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CONTENTS

USING A COMPUTER TO ESTIMATE NORMALS OF TEMPERATURE AND DERIVED VARIABLES FOR ANY POINT ON THE GREAT PLAINS[1]

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INTRODUCTION

CLIMATE IS ONE OF THE MOST IMPORTANT FACTORS IN DETERMINING THE USEFULNESS OF LAND FOR AGRICULTURE, FORESTRY OR OTHER PURPOSES. THERE IS INCREASING DEMAND FOR CLIMATIC DATA TO ASSIST IN THE OBJECTIVE ASSESSMENT OF LAND CAPABILITY, PARTICULARLY IN SOME RATHER THINLY POPULATED AREAS WHICH OFTEN HAVE QUITE SPARSE CLIMATOLOGICAL OBSERVING NETWORKS.

THE AGROMETEOROLOGY SECTION HAS RECENTLY DEVELOPED TWO COMPUTER PROGRAMS FOR ESTIMATING NORMALS OF CERTAIN CLIMATIC ELEMENTS OF PARTICULAR INTEREST TO AGRICULTURE, FOR ANY POINT ON THE CANADIAN GREAT PLAINS. ONE PROGRAM IS FOR USE WITH THE IBM 1620, THE OTHER FOR THE IBM 360–65. REGRESSION COEFFICIENTS DEVELOPED BY DR. J.W. HOPKINS OF NATIONAL RESEARCH COUNCIL'S DIVISION OF BIOSCIENCES ARE USED TO PREPARE REGRESSION ESTIMATES OF TEMPERATURE, GIVEN THE LATITUDE, LONGITUDE AND ELEVATION OF THE POINT. THE TEMPERATURE ESTIMATES ARE THEN EMPLOYED BY THEMSELVES OR IN COMBINATION WITH ESTIMATES OF OTHER ELEMENTS FROM OTHER SOURCES, TO COMPUTE NORMALS OF CERTAIN DERIVED VARIABLES, USING METHODS ADAPTED FROM VARIOUS OTHER AUTHORS.

THE PROGRAMS HAVE BEEN USED TO PREPARE ESTIMATES FOR HUNDREDS OF LOCATIONS, AND SOIL SCIENTISTS HAVE FOUND THE RESULTS VERY USEFUL IN CLASSIFYING LAND CAPABILITY FOR THE ARDA CANADA LAND INVENTORY. THE PURPOSE OF THIS PAPER IS TO DESCRIBE THE METHOD AND TO INDICATE SOME FURTHER IMPROVEMENTS AND MODIFICATIONS WHICH ARE BEING MADE.

1. CONTRIBUTION NO. 163 OF THE PLANT RESEARCH INSTITUTE. THIS IS A MODIFIED VERSION OF A PAPER PRESENTED AT THE FIRST NATIONAL CONGRESS OF THE CANADIAN METEOROLOGICAL SOCIETY HELD AT CARLETON UNIVERSITY, OTTAWA, MAY 24–26, 1967.

2. SECONDED FROM METEOROLOGICAL BRANCH, CANADA DEPARTMENT OF TRANSPORT.

CHOICE OF ELEMENTS AND METHOD OF COMPUTATION

NORMAL MONTHLY AND ANNUAL MEAN TEMPERATURES ARE COMMONLY USED TO INDICATE THE TEMPERATURE CLIMATE OF A LOCATION. MONTHLY NORMALS OF MEAN DAILY MAXIMUM AND MINIMUM TEMPERATURES GIVE CONSIDERABLE FURTHER INFORMATION FOR SUCH AGRICULTURAL PURPOSES AS THE CONSIDERATION OF PLANT GROWTH. MONTHLY AND ANNUAL AVERAGES OR NORMALS OF MEAN, MEAN DAILY MAXIMUM AND MEAN DAILY MINIMUM TEMPERATURE FOR THE 1931–60 PERIOD ARE AVAILABLE FOR MANY STATIONS (CANADA TRANSPORT 1962, 1964, 1965A, B, C), AND MOST POTENTIAL USERS OF THE ESTIMATES WOULD BE FAMILIAR WITH THESE PUBLISHED NORMALS. IT WAS THEREFORE DECIDED TO HAVE THE COMPUTER PROGRAMS MAKE 39 DIFFERENT ESTIMATES OF TEMPERATURE NORMALS FOR EACH LOCATION: ONE EACH FOR THE MEAN DAILY MAXIMUM, THE MEAN DAILY MINIMUM AND THE MEAN TEMPERATURE FOR EACH MONTH AND FOR THE YEAR. IT WAS DESIRABLE THAT THE ESTIMATES RELATE TO THE 1931–60 PERIOD, SO THAT THEY WOULD BE COMPARABLE TO CURRENTLY AVAILABLE PUBLISHED NORMALS.

SUCH ESTIMATES MIGHT, OF COURSE, BE MADE BY INTERPOLATION BY HAND OR USING ELECTRONIC SCANNING DEVICES, IF AT LEAST 24 TEMPERATURE MAPS, 12 EACH FOR THE MAXIMUM AND THE MINIMUM, WERE AVAILABLE FOR THE PERIOD AND AREA REQUIRED. THE ISOTHERMS WOULD PROBABLY HAVE BEEN PLACED ON SUCH MAPS RATHER SUBJECTIVELY, AND THEY WOULD NOT ADEQUATELY REFLECT THE EFFECT OF ALTITUDE AT ANY PARTICULAR POINT.

MAKING THE ESTIMATES BY HAND FROM MAPS WOULD BE EXTREMELY TIME CONSUMING IF A LARGE NUMBER OF POINTS WERE INVOLVED. IT WOULD ALSO MEAN THAT WHENEVER NORMALS OF A DERIVED VARIABLE, SUCH AS GROWING DEGREE–DAYS, WERE REQUIRED FOR SOME LOCATION THE TEMPERATURES WOULD FIRST HAVE TO BE ESTIMATED BY HAND FOR THAT POINT AND THEN USED AS INPUT TO A COMPUTER PROGRAM TO PREPARE THE DEGREE–DAY ESTIMATES. USING A COMPUTER TO PREPARE MAPS FROM THE AVAILABLE NORMALS AND THEN TO SCAN THEM TO INTERPOLATE THE TEMPERATURES WOULD BE INEFFICIENT AND WOULD INVOLVE UNNECESSARILY ELABORATE INPUT AND OUTPUT FACILITIES. IT THEREFORE SEEMED MOST LOGICAL AND EFFICIENT TO MAKE THE ESTIMATES USING A NUMERICAL TECHNIQUE WHICH WAS AS OBJECTIVE AS POSSIBLE AND WAS BASED ON THE AVAILABLE 1931–60 TEMPERATURE NORMALS.

THE "LEAST–SQUARES" REGRESSION TECHNIQUE IS A WIDELY USED AND PRACTICAL STATISTICAL ESTIMATION PROCEDURE. NEARLY 30 YEARS AGO HOPKINS SHOWED HOW REGRESSION TECHNIQUES COULD BE USED TO ESTIMATE TEMPERATURE NORMALS FOR LOCATIONS IN CENTRAL AND SOUTHERN ALBERTA AND SASKATCHEWAN (1938). RECENTLY HE HAS BEEN UPDATING AND EXPANDING HIS METHODS, USING NORMALS FOR THE 1931–60 PERIOD FOR 206 CLIMATOLOGICAL STATIONS (INDICATED BY THE DOTS ON THE MAP, FIGURE 1).

IN 1965 HE DEVELOPED A TRIVARIATE QUADRATIC MODEL OF THE FOLLOWING FORM:

$$T = D_1 + D_2N + D_3W + D_4U + D_5N^2 + D_6W^2 + D_7U^2 + D_8NW + D_9NU + D_{10}WU$$

WHERE N STANDS FOR NORTHWARD (LATITUDE), W FOR WESTWARD (LONGITUDE) AND U

FOR UPWARD (ELEVATION). THE TEMPERATURE NORMAL, T, IS THUS ESTIMATED FROM LINEAR, SQUARED AND CROSS-PRODUCT TERMS OF LATITUDE, LONGITUDE AND ELEVATION.

THERE ARE ACTUALLY 36 SETS OF THE REGRESSION COEFFICIENTS D_1 TO D_{10}: ONE SET FOR ESTIMATING THE NORMAL MEAN DAILY MAXIMUM, ONE FOR THE MINIMUM AND ONE FOR THE MEAN AIR TEMPERATURE, FOR EACH MONTH OF THE YEAR. IN THE PUBLISHED NORMALS, BASED ON OBSERVED DATA, THE NORMAL MEAN TEMPERATURE FOR A MONTH IS THE AVERAGE OF THE NORMAL MEAN DAILY MAXIMUM AND THE NORMAL MEAN DAILY MINIMUM. HOWEVER, SINCE THE RELATIONSHIP BETWEEN THE NORMAL MAXIMA AND LATITUDE, LONGITUDE AND ELEVATION DIFFERED FROM THE CORRESPONDING RELATIONSHIP INVOLVING NORMAL MINIMA, THE BEST ESTIMATE BASED ON REGRESSION ANALYSIS WITH THE NORMAL MEANS MIGHT NOT ALWAYS BE THE ARITHMETIC AVERAGE OF THE BEST ESTIMATES OF THE NORMAL MAXIMUM AND THE NORMAL MINIMUM. SO IT SEEMED LOGICAL TO PREPARE THREE SEPARATE SETS OF REGRESSION COEFFICIENTS, RATHER THAN TO CALCULATE THE MEAN FROM THE MAXIMUM AND THE MINIMUM.

AN INDICATION OF THE RELIABILITY OF THE ESTIMATION PROCEDURES CAN BE OBTAINED BY COMPARING ESTIMATES FOR CLIMATOLOGICAL STATIONS WITH THE PUBLISHED NORMALS. SUCH A COMPARISON WAS MADE FOR SEVEN STATIONS, ONE EACH IN THE NORTHWEST TERRITORIES, SASKATCHEWAN AND MANITOBA AND FOUR IN ALBERTA, FOR EACH MONTH OF THE YEAR, GIVING A TOTAL OF 84 CASES. IN 55 OUT OF THE 84 CASES THE ESTIMATED NORMAL MEAN MAXIMUM WAS WITHIN ONE DEGREE OF THE PUBLISHED NORMAL. IN 79 CASES IT WAS WITHIN TWO DEGREES, AND IN ALL 84 WITHIN THREE DEGREES (TABLE 1).

THE DIFFERENCES WERE GREATER FOR MINIMUM TEMPERATURES: IN ONLY 27 OUT OF 84 CASES WERE THE ESTIMATES OF NORMAL MINIMUM WITHIN A DEGREE OF THE PUBLISHED NORMALS, AND SOME OF THE DIFFERENCES WERE NEARLY FIVE DEGREES. AS MIGHT BE EXPECTED THE DIFFERENCES FOR THE MEANS WERE INTERMEDIATE BETWEEN THOSE FOR MAXIMUM AND MINIMUM TEMPERATURES.

TABLE 1

NUMBER OF MONTHS IN 84 (12 MONTHS X 7 STATIONS) WHEN DIFFERENCE BETWEEN ESTIMATED AND OBSERVED WAS $\leq$

	1 °F	2 °F	3 °F	4 °F	5 °F
MAX.	55	79	84		
MIN.	27	49	67	76	84
MEAN	51	73	81	84	

THE DIFFERENCES SHOULD NOT BE CONSIDERED SIMPLY AS "ERRORS". THE REGRESSION TECHNIQUE IS A SMOOTHING TECHNIQUE, WHICH IN THIS APPLICATION TENDS TO REMOVE LOCAL EFFECT. AN ESTIMATE FOR A PARTICULAR LOCATION MAY GIVE A BETTER REPRESENTATION OF THE AERIAL CONDITIONS WITHIN, SAY, A 20 MILE RADIUS OF THAT POINT THAN WOULD THE RESULTS OF ACTUAL OBSERVATIONS AT THE POINT, WHICH MIGHT HAVE BEEN STRONGLY INFLUENCED BY SOME VERY LOCAL EFFECT. IT ALSO SHOULD BE NOTED THAT THE DIFFERENCES WERE GENERALLY LESS IN SUMMER THAN IN WINTER, WHICH WAS CONVENIENT SINCE IN AGRICULTURE CONDITIONS DURING THE GROWING SEASON ARE OF MOST INTEREST.

POTENTIAL EVAPOTRANSPIRATION (PE) DATA IS WIDELY USED IN IRRIGATION AND SOIL MOISTURE STUDIES (BAIER, 1965). THE ESTIMATION OF DAILY LATENT EVAPORATION FROM SIMPLE WEATHER AND ASTRONOMICAL DATA WAS DESCRIBED BY BAIER AND ROBERTSON (1965), AND THE CONVERSION OF LATENT EVAPORATION TO POTENTIAL EVAPOTRANSPIRATION WAS DISCUSSED BY HOLMES AND ROBERTSON (1958). THESE TECHNIQUES HAVE BEEN ADAPTED FOR USE IN ESTIMATING NORMAL MONTHLY PE (IN INCHES) IN THE PRESENT PROGRAMS. THE PE ESTIMATES ARE MADE USING THE TEMPERATURE NORMAL ESTIMATES, TOGETHER WITH PHOTOPERIOD AND SOLAR ENERGY DATA AND ESTIMATES OF SUN, WIND, AND DEW POINT FOR EACH LOCATION OBTAINED FROM OTHER SOURCES OR MADE FROM MAPS AND ENTERED AS INPUT DATA TO THE COMPUTER PROGRAMS.

GROWING DEGREE-DAYS (SOMETIMES KNOWN AS "HEAT UNITS") HAVE A NUMBER OF APPLICATIONS IN AGRICULTURE. GROWTH RATES OF VARIOUS CROPS ARE CONSIDERED TO BE PROPORTIONAL TO THE DEGREE-DAY ACCUMULATIONS ABOVE VARIOUS BASE TEMPERATURES (HOLMES AND ROBERTSON, 1959). THE USUAL METHOD OF COMPUTING DEGREE-DAYS EMPLOYS DAILY MEAN TEMPERATURES, WHICH ARE NOT AVAILABLE IN THESE PROGRAMS. H.C.S. THOM (1954) SHOWED HOW MONTHLY MEAN TEMPERATURE NORMALS, TOGETHER WITH STANDARD DEVIATIONS OF MONTHLY MEANS, COULD NE USED IN COMPUTING NORMAL DEGREE-DAYS. IN THE PRESENT PROGRAMS THE TEMPERATURE NORMAL ESTIMATES ARE USED TOGETHER WITH STANDARD DEVIATION NORMALS ESTIMATED FROM OTHER SOURCES (KENDALL AND ANDERSON, 1966) TO ESTIMATE DEGREE-DAYS ABOVE OR BELOW ANY BASE. THE ESTIMATED NORMALS OF DEGREE-DAYS ABOVE 42^0F ARE OF PARTICULAR INTEREST TO THE SCIENTISTS INVOLVED IN LAND CAPABILITY STUDIES. DEGREE-DAYS BELOW VARIOUS BASES, PARTICULARLY 65^0F, ARE OF INTEREST TO ENGINEERS AND FUEL COMPANIES IN CONNECTION WITH THE HEATING NEEDS OF BUILDINGS.

THE "GROWING SEASON" IS SOMETIMES CONSIDERED AS THE PERIOD FROM THE TIME WHEN THE ANNUAL CURVE OF DAILY MEAN TEMPERATURE RISES ABOVE 42^0F IN THE SPRING UNTIL THE TIME WHEN IT FALLS BELOW 42^0F IN THE FALL. FOR SOME CROPS THE SEASON ABOVE TEMPERATURES OTHER THAN 42^0F MAY BE OF INTEREST. BROOKS (1943) PROVIDED TABLES WHICH COULD BE USED TO INTERPOLATE TO FIND THE DATES OF BEGINNINGS AND ENDINGS OF SUCH SEASONS USING MONTHLY TEMPERATURE NORMALS. HIS TABLES AIDED THE USER IN COMPUTING THE DATE CORRESPONDING TO A PARTICULAR TEMPERATURE, ASSUMING THAT THE TEMPERATURE FOLLOWED PART OF A SINE-WAVE CURVE FITTED TO THE MONTHLY TEMPERATURE NORMALS OF THREE CONSECUTIVE MONTHS. THE PRESENT AUTHOR CONSIDERED BROOKS' ASSUMPTIONS TO BE ADEQUATE, BUT FOUND THAT IT WAS BETTER TO ADAPT BROOKS' FORMULAS THAN TO HAVE THE PROGRAMS USE THE INTERPOLATION TABLES, WHICH HAD BEEN DESIGNED FOR HAND USE.

NORMAL DATES OF FIRST AND LAST FREEZE AND LENGTHS OF FREEZE-FREE SEASONS ARE OF CONSIDERABLE INTEREST TO AGRICULTURISTS. IN ORDER TO ESTIMATE THESE IN THESE PROGRAMS, SOME RELATIONSHIP BETWEEN THE AVAILABLE TEMPERATURE NORMALS AND NORMALS OF FIRST AND LAST FREEZE DATES WAS NEEDED. CHAPMAN AND BROWN (1966) REPORTED THAT THE AVERAGE LAST DATE IN THE SPRING AND FIRST IN THE FALL WITH TEMPERATURES OF 32^0F OR LOWER IN THE SCREEN WERE THE DATES WITH CERTAIN NORMAL DAILY MINIMUM TEMPERATURES, AND IN THE PRAIRIES THESE EMPIRICAL VALUES DEPENDED ON ALTITUDE. FOR INSTANCE, AT ALTITUDES BETWEEN 2600 AND 3000 FEET ON

THE PRAIRIES THE AVERAGE FREEZE-FREE SEASON IS APPROXIMATELY THE SEASON WITH MEAN DAILY MINIMUM TEMPERATURE ABOVE 41.5°F. THE PROGRAMS USE THE SINE-WAVE INTERPOLATION METHOD TO DETERMINE THE BEGINNING AND ENDING DATES OF THE NORMAL FREEZE-FREE SEASON BY INTERPOLATING WITH THE ESTIMATED MONTHLY NORMALS OF MEAN DAILY MINIMUM TO FIND THE DATES WITH THE APPROPRIATE MEAN MINIMUM IN EACH CASE.

