Weather Forecasting for Health and Society in Canada at National and Local Scales

Lawrence NKEMDIRIM

Department of Geography, Earth Science 324, University of Calgary,
Calgary, AB, Canada T2N 1N4
e-mail: nkemdiri@ucalgary.ca

Abstract

Canada is a very big country with large relief features resulting in many climates and several climatic regions. The Canadian Meteorological Service reflecting the diversity of weather conditions in the country provides weather forecast for the nation through its national, regional and local centres. This review focuses on Canada's weather forecasting system both short term, long range and seasonal, and forecast products for people and environments. The Chinook, which causes abrupt and short term changes in weather, is used to illustrate weather-health relationships in Canada at a regional scale. Chinook type 1 events cause very poor air quality to which a variety of illnesses among susceptible populations has been attributed. Chinook type 2 is also correlated with poor health ranging from irritability to severe mental depression, suicides and heart attack.

Key words: chinook, föhn, weather-health forecasting, weather-health relationship, windchill

1. Introduction

Perhaps due to its high latitude location in the Northern Hemisphere, the most common view of Canada's climate is perpetual cold. While the country above the Arctic Circle may deserve this reputation, the southern parts where the vast majority of the people live, have many climates ranging from mild Mediterranean types along the Pacific and Atlantic Coasts to a moderately continental climate around the Great Lakes. The Prairies which extend width-wise from just west of the Great Lakes to the foot of the Rocky Mountains and length-wise from the Canada-United States border to the Boreal forest, is colder than the rest of southern Canada. Winters in the Prairies can be very cold and summers cool and short. However, it is in this region that we find one of the more fascinating examples of short-term weather phenomenon, the Chinook.

In areas of the world where long mountain chains lie more or less at right angle to the prevailing wind, given the right set of conditions, strong and frequently gusty winds may occasionally blow down the lee slopes of the mountains affecting weather in large areas downwind. Some of the best known mountain winds include the North American Chinook, the Zonda in Argentina, Föhn (Germany and Central Europe), Santa Ana (California, United States), Bergwind (South Africa) and the Northwester (New Zealand). These winds which are normally dry and warm relieve cold weather in winter and exacerbate high temperatures in spring and summer. Their arrival is often marked by very steep temperature rise within short time intervals. In Spearfish, South Dakota, for example, temperature rose from –20°C to +7°C in 2 minutes to mark the arrival of the Chinook on January 20, 1943. Their end can be equally abrupt. The warm event in Spearfish lasted 90 minutes. Thereafter temperature dropped 32° in 27 minutes. Although such mountain winds bring welcome relief from cold weather in the winter, they can be environmentally unfriendly. They melt winter snow packs thereby upsetting the natural water balance cycle. They may fool vegetation into budding in mid-winter, a phenomenon known to damage the long term health of forests. They fan forest and grass fires. In Canada, Chinooks are correlated with poor air quality and ill health among susceptible populations.

Weather forecast is part of life in Canada. People wake up to it in the morning and retire to bed at night knowing what the next day's weather may hold in store. It influences what they wear, how they commute to work, their leisure activity and even what to eat and drink. The irony is that most Canadians are not even aware that those actions reflect their response to the forecast. It is only during severe weather emergency or when the forecast is wrong does weather forecasting receive the recognition it deserves. Although the economic and social benefits to Canadians from weather forecasting are valued in billions of dollars (Ambury, 2005; Mjelde & Penson, 2000), Canada accepts that forecasting is a public good and funds it mostly with tax money.

The main provider of weather forecast in Canada is Environment Canada's Meteorological Service of Canada (MSC). It does it through its national centre located in Montreal, and regional and local offices spread almost evenly across the country. Although weather-health relationships are not explicit in daily forecasts, MSC's forecast products are being used in the private sector to develop and market such relationships. As well, MSC has developed or helped develop indices to measure relationships between well-being and severe weather. This review does the following: (a) describe Canada's weather forecasting system, forecast products and dissemination of forecasts; (b) describe current state of weather-health forecast in Canada; (c) explain the synoptic conditions associated with the Chinook; (d) review present knowledge of Chinook driven health impacts.

2. Weather Forecasting in Canada

MSC operates a National Prediction Programs branch which leads and coordinates weather forecast in the country. Within this program, the Canadian Meteorological Centre (CMC) provides the analysis, forecast output and guidance used by the national and five regional prediction centres. Typically, the national centre prepares the national weather outlook which forms the broad background for the more detailed regional forecasts performed at the regional centres. The local forecast uses local knowledge and data to further detail the prediction at the sub-regional scale. CMC forecasting system consists of the following major steps – data collection, data assimilation, numerical weather prediction and model output-post processing. The data utilised include the worldwide network of stations, ships and buoys coordinated by the World Meteorological Organisation, traditional observations of surface atmospheric pressure, temperature, wind velocity, humidity and precipitation from hundreds of manual and automatic weather stations in Canada and across the United States, and upper air data from radiosondes, weather satellites and doppler radar.

