Climatological Bulletin

Vol. 23, No. 1, April/Avril 1989

Bulletin climatologique

Canadian Meteorological and Oceanographic Society

La Société Canadienne de Météorologie et d' Océanographie

Information for Contributors and Subscribers

As a publication of the Canadian Meteorological and Oceanographic Society, the CLIMATOLOGICAL BULLETIN provides a medium of information on climatology. The Editorial Board gives special encouragement to the submission of manuscripts on applied climatology (e.g., agriculture, commerce, energy, environment, fisheries, forestry, health, recreation, transportation, and water resources), climatic change and variability, climate impact studies, climate model applications (including physical climatology), and regional studies (including ocean areas). It is published with the aid of a grant from the Government of Canada through the Natural Sciences and Engineering Research Council.

Authors may submit their manuscripts to "Articles", "Research Notes" or "News and Comments". This should be indicated in the cover letter accompanying the manuscript. Articles and Notes are independently reviewed by at least two anonymous referees. News or comments are reviewed by the Editor in consultation with the Editorial Board. Manuscripts are accepted in either English or French. An abstract (in both English and French) is required for Articles and Notes.

Contributors should submit manuscripts to Alexander H. Paul, editor, CLIMATOLOGICAL BULLETIN, Department of Geography, University of Regina, Regina, Saskatchewan, S4S 0A2. All manuscripts should be typed double spaced on one side of good quality white paper, 28 cm x 21.5 cm, or its nearest equivalent. The abstract, list of references, tables, and a list of figure captions should be typed doubled spaced on separate sheets. Comments (including book reviews and opinions) and news items should not exceed 1 500 words. Furnish an original and three copies if possible, in the order listed below.

TITLE PAGE should include the full names of author(s), and professional affiliation(s).
The ABSTRACT should be less than 250 words, and typed on a separate page.
The TEXT of longer contributions should be typed double spaced on numbered pages, and divided into sections, each with a separate heading and numbered consecutively. The section heading should be typed on a separate line.
ACKNOWLEDGEMENTS are typed on a separate sheet immediately following the text.
If FOOTNOTES are required, they should be typed, double spaced, on a separate sheet under the heading "Notes" at the end of the text.
REFERENCES should be arranged alphabetically by senior author's last name. The text citation should consist of name(s) of the author(s) and the year of publication, for example Jones (1975) or (Jones, 1975). When there are two or more cited publications by the same author in the same year, distinguishing letters a, b, etc., should be added to the year. A reference to "in press" implies that the paper has been accepted for publication. Titles of periodicals should be given in full.
FIGURE LEGENDS must be provided for each figure, and should be typed together, double spaced, on a separate sheet.
ILLUSTRATIONS should be numbered sequentially. Original drawings, lettering, and symbols should be large enough so that after reduction, the smallest characters will be at least 1.5 mm high.
Each TABLE should be numbered sequentially. Type all tables double spaced on separate sheets.

Authors should use the International System of units, but may show other units in parentheses. Authors should provide instructions in the margin for any special type required (Greek letters, capitals, bold face, etc.).

Authors of articles and research notes are assessed publication charges of $50 per journal page and are then entitled to 25 free copies. Lesser charges may be negotiated in cases of financial hardship, but do not entitle the authors to any free copies.

Correspondence regarding Society affairs, membership, Institutional subscriptions and back issues of the journal should be directed to the Corresponding Secretary, Canadian Meteorological and Oceanographic Society, P.O.Box 334, Newmarket, Ontario L3Y 4X7. Telephone (416) 898-1040, Fax. (416) 898-7937.

Renseignements pour les collaborateurs et les abonnés

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

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

Les collaborateurs sont priés de soumettre leurs manuscrits à Alexander H. Paul, rédacteur en chef, BULLETIN CLIMATOLOGIQUE, Département de geographie, Université Regina, Regina, Saskatchewan, S4S 0A2. Il faut dactylographier tous les manuscrits à double interligne, sur un côté d'un papier blanc de bonne qualité, de 28 sur 21,5 cm ou des dimensions les plus rapprochées. Il faut dactylographier à double interligne, sur des feuilles à part, le résumé, la liste des références, les tableaux et la liste des légendes. Les commentaires, les critiques, les opinions et les informations ne doivent pas dépasser 1 500 mots. Fournir l'original et, si possible, trois copies, selon la disposition suivante:

LA PAGE DE TITRE doit comprendre: nom, prénoms des auteurs, ainsi que les affiliations professionnelles.

LE RÉSUMÉ, dactylographié sur une page à part, ne doit pas compter plus de 250 mots.

LE TEXTE. Il faut taper à double interligne, sur des pages numérotées, le texte des articles plus longs et le diviser en sections, chacune dotée d'une en-tête à part et numérotée dans l'ordre. Il faut dactylographier l'en-tête de section sur une ligne à part.

LE REMERCIEMENTS doivent être dactylographiés sur une page à part, après le texte.

LES NOTES DE BAS DE PAGE doivent être dactylographiées à double interligne, sur une feuille à part, au-dessous de l'en-tête "Notes", à la fin du texte.

LES RÉFÉRENCES doivent être disposées dans l'ordre alphabétique, d'après le nom de l'auteur principal. Les citations doivent comprendre le ou les noms du ou des auteurs et l'année de publication, comme Jones (1975) ou (Jones, 1975). Si l'on cite deux ou plusieurs publications du même auteur pendant la même année, il faut ajouter à l'année des lettres qui permettent de les différencier, comme a, b, etc. La mention "à l'impression" implique qu'on a accepté de publier la communication. Il faut indiquer les titres des périodiques en entier.

LES LÉGENDES: elles sont requises pour chaque figure. On dactylographiera ces légendes ensemble, à double interligne, sur une feuille à part.

LES ILLUSTRATIONS doivent être numérotées dans l'ordre. L'original des dessins, des caractères et des symboles doit être assez grand pour que, après réduction, le caractère le plus petit mesure au moins 1,5 mm de haut.

LES TABLEAUX doivent être numérotés dans l'ordre. La dactylographie pour tous les tableaux doit être à double interligne sur des feuilles à part.

Les auteurs doivent utiliser le système international de mesure, mais ils peuvent indiquer d'autres mesures entre parenthèses. Les auteurs doivent porter dans la marge des instructions pour tout caractère spécial voulu (lettres grecques, majuscules, caractères gras, etc.).

Les auteurs d'articles et de notes de recherche doivent payer des frais de publication de 50 $ par page, ce qui donne droit à 25 copies gratuites. On peut négocier un taux réduit en cas de difficultés financières, mais l'auteur n'aura pas droit à des tirages gratuits.

La correspondance concernant les activités de la Société, les souscriptions des membres et des institutions et les numéros déjà parus, devrait être adressée au Secrétaire-correspondant, Société canadienne de météorologie et d'océanographie, C.P. 334, Newmarket, Ontario L3Y 4X7. Téléphone (416) 898-1040, Fax. (416) 898-7937.

Climatological Bulletin
Bulletin climatologique

Vol. 23, No. 1, April/Avril 1989

ISSN 0541-6256

Foreword / Avant-Propos

This issue of *Climatological Bulletin* contains an article on wind modelling over rough terrain, a review of severe local storm research in Canada, and a climate-change impact assessment for the forest regions of Quebec-Labrador. A balance of this kind is only possible when a good flow of manuscripts is maintained, something which does not always happen. I would encourage readers to submit manuscripts and to promote the journal among their colleagues. We continue to strive to improve the *Bulletin*, and good manuscripts on climatological research are always welcome.

Ce numéro du *Bulletin climatologique* se compose d'un article sur la modélisation du vent au-dessus d'un terrain accidenté, d'une revue des recherches concernant les tempêtes estivales au Canada, et d'une étude de l'impact potentiel d'un changement climatique pour les régions forestières du Québec-Labrador. Un tel équilibre dépend de l'abondance de manuscrits, une chose qui ne nous arrive pas toujours. J'encourage donc les lecteurs à nous soumettre des manuscrits et à promouvoir la revue parmi leurs collègues. On essaie toujours d'améliorer le *Bulletin* en accueillant des manuscrits de bonne qualité qui portent sur des recherches climatologiques.

Alec Paul
Editor/Rédacteur en chef

Simple Guidelines for Estimating Wind Speed Variations due to Small-scale Topographic Features – An Update

J.L. Walmsley[1]
P.A. Taylor[1,3]
J.R. Salmon[2]

[Original manuscript received 24 February 1988;
in revised form 12 December 1988]

ABSTRACT

The paper by Taylor and Lee (1984), describing simple guidelines for estimating wind speeds on hilltops and at similar complex terrain locations, has attracted considerable attention and the methods are being widely applied. In our use of these guidelines we have found it desirable to make minor changes and additions to the procedures, and to code the guidelines as an interactive program for use on IBM compatible micro-computers. The present article documents the changes, describes the computer code and presents a simple application as an example of its use.

RÉSUMÉ

L'article de Taylor et Lee (1984) qui porte sur des procédés simplifiés pour l'estimation des vitesses du vent par-dessus des collines et d'autres lieux semblables de topographie complexe, a été bien regardé. Beaucoup de monde se servent des méthodes y présentées. En utilisant nous-même ces procédés, nous avons préféré faire de petits changements et additions, et ensuite coder les procédés comme programme interactif convenable à un micro-computer IBM-compatible. Cet article-ci précise les changements, décrit le code informatique et présente un exemple d'une application simple.

[1] Boundary-Layer Research Division, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4.
[2] 24 Heslop Drive, Toronto, Ontario, Canada M8W 4R1.
[3] Present affiliation, Department of Earth and Atmospheric Science, York University, 4700 Keele Street, North York, Ontario, Canada M3J 1P3.

Climatological Bulletin / Bulletin climatologique 23(1) 1989

1. INTRODUCTION

Taylor and Lee (1984) present simple guidelines for estimating wind speed variations due to small-scale topographic features. These guidelines are based on the ideas of Hunt (1980) for flow over low hills and Elliott (1958) for flow downwind of a step change in roughness. Taylor and Teunissen (1984) also discuss the guidelines with emphasis on the estimation of design wind speeds while Lemelin *et al.* (1988) have used them as a basis for further studies leading to their 'LSD' model. The Applications and Impact Division of the Canadian Climate Centre has used the guidelines extensively to assist in the estimation of design wind loads for structures, *e.g.* antenna towers, to be built in complex terrain. The Boundary-Layer Research Division of AES has also used the guidelines in a joint study with Hydro-Québec to estimate the wind energy potential of hilltop sites in the Îles-de-la-Madeleine (Taylor *et al.*, 1986) and in studies of the representativeness of island-based wind data for the surrounding waters (Walmsley *et al.*, 1985).

During the course of these applications, the authors of this paper have identified and corrected some minor ambiguities in the original documentation. We have also added an option to allow the use of wind data from a nearby reference site if there are none available for a location just upwind of the topographic feature or roughness change under consideration. In addition, the present article describes guidelines software for IBM-compatible micro-computers.

We should remark that similar guidelines or 'rules of thumb' have been described by other authors. Jensen *et al.* (1984) present methods which are similar to those in Taylor and Lee's guidelines while Businger (1987) discusses models of the roughness-change situation. Businger's model includes thermally stratified cases. Lemelin *et al.* (1988) have developed detailed approximations for flow over topographic features which include upper bound estimates for wind speed variations at locations above hillsides and escarpment slopes as well as above the summit. These upper bounds may be conservative in some instances, and Taylor and Lee's suggestion (p. 19) of linear interpolation between an upstream slow-down at the base of the hill and the hilltop speed-up may be preferable. For detailed wind speed estimates at general locations in complex terrain, we recommend the use of the MS3DJH model wherever feasible. The model is decribed in Taylor *et al.* (1983) and Walmsley *et al.* (1986) and a micro-computer code is now available (Salmon and Morris, 1987). However, this requires a substantially larger effort to apply than do Taylor and Lee's guidelines or the LSD model, and may not yet be practical for day-to-day applications. As GISs (Geographic Information Systems) and high resolution DEMs (Digital Elevation Models) become available, however, the need to digitise topographic maps may be avoided and the effort reduced. Lemelin *et al.* (1988) also adopt a different approximation for the decay of the fractional speed-up ratio, ΔS, with height above terrain, Δz, to that assumed by Taylor and Lee (1984) in their equation (14). The LSD algebraic form for the vertical variation of ΔS appears to be a better fit to wind-tunnel and MS3DJH numerical model results at large and small heights, but Taylor and Lee's exponential approximation matches the height variation of Askervein hilltop field data (Mickle *et al.* 1988) slightly better. Both appear satisfactory over the height range required for typical applications. We commend the work of Lemelin *et al.* but have chosen here to retain the original exponential approximation of Taylor and Lee and to restrict our attention, in the present guidelines, to summit locations where we believe the estimates to be most accurate.

2. REVIEW OF TAYLOR AND LEE'S GUIDELINES

Consider the idealised situation shown schematically in Figure 1. Three locations are depicted: a reference site, *R*, an upstream site, *U*, and a prediction site, *P*. The upstream site should be flat, of uniform roughness, z_{ou}, and directly upwind of *P*.

