Canadian Meteorological and Oceanographic Society

La Société canadienne de météorologie et d'océanographie

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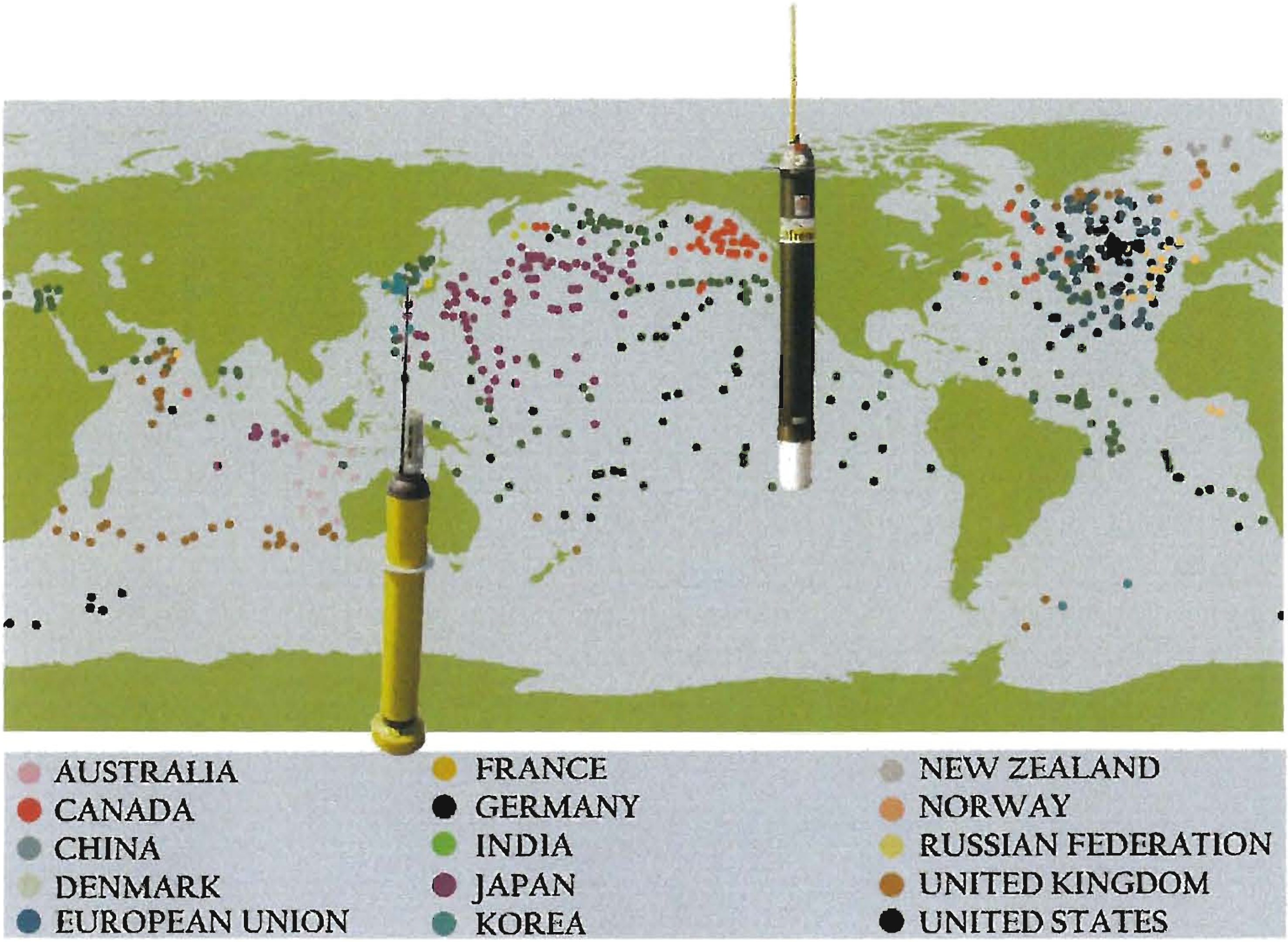

CMOS Bulletin SCMO
"at the service of its members
au service de ses membres"

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Cover page: The figure shown on the cover page includes a map showing the location of Argo floats, colour-coded by the country launching the floats, positions appropriate as of 24 October, 2002. Two floats are shown: on the left an APEX and on the right a PROVOR float. Beneath the map are shown the Argo logo (left) and the Canadian Argo logo (right). In the centre is an icosahedral pseudo-globe, showing current float locations, which you can download and assemble. For instructions see the article starting on page **135**.

Page couverture: L'image de la page couverture montre la position des bouées flottantes ARGO codées avec des couleurs représentant les pays qui les ont lancées; les positions sont celles du 24 octobre 2002. On voit deux modèles de bouées, à gauche une APEX et à droite une PROVOR. Sous la carte, il y a le logo de ARGO (à gauche) et le logo de ARGO Canada (à droite). Au centre se trouve un pseudo-globe isocahedral montrant les positions actuelles des bouées, que vous pouvez télécharger et assembler. Pour savoir comment le faire, lire l'article débutant en page **135**.

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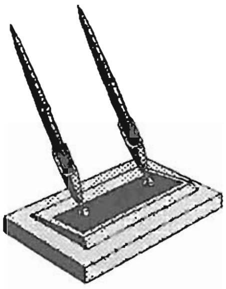
Canadian Meteorological and Oceanographic Society (CMOS)

Société canadienne de météorologie et d'océanographie (SCMO)

....from the President's Desk



CMOS Friends:

Everyone knows that early Fall brings the same predictable events: kids return to school, work life seems to ramp up a few notches, and hurricane season runs full tilt! As I write this, we have just said good-bye to the last remnants of Lili and Isadore, although Kyle still churns indecisively in the Atlantic. Thankfully, Isadore and Lili turned out to be less devastating than first thought. I admit that, like many of you, I am a hurricane junkie. As a storm ratchets up, I am glued to my many website resources and any TV storm footage that I can find. I am always thankful to see a storm pass, just so that I can get some sleep again!

I would like to say in this forum how impressed I was with the work of the National Hurricane Center over the past two weeks. What an incredible job those forecasters did of predicting the path of these storms. Surely, such predictions and forewarning to the public, coupled with collaboration with the emergency management personnel, played a large part in why these storms caused so few casualties, relative to their size and strength. And so, my colleagues, I've been spending a lot of time in the past few weeks thinking about the power of collaboration.

The power of collaboration versus the power of conflict plays out inside and among organizations every day across the nation. I am so thrilled to report to you that CMOS over and over again epitomizes the power of what collaborating individuals and organizations can achieve. Just this past September I was most honoured to meet Professor Godwin O.P. Obasi, Secretary General of the World Meteorological Organization.

Dr. Obasi was here to attend the ICAO conference in Montréal, and he made time to visit Météomédia for a tour and a chat. Wearing two hats, President of this Society and Vice-President of meteorology for The Weather Network/Météomédia, I met Professor Obasi along with Pierre Morrissette, CEO of Pelmorex Communciations Inc., and Bruce Angle, Senior Advisor on International Affairs from MSC. We spent the morning discussing the continued progress and collaboration of private, government and academia sectors in Canada. I was amazed to hear Professor Obasi say that in all of his travels, he mostly visited government and academic institutions and that Météomédia was the largest private meteorological organization he had ever visited! More importantly, he said that he was very impressed with MetéoMedia's operations and also with CMOS's continued efforts to bring government, universities and the private sector all working together, and he thought that Canada was a leader in this regard.

(Continued on next page)

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Inside / En Bref

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CMOS exists for the advancement of meteorology and oceanography in Canada.

Le but de la **SCMO** est de stimuler l'intérêt pour la météorologie et l'océanographie au Canada.

Indeed, though there are still have many barriers amongst us, CMOS has, with the private sector initiative, aggressively started to break these barriers down. In particular, the private sector is actively working with government to move many issues forward and to better understand the role that each has to play in providing weather services to Canadians. Time and time again, CMOS has demonstrated that we can professionally disagree on many matters, but we are a united body in representing to policy decision-makers and others the voice of climatologists, oceanographers and meteorologists in this country. I am grateful that collaboration is a process we value and we practise on a routine basis.

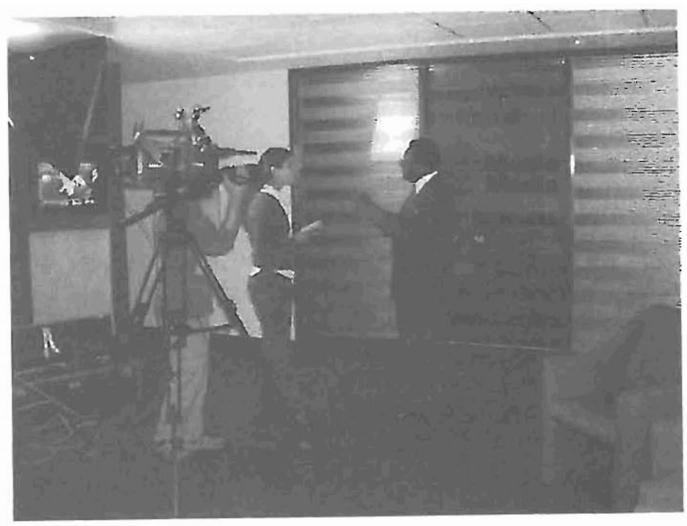
There are many other great activities taking place in CMOS, and I encourage you to visit the website http://www.cmos.ca to catch up on the Society's latest news. The one event that I would like to highlight, however, is the CMOS Congress 2003.

The theme implies it will be one of our best congresses ever: **"ATMOSPHERE-OCEAN SCIENCE: IMPACTS AND INNOVATION"**. The 2003 Congress will be held at the Crowne Plaza Hotel, within walking distance of Parliament Hill, during the week of June 2nd to 5th. Mark those dates on your calendar so that you can keep that time free to attend!

On a final note, the CMOS Council continues to work on your behalf on a multitude of issues. If there is anything specific you would like to comment on, there are several contact names on the website under "Contact us". We would like to hear from you because, my dear colleagues, that is where collaboration begins.

Ron Bianchi,
President / Président

From left to right: Ron Bianchi, President of CMOS, Professor Obasi, Secretary General of WMO and Pierre Morrissette, CEO of Pelmorex Communciations Inc.



Professor Obasi being interviewed by MétéoMédia for a news story about his visit to Montréal and what significant role Canada plays in the WMO.

STOP PRESS!!!

Seimac Ltd. and Pelmorex Inc. (two well known companies) are listed among the top one hundred companies to work for in Canada. Our association with these two companies is through Susan Woodbury, Meteorology Division Manager at Seimac, Chair of the CMOS Halifax Centre and Chair of the CMOS Private Sector Committee; and through Ron Bianchi, our President and Vice-President-Meteorology at Pelmorex. The list was published in the October 28, 2002 edition of Macleans Magazine under the headline "THE TOP 100".

CMOS extends congratulations to both companies for this well-deserved recognition.

August 15, 2002

Re: *A SHARED RESPONSIBILITY: THE FUTURE OF UNIVERSITY RESEARCH IN CANADA*, an open letter to the Provinces from the Canadian Consortium for Research

Dear Premier,

The Canadian Consortium for Research (CCR) is an advocacy coalition comprised of front-line researchers in both the public and private sectors, as well as the down stream users of research in government, private businesses and public institutions such as schools and hospitals. Our goal is to ensure that Canada is a world leader in the full spectrum of research: in the bio-medical sciences, the natural sciences, the social sciences and the humanities.

The Consortium believes that a research-intensive economy will provide Canadians with the best quality of life and the highest possible standard of living. We also believe that achieving this success depends on an accessible and high-quality post-secondary education system and a strong university research sector.

PUBLIC POLICY

The CCR is uniquely placed to bring the experience of researchers to the public policy debate. In carrying out this task our voice has traditionally been directed towards the federal government. As Ottawa's transfer payments for post-secondary education declined, the Consortium took up the provinces' cause, arguing that continued excellence in post-secondary education depended on the federal government maintaining its long-standing commitment to bearing a share of the costs of the university system.

Unfortunately, our effort in this regard has met limited success. Ottawa's position has been that lack of provincial accountability with respect to such transfers is a powerful disincentive to restore funding levels.

For front-line researchers, the dispute between the two levels of government is the source of great concern. As jurisdictional arguments continue, the post-secondary education system in Canada is falling further and further into disrepair. To reverse this decline the Consortium has decided to broaden its efforts by reaching out not just to the federal government, but to provincial capitals as well. Our hope is that our voice can encourage both levels of government to accept a shared responsibility for the health of post-secondary education and to work together for the benefit of all Canadians.

POST-SECONDARY EDUCATION - RESEARCH'S CRITICAL LINK

Universities are the backbone of Canada's research enterprise. Two thirds of all scientific papers published in Canada emanate from universities and much of the country's cutting edge research is performed by university faculty. Universities are also where the next generation of researchers prepare for their careers. To continue in this crucial role, three components of the post-secondary education system require particular attention.

Students, the future of research, need low tuition and generous support to pursue both graduate and post graduate studies.

At the staff level, universities need the resources to attract and keep the best minds and to allow faculty to do the best possible job – both as teachers and as researchers.

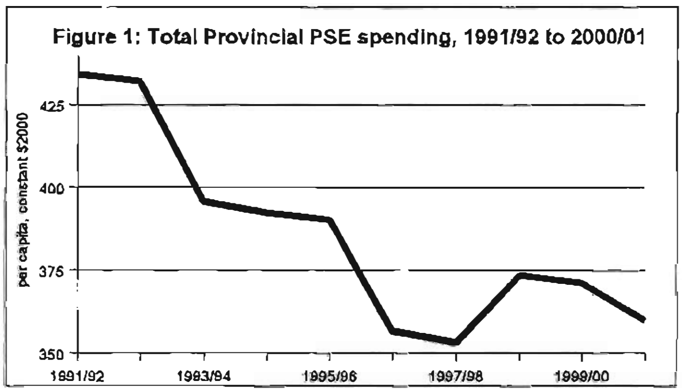
Finally, the success of universities is also dependent on the condition of university infrastructure – laboratories, libraries and teaching facilities. Crumbling buildings and empty book shelves are not conducive to pushing forward the frontiers of knowledge.

ROADBLOCKS TO SUCCESS

All governments in Canada have spoken out strongly about the importance of research and education. However, these words are not matched by deeds. The federal government sharply reduced transfers to the provinces for post-secondary education, reductions that, when inflation and population growth are factored in, have not yet been restored. The provinces, in turn, have steadily decreased their own spending on education. The combination of funding cutbacks by these two levels of government is creating a crisis in Canada's research community.

THE PROVINCIAL RECORD

The numbers speak for themselves. Figure 1 demonstrates the slide in provincial expenditures on post-secondary education over the last ten years.

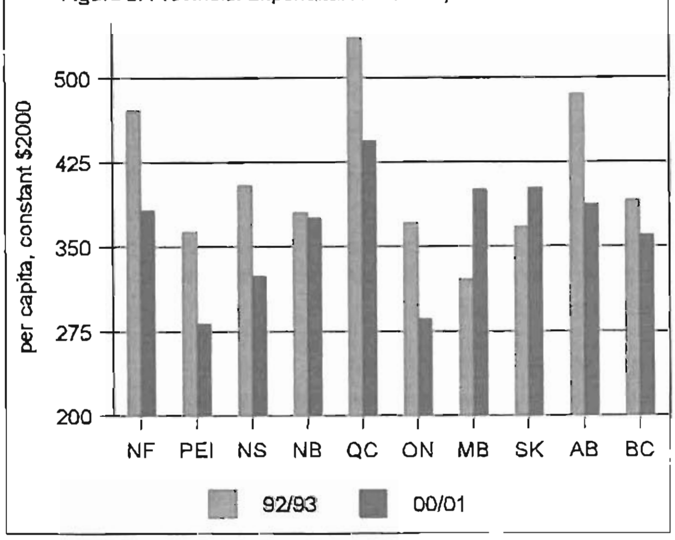


Source: Calculations based on Statistics Canada, Provincial and Territorial General Government Revenue and Expenditures, Financial Management System Basis

Provincial funding for post-secondary education, on a constant dollar per capita basis, is 27% below 1992/93 levels.

Figure 2 provides a province by province breakdown of the funding picture. The biggest declines have occurred in Canada's two richest provinces, Ontario and Alberta. Interestingly, two of Canada's smaller provinces, Saskatchewan and Manitoba, have actually managed to increase spending in this sector.

Figure 2: Provincial Expenditures on PSE, 1992/93 and 2000/01



Source: Calculations based on Statistics Canada, Provincial and Territorial General Government Revenue and Expenditures, Financial Management System Basis.

IMPLICATIONS FOR RESEARCH

The damage caused by these funding cuts is manifesting itself in a number of ways.

The cuts are leading to significantly increased student tuition, which in turn results in diminished access to a university education and an increase in the size of student loans at graduation. High fees and high student debt are a growing impediment to equal access to university by Canadians and a serious disincentive to students who would like to pursue graduate programs. The consequence is a great loss to Canada's research capacity.

Funding cutbacks are also taking their toll on staff. Universities have seen a decrease in the number of faculty, which in turn has increased class size and diminished the quality of student-teacher interaction.

To cope with financial shortfalls, university administrations are deferring the maintenance of physical infrastructure. A recent Canadian Association of University Business Officers (CAUBO) report conservatively estimates the accumulated deferred maintenance at Canadian universities at $3.6 billion. As the learning, living and research environment on campuses deteriorates, Canada's research capacity declines.

The financial crisis has also damaged university libraries. Of the top 111 research libraries in the United States and Canada only thirteen are Canadian institutions. Even more disturbing, of the 111 only twelve have reduced their total library expenditures in the last decade and of this twelve, eleven are Canadian.

THE WAY FORWARD

Canada's future depends on a vibrant post secondary education sector. At no time in our country's history has this been more important.

To ensure that the challenges of providing accessible university education and high quality university research are met, the Canadian Consortium for Research urges both senior levels of government to come to transparent and accountable arrangements that allow for the adequate funding of our universities. Without this cooperation, Canada's educational institutions will continue to struggle.

The CCR urges provincial governments to reinvest in post-secondary education at levels that will adequately sustain it now and in the future. This investment needs to return to 1991/1992 per capita levels and then be adjusted upwards in constant dollars to account for inflation and population growth.

Ottawa and the provinces must co-operate on the development of a renewed federal/provincial funding mechanism specifically for post-secondary education that addresses the issues of adequacy, accountability, transparency and fairness. The development and implementation of this mechanism needs to be accomplished quickly as our universities struggle under current conditions.

