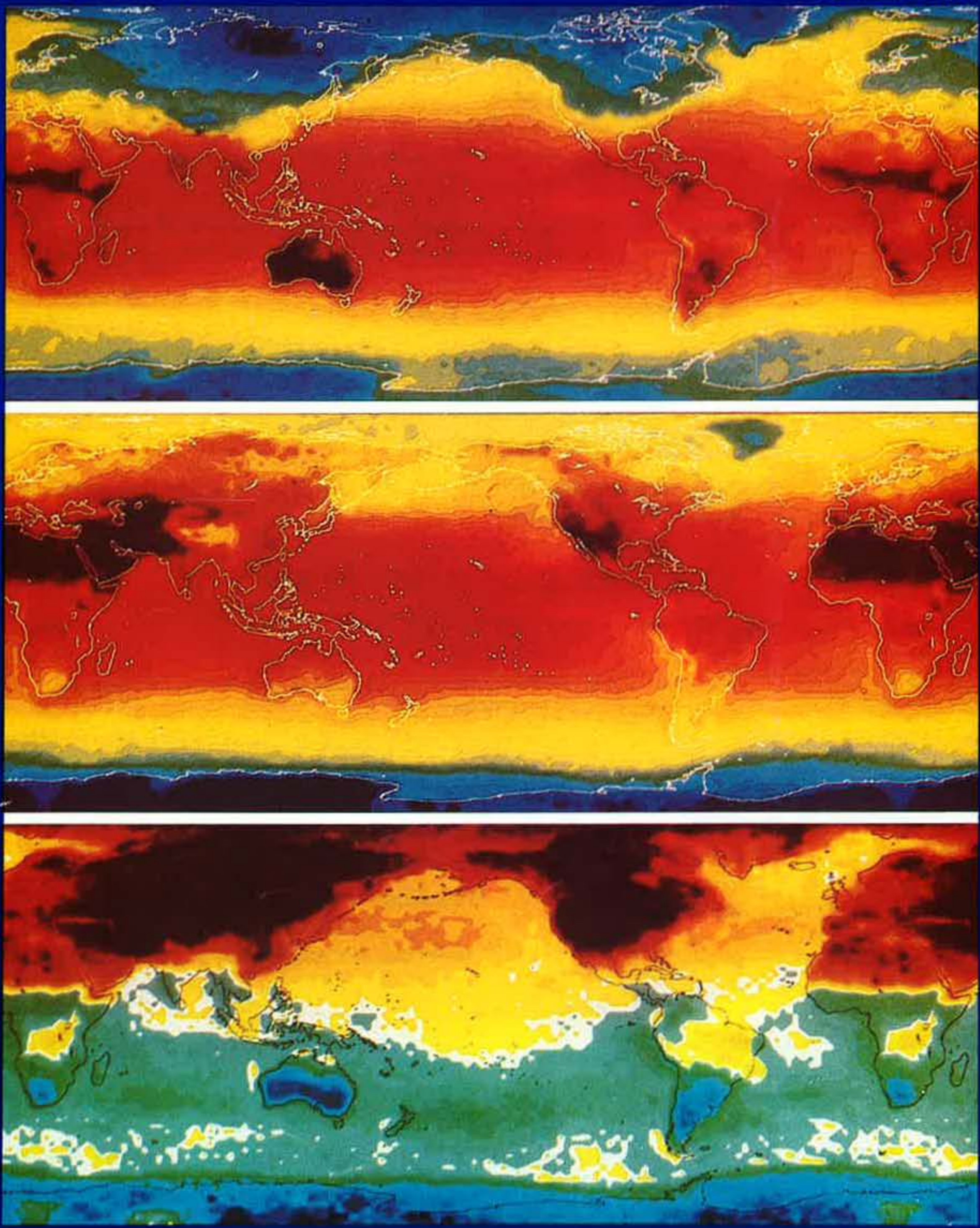
Chinook

THE MAGAZINE OF WEATHER, ENVIRONMENT AND OCEANS

VOL. 6 NO. 4

FALL 1984



NEWS AND NOTES

Instructional Meteorology Kits

Instructional "Meteorology Kits", assembled by the Halifax Centre of the Canadian Meteorological and Oceanographic Society, in association with the Nova Scotia Museum, are being used in Nova Scotia schools. The kits, which are presently being upgraded and modernized, consist of various instructional aids, simple meteorological instruments and experiments, weather map and satellite imagery packages, as well as a study guide for teachers. A recent survey on their use indicates that they are a valuable teaching and learning aid, especially to teachers and students at the Junior High School level. One of these kits, referred to as a "Weather Kit", is available to the public at the Nova Scotia Museum in Halifax.

Meteorology and Oceanography Prizes at Nova Scotia Science Fairs

Prizes for meteorology and oceanography exhibits at school science fairs in Nova Scotia are offered by the Halifax Centre of the Canadian Meteorological and Oceanographic Society.

At the Halifax-Dartmouth Regional Science Fair in April 1984, the prize for the best exhibit in oceanography was awarded to Andre Dessureault of Dartmouth High School for his project entitled "Conductivity of Salt Water". The project "Oysters' Reaction to Pollutants" by Kerry Newkirk of Cunard Junior High School received honourable mention. The prize for the best exhibit in meteorology at the Halifax-Dartmouth Fair was awarded to Todd Douglas Murray of Major Stevens Junior High for his model of a hurricane. In addition, a one-year subscription to *Oceanus* was awarded to Andre's school library, and a one-year subscription to *Chinook* to Todd's school library.

The Centre also supported the Cape Breton Regional Science Fair in 1984, although no project was found to be suitable for the CMOS prize.

The Halifax Centre of CMOS will again be offering prizes for the best projects in meteorology and oceanography at Nova Scotia science fairs in 1985.

Contributions, enquiries, comments and suggestions from readers are welcome. They should be addressed to:
Editor, *Chinook*, Suite 805, 151 Slater Street, Ottawa, Ont. K1P 5H3.

Chinook

Fall 1984 Volume 6 Number 4

ARTICLES

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Printed and produced in Canada and published quarterly by the Canadian Meteorological and Oceanographic Society, Suite 805, 151 Slater Street, Ottawa, Ont. K1P 5H3. Registered in Ottawa as second class mail, registration number 4508. Subscription rates for one year are $7.50 in Canada and the USA and $9.00 in other countries.

THE COVER

Global ocean temperatures measured by NASA depict seasonal temperatures and variations. For a detailed description see the write-up on page 97, also the article on The Oceans and How They Affect Our Climate on page 88.

THE OCEANS AND HOW THEY AFFECT OUR CLIMATE

by Fred Dobson

WHY STUDY CLIMATE?

Over the last few years there have been a number of spectacular climatological phenomena in the news that have drawn the attention of the general public to the influence of climate on our daily lives: the agonizing droughts in Africa, the "Greenhouse Effect", "*El Niño*" in the Pacific Ocean, the eruption of El Chichón in Mexico, and the "Nuclear Winter" debate are some good examples. Here in Canada, we had "The Winter that Wasn't" in 1982-83, which was probably the direct result of the greatest El Niño of all time, in the fall of 1982. Such events are happening, in fact, regularly on a climatological time-scale. It has been the combination of all these events which has made our global climate especially newsworthy.

That such climate variability matters to Canada, a fully developed nation in its prime, should not be questioned. A look at any good atlas will show Canada's population thinly distributed along the border with our good neighbours to the South. We live this way not so much to be cosy with our neighbours as to avoid the inhospitable climate we are faced with if we move north. Even a minor change in the climate can have an enormous effect on our economy and on our daily lives. To have the ability to model and predict climate change would make an enormous difference to our success as a nation.

More later concerning the structure of recent climate phenomena, but I will begin with a description of our climate and how it works which will, I hope, serve to explain why an oceanographer should be interested in writing this article in the first place.

The climate I wish to write about is relevant to, but separate from, our weather, which remains a central topic of interest particularly in the Atlantic Provinces of Canada, where we have weather worth talking about most of the time. The climate most of us think about is that defined by the Atmospheric Environment Service's climatological publications, which is an average over about thirty years. For the purposes of this article, I will call climate the average weather, where the averaging period can be anywhere from ten days to ten thousand years.

HOW THE CLIMATE SYSTEM WORKS

The Earth's climate is determined at the most fundamental level by astronomy. The sun provides us with radiant energy, mostly in the form of visible light. It sends 1370 watts per square metre towards the Earth which, because of geometry, only can make use of about 300 watts per square metre. The Earth's revolution around the sun gives us the seasons and the rotation on its own axis gives us the daily cycle. The Earth is heated by this incoming visible radiant energy to a yearly mean temperature that is just sufficient for it to reradiate an exactly equal amount of energy to space as infrared radiation, thus maintaining an approximately constant yearly mean temperature. This defines the basic climate system, but it is far from enough to explain what makes our world the habitable place it actually is.

