêcherie, la sylviculture, la santé, les loisirs, les transports, et les ressources en eau), les changements et la variabilité du climat, la prospective climatologique, les applications des modèles du climat (inclus la climatologie physique), et les études régional (inclus les océans). Il est publié grâce à une subvention accordée par le gouvernement canadien par l'intermédiare du Conseil de recherches en sciences naturelles et en génie.

Les auteurs peuvent choisir de soumettre leurs manuscrits aux "Articles", "Notes de Recherches", ou "Nouvelles et Commentaires". Ils doivent l'indiquer sur la lettre d'accompagnement du manuscrit. Les articles de recherche et les "Notes" sont indépendamment soumis à l'examen d'au moins deux appréciateurs anonymes. Le rédacteur en chef examine les "Nouvelles et Commentaires" conjointement avec le comité de rédaction. On accepte les articles soit en français, soit en anglais. Il faut envoyer un résumé, de préférence en français et en anglais.

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Foreword / Avant-Propos

This issue includes a new feature, "CLIMATE REVIEW / REVUE DU CLIMAT" which will consist of regular surveys of Canada's climate from a number of contributors. The 1984 severe storm survey was published as a note in the February 1987 issue. M.J. Newark et al. have assembled the 1985 survey to inaugurate the new section of the Bulletin. In future issues, we hope to include other climate reviews for continental and ocean areas.

My term as editor expires this year, and I am pleased to announce the appointment of Professor Alexander H. Paul of the University of Regina as the new editor of the Bulletin. All correspondence, including manuscripts and news items, should be submitted to Professor Paul at the following address:

c/o Department of Geography
University of Regina
Regina, Saskatchewan
S4S 0A2

I am also pleased to announce the appointments of Dr. Ken Drinkwater and Professor Jerry Hall to the Board as Associate Editors. My sincere thanks to Dr. John Lazier and Professor Geoff McBoyle whose terms have expired. All the above nominees were approved by CMOS Council on 16 June 1987 at the Annual Congress in St. John's.

Distribution of Blocks in Data from the Canadian Climate Centre General Circulation Model

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ABSTRACT

Data from the Canadian Climate Centre general circulation model (GCM) are examined for blocking episodes. The data set consists of seven months of daily 500 and 1000 mb geopotential height charts of the Northern Hemisphere. The blocks are identified using the Treidl (Treidl et al, 1981) definition. Model blocks are compared to observed climatology. The blocks are found to have latitudinal and longitudinal distributions and frequency of occurrence similar to climatology. The model blocks tend to be of shorter duration and have less intense 500 mb height anomalies. They are identified well by the Knox and Hay (1984) blocking criterion.

RÉSUMÉ

Des données produites par le modèle de circulation générale du Centre Climatologique Canadien sont examinées en vue d'y déceler des épisodes de blocage atmosphérique. Les données consistent en sept mois de cartes quotidiennes contenant les isohypses de l'hémisphère nord a 500 et 1000 mb. Les épisodes sont identifiés selon le critere de Treidl (Treidl et al, 1981). Les blocs du modèle sont comparées aux observations climatologiques. Leurs distributions latitudinale, longitudinale, et en fréquence sont similaires à la climatologie. Ils sont par contre d'une durée et d'une intensité réduite au niveau de 500 mb. Enfin, ils sont bien identifiés par le critère de blocage de Knox et Hay (1984).

1. INTRODUCTION

Atmospheric blocking is a well known meteorological phenomenon. A block is characterized by a well developed stationary anticyclone usually flanked by cyclones. The zonal flow is split in northerly and southerly branches around the block, rejoining downstream of the anticyclone. Blocks tend to persist eight to ten days but have been known to persist over fifty days (Treidl et al, 1981).

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The interruption of the progression of alternating cyclones and anticyclones by a block can have a profound influence on agricultural production, forest fire prevention, community water supply and domestic energy consumption.

The precise definition of a block has varied from study to study. The climatology of blocking is however fairly well known. Rex (1950) produced the first major observational study on blocking. He used 13 years of 500 and 700 mb data and identified 112 blocks. He stipulated that blocks must last at least ten days and cover 45° in longitude.

There have been recently several extensive studies of blocking using observational data. Treidl et al (1981) analyzed Northern Hemisphere data for the period of 1945-1977. Their definition of a block included the presence of closed isopleths and a minimum duration of five days. Knox and Hay (1984) examined a similar data set from 1946-1978. Geopotential height anomalies (i.e. deviations from climatological averages) for five day periods were calculated; these were then correlated with actual blocking episodes and empirical formulas for block identification were obtained. Dole and Gordon (1983) examined the distribution of height anomalies, and found that regions of high frequency of the anomalies coincided with blocking activity. Mullen (1986) examined the vorticity and heat balances for blocking flows in the NCAR Community Climate Model, and found that dynamical processes associated with the vorticity balance may be more important than those associated with the heat balance.

In this study, we use data from the Canadian Climate Centre (CCC) general circulation model (GCM) to examine blocking statistics. These are compared to climatological results of Treidl et al (1981) and Knox and Hay (1984).

2. COMPARISON OF MODEL BLOCKS AND CLIMATOLOGY

2.1 The Model

The GCM is described in detail by Boer et al (1984a). We give here a brief description of the various features of the model. The model, like other general circulation models, is based on the primitive equations (momentum, thermodynamic, moisture and mass continuity). The model explicitly includes the main physical processes that produce both weather and climate, including those that govern the hydrological cycle. Horizontal fluxes due to unresolved motions are parameterized using stability dependent eddy diffusivities and bulk transfer coefficients. A parameterization of the momentum transport induced by topographically generated gravity waves is also included. Radiation calculations include both the annual and diurnal cycles. The model variables are represented in the horizontal by a spectral formulation using an expansion in spherical harmonics. The model variables are expanded to twenty wavenumbers (T20 resolution). This resolution is such that synoptic scale phenomena are well represented. Vertical derivatives are approximated by finite differences. Other features of the numerics include semi-implicit time-stepping and the use of a weak time filter. Boundary conditions are prescribed with the topographical heights of all major land masses. Land and ice surface temperatures are calculated using surface energy balance equations. Sea surface temperatures are specified using monthly mean values.

In a companion study Boer et al (1984b) used a five year simulation to show that the model is quite successful in reproducing the climatology of the atmosphere. Time mean fields of zonal wind, temperature, meridional streamfunction, specific humidity, eddy kinetic energy, mean sea level pressure, precipitation rate, 500 mb geopotential height field were compared to observed values. Tropospheric model values generally agree well with observed climatology.

The data set used in this study consists of seven months of daily 500 mb and 1000 mb Northern Hemisphere charts. The charts are obtained from a simulation initialized with January 2, 1979 FGGE-IIIb data and cover the period from "Feb. 1, YR1" to "Aug. 31, YR1". We note that the relative short integration period may not generate statistics representative of the model's climatology. However, the model blocking climatology is fairly well represented, as we will show in this study.

2.2 Identification of Blocks

As discussed in the introduction, there are two traditional approaches to block identification: the first is a subjective approach where blocks are visually identified by experienced analysts, and the second approach uses anomalous 500 mb heights. In this study, we use both methods in analyzing GCM blocks.

TABLE I. Data for the GCM Blocks

	Date		Duration	Location	
Block	Start	finish	(days)	Start	finish
1	Feb. 8	Feb. 13	6	70/157W	80/135W
2	Feb. 19	Feb. 25	7	48/130W	65/135W
3	Mar. 5	Mar. 11	7	40/5E	45/5E
4	Mar. 17	Mar. 21	5	50/23W	45/3E
5	Apr. 8	Apr. 14	7	48/15W	65/22E
6	Apr. 8	Apr. 12	5	60/55E	50/55E
7	Apr. 21	Apr. 30	10	63/18E	70/50E
8	May 20	May 28	9	55/140W	64/145W
9	Jun. 9	Jun. 15	7	63/150W	50/138W
10	Jun. 20	Jun. 25	6	55/140W	64/145W
11	Jun. 27	Jul. 1	5	55/26W	75/30W
12	Jul. 9	Jul. 14	6	68/40W	50/30W
13	Jul. 17	Jul. 28	12	60/35W	64/40W
14	Aug. 25	Aug. 31	7	65/110E	80/135E

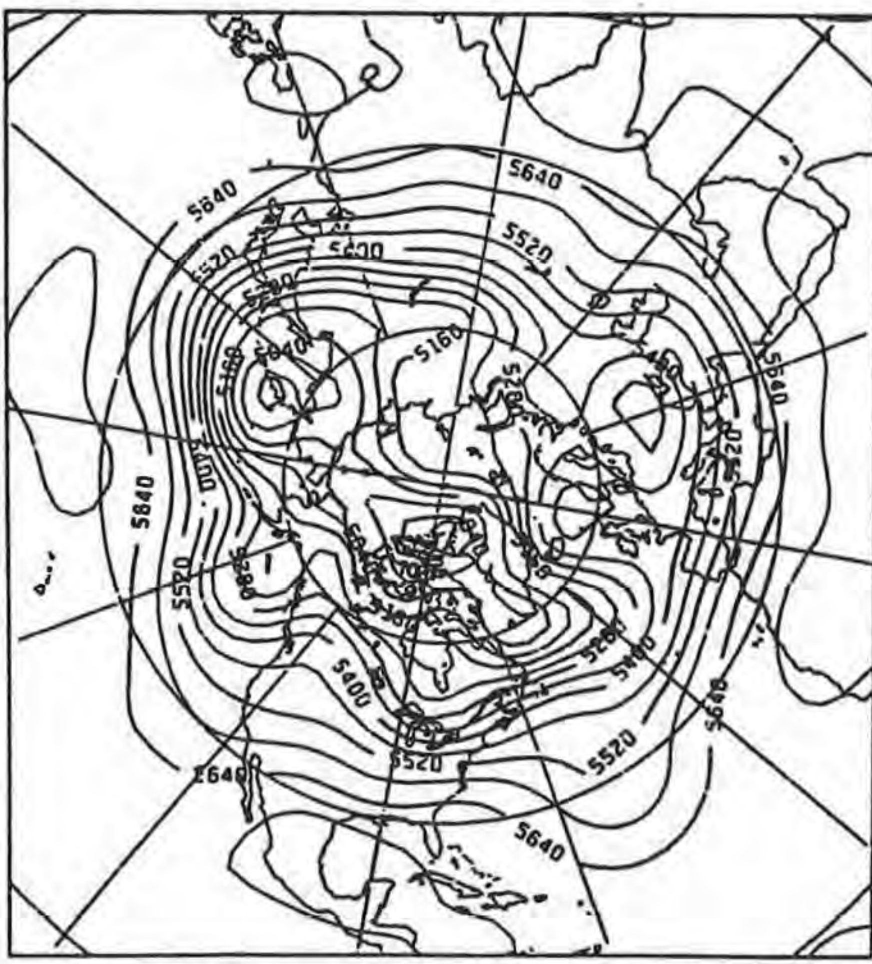

FIGURE 1. Block 5,6 500 mb geopotential heights in units of decameters (dam)

The Treidl (Treidl et al, 1981) definition of a block is used as the first means of block identification:

1) closed isopleths must be present simultaneously in the surface and 500 mb charts, splitting the westerly current aloft into two branches;
2) the latitude belt where the high occurs must extend northward from 30°N;
3) the minimum duration of the high must be five days.

For our data set covering the seven month period, fourteen blocking episodes satisfy the Treidl definition. Starting and ending dates, duration in days, longitude and latitude of the blocking anticyclone centre are recorded for each episode. This is shown in Table I. One example of a block (5,6) at its most mature stage is shown in Figure 1.

The model blocks are compared to the Treidl climatology using frequency, duration, and longitudinal and latitudinal distributions. We note the relatively small size of the CCCGCM data set (7 months, 14 blocks) compared to the Treidl data set (33 years, 664 blocks). However a qualitative comparison between the data sets is still possible.

The seven month period of GCM data produced 14 blocking episodes. This is a rate of 24 blocks a year if a uniform annual distribution is assumed. Treidl found an average of 20 blocks a year with the rate of blocking expected to fall between sixteen and twenty-four per year. The blocks found in the GCM data tend to be of shorter duration. Treidl's data indicated an average of twelve days and a mode of eight days. The GCM blocks have an average and mode of seven days. Figures 2 and 3 depict these distributions.

The longitudinal distribution of model blocks tends to agree with observations: a dominant peak occurs between 40°W to 50°E for the start of block location from observations, and between 60°W and 60°E for model data.