Canada's universities are essential to enhancing social and economic growth. They need your help and they need it now. Canadians in every province value universities, university-based research and a university education. They want their governments to take action.

Please join with us and your fellow governments to ensure a healthy, productive and adequately funded university sector that helps Canada meet its challenges of today and tomorrow. Canadians want this for themselves and their children.

Yours sincerely,

Paul Ledwell, Chair
Canadian Consortium for Research

RAOB 5.1

by Sander Schimmelpenninck, M.A.

Pavel A. Molchanov started something when he launched a radiosonde at Pavlovsk, near St Petersburg (then Leningrad) in January 1930. The idea caught on: the US Weather Bureau adopted the system in 1936. Today, meteorologists launch radiosondes twice daily at about 1,000 sites around the world. Of those, about 800 publish soundings on the Internet. Their output includes winds, altitude, pressure, temperature and humidity.

Some websites offer upper-air soundings and isopleths, including the most common stability data such as the popular lifted and k-indices and convective available potential energy (CAPE). See for example twister.sbs.ohio-state.edu and weather.uwyo.edu/upperair. However, Ohio State's analyses are slow to appear and often missing, and the University of Wyoming has a confusing chart combining lifted- and k-indices. Radiosondes climb roughly 300 m/sec in the troposphere, where most of the action is, so ground stations get usable data in little more than an hour.

To the rescue comes RAOB v5.1, a Windows-based software package by John Shewchuck (ers@raob.com) at Environmental Research Services of Matamoras, PA. RAOB ingests raw upper-air data in several formats and analyzes those of individual ascents in more ways than you can shake a stick at — far more than you get at the websites mentioned.

The first thing you see after choosing a site is upper-air temperature and dewpoint traces, scaled in your favourite format: skew-t, tephigram, or the less common emagram (no Stüve). The display also lists basics: a few stability parameters, tropopause height, helicity, precipitable water, things like that. With so much to show on one screen, the display looks a bit spidery, but it's certainly clear. Shewchuk plans to improve the typography. Version 5.2 is already in the works, and the author listens to users.

The excitement is in the toolbar at the top of the main display. There Analyze is RAOB's pièce de résistance: it gives you 17 ways to massage the data. I particularly like Severe Weather. It applies 24 tests to help predict convection. For each test RAOB gives the bounds between low, moderate, and severe. Also, each test can have 1 to 10 votes, like shareholders of Martha Stewart Omnimedia. When you click on Severe Weather, you get the vote counts for the three above risk levels. Anecdotal experience suggests the predictions are fairly reliable in the default settings.

I have not tried rigging the votes, because I would not pass muster as a thermodynamicist, but this is one obvious opportunity for fine-tuning—if only by geography. For instance, Ron Bianchi, VP at The Weather Network, told me that a lifted index of -1 to -1.5 in Calgary poses the same threat as -4 in Toronto. I scoured the Internet and my small group of meteorologist friends for validation of the various predictors and came up with nothing. But then Houdini never told the world how he escaped from chain-wound submerged safes. Perhaps correlating RAOB's 24 indices with ensuing weather would make a PhD thesis for a budding genius in met school, where they have *big* computers with flashing lights and liquid nitrogen.

Note from the Editor

Sander Schimmelpenninck, a 59-year old amateur meteorologist, has been a volunteer climatological observer for the Meteorological Service of Canada (MSC) since 1990 and an instrument-rated private pilot for 10 years in the 1970s and '80s. He contributed to the 8th revision of MSC's internal Manual of Observations as the only amateur invited to comment.

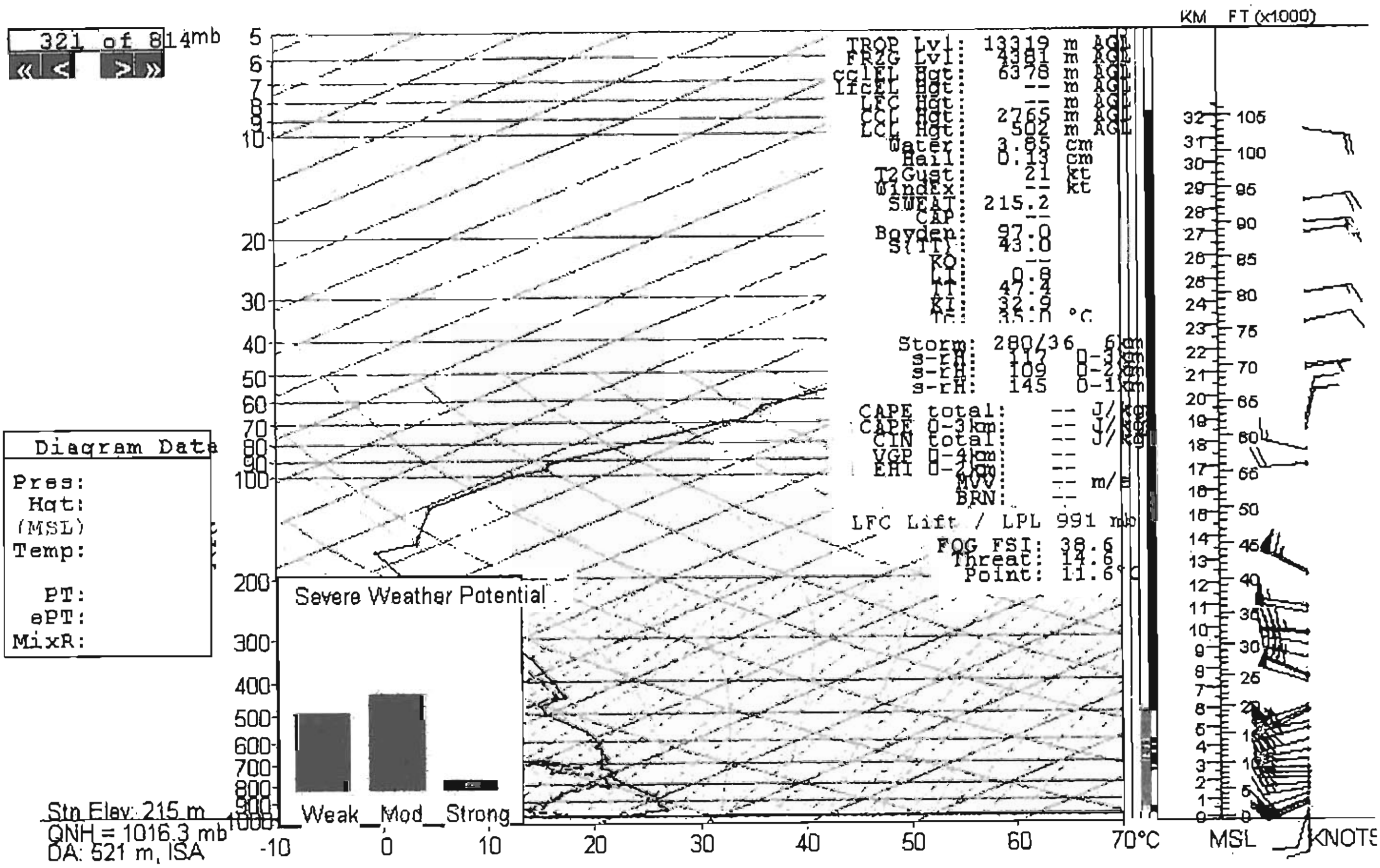
Schimmelpenninck reviewed Digital Atmosphere, an isopleth-mapping program, in the CMOS Bulletin in 1998. He has also written technical articles in Pilot, a magazine of the Canadian Owners and Pilots Association.

Other toolbar choices give detailed listings for the really prurient and soaring forecasts. However, glider pilots now have free daily access to BLIP, Boundary Layer Information Prediction, by Dr John W. ("Dr Jack") Glendening, PhD at www.drjack.net. He is a meteorologist at the US Naval Research Laboratory in Monterey, CA.

Bucking a bad trend, RAOB comes with a readable, clear, printed manual replete with algorithms and hordes of scientific references.

RAOB can be improved further, and I hope it will. Most of all, I would like to see isopleths. The program lets you toggle between two sites, e.g. a nearby one and another upwind at the steering level, but that does not give you the big picture. It would also be nice if RAOB fetched raw data from the Internet at the touch of a button, but that chore is up to the user. I got around that by downloading soundings with Digital Atmosphere (reviewed in an earlier edition of the CMOS *Bulletin*), an outstanding weather mapper by Weather Graphics, www.weathergraphics.com. Two good sources are the College of Dupage and Albany (NY) State University. And RAOB should incorporate Windows' Ctl-F function to find stations.

To get Buffalo I have to trundle tediously past Amundsen-Scott, Aleksandrovskoye, Barabinsk, Brno Rebesovice and other places only Danny Kaye could have pronounced.



The upper air at Buffalo 22 August 2002 12 UTC. Bar graph on lower left shows slight to moderate chance of severe weather.

Prochain numéro du CMOS Bulletin SCMO

Le prochain numéro du *CMOS Bulletin SCMO* paraîtra en décembre 2002. Prière de nous faire parvenir au plus tôt vos articles, notes, rapports d'atelier ou nouvelles à l'adresse indiquée à la page ii. Nous avons un besoin **URGENT** d'articles.

Next Issue CMOS Bulletin SCMO

Next issue of the *CMOS Bulletin SCMO* will be published in December 2002. Please send your articles, notes, workshop reports or news items at the earliest to the address given on page ii. We have an **URGENT** need for your articles.

The Argo Armada – how far has it come

by Howard Freeland[1] and Bob Keeley[2]

Introduction

In March and April of 2001 Howard Freeland was the CMOS Tour Speaker with a presentation that described imminent plans to begin the deployment of a global climate observing system. Much has changed since that tour took place and the intention with this presentation is to provide CMOS members with an update on progress towards the full implementation of the Argo Armada.

Some CMOS members may have missed the tour presentation in 2001, so we will start by outlining the nature of Argo and proceed to describe the technology that makes Argo possible. We will then outline the progress towards the installation of a global ocean climate-monitoring array, describe the Argo data system and brief members on how they can gain access to Argo data.

What is Project Argo?

Working from the principle that much of the variability in the Earth's climate system is mediated through the ocean, the idea was mooted in 1998 that it might be possible to deploy robotic devices to monitor the climatic state of the oceans. A meeting in Tokyo in 1998, outlined the concept and succeeded in demonstrating sufficient interest to take the next step and discuss the possible actual implementation of such a robotic array. The problem being addressed is that traditional oceanographic measurement systems can never supply the information required for, as an example, seasonal climate forecasting. Over the last 100 years there has been no dramatic change in the speed of a ship, and the speed with which we lower instruments in the water column is still limited by the terminal velocity of those instruments, and so has not changed. Thus a CTD section across the Atlantic Ocean that took 29 days during the Meteor Expedition of 1926 took a similar amount of time in 1992 during the World Ocean Circulation Experiment. To meet the requirements of seasonal climate forecasting, surveys must be conducted **much** faster than is possible from ships at sea.

The International Argo Science Team was created following the Tokyo meeting and met for the first time in 1999 at which point it became evident that strong national commitments were emerging very rapidly to support the concept. In a very short time the Science Team agreed that floats should be launched to profile from a depth of 2000 metres, and most importantly that the data should be made available in real-time on the Global Telecommunications System and the World Wide Web. Implementation of that part of the plan was delegated to a Data Management Committee.

An important step was taken in 2000 when a meeting of the Intergovernmental Oceanographic Commission unanimously passed resolution XX-6 which affirms the principle that, briefly, floats can be launched anywhere and that data could be released for general use by any country, from inside or outside any Exclusive Economic Zone. In doing so we are consistent with the United Nations Convention on the Law of the Sea, and do not violate national sovereignties.

Finally, Argo is one of two projects aimed at supplying data to support a new concept, Operational Oceanography. The sister project is Jason, a satellite that continues the very successful Topex-Poseidon satellite mission that has observed variations in ocean height to a resolution of 2 cm globally. In some respects Argo and Jason can be viewed as the field programs which supply data to an umbrella program, GODAE.

The original plan for Argo is still available on the World Wide Web and is useful reading for anyone who wishes to examine it. See the list of useful links below.

How does the hardware work?

Critical to the Argo concept is the profiling float, which over its evolution has gone by a variety of names. Originally the ALACE float was conceived by Russ Davis (Scripps Institute of Oceanography) specifically to measure deep ocean currents without recourse to efficient sound propagation in the SOFAR channel. The float was able to vary its volume by moving oil in and out of the body of the float using a piston. As oil is moved outwards a rubber bladder expands into the ocean increasing the volume of the float and so decreasing its density. It would rise to the surface to be positioned by a satellite, then return to a pre-programmed depth for a fixed time interval.

The ALACE floats were used extensively during WOCE specifically to measure deep ocean velocities. It now seems surprising that it took so long, but eventually someone suggested adding a temperature sensor and reporting a temperature profile following every ascent. That worked well and the next logical step was to add salinity sensors. That was harder and took longer, but the problems were beaten and at that time the ALACE float turned into

[1] DFO, Institute of Ocean Sciences
Sidney, BC, Canada

[2] DFO, Marine Environmental Data Service
Ottawa, ON, Canada

the P- or Profiling-ALACE float. Subsequently the P-ALACE concept was redesigned and we now have a variety of floats being launched in support of Argo. The current models in use are:

1) The APEX float built by the Webb Research Corporation of Falmouth, Massachusetts.

2) The PROVOR float originally designed by the Martec Corporation in Brest, France, but manufactured by both Martec and the Metocean Corporation in Canada.

3) The SOLO float manufactured at the Scripps and Woods Hole Institutes of Oceanography for their own use.

Floats most commonly use SeaBird sensors to measure pressure, temperature and salinity profiles though a few use the Falmouth Scientific Instruments sensors. The observations are of a very high quality with temperature and salinity being reported with a resolution of about 0.002 degrees or psu. The SeaBird salinity sensors show very little tendency to drift and in most cases probably remain good to within 0.005 psu for the lifetime of the float. Most commonly the floats are reporting profiles from a depth of 2000 metres at 10-day intervals. The battery packs carry sufficient energy that they could supply up to 200 profiles – a potential lifetime of over 5 years.

The Argo deployment strategy calls for floats to have a nearest-neighbour separation of about 300 km; doing that globally requires about 3000 floats. It is sobering to think about the consequences of having such a global array. When Argo is fully implemented it will acquire more temperature and salinity profiles in the southern ocean in just one year than has been gathered by all previous research missions to the southern ocean!

Progress towards deployment of a global array

As of 22 August 2002 there are 541 floats reporting. Most of these are deployed in the northern hemisphere oceans, largely because these have been the easiest to get to. A few are starting to appear in the Southern and Indian Oceans. The map on the cover shows the distribution of profiles collected during August, 2002. A number of these profiles are from older model floats that collect only temperature profiles but all of the more recently deployed floats return both temperature and salinity profiles.

One of the challenges for Argo will be to deploy floats into ocean regions that are not frequently visited. Up until now, most of the floats have been deployed from ships, either research or commercial vessels. However, a few floats have been deployed from aircraft. This is likely to be the strategy used for more remote ocean regions. The APEX float has been certified for launch from C-130 (Hercules) aircraft. Several researchers have expressed interest in pursuing certification for launch from P-3 (Aurora) aircraft.

A second challenge will be to keep the desired 300 km spacing of floats; that is in reseeding ocean areas from which floats have left or that have ceased operating. To do this effectively will require constant monitoring of the location of floats and co-operation of countries to deploy new floats in empty areas.

The Argo data system

The present generation of floats transmit their data through transponders, mostly on the NOAA series of satellites, to ground stations in the US and France and operated by Service Argos. In Canada, the data are downloaded 4 times a day by MEDS in Ottawa and processed automatically to construct profiles from the data stream. The data are passed through automated quality control procedures with the philosophy of allowing some problem observations to get through but ensuring that good data are not restricted from distribution. Typically, about 90% of the data are distributed within 24 hours of the float surfacing. The Canadian data system is typical of the systems generally being established by Argo partner countries.

There are two distribution streams for the data. The first is the Global Telecommunications System, GTS, used by both meteorologists and oceanographers to exchange data globally. Only the profiles collected by the floats travel on this system and as TESAC messages. The second stream uses two mirrored Internet servers set up in Brest, France and Monterey, USA. (URLs are listed below) These servers offer ftp and http access to the data, a number of data subsetting and visualization tools and download capabilities. The data on the Argo servers are in netCDF format, but other formats are gradually being made available.

At the same time that the data are relayed to both the GTS and Internet servers, they are also sent to national PIs in the program, Howard Freeland at IOS and Allyn Clarke at BIO. These scientists are responsible for the more careful scientific quality control required to detect more subtle errors, such as salinity drifts, that are known to exist in data from floats. It is the intention that these more carefully scrutinized data will be sent to the Internet servers within a few months and will replace the first versions sitting on the servers. As others look at the data and other problems are found, updated versions of the data will be posted to the servers.

