ISSN 1195-8898

# CMOS BULLETIN SCMO

Canadian Meteorological and Oceanographic Society

La Société canadienne de météorologie et d'océanographie

February / février 2003 Vol.31 No.1

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

Editor / Rédacteur: Paul-André Bolduc
Marine Environmental Data Service
Department of Fisheries and Oceans
12082 - 200 Kent Street
Ottawa, Ontario, K1A 0E6, Canada
☎ (613) 990-0300; Fax (613) 993-4658
E-Mail: paulandre.bolduc@sympatico.ca
Canadian Publications Product Sales Agreement #0869228
Envois de publications canadiennes Numéro de convention #0869228

**Cover page:** The two superimposed cloud photos shown on the cover page give an unmistakable indication of the very severe storm which happened at Pine Lake, Alberta, in July 2000. To learn more, read the article written by Geoff Strong on Canadian Prairie thunderstorms on **page 11.** The top photo (Pine Lake storm) is compliments of Dr. Terry Krauss while the bottom photo (of a larger concurrent Saskatchewan storm) is from Arjen Verkaik of SkyArt Productions (http://www.skyartpro.com/).

**Page couverture:** Les deux photographies superposées de nuages illustrées en page couverture donnent une indication non équivoque d'une tempête très violente qui a eu lieu à Pine Lake, Alberta, au mois de juillet 2000. Pour en savoir plus, lisez l'article de Geoff Strong sur les tempêtes dans les prairies canadiennes en **page 11**. La photo du haut (la tempête de Pine Lake) est la gracieuseté du Dr Terry Krauss alors que celle du bas (une plus forte tempête de la Saskatchewan concurrente avec celle de Pine Lake) est de Arjen Verkaik des productions SkyArt (http://www.skyartpro.com/).

**CMOS Executive Office**
**Bureau de la SCMO**

Suite112, McDonald Building
University of Ottawa
150 Louis-Pasteur Ave.
Ottawa, Ontario, Canada K1N 6N5
cmos@meds-sdmm.dfo-mpo.gc.ca
homepage: http://www.cmos.ca
page d'accueil: http://www.scmo.ca

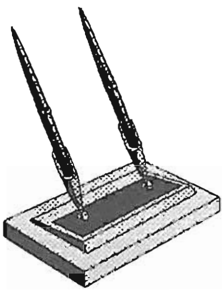
Dr. Neil Campbell
Executive Director - Directeur exécutif
Tel: (613) 990-0300; Fax: (613) 993-4658
E-mail: cmos@meds-sdmm.dfo-mpo.gc.ca

Dr. Richard Asselin
Director of Publications; Directeur des publications
Tel: (613) 991-0151; Fax: (613) 993-4658
E-mail: pubs@meds-sdmm.dfo-mpo.gc.ca

## Canadian Meteorological and Oceanographic Society (CMOS)

## Société canadienne de météorologie et d'océanographie (SCMO)

....from the President's Desk



Dear Colleagues:

A new year has begun and I hope you all had a safe and happy holiday season. For those meteorologists among us who celebrate Christmas, it can be a difficult holiday, with expectations of an accurate forecast on whether we will have a "white Christmas" or not. If you nail the forecast, it's fine, but let's say you predict a green Christmas for parts of Southern Ontario and it turns out to be the perfect white Christmas.... well, I can tell you from experience, turkey dinner with the family can be unbearable...

It's hard to get respect from those who don't understand how difficult it is to do what we do! But I suppose it is unrealistic for us to expect those outside our professions to really, truly, understand and appreciate us. Which brings us to my thoughts for this issue: it is time to recognize and appreciate our colleagues and our professions and through CMOS, there are several important ways that we can do this.

**CMOS Awards and Fellowships:** We are fortunate to have so many talented and dedicated professionals among us and the CMOS Awards are a terrific way of recognizing some of these individuals. This is the best opportunity for our professions to recognize those individuals who really make a difference and I encourage everyone to think about nominating a deserving colleague. Details of the various awards and criteria can be found in the *CMOS Bulletin SCMO* on page 187 of the December issue (Vol.30, No.6) and on the CMOS website. **The deadline for submission is February 15.**

There are also members of the Society who make exceptional contributions to the scientific, professional, educational and weathercasting fields in atmospheric and ocean sciences. These individuals should be nominated as Fellows of the Society. This issue of the *CMOS Bulletin SCMO* (on page 30) and the website give details regarding the nominating process and criteria as well as a list of past recipients of this prestigious award. **The deadline is April 15.**

Every year, we have far fewer nominations than there are deserving members – I urge every member to consider nominating a fellow member. If you know someone who should be nominated, please call or email your local executive.

(Continued on next page)

*Volume 31 No. 1*
*February 2003 - février 2003*

**Inside / En Bref**



Printed in Kanata, Ontario, by Gilmore Printing Services Inc.
Imprimé sous les presses de Gilmore Printing Services Inc., Kanata, Ontario.



**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.

**2003 CMOS Congress:** An important way to recognize colleagues and their work is to come and participate in the 2003 CMOS Congress in Ottawa during the week of June 2nd to 5th. The Ottawa local arrangements committee has put together a strong program as well as great opportunities for networking and catching up with colleagues and friends. The theme of the CMOS 2003 Ottawa Congress is: "ATMOSPHERE-OCEAN SCIENCE: IMPACTS AND INNOVATION". Papers are now being accepted for the Congress on a variety of topics, with a **deadline of Friday, February 28, 2003**. Please visit the CMOS website for details.

By participating in these major CMOS events, our awards program and our Congress, you support the Society and you support your colleagues. You also help set the bar on what excellence looks like in our professions, which is an outcome that can only strengthen our professions in the long-term. There are many benefits to you as an individual member in participating in these events including networking, hearing the latest research and catching up with old friends. At the very least these events are an opportunity to pat ourselves on the back and set our sights higher for the coming year. I look forward to receiving your nominations and seeing you in Ottawa next June.

Follow Up Notes from the last issue of the Bulletin:

**1) CMOS Statement on the Kyoto Accord**: In the last issue, I spoke of our need to create a statement that spoke directly to the Society's position on the Kyoto Accord. I am pleased to announce that the Scientific Committee has done tremendous and speedy work on this very important document. We expect that a draft statement will be presented shortly to the Council for approval. My thanks to all of the Scientific Committee members for their work.

**2) New CMOS Database "AMSoft":** I am very excited to tell you that the Society is finalizing its plans to purchase a new database from Minasu Information Systems Ltd., an Ottawa based company. This software "AMSoft" is designed for not-for-profit associations like CMOS, and therefore is very adept at handling all aspects of the Society's affairs: membership, subscriptions, meetings including the Congress, continuing education and accreditation. The Council believes that this software will revolutionize the way that CMOS conducts business with its members. We believe that we can be more effective, more timely and more cost efficient with this new database. Implementation will take the next few months and we hope to showcase the new software at the Annual General Meeting at the Congress in June.

*Ron Bianchi,*
*President/Président*

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

1) *Emissions Scenarios*, Intergovernmental Panel on Climate Change, Cambridge University Press, Paper Cover, 0-521-80493-0, 2000, $44.95.
2) *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.
3) *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.
4) *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.
5) *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.
6) *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.
7) *Coastal Environment, Environmental Problems in Coastal Regions IV*, Editor: C.A. Brebbia, Wessex Institute of Technology, Hardback Cover, 1-85312-921-6, $247.00US.
8) *Ecohydrology: Darwinian Expression of Vegetation Form and Function*, Peter S. Eagleson, Cambridge University Press, Hardback Cover, 0-521-77245-1, $110.00US.

---

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 below. Of course, when completed, the book is yours. The instructions to be followed when reviewing a book for the *CMOS Bulletin SCMO* will be provided with the book. Thank you for your 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 ci-bas. Bien entendu, le livre vous appartient lorsque vous avez terminé la critique. Les instructions qui doivent être suivies lors de la critique d'un livre dans le *CMOS Bulletin SCMO* vous parviendront avec le livre. Merci pour votre collaboration.

*Paul-André Bolduc*
*paulandre.bolduc@sympatico.ca*

December 27, 2002

**IPCC Climate Change 2000**

In Climate Change 2000, page 11, it is stated that most of the warming of the last 50 years has been attributable to human activities and that natural forcing does not explain the warming of the last 25-50 years.

This is a misconception of factual evidence, for the last 50 years has comprised 30 years of cooling and only 20 years of warming. This is atypical of the partial generalisations so often found in the IPCC guidance to policymakers which tend to mitigate some of the reservations and undercainties in the WGI reports submitted by scientists.

Those of us with operational and research climate experience over the last 50 years, will recall the concern that we conveyed to the public, particularly during the 1970s, when, after over 30 years of cooling, we were convinced that a return to Little Ice Age conditions was imminent (Hare, K, 1979).

WMO convened an international conference in Geneva, in February 1979, to discuss impending catastrophe. The consensual view of we participants was that GHGs were causing cooling! How stupid could we be? Within two years, the current 20 years of significant warming commenced and we are now advising the public that GHGs are the main cause of this anomaly. Will we be found just as stupid in 2020?

Probably; because we are obsessed with simplistic GHG modelling, we are not investigating with equal enthusiasm the characteristics of the main components of climate change prior to 1850 – those of natural variability. The IPCC acknowledges this deficiency in our models.

Despite isotopic analyses which confirm historical documentation of considerable climate variability when GHGs were relatively stable, such evidence and its proponents (even the venerated climate historian – Hubert Lamb) are now being derided by modellers and their supporters. Current models (which still lack major integers) when hindcast back to AD1000 fail to explain such scientific and documentary evidence, yet modellers prejudicially dismiss the latter as possibly being local but not global events.

In 1990, distinguished internal solar and paleo-climatic scientists held a conference in London on solar variation and its impact on climate change. It was concluded that the main contributors to longer term temperature change were the Gleissberg and Suess cycles of solar variability approximately of 80 and 200 years periodicity respectively. (Pecker, J. and Runcorn, S., 1990); a conclusion which has never been referred to in IPCC documentation.

The Gleissberg cycle induces some 40 years of alternate warming and cooling. Has this been contributary to, or is it just coincidental that instrumental data over the past 200 years has shown this temperature variability – 1810-1850 warming, 1860-1900 cooling, 1900-1940 warming, 1940-1975 cooling? Recent warming since that time could have been mainly solar induced and should turn to cooling around 2020, if this cycle prevails.

> "I am appalled by the number of IPCC statements which, without some qualification, are inaccurate. One whole section based on "the last 50 years of warming" is typical, as 30 years of that period was a cooling phase which is an unexplained embarrassment to global warming proponents."
>
> *M.R.M.*

Oceanographers at Woods Hole Institute and Princeton University, in the USA, have been monitoring the cooling temperatures and failing strength of the Gulf Stream relative to the oceanic circulation of the northwest Atlantic Ocean over the past 40 years. It appears that the thermohaline pump in the Greenland Sea is faltering and, if this continues unabated, a return to ice age conditions could occur in the matter of a few decades.

It is time for we meteorologists to be taking off our GHG blinkers and cooperating with solar scientists and oceanographers in developing more realistic models—models based on fundamental natural integers of climate variability in the past, rather than the peripheral integer of $CO_2$ forced upon us by governments to meet political ends. If the solar scientists and oceanographers are closer to the mark in their predictions, then global cooling will engender a far more devastating situation for policymakers to face. A world with double its current population, with less habitable and productive farmland, would be even more catastrophic than any global warming scenario currently envisaged.

*M. R. Morgan*
*Dartmouth, Nova Scotia*

References:

Geissberg, W., 1966: Ascent and Descent in the 80 year cycles of solar activity, H.Brit.Astro.Soc, 76, p.265-270.

Hare, K., 1979: Climate Variation and Variability: empirical evidence from meteorological and other sources, World Climate Conference, Geneva, Feb.79, WMO 537, p.51-87.

Lamb, H., 1982: Climate History and the Modern World, Methuen, London and New York.

Pecker, J. & Runcorn, S., 1990: The earth's climate and variability of the Sun over the recent millennium, Royal Soc. London, Phil. Trans, A330, p.399-402 and p.685-687.

January 2, 2003

**Science and the Kyoto Protocol**

Madhav Khandekar, writing just before the recent Canadian ratification of the Kyoto Protocol, asks whether we, as the only atmospheric-science community in Canada should not "discuss the science of global warming before the Kyoto accord is ratified?" He even claims that "the very science which brought in the Kyoto Accord is now being excluded from being debated" (CMOS Bulletin SCMO, Vol.30, No.6, Dec. 2002).

Well, I'm certainly with him on the importance of climate science as a topic of interest for the CMOS Bulletin SCMO. I went back to my recent issues of the Bulletin and was pleased to discover an article on "Carbon -The Heart of Climate Change" (T. Murdock and R. Lee, 28, 1) which reviews issues about carbon cycling, sources and sinks; a critique of climate models ("Canadian Climate Models as Windows to the Future: How Credible are they?" by H. Hengeveld and D. Francis, 28, 4); a discussion of the research programs of the Canadian Climate Research Network (I. Rutherford, 28,5); announcements of research objectives and a description of research projects and networks funded by the Canadian Foundation for Climate and Atmospheric Sciences (29,1; 29, 5; 29, 6); a discussion of the vulnerability to climate change by H. Dolan (30, 4) and other more specialized contributions. Clearly, there is no lack of discussion and information on climate science in the CMOS Bulletin SCMO. Neither is there within the Canadian research community, with many prominent Canadian scientists publishing original research in refereed journals and contributing to the IPCC process. The recent creation of the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) — an arm's-length foundation answering to the CMOS council — has boosted climate research in Canada. CFCAS has to date committed over $30 million to university-led research projects and networks - last spring, it held, jointly with the Meteorological Service of Canada, a widely attended workshop in Ottawa to discuss climate research priorities for Canada; in February 2003, it will sponsor an Arctic Climate Workshop, again in Ottawa. There is more climate research activity going on now than ever before in Canada, and although one might wish that more summaries and discussions of results should appear in the CMOS Bulletin SCMO, there is certainly no evidence of exclusion.

So, assuming that Khandekar is well informed of all the above, as an up-to-date climate consultant should be, what does he mean? Presumably, he would like more discussion of the seven "scientific issues" which he summarizes in his letter. Some of these - for example the link between global warming and extreme weather - remain worthwhile subjects of research. Others are perhaps less appropriate or tainted with familiar sophistry ("Canada is getting less cold, not warmer"). For example, none of the serious climate simulations support the contention that recent global warming is due to natural causes. That changes in solar irradiance, land-use, aerosols, large-scale atmospheric oscillations, ocean circulation, etc... all have some influence on climate, is recognized and included in models; their combined influence cannot explain the observed recent climate fluctuations without anthropogenic inputs (see for example Tett et al., J.G.R. - Atmospheres, 27 Aug 2002). There may have remained some doubt at the time of the formulation of the Kyoto accord; there is little left to debate on this issue today.

> "The Kyoto accord was hammered out as a compromise on the path to greenhouse gas reduction. No one thinks it is perfect but it leaves a lot of latitude to each country to develop its own plans ('made in Canada')."
>
> *P.L.*

Whatever merit Khandekar's topics may have as subject of debate within the pages of the Bulletin, the insistence that we should know all the answers to all the questions before ratifying the Kyoto protocol makes no sense and is at best a dilatory tactic. To insist that every aspect of an uncertain future be understood and explored before taking action to ward off the most obvious and direct consequences is simple folly. Indecision is deadly; the way to survive is to recognize danger early and act. By identifying long-term hazards and taking some first steps towards countering their impact, government scientists and policy-makers have acted with due diligence in the interests of the public good.

The Kyoto accord was hammered out as a compromise on the path to greenhouse gas reduction. No-one thinks it is perfect but it leaves a lot of latitude to each country to develop its own plans ("made in Canada"). It is a first step towards a willing international collaboration to solve a global problem, a problem which has no solution without international collaboration. In any enterprise of such a magnitude, that first step is crucial, as the Marquise du Deffand (1) recognized more than two centuries ago: "La distance n'y fait rien; il n'y a que le premier pas qui coûte". We have now taken that first step and better science will guide us along the path..

*Paul LeBlond*
*Galiano Island*
*British Columbia*

(1) Marie de Vichy-Chamrond, marquise du Deffand, (1697-1780) - woman of letters and a leading figure in French society. She was the mistress of the regent, Philippe d'Orléans, and a close friend of Voltaire and of Horace Walpole.

## A DFO Antarctic Research Program?

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

An article in the CMOS Bulletin SCMO (Vol.30, No.5, page 135) outlined recent progress in implementing the Argo array. If ever we are to create a truly global ocean monitoring network then it will be necessary to deploy floats in all of the oceans of the world (with the notable exception of the Arctic; Argo floats cannot penetrate ice cover). As Canada is a significant contributor to the global program we are expected to deploy floats to meet our own needs and also to contribute to the establishment of a global array. To this end six Canadian floats were recently deployed from a C-130 aircraft in the deep southern ocean, west of Chile as shown in Figure 1.

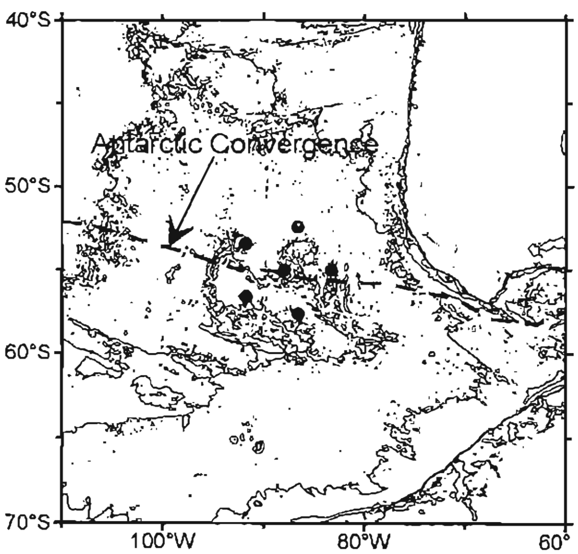



Figure 1: The actual launch locations of six Canadian floats relative to the Antarctic Convergence.

The floats were launched on December 14th and 15th , 2002 and were the first floats launched by air in the Canadian Argo program. The flights left Punta Arenas on two consecutive days and the deployments were all completely normal. The floats were activated then launched from the aircraft, descending to the sea surface on a small parachute. As expected, they remained at the sea surface for 6 hours and transmitted information allowing us to verify that they were electronically healthy. After this time the floats are programmed to retract a piston and oil bladder allowing them to sink to the planned drift depth of 2000 metres. If they remain healthy then the first profiles will be reported on December 24th and 25th.

The floats were launched on the Antarctic Convergence near the axis of the region where it is believed the Antarctic Intermediate Water mass is formed. The floats will yield a deep velocity structure and data that will allow geostrophic velocity calculations to the sea surface. During the winter we expect surface waters to be cooled and water to sink to 800-1000 metres. The vortex stretching should generate relative vorticity which might allow an estimate of the areal averaged sinking velocity and so allow estimates of the mass flux in the subduction region. As with all other Canadian Argo floats, the data will be processed in near real-time and should become available very promptly on the global Argo servers in the USA and France. The real-time data may also be found on Canadian and Japanese servers.

Subject: RE: The DFO Antarctic Research Program...
Date: Wed, 25 Dec 2002 09:39:40 -0500
From: FreelandHj@pac.dfo-mpo.gc.ca
To: paulandre.bolduc@sympatico.ca
FreelandHj@pac.dfo-mpo.gc.ca
bennettj@polarcom.gc.ca
oloken@sympatico.ca

And as a final update, batting six out of six following a rather risky air deployment of the floats is not bad at all. The four floats deployed Dec 14th, reported good profiles and dived on schedule to 2000 metres. The two launched on Dec 15th are at the surface as I am writing reporting what appears to be good data and I have no doubt that they will dive too. The profiles for the first group of four were processed efficiently by MEDS and the data now appear on the global Argo data servers. Doubtless the data from all six will be available within about 12 hours.