The data go through the assimilation phase aimed at gaining an understanding of current conditions which MSC considers the most critical part of the forecast. Information gained from the most recent data is used in conjunction with a numerical model's forecast for the time of the recent data, to produce meteorological analysis charts. Together the charts present best three-dimensional estimates of current distribution of temperature, moisture and wind, one for Canada and a second for the Northern hemisphere. The next stage in preparing the forecast is numerical weather prediction (NWP). NWP is a supercomputer simulation of the atmosphere. In Canada, NWP is accomplished with the Canadian Meteorological Centre's Global Environmental Multiscale (GEM) model. This model takes the analysis produced at the assimilation stage as a starting point from which it evolves the atmosphere fast forward through time based on the laws of physics and fluid dynamics. The underlying principle is as follows. For a given location, the weather forecast is determined from knowledge of the present weather at both the location and upstream from where the next weather will likely come. The forecast is then produced by estimating when the upstream weather will arrive at the target location and how it will be modified in transit. The longer the time frame of the forecast, the further upstream knowledge of present weather must extend. The configuration of the GEM model operates on cells that are each 0.3 degree of latitude by 0.45 degree of longitude at time steps of 45 minutes. In this way the changes that occur in the state of the fluid (the atmosphere) is captured at discrete time intervals ranging from hours to days. The computer output for the intervals serves as the basis for the forecast. NWP is normally performed twice daily.

The model output is post processed before it is handed to the forecaster. Post processing often involves use of statistical or other numerical techniques to remove from the output known bias built into the model. It may also require adjustments based on consensus among other numerical forecast models. The later procedure, normally referred to ensemble, is performed in recognition of the chaotic nature of the atmosphere and possible presence of errors which may have been introduced into the computation by poor or inadequate data that may amplify forward. The detail that can be given in a forecast therefore decreases with time as errors and chaos increase to a point where the forecast no longer reflects future weather. Ensemble procedures help identify the time horizon of a useful forecast.

At the final stages of the projection, the meteorologist may be guided by experience with similar weather patterns that occurred in the past to interpret the weather conditions inferred from the post processed data. The interpretation and guidance are made available to the regional and local centres for use in preparing the final forecast product for the public and other clients. Regional and local centers further detail the forecast based on local conditions. Particularly at the regional and local levels, forecasters apply a technique known as *nowcasting*. Nowcasting is used to project weather in a time scale ranging from now to about 6 hours. It is driven primarily by human interpretation of incoming weather, normally small scale events ranging from individual shower clouds to severe but localised storms to frost pockets that are too small to be resolved with reasonable accuracy by dynamic models. Nowcasting is aided by late radar, local and satellite data as well as eye witness reports of phenomenon such as funnel clouds.

The main products of Canada's weather forecasting are as follows:

(a) Weather warnings and watches where safety and security of life and property are threatened. Severe thunderstorms, tornados, hurricanes, blizzards and heavy snow are of particular interest in land areas. Severe storms at sea are of interest to off-shore oil rig operators, fishing, shipping and aquatic recreational activities.
(b) Weather forecast for use by weather sensitive activities including aviation and transportation
(c) Forecast for agriculture, forestry, construction and air quality
(d) General interest public use forecast.

Seasonal Forecast

In Canada, interest in long range and seasonal weather forecast, prudently referred to by weather offices as *outlooks,* has grown driven in part by experience with severe El Niño – Southern Oscillation (ENSO) episodes especially the 1982-1983 event and its negative social and environmental impacts. Today, seasonal forecast is utilized in industries such as agriculture, forestry, utilities and municipalities for planning and management. CMC produces outlooks for temperature and precipitation ranging from 0-9 months ahead. The 0-3 month outlook which began in 1995 is based on an ensemble of 12 model runs split between two dynamic models (Delorme *et al.*, 2001), the GEM (Côté *et al*., 1998) and CMC's General Circulation Model 2 (McFarlane *et al*., 1992). The models are forced by sea surface temperature (SST), sea ice and snow. In the GEM, the SST anomalies in the 30 days preceding the forecast are fixed throughout the forecast period and they are added to the evolving climatology. The sea ice extent and snow cover analyses are relaxed toward the climatology during the first 15 days of the forecast period. In GCM2, the SST is treated similarly as in GEM. However, sea ice cover is climatological all along the numerical integrations. The snow cover is a prognostic variable of the model. Historical data are utilised to reduce drift in the models. The outlook for air temperature is achieved by (a) determining the average daily temperature via the model runs and (b) subtracting the climatologies of the models from the mean forecast seasonal temperatures to derive the forecast anomalies of each model. The anomalies derived from the two models are then normalized and averaged to determine the outlook anomaly, expressed as above, near normal and below normal. Outlook for precipitation is prepared in a similar manner except that precipitation totals are used rather averages.