The first diagram has two parts: the top (Figure 1a) shows the mean latitudinal distribution of incoming visible and outgoing infrared radiation at the Earth's surface (the given radiation values were averaged over all longitudes), and the bottom (Figure 1b) shows the mean surface temperatures of the

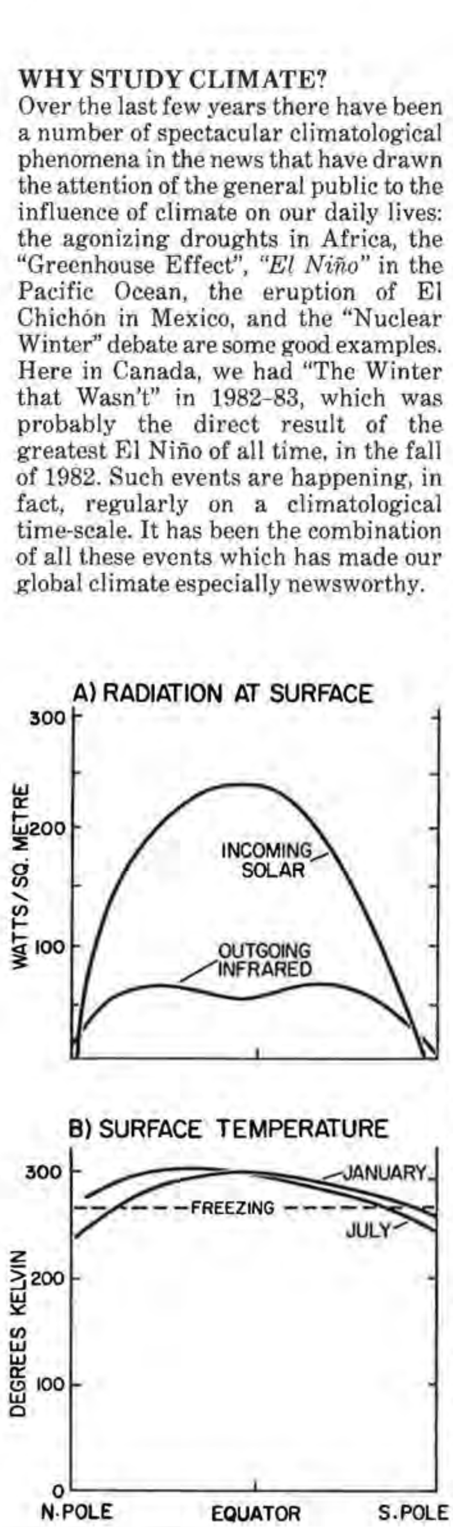


Figure 1 Solar/Infrared Radiation and Temperature at the Earth's Surface

The two diagrams display the latitudinal variation of (top) the net mean incoming solar and the net mean outgoing infrared radiation at the Earth's surface, and (bottom) the mean surface temperature of the Earth in January and July. The radiation is expressed in watts per square metre (1 watt of radiant energy will raise the temperature of a cubic centimetre of water 1°C every four seconds); the temperature is given in degrees kelvin. (The kelvin degree is the same size as the Celsius degree, but the scale starts at absolute zero or about −273°C.)

The incoming solar radiation received at the Earth's surface is determined mostly by geometry: it is a maximum at the equator, a minimum at the poles. The outgoing infrared radiation distribution is more complex. The dip at the equator is caused by the greater-than-average cloud cover there.

The surface temperature of the earth varies surprisingly little from pole to pole and from season to season (see the cover of this issue of *Chinook* for more detail). The seasonal range is less in the south because there is more ocean there, and water has an enormous capacity for heat storage. The latitudinal variation is so small because the atmosphere and the ocean carry great quantities of heat from the tropics towards the poles, allowing mankind to prosper in temperate, and survive in polar, regions.

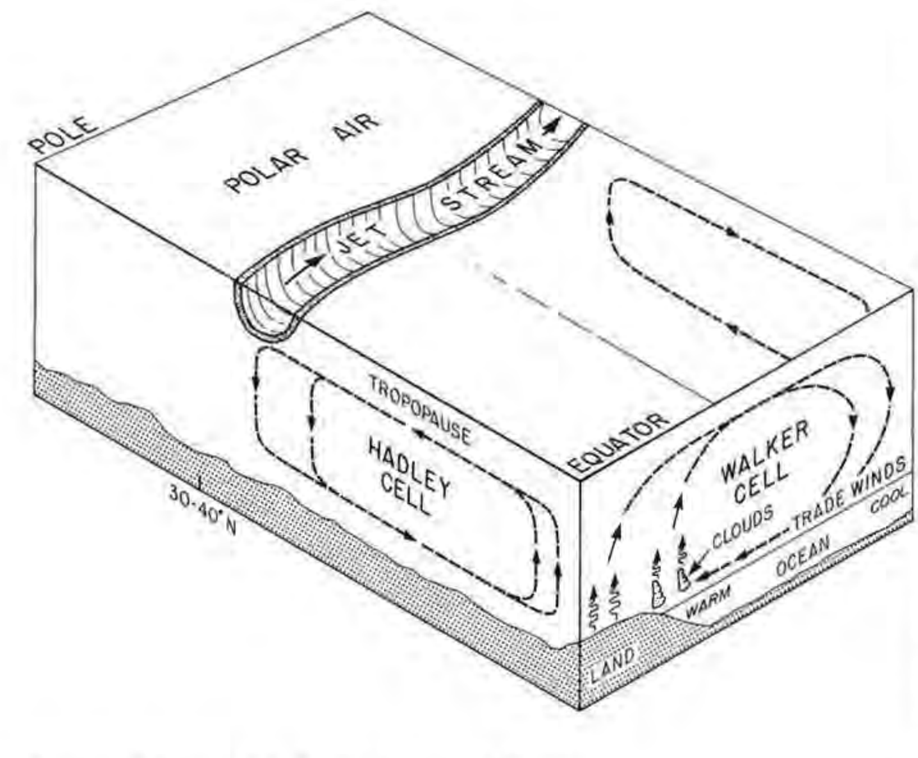


Figure 2 Schematic of the Earth's Atmospheric Heat Pump
This diagram gives a rough idea of the atmospheric circulations that carry heat polewards from equatorial regions. The circulation in the North-South vertical plane, called a Hadley cell, is driven by strong vertical uplift of air over the continents and on the western sides of the oceans where surface heating is greatest and surface ocean waters are warmest, being driven westward by the Trade Winds of the great East-West circulation, called the Walker cell.

Both cells are topped by the tropopause, the level at which most cloud activity (and the strongest cooling) is concentrated. The Hadley cells are bounded polewards by the jet stream, a strong, highly-concentrated west-to-east flow near the tropopause that "steers" the storms that form in temperate latitudes along the front between polar and tropical air masses. The jet stream's path is strongly influenced by the position and strength of the Hadley and Walker cells, which in turn are strongly affected by the position of the warmest surface waters in the Pacific. In El Niño years the Trade Winds relax, causing the warm waters usually piled up in the western Pacific to spread eastwards, disturbing the Hadley and Walker cells, the jet stream path, and thence the weather in temperate latitudes all over the globe.

Earth in winter and summer, also as a function of latitude (note that the scale is in degrees kelvin, the so-called "absolute temperature" scale). It says a lot. If it were left to radiation alone to determine our heat balance, it is clear from the diagram that the equatorial regions would be excessively hot (probably enough to boil the oceans there), and the polar regions near the temperature of outer space (20 K or so). But the lower diagram, and the beautiful overall picture of the global temperature distribution on the cover of this issue of *Chinook*, tells us that this is not so. Why? The answer must be that the excess heat from equatorial regions is transported towards the poles. The transporters are, of course, the atmosphere and the ocean.

The *climatic "heat pump"* works roughly as follows (refer to Figures 2 and 3). In the atmosphere, the enormous heating of the land and sea at the equator does two things: it causes the equatorial air to rise, setting up circulations in the N-S vertical plane called *Hadley cells* (after their discoverer), in which rising air over the continents and over the western sides of the oceans is replaced by cooler air from mid-latitudes (30–45°N and S), and circulations in the E-W vertical plane called *Walker cells* (the one over the Pacific Ocean is named after Sir Gilbert Walker, an important figure in the quest for understanding the global circulation of heat; I will use the term for all such circulations) caused by the different radiation absorption properties of the continents and the oceans. Both circulations play central roles in the poleward transport of heat, as Figure 2 indicates. They have typical circulation times of a few days at most.

Similar, but much slower, circulations are set up in the oceans (refer to Figure 3). The so-called *thermohaline circulations* are driven by the descent into the deepest parts of the ocean of water that has been cooled and made saline in polar regions, by transfer of its heat to the air and brine rejection during the formation of sea ice, causing it to become more dense. Warm tropical water formed by excessive heating at the equator is forced to move polewards, which leads to the upwelling of deeper water. The thermohaline circulations have time-scales measured in hundreds of years.

The great wind-driven *oceanic gyres*, such as the Gulf Stream, are constrained to single ocean basins by the continental systems, and to the north and south by the major oceanic wind patterns. They give up the heat they gain in the tropics to the air in the regions that they themselves make temperate. A typical time for one circuit of the Gulf Stream, for instance, is about one year. The big differences between the atmosphere and the ocean are *heat storage capacities* and *transport rates*.

