ISSN 1195-8898

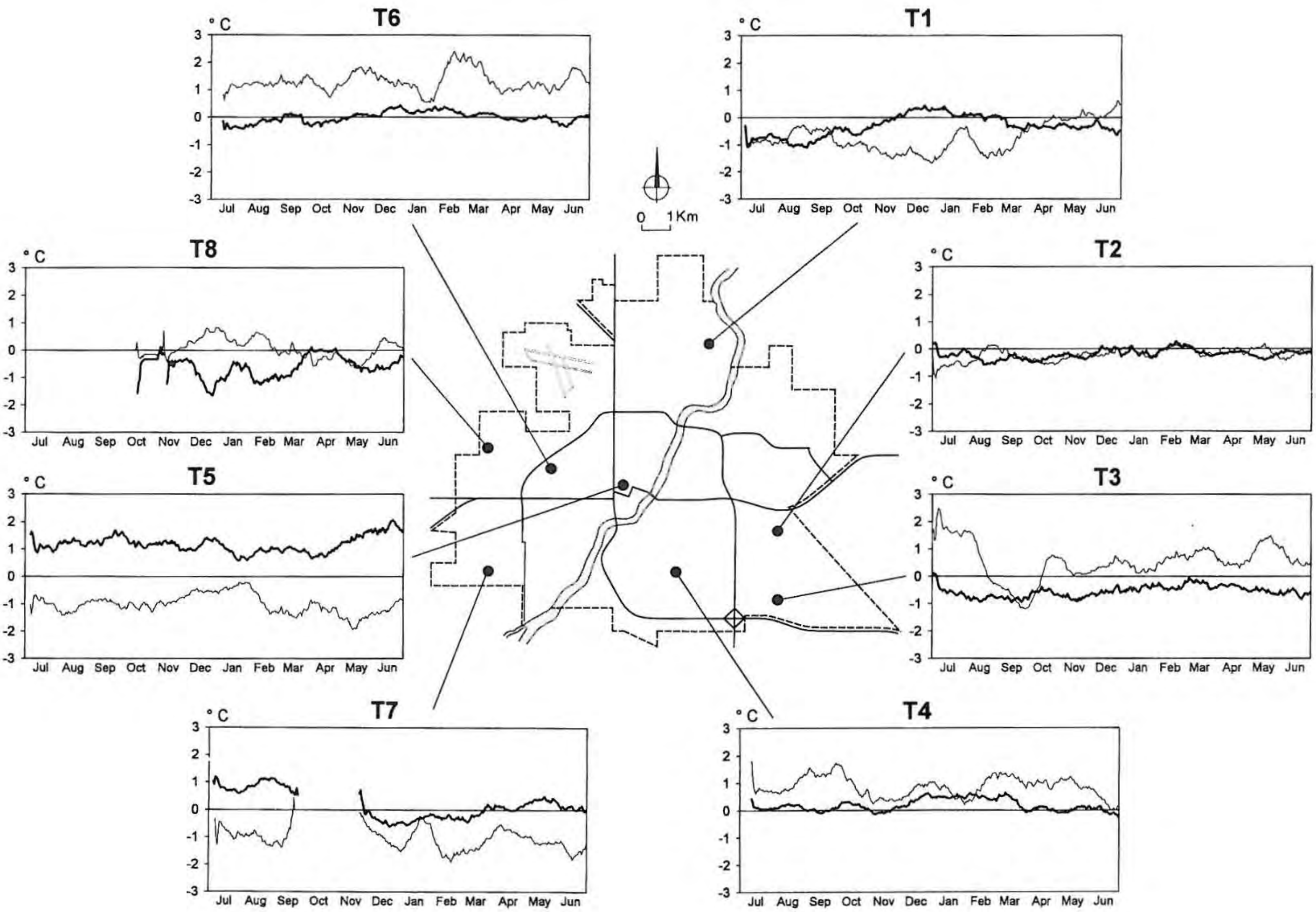
CMOS BULLETIN SCMO

Canadian Meteorological and Oceanographic Society

La société canadienne de météorologie et d'océanographie

June / juin 1996

Vol. 24 No. 3



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
1202 - 200 Kent Street
Ottawa, Ontario, K1A 0E6, Canada
☎ (613) 990-0231; Fax (613) 993-4658
E-Mail: BOLDUC@OTTMED.MEDS.DFO.CA
Canadian Publications Product Sales Agreement #0869228
Envois de publications canadiennes Numéro de convention #0869228

Cover page: Knowledge of the time and space variations of meteorological variables is an important part of any climate study. A study of temperature data in the city of Saskatoon examined long-term datasets as well as data from a temporary network set up in residential backyards across the city. Shown here are smoothed daily maximum (thin lines) and minimum (thick lines) temperature departures from the group average during the period July 1994 to June 1995. A detailed description starts on page 57.

Page couverture: La connaissance des variations temporelles et spatiales des variables météorologiques est un aspect important de l'étude climatique. Une étude des données de température prises dans la ville de Saskatoon examine les données prises à long terme ainsi que les données d'un réseau temporaire installé dans les cours extérieures des résidences dans la ville. On illustre ici les anomalies lissées du maximum (lignes fines) et du minimum (lignes grasses) journalier calculées à partir de la moyenne du groupe pour la période allant de juillet 1994 jusqu'au mois de juin 1995. Voir détails à l'intérieur à partir de la page 57.

Stop press!
CMOS Member being honoured

A CMOS member who has been instrumental in directing Canadian research and public policy on critical environmental issues will be awarded the Massey Medal for 1996. James P. Bruce, a CMOS life member, has co-ordinated pioneering research on Great Lakes water quality, acid rain and climate change. His long dedicated work has led to international agreements on the Great Lakes and the reduction of sulphur dioxide emissions. The Massey Medal, the highest Canadian award for individual achievement in geography and related fields, is awarded each year by the Royal Canadian Geographical Society.

INSIDE / EN BREF

Volume 24 No.3
June 1996 - juin 1996

Articles

Information

Printed in Stittsville, Ontario, by Love Printing Service Ltd.

Imprimé sous les presses de Love Printing Service Ltd, Stittsville, Ontario.

Next Issue - Prochain numéro

The next issue of the *Bulletin 24 (4)*, August 1996, will go to press by mid-August. We need your contributions, short articles, notes, presentations, chronicles, etc., by early August. Don't miss your chance! Le prochain numéro du *Bulletin 24 (4)*, Août 1996 sera mis sous presse vers la mi-août. Vos contributions sont toujours les bienvenues. Veuillez bien me les faire parvenir d'ici le début du mois d'août. Ne manquez surtout pas votre coup!

Inter-comparisons of the Vaisala and Airsonde Sounding Systems during BOREAS

G.S. Strong, A.G. Barr and C.L. Hrynkiw[1]

ABSTRACT

Most Canadian radiosonde sites have now been converted from the 1970s ADRES system to either the Vaisala/RS80 or the VIZ/WO-9000 radiosonde system. The advantages include automation, higher data resolution, and more accurate data. However, during early processing of upper-air data from the 1994 BOREAS[2] radiosonde network, some unusual-looking wind profiles from the newer systems were occasionally noted. There was also some suspicion of negatively-biased relative humidity data from both systems. At the same time, it was desirable to evaluate a peculiar noon-time drop in vapour mass noted in Airsonde® soundings released during the 1991 Regional Evaporation Study, and whether this phenomenon is common only to that system.

Some impromptu, albeit limited field and laboratory tests were therefore carried out during late-July, 1994 in order to verify and quantify any such data errors. Vaisala and Airsonde sondes were released simultaneously at two-hour intervals on three consecutive sunny days at Candle Lake, Saskatchewan. The Vaisala system employed a Loran-tracking system for winds, while Airsonde balloons were tracked manually using an auto-tracking optical theodolite system. A second theodolite was used to track the Vaisala balloon, and extensive manual surface observations of temperature and humidity were recorded on site during soundings.

Analyses of these field data are presented, together with some later results carried out under controlled laboratory conditions. Slight biases in Vaisala humidity data are noted, while the wind data prove to be surprisingly good with minor exceptions.

1. Background

During early processing of upper air data from the 1994 BOREAS project, a number of unusual wind and humidity profiles were noted from the Saskatoon VIZ (WO-9000) radiosonde site and from three VAISALA (RS-80) systems which were installed specifically for BOREAS. The VAISALA radiosonde system is relatively new for Canada, the first operational system having been installed during early-1993. Most Canadian radiosonde sites have now been converted to this system, replacing the ADRES system in use since the 1970s. Many users would be rather unfamiliar with the operation of these two systems, particularly with the much higher density of data available with newer technology.

The Atmospheric Environment Service (AES) no longer maintains a group dedicated to testing instrumentation, so that inter-comparison tests of new equipment are difficult to carry out on a regular basis, except during field research experiments. Since BOREAS data users are very dependent on the special upper air data sets provided, the possibility of uncertain data necessitated some field tests, first to determine whether there were data problems, and if so, to attempt to quantify and correct as necessary. The fact that BOREAS upper air operations were being conducted in Saskatchewan provided an excellent opportunity to conduct such tests during the summer of 1994.

Random instrumentation errors and human observer errors resulting from operational procedures are often easily detected, but are difficult to correct. On the other hand, systematic errors resulting from sonde characteristics, calibration and data reporting procedures, or data reduction techniques, may not be as obvious but can be corrected once identified. Over the past 25 years, various studies have addressed these issues, particularly with respect to new sounding systems, and some have provided correction procedures or data reduction algorithms for specific problems.

For example, Morrissey and Brousaides (1970) and Teweles (1970) investigated temperature-induced humidity errors caused by solar radiation, and suggested some simple sonde modifications to overcome the problem, namely: to apply a shiny reflector to the top surface of the sonde, and to paint the interior surface of the humidity duct black to prevent reflected radiation from reaching the hygristor. Friedman (1972) presented a new sonde design with a curved humidity duct which was reported to eliminate the solar heating problem. This design is still used in the A.I.R. (Atmospheric Instrumentation Research,

1 Atmospheric Environment Service, 11 Innovation Boulevard Saskatoon, Saskatchewan. E-Mail: StrongG@nhrisv.nhrc.sk.doe.ca

2 Boreal Ecosystem-Atmosphere Study

Boulder) Airsonde®, for example. Both Friedman (1972) and Riehl and Betts (1972) provided what was thought to be convincing evidence (e.g., see Quiring, 1973) that these design changes had apparently eliminated both the solar heating and radiation problems, and at the same time, reduced sensor lag with an increased ventilation rate. The problem has since been discussed very little in the literature, presumably because it appeared to be resolved. However, peculiar drops in the surface to 400 mb vertically-integrated profiles of vapour mass near noon during the 1991 Regional Evaporation Study (RES-91, Strong, 1996) prompted a review of the problem.

Luers and Eskridge (1995) reported on temperature corrections derived for the VIZ and Vaisala sondes, using multithermistor Airsondes and VIZ sondes developed by the U.S. National Aeronautical and Space Administration (NASA). The NASA sonde uses three rod thermistors with white, aluminum, and black paint coatings, allowing the simultaneous solution of a system of three heat balance equations for the air temperature correct to ±0.3°C. Their analysis suggests that Vaisala factory corrections under-estimate temperatures above 20 km by up to 1°C at night, and slightly over-estimate temperatures by day. Vaisala profiles exhibited a random error component of 0.5°C against <0.2°C for the VIZ and Airsondes. There was also a +0.4°C bias in Airsonde temperatures between 5 and 10 km due to a spurious lag error resulting from an incorrect timing bias.

Other authors have addressed temperature and humidity lag errors resulting from differing time constants of sensors. Sugita and Brutsaert (1990) attempted to correct Airsonde lag errors by adjusting the pressure data. Connell and Miller (1995) show that a consistent mean lag error of 2% in RH results in a 1 kg m^2 error in the integrated vapour mass, while a 5% RH error can result in a 3 kg m^{-2} error in vapour mass. However, for computations of atmospheric vapour mass based on at least two soundings, errors resulting from consistent lag error would be < 0.1 kg m^{-2}.

Inaccuracies in temperature and humidity data from sensor problems other than radiation errors, and those resulting from data reduction and reporting procedures, have not gone unnoticed, and surprisingly, there are few international standards. For example, the U.S. National Weather Service in 1973 adopted the procedure to terminate the evaluation of relative humidities < 20% in an attempt to provide more realistic dew point temperatures (Quiring, 1973); Canada reports relative humidity for temperatures down to -65°C; and, as a result of the 'SONDEX' radiosonde intercomparison of 1981, Richner and Phillips (1982) recommended widespread adoption of the Swiss practice of discounting any humidity data altogether above the 200 mb level. The implications of such reporting procedures and errors, as emphasized by Garand et al. (1992), impact most on global change models (GCMs) and on numerical weather prediction models.

These problems reported in the literature, together with suspected discrepancies in radiosonde humidity and wind data recorded early during the BOREAS project, as well as the unexplained drops in noontime vapour mass recorded during RES-91, prompted a series of intercomparison tests between the Vaisala and Airsonde systems during BOREAS in July, 1994. The study was initiated with the following objectives in mind:

1. to provide a quick overview of the capabilities of the Vaisala system;
2. to quantify biases in temperature, relative humidity, and wind data between the Vaisala and Airsonde systems;
3. to alert operational meteorologists to any potential errors in Vaisala radiosonde data;
4. to confirm the existence of and determine the source of the relative drop in atmospheric vapour mass as identified in the RES-91 data.

The VIZ Accu-Lok® hygristor employed in both the VIZ WO-9000 and the A.I.R. Airsonde® systems use a transfer equation employing different sets of coefficients for relative humidities above and below 20%. Wade (1994) showed that the lock-in resistance provided with these hygristors (nominally ~10,000 ohms) can be in error by several hundred ohms, giving errors of < 2% RH above 60% RH and 25°C, becoming negligible for colder temperatures, but could exceed 6% RH error at low humidities. Wade shows that using the same coefficients over all ranges of RH (as for RH > 20%) will yield better accuracy. The Airsonde used during both RES-91 and the field tests reported here contained the VIZ Accu-Lok hygrsitor. It is understood that A.I.R. now manufactures their own hygristor which was not used in this study. The Vaisala sonde employs a capacitive thin film humidity sensor (Humicap®), which is claimed to provide reliable response even in low temperatures and after exposure to condensation.

2. FIELD and LABORATORY TESTS

Three consecutive days were chosen during late-July, 1994 for sonde inter-comparison. The field tests involved the simultaneous release of Vaisala and Airsonde sondes at two-hour intervals from 1400 through 2400 UTC on 25-27 July, 1994 at the Vaisala site in Candle Lake, Saskatchewan. These tests had two main objectives:

1. Intercomparison of the Airsonde and Vaisala humidity sensors:

- with special emphasis on differences within two hours of solar noon; baseline humidity information was obtained from the pre-release data from each sonde, as well as frequent manual observations of dry and wet bulb temperatures from an unventilated Stevenson Screen at the site, and from an aspirated (sling) psychrometer in both shaded and unshaded conditions.

2. Intercomparison of Airsonde and Vaisala wind profiles:

- two different tests were required here, both carried out simultaneously with the humidity tests;

a) comparison of Airsonde and Vaisala wind profiles from sondes released simultaneously;

b) comparison of Vaisala wind profiles derived from tracking the Vaisala sonde with both LORAN-C and optical theodolite simultaneously.

Actual sounding release times were planned for 30-45 minutes before the specified sounding time, in order to conform to standard operational practices; e.g., the release window for the 1400 UTC sounding was 1315-1330 UTC. It should be emphasized that these comparisons were conducted using sondes released simultaneously on separate balloons. The necessity to maintain consistency in Vaisala operations, and in nominal ascent rates for the Airsonde and Vaisala sondes (3 and 6 m s^{-1} respectively), made single balloon payloads unfeasible.