Merry Xmas to you all; DFO has an Antarctic Research Program! DFO has deployed six floats that will give us the first ever chance of witnessing formation events of Antarctic Intermediate Water. Nobody has ever witnessed that before.

*Howard Freeland*

[1] Institute of Ocean Sciences, Sidney, B.C.

[2] Marine Environmental Data Service (MEDS), Ottawa, Ontario.

# Large Perturbations to Terrestrial Climate Models and a Simulated Runaway Greenhouse Effect

by Kevin Hamilton[3] and Weijun Zhu[3]

## Introduction

Planetary scientists have proposed a possible explanation for the very thick Venusian atmosphere (roughly 100 times as massive as the Earth's) in terms of the so-called "runaway greenhouse effect" (Ingersoll, 1969; Nakajima et al., 1992). Consider an Earth-like planet arbitrarily moved closer to the sun, and thus subject to a higher incident solar flux. It is proposed that at some point it will no longer have a stable climate consistent with the availability of liquid water at the surface. What ensues would then be the extensive evaporation of the oceans and production of such warm temperatures that significant carbon dioxide would be evolved from the surface rocks. This would then ultimately lead to a massive and extremely hot atmosphere like that observed today on Venus.

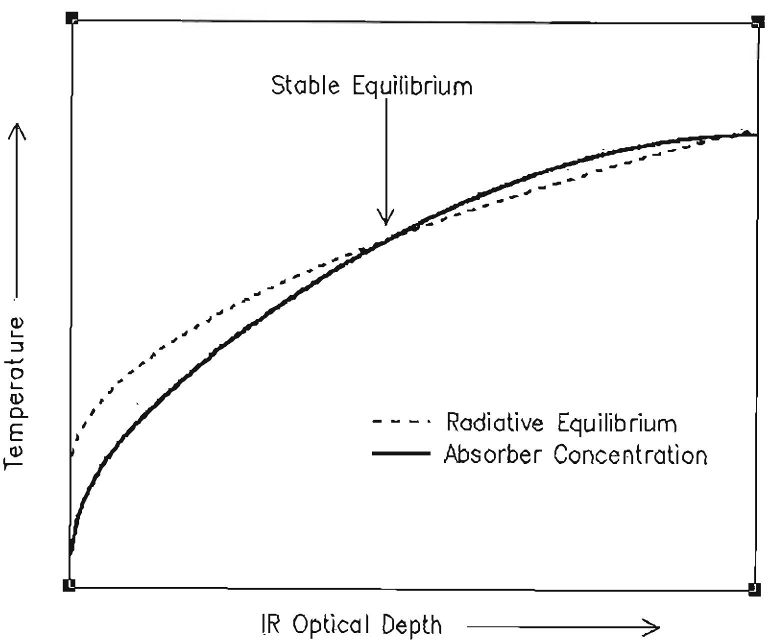



Fig. 1. Schematic showing the expected optical depth given the surface temperature (solid) and the radiative equilibrium relation between surface temperature and atmospheric optical depth (dashed).

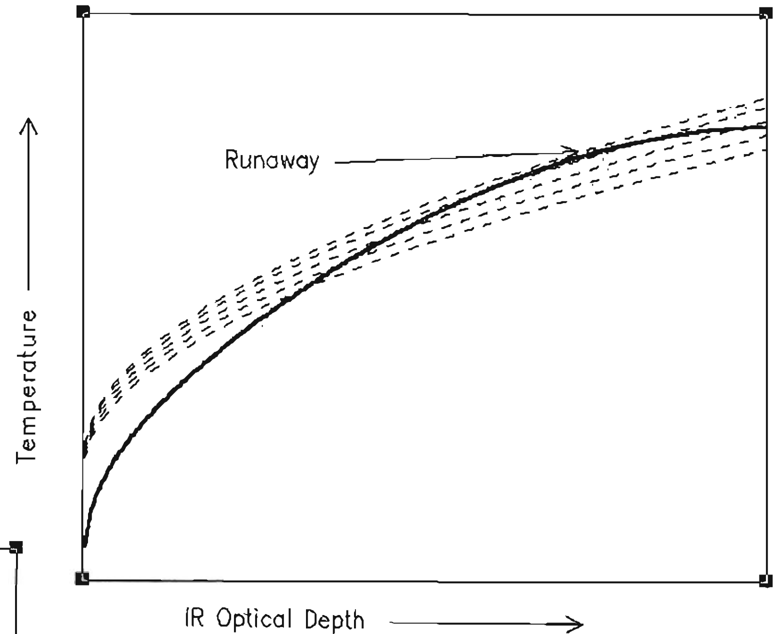



Fig. 2. As in Fig. 1, but now considering the radiative equilibria for cases with different solar constants. The highest dashed curve shows the radiative solutions corresponding to a solar constant just big enough to trigger a runaway greenhouse effect.

The basic cause of the runaway greenhouse effect can be illustrated in very simple models. Consider a one-dimensional "semi-gray" radiative equilibrium model of the globally-averaged atmosphere. Here the absorbtivity is assumed to be zero over the solar spectrum and some constant over the wavelengths in which terrestrial radiation is emitted. It is easy to show that in radiative equilibrium the surface temperature in such a model is

$$T_s = [S\,(1 + \tfrac{1}{2}\tau) / \sigma]^{1/4} \qquad (1)$$

where $\tau$ is the IR optical depth of the atmosphere, and S is the global-mean net solar radiation at the top of the atmosphere. This is shown schematically as the dashed curve in Fig. 1. The IR optical depth depends on the distribution of absorbers, and most notably on the water vapour in the atmosphere. One could expect warmer temperatures to lead to enhanced water vapour concentrations, and if this scales at all like the saturation

[3] International Pacific Research Center, University of Hawaii, Honolulu, Hawaii. USA 96826

water vapour mixing ratio near the surface, then the optical depth versus surface temperature relation might resemble the solid curve in Fig. 1. As drawn in the figure, the two curves intersect twice. It is possible to show that the lower temperature intersection should be stable to small perturbations, while the higher temperature one is unstable. Thus the present terrestrial climate should be represented by the point marked "stable equilibrium" in Fig. 1.

Fig. 2 shows what happens when different values of S are considered. The radiative solution scales simply as $S^{1/4}$, and assumption is that the functional dependence of $\tau$ on $T_s$ in the solid curve is not affected by the value of S. As S is increased, the equilibrium $T_s$ rises, until S becomes so large that no equilibrium is possible, and one expects the runaway greenhouse instability to take over.

How much would the solar constant have to increase before the Earth's climate becomes unstable? In published simple model treatments of this problem (Ingersoll, 1969; Nakajima et al., 1992) this threshold depends on how the atmospheric composition (notably water vapour concentration) is assumed to vary with atmospheric temperature. Nakajima et al. (1992) find that instability sets in once the globally-averaged net solar flux (incoming minus reflected) exceeds 385 $W/m^2$, while Ingersoll estimated the threshold between 321 and 655 $W/m^2$. At present this value is about 240 $W/m^2$ and if the albedo is assumed to remain constant, this would imply a 34% increase in solar constant would be needed to exceed even Ingersoll's lowest estimated threshold.

Even the 34% figure is a very large value and there is presumably no reason to be concerned that such large solar constant changes will actually occur in the near future. However, the possibility of comparably large anthropogenic perturbations to the tropospheric climate system cannot be completely ruled out. Doubling of existing carbon dioxide concentrations is thought to produce a radiative forcing of the troposphere of about 5 $W/m^2$, comparable to that of about a 2% increase in solar constant (Manabe and Wetherald, 1975; Wetherald and Manabe, 1975). A doubling of current carbon dioxide levels in the next century or so is almost inevitable. The likelihood is that global carbon dioxide emissions will rise continuously in subsequent centuries, and the eventual quadrupling of current levels (corresponding roughly to 10 $W/m^2$ forcing) seems quite likely (e.g., Manabe and Stouffer, 1994). The most extreme of the 40 emission scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC) in their 2001 report has carbon dioxide fossil fuel emissions in 2100 at 6 times larger than those in 2000 and the emissions in this scenario are still rising quickly at century's end. It is certainly possible that mankind could burn fossil fuel at still higher rates. Walker and Kasting (1992) made a serious effort to estimate the likely long-term evolution of atmospheric carbon dioxide concentrations, and concluded that an 8-fold increase in pre-industrial values in the 23rd century was quite plausible (corresponding to about a 15 $W/m^2$ climate forcing, e.g. Kiehl and Dickinson, 1987). Disconcertingly, the main limitation on the peak carbon dioxide concentration found in Walker and Kasting's scenarios was provided by the total reserve of fossil fuel that was assumed to be economically exploitable, and the value for this reserve is itself known rather imperfectly. So it is at least possible that still higher values of atmospheric carbon dioxide could occur. Anthropogenic activities could also lead to large increases in methane and other long-lived greenhouse gases. A truly irresponsible policy could also see the production of large quantities of artificial compounds (such as chlorofluorocarbons) that are even much more efficient greenhouse gases. A human population completely heedless of the consequences could conceivably produce anthropogenic tropospheric climate forcing of the order of several 10's of $W/m^2$.

The threat of very large changes in greenhouse forcing could also be plausible if some geochemical feedback were to be strongly activated by climate change (e.g. current speculations that the methane locked up near the land surface and the bottom of the ocean could be released in response to climate change). Thus there may be some practical interest in seeing how current atmosphere-ocean climate models respond to large positive forcing perturbations.

**Expected Response of a Coupled Ocean-Atmosphere Model to a Sudden Change in Solar Forcing**

The issue of runaway greenhouse effect has apparently been addressed so far only in the context of simple one-dimensional radiative equilibrium or radiative-convective equilibrium models. In these models some assumption needs to be made of how the atmospheric radiative properties scale with temperature. In principle, the response of the atmosphere to large changes in climate forcing and the possibility of a runaway greenhouse effect could be studied with comprehensive atmospheric general circulation models. Such models allow for an accurate treatment of the radiative transfer part of the problem and provide a self-consistent calculation of how the atmospheric composition (water vapour, clouds) changes in response to temperature changes, effectively allowing both equation (1) and the relation embodied by the solid curve in Fig. 1 to be generalized to include the effects of clouds and realistic treatment of water vapour. In practice, there are potential difficulties in using currently available versions of such models, since they have generally been designed to function only in some neighbourhood of the present climate. Such models may simply not execute when, e.g. the temperature at some point in the atmosphere exceeds some threshold beyond which their code is not designed to compute saturation mixing ratios or transmission functions. Such a model could be run to equilibrium in a series of experiments with different climate forcing (e.g. by imposing different levels of solar constant). At some level of forcing the model will presumably not reach equilibrium and would just produce some kind of error from passing temperature limits in the code. In practice, however, it may be hard to interpret the meaning of such an error when it occurs.

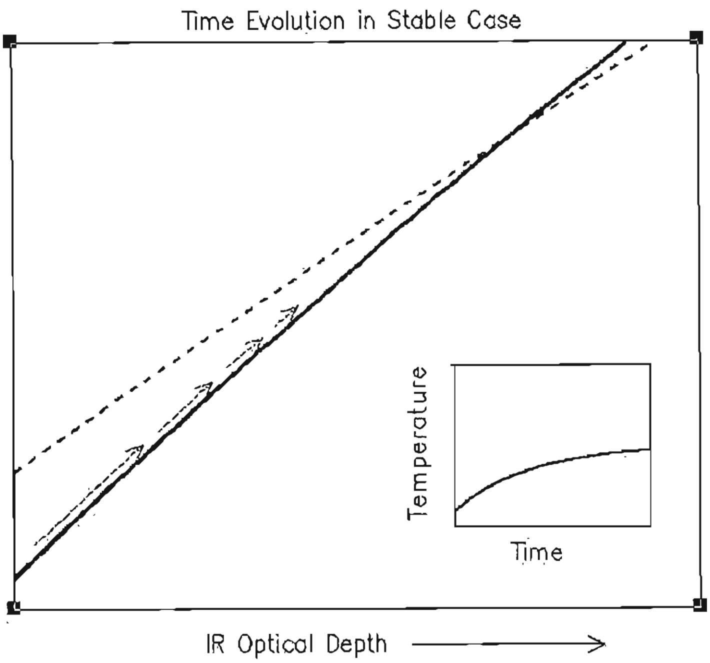



Fig. 3. A closeup of a schematic like Fig. 1 near a stable equilibrium. The arrows show the expected evolution of the climate system with thermal inertia after the solar constant is increased. The arrows get smaller to indicate that the progress slows down. The inset panel shows a schematic of the surface temperature as a function of time.

Another approach is simply to run coupled ocean-atmosphere models from present day initial conditions but with higher climate forcing (e.g. by increasing the value of the solar constant). This has the additional advantage of including explicit self-consistent treatment of the ocean circulation response. Fig. 3 shows a schematic of a case where the equilibrium situation of Fig. 2 is changed by increasing solar constant to a value consistent with a warmer equilibrium. The assumption is that the ocean provides the system a significant thermal inertia and so the time evolution of the global mean surface temperature should be governed by a relation like

$$C\ \delta T_s / \delta T = -A\ (T_s - T_r) \qquad (2)$$

where C is a constant proportional to the effective heat capacity of the system, and $T_r$ is the radiatively determined equilibrium surface temperature consistent with the instantaneous atmospheric composition. It is reasonable to suppose that the atmospheric composition will adjust nearly instantaneously to the temperature, so the climate should evolve along the black line in Fig. 3, and the rate of temperature increase at any time should be proportional to the vertical separation between the dashed and solid lines. For the case shown in Fig. 3, an atmosphere moving towards a new stable equilibrium, this will lead to the asymptotic approach of $T_s$ shown in the inset panel. Fig. 4 shows the expected evolution when the solar constant is increased past the runaway greenhouse threshold. In this case the temperature evolution should look like that in the inset - with downward curvature initially but switching to positive curvature and something like an exponential instability. In a real model integration it may not be possible to follow much of the instability phase, but the initial bending up of the global temperature versus time curve should be an indication that the solar forcing has exceeded the runaway greenhouse threshold.

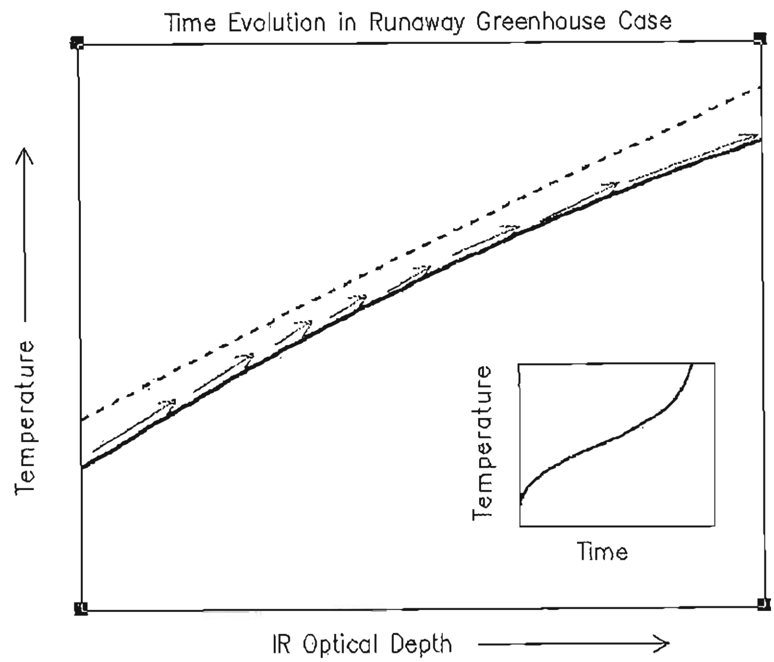



Fig. 4. As in Fig. 3, but now for an increase in solar constant to a level that is past the runaway greenhouse threshold.

**Results for the NCAR Climate System Model**

The response of the climate system to large perturbations has been investigated by the authors using the NCAR Climate System Model (CSM1.4) coupled ocean-atmosphere GCM, and some preliminary results will be presented here. The NCAR CSM is described by Boville and Gent (1998). The model was run at triangular-31 truncation for three 50-year integrations: a control run with the standard realistic value for the solar constant, and runs in which the solar constant was increased instantaneously to 1.025 and 1.25 times the standard value. Initial conditions for both the atmosphere and ocean were standard values provided by NCAR.

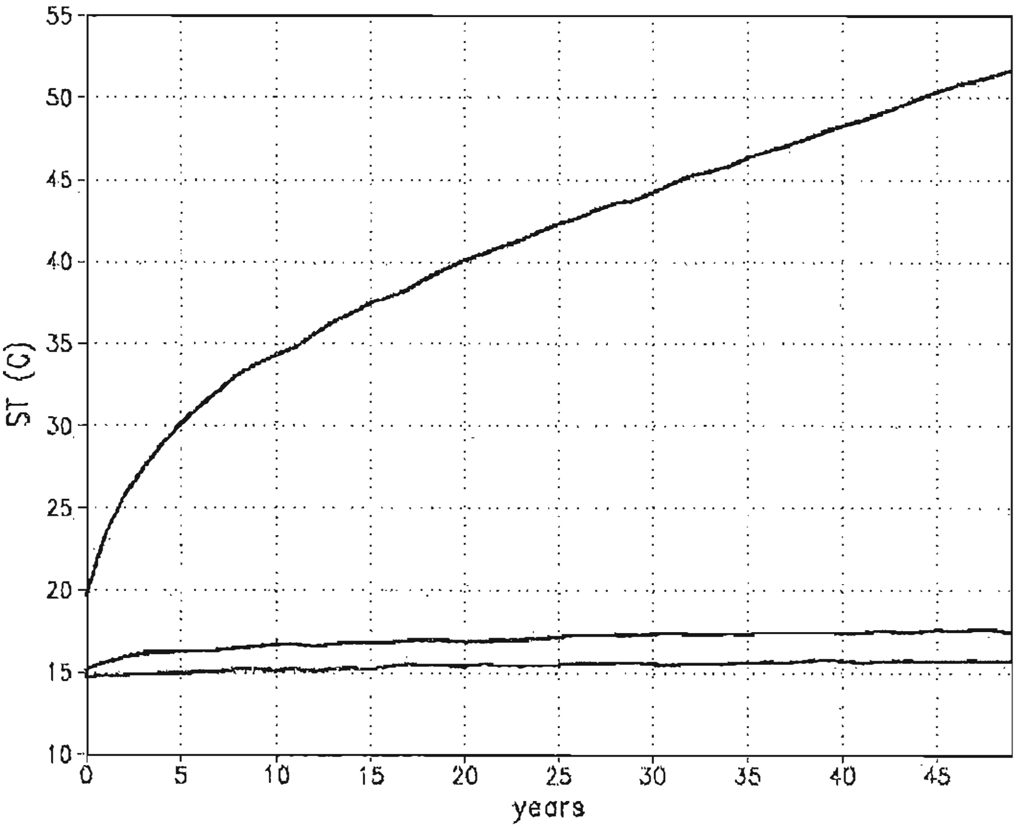



Fig. 5. The annual-mean global-mean surface temperature in integrations of the NCAR CSM coupled ocean-atmosphere model. Integrations conducted for standard solar constant (lowest curve), solar constant increased by 2.5% over control, and increased by 25% (top curve).