The objective of Taylor and Lee's (1984) guidelines is to compute the wind speed, U_p, at the prediction height above local ground level, $\triangle z_p$ (or at a series of heights to form a velocity profile) at *P*. The guidelines provide an estimate for U_p relative to $U_o(\triangle z_p)$, the upstream velocity at the same height at *U*. Two effects are allowed for:

a) Wind speed changes, $\triangle U_T$, due to flow over the topographic feature, of height, h. The change may be speed-up for hills (h positive) or a reduction in speed if the feature is a valley or hollow (h negative). The length scale, L, of the topographic feature is taken as the upwind distance from the hilltop, or other extreme point, to the point whose height above the surrounding terrain is h/2. This is sometimes referred to as the 'half-width at half-height'.

b) Wind speed changes, $\triangle U_R$, due to a change in roughness between *U* and *P* at a distance r upwind of *P*.

The key equations, as described by Taylor and Lee, are:

$$\triangle U_T = \triangle S\, U_o(\triangle z_p) \tag{1}$$

where

$$\triangle S = \triangle S_{max} \exp(-A\triangle z/L), \tag{2}$$

with

$$\triangle S_{max} = Bh/L, \tag{3}$$

and, for $\triangle z_p < \delta_1$,

$$U_R = \{[\ln(\triangle z_p/z_o)/\ln(\delta_1/z_o)][\ln(\delta_1/z_{ou})/\ln(\triangle z_p/z_{ou})]-1\}\, U_o(\triangle z_p) \tag{4}$$

where the depth of the internal boundary-layer, δ_1, is given by

$$\delta_1/z_o = 0.75(r/z_o)^{0.8}. \tag{5}$$

This is Elliott's (1958) approximation for $m = z_o/z_{ou} = 1$ and was considered

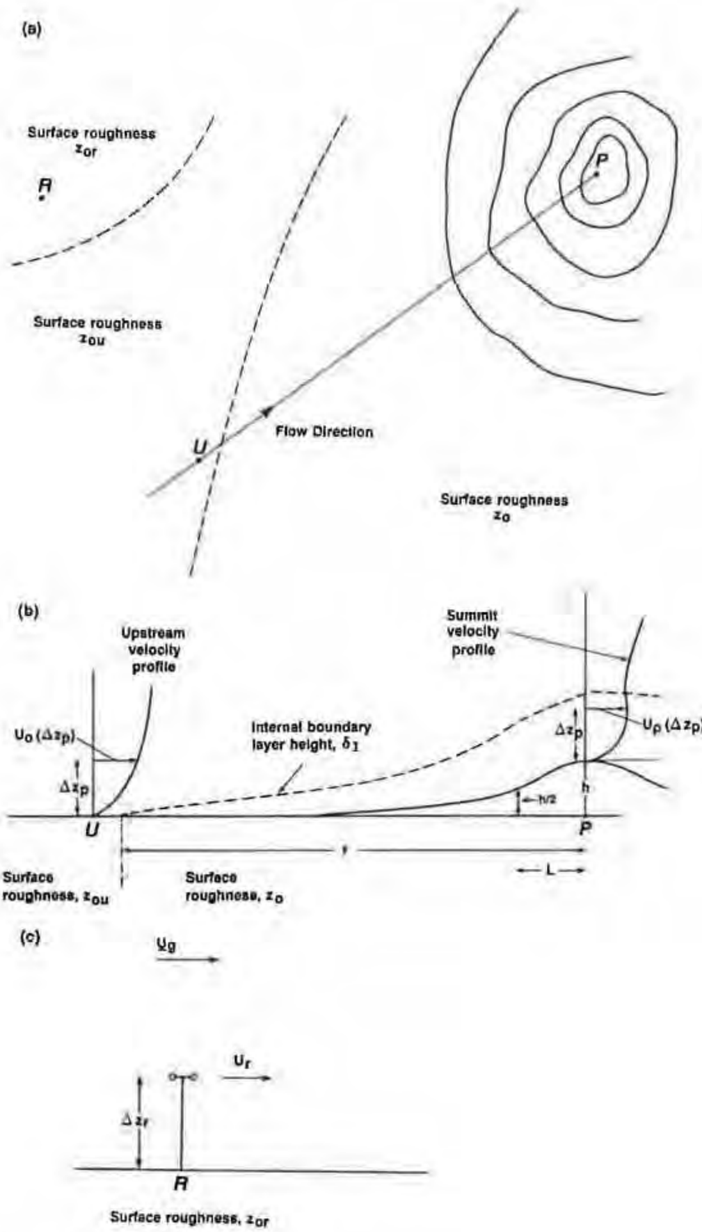

FIGURE 1. Schematic diagram illustrating the flow situation.

a) Plan view or map.
- - - - - - Roughness boundaries.
———— Contour lines.

b) Topographic cross-section.

c) Reference site.

satisfactory by Taylor and Lee for modest roughness changes. For general use, however, we now suggest Panofsky and Dutton's (1984) equation

$$r' = a\,[\delta'(\ln \delta' - 1) + 1], \tag{6}$$

where $r' = r/z_0$, $\delta' = \delta_1/z_0$ and $a = 2$. This equation is solved iteratively for δ_1 by Newton's Method using a modified form of (5) as an initial guess. It gives better agreement with observations (Walmsley, 1989) and is used in the guidelines software to be described below. Eq. (6) is derived from $d\delta_1/dr = \sigma_W/u(\delta_1)$, where $\sigma_W = 1.25\,u_*$ (Panofsky and Dutton, 1984) and $u(\delta_1) = (u_*/\kappa)\ln(\delta_1/z_0)$, with the von Karman constant, $\kappa = 0.4$ and $\delta_1 = z_0$ at $r = 0$.

Note that we have made some slight notation changes for compatibility with the computer program to be described later. Table 1 gives the recommended values for the coefficients A and B for different types of topographic feature. We use the guidelines to compute the velocity corrections due to each effect separately and then just add them, *i.e.* $\Delta U = \Delta U_T + \Delta U_R$. In doing this, there is an implied assumption that the corrections are small and that linear superposition is appropriate. In practice the corrections may be quite large (-80% to $+120\%$ of $U_0(\Delta z_p)$) and the assumption less valid than for small corrections.

The guidelines assume neutral thermal stratification and were developed for use in moderate-to-high wind situations. They also assume logarithmic upstream and reference site velocity profiles. This makes them most appropriate for topography and roughness variations on horizontal scales (L,r) which are less than about 2000m. Taylor and Lee also noted that the estimates may lose accuracy for $L<100$m. Recent experience has shown that we can relax this criterion somewhat and we now generally endorse the use of the guidelines for cases with $L/z_0 > 10^2$. The range of heights for which guidelines are considered appropriate is $z_0 \ll \Delta z < 150$m, with the upper bound determined by the height to which the upstream profile may be considered as approximately logarithmic (see Panofsky, 1974). For estimating roughness change effects from Elliott's scheme it is also desirable to have $\delta_1 < 150$m at the prediction site, although the consequences of exceeding this slightly (perhaps as far as $\delta_1 < 500$m) should not be too severe, given Taylor's (1969) findings that surface-layer and Planetary Boundary Layer (PBL) models of flow over roughness changes give similar results near the surface. The essential point is that the internal boundary layer should remain significantly shallower than the entire PBL.

TABLE 1. Coefficients for use with guidelines estimates of wind speed changes due to topography.

Terrain type	A	B
2D hills (ridges)	3.0	2.0
3D hills	4.0	1.6
2D escarpments	2.5	0.8
2D rolling terrain	3.5	1.55
3D rolling terrain	4.4	1.1
Flat terrain	0.0	0.0

ERRATA

Simple Guidelines for Estimating Wind Speed Variations due to Small-scale Topographic Features – An Update

J.L.Walmsley[1], *P.A. Taylor*[2] and *J.R. Salmon*[3]

The authors would like to point out the typographic errors in Equation (7) of their recent paper, Walmsley *et al*. (1989). The correct form of the equation should have been:

$$U_g/u_* = ((\ln(u_*/fz_o) - b)^2 + a^2)^{1/2}/\varkappa \qquad (7)$$

where $x = 0.4$, $a = 4$ and $b = 2$. The corresponding equation in our "Guidelines" software was and is correct.

In the references of the paper, the spelling of Tampieri was incorrect.

We would like to thank Tsoi-Ching Yip for spotting the missing power of 2 on the constant, a.

REFERENCE

Walmsley, J.L., P.A. Taylor and J.R. Salmon, 1989: *Climatol. Bull.*, 23(1), 3–14.

[1] Atmospheric Environment Service,
4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4

[2] Department of Earth and Atmospheric Science,
York University, 4700 Keele Street, North York, Ontario, Canada M3J 1P3

[3] 24 Heslop Drive, Toronto, Ontario, Canada M8W 4R1

The ideal situation for application of the guidelines is when data are available for a reference location directly upwind of *P*. This will not always be the case, however, and if we want an estimate of the wind speed at *P*, either as a short term (say 1h) average or as a climatological average or climatological extreme, we will have to use data from a reference site, *R*, which may be some distance from the prediction site. In addition, the reference site may be characterised by a surface roughness, z_{or}, which is different from z_{ou}. In these circumstances, we have adopted a procedure based on the use of "Resistance Laws" for the neutrally-stratified planetary boundary-layer (see for example Jensen *et al.*, 1984, p.34 or Taylor, 1987) and the assumption that the geostrophic wind, U_g, is the same above *U* as it is above *R*. This assumes an equilibrium relationship betwen the surface friction velocities, u_*, and the scalar magnitude of the geostrophic wind, U_g, at each location. Denoting the Coriolis parameter by f and with = 0.4, the Resistance Law is

$$U_g/u_* = ((\ln(u_*/fz_o)-b)^2 + a)^{1/2}/ \qquad (7)$$

with coefficients a = 4 and b = 2. This is assumed to hold with values of z_o and u_* appropriate to either *R* or *U*. Given the reference site wind speed, U_r, at height $\triangle z_r$ (often 10m) we compute u_{*r} assuming a logarithmic surface layer profile, use equation (7) to determine U_g and then again to determine the u_{*u} corresponding to z_{ou}. This allows us to compute the upstream velocity U_o at any prediction height, $\triangle z_p$, again assuming a logarithmic profile. An alternative scheme has been proposed by Wieringa (1986) based on an assumed constancy of a 60m "mesowind". The calculations in this case are slightly simpler, but the 60m height is somewhat arbitrary and we prefer the more general Resistance Law formulation for this application.

4. THE TREATMENT OF ROLLING TERRAIN

In the present version of the guidelines, we treat rolling terrain cases slightly differently from Taylor and Lee (1984). Equations (1) to (3) above are now used to estimate hilltop or valley bottom wind speed perturbations, $\triangle U_T$. The upstream wind $U_o(\triangle z_p)$ is taken as an areally averaged wind over similar, rolling terrain with uniform surface roughness, z_{ou}, and replaces $(U_H + U_V)/2$ in Taylor and Lee's equation (11). We take h as the hilltop-to-valley-bottom elevation difference and L as one half of the hilltop-to-valley bottom distance in the upstream flow direction. For use in equation (3) we set h positive for hilltops but negative for valley bottoms. Values suggested for the coefficient B in equation (3) above are 1.55 and 1.1 for 2D and 3D cases respectively. Vertical decay of $\triangle S$ is assumed to follow the same exponential curve postulated by Taylor and Lee, *i.e.*, equation (2) above with A = 3.5 or 4.4 for 2D and 3D rolling terrain respectively, as indicated in Table 1. These numerical values of A were obtained by approximately fitting equation (2) to the height decay of solutions obtained with the MS3DJH model. As in the case of isolated topography, the fit is best for $\triangle z<0.3L$.

5. THE GUIDELINES SOFTWARE

We have recently coded an interactive version of the guidelines in Microsoft QuickBASIC version 4.0 for use on IBM-compatible computers running under the MS-DOS operating system. A source code and executable programs for use on machines with or without math coprocessors (8087, 80287 etc.) are available at no charge from J.L. Walmsley – but please send a blank 5.25 inch, double-sided double-density or 3.5 inch high density diskette with your request.

The programs use the revised guidelines with essentially the same constraints as those indicated by Taylor and Lee, Figure 13, except that:

a) The upper limit of terrain slope is increased from $h/L = 0.5$ to 0.6, in the light of recent wind tunnel studies and Salmon *et al.*'s (1988) comparisons with Askervein field data. If $h/L>0.6$ then L is adjusted, set equal to $h/0.6$ and execution continues. We adopt this procedure because limiting h/L keeps $\triangle S_{max}$ realistic (equation (3)), and increasing L to h/0.6 causes a slower exponential decay of $\triangle S$ with height (equation (2)). The two effects combine to give what we believe are reasonable estimates for steep terrain although they will be less reliable than those for gentler slopes.
b) For valleys or hollows we require that $h/L>-0.4$ since the flow would almost certainly separate over valleys which were as steep as this (see Tampieri, 1987), and the wind estimates would then be unreliable.
c) The programs will accept reference site wind speeds less than $3ms^{-1}$, but a caution is issued to remind the user that the guidelines are primarily intended for use in high wind situations.
d) Stratification effects are not considered explicitly, and users are expected to make assessments of these for themselves.
e) Inner layer depths, ℓ, from Taylor and Lee, equation (5), are not computed and the height decay of the fractional speed-up ratio, $\triangle S$, from Taylor and Lee, equation (14), is applied at all heights.
f) A warning is given that the measurement and prediction heights, $\triangle z_r$ and $\triangle z_p$, respectively, must be much greater than the roughness lengths (z_{or}, z_{ou} and z_o) and checks are made to ensure that $\triangle z_r > z_{or}$ and $\triangle z_p > z_{ou}, z_o$. Checks are also made to see whether $\triangle z_r$, $\triangle z_p$ or δ_1 are greater than 150m and warnings are issued if this condition occurs.