A year later, outlooks for 3-9 months were introduced. However unlike the 0-3 month outlook, the preferred forecast model is the Canonical Correlation Analysis (CCA). CCA is an extension of multiple regression analysis. But unlike traditional regression analysis in which one predictand variable is regressed against two or more predictors, CCA regresses a set containing multiple variables (predictands) against another set of predictors. This widely used statistical technique was adapted by Environment Canada's Climate Monitoring and Data Interpretation Division to produce seasonal forecasts of surface air temperature and precipitation anomalies for Canada. The forcing is provided by fields of SST anomalies for each of the 12 months preceding the forecast. The SST anomalies are averaged spatially over 10 × 10 degree grid cells and over three-month periods. The analysed values are then used to project temperature and precipitation from a statistical relationship developed between subsequent SST anomalies (predictors) and precipitation and temperature anomalies (predictands) trained with a 35-year data base (Shabbar & Barnston, 1996). Skill in the forecast (agreement between forecast and observation) was determined from the same data base. CCA forecasts are available for 51 Canadian stations for temperature and 69 stations for precipitation. The stations were chosen to cover the Canadian area as uniformly as possible (Environment Canada, 2005).

3. Destination of the Forecast

The end user is one of the most important component of weather forecast. The users include the general public, the aviation, marine and fishing industries, environmental agencies, forestry service, power and utility companies, roads and highways, Emergency services and increasingly hospitals. The forecaster requires knowledge of the target user and what is important for its operation to prepare a suitable forecast and do so in appropriate terms and language. For example, the aviation industry is concerned about fog, visibility and cloud ceilings that may compromise landing ease. Turbulence, icing potential, both on the ground and during flight; thunderstorm activities as well as the location of jet streams that may enhance or reduce fuel efficiency are the types of information given to the crew before take off and updated in flight.

The Canadian Meteorological Service (CMS) provides forecast for all end users from its regional offices through direct briefing, direct telephone conversation or via recorded messages and the Internent. In Canada, radio and television which provide regular bulletins to viewers and listeners round the clock are typical outlets for CMS forecasts. One of them, Weather Network Canada is a cable television station dedicated exclusively to providing continuous weather bulletin to the public nation wide. Owned and operated by Pelmorex Inc, it has a website which serves the public similarly. As well, MSC operates its own radio broadcast. Weatheradio Canada is a nationwide network of radio stations broadcasting weather and environmental news 24 hours a day in English and French directly from Environment Canada's storm prediction centres. The majority of these stations broadcast on VHF band to permit the transmission of a 1,050 Hz tone that will trigger a Weatheradio receiver's internal alert system during an emergency. In particular, Weatheradio Canada carries timely warnings and watches for imminent severe weather for land and sea.

4. Weather and Health Impacts

Weather impacts on human health and sense of well being has been suspected for a long time. However, such impacts are often difficult to quantify, hence difficult to prove. This is in part due to the many variables that make up the weather and the sensitivity of people to different sets of them. Often the number of "sufferers" is so small that real effects are dismissed. Over the years, however, a consensus has emerged that weather affects health. Studies show that conditions such as migraines are aggravated among susceptible persons in areas that experience sudden warming (Nursall & Phillips, 1980). Chronic pain and arthritis are worsened by changes in temperature, dampness and precipitation. A rapid change in pressure can cause illness as well. Indeed, anomalous increases in incidents of heart attacks, high blood pressure and blood clots have been linked to airmass change (Stoupel & Shimshoni, 1991). The duration and quality of light is a major factor in Seasonal Affective Disorder (SAD).

In Germany, the National weather service incorporates weather-health relationships in its daily forecast. This includes an index which measures the risk to particular health conditions associated with incoming weather (http://www.donnerwetter.de/). In the United Kingdom, they have applied this knowledge in a slightly different manner. During the 2000-2001 winter, the meteorological office and the department of health conducted a pilot study aimed at forecasting hospital workload based on the probability of increased incidences of heart attacks, respiratory difficulties, falls and broken bones linked to specific weather types. During a two-week period which forecasted a slower than normal workload, one hospital was able to schedule an additional 150 elective surgeries at a savings of $1.2 million (EnviroZine, 2001). The CMC does not provide weather-health forecasts similar to those available in Europe. However, the Weather Channel, a Cable Network based in the United States, has been providing health related weather forecast for some Canadian stations on television and web page. It is also available as a desktop (http://www.weather.com/common/help/maps/achesandpains.html). On the channel, the Aches and Pains Index map, for example, graphically depicts areas of higher or lower levels of weather-related pain. The site claims that "areas of quiet, dry weather during the warmer times of the year are most commonly associated with lower levels of aches and pains. High (or rising) surface pressure, low (or falling) humidity values, low probability of precipitation, calm winds, and daytime temperatures higher than 21°C would all be expected for lower levels of aches and pains to occur from a meteorological standpoint." Maps for common ill health such as colds and influenza are also available. MediClim™ developed indices based on 14 groups of weather conditions to forecast weather related sickness (EnviroZine, 2001). Prototype of weather-health maps have been developed for ailments such as migraine.