It is intended to provide only an overview of these tests in this paper. Complete results will be reported in a follow-up paper.

3. RESULTS

3.1 Temperature Measurements:
Figure 1 plots the Vaisala(**V**)-Airsonde(**A**) air temperature difference (**V-A**) as a function of the mean (**VA**) temperature. The temperature data were interpolated to 5 mb intervals. On average, the Airsonde temperature was 0.5 to 1°C warmer than Vaisala temperature, but the **V-A** difference was smallest at high temperature, increasing (in both magnitude and scatter) with lower temperatures. The figure also shows four distinct 'groups' of outliers with a positive temperature difference. The groups came from individual soundings, suggesting occasional incorrect calibrations on one or both sonde types. It is possible that these anomalous plots resulted from an anomalous and small bias in either temperature or pressure. No independent justification was found to either reject these outliers or to judge which sonde was more accurate. The differences are generally within the manufacturer's specifications for accuracy.

3.2 Humidity Measurements:
Figure 2 depicts the **V-A** relative humidity (RH) difference as a function of the mean **VA** RH. At RH above 30% the **V-A** RH difference was <4% RH and remained relatively constant with average RH. At RH less than 30%, the **V-A** RH-difference increased with decreasing RH to an average of 10% for RH below 20%.

Following BOREAS field operations, laboratory tests were carried out on Vaisala humidity sensors (Barr & Betts, 1994). Four sondes were evaluated, drawn from two different batches. Again, these were limited preliminary tests on only the Vaisala sensor, and in this case, all laboratory tests were carried out at 21°C, with each sonde evaluated on a different day. The test system involved a General Eastern Hygro **M2** dew-point hygrometer and relative humidity generator and a platinum resistance thermometer.

The Vaisala RH sensor was first equilibrated at 15% RH for 60 minutes. The **M2** RH was then altered by 10% RH steps every 20 minutes, ascending from 15% to 85% RH, then descending from 85% to 15% RH. Data were sampled and averaged for the final three minutes at each step at sampling periods of 5 seconds (**M2**) and 1.5 seconds (Vaisala). Figure 3 summarizes the laboratory RH calibration tests. The sensor had a well-defined and quite repeatable negative bias. The bias increased for ascending RH from 1% RH at 15% RH to nearly 5% RH at 75% RH, and decreased for descending RH to a positive bias of 0.5% RH. Hysteresis of approximately 1% was found between the ascending and descending RH sequences. This bias accounted for much of the observed **V-A** difference for RH above 30% shown in Figure 2, but it did not account for the increased difference at low RH. However, the large positive bias of the VIZ carbon hygristor at RH below 20% is well documented (Teweles, 1970; Richner and Phillips, 1981; Wade, 1994).

It would appear that the Airsonde/VIZ humidity data were more accurate at high humidities and the Vaisala more accurate at low humidities; however, we emphasize that this is based on very limited field trials. These suppositions cannot be confirmed based on these limited tests since the laboratory trials could not be carried out for the full range of pressures and temperatures which would be realized in the lowest 250 mb of the atmosphere. Such tests should be carried out, especially since most of Canada's radiosonde sites now use Vaisala sensors. One can only guess at the effect of a 5% RH deficit on existing numerical models of the atmosphere, especially GCMs.

3.3 Wind Measurements:
A number of unusual-looking Vaisala wind profiles during early 1994 BOREAS operations prompted the inclusion of wind inter-comparisons. The unusual profiles mainly pertained to unexpected directional shear either in the boundary layer or at very high altitude. The latter profiles originated mainly from the Churchill, Manitoba site, which was using Omega Navaid signals. However, field logistics dictated that the field trials be conducted at the Candle Lake site where Loran-C Navaid was used, but such inter-comparisons still seemed in order.

During the field tests, both the Vaisala and Airsonde balloons were manually-tracked with optical theodolites in addition to the Vaisala Loran-C tracking, providing three sets of wind profiles for each sounding time. Observers carefully tracked both balloons using optical theodolites, while data were automatically recorded every 15 seconds using Airsonde receivers. Vaisala 'theodolite' wind profiles were obtained by merging theodolite (azimuth/elevation) and elapsed time data for the Vaisala balloon with a copy of the Vaisala thermodynamic data prior to computing geopotential heights and winds. Surface wind speeds for the Airsonde were obtained using a hand-held anemometer, while Vaisala surface winds were estimated by the observer on duty. All surface wind directions were estimated.

Figure 4 shows example profiles of u- and v-components for the Vaisala/Loran-C, Vaisala/theodolite, and Airsonde/theodolite for soundings at 2322 UTC, 27 July, 1994. Vaisala/Loran-C winds are computed by the Vaisala

Figure 1: Vaisala minus Airsonde temperature difference as a function of the mean (Vaisala/Airsonde) temperature for all soundings at Candle Lake, Saskatchewan, 25-27 July, 1994.

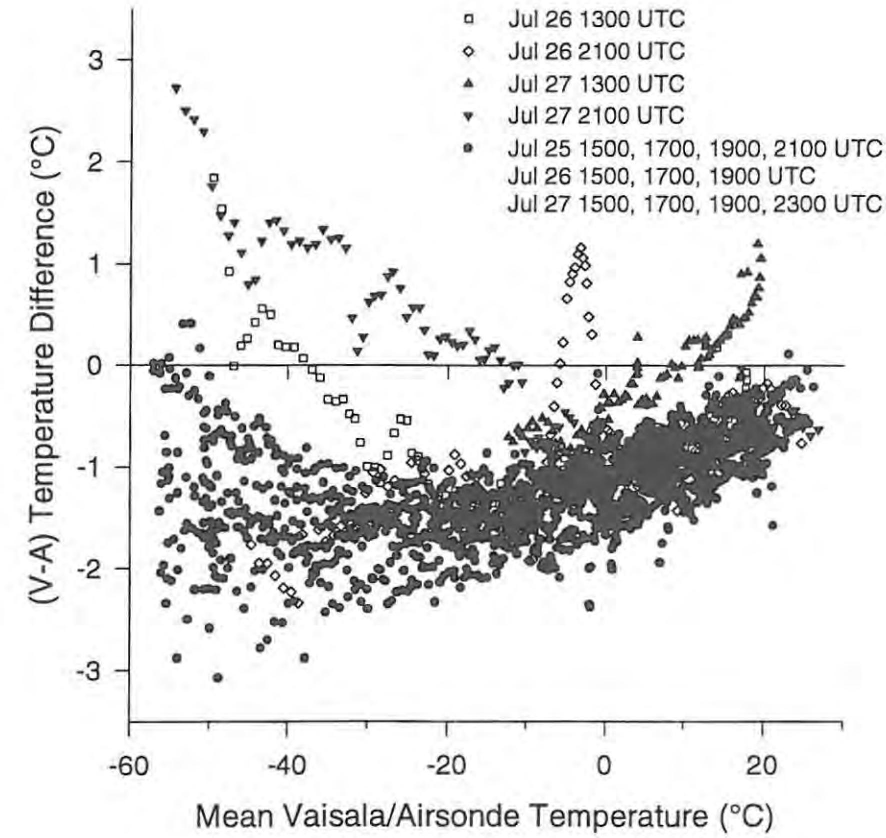
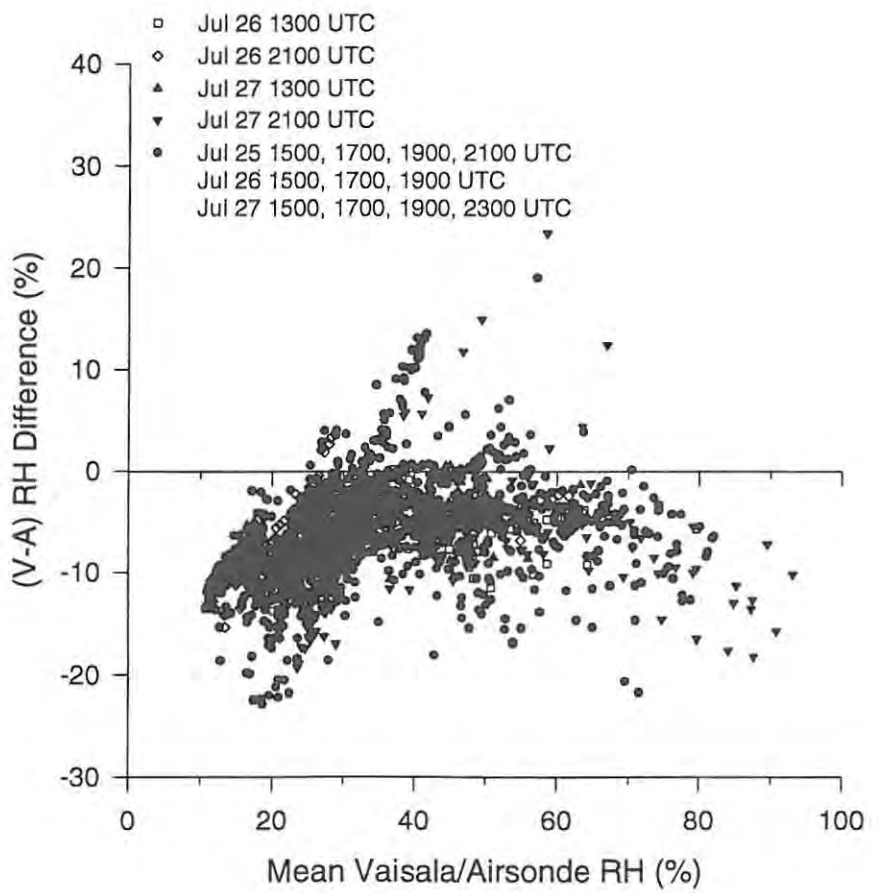


Figure 2
Vaisala minus Airsonde relative humidity (% RH) difference as a function of the mean (Vaisala/Airsonde) RH for all soundings at Candle Lake, Saskatchewan, 25-27 July, 1994.



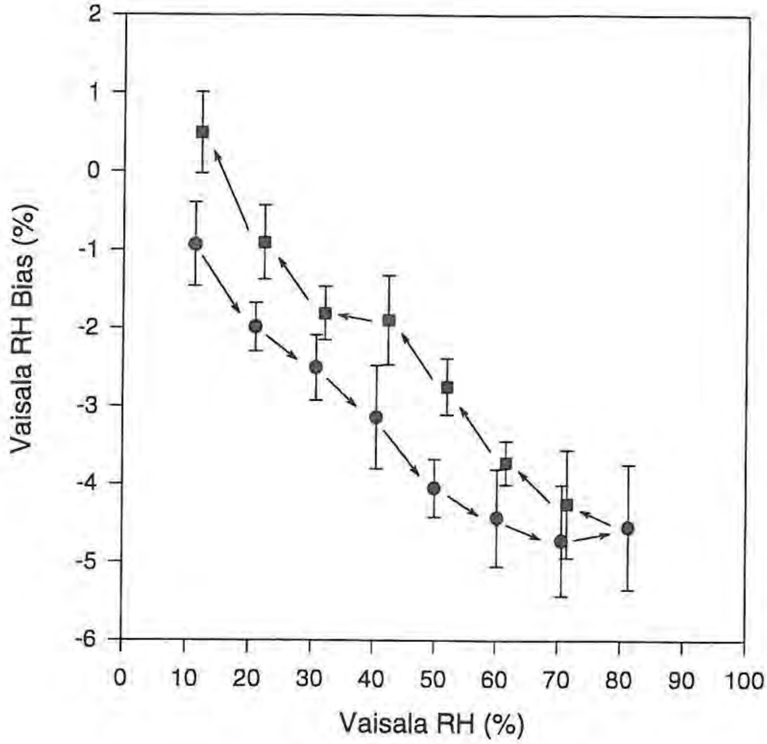
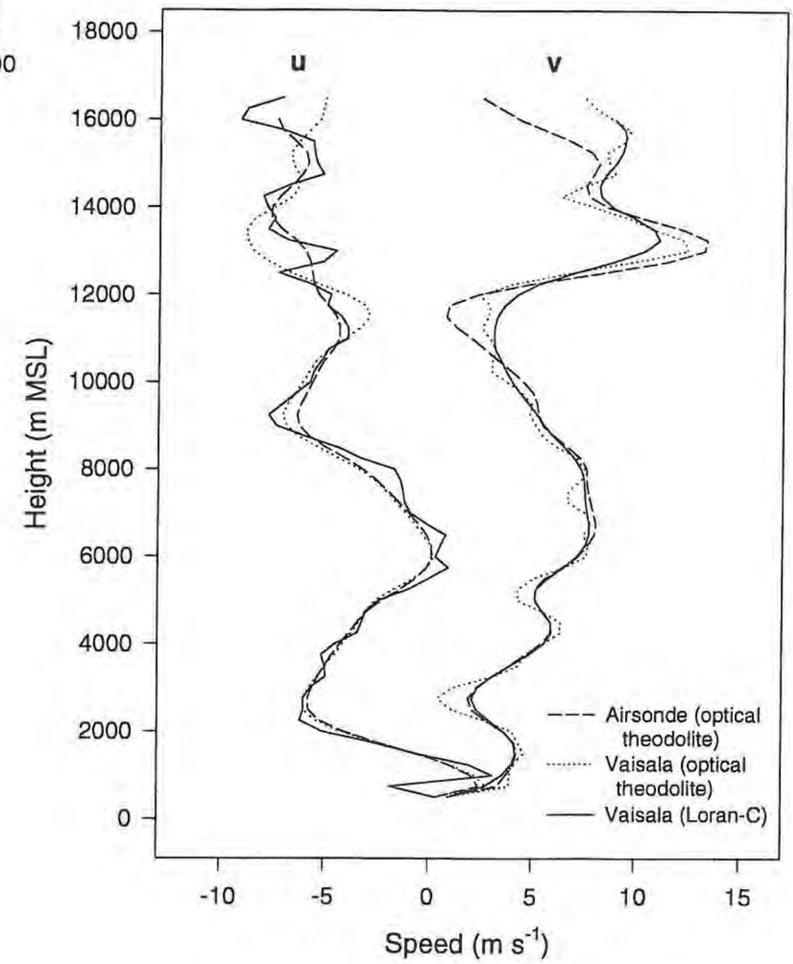


Figure 3

Summary of laboratory tests, showing a well-defined negative bias of -5%RH at 75%RH, decreasing to near zero at 15%RH for ascending RH. Arrows indicate the progression of controlled **(M2)** RH values.

Figure 4

Example profiles of u- and v-wind components for the Vaisala/Loran-C, Vaisala/theodolite, and Airsonde / theodolite for the soundings released at 2322 UTC, 27 July, 1994 at Candle Lake, Saskatchewan.



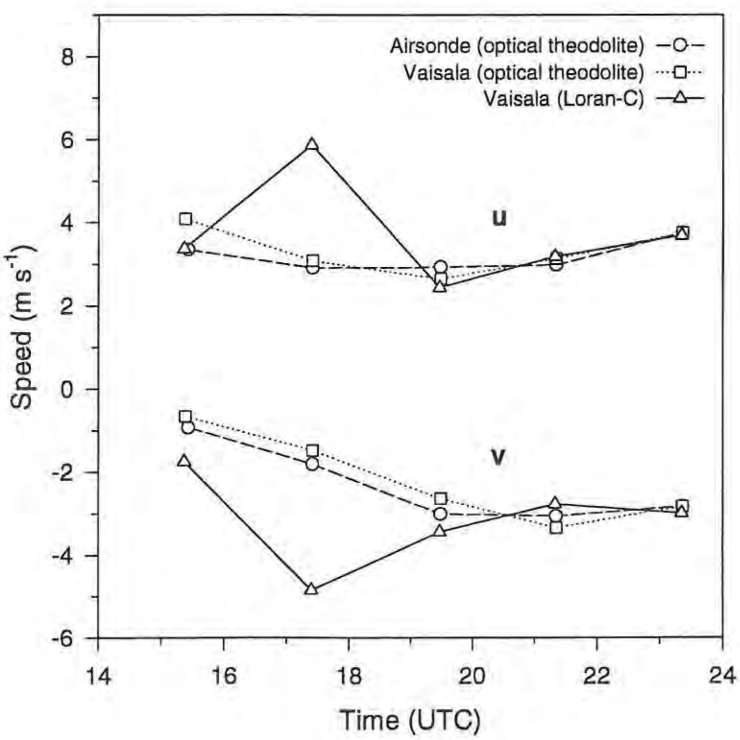


Figure 5

Average 1-4-km u/v-wind components for five comparative soundings at Candle Lake, Saskatchewan, 27 July, 1994.