The structure of the programs is slightly different from Taylor and Lee's flow chart (Figure 13) so that separate reference and upwind sites can be treated as discussed above. We have also set up the program to allow computations at a sequence of heights at the prediction site without repetition of the full input procedure. The programs are intended to be "user-friendly" and relatively foolproof – but we make no guarantees!

6. A SIMPLE APPLICATION

As an illustration of the use of the guidelines program, we have chosen a two-dimensional ridge of height, h = 50m and horizontal scale, *i.e.* half-width at half-height, L = 250m. The roughness lengths at the reference, upstream and prediction sites are assumed to be 0.03m, 0.01m and 0.1m, respectively, making this an example of a smooth-to-rough transition with reference wind data available at a site with different roughness from that of the upwind terrain. The upwind distance from the prediction site to the change in roughness is r = 400m. The reference wind speed is taken as $10ms^{-1}$ at a height of 20m above the ground. Since the reference and upstream roughness lengths are not equal, the program applies the neutral PBL Resistance Law and requires the site latitude (45°) as input.

Table 2 displays the printed output from this sample run. Header information includes a user-defined label in line 2 and a user-specified file to contain the output in line 3. Subsequent lines list all input data, the results of some intermediate calculations and the final predicted wind speeds. These are given to the nearest $0.01ms^{-1}$ but they are only estimates and should not be considered as reliable as this! In this example the geostrophic speed was determined to be $16.85ms^{-1}$ and the internal boundary layer (IBL) height, δ_I, was 40.04m at the prediction site. Prediction heights were specified as 5, 10 and 20m. Upstream speeds at those heights ranged from 8.8 to $10.8ms^{-1}$, increasing with height above ground. The ridge induced a speed-up of about $3ms^{-1}$ at all three levels, whereas the change in roughness caused a slow-down of $1.13ms^{-1}$ at 5m, decreasing with height to $0.38ms^{-1}$ at 20m. The combined effects gave a wind profile with speeds varying from $11.0ms^{-1}$ at 5m to $12.5ms^{-1}$ at 10m and $13.8ms^{-1}$ at 20m.

In Figure 2 we display the results of the above calculations, augmented by additional evaluations at other elevations. Here one can clearly see that the roughness effects become negligible (less than $0.5ms^{-1}$) at about 20m, the topographic effect has a maximum near 10m and the prediction site profile has a local maximum near 60m. Significant speed-up, say $>2ms^{-1}$, occurs between 5m and 60m.

7. CONCLUSIONS

Taylor and Lee's "simple guidelines" have provided a useful, practical tool for estimating wind speed variations caused by small scale topography and roughness changes. The guidelines have been extended to allow the wind profile at the upwind location to be estimated from a wind measurement at a separate reference site, using the PBL Resistance Law. Also, the treatment of two- and three-dimensional rolling terrain has been improved. These factors should increase the usefulness of the guidelines. Moreover, with the availability of the user-friendly computer program, they will now be easier to apply.

TABLE 2. Excerpts from an Output File from the Guidelines Program.

GUIDELINES ESTIMATES FOR WIND SPEED AT COMPLEX TERRAIN SITE		
SAMPLE RUN		
File SAMPLE.OUT	Mo-Da-Year: 02-15-1988 Time: 13:23:24	
REFERENCE SITE INPUT		
Wind speed		10 m/s
Anemometer height		20 m
Wind direction		270 deg
Roughness length		.03 m
UPSTREAM AREA		
Roughness length		.01 m
Neutral PBL Resistance Law used to compute upstream wind speeds since z_{ou} different from z_{or}.		
Latitude		45 degrees
Geostrophic wind speed		16.85 m/s
PREDICTION SITE INPUT – TOPOGRAPHIC		
2-dimensional ridge or valley	A = 3	B = 2
Height (h)		50m
Horizontal length scale (L)		250 m
h/L		0.200
PREDICTION SITE INPUT – ROUGHNESS		
Roughness length at prediction site		.1 m
INTERNAL BOUNDARY LAYER (IBL) CALCULATIONS		
Upstream distance to roughness change		400 m
IBL height at prediction site		40.04 m
Upstream speed at IBL height		11.74 m/s
Wind speed at IBL height at prediction site		14.64 m/s
Prediction height		5 m
WIND SPEED PREDICTION		
Upstream speed at prediction height		8.79 m/s
Wind speed correction – topographic		3.31 m/s
Wind speed correction – roughness		−1.13 m/s
Wind speed at prediction height		10.98 m/s
Prediction height		10 m
WIND SPEED PREDICTION		
Upstream speed at prediction height		9.78 m/s
Wind speed correction – topographic		3.47 m/s
Wind speed correction – roughness		−0.75 m/s
Wind speed at prediction height		12.49 m/s
Prediction height		20 m
WIND SPEED PREDICTION		
Upstream speed at prediction height		10.76 m/s
Wind speed correction – topographic		3.38 m/s
Wind speed correction – roughness		−0.38 m/s
Wind speed at prediction height		13.76 m/s

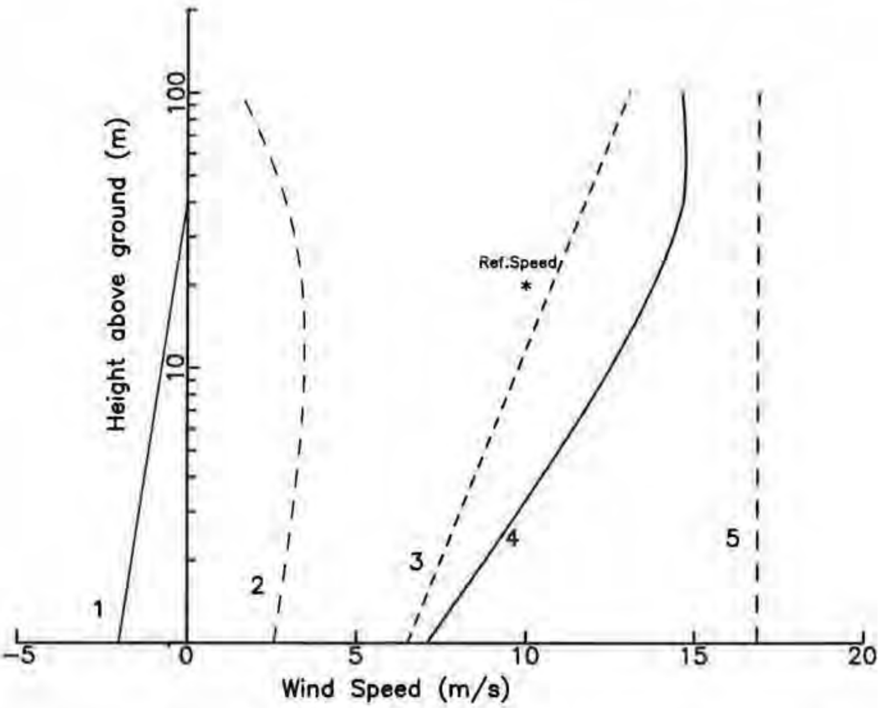

FIGURE 2. Wind speed profiles for sample run with calculations at additional prediction heights.
Curve 1 Wind speed reduction due to roughness change.
Curve 2 Wind speed increment due to effect of ridge.
Curve 3 Wind speed profile at upstream site ($z_{ou} = 0.01$m).
Curve 4 Wind speed profile at prediction site ($z_o = 0.1$m).
Curve 5 Geostrophic wind speed (45° latitude)
*Reference wind speed ($z_{or} = 0.03$m).

ACKNOWLEDGEMENTS

The refinement of the guidelines procedures has been prompted, in part, by the reactions of users of the original version. Chief among these have been Bob Morris and Les Welsh of the Canadian Climate Centre. We thank them both for their enthusiastic feed-back.

REFERENCES

Businger, J.A., 1987: Some Effects of Change of Terrain, Mesoscale Divergence, and Entrainment on the Structure of the Surface Layer and Its Consequences for Dry Deposition. *Air Pollution Modelling and its Application*, 6, Plenum, New York, 3–13.

Elliott, W.P., 1958: The Growth of the Atmospheric Internal Boundary Layer. *Transactions of the American Geophysical Union*, 39, 1048–1054.

Hunt, J.C.R., 1980: Wind Over Hills, in: J.C. Wyngaard (Ed.), *Workshop on the Planetary Boundary Layer*. American Meteorological Society, Boston, 107–144.

Jensen, N.-O., E.L. Petersen and I. Troen, 1984: *Extrapolation of Mean Wind Statistics with Special Regard to Wind Energy Applications*. WMO Publ. WCP–86.

Lemelin, D.R., D. Surry and A.G. Davenport, 1988: Simple Approximations for Wind Speed-Up Over Hills. *Journal of Wind Engineering and Industrial Aerodynamics*, 28, 117–127.

Mickle, R.E., N.J. Cook, A.M. Hoff, N.-O. Jensen, J.R. Salmon, P.A. Taylor, G. Tetzlaff and H.W. Teunissen, 1988: The Askervein Hill Project: Vertical Profiles of Wind and Turbulence. *Boundary-Layer Meteorology*, 43, 143–169.

Panofsky, H.A., 1974: The Atmospheric Boundary Layer Below 150 Meters. *Annual Review of Fluid Mechanics*, 6, 147–177.

Panofsky, H.A., and J.A. Dutton, 1984: *Atmospheric Turbulence: Models and Methods for Engineering Applications*. John Wiley & Sons, New York, 397 pp.

Salmon, J.R. and R.J. Morris, 1987: MS-Micro: A Microcomputer Version of a Three-Dimensional Wind Flow Model for Use in Complex Terrain, in: V. Lacey (Ed.), *Proceedings, Second National Conference, Canadian Wind Energy Association*, Quebec, 26–28 October 1986, CanWEA, Ottawa, 253–266.

Tampier, F., 1987: Separation Features of Boundary-Layer Flow over Valleys. *Boundary-Layer Meteorology*, 40, 295–307.

Taylor, P.A., 1969: The Planetary Boundary-Layer above a Change in Surface Roughness. *Journal of the Atmospheric Sciences*, 26, 432–440.

Taylor, P.A., 1987: Comments and Further Analysis on Effective Roughness Lengths for Use in Numerical Three-Dimensional Models. *Boundary-Layer Meteorology*, 39, 403–418.

Taylor, P.A. and R.J. Lee, 1984: Simple Guidelines for Estimating Wind Speed Variations Due to Small Scale Topographic Features. *Climatological Bulletin*, 18(2), 3–32.

Taylor, P.A. and H.W. Teunissen, 1984: Estimation of Design Wind Speed Variations Due to Small Scale Topographic Features. *Proceedings, Fourth Canadian Workshop on Wind Eng.*, November 1984, CWEA/NRC Publ., 234–259.

Taylor, P.A., J.L. Walmsley and J.R. Salmon, 1983: A Simple Model of Neutrally Stratified Boundary-Layer Flow Over Real Terrain Incorporating Wavenumber-dependent Scaling. *Boundary-Layer Meteorology*, 26, 169–189.

Taylor, P.A., J.L. Walmsley and J.R. Salmon, 1986: Guidelines and Models for

Estimating Wind Speeds at WECS Sites in Complex Terrain. *INTERSOL 85*, Proceedings, Ninth Biennial Congress of the International Solar Energy Society, Montreal, Canada, 23–29 June, 1985. Pergamon Press, New York, 2009–2014.

Walmsley, J.L., 1989: Internal Boundary-Layer Height Formulae – A Comparison with Atmospheric Data. *Boundary-Layer Meteorology*, in press.

Walmsley, J.L., P.A. Taylor and T. Keith, 1986: A Simple Model of Neutrally Stratified Boundary-Layer Flow Over Complex Terrain with Surface Roughness Modulations (MS3DJH/3R). *Boundary-Layer Meteorology*, 36, 157–186.

Walmsley, J.L., P.A. Taylor and J.R. Salmon, 1985: Boundary-Layer Studies of Winds Over Islands with Applications to Surface Wind Data from Grindstone Island (Îles-de-la-Madeleine) and Sable Island, in T.A. Agnew and V.R. Swail (Eds.), *Proceedings, International Workshop on Offshore Winds and Icing*, Halifax, Nova Scotia, October 7–11, 1985. 165–174.