THE IMPORTANCE OF THE "FREEZE-FREE" EASON IN AGRICULTURE ARISES FROM THE FACT THAT FREEZING DAMAGES MANY PLANTS. SOME PLANTS CAN WITHSTAND AIR TEMPERATURES MUCH LOWER THAN 32°F BEFORE SUCH DAMAGE OCCURS. IN MANY AGRICULTURAL APPLICATIONS, AN AIR TEMPERATURE OF 28°F IS CONSIDERED AS A "KILLING FROST". THE PROGRAMS THEREFORE COMPUTE DATA FOR FREEZE-FREE SEASONS BASED ON BOTH 32 AND 28°F. THE LATTER ARE COMPUTED BY ARBITRARILY SUBTRACTING 4 DEGREES FROM THE MEAN MINIMUM TEMPERATURE VALUES USED IN COMPUTING THE FREEZE-FREE SEASONS BASED ON 32°F. THIS PROCEDURE WAS CONSIDERED TO GIVE ESTIMATES FOR THE 28 DEGREE FREEZE-FREE SEASON DATES WHICH WERE, FOR ALL PRACTICAL PURPOSES, JUST AS ACCURATE AS THE 32 DEGREE FREEZE-FREE SEASON DATES.

THE PRDGRAMS ALSO COMPUTE THE NUMBER OF HOURS OF DAYLIGHT IN EACH FREEZE-FREE SEASON AND SEASON ABOVE ANY BASE TEMPERATURE. THIS DATA ALSO IS OF INTEREST SINCE PLANTS RESPOND TO THE LENGTHS OF PHOTOPERIODS AS WELL AS TO TEMPERATURE.

USING THE PROGRAMS

A SAMPLE OF THE OU PUT FROM ONE OF THE PROGRAMS FOR ONE LOCATION IS GIVEN IN TABLE 2. EACH TIME THE PROGRAM IS RUN, A SET OF 97 STANDARD CARDS PLUS ONE CONTROL CARD ARE REQUIRED AS INPUT, PLUS THE LATITUDE, LONGITUDE AND ELEVATION FOR EACH LOCATION FOR WHICH ESTIMATES ARE TO BE MADE. SUN, WIND AND DEW POINT DATA (SHOWN UNDER "MONTHLY VALUES FOR THIS LOCATION" IN THE SAMPLE OUTPUT) MUST ALSO BE ENTERED FOR ANY LOCATION FOR WHICH POTENTIAL EVAPOTRANSPIRATION IS TO BE COMPUTED, AND STANDARD DEVIATION DATA ("SD") FOR ANY FOR WHICH DEGREE-DAY COMPUTATIONS ARE TO BE MADE.

THE PROGRAM WRITTEN IN FORTRAN II, DEPARTMENT OF AGRICULTURE PROGRAM NUMBER 1025-0802 TAKES ABOUT TWO MINUTES TO PREPARE THE ESTIMATES FOR EACH LOCATION USING THE IBM 1620. PROGRAM 1025-0803, IN FORTRAN IV-E TAKES TWO OR THREE SECONDS PER LOCATION USING THE IBM 360-65.

THE OUTPUT ALWAYS INCLUDES, FOR EACH LOCATION, THE 39 TEMPERATURE NORMAL ESTIMATES AND THE FREEZE-FREE SEASON DATA. ALSO INCLUDED ARE THE VALUES, OBTAINED FROM THE STANDARD INPUT CARDS, OF THE LENGTH OF DAYLIGHT IN HOURS (DL), AND THE SOLAR RADIATION AT THE TOP OF THE ATMOSPHERE IN CALORIES PER SQUARE CM PER DAY (QO), FOR THE 15TH OF EACH MONTH AT THE NEAREST WHOLE DEGREE OF LATITUDE LINE.

THE PE IS COMPUTED AND OUTPUT ONLY IF THE SUN, WIND AND DEW POINT DATA HAVE BEEN ENTERED. DEGREE-DAYS ARE COMPUTED AND OUTPUT ONLY IF THE STANDARD DEVIATION DATA HAVE BEEN ENTERED, AND SOME BASE TEMPERATURES HAVE BEEN INDICATED BY THE CONTROL CARD. DEGREE-DAYS CAN BE OUTPUT FOR UP TO NINE DIFFERENT BASES IN ONE PASS THROUGH THE COMPUTER. WHEN THE CONTROL CARD INDICATES DEGREE-DAYS ABOVE CERTAIN BASES ARE TO BE COMPUTED, THE PROGRAM ALSO COMPUTES SEASONS WITH MEAN TEMPERATURES ABOVE THOSE BASES, WHETHER OR NOT THE STANDARD DEVIATION DATA ARE AVAILABLE, AS THE STANDARD DEVIATIONS ARE NOT REQUIRED IN THE SEASON CALCULATIONS.

WHERE SUN, WIND, DEW POINT AND STANDARD DEVIATION DATA HAVE BEEN ENTERED FOR A LOCATION, THEY ARE ALSO SHOWN IN THE OUTPUT.

A TECHNICAL BULLETIN DESCRIBING THE BASIS OF THE PROGRAM IN DETAIL AND LISTING THE FORTRAN II VERSION, WITH SAMPLE INPUT AND OUTPUT, IS AVAILABLE FROM THE AUTHOR (WILLIAMS AND SHARP, 1967).

FURTHER DEVELOPMENT

THE USE OF GROWING DEGREE-DAYS ABOVE A BASE TEMPERATURE SUCH AS 42 ASSUMES THAT FOR A PARTICULAR CROP A SPECIFIC NUMBER OF DEGREE-DAYS ARE REQUIRED TO MATURE THE CROP. M.Y. NUTTONSON IN THE U.S. (1957), HOWEVER, HAS SHOWN THAT THE DEGREE-DAY REQUIREMENT VARIES WITH LATITUDE DUE TO THE VARIATION IN DURATION OF DAYLIGHT AND HAS PROPOSED COMBINING PHOTOPERIOD AND DEGREE-DAYS TO OBTAIN "PHOTO-THERMAL UNITS".

THE PHOTOPERIOD AND DEGREE-DAY DATA CAN BE COMBINED IN VARIOUS WAYS. WORK UNDERWAY IN THE AGROMETEOROLOGY SECTION (ROBERTSON, 1966) SUGGESTS THAT IMPROVED RESULTS CAN BE OBTAINED BY SUBTRACTING SOME BASE NUMBER OF HOURS FROM THE PHOTOPERIOD BEFORE COMBINING WITH DEGREE-DAYS. THE PRESENT AUTHOR PROPOSES TO SUM THE PRODUCTS OF DEGREE-DAYS ABOVE A BASE SUCH AS 42^0F AND THE PHOTOPERIOD ABOVE SOME BASE SUCH AS 10 HOURS. IN DOING THIS, USING MONTHLY NORMAL DEGREE-DAY VALUES AND MEAN MONTHLY PHOTOPERIODS, THE SINE-WAVE INTERPOLATION METHOD IS TO BE USED TO ESTIMATE DEGREE-DAY AND PHOTOPERIOD VALUES FOR ANY POINT IN TIME, AND THE PRODUCT IS TO BE INTEGRATED FOR PERIODS OF A MONTH OR LESS, THAT IS,

$$\text{PHOTO-THERMAL UNITS} = \int F_1(T)F_2(T)DT$$

WHERE T IS TIME

$F_1(T)$ = DAILY DEGREE-DAYS ABOVE DEGREE-DAY BASE

$F_2(T)$ = PHOTOPERIOD ABOVE PHOTOPERIOD BASE

$F_J(T)$ = $A_J \cos T + B_J \cos T + C_J$

-CONTINUED ON PAGE 117

SUMMER RAINFALL IN INDIA

A REVIEW OF MONSOONAL AND EXTRAMONSOONAL ASPECTS - II

A. K. CHAKRAVARTI

IN THE EARLIER PART OF THIS STUDY (ATMOSPHERE VOL. 6, NO. 1, 1968), IT WAS SHOWN THAT THE ATMOSPHERIC DISTURBANCES AND PERTURBATIONS RELATED TO SUMMER RAINFALL IN INDIA CAN BE DIVIDED INTO THREE BROAD GROUPS, VIZ. -

1. AIR MASSES AND FRONTS IN THE MONSOON CIRCULATION,
2. UPPER ATMOSPHERIC PERTURBATIONS,
AND 3. EXTRATROPICAL DISTURBANCES.

MANY METEOROLOGISTS STILL BELIEVE IN AIR MASS ANALYSIS AND FRONTAL EXPLANATIONS FOR THE SUMMER RAINFALL IN INDIA ALTHOUGH THERE IS MUCH CONTROVERSY REGARDING THE NATURE OF FRONTS AND THE ROLE OF THE INTER TROPICAL CONVERGENCE (ITC) ZONE. HOWEVER, WITH INCREASING KNOWLEDGE OF THE UPPER ATMOSPHERIC CONDITIONS, MORE AND MORE THEORIES ARE BEING EVOLVED REGARDING THE DIRECT CONNECTION BETWEEN SUMMER RAINFALL AND THE UPPER (500- TO 150-MB) LEVEL ATMOSPHERIC FLOW AND PERTURBATIONS. MOREOVER, EXTRATROPICAL DISTURBANCES ALSO CONTRIBUTE A FAIR AMOUNT OF RAINFALL DURING THE SUMMER MONSOON SEASON. IN THIS STUDY THE ROLE OF THESE REMAINING TWO GROUPS OF DISTURBANCES WILL BE EXAMINED.

UPPER ATMOSPHERIC FLOW PATTERNS AND RAINFALL

A. BURST OF MONSOON RAINFALL

A VERY SIGNIFICANT STUDY IN THIS DIRECTION IS YIN'S (1949) HYPOTHESIS OF THE BURST (OR SUDDEN ONSET) OF THE MONSOON. HIS STUDY HAS SHOWN THAT THE ADVANCE OF THE MONSOON (EQUATORIAL CONVERGENCE ZONE) OVER INDIA IS CLOSELY LINKED WITH THE WESTWARD DISPLACEMENT OF A LOW LATITUDE TROUGH AT THE 500-MB. LEVEL FROM 85^0 E. LONGITUDE TO 75^0 E. LONGITUDE. HE BELIEVES THAT THE ADVANCE OF THE MONSOON OVER INDIA IS RETARDED DUE TO A BRANCH OF THE WESTERLY JET STREAM SKIRTING THE SOUTHERN MARGIN OF THE HIMALAYAN MOUNTAINS. AS SUMMER ADVANCES, THE BRANCH OF THE WESTERLY JET IS DISPLACED

NORTHWARD OF THE MOUNTAINS, THE TROUGH SHIFTS WESTWARD RAPIDLY, AND THE BURST OF MONSOON COINCIDES ABRUPTLY WITH THE COLLAPSE OF THE SOUTHERN JET. ALTERNATE RETURN AND COLLAPSE OF THE JET SOUTH OF THE HIMALAYAS CAUSE BREAK AND BURST CONDITIONS IN THE MONSOON. ULTIMATELY, THE JET DISAPPEARS DURING THE FULL MONSOON SEASON. HOWEVER, ON THE BASIS OF INVESTIGATIONS MADE BY PISHAROTY AND DESAI (1956), YIN'S HYPOTHESIS MAY BE CRITICIZED ON TWO COUNTS:

1. THAT THE BURST OF THE MONSOON OVER SOUTH INDIA IS LARGELY DETERMINED BY THE GENERAL CIRCULATION IN THE SOUTH INDIAN OCEAN AND OCCURS EVEN WITHOUT THE DISAPPEARANCE OF THE UPPER WESTERLY CURRENT SOUTH OF THE HIMALAYAS.

2. THAT THIS WESTERLY CURRENT MAY PREVENT THE BAY OF BENGAL BRANCH OF THE MONSOON FROM EXTENDING UP TO BIHAR OR UTTAR PRADESH, BUT DEFINITE INSTANCES HAVE BEEN FOUND WHEN THE ARABIAN SEA BRANCH OF THE MONSOON HAS EXTENDED UP TO PUNJAB DUE TO AN ACTIVE WESTERN DISTURBANCE SOUTH OF THE HIMALAYAS.

ANOTHER STUDY, MADE BY KOTESWARAM (1958A) HAS ALSO INDICATED THAT THE WESTERLIES MAKE INCURSIONS INTO WEST PAKISTAN EVEN AFTER THE BURST OF THE MONSOON. HOWEVER, THE WESTERLIES DO NOT DISAPPEAR COMPLETELY FROM THE SOUTH OF THE HIMALAYAS UNTIL THE SUB-TROPICAL ANTICYCLONE IS ESTABLISHED OVER THE HIMALAYAS. ON THE OTHER HAND, HE HAS GIVEN A DIFFERENT EXPLANATION OF THE BURST OF THE MONSOON OVER PENINSULAR INDIA. HE CONTENDS THAT THE BURST OF MONSOON ALONG THE MALABAR COAST IS ASSOCIATED WITH THE ADVANCE OF THE EASTERLY JET STREAM (KOTESWARAM, 1958B).

FLOHN'S (1958) INVESTIGATION PRESENTS A MORE COMPLEX PATTERN OF UPPER ATMOSPHERIC CIRCULATIONS CONNECTED WITH THE BURST OF THE MONSOON. HE THINKS THAT THE BURST OF THE MONSOON IS LINKED WITH THE FORMATION OF A HIGH PRESSURE AREA OVER THE TIBETAN PLATEAU DURING JULY AND AUGUST. THE FORMATION OF THIS CELL RESULTS IN THE REVERSAL OF THE NORMAL TEMPERATURE AND PRESSURE GRADIENTS BETWEEN THE 600- AND 300-MB. LEVELS. THIS REVERSAL ACTS LIKE A SWITCH COLLAPSING THE WESTERLY JET ALONG THE SOUTHERN HIMALAYAS, AND ALLOWING THE ADVANCE OF THE ITC ZONE THE EXTENSION OF THE EQUATORIAL WESTERLIES, AND THE BURST OF THE MONSOON.

THE RECENT INVESTIGATIONS INTO THE EASTERLY JET STREAM AND THE TIBETAN HIGH PPESSURE CELL HAVE THROWN MUCH LIGHT ON THE MONSOON CIRCULATION AND CAUSES OF RAINFALL IN INDIA. IT IS REALIZED, HOWEVER, THAT A BETTER UNDERSTANDING OF THE NATURE OF THE BURST OF MONSOON AND SUMMER RAINFALL IN INDIA WILL BE ACHIEVED BY A THOROUGH KNOWLEDGE OF THE WESTERLY JET, THE EASTERLY JET, THE TIBETAN HIGH AND THEIR RELATIONSHIP WITH THE MONSOON TROUGH. UNDER THE PRESENT CIRCUMSTANCES, SUCH A DETAILED INVESTIGATION WOULD APPEAR TO BE DIFFICULT DUE TO THE LACK OF UPPER AIR DATA PARTICULARLY FROM TIBET AND THE NEIGHBORING MOUNTAINOUS COUNTRIES.

B. EASTERLY JET STREAM AND RAINFALL

SOME OF THE MOST REVOLUTIONARY CONTRIBUTIONS REGARDING THE SUMMER RAINFALL OF INDIA HAVE BEEN MADE WITH THE DISCOVERY OF AN EASTERLY JET STREAM IN THE TROPICS. KOTESWARAM HAS POINTED OUT THAT THE CORE OF THE EASTERLIES IS NEAR 15^0 N. LATITUDE. THEY REACH VELOCITIES OF 80 TO 90 KNOTS OR MORE BETWEEN 30,000 TO 40,000 FEET ABOVE SEA LEVEL (KOTESWARAM, 1958A). IN THE LOW LATITUDES, THE WESTERLIES (SOUTHWEST MONSOON) ARE REPLACED EVERYWHERE BY THE EASTERLIES AT 500-MB. MUCH OF THE GENERAL DISTRIBUTION OF SUMMER RAINFALL IN INDIA HAS BEEN ACCOUNTED FOR BY THE EXISTENCE OF THIS EASTERLY JET STREAM. EXTENSIVE RAINFALL AND CLOUDINESS OVER NORTHEAST INDIA EAST OF 75^0 E. LONGITUDE, HAVE BEEN EXPLAINED AS A RESULT OF THE ENTRANCE AND ACCELERATION OF THE EASTERLY JET STREAM ASSOCIATED WITH THE LARGE SCALE ASCENT OF THE AIR. ON THE OTHER HAND, DROUGHT PREVAILS WEST OF 75^0 E. DUE TO THE EXIT AND DECELERATION OF THE JET ASSOCIATED WITH THE LARGE SCALE DESCENT OF THE AIR. SOUTH OF THE CORE, THE PATTERN IS REVERSED SO THAT THE WESTERN PART OF THE PENINSULAR INDIA IS RAINIER THAN THE EASTERN PART WITH THE SLIGHT MODIFICATION IMPOSED BY THE WESTERN GHATS. THE RAINFALL PATTERN DURING JULY AS RELATED TO THE EASTERLY JET STREAM IS SHOWN IN FIGURE 1.