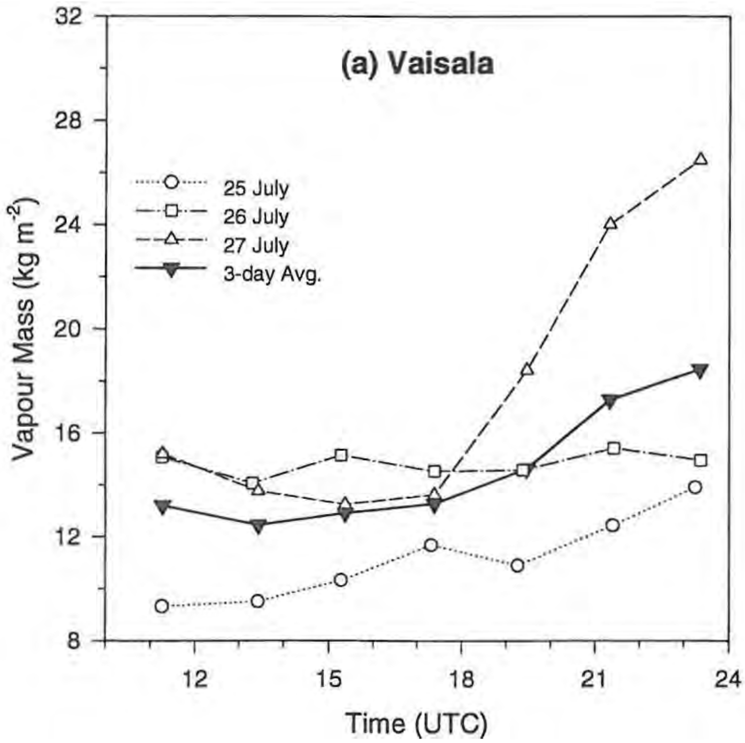
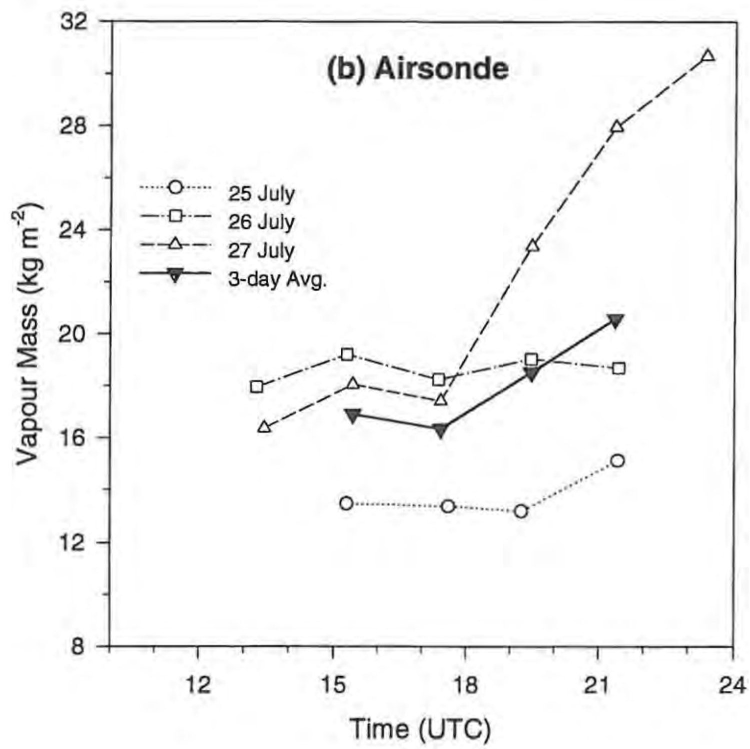


Figure 6

Daily and average three-day time series of Vaisala (a) and Airsonde (b) surface to 400 mb vapour mass totals from soundings at Candle Lake, Saskatchewan, 25-27 July, 1994.



radiosonde system following an automatic data selection and filtering process (Vaisala, 1993). Vaisala/theodolite and Airsonde/theodolite winds were computed from measured azimuth/elevation angle data, elapsed-time and height data from the respective systems. The u/v wind components were subsequently filtered using a three-point triangular filter to approximate the degree of smoothing produced by the Vaisala system.

Winds produced using an optical theodolite are of course subject to data loss from the radiosonde package entering clouds, haze, or moving into a direct line with the sun (the latter occurred near noon hour on all three days of this study). Winds produced using Navaid systems to track the sonde are not subject to these problems, but can incur errors due to noisy signals on occasion. Figure 5, which shows the average 1-4-km u/v wind components for five comparative soundings on 27 July, 1994, provides an apparent example of this. In this case, the 1725 UTC Vaisala/Loran-C winds are clearly in error compared with the two independent sets of winds produced from optical theodolites.

Excepting two such cases of poor Loran-C winds, the wind comparisons turned out to be quite positive overall. The mean differences (Vaisala/Loran-C minus Vaisala/theodolite) for 12 serial sounding comparisons (25-27 July, 1994) were -1.3° for wind direction and 0.14 m s^{-1} for wind speed. These values are well within acceptable accuracy for wind profiling systems under these conditions; e.g., the uncertainty in determining true north for the temporary Airsonde site using a directional compass was no better than 1°. The RMS differences were similarly reassuring, yielding 2.8 m s^{-1} and 14°

The anomaly noted in Figure 5 may have been due to weak or noisy Loran-C signals, but this cannot be confirmed. For the 'bad' Vaisala wind profile, the maximum differences in wind direction and speed between the theodolite and Loran-C winds interpolated to 250-m intervals were 105 degrees and 8 m s^{-1}. This by itself is not an estimate of the uncertainty in Loran-C winds, since the differences for other 'good' profiles, were within manufacturer's tolerances. However, it provides a real example of how poor Navaid signals (or other error sources) can yield inaccurate winds.

3.4 Vertically-Integrated Vapour Mass:
These field and laboratory radiosonde tests were first precipitated by the appearance of mid-day decreases in the vertically-integrated profiles of vapour mass from RES-91 data (Strong, 1996). Figure 6, which compares the daily and three-day average time series of vertically-integrated vapour mass at Candle Lake during 25-27 July, 1994, shows a similar drop or leveling out of vapour mass before noon (1800 UTC) for the Airsonde data. The Vaisala time series indicated only a hint of this effect, showing a near constant vapour mass until noon. The drop in vapour mass was not as obvious as for RES-91 data over the Prairies in the wet-soil conditions of 1991, perhaps partially due to lower evapotranspiration rates over the Boreal forest during late-July, 1994; i.e., only modest daily increases in atmospheric vapour mass were experienced in the current study.

While we were unable to isolate the cause of this peculiarity with either RES-91 or BOREAS data sets, the more obvious effect yielded by the Airsonde VIZ hygristor would appear to be related to the temperature-induced humidity errors caused by solar radiation as identified by Morrissey and Brousaides (1970). Sonde manufacturers have followed earlier recommendations in varying degrees over the intervening years -- for example, the humidity duct for the airsonde used in this study was painted completely black, including the top opening, while other sondes also have shiny reflectors applied to the top of the sonde.

Friedman (1972), Riehl and Betts (1972), and Quiring (1973) all concluded that the newly-designed sondes had eliminated the radiation problem. However, the tests conducted in this study suggest that some related effect remains, and that it is not just confined to carbon hygristor sondes such as the Airsonde; for example, the Vaisala sonde uses a much different design, the Humicap®, yet produced a similar though less obvious effect. We note that, in the Riehl and Betts (1972) study, all soundings were released between 0400 and 1000 local time, during the passage from nighttime into daylight, with no soundings near noon when radiation problems might be maximized because of high sun angles. Our limited tests suggest that the problem may be more serious near local noon, that is, between 1000 and 1400 local time with high sun angles. The characteristic near-noon drop in vapour mass noted by Strong (1996) appears to have gone unnoticed since the 1970s in North America, partly because operational soundings, conducted worldwide at 1200 and 0000 UTC under WMO agreements, do not provide for noontime soundings in North America.

4. SUMMARY and RECOMMENDATIONS

Vaisala temperatures exhibited a negative bias of up to 1°C with respect to Airsonde temperatures; no attempt was made to determine which was more accurate. The Vaisala humidity sensor was shown in laboratory tests to have a well-defined negative bias of up to 5% RH (at 75% RH). No laboratory tests of the Airsonde humidity sensor (VIZ hygristor) were carried out, emphasis being on the current (Vaisala) main operational system in use in Canada.

Wind direction and speed determined from the Vaisala Loran-C Navaid system were accurate to at least 14° and 2.8 m s^{-1}. However, occasional large anomalies in winds occurred, possibly due to noisy Loran-C signals.

This paper was not intended to provide a definitive error analysis of the radiosonde systems in use in Canada. The results are quite limited and cannot be interpreted as conclusive. However, the intent of this paper was to alert users of radiosonde data to the pitfalls of implementing new systems without conducting controlled field tests, and if possible, laboratory experiments to modify manufacturer's specifications to one's own applications. This is especially true of new systems becoming available, which have built-in data quality control and filtering functions with little or no user control.

In particular, it is recommended that extensive field and laboratory tests be carried out on all operational systems in use in Canada, independent of manufacturer's tests, since the latter may not be carried out in the same operational conditions presented by Canadian environments. In addition, more tests are required to isolate the exact cause, solar radiation or otherwise, of the mid-day decrease in vapour mass noted in this study and in the RES-91 data.

Where the Airsonde system is slightly biased towards higher temperatures and humidities, the Vaisala may be equally biased towards lower values. No attempt has been made to determine which system provided the best accuracy here, except that we believe that Vaisala humidities are more accurate below 20% RH by virtue of the fact that VIZ hygristors (used in the Airsonde) are not calibrated below this. Both systems were extremely sensitive to the most minute temperature and humidity fluctuations in the atmosphere, identifying dry or moist layers to within the vertical resolution of each system, thereby providing mutual confidence in identical layers. The Airsonde system, now in use for 15 years, is ideally suited for research applications because of its greater portability and ease of use compared with other systems.

The authors were generally pleased with the operation and accuracy of both systems. However, a significant and systematic difference was found in both the temperature and humidity measurements from the Airsonde and Vaisala sondes. The differences were large enough to cause concern in the operational use of data from different sounding systems without due attention to the biases of each system. At present, Canada deploys 31 Vaisala and 6 VIZ-9000 upper air systems. The VIZ sonde contains the same hygristor type as used in the Airsonde, with a similar thermistor design.

Finally, we strongly urge operational users to take advantage of the much improved data resolution now available in these systems, and archive the highest resolution data sets containing the rawest form of data (e.g., relative humidity rather than dew point data) available from the system in use.

5. ACKNOWLEDGEMENTS

The authors acknowledge the financial support of AES and NASA in this study. Mr. Dan Matthews of AES assisted in field operations. The technical assistance of Mr. Tom Maxin of the National Hydrology Research Institute in conducting laboratory tests is also appreciated.

6. REFERENCES

Barr, A. and A.K. Betts, 1994, *Preliminary summary of BOREAS upper-air soundings, Candle Lake and Thompson, 1994 Intensive Field Campaigns*, AES internal report, Saskatoon, 92 pp.

Brousaides, F.J., 1975, *The radiosonde hygristor and low relative humidity measurements*, Bull. Amer. Meteor. Soc., 56, 229-233.

Connell, B.H., and D.R. Miller, 1995, *An interpretation of radiosonde errors in the atmospheric boundary layer*. J. Appl. Meteor., 34, 1070-1081.

Friedman, M., 1972, *A new radiosonde case: the problem and the solution*, Bull. Amer. Meteor. Soc., 53, 884-887.

Garand, L., C. Grassotti, J. Hallé, and G. Klein, 1992, *On differences in radiosonde humidity-reporting practices and their implications for numerical weather prediction and remote sensing*, Bull. Amer. Meteor. Soc., 73, 1417-1423.

Luers, J.K., and R.E. Eskridge, 1995, *Temperature corrections for the VIZ and Vaisala radiosondes*. J. Appl. Meteor., 34, 1241-1253.

Morrissey, J.F., and F.J. Brousaides, 1970, *Temperature-induced errors in the ML-476 humidity data*, J. Appl. Meteor., 9, 805-808.

Quiring, R.F., 1973, *Low humidity: Still a problem with the modified NWS radiosonde?* Bull. Amer. Meteor. Soc., 54, 551-552.

Richner, H., and P.D. Phillips, 1981, *Reproducibility of VIZradiosonde data and some sources of error*. J. Appl. Meteor., 20, 954-962.

Richner, H., and P.D. Phillips, 1982, *The radiosonde intercomparison SONDEX*, Spring 1981, Payerne, Pageoph., 120, 852-915.

Riehl, H. and A.K. Betts, 1972, *Humidity observations with the 1972 U.S. radiosonde instrument*. Bull. Amer. Meteor. Soc., 53, 887-888.

Strong, G.S., S.R. Macpherson, and C.M. Sackiw, 1993, *The Regional Evaporation Study: III. A Meteorological Data Management System*, WMO Sympos. on Precip. & Evap., Slovak Min. of Envir., Bratislava, Sept. 20-24, 1993.

Strong, G.S., 1996, *Atmospheric Moisture Budget Estimates of Regional Evapotranspiration from RES-91*. Submitted to Atmosphere-Ocean.

Sugita, M., and W. Brutsaert, 1990, *How similar are temperature and humidity profiles in the unstable boundary layer?* J. Appl. Meteor., 29, 489-497.

Teweles, S., 1970, *A spurious diurnal variation in radiosonde humidity records*, Bull. Amer. Meteor. Soc., 51, 836-840.

Vaisala, 1993, *Vaisala UAD Technical Manual for DigiCORA II MW15*, Technical description, 12 August, 1993, pp 1-70.

Wade, C.G., 1994, *An evaluation of problems affecting the measurements of low relative humidity on the United States radiosonde*, J. Atmos. Oceanic Technol., 11, 687-700.

Time and Space Patterns of Daily Temperatures in Saskatoon

E. A. Ripley[1], O. W. Archibold[2] and D. L. Bretell[2]

ABSTRACT

Since 1900, daily maximum and minimum temperatures in Saskatoon have increased 1.2 and 2.1°C, respectively. One may speculate whether these changes are due to urbanization, global warming or climatic "noise". In order to investigate the cause, maximum and minimum temperatures were measured daily at a network of eight locations in Saskatoon over a 12-month period and compared with each other and with similar observations from Saskatoon Airport. In general, the network temperatures averaged 2-3°C higher than those at the Airport, with the greatest deviations being noted for summertime maxima. The highest maxima were found in the residential areas most remote from the edges of the city, and the lowest in an open downtown area. The downtown site had the highest minimum temperatures, while the lowest minima were found in the southeast corner of the city. Some variation was noted with time of year. While most of the temporal trend in Airport temperature is likely due to general climatic warming, the observed differences between network sites are probably related to the urban heat island.

1. Introduction

The city of Saskatoon (latitude 52° 10' N ; longitude 106° 41' W) is situated in the parkland region of southern Saskatchewan on the banks of the South Saskatchewan River. First settled in 1883, it has become the administrative centre of the Province's agriculture, oil and mining industries. After an early period of rapid growth, its population levelled off at just over 40,000 until the early 1950s when it began a steady rise toward the present level just under 200,000.