Wieringa, J. 1986: Roughness-dependent Geographical Interpolation of Surface Wind Speed Averages. *Quarterly Journal of the Royal Meteorological Society*, 112, 867–889.

Understanding the Severe Local Storm Hazard in Canada: Where do we go From Here?

Michael J. Newark
Atmospheric Environment Service,
Downsview, Ontario

[Original manuscript received 12 May 1988;
in revised form 13 October 1988]

ABSTRACT

The history of climatological research in severe local summer storms shows that progress has been made in understanding the distribution across Canada of certain phenomena such as hailstorms and tornadoes. However, this work is still in its infancy and much remains to be done to advance our understanding of the hazards due to such storms. This paper briefly reviews what has been done, and examines the challenges yet to come.

RÉSUMÉ

Concernant les tempêtes estivales, l'histoire de la recherche climatologique au Canada nous indique que nous avons fait des progrès pour comprendre la distribution temporelle et géographique des phénomènes tels que les tornades et les tempêtes de grêle. Toutefois, ce travail-ci est dans son bas âge et il reste beaucoup à faire pour avancer notre connaissance des dangers de telles tempêtes. Cet article revoit en bref l'histoire de la recherche et examine les défis de l'avenir.

INTRODUCTION

Thunderstorms which cause damage due to tornadoes, hail, strong non-tornadic winds, or heavy rain can be defined as severe local storms. A knowledge of their climatology and their impact upon society forms the basis for understanding this natural hazard. The average annual losses due to such storms in Canada are not known, but as an order of magnitude estimate they must amount to some $\$10^9$ in crop and property damage. Additionally, over the last 5 years, there has been an average of 10 fatalities and approximately 90 injuries caused by severe storms each year.

Although study of the climatology of severe storms is not well organized on a national scale in Canada, there has been some regional activity in the compilation of severe local summer storm statistics. For example, data on hail climatology exist for parts of Alberta (30 years), and Saskatchewan (5 years).

Also, individual efforts have resulted in various sets of tornado statistics across the country, and for approximately the last decade, sets of annual severe local storm statistics of various types have been compiled by several of the AES regional organizations.

From a climatological point of view, the challenges that lie ahead can be categorized as follows:

1. *Data Management*, i.e. to locate and collate all these existing data, to develop common formats, design a standard database, maintain and update the archive, and to use consistent definitions of the severe storm phenomena;
2. *Data Collection and Analysis*, i.e. to collect the mesoscale information (both old and new) necessary to fill the gaps in time and space, and to analyze the data at an appropriate scale;
3. *Climatological Research*, for example to compare the analyzed data with other climatological parameters in order to examine their interrelationships;
4. *Impact Assessment*, i.e. to determine the impact of severe storms upon Canadian society in order to allow for the development of appropriate emergency strategies and fiscal planning.

HISTORY

Compared to the United States, where the first comprehensive tabulation of tornadoes was made in 1884 (in Court, 1970), and the first active hail research began in the late 1930's (Changnon, 1977), Canada has been very slow in realizing the magnitude and nature of the severe local storm hazard. Not until the pioneering work of McKay and Lowe in Western Canada during the mid to late 1950's was any progress made in understanding the scope of the tornado problem in this country. Not until 1971 was the first attempt made to examine the climatology and impact of all types of severe storm in the context of "all-hazards-at-a-place" (Hewitt and Burton, 1971). The first summary of the severe local storm season on a national scale was for the year 1980 (Newark, 1981).

Tornadoes

Before 1978. Before the first AES volunteer weather watcher network was organized in 1978, tornado (and most other severe local storm) information was collected in an intermittent and infrequent fashion and was usually published in the form of a case study. Data gathering was mainly an individual effort. As a result there was no clear picture of the climatology of tornadoes in Canada; nor was it known how they related to the general physical controls of weather and climate; and little was known about their impact upon society in terms of damage, injury, and death.

In the late 1950's a determined individual effort was made to seek information from unconventional sources concerning the climatology of tornadoes in Western Canada (McKay and Lowe, 1960), and similar individual attempts were begun in the early 70's to expand the information for particular regions (East, 1974; Hage, 1987; Milton and LaDochy, 1981; Newark, 1977; Blair and Paul, 1982; Raddatz *et al.*, 1983; Shannon, 1976), and for the country as a whole.

After 1978. After the AES volunteer weather watcher network was organized, severe storm statistics were routinely collected by Regional Weather Centres mainly for the purpose of verifying severe local storm watches and warnings. This institutional activity continues and annual reports containing climatological statistics are regularly prepared by the Weather Centres. At the AES Headquarters level, the tornado project of 1982 resulted in the first national climatology of tornadoes in Canada (Newark, 1984).

Hail

In 1956, the Stormy Weather Group at McGill University initiated (at the request of the Alberta government) the first intensive regional study of hail in Canada. Known as the Alberta Hail Studies Project (ALHAS), its major goals were to gather detailed information on hail climatology and hail dynamics. As a result of the project (which was terminated in 1987), there is today an extensive knowledge of the structure, behaviour, climatology, and impact of hailstorms in a part of Alberta (Wojtiw 1975, 1981). However, statistically conclusive evidence of the ability to modify hailstorms has been elusive.

The Saskatchewan Hail Research Project (SHARP) was initiated in 1973 by A.H. Paul of the University of Regina. He made the point that Saskatchewan alone suffers 10% of the total crop-hail losses in North America, and published the results of 5 years of data gathering in the southeastern portion of the province (Paul, 1980).

For other regions in Canada, very little is known about the magnitude of hail swaths, the distribution of hail size, the temporal and spatial characteristics of hailstorms, the frequency of severe hailstorms or their impact upon the economy. The fact however that severe hailstorms (with hailstones of golf ball size or larger) occur annually in many parts of the country is clear from the anecdotal evidence.

Locally Heavy Rain

Agencies concerned with hydrometeorology have shown an interest in gathering information concerning extremely heavy local downpours. The collection of this type of data is usually restricted to individual cases. Early case studies were typically anecdotal, but since 1961 an informal agreement between agencies including AES, the Inland Waters Directorate, and various provincial water resource groups has resulted in "bucket" surveys (i.e. quantitative rainfall estimates made from the contents of whatever containers can be found, and systematic mapping of rainfall areas and times of occurrence) of the more damaging events. The results of this type of work are available in published form (Environment Canada, 1984 for example).

Some literature concerning the regional climatology of locally heavy rain exists (e.g. Storr 1963, Wojtiw and Verschuren, 1981) and national lists of days with locally heavy summer rains have also been made (e.g. Newark *et al.*, 1987).

Of all the various elements of the severe local storm, locally heavy rain is the most amenable to study by means of radar. While AES maintains an archive of digital radar data which is cycled every five years when the storage tapes are filled, there is no radar climatology program such as that proposed by Hogg (1978) to analyze the stored data.

Damaging Thunderstorm Winds

Data concerning this type of non-tornadic storm are very sparse. Some anecdotal information is available from unconventional meteorological sources such as newspapers, and some case studies of damage have been made. Since the late 1970's, AES Regional Weather Centres have compiled frequency statistics (mainly from newspaper clippings, but also from volunteer storm watchers and field investigations) as a result of their severe weather warning verification activities. Rudimentary regional climatological analysis of such statistics has been attempted (e.g. Newark 1982, 1983), and national lists of days with damaging winds have also been compiled (Newark *et al.*, 1987).

INFORMATION REQUIREMENTS

Public Information

During the past decade there has been a growing public demand for information on the characteristics and climatology of severe local storms and particularly tornadoes. In general, the areas of interest can be categorized as follows:

1. *Emergency Preparedness*, for example, the development of contingency plans on different scales (individual, institutional, community, provincial, national); flood forecasting and water level management.
2. *Public Education*, for example, media programming and articles; school and university projects; public lectures and talks.
3. *Building Codes*, for example, the Farm Code, Provincial and National Building codes; the design of hydrologic structures.
4. *Legal and Economic*, for example, the insurance industry requirement for damage probability. Liability litigation.
5. *Energy*, for example, the design of electrical transmission lines; the risk to nuclear energy facilities.

Clearly, not all of these demands can be met at a regional level. Even when they can, there is sometimes the requirement for a national perspective in order to help the user to better understand the problem at hand.

Watch and Warning Verification

There is an ongoing requirement for statistics in order to verify warning programs. At present there is no national standard for collecting the data used to estimate such statistics, nor is there a common data base or archive. As a result, verification statistics (and the climatology of severe storms which is based on such statistics) are incompatible from one AES region to another. There is also difficulty in dealing with events which straddle regional and international boundaries. These problems have been recognized for some time, and were identified by the AES (at the first national Workshop on summer severe weather in January 1988) as items in need of action.

Research

There is a need for research in order to understand: (a) the behaviour of severe storms in relation to each other (for example, is damaging hail more or less likely than tornadoes, and if so, where and when); (b) the behaviour of Canadian severe storms in a North American context; (c) to relate the climatological behaviour of severe local storms to other climatological variables in order to better define their temporal and spatial likelihood; (d) the effect of climatic change.

Although LaDochy (1985) related the climatology of severe storms in Manitoba to the synoptic weather conditions conducive to their development, there is very little of this type of research being carried out at present, either in universities or by government agencies. It should be noted, however, that the Alberta Research Council recently began exploring ways of establishing a mesoscale research centre in their province.

Impact Monitoring

There is a need to monitor the impact of severe local storms primarily to determine their effect upon the Canadian economy and the security of Canadians (thus finding the best way of responding to the hazard), and secondarily to help determine the effectiveness of AES warning programs in terms of cost and utility.

SUMMARY

As yet, there is no overall co-ordination of the collection of severe local storm statistics to ensure uniformity of the data bases, to identify the objectives of the collection activities, or to analyze the data and impacts on a national scale. Nor have the data used in the AES tornado project been updated. The longer this situation continues, the harder it will be to reconcile the diverging activities of the various agencies and to make up for lost ground, and the more difficult to respond to a growing user demand.

Hand in hand with the need for co-ordinated severe storm activities, there has been a growing interest in tornadoes and an increasing public demand for tornado data for a variety of uses. The great value of knowledge of severe storm return periods, probability, distribution, magnitude, severity etc., to the economy and security of Canadians is indisputable even if it cannot be quantifiied.

PROPOSAL

In order to properly understand the scope, nature, and effect of severe local storms in Canada, a large and complex task awaits. The collection, archiving, analysis and dissemination of severe local storm data are activities which should be carried out in an organized, co-operative fashion by all participants. It will be necessary (a), to re-examine the methods by which data is gathered, (b) to establish a central data bank and (c), to establish the mechanisms that will foster co-operation and allow the exchange and dissemination of ideas, research results, and information.

To facilitate these aims, a number of initiatives are proposed as follows:

1. bring the participants together by means of a special interest group, (for example, a CMOS special interest group) and by means of regular workshops, seminars and training courses;
2. identify the users of the information;
3. define the terms and objectives of the activities;
4. develop common data base formats;
5. establish a central archive;
6. establish centralized co-ordination of the procedures;
7. establish a vehicle for the dissemination of information;
8. develop international co-operation, and liaison between participating agencies.

The results of such activities should be easily accessible and readily available data sets of good quality that can be applied to the diverse needs of society.

REFERENCES

Blair, D.E., and A.H. Paul, 1982: Climatology of Tornadoes in Saskatchewan. Paper presented at Annual Meeting, Canandian Association of Geographers, Ottawa, Ontario.

Changnon, S.A., 1977: The Climatology of Hail in North America. *Meteorological Monographs*, Vol. 16, No. 38, American Meteorological Society, 107–128.

Court, A., 1970: Tornado Incidence Maps. ESSA Technical Memorandum ERLTM-NSSL 49, U.S. Department of Commerce, Norman, Oklahoma.

East, M.C., A. Lehman, S. Lapierre, D. O'Donoughue, 1974: Recherche sur les tornades. Université du Québec à Montréal. Research Project for Hydro-Québec.

Environment Canada, 1984: Storm Rainfall in Canada. Analysis No. ONT–8–84, Atmospheric Environment Service, Downsview, Ontario.

Hage, K.D., 1987: A Comparative Study of Tornadoes and other Destructive Windstorms in

Alberta and Saskatchewan. *Proceedings of the Symposium/Workshop: The Impact of Climate Variability and Change on the Canadian Prairies, September 9–11, 1987*. Edmonton, Alberta, 351–377.

Hewitt, K., and I. Burton, 1971: *The Hazardousness of a Place: A Regional Ecology of Damaging Events*. University of Toronto Press, Toronto, Ontario, 154 pp.

Hogg, W.D., 1978: Quality Control and Analysis of an Archive of Digital Radar Data. *Preprints, 18th Conference on Radar Meteorology*, Atlanta, Georgia, American Meteorological Society.

LaDochy, S.E.G., 1985: *The Synoptic Climatology of Severe Thunderstorms in Manitoba*. Ph.D. Thesis, University of Manitoba, Winnipeg, Manitoba.

McKay, G.A., and A.B. Lowe, 1960: The Tornado in Western Canada. *Bulletin of the American Meteorological Society*, 41(1), 1–8.