The ocean absorbs most of the radiation it receives (about 94%) and, because of water's enormous heat capacity (a thousand times that of air), stores the heat for release at another time of year and another place. To give an example of the size of the effect, the Atlantic Ocean delivers one petawatt (10^{15} watts) northward across 24°N latitude every year: equivalent to the combined output of a line of 1-megawatt power plants every kilometre along the equator from Rio to Dakar. The atmosphere, on the other hand, cannot store very much heat energy directly, but moves very fast. It transports much of its heat as water vapour, which it gains from the tropical oceans and forests and delivers to cooler climes as precipitation. It delivers polewards about the same amount of heat as the ocean does at 24°N, at least over the North Atlantic.

Why do I use 24°N? A number of estimates of polewards heat transport have been made there, based on different techniques, and they all seem to agree. The way in which the estimates were made provides some insight into the way that scientists work to solve unanswered questions. Abraham Oort and Thomas Vonder Haar, two atmospheric scientists with interests in the global distributions of temperature, winds, and atmospheric water vapour, and in the global radiation balance, computed the difference, averaged in 10° latitude bands, between the net incoming radiation and the heat transported polewards by the atmosphere; the residual must then be the oceanic heat transport. They computed a combined poleward heat transport for the North Atlantic and North Pacific of 2.2 petawatts.

Andrew Bunker, a meteorologist who worked at the Woods Hole Institution of Oceanography, has calculated the net exchange rate of heat between the air and the sea surface, averaged over the year, and summed it over the entire North Atlantic Ocean. The amount by which the ocean poleward of a given latitude has been cooled by loss of heat to the atmosphere through the sea surface must be carried polewards by that ocean, if the yearly mean ocean temperature is to remain constant. Bunker obtained the heat exchange rates from millions of ship meteorological observations, archived by the World Data Center managed by NOAA at Asheville, N.C. He used empirical formulas to relate the heat exchange rates to measured meteorological quantities, including air and sea temperatures, wind and humidity. Bunker's average compared favourably with that of Oort and Vonder Haar, when their latitude average was fractioned into "North Atlantic" plus "The rest".

Harry Bryden and Mindy Hall, oceanographers from Woods Hole Oceanographic Institution, made their estimate from purely oceanographic data. They used a line of temperature and density profiles across the North Atlantic Ocean at 24°N, plus data on the transport of heat and mass through the Florida Straits by the Gulf Stream, to make a direct estimate of the oceanic heat transport across 24°N. Their estimate, 1.2 petawatts, agreed quite closely with the other two. More about this later. First, I would like to describe the steps now being taken to make use of, and if possible improve on, these estimates with the intention of understanding our climate better than we do now.

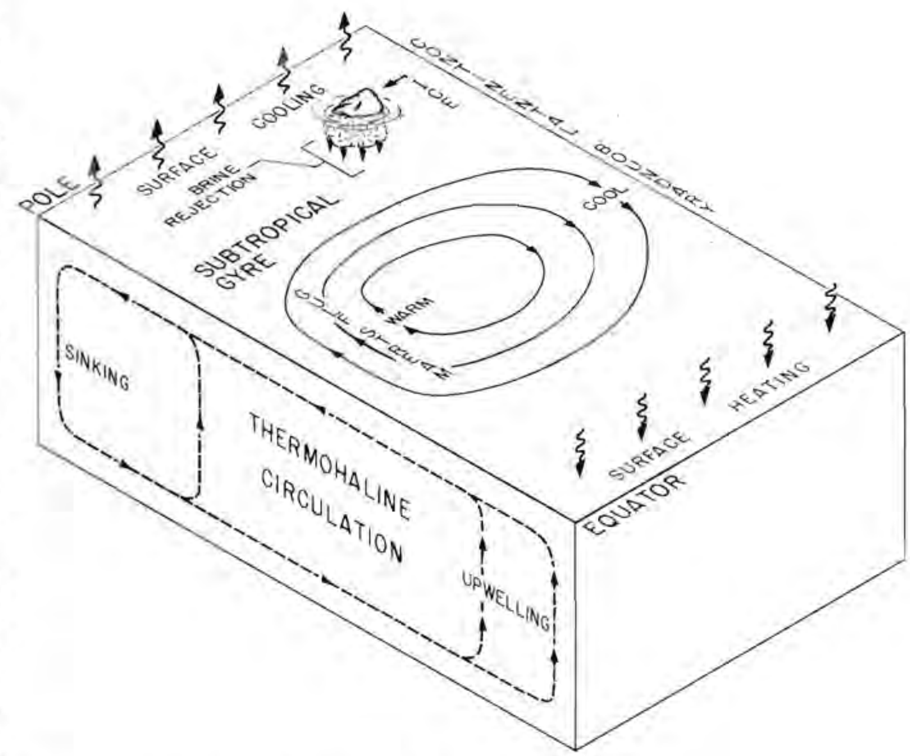


Figure 3 Schematic of the Oceans' Heat Pumps

Like the atmosphere, the oceans have two circulations: the thermohaline circulations in the North-South vertical plane, which are driven by equator-to-pole differences in heat and salt content (both affect the water density), and the circular, or gyral, circulations in the horizontal plane, which are driven by the winds. Both are confined on the east and the west by the continents. The thermohaline circulation is bounded to the north and south by the ice-packs and the equator, and the gyral circulations by the major wind patterns.

The main driving force of the thermohaline circulation is the deep sinking of strongly-cooled surface waters, which are made denser than the surrounding waters by cooling and by the addition of salt from brine rejection during the formation of sea ice. The dense water so formed flows slowly equatorwards, causing a gradual upwards movement of the water it replaces; this movement is strongest at the equator. One circuit of the thermohaline circulation takes about a hundred years in the Atlantic Ocean, and much longer – as much as a thousand years – in the North Pacific.

The best example of a wind-driven gyre is the Gulf Stream. it is driven westwards in the south by the Trade Winds, and eastwards in the north by the prevailing temperate westerlies. It is constrained by the Earth's rotation to be a circular gyre, intensified on its western side. One circuit takes roughly a year.

Both circulations carry heat polewards. The surface waters of the gyres deliver the heat they gain in the tropics to the atmosphere at temperate latitudes by means of the intense exchange of heat and moisture between the sea surface and cold, dry polar air from the continents and the ice-caps.

THE WORLD CLIMATE RESEARCH PROGRAMME

The World Meteorological Organization has now set up a World Climate Research Programme, which has as one of its principal immediate goals an improvement in the data base available to those who are using large computer models of the atmospheric and oceanic circulations in the attempt to improve the models to the stage where they are ready to begin *modelling the complete, fully-coupled climate system*. One of the main hopes is that a large part of the much-needed data set will come from a series of new meteorological and oceanographic satellites that are due to be launched over the next decade. These exciting new tools are expected to give well-calibrated, global distributions of such important quantities as incoming and outgoing radiation, cloud distribution, wind speed and direction, air and water surface temperatures, atmospheric water vapour content and ocean currents.

Meanwhile, attempts are being made over the next decade to organize a large ground-based meteorological and oceanographic observation and modelling effort. This will involve the use of innovative techniques, now being tested, including automatic radiosonde (upper-air sampling) stations on merchant ships of opportunity; far-reaching underwater sound pulses to map the average properties of millions of square kilometres of ocean with a technique called *acoustic tomography*, a technique now being used by doctors to map the internal workings of people; instrumented, unmanned *drifting buoys* in oceanic areas seldom visited by ships; and special *diagnostic computer models* to help determine which quantities we need to measure in each area and the required accuracies.

What do we hope to gain by all this proposed research activity? The rewards for even a small degree of predictive skill are incalculable. The occurrences of El Niño, for instance, have plagued mankind literally for ages. Most of all, it has been the unpredictability of the phenomenon that has invoked the real hardship.

The Peruvian fishing industry has been traditionally a "boom or bust" occupation – and a huge one – which is utterly dependent on the presence or absence of upwelling off the northwest coast of South America resulting from the normally strong easterly Trade Winds. In an El Niño year these winds slacken unaccountably, the upwelling of nutrient-rich water stops, and all the marine populations suffer. In addition, warm surface waters normally held in the western Pacific by the Trades migrate eastwards, bringing with them the areas of intense upwards convection in the atmosphere with which they are always associated. These huge movements of warm water affect in turn the main circulation cells (the Hadley and Walker cells: see Figure 3), causing them to change the course and speed of the jet stream, a high-flying air current at mid-latitudes, which steers the storms in temperate regions. The last El Niño, as I have already pointed out, spelled "abnormal" for the entire world (see the *National Geographic*, February 1984 issue). With prediction, at least we could have prepared and saved lives and the Peruvian gross national product as a result.