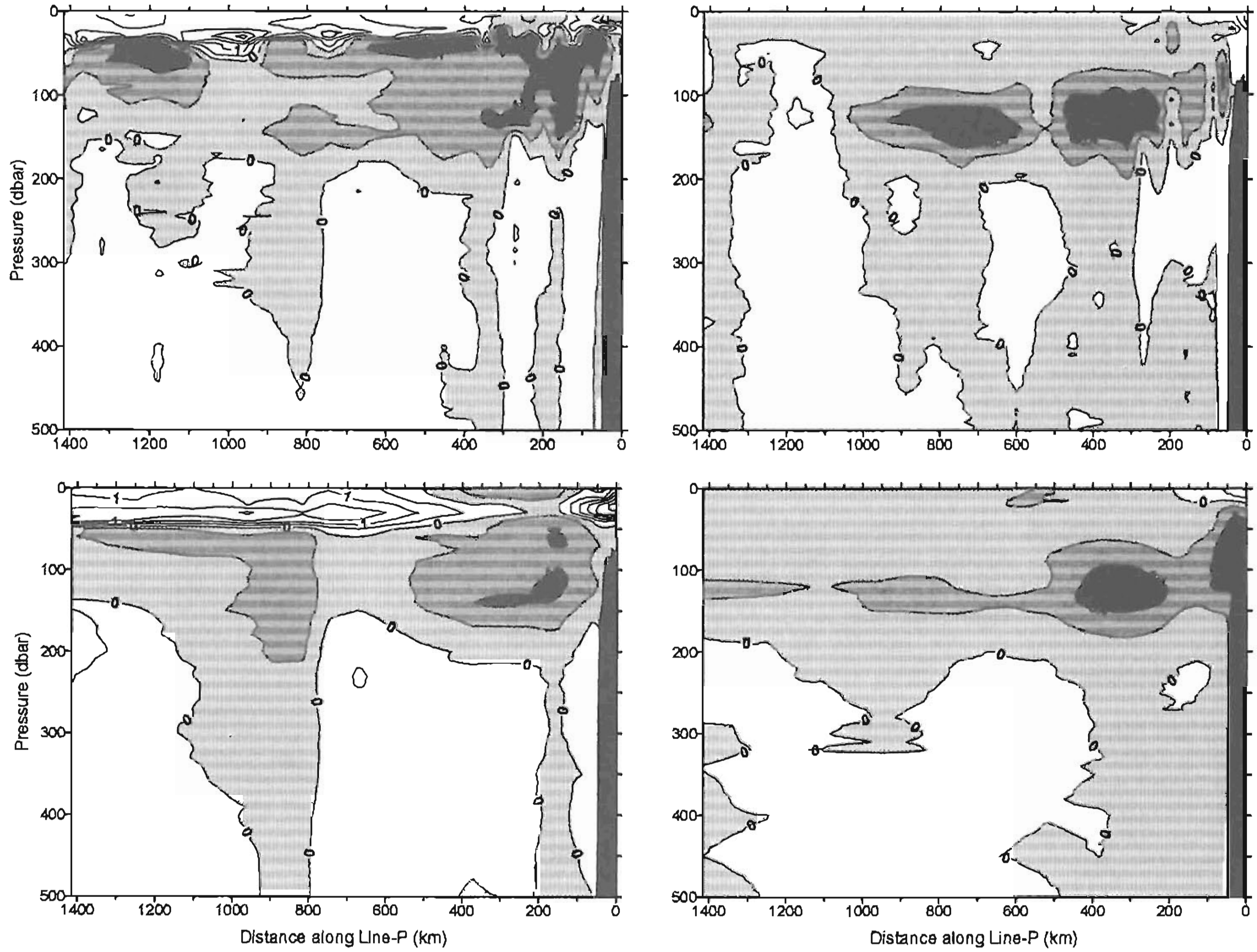


Figure 1: The top row shows the difference between temperature (left) and salinity (right) observed during a survey in June/July 2002 and a long-term Line-P climatology. The lower panels show the same differences simulated by interpolation from Argo observations and using the same climatology. In all cases shading indicates negative anomalies.

In contrast to the GTS data stream, which only has the profile data, the Internet servers contain not only the profiles but also whatever surface or deep trajectory data that may be returned from the floats. In addition there is information about the type of float deployed, where and when the float was deployed, calibration information and even such engineering information as battery voltages and piston positions. Not all of this information is yet available from the Internet servers, but as the data system develops these will augment the existing profile data.

Anyone in the world with Internet access can visit these two servers and download any and all data that they wish to use. There is no requirement to be a part of the Argo program, though, naturally, participation in Argo is welcome and encouraged.

Products available now and coming soon

Argo is still in the very early stages of development and products are beginning to appear. Some products already exist but are almost invisible. Several organisations issue monthly analyses of the climatic state of the ocean, including sea-surface temperature maps. Previously these were based almost entirely on XBT measurements. The maps have improved in quality during the last 18 months and that is largely because the systems are now ingesting Argo data in real time. Most users of the maps would not be aware of this change in technology. Argo will be able to supply many more descriptive products because of the high quality of measurements and in particular because of the availability of velocity measurements and high quality salinity observations.

Compared with a typical CTD survey from a ship mapping by Argo is coarse. Figure 1 shows an attempt to reproduce an actual ship survey by using the Argo floats in the Gulf of Alaska. Clearly the Argo simulation is much coarser, but the major features are accurately reproduced. In particular we see a very warm surface layer overlying a cool intrusion of sub-arctic water. This combination of warm and cold anomalies stabilised the water column producing an anomalously thin surface mixed layer. These unusual conditions had to be accommodated by the SOLAS/SERIES project this year. In the SERIES experiment a micro-nutrient iron was injected to examine how this would stimulate biological production. Because of increased near-surface stratification, the biologically-active region was much thinner than originally expected. The thin mixed layer must have been present over the entire Gulf of Alaska and must have affected the supply of macro-nutrients to the surface, biologically active layer.

In the near future Regional Centres will be established that will have a mandate by the Argo Science Team to supply standardised products descriptive of the current state of the Argo array itself and the state of the ocean.

Acknowledgements

We would like to acknowledge support from the DFO National Capital Fund for the acquisition of the floats that allow Canadian contributions to Argo, and support from the Action Plan-2000 fund to support the implementation of Argo. The authors would also like to thank DFO Managers for their enthusiastic and energetic support.

References and Useful WWW Links:

The Design and Implementation of Argo, by The Argo Science Team 1999: URL for the Argo planning document. http://www.argo.ucsd.edu/argo-design.pdf

The Argo data User's Handbook: http://www.argo.ucsd.edu/argo-design.pdf

The Argo Data Management Handbook: http://www.coriolis.eu.org/coriolis/cdc/argo/argo_data_management_handbook_v1.1.pdf

The Canadian Argo Fact Sheet: http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/alace/Factsheet.pdf

Argo Science Team: http://www.argo.ucsd.edu

The Argo Information Centre: http://argo.jcommops.org/

Canadian Argo site at MEDS: http://www.meds-sdmm.dfo-mpo.gc.ca/meds/Prog_Int/Prog_Int_e.html

Mercator - Global Argo Data Server: http://www.coriolis.eu.org/coriolis/cdc/

US GODAE Argo Server http://www.usgodae.fnmoc.navy.mil

The current distribution of Argo floats mapped onto an icosahedral mesh which you can cut out and assemble into an icosahedral pseudo-globe (see the front cover): http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/alace/Argo_icos.pdf

Acronyms

ALACE	Autonomous Lagrangian Current Explorer
APEX	Autonomous Profiling Explorer
Argo	Argo is not an acronym
BIO	Bedford Institute of Oceanography
GODAE	Global Ocean Data Assimilation Experiment
GTS	Global Telecommunications System
IOS	Institute of Ocean Sciences
Jason	Jason also is not an acronym
MEDS	Marine Environmental Data Service
P-ALACE	Profiling – ALACE float
SERIES	Subarctic Ecosystem Response to Iron Enhancement Study
SOFAR	Sound Fixing and Ranging
SOLAS	Surface Ocean, Lower Atmosphere Study
SOLO	Sounding Oceanographic Lagrangian Observer
WOCE	World Ocean Circulation Experiment

Forecasting the El Niño of 2002

by W. W. Hsieh[1], A. Wu[1], B. Tang[2] and Y. Tang[3]

Now that an El Niño event has finally arrived after several years of cool conditions in the equatorial Pacific, we briefly examine the success and failure of the UBC forecast models for this event. There are 3 forecast models for the equatorial Pacific on our web site www.ocgy.ubc.ca/projects/clim.pred: a nonlinear canonical correlation analysis (NLCCA) model, a hybrid coupled model with a dynamical ocean coupled to a neural network atmosphere, and a neural network (nonlinear regression) model.

The NLCCA model was the most successful among the three in forecasting this El Niño. Using equatorial data till the end of January, 2002, the 12-month lead-time forecast of this model was predicting sea surface temperature anomalies (SSTA) in the Nino3.4 region in the eastern-central equatorial Pacific to exceed 1°C by winter 2003 (Fig.1).

The second best performance was achieved by the neural network (nonlinear regression) model, where using data till the end of February, 2002, the 9-month lead-time forecast was predicting Nino3.4 SSTA exceeding 1°C by late fall, 2002. The warm anomalies forecasted were somewhat weaker than those predicted by the NLCCA model. The neural network model, which has performed well in forecasting the past several years of cool conditions, predicted cool conditions in early 2002, which did not materialize.

The hybrid coupled model failed to predict this El Niño. In early 2002, it predicted cool La Niña conditions by late 2002. As the year progressed, the forecasts became warmer, but the model is still only forecasting near normal conditions in the equatorial Pacific for the winter of 2002-2003. However, it should be pointed out that in the eastern equatorial Pacific Nino1+2 region, significant negative SSTA have persisted from June to September, 2002 while the western-central equatorial Pacific was warming.

In summary, two of our 3 models were able to forecast the present El Niño as far back as the end of January, 2002 (NLCCA model) and the end of February, 2002 (neural network model). Newer empirical and hybrid coupled models are being developed which will hopefully enhance future forecast skills.

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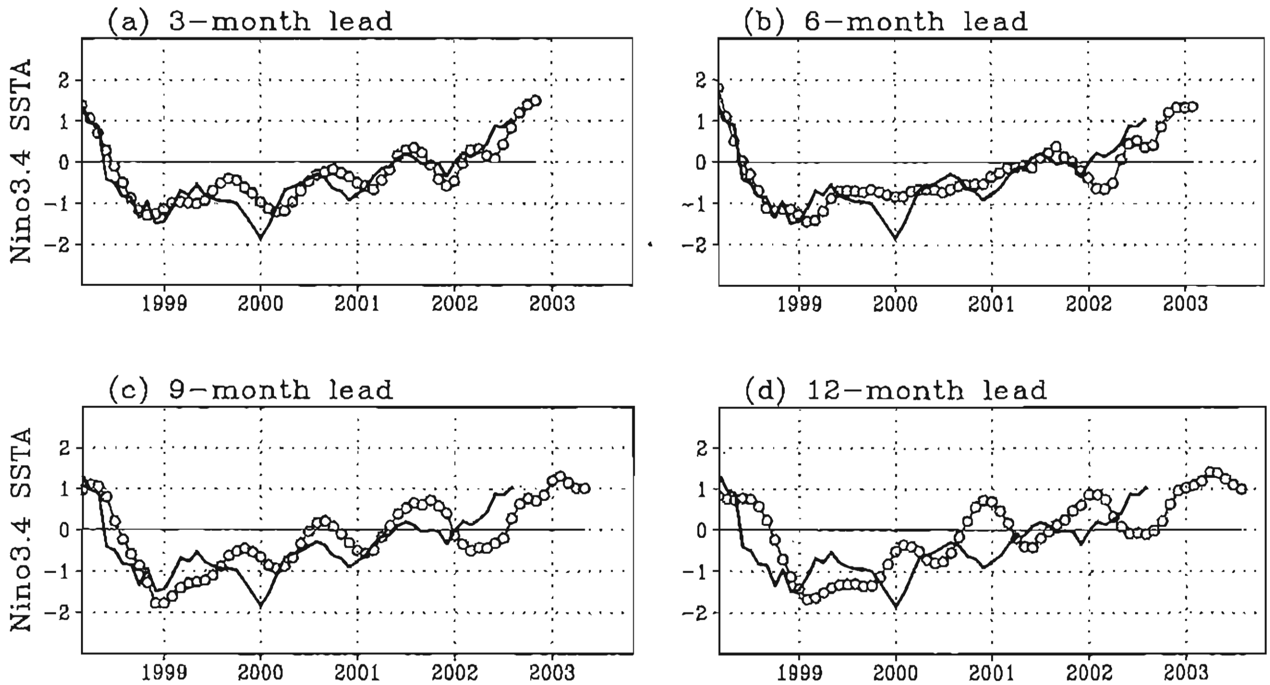

Figure 1. The SST anomalies (SSTA) (in degree Celsius) in the Nino3.4 area (170W-120W, 5S-5N) predicted by the ensemble-averaged NLCCA model at 3, 6, 9 and 12 months of lead time (circles), with observations denoted by the solid line. Tick marks along the abscissa indicate the January of the given years.

Review of Prairie Thunderstorms

by G.S. Strong, Ardrossan, AB

ABSTRACT

A review of thunderstorms over the Canadian Prairies is presented in several papers[1] in successive issues of the Bulletin, with three main objectives: (1) to summarize some of the climatology and physical processes related to prairie convective storms; (2) to identify gaps in both the science and data for all ranges of convective processes; and (3) to provide some recommendations for alleviating these gaps. Additionally, while addressing (1) we shall try to improve on a multi-scale conceptual model of severe thunderstorms described by Strong (1986, 2000), using forecasting techniques to test this model.

The review is directed towards prediction problems associated with prairie thunderstorms and associated phenomena such as large hail, heavy rain, and tornadoes. It adopts the premise that operational problems of prediction are virtually always a multi-scale problem, that storm initiation is controlled mostly by larger scale processes with a dominant downscale effect. We therefore concentrate on synoptic scale forcing, atmospheric boundary layer and mesoscale processes, climatological characteristics, and spatial/temporal characteristics of storms, as well as data systems and communications associated with the forecast system. Using the same argument, cloud microphysical processes are not covered in any detail, assuming that important microphysical feedbacks can be quantified through ensemble mesoscale measurements. Some specific prediction techniques will be addressed, but numerical modelling results are left to those far more expert in that area. The review is based primarily on published results in the literature, but also includes feedback from interviews conducted with prairie forecasters and researchers during 2000, specifically for this effort.

This series of papers has a decided emphasis on Alberta storms, resulting from almost 30 years of published research of radar, cloud physics and hail suppression studies over central Alberta from the ALHAS/AHP field programs of 1957-85, as well as the author's own personal experience and research while with AHP. Some information is included from studies over the U.S. High Plains[2] where prairie data and case studies are lacking, and to demonstrate results that apply universally to severe convective storms. This first paper in the series focuses on regional variations in storm size characteristics, and some climatology of hail, tornadoes and lightning.

RÉSUMÉ (traduit par la direction)

Les orages dans les Prairies canadiennes font l'objet d'un examen dans une série d'articles[3] dans des numéros successifs du Bulletin. Cet examen a trois grands objectifs : 1) résumer une partie de la climatologie et des processus physiques associés aux orages de convection dans les prairies; 2) relever les lacunes de la science et des données pour toutes la gamme de processus convectifs; et 3) formuler des recommandations en vue de combler ces lacunes. En outre, en adressant l'objectif 1, nous tenterons d'améliorer un modèle conceptuel multi-échelle d'orages violents décrit par Strong (1986, 2000), en utilisant des techniques de prévision pour vérifier le modèle.

Cet examen est axé sur les problèmes de prévision associés aux orages dans les prairies et aux phénomènes qui y sont associés, notamment la grêle de gros diamètre, la pluie abondante et les tornades. Nous adoptons comme prémisse que les problèmes opérationnels de prévision représentent presque toujours un problème multi-échelle, que la formation des orages est contrôlée presque entièrement par des processus de plus grande échelle avec un effet de sous-échelle dominant. Nous nous concentrons donc sur le forçage à échelle synoptique, la couche limite de surface et les processus d'échelle moyenne, les caractéristiques climatologiques et les caractéristiques spatiales et temporelles des orages, ainsi que sur les systèmes de données et les communications associées au système de prévisions. Pour la même raison, les processus microphysiques de nuages ne sont pas examinés en détails, car nous supposons que les rétroactions microphysiques importantes soient quantifiables à l'aide de mesures d'ensemble d'échelle moyenne. Certaines techniques de prévision particulières seront abordées, mais les résultats de la modélisation numérique seront laissées aux experts en la matière. L'examen est basé principalement sur les résultats publiés dans des ouvrages scientifiques, mais il comprend aussi les résultats d'entrevues avec des chercheurs et des spécialistes des prévisions météorologiques des prairies qui ont eu lieu à cette fin en 2000.

Cette série d'articles met l'accent sur les orages en Alberta, en raison des études radar et des études de la physique des nuages et de la prévention de la grêle dans le centre de l'Alberta, dont les résultats ont été publiés, qui ont été entreprises pendant presque 30 ans dans le cadre des programmes de terrain de 1957-1985 de l'ALHAS/AHP, et de l'expérience personnelle acquise par l'auteur et des

[1] This series of papers is based largely on a similar review conducted by Strong and Smith (2001) for Emergency Preparedness Canada, updated with new information.

[2] The High Plains are loosely defined as the broad region in the lee of the Rocky Mountains, generally above 500 m elevation and extending from Texas northwest to Alberta.

[3] Cette série d'articles est basée largement sur un examen semblable entrepris par Strong et Smith (2001) pour Protection civile Canada, mis à jour avec de nouvelles informations.

recherches qu'il a entreprises dans le cadre du AHP. Une partie de l'information provient de travaux effectués dans les High Plains[4] des États-Unis où les données et les études de cas sont inexistantes, afin de montrer que les résultats s'appliquent à tous les orages de convection violents. Le premier article de la série porte sur les variations régionales des caractéristiques de l'importance des orages, et sur la climatologie de la grêle, des tornades et des éclairs.

1. Scale Characteristics and Regional Climatologies

1.1 THE SEVERE STORM PROBLEM

Weather phenomena associated with prairie thunderstorms include large hail, heavy rainfalls, flooding, tornadoes and other damaging winds. All of these phenomena exact heavy annual tolls in crop and other property damage, and all too often in human lives. Such storms occur frequently during summer over the Canadian prairies; e.g., hail occurs on almost 50% of summer days over central Alberta alone, with about 1/3rd of these classified as severe (walnut or larger size hail) – see Wojtiw (1975). Some example well-documented prairie storms of the past 20 years include:

- the Calgary hailstorm of 28 July, 1981 – >$100m damage + several lives lost in flooding (see Strong, 1982);
- the Edmonton tornado of 31 July, 1987 – $250 million damage + 27 lives lost – see Charlton et al., 1998 or Atchison, 1988);
- the Calgary hailstorms of 1991 ($400m damage) and 1996 ($150m damage);
- the Winnipeg hailstorm of 16 July 1996 – $110m damage (see McCarthy et al., 2000); and
- the Pine Lake tornado of 2000 – 12 deaths, at least 140 injuries, $15m damage (see Joe and Dudley, 2000).

Detailed field research programs on severe Alberta hailstorms were carried out by the Alberta Hail Studies (ALHAS, 1957-74; see Renick, ed., 1970) initiated by McGill University (Douglas and Hitschfeld, 1959), and the follow-on Alberta Hail Project (AHP, 1975-85; see Deibert, ed., 1985) coordinated by Alberta Research Council. ALHAS/AHP included both operational and research cloud seeding programs to reduce heavy hailfall and resulting crop damage over central Alberta. Since the demise of AHP following the 1985 hail season, there has been a critical lack of coordinated research of convective storms anywhere on the prairies. During this same period, half a dozen or more of the most destructive prairie storms on record have occurred. The current operational Alberta Hail Modification Project (AHMP, 1996-present) is focused on reducing property damage from hail over major urban centres (Krauss, 1999). Interestingly, this program is completely funded by the insurance industry, a recognition of the increasing storm risk.