Even though the CMS does not provide health-related weather forecast, it has developed or helped develop indices that measure human comfort in severe weather. Two such indices are the Humidex and Wind Chill index. The Humidex first used in 1965, describes how hot humid weather feels to the average person by combining the temperature and humidity factors into an expression reflecting the perceived temperature equivalent of the two factors. Normally used when air temperature exceeds 30°C, the Humidex reflects not only how stifling the air feels when the weather is characterized by high temperature and high humidity but the imminent health danger associated with it (Table 1). While the Humidex is a hot season comfort indicator, the Wind Chill does similarly for cold weather. The wind chill represents how the temperature would feel on the skin of the average human under strong wind condition and cold air temperature. It is a measure of the effect of the wind in accelerating the transfer of heat from the warmer skin surface to the colder atmosphere through direct heat exchange and evaporative loss. Like Humidex, the Wind Chill Index carries broad comfort and health warning (Table 2). Wind Chill is included in weather forecast during cold weather.

Table 1 Humidex and human thermal comfort.

Range of Humidex	Degree of comfort
Less than 29	No discomfort
30 to 39	Some discomfort
40 to 45	Great discomfort; avoid exertion
Above 45	Dangerous
Above 54	Heat stroke imminent

Humidex = T + 0.5555 (e – 10.0)
T is air temperature °C, e is the actual vapour pressure (mb).
$e \approx 6.11 \times \exp\{5417.7530 \times [(1/273.16) - (1/T_d)]\}$,
T_d is dewpoint temperature °C.

Table 2 Risk factors associated with Windchill (T_{wc})*.

Risk of frostbite in prolonged exposure (30 minutes) at –28
Frostbite possible in 10 minutes at – 40 (shorter time if sustained wind greater than 50 km/h.)
Frostbite possible in 5 minutes at – 48 (shorter time if sustained wind greater than 50 km/h.)
Frostbite possible 2 minutes or less at – 55

*$Twc = 13.112 + 0.6215\,T - 11.37\,U^{0.16} + 0.3965\,T \times U^{0.16}$
Twc is windchill temp (°C),T is air temp and U is wind speed at 10 m.

5. The Chinook

In Canada the Chinook is a dry often gusty wind which occasionally blows down the Rocky Mountains into the lee side bringing warm weather to the eastern slopes, the foothills and the western Prairies. These three contiguous zones collectively known as Canada's Chinook belt, covers an area of about 80,000 km^2 extending eastward from the Continental Divide to the Alberta-Saskatchewan border (110 W) and northwards from the Canada-United States border (49°N) to Latitude 52.5°N. Calgary (51°N, 114°W) is the largest city in the Belt. The origin of the name, Chinook, is steeped in legend. One story credits it to the first European settlers who believed that the wind came from a territory occupied by Chinook Indians who lived in the American northwest along the banks of the Columbia River and the coast of the Pacific Ocean (Ruby & Brown, 1976). A second traces the word back to another Indian tribe, the *Blackfoot,* for whom it means the "snow eater" similar to *schneefresser* used by the Swiss for the Föhn. Yet a third legend celebrates the Chinook as the spirit of an Indian princess who was abducted in her prime in a war against a competing tribe. Now we know that the wind is a mainly pseudo adiabatic process involving the rise of a deep layer of moisture laden air from the Pacific Ocean over the Rocky Mountains and its descent down the eastern slopes of that mountain chain into the foothills and Prairies.

The Chinook begins with orographic lifting on the windward side of the Rockies which causes the air to initially cool at the dry adiabatic rate (DALR) to saturation somewhere up the mountain depending on its moisture content and temperature of the rising air (Fig. 1). Thereafter, condensation begins and the rate of cooling drops to the wet adiabatic lapse rate (WALR) which is approximately one-half of the dry rate as latent heat is released into the air stream via condensation. Precipitation from the air stream removes the moisture but leaves behind the converted latent heat. When the air descends on the leeward slope, it warms at the dry adiabatic rate. Bearing in mind that that the air is now enriched with extra heat due to the moisture lost, it will arrive at various points on the leeward slopes warmer than it was at equivalent elevations on the windward side (Fig. 1). Chinook winds characterized by the cooling-condensation-rain out-warming process are referred to in this review as Chinook *classic.* There are occasions when the process is wholly adiabatic. This occurs when there is no rain out behind the mountain. Any condensation carried in the air stream is re-evaporated during descent hence the latent heat released during condensation is reutilised. Consequently, when the air arrives on the eastern slopes, for a given elevation, the temperature is the same as it was at equivalent height on the windward side. However, because in winter, this warmer maritime air replaces a retreating shallow cold and stable Arctic airmass which normally occupies the Chinook Belt in winter, the event feels and behaves like a Chinook. The warmth is further enhanced by descent to lower grounds in the farther east (Nkemdirim, 1996). We will call this event Chinook *regular.* Normally, for an air stream with similar temperature profile upwind (windward of the mountain), Chinook *classic* is warmer than Chinook *regular.* This difference in temperature is due to the moisture content of the respective air volume at origin.