THERE IS, HOWEVER, SOME CONTROVERSY REGARDING THE NATURE AND THE SOURCE OF THE EASTERLY JET STREAM. KOTESWARAM (1958A) HAS OBSERVED THE FORMATION OF A HIGH PRESSURE AREA EXTENDING FROM THE 700- TO 500-MB. LEVELS DUE TO THE HEATING OF THE TIBETAN PLATEAU. THE EASTERLY JET STREAM HAS BEEN DESCRIBED AS THE EQUATORWARD OUTFLOW FROM THIS HIGH PRESSURE CELL. IN A SUBSEQUENT STUDY, FLOHN (1958) HAS ALSO CONTENDED THAT THE FORMATION OF THE HIGH PRESSURE CELL IS DUE TO THE HEATING OF THE MID-TROPOSPHERE OVER THE TIBETAN PLATEAU. ACCORDINGLY, THIS HIGH PRESSURE AREA LEADS TO THE FORMATION OF A DEEP AND PERSISTENT EASTERLY FLOW ABOVE THE 500-MB. LEVEL WHICH IS THEN CONCENTRATED INTO THE EASTERLY JET STREAM ABOVE 150 MB. FLOHN STATES IN THE SAME PAPER THAT THE SEASONAL WARMING OF THE TIBETAN PLATEAU CAUSES A NORTHWARD MIGRATION OF THE TROPICAL EASTERLIES WHICH EXTEND TO THE STRATOSPHERE TO FORM THE EASTERLY JET NEAR THE TROPOPAUSE. ON THE OTHER HAND, RAMANATHAN'S (1958) VIEW IS THAT THE UPPER LEVEL EASTERLIES ORIGINATE FROM THE HIGH LEVEL ANTICYCLONIC CELL LYING OVER THE PACIFIC AND EASTERN ASIA.

IT IS NOT CLEAR WHETHER THE EASTERLY JET IS PRODUCED BY -

(1) AN OUTFLOW FROM THE SOUTHERN MARGIN OF THE TIBETAN HIGH PRESSURE CELL,

OR

(2) A VERTICAL EXTENSION AND CONCENTRATION OF THE TROPICAL EASTERLIES.

FROM THE FOREGOING ANALYSIS, IT SEEMS MORE LIKELY THAT THE MERGER OF BOTH (1) AND (2) AND THEIR CONCENTRATION AT HIGHER LEVEL PRODUCES THE EASTERLY JET.

A SIGNIFICANT POINT, HOWEVER, IS THAT A DISTINCTION HAS BEEN MADE BETWEEN THE UPPER EASTERLIES COMING FROM THE PACIFIC OCEAN OVER INDIA BETWEEN 500– TO 300–MB. LEVELS AND THE EASTERLY JET STREAM RUNNING OVER THE UPPER EASTERLIES AT THE 200–MB. LEVEL (KOTESWARAM AND GEORGE, 1958). BELOW THE 500–MB. LEVEL OF UPPER EASTERLIES, THE SOUTHWEST MONSOON CURRENTS (EQUATORIAL WESTERLIES), EXTEND 10,000 TO 20,000 FEET ABOVE SEA LEVEL AND REACH AS FAR EASTWARD AS THE SOUTH CHINA SEA AND WESTERN PACIFIC (KOTESWARAM, 1958A). THE EASTERLIES EXIST ONLY AT HIGHER LEVELS REPLACING WESTERLIES EVERYWHERE AT THE 500–MB. LEVEL EXCEPT IN A NARROW BELT BETWEEN THE AXIS OF THE MONSOON TROUGH AND THE SOUTHERN MARGIN OF THE HIMALAYAS, WHERE THEY DESCEND DURING THE SUMMER MONSOON SEASON, FIGURE 2. HOWEVER, RECENT INVESTIGATIONS INTO THE CAUSES OF SUMMER RAINFALL IN INDIA HAVE EMPHASIZED THE DIRECT ROLE OF PERTURBATIONS AND VELOCITY INCREASES IN THESE UPPER EASTERLIES, AND HAVE ASSIGNED ONLY AN INDIRECT AND PASSIVE ROLE TO THE SOUTHWEST OR THE BAY OF BENGAL MONSOONS.

C. MONSOON DEPRESSIONS AND RAINFALL DUE TO UPPER ATMOSPHERIC PERTURBATIONS

IT HAS BEEN DEMONSTRATED THAT – (1) THE SURGES IN THE EASTERLY JET STREAM, AND (11) THE EASTERLY WAVES IN THE UPPER EASTERLIES HAVE SEPARATE INFLUENCES IN CREATING DEPRESSIONS AND CAUSING RAINFALL DURING THE SUMMER SEASON.

(1) SURGES IN THE EASTERLY JET STREAM

KOTESWARAM AND GEORGE (1958) HAVE OBSERVED THAT THE OCCASIONAL STRONG WINDS AS SURGES IN THE EASTERLY JET STREAM HAVE A DIRECT RELATIONSHIP WITH THE FORMATION OF SURFACE DEPRESSIONS AND SUBSEQUENT RAINFALL. THEY HAVE NOTED THAT A PRE–EXISTING SURFACE TROUGH OVER THE NORTHERN PART OF THE BAY OF BENGAL INTENSIFIED INTO A DEPRESSION WITH THE APPROACH OF A WIND MAXIMA OR A SURGE IN THE EASTERLY JET STREAM. FURTHER, THE DEPRESSION TENDED TO DISSIPATE AND THE CIRCULATION WEAKENED WITH THE PASSAGE OF THE WIND MAXIMA.

(11) EASTERLY WAVES AND MONSOON DEPRESSIONS

THE SAME AUTHORS HAVE ALSO NOTED THE RELATIONSHIP BETWEEN THE EASTERLY WAVES AND THE FORMATION OF MONSOON DEPRESSIONS. THESE WAVE–LIKE DISTURBANCES HAVE BEEN OBSERVED IN THE UPPER EASTERLIES BETWEEN 500– AND 300–MB. BELOW THE EASTERLY JET STREAM (KOTESWARAM AND GEORGE, 1958). THREE IMPORTANT FEATURES OF THE EASTERLY WAVES WERE POINTED OUT:

1. THE PASSAGE OF AN EASTERLY WAVE WAS ALWAYS PRECEDED BY UNSETTLED WEATHER OR THE EXTENSION OF THE SEASONAL (MONSOON) TROUGH FROM THE LAND TOWARDS SOUTHEAST INTO THE BAY OF BENGAL.

2. IF THE SEASONAL TROUGH HAD ALREADY EXTENDED OVER THE BAY OF BENGAL THEN THE PASSAGE OF THE WAVES RESULTED IN THE FORMATION OF A SURFACE DEPRESSION.

3. WHEN THE WAVE HAD OVERTAKEN AND PASSED THE TROUGH, THE DEPRESSION WEAKENED.

A SIGNIFICANT CONCLUSION DRAWN FROM THIS STUDY IS THAT THE PASSAGE OF AN EASTERLY WAVE OR A SURGE IN THE EASTERLY JET STREAM WOULD USUALLY TRANSFORM A TROUGH INTO A DEPRESSION. THE DEPRESSION BORN OVER THE BAY OF BENGAL TRAVELS INLAND AND PRODUCES WIDESPREAD RAINFALL ALONG ITS TRAJECTORY. THE PATH OF DEPRESSION MAY BE DETERMINED BY THE POSITION OF THE ITC ZONE, THE LATTER IN TURN MAY BE AFFECTED BY THE COLLAPSE OF THE WESTERLY JET STREAM SOUTH OF THE HIMALAYAS AND THE EXTENSION OF THE EASTERLY JET STREAM OVER INDIA. THUS THE FREQUENCY AND AERIAL EXTENT OF SUMMER RAINFALL IN INDIA ARE MORE DIRECTLY RELATED TO UPPER ATMOSPHERIC FLOW PATTERNS THAN TO THE SURFACE CIRCULATION.

THE ONLY OTHER DETAILED STUDY OF EASTERLY WAVES AND THEIR INFLUENCE ON RAINFALL IN INDIA IS THAT BY SRINIVASAN (1960). HIS STUDY IS SLIGHTLY DIFFERENT FROM THE PREVIOUS ONE. IN THE PREVIOUS WORK THE EMPHASIS WAS ON THE EASTERLY WAVES OR THE SURGES IN THE JET STREAM AND THEIR ROLE IN THE FORMATION OF DEPRESSIONS. IN THE SUBSEQUENT WORK SRINIVASAN HAS ANALYZED THE NATURE OF EASTERLY WAVES OVER INDIA AND THEIR DIRECT ROLE IN DETERMINING THE RAINFALL PATTERN WITHOUT THE FORMATION OF SURFACE DEPRESSIONS.

THE RAINFALL PATTERN ASSOCIATED WITH THE EASTERLY WAVES ACROSS INDIA IS DIFFERENT FROM THAT ASSOCIATED WITH THE EASTERLY WAVES OBSERVED OVER THE CARIBBEAN SEA, ALTHOUGH BOTH TYPES OF WAVES MOVE FROM EAST TO WEST. IN THE CARIBBEAN EASTERLY WAVES, WHERE THE VELOCITY OF THE BASIC CURRENT DECREASES WITH HEIGHT, CONVERGENCE AND DIVERGENCE IN THE LOWER TROPOSPHERE PREDOMINATE AND CREATE THE WEATHER IN THE REAR OF THE TROUGH LINE (RIEHL, 1954). ON THE OTHER HAND, IN THE EASTERLY WAVES OVER INDIA, WHERE THE VELOCITY OF THE UPPER EASTERLIES INCREASES WITH HEIGHT, THE UPPER DIVERGENCE AHEAD OF THE TROUGH AND THE UPPER CONVERGENCE IN THE REAR OF THE TROUGH ARE DOMINANT. THESE CAUSE WEATHER AND RAINFALL AHEAD OF THE TROUGH LINE (SRINIVASAN, 1960). HOWEVER, TWO IMPORTANT CONCLUSIONS MAY BE DRAWN REGARDING THE RAINFALL FROM THE EASTERLY WAVES DURING THE SUMMER MONSOONS:

1. THAT OVER A MAJOR PORTION OF INDIA AND PARTICULARLY IN THE GANGES PLAIN, THE SUMMER RAINFALL IS PRIMARILY RELATED TO THE PASSAGE OF EASTERLY WAVES AND JET MAXIMA.

2. THAT THE PASSAGE OF THE EASTERLY WAVES CREATE ACTIVE CONDITIONS AND RAINFALL AND AN ABSENCE OF THESE WAVES MAY PRODUCE WEAK AND EVEN DRY MONSOON CONDITIONS.

THE INVESTIGATION BY SRINIVASAN HAS DEMONSTRATED THAT THE PASSAGE OF AN EASTERLY WAVE DOES NOT ALWAYS LEAD TO THE FORMATION OF A DEPRESSION AS CONTENDED BY KOTESWARAM AND GEORGE (1958). ANOTHER STUDY BY RAMANATHAN (1958) HAS ALSO CONFIRMED THAT THESE WAVES ARE NOT ESSENTIAL FOR DEPRESSION FORMATION. AN ANALYSIS OF THE SYNOPTIC CONDITIONS IN WHICH AN EASTERLY WAVE FAILS TO DEVELOP A MONSOON DEPRESSION MAY BE FOUND IN THE WORK OF CHAKRAVORTTY AND BASU (1957). THESE AUTHORS HAVE OBSERVED AN INVERSE RELATIONSHIP BETWEEN THE EASTERLY WAVES AND THE DISTURBANCES IN THE WESTERLIES OF THE NORTH. ACCORDING TO THEM, A NUMBER OF CASES HAVE BEEN NOTICED WHEN THE EASTWARD PASSAGE OF WESTERN DISTURBANCES ACROSS OR NEAR THE EASTERN HIMALAYAS HAS PREVENTED THE EASTERLY WAVES FROM DEVELOPING INTO DEPRESSIONS.

IT APPEARS, THEREFORE, THAT MONSOON DEPRESSIONS MAY FORM INDEPENDENTLY AND GIVE RAINFALL; SIMILARLY, EASTERLY WAVES MAY CAUSE RAINFALL WITHOUT ANY SURFACE DEPRESSION, AND ON CERTAIN OCCASIONS AN EASTERLY WAVE MAY DEVELOP A DEPRESSION WHICH SUBSEQUENTLY PRODUCES RAINFALL.

THE GENERAL CAUSE OF RAINFALL IN OTHER PARTS OF INDIA HAS ALSO BEEN ATTRIBUTED, BY SRINIVASAN (1960), TO EASTERLY WAVES. HIS OBSERVATIONS ARE MADE OVER THE GANGETIC WEST BENGAL. THE EXTRAPOLATION WORK FOR THE REST OF THE COUNTRY IS DOUBTFUL IN VIEW OF THE COMPLEX NATURE OF THE ITC ZONE, EASTERLY WAVES, WESTERN DISTURBANCES, AND THE EASTERLY JET STREAM. A MORE DETAILED INVESTIGATION IN OTHER PARTS OF INDIA IS NEEDED TO ASSESS THE INFLUENCE OF EASTERLY WAVES ON THE RAINFALL OVER THE REST OF THE COUNTRY.

WESTERN DISTURBANCES AND SUMMER RAINFALL

ANOTHER TYPE OF ATMOSPHERIC DISTURBANCE WHICH AFFECTS THE SUMMER RAINFALL OF INDIA IS KNOWN AS THE WESTERN DISTURBANCES. THESE DISTURBANCES, WHICH RESEMBLE EXTRATROPICAL CYCLONES, ARE THE DEVELOPMENT OF EASTWARD MOVING WAVES IN THE EXTRATROPICAL ZONAL WESTERLIES AND ARE SUPPOSED TO BE AN ASPECT OF THE INTERACTION BETWEEN THE TROPICS AND THE EXTRA TROPICS. HOWEVER, ANY SHARP FRONTAL CHARACTERISTICS HAVE NOT BEEN RECORDED IN THE WESTERN DISTURBANCES (RAMASWAMY, 1966). THESE DISTURBANCES ARE MOSTLY CONFINED TO NORTHERN INDIA GENERALLY NORTH OF 20^0 N. LATITUDE.

UNTIL RECENTLY THE WESTERN DISTURBANCES WERE THOUGHT TO OCCUR ONLY DURING THE WINTER. BUT NOW IT HAS BEEN FOUND THAT THEIR INFLUENCE DURING THE SUMMER MONSOON IS ALSO QUITE SIGNIFICANT. PARTHASARATHY (1958) HAS OBSERVED THAT THESE WESTERLY WAVES MOVING ACROSS THE LOWER HIMALAYAS ARE AS IMPORTANT AS THE EASTERLY WAVES IN DETERMINING THE INTENSITY AND DISTRIBUTION OF HEAVY RAINFALL DURING THE SOUTHWEST MONSOON PERIOD.

A SIGNIFICANT FEATURE OF THE WESTERN DISTURBANCES, HOWEVER, IS THAT THEY PLAY A DUAL ROLE IN AFFECTING THE SUMMER RAINFALL OVER INDIA. UNDER PARTICULAR SYNOPTIC CONDITIONS, THE DISTURBANCES HAVE A POSITIVE EFFECT AND INCREASE THE RAINFALL, WHEREAS UNDER OTHERS, THEIR EFFECT IS NEGATIVE AND THEY DECREASE THE RAINFALL.

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ADJUSTMENTS TO THE WEATHER - CHOICE OR CHANCE?

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1. INTRODUCTION

"CANADA HAS VERY SPECIAL NEEDS FOR METEOROLOGICAL SCIENCE". THESE COMMENTS BY PROFESSOR BREWER, PRESIDENT OF THE NEWLY FORMED CANADIAN METEOROLOGICAL SOCIETY, IN ATMOSPHERE (BREWER 1967), POINT TO THE GROWING AWARENESS OF THE IMPORTANCE IN CANADA OF METEOROLOGICAL SCIENCE. IN VIEW OF THIS, IT IS IMPORTANT FOR US TO REALISE THAT LITTLE THOUGHT HAS BEEN GIVEN, IN THE PAST, TO WHAT MAY BE CALLED THE NON-SCIENTIFIC ASPECTS OF METEOROLOGY IN CANADA. FURTHER, BECAUSE OF THE ASSUMED IMPORTANCE OF WEATHER SENSITIVE ACTIVITIES IN THE ECONOMY, IT IS CLEAR THAT THERE IS AN URGENT NEED FOR RESEARCH ON WEATHER IMPACTS AND ADJUSTMENTS TO THE WEATHER IN CANADA. TO THIS END, THIS PAPER EXAMINES SOME ASPECTS OF METEOROLOGICAL SCIENCE WHICH THE CANADIAN METEOROLOGICAL SOCIETY IN ITS FIRST YEARS, MIGHT WELL ENCOURAGE. BY SO DOING, WE BELIEVE THAT THE SOCIETY WILL BE USEFULLY SERVING THE PURPOSES FOR WHICH IT WAS FOUNDED.

2. THE SETTING

WEATHER AND CLIMATE PRESENT MANKIND WITH A CHALLENGE, HE CAN EITHER ACCEPT THEM AS GIVEN AND ALTER HIS PATTERNS OF ACTIVITY TO ACCOMMODATE THEM, OR HE CAN TRY TO ALTER THE PROCESSES WHICH PRODUCE THEM.