Approximately 70% of the city's 130 km² area is residential, 15% light industrial, 10% institutional, 4% parks, with the downtown core occupying the remaining 1%. The spatial distribution of these use classes is shown in Figure 1. While most of the city lies at an elevation near 500 m, the Sutherland moraine on the southeastern edge of the city rises to 520 m while in the river valley itself elevation drops to 470 m.

Temperature records in the Saskatoon area date from 1889 when a climate station was set up at Clark's Crossing, about 16 km northeast of the present city centre. A few years later, the station was moved into the growing settlement. Although the observation location has changed several times since then, the impact of these moves was not considered to be significant (Georgiades 1977).

Urban areas have climatic peculiarities due to surface radiative changes resulting from the substitution of building materials for soil and plants, airflow modification caused by buildings, and the release of heat and moisture from fuel combustion (Munn 1966; Frisken 1974; Oke 1987). These affect the energy exchange, and as a result, cities are usually warmer than the surrounding countryside; an effect generally referred to as the urban heat island.

The effects of urbanization on the climates of Canadian cities were summarized by Thomas (1971); and studies of specific cities include Winnipeg (Einarsson and Lowe 1955), Montreal (Lafleur 1971), Hamilton (Oke and Hannell 1970), Edmonton (Hage 1972), Detroit-Windsor (Sanderson et al. 1973), Calgary (Nkemdirim 1976), and Vancouver (Oke 1976).

This paper examines two temperature datasets for Saskatoon in terms of their time and space variations, in relation to the effects of the urban heat island and climatic change.

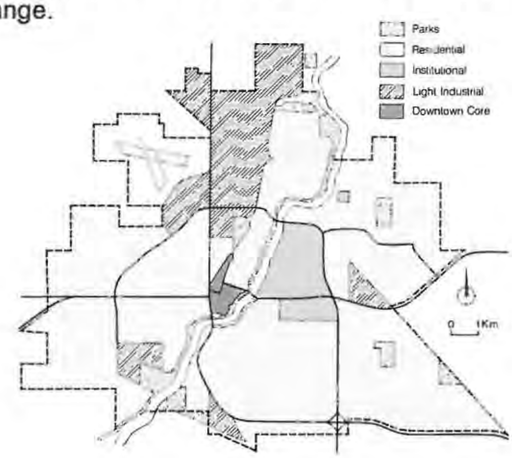


Figure 1

[1] Department of Crop Science and Plant Ecology, University of Saskatchewan, 51 Campus Drive, Saskatoon, Saskatchewan S7N 5A8

[2] Department of Geography, University of Saskatchewan, 9 Campus Drive, Saskatoon, Saskatchewan S7N 5A5

2. Data sources

The long-term temperature data used in this analysis are from the Canadian Atmospheric Environment Service monthly climate data CD-ROM. The network data were collected using eight data-logger based stations installed mainly at residential backyard locations around the city. The thermistor sensors were calibrated by running them at the same location for two periods of a week each. The data collected were daily maximum and minimum temperatures at a height of 1.5 m above the surface, which are also presented as departures from the averages of all stations, and smoothed using 20-point running means.

3. Long-term changes

Decadal means of daily maximum, mean and minimum temperatures at Saskatoon all increased about 1°C during the first two decades of the 20th century (Figure 2). After that, little trend was evident until the sharp rise of over 1°C in the 1980s. For the most part the changes in maxima and minima paralleled one another, although several decades (in particular the 1950s) had unusually high minimum temperatures, in comparison with the maxima. Over the full 90-year period, the trends were 1.2, 1.6 and 2.1°C for the maximum, mean and minimum temperatures respectively. This is consistent with increases in mean temperature of 0.9°C for the Canadian Prairie region (Findlay et al. 1994) and 1.1°C for Canada (Gullett and Skinner 1992), as well as increases of 0.28, 0.56 and 0.84 °C in maximum, mean and minimum temperatures, respectively, for the Earth as a whole (Philips 1995). The greater increase in minima than maxima has resulted in reductions in the daily range of temperature, of about 1°C per century at Saskatoon and 0.56°C for the entire Earth.

To help separate the effects of climate change and urbanization, a comparison was made of the mean annual temperature changes at Saskatoon and the hamlet of Pilger, 100 km to the east-northeast. For the 54 years during the period 1913-1992 that data were available, the temperature increased at a rate of 0.007°C yr^{-1} at Saskatoon, compared with 0.006°C yr^{-1} at Pilger. Although not statistically different, the slightly higher rate at Saskatoon may be attributable to urbanization. If so, it is consistent with the urban-rural temperature differences noted by Karl et al. (1988) for the United States and with a study by Jones et al. (1990) who found urban temperature effects to be an order of magnitude less than recent global warming. The U.S. study (Karl et al. 1988) found that over an 85-year period urbanization had increased minimum temperatures by 0.13°C and decreased maxima by 0.01°C, thus reducing the daily temperature range by 0.14°C. An analysis by Singh and Powell (1986) found a temperature increase of 0.012°C per year for the forest-grassland region of the Canadian Prairies, which includes Saskatoon. The increase, although statistically significant ($P < 0.05$), was for the period 1872-1981, and since it did not include the warm decade of the 1980s is difficult to compare with the present study.

The long-term temperature data have been grouped into 30-year periods to examine secular changes in monthly temperature. Trends in maximum (T_x) and minimum (T_n) temperatures were found to be sufficiently similar to justify treating them in terms of daily means ($½T_x$ +$½T_n$) and ranges (T_x-T_n). Mean temperatures rose from 1.16°C in 1901-1930 to 1.75°C in 1931-1960 and 2.00°C in 1961-90. The increase, however, varied with the seasons (Figure 3a). While individual months warmed by as much as 3°C during the first half of the year, changes were smaller and less consistent from July to October; and reversed to slight cooling during the final two months of the year. The decrease in daily temperature range due to the more rapid rise in minimum temperatures (Figure 3b) was most noticeable during the autumn and winter months (except December), and reversed to a slight increase during the early summer.

The seasonal variations (Figure 3a) are consistent with the findings of Raddatz et al. (1991) for the eastern Canadian Prairies, and Karl et al. (1991) for the central United States. They are equivalent to a more rapid response of the climate system to the march of the seasons, i.e. shorter lags between the summer and winter solstices and times of highest and lowest temperatures. Although the cause is unknown, it may be due to changes in observing practices, to the urban heat island, to the greenhouse effect, or merely to climatic "noise".

4. Network stations

Temperatures measured at the network sites, as a group, were higher than those at the Airport during all months of the year (Figure 4), with the maxima averaging 2.9°C, and the minima 1.6°C, warmer. In comparison with the Airport, the network maxima tended to be more extreme in summer than winter (up to 4.5°C vs. 2.0°C), while minimum temperature departures tended to be more extreme in winter (2.7°C vs. 0.6°C). Likely explanations are the Airport's more rural location and the more open exposure of the thermometer screen.

All of the eight network stations (Figure 5) were located in residential areas of the city except for the downtown site. The sensors were installed in private dwelling backyards, as typical as possible of the surrounding area, with underlying grass surface, and usually fences and sometimes shade trees. The northeastern site (T1) was in a newly-developed area close to the river, exposed to rural influence from the north and east. Sites T2 and T3 were in moderately-treed areas with rural exposure towards the south and east, while T7 and T8 were exposed to the west. Site T7 was in a heavily-treed large-

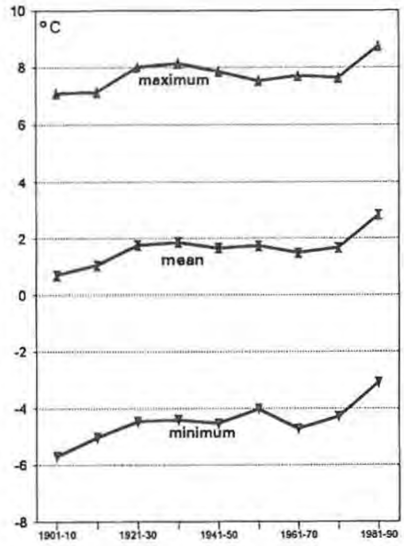


Figure 2
Decade means of daily maximum, mean and minimum temperatures at Saskatoon

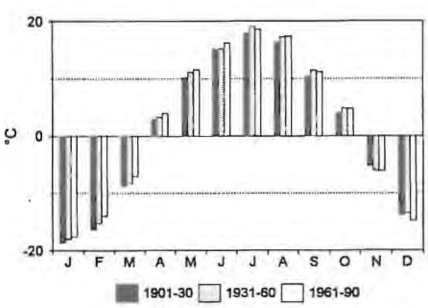


Figure 3a
30-year averages of monthly-mean temperatures at Saskatoon

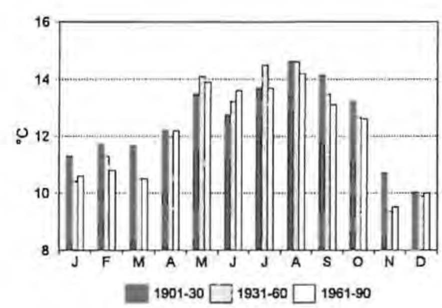


Figure 3b
30-year averages of monthly diurnal temperature range at Saskatoon

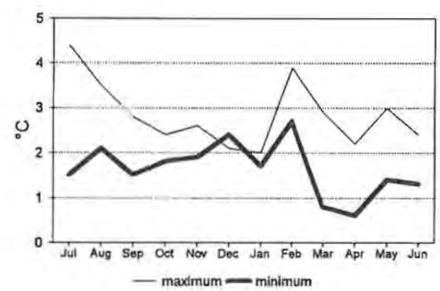


Figure 4
Differences between the monthly maximum and minimum temperature averages for the network stations and Saskatoon Airport during 1994/95.

lot residential area that had been established in the late 1940s, while T8 was in a newly-developed area on the western edge of the city. Sites T4 and T6 were in moderately-treed areas 20-30 years in age having much less rural exposure than most of the other sites. The downtown station (T5) was located in the city works department storage yard, an open area surrounded by 2 to 4-storey brick buildings.

The downtown site exhibited the greatest departures of minimum temperatures, with values averaging 1 to 2°C higher than the others. The southwest station (T7) exhibited higher minimum temperatures early in the period, most likely due to reduced long-wave cooling as a result of shading by the trees; this effect disappeared after leaf fall. The lowest minimum temperatures occurred in the southeast (T3) and northwest (T8) corners of the city, presumably because of the influence of the surrounding countryside. Several other stations (T1, T4 and T6) had higher minima in the winter, presumably because of the influence of adjacent buildings. The greatest seasonal variations (about 1.5°C) were found at T1 and T7. However the two were out of phase; T1 being cooler in summer and T7 cooler in winter. This was likely due to the effects of summer "leafing-out" on wind-speed reduction at the more-lightly treed T1 location and on radiation shading at the heavily-treed T7 site.

Consistently higher maximum temperatures (by 0.5 to 1.5°C) than the group average were found at the two stations in the main residential areas of the southern (T4) and western (T6) parts of the city. The southwest site (T7) had maxima 1°C or more below average, undoubtedly due to the effects of shading and evapo-transpirational cooling due to the dense tree canopy. Low values at the northeastern (T1) and downtown (T5) sites are not so easy to explain. The anomaly at site T3 between July and October was likely due to sheltering by garden plants early in the summer which produced complete shading by August. The effect persisted until the plants were harvested in September, after which it diminished to about 0.5°C above the group average.

Several stations showed periods of inverse correlation between the temporal variations in maximum and minimum temperatures, i.e. when the maxima were high the minima were low and vice versa. The most noticeable were T1 and T5 (in all months), T2 (from August to December), and T8 (from December to February).

5. Summary and discussion

Most of the 1.6°C increase in mean annual temperature at Saskatoon Airport over the last century was likely to have been due to climatic change, except for a few tenths of a degree which may be attributable to urbanization. Two-thirds of the change was due to the increase in minimum temperatures, which rose over 2°C. Month-to-month variations in the climatic warming are consistent with a phase change in the annual cycle, i.e. with earlier arrival of the seasons, although no explanation for this is available. The location of the Airport, on the windward edge of the city, largely isolates it from urban heat-island effects.

Residential area temperatures averaged about 2°C higher than those at the Airport, with the difference being greatest for summer maxima. Although part of the anomaly may be due to instrument exposure, it appears that most of the city's residents are exposed to somewhat higher temperatures than those reported at the Airport. Thus, in spite of its low population density (1500 km^{-2}), lack of heavy industry and abundance of parks and other open spaces, Saskatoon appears to be noticeably warmer than the surrounding countryside. The observed differences may have impacts on human comfort, residential heating and air-conditioning costs, the growth and development of plants, and the survival of small animals and birds. Continued growth of the city will likely accentuate these effects.

6. Acknowledgements

The authors are grateful to the Atmospheric Environment Service of Environment Canada for the provision of climate station data. We would like to thank Brian Fowler, Rick Holm, Geoff Hughes, Rick Lawford, and Brian Rossnagel for the loan of data loggers and sensors, and Terry Brossart, Al Hessdorfer, Bohdan Pylypec, Bob Holowaty, and the City of Saskatoon for allowing us to install sensors on their property. Special thanks is due Keith Bigelow of the Department of Geography for drafting.

References

Einarsson, E. and A.B. Lowe, 1955, *A Study of Horizontal Temperature Variations in the Winnipeg Area on Nights Favouring Radiational Cooling*, Department of Transport, Meteorological Division, Toronto, ON.

Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft. W.R. Skinner, L. Vincent and R. Whitewood, 1994, *Canadian national and regional temperature departures*, **In:** T.A. Boden, D.P. Kaiser, R.J. Sepanski and F.W. Stoss (Eds). Trends '93: A Compendium of Data on Global Change. ORNL/CDIAC-65, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, TN, USA, pp. 738-764.

Frisken, W.R., 1974, *The Atmospheric Environment of Cities*, Environment Canada, Toronto, 30 pp.

Georgiades, A.P., 1977, *Trends and cycles of temperature in the Prairies*, Weather 32, 99-101.