The Chinook events reviewed to this point are those that reach ground. We classify them as Chinook Type 2. A similar warm event that remains at height precluded from the ground by a fairly deep and stable layer of cold Arctic air which normally occupies the Chinook Belt during the winter is also called a Chinook and designated a Type 1 event. Although Chinook Type 1 may mark the incipient stage of a Type 2 condition, it could stay aloft through several days and may never reach the ground (Fig. 2). Chinook Type 1 represents an extreme case of temperature inversion in the Belt. The inversion may con-

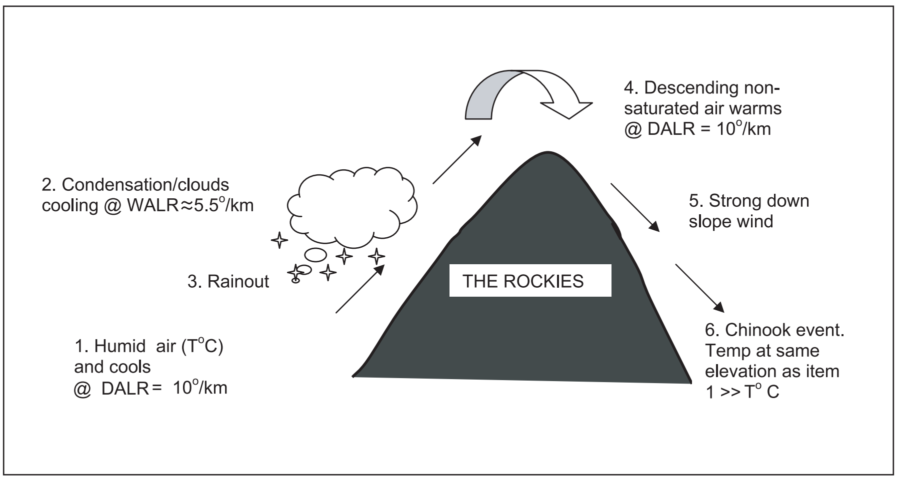

Fig. 1 Chinook Classic process.
The numbers progressively indicate the sequence of changes occurring in the air volume from its Pacific Ocean origin to its Chinook Belt destination.

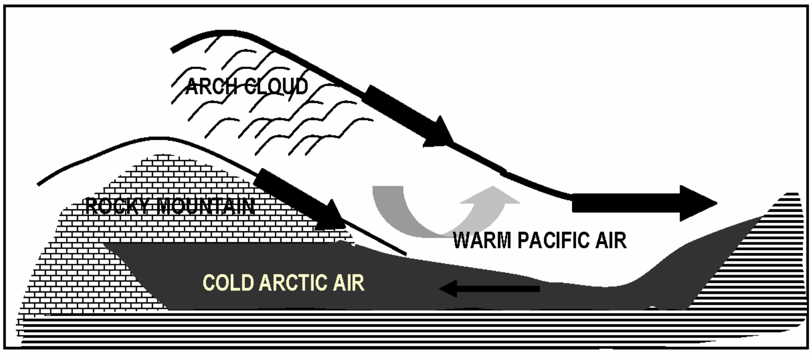

Fig. 2 Chinook Type 1 process.
The warm maritime air is precluded from the ground by the stable cold Arctic air mass.

tinue even when the feature evolves into a Type 2 case following the retreat (advance) of the cold air from the Belt or its erosion. Chinook Type 1 is frequently referred to as a *pre-chinook* condition (Cooke *et al*., 2003) even when it ends without ever touching ground.

6. Synoptic Setting for Chinook Events

Figure 3 shows a typical synoptic setting for Chinooks. This 500 hpa map shows (a) a Low off the Pacific Coast and (b) a high centred in Northwest United States ridging over the Canadian Rockies and (c) a Low extending from the Hudson Bay into the western prairies. The counter clockwise airflow in the Pacific low becomes the clockwise motion that draws the Pacific air across the mountains towards the Low in western Prairies. The sea level pressure map (Fig. 4) shows the wind blowing into Calgary from the southwest. Oard (1993) used a similar configuration to forecast Chinook weather in Montana, the American state immediately south of the Canadian Chinook belt. Arrival of both Chinook *classic* and *regular* is announced by the following weather conditions: (1) sustained winds from the west, specifically from any direction between SSW and WNW inclusive; (2) a fairly strong wind, the threshold value is 16.4 km h^{-1}; (3) a sharp rise in temperature with the eventual mean daily value exceeding the daily normal; (4) a drop in relative humidity; (5) a requirement that the timing of items (3) and (4) correlate perfectly with the shift in wind to the westerly direction (Nkemdirim, 1995). Some of these features are demonstrated in a Chinook event recorded February 11-12, 1985 (Fig. 5). While the patterns shown in Figs. 3 and 4 are identifiable in national prognostic charts, those of Fig. 5 are done in the region and local centres in the nowcasting mode. Because the Chinook is not always active simultaneously through the belt, local observation is critical to a successful forecast of the event especially its onset and termination.