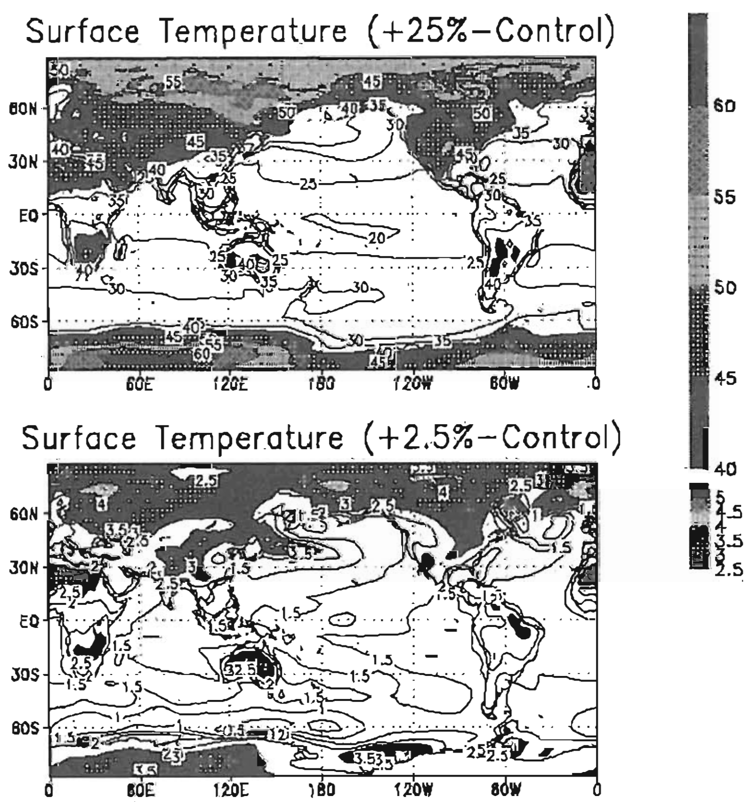



Fig. 6. (top) The surface temperature in the 25% increased solar constant run minus that in the control averaged over years 41-50. (bottom) As above but for the 2.5% control run.

Fig. 5 shows the time series of annual-mean global-mean surface temperatures in each of these integrations. The control run shows at most a very small climate drift. The temperature in the +2.5% run appears to be equilibrating at about 2°C above the control run. This is roughly the same warming that has been found by other investigators when the atmospheric carbon dioxide concentration in this model is doubled. The NCAR CCM is one of the least sensitive of the comprehensive climate models reviewed in the latest IPCC report.

The +25% solar constant run shows a continuously rising temperature through the full 50 years of integration. It is not clear if the climate in this case will reach equilibrium, but by year 50 the temperature is almost 35°C warmer than the control. It is possible that the continual and unabated warming in this experiment indicates that the model with +25% solar constant is at or close to the runaway greenhouse instability. It should be emphasized that this model includes only water vapour and cloud feedback processes, since concentrations of long-lived greenhouse gases are held fixed to their control values in each experiment.

Fig. 6 shows the annual-mean surface temperature change (relative to control) averaged over years 41-50 of the +2.5% and +25% runs. The extreme warming in the +25% experiment is evident, and is almost everywhere much more than 10 times the warming in the +2.5% run. One curiosity in the results is the cooling that occurs in the northeast Atlantic region in the +2.5% run, suggesting a strong positive excitation of the Arctic Oscillation. It is not clear whether this arises simply due to limited sampling of the unforced interannual variability in the model results, or if it could be considered a consistent part of the forced response of the model to a small increase in the solar constant.

**Discussion**

The preliminary results shown here suggest (although do not conclusively prove) that the NCAR CSM has reached, or is closely approaching, the runaway greenhouse instability when it is subjected to a 25% increase in solar constant (corresponding to an extra climate forcing of about 60 W/m$^2$). This level of climate forcing is not likely to be achieved in the near future, but, as noted earlier, anthropogenic climate forcings of several 10s of W/m$^2$ in the next few centuries may be in the realm of possibility. Even if the runaway greenhouse limit is avoided, the present results raise the possibility of significant nonlinearity of the temperature response to climate forcing. Manabe and Stouffer (1994) found that the response in the GFDL climate model to a quadrupling of carbon dioxide (about 10 W/m$^2$ forcing) was almost exactly twice that from a doubling (about 5 W/m$^2$ forcing). The present results suggest that for the NCAR model, somewhere between 5 W/m$^2$ forcing and 60 W/m$^2$, the global mean surface temperature response must become a significantly nonlinear function of the forcing. This issue is now under investigation by the authors with the NCAR CSM, and it might be interesting for other investigators to study this issue with different models (including models that have displayed a much stronger sensitivity to small climate forcing).

**References**


Boville, B. A., and P. R. Gent, 1998: *The NCAR Climate System Model, Version One*. J. Climate, 11, 1115-1130.

Ingersoll, A.P., 1969: *The runaway greenhouse: A history of water on Venus.* J. Atmos. Sci., 26, 1191-1198.

Kiehl, J.T., and R.E. Dickinson, 1987: *Study of the radiative effects of enhanced atmospheric carbon dioxide and methane on early earth surface temperatures.* J. Geophys. Res., 92, 2991-2998.

Manabe, S., and R. J. Stouffer, 1994: *Multiple-century response of a coupled ocean-atmosphere model to an increase of atmospheric carbon dioxide.* J. Climate, 7, 5-23.

Manabe, S., and R. Wetherald, 1975: *The effects of doubling carbon dioxide concentration on the climate of a general circulation model.* J. Atmos. Sci., 32, 3-15.

Nakajima, S., Y.-Y. Hayashi, Y. Abe, 1992: *A study on the runaway greenhouse effect with a one-dimensional radiative-convective equilibrium model.* J. Atmos. Sci., 49, 2256-2566.

Wetherald, R. and S. Manabe, 1975: *The effects of changing the solar constant on the climate of a general circulation model.* J. Atmos. Sci., 32, 2044-2059.


## Next Issue CMOS Bulletin SCMO

Next issue of the *CMOS Bulletin SCMO* will be published in April 2003. 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.

## Prochain numéro du CMOS Bulletin SCMO

Le prochain numéro du *CMOS Bulletin SCMO* paraîtra en avril 2003. 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.

# Review of Prairie Thunderstorms

by G.S. Strong, Ardrossan, AB

**ABSTRACT**

This is the second paper in a series reviewing prairie thunderstorms. The review has 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. The review is directed towards prediction problems associated with prairie thunderstorms and associated phenomena such as large hail, heavy rain, and tornadoes. The first paper addressed scale characteristics and regional climatologies of storms across the prairies. The current paper addresses synoptic and mesoscale processes associated with these phenomena. Alberta storms are emphasized because of the large source of published literature from the ALHAS/AHP field programs of 1957-85, as well as the author's own personal experience and research while with AHP. Results are borrowed from published studies over the U.S. High Plains where prairie data and case studies are lacking, but also to demonstrate results that apply universally to convective storms. Reference to other papers in this series will be by Section number; e.g., Section 1 refers to paper #1 (in CMOS Bulletin SCMO, 30, #4, October 2002). Figures and tables are numbered similarly.

**RÉSUMÉ (traduit par la direction)**

Cet article est le deuxième d'une série d'articles faisant l'examen des orages dans les prairies. 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 toute la gamme de processus convectifs; et (3) formuler des recommandations en vue de combler ces lacunes. L'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. Le premier article a porté sur les caractéristiques d'échelle et les climatologies régionales des orages dans les prairies. Le présent article porte sur les processus synoptiques et les processus d'échelle moyenne qui sont associés à ces phénomènes. L'accent est mis sur les orages en Alberta en raison du grand nombre d'articles publiés sur les travaux entrepris 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 recherches qu'il a entreprises dans le cadre de l'AHP. Des résultats sont tirés de travaux effectués dans les High Plains des États-Unis où les données et les études de cas sont inexistantes, afin de mettre en évidence des résultats qui s'appliquent à tous les orages de convection. Les renvois à d'autres articles dans cette série se feront par numéro de section : p. ex. Section 1 renvoie à l'article n° 1 (dans le CMOS Bulletin SCMO, 30, n° 4, octobre 2002). Les figures et les tableaux seront numérotés de la même façon.

## 2. Synoptic to Mesoscale Processes

### 2.1 SCALE INTERACTIONS AND ATMOSPHERIC ENERGETICS

Before discussing thunderstorm processes, it is necessary to establish the physical connections between large-scale energetics in the atmosphere and thunderstorm systems at the mesoscale. This begins with the most important findings of the dynamicists of the 1940s and 50s, and links with related results at the mesoscale. We then consider how severe storm research has evolved, and where the science is today, concentrating on diagnostic, and not numerical model studies. Relevant results are reviewed and forecasting applications are highlighted.

#### 2.1.1 Planetary-Synoptic Scale Energetics

Long before physical interactions between scales of motion were recognized, it was known that synoptic disturbances, alternately referred to as baroclinic waves or extra-tropical cyclones, experience an increase in kinetic energy as they intensify. Several schools of thought emerged as to how this increase in kinetic energy occurred. The original theory, attributed to Margules (1903), was that the kinetic energy (KE) of a cyclone increased through an *in situ* conversion of available potential energy (APE)[1] by an overturning or readjustment of airmasses of different density.

During the 1940s, revelations of the tremendous kinetic energy carried by the upper tropospheric jet streams led to renewed interest in energy conversion processes. Thereafter, Margules' theory came into question when Charney (1947) and Eady (1949) independently showed that APE of the zonal (planetary mean) flow was converted to (synoptic scale) KE in developing cyclones. Their work appeared to be in conflict with Kuo (1949), who

[1] Margules (1903) recognized a maximum attainable gain of kinetic energy through the adiabatic redistribution of total potential energy, and called it the *available kinetic energy* (AKE). Lorenz (1955) redefined this as the *available potential energy* (APE), being equal to the maximum amount of the total potential energy available for conversion into kinetic energy under adiabatic redistribution of mass.

demonstrated how the KE of a cyclone could come directly from KE of the planetary mean flow. Meanwhile, Starr (1948) and Rossby (1949) showed mathematically that single cyclones could not be even approximated as closed systems, and confirmed that the planetary and synoptic scale processes did indeed interact through exchanges of potential and kinetic energy. Using scaling arguments, Rossby showed that this is so because it is impossible to have a KE source in a closed system without also having sinks of KE, *independent of frictional sinks*, and that frictional dissipation alone does not account for the total energy sink observed in single cyclones.

In one of the earliest diagnostic studies of energetics, Starr (1953) introduced another complexity by showing that the synoptic scale feeds back at least some of its KE to the mean planetary flow, thereby maintaining the latter against frictional dissipation. From these studies, it was inferred that adjacent weather systems work in tandem, such that the KE of one system can feed a downstream system through conversion of energy between KE and APE. Hence, the minimum domain size for all large-scale numerical weather depiction models is a hemisphere, in order to include adjacent interacting weather systems. Lorenz (1955) confirmed these processes using diagnostic data, and, by partitioning the APE and KE budget equations into zonal and eddy components, showed that both the Charney/Eady and Kuo theories were possible. Perhaps more importantly, he suggested that there must exist intermediate scale eddies which hold the balance of energy between the observed synoptic scale and friction, thus giving rise to the distinction between *frictional* and *eddy* dissipation.

White and Saltzman (1956) may have been the first to speculate on the possibility of specific interactions between the synoptic scale and severe extra-tropical (mesoscale) thunderstorm systems. Forecasters since the mid-1950s simply assumed that synoptic scale systems were a primary 'trigger' for mesoscale thunderstorms, without actually identifying the mesoscale as one of Lorenz's intermediate 'eddies'. However, Richardson (1922), who also first conceived the equations of motion in finite difference form for later numerical models, may have been the first meteorologist to deduce the *scale interaction* process, likely from intuition, when he summarized it in a simple verse:

> *Big whirls have little whirls*
> *that feed on their velocity,*
> *And little whirls have lesser whirls*
> *and so on to viscosity.*
>
> L.F. Richardson (1922)

The above studies in atmospheric dynamics considered both the *downscale* and *feedback* modes of energy in the atmosphere. Following the lead of Lorenz (1955), synoptic scale diagnostic studies of energetics became quite popular in the literature. For example, Sechrist and Dutton (1970) showed that a developing shortwave cyclone, in varying degrees depending on the weather system, extracts upper level kinetic energy from the mean planetary flow upstream (the *downscale process*), while converting potential energy at low-levels in the atmosphere to kinetic energy of the mean flow at intermediate levels downstream (the *upscale process*).

### 2.1.2 Synoptic-Mesoscale Scale Energetics

Eliassen (1966) confirmed that there is both APE and AKE at adjacent scales (e.g., planetary and synoptic) for conversion to (eddy) perturbation energy of both types, and these could be redistributed either upscale or downscale. This vindicated Margules' (1903) original theory for the most part, but also introduced interesting possibilities for interactions between synoptic processes and mesoscale convective processes.

Diagnostic studies at the mesoscale were (and still are) limited by lack of mesoscale radiosonde data over an adequate domain size. However, during 1966-67, the National Severe Storms Laboratory (NSSL) in Oklahoma provided a radiosonde network of 10-11 sites with mean spacing of 100 km for several severe thunderstorm days. McInnis and Kung (1972) subsequently published the first energy budget results at the mesoscale, followed up by an eddy perturbation analysis by Kung and Tsui (1975) and Tsui and Kung (1977) using the same dataset. One of their most important conclusions, that KE dissipation from the synoptic scale west of severe storm complexes provided KE directly to the developing mesoscale thunderstorm system, was largely ignored by the severe storm research community until well into the 1980s, even though it paralleled the results of Sechrist and Dutton (1970) for synoptic-planetary wave interactions. Later studies, using 1979 SESAME (Severe Environmental Storms and Mesoscale Experiment) data, also over Oklahoma, partially confirmed these early scale interaction results at the mesoscale (Fuelberg and Jedlovec, 1982; Fuelberg and Printy, 1983). However, the Fuelberg group concentrated more on the energy feedback from the severe storm to the mean flow, neglecting the downscale process as a triggering mechanism on the west flank of the severe storm. We now know that the earlier deductions by the Kung group were correct; that is, that thunderstorms can consume energy supplied from the larger scale in addition to that generated through latent heat release. This process is probably most important during the pre-storm environment and storm initiation stages, while energy feedback is maximized during the mature storm period.

Strong (1986) made a detailed analysis of two SESAME severe storm cases, 09 May and 20 May, 1979, focusing on the mesoscale vertical motion fields. He noted that the severe storms in both cases were triggered by decaying synoptic systems, while the mesoscale systems grew in intensity. This corresponds with the Lorenz (1955) requirement for intermediate eddy dissipation of large-scale KE.

## 2.2 THE EVOLUTION OF CONCEPTUAL MODELS OF THUNDERSTORM PROCESSES

Once scientists recognize a problem, the traditional methodology is to consider some knowledge of the processes involved and some intuition as to the solution, develop a conceptual model (hypothesis) based on the known processes and intuitive solution, develop tests for the model, then revise the model accordingly and develop new tests, and so on. However, as Lorenz (1984) aptly but half jokingly pointed out, *"even the purest of mathematicians use intuition to obtain preliminary estimates, but in meteorology these estimates are often the final products"*. While slightly cynical, that statement has an element of truth to it. To some extent then, the direction of research on severe convective storms has been dictated to a large degree by the way in which conceptual models of thunderstorms have evolved. In turn, the instrumental tools that have been developed, most especially radar and research aircraft following World War II, have driven these conceptual models. It is therefore helpful to review this evolution in chronological order, a few models of which appear in Figures 2.1–2.6, from 1884-1986. This is not an exhaustive list, just enough to illustrate their influence on convective research.

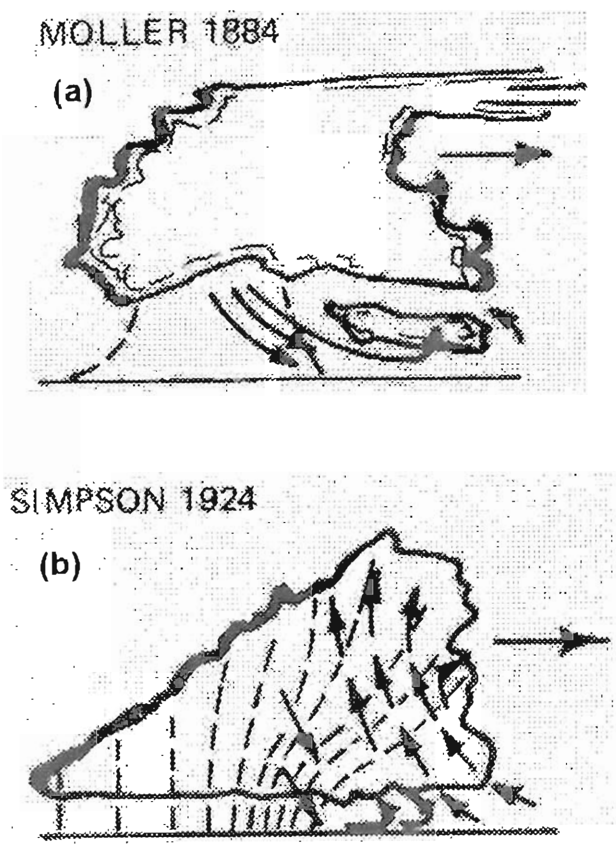



**Figure 2.1:** (a) An early conceptual model of a thunderstorm by Moller (1884), indicating updrafts/downdrafts, anvil, and storm motion; (b) model by Simpson (1924) adds precipitation. (Reproduced from Barnes (1976).

Figure 2.1, reproduced from Barnes (1976), depicts (a) the earliest known thunderstorm concept, attributed to Moller (1884), and (b) a model by Simpson (1924) with precipitation shafts added, but little else. These early models correctly depict low-level convergence, updrafts and downdrafts, and the anvil shape of thunderstorms, all from visual observations with very little instrumental data.

One of the most well known conceptual models, still used in introductory texts, is the simple three-stage thunderstorm model of Byers and Braham (1949), reproduced in Figure 2.2. This concept evolved from the *Thunderstorm Project* following World War II, when decommissioned military radar systems and aircraft became readily available for meteorological research in the U.S. It includes all basic cloud-scale and microphysical processes, but still does not indicate any interaction with synoptic scale or mesoscale processes.

A departure from the research focus on the *visual* storm came when Beebe and Bates (1955) described how synoptic-scale processes, including interacting upper and lower jets, provided favourable conditions for severe thunderstorm development, with low-level ascent causing adiabatic cooling of the boundary layer and effectively removing the *capping lid*, allowing free convection to take place. This was described in Section 1.6.1, Figure 1.10 (Strong, 2002).

By the 1960s, three-dimensional depictions of thunderstorm models were introduced, the first step towards incorporating extra-storm (environmental) concepts (Figure 2.3). The Newton (1960) model shows some tentative interacting environmental flow, while Fankhauser (1971) described a mesoscale environmental circulation interacting with the storm circulation (Figure 2.3b).

Chisholm and Renick (1972) expanded the concept of multicell and supercell storms (Figure 2.4a), describing storm evolution and propagation resulting from individual new cell growth and motion. They also presented distinct typical wind profiles for single cell, multicell, and supercell storms (Figure 2.4b).