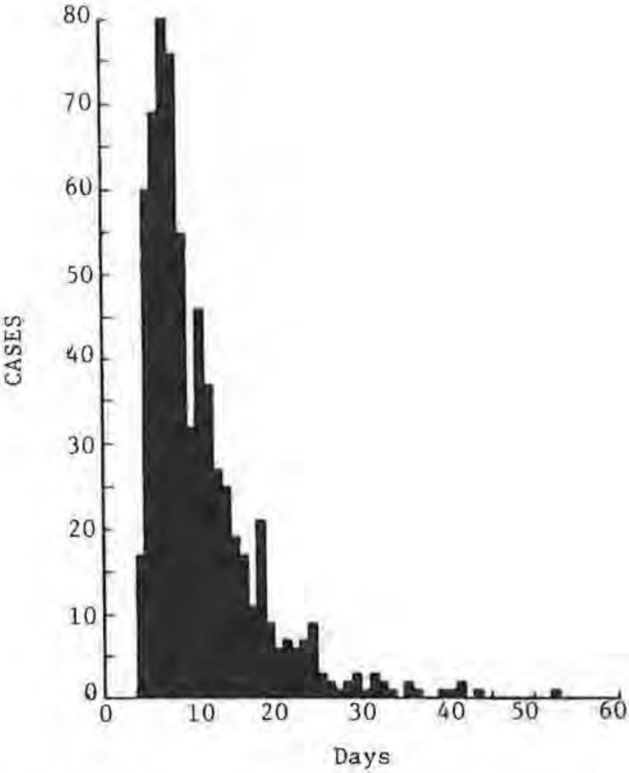

FIGURE 2. Frequency of block duration (from Treidl et al, 1981)

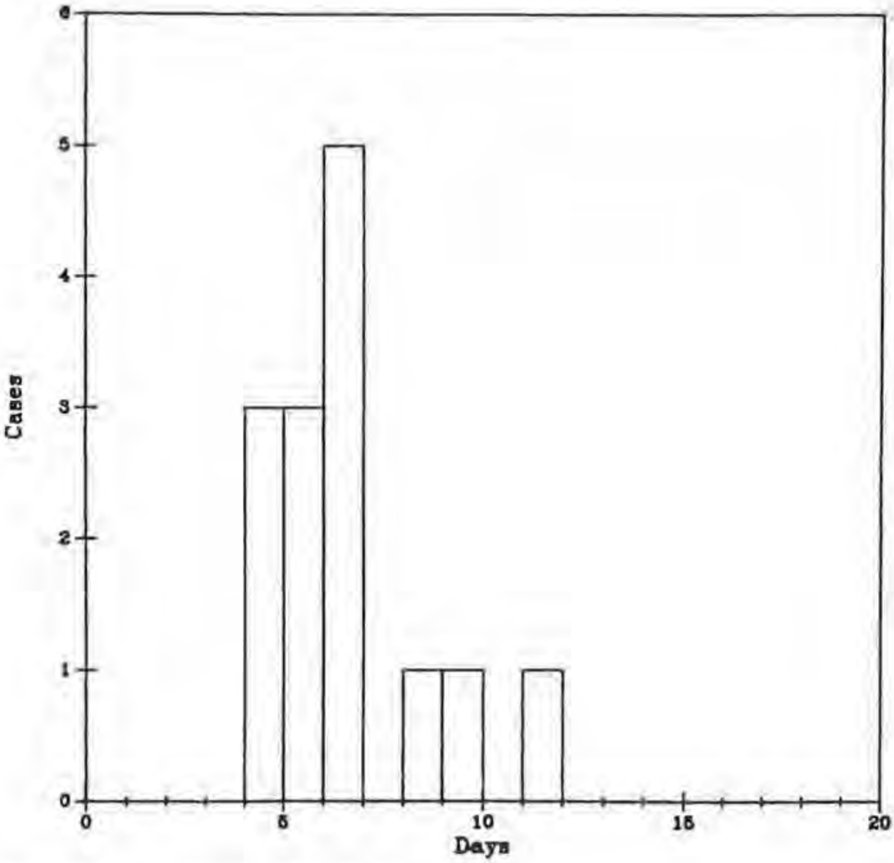

FIGURE 3. Frequency of block duration (model blocks)

A secondary peak occurs between 120°-160°W in both data sets (Figures 4 and 5). Similar agreement is noted for the end of block longitudinal locations, with both model and observation results shifted 10°-20°E.

The latitudinal distributions of the two data sets also agree well. Treidl concluded that the main region of the start of the block was 46°-68°N and virtually the same for block termination. The GCM results have the same distribution for block initiation with a slight (5°) shift north for block termination (See Figures 6 and 7).

2.3 Anomalous Heights for CCCGCM Blocking

It has only been in recent years that blocks have correlated to anomalous 500 mb heights. Knox and Hay (1984, 1985) investigated this relationship in an exhaustive study using a 33 year data set (1946-1978) similar to the Treidl data set. They examined five day (pentad) geopotential height averages and their

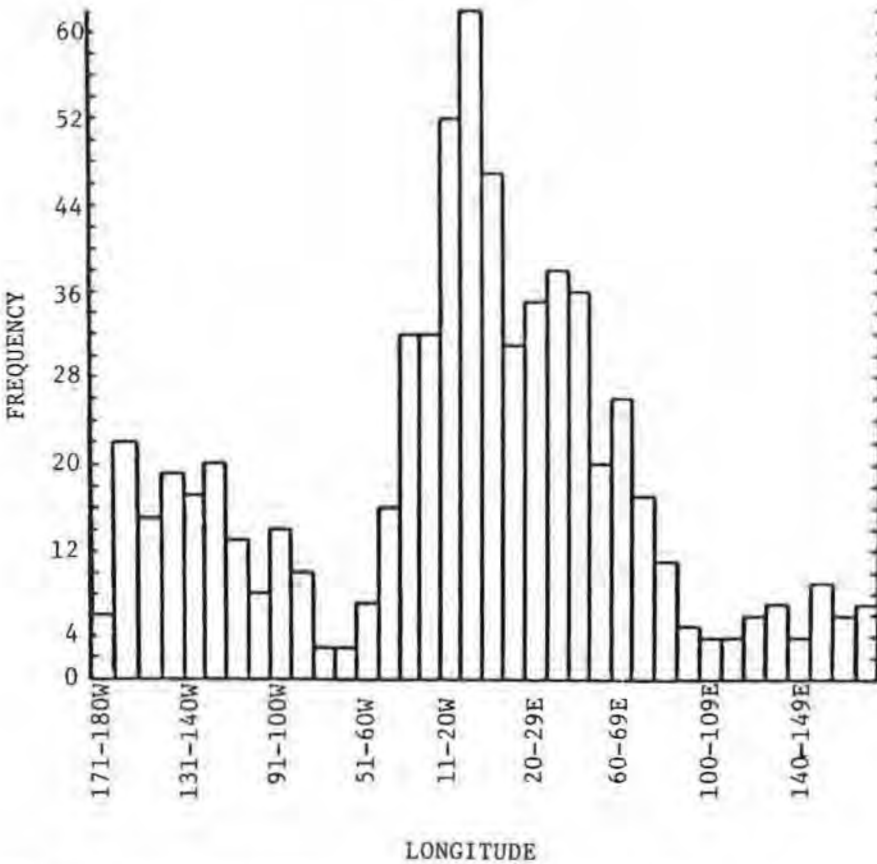

FIGURE 4. Longitudinal distribution of blocking (from Treidl et al, 1981)

deviations from climatological averages, i.e. anomalies. The climatological means were taken to be the thirty-three year pentad averages. All anomaly centres exceeding 5 decametres (dam) are catalogued. They correlated these anomalies with actual blocking episodes and derived an empirical relationship for block identification. The relationship is:

$$\text{Winter} \quad (A - 15)(f - 49) > 16$$

$$\text{Summer} \quad (A - 10)(f - 53) > 9$$

where A is the anomaly magnitude (dam) and f is is the latitude of the anomaly centre in degrees. The results had a success rate of 62% for one pentad anomalies and 96% success rate for greater than one pentad anomalies. Knox and Hay suggested the lower success percentage of the one pentad anomalies may be due to the presence of prominent transient ridges.

The 500 mb geopotential height anomalies are calculated for the

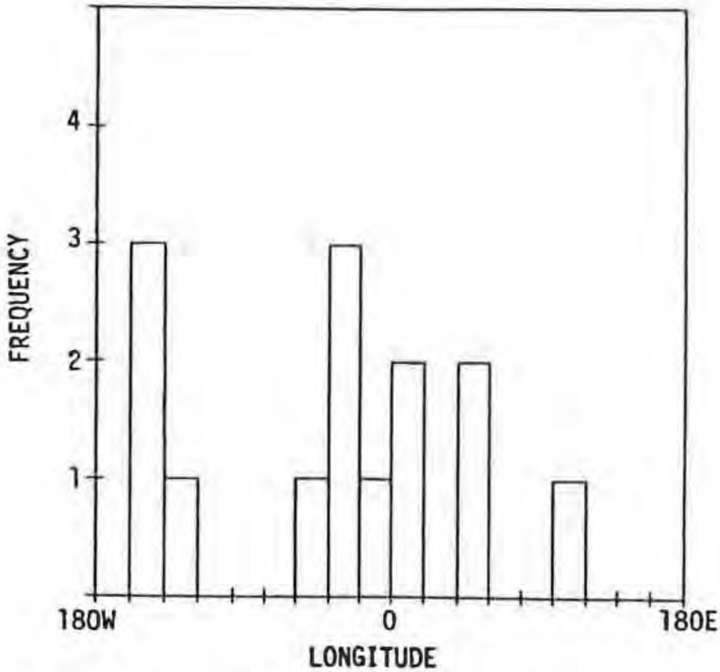

FIGURE 5. Longitudinal distribution of blocking (model blocks)

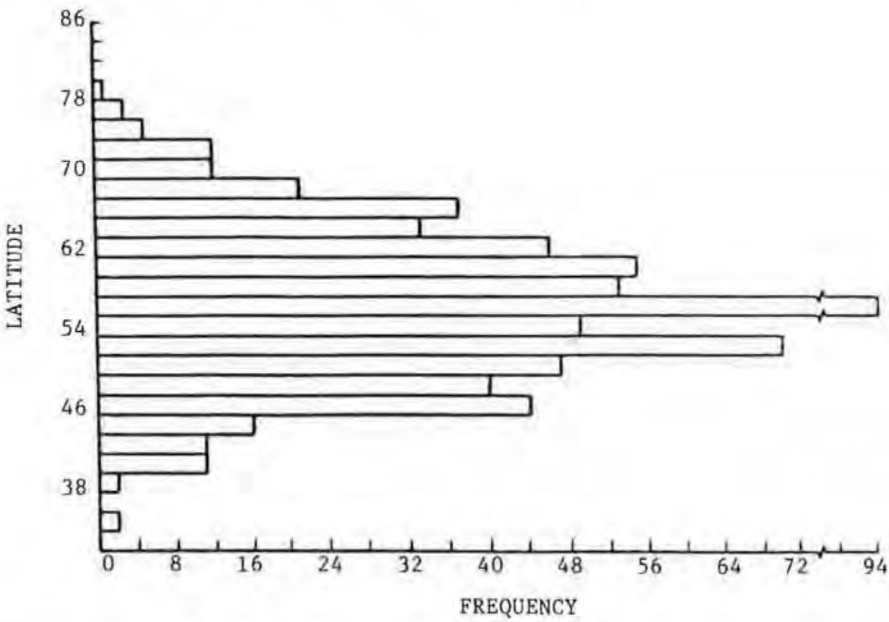

FIGURE 6. Latitudinal distribution of blocking (from Treidl et al, 1981)

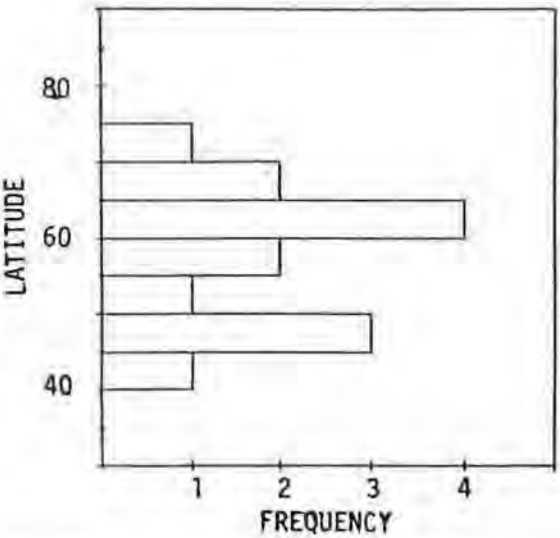

FIGURE 7. Latitudinal distribution of blocking (model blocks)

blocking episodes already identified in our GCM data set. Five year seasonal averages of the 500 mb height field are first calculated. The height anomalies are then calculated by subtracting the seasonally averaged fields from the block height field time averaged over the duration of the block. This is done for 12 of the blocks listed in Table I; blocks 5 and 6 are combined and block 11 is eliminated as it extends over two monthly periods whereas CCCGCM data is archived according to months. A typical chart is shown in Figure 8. Each chart is examined for height anomalies exceeding 5 dam. Knox and Hay's criterion is evaluated for each anomaly. The results are shown in Table II. The anomaly listed first for each blocking episode corresponds to the blocking anomaly. The anomaly for the ninth blocking episode was also included despites failing to achieve the minimum 5 dam cutoff. Block 9 was an atypical block with a more dominant southern branch and a relatively weak northern branch producing a small positive anomaly. Eight of the twelve GCM blocks satisfy the Knox and Hay criterion for blocking. Four of the remaining thirteen anomalies listed in Table II also satisfy the Knox and Hay criterion. These four anomalies represent persistent prominent ridges or blocking like flows that failed in some respect to satisfy the Treidl definition. The failure of four blocks to satisfy the Knox and Hay criterion is not surprising. As noted earlier Knox and Hay's criterion has a better success for longer blocks (i.e. greater than 10 days). The differences in the choice of climatological means may have contributed to lower height anomalies in these particular blocking cases.