IN THE FIRST CASE MAN CAN EITHER - (A) DO NOTHING, (B) RE-SCHEDULE ACTIVITIES (PROVIDING HE HAS FAITH IN THE WEATHER THAT IS FORECAST), OR, (C) IMPROVE "THE TECHNOLOGY OF WEATHER PROTECTION" SUCH AS, BY DEVELOPING DROUGHT RESISTANT CROPS, "HURRICANE PROOF" CITIES, OR MORE ECONOMICAL AIR-CONDITIONING. IN THE SECOND CASE HE CAN TRY TO ALTER THE AMOUNT OR TEMPORAL DISTRIBUTION OF PARTICULAR WEATHER ELEMENTS, BY ALTERING THE ATMOSPHERIC CIRCULATION IN RELATION TO A SMALL AREA (PLANT), A MEDIUM AREA (CLOUD, STORM), A LARGE AREA (RIVER BASIN, STATE, URBAN AREA), OR AN EXTENSIVE REGION (EUROPEAN OR PACIFIC).

FOR THE MOST PART MAN HAS CONCENTRATED HIS ATTENTION ON THE FIRST ALTERNATIVE, SEEKING OUT THOSE LOCATIONS WHERE THE CLIMATE IS NOT TOO SEVERE FOR

THESE ARE IMPORTANT BECAUSE –

(A) IF THE PRESENT USE OF PRESENT WEATHER FORECASTS IS NOT KNOWN, THEN IMPROVEMENT OF WEATHER FORECASTS – FROM THE CLIENTS' VIEWPOINT – MAY BE A WASTE OF TIME.

(B) IT IS PROBABLE THAT MORE EFFECTIVE USE OF PRESENT DAY FORECASTS WOULD ACHIEVE SIMILAR, IF NOT BETTER, 'RESULTS' THAN AN IMPROVEMENT IN THE ACCURACY OF WEATHER FORECASTING.

(C) IF WE KNOW WHAT THE WEATHER IS GOING TO BE, AND WHAT THE EFFECT OF THAT WEATHER WILL BE, THEN WE ARE IN A POSITION TO ALTER OUR PRODUCTION SCHEDULE, PLANT A DIFFERENT TYPE OF CROP, OR CALL UPON THE RAINMAKER,

BUT

(D) IF WE DO NOT KNOW THE IMPACT OF WEATHER ON AN ACTIVITY, OR AN AREA, THEN WE ARE HARDLY IN A POSITION TO KNOW HOW MUCH TO MODIFY THE WEATHER AND WE SURELY SHOULD NOT MODIFY THE WEATHER IF WE DO NOT KNOW WHAT THE RESULTS OF SUCH MODIFICATION WILL BE.

4. THE USE OF WEATHER INFORMATION

IT IS GENERALLY ASSUMED THAT THE PROVISION OF BETTER INFORMATION WILL LEAD TO BETTER DECISIONS. MUCH DEPENDS, HOWEVER, ON THE WAY IN WHICH PEOPLE USE WEATHER INFORMATION. WE ALL PAY FOR WEATHER SERVICES EITHER DIRECTLY OR INDIRECTLY, BUT HAVE WE MUCH SAY IN WHAT TYPE OF INFORMATION IS GIVEN TO US? HOW OFTEN, FOR EXAMPLE, HAVE YOU BEEN ASKED WHAT TYPE OF WEATHER INFORMATION YOU WOULD LIKE TO HAVE. OR, PROBABLY EVEN MORE PERTINENT, HOW OFTEN HAS THE CANADIAN METEOROLOGICAL SERVICE ASKED THEIR CLIENTS WHAT TYPE OF INFORMATION OR SERVICES THEY REQUIRE? IS THE METEOROLOGICAL SERVICE AWARE OF THE VALUE OF ITS PRODUCT?WE UNDERSTAND THAT SOME SUCH STUDIES HAVE BEEN MADE, INCLUDING AN INVESTIGATION BY K.T. MCLEOD ON THE "WEATHER REQUIREMENTS" OF PUBLIC UTILITIES IN METROPOLITAN TORONTO,AND IN THE LAST 12 TO 18 MONTHS THE U.S.WEATHER BUREAU HAS SPONSORED A NUMBER OF STUDIES TO DETERMINE THE VALUE OF THEIR WEATHER FORECASTS.[2]

ONE INDICATION OF THE VALUE OF WEATHER INFORMATION IS THE PRICE THAT PEOPLE WOULD BE PREPARED TO PAY FOR IT IF THEY WERE CHARGED. IF WEATHER FORECASTS

2. C. VON BICKERT OF THE UNIVERSITY OF DENVER, FOR EXAMPLE, IS ENGAGED IN A SOCIAL PSYCHOLOGY STUDY OF HOW PEOPLE ARE USING WEATHER INFORMATION.

HUMAN COMFORT AND WHERE ECONOMIC ACTIVITIES CAN BE PURSUED AT REASONABLE COST, AND TRYING TO DEVELOP WAYS OF REDUCING THE IMPACT OF VARIATIONS IN THE WEATHER. ATTEMPTS TO MODIFY THE WEATHER HAVE BEEN MADE SINCE THE DAWN OF CIVILISATION BUT SOME CLAIMS AS TO SUCCESS HAVE BEEN REGARDED WITH MUCH SCEPTICISM, ESPECIALLY BY THE SCIENTIFIC FRATERNITY. IT SEEMS, HOWEVER, THAT THIS SCEPTICISM IS DECLINING FOR, RESULTS OF RESEARCH IN SEVERAL COUNTRIES, SUGGEST THAT WAYS HAVE BEEN FOUND TO MODIFY THE WEATHER IN CERTAIN CIRCUMSTANCES.[1]

3. ECONOMIC AND SOCIAL ASPECTS OF METEOROLOGY

ALTHOUGH THE RAISON D'ETRE OF THE METEOROLOGICAL PROFESSION IS ROOTED IN MAN'S SEARCH FOR MORE EFFICIENT ADJUSTMENTS TO VARIATIONS IN THE WEATHER, IT IS CLEAR FROM AN APPRAISAL OF THE LITERATURE THAT THE WORLD OF METEOROLOGY HAS NOT THOUGHT VERY MUCH ABOUT WHAT ONE COULD CALL THE ECONOMIC AND SOCIAL ASPECTS OF THE PROFESSION. AS THOMPSON (1966) RECENTLY SAID – "LITTLE ATTENTION HAS BEEN GIVEN BY METEOROLOGISTS TO THE NON-SCIENTIFIC GAINS OF THEIR PROFESSION". AS WE LOOK TO THE FUTURE – WITH ITS EVER GROWING TECHNOLOGY, WORLD WEATHER WATCH PROGRAM, AND THE POSSIBILITY OF ACCURATE LONG-RANGE WEATHER FORECASTING, AS WELL AS THE GROWING CONCERN OVER WEATHER MODIFICATION AND AIR POLLUTION, IT IS IMPERATIVE THAT WE TAKE A LOOK AT THE ECONOMIC AND SOCIAL IMPLICATIONS OF ALTERNATIVE ADJUSTMENTS TO THE WEATHER.

SUPPOSE THAT A MAJOR SNOWSTORM IS FORECAST FOR OTTAWA NEXT MONDAY, DO YOU – (A) ACCEPT THIS, AND ADJUST ACCORDINGLY, OR, (B) TRY AND PREVENT THE SNOWSTORM OCCURRING (PERHAPS ALTER ITS PATH TOWARDS EXPO INSTEAD)? IN EITHER CASE, IF WE KNOW SOMETHING ABOUT THE IMPACTS OF A SNOWSTORM IN LATE MAY IN OTTAWA, THEN WE WOULD BE IN A BETTER POSITION TO DECIDE WHICH OF THE ABOVE ACTIONS WE WOULD TAKE. BUT DO WE KNOW WHAT THESE IMPACTS WOULD BE?

IN LOOKING AT THE QUESTION OF ADJUSTMENTS TO THE WEATHER, TWO ITEMS SEEM TO STAND OUT AS BEING MOST IMPORTANT. THESE ARE:

(A) THE USE OF WEATHER INFORMATION,

(B) THE IDENTIFICATION OF WEATHER IMPACTS.

1. ON THE MICROSCALE, WEATHER MODIFICATION IS A REALITY, AND THERE HAS BEEN LITTLE SCEPTICISM FOR A NUMBER OF DECADES (SEE, FOR EXAMPLE, MUNN, 1966). NEVERTHELESS, THERE IS STILL CONSIDERABLE DOUBT AS TO JUST HOW "SUCCESSFUL" THE WEATHER MODIFIERS HAVE BEEN CONSIDERING THE OVERALL EFFECTS IN AN AREA.

WERE SOLD TO THE C B C AND TO THE NEWSPAPERS, AND IF PEOPLE WERE CHARGED FOR CALLING THEIR LOCAL WEATHER OFFICE FOR THE LATEST FORECAST, FOR EXAMPLE, WHAT WOULD BE A FAIR CHARGE TO MAKE FOR THIS INFORMATION? FURTHER, HOW MUCH WOULD THE C B C, THE NEWSPAPERS, AND 'JOHN CITIZEN' BE PREPARED TO PAY FOR THE WEATHER FORECAST?

UNLIKE SOME SCIENTIFIC ORGANIZATIONS, METEOROLOGICAL SERVICES HAVE A DUAL FUNCTION TO PERFORM. THE FIRST COULD BE CALLED THE SCIENTIFIC ANALYSIS AND PREDICTION OF THE ATMOSPHERE. IT IS HOWEVER, THE SECOND FUNCTION THAT DISTINGUISHES THE METEOROLOGICAL SERVICE FROM OTHER DEPARTMENTS OF STATE, NAMELY, IN ITS SERVICE TO ITS CONSUMERS. IN OTHER WORDS, THE METEOROLOGICAL SERVICE HAS A PRODUCT WHICH IS READILY "SALEABLE" TO A VAST NUMBER OF PEOPLE. IN MOST CASES THERE IS NO CHARGE FOR THE SERVICE, BUT THIS IS NO REASON WHY THE VALUE OF THESE SERVICES SHOULD NOT BE ASSESSED. FURTHER, AS TAXPAYERS, WE SHOULD BE VITALLY CONCERNED ABOUT SEEING THAT THE INFORMATION AND SERVICES PROVIDED BY THE METEOROLOGICAL SERVICES ARE USED TO THE FULLEST POSSIBLE ADVANTAGE.

5. WEATHER FORECASTING

ONE ASPECT OF THESE SERVICES, AND RIGHTLY OR WRONGLY, THE ONE BY WHICH THE MAN IN THE STREET ASSESSES THE METEOROLOGICAL PROFESSION, IS WEATHER FORECASTING. WE HAVE A LOT TO LEARN ABOUT THE SCIENCE OF WEATHER FORECASTING, AS WE ARE ALL AWARE, BUT THERE ARE SOME ASPECTS OF WEATHER FORECASTING – THE NON-SCIENTIFIC ASPECTS – OF WHICH WE ARE, IN MANY CASES, TOTALLY IGNORANT. FOR EXAMPLE, CONSIDER THE FOLLOWING:

(A) HOW MANY PEOPLE READ THE WEATHER FORECAST IN THEIR LOCAL NEWSPAPER OR LISTEN TO A WEATHER FORECAST ON THE RADIO, OR LOOK AT THE T.V. WEATHERCAST OF THESE, HOW MANY REMEMBER WHAT WAS SAID AFTER 5 MINUTES, 1 HOUR, OR NEXT MORNING?

(B) HOW OFTEN DO THE THOUGHTS OF THE WEATHER FORECASTER GET THROUGH TO THE AVERAGE PERSON? (THIS DEPENDS IN PART ON HOW THE THOUGHTS OF THE WEATHER FORECASTER ARE "TRANSLATED" INTO THE WEATHER FORECAST,[3] AND HOW THE WEATHER FORECAST IS "TRANSLATED" THROUGH THE MEDIUM OF RADIO, TV, OR NEWSPAPER TO THE AVERAGE PERSON).

3. IN THIS REGARD IT IS INTERESTING TO NOTE THAT THE U.S. WEATHER BUREAU HAS RECENTLY INTRODUCED PROBABILITY STATEMENTS INTO THEIR DAILY WEATHER FORECASTS. NEVERTHELESS, IT IS DOUBTFUL IF A FORECAST OF A "20 PER CENT CHANCE OF RAIN" MEANS THE SAME THING TO THE WEATHER FORECASTER AND HIS MANY CONSUMERS.

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CENTENNIAL WEATHER - 1967

M.K. THOMAS

MOST OF CANADA EXPERIENCED COLDER AND STORMIER WEATHER THAN NORMAL IN 1967. ALTHOUGH IN MOST MONTHS TEMPERATURES AVERAGED ABOVE NORMAL IN BRITISH COLUMBIA AND ALBERTA, CENTRAL AND EASTERN CANADA EXPERIENCED ABNORMAL COLD IN SEVERAL MONTHS OF THE YEAR, AND STATIONS IN THE EASTERN ARCTIC REPORTED THIS TO BE THE COLDEST YEAR IN THEIR METEOROLOGICAL HISTORY. THE DROUGHT IN NOVA SCOTIA ENDED EARLY IN THE YEAR, BUT THERE WAS A DRY SUMMER IN SOME PARTS OF THE PRAIRIE PROVINCES AND IN SOUTHERN BRITISH COLUMBIA. UNUSUALLY ABUNDANT SNOW FELL DURING THE SPRING IN SOUTHERN ALBERTA, AND DURING THE EARLY WINTER IN NORTHERN ONTARIO AND IN CENTRAL NEW BRUNSWICK. ON THE WEST COAST OF BRITISH COLUMBIA A NEW CANADIAN RECORD FOR PRECIPITATION ON ONE DAY WAS ESTABLISHED.

COLD

EASTERN CANADA WAS PLAGUED BY A NUMBER OF EXCEPTIONALLY COLD MONTHS. IT WAS THE COLDEST FEBRUARY IN MORE THAN THIRTY YEARS IN ONTARIO AND QUEBEC, AS DEPARTURES FROM NORMAL EXCEEDED 12 DEGREES IN SOME LOCATIONS. THE SPRING MONTHS WERE MARKEDLY COOL IN THE ATLANTIC PROVINCES. SEVERAL STATIONS REPORTED THE COLDEST MARCH SINCE 1923, AND BOTH APRIL AND MAY WERE THE COLDEST ON RECORD AT SOME STATIONS. AT HALIFAX, N.S., APRIL AND MAY TOGETHER WERE THE COLDEST TWO SPRING MONTHS SINCE 1882.

IN THE CENTRAL PROVINCES OF ONTARIO AND QUEBEC, MANY STATIONS REPORTED THE COLDEST MAY IN THE PAST SIXTY YEARS. JUNE WAS WARMER THAN JULY AT SOME STATIONS IN SOUTHWESTERN ONTARIO, THE FIRST TIME THAT SUCH AN ABNORMAL TEMPERATURE PATTERN HAS OCCURRED AT TORONTO SINCE 1895. IN ADDITION, TEMPERATURES IN SOUTHERN ONTARIO WERE SIGNIFICANTLY BELOW NORMAL IN AUGUST, SEPTEMBER AND NOVEMBER.

APRIL WAS EXCEPTIONALLY COLD THROUGHOUT ALL OF WESTERN CANADA – IN SOUTHERN ALBERTA, WHERE MEAN TEMPERATURES WERE NEAR FREEZING, IT WAS 10 TO 12 DEGREES BELOW NORMAL, MAKING THIS THE COLDEST APRIL ON RECORD. IN THE

ARCTIC, FROBISHER BAY, N.W.T. REPORTED TEMPERATURES 18 DEGREES BELOW NORMAL IN FEBRUARY, AND IN NOVEMBER RESOLUTE REPORTED 13 DEGREES BELOW NORMAL – BOTH NEW LOW MONTHLY RECORDS. APRIL WAS ALSO BITTERLY COLD IN THE HUDSON BAY AREA OF THE SUB–ARCTIC, AS WAS JUNE ALONG THE WESTERN ARCTIC MAINLAND COAST. BOTH RESOLUTE AND FROBISHER BAY REPORTED 1967 TO BE THE COLDEST YEAR ON RECORD.

WARM

AT TORONTO, A MAXIMUM TEMPERATURE OF 61^0 ON JANUARY 25 WAS THE WARMEST JANUARY TEMPERATURE ON RECORD SINCE OBSERVATIONS WERE BEGUN IN 1840. IT IS INTERESTING TO NOTE THAT THIS RECORD WAS ESTABLISHED IN THE TRADITIONAL "JANUARY THAW" PERIOD. MAY WAS AN EXCEPTIONALLY MILD MONTH IN THE NORTHEAST ARCTIC, WHERE SEVERAL STATIONS REPORTED TEMPERATURE ANOMALIES RANGING TO 12 DEGREES. IT WAS THE WARMEST AUGUST ON RECORD ON THE ISLAND OF NEWFOUNDLAND, WITH MEAN TEMPERATURES RANGING TO 7 DEGREES ABOVE NORMAL. ABNORMALLY WARM SPELLS OCCURRED IN WESTERN CANADA DURING THE LATE SUMMER, AS BOTH AUGUST AND SEPTEMBER WERE THE WARMEST SUCH MONTHS ON RECORD AT SEVERAL LOCATIONS. FOR TEN CONSECUTIVE DAYS – AUGUST 11–20, COLUMBIA GARDENS, NEAR TRAIL, B.C. REPORTED MAXIMUM TEMPERATURES OF 100 DEGREES OR MORE. DURING THE FIRST WEEK OF SEPTEMBER MANY STATIONS IN ALBERTA AND SASKATCHEWAN REPORTED THE HIGHEST TEMPERATURES EVER REPORTED IN THAT MONTH, INCLUDING A TEMPERATURE OF 101^0 AT EMPRESS, ALBERTA, ON THE 5TH. OVER THE MONTH AS A WHOLE, THIS WAS THE WARMEST SEPTEMBER IN MANITOBA SINCE 1948, IN SASKATCHEWAN SINCE 1938, AND THE WARMEST ON RECORD IN ALBERTA.