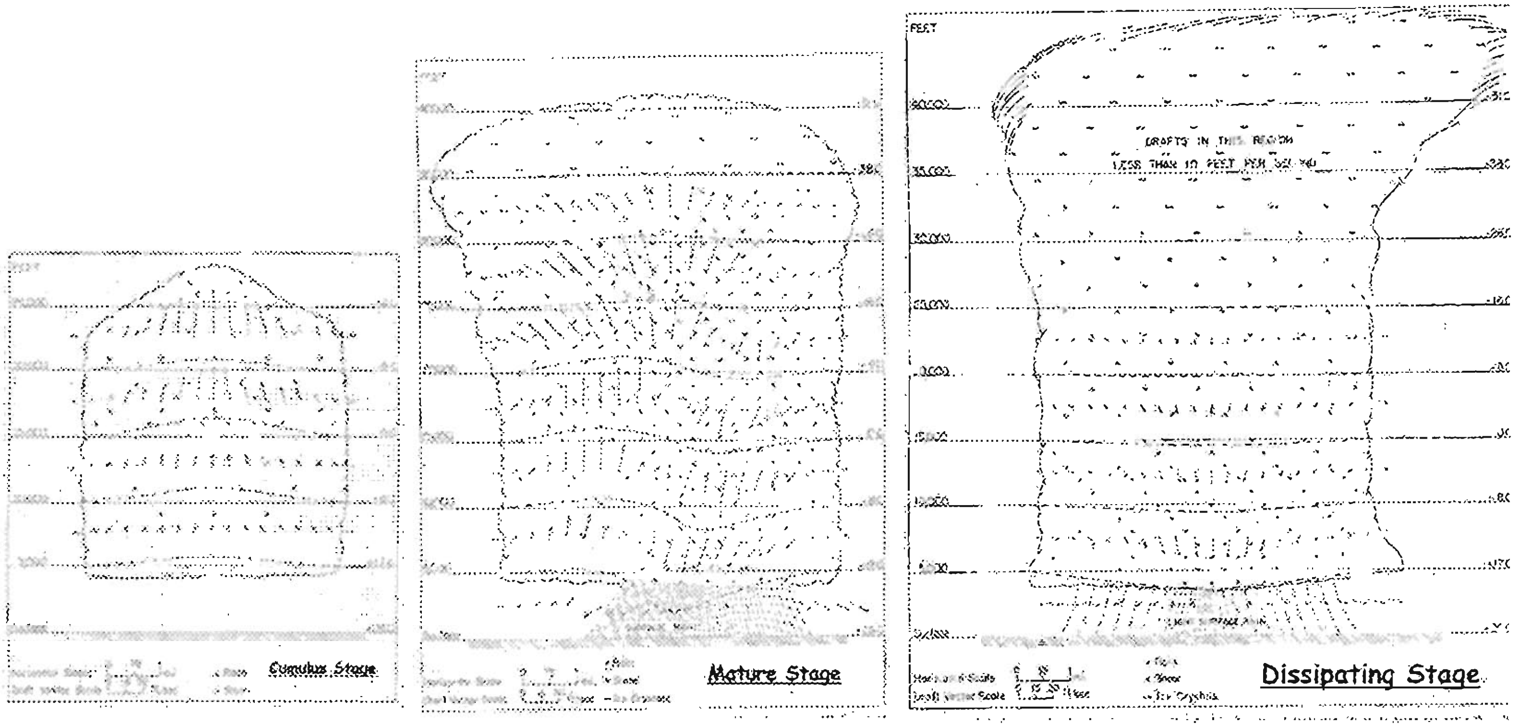



**Figure 2.2:** Three stages of thunderstorm development (reproduced from Byers and Braham, 1949).

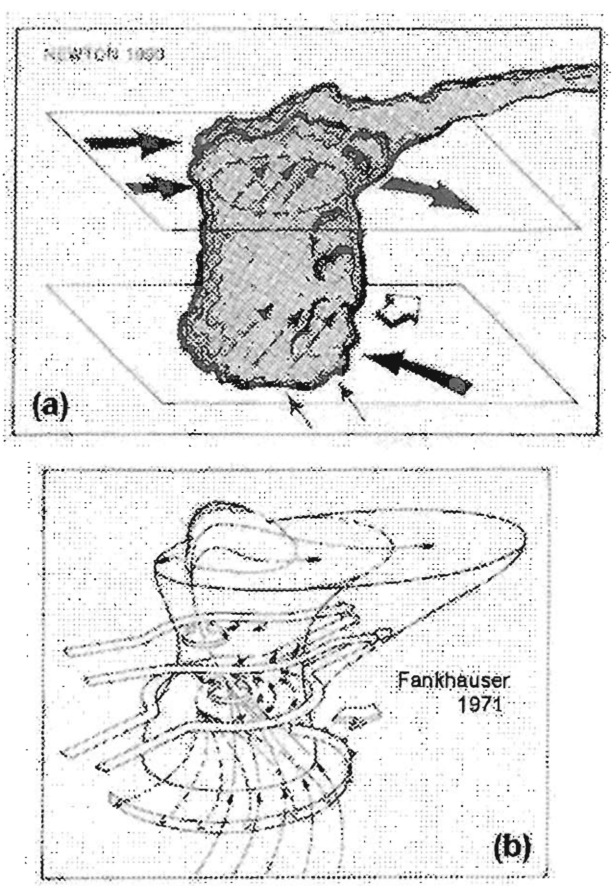



**Figure 2.3:** (a) Newton (1960) provided an early 3-D picture, which included a simple interpretation of environmental flow entering/departing the main storm. (b) Fankhauser (1971) introduced a mesoscale environmental circulation interacting with the storm circulation. (Reproduced from Barnes (1976).)

Lemon and Doswell (1979) extended the Fankhauser model to include the evolution of updrafts and downdrafts, tornado, and the mesocyclone in an evolving supercell with interacting mesoscale environmental flow (Figure 2.5). Maddox (1980) coined the term Mesoscale Convective Complex (MCC), based on much improved satellite data during the late-1970s. These MCCs, consisting of clusters of interacting thunderstorms, exhibited mesoscyclone organization and circulation patterns not unlike synoptic scale systems in many instances, and suggested a strong link to synoptic processes. These developments revived the synoptic-mesoscale connection suggested by White and Saltzman (1956), and verified in limited case diagnostic studies by the Kung groups. It also led to more detailed mesoscale analyses of the pre-storm and storm environment through the use of multi-scale field experiments such as SESAME in Okalahoma, 1979 (Barnes, 1981), CCOPE in Montana, 1981 (Knight, 1982), and the LIMEX studies in Alberta, 1980-85 (Strong, 1989).

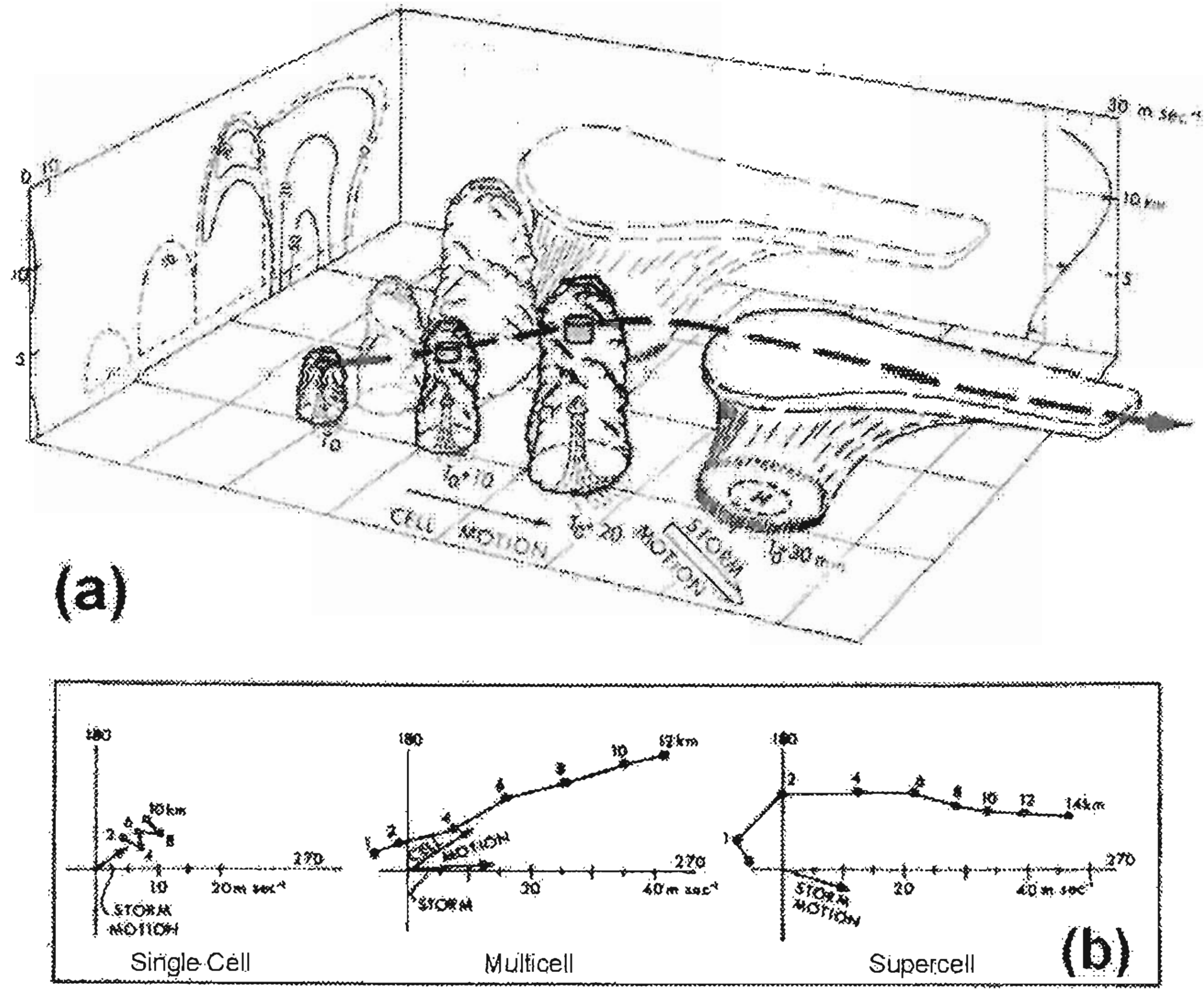



**Figure 2.4: (a)** Artistic view of a multicell storm illustrating the time variations in the lifetime of a single cellular element; **(b)** typical wind hodographs for single cell, multicell, and supercell thunderstorms. (Reproduced from Chisholm and Renick, 1972.)

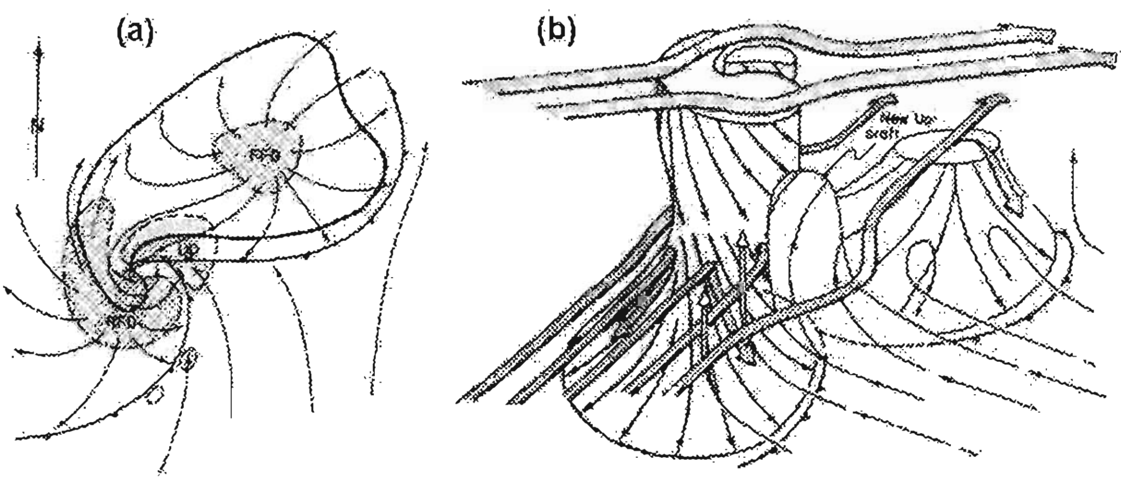



**Figure 2.5: (a)** Schematic plan view of tornadic thunderstorm at the surface, showing the updraft (UD), front flank downdraft (FFD), rear flank downdraft (RFD), and tornado (T) inside the 'hook'; **(b)** schematic 3-D depiction of the drafts, tornado, mesocyclone, and environmental flow for a supercell storm. (Reproduced from Lemon and Doswell, 1979.)

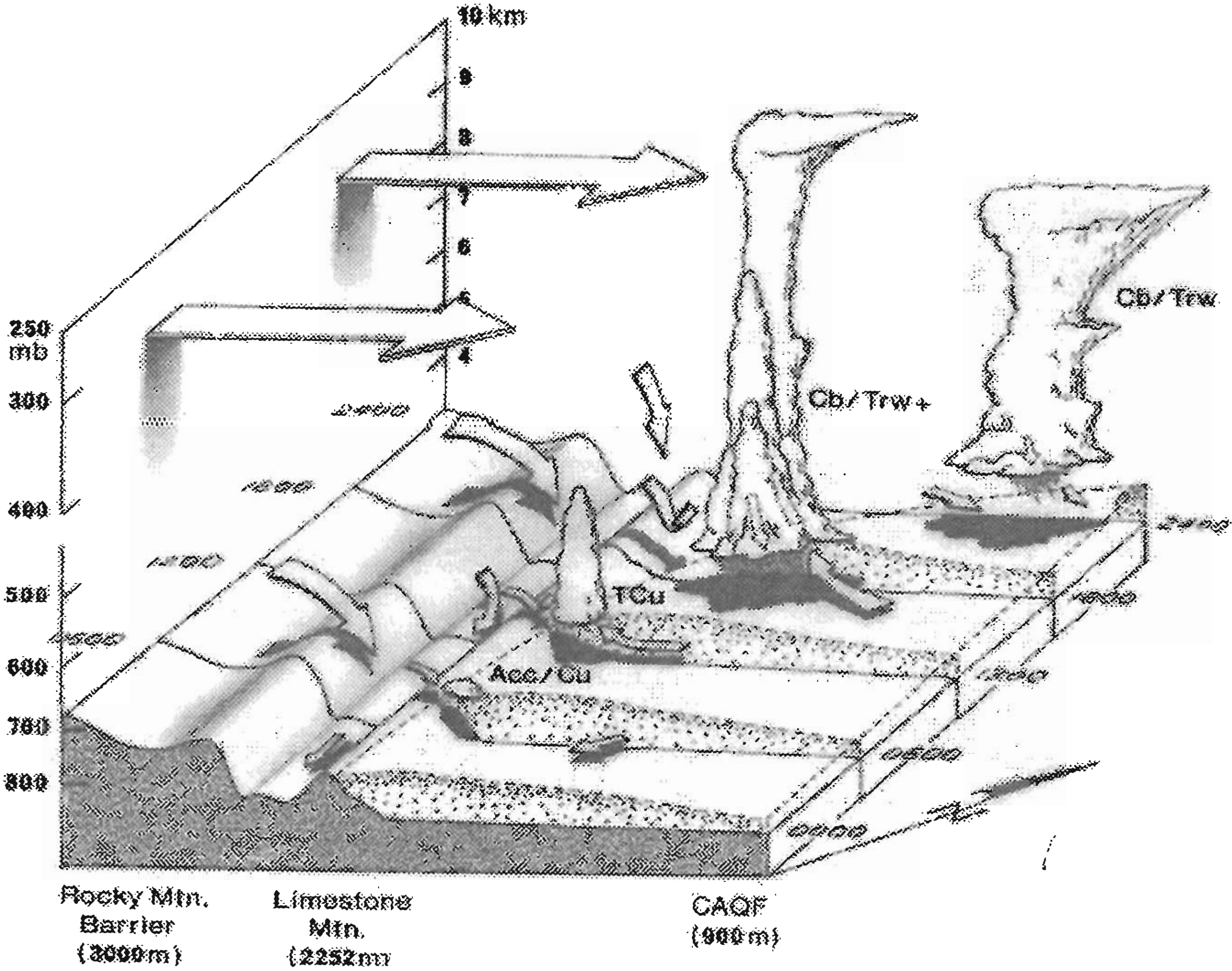



**Figure 2.6:** A 3-D depiction of the multi-scale conceptual model of severe Alberta thunderstorms (Strong, 1986; 2000), which incorporates synoptic processes, topographic forcing, sensible/latent heat factors, and the *capping lid* in storm initiation and morphology.

Strong (1986; 2000) described a multi-scale conceptual model for Alberta thunderstorms (Figure 2.6) with a particular focus on the capping lid. This model incorporates many of the synoptic scale, mesoscale, and cloud scale processes described above. The lid initially starts to form with large-scale subsidence warming in advance of an upper ridge, creating an unstable layer at mid-levels. The subsidence and unstable layer is extended to low-levels close to the mountains through orographic subsidence warming in a southwest flow. Nocturnal cooling then creates a surface inversion that is strongest over the foothills due to the combined sources of subsidence. With the approach of an upper shortwave and surface cyclogenesis a day or so later, low-level ascent initiates boundary layer convergence over the foothills, inducing a differential easterly component, the ascent thereby enhanced by orographic upslope flow. The easterly boundary layer flow advects moisture into the foothills from the plains, where grain crops provide a ready source of moisture from daytime evapotranspiration. The adiabatic lift and cooling initially raises and cools the surface inversion, while the boundary layer is warmed adiabatically through surface heating, creating the *capping lid*; that is, a moist boundary layer, capped by a shallow inversion, and topped by a dry unstable layer above. The low-level ascent that creates the lid is also its undoing, as continued adiabatic cooling of the lid, and continued adiabatic warming of the boundary layer through surface heating, eventually weakens the lid to the point where free convection can take place. The latter is often explosive, with thunderstorms suddenly forming where the skies may have been clear a few minutes to an hour previously. When these factors combine over a region of the foothills where there are 'foothill peaks', such as Limestone Mountain west of Red Deer (shown schematically in Fig. 2.6), the stable lid will tend to be initially strongest just east of those peaks, but also weaken fastest due to enhanced orographic lift on the east slopes. The result is that the most severe Alberta thunderstorms tend to form first on the east slopes of these foothill peaks. A revised version of this model to include *dryline* influences will be presented in a forthcoming paper in this series.

To summarize, most severe storm research conducted up until the late-1970s neglected interactions with synoptic scale processes in favour of the *visible* cloud microphysics processes, with radar and cloud physics aircraft the major tools. This changed after the introduction of three-dimensional conceptual models in the 1970s, and with the recognition of MCCs by Maddox (1980), when storm environment flow could no longer be ignored. During that period, however, a small contingent of meteorologists, led by Beebe and Bates (1955), had effectively started a parallel mode of severe storm research dedicated towards the thunderstorm *environment* and forecasting, a group that included Miller (1959), Maddox (1973), and others.

Almost 25 years passed before the two groups started working closely again with the SESAME project in Oklahoma. Meanwhile, the forecasting community developed useful forecasting techniques based on synoptic scale influences interacting closely with mesoscale (and smaller) convective processes (e.g., Fawbush et al., 1951; Galway, 1956; Miller, 1959; Sly, 1966; Maddox, 1973; Strong, 1979).