Milton, D.J., and S. LaDochy, 1981: Tornadoes in Manitoba. Paper presented at Annual Meeting, Canadian Association of Geographers, St. John's, Newfoundland.

Newark, M.J., 1977: Tornadoes in Ontario Before 1900. *Ontario History*, Vol. 69, No. 4, 257–276.

Newark, M.J. 1981: Severe Local Storms of 1980. In: *Canadian Climate in Review – 1980*, D.W. Phillips and G.A. McKay (Eds,), AES, Toronto, 96–99.

Newark, M.J., 1982: *Severe Local Storms in Ontario during 1981*. CLI 2–83, AES, Toronto, 31 pp.

Newark, M.J., 1983: *Severe Local Storms in Ontario during 1982*. CLI 4–83, AES, Toronto, 37 pp.

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

Newark, M.J., M. Leduc, F. Letchford, G. Machnee, S. Siok and D. Waugh, 1987: Summary and Highlights of the 1985 Severe Local Storm Season. *Climatological Bulletin*, 21(3), 44–54.

Paul, A.H., 1980: Hailstorms in Southern Saskatchewan. *Journal of Applied Meteorology*, 19(3), 305–314.

Raddatz, R., R.R. Tortorelli, and M.J. Newark, 1983: *Manitoba and Saskatchewan Tornado Days, 1960–1982*. CLI 6–83, Atmospheric Environment Service, Downsview, Ontario, 57 pp.

Shannon, T.B., 1976: Manitoba Tornadoes, 1960–1973. Project Report No. 29, Atmospheric Environment Service, Downsview, Ontario.

Storr, D., 1963: *Maximum One-day Rainfall Frequencies in Alberta*. CIR 3796 TEC 451, Meteorological Branch, Department of Transport, 9 pp.

Wojtiw, L., 1975: *Climatic Summaries of Hailfall in Central Alberta (1953–1973)*. Alberta Research, Edmonton. Atmospheric Sciences Report 75–1, 102 pp.

Wojtiw, L., 1981: Climatology of Hailfalls and Hailswaths in Central Alberta, Canada. *Extended Abstracts, 8th Conference on Inadvertent and Planned Weather Modification*, Reno, Nevada, American Meteorological Society, 134–135.

Wojtiw, L., and J. Verschuren, 1981: Climatology of Severe Rainstorms in Alberta, Canada. *Preprints, 4th Conference on Hydrometeorology*, Reno, Nevada, October 7–9, 1981, American Meteorological Society, 21–26.

1613 – Champlain reported a windfall of uprooted trees.
1763 – Captain Cook reported waterspouts on Queen Charlotte Sound.
1792 – First report of a tornado in Canada (in the Township of Thorold, Ontario).
1826 – First eyewitness report of a tornado in Western Canada (in present day Winnipeg, Manitoba).
1829 – First eyewitness report of a tornado in Eastern Canada (in Guelph, Ontario).
1839 – Magnetic and Meteorological Observatory established in Toronto.
1844 – First reported tornado death (near Galt, Ontario).
1850 – First multiple deaths in a major tornado (near Lake Scugog, Ontario).
1856 – North America's first published illustration of an actual tornado (in the Earl of Southesk's journal).
1878 – First published field survey of tornado damage in Canada (near Norwood, Ontario).
1879 – New Brunswick's worst tornado tragedy (5 fatalities near Buctouche).
1884 – First known photograph of a tornado in North America (near Howard, South Dakota).
1888 – Québec's worst tornado disaster (9, possibly 11 fatalities near St-Zotique).
1892 – First published illustration of Canadian tornado damage (in the *Montreal Witness)*.
1898 – First illustration of a Canadian tornado (in *The Globe*, Toronto).
1909 – First known photograph of a Canadian tornado (at Oak Lake, Manitoba).
1912 – Canada's worst tornado tragedy (28 fatalities in Regina, Saskatachewan).
1922 – Manitoba's worst tornado outbreak (8 tornadoes, 5 fatalities).
1926 – British Columbia's worst tornado (damage trail 80 km through forest terrain in the Caribou region, no fatalities).
1928 – The most large animals killed by a hailstorm (3 horses and 750 sheep killed near Constance, Saskatchewan).
1943 – First meteorological use of radar in Canada.
1946 – Ontario's worst tornado tragedy (17 fatalities in Windsor).
1947 – First published work of the Stormy Weather Group at McGill University, Montreal.
1948 – At Windigo Lake, Ontario, unverified (but reliable) report of Canada's largest known diameter hailstones (weight 255 g, diameter 127 mm).
1956 – Start of the *Al*berta *Ha*il *S*tudies Project (ALHAS).
1957 – First tornado warning issued by the Canadian Meteorological Service (by the Forecast Office in Toronto for southwestern Ontario).
1960 – First published climatology of tornadoes (by Lowe and McKay for Western Canda).
1963 – Weather satellite pictures first received.
1968 – First geostationary satellite pictures received.
1971 – First published work to examine the climatology and impact of severe local storms in the context of all hazards at a place (by Hewitt and Burton, University of Toronto).
1973 – *S*askatchewan *Ha*il *R*esearch *P*roject (SHARP) started by A.H. Paul of the University of Regina.
– The first network of hailpads used for hail research in Alberta.

– Near Cedoux, Saskatchewan, verified observations of the heaviest known hailstones (weight 290 g, diameter 102 mm) in Canada.

1978 – First volunteer "severe storm" watchers recruited by the Atmospheric Environment Service.

1981 – A hailstorm in Calgary, Alberta (with damage costs exceeding $100 million, this is generally acknowledged as the most damaging hailstorm in Canada).

1984 – First national climatology of tornadoes (by Newark).

1985 – Largest known tornado outbreak (12 occurred in southern Ontario, and one in neighbouring Québec on May 31, 1985, narrowly exceeding a one-day outbreak of 12 tornadoes in southern Ontario in 1968).

– At Parkman, Saskatchewan, 380 mm of rain in 18 hours is the greatest documented rainfall from a thunderstorm complex in Canada.

1987 – Alberta's worst tornado tragedy (27 fatalities in Edmonton).

– First published national map of hail climatology.

1988 – First national workshop on severe local storms (at Centre Météorologique du Québec, Montréal).

Prospectives d'un changement climatique dû à un doublement de CO_2 atmosphérique pour la distribution forestière du Québec-Labrador

Bhawan Singh
Département de géographie
Université de Montréal
C.P. 6128, Succursale A
Montréal (Québec) H3C 3J7

[Manuscrit reçu le 18 avril 1988;
en forme révisée le 3 décembre 1988]

ABSTRACT

This study evaluates the potential areal displacements and growth rate changes of the major forest communities of Quebec-Labrador following a climate change due to a doubling of atmospheric CO_2. Area changes are deduced using the Holdridge Life Zone classification whereas changes in the growth rate of the boreal forest are calculated using a method suggested by Kauppi and Posch (1985) for Finland. The GFDL (A) and GISS (B) climate change scenarios are used. According to our results major northward displacements and area changes are to be expected for the main forest communities of Quebec-Labrador. For the boreal forest decreased acreage is likely to be compensated for by increased growth rates.

RESUME

Cette étude porte sur les déplacements potentiels, en terme de superficie, et les changements du taux de croissance des majeures écosystèmes forestiers du Québec-Labrador, suivant un changement climatique dû à un doublement de CO_2 atmosphérique. Les changements de superficie sont déduits à part du système de classification écoclimatique selon Holdridge (1947), alors que les changements du taux de croissance de la forêt boréale sont calculés selon une méthode developpée par Kauppi et Posch (1985) pour la Finlande. Les scénarios d'un changement climatique GFDL et GISS ont été utilisés. Selon nos résultats, des majeurs déplacements méridionaux et des majeures modifications de superficie sont attendus pour les principaux écosystèmes forestiers du Québec-Labrador. Pour la forêt boréale, la perte de superficie devrait être compensée par un plus grand taux de croissance.

Un doublement possible de CO_2 atmosphérique pourrait avoir des conséquences importantes pour la végétation forestière (Solomon et West, 1986). Dans cette étude on va essayer d'évaluer les impacts d'un changement climatique provenant d'un doublement de CO_2 atmosphérique au niveau de la distribution spatiale des majeures zones forestières et en second lieu au niveau des changements du taux de croissance de la forêt boréale pour la province de Québec et le Labrador.

Méthodologie et sources de données

Afin d'évaluer les impacts potentiels sur les zones forestières du Québec d'un changement climatique dû à un doublement de CO_2 atmosphérique, on a retenu deux approches. En premier lieu, on a adopté le système de classification des zones écoclimatiques (Life Zone Classification) selon Holdridge (1947, 1964). Ceci est utilisé pour tester la sensibilité de la distribution des écosystèmes forestiers de la province de Québec aux changements climatiques.

Deuxièmement, on a utilisé une méthode suggérée par Kauppi et Posch (1985) pour évaluer la productivité de l'écosystème boréal de la province de Québec, par suite d'un changement climatique.

Les données de base pour effectuer ces études d'impacts climatiques sont les températures et les précipitations normales (1951–80), leurs changements selon un doublement de CO_2 atmosphérique, et les valeurs projetées de température et de précipitation ($2 \times CO_2$) pour la province de Québec, d'après les modèles GFDL (General Fluid Dynamics Labratory) de Manabe et Stouffer (1980), scénario A ici, et GISS (Goddard Institute for Space Studies) de Hansen *et al.* (1983), scénario B.

À partir des trois variables climatiques, la biotempérature moyenne annuelle (BT °C), la moyenne de la précipitation totale annuelle (PA, mm) et le ratio d'évaporation potentielle (REP), le schéma de Holdridge permet d'identifier trente types d'écosystèmes forestiers. Cette classification végétale a été calibrée par Holdridge (1947, 1964) et par d'autres chercheurs (Sawyer et Lindsey, 1963; Steila, 1966) dans des diverses régions du monde. D'ailleurs Emmanuel *et al.* (1985) et Solomon (1986) ont démontré que le système de classification écoclimatique de Holdridge est une excellente méthode pour évaluer l'impact des changements climatiques, dûs à une hausse de CO_2 atmosphérique, sur la distribution spatiale d'écosystèmes forestiers, surtout à cause de sa facilité d'application.

Dans cette étude, on a développé un algorithme pour calculer les différents types d'associations végétales qui conviennent d'après Holdridge aux valeurs spécifiques des indices BT, PA et REP. BT est la moyenne des températures mensuelles, PA la sommation des précipitations mensuelles, et (Holdridge 1947, 1964):

$$REP = \frac{58.93 \times BT}{PA} \quad (1)$$

où la valeur 58.93 représente une constante de proportionalité. Le REP est donc un indice de l'humidité effective. Etant donné l'absence des montagnes importantes au Québec, on a négligé ici la correction altitudinale de Holdridge.

Ces indices (BT, PA et REP) sont calculés des données normales de 1951–80 et des valeurs projetées (2 × CO_2) pour les deux scénarios, A (GFDL) et B (GISS). À partir de ces résultats, des diverses cartographies de la distribution spatiale de la végétation forestière de la province de Québec sont produites.

Le deuxième but, c'est viser à la productivité de l'écosystème forestier boréal de la province de Québec qui occupe présentement la région entre 48°N et 55°N (Morisset et Payette, 1983). La forêt boréale a été retenue en raison de son importance commerciale et en raison de la disponibilité de données.

Selon Kauppi et Posch (1985), la productivité des écosystèmes forestiers sur une grande échelle est limitée par la température et non par l'humidité du sol. En se fiant à cette hypothèse de départ Kauppi et Posch (1985) ont développé une relation simple entre la température et la productivité de la forêt boréale de Finlande. Ils ont introduit un modèle de régression linéaire qui calcule la magnitude du changement de productivité de la forêt boréale selon le changement de la somme annuelle de la température effective (ETS, degrés-jours), ce qui est définie comme le cumul total des températures diurnes moyennes qui dépassaient une température de 5°C.

Selon Kauppi et Posch (1985) le ETS devrait incorporer deux facteurs importants qui influent sur la productivité forestière, soit la longueur de la saison de croissance et le niveau d'activité (croissance) diurne de l'écosystème de la saison de croissance.

Kauppi et Posch (1985) ont développé une équation de régression linéaire qui calcule le taux de croissance végétale (G: "Tree growth rate" en m^3ha^{-1} année^{-1}) à partir de ETS. Cette équation, qui est déduite de la distribution des points de la Fig. 1, s'écrit ainsi:

$$G = a \times ETS - b \qquad (2)$$

où a = 0.0066135 et b = 3.61157.

L'équation (2) s'applique facilement à des études de productivité régionale, étant donné qu'elle décrit la croissance régionale de la forêt et non seulement la croissance individuelle des arbres.