There is no seasonal forecast for the Chinooks equivalent to the national outlook provided by MSC. Although the winds do not exhibit meaningful periodicities, they tend to be more numerous when winters

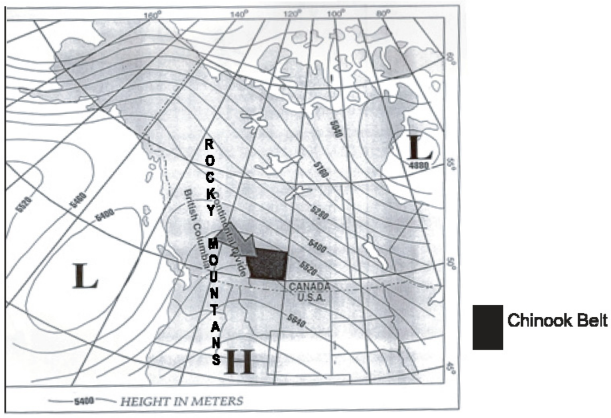

Fig. 3 Typical 500 kpa map during a chinook event.
The counterclockwise flow in the Low off the Pacific becomes a clockwise motion in the ridge over the Rockies.

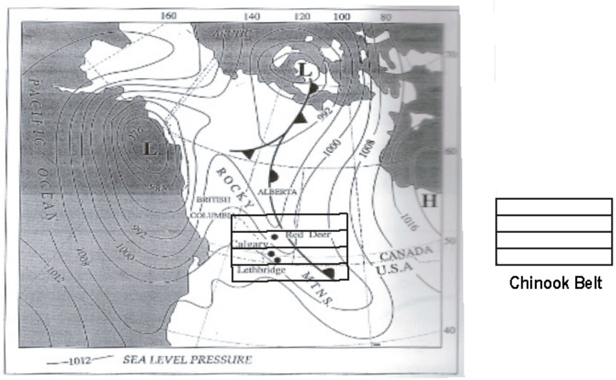

Fig. 4 Typical sea level pressure map during a chinook event.

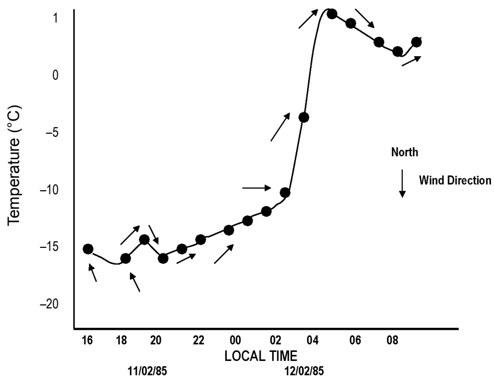

Fig. 5 A typical Chinook event.
Note the correspondence of rising temperature with westerly winds.

Table 3 Probability for runs of Chinook days in Calgary, Canada.

Run Length (days)	Probability
1	0.36
2	0.24
3	0.14
4	0.12
5	0.06
6	0.05
20	0.0002

(Source: Nkemdirim, 1997)

Table 4 Transition probability matrix from Chinook event of x day(s) to event $x + i$ days.

Event x (days)	Event $x + i$ days					
	1	2	3	4	5	6
1	.40	.24	.08	.14	.07	.06
2	.32	.26	.21	.09	.06	.05
3	.39	.25	.15	.11	.05	.04
4	.29	.29	.15	.14	.08	.05
5	.41	.22	.09	.16	.09	.03
6	.52	.04	.31	.13	.00	.00

(Source: Nkemdirim, 1997)

are warm but they are not, by themselves, the cause of warm winters (Nkemdirim, 1997). That said; planners may be guided by tables which provide probabilities of Chinook events for each winter month, the expected monthly run length (the number of consecutive Chinook days) as well as transitional probabilities from 1 to 20 days (Nkemdirim, 1997). Tables 3 and 4 are samples taken from those tables.

7. Health Impact of the Chinook

One of the reasons cited by Calgarians for their deep affection for their city is the Chinook. This warm wind provides welcome relief from bone chilling prairie winter cold, –30° for example. The wind boosts commerce, construction, and recreational and other forms of outdoor activities. However, a small but statistically significant minority claims to be adversely affected by the event (Nkemdirim & Baines, 1985). Their complaints range from irritability to physical and mental health impairment including attempted suicide and a variety of cardio-vascular conditions (Nkemdirim, 1995). Some sufferers claim that they can predict the arrival of the Chinook several days in advance because of progressive signs of ill health felt. Previously, the complaints were mostly anecdotal but over the last two decades, there are theoretical, empirical and clinical evidence supportive of Chinook induced health hazards. Normally, air quality in this city of 1 million is characterized as clean. Air Quality Index (AQI) ranges from 1-25 most of the year. However, during Chinook type 1 events, the city's AQI often exceeds 100 indicating severe pollution (Hicks & Matthews, 1979). As well in spite of strong winds air quality is also lower during Chinook Type 2 (Nkemdirim & Leggat, 1978; Mintz *et al*., 2003). Several studies indicate strong quantitative correlation between air pollution and various forms of ill health. In Canada, Health Canada estimated that 5,900 Canadians die each year due to air pollution. Experiments in California confirm strong linkage between asthma and air pollution (McConnell *et al*., 2002; Thurston & Bates, 2003). These findings collaborate the increased number of pulmonary ailments in Calgary hospitals during both Chinook Types. In an exhaustive clinical study in Calgary's Headache Research Unit, Cooke *et al*. (2000) measured the probability of migraine under Chinook and non Chinook weather. The following paragraph quotes directly from their paper. Note that pre-Chinook are the same as Chinook Type 1. Chinook is Chinook Type 2.