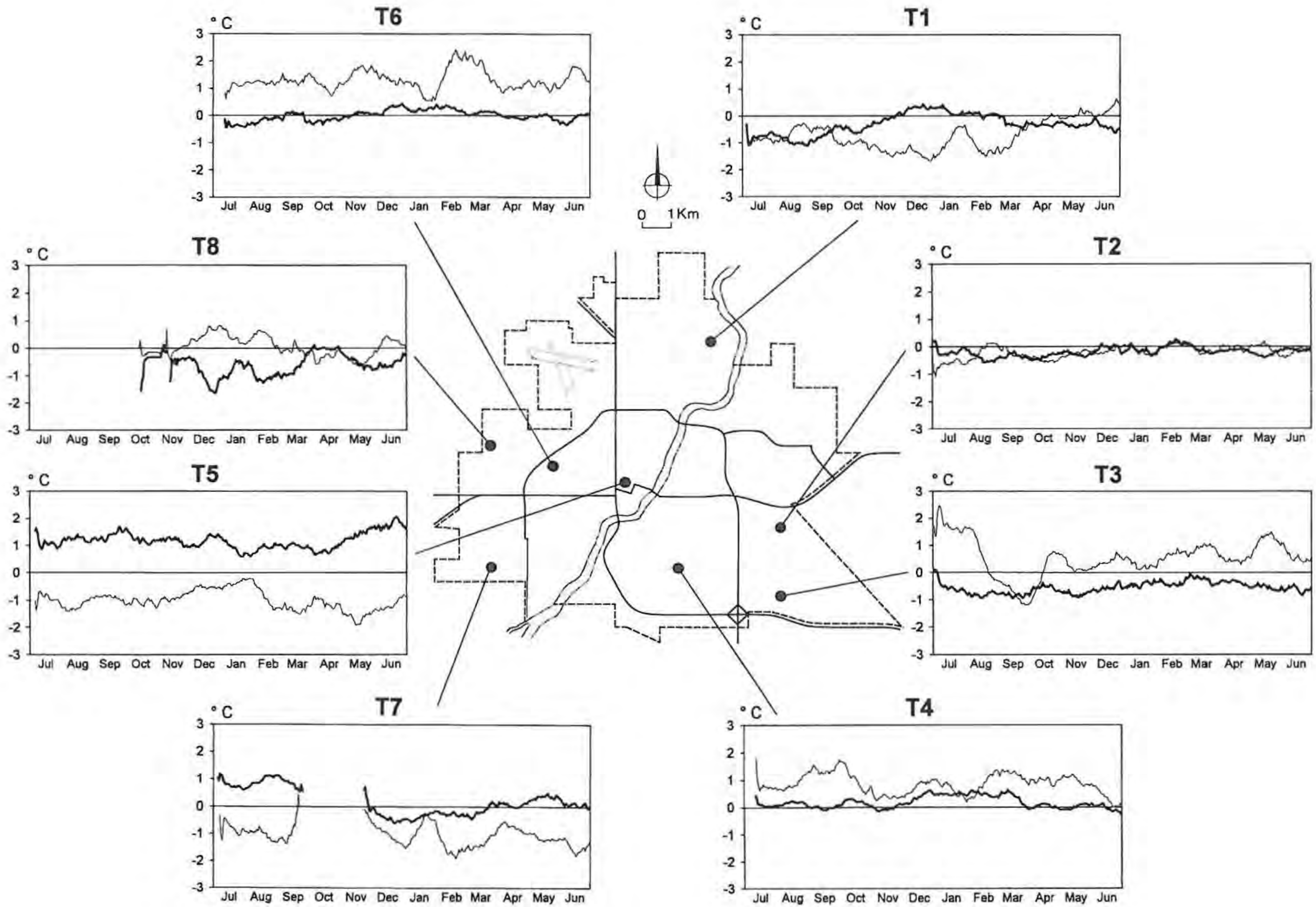

T6
T1
T8
T2
T5
T3
T7
T4
° C
3
2
1
0
-1
-2
-3
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun
0 1Km

Figure 5

Gullett, D.W. and W.R Skinner, 1992, *The State of Canada's Climate: Temperature Change in Canada 1895-1991*, State of the Environment Report 92-2, Environment Canada, Ottawa, 36 pp.

Hage, K.D., 1972, *Nocturnal temperatures in Edmonton, Alberta*, J. Appl. Meteorol. 11, 123-129.

Jones, P.D., P.Ya. Groisman, M. Coughlan, N. Plummer, W.C. Wang and T.R. Karl, 1990, *Assessment of urbanization effects in time series of surface air temperature over land*, Nature 347, 169-172.

Karl, T.R., H.F. Diaz and G. Kukla, 1988, *Urbanization: its detection and effect in the United States climate record*, J. Clim. 1, 1099-1123.

Karl, T.R., R.R. Heim and R.G. Quayle, 1991, *The greenhouse effect in central North America: If not now, when?* Science 251: 1058-1061.

Lafleur, D., 1971, *Weather and human comfort in Montreal: an example of summer conditions*, Climatological Bull. (McGill University) 10, 13-23.

Munn, R.E., 1966, *Descriptive Micrometeorology*. Academic Press, New York, 245 pp.

Nkemdirim, L.C., 1976, *Dynamics of an urban temperature field - a case study*. J. Appl. Meteorol. 15, 818-828.

Oke, T.R., 1976, *The distinction between canopy and boundary layer urban heat islands*, Atmosphere 14, 268-277.

Oke, T.R., 1987, *Boundary Layer Climates*, 2nd Edition. Methuen, London, 435 pp.

Oke, T.R. and F.G. Hannell, 1970, *The form of the urban heat island in Hamilton, Canada*. WMO Technical Note 108, WMO No. 254 TP 141, pp. 113-126, World Meteorological Organization, Geneva.

Philips, D. (Ed.), 1995, *The Global Climate System Review, Climate System Monitoring, June 1991 - November 1993*, World Meteorological Organization, Geneva, Switzerland, 150 pp.

Raddatz, R.L., J. Maybank and G.B. Atkinson, 1991, *Mean daily temperature normals from 1901-30 to 1961-90 on the eastern Canadian Prairies*. Climatological Bull. 25, 118-123.

Sanderson, M. I., Kumanan, T. Tanquay and W. Schertzer, 1973, *Three aspects of the urban climate of Detroit-Windsor*. J. Appl. Meteorol. 12, 629-638.

Singh, T. and J.M. Powell, 1986, *Climatic variation and trends in the boreal forest region of western Canada*, Clim. Change 8: 267-278.

Thomas, M.K., 1971, *A Survey of the Urban Effect on the Climates of Canadian Cities*. Atmospheric Environment Service, Environment Canada, Toronto, ON, 28 pp.

The North Atlantic Ocean Currents, Climate, Weather and Environment Conference

Scientific Conference Co-sponsored by:
Intergovernmental Oceanographic Commission
November 18-20, 1996 in Copenhagen, Denmark

The focus of this scientific conference will be on:

- Decadal variability in meteorological and ocean conditions;
- Ocean currents, climate, weather, food and environment;
- Heat fluxes;
- Process studies;
- Exchange with the Nordic Seas;
- Ocean modelling results;
- Climatic impact on fish stocks;
- The North Atlantic Component of the Global Ocean Observing System (GOOS).

Introductory lectures are planned. Scientists working on the above mentioned subjects are invited to participate in the conference. Oral and poster presentations are welcomed. Your registration and abstract should be sent before July 1 1996 to:

Dr. Erik Buch
Royal Danish Administration of Navigation
and Hydrography
Overgaden o Vandet 62B
1023 Copenhagen K
Denmark

A lire dans le prochain numéro du CMOS Bulletin SCMO l'article de Michel Slivitzky et Guy Morin portant sur les **"Impacts of climatic changes on the hydrological regime: the Moisie river case revisited"**.

In the next issue of the CMOS Bulletin SCMO, don't miss the article written by Michel Slivitzky and Guy Morin on **"Impacts of climatic changes on the hydrological regime: the Moisie river case revisited"**.

Arrhenius' Greenhouse Effect Hypothesis: One Century Later

by Henry Hengeveld[1]

Introduction

The realization that the earth's atmosphere acts somewhat like the glass of a greenhouse, letting through short-wave light rays from the sun but retaining long-wave "dark" rays from the earth's surface, has a long history. This "greenhouse effect" concept was already hypothesized by the French mathematician Jean Baptist-Joseph Fourier as early as 1827 (Fourier, 1827), and was further elaborated in subsequent decades by other 19th century scientists such as Claude Pouillet (1838), John Tyndall (1865) and Samuel Langley (1890).

However, the first estimates as to how changes in global concentrations of "carbonic acid" (a primary greenhouse gas now more commonly referred to as carbon dioxide) might affect average global surface temperatures were made by the Swedish chemist Dr. Svante Arrhenius exactly one century ago. Dr. Arrhenius first discussed his estimates in a presentation to a meeting of the Royal Swedish Academy of Sciences in December, 1895, and subsequently published his research results in the British *Philosophical Magazine* in April, 1896 (Arrhenius, 1896). Not surprisingly, Arrhenius' calculations were not undertaken to predict the influence of human emissions of carbon dioxide on global climate, but to help explain how global climates can vary from glacial to interglacial conditions. While modern scientists may argue with many of the assumptions and arguments he used in developing his prediction, his work nevertheless remains a remarkable pioneering effort that introduced a number of important conclusions considered still to be valid today.

Description of Arrhenius' Radiative Climate Model

Arrhenius' calculations for the response of temperature to changing CO_2 concentrations were developed using a two-layer equilibrium radiative model of the atmosphere that included a simple water vapour feedback process. Arrhenius assumed that, to achieve equilibrium, the net solar radiation entering the earth's atmosphere and the net heat radiation released by earth to space are in balance. He further estimated the quantity of heat radiated by a warm body to be a function of the fourth power of the body's temperature, as calculated using Stefan's law of radiation. Both of these fundamental principles of atmospheric radiative fluxes are still accepted today. Albedo of the earth's surface was prescribed in Arrhenius' calculations to vary from 78% over cloud to 50% over old snow cover, 7.5% over oceans and 0% over snow-free land. Average cloud cover was prescribed at 52.5% (about 12% less than current cloud climatology estimates). Water vapour feedback was based on an assumed constant relative humidity. Values of absolute humidity were prescribed to vary by season and 10° latitude bands on the basis of observations recorded at some 780 stations around the world, and were then used to calculate water vapour content by time and space.

The absorption coefficients for carbon dioxide and water vapour used in the model were developed largely on the basis of adjustments to data collected and published by the US physicist S. Langley. Langley developed his estimates for these coefficients by measuring, at different wavelengths, the intensity of radiation from the moon for various seasons of the year and heights of the moon above the horizon (and hence through differing atmospheric path lengths) (Langley, 1890).

Model Experiment and Results

Using the above model, Arrhenius calculated the global temperature response to changing atmospheric concentrations of carbon dioxide. The range in estimated temperature response varied from a global annual average cooling of about 3°C if carbon dioxide concentrations decreased by about 1/3 to a warming of 7-9°C for a tripling of carbon dioxide concentrations. Doubling CO_2 concentrations resulted in a 5°C warming at the equator, increasing to 6 degrees at higher latitudes. Arrhenius concluded that a geometric increase in carbon dioxide concentrations caused an arithmetic increase in mean surface temperatures (i.e. a logarithmic response). Because of the varying water vapour feedback with latitude, the effects of enhanced CO_2 concentrations on temperature increased somewhat with increasing latitude, peaking between 50 and 70° latitude. He suggested that consideration of a secondary albedo feedback due to snow cover response would move the maximum temperature response further towards the poles. The temperature response was also generally greater in winter than summer, particularly in the Northern Hemisphere.

On the basis of his analysis, Arrhenius argued that past changes in atmospheric concentrations of carbon dioxide, which he attributed to variations in outgassing from volcanoes, provided the most likely explanations for large variations in the earth's past climate. He cited studies by contemporary scientists to refute orbital and solar variabilities as possible causes. When comparing his model results with estimated temperatures for past periods in the earth's history, Arrhenius suggested that temperatures some 8-9°C warmer than present that

[1]Atmospheric Environment Service

occurred during the Tertiary period (several million years ago) corresponded well with an atmosphere having concentrations of carbon dioxide three times that of ambient concentrations reported by his contemporaries. By contrast, temperatures approximately 4-5°C colder than today during the peak of the last ice age (about 25,000 years ago) might correspond to a relative decrease in CO_2 concentrations of about 55 to 62%. He also opined that the effect of human emissions of CO_2 from industrial activities on atmospheric concentrations should be minimal. This conclusion was based on his assumption that CO_2 absorption from the atmosphere by chemical weathering of silicate-based minerals was of the same order of magnitude as human emissions, and hence offsetting.

Shortly following the release of Arrhenius' pioneering work, the American geologist T.C. Chamberlin published a series of papers that supported the principal conclusions of Arrhenius and expanded on the possible explanations as to how concentrations of atmospheric CO_2 might change with time. Foremost in his theories were the processes of CO_2 emissions into the atmosphere from volcanic eruptions, the absorption and outgassing of CO_2 into and out of the world's oceans, and the role of rock formation and weathering in controlling terrestrial carbon reservoirs.

Evolution of Climate Change Theories Since Arrhenius

The theories of Arrhenius, and later Chamberlin, with respect to the role of changing atmospheric CO_2 concentrations as a primary explanation of past fluctuations in earth's climate, although prevalent for a short period of time, were in general conflict with the broadly held perceptions of their contemporaries. During the late 19th century, there was a general consensus amongst atmospheric scientists that absorption of heat radiation by water vapour so dominated the long wave portion of the radiative spectrum as to make the effects of changes in CO_2 concentrations negligible. Hence Arrhenius' calculations and related theories were soon abandoned by the broader science community and largely forgotten for the next forty years.

It was not until 1938 that the British engineer G.S. Callendar reintroduced Arrhenius' work into the scientific debate. On the basis of much improved analyses of absorption spectra for different gases, Callendar demonstrated that CO_2 indeed did have important absorption bands outside of those dominated by water vapour, and that increased CO_2 concentrations could have significant global effects on surface temperatures. Callendar also, for the first time, suggested that humans could have a significant influence on atmospheric CO_2 concentrations, but estimated that it would take several centuries of continued industrial emissions to achieve a doubling of concentrations. Furthermore, he proposed that a modest warming of this kind could be generally beneficial to humanity. His milestone paper led to a series of subsequent studies by various scientists during the next 15 years. By the mid 1950s, post war emissions of carbon dioxide began to escalate rapidly, leading to a pivotal paper by Roger Revelle and Hans Suess that proposed that humans had begun an unprecedented "large scale geophysical experiment" with the planet (Revelle and Suess, 1957). Revelle was instrumental in establishing the first station for long-term monitoring of CO_2 concentrations at Mauna Loa, Hawaii, and in launching an accelerated international research program into climate modelling and better assessment of the potential human influence on the climate system. Climate change had now become an "environmental" concern.

Significance of Climate Change Projections by Arrhenius

Despite the dormancy of Arrhenius' work for a period of some forty years, his work remains of pioneering significance and a testimony to the longevity of many of the principles he espoused. Many of the assumptions used by Arrhenius in his work are, of course, no longer accepted today, and some of his data and calculations are now considered incorrect. For example, modern theories re the possible causes of glacial-interglacial cycles have re-introduced orbital changes and solar variability as primary triggering mechanisms. Furthermore, his very simple model of the atmosphere failed to address the complex feedbacks of the climate system, particularly with respect to clouds, oceans and ice cover. His estimates for absorption coefficients of carbon dioxide, for albedo and for cloud cover have also been adjusted significantly over the past century as a result of long term monitoring and more accurate spectral analysis.

However, based on significant temperature-CO_2 correlations found in recent data extracted from glacial ice cores, theories on causes of glaciation continue to recognize that changes in atmospheric concentrations of greenhouse gases have in the past provided an important feedback process that significantly amplified climate changes triggered by other primary forces (such as orbital change or solar variability). In many other respects, the early estimates and conclusions of Arrhenius concerning the response of the climate system to increased carbon dioxide concentrations are also consistent with those provided by the much more complex climate models used today. Some of these similarities are illustrated in the following comparisons with recent conclusions of the comprehensive assessment of climate change science conducted by the scientific community under the auspices of the Intergovernmental Panel on Climate Change (IPCC).

References

Arrhenius,S. 1896, *On the influence of carbonic acid in the air upon the temperature of the ground*, Philosophical Magazine and Journal of Science 41:237-276.

Callendar,G.S. 1938, *The artificial production of carbon dioxide and its influence on temperature*, Quarterly Journal Royal Meterological Society 64:223-237.

Fourier,J. 1827, *Mémoire sur les temperatures du globe terrestre et des espaces planétaires*, Mem. de l'Academie Royale des Sciences de l'Institut de France 7:569-604.

Langley,S.P. 1890, *The temperature of the moon*, Mem. of the National Academy of Sciences iv:193.

Pouillet, C.S.M. 1838, *Comptes rendus* vii:41.

Revelle,R. and Suess,H.E. 1957, *Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during the past decades*, Tellus 9:18-27.

Tyndall,J. 1861, *On the absorption and radiation of heat by gases and vapours, and on the physical connection of radiation, absorption, and conduction*. Phil. Magazine 22:169-194.