WET

IN NOVA SCOTIA, 1965 AND 1966 HAD BEEN TWO OF THE DRIEST YEARS ON RECORD, BUT THE DROUGHT WAS BROKEN BY THE LATTER HALF OF 1967 AFTER THAT PROVINCE REPORTED SEVERAL MONTHS OF ABOVE NORMAL PRECIPITATION, CULMINATED BY DECEMBER TOTALS THAT EXCEEDED 13 INCHES AT MANY STATIONS.

ON THE PRAIRIES, EXCESSIVE RAINFALL AND RESULTING FLOODS WERE REPORTED FROM THE AREA SOUTHWEST OF CALGARY LATE IN MAY. HEAVY RAINS IN ONTARIO DURING JUNE PRODUCED MUCH DAMAGE, AT TAVISTOCK 13.27 INCHES OF RAINFALL WERE REPORTED, THE MOST RAIN EVER REPORTED AT ANY STATION IN ONTARIO DURING JUNE. JULY AND AUGUST WERE ALSO WET IN PARTS OF ONTARIO, BUT IT WAS IN BRITISH COLUMBIA THAT PRECIPITATION BECAME EXCESSIVE DURING THE LATTER PART OF THE YEAR. THE NORTH COAST AREA OF BRITISH COLUMBIA REPORTED TWICE NORMAL PRECIPITATION IN JULY, AND ABNORMAL AMOUNTS AGAIN IN SEPTEMBER AND OCTOBER. RAINFALL IN VANCOUVER AMOUNTED TO 17.87 INCHES IN OCTOBER, THE WETTEST MONTH ON RECORD SINCE JANUARY 1935. CONSIDERABLE RAINFALL ALSO OCCURRED AT QUEBEC AIRPORT, WHERE THE JUNE TO AUGUST PRECIPITATION TOTALLED 19.52, THE GREATEST SUMMER ON RECORD SINCE 1943.

DRY

THERE WERE DROUGHT AREAS IN WESTERN CANADA DURING THE SPRING AND SUMMER, WHERE REGINA, SASKATCHEWAN REPORTED THE DRIEST SUMMER ON RECORD, AS BUT 2.69 INCHES OF PRECIPITATION FELL OVER THE PERIOD FROM APRIL THROUGH AUGUST, FAR SHORT OF THE NORMAL 9.80 INCHES. IT WAS ALSO A VERY DRY SUMMER IN SOUTHERN BRITISH COLUMBIA, CAUSING A PERIOD OF HIGH FOREST DANGER AND CRITICAL WATER SHORTAGES.

SNOW

RECORD SNOWFALLS WERE REPORTED IN SOUTHERN ALBERTA LATE IN APRIL AS TWO STORMS, A WEEK APART, BROUGHT TOTALS OF FROM 60 TO 80 INCHES OF FRESH SNOW TO STATIONS IN THE AREA. A THIRD STORM, EARLY IN MAY, ADDED A FURTHER 6 TO 8 INCHES. EARLIER NEW MONTHLY SNOWFALL RECORDS HAD BEEN ESTABLISHED AT SOME STATIONS ON THE PRAIRIES IN JANUARY, AT FREDERICTON, N.B. IN FEBRUARY, AND IN SOME PARTS OF NOVA SCOTIA IN MARCH. BLIZZARD CONDITIONS ON MARCH 29–30 DISRUPTED COMMUNICATIONS AND TRANSPORTATION IN SASKATOON AND REGINA ON THE PRAIRIES, AND THE EASTER WEEKEND STORM LEFT FROM 1 TO ALMOST 4 FEET OF FRESH SNOW ACROSS A LARGE PART OF THE MARITIME PROVINCES. EARLY IN DECEMBER A MAJOR STORM LEFT OVER 2 FEET OF SNOW ON PARTS OF NEW BRUNSWICK, AND FREDERICTON REPORTED A RECORD 31 INCHES ON DECEMBER 4, AND 59 INCHES OF SNOWFALL DURING THF MONTH. BOTH CALENDAR YEAR AND WINTER SEASON SNOWFALL RECORDS WERE ESTABLISHED IN SUCH WIDELY SEPARATED REGIONS AS THE YUKON, SOUTHERN ALBERTA AND NEW BRUNSWICK. IN THE SUB–ARCTIC UNUSUALLY HEAVY SNOWFALLS WERE REPORTED IN THE SOUTHERN YUKON DURING THE 1966–67 SEASON, AS INDICATED BY A TOTAL OF 79 INCHES AT WHITEHORSE. IN SOUTHERN ALBERTA, ANNUAL TOTALS AS HIGH AS 294 INCHES AT WATERTON PARK HEADQUARTERS WERE REPORTED, WHILE THE 157 INCHES AT LETHBRIDGE DURING THE WINTER OF 1966–67 MADE THAT THE SNOWIEST WINTER ON RECORD. THE CALENDAR YEAR 1967 WAS THE SNOWIEST ON RECORD AT BOTH FREDERICTON (185 INCHES) AND MONCTON (208 INCHES).

GREATEST PRECIPITATION IN ONE DAY

A NEW CANADIAN RECORD OF PRECIPITATION ON ONE DAY WAS ESTABLISHED AT UCLUELET BRYNNOR MINES, B.C., WHERE 19.26 INCHES OF RAIN FELL ON OCTOBER 6. THE TOTAL FOR THE MONTH AT THIS WEST COAST STATION WAS 72.60 INCHES, SOME 7 INCHES SHORT OF ANOTHER ALL–TIME CANADIAN RECORD. THE PREVIOUS RECORD FOR THE GREATEST PRECIPITATION IN ONE DAY HAD BEEN ESTABLISHED AT HENDERSON LAKE, ALSO ON THE WEST COAST OF VANCOUVER ISLAND, ON DECEMBER 30, 1926 WHEN 16.61 INCHES FELL.

FOG AND SUNSHINE

IT WAS THE FOGGIEST SUMMER ON RECORD ALONG THE ATLANTIC COAST OF NOVA SCOTIA, WHERE AT YARMOUTH, FOG WAS REPORTED ON 85 OF THE 92 DAYS IN JUNE, JULY AND AUGUST. THE ATMOSPHERIC CIRCULATION WAS SUCH, HOWEVER, THAT 350 MILES TO THE NORTH AT SYDNEY, ONE OF THE BEST VACATION SUMMERS ON RECORD WAS REPORTED, AS THERE WAS IN NEWFOUNDLAND. DESPITE THE GENERAL COLD AND STORMY WEATHER ACROSS THE COUNTRY, MANY STATIONS REPORTED NEW BRIGHT SUNSHINE RECORDS, SUCH AS 236 HOURS AT GANDER, NFLD. IN JUNE, 354 HOURS AT PRINCE GEORGE, B.C. IN JUNE, 351 HOURS AT WINNIPEG IN AUGUST, 344 HOURS AT EDMONTON IN AUGUST, 322 HOURS AT VANCOUVER IN AUGUST, 346 HOURS AT REGINA IN SEPTEMBER. ON THE OTHER HAND, VICTORIA HAD THE DULLEST OCTOBER SINCE SUNSHINE RECORDS WERE COMMENCED IN 1914, AS BUT 83 HOURS WERE REPORTED.

CENTENNIAL WEATHER IN THE LARGE URBAN AREAS

MONTREAL

CENTENNIAL YEAR IN MONTREAL WAS COOL AND RELATIVELY DRY, AND IN GENERAL, THE WEATHER WAS EXTREMELY FAVOURABLE DURING THE PERIOD OF EXPO FROM APRIL 27 TO OCTOBER 30. BOTH TEMPERATURE AND PRECIPITATION AVERAGED NEAR NORMAL, THERE WERE NO EXTREMELY HOT DAYS, AND BUT ONE PROLONGED PERIOD OF WARM, HUMID WEATHER FROM JULY 19 TO 24. PRIOR TO THE OPENING OF EXPO, HOWEVER, BOTH FEBRUARY AND MARCH HAD BEEN EXTREMELY COLD IN MONTREAL, AND FEBRUARY, WITH AN AVERAGE TEMPERATURE OF 7^0, WAS THE COLDEST MONTH ON RECORD IN THE 26 YEARS OF OBSERVATIONS AT DORVAL AIRPORT.

TORONTO

NINE MONTHS OF 1967 WERE COLDER THAN NORMAL. THE JULY MEAN TEMPERATURE WAS LOWER THAN THAT FOR JUNE, AND AT NO TIME DURING THE SUMMER DID THE TEMPERATURE GO ABOVE 90^0F. BOTH FEBRUARY AND MARCH AVERAGED 5 DEGREES BELOW NORMAL, AND A TEMPERATURE OF -12^0 REPORTED ON FEBRUARY 12 WAS THE COLDEST REPORTED IN TORONTO SINCE EARLY 1950.

VANCOUVER

THE YEAR 1967 WAS WET WITH PARTICULARLY HEAVY FALLS IN OCTOBER WHEN 17.87 INCHES FELL IN THE CITY, MORE PRECIPITATION THAN IN ANY OTHER MONTH SINCE 1935.

THE SUMMER MONTHS WERE WARM AND DRY. AUGUST WAS DRIER AND SUNNIER THAN ANY PREVIOUSLY ON RECORD. OVER THE YEAR FOG OCCURRED AT THE AIRPORT ON ONLY 30 DAYS, A RECORD LOW AND LESS THAN HALF THE AVERAGE NUMBER OF DAYS.

WINNIPEG

AT WINNIPEG, 1967 WAS THE FOURTH CONSECUTIVE YEAR WITH A BELOW NORMAL ANNUAL MEAN TEMPERATURE. AFTER A COOL, WET SPRING, JUNE WAS A PLEASANT MONTH, BUT IN JULY HEAVY RAINSTORMS OCCURRED, INCLUDING ONE ON THE 23RD DURING THE OPENING CEREMONIES OF THE PAN-AMERICAN GAMES. AUGUST WAS THE SUNNIEST ON RECORD, AND A PROLONGED DRY SPELL IN SEPTEMBER GAVE IDEAL HARVESTING WEATHER.

OTTAWA

1967 WAS COOL AND WET. FEBRUARY WAS THE COLDEST MONTH IN THE LAST 31 YEARS, AND MAY, THE COLDEST SINCE AT LEAST 1890.

HAMILTON

MAY WAS AN EXCEPTIONALLY COLD MONTH, JUNE WAS VERY WET, AND JULY AND AUGUST COMPARATIVELY COOL. EARLY WINTER SNOWFALLS WERE LIGHT, WITH LITTLE SNOW ACCUMULATION ON THE GROUND UNTIL AFTER CHRISTMAS.

QUEBEC

AFTER FOUR CONSECUTIVE EXCEPTIONALLY COLD MONTHS, NORMAL TEMPERATURES RETURNED IN JUNE, BUT EACH OF THE SUMMER MONTHS WAS WET, WITH A RECORD TOTAL OF 19.52 INCHES FALLING DURING THE THREE MONTHS.

EDMONTON

AUGUST AND SEPTEMBER WERE REMARKABLE MONTHS. AUGUST WAS BOTH THE WARMEST AND SUNNIEST EVER RECORDED IN THE CITY, WHILE SEPTEMBER WAS THE WARMEST AND THE SECOND SUNNIEST SEPTEMBER EVER REPORTED.

CALGARY

CALGARY REPORTED MORE BRIGHT SUNSHINE, 2470 HOURS, THAN ANY YEAR ON RECORD SINCE 1933, WHEN SUCH OBSERVATIONS WERE BEGUN. DURING THE FIRST HALF OF THE YEAR TEMPERATURES WERE GENERALLY BELOW NORMAL, AND THERE WAS ABUNDANT SNOWFALL, WITH THE LAST MEASURABLE FALL OCCURRING ON JUNE 10. THIS RESULTED IN ONE OF THE LATEST SEEDING OPERATIONS ON RECORD, BUT THE EXCEEDINGLY WARM, DRY SUMMER MONTHS PERMITTED A NORMAL CROP TO BE HARVESTED IN NEAR RECORD TIME.

HALIFAX

THE MOST IMPORTANT WEATHER FEATURE OF 1967 WAS THE ENDING OF THE SERIOUSLY DRY CONDITIONS THAT HAD PREVAILED THROUGH 1965 AND 1966. IN 1967, NEARLY 67 INCHES OF PRECIPITATION FELL, MAKING THIS THE WETTEST YEAR SINCE 1910. BOTH JULY AND AUGUST WERE RECORD FOGGY MONTHS, AND OVER THE YEAR AS A WHOLE, THERE WERE 121 FOGGY DAYS, THE MOST ON RECORD, EXCEPT FOR THE 125 DAYS IN 1946.

ACKNOWLEDGMENTS

THE MONTHLY METEOROLOGICAL SUMMARIES PREPARED BY ABOUT 40 OBSERVING STATIONS WERE OF GREAT ASSISTANCE IN PREPARING THIS REPORT. THE ASSISTANCE OF THE REGIONAL METEOROLOGISTS AND OFFICERS-IN-CHARGE OF SEVERAL WEATHER CENTRALS AND OFFICES IS ALSO GRATEFULLY ACKNOWLEDGED.

INTER ALIA

THE PRODUCTION STAFF IS LEARNING AS IT WORKS. AN INNOVATION IN THIS ISSUE IS BREAKS IN THE ARTICLES. WHILE IT IS RECOGNIZED THAT "CONTINUED ON PAGE XX" CAN BE A LITTLE ANNOYING, THE STEP HAS BEEN TAKEN IN THE INTEREST OF ECONOMY. OUR POLICY OF FIFTY FREE REPRINTS TO AUTHORS HAS BEEN RATIFIED BY COUNCIL. IN ORDER TO CARRY IT OUT AT A REASONABLE COST, THE PAGING OF THE ISSUE MUST BE SPECIALLY ARRANGED TO MINIMIZE EXTRA PHOTOGRAPHING AND OTHER LABOUR AT THE PRINTERS.

WE HOPE THAT YOU LIKE OUR NEW LOOK, AND THAT YOU DO NOT FIND THE BREAKS IN THE ARTICLES TOO IRRITATING.

ERRATTA

1. VOL. 6, NOS. 1 AND 2, INSIDE FRONT COVER. SUBSTITUTE V. TURNER FOR V. MARSH UNDER ASSOCIATE EDITORS.

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LA SOCIÉTÉ DE MÉTÉOROLOGIE DE QUÉBEC

PAR G. OSCAR VILLENEUVE

POUR FAIRE SUITE A UN RAPPORT PUBLIÉ DANS ATMOSPHERE (VOL. V (4): 31–33) ET CONTINUER LE RÉCIT DES ACTIVITÉS DE LA SOCIÉTÉ DE MÉTÉOROLOGIE DE QUÉBEC, NOUS NOUS DEVONS DE MENTIONNER LES NOMS DES MEMBRES DU CONSEIL D'ADMINISTRATION ÉLUS EN AVRIL 1967, LES CAUSERIES PRÉSENTÉES AU COURS DE LA DERNIÈRE ANNÉE ET LA COMPOSITION DU NOUVEAU CONSEIL D'ADMINISTRATION ÉLU POUR LE PROCHAIN EXERCICE 1968–69.

EN AVRIL DERNIER, LE CONSEIL D'ADMINISTRATION ÉTAIT COMPOSÉ COMME SUIT:

PRÉSIDENT	–	LAWRENCE–J. O'GRADY, PH.D. DIRECTEUR DÉPARTEMENT DES SOLS FACULTÉ D'AGRICULTURE DE L'UNIVERSITÉ LAVAL
VICE–PRÉSIDENT	–	RENALD NAUD, M.A. PROFESSEUR DE MATHÉMATIQUES ET DE MÉTÉOROLOGIE FACULTÉ DE FORESTERIE DE L'UNIVERSITÉ LAVAL
SEC.–TRÉS.	–	MICHEL FERLAND, M.A.
CONSEILLERS	–	CYNTHIA WILSON, GÉOGRAPHE JULES DIONNE, ING. F. CLAUDE PESANT, ING.C. RAYMOND PERRIER, M.A. J.–GUY FRECHETTE, M.F.

REPRÉSENTANT A LA SOCIÉTÉ DE MÉTÉOROLOGIE DU CANADA: G.–O. VILLENEUVE.

AU COURS DE L'ANNÉE 1967–68, LA SOCIÉTÉ A TENU QUATRE RÉUNIONS D'INFORMATION ET UNE ASSEMBLÉE GÉNÉRALE DES MEMBRES. LE CONSEIL D'ADMINISTRATION S'EST RÉUNIT TROIS FOIS, SOIT EN SEPTEMBRE 1967, JANVIER 1968 ET AVRIL 1968.

LES CONFÉRENCIERS INVITÉS AU COURS DE L'ANNÉE PAR LA SOCIÉTÉ FURENT PAR ORDRE CHRONOLOGIQUE:

26 OCTOBRE 1967 – J.–G. FRECHETTE, M.F., R. NAUD, M.A., C. PESANT, ING. ET R. ROY, ING.
"RECHERCHES ET PROJETS EN COURS SUR LE BASSIN EXPERIMENTAL DU RUISSEAU DES EAUX VOLÉES, FORÊT MONTMORENCY".

29 NOVEMBRE 1967 – RAYMOND PERRIER, M.A.
"LA MÉTÉOROLOGIE EN FRANCE ET EN ANGLETERRE".

16 FÉVRIER 1968 – REV. CONRAD EAST, S.J., PH.D.
"COMPARISON DU RAYONNEMENT SOLAIRE EN VILLE ET À LA CAMPAGNE".

21 MARS 1968 – VICTORIN LAVOIE, D.SC.
"ASPECTS ÉCOLOGIQUES, PHYSIOLOGIQUES ET ÉCONOMIQUES DES BLEUETIERES DE LA RÉGION DU LAC ST-JEAN".