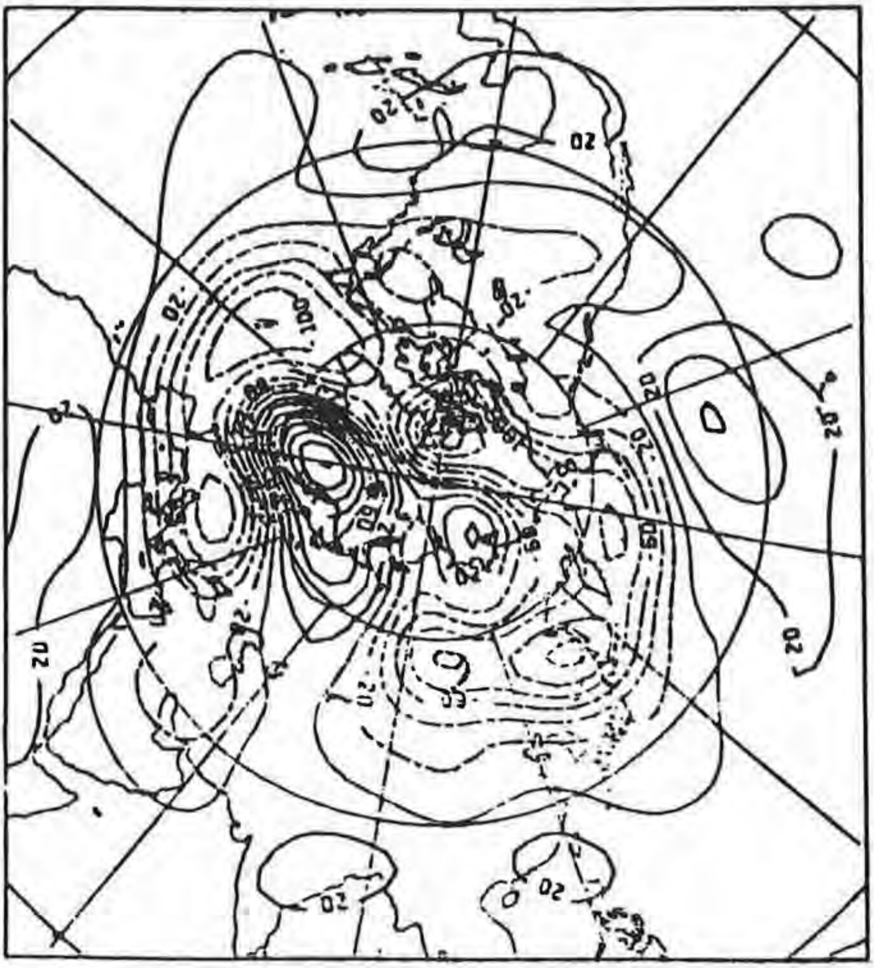

FIGURE 8. Geopotential height anomaly for Block 5,6 in units of decameters (dam)

The magnitudes of the height anomalies can also be compared. A climatological average of the Knox and Hay data produce an average height anomaly of 21 $\pm$ 7 dams for a block. For the model blocks the average was 16 $\pm$ 5 dam.

3. CONCLUSION

We see from our results that the model blocks compared favourably with the Treidl climatology in terms of spatial distribution and frequency. The data sets did not agree as well in the duration of blocking and the anomaly height magnitude. There are several possible reasons for this. We note that the data

TABLE II. Knox and Hay Block Criterion Test

Block	Duration (days)	Location (of anomaly)	Anomaly (dams)	Test
1	6	80/170W	22	yes
2	7	70/135W	17	yes
		55/60E	19	yes
		50/45W	11	no
3	7	55/0	12	no
4	5	60/0	19	yes
		50/150W	12	no
6	7	70/0	17	yes
7	10	70/3E	17	yes
		55/45W	20	yes
		45/150W	11	no
8	9	55/45E	25	yes
		45/180	30	no
		50/60W	25	no
9	7	75/135W	2	no
		60/45E	7	no
10	6	75/160W	9	no
12	6	60/45W	13	yes
		55/160E	15	yes
		70/100E	10	no
13	12	65/45E	15	yes
		60/30E	12	yes
14	7	75/120E	9	no
		55/130W	11	no
		60/15W	10	no

set, being of fairly short duration (seven months) may merely be a "short blocking, low amplitude anomaly" period. It would be of great interest to perform the analysis with a larger data set, such as using the 5-year 500 mb heights for the height anomaly study. However, should the data set be representative, we speculate on possible explanations for the discrepancy. The model does not have an interactive ocean at the lower boundary. Specified monthly averaged sea surface temperatures are used instead. Atmospheric blocking has been correlated to sea surface temperature anomalies (Namias, 1964). Tibaldi and Ji (1983) suggested model resolution may also have an effect on the duration of a block. They found using a model simulation that a block was maintained for a longer duration at a higher resolution. This may be due to the better resolution of the transient eddies; the forcing due to the latter are known to be important for the maintenance of blocks (Mullen, 1986). Finally the model may, for the above reasons or other considerations, produce less variable weather with less extreme departures from the mean. This is supported by the smaller values for the average height anomalies of the model blocks. We note that Pratt (1979) found that both the NCAR and GFDL general circulation models have less energy in the low frequency planetary waves in the mid-latitudes. This is consistent with our finding few long duration blocks in the GCM.

Our results suggest that the GCM can produce fairly realistic blocks. Thus model data should be used more extensively in the study of blocking. When compared to observational data, GCM data have the advantage of being more self-consistent, less noisy, easier to manipulate and to archive. In addition, numerical experiments can be performed with GCM simulations, e.g. data from GCM simulations with an interactive ocean can be compared to those without an ocean. Further studies with GCM data will thus contribute to the better understanding of the nature of blocking in the atmosphere.

ACKNOWLEDGEMENTS

The general circulation model data were kindly made available by Dr. George Boer of the Canadian Climate Centre. The use of the Centre's computing resources is gratefully acknowledged. This work is supported by grants from the Natural Science and Engineering Research Council (NSERC), and the Atmospheric Environment Service (AES) Subvention Program. Helpful comments from two anonymous reviewers which led to an improvement of the manuscript are gratefully acknowledged.

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Winter Fog and Air Transportation in Sacramento, California

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ABSTRACT

During the winter months of December and January, Sacramento experiences a considerable amount of fog. Impacts upon commercial air transportation for December 1984-January 1985 at Metropolitan Airport were analyzed by studying flight cancellations, delays and diversions caused by foggy conditions. Twenty-three percent of all flights were affected on severely foggy days. Although one air freight company has permanently rerouted all of its incoming flights to San Francisco and subsequently trucks its freight to Sacramento during the fog season, commercial airline officials did not perceive fog as a significant problem in the long run based on the precept that technological advances will overcome the negative impacts. General aviation at Executive Airport was studied utilizing an assessment of daily fuel loadings. Flight operations were found to be significantly reduced on foggy days at this facility. Airport officials in this case felt that the important impacts of fog upon flight operations will likely persist into the future. These examples illustrate the varied relevance of the fog hazard to air transportation activities.

RÉSUMÉ

Durant décembre et janvier, mois d'hiver, la ville de Sacramento se trouve souvent sous le brouillard. Une analyse des vols annulés, des délais, et des détournements dus au brouillard, durant les mois de décembre 1984 et janvier 1985, à l'aéroport Metropolitain de Sacramento, montre l'influence du brouillard sur le transport aérien. Onze pour-cent de tous les vols et 23% des envolées durant les journées très brumeuses ont été affectés. Une compagnie de transport de fret aérien a dirigé, de façon permanente, durant la saison des brouillards, toutes ses envolées vers San Francisco et transporte le matérial à Sacramento par camions. Par contre, les compagnies de transport aérien de passagers ne voient pas le brouillard comme un problème important car ils comptent sur les développements technologiques modernes pour compenser les conditions météorologiques négatives. A l'aéroport Executive, qui sert l'aviation générale, on a étudié l'influence du brouillard en comparant les quantités de carburant chargé quotidiennement dans les avions. A cet aéroport, le nombre d'envolées a été très réduit

durant les jours de brouillard intense. Les autorités de l'aéroport, en ce cas, croient que les effets du brouillard vont continuer dans le futur. Ces examples montrent la variabilité des effets du brouillard sur les opérations des aéroports de Sacramento.

1. INTRODUCTION

California's Central Valley exhibits between 30 and 40 days of fog per year on average (Court and Gerston, 1966; Hardwick, 1973). These fogs are primarily caused by nocturnal radiative cooling especially during the winter when damp soils and a general increase in humidity caused by the seasonal rains prevail (Stone, 1936; Lantis et al., 1981). Cooler temperatures, increased humidity borne of precipitation and the entrapment of maritime polar air, coupled with the positioning of a high pressure cell over the Great Basin and Columbia Plateau regions which create an upper level inversion, cause the winter fog maxima (Lockhart, 1931; Stone. 1936). Hot temperatures and a lack of atmospheric moisture negate summer formation.

Byers (1959) comments that damp ground can supply enough moisture for condensation in the lowest layers below the inversion. Such conditions are indicative of California's Central Valley, which is denoted by damp and swampy ground. These swampy areas have been traditionally typified by the presence of Mexican bulbrush and tules, hence the regional name "Tule Fog" (Deeward, 1923; Stone, 1936). Subsequent to the reports by Deeward and Stone, many of the tule bottoms have been drained and are currently being used for crops such as rice.

Although lacking the spectacular violence of other meteorological hazards such as tornadoes and hurricanes, fog does nonetheless present an important problem to human activities – that of reduced visibility. A reduction in visibility has a profound effect upon air transportation endeavors. Plagued by persistent wintertime fog, and yet functioning as a full service transportation centre, Sacramento, California is a prime choice for a study of fog and its relationship to transportation. Transportation has always been a significant activity for Sacramento. Historically, the city served as a gateway to the Sierra Nevada goldfields and formed the western terminus for both the Pony Express and the first trans-continental railroad. Today, Sacramento functions as a regional air center for both commercial and general aviation.

2. STUDY AREA

Central Sacramento lies 35 km west of the Sierra Nevada and 46 km east of the Coastal Ranges. The only breach in these mountainous barriers occur roughly 80 km southwest of Sacramento as the Coastal Ranges give way to the Carquinez Strait and San Francisco Bay. Sacramento is in the midst of an extremely flat valley bottom. Topographic map analysis at the 1:250,000 scale indicates, for example, an average slope of only 0.35% extending from

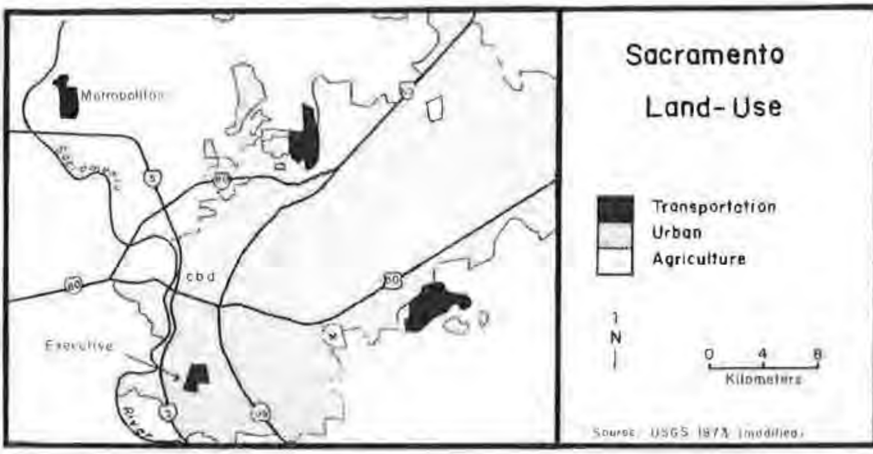

FIGURE 1. General land use pattern for the Sacramento area including the location of Metropolitan and Executive Airports.

Sacramento's central business district to the Sierra Nevada base.

Meteorological data published in summary form by the National Oceanic and Atmospheric Administration (NOAA) are available for Sacramento Metropolitan and Executive Airports (Figure 1). December and January exhibit an average of 9 and 10 days of fog, respectively and are characterized by long periods of continuous fog (Martini, 1984). For example, Martini reports that January 1961 had 23 consecutive foggy days, while December 1947 recorded 21. An analysis of hourly weather records for the winter months of December and January for six seasons (December 1979 – January 1980 through December 1984 – January 1985) revealed that foggy conditions were experienced over 50% of the time.

3. FOG AND AIR TRANSPORTATION AT METROPOLITAN AIRPORT

Originally built in 1967, Sacramento Metropolitan Airport operates one 2600 m runway and is served by seven commercial airlines. The airport is equipped with an instrument landing system designated by the Federal Aviation Administration (F.A.A.) as Category II, which permits flight operations in restricted visibilities to as low as 365 m. It should be noted that instrument systems rated Category III allow for operation at zero visibility while Category I rating requires a minimum visibility of 805 m.

Inter-department correspondences between the Deputy Director of Flight Operations and the Chief of Fire and Rescue Operations for Metropolitan Airport itemizing cancelled, delayed, or diverted flights and their cause coupled with a summarized flight schedule provided by the Flight Operations Department were used to determine the number of cancelled, diverted, or delayed flights (a flight constitutes a landing or takeoff) during the

December 1984 – January 1985 fog season. Records were not available for previous years. The data provided were only for weekdays (Monday through Friday); thus the following statistics are based on a December-January fog season of weekdays only, constituting 44 days.

During the 44-day fog season, 11.0% or 301 of 2,718 total scheduled flights were either cancelled, diverted, or delayed due to fog-impaired visibility conditions (Table 1). All affected flights occurred during the 21 days experiencing at least 16 fog hours. This situation is not surprising since radiation fog is primarily nocturnal and the airport operates chiefly during daylight hours. When calculated only for these 21 severely foggy days, 23.1% of all flights were affected, with cancellations (totally 165) being more common than delays or diversions.