Toutefois, la productivité forestière n'est pas attribuable seulement aux caractéristiques climatiques, mais aussi aux conditions édaphiques, et aux méthodes d'aménagement forestier. Aussi le nuage des points de la Fig. 1 se limite aux taux de croissance (G) de 5.2m^3 /ha /année et aux ETS de 1300 degrés-jours environ. Pourtant dans notre cas, les valeurs de ETS et de G (tableau 3) dépassaient ces valeurs maximales, surtout pour les données projetées. Ceci attesterait aux problèmes de recherche en ce domaine et il serait souhaitable de développer les indices de croissance pour le Canada, tout en adoptant l'approche de Kauppi et Posch (1985). Cependant en raison des hausses significatives de la précipitation

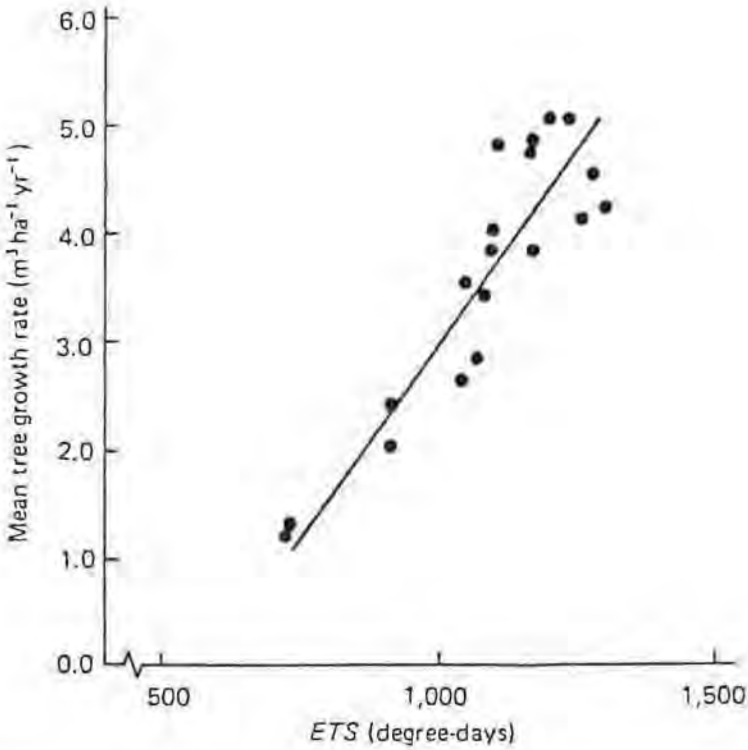

FIGURE 1. Régression entre la somme de la température effective (ETS) et le taux de croissance annuelle (G) des arbres boréales selon Kauppi et Posch.

projetée pour le Québec, ce qui augmenterait le taux de croissance, on a fait une extrapolation linéaire dans la Fig. 1. Il semblerait que la relation entre G et ETS devrait suivre une équation exponentielle décroissante, comme Gates (1985) a remarqué en utilisant des simulations et des observations sur des petites plantes dans un environnement contrôlé.

D'ailleurs, l'application des indices de régression de l'équation (2) développée en Finlande aux conditions québécoises n'est pas tout à fait irréaliste. L'étude canadienne la plus complète au niveau de la croissance de la forêt boréale est par Jozsa *et al* (1984). Cette étude portait sur la largeur (mm) et la densité ($g\ cm^{-3}$) des anneaux des arbres. Ainsi les paramètres de croissance de Jozsa *et al* (1984) n'ont pas les mêmes unités que l'équation (2). Etant donné les caractéristiques climatiques et édaphiques similaires des deux pays, l'adoption de l'approche finnoise n'est pas tout à fait sans mérite. Aussi dans cette étude nous avons négligé les adjustements de continentalité de Kauppi et Posch (1985), considérant qu'une bonne partie du Québec-Labrador chevauche l'océan.

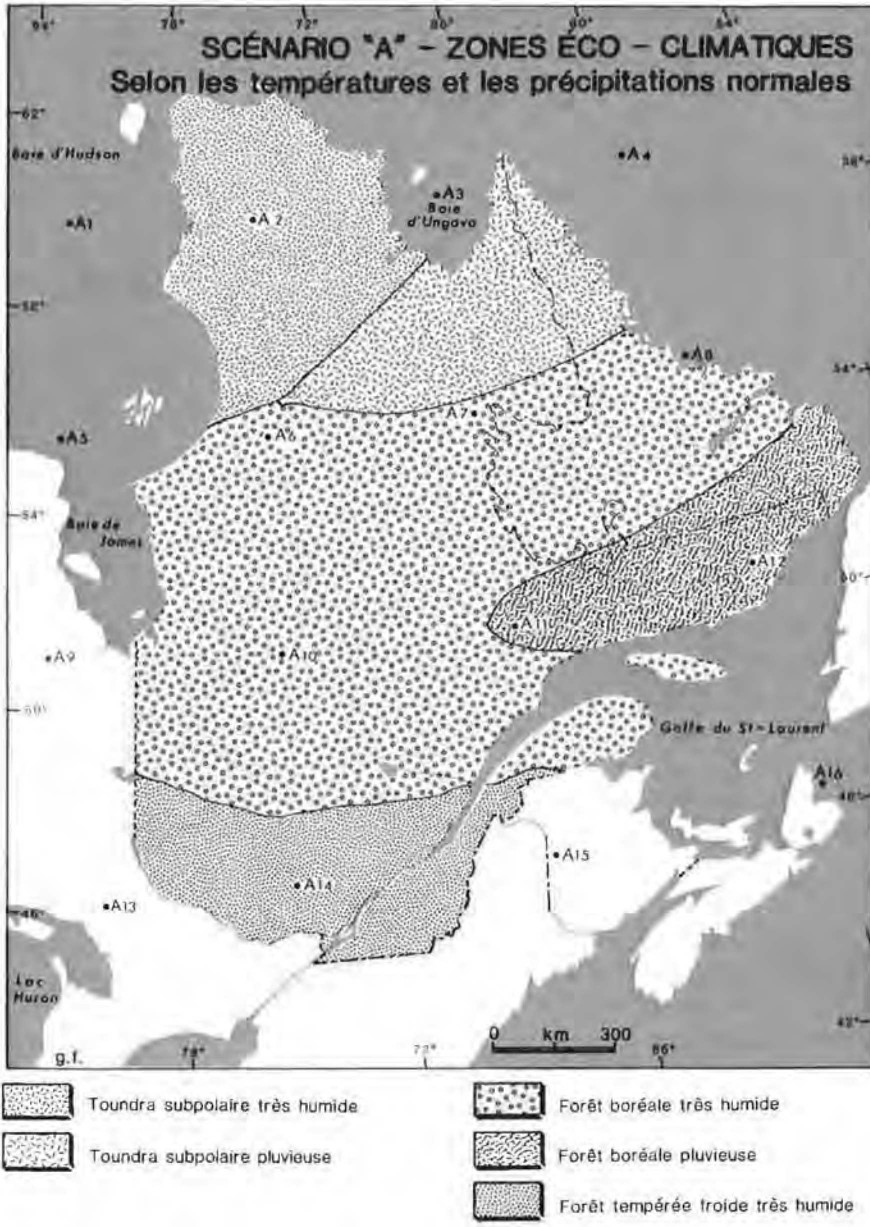
SCÉNARIO "A" - ZONES ÉCO - CLIMATIQUES
Selon les températures et les précipitations normales
Baie d'Hudson
Baie d'Ungava
Baie de James
Golfe du St-Laurent
Lac Huron
0 km 300
g.f.
Toundra subpolaire très humide
Toundra subpolaire pluvieuse
Forêt boréale très humide
Forêt boréale pluvieuse
Forêt tempérée froide très humide

FIGURE 2a

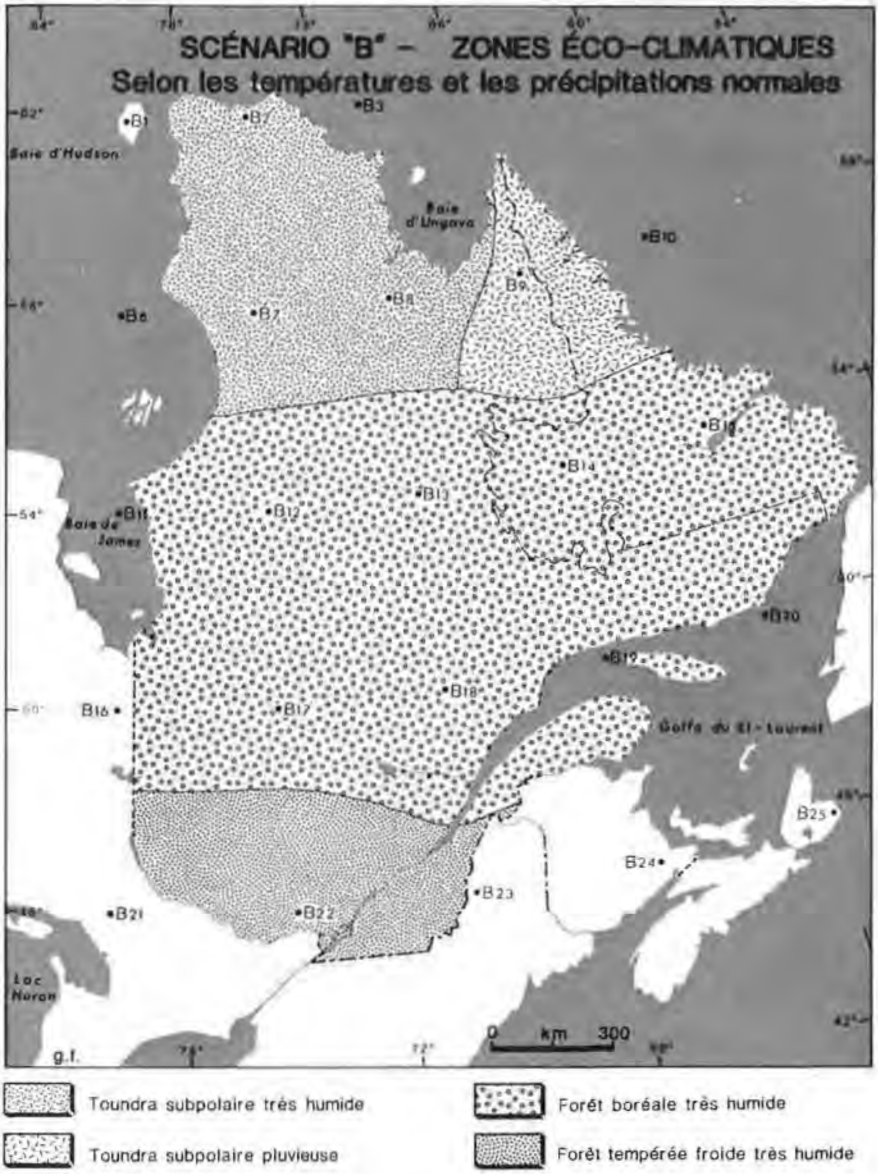
SCÉNARIO "B" - ZONES ÉCO-CLIMATIQUES
Selon les températures et les précipitations normales
Baie d'Hudson
Baie d'Ungava
Baie de James
Golfe du St-Laurent
Lac Huron
0 km 300
g.f.
Toundra subpolaire très humide
Toundra subpolaire pluvieuse
Forêt boréale très humide
Forêt tempérée froide très humide