LA RÉUNION DU 21 MARS ÉTAIT SOUS L'ÉGIDE À LA FOIS DE LA SOCIÉTÉ DE MÉTÉOROLOGIE ET DE LA SOCIÉTÉ LINNÉENNE DE QUÉBEC. ELLE SE TERMINA PAR UN VIN D'HONNEUR GRACIEUSEMENT OFFERT PAR LA SOCIÉTÉ LINNÉENNE. PARMI L'AUDITOIRE D'UNE CINQUANTAINE DE PERSONNES, ON REMARQUAIT DE NOMBREUX FONCTIONNAIRES PROVINCIAUX ET DES PROFESSEURS DE L'UNIVERSITÉ LAVAL.

LA SOCIÉTÉ A SUGGÈRE AUX RESPONSABLES AD HOC DE L'UNIVERSITÉ LAVAL LE MAINTIEN DES COURS DU SOIR DE MÉTÉOROLOGIE AU COURS DU PREMIER SEMESTRE 1968-69.

AU COURS DU PRINTEMPS 1968, LA SOCIÉTÉ EST ENTRÉE EN POURPARLERS AVEC LA SOCIÉTÉ CANADIENNE DE MÉTÉOROLOGIE AU BUT DE FORMER ASSOCIATION DANS LE SENS QUE LA SOCIÉTÉ DE MÉTÉOROLOGIE DE QUÉBEC DEVIENNE UN CENTRE LOCAL DE LA SOCIÉTÉ DE MÉTÉOROLOGIE DU CANADA. DANS CES ÉCHANGES DE VUES, LA SOCIÉTÉ DE QUÉBEC A MANIFESTÉ LE DESIR DE MAINTENIR SON AUTONOMIE ADMINISTRATIVE TOUT EN PARTICIPANT DANS LA MESURE DU POSSIBLE AUX ACTIVITÉS D'INTERET MÉTÉOROLOGIQUE. LA DISCUSSION SE POURSUIT DANS UNE ATMOSPHERE DES PLUS SYMPATHIQUE.

LA SOCIÉTÉ RÉITÉRE SES VOEUX DE LA CRÉATION À LA STATION AGRONOMIQUE DE L'UNIVERSITÉ LAVAL D'UN CENTRE DE RECHERCHES EN BIOCLIMATOLOGIE. ELLE SE PROMET DE FAIRE DES DÉMARCHES DANS CE SENS AU COURS DE LA PROCHAINE ANNÉE EN INSTIGUANT LES AUTORITÉS DE LA FACULTÉ D'AGRICULTURE DE LAVAL DE DONNER SUITE SERIEUSE À CETTE PROPOSITION.

DES SUGGESTIONS REPETÉES FAITES AUX RESPONSABLES DU MINISTÈRE PROVINCIAL DE L'AGRICULTURE PAR LES MEMBRES DU CONSEIL DE LA SOCIÉTÉ ONT FAVORISÉ L'ÉCLOSION D'UN COMITÉ PROVINCIAL D'AGROMÉTÉOROLOGIE QUI DEVRA, SOUS PEU, ÊTRE RATIFIÉ PAR QUI DE DROIT.

CE RÉSUMÉ D'ACTIVITÉS DE LA SOCIÉTÉ DE MÉTÉOROLOGIE DE QUÉBEC, PUISE DANS LE DISCOURS DU PRÉSIDENT, SERAIT INCOMPLET SANS LA MENTION DES MEMBRES DU CONSEIL D'ADMINISTRATION ÉLUS POUR LA PROCHAINE ANNÉE. CE SONT :

PRÉSIDENT – LAWRENCE-J- O'GRADY, PH.D.
VICE-PRÉSIDENT – RENALD NAUD, M.A.
SEC.-TRÉS – MICHEL FERLAND, M.A.

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– CONTINUED FROM PAGE 96

(C) WHAT EFFECT DOES THE WEATHER FORECAST HAVE ON 'JOHN CITIZEN'? DOES HE RE–SCHEDULE ANY OF HIS ACTIVITIES BECAUSE OF THE FORECAST? DOES IT MAKE ANY DIFFERENCE WHETHER OR NOT THE FORECAST IS ACCURATE? FOR EXAMPLE, DOES AN "ACCURATE" FORECAST OF WET WEATHER AFFECT THE COMMUNITY IN ANY WAY? DOES IT AFFECT SHOPPERS, TRANSPORT, TOURISM, ETC.? FURTHER, DOES AN "INACCURATE" FORECAST HAVE DIFFERENT EFFECTS FROM AN ACCURATE FORECAST?

(D) ARE LONG–RANGE FORECASTS (5 DAYS AND 30 DAYS) USED BY 'JOHN CITIZEN'? HOW MANY PEOPLE ARE INFLUENCED IN THEIR DECISIONS BY THESE FORECASTS? DOES IT MAKE ANY DIFFERENCE HOW ACCURATE THEY ARE?

AS A POSTSCRIPT IT MAY BE APPROPRIATE TO MENTION THE 1967 PRESIDENTIAL ADDRESS TO THE ROYAL METEOROLOGICAL SOCIETY BY DR. G.D. ROBINSON REPORTED BRIEFLY IN NATURE (ROBINSON 1967). THE ADDRESS HAD AS ITS PRINCIPAL THEME A WARNING THAT WEATHER FORECASTING MAY HAVE BEEN SERIOUSLY OVERSOLD. DR. ROBINSON WAS CONCERNED THAT PLANS FOR THE COLLECTION OF METEOROLOGICAL DATA ON A WORLD–WIDE SCALE, VALUABLE IN THEMSELVES, HAD BEEN JUSTIFIED BY PROMISES OF GREAT ECONOMIC BENEFITS FROM IMPROVEMENTS IN WEATHER FORECASTING AND EVEN FROM WEATHER CONTROL. ACCORDING TO DR. ROBINSON, IT MAY BE HARD TO KEEP THESE PROMISES.

THE EXTENT TO WHICH THE WEATHER WAS PREDICTABLE WAS RAISED. ROBINSON INDICATED THAT THE GLOBAL ATMOSPHERIC RESEARCH PROJECT WAS PLANNED ON THE ASSUMPTION THAT IF THE INITIAL STATE OF THE ATMOSPHERE IS KNOWN WITH SUFFICIENT ACCURACY, LARGE SCALE MOTIONS ARE PREDICTABLE "AS A DETERMINATE PHYSICAL SYSTEM FOR A PERIOD OF APPROXIMATELY TWO WEEKS". THE PROPOSALS OF THE WORLD METEOROLOGICAL ORGANIZATION FOR WHAT IS KNOWN AS WORLD WEATHER WATCH HAVE BEEN SIMILARLY JUSTIFIED. DR. ROBINSON WAS CONCERNED TO TEST THIS CLAIM, AND PARTICULARLY THE TRUTH OF THE ASSUMPTION THAT THERE IS NO FUNDAMENTAL LIMITATION OF THE PREDICTABILITY OF THE ATMOSPHERE, BUT ONLY PRACTICAL LIMITATIONS ARISING FROM THE LIMITATIONS OF COMPUTING MACHINERY AND METHODS OF MEASUREMENTS.

THIS IS NOT THE TIME OR PLACE TO FULLY DISCUSS THE IMPLICATIONS OF WHAT DR. ROBINSON IS SAYING, AND THERE WILL BE MANY WHO DISAGREE WITH HIS FINDINGS, BUT IT IS WORTH NOTING THAT HE CONCLUDED, ACCORDING TO NATURE, THAT "..... FOR PHENOMENA CHARACTERIZED BY A SCALE OF 5,000 KM, PREDICTABILITY IS LIKELY TO BE LIMITED TO 5 DAYS. EVENTS WITH A SCALE OF 5KM WILL PROBABLY BE PREDICTABLE FOR ONLY 2 HOURS IN ADVANCE".[4]

4. IT SHOULD BE NOTED, HOWEVER, THAT CLIMATOLOGICAL FORECASTING (AS CONTRASTED WITH SYNOPTIC FORECASTING) CAN BE HIGHLY SUCCESSFUL ESPECIALLY IN SUCH ENGINEERING PROBLEMS AS THE DESIGN OF DAMS, BUILDINGS, STACK HEIGHTS, SPACE CRAFT, ETC.

6. WEATHER MODIFICATION

MUCH HAS BEEN WRITTEN IN RECENT YEARS ON WEATHER MODIFICATION. THERE ARE, OF COURSE, CLAIMS AND COUNTER CLAIMS AS TO WHAT CAN AND CANNOT BE DONE, BUT THERE NOW SEEMS TO BE AGREEMENT THAT IN CERTAIN AREAS, UNDER CERTAIN CIRCUMSTANCES AND AT CERTAIN TIMES, WEATHER MODIFICATION IN THE FORM OF AN INCREASED PRECIPITATION OF THE ORDER OF 10 TO 15 PER CENT CAN BE ACHIEVED, AND THAT THE DISPERSAL OF COLD FOG, AND THE SUPPRESSION OF HAIL AND LIGHTNING ARE FEASIBLE. NEVERTHELESS, LITTLE THOUGHT HAS GONE INTO SOME FUNDAMENTAL QUESTIONS REGARDING WEATHER MODIFICATION. THE BASIC SCIENTIFIC QUESTION MAY WELL BE – CAN YOU MODIFY THE WEATHER? BUT THE MORE FUNDAMENTAL QUESTION IS – SHOULD YOU DO SO, WHERE SHOULD YOU DO SO, AND WHAT SAFEGUARDS ARE THERE EITHER IN THE FORM OF LAWS OR COMPENSATION TO PROVIDE FOR THE ERRORS WHICH OCCUR. THE QUEBEC WEATHER MODIFICATION CONTROVERSY A FEW YEARS AGO EMPHASISES THE FACT THAT THE ECONOMIC, SOCIAL AND POLITICAL IMPLICATIONS OF WEATHER MODIFICATION CANNOT BE IGNORED.

IN CANADA THERE HAVE BEEN A FEW OPERATIONAL PROGRAMS FOR WEATHER MODIFICATIONS. IN CONTRAST, IN THE U.S., FRANCE, ITALY, U.S.S.R. AND AUSTRALIA, TO MENTION ONLY A FEW COUNTRIES, NOT ONLY HAS THERE BEEN A SUBSTANTIAL RESEARCH EFFORT TO LEARN MORE ABOUT THE MECHANICS OF THE ATMOSPHERE, BUT ALSO AN INCREASING EFFORT TO IMPROVE THE STATE OF THE ART OF WEATHER MODIFICATION. EVEN MORE IMPORTANT, IN THE U.S. AT LEAST, THERE IS GROWING CONCERN WITH REGARD TO THE ECONOMIC, POLITICAL AND SOCIAL ASPECTS OF WEATHER MODIFICATION AS WELL. THESE ASPECTS WERE EXPLORED IN A SYMPOSIUM HELD AT B: DER, COLORADO IN JULY, 1965, WHICH CULMINATED IN THE PUBLICATION OF A MONOGRAPH "HUMAN DIMENSIONS OF WEATHER MODIFICATION" (SEWELL, 1966). THE NATIONAL SCIENCE FOUNDATION SUBSEQUENTLY ESTABLISHED A TASK GROUP ON THE HUMAN DIMENSIONS OF THE ATMOSPHERE TO EXPLORE THESE MATTERS IN GREATER DETAIL. THIS GROUP CONSISTING OF LAWYERS, POLITICAL SCIENTISTS, GEOGRAPHERS, ECONOMISTS, SOCIOLOGISTS, TWO METEOROLOGISTS, AND A NUMBER OF ADVISORS HAS MET SEVERAL TIMES IN THE LAST 12 MONTHS, AND THE REPORT WILL BE PUBLISHED LATER THIS YEAR.[5]

7. WEATHER SENSITIVE ACTIVITIES

THE NATURE AND SCOPE OF A WEATHER FORECASTING PROGRAM, AND THE DECISION WHETHER OR NOT TO MODIFY THE WEATHER, BOTH DEPEND UPON A KNOWLEDGE OF THE WEATHER SENSITIVITY OF VARIOUS ACTIVITIES.[6]

5. ONE OF THE PRESENT AUTHORS, W.R.D. SEWELL, WAS THE CHAIRMAN OF THE TASK GROUP. THE OTHER AUTHOR, W.J. MAUNDER, ACTED AS AN ADVISOR TO THE TASK GROUP.

6. IT IS IMPORTANT TO REALISE THAT ACCURATE WEATHER FORECASTING AND SUCCESSFUL WEATHER MODIFICATION TO THE CLIENT MAY BOTH HAVE SIMILAR EFFECTS, FOR THE CLIENT SUCH AS THE PRAIRIE FARMER IS NOT USUALLY CONCERNED ABOUT WHY IT RAINS, BUT ONLY THAT IT DOES RAIN. THAT IS, THE CONSUMER IS CONCERNED WITH WHAT IT DOES, NOT WHY.

WHAT ARE THE WEATHER SENSITIVE ACTIVITIES, AND WHAT PART DO WEATHER VARIATIONS PLAY IN THESE ACTIVITIES? CONSIDER, FOR EXAMPLE THE FOLLOWING –

(A) WHAT IS A SIGNIFICANT WEATHER VARIATION?

1^0F, 2^0F, OR MORE TEMPERATURE
1", 2" OR MORE PRECIPITATION
10 HOURS SUNSHINE, 20 HOURS SUNSHINE ...

(B) ARE THESE SIGNIFICANT WEATHER VARIATIONS THE SAME FROM ONE AREA TO ANOTHER, ONE MONTH TO THE NEXT, AND FROM ONE TYPE OF ACTIVITY TO ANOTHER? FOR EXAMPLE, DO SIMILAR WEATHER VARIATIONS, IN FACT, EFFECT ICE CREAM SALES MORE THAN GASOLINE SALES, B.C. MORE THAN ALBERTA, THE TOURIST IN WINNIPEG MORE THAN THE TOURIST IN OTTAWA, JULY RETAIL SALES MORE THAN AUGUST RETAIL SALES?

(C) WHAT EFFECT DOES A SIGNIFICANT WEATHER VARIATION HAVE ON THE WEATHER SENSITIVE ACTIVITIES. WHAT EFFECT DO THEY HAVE FOR EXAMPLE, ON AGRICULTURAL PRODUCTION, THE TOURIST, RETAIL SALES, UNEMPLOYMENT, ICE CREAM SALES, AIR CANADA, GASOLINE SALES, SPORT, HOME HEATING COSTS, ETC.? DO THESE EFFECTS VARY FROM ONE MONTH TO THE NEXT, FROM ONE AREA TO ANOTHER AREA, OR FROM YEAR TO YEAR?

(D) WHAT ARE THE OVERALL CREDITS AND DEBITS ATTRIBUTED TO WEATHER VARIATIONS: WHAT FOR EXAMPLE, IS THE IMPACT OF A LONG, HOT, DRY SUMMER ON TOURISM IN B.C., A SNOWSTORM ON THE ECONOMY OF SASKATCHEWAN, A 10 PER CENT INCREASE IN SUNSHINE ON RETAIL SALES IN METROPOLITAN TORONTO, AND THE 1966 CLIMATIC YEAR ON THE ECONOMY OF CANADA?

(E) ARE THERE AERIAL DIFFERENCES IN THE CREDITS AND DEBITS FROM WEATHER VARIATIONS? DOES, FOR EXAMPLE, CONSIDERING THE TOTAL CANADIAN ECONOMY, A WARM WINTER IN B.C. 'COMPENSATE' FOR A COLD WINTER IN ONTARIO, OR A DRY SUMMER IN QUEBEC 'COMPENSATE' FOR A CLOUDY SUMMER ON THE PRAIRIES?

ALTHOUGH SOME RESEARCH HAS BEEN UNDERTAKEN TO ANSWER QUESTIONS SUCH AS THESE, MUCH HAS STILL TO BE ACCOMPLISHED. AS NOTED BY THOMPSON (1966) SOME OF THESE STUDIES HAVE ALREADY BEEN COMPLETED. IN THIS PAPER HOWEVER, IT MAY BE MORE APPROPRIATE TO BRIEFLY MENTION A REPORT BY A STAFF WRITER OF THE WINNIPEG TRIBUNE WHO HAS RECENTLY COMPLETED A STUDY OF THE COST TO THE AVERAGE MANITOBAN OF A WINTER (TREMAYNE, 1967). IN THIS ARTICLE TREMAYNE SAYS THAT MANITOBANS INDULGE IN A PERVERSE SORT OF LUXURY DURING THE WINTER, BOASTING THAT THEY CAN TAKE THE WORST THE ELEMENTS THROW AT THEM. BUT AS TREMAYNE MENTIONS: "IT COSTS US PLENTY FOR THE PRIVILEGE OF ENDURING THE RAVAGES OF WINTER". USING INFORMATION GAINED FROM NUMEROUS SOURCES, TREMAYNE ESTIMATES THAT AN AVERAGE WINTER COSTS MANITOBAIS 959,000 RESIDENTS $246,846,800 OR $257.40 PER PERSON. WHAT, ONE MAY WELL ASK, IS THE COST IN OTHER PARTS OF CANADA, CAN A BETTER USE OF WEATHER FORECASTS AND WEATHER INFORMATION LESSEN THESE COSTS, AND HOW MUCH DO THESE COSTS VARY FROM ONE WINTER TO ANOTHER?