The degree to which an airline is affected stems largely from its technological capabilities. For example, Western Airlines operates planes that have on-board avionics that parallel the airport's Category II instrument landing system, and its crews have been certified by the F.A.A. to use such equipment. Consequently, Western experiences a cancellation rate of only 6.1% on severely foggy days. Air California does not have Category II capability and by contrast experienced a cancellation rate of 23%. Air California's airport manager noted that this technological deficiency prompted the company to cancel many flights as a means of preventing inconveniences caused by diversions or prolonged delays. Route structure was considered an incidental factor in determining this policy.

Western Airlines and Air California officials perceived wintertime fog as a seasonal hindrance that would eventually be subdued by technology and the opening of a second runway at Metropolitan. Metropolitan Airport is currently upgrading its instrument landing system to Category III, which will allow for operations in zero visibility. The F.A.A. Tower Chief reported that Category III equipment would be ready by Spring of 1987. The Flight

TABLE 1. Flight Cancellations, Diversions and Delays at Metropolitan Airport During the December 1984-January 1985 Fog Season

	number of flights	% of flights affected on 44-day season*	% of flights affected during severe fog days**
Cancellations	165	6.0%	12.6%
Diversions	84	3.1%	6.5%
Delays***	52	1.9%	4.0%
Total Affected	301	11.0%	23.1%

* 44-day season: All business days (Monday-Friday) during December 1984 and January 1985.

** Severe fog day: A 24-hour day exhibiting foggy conditions for at least 16 hours.

*** Delays are relative to times published in the official Airlines Guide and with the F.A.A. tower. These times are identical.

Operations Department noted that Pacific Southwest Airlines, United, and American Airlines are already operating with Category III airplanes and crews. Interestingly, Pacific Southwest serves a very small regional market yet has this advanced technological ability.

The second runway is under construction and is due to be operative by the late 1980's. The Air California airport manager perceived that this new runway would decrease the fog problem since "drift" may allow the second runway to be open while the first is closed. Both Western and Air California officials felt that fog was highly erratic at the micro-scale.

The fog situation did, however, cause Emory Air Freight to instigate a policy of flying into San Francisco and trucking their freight 145 km to Metropolitan during the fog season. It was noted by a company spokesman that 8 out of 21 flights were late during January 1985. The new fog season policy was implemented to alleviate "dissatisfaction among customers in sunnier parts of Sacramento and environs."

4. FOG AND AIR TRANSPORTATION AT EXECUTIVE AIRPORT

Sacramento Executive Airport functions as a general aviation facility. It is, for example, home to over 400 small airplanes or Fixed Base Operators. Normal Flight operations, based on conversations with the airport manager, require 5 km visibility, but Executive's runway number two is equipped with an instrument landing system that allows take-offs and landings to occur with only 0.8 km visibility. Runway number one does not, however, possess this capability.

Daily fuel loading records, provided by Executive Airport's Operations Department, for four fog seasons (December 1981 – January 1982 through December 1984 – January 1985) were used for this study. Specific flight operations data was nonexistent, which precluded a database for analyzing delays and separating business from pleasure activities. The daily fuel loadings were interpreted as being representative of daily flight operations, a process that undoubtedly has some inherent flaw since fuel loadings are not consistent from day to day even without fog impacts. Nevertheless, these data were used in the absence of an alternative data source to provide some insight into the potential impact of fog.

The effects of fog were determined by means of comparing average number of fuel loadings on fog days and nonfog days using the Students's t-Test. Fog days were defined as days exhibiting fog for at least 75% of the time from 6:00 through 18:00 hours, while nonfog days experienced less than 25% fog hours during the same 12-hour period. An intermediate category, days between 25% and 75% fog hours, was also used. The 6:00 through 18:00 time interval was selected because it was during the daylight hours that most flights occurred for this airport.

Results depicted in Table 2 indicate that an average of 65.1 fuel

TABLE 2. Fuel Loadings at Executive Airport During Fog Seasons December 1981-January 1982 Through December 1984-January 1985

	Fog Days	Intermediate Days	Nonfog Days
1981-82			
Number of days	25.0	14.0	23.0
Average fuel loadings	35.8	63.4	81.8
Standard deviation	12.4	31.1	29.6
1982-83			
Number of days	30.0	10.0	22.0
Average fuel loadings	28.5	64.5	58.9
Standard deviation	12.3	25.4	24.0
1983-84			
Number of days	22.0	20.0	20.0
Average fuel loadings	32.8	54.4	60.1
Standard deviation	13.4	15.0	19.8
1984-85			
Number of days	31.0	16.0	15.0
Average fuel loadings	27.4	42.4	59.5
Standard deviation	13.5	20.3	18.4
Total Average Fuel Loadings	31.1	56.4	65.1

loadings occurred on nonfog days, as compared to 31.3 fuel loadings (48% less) for fog days. T-test scores for fog days relative to both nonfog days and intermediate days during all four fog seasons, were consistently significant at the .01 level indicating significantly lower fuel loadings on foggy days. In addition, two of the four seasons (1981-1982 and 1984-1985) posted significant differences (at the .01 or .05 confidence levels) between the intermediate days and nonfog days categories. A more detailed record and analysis of the temporal variations of fuel loadings is needed to confirm the impact of fog upon flight activity.

Although Executive Airport's runway number 2 contains Category I instrumentation for limited visibility operations, it is not of the same sophistication as that at Metropolitan Airport. Executives Airport's minimum runway visibility is 805 m compared to 365 m for Metropolitan. Consequently, incoming flights are often diverted to other airports in the Sierra Nevada foothills, which are located above the Central Valley's temperature inversion layer. Such a situation minimizes the wintertime activity of airplanes based at Executive Airport since they risk being forced to land some 40-65 km away in the Sierra Nevada foothills.

Equipment that would further reduce the minimum runway visibility requirement is not currently being planned. According to airport management, capital investment in on-board avionics systems and the certification procedures operators would have to incur, will likely prevent Executive Airport from up-grading its limited visibility countermeasures to the level in existence at Metropolitan Airport. Therefore, fog effects upon aviation at Executive Airport are likely to persist indefinitely.

5. CONCLUSION

Capital investment in on-board and ground-based instrument landing systems can substantially overcome the problems of fog induced limited visibilities. This endeavor is being undertaken at Sacramento Metropolitan Airport and many of its service carriers. Metropolitan's implementation of Category III equipment will afford the opportunity for individual airlines to almost completely mitigate the fog problem.

General aviation at Sacramento Executive Airport was, by contrast, profoundly affected by fog. For example, fuel loadings averaged 48% less on fog days relative to non-fog days, and these averages proved to be significant at the .01 confidence level during every fog season. According to airport management, the problem will probably not be mitigated in the foreseeable future due to the high costs of advanced avionics systems and required pilot training. Most light aircraft operators are simply not likely to make such an investment.

The examples given by these two Sacramento airports serve to illustrate the effect of a natural hazard, in this case fog, on man's activities and his subsequent mitigation attempts to address the problem.

ACKNOWLEDGEMENTS

The cooperation of officials of the following organizations is gratefully acknowledged: Air California, Emory Air Freight, Executive Airport Management, Metropolitan Airport Flight Operations, Western Airlines. Dr. G. Allard translated the abstract into French.

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Plotting Climate Diagrams with a Microcomputer

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ABSTRACT

A microcomputer program for plotting Walter and Lieth climate diagrams is described. The program runs on MS-DOS systems and can produce outputs in a wide range of sizes on a number of graphics monitors, printers, and plotters.

RÉSUMÉ

Cet article décrit un programme pour le micro-ordinateur qui fait les diagrammes climatiques de Walter et Lieth. Le programme fonctionne sur les systèmes MS-DOS et peut faire les diagrammes d'une gamme immense de dimensions sur beaucoup de devices graphiques.

INTRODUCTION

Many climate classification systems have been devised to aid in explaining the distribution of natural vegetation on the earth's surface. Most of these are based on only temperature and precipitation data, largely because of their availability, although there is no doubt that other elements may be equally important in explaining the distribution of vegetation. It is thus important to use the data to their maximum advantage.

Some systems use only the annual values of the two elements, with or without an indication of the seasonal distribution (Köppen, 1918), while others use values for monthly or shorter periods (Thornthwaite, 1948). Although most classification methods (such as those above) tend to be subjective, recently more objective methods have been developed (McBoyle, 1971; Powell, 1978).

CLIMATE DIAGRAMS

In the early 1960s, Walter and Lieth published a large atlas containing temperature and precipitation data from the major climatological stations a)

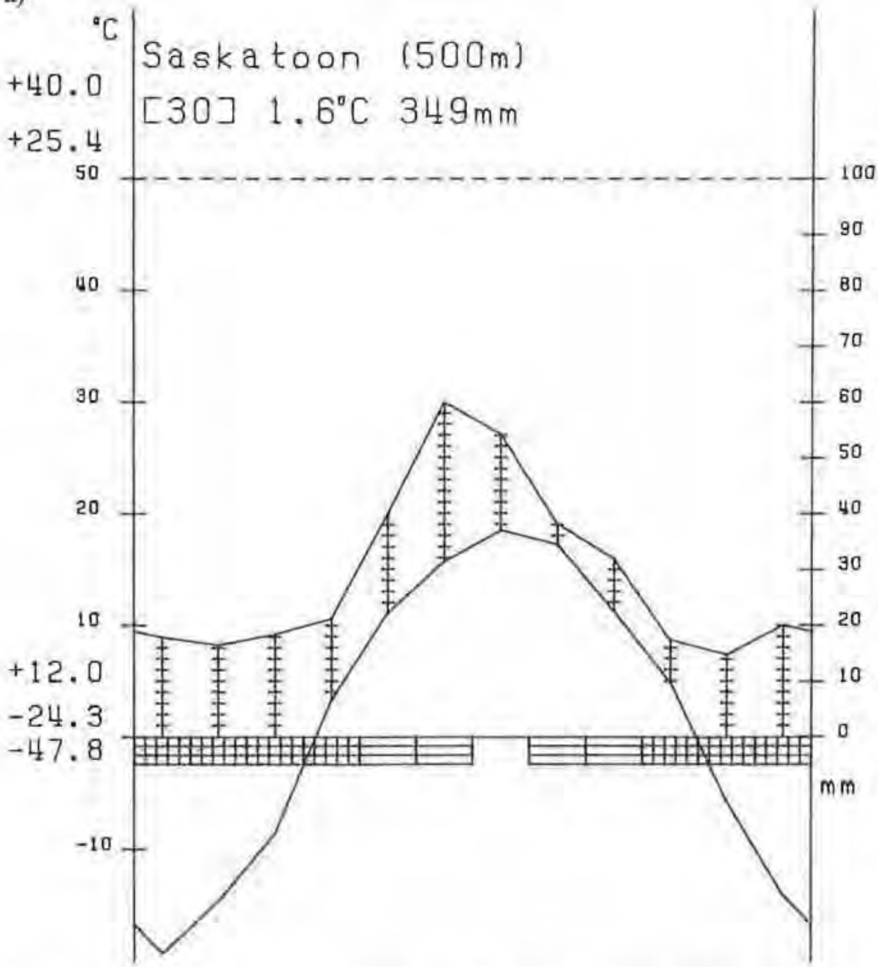
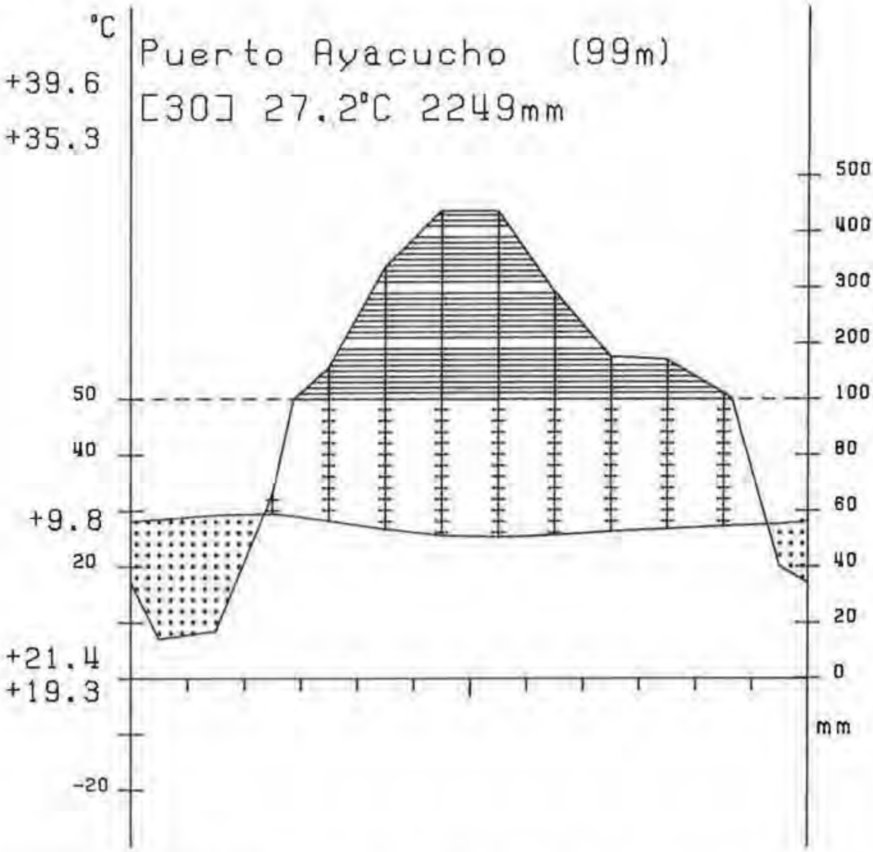


FIGURE 1. Microcomputer-plotted climate diagrams for a). Saskatoon, Canada, and b). Puerto Ayacucho, Venezuela. The curves are monthly means of precipitation and temperature. Dotted areas represent periods when the temperature curve is above the precipitation curve. Vertical and horizontally-ruled areas represent periods when the precipitation curve is above the temperature curve. The precipitation scale is changed to logarithmic above 100 mm, and ruled horizontally (as in b.). At the top of the diagram are indicated the station name and altitude, the period of record, and the annual means. At the left side, the larger numbers indicate the extreme

around the world. The data, in the form of monthly averages, were plotted as time series on the same graph (Figure 1). These pictorial representations are a type of climatograph, as defined by W.M.O. (1983). They were given the name "*climate diagrams*" and have since become widely used in many areas of vegetation science. Subsequently, a climate classification system was developed, based on these diagrams (Walter, 1973).

b)



maximum temperature for any month, the warmest-month mean maximum temperature, the mean annual daily range, the coldest-month mean minimum temperature, and the extreme minimum temperature for any month. Frost occurrence is indicated by hatching just below the X-axis. Cross-hatching indicates mean monthly minimum temperature below 0°C; horizontal hatching indicates absolute monthly minimum temperature below 0°C; and the absence of hatching indicates a freeze-free month.