A major non-scientific research problem with respect to prairie thunderstorms is the lack of synthesis of knowledge of storm processes, and in related areas such as forecasting, emergency measures, communications for dissemination of warnings, and lack of coordination between agencies. Paul (1982) wrote that "*Past research into prairie thunderstorms has largely been conducted by meteorologists and has been marked by fragmented studies rather than overall synthesis*". Five years later, following the Edmonton tornado disaster, the chair of the review team, Hage (1987a) wrote as one of his recommendations: "*The Government of Canada and the Governments of Provinces affected by severe summer weather should encourage and support research to improve early detection and prediction of severe local storms, including tornadoes*". Since the termination of AHP research and operations in 1985 and the effective breakup of the remaining ARC research group around 1987-88, there has been little published research on Alberta thunderstorm systems, and even less for Saskatchewan and Manitoba. The lack of synthesis is not due to any lack of coordination on the part of scientists and meteorologists. There is simply no critical mass of people working on these problems. The few prairie research meteorologists left in this field have become even more fragmented than at the time of Paul's statement above, while Hage's recommendations have been largely ignored. Clearly, this problem can be traced to 'no funding, no researchers'.

Ironically, the devastating effects of future severe convective storms on the prairies may well become even more frequent with expected population increases: e.g., central Alberta's 'hail alley', the Edmonton-Calgary corridor, is Canada's fastest growing population area (Statistics Canada, 2002). Hence, the need for a review at this time and encouragement for renewed research funding.

1.2 REGIONAL SEVERE STORM CHARACTERISTICS

A long-recognized scientific issue (but never documented in the literature) is *how storm characteristics and storm initiation mechanisms vary across the prairies*, and from the prairie setting to southwestern Ontario and more eastern regions of Canada. Strong (1986) provided some evidence that storms in the immediate 'lee of the Rockies' from

[4] Grosso modo, les High Plains constituent la vaste région sous le vent des Rocheuses, à une élévation généralement de plus de 500 m, qui s'étend du Texas vers le nord-ouest jusque l'Alberta.

northern Alberta south to west Texas exhibit many similarities in both type and formation mechanisms, with differences in intensity explained mainly by boundary layer depth and total available moisture. Why then does there appear to be more variation in storm characteristics west to east across the prairies? The Pine Lake tornado incident in central Alberta on 14 July 2000 provides a quick visual example of such west-east differences in storms. The infrared satellite image in Figure 1.1 just one hour before tornado touchdown shows significant-looking large convective formations over both the Dakotas and Saskatchewan. However, the storm that caused the most damage on this day and took 12 lives, is a much smaller entity over south-central Alberta (see arrow on Fig. 1.1), and to the non-professional at this image scale, looks rather insignificant by comparison, even though it had already left a long swath of hail up to golf ball size in a west-east path across the province, and was about to become tornadic. Moreover, this is a typical Alberta severe storm (in terms of its formation over the Alberta foothills and eventual size characteristics), while the larger complexes shown here are more typical of severe storms for the eastern prairies. It should also be mentioned that despite the scale differences between the Alberta and southern Saskatchewan storms here, both can be traced to the same synoptic shortwave trigger mechanism. The explanation for these differences can be attributed to orographic forcing in the case of Alberta storms. This will be discussed in more detail later in this review.

Documentation of north-south and west-east similarities and differences in characteristics between prairie convective storms is crucial to improving our understanding and prediction of these phenomena. This is all the more important on the prairies since budgetary restrictions forced the Meteorological Service of Canada (MSC) to move all of its prairie severe weather forecasting to their Winnipeg office during the 1990s.

1.3 SCALES OF ATMOSPHERIC MOTION

Severe storm research tended to follow one of two different schools of thought during the 1950s and 1960s, concentrating on two opposite ends of the scale spectrum. One approach was to focus attention primarily at the *visible* cloud scale, dealing with the physics of cloud and precipitation particles, and how these might be altered to change the type and amount of precipitation at the ground, virtually ignoring the larger environment outside the cloud. Out of this cloud physics approach was born the science of weather modification. The other approach was interested in how large-scale (synoptic) processes modify the severe storm environment, *before* the storm forms, and how the effects might be predicted. For some time, these two approaches were pursued virtually independent of each other, and tended to develop sometimes conflicting ideas as to cause and effect of convective storms.

In view of this, and the scale differences discussed in Section 1.2, it is helpful to review the range of spatial and temporal scales of motion in the atmosphere. One scheme for classifying the atmospheric 'scales' of motion is shown in Table 1.1. These scales are not discrete physical entities, but rather they represent the most common stratifications discussed in the literature (e.g., Orlanski, 1975). The reader is advised that several variations of this table appear in the literature.

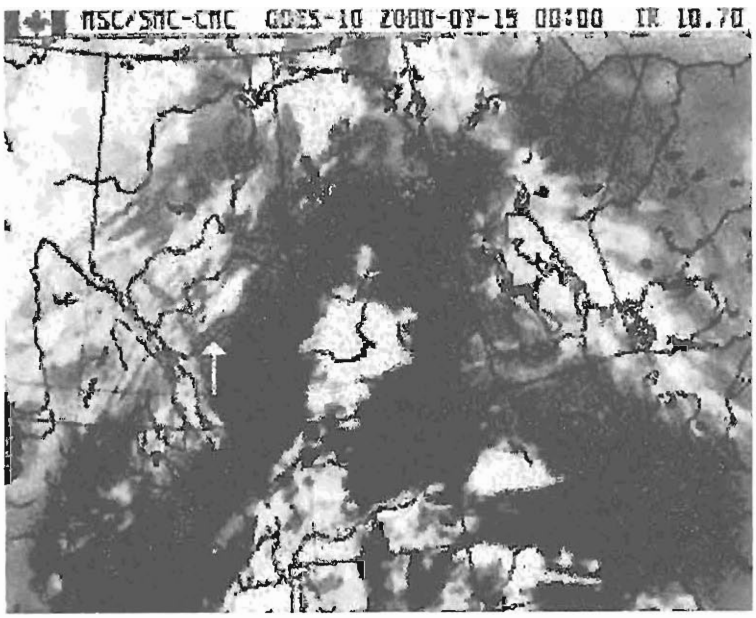

FIGURE 1.1: Enhanced infrared GOES satellite image at 0000 UTC, 15 July, 2000, showing thunderstorms over the Dakotas, southern and northern Saskatchewan, and a smaller but large hail-producing intense thunderstorm over south-central Alberta which spawned the Pine Lake tornado one hour later, leaving 12 dead in its wake. Also shown in colour on inside back cover.

TABLE 1.1: Definitions and examples of the scales of atmospheric motion discussed in this paper (from Strong, 1986).

SCALE	Range of Wavelength (km)	Time Scale of Associated Weather over region	Scale Examples	Example of Data Sources	Observing Network Avg. Data Resolution (km)	Frequency of Observation	REMARKS
MACRO or Planetary	> 5000	More than one week	Longwaves, large, persistent quasi-stationary highs, lows	Global upper air network (weekly averages)	400 - 500	Twice daily (00Z, 12Z)	Variable density; inadequate over oceans
SYNOPTIC	2000 - 5000	1 - 3 days	Intermediate and shortwaves, migratory lows, highs	N.A. upper air network	500 - 600 (Canada)	Twice daily (00Z, 12Z)	Irregular design; e.g., only 2 sites Canadian prairies
SUB-SYNOPTIC (Meso-α)	200 - 2000	12 - 48 hours	Sub-synoptic Convective Complexes (SSCCs) or TRW clusters, hurricanes, secondary lows	N.A. surface observing network	100 - 150	Hourly plus special observations	Irregular design, sites sometimes not representative
MESO (Meso-β)	+20 - 200	1 -12 hours	Mesoscale Convective Complexes (MCCs or large TRWs), cold fronts and squall lines, cumulus clusters	NSSL (1966-67) SESAME upper air networks; Alta. Foresty surface network	75 30	1.5 - 6 hours twice daily (14Z, 19Z)	Near-regular design; Irreg., limited area (Alta. Foothills)
CLOUD (Meso-γ) or Cumulus Scale	2 - 20	20 - 60 mins.	Single-cell CU, TCU, small CB, tornado, fine-scale reflectivity patterns	GOES sat. data; NOAA sat. data	4 - 16 (IR), 1 - 2 (vsbl); 1	30 minutes; 30 minutes; 4 - 8 hours	Res. deteriorates N from equator; Polar-orbiting
MICRO	Large relative range – few microns - 2 km	Seconds to minutes	Turbulent eddies, convective thermals, CU cloud turrets, wind gusts	Radar data; LANDSAT data; research aircraft	0.5 - 2.0; 0.05; < 0.01	1 minute; 1 - 2 weeks; 1 second	Uniform grid; Poor temporal; Uniform, but 1-D
VISCOUS	Molecular distances	??	Molecular motions	Electron Microscope	N/A to most meteorology applications	N/A	N/A

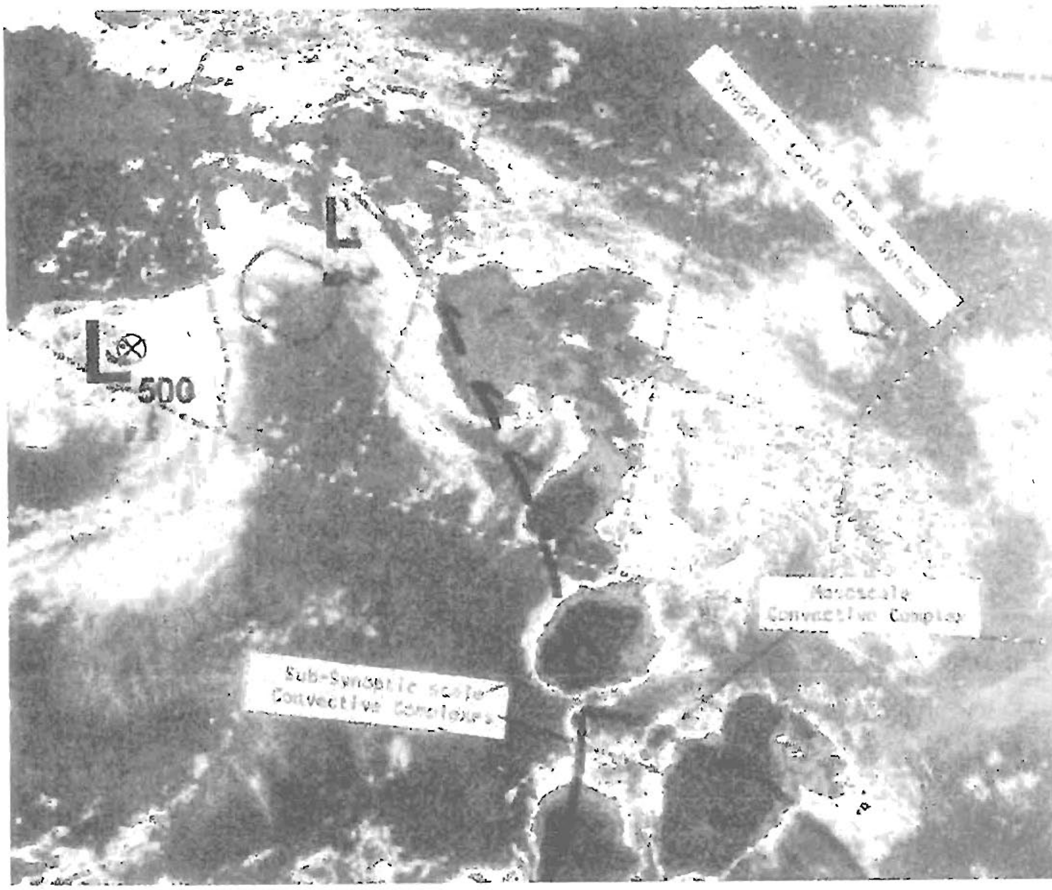

FIGURE 1.2: Enhanced infrared NOAA-6 image for 0136 UTC, 15 July, 1982, depicting three of the scales of atmospheric motion indicated in Table 1.1; super-imposed fronts, surface and 500 hPa low centers were extracted from CMC analyses. Also shown in colour on inside back cover.

FIGURE 1.3: Aerial view showing three identifiable interacting scales of motion – a meso-β scale thunderstorm complex 30-60 km across (the 'Hailstorm Giant", reproduced from Goyer, 1978), with meso-γ scale clusters (e.g., the "giant's" nose and ear), and individual microscale cloud turrets with horizontal dimensions of 1 km or less.

The infrared satellite image of Figure 1.2 shows examples of three of these scales of motion for convective processes. This includes a synoptic scale cloud system of more than 2000 km across, several sub-synoptic (or Meso-α) scale convective complexes (clusters of thunderstorms) with horizontal dimensions of 250-350 km in this case, and at least one mesoscale (Meso-β) thunderstorm complex of 50-100 km. The approximate position of the surface front is superimposed on Figure 1.2. The aerial photograph of Figure 1.3 depicts three other scales of motion from a much closer vantage point. Here the thunderstorm system is a (Meso-β) mesoscale convective complex of 50-80 km across. This complex includes cloud scale (Meso-γ) clusters of 2-10 km across, which by themselves would be identified as cumulus congestus (TCU) clouds, each of which is made up of microscale cloud turrets of the order of 1 km or less across. The precipitation patterns from such clusters were observed on radar as 'fine-scale reflectivity patterns' or FSPs (Barge and Bergwall, 1976). It had been assumed that these clusters, particularly the turrets, were a result of turbulent processes (e.g., Tennekes, 1978). However, the FSPs exhibit continuity in space and time, suggesting that such features have predictable qualities. This may require some re-examination of those features that we assume to be indeterminate three-dimensional turbulence.

A further clarification of the two convective complex scales is necessary here. Maddox (1980) defined but one scale of Mesoscale Convective Complex (MCC), having a quasi-elliptic shape and a total cloud shield area exceeding 100,000 km^2 (linear horizontal dimensions more than 350 km) for a period of six hours or more. Maddox did not place upper limits on his MCC definition, but his summary of 43 MCCs for 1978 ranged in diameter from 350 to 1000 km, with durations of 6-25 hours (except one >54 hours). Bosart and Sanders (1981) described the life history of a relatively small convective complex (at times, smaller than 300 km diameter), which originated over South Dakota, but caused disastrous flash floods over Pennsylvania four days later (well into the synoptic scale lifetime). The smallest entity noted in Figure 1.2 and largest entity in Figure 1.3 fall short of the minimum dimensions given by Maddox. These smaller severe storms are more the 'norm' for Alberta and other High Plains regions, yet many of them develop their own mesoscale circulation (Lemon and Doswell, 1979).

Since there is apparently no clear relation between complex size, intensity, and duration, it makes sense to have at least two classifications of MCC. The Maddox MCC is therefore referred to as a sub-synoptic scale convective complex (SSCC) in this series if horizontal dimensions exceed 200 km. Mesoscale convective complexes (MCC) will be defined as ranging from small clusters of cumulus clouds of 20 km across, up to small thunderstorm complexes of 200 km. While satellite imagery such as Figure 1.2 provide no proof of the scale interaction concept, the fact that groups of entities at one scale tend to be organized into entities at the next larger scale, suggests a strong relation between adjacent scales. Diagnostic studies such as the four-day storm complex documented by Bosart and Sanders (1981) provide direct evidence of the interactions between different scales of motion.

1.4 THUNDERSTORM SEVERITY

When discussing hail size, the old ALHAS/AHP definitions of: shot size (< 4 mm), pea (4-12 mm), grape (13-20 mm), walnut (21-32 mm), golfball (33-52 mm), and larger than golfball (> 52 mm) are commonly used in Canada. Hailstorms yielding *walnut or larger hail* are generally classified as *severe*. For tornadoes, the Fujita (1971) F-scale, reproduced in Table 2.1, is used universally to classify tornado strength by resulting damage. For example, the Barrie (May, 1985), Edmonton (July, 1987), and Pine Lake (July, 2000) tornadoes achieved maximum strengths of F4, F4, and F3 respectively.

For prairie forecast operations, Paruk and Blackwell (1993) classified prairie thunderstorm events as *severe* when any of the following were reported: hail greater than 20 mm diameter (walnut size or larger), strong winds with gusts above 90 km hr^{-1}, heavy rain with accumulation more than 30 mm in any one-hour period, or the report of a tornado or waterspout.

1.5 THUNDERSTORM CLIMATOLOGIES

The term 'climatology' is used rather loosely here, not referring to average values over standard climate periods, but rather to include analysis 'averages' of many cases to highlight persistent features of a phenomenon under study. This review attempts to summarize, for each of the three Prairie provinces, climatologies of the four categories of *severe* thunderstorm events recognized by the operational forecasting community which Paruk and Blackwell (1993) list as: hail greater than 20 mm diameter (walnut size or larger), strong winds with gusts above 90 km hr^{-1}, heavy rain with accumulation more than 30 mm in any one-hour period, and the report of a tornado or waterspout. Other potential climatologies discussed briefly include clouds, satellite data, radar data, and lightning. The largest and most continuous prairie severe storm datasets by far were those collected over central Alberta by the ALHAS/AHP hail research programs initiated by McGill University and coordinated by Alberta Research Council during 1957-85. Climatologies of hail in Manitoba or Saskatchewan, or of other thunderstorm phenomena, are less complete, and are mostly due to the efforts of individual researchers such as Paul (1980a, 1982, 1991, 1993), Hage (1987b, 1994), and a few operational meteorologists such as Paruk and Blackwell (1983) and Vickers (1996).

Table 2.1: The Fujita Tornado Scale Fujita (1971), usually referred to as the F-Scale, classifies tornadoes based on resulting damage.