IF WE HAD ANSWERS TO ALL THE FOREGOING QUESTIONS, THEN –

1. WE WOULD BE IN A BETTER POSITION TO EVALUATE WEATHER FORECASTING PROGRAMS,

2. THOSE INVOLVED IN WEATHER SENSITIVE ACTIVITIES COULD OPERATE MORE EFFICIENTLY, AND

3. THE ECONOMICS OF WEATHER MODIFICATION PROGRAMS COULD BE MORE PRECISELY DETERMINED.

ONCE THIS STAGE HAS BEEN REACHED, ADJUSTMENTS TO THE WEATHER WILL BE LESS OF A CHANCE (AS THEY ARE TODAY), AND MORE A MATTER OF CHOICE.

8. A GUIDE TO THE FUTURE

WE HAVE MENTIONED SOME OF THE PROBLEMS IN METEOROLOGY AS WE LOOK TO THE FUTURE. IF TOMORROW'S WEATHER IS TO BE MORE A MATTER OF CHOICE THAN CHANCE, WHAT SHOULD BE DONE?

FIRST, RESEARCH ON THE ECONOMIC AND SOCIAL ASPECTS OF WEATHER, WEATHER FORECASTING, AND WEATHER MODIFICATION MUST BE UNDERTAKEN.

SECOND, TO DO THIS, METEOROLOGY MUST BROADEN ITS VISION BY ACTIVELY ENCOURAGING RESEARCH IN THE SOCIAL AND ECONOMIC ASPECTS OF THE PROFESSION. THIS COULD BE DONE BY ENCOURAGING METEOROLOGISTS TO LOOK ANEW AT SOME OF THESE PROBLEMS, AND METEOROLOGISTS BECAUSE OF THEIR INTEREST MAY BE THE BEST PEOPLE TO DO THIS. IN ADDITION, EMPLOYMENT OF SOCIAL SCIENTISTS IN THE METEOROLOGICAL SERVICE SHOULD BE GIVEN PARTICULAR CONSIDERATION, AND SPONSORING OF RESEARCH BY SOCIAL SCIENTISTS SHOULD BE UNDERTAKEN. THERE MUST BE A TREND AWAY FROM THE NOTION THAT ONLY MATHEMATICIANS AND PHYSICISTS CAN MAKE A CONTRIBUTION TO METEOROLOGY. NO ONE QUESTIONS THE NECESSITY OF MATHEMATICS AND PHYSICS IN METEOROLOGY,BUT WE SHOULD ALWAYS BE CAREFUL TO REMEMBER THAT METEOROLOGY EMBRACES MANY THINGS BESIDES THE PHYSICAL SCIENCES.

ON THE CREST OF THE AMERICAN METEOROLOGICAL SOCIETY, FOUNDED IN 1919, WE FIND THE WORDS – INDUSTRY, COMMERCE, AERIAL AND MARINE NAVIGATION, PUBLIC HEALTH, AGRICULTURE, ENGINEERING. WITH THIS IN MIND, PERHAPS IT IS NOT TOO LATE FOR US TO LOOK AT METEOROLOGY AND THE ROLE OF THE METEOROLOGIST IN CANADA AND ASK THE QUESTION, WHAT ARE WE TRYING TO ACHIEVE?

– CONTINUED ON PAGE 115

– CONTINUED FROM PAGE 92

A. POSITIVE EFFECTS OF WESTERN DISTURBANCES ON SUMMER RAINFALL

(I) BHULLAR (1952) CONTENDS THAT THE ONSET OF MONSOON OCCURS UNDER THE INFLUENCE OF A WESTERN DISTURBANCE. AN EXAMINATION OF RECORDS OF THE ONSET OF THE MONSOON FROM 1901 TO 1950 HAS INDICATED THAT FOR TWELVE YEARS THE WESTERN DISTURBANCES CAUSED THE ARRIVAL OF THE MONSOON EITHER FROM THE BAY OF BENGAL OR THE ARABIAN SEA.

(II) PISHAROTY AND DESAI (1956) HAVE ALSO OBSERVED THAT DURING THE MONTHS OF APRIL AND MAY THE WESTERN DISTURBANCES MOVE ACROSS NORTH INDIA AS CLOSED CYCLONIC SYSTEMS ON THE SEA LEVEL CHARTS. ON THOSE OCCASIONS, WHEN THE WESTERLY TROUGH EXTENDS TO VERY LOW LATITUDE 20^0 TO 15^0 N., THE ADVANCE OF THE FRESH MONSOON OR EASTERLY WAVE FAVOURED THE FORMATION OR INTENSIFICATION OF DEEP DEPRESSIONS ON THE SOUTH-EASTERN COAST OF INDIA.

(III) THE SAME AUTHORS HAVE ALSO NOTED DEFINITE INSTANCES WHEN AN ACTIVE WESTERN DISTURBANCE HAS SERVED TO EXTEND THE ARABIAN SEA BRANCH OF THE MONSOON (WITH HIGH HUMIDITY AND RAINFALL) INTO PUNJAB VIA EASTERN RAJASTHAN, BEFORE THE EXTENSION OF THE BAY OF BENGAL BRANCH EVEN UP TO THE EASTERN UTTAR PRADESH.

(IV) IN ANOTHER INVESTIGATION, MOOLEY (1957) OBSERVES THAT THE PASSAGE OF A WESTERN DISTURBANCE ACROSS NORTHWEST INDIA LEADS TO THE PRE-SEASONAL EXTENSION OF THE BAY OF BENGAL MONSOON CURRENT RESULTING IN WIDESPREAD THUNDER AND RAIN IN WESTERN UTTAR PRADESH AND PUNJAB. FURTHER, EVEN THE SEASONAL ACTIVITY OF THE MONSOON OVER PUNJAB AND WESTERN UTTAR PRADESH IS SOMETIMES INCREASED WITH THE PASSAGE OF WESTERN DISTURBANCES ACROSS THE NORTHERN FRINGE OF INDIA.

(V) A VERY SIGNIFICANT CAUSE OF SUMMER RAINFALL OVER NORTHWESTERN INDIA WAS RECENTLY DISCOVERED BY VENKATARAMAN AND RAO (1965). THE HEAVY RAINFALL OVER A LARGE AREA IN NORTHWEST INDIA, FAR FROM THE OROGRAPHIC INFLUENCE AND THE PATH OF A MONSOON DEPRESSION, COULD BE EXPLAINED ONLY BY ANALYZING THE UPPER AIR CIRCULATION. IT WAS FOUND THAT UPPER LEVEL DIVERGENCE AHEAD OF A TROUGH IN THE WESTERLIES AT THE 500– TO 200–MB. LEVEL HAD CREATED LOW LEVEL CONVERGENCE AND WIDESPREAD RAINFALL. MOREOVER, UNDER THE INFLUENCE OF THE UPPER TROUGH, THE WESTERLY JET STREAM WAS PUSHED SOUTHWARD AND FURTHER CONTRIBUTED TO THE UPPER DIVERGENCE AND LOWER CONVERGENCE.

THE DISCOVERY OF A DIRECT RELATIONSHIP BETWEEN THE WAVES IN THE WESTERLIES AND THE RAINFALL DURING THE SUMMER MONSOON SEASON IN INDIA IS SIGNIFICANT. IT INDICATES THAT THE SHORT WAVES IN THE HIGH LEVEL WESTERLIES, WHICH PROVIDE THE IDEAL SETTING FOR CYCLOGENESIS AND PRECIPITATION IN THE TEMPERATE LATITUDES (RIEHL, 1965), ALSO CONTRIBUTE TO THE MONSOON RAINFALL OF

INDIA DURING THE SUMMER. THE GROWING EVIDENCE, THEREFORE, INDICATES THAT THE WEATHER DURING THE SUMMER IN INDIA UNDER THE TROPICAL MONSOON CIRCULATION IS NOT COMPLETELY INDEPENDENT AND SEPARABLE FROM THE WEATHER IN THE EXTRATROPICS (WESTERLIES). MANY HIGH LEVEL PERTURBATIONS OF THE WESTERLIES DO CROSS INTO INDIA.

B. NEGATIVE EFFECTS OF WESTERN DISTURBANCES ON SUMMER RAINFALL

(I) IT IS INTERESTING TO NOTE THAT THE SAME WESTERN DISTURBANCES HAVE, ON OCCASIONS, CREATED A BREAK IN THE MONSOONS AND DROUGHT CONDITION. ACCORDING TO THE ANALYSIS BY PISHAROTY AND DESAI (1956), A QUICK SUCCESSION OF WESTERLY WAVES DURING THE MONSOON SEASON LEADS TO THE 'BREAK MONSOON' CONDITION. IN THIS CASE, WESTERLY WAVES DIVERT THE SOUTHEASTERN BAY OF BENGAL CURRENT INTO A SOUTHWESTERLY CURRENT WHICH THEN MOVES TOWARDS THE EASTERN HIMALAYAS PRODUCING RAIN IN THE LATTER AREAS. SIMILARLY, EASTERN DEPRESSIONS ARE ALSO DEFLECTED MORE AND MORE TO THE EAST BY THE WESTERN DISTURBANCES UNTIL THE MONSOON GRADUALLY WITHDRAWS FROM THE NORTHERN INDIA.

(II) A DIFFERENT EXPLANATION HAS BEEN ADVANCED BY MOOLEY (1957) FOR THE 'BREAK MONSOON' CONDITION. ACCORDING TO HIM, THE DROUGHT CONDITION IS DUE TO THE SIMULTANEOUS ABSENCE OF EASTERLY WAVES AND THE MORE FREQUENT PASSAGE OF WESTERN DISTURBANCES RESULTING IN THE NORTHWARD SHIFT OF THE MONSOON TROUGH. THUS A BREAK IN THE MONSOON OCCURS OVER NORTH INDIA BUT THERE IS HEAVY RAINFALL IN THE FOOTHILLS OF THE HIMALAYAS. THE RAINFALL IN THE LATTER AREA IS, PROBABLY, DUE TO THE CONVERGENCE OF MONSOON CURRENTS AGAINST THE MOUNTAINS, AND THE WESTERN DISTURBANCES PLAY ONLY A PASSIVE ROLE.

(III) IN ANOTHER INVESTIGATION, CHAKRAVORTTY AND BASU (1957) CONCLUDE THAT WHILE THE EASTERN DEPRESSIONS HELP THE ADVANCE OF THE MONSOON, THE WESTERN DISTURBANCES HAVE A 'RETARDING EFFECT'. THE EASTERN DEPRESSIONS DO FORM, BUT WEAKEN AND DISAPPEAR BEFORE PENETRATING FARTHER INTO THE INDIAN LANDMASS IF A WESTERN DISTURBANCE IS PRESENT THERE. THIS OBSERVATION CONTRADICTS THE CONCLUSIONS REACHED BY THE PREVIOUS AUTHORS NOTED UNDER THE POSITIVE EFFECTS. THE POSITIVE OR NEGATIVE INFLUENCE OF WESTERN DISTURBANCES ON THE SUMMER RAINFALL OF INDIA PRESENTS A VERY COMPLEX PROBLEM. DESPITE THE CONTRADICTORY VIEWS, NO ATTEMPT HAS BEEN MADE TO EXPLAIN CLEARLY HOW THE WESTERN DISTURBANCES EITHER ATTRACT OR REPEL THE MONSOONS DURING THE SAME SEASON. IT APPEARS, HOWEVER, THAT THERE ARE TWO MAIN FACTORS, VIZ., (1) THE FREQUENCY AND (2) THE PATH OF WESTERN DISTURBANCES WITH RESPECT TO THE AXIS OF THE MONSOON TROUGH, WHICH DETERMINE WHETHER THERE WOULD BE RAINY OR DRY CONDITIONS. A DETAILED INVESTIGATION OF THESE ASPECTS SHOULD FURTHER OUR UNDERSTANDING OF THE NATURE OF SUMMER RAINS OVER NORTHWEST AND NORTH INDIA.

CONCLUSIONS

THE POPULAR EXPLANATIONS THAT THE SUMMER RAINFALL IN INDIA IS RELATED TO ELEMENTS WITHIN THE WARM MOIST MONSOON CURRENTS SUCH AS DIFFERENT AIR MASSES, FRONTS, DEPRESSIONS OR EVEN THERMAL CONVECTIONS AND OROGRAPHIC CONVERGENCE ARE FAR FROM ADEQUATE. IN FACT, IT IS OBSERVED THAT THE DEPTH OF MONSOON WESTERLIES DURING SUMMER MAY INCREASE UP TO 6 KM. OR MORE EVEN OVER NORTH INDIA YET, THERE MAY BE NO RAINFALL (SRINIVASAN, 1960). THERE IS GROWING EVIDENCE THAT MOST DISTURBANCES LEADING TO PRECIPITATION ARE INITIALLY GENERATED BY THE UPPER ATMOSPHERIC FLOW PATTERNS.

GREAT SIGNIFICANCE HAS BEEN ATTACHED TO THE ITC ZONE IN DETERMINING THE PATH AND FREQUENCY OF MONSOON DEPRESSIONS, THE CONVERGENCE OF DIFFERENT AIR MASSES, AND THE INTENSITY AND PATTERN OF THE DISTRIBUTION OF RAINFALL OVER INDIA. HOWEVER, THE POSITION, MOVEMENT AND THE STRENGTH OF THE ITC ZONE IN TURN, ARE DETERMINED BY HIGH LEVEL FLOW PATTERNS SUCH AS THE WESTERLY JET, THE EASTERLY JET AND THE TIBETAN HIGH PRESSURE CELL. ALSO THE 'BURST' OR THE 'BREAK' OF THE MONSOONS ARE PRINCIPALLY ASSOCIATED WITH THESE UPPER ATMOSPHERIC CIRCULATION PATTERNS.

HIGH LEVEL ATMOSPHERIC PERTURBATIONS MAKE A SIGNIFICANT CONTRIBUTION TO THE SUMMER RAINFALL. THE EASTERLY WAVES AND THE SURGES IN THE EASTERLY JET STREAM ON MANY OCCASIONS HAVE LED TO THE FORMATION OF SURFACE DEPRESSIONS OR HAVE INDUCED RAINFALL WITHOUT SUCH DEPRESSIONS. SIMILARLY, THE HEAVY PRECIPITATION ALONG THE WESTERN GHATS HAS BEEN FOUND TO BE ASSOCIATED WITH THE LOW LEVEL WESTERLY JET STREAM OR WITH SURGES IN THE EQUATORIAL WESTERLIES AND IS NOT DUE MAINLY TO OROGRAPHIC OR CYCLONIC CONVERGENCE.

FURTHERMORE, IT HAS BEEN DISCOVERED THAT THE SUMMER RAINFALL IN INDIA IS ALSO AFFECTED BY THE WESTERLIES OF THE MIDDLE LATITUDES. THE WESTERN DISTURBANCES HAVE BEEN FOUND TO HAVE BOTH POSITIVE AND NEGATIVE EFFECTS ON THE RAINFALL OF THE COUNTRY. THE PROBLEMS OF POSITIVE OR NEGATIVE EFFECTS ARE NOT CLEARLY UNDERSTOOD AND NEED FURTHER INVESTIGATION. BESIDES THE INFLUENCE OF WESTERN DISTURBANCES, THE RAINFALL OVER NORTHWESTERN INDIA IS ALSO RELATED TO WAVES IN THE UPPER WESTERLIES AND THE WESTERLY JET STREAM.

THE GENERAL SUMMER RAINFALL PATTERN IN INDIA IS PARTLY DETERMINED BY THE EASTERLY JET STREAM THROUGH CONVERGENCE AND DIVERGENCE ASSOCIATED WITH ITS ENTRANCE AND EXIT OVER THE COUNTRY. HOWEVER, THERE ALSO SEEMS TO BE SOME CONCENTRATION OF SPECIFIC ATMOSPHERIC ACTIVITIES PRODUCING PRECIPITATION IN PARTICULAR PARTS OF THE COUNTRY. FOR EXAMPLE, GREATER ACTIVITY OF –

(A) THE ITC ZONE, EASTERLY WAVES AND SURGES IN THE EASTERLY JET OVER THE GANGES PLAIN AND THE SURROUNDING AREAS.

(B) THE WAVES IN THE WESTERLIES AND THE WESTERLY JET STREAM OVER THE NORTHWESTERN INDIA.

(C) THE SURGES IN THE EQUATORIAL WESTERLIES ALONG THE WESTERN COAST HAVE BEEN OBSERVED* DURING THE MONSOON SEASON.

HOWEVER, IN ANY ANALYSIS OF THE GENESIS OF WEATHER OR RAINFALL IN INDIA, THREE IMPORTANT FACTORS MUST BE TAKEN INTO CONSIDERATION:

1. THE HIGH MOUNTAIN BARRIERS IN THE NORTH RESTRICTING OR MODIFYING THE DIRECT NORTHERN INFLUENCES OVER THE COUNTRY.

2. THE LOCATION OF THE NORTHERN PART OF THE COUNTRY IN A TRANSITIONAL ZONE WITH RESPECT TO THE INFLUENCES OF BOTH THE WESTERLY AND THE EASTERLY JET STREAMS DURING THE SUMMER.

3. INDIA'S APPENDAGE TO THE SOUTH OF THE BIGGEST LANDMASS OF THE WORLD AND AT THE SAME TIME ITS PENINSULAR PROJECTION INTO THE SUB-TROPICAL AND TROPICAL SEAS AND OCEANS.