These *climate diagrams* contain the following information: station altitude and length of record, monthly and annual mean temperatures and precipitation totals, mean daily temperature range, and annual temperature extremes. Although the same information can be found in many tables (e.g. Wernstedt, 1972; Landsberg, 1969-84), a graphical presentation (Ehrenberg, 1978; Cleveland and McGill, 1985) forces one to view the data from a particular perspective. Another method of presenting temperature and precipitation data is the *hythergraph* (W.M.O., 1983). It has a monthly precipitation scale along the X-axis and a monthly temperature scale along the Y-axis. Points are plotted for each month and joined by a dashed line to show the sequence through the year. These diagrams are useful for displaying relationships between the seasonal variations of temperature and precipitation, as well as hysteresis effects.

These *climate diagrams* also reveal relationships between the two time series, and as well give an indication of the climatic water balance. This is because of the close relationship between surface evaporation and temperature. If one assumes that evaporation from a vegetated surface decreases markedly as temperatures drop below the freezing point, then there is justification for aligning 0°C on the temperature axis with zero on the precipitation axis. The choice of scale ratios may be justified by examining the large-scale relationship between temperature and surface evaporation. Ferguson et al (1970) quote a Christiansen method of estimating evaporation from temperature and several other meteorological parameters. Their temperature effect amounts to approximately a 4% increase in evaporation per 1°C increase in temperature. Applying this to a global average of terrestrial evaporation of about 50 cm per year (Baumgartner, 1972) leads to a temperature effect of about 1.7 mm/month for a 1°C increase in temperature. This is close to the 2 mm/month implied in Figure 1. When the precipitation curve lies above the temperature curve, a moisture surplus is indicated. This is the case during the entire year at Saskatoon (Figure 1a), although a near deficit develops in late summer. Some modifications may be made to the diagram to treat this situation more realistically (Walter, 1973). The diagram for Puerto Ayacucho, Venezuela (Figure 1b), shows a pronounced moisture deficit during the winter months, which is characteristic of most tropical savanna sites. During three months, the temperature curve is above that for precipitation, implying a moisture deficit, while the remainder of the year has the precipitation curve above that for temperature, implying a surplus of moisture.

It should be stressed that the main advantage of these *climate diagrams*, and of *climatographs* in general, is their pictorial nature, which gives the viewer a "picture" of a site's climate and permits it to be compared with the climates of other sites at a glance. More detailed information concerning these diagrams may be found in Walter and Lieth (1960-67), Walter (1973) and Muller (1982).

PLOTTING PROGRAM

This computer program for plotting climate diagrams was originally written by Ostendorf et al (1981) for a main-frame computer. The program was written in the FORTRAN language, using a number of packaged plotting subroutines. The program has been adapted by the author to an MS-DOS microcomputer system, and a compiled version is available on 5.25 and 3.5 inch floppy disks. The microcomputer version is interactive, and capable of producing output on a variety of printers and plotters, as well as a graphics monitor. The size and page position of the diagrams may be chosen interactively. The source code for the main-frame version was published in Ostendorf et al (1981) while that for the microcomputer version is available from the author.

In order to use the program, an input data file (see Appendix) must be created for each climate station. This contains all of the station information described above. At run time, the program provides an opportunity for the user to specify: the desired output device (22 choices), the data filename, the desired diagram format (3 choices), the desired scale, and the x and y co-ordinates of the desired origin. A half-page size diagram takes about 2 minutes to be plotted on a HP 7470A plotter.

SUMMARY

The microcomputer program described in this article provides a simple means of plotting Walter and Lieth climate diagrams using a microcomputer and a graphics printer or plotting device. Copies of the program are available from the author.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. H. Lieth for providing a copy of the original program source code.

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Example of Input Data File

```
Saskatoon (500m)
     0      0     30          1.6  349.  -24.3  -47.8   25.4   40.0   12.0
 -19.3  -14.6   -8.6    3.3   11.1   15.7   18.5   17.2   11.2    4.9   -5.7  -14.1
  18.8   16.4   18.4   21.2   39.9   59.9   54.2   38.1   31.8   17.3   14.7   20.0
222211011222
```

The station input file consists of five lines of data.

Line *one* is the station descriptor, which usually contains the station name followed by the altitude in brackets. Up to 80 characters may be entered, but only the first 25 will appear on the diagram.

Line *two* contains 11 entries, each six characters in length. These are: data conversion specifier (0 if data are in mm and °C; 1 if data are in inches and °F); diagram format specifier (1, 2 or 3 – see text); number of years of record for temperature data; number of years of record for precipitation data (if same as temperature, leave blank); mean annual temperature; mean annual precipitation; mean daily minimum temperature of coldest month; absolute minimum temperature; mean daily maximum temperature of warmest month; absolute maximum temperature; and finally, the average annual daily temperature range (maximum – minimum). If any of the last five entries is unknown, enter 10000. in the field.

Line *three* contains the mean monthly temperatures, starting with January if the station is in the northern hemisphere, or July if the station is in the southern hemisphere.

Line *four* contains the mean monthly precipitation totals, arranged as in line three.

Line *five* contains 12 single-digit codes describing the temperature minima of each month, arranged as in line three. (0 indicates data is missing or the minimum temperature has never been less than 0°C; 1 indicates the mean minimum temperature is above 0°C, but the absolute minimum is below 0°C; 2 indicates that the mean minimum is below 0°C).

IMPROVING DROUGHT POLICY: A PLAN OF ACTION

D.A. Wilhite and *W.E. Easterling*[1]

ABSTRACT

In September 1986 the International Symposium and Workshop on Drought, sponsored by the University of Nebraska's Institute of Agriculture and Natural Resources and the Illinois State Water Survey, was held at the University of Nebraska-Lincoln in the United States. More than 150 scientists and policy makers from more than twenty-five drought-prone nations participated. The symposium was organized to review and assess our current knowledge of drought and to determine what research and information is needed to improve national and international capacity to cope with drought. The symposium and workshop provided a forum for discussion of the physical and societal implications of drought in the context of a variety of spatial scales and in various socio-economic and political settings. The purpose of the workshop was to draw attention to drought as a policy issue, one that can be managed more effectively through an interdisciplinary and cooperative effort from the scientific and policy communities. The ultimate goal of the workshop was a "plan of action" to facilitate drought planning efforts worldwide. The article reviews some of the common themes that emerged from the symposium and workshop, including major constraints to effective drought planning, research priorities, and a framework to be used by governments as a model in the development of comprehensive drought plans.

INTRODUCTION

Drought, for all its disruptive tendencies, is a normal feature of climate. Yet, as droughts come and go, left behind are the visible scars of human suffering, along with the usual debates over the effectiveness of ad hoc relief efforts and, at best, inadequate or incomplete plans for dealing with future droughts. With the first rains comes a new sense of security; relief efforts are dismantled, plans for the next drought are forgotten, and society resumes its so-called harmony with climate until the rains fail and the cycle begins anew. Despite the

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2 Illinois State Water Survey and University of Illinois

dramatic awakening of the world to the plight of Ethiopia in recent years, a few wet seasons in a row there have already prompted the abandoning of some relief efforts.

This paradox was addressed by the scientists and senior-level policy makers at the International Symposium on Drought. The scientists reviewed what is and is not known about drought, and the policy makers spoke on current efforts to cope with drought effects. A post-symposium workshop was held to explore the rudiments of effective national and international drought preparedness planning.

The symposium and workshop was held out of a basic recognition that past efforts to deal with the problems of drought have tended to address only narrow aspects of drought (e.g., desertification, agricultural production, climate system anomalies, water resources, etc.). In this meeting, a comprehensive, intersystem approach was taken which, in essence, joined discussions of physical science, social science, and policy response aspects of drought, and sought to meld these discussions into a basic strategy for improving our national and international capabilities of coping with drought.

In the following paragraphs, some of the common themes that emerged from discussions will be reviewed. Specifically, major constraints to effective drought planning are outlined; a set of recommendations and research priorities is set forth; and, lastly, a drought planning framework, which draws from previous discussions, is proposed. For a more complete discussion of these themes, the reader should refer to the full report of the symposium and workshop (Wilhite and Easterling, 1987).

CONSTRAINTS TO DROUGHT PLANNING

The initial steps toward rational planning for drought involves enumeration of the major constraints to effective response to past droughts. Workshop participants were asked to address this issue. Many of the problems that have been encountered in previous efforts to cope with droughts were identified by participants.

Drought becomes apparent in complex ways and is inherently difficult to fully comprehend by nonscientists. It is often viewed by policy makers and bureaucrats as an extreme event and, implicitly, rare and of random occurrence. Thus, drought may be viewed as something that is outside of government control. Moreover, if drought continues to be perceived by policy makers as a freak quirk of nature – one for which there can be no planning – there will be no planning.

The constraints encountered in previous efforts to cope with droughts are:

- Inadequate understanding of drought occurrence
- Uncertainty of the economics of preparedness
- Lack of drought prediction skill

- Society's variable vulnerability to drought
- Gaps in information and insufficient human resources
- Poorly developed science of water management
- Inadequate understanding of drought impact-related sensitivities and adjustment and adaptation mechanisms

Any expenditure of scarce funds to mitigate vagaries of a common resource such as the atmosphere is likely to be challenged. Indeed, a major difficulty in assessing the economics of drought preparedness is the determination of the benefits of drought planning versus the costs of drought. Preparedness costs are fixed and occur now and, given an uncertain discounting in the future, may be perceived as too high given the benefits derived. Further complicating this issue is the fact that the costs of drought are not solely economic. They must also be stated in terms of human suffering and degradation of physical resources, items whose values are inherently difficult to estimate.

The prediction of drought will always contain uncertainty. Some policy makers believe that because drought cannot be sufficiently predicted, drought planning is of limited value. As a result, many facets of drought response planning that are not necessarily dependent on predictions (e.g., food and/or water storage) are neglected as well.

There is a great spatial and temporal variability in society's vulnerability to drought. For example, some subnational regions are relatively more drought sensitive than others. As crop mixes change in an agricultural region over time because of factors such as economics (or climate), vulnerability to drought may also change. Superimposed on this spatial and temporal variability is the tendency to view drought as a regional rather than national problem, and unaffected regions are apt to be more hesitant to commit national resources to manage affected regions.

A particularly troublesome problem, especially in developing countries, is the general lack of information necessary to provide the foundation for all components of a drought plan – prediction, monitoring, impact assessment, adaptation, and response. This would include fundamental meteorological, agronomic, demographic, and economic data; and the availability of other necessary resources (e.g., trained people). This problem is compounded by insufficient data bases.

Considerably more scientific knowledge is needed of appropriate and effective water management practices, particularly with respect to drought. Drought should be viewed in a comprehensive systems context which incorporates all water-dependent biophysical processes and human activities. For example, in the Climate Impacts, Perception and Adjustment Experiment (CLIMPAX), water management behavior in the California Water Project was found to be significantly influenced by climatic fluctuations, especially drought. Furthermore, more normative research is needed that is aimed at increasing water use efficiency, especially focusing on existing technologies such as irrigation.

More knowledge is needed of the indirect impacts of drought as well as direct impacts. It is particularly important that methodologies be developed that allow establishment of credible linkages between moisture deficient conditions and associated impacts. Moreover, equal effort should be given to identifying the possible range of adjustment and adaptations available to lessen the negative impacts of drought.

STRENGTHENING THE BASIS FOR DROUGHT PLANNING: A PROGRAM OF RESEARCH

Most, if not all, of the constraints to drought planning mentioned above can be eliminated or overcome by increased understanding of the drought phenomenon, including its biophysical and societal dimensions. Indeed, drought is a topic that remains rich in unanswered research questions, and answers to many of these questions are the key to improving our abilities to cope with the many problems drought poses. In the following paragraphs, we propose a set of drought research priorities aimed at facilitating progress toward a goal of drought preparedness.