F-scale	WINDS in Km/h	TYPE of DAMAGE	FREQUENCY
F0	64 - 116	MINIMAL DAMAGE: Some damage to chimneys, TV antennae, roof shingles, trees, and windows.	29 %
F1	117 - 180	MODERATE DAMAGE: Automobiles overturned, carports destroyed, trees uprooted.	40 %
F2	181 - 253	MAJOR DAMAGE: Roofs blown off homes, sheds and outbuildings demolished, mobile homes overturned.	24 %
F3	254 - 332	SEVERE DAMAGE: Exterior walls and roofs blown off homes. Metal buildings collapsed or are severely damaged. Forests and farmland flattened.	6 %
F4	333 - 418	DEVASTATING DAMAGE: Few walls, if any, standing in well-built homes. Large steel and concrete missiles thrown far distances.	2 %
F5	419 - 512	INCREDIBLE DAMAGE: Homes leveled with all debris removed. Schools, motels, and other larger structures have considerable damage with exterior walls and roofs gone. Top stories demolished.	< 1%

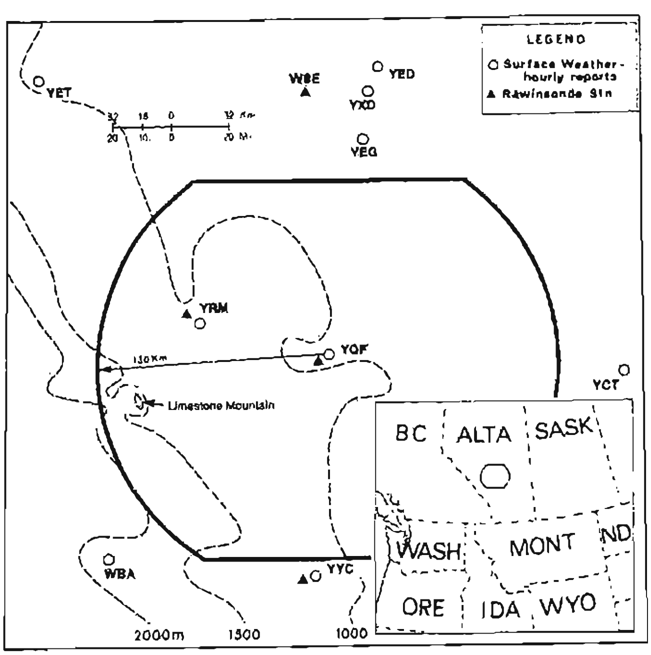

FIGURE 1.4: AHP 130-k radius operations area with coarse topography and synoptic observing sites, including Calgary Airport (YYC), Red Deer Airport (YQF), Rocky Mountain House (YRM), and Edmonton/Stony Plain (WSE).

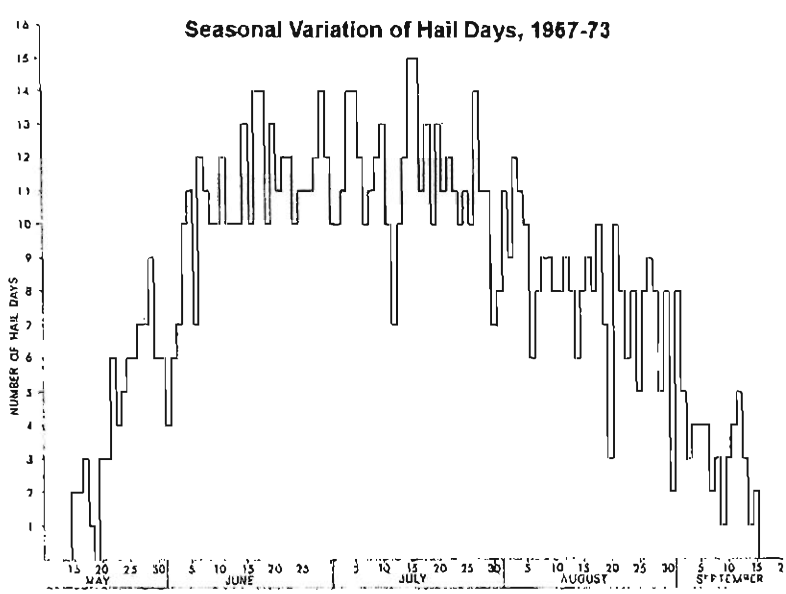

FIGURE 1.5: Seasonal variation of hail days, 1957-75 (reproduced from Wojtiw, 1975).

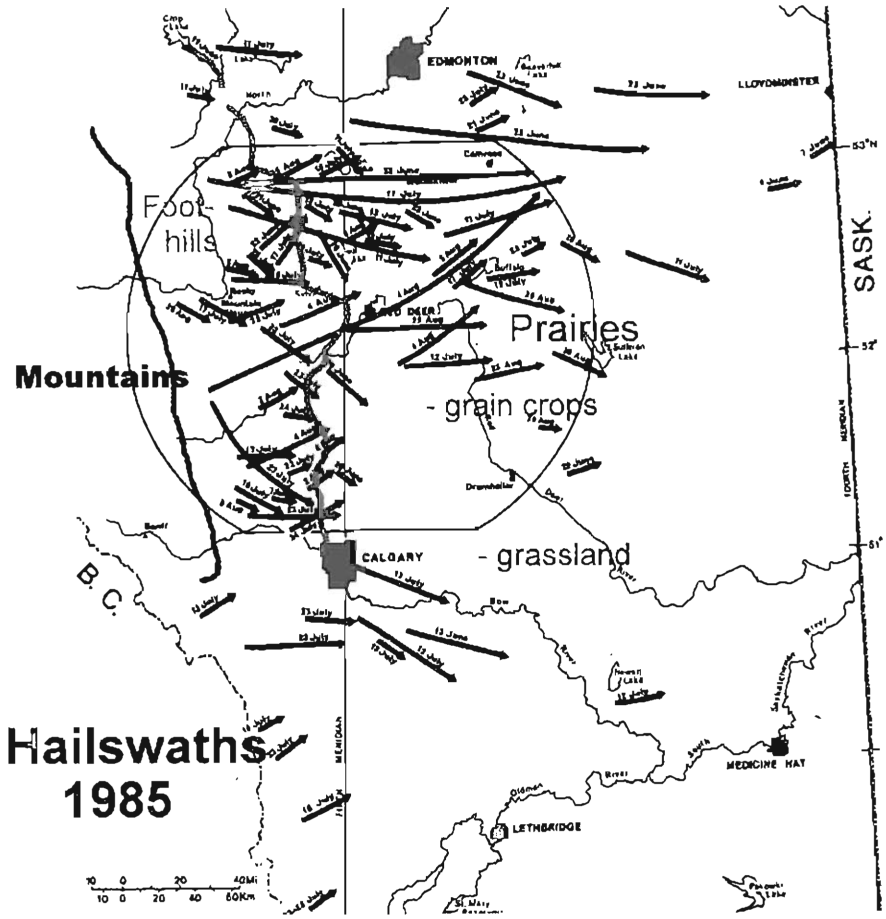

FIGURE 1.6: Major hailswaths of 1985 (reproduced from Deibert, 1985). The super-imposed jagged lines are the approximate eastern edges of the main Rocky Mountain barrier and the foothills. Also shown in colour on inside back cover.

1.5.1 Hail Climatology, Alberta

For Alberta, substantial numbers of hail reports were solicited from untrained observers in the farming community by phone and mail surveys after every hailstorm during 1957-85, primarily for the 130-km radius semi-circular area in central Alberta between Edmonton and Calgary shown in Figure 1.4, an area of almost 50,000 km^2. These volunteer hail reports were summarized by Summers and Paul (1967) in a 10-year study, then updated for the 17-year database of 1957-73 by Wojtiw (1975), and through subsequent ALHAS/AHP annual field program reports such as Deibert (1985). The two earlier studies yielded probabilities of hail on any given day in May through September of 50%, or 60-70% for June and July. Severe hailstorms (producing walnut or larger hail) occur during 15% of the period. Wojtiw's (1975) chart for the seasonal distribution of hail days, reproduced in Figure 1.5, reveals that the hail day frequency picks up rapidly between mid-May and early-June, is relatively steady through July, tails off slightly in early August, then drops rapidly in frequency in September.

Available soil moisture and the growing cycle of grain crops have a significant influence on convective cloud processes (and therefore thunderstorms and hail) on the prairies due to local evapotranspiration. Strong (1997) showed that during a season of high soil moisture, regional evapotranspiration rates averaged 5 mm day^{-1} during July, occasionally exceeding 10 mm. Applying such rates to a boundary layer 1 km deep would increase daily mixing ratios by more than 5 g kg^{-1}, which significantly increases the potential for convective clouds and thunderstorms. Similar evapotranspiration rates were provided by Raddatz (1998), who also showed that the agricultural development of the prairies, from prairie grasses with a deep root zone to grain crops with a shallow root zone, has increased the production of convective clouds and thunderstorms during the growing season due to increased evapotranspiration from crops. This would explain the drop-off in hail frequency during early-August in Figure 1.5, when grains 'head out' and crop transpiration virtually ceases, and a further drop-off in September as other vegetation commence dormant conditions. Related to this, hail and thunderstorm frequencies are lower overall during years of low soil moisture.

Annual *hailswath* maps were routinely produced from AHP hail survey reports (e.g., Wojtiw, 1975; Deibert, 1985). A hailswath was defined as a convective precipitation pattern observed at ground level from which at least six hail reports were obtained. An example hailswath map for 1985 appears in Figure 1.6, on which are super-imposed the discontinuities of the Rocky Mountain barrier (near the western edge of the AHP operations area) and of the foothills region (approximately the western half of the operations area). Two main patterns emerge in every annual hailswath map – one is the not-surprising general west-east direction of hailswaths, dictated primarily by the upper winds which control storm motion; the second pattern is that the dominant genesis region for these storms is over the foothills. This concurs with a study by Lawford (1970), using Alberta Forestry observations of hail and lightning. He determined that there were preferred areas of storm development associated with the topography, particularly over the foothills of the Rockies west of Red Deer.

Wojtiw (1975) also provided analyses of the spatial distribution of hail day frequency during 1957-73, reproduced in Figure 1.7a. This analysis shows the highest frequency southeast of Rocky Mountain House (RM), with secondary peaks near Sundre (SU) and south of Calgary. Similar analyses using more recent data are consistent with this. Wojtiw noted that hail observing density was as high as one report per 5 km^2 in some instances, or a linear spacing of just over 2 km between reports. This raises the question of how different the pattern might look with coarser data. To test this, Figure 1.7b shows the spatial frequency of hail for the seven years, 1974-80, using only data from regular synoptic stations that have an average spacing in central Alberta of well over 100 km. The coarse pattern is similar in that the main peak shows up over the foothills 'somewhere' in the vicinity of Rocky Mountain House. It should also be pointed out that the dense hail surveys on which Figure 1.7a is based would be lacking data where population density was low, that is, over or close to the mountains.

There is always an extra degree of uncertainty in using data from volunteers with little or no training. In particular, since *maximum hail size* is often used as an indicator of *storm severity*, this statistic should be examined more carefully. Figure 1.8 provides a comparison between volunteer reports of maximum hail size from mailed-in hailcards for the 1957-66 database (from Paul, 1967), the 1957-73 hailcard database (Wojtiw, 1975), and from objectively-measured hail sizes from 1973 hailpads (Strong, 1974). The hailpads were simply one-ft^2 pieces of one-inch styrofoam covered in aluminum foil (to make dents stand out), and fixed to the ground. Hailpads were calibrated by measuring dents produced by steel balls dropped from a height such as to give them the same impact kinetic energy (KE = $\frac{1}{2}mv^2$) as a hailstone of the same diameter impacting at its terminal velocity. The hail diameters estimated in this objective fashion are considered to be quite accurate, except for the smallest size category (shot size, < 4 mm size), since many of those would not make a large enough dent to be detected. In this comparison, all hailpad maximum hail sizes have been grouped into the same six size categories as for the volunteer reports. The two hailcard reporting periods yield virtually the same size distribution (±1%), but the hailpad size distribution suggests that volunteer observers (mostly from the farming community) tend to over-estimate the larger hail sizes, with over 65% of pads indicating pea maximum size where hailcards suggest <40%. The tendency to over-estimate the larger hail sizes may not be too surprising when a farmer's livelihood is threatened by hail damage to crops.

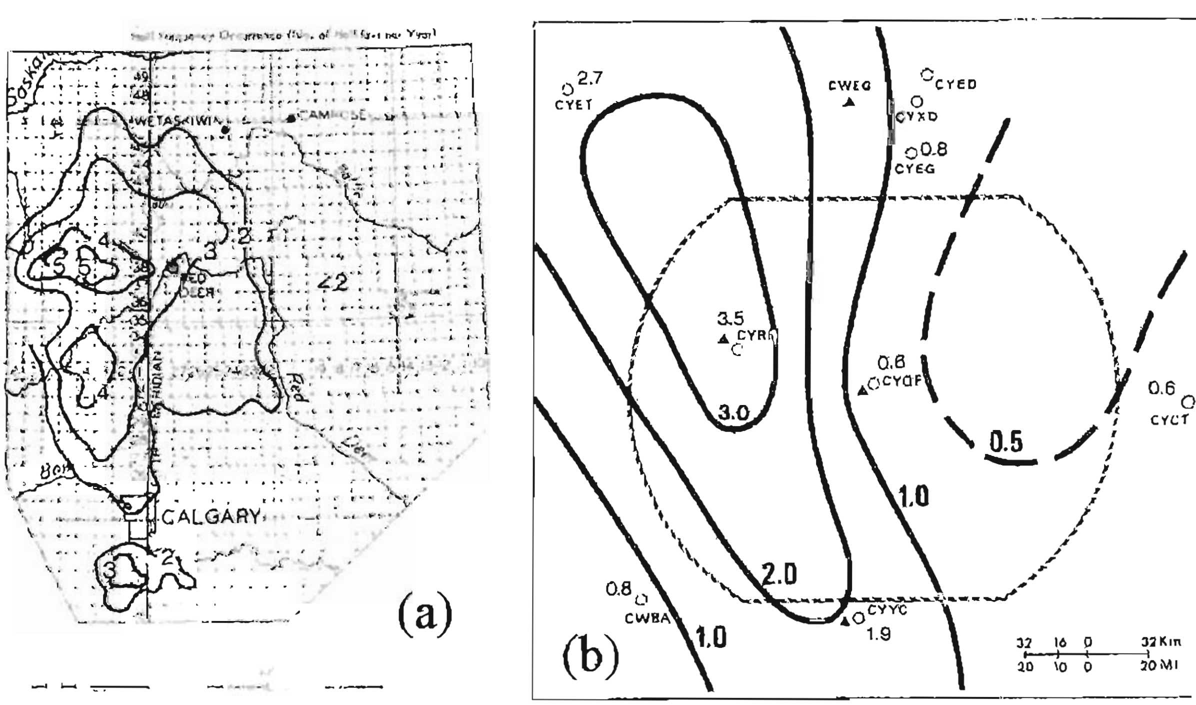

FIGURE 1.7: (a) Spatial distribution of hail day frequency, 1957-75 (reproduced from Wojtiw, 1975); (b) spatial distribution of hail day frequency, 1974-80 using only data from main synoptic stations as shown.

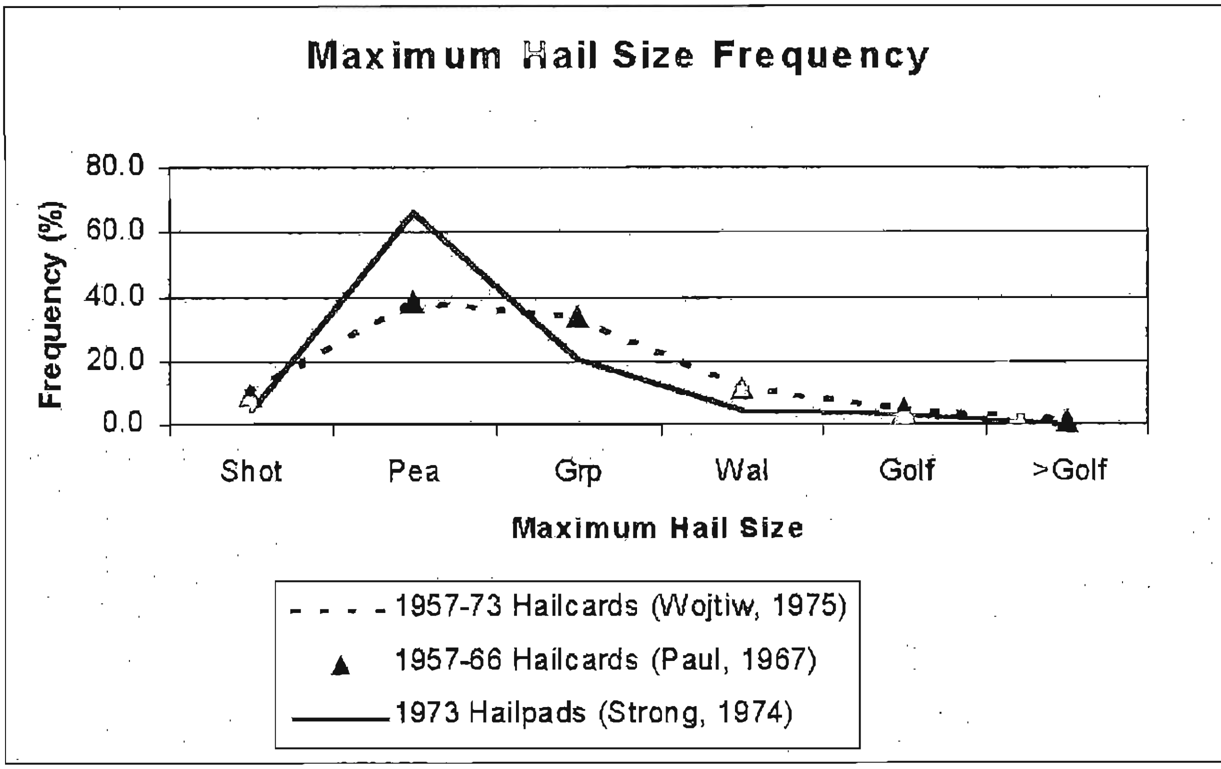

FIGURE 1.8: Comparison of maximum hail size as determined from 1957-66 hail cards (Paul, 1967), 1957-73 hailcards, (Wojtiw, 1975), and 1973 hailpads (Strong, 1974).

1.5.2 Hail Climatology, Saskatchewan and Manitoba

Paul (1980a) describes a 5-year Saskatchewan Hail Research Project (SHARP) study of hail during 1973-77, covering an area of more than 100,000 km^2, about double the area of AHP. Approximately 50% of the days recorded at least one hail report, which translates to a point frequency of half that of central Alberta. It appears that Saskatchewan's seasonal distribution differs from Alberta, with May being the peak hail month (July in Alberta), while August experiences just as much hail as July whereas hail tapers off during August in Alberta. Using proxy crop insurance data, Paul (1991a,b), discusses Saskatchewan hailstorm durations and hailswath lengths. He observes 76 hailswaths with lengths >150 km, with some exceeding 600 km and persisting from 8-10 hours. He suggests that such hailswaths may be longer than anywhere else in the world.

There has been no concerted field effort to collect comparable hail data in Manitoba, although LaDouchy (1985) used synoptic station data and crop hail insurance data to study 50 of the most serious hail days during the 1970s.

Etkin and Brun (1999) used synoptic station data for the 1977-93 period to develop an average hail frequency for all regions of Canada. Only the warm season May through September was included in the analysis in an attempt to remove erroneous hail reports due to ice pellets or snow pellets in the cold season. Based on these synoptic data, highest point frequencies were found in southwest Alberta and in the Williams Lake region of British Columbia. For province-wide averaging, the highest average provincial hail frequencies were Alberta (1.04 days), Saskatchewan (0.82), and Manitoba and British Columbia (each with 0.70). However, their analysis suggests that Alberta has experienced a near doubling of hail frequency from the 1977-82 mean of 0.64 days to a 1983-93 mean of 1.25 days, with no similar increases in any other province.