FIGURE 2b

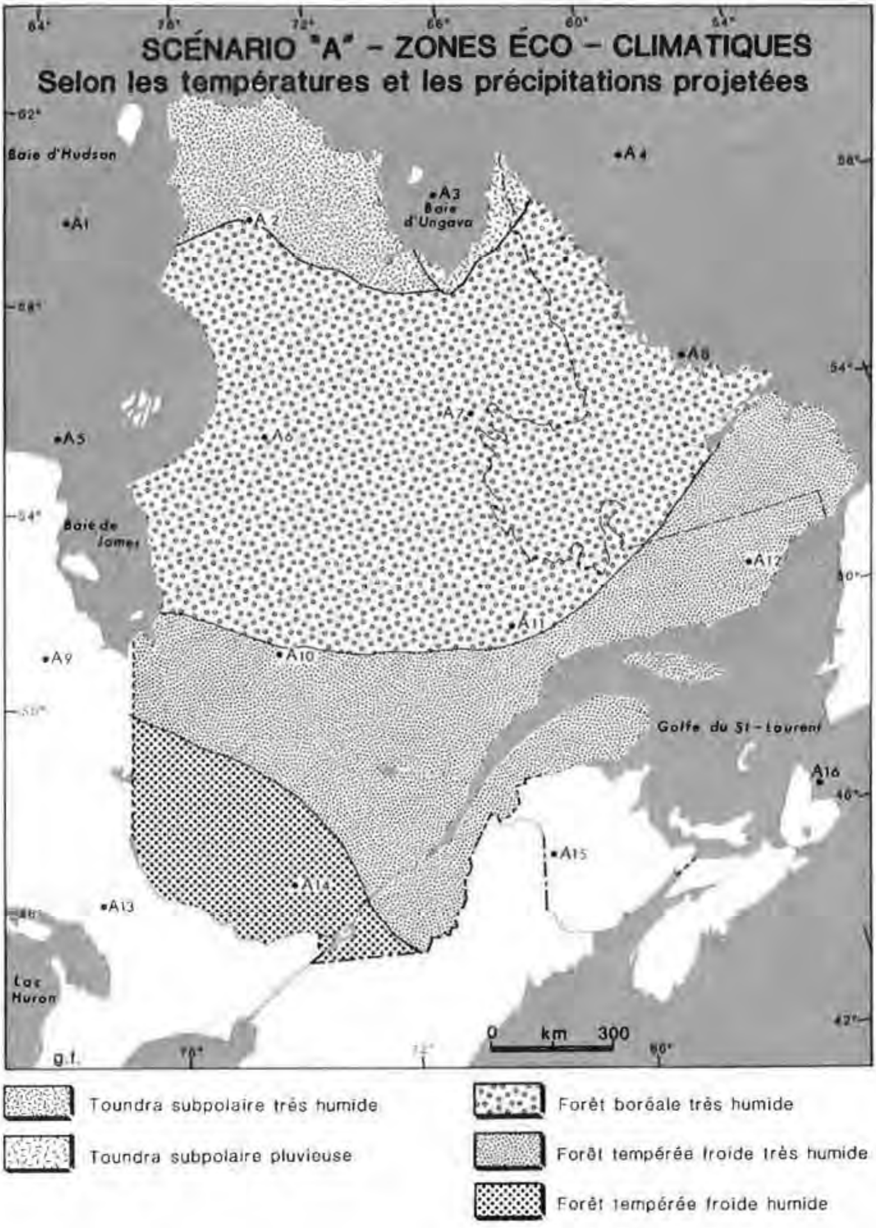
SCÉNARIO "A" - ZONES ÉCO - CLIMATIQUES
Selon les températures et les précipitations projetées
Baie d'Hudson
Baie d'Ungava
Baie de James
Golfe du St-Laurent
Lac Huron
0 km 300
Toundra subpolaire très humide
Toundra subpolaire pluvieuse
Forêt boréale très humide
Forêt tempérée froide très humide
Forêt tempérée froide humide

FIGURE 3a

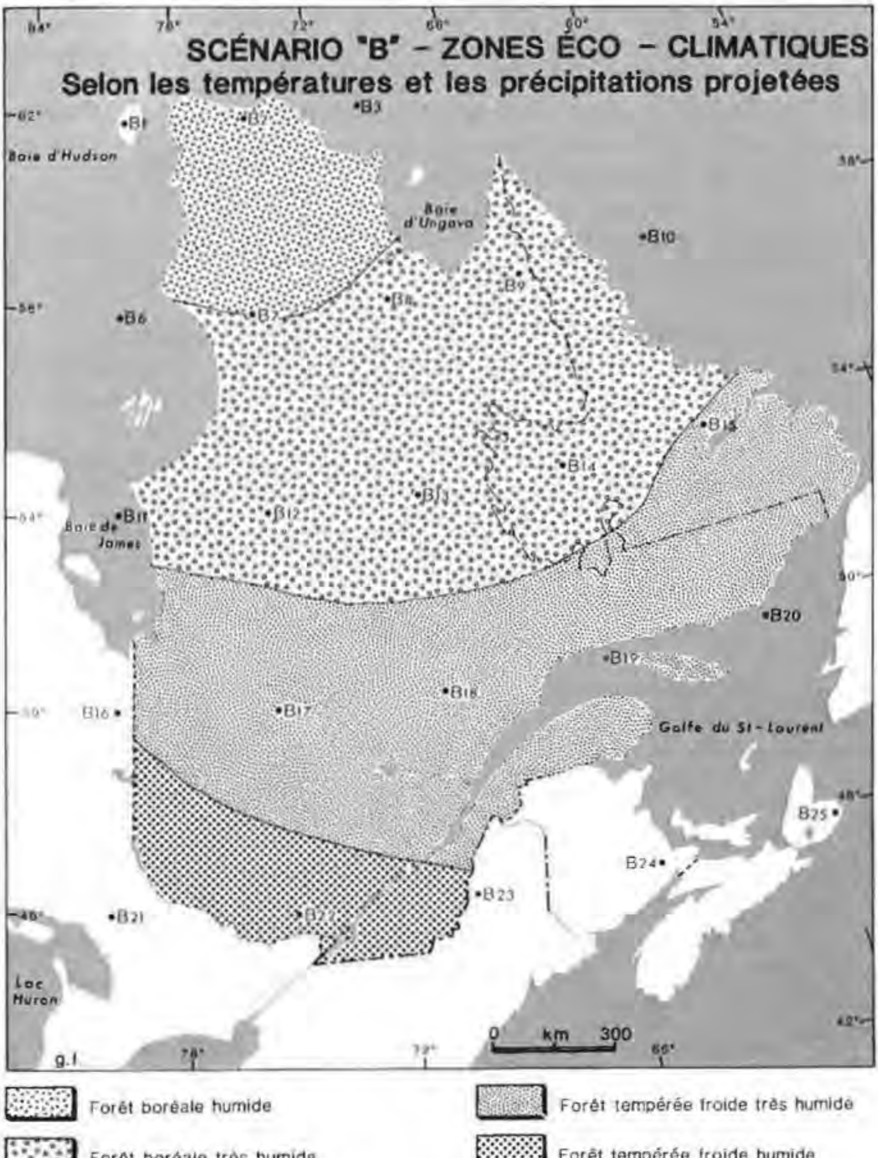
SCÉNARIO "B" - ZONES ÉCO - CLIMATIQUES
Selon les températures et les précipitations projetées
Baie d'Hudson
Baie d'Ungava
Baie de James
Golfe du St-Laurent
Lac Huron
•B1
•B3
•B6
•B7
•B8
•B9
•B10
•B11
•B12
•B13
•B14
•B15
•B16
•B17
•B18
•B19
•B20
•B21
•B22
•B23
•B24
•B25
0 km 300
g.l
Forêt boréale humide
Forêt boréale très humide
Forêt tempérée froide très humide
Forêt tempérée froide humide

FIGURE 3b

Résultats

En général, les zones biogéographiques actuelles du Québec, selon le Service de Recherche en Sols, ministère de l'Agriculture, sont sensiblement similaires aux zones écoclimatiques de Holdridge, pour les conditions normales d'après les deux scénarios (Fig. 2a et Fig. 2b). Par exemple la forêt tempérée froide très humide de Holdridge (Fig. 2a et Fig. 2b) correspond aux zones occupées par les forêts érablières et les forêts sapinières qui se trouvent dans l'extrême sud de la province, soit dans les Laurentides et les basses terres du St-Laurent. Cette correspondance générale permet de procéder avec confiance à l'application du schéma de Holdridge.

En comparant les zones écoclimatiques de Holdridge pour les conditions climatiques normales (Fig. 2a et Fig. 2b) avec celles pour les conditions climatiques projetées (Fig. 3a et Fig. 3b), il semble qu'il y aurait des changements potentiels importants au niveau de la distribution spatiale (tableaux 1 et 2).

Pour ce qui est de la zone forestière toundra subpolaire pluvieuse, il devrait y avoir une baisse de superficie importante selon les deux scénarios. (tableaux 1 et 2 et Figs. 2a, 2b, 3a et 3b). D'autre part, la zone forestière toundra subpolaire très humide devrait baisser modérément en superficie selon le scénario A et elle devrait disparaître complètement selon le scénario B.

Pour la forêt boréale pluvieuse, elle devrait disparaître complètement

TABLEAU 1. Changements des pourcentages de superficies des différentes zones forestières pour les deux scénarios.

	SCÉNARIO A			SCENARIO B		
	Normale %	Projeté %	Variation %	Normale %	Projeté %	Variation %
Toundra subpolaire pluvieuse	10.3	0.8	−91.8	4.6	—	−100.0
Toundra subpolaire très humide	16.6	9.3	−44.2	21.7	—	−100.0
Forêt boréale pluvieuse	9.6	—	−100.0	—	—	—
Forêt boréale très humide	48.6	46.0	−5.3	58.9	35.6	−39.8
Forêt boréale humide	—	—	—	—	12.3	—
Forêt tempérée froide, très humide	15.0	32.3	114.9	14.9	40.2	170.3
Forêt tempérée froide humide	—	11.7	—	—	12.0	—

N.B. 100% = 1,515,233 Km^2 de terre (normale et projeté)

Variation = $\frac{\text{projeté} - \text{normale}}{\text{normale}} \times 100$

alors que la forêt boréale très humide devrait baisser légèrement en superficie, selon le scénario A. D'autre part, le scénario B projète une baisse de superficie modérée pour la forêt boréale très humide, mais une légère hausse de superficie pour la forêt boréale humide (tableau 1 et 2 et Fig. 2a, 2b, 3a et 3b).

En ce qui concerne la forêt tempérée mixte d'arbres francs, il semblerait qu'il y aurait une augmentation importante de la forêt tempérée froide très humide (d'après Holdridge), selon les deux scénarios. Pour la forêt tempérée froide humide, qui n'existait pas selon les données climatiques normales, il y aurait des hausses de superficie très importantes selon les deux scénarios (tableaux 1 et 2 et Figs. 2a, 2b, 3a et 3b). Ces résultats sont semblables à ceux trouvés par d'autres chercheurs qui ont utilisé une approche semblable (Solomon et West, 1986; Solomon, 1986; Shugart *et al.*, 1985).

Il semblerait donc que d'après le système de classification écoclimatique de Holdridge la superficie de l'écosystème toundra subpolaire, qui occupe actuellement l'extrême nord de la province, soit la région au nord de la 55 ième parallèle environ (Fig. 2a et Fig. 3a) devrait se diminuer considérablement selon le scénario A, et complètement selon le scénario B (tableau 2).

Pour ce qui est de la forêt boréale qui occupe présentement la région latitudinale entre 48°N environ et 55°N environ (Morisset et Payette, 1983), il semblerait que la superficie totale diminuerait considérablement aussi, selon les

TABLEAU 2. Changements nets de superficie des différentes zones forestières pour les deux scénarios.

	SCENARIO A			SCENARIO B		
	Normales (10^3Km^2)	Projetées (10^3Km^2)	Variation* (10^3Km^2)	Normales (10^3Km^2)	Projetées (10^3Km^2)	Variation* (10^3Km^2)
Toundra subpolaire pluvieuse	156	12	−143	68	—	−68
Toundra subpolaire très humide	251	140	−110	328	—	−328
Forêt boréale pluvieuse	145	—	−145	—	—	—
Forêt boréale très humide	735	696	−38	892	537	−354
Forêt boréale humide	—	—	—	—	186	186
Forêt tempérée froide, très humide	227	488	261	225	608	383
Forêt tempérée froide humide	—	176	176	—	182	182

* variation = projetée − normale

N.B. Superficie total de terre de la province de Québec et du Labrador: 1,515,233 Km^2.

deux scénarios (tableau 2). Dans les deux cas (scénarios A et B), il y aurait aussi un déplacement vers le nord de la forêt boréale, qui envahisserait les régions antérieurement occupées par l'écosystème toundra subpolaire.

Finalement, en ce qui concerne la forêt tempérée froide de Holdridge (forêt mixte d'arbres francs), qui se trouve présentement dans l'extrême sud de la province, il devrait en avoir une hausse de superficie très importante d'après les deux scénarios. Dans les deux cas la forêt tempérée se déplacerait vers le nord envahissant ainsi les régions antérieurement occupées par la forêt boréale.

Toutefois, ces baisses de superficie de la forêt boréale devraient être compensées par des hausses du taux de croissance des arbres, étant donné un doublement de CO_2 atmosphérique, surtout vu que des hausses importantes de la température et de la précipitation sont prévues pour ces régions (Singh *et al.*, 1987). Négligeant l'effet direct du CO_2 pour l'instant, le tableau 3, qui est déduit des isolines de ETS et de G, pour la région entre 48°N et 55°N (Singh *et al.*, 1987), soit la région que la forêt boréale devrait occuper, démontre des hausses importantes de ETS et de G, surtout à l'extrémité septentrionale (55°N) et surtout selon le scénario B (GISS).

Le ETS devrait augmenter de l'ordre de 22–27 pourcent aux extrémités méridionales (48°N) et de l'ordre de 27 (GFDL) à 50 (GISS) pourcent aux extrémités septentrionales (55°N) (tableau 3). D'autre part, le taux de croissance des arbres devrait augmenter de l'ordre de 36 pourcent (GFDL et GISS) aux extrémités méridionales (48°N) et de l'ordre de 50 (GFDL) à 125 (GISS) pourcent aux extrémités septentrionales (55°N) (tableau 3).

TABLEAU 3. Taux approximatifs de ETS (degrés-jours) et de G (m^3/ha/année) pour la forêt boréale selon les températures normales (1951–80) et les scénarios A (GFDL) et B (GISS).

Latitude	Normales				Projetées				Augmentation							
	GFDL		GISS		GFDL		GISS		GFDL				GISS			
	ETS	G	ETS	G	ETS	G	ETS	G	ETS	G	ETS	G	ETS	G	ETS	G
48°N	2250	11	2250	11	2750	15	2850	15	500	4	22%	36%	600	4	27%	36%
55°N	1100	4	1200	4	1400	6	1800	9	300	2	27%	50%	600	5	50%	125%

Toutefois, selon la Figure 1, des valeurs de ETS au-delà de 1300 degrés-jours et de G au-delà de 5.2 m^3/ha/année sont incertaines et elles devraient donc être interprétées avec réserve.