Research Priorities: Prediction

The predictability of the climate system is inherently limited. The limits to predictability vary with region, season, and lead time. These variations have not been mapped adequately. Thus, an important task is diagnostic research to identify the "targets of opportunity": the regions, seasons, lead times, and predictands for which prediction seems most feasible.

Three components of climate research can be distinguished: (1) theory, (2) general circulation modeling, and (3) empirical analysis. All three components, as well as interaction between them, are essential for the diagnostic understanding of the climate system, which in turn is basic to the development of drought prediction. Empirically based climate prediction has made the most progress toward operational application, and further work on general circulation models (GCMs) and theory is imperative. Both empirically based and GCM-based predictions of climate anomalies are expected to possess intrinsic limitations. Further research (including the verification of forecasts on an independent data set) is needed into the limits of predictability in both methods.

Predictive research priorities are determined primarily on the need to overcome important knowledge gaps that limit predictability. Tailoring the acquired prediction skills to applications is mainly the concern of scientists working directly with users. Integration of research activities and activities of researchers working directly with users can produce more appropriate products for users from both groups. Integration also facilitates innovative adaptation of technological spinoffs from research and informs the research groups of community and policy concerns. Integration is not easy and care must be taken not to weaken the efforts of each group. Much understanding and tolerance is required on the part of research managers and others.

Research Priorities: Monitoring, Detection, and Early Warning

The primary objective of monitoring systems is to provide information to a particular client or user group in a timely and reliable manner so that effective action can be taken to alleviate potential impact. Each user group has specific needs and the information derived from any monitoring system will need to be expressed in different formats to be useful to the various groups. It is crucial that research address questions of what these needs are – how they vary among groups, across regions, and over time; and what are the most basic commonalities in characterizing the needs of user groups. Information of this nature will allow monitoring systems to provide information that is of utility to a maximum number of potential users.

Research on methodology and technique development in support of monitoring and early warning systems is a high priority. It is particularly important that these monitoring methodologies and techniques adequately take into account the data and human resource constraints that exist in developing countries. The use of satellite imagery offers tremendous opportunity for monitoring developing drought conditions. It is imperative that research on the application of this technology to the early detection of drought conditions be expanded.

Research Priorities: Impact Assessment

Many simple empirical techniques have been developed (e.g., natural experiments, case scenarios, historical analogues) to assess biophysical and societal impacts of drought for which useful data are readily available for most locations. However, these techniques are not well developed and have not gained acceptance or credibility among scientists and potential users because they have not been tested or because they seem to lack sophistication.

Research is needed to assess how simple, easy-to-use techniques that could provide useful information can be applied with greater reliability, credibility, and acceptance. The potential exists to greatly improve impact assessments without a great deal of additional technical research and developmental work.

In the long run, efforts should be focused on developing more sophisticated deterministic (quantitative) impact assessment models. The data required of these types of models, unfortunately, are not uniformly available in all regions. However, as data monitoring improves in currently data-scarce areas, more sophisticated techniques should be available to utilize such data in arriving at increasingly sophisticated impact assessments. In this regard, expert systems modeling offers an opportunity to extend more simplistic empirical impact assessments and may provide a means of bridging empirical and deterministic assessment techniques until there is adequate data and understanding to develop purely deterministic models.

Research Priorities: Adaptation and Adjustment

Human systems have remarkable capacity to adjust and adapt to dynamic environmental conditions. However, this process can be greatly speeded up when receiving direct stimulus from government and other institutions. Much of the research called for under the rubric of facilitating societal adaptation to drought concerns agricultural practices. Specific research priorities include:

1. *Water Management*. Water management research is critical since water is the major factor limiting productivity in the arid and semiarid zones. Two areas were identified as offering substantial opportunities for this research – appropriate tillage and water harvesting techniques.

   Research on appropriate tillage practices directed toward improving moisture conservation and management has shown considerable promise for various crops in arid and semiarid environments. Appropriate water harvesting methodologies need to be developed so rain water can be harvested and used in crop production.
2. *Genotypes*. Research is needed to identify and test desirable genotypes for drought tolerance, early maturity, disease resistance, high yields, and adaptation to particular agroecological zones.
3. *Climate-System Interaction*. Climate is the key factor that directly affects cropping patterns: it influences a farmer's decision to adopt a particular cropping system. There is a need to understand how cropping systems in given agroecological zones react to climate variations. Researchers also need to devise strategies that minimize the adverse effects of these variations on the productivity of different cropping systems.
4. *Alternative Crops and Alternative Uses of Established Crops*. Alternative crops should be identified and promoted for each agroecological zone. Research on alternative uses of new or minor crops must be carried out in advance to guarantee a market for these crops.
5. *Research on Fertilizer Use in Cropping Systems*. Fertilizer use may help guard against drought by encouraging development of a root system, which will utilize soil water more efficiently. There is a need to identify the economic returns associated with different rates of fertilizer application for dryland cropping systems.
6. *Alternative Land Use Systems (agroforestry, silviculture, pasture)*. It is essential that alternative land use systems that are compatible with critical production factors (such as climate and soil) be identified for drought-prone regions.

Research Priorities: Planning and Response

Perhaps the first step in planning for future droughts is to evaluate the impact of and response to previous drought. This emphasizes the importance of the evaluation process itself. Indeed, five areas of research are suggested that would advance our ability to evaluate past assessment and response efforts: (1) hydrological impact, (2) recovery of agricultural activity, (3) economic impact, (4) decisions made during drought, and (5) social response to drought. These research areas are discussed briefly below.

Drought has a considerable impact on the hydrology of a stricken area. An assessment of this impact through ground surveys and satellite monitoring would be beneficial in future planning efforts, particularly with respect to water use, energy, and agricultural activity.

Depending on the duration, intensity, and spatial characteristics of drought, the agricultural recovery of an area could be handicapped despite average or better rainfall. Input requirements (e.g., seed, fertilizer, pesticides, implements, energy) could be determined on the basis of the magnitude of the drought impact. Assessment of this type would be helpful when drought recurs.

An assessment of losses in agricultural and agriculture-based industries should be made following each drought episode. This type of assessment in developing countries must include the condition of people and livestock and market prices of essential commodities. It is also important to assess the impact of relief measures on the various economic sectors and to determine if individual citizens, industries, municipalities, or others were affected substantially but were neglected by available assistance programs. What groups or individual persons should be targeted for assistance in the future? To what extent did assistance programs discriminate against women or female children or children in general?

Decisions made by governments during periods of drought are made for humanitarian and political reasons. It will be difficult, if not impossible, to change this reasoning. Therefore, it is important that evaluations of drought assessment and response efforts are carried out by an organization other than the one with responsibility for implementing program plans.

In many developing countries the occurrence and effects of natural disasters are considered inevitable and unavoidable. The general population considers these events and their effects to be unmanageable and out of the realm of governmental influence. A change in this outlook, based on scientific explanations and approaches, could help in mitigating the effects of events such as drought. This change could be accomplished by organizing meetings and symposia in developing countries where governmental leaders could explain the strategies to the people.

There is a long tradition of responding to natural disasters purely in a crisis response mode, and drought is no exception. Airlifting hay from the American Midwest to drought-stricken farmers in the Southeast makes for good publicity, but it is very cost-ineffective drought management. In his keynote address to the symposium, Nebraska's governor, Robert Kerrey, stressed the need to plan for drought with a philosophy of risk assessment. This is far more effective than crisis management. Perhaps the most difficult of positions for an elected official is not to be able to respond to the needs of constituents during times of duress. And this is far more likely to happen in a crisis for which there has been inadequate pre-crisis planning.

In this concluding section, we have distilled and synthesized wisdom gained from symposium and workshop discussions and we propose the tenets of a plan of action predicted on risk assessment. This "plan" could serve as a model for drought planning at various levels of government and in various socioeconomic and political settings.

Figure 1 is a ten-step drought planning process that represents the culmination of previous discussion. This process is sequential and it is dynamic in the sense that several iterations are possible in which component parts (steps) can be modified or adapted to fit existing sociopolitical realities. The process is necessarily flexible and highly generalized so that it can be adapted to many geographic areas and in many levels of government.

The first three steps actually involve mustering the necessary resources to initiate development of the plan. These include:

1. creation of a joint government-industry-research task force to oversee plan development;
2. careful articulation of the specific objectives of the plan such as to:
   - provide timely and systematic data collection, analysis, and dissemination of drought-related information;
   - establish criteria for starting and ending various assessment and response activities by governmental agencies during drought emergencies;
   - provide an organizational structure that assures information flow between and within levels of government and defines the duties and responsibilities of all agencies;
   - maintain a current inventory of governmental agency responsibilities in assessing and responding to drought emergencies;
   - provide a mechanism to improve assessments of the impacts of drought on agriculture, industry, municipalities, vulnerable population groups, etc.; and

Appointment of
Drought Task Force
(STEP 1)

Statement of Purpose
and Objectives
(STEP 2)

Inventory of Natural and Human
Resources, Financial Constraints
(STEP 3)

Development of Drought Plan
(STEP 4)

Identification of Research Needs
and Institutional Gaps
(STEP 5)

Synthesis of Drought Management
Science and Policy
(STEP 6)

Identification of Response Options
(STEP 7)

Implementation of Drought Plan
(STEP 8)

Development of Educational
and Training Programs
(STEP 9)

Development of
System Evaluation Procedures
(STEP 10)

Figure 1. A ten-step drought planning process.

3. careful inventory of natural and human resources available to help meet these objectives should be undertaken by the task force.

Development of the actual plan (Step 4) can be accomplished through establishment of three interdependent organisms: (1) moisture assessment committee, (2) impact assessment committee, and (3) policy committee.

The moisture assessment committee will have four primary objectives: (1) to inventory data quantity and quality from current observational networks, (2) to determine the needs of primary users, (3) to develop a drought monitoring system, and (4) to develop or modify current data and information delivery systems. The functions of this committee will necessitate close interaction with the impact assessment committee.

The impact assessment committee's responsibility is not only to ascertain the impacts of drought but also to identify and muster available resources to mitigate those effects. The committee must then identify those government agencies and nongovernmental organizations that can provide some level of assistance in response to drought as well as the exact nature of that assistance. The committee must also determine the proper protocol for requesting assistance by affected groups.

The policy committee, comprising senior-level officials, will serve as a coordinating body to oversee the activities of the moisture assessment committee and the impact assessment committee(s), keep political officials advised of the status of impacts in the distressed area, and make recommendations about further actions that need to be taken. This coordinating committee would have direct access to political leaders. The task force could evolve into this policy committee following completion of the plan, since the composition of the two groups is similar.

To be carried out concurrently with Step 4, the purpose of Step 5 is to identify research needed in support of the objectives of the drought plan and to recommend research projects to remove deficiencies that may exist. Early assessments of the likely impact of drought on crop yield, for example, may require the development of plant response models or the calibration of existing models.

Institutional deficiencies in drought response should be identified as part of Step 5. Agency responsibilities or missions may need to be modified to support activities to be performed under the rubric of the drought plan.

An essential aspect of the planning process is the synthesis of the science and policy of drought and drought management (Step 6). Previous steps in the planning process have considered these issues separately, concentrating largely on assessing the status of the science or on the existing or necessary institutional arrangements to support the plan. It is clear from the workshop discussions that communication and understanding between the science and policy community is poorly developed and must be enhanced if the planning process is to be successful. Direct and extensive contact is required between the two groups in order to distinguish what is feasible from what is desirable for a broad range of science and policy issues. Integration of science and policy during the planning process will also be useful in setting research priorities and synthesizing current understanding.

In Step 7, reasonable response options must be determined for each of the principal affected sectors identified by the impact assessment committee in Step 4. These options should examine appropriate drought mitigation measures on three timescales: (1) short-term (reactive) measures implemented during the occurrence of drought, (2) medium-term (recovery) measures implemented to reduce the length of the post-drought recovery period, and (3) long-term (proactive) measures or programs implemented in an attempt to reduce societal vulnerability to future drought. Again, it should be noted that societal vulnerability to drought may be influenced substantially by non-drought-related actions taken or policies implemented during nondrought periods. Thus, government must establish agricultural, environmental, and natural resource programs only after giving full consideration to their effects on the vulnerability of drought-prone regions.

The drought plan should be implemented in such a way that it gives maximum visibility to the program and credit to the agencies and organizations that have a leadership or supporting role in its operation. It is suggested that all or a portion of the system be tested under simulated drought conditions before it is implemented (Step 8). It is also suggested that announcement and implementation occur just before the most drought-sensitive season to take advantage of inherent public interest. The media is essential to publicizing the plan and must be informed fully of its purpose, objectives, and organizational framework.

Educational programs must be established to heighten public awareness of the drought problem and the need for water conservation and environmental management in the long run (Step 9). These programs must be long-term and directed to all age groups and economic sectors. If such a program is not developed, it is likely that interest in and support for drought planning by government officials and the public will wane during long periods of nondrought conditions.

The final step (Step 10) in the establishment of a drought plan is the creation of a detailed set of procedures to ensure adequate system evaluation. To maximize the effectiveness of the system, two modes of evaluation must be in place:

1. An ongoing or operational evaluation program that considers and incorporates, as appropriate, new technology, the availability of new research results, legislative action, changes in political leadership, and so forth, as they may affect the operation of the system.
2. A post-drought evaluation program that documents and critically analyzes the assessment and response actions of government and offers recommendations for improving the system.