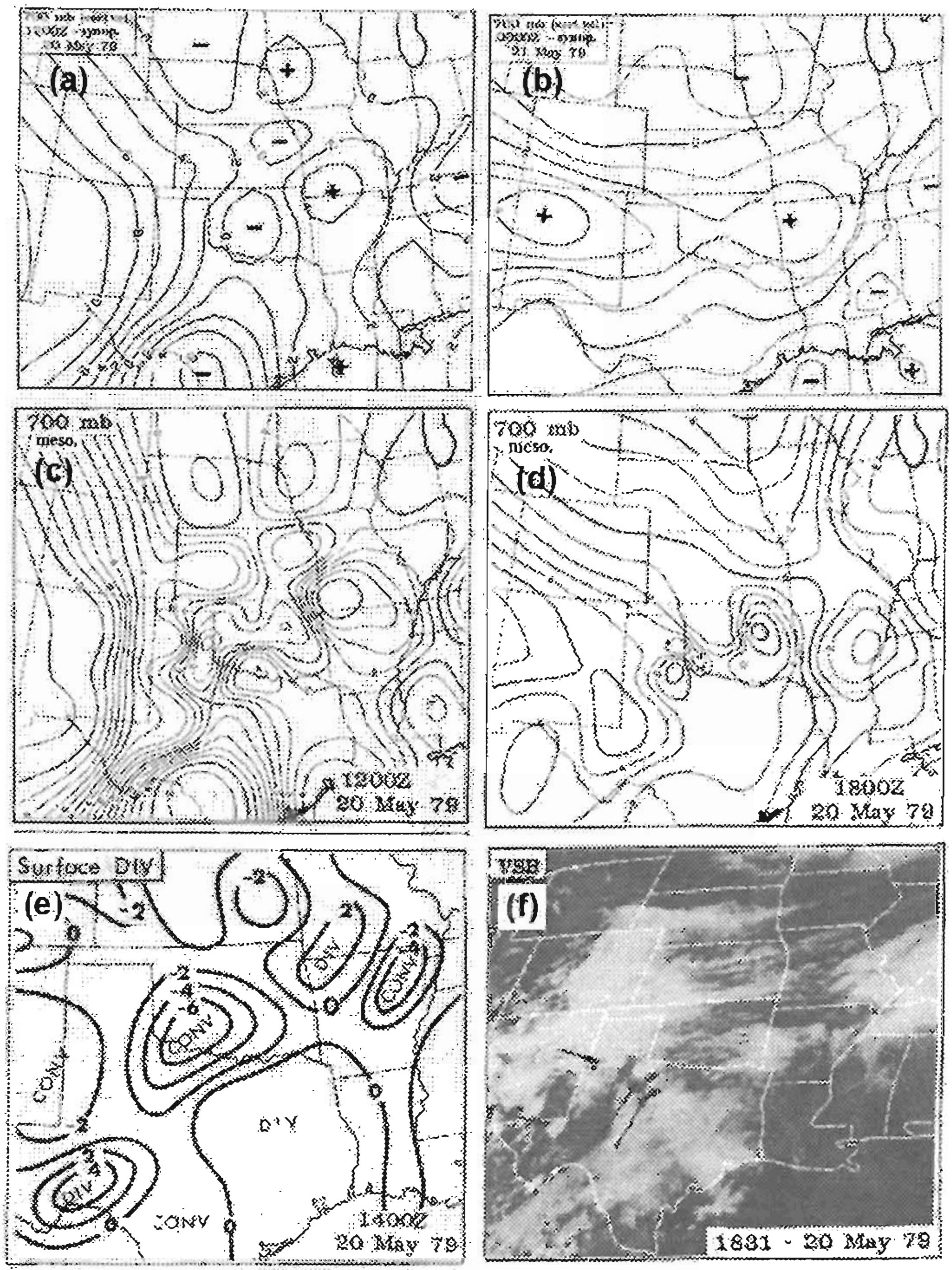



**Figure 2.7:** 700 hPa Synoptic scale vertical velocity (cm $s^{-1}$) at **(a)** 1200 and **(b)** 2400 UTC, mesoscale analysis of vertical velocity at **(c)** 1200 and **(d)** 1800 UTC, **(e)** surface divergence ($s^{-1}$) at 1400 UTC, and **(f)** GOES visible image at 1830 UTC, 20 May 1979, Oklahoma SESAME data. [Divergence field (e) reproduced from Sikdar & Fox, 1983; others from Strong, 1986.]

## 2.3 THUNDERSTORM PROCESSES AND SCALE INTERACTIONS

### 2.3.1 Storm Environment Dynamics

The importance of large-scale physical processes such as temperature advection, moisture convergence, and ascent to convective storm development has been recognized for at least 50 years (e.g., Fawbush et al., 1951). High degrees of air mass instability in the absence of significant dynamics to organize a storm, and to prolong its lifetime, simply results in short-lived cumulus congestus clouds which can create large raindrops, but which fall back in on the cloud, destroying the updraft which created it, and ending that convective cycle early. This is as close as nature comes to a single-cell storm, which has a lifetime measured in minutes, and is typical of tropical convection where often there may be little or no larger dynamics occurring. However, high instability in the presence of favourable dynamics usually results in a severe thunderstorm that continues to generate new storm cells (as described by Chisholm and Renick in Fig.2.4a), such that the full storm cycle can last many hours while travelling long distances. Deep convective clouds can result simply from advection of cooler air aloft, which has the effect of destabilizing the airmass in much the same way as strong surface heating. However, to achieve a *severe thunderstorm* usually requires a sustained mesoscale region of low-level convergence and ascent, together with the release of sensible and latent heat.

The 1979 Oklahoma SESAME (Severe Environmental Storms and Mesoscale Experiment) severe storm cases are of particular interest, as the special radiosonde network during SESAME allowed comparative synoptic scale (sites at average 370-km spacing and 3-6-hour soundings) and mesoscale analyses (20 sites at average 80-km spacing providing 1.5-3-hour soundings) of storm environment parameters not possible using any Canadian dataset. Some pre-storm and early-storm analyses for the SESAME case of 20 May, 1979 are provided in Figure 2.7 (from Strong, 1986). The 700 hPa synoptic scale vertical velocity field at 1200 UTC in (a) shows subsidence from south-central Texas northward through central Oklahoma. However, the addition of the Oklahoma mesoscale radiosonde network data reveals a small region of ascent (c) along the Oklahoma-Texas border exceeding 4 cm $s^{-1}$, virtually super-imposed over the synoptic scale subsidence. This region of ascent persisted through 1800 UTC (d), when several severe thunderstorms formed (f) just southwest of Oklahoma and over the Texas Panhandle. The 1200 UTC mesoscale vertical velocity field (c) over southwest Oklahoma corresponds well with a region of surface convergence over that region at 1400 UTC (negative values in Fig. 2.7e). Since the mesoscale ascent and surface convergence were present at least eight hours prior to first radar echoes of convective clouds (after 1800 UTC), one can easily argue that these were induced by the synoptic scale system upstream (ascent west and southwest). One might further speculate that this Oklahoma storm was partly initiated by downscale eddies from the synoptic scale, although we have no quantitative evidence that this was clearly the case. The storms shown in (f) formed a well-defined mesoscale convective complex (MCC) covering most of Oklahoma over the following three hours. The storm-scale ascent eventually swamped even the synoptic scale analysis by 2400 UTC (b), with ascent evident throughout Oklahoma.

This SESAME example demonstrates how well computed fields of low-level convergence or ascent correspond to storm regions, even several hours prior to convective initiation. Chen & Orville (1980) suggested that to effectively forecast cloud scale convection 3-6 hours in advance, some knowledge of the mesoscale convergence field (or of low-level vertical motion) was necessary, at least qualitatively if not quantitatively.

Ogura et al. (1982) carried out a detailed mesoscale analysis of severe tornadic thunderstorms developing along a cold front over the Texas-Oklahoma panhandles, which subsequently swept down over the SESAME mesoscale radiosonde network on 09 May, 1979. This case featured a very prominent and strong capping lid over a wide area, which they concluded was removed by mesoscale ascent associated with the front. Stobie et al. (1983) studied severe storms on the same day just north of the SESAME network, and concluded that gravity wave trains initiated the convective storms by extracting energy from the synoptic flow through 'critical level interaction', which presumably is the same thing as the eddy dissipation of Lorenz (1955). Carlson et al. (1983), Lanicci and Carlson (1983), and Strong (1986) conducted detailed analyses for this case, and discussed the importance of differential advection, ascent, and various thermodynamic variables in the initiation of severe convective storms in Texas and Oklahoma.

Honch and Strong (1990) and Brennand (1992) used LIMEX-85[2] mesoscale radiosonde data (described by Strong, 1989) to highlight mesoscale moisture convergence and low-level ascent in the initiation of Alberta storms. Synoptic (500 hPa and surface) analyses for the 11 July, 1985 case are shown in Figure 2.8, along with an S-Band radar PPI of the mature storm stage. The latter also shows 8 sites of the radiosonde network (missing site ABP is 160 km west-southwest from Red Deer, AQF). The main storms on this date remained north of the LIMEX network. Soundings were representative of storm inflow, and therefore of great value in analysis.

[2] The Limestone Mountain Experiment, a mesoscale data network consisting of 9 upper air sites at 50-60 km spacing, and 8 surface mesonet sites at 20-km spacing, was designed to investigate the capping lid and pre-storm environment over Alberta foothills during 08-23 July, 1985 (described in detail by Strong, 1989).

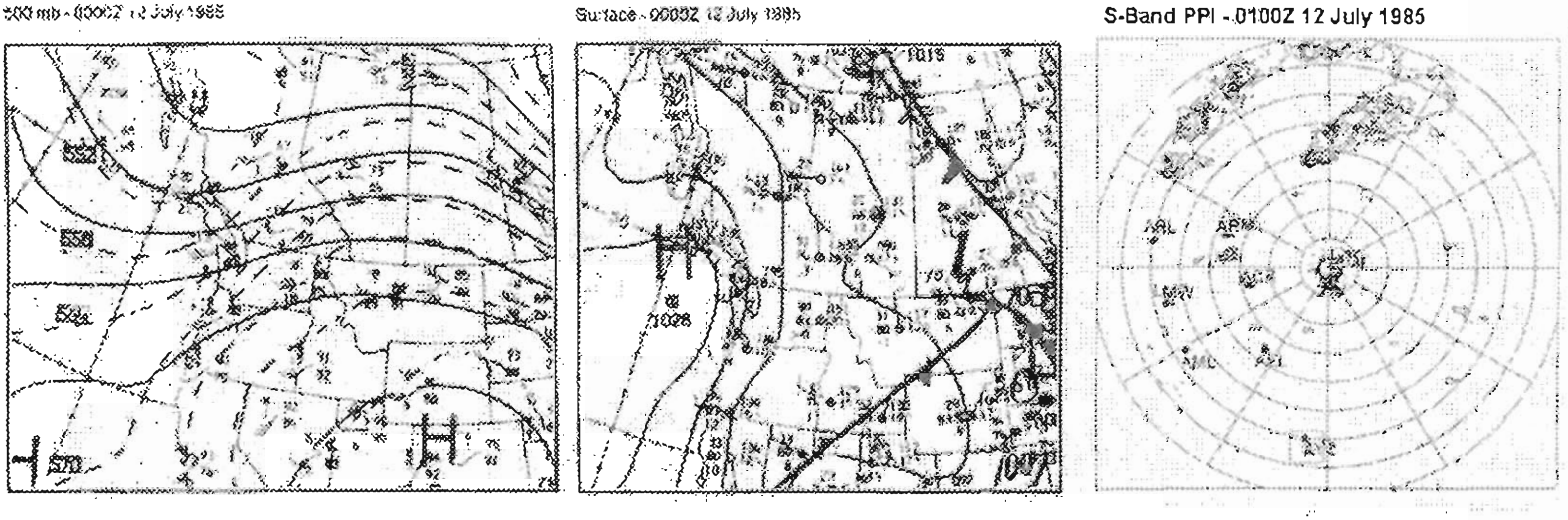



**Figure 2.8:** 500 hPa and surface analyses for 0000 UTC, and S-Band radar PPI for 0100 UTC, 12 July, 1985. Latter also shows locations of LIMEX-85 upperair sites.

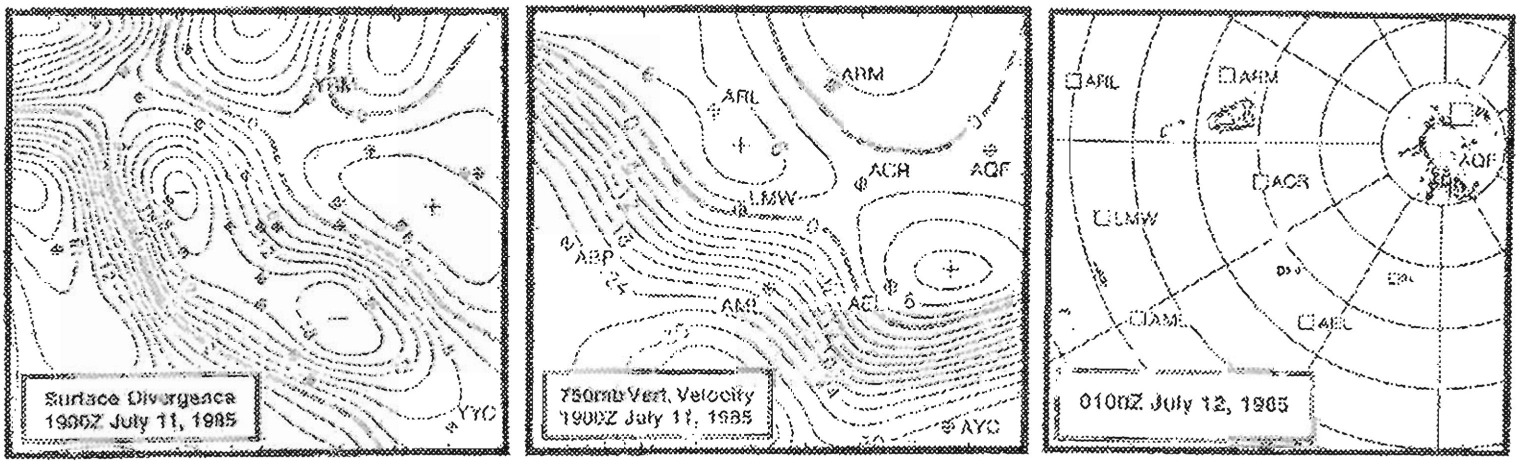



**Figure 2.9:** LIMEX-85 surface divergence ($s^{-1}$) and 750 hPa vertical velocity (cm $s^{-1}$) for 1900 UTC, 11 July, 1985, and S-band radar PPI for 0100 UTC, 12 July 1985. Centres of divergence and ascent are indicated by plus (+) signs. (Reproduced from Honch and Strong, 1990).

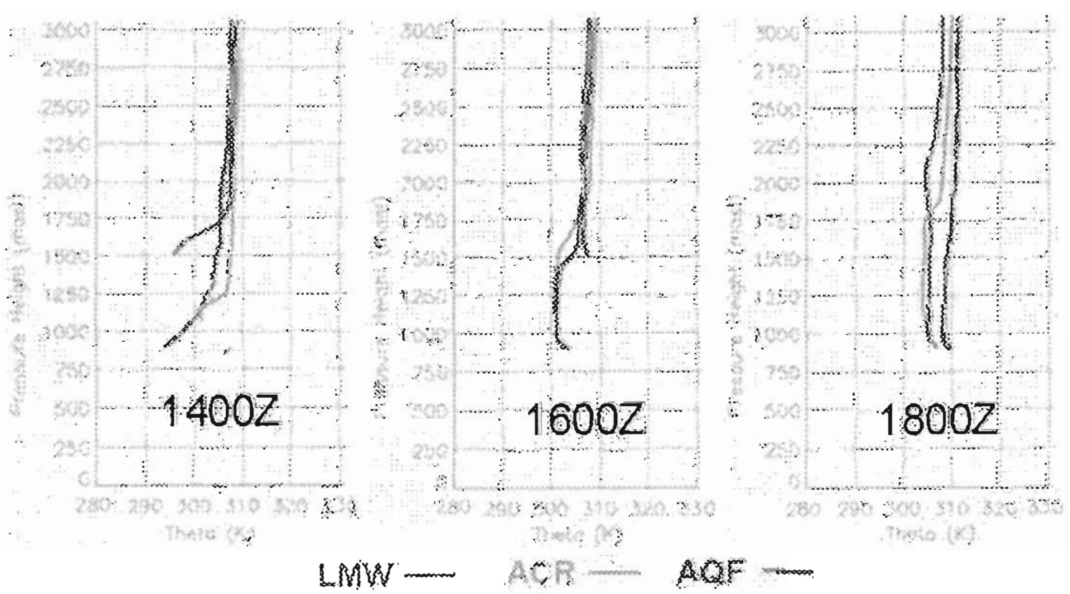



**Figure 2.10:** Four-hour change in profiles of potential temperature at three LIMEX-85 sounding sites west-east across the Alberta foothills on 11 July, 1985.

Figure 2.9 shows comparative surface divergence and 750 hPa vertical velocity fields at 1900 UTC, 11 July 1985, and the S-band radar PPI five hours later. The surface divergence field shows a line of strong convergence from the northwest corner of the grid southeastward to Calgary (YYC). The corresponding line of 750 hPa ascent lies 25-30 km northeast of the convergence line. A small thunderstorm formed 20 km further northeast of the line of ascent (between ARM and ACR) two hours later, with reflectivity later exceeding 50 dBZ. The major severe storm on this day formed northwest of ARM, and remained outside the LIMEX network.

2.3.2 Sensible and Latent Heat Flux

Sensible and latent heat fluxes are essential elements in the development of thunderstorms. Surface heating usually warms the atmospheric boundary layer (ABL) quite rapidly. Figure 2.10 for 11 July, 1985 during LIMEX-85 shows that the ABL potential temperature profile was 300K isothermal in the lowest 500 m by 1600 UTC (10:00 local time), and this increased to almost 310K isothermal to well above 2000 m above ground by 1800 UTC. Such rapid changes in boundary layer profiles during late morning are typical for the Alberta foothills.

The Canadian prairies are generally a moisture sink during summer, with evapotranspiration exceeding precipitation by factors of 2-4 times (Strong, 1997). Convective storms derive most of their moisture needs from the atmospheric boundary layer (ABL). Moisture advected from the Pacific Ocean to the prairies at 2-3 km ASL elevation does not reach the ABL directly, but must first be precipitated out by larger-scale systems in the form of rain or snow for days, weeks and months before convective storms can draw on resulting soil moisture. Prairie convective storms derive negligible amounts of advected moisture from the north. Manitoba storms can benefit from moisture advected from the southeast quadrant, especially in a prolonged southerly upper flow. Saskatchewan benefits less than Manitoba from moisture advection from the south, while drier regions south of Alberta (e.g., Montana) are rarely a moisture source for Alberta storms. Hence, convective storms for most of the prairies feed off recycled soil moisture, and have the important role of redistributing moisture more evenly across the prairies. Otherwise, prairie agriculture would be considerably more limited. Soil moisture is highly variable at the start of summer, being dependent on antecedent precipitation from the previous fall, melt from winter snowfall, and the occurrence of one or more spring 'cold lows' to bring the moisture which farmers depend on for crop germination. Once germinated, grain crops transpire copious amounts of water back to the ABL during mid-June through mid-August, sometimes at rates as high as 10 mm $d^{-1}$ (Strong, 1997).

Thus, local evapotranspiration is a major source of moisture for producing deep convective clouds on the prairies, most especially in Alberta, and slightly less so further east across the prairies. Some evidence for this is found in the LIMEX-85 data. For example, large diurnal increases in precipitable water are noted on 11 July, 1985 (Figure 2.11), especially over the foothill sites at Rocky Mountain House (ARM, 8.7 mm) and Caroline (ACR, 7.0 mm). Lesser increases are indicated at Limestone Mountain West (LMW, 4.8 mm), close to the main Rocky Mountain barrier, and at Red Deer (AQF, 4.2 mm) just east of the foothills. The Edmonton sounding (at Stony Plain, WSE), which lies considerably further northeast from the foothills and mountains, exhibited only a minor increase (0.3 mm), although only two operational soundings were available to reflect this. While these increases cannot be attributed solely to local evapotranspiration from this simple analysis, one would be hard-pressed to find a distant source of low-level moisture advection in the southwest flow aloft (Figure 2.8) in this instance.