ALL THESE FACTORS MAKE INDIA A PECULIAR REGION SUSCEPTIBLE TO MULTIPLE WEATHER INFLUENCES. THE PRESENT PROBLEM IS NOT ONLY TO EXAMINE THE INDIVIDUAL ROLE OF SURFACE DISTURBANCES AND UPPER AIR PERTURBATIONS WHICH DETERMINE THE RAINFALL, BUT TO ESTABLISH THE INTER-RELATIONSHIP BETWEEN THEM AND TO EVOLVE AN INTEGRATED PICTURE. THE FOCUS OF RECENT INVESTIGATIONS HAS ALREADY SHIFTED FROM THE SURFACE TO THE UPPER ATMOSPHERIC CONDITIONS. IT HAS BEEN DEMONSTRATED THAT WHILE THE MONSOONS PROVIDE THE SOURCE OF MOISTURE, THE UPPER ATMOSPHERIC PERTURBATIONS ACT AS 'TRIGGERS' FOR RELEASING RAINFALL. IT WILL, THEREFORE, BE PREPOSTEROUS TO LIMIT THE CONCEPT PURELY TO MONSOONS, SINCE THE CAUSES OF SUMMER RAINFALL IN INDIA APPEAR TO BE SIGNIFICANTLY LINKED TO THE EXTRAMONSOONAL CIRCULATION AND PERTURBATIONS.

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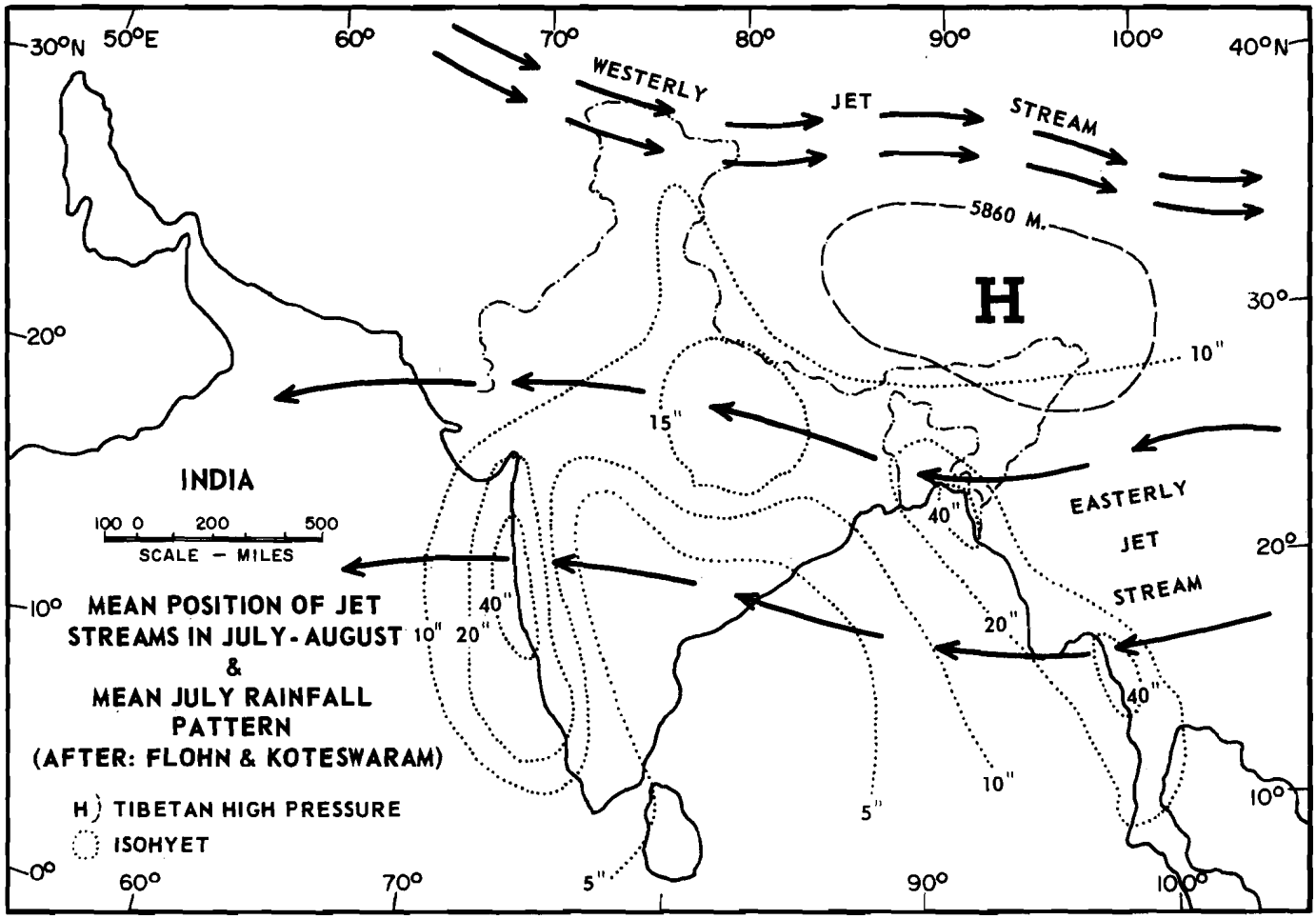
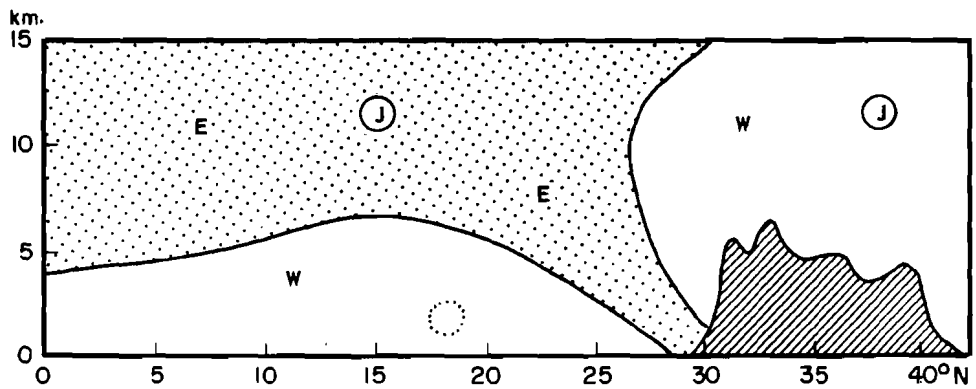


FIGURE 1



SCHEMATIC PROFILE OF THE WIND SYSTEMS
ALONG 78° E. DURING JULY-AUGUST
(J) JET STREAMS, ⋯ LOWLEVEL JET
(AFTER: FLOHN, KOTESWARAM,
JOSEPH & RAMAN)
FIGURE 2

–CONTINUED FROM PAGE 102

ABOUT OUR MEMBERS

THIS COLUMN IS INTENDED TO INCLUDE INFORMATION ABOUT MEMBERS OF THE SOCIETY. HOWEVER, THROUGH HUMILITY OR SOMETHING ELSE, MEMBERS HAVE NOT BEEN PASSING ALONG RELEVANT INFORMATION. THE FOLLOWING TWO ITEMS ARE INCOMPLETE BECAUSE THEY ARE WRITTEN FROM SECOND OR THIRD HAND INFORMATION.

DR. W. MOROZ HAS LEFT THE UNIVERSITY OF TORONTO AND THE ONTARIO DEPARTMENT OF HEALTH TO BECOME A PROFESSOR IN FACULTY OF ENGINEERING AND DIRECTOR OF THE ENVIRONMENTAL CENTRE AT PENN STATE UNIVERSITY.

MR. L. SHENFELD HAS LEFT ONTARIO HYDRO TO ACCEPT A POSITION WITH THE AIR POLLUTION CONTROL SERVICE OF THE ONTARIO DEPARTMENT OF HEALTH.

– CONTINUED FROM PAGE 108

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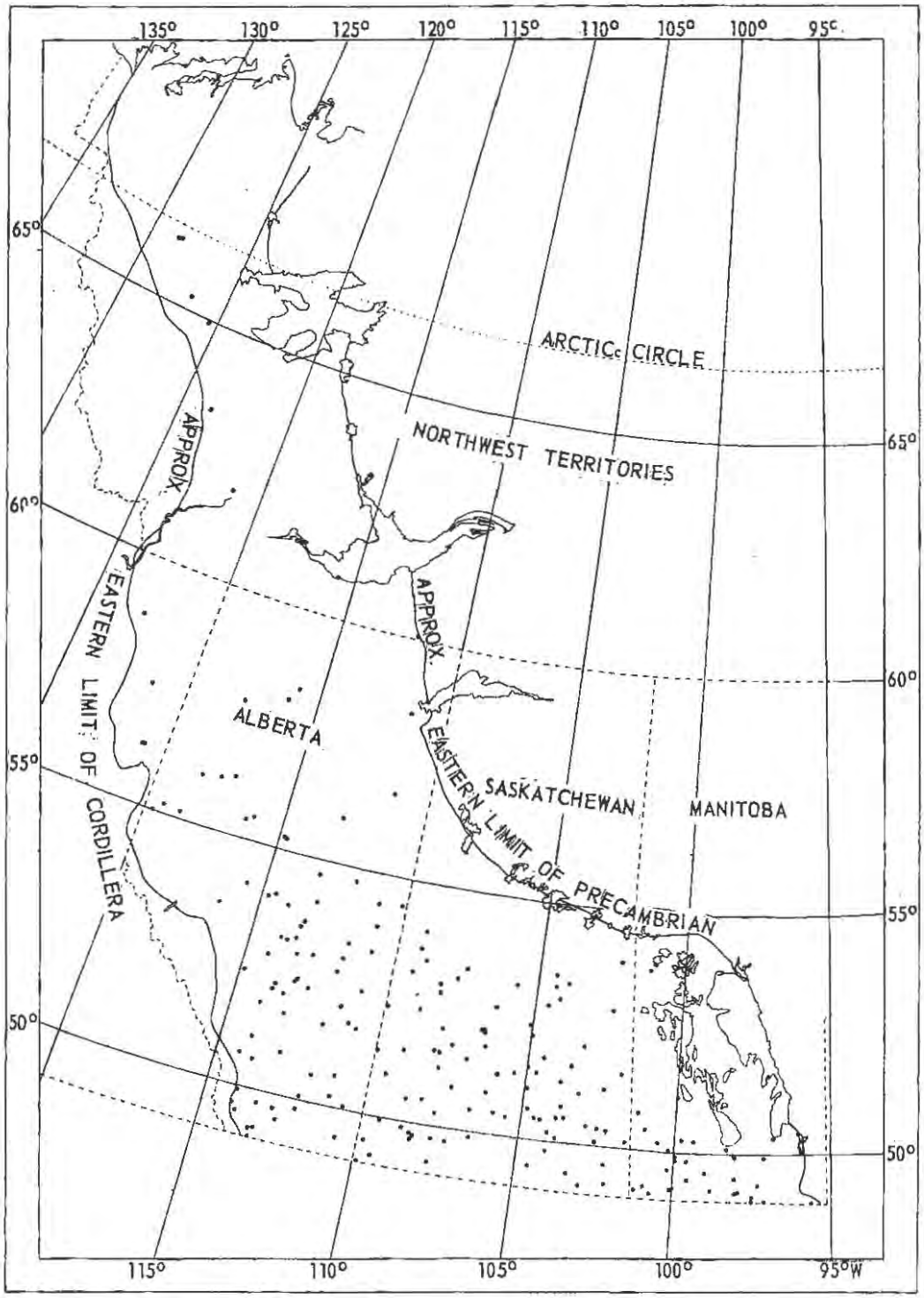

Figure 1. Locations of stations used in Hopkins' regression analyses (courtesy J.W.Hopkins).

–CONTD. FROM PAGE 86

THE RESULTING INTEGRALS WILL BE ADDED TO OBTAIN THE NORMAL TOTAL PHOTO–THERMAL UNITS FOR A SEASON, SUCH AS THE FREEZE–FREE SEASON.

A NEW PROGRAM IS BEING DEVELOPED WHICH WILL COMPUTE THESE PHOTO–THERMAL UNITS, AND THESE ESTIMATES SHOULD BE QUITE USEFUL, FOR EXAMPLE, IN COMPARING THE CLIMATE OF NORTHERN AND SOUTHERN ALBERTA FROM THE STANDPOINT OF LAND USE CAPABILITY.

THE NEW PROGRAM WILL ALSO INCORPORATE SEVERAL OTHER MODIFICATIONS AND IMPROVEMENTS. IN PLACE OF THE TEN–TERM QUADRATIC MODEL USED IN THE PRESENT PROGRAM, A NEW 22–TERM QUARTIC MODEL RECENTLY DEVELOPED BY DR. HOPKINS AND INVOLVING UP TO THIRD AND FOURTH POWERS OF THE VARIABLES WILL BE USED. DERIVED VARIABLES WILL BE COMPUTED USING UN–ROUNDED VALUES OF THE TEMPERATURE ESTIMATES. IT IS ALSO EXPECTED TO BE ABLE TO HAVE THE PROGRAM MAKE REGRESSION ESTIMATES OF THE STANDARD DEVIATIONS, SO THAT IT WILL NOT BE NECESSARY TO PREPARE STANDARD DEVIATION ESTIMATES IN ADVANCE AND INCLUDE THEM AS INPUT FOR EACH LOCATION FOR WHICH DEGREE–DAYS OR PHOTO–THERMAL UNITS ARE TO BE CALCULATED AS IS THE CASE WITH THE ORIGINAL PROGRAMS.

THE REGRESSION ESTIMATES OF TEMPERATURE SHOULD BE MADE ONLY FOR LOCATIONS IN THE REGION FROM WHICH THE DATA USED IN DEVELOPING THE REGRESSION COEFFICIENTS WERE OBTAINED, THAT IS THE CANADIAN GREAT PLAINS IN THE CASE OF THE PRESENT PROGRAMS. REGRESSION ANALYSES MIGHT BE CARRIED OUT USING DATA FROM OTHER REGIONS, HOWEVER, TO PERMIT THE ESTIMATION OF TEMPERATURE AND DERIVED VARIABLES IN THOSE AREAS. THE AGROMETEOROLOGY SECTION HAS RECENTLY BEEN EXPERIMENTING WITH THE ESTIMATION OF JULY MAXIMUM TEMPERATURES IN BRITISH COLUMBIA. THERE IS SOME INDICATION THAT IN SPITE OF THE OCEAN AND THE MOUNTAINS IT MAY BE POSSIBLE TO MAKE USEFUL ESTIMATION EQUATIONS FOR TEMPERATURE NORMALS IN BRITISH COLUMBIA. IN THAT AREA AND ELSEWHERE IT SEEMS LIKELY THAT ACCURACY MIGHT BE IMPROVED BY ADDING TO THE PRESENT VARIABLES (LATITUDE, LONGITUDE AND ELEVATION) OR BY REPLACING SOME OF THEM, WITH SOME NEW VARIABLES RELATING TO LOCAL TOPOGRAPHY AND DIRECTION AND DISTANCE TO LARGE OPEN WATER AREAS, ETC .

ACKNOWLEDGEMENTS

THE REGRESSION COEFFICIENTS WERE PROVIDED BY DR. HOPKINS IN PRIVATE COMMUNICATION. THE PROGRAMS FOR MAKING THE ESTIMATES OF TEMPERATURE AND DERIVED VARIABLES WERE WRITTEN BY W.R. SHARP OF THE AGROMETEOROLOGY SECTION, USING THE FACILITIES OF THE CANADA DEPARTMENT OF AGRICULTURE DATA PROCESSING SERVICE AND THE CANADIAN GOVERNMENT CENTRAL DATA PROCESSING SERVICE BUREAU.

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TABLE 2

LAT. = 55 11, LONG. = 119 22, ELEVATION (FEET) = 2500. BEAVERLODGE CDA

CLIMATIC VALUES SHOWN ARE ESTIMATES PREPARED BY COMPUTER

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	YEAR
MEAN MAX.	16	22	33	49	62	67	72	69	61	50	32	21	46
MEAN MIN.	-3	0	11	26	37	44	47	44	37	28	14	2	24
MEAN	6	12	22	38	50	56	60	57	49	39	23	11	35
PE	0.0	0.0	0.0	0.0	5.0	5.1	5.5	4.3	2.6	1.1	0.0	0.0	23.6
DEG. DAYS ABOVE 32	99	47	63	265	558	720	868	775	510	267	148	55	4375
DEG. DAYS ABOVE 42	25	10	14	111	262	420	558	465	222	98	63	15	2263
DEG. DAYS BELOW 65	1829	1484	1333	810	465	274	164	252	480	806	1260	1674	10831
DEG. DAYS BELOW 32	904	609	375	93	0	0	0	0	0	52	418	726	3177

SEASON ABOVE 32 DEG. FROM APR. 4 TO OCT. 30, 209 DAYS, 3080 HOURS DAYLIGHT

SEASON ABOVE 42 DEG. FROM APR. 24 TO OCT. 9, 168 DAYS, 2585 HOURS DAYLIGHT

FREEZE-FREE SEASON (32) FROM JUNE 5 TO AUG. 26, 82 DAYS, 1348 HOURS DAYLIGHT

FREEZE-FREE SEASON (28) FROM MAY 18 TO SEP. 12, 117 DAYS, 1887 HOURS DAYLIGHT

MONTHLY VALUES FOR THIS LOCATION

SUN	77	108	157	214	269	266	300	258	181	133	81	65
WND	166	168	180	223	230	211	194	175	187	192	163	154
DP	0	0	18	29	40	47	51	49	42	32	17	0
SD	114	82	54	52	28	24	18	22	25	41	82	87
DL	7.7	9.7	11.7	14.0	16.1	17.3	16.9	15.1	12.8	10.6	8.5	7.2
QO	144	282	480	720	914	1011	971	813	587	363	188	115

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