The operational evaluation program is proposed to keep the drought assessment and response system current and responsive to the needs of society.

Governments should conduct or commission a post-drought evaluation of the responses to each major drought episode. These evaluations should include an analysis of the physical aspects of the drought itself; its impacts on soil, ground water, plants, and animals; its economic and social consequences; and the extent to which pre-drought planning was useful in mitigating impacts, facilitating relief or assistance to stricken areas, and in post-drought recovery. In this regard, attention must be directed to situations in which drought coping mechanisms worked and where societies exhibited resilience; evaluations should not focus only on those situations in which coping mechanisms failed. Evaluations of previous responses to severe drought are recommended as a planning aid to determine those relief measures that have been most effective. Questions to be addressed by the post-drought evaluation review team as part of this evaluation process are included in the report of Task Group 5.

It is recommended that governments place the responsibility for evaluating drought and societal response to it in the hands of a nongovernmental organization to ensure an unbiased appraisal of actions taken. Much of the talent needed for the conduct of such studies lies in the world's universities. Private foundations and research organizations should be encouraged to support post-drought evaluations. In many countries there are specialized agencies or corporations capable of analyzing climate impact.

International agencies, both intergovernmental and nongovernmental, should realize the value of post-drought evaluations and be prepared to sponsor them when an emergency extends beyond national boundaries, especially when internationally coordinated relief projects might be mounted.

In conclusion, it is stressed that these steps represent only the superstructure of an effective comprehensive drought response plan. It is incumbent on individual states, provinces, nations, or regions to adapt this superstructure to particular instances. Indeed, some aspects of this model may already be in place in some cases. In other cases, there will undoubtedly be aspects of the model that are irrelevant or impractical. Such is the liability of striving for absolute maximum applicability. However, this model represents state-of-the-art thinking by experts on how best to join science and policy in bettering humankind's response to drought.

Finally, it is recognized that the impacts of drought on society and the environment often linger for years after the drought itself has passed. Conversely, actions taken during nondrought periods often determine the level of vulnerability to future drought episodes. Thus, it is necessary to avoid the pitfall of focusing only on the impacts of drought and ignoring the effects and interrelationships of decisions made and actions taken during nondrought periods. Governments must commit the financial and human resources necessary to complete evaluations of drought impact and drought recovery to gain a full appreciation of the lingering societal effects.

SUMMARY

To those that study drought, regardless of our perspective, it is clear that drought is a normal feature of climate and its recurrence is inevitable. And, the widespread occurrence of severe drought during the past decade has once again underscored the vulnerability of both developed and developing societies to its ravages. Whether referring to the well-documented recent tragedies of Ethiopia or the physical and socioeconomic impacts of the 1986 drought in the southeastern United States, the message seems clear – society has typically chosen to react (i.e., employ crisis management) to drought rather than prepare (i.e., employ risk management) for it. With few exceptions this approach has been grossly ineffective.

Progress toward improving the drought coping capacity of national and provincial governments and international (as well as donor) organizations through better planning was the principal goal of the International Symposium and Workshop on Drought. The information, experiences, and recommendations presented in the proceedings of this meeting represent the collective wisdom of an interdisciplinary and international roster of scientists and policy officials. Perhaps their insights and recommendations will provide a model that can assist all drought-prone nations in achieving a more effective drought management strategy.

ACKNOWLEDGEMENTS

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REFERENCE

Wilhite, D.A. and W.E. Easterling (eds.). 1987. Planning for Drought: Toward a Reduction of Societal Vulnerability. Westview Press, Boulder, Colorado. 597 pp.

WORKSHOP ON IMPACT OF CLIMATE ON FISHERIES

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The Nova Scotia Climate Advisory Committee, with support from the Canadian Climate Program, sponsored a workshop on the impact of climate on the fishing industry in Nova Scotia. The workshop was held in Halifax on May 11, 1987.

Eleven papers were presented on various topics linking atmospheric and oceanographic climate to fisheries resource management and exploitation. About 45 participants representing AES, DFO, several universities, the private sector and provincial governments attended. The workshop was designed to focus on the practical application of atmospheric and oceanographic climate knowledge to the fishing industry. Proceedings will be available in August, 1987. Anyone desiring a copy should contact:

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ERICA PROJECT

The Office of the Chief of Naval Research, Arlington Virginia U.S.A., has recently published an overview document describing the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA). The study will examine winter storms at the hemispheric, cyclonic, and sub-cyclonic scales, the latter requiring extensive field work. The field project will concentrate on the ocean area extending from North Carolina to Newfoundland during the 1988-1989 winter season.

Copies of the overview document and other information on ERICA can be obtained from

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SUMMARY AND HIGHLIGHTS OF THE 1985 SEVERE LOCAL STORM SEASON

M.J. Newark[1], *M. Leduc*[2], *F. Letchford*[3], *G. Machnee*[4], *S. Siok*[5], and *D. Waugh*[1]

ABSTRACT

This report provides an overview and summary of the 1985 several local storm season in the broad region from the Rocky Mountains to Québec. Storm statistics were compiled from the seasonal report prepared by each of four Atmospheric Environment Service regions, and are summarized in tabular form. Highlights of the season are presented from an overall point of view and also by region.

RÉSUMÉ

Ce rapport donne un perspective global et un sommaire du temps violent estival de 1985 dans la vaste region du Canada des montagnes rocheuses jusq'à Québec. On a compilé les statistiques des orages du rapport saisonal qu'on preparait à chaque un des quatre regions de la service d'environnement atmospherique (SEA), et on les disposait en tableaux. On presente généralment les clous de la saison et on les presente aussi par region de la SEA.

1. INTRODUCTION

This report has been compiled mainly from information contained in the annual reports of the 1985 severe local storm season prepared by the Atmospheric Environment Service weather centres in 4 regions (Western,

1 Canadian Climate Centre, Downsview, Ontario
2 Ontario Weather Centre, Toronto, Ontario
3 Alberta Weather Centre, Edmonton, Alberta
4 Prairie Weather Centre, Winnipeg, Manitoba
5 Centre météorologique du Québec, Montréal, Quebec

Central, Ontario, and Québec) and is the second of a series (see Newark et al., 1987). The purpose is to summarize the statistics of the season and place them in an overall perspective, and to present seasonal highlights in narrative form.

The statistics should be interpreted with care because the definition (Table 1) of what constitutes a convective severe local storm varies from region to region and therefore, strictly speaking the statistics are not comparable from one region to another. However, because the definitions are somewhat similar, the numbers do approximate the picture across part of the country. Counting the number of events is also a problem which is approached differently from region to region (see Section 2). Although a "national" summary is provided (Table 2), it does not include information from Canada's north, much of British Columbia, or from the Atlantic Provinces. Some severe local storms are known to occur each year in these regions, but a systematic record of them is not maintained, and indeed, in some areas is impossible to compile due to lack of information. A map of the four regions is given in Figure 1 of Newark et al. (1987), and it can be seen that they cover the part of Canada most susceptible to such storms.

TABLE 1. Regional Definitions of a Severe Convective Weather Event

Western Region

1) tornado, waterspout, or funnel cloud;
2) hail ≧ grape-size (12 mm);
3) wind gusts ≧ 100 km/h;
4) rainfall amounts ≧ 25 mm in one hour.

The observation of any of the above conditions, singly or together is necessary for an event to be labelled severe. Some subjective screening is required to eliminate synoptic scale wind events.

Central Region

1) tornadoes or waterspouts;
2) hail ≧ 20 mm;
3) wind speeds or gusts ≧ 100 km/h;
4) rain amounts ≧ 50 mm from a storm or widespread heavy thunderstorms.

Ontario Region

1) tornado;
2) hail ≥ 10 mm diameter;
3) damaging thunderstorm wind gusts or, if winds measured, gusts ≥ 80 km/h (44 kts);
4) flooding downpours.

Québec Region

Objective criteria:

1) tornado;
2) hail ≧ 15 mm diameter;
3) strong gusts ≧ 83 km/h (45 kts);
4) heavy downpour ≧ 25 mm/h or, ≧ 50 mm/24 h.

Subjective criteria:

report of material damage or loss of life or injury caused by strong winds or heavy downpours.

From a climatological point of view one would like to know the number of severe local storms obtained by treating each observation of a phenomenon as a distinct event. These have been referred to as "proper-events" (Legal, 1984). In practice, difficulties arise when this is attempted because often there is not enough information available to distinguish each unique event. Even when there is sufficient information, it is not always possible to determine whether a series of damage incidents very closely related in time and space was the result of one intermittent storm, or a succession of independent storms.

The Québec region circumvents this problem by recording severe local storms in terms of "region-events" (Siok, 1984). According to this

TABLE 2. Severe Local Storm Summary Year 1985

AES REGION	WESTERN		CENTRAL			ONTARIO	QUÉBEC		NATIONAL
PROVINCE	NERN BC	ALTA	SASK	MAN	NWRN ONT	ONT	SERN ONT	QUÉ	
SEVERE LOCAL STORMS[a]									
Number of events	0	52	36	19	6	72	M	M	M
Number of days	0	26	18	13	5	26	3	17	78
Number of deaths	0	0	0	0	0	12	1	0	13
Number of injuries	0	1	0	6	0	155	M	8	170
Date season started	May 2			May 10		Apr 4	May 13		Apr 4
Date season ended	Aug 25			Aug 31		Oct 4	Sep 4		Oct 4
Length of season (days)	116			114		184	115		184
TORNADOES									
Number of events	0	13	5	3	1	22	2	5	51
Number of days	0	9	4	3	1	8	2	5	28
Number of deaths	0	0	0	0	0	12	1	0	13
Number of injuries	0	1	0	6	0	155	M	8	170
Date season started	May 7		Jun 5	May 25	Jun 8	May 31	May 31		May 7
Date season ended	Aug 3		Aug 30	Jul 3	Jun 8	Oct 4	Sep 7		Oct 4
Length of season (days)	89		87	40	1	127	100		151
HAIL									
Number of events	0	30	19	13	2	29	M	M	M
Number of days	0	16	11	10	2	16	0	6	48
Date season started	May 3		Jun 15	May 10	Jun 8	Apr 18	May 13		Apr 18
Date season ended	Aug 25		Aug 30	Aug 31	Jul 7	Sep 19	Aug 8		Sep 19
Length of season (days)	1 5		77	114	30	155	88		155
WIND									
Number of events	0	5	15	2	2	17	M	M	M
Number of days	0	4	7	2	2	13	1	0	27
RAIN									
Number of events	0	4	6	3	2	10	M	M	M
Number of days	0	4	3	3	2	5	0	10	23
WATERSPOUTS									
Number of events	0	1	0	0	0	3	M	M	M
FUNNEL CLOUDS									
Number of events	1	4	14	14	1	25	M	M	M
LIGHTNING									
Number of deaths	0	1	0	0	0	M	M	M	M

M = Not known

Some statistics in the "National" column are not truly representative due to regional differences in definition (see Table 1).

a = Not including waterspouts or funnel clouds.

scheme, weather occurrences which take place within a given forecast region are counted as one region-event provided they occur within an hour or so of each other. The remaining regions attempt to record proper-events. With resources that vary from year to year, and from region to region, and without a clear definition of what constitutes a proper-event, the number of events shown in Table 2 should be treated with great caution because it is not known how well they represent the true numbers. The number of tornadoes is perhaps an exception because a greater effort is expended on collecting information about them and identifying each one.

For an excellent summary of the problems related to identifying single storm events, and the nonmeteorological factors with cloud the issue of interpreting severe thunderstorm data, the reader is referred to Kelly and Schaefer (1985).

3. DATA SOURCES

Reports of severe local storms in 1985 were gathered as follows: (a) from the primary observing network of AES; (b) from volunteer weather watchers in each region; (c) from newspaper clippings; (d) from field surveys of storm damages (for example, Hopkinson, 1986; Lawrynuik et al, 1985); (e) from contacts with the media, private individuals, provincial agencies, insurance companies, etc. More detailed information concerning sources can be found in the individual regional reports (Leduc, 1985; Letchford and Waugh, 1985; Machnee, 1985; and Siok, 1985). It should be noted that the information is gathered primarily from populated areas (approximately shown by the shaded areas in Figure 1 of Newark et al., 1987).