The higher initial values of precipitable water at WSE and AQF early in the day reflect their location over the grain-growing area of Alberta with high evapotranspiration rates, perhaps from the previous day. The band of low-level convergence over the foothills (Figure 2.9) in advance of an approaching shortwave trough (Figure 2.8) is typical of Alberta severe storm days, fed by transpiring moisture from grain fields to the east. This convergence band also contributes to drying out areas to the west close to the mountains later in the day (e.g., LMW). The values of precipitable water shown in Figure 2.11 are typical of Alberta storm days, and help explain why Alberta storms tend to initiate over the foothills, then propagate eastward with the upper winds and towards the moisture source east of the foothills. These facts also suggest that a foothills radiosonde site, where the majority of severe Alberta storms initiate, would be extremely helpful to the forecaster during summertime.

Related to this, Raddatz (1998) showed that the transformation of vegetation on the prairies over the past 100 years due to agriculture, has resulted in more frequent and probably more severe thunderstorms during the growing season, due to higher evapotranspiration rates over grain crops than over natural prairie grasses. Conversely, convective storms are probably less frequent prior to crop emergence in the early summer, and again during the senescence and post-harvest stages. There is a strong signal for this in the seasonal variation of hail days in Alberta shown in Figure 1.5 of Section 1 (Strong, 2002), with hail frequency increasing rapidly in late-May to early-June during crop emergence, and falling off by August when grain crops mature and stop growing and transpiring. Rabin et al. (1990) concluded that, in the absence of significant soil moisture, the flux of sensible heat warms and deepens the atmospheric boundary layer, generally reducing the low-level humidity, and favouring the development of fair-weather cumulus clouds rather than deep convection.

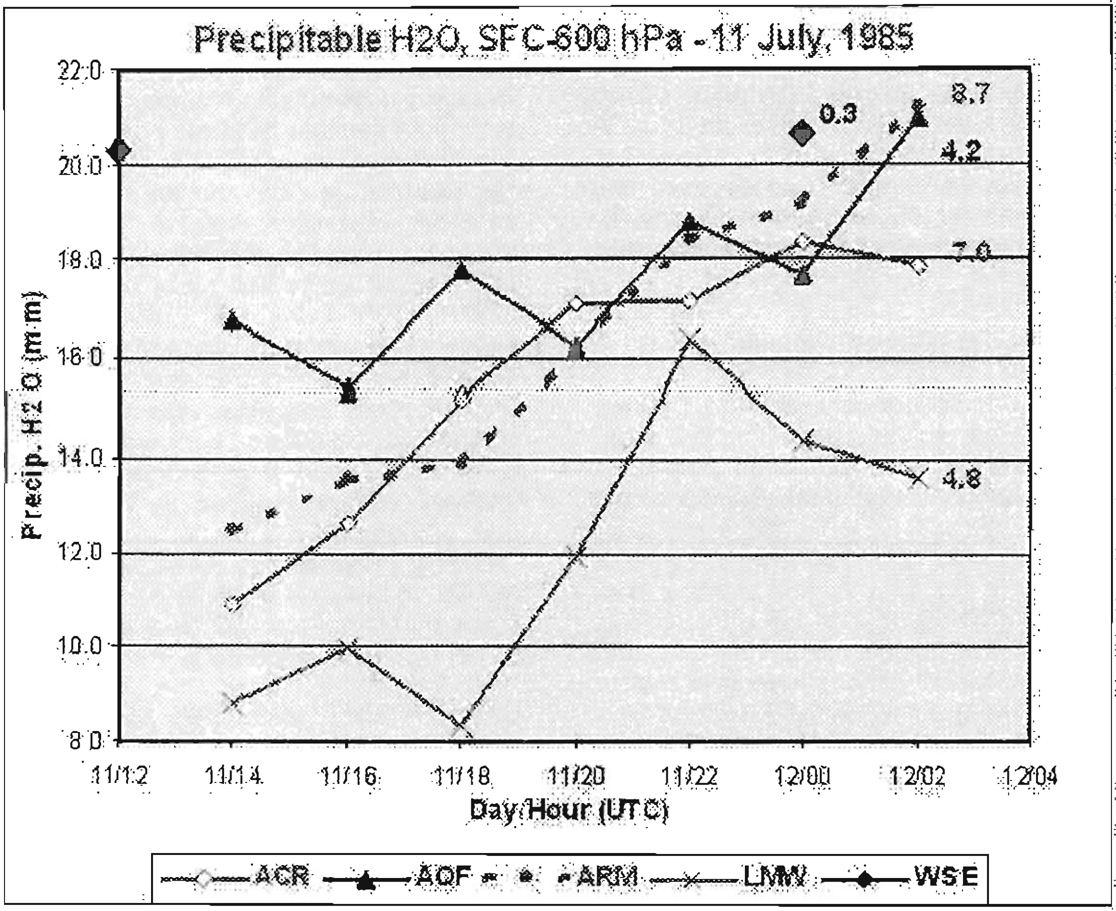



**Figure 2.11:** Diurnal increase in precipitable water on 11 July, 1985 during LIMEX-85. Plotted numbers are net increase for the day.

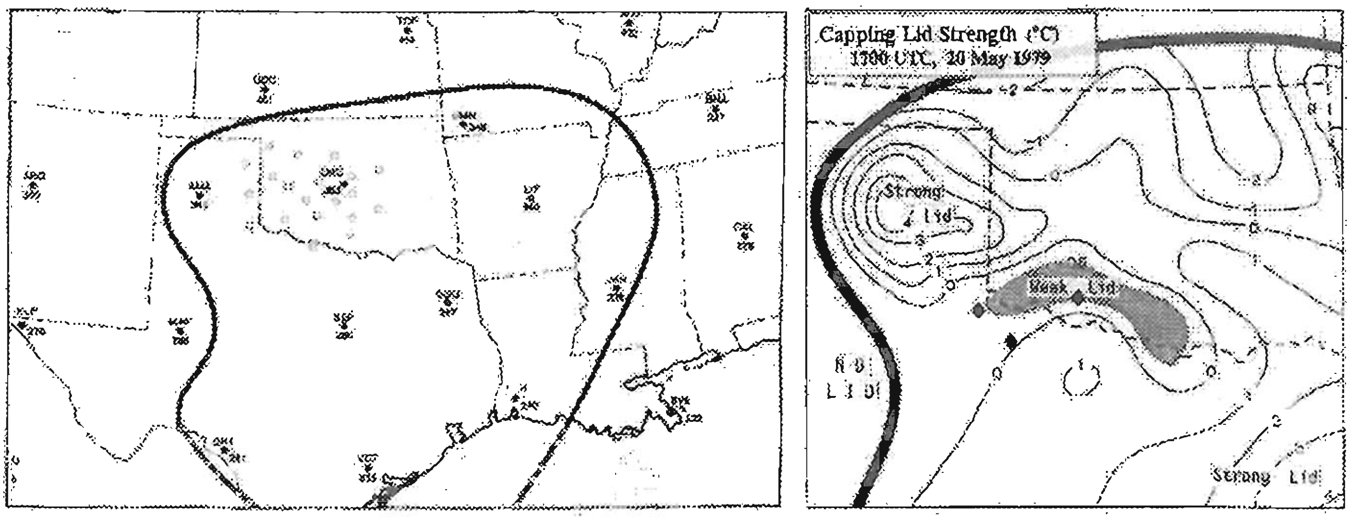



**Figure 2.12:** (a) Areal extent of capping lid and (b) lid strength at 1700 UTC during SESAME severe storm case of 20 May, 1979. Weakened lid region is indicated by the hatched area, and first radar cell echoes by the solid diamonds. (Reproduced from Strong, 1986).

Raddatz (2000) has also shown that 25-35% of the total summer rainfall during June-August of 1997-99 was recycled; that is, water that had previously fallen as rain being recycled through local evapotranspiration. Some of the original precipitation would have been non-convective, while the recycled rain was primarily convective. This suggests that a major thunderstorm system on one day can enhance the probability of storms on the following day, contributing to convective outbreak periods.

2.3.3 The Capping Lid, Drylines, and Jet Coupling

The *capping lid* was described in Section 1.6.1 (Strong, 2002) and 2.2 as a shallow stable layer with four main features: a moist ABL of 500 to 1500 m deep, capped by an inversion of temperature, or more correctly, of potential temperature, with dry air above the lid and a mid-level unstable layer. A strong capping lid frequently precedes a severe convective storm, but it is neither a necessary nor a sufficient condition for storms by itself. A capping lid can temporarily collect and trap moisture within the ABL, and prevent convection and latent heat release until such a time as the lid is weakened or removed. Capping lids can cover very extensive regions, and lid weakening can happen over as short a time as 2-3 hours. For example, Strong (1986) documented a large lid area covering most of five states during the SESAME severe storm case of 20 May, 1979 (Figure 2.12(a)). The low-level ascent and convergence indicated in Figure 2.7 caused the lid to weaken most rapidly over southwest Oklahoma by 1700 UTC (Figure 2.12b), and where the first severe storm cells were initiated 1.5 hours later.

Capping lids are also common across the Canadian prairies during summer, and the appearance of a lid often foretells an impending severe storm, but there has been no documentation of areal extent of the lid in any given situation. Strong (2000) provided an excellent example of the progressive weakening of a lid through adiabatic lift and cooling during the LIMEX-85 case of 11 July, 1985.

Severe weather forecasters, especially in the U.S., have been trained for many years to identify *drylines* as a signature to a severe storm situation. The physics involved was explained by Danielson (1977), who showed that westerly momentum is transported downward rapidly in the deep, dry mixed layer on the west side of the line separating dry hot desert air from moist air moving northward from the Gulf of Mexico, and that this downward westerly momentum can generate severe convective storms.

Some confusion occasionally arises over what constitutes a dryline for severe convective storms. Fawbush et al. (1951) and Miller (1959) spoke of a distinct 'dry tongue' at middle levels (700 hPa), and one rule for predicting the location of severe weather was *where the upper dry tongue crosses over the lower moist wedge*. However, Carlson and Ludlam (1968) defined the dryline as *a very rapid transition at screen-level from dew points of 18 °C or more in the moist southerly flow to values of 0 °C or less on the west side*. Schaefer (1973) described it being nearly vertical through the lowest 900-1200 m, having a slightly unstable or neutral temperature profile on the dry (west) side, and a low-level inversion or stable layer on the moist (east) side. He also indicated that the dryline exhibits the sharpest moisture discontinuity during the afternoon. Another important point was that the rapid motion of the dryline could not be accounted for by the mean wind across it. McGinley and Sasaki (1975) applied KE and momentum budgets with synoptic data to relate sources and sinks to the occurrence of severe thunderstorms in the vicinity of drylines. They concluded that the process involved in drylines is baroclinic symmetric instability, whereby momentum, assisted by turbulent mixing from surface heating, reaches ground level, increasing surface winds that produce strong local convergence and ascent, favouring thunderstorm development. This process also results in waves or bulges on the dryline, often accompanied by mesoscale surface lows on the dryline and strong westerly wind streaks.

Carlson (1982) emphasized the effect of differential advection of warm, dry air from the arid elevated Mexican plateau overrunning moist air over Texas and immediate areas. Ogura et al. (1982), describing the SESAME tornadic storm case of 09 May, 1979 over the Texas panhandle, observed a well-defined dryline present, but that it did not seem to have contributed directly to the initiation of storms in that case. Studies using satellite imagery frequently refer to the *dry slot* region generally in the southwest quadrant of synoptic cloud systems as regions of potential severe storm formation (e.g., Rockwood and Maddox, 1988). In these cases, the authors are obviously referring to a dryline throughout the troposphere. Parsons et al. (1991) describe the dew point gradient on a west Texas dryline as varying *18 °C* or more in distances less than 10 km. Doppler lidar measurements suggested that dryline convergence is intense with maximum ascent rates of 5 $ms^{-1}$. They observed a retrogressing dryline as hot, dry air overrunning a westward-moving denser, moist flow, with gravity waves observed above the dryline interface.

More recent studies clearly refer to a *surface dryline*, and also relate these to lines of convergence (e.g., Hane et al., 2000). Knott and Taylor (2000) describe a severe Alberta weather outbreak on 29 July, 1993, which they conclude was triggered by a dryline that originated in the southwest corner of the province, and then moved northeastward. The ensuing storms spawned three tornadoes, one of F3 intensity, and two of the four severe storms split. Their motivation in this study was to highlight synoptic and mesoscale features that suggest dryline formation, storm genesis, and storm splitting, so that forecasters can identify potential severe thunderstorm and tornado hazards.

The literature on convective storms over the southern U.S. often associate the *low-level jet* (LLJ) with the top of the capping lid, generally 800-1200 m above ground. Bonner

(1968) described it as primarily a night-time phenomenon, and offered various theories as to its cause, including diurnal oscillations in eddy viscosity, diurnal changes in temperature fields over sloping terrain, and blocking of the large-scale flow by the Rocky Mountains. Other than oblique references to 850 hPa wind maxima, the LLJ has not been well-documented on the Canadian prairies due to simple lack of data; i.e., only two long-term radiosonde sites for all three prairie provinces. The bulk of the literature on this phenomenon has resulted from studies over the U.S. High Plains, and includes theories relating upper- and lower-level jet (ULJ/LLJ) coupling to severe tornadic storms (e.g., Beebe and Bates, 1955; Uccellini and Johnson, 1979). The lack of prairie data on LLJs, especially on the frequency of this feature, makes it a prime target for future research on the prairies. Intuitively, it would seem that capping lids, drylines on the west side of the lid, and LLJs near the top of lids, and coupling of the LLJ and ULJ near storm initiation time, are intricately related, and are probably a link in the transfer of eddy energy from the large-scale to the severe storm environment.

2.3.4 Processes and Characteristics from Cloud Photography

Photography can be used to confirm cloud processes and characteristics, especially when using remotely sensed data such as radar and satellite images. Time-lapse photography has been instrumental in validating and documenting the history and lifetimes of new cells that merge into a main thunderstorm from the *feeder* and *shelf cloud* zones. Neither radar nor satellite images can measure returns on as fine a scale as photography allows. In the past, stereo-photographic techniques have also been used to obtain quantitative measurement of cloud dimensions (Renick and Douglas, 1970).

Section 1.2 raised the challenge of how storm characteristics and storm initiation mechanisms vary across the prairies. The Pine Lake tornado case of 14 July 2000 (see Joe and Dudley, 2000) provides a classic case of contrasting storm scale size characteristics. A large, rather ominous looking convective complex over southern Saskatchewan over-shadowed the smaller scale size Pine Lake storm over central Alberta earlier that day. The Alberta storm did not look severe (compared with the Saskatchewan storm) on a GOES infrared satellite photo at 0000 UTC, 15 July (Figure 1.1), but it had already left a 3-hour hailswath of up to golfball size hail across central Alberta, and would hit the Pine Lake trailer park 45 minutes later (where it caused 12 deaths).

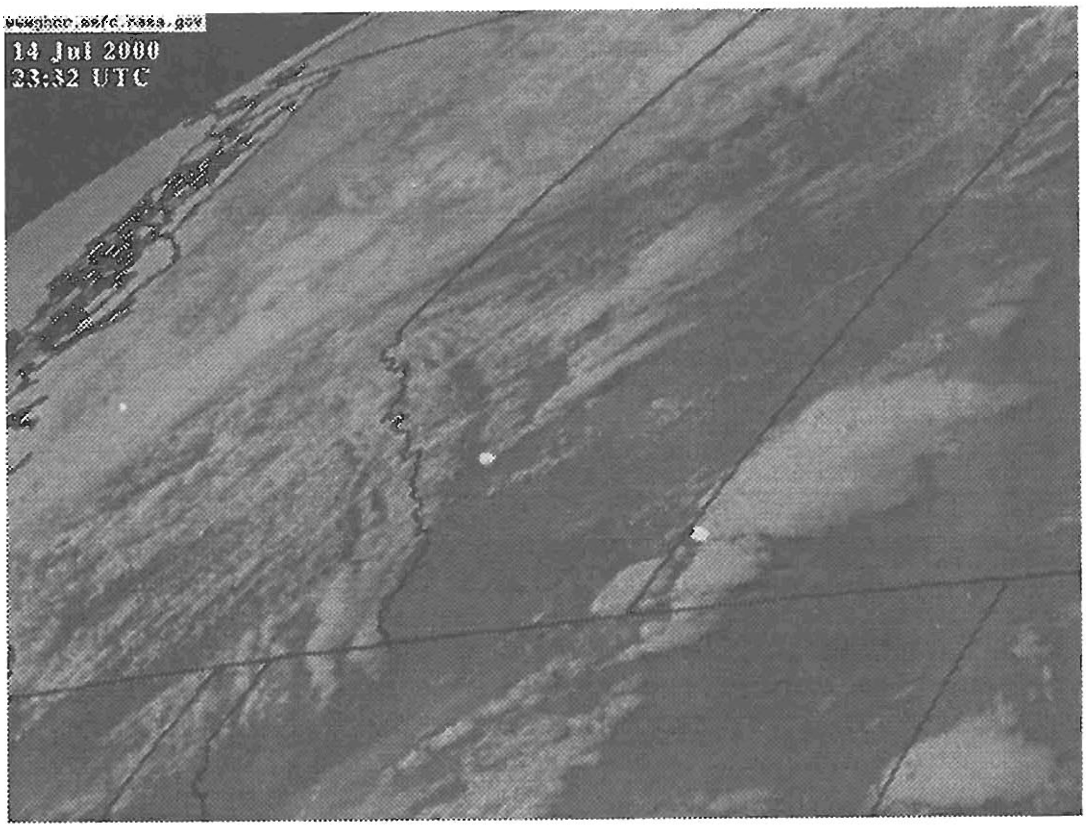



**FIGURE 2.13:** (a) Oblique visible satellite image of central Alberta & southern Saskatchewan storms, 23:32 UTC, 14 July, 2000. Pine Lake tornado storm is the southernmost one over central Alberta; white dots indicate locations where photographs shown on next page were taken.