The *Greenhouse Effect* has been given wide coverage in the press, largely because of its possible implications for humankind. We have for the past decade been noticing a slow but steady rise in the concentration of carbon dioxide (CO_2) in the atmosphere. This increase is attributed to our burning of fossil fuels, such as oil and coal, and the simultaneous destruction of the tropical forests, which would otherwise utilize our excess production. This CO_2 in the air acts like the glass in a greenhouse: it lets in short-wave solar radiation, but absorbs outgoing long-wave radiation. Thus, we should soon begin to see our mean atmospheric temperature increasing. However, we don't see it immediately because its effect is masked by the high natural variability of the climate system. The best currently available models predict a doubling of CO_2 concentration by the year 2020; that in turn is predicted to increase the mean air temperature of the Earth by about 3°C, with the majority of the warming occurring at high latitudes. Will such a warming be sufficient to melt the ice-cap in Antarctica, flooding vast areas of low-lying coastal regions? How will our weather be affected? The models may not be good enough yet to tell us even if we should worry about it. No one knows how fast the ocean can take up excess CO_2, or heat for that matter. This problem alone has been a major impetus for the World Climate Research Programme.

The development of towering cumulus clouds over the North Atlantic is a visible manifestation of the complex interactions between ocean and atmosphere.

At the Bedford Institute of Oceanography in Nova Scotia we are involved in a number of studies that will contribute directly to the World Climate Research Programme. We are studying, for example, how deep water is formed at high latitudes by the processes of cooling and ice formation, in turn driving the thermohaline circulation. We are studying the dynamics of the Gulf Stream as it passes along the east coast of our continent carrying heat and salt northwards. We are also in the midst of a controversy about which formulas to use for estimating the exchange of heat with the atmosphere through the sea surface. We have recently recalibrated the formulas used by Bunker to estimate heat transfer rates across the sea surface, against the best data we could find. If the new formulas were used to calculate, for example, the poleward heat transport of the North Atlantic, we are beginning to suspect that the value obtained would no longer agree with that obtained earlier in the studies carried out by Oort and Vonder Haar, and Bryden and Hall.

A tremendous effort is now getting under way to better understand the climate of our Earth. It will involve the use of exciting new technology, of extensive scientific management on an international scale and, most important of all, it will involve the ingenuity and energy of a large new generation of meteorologists and oceanographers. Where will they all come from? There is only one answer: from our schools. There stands the challenge, for teacher and student alike.

RECOMMENDED READING

T.Y. Canby, 1984: El Niño: Global Weather Disaster. *National Geographic*. Vol. 165, No. 2, February, pp. 144–184.

The Dynamic Earth. *Scientific American*, Vol. 249, No. 3, September 1983.

Fred Dobson is a physical oceanographer with the Department of Fisheries and Oceans, in the Ocean Circulation Division of the Bedford Institute of Oceanography, at Dartmouth, Nova Scotia. His specialty is the study of air-sea interaction; he has concentrated on the growth of wind waves and the large-scale transport of heat, moisture and momentum from air to sea. He has an active interest in science education.

RÉSUMÉ *Cet article expose les raisons impérieuses qui ont entraîné la création d'un ambitieux programme de recherche pour une meilleure compréhension de notre climat : le Programme mondial de recherches sur le climat. Parmi ces raisons on compte les sécheresses désastreuses en Afrique, la controverse soulevée par l'effet de serre et les anomalies climatiques récentes, à l'échelle mondiale, causées par un El Niño plus qu'anormal.*

Un aperçu des mécanismes du climat nous montre que la balance énergétique de la planète dépend des radiations solaires et de la nature de la surface. On doit mieux comprendre l'interaction atmosphère-océan et leur énorme capacité de stockage et de transport d'énergie pour expliquer l'habitabilité de la terre. Mais, avant de pouvoir modéliser et, un jour, de prévoir le climat on doit répondre aux questions suivantes : Quelles sont les quantités de chaleur transportées par l'océan, par l'atmosphère? Quelle est la fréquence de l'El Niño? À l'échelle du globe, quel sera le réchauffement apporté par l'effet de serre dû au CO_2?

L'auteur conclut en décrivant quelques-uns des nouveaux développements en technologie actuelle et expérimentale utilisés lors du programme, tels que les capteurs satellitaires, la tomographie acoustique, les bouées dérivantes et les modèles d'ordinateurs. Le premier défi à relever sera de trouver le personnel scientifique nécessaire.

HOW WEATHER CONDITIONS AFFECT EVAPORATION: DRYING LAUNDRY OUTDOORS IN NORTHERN ONTARIO WINTERS

by Piers Nash

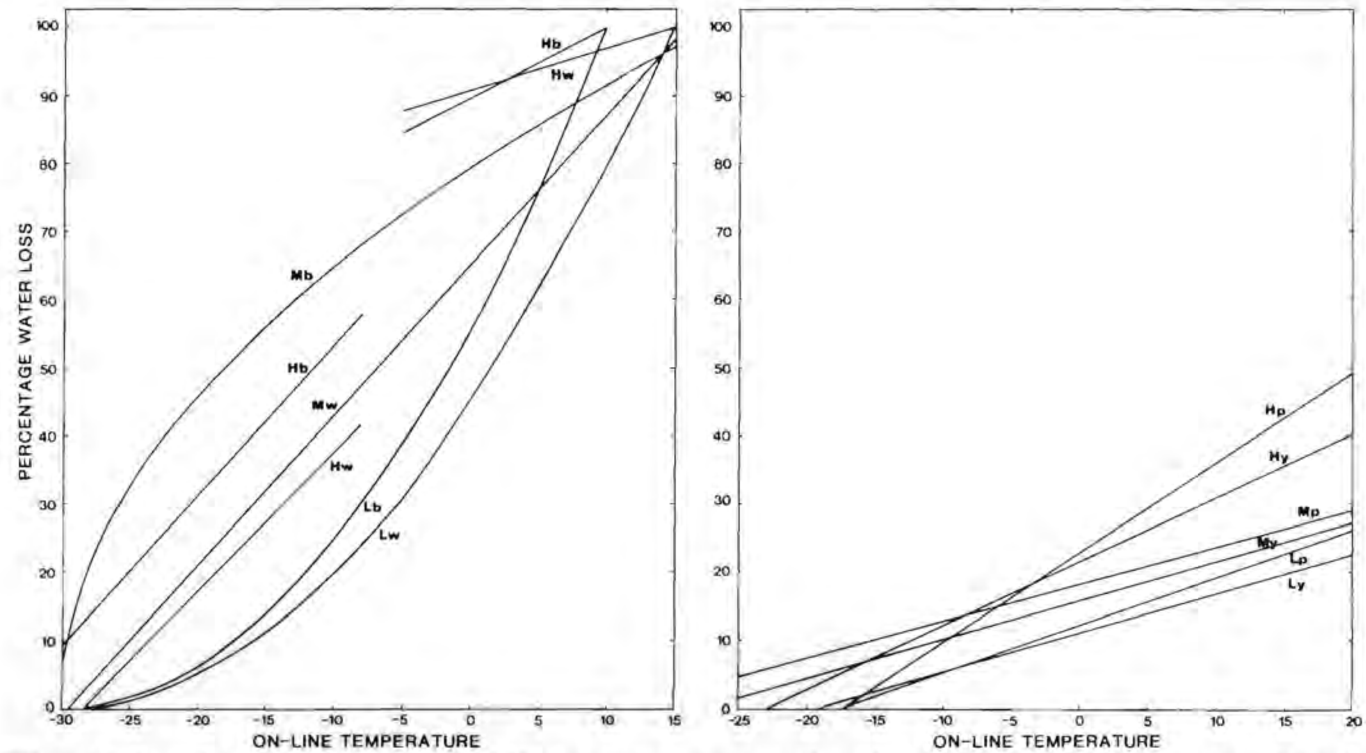
In the Fall of 1982 my family had to make a decision. Which did we need more, an electric clothes drier, or a home computer? I knew what I wanted. The clothes had always dried outside, but there was the problem of which days were best for getting the laundry done. In winter, it seemed quite unpredictable, so it was understandable that a lot of people would want to go with the drier. The computer would use a lot less energy. It costs thousands of dollars to run a drier. But with the whole family taking turns to do the laundry, we needed a way of predicting the best time to do it. So I started to think about evaporation.

About 150 years ago, John Dalton formulated what came to be known as Dalton's Laws of Evaporation. Although his work was done in a laboratory using a vacuum, the rules became accepted as the Laws, and little further work was done until now. Over the past two years, I have conducted an investigation into evaporation under the meteorological conditions of the northern winter. First, in 1982–83, I set out to discover what factors actually did affect the rules of evaporation outdoors at sub-zero temperatures.