Comparisons of Some of Arrhenius' 1896 Estimates/Assumptions with those of IPCC 1995 Assessment

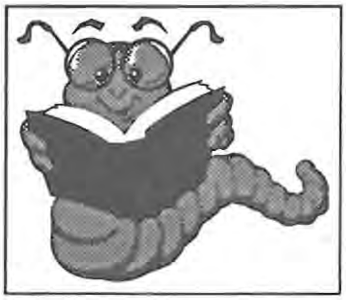
	Arrhenius 1896	IPCC 1995
CO_2 Concentration during ice age	165-185 ppmv	200 ppmv
Climate response to increased CO_2	logarithmic	logarithmic
Climate response to CO_2 doubling	5 to 6°C	1.5 to 4.5°C
Latitudinal response	increasing poleward	increasing poleward
Seasonal response	greater in winter	greater in winter

New Views on an Old Planet, (2nd Ed.)

by Tjeerd H. van Andel, Cambridge University Press, 1994. 439 pp.

ISBN 0-521-44243-5

Book reviewed by Dr Paul LeBlond, U. of British Columbia, Vancouver, B.C.



"The earth is changing. It is changing before our eyes, and life is changing with it at an ever faster rate. Awareness of this fact has been slow in coming, because we have always thought of nature as dependable and constant, of the earth as rigid, and of the sea as eternal. We are confused by this new perspective and worried by the many voices that cry danger but seldom offer true solutions". Thus begins van Andel's presentation of the revised edition of this book, aptly sub-titled:"A History of Climate Change".

While earth scientists might object to this point of view, claiming that they certainly do not think of "the earth as rigid, or the sea as eternal", this book is not written mainly for them, but for the general educated public, with whom the author tries to identify right from the start. Having started life as a student of art history, van Andel is well aware of the vast misconceptions and residual misinterpretations which surround the history of our planet.

Climate change has become an issue of public policy, with repercussions far beyond scientific circles. Politicians now understand that environmental issues are more than just a matter of aesthetics; they are faced with decisions which must be guided by expert knowledge as much as by public pressure.This book is an accessible introduction to earth sciences and climate for those who wish to go beyond a superficial understanding of the issues without becoming entangled in jargon and academic arguments.

Van Andel addresses the big questions - the origin of sea salt, the birth of continents, the role of life - in simple words, with simple line-drawing illustrations adapted to his text. The chapters are short and cut up in easily assimilated sections; perspective paragraphs summarize the important points. Specialists in earth sciences will also appreciate, as I did, the broad perspective and the direct presentation.

After a chapter of foundations explaining some basic concepts in geology and geochronology, the story begins with the "snows of yesteryear" - the ice ages, the evidence and explanations of their occurrence. Delving deeper into time, the author guides the reader through the evidence and the ideas of plate tectonics, the story of Pangea and the fate of its fragments. Climates of the past are then explored in the light of changing sea-levels and wandering continents. The final chapters take a definite historical approach, exploring the birth of continents, the origin of sea water, the evolution of the atmosphere, and finally the development of life and its role in climate.

The presentation is everywhere anchored on evidence and clear understanding of mechanisms. Van Andel is clearly wary of model results, "impressively qualitative, but ... no better than the data that are entered and the premises that underlie the model." While he recognizes the important biogeochemical role of life, "outpacing every other process on earth for its infinite capacity for change and variety," he is also suspicious of holistic ideas, like the Gaia hypothesis, which he sees as "unnecessary" and reflecting "an unwillingness to accept that understanding the earth is hard, slow work, accomplished in small steps".

There is a glossary, a good index, and very few errors. In Fig 2.2, the labels for alpha particles (like helium nucleus) and gamma rays (like x-rays) are inverted. Bezimianny volcano is misspelled in Fig. 3.8. Oceanographers will also know that the core of the Mediterranean outflow is at about 1000 m, and not "just above the bottom" in the Atlantic (p 207). What I also missed were references to works mentioned in the text. The author tells us that he has refrained on purpose from citing from the scientific literature because he is writing for people who "would not benefit from innumerable citations in the text". He does provide however, at the end of each chapter, a list of additional readings which should provide some satisfaction to the more enquiring readers.

I have found this book useful as a source of illustrations and clear explanations in an introductory Earth System Science course.It is a particularly enriching presentation - science as culture - which I strongly recommend to fellow earth scientists eager to reach beyond the bounds of their specialty.

CMOS Business Office has recently moved to University of Ottawa. Please note their new numbers: ☎ (613) 562-5616; Fax: (613) 562-5615 E-Mail: cap@physics.uottawa.ca

Introduction to Space Science

Margaret G. Kivelson and
Christopher T. Russell (Eds.)
Cambridge University Press, New York,
568 pp, 1995, $42.95 US paperback.

Book reviewed by Donald J. McEwen
Department of Physics and Engineering Physics
University of Saskatchewan, Saskatoon

This book covers all aspects of space plasmas, starting with the sun and solar wind and extending down through the magnetosphere and ionosphere. It begins with a brief history of solar terrestrial physics - from early auroral sightings back to 600 BC and magnetic field investigations beginning in the 11th century, through the "explosive growth of our knowledge" beginning in 1957 with the first satellite, to planetary studies underway and projected beyond 2000 AD! Excellently done, and followed by basic theoretical concepts involved in space plasmas.

The succeeding chapters, each written by experts in their specific fields, combine to give a comprehensive survey of both observation and theory. Chapters 3 and 4 on the sun and solar wind are good, with up-to-date observations giving "a view transformed in the past few years". The chapter on magnetospheric configuration is straigthforward and clear, assuming little prior knowledge. The coverage of aurora is a bit terse and tutorial but has basic explanations with excellent discussions on related phenomena. The editors have succeeded in making the chapters flow together fairly consistently, but there are a few repetitions. Auroral substorms have been covered in two successive chapters with similar diagrams (Figures 13.15 and 14.10). Gyroradii of electrons and ions as a function of energy and magnetic field strength are quoted twice (Figure 2A.1 and Table 10.1), the latter with the relativistic correction included while equation 10.2 omits it.

The book has been designed and tested as a text for senior undergraduates or beginning graduate students with a knowledge of classical mechanics and electromagnetism. Most chapters include some references for additional reading and a number of useful problems. It can fill a major current need as a student text, and I look forward to using it soon! For reseachers in related fields of physics (e.g. meteorology or oceanography) it is excellent and I highly recommend "Introduction to Space Science" as a reference for your library! For the space physicist too, the coverage of topics outside one's own specialty makes it a valuable information source. This book is a must for a large audience and I commend the authors for their efforts.

WOCE News
A Canadian Community Modelling Effort

As an adjunct to the Canadian WOCE programme, a group of research scientists at BIO, Dalhousie University and the University of Victoria has initiated the development of a fine-resolution ocean circulation model focussed on the North-Atlantic. The model development is funded through the Canadian Climate Research Network. The group aims:

- to improve understanding of the dynamics determining large-scale currents and watermass structures;
- to encourage collaboration on large-scale modelling activities within the Canadian WOCE community; and ultimately,
- to provide the Canadian Atmospheric Environment Service with an ocean model suited as a component of the global climate model.

The project is still in the early stages. At present, we are evaluating available models and considering how to blend them in order to achieve a model best suited for our needs. We will be discussing our progress at the WOCE session of the 1996 CMOS meeting in Toronto. We hope this presentation will serve to initiate useful collaboration, and invite inquiries from all interested parties.

Preliminary expressions of interest should be sent to:
Dr. Dan Wright
Bedford Institute of Oceanography
Box 1006
Darmouth, N.S. B2Y 4A2
Canada
☎ (902) 426-3147; Fax (902) 426-2556
E-Mail: dwright@emerald.bio.ns.ca

125th Anniversary of Weather Services in Canada

Planning is under way to dedicate the December 1996 issue of the CMOS Bulletin SCMO to the 125th Anniversary of Weather Services in Canada, but we need your help to pull it off. How about digging through your old photograph albums/diaries, etc. and search out old photos, clippings or articles that have been gathering dust for years. Failing such sources, test your memory and go back in time and bring to life some of those long-forgotten anecdotes, old stories, events, whatever, and send them to us by mail, Fax or E-Mail along with your credit lines. You have until the end of August 1996 to get your material to us. Photographs are particularly welcome but should be glossy, titled and dated.

Get a move on it and support your Bulletin!

Paul-André Bolduc, CMOS Bulletin SCMO Editor.

SCIENTIFIC TOOLS for COASTAL MANAGEMENT and POLICY

Report of a Workshop held under the auspices of the Japan-Canada Science and Technology Agreement in Vancouver, B.C. 22-25 January 1996.

by Paul H. LeBlond[1]

Background

At the end of 1994, the Canadian Ocean Frontiers Research Initiative (COFRI) presented to Canada's Federal Government a proposal for research in the marine environment. An important part of this proposal was an interdisciplinary project for modelling oceanographic conditions in the Strait of Georgia with application to the management of development activities around its periphery.

At the instigation of John Spence, SPARKS Ocean Champion at the Science Council of British Columbia, two of the proponents of the Georgia Basin project, P. LeBlond and J. Garrett, obtained support from the Department of Foreign Affairs and International Trade to visit Japanese scientists and institutions concerned with coastal modelling and management.

During their visit to Japan, at the end of March 1995, Garrett and LeBlond found many points of common interest and concern with Japanese colleagues and agencies. A report submitted upon their return recommended that issues of common concern be examined in a bi-lateral workshop, to be held in Canada. The workshop was held in Vancouver 22-25 January 1996.

1. Participants

Participants were selected from government, academe and industry for their interest and experience in coastal modelling and management. They included scientists, engineers, managers and policy makers. The Japanese co-chairman, Prof. T.Yanagi, of Ehime University, identified Japanese participants. Canadian participants were selected by the Canadian co-chairman, P. LeBlond, in consultation with J Garrett, J. Spence and others. The following attended:

From Japan:
- Mr. M. Babasaki, Port and Harbour Bureau, Fukuoka City;
- Dr. K. Kawana, Chugoku National Lab. Kure, Hiroshime;
- Dr. M. Kishi, Ocean Research Inst. Univ. Tokyo;
- Mr. Takeaki Kuramoto, METOCEAN, Yokohama;
- Dr. K. Murakami, Prt & Harbour Res. Inst., Yokosuka City;
- Dr. M. Odamaki, Maritime Safety Agency, Tokyo;
- Dr. M. Okada, Hiroshima Univ. , Hiroshima;
- Dr. T. Yanagi, Ehime Univ. , Matsuyama.

From Canada:
- Dr. Gary Borstad, Borstad Assoc., Sidney, BC;
- Dr. W. Crawford, IOS, Sidney, BC;
- Dr. R. Elner, Environment Canada, Delta, BC;
- Dr. D. Hodgins, Seaconsult Ltd., Vancouver, BC;
- Mr. D. Howes, Land Coordination Office, BC Govt;
- Dr. P. LeBlond, UBC, Vancouver, BC;
- Dr. T. Pedersen, UBC, Vancouver, BC;
- Dr. J. Spence, Science Council of BC, Burnaby, BC;
- Dr. R. Thomson, IOS, Sidney, BC;
- Dr. K. Thompson, Dalhousie Univ. Halifax, NS;
- Mr. J. Truscott, Min. Ag., Fish. and Food, BC Govt;
- Mr. R. Wilson, IOS, Sidney, BC;
- Mr. K. Yuen, DFO, Ottawa.

2. Workshop activities

The Japanese participants arrived in Vancouver on 22 January 1996; they were greeted by the Canadian co-chairman and provided with final details about workshop logistics. CV's and presentation materials brought by Japanese and other participants on that day were collated for distribution at the opening session on 23 January.

Following words of welcome and orientation, the first part of the workshop consisted of brief presentations by all participants of the issues which they thought of interest and of pertinent case studies. Simultaneous translation was provided throughout and discussion followed each presentation. These interactions established a level of familiarity between participants and their interests which greatly facilitated further discussions.

The participants then split up in two groups, concerned

[1]Dept. Oceanography, University of British Columbia, Vancouver, BC V6T 1Z4 (leblond@ocgy.ubc.ca)

respectively with scientific/technological issues and management/policy issues. After half-a-day, these groups reported on their deliberations. Issues of primary importance were identified and recommendations formulated in a general discussion. These are presented in the next sections.

Social activities included a reception/dinner at the hotel on the first day and dinners in restaurants on the other days. A visit to the Aquarium was arranged at the end of the last afternoon. Japanese visitors were introduced to some COFRI leaders (J. Madden; J. Nightingale).

3. Issues of common interest.

3.1 Introduction

Coastal zone management includes all measures aiming at the sustainable development of the coastal area. Presentations and interventions by participants made it clear that the coastal zone covers the width of a country's EEZ and that management concerns span a broad range from marine safety to fisheries resources. The link between human impact on the marine environment and the ability of the coastal zone to support fishing and aquaculture was repeatedly made. It is clearly no longer possible to think of coastal zone management and fisheries management as unrelated activities: the emphasis, in both countries (and elsewhere[2]), has shifted to concern for the coastal ecosystem.

Issues discussed are presented here in an order which progresses from the scientific to the managerial. In many cases, participants found that they had specific common interests which could expand into fruitful collaborations. Others, from both countries, might of course also be attracted to such collaborations and should be informed of the issues raised through dissemination of this report.

3.2 Current predictions

At a basic level, some understanding of ocean currents is required for all applications. Marine safety and navigation require short-term prediction, as for tidal currents, and in some narrow straits, real-time announcements of actual currents to approaching vessels is desirable. In addition to common concerns for accurate and timely current prediction, Canadian and Japanese participants most concerned with ocean currents (Crawford, Odamaki) shared a particular interest in methods for measuring and communicating strong, rapidly-varying and highly-sheared currents in narrow straits. This concern addresses issues of marine safety and pollution prevention through reducing the risk of collisions and spills.

3.3 Water quality standards

There is a generally perceived need to maintain marine water quality at a level where impacts on the ecosystem are minimized: dissolved oxygen levels must remain sufficiently high for benthic organisms to flourish; industrial and domestic contaminant levels must be sufficiently low that marine animals and plants are not affected. While in many cases discharge standards have been defined for shore-based factories, permissible levels in the ocean itself are less easily established and may vary from place to place depending on local conditions. Scientific discussion on the methods to be used for defining acceptable levels of various anthropogenic materials and tracing their distributions in the coastal area was recognized as desirable. Setting realistic discharge and accumulation limits would require a deeper understanding of coastal ecosystems.

3.4 Models

Management of the coastal environment, including its living resources, requires quantitative tools which allow prediction of the impacts of human interactions. Such tools are "models", i.e. structured explanations based on an understanding of physics, chemistry and biology, from which coastal currents and property distributions as well as the time history of key species of the ecosystem may be calculated. Without quantitative, predictive models, coastal management remains poorly based in science and unable to assess the relative impacts of various human activities. Without reliable models, managers operate with questionable assumptions and policy-makers remain at the mercy of conflicting interests, unable to convincingly justify proposed strategies.

While participants generally agreed on the need and utility of models as scientific tools for coastal zone management, there was much discussion on the specifics of such models, the need to assess their reliability and to establish standards of performance. Joint discussions on the identification of techniques for addressing the degree of uncertainty in model results and particularly in predictivity were called for.

Models of the coastal environment used to focus on explaining the circulation and the distribution of physical properties of the sea. Nowadays, as illustrated by many presentations at the workshop, modellers are more ambitious and extend their efforts to include the basis of the marine ecosystem by linking nutrients to phytoplankton and zooplankton. Such ecosystem models are now the state-of-the-art and are gradually developing to include higher trophic levels and ultimately species of commercial interest. Strategies for the development of such ambitious models are the subject of intense scientific discussion in all countries. Canada and Japan are leaders in this matter; a closer collaboration would enhance the scientific credibility and reliability of coastal models in both countries and improve the applicability of ecosystem models as scientific tools for management of marine resources.