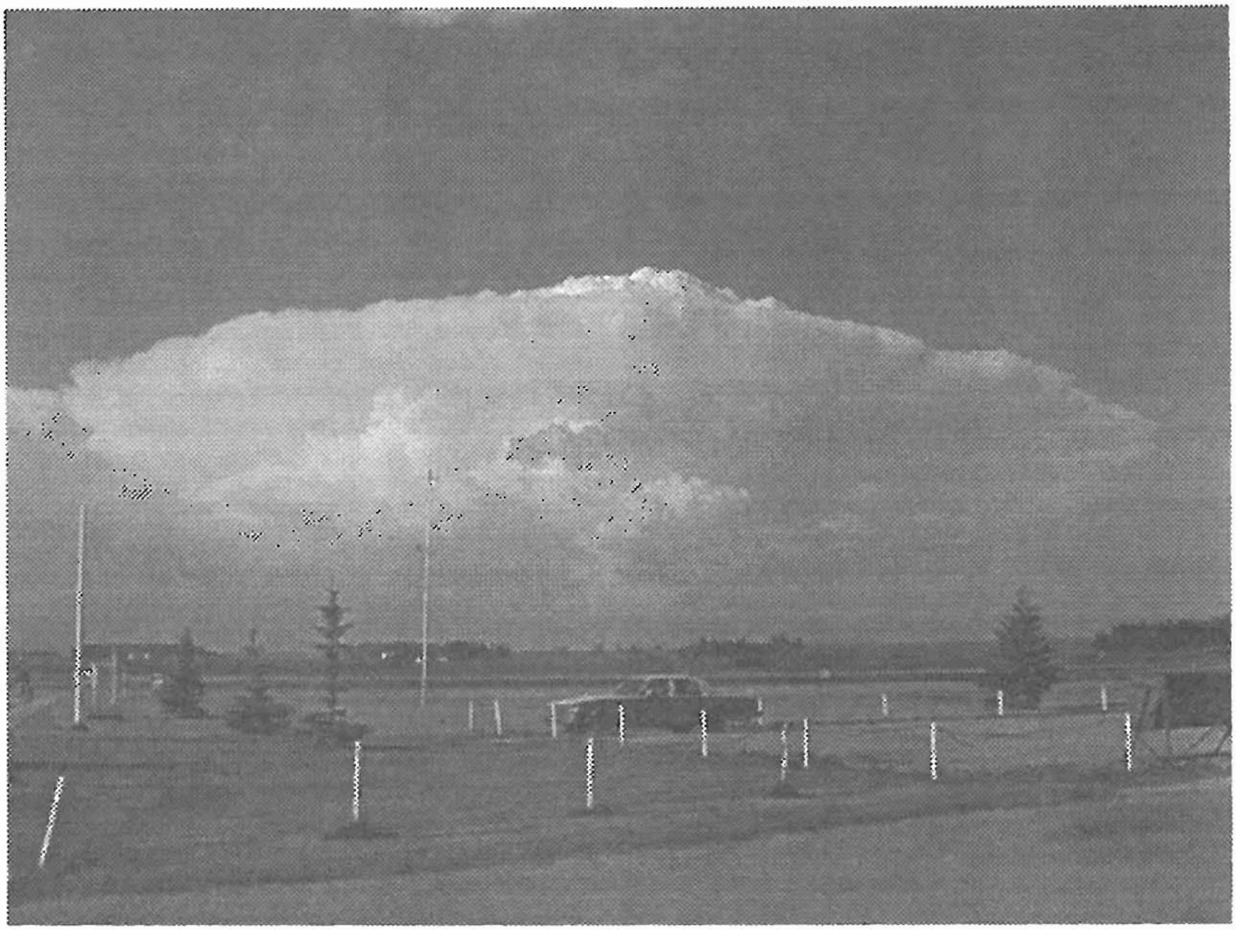


**FIGURE 2.13:** (b) Rear view (from Olds-Didsbury Airport) of Pine Lake Tornado storm, ~24:00 UTC, 14 July, 2000 (compliments Dr. Terry Krauss, WMI, Red Deer, AB). Also shown in colour on cover page (top photograph).

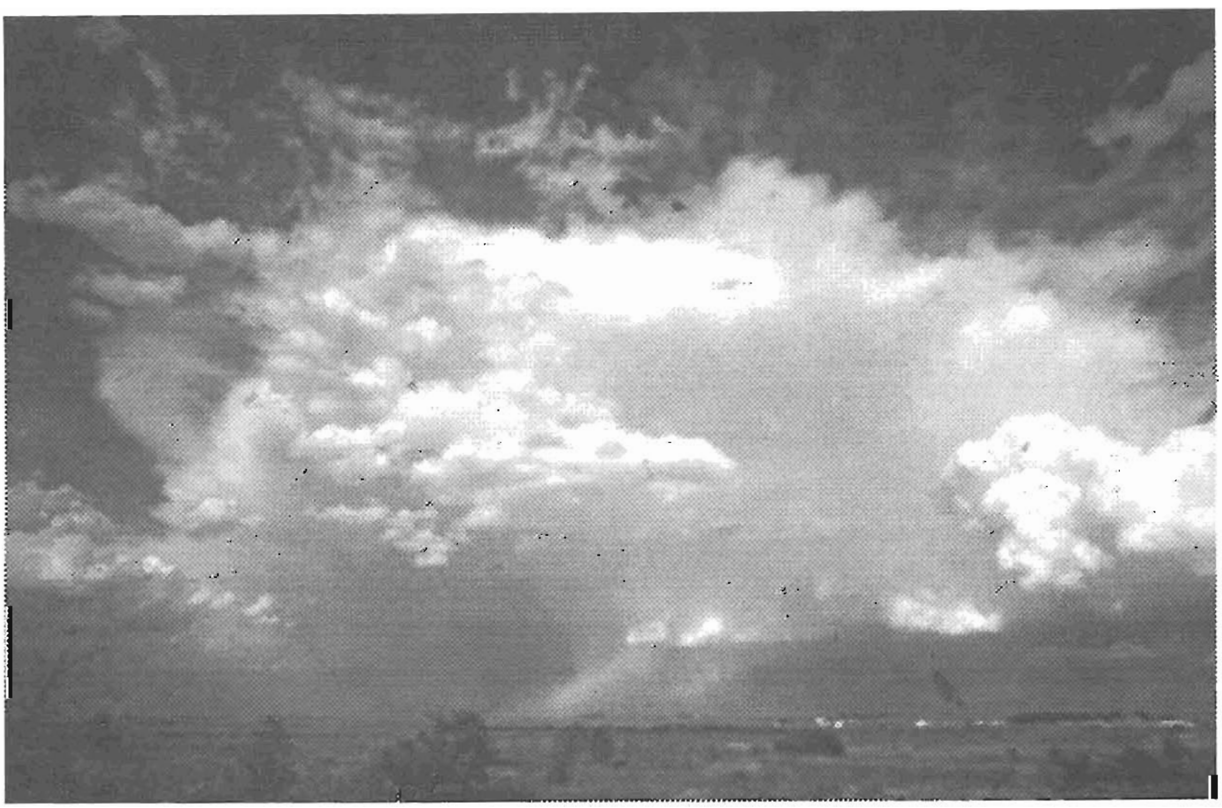


**Figure 2.13:** (c) Rear view (from near Maple Creek) of southern Sask. storms, 23:33 UTC, 14 July, 2000 (compliments of Arjen Verkaik, SkyArt Productions, Elmwood, ON). Also shown in colour on cover page (bottom photograph).

During this Pine Lake supercell storm, the professional *storm chase* team of Arjen and Jerrine Verkaik happened to be photographing the southwest Saskatchewan storm. Figure 2.13 shows an oblique-angled visible satellite image of both storms, a rear-flank photograph of the Pine Lake supercell with over-shooting top (taken from Didsbury-Olds Airport by Terry Krauss, pers. comm.), and a comparable rear-flank photograph of the decaying Saskatchewan storm by the Verkaiks, all within one half hour of each other. Figure 2.13 gives a different perspective on these storms than the larger GOES image of Figure 1.1. White dots on the satellite image indicate approximate locations from where the photos were taken. The two ground-based photographs give an unmistakable indication of the more severe storm, with clearer definition and over-shooting top on the Pine Lake storm.

### 2.4 Summary

Section 2 of this review has attempted to bring the concept of interacting scales of motion into focus as primary mechanisms in severe thunderstorm initiation and life cycle. The concept has been well-known and accepted at the planetary and synoptic scales since the late-1940s. Starr (1948) and Rossby (1949) showed how synoptic scale systems interact at the same scale, and that there must be sinks of kinetic energy independent of frictional sinks. Lorenz (1955) suggested that there must exist intermediate scale *eddies* which hold the balance of energy between the observed synoptic scale and friction, providing the distinction between *frictional* and *eddy* dissipation.

White and Saltzman (1956) speculated that one form of these eddies might be thunderstorm systems. Kung and Tsui (1975) used an early mesoscale radiosonde dataset to show that KE dissipation from the synoptic scale west of severe storm complexes can indeed provide KE directly to the developing mesoscale convective complex. However, the severe storm research community largely ignored this revelation until well into the 1980s, while they continued to focus research almost entirely on the visible mature storm processes, aided by rapidly developing Doppler radar systems. The concept of mesocyclones, improved satellite imagery, and the recognition of MCCs, presented a clearer visible connection between synoptic and mesoscale processes, and exchange of energy between scales.

Throughout these periods, it appears that weather forecasters had no difficulty with these concepts, and qualitatively applied them daily in predictions of convective weather phenomena.

There is a great need for research quantifying interactions between the synoptic and mesoscales prior to and during severe convective weather. Such studies have been rare in the past because of the high cost of the necessary radiosonde data at the mesoscale. However, new emerging technologies such as wind profilers, satellite soundings, atmospheric emitted radiance interferometers (AERI), and GPS moisture integrators provide the means to greatly offset such costs. Scale interaction and related studies required in this area include atmospheric KE, APE, and moisture budgets. The Canadian prairie situation also calls for field studies to better quantify scale characteristics of storms and related severe weather phenomena such as large hail and tornadoes, the roles of local evapotranspiration, the capping lid, drylines, the low-level jet, and other boundaries, and the delicate prairie balance between atmospheric moisture and surface water.

### 2.5 Acknowledgements

This paper is derived partly from a review funded by Emergency Preparedness Canada (EPC) to Strong and Smith (2001). The author also acknowledges the many contributions to severe storm research by scientists involved in Alberta Hail Studies and the Alberta Hail Project over the period 1957-85.

### 2.6 Bibliography

1) Barnes, S.L., 1976: Severe local storms: concepts and understanding. *Bull. Amer. Meteor. Soc.*, 57, 412-419.
2) Barnes, S.L., ed., 1981: *Project SESAME 1979 Data User's Guide*. NOAA, ERL, Boulder, Col., Feb. 1981, 236 pp.
3) Beebe, R.G., and F.C. Bates, 1955: A mechanism for assisting in the release of convective instability. *Mon. Wea. Rev.*, 83, 1-10.
4) Bonner, W.D., 1968: Climatology of the low level jet. *Mon. Wea. Rev.*, 96, 833-850.
5) Brennand, M.P., 1992: *Convective Storms and Moisture Fields in LIMEX85: A Case Study*. M.Sc thesis, University of Alberta, Edmonton, 136 pp.
6) Byers, H.R., and R.R. Braham, 1949: *The Thunderstorm. Final Rep.*, Dept. Meteor., Univ. Chicago, Chicago, Ill., 287 pp.
7) Carlson, T.N., 1982: The role of the lid in severe storm formation: Some synoptic examples from SESAME. *Preprints 12$^{th}$ Conf. Sev. Lcl Storms*, San Antonio, Amer. Meteor. Soc., Jan. 1982, 221-224.
8) Carlson, T.N., and F.H. Ludlam, 1968: Conditions for the occurrence of severe local storms. *Tellus*, 20, 203-226.
9) Carlson, T.N., S.G. Benjamin, G.S. Forbes, and Y-F. Li, 1983: Elevated mixed layers in the regional severe storm environment: conceptual model and case studies. *Mon. Wea. Rev.*, 111, 1453-1473.
10) Charney, J.G., 1947: The dynamics of long waves in a baroclinic westerly current. *J. Meteor.*, 4, 135-162.
11) Chen, C-H, & H.D. Orville, 1980: Effects of mesoscale convergence on cloud convection. *J. Appl. Meteor.*, 19, 256-274.
12) Chisholm, A.J., and J.H. Renick, 1972: Supercell and multicell Alberta hailstorms. *Proc. Int. Cloud Phys. Conf.*, London, Eng., Aug. 1972, 1-8.
13) Danielson, E.F., 1977: A conceptual theory of tornadogenesis. Part I: Large-scale generation of severe

storm potentials. *Meteor. Monogr.*, Amer. Meteor. Soc.
14) Eady, E.T., 1949: Long waves and cyclone waves. *Tellus*, 1, 33-52
15) Eliassen, A., 1966: Motions of intermediate scale: fronts and cyclones. *Adv. in Earth Sci.*, M.I.T. Press, Cambridge, Mass., 98, No. 5, 111-138.
16) Fankhauser, J.C., 1971: Thunderstorm-environment interactions determined from aircraft and radar observations. *Mon. Wea. Rev.*, 99, 171-192.
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) Fuelberg, H.E., and G.J. Jedlovec, 1982: A subsynoptic-scale kinetic energy analysis of the Red River Valley tornado outbreak (AVE-SESAME I). *Mon. Wea. Rev.*, 110, 2005-2024.
19) Fuelberg, H.E., and M.F. Printy, 1983: Meso beta-scale thunderstorm environment interactions during AVE-SESAME V (20-21 May, 1979). *Bull. Amer. Meteor. Soc.*, 64, 1144-1156.
20) Galway, J.G., 1956. The lifted index as a predictor of latent instability. *Bull. Amer. Meteor. Soc.*, 37, 528-529.
21) Hane, C.E., R.M. Rabin, T.M. Crawford, H.B. Bluestein, and M.E. Baldwin, 2000: Severe thunderstorm initiation along the dryline: A mesoscale case study. *Procs. 20th Conf. Sev. Lcl Storms*, Orlando, FL, Sept. 2000. Amer. Meteor. Soc., 80-83.
22) Honch, R.W., and G.S. Strong, 1990: Mesoscale dynamics associated with convection during LIMEX-85. *16th Conf. Sev. Loc. Storms*, Kananaskis Park, Alta., 22-26 Oct., 1990, Amer. Meteor. Soc., Boston, 681-686.
23) Joe, P., and D. Dudley, 2000: A quick look at the Pine Lake storm. *CMOS Bull. SCMO*, 28, #6, 172-180.
24) Knight, C.A., ed., 1982: The Cooperative Convective Precipitation Experient (CCOPE), 18 May – 7 August, 1981. *Bull. Amer. Meteor. Soc.*, 63, 386-398.
25) Knott, S.R.J., and N.M. Taylor, 2000: Operational Aspects of the Alberta Severe Weather Outbreak of 29 July, 1993. *National Weather Digest*, 24, 11-23.
26) Kung, E.C., and T.L. Tsui, 1975: Subsynoptic-scale kinetic energy balance in the storm area. *J. Atmos. Sci.*, 32, 729-740.
27) Kuo, H-L., 1949: Dynamic instability of two-dimensional nodivergent flow in a barotropic atmosphere. *J. Meteor.*, 6, 105-122.
28) Lanicci, J.M., and T.N. Carlson, 1983: Three-dimensional numerical simulations of dryline and elevated mixed layer evolution as related to soil moisture distribution. *Preprints AMS 13th Conf. Sev. Loc. Storms*, Tulsa, Okla., 17-20 Oct., 1983, 328-331.
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) Lorenz, E.N., 1955: Available potential energy and the maintenance of the general circulation. *Tellus*, 7, 157-167.
32) Lorenz, E.N., 1984: Irregularity: a fundamental property of the atmosphere. *Tellus*, 36A, 98-110.
33) Lowe, A.B., and G.A. McKay, 1962: Tornado composite charts for the Canadian Prairies. *J. Appl. Meteor.*, 1, 157-162.
34) Maddox, R.A., 1973: A severe thunderstorm surface potential index (SPOT). *Preprints 8th Conf. Sev. Lcl Storms*, Denver, CO. Amer. Meteor. Soc., Oct. 1973, 252-256.
35) Maddox, R.A., 1980: Mesoscale convective complexes. *Bull. Amer. Meteor. Soc.*, 61, 1374-1387.
36) Margules, M., 1903: *Uber die Energie der Sturme. Jahrb. kais-kon Zent. fur Met.*, Vienna. Translation by C.Abbe in Smithson. *Inst. Misc. Coll.*, 51, 1910.
37) McGinley, J.A., and Y.K. Sasaki, 1975: The role of symmetric instabilities in thunderstorm development on drylines. *Preprints 9th Conf. Sev. Lcl Storms*, Norman, OK. Amer. Meteor. Soc., Oct. 1975, 173-180.
38) McInnis, D.H. and E.C. Kung, 1972: A study of subsynoptic scale energy transformations. *Mon. Wea. Rev.*, 100, 126-132.
39) Miller, R.C., 1959: Tornado-producing synoptic patterns. *Bull. Amer. Meteor. Soc.*, 40, 465-472.
40) Newton, C.W., 1960: *Hydrodynamic interactions with ambient wind field as a factor in cumulus development*. Cumulus Dynamics, Oxford, Pergamon Press, 135-144.
41) Ogura, Y., H-M. Juang, K-S. Zhang, and S-T. Soong, 1982: Possible triggering mechanisms for severe storms in SESAME-AVE-IV (9-10 May, 1979). *Bull. Amer. Meteor. Soc.*, 63, 503-515.
42) Parsons, D.B., M.A. Shapiro, R.M. Hardesty, R.J. Zamora, and J.M. Intrieri, 1991: The finescale structure of a west Texas dryline. *Mon. Wea. Rev.*, 119, 1242-1258.
43) Raddatz, R.L., 1998: Anthropogenic vegetation transformation and the potential for deep convection on the Canadian prairies. *Can. J. Soil Sci.*, 78, 657-666.
44) Raddatz, R.L., 2000: Summer rainfall recycling for an agricultural region of the Canadian prairies. *Can. J. Soil Sci.*, 80, 367-373.
45) Renick, J.H., and R.H. Douglas, 1970: *Cloud Photogrammetry.* Stormy Weather Group Report MWT-7. McGill Univ., Montréal, 25 pp.
46) Richardson, L.F., 1922: *Weather Prediction by Numerical Process*, Cambridge University Press, London, 236 pp. Reprinted by Dover.
47) Rockwood, A.A., and R.A. Maddox, 1988: Mesoscale and synoptic scale interactions leading to intense convection: the case of 7 June, 1982. *Wea. Forecasting*, 3, 51-68.
48) Rossby, C-G., 1949: On a mechanism for the release of potential energy in the atmosphere. *J. Meteor.*, 6, 163-180.
49) Schaefer, J.T., 1973: The motion of the dryline. *Preprints 8th Conf. Sev. Lcl Storms*, Denver, CO. Amer. Meteor. Soc., Oct. 1973, 104-107.
50) Sechrist, F.S. and J.A. Dutton, 1970: Energy conversions in a developing cyclone. *Mon. Wea. Rev.*, 98, 354-362.
51) Sikdar, D.N., and D. Fox, 1983: An evolving severe storm complex during SESAME: Its large scale environment and momentum budget. Preprints 13th *AMS*

*Conf. Sev. Loc. Storms*, Tulsa, Okla., 17-20 Oct., 1983, 312-315.
52) Sly, W.K., 1966: A convective index as an indicator of cumulonimbus development. *J. Appl. Met.* 5, 839-846.
53) Starr, V.P., 1948: On the production of kinetic energy in the atmosphere. *J. Meteor.*, 5, 193-196.
54) Starr, V.P., 1953: Note concerning the nature of the large-scale eddies in the atmosphere. *Tellus*, 5, 494-498.
55) Stobie, J.G., and F. Einaudi, 1983: A case study of gravity waves - convective storm interaction: 9 May, 1979. *J. Atmos. Sci.*, 40, 2804-2830.
56) Strong, G.S., 1979: Convective Weather prediction based on synoptic parameters. Preprints 11th *AMS Conf. Sev. Loc. Storms*, Kansas City, Mo., Oct. 1979, 608-615.
57) 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.
58) Strong, G.S., 1989: LIMEX-85: 1. Processing of data sets from an Alberta mesoscale upper-air experiment. *Clim. Bull.*, 23, 98-118.
59) Strong, G.S., 1997: Atmospheric Moisture Budget Estimates of Regional Evapotranspiration from RES-91. *Atmos.-Ocean*, 35, 29-63..
60) Strong, G.S., 2000: A multi-scale conceptual model of severe thunderstorms. *CMOS Bull. SCMO*, 28, No. 2, 45-54, April 2000.
61) Strong, G.S., 2002: Review of prairie thunderstorms: 1. Scale characteristics and regional climatologies. *CMOS Bull. SCMO*, 30, No. 5, October 2002, 140-156.
62) Strong, G.S., and E.P. Lozowski, 1977: An Alberta study to objectively measure hailfall intensity. *Atmosphere*, 15, 33-53.
63) Strong, G.S., and E.P. Lozowski, 1980: Hailpad wind measurements and hailfall sampling errors. Pres. At 14th *Ann. Congress, Can. Meteor. & Oc. Soc.*, Toronto, May 1980, 28 pp.
64) Strong, G.S., and C.D. Smith, 2001: *Assessment and Prediction of Prairie Severe Thunderstorm Weather Phenomena*. Fin. Rep. to Emergency Preparedness Canada, 26 March, 2001, 158 pp.
65) Tsui, T.L., and E.C. Kung, 1977: Subsynoptic-scale energy transformations in various severe storm situations. *J. Atmos. Sci.*, 34, 98-110.
66) 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.
67) White, R.M., and B. Saltzman, 1956: On conversions between potential and kinetic energy in the atmosphere. *Tellus*, 8, 357-363.