1.5.3 Tornado Climatology

Tornado reports are far less frequent than hail, but attract significant attention due to their destructive potential. It is a fact that not all tornadoes are reported, a problem due simply to our low population densities in regions where they occur, and particularly on the prairies. Therefore, we treat most tornado statistics as 'relative'. We can, however, make generalizations such as locations where they are most frequent, or when they are most frequent.

Newark (1984) provided some maps and statistics on tornado F-strength, path length/width, probability of damage, and annual frequency for the period 1950-79, including a composite North American map of annual frequency. The latter shows an extension of the U.S. mid-west tornado frequencies into southwestern Ontario and southeastern Manitoba. The highest annual probability of tornado damage in Canada is in southwestern Ontario at 0.05-0.1% per 10,000 km^2, followed by southeastern Manitoba at 0.05%, while central Alberta was 0.02%. He points out that the tornadoes of Alberta appear to be distinct from those of the eastern prairies.

Hage (1987a) completed a 50-year (1910-60) study of 740 Alberta and Saskatchewan tornadoes and over 1200 other destructive windstorms. By considering the total number of tornadoes reported in the seven largest urban centres along with their average areas, he extrapolates to a constant reference area of 10,000 km^2, then computes an average tornado frequency for these locations to be 13.5 per 10,000 km^2 per year, significantly higher than the comparable value for Oklahoma of 3.2 per 10,000 km^2 per year (Kessler and Lee, 1976), emphasizing how sensitive tornado statistics are to population density. He computes two large area peaks in each of the two provinces exceeding 5 tornadoes per 10,000 km^2 per year. Furthermore, unlike hail, which peaks during July in Alberta, significant tornadoes appear to have a June peak. Hage (1994) has also produced a large table of tornado, windstorm, and lightning fatality records for the 1879-1984 period. In a newspaper article, Hage (2000) confirmed popular notions that the frequency of tornadoes in Alberta has increased since the 1980s, but attributes this mainly to increased awareness on the part of both our weather services (MSC) and the general public. He points out that when one considers only tornadoes that cause death, injuries, or destruction of at least one substantial building, then the number of significant Alberta tornadoes peaked at 32 for the 10-year period ending in 1924, and have decreased steadily since then to only 6 for the 10-year period ending in 1984.

A climatological study of tornado days by Raddatz and Hanesiak (1991) appears to provide conflicting values of tornadoes per 10,000 km^2 per year to those of Hage (1987a). The more recent study, using weather watcher or spotter networks established by the weather service (MSC) in each province for the 1978-89 period, yields values of 0.1 to a maximum of 1.5 tornado days per 10,000 km^2 per year, where Hage's estimates were a factor of 5-10 times larger. However, they used tornado 'days' where Hage used 'sightings', and their weather watchers each had to cover areas of some 17,000 km^2, which may leave some doubt as to whether all tornado days were observed. The differences simply reinforce Hage's caution on sensitivity to population density. Both studies indicate similar locations for maximum frequencies, with the highest (prairie) peak in Red River Valley south of Winnipeg.

Cummine and Noonan (2001) suggest that the steady increase in Manitoba tornado reports by decade, from <10 in the 1860s to ~100 during the 1990s, indicates that these reports are increasing more in conjunction with population density and 'awareness' than with actual occurrence. The data are thus becoming more complete with time. Manitoba tornadoes have occurred as early as 17 April and as late as 10 October. Based on statistics since 1980, the highest risk months are July (33 occurrences) and August (32), and the average season-length for tornadoes is 64 days in Manitoba. The highest risk area for tornadoes in Manitoba once again was the Red River Valley.

1.5.4 Lightning and other Thunderstorm Climatologies

In addition to severe hail (size > 20 mm) and tornadoes, Paruk and Blackwell (1993) indicate that the meteorological service (MSC) includes heavy rain (> 30 mm in any one hour) and strong wind (gusts > 90 kph) as severe thunderstorm events. They note several problems in the climatology of these four types of severe events. One is that the definition of 'severe' has varied over the past 15 years; e.g., heavy rain was previously defined as 25 mm in one hour, severe winds were defined as > 100 kph, and prior to 1986, severe hail was 15 mm or greater. Another problem with volunteer reports in particular, is the subjective nature of the observation, which can vary depending on the observer's qualitative perception of the event at the time, what other things may be occupying his time, and the intangible degree of stimulation to report the event at the time. Incorrect dates and times are another problem, although these can usually be verified through other related data.

Despite these problems, Paruk and Blackwell compiled a severe weather climatology for Alberta using a compilation of 800 summer storm events occurring between 1982 and 1991. Data were corrected for population distribution, suggesting that there were 300 events (34% of the total number) that went unobserved or unreported each year. The most active hail, rain, and wind events occur in July, while more tornadoes are reported in June. Most events occur around 17:00 local time, except for a maximum number of damaging winds reported after 19:00. There was a high correlation between population density and observations with some known storm tracks evident in the analysis, which was the impetus for correcting the number of observations by using population density. When re-mapped, the axis of maximum severe event frequency shifted away from the Edmonton-Calgary corridor to a line running from east-central Alberta (Oyen) northwest to Edmonton. More frequent events of hail and wind occurred in the foothills as opposed to tornadoes and heavy rain that were more frequent farther east. This is largely due to storm dynamics, with many storms forming over the foothills, then propagating eastward where the later stages of mature storms favour heavy rain over hail, and a few develop tornadoes. While the authors caution use of these data in decision-making, the summary presents an interesting set of severe weather climatology that is more difficult to produce than other climatic variables because of the qualitative nature of the data. Brooks (2000) recommends an approach similar to the Paruk and Blackwell study; that is, to use limited datasets of "high-end" events in which there is more confidence to build statistical models and climatologies. Brooks also discusses the problem of forecast verification using the "low-end", low confidence data. This leads to our final observations and recommendations on this topic as follows.

In a study of non-tornadic severe weather events in southern Ontario for 1980-92, Etkin and Leduc (1994) show an average 68 severe events per year with an expected summertime peak, but then suggest that because of poor records on severe weather due to their small-scale nature along with varying population densities, that the true number could be an order of magnitude higher. Although the data magnitudes are unreliable, the study did highlight high-risk areas.

Taylor (1999) compiled a 31-year (1966-96) climatology of convective sounding parameters for central Alberta using 4743 soundings released at 0000 UTC from Stony Plain, west of Edmonton. Among the variables processed were convective available potential energy (CAPE), precipitable water, wind shear, storm relative helicity, and other parameters. He stratified some of the outputs according to large and small hail (> or < 30 mm), and severe and non-severe weather days. The CAPE outputs were compared with lightning and hail data.

There is a great need for climatologies of other forms of severe weather data only recently available, which should be more quantitative to deal with than the above studies encountered. The addition of new operational weather radars over the past 10 years now provides near complete radar coverage of the prairie regions. In the past five years, Environment Canada has also assembled a network of 81 lightning detector systems, which can pinpoint strikes to within a few hundred metres (Lanken, 2000), including complete coverage of the prairies. Most strikes are detected by 4-10 stations, and its strength, location, polarity, and time are recorded. Lightning studies such as Williams et al. (1989), Reap (1993), and Moller et al. (1994) suggest techniques to use lightning data to determine the convective state of thunderstorms, detect severe thunderstorms at key surface locations, and to recognize supercell thunderstorm environments and storm structures.

Closer to home, Anderson (2000) suggested a technique for predicting rainfall amounts from lightning flash density, but with mixed results. Burrows et al. (2002) show persistent lightning flash maxima along the Alberta foothills with decidedly lower counts over the mountains (Figure 1.9, reproduced from Burrows et al., 2002). The peak in lightning frequency over the foothills confirms the high incidence of thunderstorm activity inferred from radar and hailswath data. Figure 1.9 also reveals a hot-bed of thunderstorm activity over southern Saskatchewan and the U.S. high plains.

Lightning data offer a valuable new insight to studies of thunderstorm phenomena, and for developing new predictor variables for forecasting. Prairie-based climatologies of radar and lightning data for 1, 5, and 10-year periods, along with comparable synoptic surface and upper air climatologies would provide excellent tools to begin the process of documenting severe weather events. Statistical relations between various predictor variables based on these data should be developed. A quantitative investigation of spatial/temporal similarities and differences in storm characteristics across the prairies is crucial to investigators and forecasters alike, to enable them to distinguish the important characteristics of severe storm situations such as the Pine Lake tornado case in Figure 1.1.

Finally, it is unfortunate that one major downside of automating surface observation sites has been the loss of data from a well-developed observing art-form, that of cloud types and amounts. Regardless, a cloud climatology of the period prior to complete automation (~ the mid-1980s) would provide additional insight to storm characteristics. With the degree of computing power only recently available, a satellite cloud climatology is also now feasible, and might be designed in such a way as to augment the manual cloud observations since the mid-1980s.

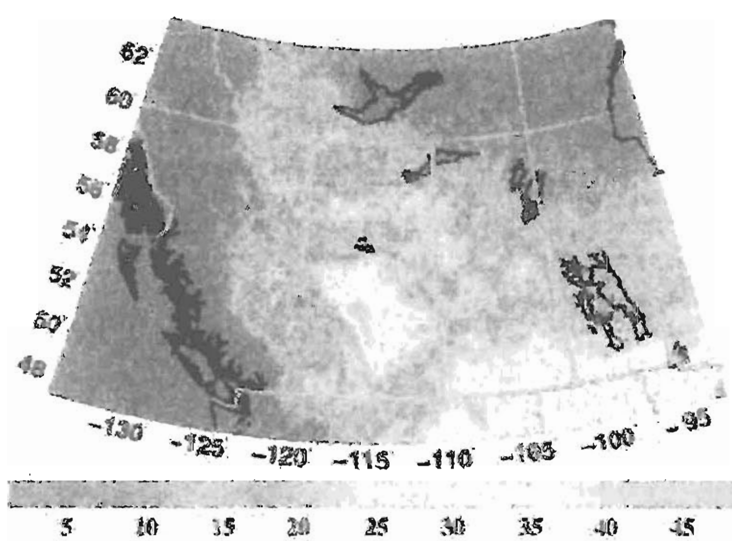

FIGURE 1.9: Mean annual lightning occurrence (days yr^{-1}) for western Canada region, Feb. 1998 to Dec. 2000 (reproduced with permission from Burrows et al., 2002) Also shown in colour on inside back cover.

1.6 STORM ENVIRONMENT CLIMATOLOGY

Meteorologists now agree that synoptic scale processes organize the mesoscale environment so that convective storms may form (e.g., Fawbush et al., 1951; Beebe and Bates, 1955; Ogura and Chen, 1977; Doswell, 1980). Until the early 1980s, however, some investigators argued that larger thunderstorms, once formed, developed some sort of autonomous mesoscale circulation, moving quite independently of, yet feeding back energy to, the mean synoptic flow. The real mesoscale storm is now known to be far more complex and variable, being intricately tied to synoptic scale processes as well as local microscale effects such as topography and local fluxes of sensible and latent heat feeding the storm. The larger scale processes not only help to initiate the severe storm, but also continue to exert control throughout the storm's life cycle.

The motivation for research into synoptic scale influences on severe storms came not from the research community, but from severe weather forecasters, because of the necessity for improved forecasts of destructive and life-threatening storms. While the need for mesoscale predictions was recognized, progress in developing forecasting techniques was impeded by the lack of resolution of routinely available (upper air and surface) thermodynamic and wind data, which were of synoptic to sub-synoptic scale at best. Partly because of this, early research in this area concentrated on synoptic kinematics, climatological studies, and statistical forecast models, rather than on a theoretical approach.

1.6.1 The "Capping Lid" and Synoptic Kinematics

One of the earliest significant advances here was the kinematic model developed by Beebe and Bates (1955), then of the Kansas City Severe Storms Center. They described how synoptic scale ascent might change a previously stable sounding into the type observed in the vicinity of severe thunderstorms (Figure 1.10). This conceptual model partially explained the role of the *capping lid*[5], a thermodynamic signature 0.5-1.5 km above ground, which often precedes severe thunderstorms over the High Plains. We look for four main signatures on the capping lid sounding, as indicated in the figure: a moist boundary layer of 500-1000 m deep, capped by an inversion of *potential* temperature (the *lid*), dry air above the lid and a mid-level unstable layer (usually dry adiabatic). The basic role of the lid is to *temporarily* trap moisture within the boundary layer, and to prevent convection and latent heat release. For Alberta severe storm days, early morning soundings (standard soundings are released for 1200 UTC, 0600 MDT) often exhibit only a shallow nocturnal inversion initially. If the lower few hundred metres are moist (sometimes confirmed by morning fog patches), and dry above the inversion, this can change very rapidly during late morning into the type of sounding shown in Figure 1.10. Thereafter, adiabatic cooling provided by synoptic scale ascent can partially remove the inversion, allowing sudden release of the trapped energy, and often an explosive growth of a severe thunderstorm.

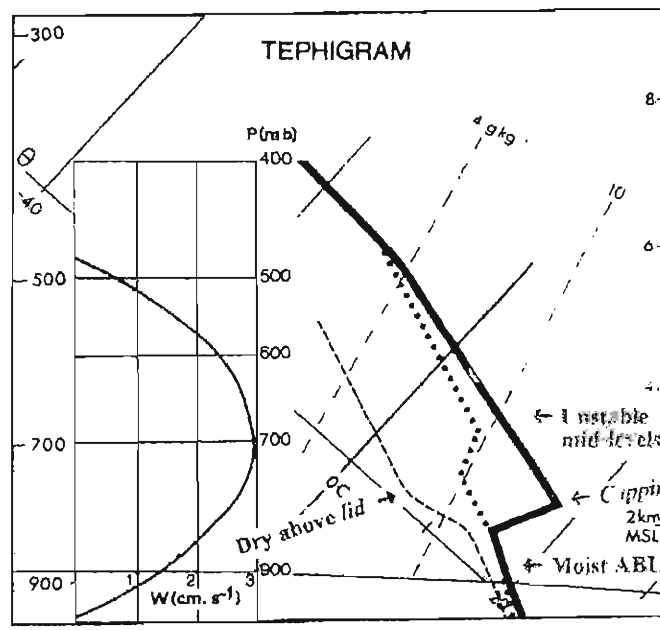

FIGURE 1.10: Average pre-tornado sounding emphasizing the boundary layer with *capping lid* temperature (solid line), dew point (broken line), and mean tornado-vicinity temperature sounding (dotted line) following hypothetical profile of synoptic scale adiabatic ascent as shown. Typical upper/lower jet couplings for severe storm cases are also indicated. (After Beebe and Bates, 1955.)

Darkow (1969) confirmed partial or complete removal of the capping lid in advance of storms. This was also established by the LIMEX studies in Alberta (Strong, 1986, 2000). It is further supported by observations of low-level convergence often preceding radar echoes of convection (e.g., Doneaud et al, 1983; Strong, 1986; Honch, 1989). The important factor here is that the ascent and cooling, whether synoptic scale ascent or otherwise, commences *before* the storm forms.

[5] The *capping lid* is an important severe storm signature throughout the High Plains regions from Texas to Alberta. The creation and breakdown of the lid, including the role of topography and local fluxes of sensible and latent heat, is important to the overall understanding of severe storms, and is one of the main similarities between storms of west Texas/Oklahoma and those of Alberta.

Closely related to this adiabatic cooling was Beebe and Bates model of upper and lower jet structures that assist in the release of convective instability. The left exit of a cyclonically curved upper jet, for example, is a preferred region for high level divergence and ascent at lower levels favourable to storm development. The left entrance region of an upper jet will favour convergence, and is therefore likely to be associated with subsidence below this level, not conducive to storms. Upper level convergence would also favour cirrus clouds at these levels, which is one way to recognize its presence in the absence of other data. Often, a low-level jet is also part of the atmospheric structure, slightly downstream from the upper jet core and oriented across it. It will have a similar stucture of divergence and convergence associated with it, with low-level convergence favouring ascent aloft. The intersection region where both jet structures favour ascent is the ideal region for thunderstorm formation. In the presence of an anticyclonic-curved jet, the favoured conditions for convection are slightly different. Then, divergence is most probable in the right entrance region aloft, with the lower jet beneath or upstream from the upper jet core.

Uccellini and Johnson (1979) quantified these relations between wind jets and convective storms through diagnostic and numerical model results, and provided an explanation of how the upper and lower jets are physically coupled through mass-momentum adjustments and transverse circulations within the exit region of the upper jet. Lemon and Doswell (1979) provided a model of how jet coupling assists in tornadogenesis (see Figure 2.4). Thus, the Beebe and Bates models still have relevance to the understanding and forecasting of thunderstorms almost fifty years after their formulation.

Miller (1959) manually compiled synoptic charts for more than 300 tornado days in the U.S., and stratified these into five major synoptic map types. The difficulty with this approach is that the types are not always mutually exclusive, while other cases would be difficult to classify at all.

1.6.2 Synoptic Scale Climatology

Synoptic climatology has been one means of investigating severe storms. In Canada for instance, Lowe and McKay (1962) produced climatological charts that imply that tornadoes over Manitoba and Saskatchewan occur primarily along a cold frontal trough, preceding an associated upper (500 hPa) shortwave trough (Figure 1.11). [Note the use of *mb* for pressure units in older charts; 1 mb = 1 hPa.] Slightly contrary to this, a similar investigation of severe Alberta hailstorms (Longley and Thompson, 1965) provided mean charts that suggest Alberta storms occur predominantly *behind* the low-level trough, in the cold baroclinic zone, but still preceding the upper trough (Figure 1.12).