Of particular interest in the development and application of models is the question of whether improvements in their structure (better physics or better biology) should give way to efforts to increase the rate of feeding recent information into the models. Continuously correcting model output by inserting recently obtained information is called "data assimilation", a technique now commonly used in weather predicting. The development of data assimilation techniques, as discussed by Drs. Thompson and Yanagi, to improve the predictive abilities of coastal models and their extension to ecological models is an area of great mutual interest to Japanese and Canadian scientists.

3.5 Information

Data assimilation requires a steady stream of information. A variety of remote sensing techniques for monitoring the coastal ocean, by acoustic, radar, satellite and aircraft observation are currently being developed and applied in a variety of areas. New techniques will have to be developed for the observation and characterization of ecosystem variables. Exciting possibilities, both at the scientific and technical level, are arising in this area.

3.6 Areas of geographical application

Practical applications of modelling where Japanese and Canadian scientists could collaborate and compare models and observation techniques include parts of the Seto Inland Sea of Japan and Saanich Inlet in British Columbia. That latter embayment was recognized as a particularly interesting area for joint work because of concerns about its possible eutrophication echo those found in Japanese bays.

A number of workshop participants, from both countries, have applied modelling techniques to fisheries problems. Numerical models of ocean currents allow examination of larval drift or fish migrations and may lead to better descriptions and assessment of mobile marine populations. Many participants identified this area as one of particularly promising and useful collaboration.

3.7 Communication of results

Beyond the development of models as scientific tools, there is a clear need to refine methods for presenting model results to decision makers. Models will have little impact if their results are not clearly understood. As models are extended to include biological response, as well as other indicators of stress or damage to the natural environment, their output must be adapted to the specific needs of decision makers. The results must be expressed in terms of the consequences of particular decision or imposed policy; often, this may require dealing with economic consequences, or with restrictions on resource use, rather than, for example, expressing the output in terms of effects on a single species. In general, this approach will require coastal zone scientists and engineers to think of how to extend the output from their models into readily comprehended results, driven by the differing needs of decision makers, stakeholders and the public.

It is also important to quantify uncertainty in models and to explain its meaning. Uncertainty is too often ignored or misunderstood. Ignoring it leads to an illusion of certainty and to poor decisions. Poorly defined uncertainty is also often misinterpreted, sometimes maliciously, as indicating worthlessness, thus negating the value of models as objective scientific tools. In this regard, uncertainties in model formulation can be expressed in probabilistic form, and results can be derived giving the consequences of policy decisions as a risk function. At the present level of development, the coastal zone models examined at this workshop did not incorporate uncertainty, or use risk modelling concepts for expressing their output. There was general agreement that the development of such modelling techniques was warranted and would form a useful area of collaboration between Canada and Japan.

3.8 Decision-making

To use scientific tools, an appropriate decision-making framework must be available. Canadian and Japanese practices have both similarities and differences in this respect and both sides can learn from the successes and difficulties of the other. While there exists software which may be used in assisting decision-making, the process itself, and the way in which it uses and presents scientific results, is an important component of coastal zone management.

As a part of the decision-making process, some participants identified the role of integrators, persons within institutions who have the ability to see the broader picture and apply the results of various models, both scientific, economic and managerial to the problems at hand.

4. Recommendations

Several common themes, of interest to scientists in both countries, were identified as likely to improve the management of the coastal zone. These are enumerated below in the form of recommendations for bi-lateral collaboration.

4.1 Enhanced exchange of coastal oceanographic information, as well as prediction and communication techniques, will improve the coastal hydrographic services provided to their respective communities and should be encouraged. In specific terms, identification of topics of greatest mutual interest (e.g. real-time current warnings) through focused interactions of individuals researchers should be the first step in this process.

4.2 There is a perceived benefit for Canadian and Japanese scientists to interact in defining methods for establishing acceptable levels of marine contaminants appropriate to conserving coastal ecosystems; cooperation in this endeavour should be encouraged.

4.3 Modelling is recognized as an essential scientific tool for coastal management. Modelling practice has progressed beyond representation of circulation and physical properties to include the basic levels of the coastal ecosystem. Rapid development of ecosystem modelling is of great interest to Japanese and Canadian scientists. Ecosystem modelling promises to greatly enhance the scope and applicability of models as scientific tools for coastal management.

In view of the complex nature of ecosystem modelling and of the significant commitment of resources to monitoring which it requires, there is a need for a solid business case to be made for developing this kind of management tool. One of the first steps in the elaboration of this plan should be the preparation of a background report summarizing current ecological models and evaluating their functionality. It should also identify key issues that need discussion prior to project planning. This background report could serve as a starting point for a future joint ecological modelling workshop, as proposed below.

4.4 Data assimilation, a method of inserting observations for keeping models on track widely used in weather prediction, was identified as a major focus of interest in the development of practical predictive models. The development of practical methods for the assimilation of a wide range of ecosystem properties into coastal models should become a priority within each country's modelling community and bilateral interchange of ideas and results encouraged.

4.5 The development of monitoring techniques capable of providing information at low cost and a solid basis for data assimilation is also a matter of great relevance to coastal management. Modern techniques include acoustic methods, radar measurements of waves and currents, airborne scanning and satellite altimetry. In recent years, there has been extensive technological development of these techniques, especially within Canada's private sector. Comparison of capabilities with those existing in Japan may lead to fruitful international collaboration and should be strongly encouraged.

4.6 An important aspect in the development of scientific tools is that of improving methods for making model results clear to non-technical audiences. In particular, the need to quantify uncertainty in model predictions was identified as an important factor when models are used as a basis for decision. Efforts towards developing explanatory visual output, especially in collaboration with communication experts, and towards adapting model results to use in decision-making frameworks should be encouraged in both countries and through bilateral collaboration.

4.7 There is a need to discuss these topics further to identified joint projects, along the lines described above, which would be of mutual advantage. A second workshop has been suggested as a means to advance cooperation. Individual visits, exchanges of scientific personnel, and exchange of correspondence were recommended as a way of preparing joint projects (e.g. workshops or joint modelling of areas of interest, such as Saanich Inlet).

It has also been suggested that in order to enhance benefits to both countries the second workshop should focus on identifying specific projects and discussing mechanisms to bring about actionable projects. Means of financing collaborative work on both sides should be explored and a greater number of private sector companies from both sides should be invited to participate.

4.8 The results of this workshop should be circulated widely within the scientific and coastal engineering and management community of both countries to encourage broad participation in the research and activities described above.

5. Follow-up

As a first step, reports of workshop proceedings are being disseminated through appropriate bulletins and newsletters. To maintain contact with Japanese colleagues and exchange information, an electronic bulletin board will be set up.

Projects addressing issues of mutual interest are to be developed. The Japan-Canada 2000 Program will provide assistance to locally funded projects for international bilateral exchange activities.

Expressions of interest and suggestions for increasing the effectiveness of the process are solicited (leblond@ocgy.ubc.ca); after all, participation at the workshop had to be very limited and the organizers are conscious that many other people are concerned with these issues. Information on the COFRI Foundation may be found at the URL http://www.cofri.org.

[2] cf for example: Setting a New Course for U.S. Coastal Science, National Science and Technology Council, Washington, D.C. 1995. Reviewed by D.F. Boesch and E.R.Urban in OCEANOGRAPHY, 8, No.5, 97-99, 1995.

Broadening Perspectives on Water Issues by James P. Bruce

This is the title chosen for a report[1] prepared for Environment Canada at that Department's request, by the Canadian Global Change Program and the Canadian Water Resources Association. The lead authors of the report were J.P. (Jim) Bruce of the CGCP and Chair of Canadian Climate Program Board, and Bruce Mitchell, University of Waterloo, a former CWRA President. The report was based on the outcome of one national workshop and eight regional workshops involving some 500 Canadians concerned with water resources.

The report notes a striking paradox. On the one hand the Workshop participants outlined many reasons for considering water to be a significant issue into the 21st century, and identified a number of important federal roles. On the other hand decisions in Environment Canada and the federal government have seriously reduced the capacity at the federal level to deal with Canadian and Canada-U.S.A. water issues. Inland Waters Directorate was dismantled, the Interdepartmental Committee on Water and Federal Water Policy of 1987 abandoned. Funding under the Canada Water Act is dropping to a level less than $1 million from a high in the 1970s and 1980s of close to $20 million.

The report notes a striking paradox. On the one hand the Workshop participants outlined many reasons for considering water to be a significant issue into the 21st century, and identified a number of important federal roles. On the other hand decisions in Environment Canada and the federal government have seriously reduced the capacity at the federal level to deal with Canadian and Canada-U.S.A. water issues.

Much of the change in Environment Canada was due to increased emphasis on an "ecosystem approach" seeking to break down traditional sectoral barriers to such comprehensive environmental analyses and actions. At the same time, budget reduction pressures have been severe.

However, as one workshop participant characterized the present approach as one "that may be embarking on a course that smacks of profound superficiality". Profound in that it recognizes the importance of an ecosystem approach, but "superficial" in its lack of attention to water in all its dimensions.

The report concludes with a number of recommendations, directed towards Environment Canada, but with implications as well for Provinces and the private sector. In developing the Recommendations, a clear definition of the federal obligations in water is repeated, drawn largely from the Federal Water Policy review (Pearse et al, 1985). These obligations derive primarily from bilateral (Canada/U.S.A.) international, interprovincial responsibilities, legislative responsibilities over fisheries, migratory waterfowl and navigation, and the management of federal lands, including First Nations' Lands, National Parks, etc. The Workshop also confirmed an agreed federal responsibility for promotion and conduct of research. It was recognized that in some cases, transfer of administrative responsibility to Provinces for some of the legislative obligations may be beneficial, but the federal government should ensure that one way or another the federal responsibilities are met.

With this background, the 29 recommendations fell under the main headings of leadership, a river basin ecosystem approach, water as hazard, water demand and economic analysis, Canada/U.S.A. issues, international water issues, systematic measurements, standards and research.

Among the 29 specific recommendations under these headings were:

1) restate the Federal Water Policy (1987), and revise the Canada Water Act (1970);
2) lead inter-departmental coordination on water issues and consider formation of a Canadian Water Council (Private Sector, Governments, First Nations);
3) to foster a "nested river basin ecosystem " approach, with the federal role to cooperate in establishing guidelines for large inter/provincial and international basins;
4) establish a central Boundary Waters Unit to ensure consistency and equity in dealing with U.S.A. under the Boundary Water Treaty;
5) Environment Canada develop with CIDA, a multi-sectoral consortium approach for international outreach on water issues and promotion abroad of Canada's expertise and technologies;
6) maintain and up-date the Flood Damage Reduction Program;
7) hydrometric and water quality measurements and assessment program be maintained to meet federal obligations and provide a basis for sustainable water management;
8) continue widely-accepted and important role in water-related research, both in natural and socio-economic sciences, designed to address federal obligations, sustainable water resource management and ecosystem protection.

Environment Canada was requested to publicly report by September 1996 and periodically thereafter on progress in addressing Canadian Water issues and meeting the recommendations of the workshops and report.

[1]: Incidental Report #IR95-1, Royal Society of Canada, August 1995, 38p.

Rapport sur l'Expo-Sciences de l'Outaouais 1996

Sous le thème général de "Explose tes idées", l'Expo-Sciences de l'Outaouais 1996 regroupait soixante-trois (63) exposants des niveaux primaire et secondaire. L'événement, organisé par le Conseil du loisir scientifique de l'Outaouais en collaboration avec l'École secondaire Saint-Joseph de Hull, se tenait au Centre Père Arthur-Guertin de Hull, du 23 au 25 mars 1996.

Cinq des projets comportaient des éléments météorologiques ou océanographiques et furent évalués attentivement en vue de l'attribution de l'un ou l'autre des prix de la SCMO. En tenant compte du nombre de projets de cette catégorie et de leurs qualités compartives, il fut décidé d'attribuer les deux prix suivants:

Premier prix: certificat de mérite et bourse de 75 $ à Nicolas Sabourin (17 ans) et Mathieu Lavigueur-Lachance (15 ans) de l'École internationale de l'Outaouais pour le projet "Les caprices d'El Nino". À l'aide de graphiques, de photos, de données d'ordinateur, d'explications orales et d'un quiz informatisé, ce projet visait à expliquer le phénomène d'El Nino, sa mécanique, ses conséquences en Amérique et ailleurs dans le monde (sécheresses, inondations, tempêtes, etc.) ainsi que les perspectives quant à la possibilité d'en prévoir l'arrivée dans l'avenir.

Deuxième prix: certificat de mérite et bourse de 50 $ à Manon Lecot (17 ans) de la polyvalente Nicolas-Gatineau pour le projet "Soleil + peau = danger". Ce projet portait essentiellement sur l'effet des rayons UV sur la peau. Au moyen de graphiques, de maquettes, de photos, de tableaux et d'explications orales, on y expliquait le phénomène de l'amincissement de la couche d'ozone, son lien avec l'intensité du rayonnement ultraviolet ainsi que les incidences sur les diverses formes de cancer de la peau résultant de l'accroissement du rayonnement UV-A et UV-B à la surface de la terre.

Bravo les jeunes!

Yvon Bernier, Centre d'Ottawa de la SCMO.

Position in Modelling Atmospheric Radiation York University

Applicants are invited to apply for a Research Associate position in the area of Atmospheric Science at York University in the Department of Earth and Atmospheric Science and the Centre for Research in Earth and Space Science. We are interested specifically in candidates who have demonstrated excellence in modelling and analysis of the radiative energy budget of the Middle and Upper Atmosphere. The successful candidate will be expected to work in a team involved with the upward extension of the Canadian Middle Atmosphere Model (MAM) as well as carry out numerical experiments under the MAM project. Applicants must have a PhD degree at the time of appointment. The appointment duration is of up to 3-4 years, with a starting date of August 15 or as soon as possible thereafter. Salary will be commensurate with qualifications and experience.

Candidates should send their application with curriculum vitae and the name of three (3) referees to Prof. John C. McConnell, Department of Earth and Atmospheric Science, 4700 Keele Street, North York, Ontario, M3J 1P3, Canada (Tel: 416-736-2100; Fax: 416-736-5817; InterNet: jack@nimbus.yorku.ca). In accordance with Canadian immigration requirements, this advertisement is directed to Canadian citizens and permanent residents.