According to Dalton, there would be several factors to consider as I designed my investigation. The first was the area of exposed surface. I controlled this factor by using small squares of fabric with 30-cm sides, four pieces being of a smooth material, cotton-polyester, and four of thick terry-cloth. The second was the dryness of the air, which I could not control, and which I therefore recorded as Relative Humidity. Two other factors that could not be controlled were wind speed and barometric pressure. These were recorded in kilometres/hour and kilopascals, respectively. Other possible factors were the colour of the fabric - dark fabric might absorb sunlight more and dry more quickly - and the initial temperature of the wet clothes, since some scientists have found that warm water freezes more quickly than cold in winter. Therefore I used two dark-coloured and two light-coloured cloths of each fabric, and controlled the initial temperatures. (Subsequently I tried the experiment with different initial water temperatures and found it made no difference.) Then I began to record the rates of evaporation for each of the two sets of four cloths by weighing them at the beginning and end of 30-minute periods of drying at various temperatures, wind speeds, sunlight intensities and humidities. To ensure rapid transfer of the cloths from inside to the outside conditions, I constructed an "anchor-cloth", a strip of cotton fabric with "velchro" tabs. By attaching the fabric squares to this, I saved valuable time during weighing and avoided distortion of the evaporation rates, which would have happened if water had been trapped under clothes-pins on each cloth. Thus the anchor-cloth increased the accuracy of the data in two ways.

By the end of the winter of 1983, I had over 2000 pieces of data on evaporation under almost every possible combination of weather conditions in winter. To determine what factors had been effective in helping or hindering drying, I used a statistical analysis of variance (general anova). This showed that only sunlight, temperature and wind speed had any effect. Barometric pressures and sunlight were closely correlated and pressure had no overriding effect. Except when precipitation occurred, humidity variations had no effect. Dark and light cloths dried at similar rates. Having determined the limits of Dalton's Laws of Evaporation under winter conditions, I was ready to go on to the next phase, which was to find out the actual relationships between the factors. It was obvious that if the thermometers were hung alongside the cloths, sunlight could be eliminated as a factor. What was puzzling, and probably the source of the original dif-

Author and exhibit.



Differential effects of low, moderate and high (L, M, H) wind speeds on evaporation from black and white (b, w) cotton fabric and yellow and purple (y, p) terry-cloth at various temperatures.

Table 1 Evaporation Rates (y) against Temperature (x) at Low, Moderate and High Wind Speeds

Wind Speed	Cloth	Relationship	Formula
Low	1 White Cotton	Parabolic	$y = (x + 30)^2/20$
	2 Black Cotton	Parabolic	$y = (x + 30)^2/16$
	3 Yellow Terry	Linear	$y = 4x/7 + 78/7$
	4 Purple Terry	Linear	$y = 0.7x + 12.3$
Moderate	1	Linear	$y = 15x/7 + 65$
	2	Radical Equation	$y = 14.5\sqrt{x + 30}$
	3	Linear	$y = 6x/11 + 174/11$
	4	Linear	$y = 0.53x + 18$
High	1	Linear Systems	by range*, Set 1
	2	Linear Systems	by range*, Set 2
	3	Linear	$y = 12x/13 + 21.5$
	4	Linear	$y = 1.31x + 23$

*Range of x	Set 1	Set 2
below -8°	$y = 2x - 57$	$y = 11x + 75$
-8° to -5°	y = 42-88	y = 58-85
above -5°	$y = 3x/5 + 91$	$y = x + 90$

ficulties of predicting good drying conditions, was the effect of wind speed. Everyone knows that in summer laundry dries well on a sunny, windy day, but in winter this did not seem to be the case.

The second phase of the project, 1983-84, involved finding out the differential effects of wind speed on evaporation. This time I was interested to see just what happened as the temperature hovered around zero; therefore I measured evaporation under summer and winter conditions with low, moderate and high wind speeds. It seemed likely that windchill factors would come into play, so that the windy day that speeds drying in summer would contribute to freezing and slow drying in winter. This time 1644 pieces of data were collected, and the analysis could be done using graphs to show the relationships.

One graph was constructed for each type and colour of cloth for each range of wind speed. On each of the 12 graphs, rates of evaporation were plotted against temperature. One series was for wind speeds of 0 km/h, one for 1-7 km/h and one for >7 km/h. From these graphs formulae were derived to express and predict (roughly) the rates of drying for the different fabrics under different weather conditions. Table 1 summarises the results of these analyses. In the formulae, x is the temperature in °Celsius, and y is the percentage of the original moisture in the cloths that evaporated during a 30-minute period.

The graphs showed that the thicker cloths dried evenly, while the thinner ones dried erratically as would be expected if higher winds cause freezing over a wider range of temperatures above and below 0°C.

By using the formulae in a computer programme, I am now able to predict roughly how long it would take towels and sheets to dry outside in the winter. Thus our computer can substitute for the drier we didn't get. I can call the weather office to check the P.O.P., load my programme, and feed in current or expected temperature and wind speed values and information about the colour and type of fabric to be dried. My computer tells me whether we should do the laundry and how long it will take to dry.

Piers Nash is a Sudbury high school student who received the CMOS Award at the Canada-Wide Science Fair '84 held at St. Mary's University, Halifax, for his project, Differential Effects of Wind Speed. This article presents the results that he discovered.

THE QUÉBEC-ST. MALO TRANSAT "TAG" RACE
VIEWED FROM ITS SUPPORTING WEATHER FORECAST CENTRE IN BEDFORD, NOVA SCOTIA

by Ed Guimond

The Québec-St. Malo transatlantic sailing race, commemorating the 450th anniversary of Jacques Cartier's historical crossing, began with a cannonade in the early afternoon of Sunday, 19 August 1984.

The fifty-plus craft participating were to follow a route down the St. Lawrence River, through the Gulf of St. Lawrence, along the south coast of Newfoundland near St. Pierre and Miquelon, then cross the Atlantic to the port of St. Malo in northeastern France.

Because of its national significance within the scope of the Québec-84 Summer Celebration, the Atmospheric Environment Service of Canada had agreed to provide meteorological support for this race.

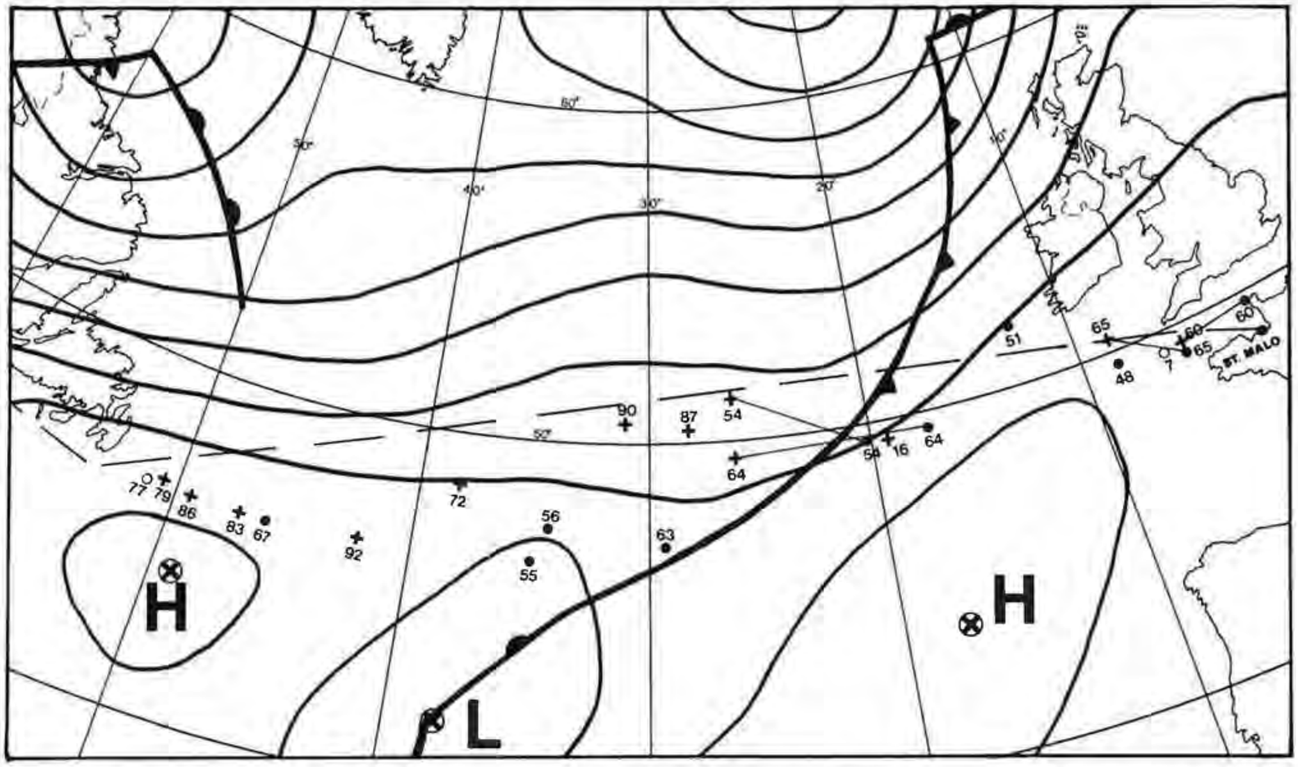
The Maritimes Weather Centre (MWC) in Bedford, N.S. was assigned the task of providing two daily marine weather bulletins for each changing trajectory of the course. These forecasts, valid for 36-hour periods, would have to extend as far as longitude 8°W, a line adjoining central Ireland and western Spain. From there, France's Brest Meteorological Centre would take over the supporting role.