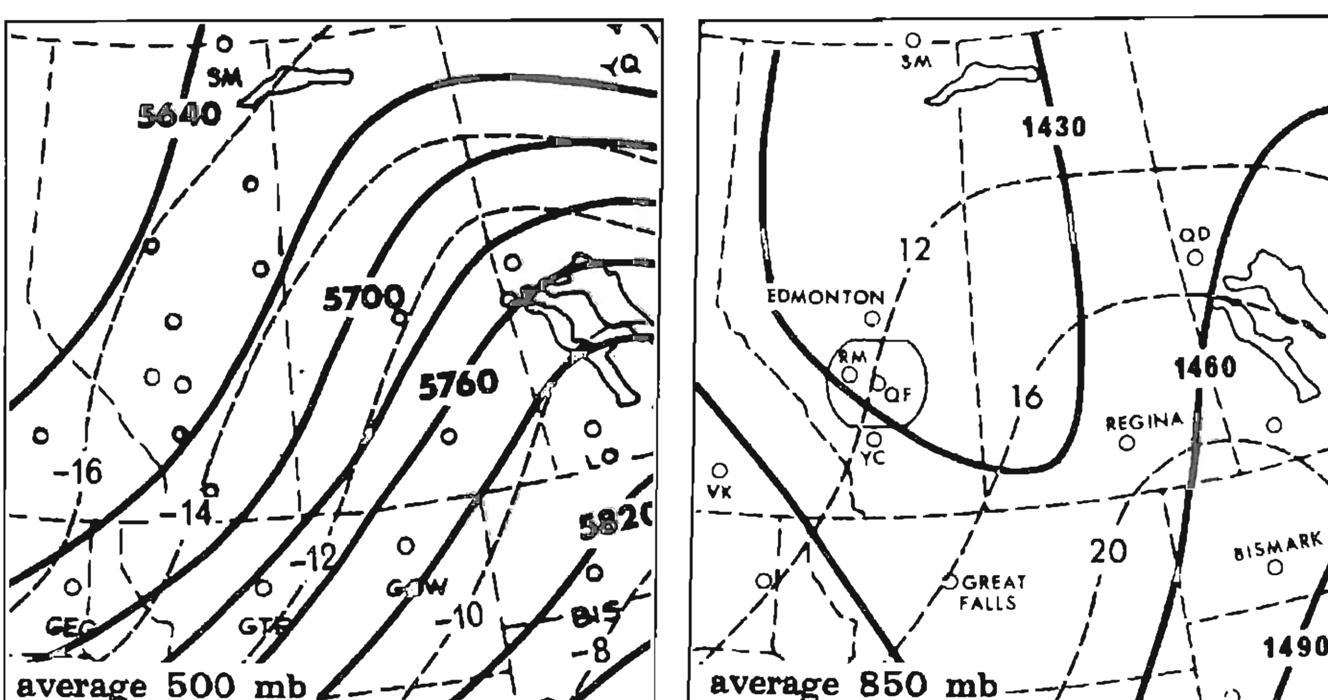

FIGURE 1.11: Average 500 and 850 mb (hPa) flow patterns for Saskatchewan tornado occurrences (reproduced from Lowe and McKay, 1962).

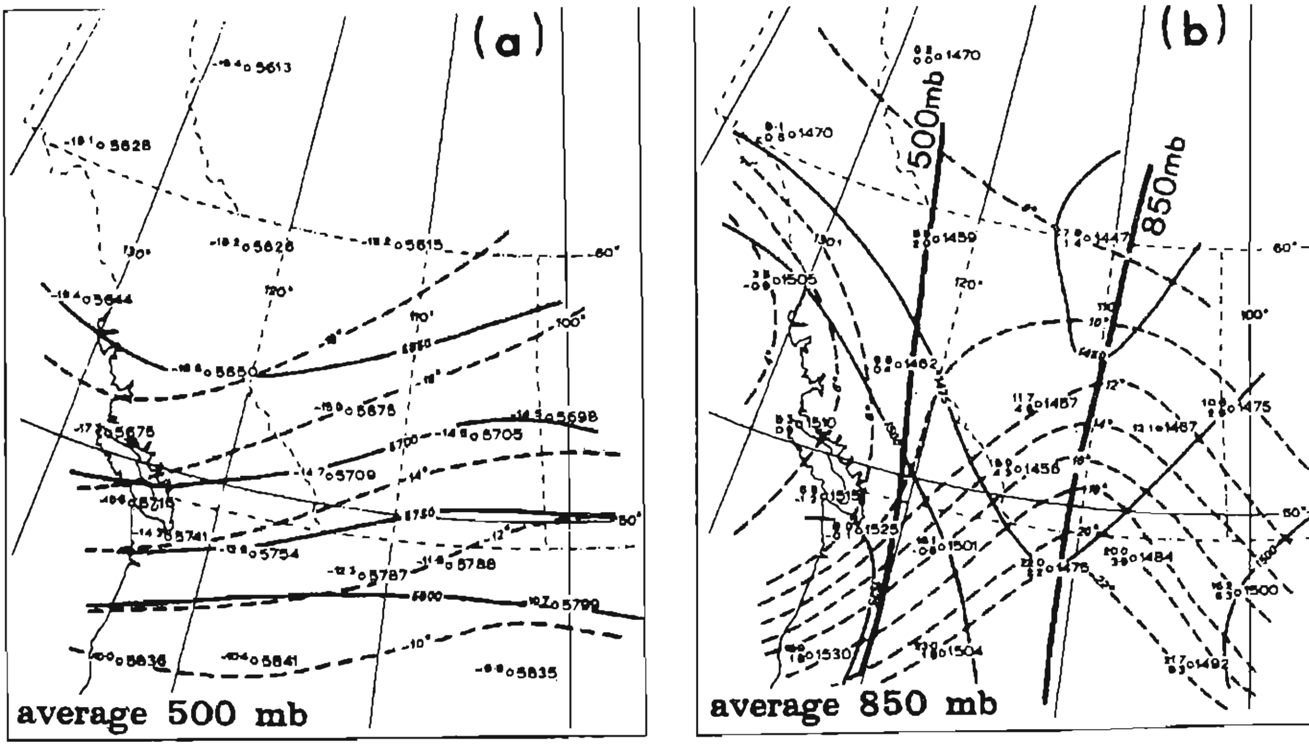

FIGURE 1.12: Average 500 and 850 mb (hPa) flow patterns for severe Alberta hailstorm occurrences (reproduced from Longley and Thompson, 1965).

1.7 SUMMARY

The example severe thunderstorm disasters mentioned in Section 1.1 clearly underscore the urgent need for prairie thunderstorm research, and for clear recommendations for improving the knowledge base, forecasting and mitigation of impacts of severe thunderstorm hazards. The mesoscale climatology of thunderstorms and thunderstorm environments are very incomplete for the prairies. New data systems such as the lightning network can help alleviate this. The high frequency storm areas are well documented, so that we know that Alberta foothills is a prime thunderstorm generation area, while agricultural areas immediately east of the foothills have the highest frequency of hail in Canada. Severe storm phenomena such as tornadoes also have a relatively high frequency in this 'hail alley' (Edmonton-Calgary) region. This region has also become Canada's fastest growing population area, underscoring the need for research. Another high population growth region is the Winnipeg area, also a region of high tornado frequency, while southern Saskatchewan appears to have a high frequency of lightning.

Despite very significant advances in numerical weather prediction models in the last 10-15 years, key mesoscale processes, particularly in the atmospheric boundary layer, are not well predicted. Thus, our weather service is still unable to predict with great confidence the initiation region, timing, and severity of mesoscale systems such as severe thunderstorms, and even less so, related phenomena such as large hail, tornadoes, heavy precipitation, and high winds.

Subsequent parts of this review series will discuss various conceptual models of thunderstorms, focus more on studies of physical processes, and test a multi-scale conceptual model of severe thunderstorms described by Strong (1986, 2000), using forecasting techniques to test this model.

A major step to improve cloud seeding techniques for suppressing severe hailfall, for example, is to improve the short-range DAY-1 (3-12 hours) prediction capability and early-warning (1-3 hours) of storms (Krauss, 1999). This should also be one of the primary objectives of any new severe storm research efforts, hence the desirability of close collaboration with regional MSC offices, numerical modeling communities, and user-groups such as federal and provincial environment, forestry, and emergency agencies. The current study will describe the important multi-scale processes involved in the initiation and life cycle of severe prairie thunderstorms, and provide recommendations for reaching the longer-term goal of accurate forecasts of the related phenomena.

1.8 ACKNOWLEDGEMENTS

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1.9 BIBLIOGRAPHY

1) Anderson, K., 2000: Predicting convective rainfall amounts from lightning flash density. Preprints *20th AMS Conf. Sev. Loc. Storms*, Orlando, FL., Sep., 2000, 166-168.

2) Atchison, G., 1988: Forecaster tells Edmonton tornado story. *Chinook*, Winter, 1988, 8-14.

3) Barge, B.L., and F. Bergwall, 1976: Fine scale structure of convective storms associated with hail production. Proc. *2nd W.M.O. Sci. Conf. on Wea. Mod.*, Boulder, Col., 2-6 Aug. 1976, 341-348.

4) Beebe, R.G., and F.C. Bates, 1955: A mechanism for assisting in the release of convective instability. *Mon. Wea. Rev.*, 83, 1-10.

5) Bosart, L.F., and F. Sanders, 1981: The Johnstown flood of July 1977: A long-lived convective system. *J. Atmos. Sci.*, 38, 1616-1642.

6) Brooks, H.E., 2000: The climatology of severe thunderstorms: What we can know. Preprints *20th AMS Conf. Sev. Loc. Storms*, Orlando, FL., Sep., 2000, 126-129.

7) Burrows, W.R., P. King, P.J. Lewis, B. Kochtubadja, B. Snyder, and V. Turcotte, 2002: Lightning occurrence patterns over Canada and adjacent United States from lightning detection network observations, *Atmos.-Ocean*, 40(1), 59-81.

8) Charlton, R.B., M.K. Bradley, and L Wojtiw, 1998: The Edmonton tornado and hailstorm: a decade of research. *CMOS Bull. SCMO*, 26, spec. issue, Aug., 1998, 56 pp.

9) Cummine, J., and M. Noonan, 2001: Tornado-day climatology of Manitoba 1980-1999. *CMOS Bull. SCMO*, 29, 3-8.

10) Darkow, G.L., 1969: An analysis of over sixty tornado proximity soundings. *Preprints 6th AMS Conf. Sev. Loc. Storms*, Apr. 1969, Chicago, Ill., 218-221.

11) Deibert, R.J., ed., 1985: *Field Program 1985, Atmospheric Sciences.* Alta. Res. Coun., Edmonton, 70 pp.

12) Doneaud, A.A., J.R. Miller, D.L. Priegnitz, and L. Viswanath, 1983: Surface mesoscale features as potential storm predictors in the northern Great Plains - two case studies. *Mon. Wea. Rev.*, 111, 273-292.

13) Doswell, C.A., 1980: Synoptic-scale environments associated with High Plains severe thunderstorms. *Bull. Amer. Meteor. Soc.*, 61, 1388-1400.

14) Douglas, R.H., and W. Hitschfeld, 1959: Patterns of hailstorms in Alberta. *Q.J.R.M.S.*, 85, 105-119.

15) Etkin, D., and M. Leduc, 1994: A non-tornadic severe storm climatology of southern Ontario adjusted for population bias: Some surprising results. *CMOS Bull. SCMO*, 22, #3, 4-8.

16) Etkin, D., and S.E. Brun, 1999: A note on Canada's hail climatology: 1977-1993. *Int. J. Clim.*, 19, 1357-1373.

17) Fawbush, E.J., R.C. Miller, and L.G. Starrett, 1951: An empirical method of forecasting tornado development. *Bull. Amer. Meteor. Soc.*, 32, 1-9.

18) Fujita, T.T., 1971: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, 38, 1511-1534.

19) Goyer, G.G., 1978: The Hailstorm Giant. *Bull. Amer. Meteor. Soc.*, 59(4), p.429.

20) Hage, K.D., 1987a: *Review of the Weather Warning System associated with the Edmonton tornado of July 31, 1987.* 85 pp plus apps.

21) Hage, K.D., 1987b: A comparative study of tornadoes and other destructive windstorms in Alberta and Saskatchewan. *Procs. Sym. On the Impact of Clim. Variability and Change on the Can. Prairies*, Edmonton, Sept., 1987, 351-377.

22) Hage, K.D., 1994: *Alberta tornadoes, other destructive windstorms and lightning fatalities, 1879-1984.* Pub. By Keith D. Hage, Spruce Grove, AB, 67 pp.

23) Hage, K.D., 2000: Probability of tornado strikes has increased with population settlement. Letter to ed., *Devon Dispatch News*, Aug. 25, 2000, p.3.

24) Joe, P., and D. Dudley, 2000: A quick look at the Pine Lake storm. *CMOS Bull. SCMO*, 28, #6, 172-180.

25) Krauss, T.W., ed., 1999 : *Alberta Hail Suppression Project Final Report 1999.* Weather Modification Inc., Fargo, ND, 79 pp.

26) LaDochy, S., 1985: *The Synoptic Climatology of Severe Thunderstorms in Manitoba.* Ph.D thesis, Univ. Manitoba, Winnipeg, pp.

27) Lanken, D., 2000: Struck by lightning. *Can. Geog.*, July/August, 2000, Ottawa, 20-32.

28) Lawford, R.G., 1970: The Behavior of Thunderstorms over Alberta Forests. M.Sc. thesis, University of Alberta, Edmonton, Alberta, 176 pp.

29) Lemon, L.R., and C.A. Doswell, 1979: Severe thunderstorm evolution and mesocyclone structure as related to tornadogenesis. *Mon. Wea. Rev.*, 107, 1184-1197.

30) Longley, R.W., and C.E. Thompson, 1965: A study of the causes of hail. *J. Appl. Meteor.*, 4, 69-82.

31) Lowe, A.B., and G.A. McKay, 1962: Tornado composite charts for the Canadian Prairies. *J. Appl. Meteor.*, 1, 157-162.

32) Maddox, R.A., 1980: Mesoscale convective complexes. *Bull. Amer. Meteor. Soc.*, 61, 1374-1387.

33) McCarthy, P.J., A. Erfani, and D. Patrick, 2000: Multiple bounded weak echo regions in the 16 July 1996 Winnipeg, Manitoba, Canada, hailstorm supercell. *Preprints 20th AMS Conf. Sev. Loc. Storms*, Orlando, FL., Sep., 2000, 481-484.

34) Miller, R.C., 1959: Tornado-producing synoptic patterns. *Bull. Amer. Meteor. Soc.*, 40, 465-472.

35) Moller, A. R., C. A. Doswell, M. P. Foster, and G. R. Woodall, 1994: The operational recognition of supercell thunderstorm environments and storm structures, *Wea. Forecasting.* 9, 327-347.

36) Newark, M.J., 1984: Canadian Tornadoes, 1950-1979. *Atmosphere-Ocean*, 22(3), 343-353.

37) Ogura, Y., and Y-L. Chen, 1977: A life history of an intense convective storm in Oklahoma. *J. Atmos. Sci.*, 34, 1458-1476.

38) Orlanski, I., 1975: A rational subdivision of scales for atmospheric processes. *Bull. Amer. Meteor. Soc.*, 56, 527-530.

39) Paruk, B.J., and S.R. Blackwell, 1993: *A severe thunderstorm climatology for Alberta*. Alberta Wea. Cent. Tech. Note 93-01, Mar. 1993, 7 pp.
40) Paul, A.H., 1967: *Hailfall in Central Alberta*. M.Sc. thesis, University of Alberta, Edmonton, Alberta, 124 pp.
Paul, A.H., 1980a: Hailstorms in southern Saskatchewan. *J. Appl. Meteor.*, 19, 305-314.
41) Paul, A.H., 1980b: personal communication on storms of 21 July 1976.
42) Paul, A.H., 1982: The thunderstorm hazard on the Canadian Prairies. Geoforum, 13(4), 275-288.
43) Paul, A.H., 1991a: A comment on hailswath lengths. *Clim. Bull.*, 25(2), 125-127.
44) Paul, A.H., 1991b: Studies of long-lived hailstorms in Saskatchewan, Canada from crop insurance data. *Nat. Hazards*, 4, 345-352.
45) Paul, A.H., 1993: The thunderstorms of 8 July 1989 in the northern Great Plains. *Clim. Bull.*, 27, #3, 170-178.
46) Raddatz, R.L., 1998: Anthropogenic vegetation transformation and the potential for deep convection on the Canadian prairies. *Can. J. Soil Sci.*, 78, 657-666.
47) Raddatz, R.L., and J.M. Hanesiak, 1991: Climatology of tornado days 1960-1989 for Manitoba and Saskatchewan. *Clim. Bull.*, 25(1), 47-59.
48) Reap, Ronald M., 1993: The use of network lightning data to detect thunderstorms near surface reporting stations. *Mon. Wea. Rev.*, 121, 464-469.
49) Renick, J.H., ed., 1970: *Alberta Hail Studies Field Program 1970. Hail Studies Report 70-1*, Research Council of Alberta, 49 pp.
50) Statistics Canada, 2002: see http://www12.statcan.ca/english/census01/release/index.cfm.
51) Strong, G.S., 1974: *The Objective Measurement of Alberta Hailfall*. M.Sc. thesis, Univ. of Alberta, Edmonton, Alberta, 182 pp.
52) Strong, G.S., 1982: Hailstorms! - Why Alberta? *Chinook*, Winter/Spring, 21-23.
53) Strong, G.S., 1986: *Synoptic to Mesoscale Dynamics of Severe Thunderstorm Environments: A Diagnostic Study with Forecasting Applications*. PhD thesis, University of Alberta, Edmonton, 346 pp.
54) Strong, G.S., 1997: Atmospheric Moisture Budget Estimates of Regional Evapotranspiration from RES-91. *Atmos.-Ocean*, 35, 29-63.
55) Strong, G.S., 2000: A multi-scale conceptual model of severe thunderstorms. *CMOS Bull.*, 28, No. 2, 45-54, April, 2000.
56) Strong, G.S., and C.D. Smith, 2001: Assessment and Prediction of Prairie Severe Thunderstorm Weather Phenomena. Fin. Rep. to Emergency Preparedness Canada, 26 Mar. 2001, 158 pp.
57) Summers, P.W., and A.H. Paul, 1967: Some climatological characteristics of hailfall in central Alberta. *Procs. 5th AMS Conf. Sev. Loc. Storms*, St. Louis, MO, 17-26.
58) Taylor, N.M., 1999: *Climatology of sounding parameters identifying the potential for convective storm development over central Alberta*. M.Sc thesis, University of Alberta, Edmonton, 121 pp.
59) Tennekes, H., 1978: Turbulent flow in two and three dimensions. *Bull. Amer. Meteor. Soc.*, 59, 22-28.
60) Uccellini, L.W., and D.R. Johnson, 1979: The coupling of upper and lower tropospheric jet streaks and implications for the development of severe convective storms. *Mon. Wea. Rev.*, 107, 682-703.
61) Vickers, G., 1996: 1996 *Summer Severe Weather Report, Central and Northern Alberta*. Environment Canada, Edmonton, 37 pp.
62) Williams, E. R.; Weber, M. E., and Orville, R. E. 1989. The relationship between lightning type and convective state of thunderclouds. *J. Geophys. Res.*, 94(D11), 13, 213-13,220.
63) Wojtiw, L., 1975: *Climatic summaries of hailfall in central Alberta (1957-1973).* Alberta Research Atmospheric Science Report 75-1, Edmonton. 102 pp.