Cependant, d'après Gates (1985), si l'on ajoute l'influence directe d'un doublement de CO_2 atmosphérique à ces analyses, le taux net de fixation de carbone et donc de la croissance des arbres pourrait s'augmenter d'un taux additionel de 25 à 50 pourcent. Les projections du tableau 3, même si elles sont incertaines, ne sont pas tout à fait irréalistes.

DISCUSSIONS

D'après les résultats présentés, étant donné un doublement de CO_2 atmosphérique, il semble qu'il y aurait un déplacement vers le nord des écosystèmes forestiers du Québec (Fig. 3a et Fig. 3b). En même temps, il semble qu'il y aurait des modifications importantes des zones forestières actuelles ainsi que des changements importants du taux de croissance de la forêt boréale.

Etant donné l'importance commerciale de la forêt boréale, surtout pour les industries de la pâte et du papier et du bois, ces pertes significatives de superficie, si elles se produisaient, pourraient avoir des retombées socio-économiques très importantes, surtout où ces industries sont fortes, par exemple, dans les régions de Trois-Rivières–Lac St-Jean et Val d'Or-Abitibi.

Cependant, pour la forêt boréale, et fort possiblement pour la forêt tempérée mixte, il y aurait aussi des changements importants du taux de croissance des arbres (tableau 3). Ces hauts taux de croissance pourraient aussi influer sur l'industrie forestière de la province de Québec.

Si les écosystèmes tempérés d'arbres francs s'installaient dans la province, à mesure que projètent les deux scénarios, les retombées socio-économiques s'avéreraient très importantes. Ces modifications pourraient stimuler l'industrie forestière à chercher de créer des nouveaux usages d'arbres francs.

Aussi, en raison de la hausse des températures surtout, et des précipitations projetées pour ces zones (Singh *et al.*, 1987), il est fort probable que la fréquence des feux de forêts ainsi que les opérations liées à la coupe et au transport du bois soient affectées. Les conséquences économiques de ces changements potentiels dans l'industrie forestière devraient être considérées.

Toutefois, ce ne sont que des changements potentiels, basés essentiellement sur les conditions climatiques. Pour avoir une analyse plus compréhensive et plus complète, il va falloir tenir compte d'autres facteurs tels que les conditions édaphiques, les taux de migration et de génération de différentes communautés forestières, et l'influence directe d'une hausse de CO_2 atmosphérique sur la croissance forestière. D'ailleurs, les changements climatiques pourraient bien influencer les épidémies d'insectes et de pathogènes.

REMERCIEMENTS

Cet article est produit grâce aux fonds, sous contrat, accordés par le Service de l'Environnement Atmosphérique (SEA) d'Environnement Canada.

BIBLIOGRAPHIE

Emmanuel, W.R., J.H. Shugart et M.L. Stevenson, 1985. Climate change and the broad-scale distribution of terrestrial ecosystem complexes. *Climatic Change* 7:29–43.

Gates, D.M., 1985. Global biospheric response to increasing atmospheric carbon dioxide concentration. *Direct Effects of Increasing Carbon Dioxide on Vegetation*. B.R. Strain and J.D. Cure (eds.), DOE/ER–0238, U.S. Dept. of Energy: 171–204.

Hansen, J., G. Russell, D. Rind, P. Stone, A Lacis, S. Lebedeff, R. Ruedy et L. Travis, 1983. Efficient three-dimensional global models for climate studies: Models I and II. *Monthly Weather Review*, 111:609–662.

Holdridge, L.R., 1947. Determination of world plant formations from simple climatic data. *Science*, 105:367–368.

Holdridge, L.R., 1964. *Life Zone Ecology*. Tropical Science Center, San José, Costa Rica.

Jozsa, L.A., M.L. Parker, P.A. Branhall et S.G. Johnson, 1984. How climate affects tree growth in the boreal forest, *Information Report NOR-X-255*, Northern Forest Research Centre, Canadian Forestry Service, Environment Canada.

Kauppi, P. et M. Posch, 1985. Sensitivity of boreal forests to possible climatic warming. *Climatic Change*, 7:45–54.

Manabe, S. et R.J. Stouffer, 1980. Sensitivity of a global climate model to an increase of CO_2 concentrations in the atmosphere. *Journal of Geophysical Research*, 85:5529–5554.

Morisset, P. et S. Payette, 1983 (eds.). *Tree-Line Ecology*. Proceedings of the Northern Quebec Tree-Line Conference, Collection Nordicana, Centre d'études nordiques, Université Laval, No. 47.

Sawyer, J.O. et A.A. Lindsay, 1963. The Holdridge bioclimatic formations of the eastern and central United States. *Indiana Academy of Science Journal*, 173:105–112.

Shugart, H.H., M.J. Antonovstey, P.G. Jarvis et A.P. Sandford, 1985. *Climatic Change and Forest Ecosystems:* assessing the responses of global forests to increasing CO_2. WMO/ICSU/UNEY International Assessment of the Impact of an Increased Atmospheric Concentration of Carbon Dioxide on the Environment, Chapter 9.

Singh, B., L. Grégoire, D. Skiadas, G, Renaud, A. Viau et R. Morasse, 1987. *Prospectives d'un changement climatique dû à un doublement de CO_2 atmosphérique pour les ressources naturelles du Québec*. Rapport Spécial pour Environnement Canada, 291 pp.

Solomon, A.M. 1986. Transient response of forests to CO_2-induced climate change: simulation modelling experiments in eastern North America. *Ecologia* (Berlin), 68:567–579.

Solomon, A.M. et D.C. West, 1986. Simulating responses to expected climate change in eastern North America: Applications to decision-making in the forest industry, Dans W.E. Shands (ed). *Proceedings of the Conference on Rising CO_2 and Changing Climate; Forest Risks and Opportunities*. Conservation Foundation, Washington, D.C.

Steila, D., 1966. An evaluation of the Thornthwaite and Holdridge classifications as applied to the Mediterranean Borderland. *The Professional Geographer*, 18:358–364.

News and Comments
Nouvelles et commentaires

CANADIAN SOCIETY OF AGROMETEOROLOGY

The Canadian Society of Agrometeorology (CSAM) held its third Technical Session and second annual business meeting on Tuesday, August 23, 1988 during the 68th annual conference of the Agricultural Institute of Canada held in Calgary, Alberta. The attendance varied from 20 to 34 people at the Technical Session, during which 15 papers were presented. There were about 15 concurrent sessions held by other scientific societies that same day, most with comparable attendance figures.

The CSAM will hold another Technical Session and annual business meeting at the:

Agricultural Institute of Canada (AIC) Annual Conference
at
McGill University, Montreal, Quebec
July 9–12, 1989

The link between agrometeorology and the AIC Conference theme of "Trade and Development" may be indirect but the presence of over a thousand scientists interested in various aspects of agricultural research and development should provide an ideal forum to present and share information about our end of the discipline. The Agmet Session will include papers on research, extension and/or service activities in areas from micrometeorology to climatology. Whether dealing with advances in concepts or with applications to agronomy, pest control, engineering or others, we hope to use this opportunity to make ourselves and others aware of our activities and familiarize ourselves, at the same time, with what is happening in the agricultural industry in Canada on a larger scale.

For further information on the CSAM Technical Session at AIC Montreal, contact:

Dr. Peter Schuepp
Department of Renewable Resources
Macdonald College of McGill University
Ste. Anne-de-Bellevue, Quebec H9X 1C0
Phone: (514) 398-7935

For more information about CSAM contact:

Peter Dzikowski, P.Ag.
Secretary-Treasurer, CSAM
c/o Alberta Agriculture
Room 206, 7000 – 113 Street
Edmonton, Alberta T5H 5T6
Phone: (403) 422-4385

TWENTY-THIRD ANNUAL CONGRESS, CMOS

Atmospheric and Oceanic Hazards: Modelling and Observations

The Rimouski Centre of the Canadian Meteorological and Oceanographic Society (CMOS) will host the Twenty-Third Annual CMOS Congress 6–9 June 1989 at Université du Québec à Rimouski, Rimouski, Québec.

General theme
January 1, 1990 will see the beginning of the Hazard Reduction Decade. The United Nations General Assembly has designated the 1990s a decade in which the international community will pay special attention to natural disaster reduction. The Rimouski Congress follows this theme.

Special sessions
Besides the usual sessions in meteorology and oceanography, there will be special sessions on atmospheric and oceanic chemistry, biological oceanography, lagoons and bays, the Hazard Reduction Decade, JGOFS and WOCE, the St. Lawrence system, Hudson and James Bays, and El Niño.

The venue
Rimouski is located on the south shore of the St. Lawrence Estuary, near the Gaspé peninsula. The nearest airport is located in Mont-Joli (with limousine service to all major hotels in Rimouski). The local institutions include le Département d'Océanographie de l'Université du Québec à Rimouski, (DOUQAR), l'Institut National de la Recherche Scientifique (INRS-Océanologie), l'Institut Maurice Lamontagne (IML), le groupe de recherche en Gestion des Ressources Maritimes (GERMA), and l'Institut Maritime du Québec (IMQ).

For additional information
Contact *Dr Vladimir G. Koutitonsky* (Local Arrangements Committee), INRS-Océanologie, 310 Des Ursulines, Rimouski, Québec, Canada G5L 3A1, tel: 418-724-1763, or *Dr Yves Gratton* (Scientific Program Committee), Département d'Océanographie, UQAR, 300 Des Ursulines, Rimouski, Québec, Canada G5L 3A1, tel: 418-724-1761.

VINGT-TROISIÈME CONGRÈS ANNUEL, SCMO

Les catastrophes atmosphériques et océaniques: modélisation et observations

Le Centre de Rimouski de la Société canadienne de météorologie et d'océanographie (SCMO) sera l'hôte du vingt-troisième congrès annuel de la SCMO du 6 au 9 juin, qui aura lieu à l'Université du Québec à Rimouski, Rimouski, Québec.

Le thème
La décennie débutant le 1er janvier 1990 sera celle de la prévention des catastrophes. L'Assemblée Générale des Nations Unies a désigné la dernière décennie du vingtième siècle comme celle où la communauté internationale devra se pencher en priorité sur la prévention des catastrophes naturelles. Le congrès de Rimouski a adopté ce thème.

Sessions spéciales
En plus des sessions habituelles en météorologie et en océanographie, nous prévoyons des sessions spéciales sur la chimie atmosphérique et océanique, l'océanographie biologique, les lagunes et les baies, la décennie de prévention des catastrophes, les programmes JGOFS et WOCE, le système du St-Laurent, les baies James et d'Hudson, et El Niño.

L'endroit
Rimouski est située sur la rive sud du St-Laurent, près de la péninsule gaspésienne. L'aéroport le plus près est situé à Mont-Joli (avec un service de limousine desservant les grands hotels de Rimouski). Les organismes locaux comprennent : Département d'Océanographie de l'Université du Québec à Rimouski (DOUQAR), l'Institut National de la Recherche Scientifique (INRS-Océanologie), l'Institut Maurice Lamontagne (IML), le groupe de recherches en Gestion des Ressources Maritimes (GERMA), et l'institut Maritime du Québec (IMQ).

Pour de plus amples informations
Contactez le *M. Vladimir G. Koutitonsky* (Comité des arrangements locaux), INRS-Océanologie, 310 Des Ursulines, Rimouski, Québec, Canada G5L 3A1, tel : 418-724-1763, ou le *M. Yves Gratton* (Comité de la programmation scientifique), Département d'Océanographie, UQAR, 300 Des Ursulines, Rimouski, Québec, Canada G5L 3A1, tel : 418-742-1761.

MUSINGS ON THE NEWS AND COMMENTS SECTION

As stated in the Foreword of the December 1988 issue of the *Bulletin*, this section of the journal has been reduced in size recently in response to increased financial pressures. I asked readers to react to the questions of (a) whether this reduction is acceptable, and (b) whether publication charges should be levied for at least part of the News and Comments section, for instance, comments of over half a page, or announcements of conferences, etc. Please send your opinions.

At the time of going to press with the current issue, only two such reactions have been received, but the time interval since the appearance of the December 1988 issue has been very short. The intent is to summarize reactions in the August 1989 issue.

Readers should be aware that the publication of items in this section of the journal depends very much on what comes in. Periodic requests for news and/or comments are made to the Editorial Board, which constitutes one source. The readership provides another, and there are also items which are sent to me from government agencies, other associations, and various scattered sources. Sometimes I have lots, sometimes not so many.

The ultimate decision as to what is included rests largely with myself. Given the transfer of editorship a year and half ago from southern Ontario to Saskatchewan, it is not surprising that I receive more items from western than from eastern Canada. If you want to see more news from your region in *Climatological Bulletin*, then send it or give me a call at (306) 585-4223.

Alec H. Paul