4. SEASONAL HIGHLIGHTS

4.1 "National"

Severe local storms (as defined in Table 1) occurred on 78 days during a season which began on April 4th, and ended on October 4th, and which lasted 184 days. The storms were responsible for at least 13 deaths and 170 injuries. All but one of the deaths and most of the injuries were due to the multiple tornado outbreak of May 31st, in southern Ontario. This was the third worst tornado outbreak in Canada's history (Newark, 1985) in terms of fatalities. A number of studies and reports concerning it have been published (Allen, 1986; Boone, 1985; Clark, 1986; Gorski, 1985; Lawrynuik et al, 1985; Leduc et al, 1986; Morris and Armstrong, 1986; Newark, 1985; Ransom, 1986) covering concerns ranging from building design to emergency hospital procedures to the impact upon the hydro electric system. Other notable events occurred on May 30th, when destructive hail in southwestern Ontario ruined much of the newly planted tomato, cucumber and vegetable crops, and on August 3rd, when 380 mm of rain (probably the greatest 24-hour rainfall at any point in Canada east of the Rockies) was unofficially recorded near Parkman, Saskatchewan

TABLE 3. Yearly Comparison of "National" Severe Storm Statistics

	1980[a]	1984[c]	1985
SEVERE LOCAL STORMS			
Date season started (Julian number)	Apr 6 (097)	Apr 27 (118)	Apr 4 (094)
Date season ended (Julian number)	Oct 11 (285)	Oct 3 (277)	Oct 4 (277)
Length of season in days	189	160	184
Number of storm days (return period)	64 (3)	81 (2)	78 (2)
Number of days of severe wind (return period)	M	48 (3)	27 (7)
Number of days of severe rainstorms(return period)	M	37 (4)	23 (8)
Number of deaths (excluding lightning caused)	7	4	13
Number of injuries	21	45	170
TORNADOES			
Data season started (Julian number)	Apr 6 (097)	Apr 27 (118)	May 7 (127)
Date season ended (Julian number)	Sep 28 (272)	Oct 3 (277)	Oct 4 (277)
Length of season in days	176	160	151
Number of tornado days (return period)	39 (5)	31 (5)	28 (5)
Number of tornadoes (at least)	72[b]	74	51
SEVERE HAIL			
Date season started (Julian number)	M	May 12 (133)	Apr 18 (108)
Date season ended (Julian number)	M	Sep 2 (246)	Sep 19 (262)
Length of season in days	M	114	155
Number of hail days (return period)	M	50 (2)	48 (3)

The return period is the rounded value of the length of the season divided by the number of days on which the phenomenon occurred (a = statistics unavailable prior to 1984, except values for 1980 from Newark, 1981; b = excluding 7 in the Maritime provinces; c = from Newark et al 1987; M = not available).

(Hopkinson, 1986). During this season there were 27 days with severe wind storms and 23 days with severe rain storms.

The tornado season began on May 7th, ended on October 4th, and lasted a total of 151 days. There were at least 51 tornadoes on a total of 28 days during the season.

Severe hail occurred on 48 days during a season which began on April 18th, ended on September 19th, and which lasted 155 days.

There were at least 4 waterspouts reported and 59 funnel clouds.

A summary of these statistics is provided in Table 2. Table 3 compares the statistics on a yearly basis from which it can be seen that severe storms have been experienced every 2 or 3 days during the season, with tornadoes every 5 days on average. Tables 4 to 8 show the days when the various types of storms occurred in the four regions.

TABLE 4. Severe Local Storm Days, 1985

1 – NERN BC; 2 – ALTA; 3 – SASK; 4 – MAN; 5 – NWRN ONT; 6 – ONT; 7 – SERN ONT; 8 – QUE;
9 – NATIONAL

	1	2	3	4	5	6	7	8	9
Apr 4						*			
6						*			
18						*			
19						*			
May 2		*							
3		*							
7		*							
10				*					
13								*	
20								*	
22		*							
24			*						
25				*		*			
29			*						
30						*			
31						*	*	*	
Jun 5			*						
6				*					
7		*							
8					*				
9		*				*			
13		*							
14		*							
15			*						
18								*	
19		*	*						
20		*		*		*			
21					*				
22		*							
23		*							
24		*	*					*	
25					*				
28		*							
29						*			
30				*					
Jul 3			*	*					
5						*			
6			*			*		*	
7					*				
8				*	*				
10		*	*						
11		*							
12		*	*						
13			*	*					
14						*			
15						*		*	
16		*		*				*	
17			*						
18		*							
21						*		*	
22		*							
23		*						*	
25								*	
26								*	
28						*			
29							*	*	
Aug 3		*	*	*					
4		*							
5			*						
7						*			
8			*	*				*	
9		*			*				
11		*							
18						*			
20			*						
21			*						
25		*				*			
26						*			
27								*	
30			*	*					
31				*					
Sep 3								*	
4						*			
5						*			
7							*		
8						*			
19						*			
Oct 4						*			
Total	**0**	**26**	**18**	**13**	**5**	**26**	**3**	**17**	**78**

TABLE 5. Tornado Days, 1985

1 – NERN BC; 2 – ALTA; 3 – SASK; 4 – MAN; 5 – NWRN ONT; 6 – ONT; 7 – SERN ONT; 8 – QUE;
9 – NATIONAL

	1	2	3	4	5	6	7	8	9
May 7		*							
20								*	
22		*							
25				*					
31						*	*	*	
Jun 5			*						
6				*					
7		*							
8					*				
18								*	
23		*							
28		*							
Jul 3				*					
6			*			*		*	
11		*							
12		*							
17			*						
21						*			
22		*							
29								*	
Aug 3		*							
18						*			
25						*			
30			*						
Sep 4						*			
5						*			
7							*		
Oct 4						*			
TOTAL	**0**	**9**	**4**	**3**	**1**	**8**	**2**	**5**	**28**

TABLE 6. Severe Hail Days, 1985

1 – NERN BC; 2 – ALTA; 3 – SASK; 4 – MAN; 5 – NWRN ONT; 6 – ONT; 7 – SERN ONT; 8 – QUE; 9 – NATIONAL

	1	2	3	4	5	6	7	8	9
Apr 18						*			
19						*			
May 3		*							
10				*					
13								*	
30						*			
31						*			
Jun 7		*							
8					*				
9		*							
14		*							
15			*						
19		*							
20		*		*		*			
22		*							
23		*							
24								*	
29						*			
30				*					
Jul 3			*	*					
5						*			
6			*			*		*	
7					*				
8				*		*			
10		*	*						
11		*							
12		*	*						
13			*	*					
15						*			
16				*					
18		*							
21						*			
23		*						*	
28						*			
29								*	
Aug 4		*							
5			*						
7						*			
8			*	*				*	
11		*							
20			*						
21			*						
25		*							
26						*			
30			*	*					
31				*					
Sep 8						*			
19						*			
TOTAL	**0**	**16**	**11**	**10**	**2**	**16**	**0**	**6**	**48**

TABLE 7. Days with Severe Local Wind, 1985

1 – NERN BC; 2 – ALTA; 3 – SASK; 4 – MAN; 5 – NWRN ONT; 6 – ONT; 7 – SERN ONT; 8 – QUE; 9 – NATIONAL

	1	2	3	4	5	6	7	8	9
Apr 4						*			
6						*			
May 2		*							
24			*						
26						*			
30						*			
31						*			
Jun 9						*			
19		*	*						
23		*							
24			*						
25					*				
Jul 3				*					
8						*			
10		*	*						
12			*						
15						*			
16				*					
21						*			
29								*	
Aug 7						*			
8			*						
9					*				
18						*			
26						*			
30			*						
Oct 4						*			
TOTAL		**4**	**7**	**2**	**2**	**13**		**1**	**27**

TABLE 8. Days with Heavy Local Rain, 1985

1 – NERN BC; 2 – ALTA; 3 – SASK; 4 – MAN; 5 – NWRN ONT; 6 – ONT; 7 – SERN ONT; 8 – QUE; 9 – NATIONAL

	1	2	3	4	5	6	7	8	9
May 10				*					
29			*						
30						*			
Jun 7		*							
8					*				
13		*							
20				*					
21					*				
28		*							
Jul 6			*					*	
14						*			
15						*		*	
16								*	
21								*	
23	*								
25								*	
26								*	
29								*	
Aug 3			*	*					
15								*	
26						*			
27								*	
Sep 3								*	
4						*		*	
TOTAL		**4**	**3**	**3**	**2**	**5**		**10**	**23**

4.2 The Western Region (Northeastern B.C. and Alberta)

The summer of 1985 was a dry year over the majority of the forecast district with drought conditions continuing in many areas. Precipitation totals for the months of June, July and August were below the long-term normal at almost all observing sites. Numerous stations recorded less than 75% of normal precipitation while some areas such as Medicine Hat, were below 50% of normal. It is not surprising, therefore, that 1985 was a "quiet" year from a convective standpoint. Almost all observing stations had a below normal frequency of thunderstorms, with stations such as Lethbridge and Medicine Hat recording less than 25% of normal activity. Overall, thunderstorm activity was down almost 20% from 1984. Another interesting feature was the shift in maximum activity in 1985 into June whereas climatological data support a peak in convective activity during the month of July.

There was a significant decrease in severe convective activity in 1985 compared to the previous two years. It is felt that the numbers for 1983 may even be conservative since the volunteer Weather Watch network was not operational until 1984. Although the number of tornado days (7) during June, July and August 1985 was the same as in 1984, the total number of probable tornadoes was significantly diminished. Also very striking, was the drop in the number of severe-hail days to 17 from around 30 the previous two years. This is supported by a report from the Alberta Hail Project which states that "in the experimental region between Red Deer and Edmonton hail reports were 85% of normal but between Red Deer and Calgary only 40% of the normal hail reports were received (Alberta Research Council, 1985). The number of severe weather days was also down significantly, with June being the most active month.

Of particular note in 1985 was the lack of a "classical" severe weather day such as the tornado outbreak of June 29th, 1984 or the Lloydminster tornado day of 1983, although both June 23rd, and August 4th, were fairly active.

4.3 The Central Region (Saskatchewan, Manitoba, Northwestern Ontario)

The season was relatively quiet with 61 severe weather events recorded. There were 36 in Saskatchewan, 19 in Manitoba and 6 in northwestern Ontario. Tornadoes decreased in number from 35 in 1984 to 9 in 1985. While the number of severe weather days has averaged 41 since 1980, there were only 31 severe weather days in 1985.

The 1985 season started May 10th, with heavy rain and hail in southwestern Manitoba. About 100 mm of rain were reported at Cromer and hail 60 mm in diameter at Bolder.

There were heavy rainfalls in Manitoba on June 20th, August 4th, 16th, and 17th. There were significant hailstorms in Manitoba on July 3rd, August 8th, and August 30th.

In northwestern Ontario there were heavy thunderstorms on June 8th, and August 9th, and heavy rainfalls on June 21st, and 25th.

The season in Saskatchewan was quite active, with significant hail events on June 15th, when a hailstorm dumped 20 cm of hail on the ground at Carrot River. On July 6th, the Martensville and Aberdeen areas received 15 cm of pea to marble size hail on the ground. A hailstorm hit the Francis area on August 21st. Windstorms were reported in the Kindersley area on June 19th, and in southwestern Saskatchewan on July 12th. Heavy rainfalls of up to 380 mm were reported in the Parkman area on August 3rd, (Hopkinson, 1986). A significant hailstorm and tornadoes were reported in the Lintlaw-Okla area and surrounding regions on August 30th.

There were no deaths reported as a result of severe weather, but a few people were hurt by a tornado at St. Genevieve, Manitoba, on May 25th.

4.4 The Ontario Region (excluding northwestern and extreme southeastern sections of Ontario)

On May 31st, a series of major tornadoes moved through southern and central Ontario during the afternoon and early evening hours. The storms left twelve people dead and property damage around one hundred million dollars. The two main storms struck Barrie and a string of communities from Grand Valley to the Holland Marsh. It has been estimated, from the severity of the damage, that winds with both these storms exceeded 400 km/h. At least ten other tornadoes, large hail, and other damaging winds were reported from numerous other localities across southern and central Ontario on May 31st.

Besides May 31st, there were other notable severe weather days in Ontario especially involving hail. On May 30th, a severe hailstorm in Essex County in southwestern Ontario resulted in tens of millions of dollars damage to tender vegetable crops and greenhouses. There was lesser but still significant crop damage from hail in southwestern Ontario on July 5th, and again on July 8th. On July 21st, another major hailstorm, with stones reported as large as baseballs, caused millions of dollars crop damage in the Kirkland Lake area. On September 19th, golfball-sized hail was reported at Nakina, and a 125 mm deluge of rain at Geraldton.

Tornadoes in 1985 occurred on eight days other then May 31st, but all of these storms have been classified as weak. The most noteworthy ones included Mississauga on July 6th, and Big Rideau Lake on September 7th. The September 7th storm killed one person when it overturned a house boat which was cruising on the lake. The tornado season ended on October 4th, with a small tornado at Wheatley.

4.5 The Québec Region (southeastern Ontario, Québec)

The summer of 1985 was a normal severe weather season in Québec with 50 recorded region-events which occurred on 18 days. The season began on May 13th, ended on September 4th, and lasted 115 days. In total, hail was reported on 6 days and tornadoes on 5 days. However, heavy downpours were the most predominant phenomenon, occurring on 10 days. The Eastern Townships and the southern Montréal regions were the most affected, reporting severe weather on 8 days.

On May 13th, extensive hail fell in 4 regions. Hail the size of tennis balls fell at St-Marguerite-de-Lingwick in the Eastern Townships, fortunately causing little property damage. On July 29th, hail and strong winds caused an estimated $3 million in damage to farm buildings and cash crop losses at Ange-Gardien and St-Cesaire (south of Montréal). This was the most active day of the season with severe storms in many localities. The Ange-Gardien storm caused wind damage (particularly to trees) as well as local flooding along a track through the communities of St-Joan-de-Richelieu, Huntsville and Johnsville. Another storm complex the same day caused hail and wind damage at Chelsea and Shawville, north of the Ottawa river.

The most destructive tornado of the season (rated F2 to F3) occurred at St-Sylvère (south of Trois Rivières) on June 18th. Three people were injured and property losses were estimated at $1 million. From a meteorological point of view, the most unusual event was an F1 tornadic storm on May 20th, at St-Raphael-de-Bellechase (east of Québec City) which had a vertical extent of only 7 kilometres.

A multiple – event storm produced hail, heavy downpours and a probable tornado in the area from Hemmingford to Lacolle to St-Paul-de-l'Île-aux-Noix (south of Montréal) on July 6th. Five people were injured and property damage was estimated as hundreds of thousands of dollars.

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