In cooperation with the Halifax Coast Guard Marine Radio, bilingual weather bulletins were broadcast on several voice channels, directly from the Bedford Weather Office. Copies of the forecasts were also relayed to a race sub-control centre in Québec City, where a 24-hour watch on the event was maintained. On staff at this centre was the Meteorological Coordinator of Québec-84, forecaster Denis Poupart.

Three classes of sails would share the race course including the thoroughbreds of sailing craft, the "TAG" boats (TAG = Technique d'avant garde). These long multi-hull vessels, with lofty masts and billowing spinnakers, had been properly poised well back of the fleet at the start of the race. At the outset light winds prevailed; however, these cata-

The *Région Nord Pas de Calais* on the St. Lawrence River before the race. Skipper Patrick Toyon is shown at the right.

One of France's participants in the almost 3000-nautical-mile race from Québec City to St. Malo, the *Région Nord Pas de Calais*.



Typical plot of ships' progress via Argos instruments, with surface weather map for 0000 GMT 28 August 1984 superimposed, and positions for 1600 GMT 27 August (+) and/or 0900 GMT 28 August (•), and 17-hour motions; approximate position during period (O). Selected ships are indicated by numbers (west to east): 77 *Mascaret Steinberg*, 56 *Radio-Canada*, 63 *Travacrest Seaway*, 54 *Région Nord Pas de Calais*, 64 *Umupro Jardin V*, 51 *Formule TAG*, 65 *Fleury Michon*, 7 *Charente Maritime*, 60 *Royale*. The wind is westerly along 50° North. The dashed line marks the shortest route.

maran-type racers overtook and easily outdistanced the mass of sails within sight of the "Old Port".

In their weather forecasts at MWC for the first two days of the race, the author and Raymond St-Pierre offered little hope of any significant winds. On the third day, however, a low pressure centre developed along the Eastern Seaboard and intensified as it moved into Newfoundland. It continued on a northeastward track into the Atlantic, paused briefly south of Greenland, and eventually settled near Iceland.

This particular disturbance was perhaps the most significant one to occur during the race. Those TAG boats fortunate enough to have entered the Gulf of St. Lawrence prior to the deepening of the low were suddenly whisked through its waters at speeds reaching close to 30 knots. Then, as surfers would to a favourable wave, they latched onto the peripheral winds of this low until well beyond the halfway point of the course. Thereafter, several low pressure centres to the north maintained a band of strong westerly winds along the shortest destination route.

For the leading TAG boats, these ideal winds persisted to about longitude 15°W. From there, they sailed somewhat less briskly through the northern section of a high pressure area just off the Spanish coast. For the rest of the fleet, westerlies also prevailed, but their strength varied in the measure that the crews were willing to face the accompanying heavier seas to the north.

After more than 2897 nautical miles, and within less than ten days, the tall French craft *Royale* crossed the finish line. It arrived a mere 16 minutes ahead of the highly favoured *Charente Maritime* also of France. Third place was won by *Fleury Michon* 6 hours later.

For many, the glory of the race ended with the arrival of the speedy TAG boats. This was not true for the remainder of the fleet, still stretched out across the Atlantic. Another twelve days elapsed before the last of the racing sailboats crossed the finish line.

It should be noted that owing to the slow start of the race no new transatlantic crossing records were set. However, the 24-hour distance record was broken by several of the TAG racers. The record distance of 525 nautical miles in 24 hours was set by the fifth place finisher, the Canadian *Formule TAG*.

Many mishaps occurred during the race, but fortunately none was tragic or directly attributable to the weather. The most significant include: the burning and sinking of the *Mascaret-Steinberg*, stranding its all-women crew 500 nautical miles from its goal; the wrecking of the strong U.S. contender, *Silver Bullet*, after striking a log on the high seas; the dismasting of the *Radio-Canada* in mid-ocean; and the structural failure of the *Goldie Italia* just off Newfoundland.

Each sailing craft was equipped with a sophisticated instrument named Argos (after the mythical Greek prince with a hundred eyes, half of which were always open). The automatic device sent continuous satellite-relayed messages of its position, ambient temperature and atmospheric pressure. Four times daily, this information was collected and plotted on surface weather charts, giving an instant view of the progress of the race. In addition to supplying valuable weather data, it fulfilled a most vital function through its ability to generate distress signals with the proper intervention. It was through this mode of communication that the Race Control Centre was made aware of the then unknown plight of the *Mascaret-Steinberg*.

That unnerving experience, as well as the others mentioned, is a glaring example of the perils risked by the sailing crews of transatlantic races. It is also a tribute to the preparedness of those involved who having incurred the wrath of the Atlantic survived its fury.

As part of the pomp and circumstance surrounding the 450th anniversary of Jacques Cartier's first voyage to North America, the people of Québec City welcome one of the Tall Ships, the Venezuelan vessel *Simon Bolivar.*

The fifth place finisher, the Canadian *Formule TAG*, and the *Travacrest Seaway* moored before the race in Québec City's Old Port.

The *Radio-Canada* was the victim of an unfortunate mishap in the mid-Atlantic.

Mr. Guimond is a meteorologist at the Maritimes Weather Centre in Bedford, Nova Scotia.

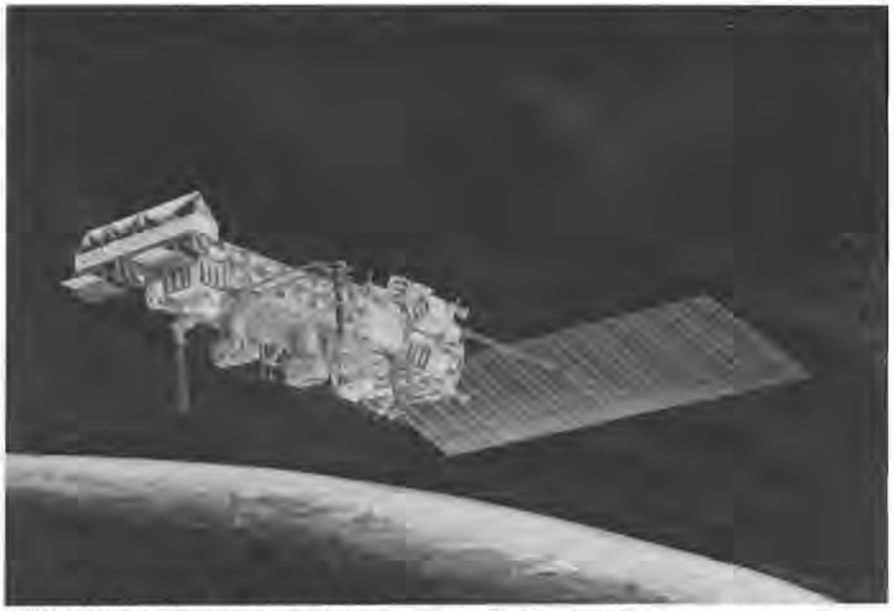
The pictures were provided by Gilles de C. Paquette of the AES Bureau météorologique at the Aéroport de Québec.

GLOBAL SURFACE TEMPERATURES

by M. Chahine and J. Susskind

As the sun migrates annually between hemispheres, the atmosphere, land and ocean system responds with annual temperature variations. While the atmosphere and land experience enormous temperature changes in the high and mid-latitudes, the oceans remain more constant. This is due to the high heat capacity of water relative to that of air and land. Without the oceans, the Earth's temperature would fluctuate radically. Thus, the waters covering 70% of our planet's surface act as a massive thermostat, which moderates our global climate. Conversely, small changes in ocean temperature patterns can result in dramatically altered global weather, such as the El Niño phenomenon.

Monitoring global temperatures, especially from the oceans, has traditionally been impossible because of the lack of data from many areas. Now, satellite sensors are used to observe month-to-month and year-to-year changes in surface temperatures. Examples are the images [on the front cover] produced using data from the High Resolution Infrared Sounder (HRS) and the Microwave Sounding Unit (MSU). Both of these instruments measure natural radiation emitted from the Earth's surface and atmosphere, and have been flying on NOAA weather satellites since 1979. Temperatures are on an absolute kelvin scale (273°kelvin = 0° Celsius = 32° Fahrenheit). Temperatures below freezing (273°K) are green and blue. Warmer temperatures are red and brown.



A TIROS-N spacecraft in polar orbit scanning the Earth and its atmosphere using the HIRS and MSU instruments mounted on the bottom of the satellite, at the left end as depicted.

(Top) In January 1979 the Northern Hemisphere is experiencing extreme cold. Siberia and most of Canada record temperatures approaching −30°C (−22°F). In eastern Europe and the northern United States, temperatures are below 0°C. In the Southern Hemisphere, the people at mid-latitudes (30 to 50°S) are enjoying summer with temperatures ranging from 20 to 30°C (68 to 86°F). In the open oceans, the isotherms (or contours of equal temperature) show deviations from their zonal patterns on the eastern and western sides of the various oceans. Generally in the subtropics of both hemispheres (10 to 30° latitude), the western sides of the oceans are warmer than their eastern counterparts, primarily because of ocean currents. An exception to this rule is the Gulf Stream, a warm current in the western Atlantic. The current moves along the North American continent, then turns northeastward transporting warm waters across the Atlantic that moderate the climate of Western Europe.