> *"The probability of migraine onset was increased on both pre-Chinook (Chinook Type 1) days (odds ratio 1.24; 95% CI 1.08 to 1.42) and on days with Chinook winds (Chinook Type 2) (1.19; 1.02 to 1.39) compared with non Chinook days. Analysis of Chinook wind velocities revealed that for Chinook days, the relative risk of migraine onset was increased only on high-wind Chinook days (velocity > 38 km/h) (odds ratio 1.41; 95% CI 1.06 to 1.88). A subset of individuals was sensitive to high-wind Chinook days, and another subset was only sensitive to pre-Chinook days. Only two patients were sensitive to both weather conditions, and the majority of patients was not sensitive to either. Neither weather condition had a protective effect. Increasing age was associated with high-wind Chinook sensitivity (p = 0.009) but not pre-Chinook sensitivity (p = 0.389). Conclusions: Both pre-Chinook and high-wind Chinook days increase the probability of migraine onset in a subset of migraineurs."*

Earlier in this review the connections between rapidly changing weather, especially the onset of sudden and rapid warming, and serious illness in human was reviewed. It is not surprising that a rise in hospital visits and phone calls to emergency centres in Calgary correlate significantly with Chinook weather (Nkemdirim, 1993).

The role played by atmospheric ions in sense of well being is controversial. Ions are small particles that take on an electrical charge. It is believed that in nature, ions are generated in abundance wherever energy is transferred into the air. Ultraviolet light from the sun, lightning and thunderstorms, and friction within wind and rain enrich the air with ions. When enough energy acts upon a molecule such as carbon dioxide, oxygen, water, or nitrogen to eject an electron, the displaced electron attaches itself to a nearby molecule, which then becomes a negative ion. In nature we tend to find between a few hundred to a few thousand of them per cubic centimeter (Sulman, 1980). The small particles that take on this charge are either negatively charged, positively charged or neutral. Atmospheric ions are not always in balance at a location. Waterfalls and their immediate surroundings and high mountains are negative ion rich while positive ions dominate just before a thunderstorm. Chinook type winds in both North America and Europe are also associated with an abundance of positive ions (Sulman, 1980). Laboratory experiments show that abnormally high concentration of negative ion enhances oxygen intake (Bhartendu & Menon, 1978) accounting for the improved well being experienced in mountain resorts and similar recreational environments. An abundance of positive ions is believed to have the opposite effect. Sulman (1980) showed that the dry Sharav winds which are similar to warm mountain winds cause the types of illnesses identified with the Chinook. Relationship between serotonin and atmospheric ions has been used to explain Chinook-induced illness. Serotonin is a hormone found in the brain, blood and digestive tracts. It acts as a chemical messenger that transmits signals between nerve cells. It also causes blood vessels to widen or narrow (Konig & Krueger, 1981; William, 1998). While serotonin has been used in healing (William, 1998), it has also been linked with poor health. While studying positive ion victims of the hot, dry Sharav winds in Jerusalem, Sulman demonstrated three effects of positive ion excess: irritation and tension, exhaustion, and hyperthyroid response. Most of these conditions, along with symptoms of depression, anxiety, headaches, and low-energy physical and mental functions, were shown to be alleviated or totally eliminated by increasing the negative ion count in the air (Sulman, 1980). Cramer (1995) believes that Sulman's conclusions are applicable to Canada and California because of the Chinook and Santa Ana respectively. However, extension of Sulman's conclusion to North America awaits credible empirical support.

8. Conclusion

Polls indicate that 92% of Canadians consult at least one weather forecast each day. The same percentage said that the information is of some value to their daily lives and is largely satisfied with access to weather information. At the beginning of the 20th century, weather related disasters numbered less than 20 per year. At the conclusion of that century, that number had risen to 130. In 1998, Canada spent $3 billion to repair damage caused by high impact weather. Future outlook on heavy weather is much bleaker. Global warming, now underway, will cause even more such weather. The need for improvement in ability to predict severe weather with lead time superior to what we have today is imperative. Environment Canada has identified areas of concern including air pollution and health for future focus. They are building capacity among users and scientists to improve knowledge on weather-societal connections and optimize benefits.

The private meteorological sector in Canada is extremely small. However, it includes considerable talent in universities, commercial units and Non-governmental Organisations (NGO). It is within this group that most progress in health-weather relationships is expected.

References

Ambury, S. (2005) On the economic value of probability of precipitation forecasts in Canada. *Science,* 310: 248-249.