F. Kenneth Hare
1919 - 2002

Professor Ken Hare died on September 3, 2002, at his home in Oakville, Ontario. A well-known and internationally recognized geographer, climatologist and environmental scientist, Ken had been unwell for some time. He was born in Wylye, England and graduated from University of London, King's College before serving during World War II as an operational meteorologist and climatologist with the United Kingdom Air Ministry.

Ken emigrated to Canada late in 1945 to take a teaching and research position at McGill University. For his research in arctic climatology and geography he was awarded a Ph.D. at the University of Montreal in 1950. That year Ken became Chairman of the Geography Department and organized an Arctic Meteorological Research Group which joined with Stewart Marshall's Stormy Weather Research Group to form McGill's Department of Meteorology (now Atmospheric and Oceanic Sciences) in 1959. Ken served as McGill's Dean of Arts and Science from 1962 to 1964 and during his time at McGill, he became a leading authority on heat and water balances, on climate change and on environmental and land-use matters. Ken also found time to serve as a senior officer in the Canadian and American meteorological and geographical societies, and the Arctic Institute. He was named a member of the National Research Council of Canada in 1962-1964.

In 1964, Dr. Hare was invited to return to the University of London to serve as Master of Birkbeck College and as a professor at King's College. While at the university he participated in many official enquiries in England and on the continent, became president of the Royal Meteorological Society (1967-68), and was a founding member of the UK Natural Environment Research Council. In 1968 he was invited to return to Canada and become president of the University of British Columbia at Vancouver. He was elected a fellow of the Royal Society of Canada that year and shortly moved to Toronto where he received a joint appointment from the Physics and Geography Departments at the University of Toronto and returned to teaching and research.

Shortly after Environment Canada was established Ken was seconded from the university to Ottawa in 1972 and 1973 as the department's first director-general of research coordination. Returning to the university he became director of the Institute of Environmental Studies from 1974 to 1979. Then, Ken served as Provost of Trinity College in Toronto from 1979 to 1986 and as Chancellor of Trent University in Peterborough from 1988 to 1995. During this period he also served as chairman of Environment Canada's Climate Planning Board from 1979 to 1990, chairman of University of Toronto's Advisory Board of the Institute of International Programs from 1990 to 1994, chairman of the Technical Advisory Panel on Nuclear Safety of Ontario Hydro from 1991 to 1994, and chairman of the Royal Society's Commission on Lead in the Environment. Over this extended period Ken became recognized as an authority on acid deposition, nuclear waste disposal and global change.

> "He wanted people to conserve. Waste was a great horror word in his thinking. He was not, however, 'a flag waver'. Instead, he chose to validate his concerns with solid research and hold discussions with academics as well as government and industry representatives".
>
> *Helen Hare*, his wife of 48 years.

Dr. Hare's published books include *The Restless Atmosphere* (1953), *On University Freedom* (1967), *Climate Canada* (with Morley Thomas, 1974 and 1979), and *The Experiment of Life* (editor, 1982). He also published about 250 articles on geography, climatology and the environment in professional and popular scientific journals and yearbooks. Over these years he received honorary degrees from eleven Canadian and Australian universities, the Patterson Medal in 1973, and the Massey Medal in 1978. He was made an Officer of the Order of Canada in 1979 and elevated to Companion, Canada's highest honour, in 1987. At the time of his death Dr. Hare was a University Professor Emeritus at the University of Toronto.

Dr. Hare's technical knowledge, his organizational skills and his communication abilities brought requests for his participation in international environment affairs. As the program organizer he played a leading role in the World Meteorological Organization's first World Climate Conference in 1979 and later he was the first chairman of the international Advisory Group on Greenhouse Gases. In 1988 the WMO honoured him with international meteorology's premier award, the International Meteorological Organization (IMO) Medal. Other international honours include the Patron's Medal of the Royal Geographical Society in 1977 and the Cullum Medal of the American Geographical Society in 1987.

Ken Hare was a giant in Canadian climatology and meteorology and he contributed immensely in teaching, research and administration. His gentle kindness earned the affection and respect of all who knew him. Ken is survived by his wife Helen, two sons, a daughter and grandchildren.

Morley Thomas

Call for Nominations for CMOS Prizes and Awards

Background:

The Prizes and Awards Committee is anxious to receive nominations for CMOS awards and offers the following background information for potential nominators. The Committee is made up of meteorological and oceanographic researchers and managers from academia, government and non-government agencies.

1) The Committee requires a nominating letter which should include an up-to-date CV and a summary of the candidate's work that is to be considered for an award. Note that the President's Prize pertains to a specified scientific paper, book or other major publication.

2) Letters of support are essential and should indicate the extent of influence of the candidate's work.

3) The Committee prefers that nominations and supporting documentation be submitted in electronic format; however, hard-copy material will be accepted if electronic material is not available.

Appel de mises en candidature pour les Prix et Honneurs de la SCMO

Préambule:

Le Comité des prix et honneurs de la SCMO attend avec impatience les mises en candidature pour les prix de la SCMO et désire donner l'information pertinente suivante aux nominateurs. Le Comité est constitué de chercheurs et gestionnaires en météorologie et océanographie du monde universitaire, du gouvernement et des agences non-gouvernementales.

1) Le Comité demande une lettre de nomination dans laquelle on devrait trouver un curriculum vitae mis-à-jour et un sommaire du travail du candidat qui devrait être considéré pour l'attribution d'un prix. Prière de prendre note que le Prix du Président s'adresse spécifiquement à une communication scientifique, un livre ou une publication d'importance.

2) Des lettres supportant la candidature sont essentielles et devraient indiquer l'étendue de l'influence du travail du candidat.

3) Le Comité préfère recevoir les nominations et les documents les supportant sous forme électronique; par contre, des copies papier seront acceptées en l'absence de document électronique.

CMOS Prizes and Awards Committee Members

- Rick Thomson (IOS), (Chair) ThomsonR@pac.dfo-mpo.gc.ca
- Jean-Guy Desmarais (CMC) jean-guy.desmarais@ec.gc.ca
- Henry Leighton (McGill) henry@zephyr.meteo.mcgill.ca
- Lawrence Mysak (McGill) mysak@zephyr.meteo.mcgill.ca
- Keith Thompson (Dalhousie) keith.thompson@dal.ca
- Mike Leduc (Secretary) mike.leduc@ec.gc.ca

Membres du Comité des Prix et Honneurs de la SCMO

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- Lawrence Mysak (McGill) mysak@zephyr.meteo.mcgill.ca
- Keith Thompson (Dalhousie) keith.thompson@dal.ca
- Mike Leduc (secrétaire) mike.leduc@ec.gc.ca

CMOS Prizes and Awards: NOMINATIONS

The Canadian Meteorological and Oceanographic Society's annual call for nominations for Prizes and Awards is under way. All Society members are encouraged to consider nominating individuals of the meteorological or oceanographic community who have made significant contributions to their fields. The award categories are:

a) The President's Prize;
b) The J.P. Tully Medal in Oceanography;
c) The Dr. Andrew Thomson Prize in Applied Meteorology;
d) The Prize in Applied Oceanography;
e) The Rube Homstein Medal in Operational Meteorology;

f) Tertia M. C..Hughes Memorial Graduate Student Prize;

g) Citations (including Environmental Citations).

Each category has different and specific nomination criteria which must be met before any nomination can be considered. For more details, please consult the web at www.cmos.ca or contact Mike Leduc at the address given below.

This year the deadline is **February 15, 2003** for nominations to be received by the Secretary.

Mike Leduc (Secretary)
Meteorological Service of Canada
4905 Dufferin Street
Downsview, ON M3H 5T4
Tel: 416-739-4474; Fax: 416-739-4603
email: mike.leduc@ec.gc.ca

NOMINATIONS: Prix et Honneurs de la SCMO

L'appel annuel de la Société canadienne de météorologie et d'océanographie pour les prix et honneurs est lancé. Tous les membres de la société sont encouragés à présenter des nominations de personnes considérées comme ayant contribué de façon significative dans leur sphère d'activités tant en océanographie qu'en météorologie. Les catégories de prix sont:

a) Prix du président;
b) Médaille de J.P. Tully en océanographie;
c) Prix du Dr. Andrew Thomson en météorologie appliquée;
d) Prix en océanographie appliquée;
e) Médaille de Rube Hornstein en météorologie opérationnelle;
f) Prix commémoratif étudiant de deuxième cycle Tertia M.C. Hughes;
g) Citations (citations environnementales incluses).

Chaque catégorie a des critères différents et spécifiques de sélection qui doivent être rencontrés pour être considérés. Pour de plus amples détails, prière de consulter la toile à www.scmo.ca ou de contacter Mike Leduc à l'adresse donnée plus bas.

Cette année toutes les soumissions doivent être reçues par le secrétaire avant le **15 février 2003.**

M. Mike Leduc (secrétaire)
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courriel: mike.leduc@ec.gc.ca

Call for Papers CMOS 37th Annual Congress Ottawa, Ontario, Canada 2 - 5 June 2003

The Ottawa Centre of the Canadian Meteorological and Oceanographic Society will host the Society's 37th Annual Congress at the Crowne Plaza Hotel, Ottawa, Ontario, Canada, from 2 to 5 June 2003. The theme, "Atmosphere-Ocean Science: Impacts and Innovation" is forward-looking and deliberately inclusive.

Titles, authors, affiliations and abstracts (1 page, no figures) are to be sent electronically to the Scientific Program Committee at: cmos03@yorku.ca by **Friday, February 28, 2003.**

Appel de communications scientifiques 37ième Congrès annuel de la SCMO Ottawa, Ontario, Canada 2 au 5 juin 2003

Le Centre d'Ottawa de la Société canadienne de météorologie et d'océanographie sera l'hôte du 37ième Congrès annuel de la Société, qui sera tenu à l'hôtel Crowne Plaza d'Ottawa (Ontario), Canada du 2 au 5 juin 2003. Le thème choisi pour le congrès, SCIENCE DE L'ATMOSPHÈRE-OCÉAN: IMPACTS ET INNOVATION, se veut progressif et englobant.

Les résumés ainsi que le titre de la communication, son ou ses auteurs, son ou leur affiliation (le tout sur une seule page, aucun diagramme) doivent être acheminés par voie électronique au comité du programme scientifique à: cmos03@yorku.ca au plus tard le **vendredi 28 février 2003.**

Books in search of a Reviewer / Livres en quête d'un critique

Emissions Scenarios, Intergovemmental Panel on Climate Change, Cambridge University Press, Paper Cover, 0-521-80493-0, 2000, $44.95.

Synoptic and Dynamic Climatology, by Roger G. Barry and Andrew M. Carleton, Routledge, Paperback, 0-415-03116-8, $60.00US

Climate Change 2001, Synthesis Report, Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, by Robert T. Watson, Editor, April 2002, Cambridge University Press, Paperback Cover, 0-521-01507-3, $40.00US

Scattering, Absorption and Emission of Light by Small Particles, by Michael I. Mishchenko, Larry D. Travis and Andrew A. Lacis, June 2002, Cambridge University Press, Hardback Cover, 0-521-78252-x, $90.00US.

Air Pollution X, Edited by C. A. Brebbia and J. F. Marin-Duque, September 2002, Wessex Institute of Technology, Hardback Cover, 1-85312-916-X, $385.00US.

Environmental Change, Climate and Health: Issues and Research Methods, edited by Pim Martens and Anthony J. McMichael, Cambridge University Press, Hardback Cover, 0-521-78236-8, $90.00US.

Atmospheric Pollution: History, Science and Regulation, by Mark Z. Jacobson, Cambridge University Press, Hardback Cover, 0-521-81171-6, $110.00US.

The State of The Nations's Ecosystems: Measuring the Lands, Waters and Living Resources of the United States, The H. Heinz III Center for Science, Economics and the Environment, Cambridge University Press, Paperback Cover, 0-521-52572-1, $25.00US.

Meteors in the Earth's Atmosphere: Meteoroids, and Cosmic Dust and their Interactions with the Earth's Upper Atmosphere, Edited by Edmond Murad and Iwan P. Williams, Cambridge University Press, Hardback Cover, 0-521-80431-0, $80.00US.

If you are interested in reviewing one of these books for the *CMOS Bulletin SCMO*, please contact the Editor at the e-mail address provided on page ii. Thank you for your valuable collaboration.

Si vous êtes intéressés à faire la critique d'un de ces livres pour le *CMOS Bulletin SCMO*, prière de contacter le rédacteur-en-chef à l'adresse électronique mentionnée à la page ii. Merci pour votre inestimable collaboration.

CMOS ACCREDITED CONSULTANTS / EXPERTS-CONSEILS ACCRÉDITÉS de la SCMO

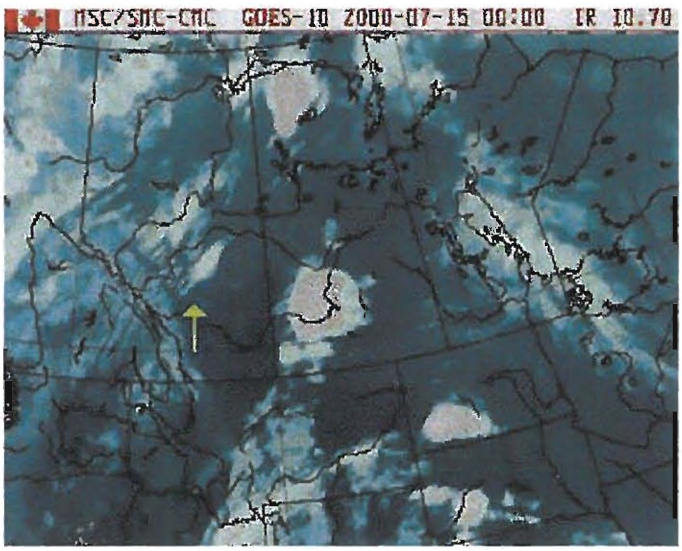

FIGURE 1.1: Enhanced infrared GOES satellite image at 0000 UTC, 15 July, 2000, showing thunderstorms over the Dakotas, southern and northern Saskatchewan, and a smaller but large hail-producing intense thunderstorm over south-central Alberta which spawned the Pine Lake tornado one hour later, leaving 12 dead in its wake. From page 142.

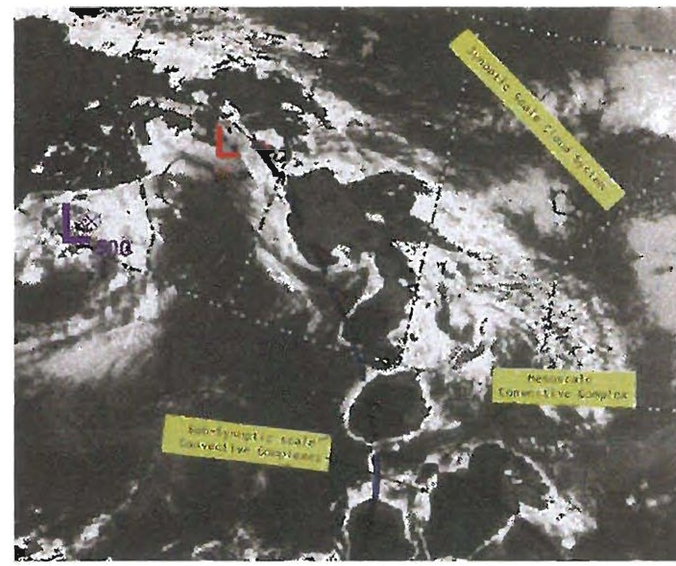

FIGURE 1.2: Enhanced infrared NOAA-6 image for 0136 UTC, 15 July, 1982, depicting three of the scales of atmospheric motion indicated in Table 1.1; super-imposed fronts, surface and 500 hPa low centers were extracted from CMC analyses. From page 144.

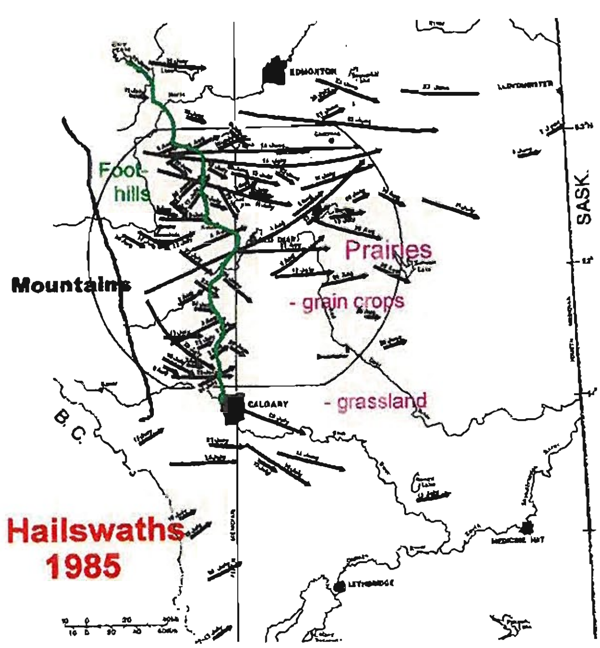

FIGURE 1.6: Major hailswaths of 1985 (reproduced from Deibert, 1985). The super-imposed jagged lines are the approximate eastern edges of the main Rocky Mountain barrier and the foothills. From page 147.

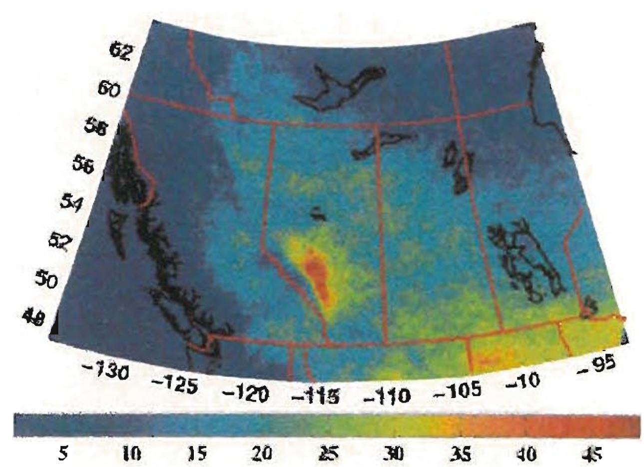

FIGURE 1.9: Mean annual lightning occurrence (days yr^{-1}) for western Canada region, Feb. 1998 to Dec. 2000 (reproduced with permission from Burrows et al., 2002). From page 151.