(Middle) By July, areas of the Northern Hemisphere have warmed to 10 to 20°C (50 to 68°F). Equatorial Africa and India are the hottest in dramatic contrast to the frozen Himalayan Mountains. In the Arctic, Greenland remains frozen, while Hudson Bay has thawed.

In the Southern Hemisphere, Antarctica is much cooler than the Arctic and ice has formed in the Weddell Sea. At this high latitude, zones of constant temperature are much more zonal than in the northern oceans. Here, the ocean driven by strong westerly winds moves in a circular path around Antarctica from west to east.

(Bottom) Temperature differences between January and July show that the greatest warming and cooling has occurred over land (dark blue, brown). Marked seasonal changes of up to 30°C are seen in both hemispheres. In contrast the changes in ocean temperature rarely exceed 8 to 10°C (14 to 18°F). The greatest deviations are in the mid-latitudes, while the near-equatorial regions are quite stable. In the Northern Hemisphere, mid-latitude changes in ocean temperature are influenced by the position of continents. The continents divert the ocean currents, and affect wind patterns. In the Southern Hemisphere, which has one half the land area of the Northern Hemisphere, changes are primarily due to seasonal variations in incoming solar radiation. Thus, the oceans in the two hemispheres interact in fundamentally different ways with the atmosphere and land.

Using global data collected from satellites, scientists are paving the way for future development of predictive models for the Earth's climate. These studies will help elucidate the dynamics of the ocean-atmosphere-land climate system, and will lead to improved long-term forecasting.

ACKNOWLEDGEMENT

The satellite images on the front cover of this issue of *Chinook* and the above description are provided through the courtesy of M. Chahine, Jet Propulsion Laboratory, and J. Susskind, Goddard Space Flight Laboratory, of the United States National Aeronautics and Space Administration (Publication JPL 400-222F 2/84).

HURRICANE *DIANA* OF 1984

by Oscar Koren

Figure 1 Infrared image of Hurricane *Diana* showing the eye, the central dense overcast region, the relatively smooth-edge inflow region and the fibrous cirrus streaks of the outflow region. The image was taken on 13 September 1984 at 0004 GMT.

At one time it was believed that hurricanes formed as a result of the heating of the ocean surface, causing warm, moist air to ascent to levels where condensation would produce cumulonimbus clouds. These clouds then coalesced and were spun into a cyclonic (counterclockwise) circulation. In many cases this hypothesis did not match the reality. The mechanism triggering the hurricane generation is still under investigation. However, what is becoming clear now is that hurricanes occur when divergent flow in the upper atmosphere, caused by an upper-level high pressure area, becomes superimposed upon an area of convergent flow near the surface. Satellite imagery and weather maps show that the low-level winds in hurricanes spiral inward towards the hurricane's eye, while the high-level winds diverge away from the hurricane's eye in an anticyclonic (clockwise) circulation.

Figure 1 shows the infrared satellite image of Hurricane *Diana* on 13 September 1984 at 0004 GMT, located just south of Wilmington, North Carolina. This was the first Atlantic hurricane of the 1984 season. The satellite image clearly shows the hurricane's eye, which was reported to be about 20 km in diameter. Surrounding the eye are heavy cloud bands from which torrential rains were falling. Reports of 43 cm of rainfall over a 48-hour period were received from the area, and winds attained speeds as high as 217 km per hour. Another feature on the image is the low-level inflow region along the cloud edge in the southeast quadrant. This region is characterized by faint bands of low clouds. The high-level outflow region is indicated by streaks of cirrus clouds radiating outwards from the northern rim of the hurricane.

Figure 2 presents a close-up of the same hurricane taken a few hours earlier. This is a near-infrared image taken on 12 September 1984 at 1953 GMT. Of particular interest are the details of the cloud structure that show several small

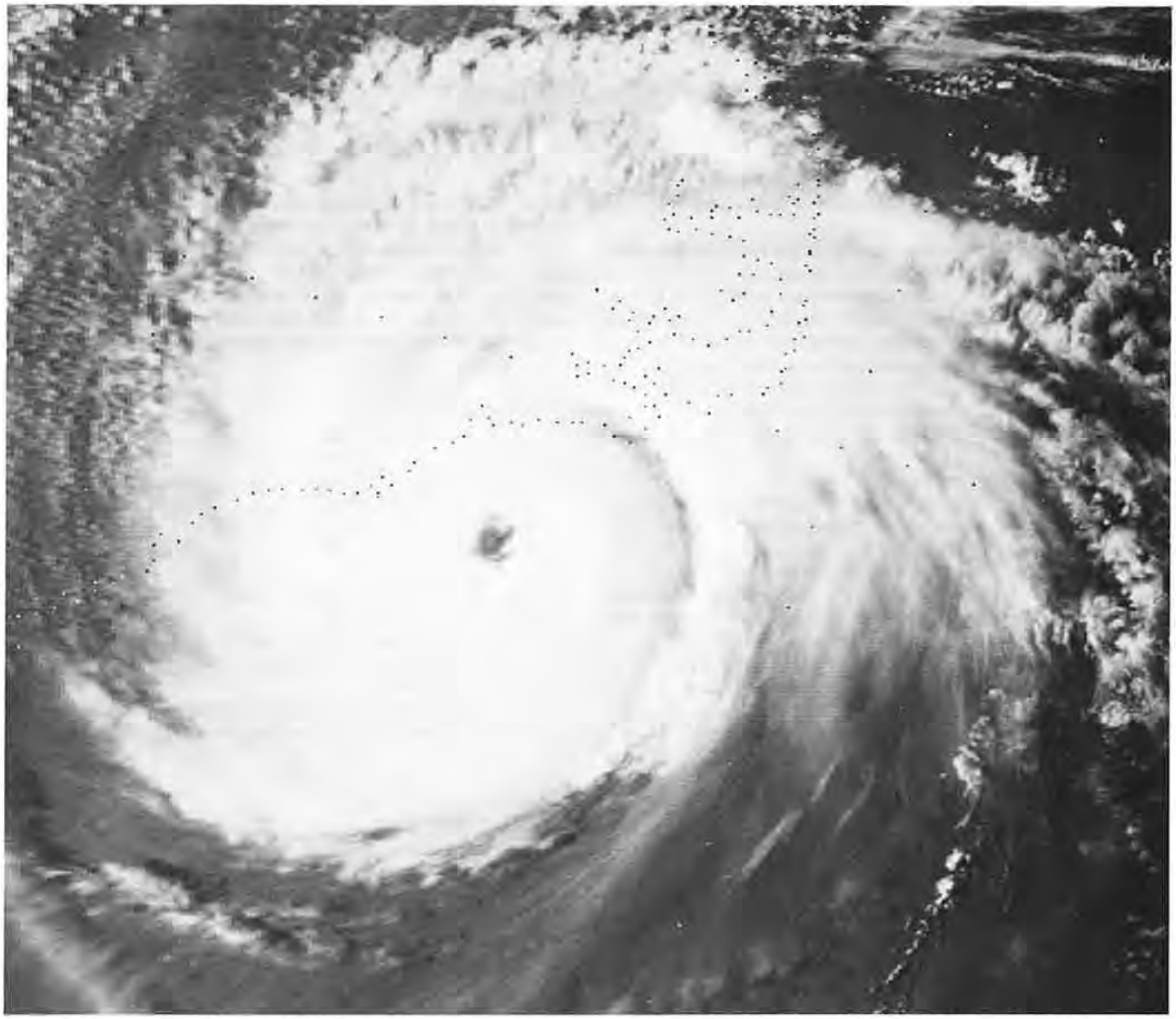


Figure 2 Near-infrared image of Hurricane *Diana* showing a close-up view of the cloud structure. The image was taken on 12 September 1984 at 1953 GMT.

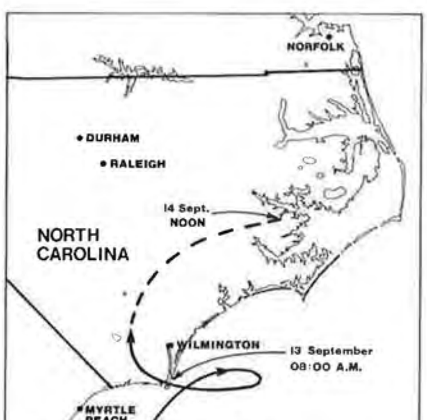


Figure 3 Map showing the path of Hurricane *Diana*, which crossed inland on the morning of 13 September 1984 after making a loop over the ocean southeast of Wilmington, North Carolina.

storms especially northwest of the eye.

Figure 3 shows the path of Hurricane *Diana*. It crossed inland on the morning of 13 September after making a loop over the ocean southeast of Wilmington. By evening the winds dropped to below 120 km per hour when *Diana* was downgraded by the U.S. National Hurricane Center to a tropical storm, but not before it had inflicted so much damage that the U.S. National Weather Service called it "the worst hurricane since Hazel" to occur in the Cape Fear area.