## Rectificatif

Dans le dernier numéro du *CMOS Bulletin SCMO*, Vol.30, No.6, page 170, l'article "Le glas sonne pour les neiges du Kilimandjaro" a été publié originalement dans le journal *Le Monde*. L'article a été reproduit avec l'autorisation du journal *Le Monde*.

## 2002, deuxième année la plus chaude depuis un siècle et demi

Agence France-Presse

Genève — L'année 2002 devrait être la deuxième année la plus chaude depuis que les premiers relevés météorologiques ont été mis en place, en 1860, a annoncé l'Organisation météorologique mondiale (OMM).

La température moyenne à la surface du globe en 2002 devrait dépasser de 0,5° Celsius la normale calculée pour la période 1961-90, a précisé l'OMM. 1998 a été l'année la plus chaude depuis 1860. 2001 occupe la troisième place au palmarès.

L'OMM, (...) confirme que la planète continue de se réchauffer à un rythme accéléré: sa température moyenne a progressé depuis 1976 à un rythme trois fois plus élevé que celui qui a prévalu sur un siècle. La hausse globale de température depuis 1900 atteint désormais 0,6°. Signe de ce réchauffement souligne l'OMM, l'étendue de la couche de glace de l'océan Arctique en septembre 2002 a été la plus faible pour un mois de septembre depuis 1978, date des premières observations par satellite.

En revanche, l'état de la couche d'ozone, qui protège la Terre des rayons ultraviolets, s'est amélioré en 2002: le trou d'ozone au-dessus de l'Antarctique a été le plus petit et le moins profond observé depuis 1988. L'OMM estime que certaines des anomalies climatiques constatées en 2002 — printemps glacial au Canada ou canicule et sécheresse en Australie, par exemple — peuvent s'expliquer par "un épisode El Niño d'intensité modérée".

El Niño, dont on a constaté le retour en juin, se produit quand la température à la surface de l'Équateur demeure au-dessus des normales saisonnières pendant plusieurs mois. Une réaction en chaîne peut se faire sentir en différents endroits de la planète.

Source: *Le Devoir*, mercredi, le 18 décembre 2002, page A9.

# VALUE-ADDED PRODUCTS and SERVICES in the METEOROLOGICAL SECTOR

Adapted from a presentation by Robert Boggs
at the Hydraulic Integrated Resource Management Interest Group
on behalf of the Canadian Meteorological and Oceanographic Society
Private Sector Task Force

A burgeoning private sector industry has developed in Canada to provide products and services related to weather and to meet the needs of Canada's economy. Private sector meteorologists are playing an increasingly larger role in the provision of weather services in Canada.

The Canadian Meteorological and Oceanographic Society (CMOS), Private Sector Task Force (PSTF), has developed a document titled "A Meteorological Industry Strategy for Canada". This study was done with the support and encouragement of the Meteorological Service of Canada (MSC). This brief note is to increase the awareness of the meteorological private sector and the value-added products and services that are available today.

The Private Sector Task Force is determining the exact size of the private sector in Canada. Current estimates place the numbers somewhere between 50 and 100 firms in Canada which provide services in a wide range of weather disciplines. These companies range from individuals who often function as consultants, to small firms consisting of only one or two people, and to large companies such as Pelmorex–The Weather Network, Seimac Limited and World Weatherwatch. Some companies provide operational weather forecasting to a variety of sectors, such as offshore oil and gas, transportation, fire weather and the media. Others provide consulting services in data analysis, climate change, forensic meteorology, air quality and so forth. Still others supply weather instrumentation and weather observing services. Today, approximately 20% of Canadian weather services are being delivered by the value-added private sector.

The MSC is refocusing its relationship with the private sector and has set a policy not to bid on competitive Requests for Proposal, if the services can be provided by the private sector. MSC is also in the midst of restructuring data access and lowering data charges. These changes will make it more financially feasible for the private sector to deliver value-added services and for all Canadians to access weather and climate data.

The growth of the private sector over the next ten years will result in better prices for weather-related goods and services. Such developments will increase the demand for these services and lead to greater innovation in service preparation, presentation and delivery, spurred by the additional competition for private business.

High-speed computing and telecommunications and the emergence of the Internet have fuelled the demand for and ease-of-access to dynamic weather services at the local, regional, national and international levels.

We are developing a uniquely Canadian public-private partnership so that:

■ all citizens and all organizations have instant access to the critical weather and climate information they need, when they need it and wherever they need it, from Canadian suppliers;

■ the Canadian economy knows about and adapts to the weather-related risks and opportunities better than any other country in the world;

■ the accuracy of Canadian weather forecasting has improved, decade after decade, generating net benefits for the economy;

The private weather and climate sector will be:

■ Advancing Canada's innovation in research, technology, communications and resources;

□ Developing leading-edge "content" for the country's "Connecting Canadians" agenda;

□ Providing new growth opportunities in the information, high tech and science sectors;

■ Creating new career opportunities and high-quality jobs;

■ Expanding from an industry generating some $65-million in annual revenue to perhaps $185-million by 2011, with associated economic spin-offs.

The weather-sensitive sectors of the economy – and the economy as a whole – will benefit substantially, through the economic and social benefits that flow from improved weather forecasting, climate forecasting and through improved availability of weather and climate information to weather-sensitive users.

The markets served by the private sector include the following: media, marine (fishing, shipping, offshore oil and gas exploration and production), truck and rail transportation, aviation, utilities - including hydroelectric operators, construction, agriculture, education, legal, insurance, leisure and tourism, government, and many others. Recently, new markets, such as "weather derivatives for the financial industry", have emerged, and other markets, such as renewable energy, have taken on new emphasis.

Private sector companies are currently providing many services to the Canadian energy sector. There are companies that specialize in the provision of site-specific forecasts and ancillary services to the offshore oil and gas explorers and producers. There are companies that also specialize in the provision of forecasts and studies for wind energy generation. There are still others that provide forecasts and support data for load forecasting and more.

Some examples of products and services include:

- Quantitative precipitation forecasts over a basin out to five days;

- Climatological outlooks of precipitation and temperature for planning purposes;

- Data analysis and calculation of extremal values of precipitation;

- Load forecasting – sky cover, maximum and minimum temperatures, wind speed and direction, precipitation type and occurrence – over a period of days and including warnings of hazards such as freezing precipitation, volume precipitation (flooding) and so forth.

The weather derivative sector is another area of growth for the Canadian private weather services companies. On a world-wide basis, weather derivatives are estimated to be a $4 billion US per year industry. While in its infancy in Canada, it is expected to grow over the next ten years and the Canadian weather private sector will be the main support to Canadian and indeed foreign companies that will operate in this market.

In the United States weather-related disasters over the past 22 years numbered 52 and costs exceeded $ 1 billion. It is estimated that 1/7$^{th}$ of the US economy is weather-sensitive, a staggering $1 trillion. During this same period of time the number of meteorologists in the private sector has increased from 800 in 1982 to over 3,500 and the number of private sector companies from 100 to more than 400.

MSC and the private sector working together will continue to provide services to weather-sensitive industries and to all Canadians:

- MSC acquires and analyzes observations and issues area forecasts and warnings for defined regions of the country;

- Private sector firms use government data and products as a basis for creating information and special products for the media, and site-specific products for weather sensitive clients;

- MSC and electronic media disseminate atmospheric information, forecasts, and warnings to the public;

- Tailored products provided by the private sector are disseminated through information networks such as the Internet or dedicated channels;

- Scientists in the academic community, the government, and the private sector advance atmospheric understanding and assist in creating capabilities for service;

- Private sector firms work with MSC to commercialize research projects and develop new products for the user community.

---

## Stop the Press!

### Summer Meteorology Workshop
### Project Atmosphere 2003 (AMS-NOAA)

For a call for applications by pre-college teachers to attend this year's Workshop (27 July to 1 August 2003, in Kansas City, Missouri, USA) check the CMOS web site "About CMOS -SCMO Scholarships and Awards".

*Uri Schwarz*

## Dernière heure!

### Atelier d'été en météorologie
### Projet Atmosphère 2003 (AMS-NOAA)

Si vous êtes intéressés à l'atelier d'été en météorologie, veuillez consulter le site web de la SCMO "À propos de la SCMO - Bourses et prix de la SCMO". Les enseignants du niveau pré-collégial y trouveront les détails d'application pour participer à l'atelier de cette année qui aura lieu du 27 juillet au 1 août 2003, à Kansas City, Missouri, EUA.

*Uri Schwarz*

## NOMINATIONS for CMOS FELLOWS

Since the first appointments in 1999, 11 of our members have been given the title of "Fellow".

The appointment of a member to a "Fellow" offers us the opportunity of recognizing our own members for their contribution to the Society and for their achievements in their own field of endeavour. The title "Honorary Fellow" is one that the Society may use to recognize an individual outside of the Society who, by virtue of his/her endeavours, is recognized as an outstanding individual and contributor to society as a whole.

It is now time for members or non-members to nominate new Fellows or Honorary Fellows to the Society. In considering the nominations, the Fellows Committee shall take into account the contributions of the individual to the scientific, professional and educational fields in atmospheric and ocean sciences or services as well as to Canadian society as a whole. These contributions can be illustrated through the following general criteria: research, teaching, technology, professional services, administration in academia, industry, government or other institutions, communication and interpretation of atmospheric and oceanographic phenomena, weathercasting, international meteorological and/or oceanographic affairs.

Each nomination should be signed by the primary sponsor and supported by two others, at least one of whom must be from an establishment other than that of the nominee.

Application forms are available from the Executive Director in the CMOS Office or on the CMOS web site (http://www.meds-sdmm.dfo-mpo.gc.ca/cmos/fellows.html).

The Chair of this year's Fellows Committee is Dr. Ronald Stewart who can be reached by email (Ronald.Stewart@mcgill.ca), phone (514-398-1380) or mail (Dept. of Atmospheric and Oceanic Sciences, McGill University, Montreal, Quebec H3A 2K6).

Nominations are to be postmarked no later than **April 15, 2003**.

*Ron Stewart*

### NOMINATIONS des «FELLOWS» de la SCMO

Depuis la première nomination en 1999, onze de nos membres ont reçu le titre de "Fellow".

La nomination d'un membre à titre de Membre émérite ("Fellow") nous donne l'occasion de souligner la contribution de nos propres membres à la Société ainsi que de reconnaître leurs réalisations dans leurs champs d'activité respectifs. Le titre de Membre honoraire ("Honorary Fellow)", quant à lui, permettra à la Société d'honorer un individu de l'extérieur de la Société pour son travail exceptionnel et sa contribution exemplaire à la société en général.

Le moment est arrivé pour les membres et les non membres de soumettre le nom de candidatures pour des nouveaux Membres émérites ou Membres honoraires. Lors de l'étude des candidatures, le comité des "Fellows" doit tenir compte des contributions d'un individu aux domaines scientifique, professionnel et pédagogique des sciences ou services atmosphériques ou océanographiques ainsi qu'à la société canadienne en général. Des exemples de ces contributions sont indiqués dans la liste suivante: la recherche; l'enseignement; la technologie; les services professionnels; l'administration au sein d'une université, d'une industrie, du gouvernement ou d'une autre institution; la transmission et l'interprétation des phénomènes atmosphériques et océanographiques; les prévisions météorologiques; les affaires internationales en météorologie et/ou en océanographie.

Chaque candidature doit être signée par le parrain principal et par deux autres personnes, et au moins une de ces trois personnes doit faire partie d'une institution autre que celle du candidat.

Les formulaires de nomination peuvent être obtenus du Directeur exécutif, au bureau de la SCMO, ou sur le site Web (http ://www.meds-sdmm.dfo-mpo.gc.ca/cmos/fellows.html).

Cette année, le Président du comité des "Fellows" est représenté par Ronald Stewart. On peut le joindre par courriel (ronald.stewart@mcgill.ca), par téléphone (514-398-1380) ou par la poste (Département des sciences atmosphériques et océaniques, Université McGill, Montréal, Québec H3A 2K6).

La date limite pour les nominations est le **15 avril 2003**, le cachet de la poste faisant foi.

*Ron Stewart*

## Workshop on Arctic Climate

### Château Laurier Hotel, Ottawa
### February 20-21, 2003

The meeting will be in the Drawing Room, main floor, Chateau Laurier Hotel, 1 Rideau Street. It will begin on Thursday, February 20 at 1:00 p.m. (registration from 1200 noon). A reception will be held immediately following the Thursday sessions. The meeting will conclude at 1600 hours on Friday, February 21.

Air Canada is the "official carrier" for the Workshop. Participants can get a 5% to 10% discount on their fares (depending on fare class), by quoting convention number CV030536 when booking. Air Canada's toll free number is 1-800 361-7585.

A block of guestrooms has been reserved for out-of-town participants at the Château Laurier for the night of February 20. To get the special rate of $149/night (+ tax) you will need to reserve by January 21, 2003.

Reservations can be made directly with the Château Laurier by calling the toll-free number 1-800-441-1414, by E-mailing lhreservations@fairmont.com or by completing the attached reservation form. Please quote the group code CFCA2.

If you have not already done so, you are asked to confirm your attendance to Lise Harvey by E-mail at lharvey@cfcas.org or by phone to (613)238-2223. We look forward to seeing you at the Workshop.

Some of the highlights of the proposed agenda include:

- Formal opening by the Honourable David Anderson, Minister of the Environment, to be confirmed (t.b.c.).

- Workshop objectives & key issues by Gordon McBean.

- Strategic importance of Arctic climate research; an overview of opportunities; international initiatives, partnerships, key players and their interests by Peter Johnson, President, Canadian Polar Commission.

- The Global View will be presented by two speakers: Robert Dickson, North Atlantic Oscillation, Ministry of Agriculture, Fisheries and Food, U.K. and another speaker on regional climate issues in the North (t.b.c.).

- Canadian perspectives: needs and activities; the session chair will be Denis St-Onge, NRCan. Past president, Canadian Geoscience Council. Five representatives (Wendy Watson-Wright, ADM, DFO, Dave Barber, University of Manitoba, John Drexhage, International Institute for Sustainable Development, Representative of industry and Representative of northern residents) of stakeholder groups will present snapshots of current networks, initiatives, priorities and perceived needs.

- Social and Economic implications by Paul Okalik, Premier, Nunavut.

- Speaker at the evening reception is Ms Mary Simon, Ambassador for Circumpolar Affairs.

- Panel discussion on challenges in resourcing and conducting research in high latitudes & cold regions; the session chair will be Claire Eamer, C-CAIRN North/Yukon College. Discussion will be on costs, risks & uncertainties, coordination, logistical & physical challenges); panel members will be: Martin Sharp, U. Alberta, Ian Stirling Canadian Wildlife Service (t.b.c.), Humphrey Melling, DFO (t.b.c.), Representative of federal funding council (t.b.c.), Northern representative (t.b.c.).

- Discussion groups on Canada's role in international Arctic research programs and policy and priority-setting aspects of northern and cold climate research (including social and economic issues; policy imperatives). Resource persons for the groups are Roy Koerner (NRCan), Warwick Vincent (U. Laval), Barry Goodison (MSC), and others.

- Opportunities for cooperation; the session chair will be Barry Goodison, CliC / Meteorological Service of Canada. One of the participants will be Jamie Morison, SEARCH/Polar Science Center, U. Washington.

- Next steps ahead: a discussion chaired by G. McBean.

*Dawn Conway*
*Executive Director*
*Canadian Foundation for Climate and Atmospheric Sciences*

---

## ECOR

### Wave Energy Workshop at CMOS Congress

The Engineering Committee on Ocean Resources (ECOR) is an international organization that fosters and facilitates linkages at the government, private sector, university, and individual professional levels. The Committee also supports marine engineering initiatives that have reached the "proof of concept" stage but that have not gained sufficient attention to be identified for a useful and cost effective role in today's society. ECOR applies a traditional working group approach to deal with these issues. This approach features communications, meetings when possible, and eventually the publication of comprehensive and timely reports.

With respect to this endeavour, and for the last four years, ECOR has supported a working group of international experts reviewing the scope of wave energy conversion. The results of that work are to be published, in text book form, early this year. With that background, the ECOR executive have concluded that it is time to organize a forum of potential interested persons in Canada to review and discuss the various methods of alternative energy. The Canadian National Committee of ECOR (CNC/ECOR) will hold a workshop in conjunction with the CMOS Congress in June 2003 in Ottawa.

The ECOR organizers would like to know if you, or a member of your organization, would be interested in attending such a review? Also, what would be your particular interest in the broader area of renewable energy resources? The only urgency at this juncture is that we would like to have some idea of the number of potential participants. A tentative agenda for the (approximately two hour) session on "Wave Energy in Relation to other Renewable Energies", is expected to be structured along the following lines:

Subjects for discussion:

1. What is the present status of wave energy?

2. What is the present status of any existing "on line" wave energy systems and past experimental units?

**Speaker**: Wave energy — possibly a member of the ECOR working group.

3. What are the existing and planned renewable energy resources in Canada?

4. What areas of Canada have potential for wave energy development?

**Speakers**: Power Co. Technical manager and a Government official.

The session would include a panel discussion, with questions and discussion of new ideas from all attendees. It is expected that the session will result in a summary report for publication in a future *CMOS Bulletin SCMO* and in ECOR Journal publications.

It would be appreciated if interested participants could indicate, to the undersigned, their interest in participating in this session, as soon as possible.

*John Brooke*
*Chair, Wave Energy Conversion,*
*Vice-President, ECOR.*
*Email: az337@chebucto.ca*

## CMOS Accredited Consultants
## Experts-Conseils accrédités de la SCMO

### Mory Hirt

Applied Aviation & Operational Meteorology

*Meteorology and Environmental Planning*
*401 Bently Street, Unit 4*
*Markham, Ontario, L3R 9T2 Canada*
*Tel: (416) 477-4120*
*Telex: 06-966599 (MEP MKHM)*

### Douw G. Steyn

Air Pollution Meteorology
Boundary Layer & Meso-Scale Meteorology

*4064 West 19th Avenue*
*Vancouver, British Columbia, V6S 1E3 Canada*
*Tel: (604) 822-6407; Home: (604) 222-1266*

### Bill Thompson

Flood Warning, Marine Applications
Integrated Monitoring & Prediction Systems
International Aid and Development Projects

*Atmospheric Environmental Consultants*
*112 Varsity Green Bay NW*
*Calgary, Alberta, T3B 3A7 Canada*
*Tel / Fax: (403) 286-6215*
*E-mail: thompsow@cadvision.com*