125e anniversaire des services météorologiques au Canada

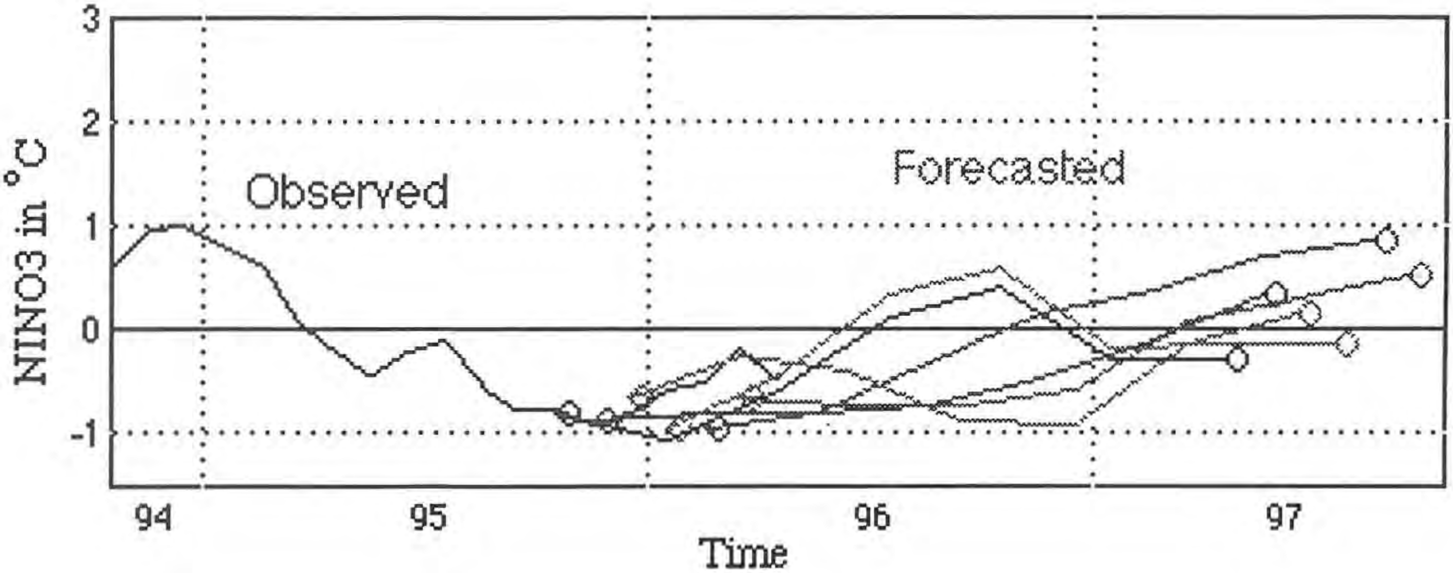
La planification est bien avancée dans la préparation du numéro spécial de décembre 1996 du CMOS Bulletin SCMO qui sera dédié au 125e anniversaire des services météorologiques au Canada. Mais nous avons besoin de votre aide pour compléter le travail. Pourquoi ne pas aller fouiller dans vos albums photographiques pour rechercher quelques vieilles photographies, des articles de presse ou des articles qui sont encore recouverts de poussière accumulée au cours des années? Si cela vous manque, testez votre mémoire, reculez dans le temps et ressuscitez des anecdotes longtemps oubliées, de vieilles histoires et des événements spéciaux, quelqu'ils soient, et envoyez les nous par courrier, fac-similé ou courrier électronique. N'oubliez pas d'inclure la provenance du matériel soumis. Vous avez jusqu'à la fin août pour nous envoyer vos trouvailles. Les photographies sont particulièrement les bienvenues mais elles devraient être lustrées, titrées et datées.

Au travail et supportez votre Bulletin!

Paul-André Bolduc,
Éditeur du CMOS Bulletin SCMO.

El Nino unlikely for winter 1996/97
by the UBC Climate Prediction Group

The UBC Climate Prediction Group is now issuing regular seasonal forecasts of the average tropical Pacific sea surface temperature (SST) in the NINO3 region (5N-5S, 150W-90W), which is widely used as an El Nino index. The forecasts are updated monthly over the World Wide Web (address: http://www.ocgy.ubc.ca/).



The above figure shows our latest forecast using a neural network model trained with data up to April 1996. The solid curve to the left is the observed SST, and the 6 curves with small circles are forecasts up to 18 months initiating from October 1995 to March 1996. Note that a forecast does not start from the raw data. Instead, it starts from the output obtained in the training of the model, in a way similar to the adjoint initialization of a dynamical model. Our forecast calls for a normal, or a slightly cool tropical condition in the 96/97 winter. We caution that our forecast model using data up to February 1996 (see CMOS Bulletin SCMO, Vol 24, No. 2, page 35) called for a warm 96/97 winter; but with the March and April 1996 data, the forecast changed. This sensitivity to the addition of new data usually indicates a time of low confidence forecasts, as is typical of most El Nino forecast models during spring.

Antarctic Ozone Hole Again Large and Deep[1]

The Antarctic Ozone Hole emerged earlier and grew more rapidly in 1995 than the record Ozone Holes of 1993 and 1994, and was of equivalent maximum size and depth according to reports from the World Meteorological Organization. Observed by ground-based measurements at Antarctic research stations operated by Argentina, Finland, France, Italy, Germany, New Zealand, Russia and the United Kingdom and satellite readings from the U.S. TIROS Operational Vertical Sounder (TOVS) provide data for analysis of the 1995 hole.

Even before the onset of austral spring, there were indications that the 1995 ozone depletion over the Antarctic would again be severe. During the late austral winter (July and August), average ozone levels over the Antarctic were 10 percent below the "pre-hole" averages with individual periods (August 5 - 10 and August 10 - 20) as much as 30 percent below normal. The average 1995 ozone depths ranged from 210 to 240 Dobson Units (DU) in August.

The 1995 Ozone Hole rapidly deepened in August with ozone thickness 25 to 30 percent below pre-ozone-hole averages and 10 percent lower than August of 1994 which had a record deficiency. Most stations reported days with depths below 200 DU.

The rapid decline of August continued into September. By mid-month, the overall ozone deficiency above the Antarctic was 35 to 38 percent below pre-hole averages and greater than had been observed previously. The area where ozone depths were less than 220 DU exceeded 12 million square kilometres at mid-month and 22 million square kilometres by month's end. Most observing sites reported levels below 150 DU. Over 80 percent ozone loss was reported in the stratosphere from 16 - 20 km altitude.

The size of the Ozone Hole remained between 22 and 23 million square kilometres through October with most of the continent below 130 DU. Nearly complete destruction between 15 and 20 km was observed from mid-September to mid-October. The October mean levels at several sites reached record low levels slightly lower than the record low levels of last year.

In mid-October (12-14), the Ozone Hole expanded in the direction of South America covering populated areas of the southern cone region of the continent. The station at Ushuaia, Argentina, reported total ozone depth of 189 DU, about 50 percent below the long-term average. In late October, the areal extent of the Ozone Hole still covered the entire Antarctic continent and adjacent ocean waters to 64 degrees South latitude. The 1995 event reached size and ozone deficiencies similar to the record holes observed in 1993 and 1994.

The 1995 Ozone Hole began to fill in early November, but as of November 21, had not broken up. It has currently shrunk to 15 million square kilometres and become irregular in shape. Thus, areas of Antarctica under the hole report ozone from 150 - 170 DU while areas outside report levels above 300 DU. Measurements over New Zealand and Australia are 350 - 420 DU, close to normal for this time of the year.

The strength of the polar vortex in late November indicates that the 1995 Ozone Hole will likely continue for some time. Since the event began in early August, it is now the longest-lasting ozone hole event ever observed. The ozone depths above monitoring sites at Marambio, Nuemayer and Syowa have reported nearly complete annihilation of the ozone layer between 14 to 19 km for nine consecutive weeks. This continued depletion has maintained temperatures in the lower stratosphere more than 10 degrees C below normal. These low temperatures facilitate the continued destruction of the ozone layer and maintain a strong polar vortex.

Reference: World Meteorological Organization, *Antarctic Ozone Bulletins 1 - 9, 1995,* Geneva.

Has the Ozone Hole Peaked?[1]

In 1991, the eruption of Mt Pinatubo spewed tonnes of dust and gas high into the atmosphere which caused global reductions in the ozone layer for several years. By 1995, almost all of the volcanic material had settled out of the atmosphere. Thus, as austral spring approached, questions arose concerning the 1995 Antarctic Ozone Hole. Would the Hole be "healed" from the injury caused by Mt Pinatubo and less in depth and extent than the previous two seasons? Or would the deepening continue as the atmospheric concentration of ozone-depleting substances increased, pushing the Hole ever deeper and larger?

By mid-November, the news has been mixed. The 1995 Ozone Hole reached depletion levels and areal extent equivalent to the record holes of 1993 and 1994 with almost complete loss of ozone between 10 and 20 kilometres altitude lasting more than nine weeks. As of this writing (November 21, 1995), the 1995 event had not ended, making it the longest ozone hole event ever observed.

However, new computer models suggest that the depletion and size of the Antarctic Ozone Hole may have nearly reached its maximum. Scientists at NASA Goddard Space Flight Center have built a computer model which simulates the variations of the Antarctic polar vortex and chemistry of ozone destruction. The model was able to reproduce year-to-year variations in the size and depth of the ozone hole from 1980 to the early 1990s. According to the model, future Antarctic Ozone Holes should be similar to the 1993-1994 holes. The holes will "go down faster each year, but won't get deeper or wider," according to Dr Mark Schoeberl, atmospheric scientist at Goddard. The reason is that the region of the atmosphere where ozone-depleting reactions occur has already reached nearly complete depletion and the region is unlikely to expand.

Dr Arthur Neuendorffer of the US NOAA believes that the future holes may not exceed the 22 to 23 million square kilometre area reached the last three years. The growth of the hole now nearly fills the inner boundaries of the polar vortex, the strong winds which blow in the upper atmosphere around the southern pole. The vortex is known to act as a physical barrier to the mixing of air over the Antarctic with that outside the vortex region, and it is within the polar vortex that the ozone hole appears.

Reference: Kerr, R.A., 1995: *Ozone Hole Won't Worsen?* Nature, 270, 20 October 1995, p.376.

1: Articles taken from "The UVB Impacts Reporter", Volume 2, No 4, November 1995, Written and edited by Keith C. Heidorn, PhD, ACM. © 1995. Correspondence may be sent to #302-3220 Quadra St., Victoria, B.C. Canada V8X 1G3. ☎ (604) 388-7847. Reprinted here with written permission of the Editor.

Le Bureau d'affaires de la SCMO a récemment déménagé, Prière de noter leurs nouveaux numéros:

☎ (613) 562-5616
Fac-similé: (613) 562-5615
Courrier électronique: cap@physics.uottawa.ca

ACCREDITED CONSULTANTS
EXPERTS-CONSEILS ACCRÉDITÉS

MEMBERSHIP APPLICATION FORM - 1996
DEMANDE D'ADHÉSION - 1996

CANADIAN METEOROLOGICAL AND OCEANOGRAPHIC SOCIETY
LA SOCIÉTÉ CANADIENNE DE MÉTÉOROLOGIE ET D'OCÉANOGRAPHIE
903 - 151 SLATER, OTTAWA, ONTARIO, K1P 5H3
TEL.: (613) 237-3393 FAX: (613) 238-1677

PLEASE PRINT IN BLOCK LETTERS - ÉCRIRE EN LETTRES MOULÉES S.V.P.
(NAME, ADDRESS AND POSTAL CODE - NOM, ADRESSE ET CODE POSTAL)

TITLE / TITRE: ☐ DR. / DR. ☐ MR. / M. ☐ MS / MME ☐ OTHER / AUTRE ______

AREA OF WORK / SECTEUR D'EMPLOI: ☐ INDUSTRY / INDUSTRIE ☐ GOV'T / GOUV. ☐ UNIV. / UNIV. ☐ RES. INST. / INST. RECH. ☐ OTHER / AUTRE

LANGUAGE OF PREFERENCE / LANGUE PRÉFÉRÉE: ☐ ENGLISH ☐ FRANÇAIS

TEL. (B) FAX

E-MAIL

TEL. (R)

MAIN INTEREST - INTÉRÊT PRINCIPAL: ☐ METEOROLOGY - MÉTÉOROLOGIE ☐ OCEANOGRAPHY - OCÉANOGRAPHIE

☐ LOCAL CENTRE / CHAPTER - CENTRE / SECTION LOCALE

VIS	VANCOUVER ISLAND CENTRE	MTL	CENTRE DE MONTRÉAL
BCM	B.C. MAINLAND CENTRE	QUE	CENTRE DE QUÉBEC
ALT	ALBERTA CENTRE	RIM	CENTRE DE RIMOUSKI
SSK	SASKATCHEWAN CENTRE	HFX	HALIFAX CENTRE
WIN	WINNIPEG CENTRE	NFD	NEWFOUNDLAND CENTRE
TOR	TORONTO CENTRE	NBK	NEW BRUNSWICK CHAPTER
OTT	OTTAWA CENTRE	INT	INTERNATIONAL & USA

OPTIONAL - FACULTATIF

GENDER / SEXE: ☐ MALE / MASC. ☐ FEMALE / FÉMININ   DATE OF BIRTH / DATE DE NAISSANCE: Y-A M D-J

IF THIS IS A STUDENT APPLICATION PLEASE PROVIDE THE NAME AND SIGNATURE OF ONE OF YOUR PROFESSORS.
FOR RECORDS ONLY; PLEASE INDICATE THE INSTITUTION AND YEAR STUDIES WILL BE COMPLETED.
SI VOUS DÉSIREZ DEVENIR MEMBRE ÉTUDIANT, S.V.P. OBTENIR LE NOM ET LA SIGNATURE D'UN DE VOS PROFESSEURS.
POUR DOSSIERS SEULEMENT; S.V.P. INDIQUEZ LE NOM DE VOTRE INSTITUTION ET L'ANNÉE OÙ VOUS FINIREZ VOS ÉTUDES.

PROFESSOR'S NAME AND SIGNATURE - NOM ET SIGNATURE D'UN PROFESSEUR

INSTITUTION   YEAR - ANNÉE

☐ DO NOT CIRCULATE MY NAME OUTSIDE CMOS
S.V.P. NE PAS FOURNIR MON NOM À D'AUTRES ORGANISMES

☐ DO NOT PUBLISH MY NAME IN DIRECTORY
NE PAS PUBLIER MON NOM DANS LE REPERTOIRE

MEMBERSHIP FEES - COTISATION DE MEMBRE	RATE - TARIF	REMITTANCE REMISE
REGULAR - RÉGULIER	$ 45.00	
STUDENT - ÉTUDIANT *	$ 20.00	
CORPORATE - CORPORATION * (FIRMS/CORPORATIONS, INSTITUTIONS)	$225.00	
SUSTAINING - DE SOUTIEN * (INDIVIDUALS ONLY/PARTICULIERS)	$170.00	
RETIRED - RETRAITÉ	$ 30.00	
* INCLUDES ALL PUBLICATIONS * DONNE DROIT À TOUTES LES PUBLICATIONS		

SPECIAL INTEREST GROUPS GROUPES D'INTÉRÊTS SPÉCIAUX		
INDICATE YOUR CHOICE (OPTIONAL) - DONNER VOTRE CHOIX (FACULTATIF)		
HYDROLOGY - HYDROLOGIE	--	
AGRICULTURE & FOREST - AGRICULTURE ET FORÊT	--	
OPERATIONAL METEOROLOGY - MÉTÉOROLOGIE D'EXPLOITATION	--	
FLOATING ICE - GLACES FLOTTANTES	--	
FISHERIES OCEANOGRAPHY - OCÉANOGRAPHIE DES PÊCHES	--	
MESOSCALE METEOROLOGY - MÉTÉOROLOGIE DE L'ÉCHELLE MESO	--	

PUBLICATIONS SUBSCRIPTIONS ABONNEMENTS AUX PÉRIODIQUES		
CMOS BULLETIN SCMO	GRATIS	
ATMOSPHERE - OCEAN *	$ 37.45	
PROGRAM & ABSTRACTS - PROGRAMME ET RÉSUMÉS	GRATIS	
* OUTSIDE OF CANADA * EXTÉRIEUR DU CANADA	$ 35.00	

TOTAL NOTE: G.S.T. INCLUDED - T.P.S. INCLUSE G.S.T. / T.P.S. No. R 118834449 $

I WISH TO PAY BY:
JE DÉSIRE PAYER PAR:

☐ CHEQUE / CHÈQUE ☐ MONEY ORDER / MANDAT

OR / OU CHARGE MY / CARTE ☐ MasterCard ☐ VISA

CARD # CARTE

EXPIRY DATE / DATE EXP.: M Y-A

X ______ SIGNATURE

SIGNATURE OF APPLICANT - SIGNATURE DU DEMANDEUR

SIGNATURE   DATE

CMOS-SCMO
Suite 112, McDonald Building
University of Ottawa
150 Louis-Pasteur Ave.
Ottawa, Ontario
K1N 6N5

Canadian Publications
Product Sales Agreement
0869228

Envois de publications
canadiennes Numéro de
convention # 0869228

CMOS - SCMO

Canadian Meteorological and Oceanographic Society

Société canadienne de météorologie et d'océanographie

SCMO - CMOS

Visit CMOS Homepage on InterNet
Consultez la page d'accueil de la SCMO sur le réseau InterNet

http://192.139.141.69/cmos/