Bhartendu, S. and I. A. Menon (1978) Effects of atmospheric small negative ions on the oxygen consumption of mouse liver cells. *International Journal of Biometeorology,* 22: 43-52.

Cooke, L. J., M. S. Rose and W. J. Becker (2003) Chinook winds and migraine headache. *Neurology,* 54: 302-307.

Côté, J., S. Gravel, A. Méthot, A. Patoine, M. Roch and A. Staniforth (1998) The operational CMC-MRB Global Environmental Multiscale (GEM) model: Part I – Design considerations and formulation. *Mon. Wea. Rev.,* 126: 1373-1395.

Cramer, G. (1995) Advanced research on atmospheric ions and respiratory problems. *Journal of Alternative and Complementary Medicine,* 1: 87-92.

Delorme J., G. Brunet, A. Plante, N. Gagnon, G. J. Boer, F. W. Zwiers, S. J. Lambert, J. Sheng and H. Ritchie (2001) Seasonal predictions based on two dynamical models. *Atmos. Ocean.,* 39: 485-501.

Environment Canada (2005) CMC seasonal forecast. (http:// www.cccma.bc.ec.gc.ca/data/cmc/cmc.shtml)

EnviroZine (2001) Is the weather affecting your health? Issue 15, December 19, 2001.

Hicks, R.B. and T. Matthews (1979) Impact of Chinooks on Calgary's air quality: acoustic sounder observations in atmospheric stability. *Wat. Air, Soil Poll.* 11: 159-172.

Konig, H.L. and A.P. Krueger (1981) Topics in environmental physiology in medicine. *In*: K.E. Schaefer, ed., *The Biologic effects of environmental electromagnetism*, Springer-Verlag, Inc. New York-Berlin-Heidelbeg.

McConnell, R., K. T. Berhane and F. Gilliland (2002) Asthma in exercising children exposed to ozone: A cohort study. *Lancet*, 359: 386-91.

McFarlane, N.A., G.J. Boer, J.-P. Blanchet and M. Lazare (1992) The Canadian Climate Centre second-generation general circulation model and its equilibrium climate. *J. Climate,* 5: 1013-1044.

Mintz, R., B.R. Young and W.Y. Svrcek (2003) Fuzzy logic modelling of air pollution during Chinook winds. *Air Pollution XI*, Transaction: *Ecology and the Environment,* 66: 36-41.

Mjelde, J.W. and J.B. Penson (2000) Dynamic aspects of the impact of the use of perfect climate forecasts in the Corn Belt region. *Journal of Applied Meteorology,* 39: 67-79.

Nkemdirim, L.C. (1993) Do Chinooks cause illness, Biometeorology, Proceedings of the International Congress of Biometeorology, September 12-18, Calgary, Canada, 3: 540-554.

Nkemdirim, L.C. (1995) An estimate of horizontal heat transport during a Chinook, *Journal of Applied Meteorology,* American Meteorological Society, 34: 2533-2542.

Nkemdirim, L.C. (1996) Canada's Chinook belt, *International Journal of climatology,* Royal Meteorological Society, 16: 441-462.

Nkemdirim, L. C. (1997) On the frequency and sequencing of Chinook events. *Physical Geography,* 12: 101-113.

Nkemdirim, L.C. and D. Baines (1985) What Calgarians know about the Chinook. Applied Climatology in Alberta, *Environment Canada*, 99: 39.

Nkemdirim L.C. and K. Leggat (1978) The effect of Chinook weather on urban heat islands and air pollution. *J. Wat., Air, Soil Poll.,* 9: 53-76.

Nursall, A. S. and D. W. Phillips (1980) The effects of weather on the frequency and severity of migraine headaches in southwestern Ontario. Canadian Climate Centre Report 80-7, unpublished manuscript, *Environment Canada*, 21.

Oard, M. J. (1993) A method for prediction Chinook winds east of the Montana Rockies. *Weather and Forecasting*, 8: 166-180.

Ruby, R. H. and J. A. Brown (1976) *The Chinook Indians: Traders of the lower Columbia River,* University of Oklahoma Press, ISBN 0806113251; 0806121076.

Shabbar, A. and A. G. Barnston (1996) Skill of seasonal climate forecasts in Canada using canonical correlation analysis. *Mon. Wea. Rev.*, 124: 2370-2385.

Stoupel, E. and M. Shimshoni (1991) Hospital cardiovascular deaths and total distribution of deaths in 180 patients with different cosmic physical activity – a correlative study (1974-1988). *Int. J. Biometeor.*, 35: 6-9.

Sulman, F.G (1980) The effect of air ionization, electric fields, atmospherics and other electric phenomena on man and animal. Charles C. Thomas, Bannerstone House.

Thurston G. D. and D. V. Bates (2003) Air Pollution as an underappreciated cause of Asthma Symptoms, *Journal of the American Medical Association*, 290: 1915-1917.

Williams, S. P. (1998) The serotonin transporter: a primary target for antidepressant drugs. *J. Psychopharmacol*, 12: 115-121.

(Received 18 January 2007, Accepted 5 March 2007)