In retrospect, some people still remember Hurricane *Diana* of 1955, which brought severe floods to the northeastern United States and killed 200 persons and caused $700 million in damage. Hurricane *Diana* of 1984, perhaps not as destructive as her namesake and predecessor, is considered to be one of the major hurricanes of the 1984 season.

Oscar Koren is a meteorologist with the Field Services Directorate of the Atmospheric Environment service in Toronto who is interested in the meteorological applications of satellite data.

ART APPRECIATION - PHYSICAL PRINCIPLES

by Philip Chadwick

Why is the sky blue? Why is the ocean blue ... sort-of?

These questions may seem trivial but the answers certainly are not. Artists do not tend to ask themselves such piercing queries, and so may be excused when they capture the beauty surrounding them on canvas. Meteorologists, however, should not be allowed such frivolities. Explanations for these and even more pressing questions must be on hand for every true scientist. The following guide will direct budding Meteorologists through the galleries of realistic art so that they may see the light - as it was meant to be - and understand why!

Dark and Light; Warm and Cold

My art instructor, Mario Airomi, often told me "Pheeal, ... always remember: Dark an' light and warm an' cold!!" The full significance of this brief phrase still surprises me. What Mario had intended was to break down the study of light into two distinct categories, intensity and colour. Although aspects of the same entity, they are best considered separately to ease the understanding of the complexities of light.

The following pages will consider each category and give detailed rules for deciphering these characteristics of light that are observed in nature and realistic art. A sample painting by an authentic, starving artist will then be used to illustrate the interpretation of these rules.

ATTENUATION OF LIGHT

Dark and Light - Intensity

Attenuation of light in the atmosphere is the process of reducing its intensity. For the purpose of this study, intensity can be thought of as the number of photons passing through a unit area in one time unit. Photons are simply a quantum of radiant energy. It follows that few photons emanate from a dark surface while many come from a bright one. The difficult part of the problem is to understand what controls the number of photons reaching an observer from any particular surface.

Attenuation of a light beam in any media is accomplished by either scattering or absorption.

Scattering is a process whereby small particles suspended in a medium of a different refractive index diffuse a portion of the incident radiation in all directions. The efficiency of the scattering process depends on the ratio of the particle diameter to the radiation wavelength. Rayleigh scattering sends short wavelengths strongly in all directions and applies if the ratio is less than one-tenth (Figure 1). This is the case for light and molecules. If the ratio is larger, Mie scattering applies and the longer (red) wavelengths are most strongly scattered in a forward direction, (Figure 2). Mie Theory applies to cloud droplets and particulates in the atmosphere.

Absorption is a process by which incident radiation is retained by a medium. The radiation may be re-emitted but only after an energy conversion has taken place in the absorbing medium. An idealized black body is a perfect absorber of radiation, whereas a white body is a perfect reflector.

The relative probabilities of scattering and absorption in a medium are governed by the density of the scattering particles. For example, a high density of scattering particles keeps the distance between scattering events relatively short. As the density of particles increases, the medium becomes optically thick. Photons cannot enter the medium before being quickly scattered. Scattering will occur regardless of the photon's wavelength and the scattering efficiency of the particles. An optically thick medium with little absorption must always appear bright and white due to the relatively large numbers of photons of all wavelengths scattered in all directions.

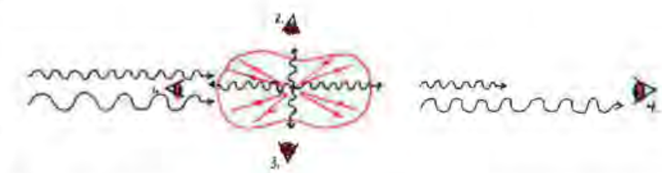


Figure 1 RAYLEIGH SCATTERING: The scattering particle is less than 1/10 the radiation wavelength.

NOTE:
1 The scattering is symmetric.
2 Observers at positions 1, 2 and 3 see the scattered radiation.
3 An observer at 4 sees radiation that is relatively devoid of the radiation that is scattered out of the beam.

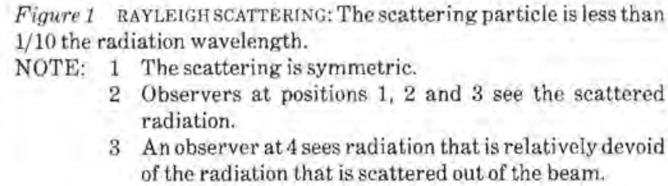


Figure 2 MIE SCATTERING: The scattering particle is greater than 1/10 the radiation wavelength.

NOTE:
1 The scattering is concentrated in the forward direction. This forward scattering increases as the particle size increases.
2 Observers at positions 1, 2 and 3 see little scattered radiation.
3 An observer at 4 sees a beam rich in scattered radiation.

Three basic concepts:

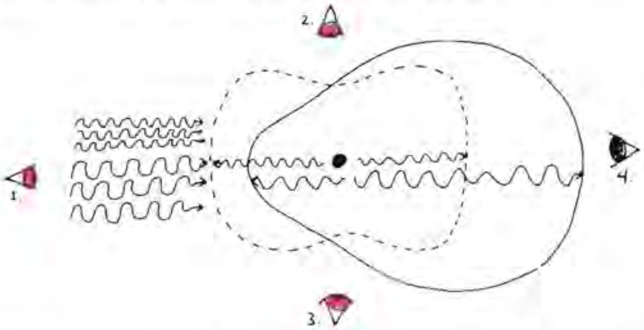
1. **Molecules scatter blue light best in all directions. Larger particles scatter red light best mainly in the forward direction.**
2. **Absorption increases as the surface approaches that of a black body and as the optical path length in the medium increases.**
3. **The probability of scattering versus absorption increases with increasing density of scattering particles in the medium. If the scattering particles are sufficiently dense that scattering dominates absorption, the medium is optically thick and must appear bright white.**

TINTING ATTENUATION OF LIGHT

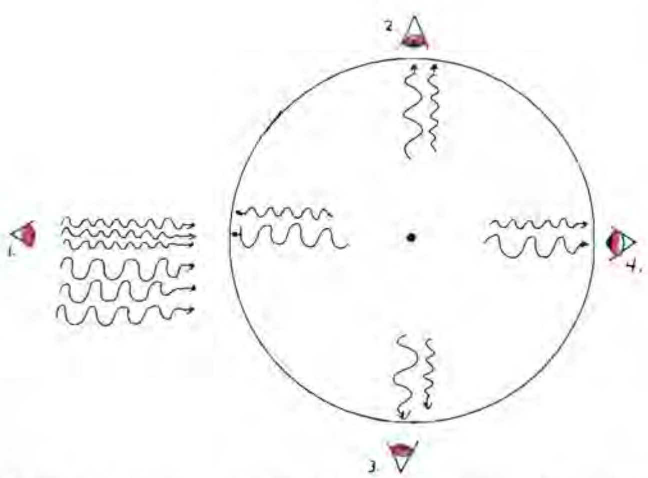
Warm and Cold - Colour

Colour was alluded to briefly in the preceding section. But there is more to discuss before we can correctly apply the principles involved. Radiation can be selectively tinted by the process of differential attenuation. The terms warm and cold refer to the artist's interpretation of colour, with warm referring to yellow, red and brown hues, and cold to the green and blue hues.

Differential scattering is the preferred scattering of one wavelength of light over another. As mentioned previously, molecular (Rayleigh) scattering is especially efficient for short wavelengths: blue light. Particulate (Mie) scattering of light is more efficient for long wavelengths: red light. The observer must decide whether direct or diffuse radiation is being detected in order to understand the effects that differential scattering will have on the light sensed. The direct radiation will be relatively devoid of the wavelength of light that is being scattered out of the beam with the effect increasing with optical path. The diffuse radiation will be rich in the preferentially scattered radiation (Figure 3).



The increased symmetry resulting from many scattering events in an optically thin medium. The observations at positions 1, 2, 3 and 4 still have the characteristics of individual scattering but the distribution is more symmetric.



Complete symmetry resulting from numerous scattering events in an optically thick medium. The intensities of the observed radiation beams are the same in all directions.

Figure 3 MULTIPLE SCATTERING: Optically thin and thick media. The intensity distribution for scattering by a large number of scatterers tends to increase in symmetry compared with that of the single-scattering distribution.

Differential absorption is the preferred absorption of a particular wavelength of radiation and its effect increases with optical depth (Figure 4). For example, pure water absorbs red light more efficiently than blue light. But transmission through several metres of water is required before selective absorption is apparent.

> Two important questions:
> 1 Is direct or diffuse radiation being viewed, and what is the size of the scatterer in question? As a key just remember that "Little Violet gets scattered while Big Red barges straight through" and "Big Particles deflect Big Red".
> 2 Is differential absorption important in the medium, and is the optical path sufficient to make any apparent change in the radiation?

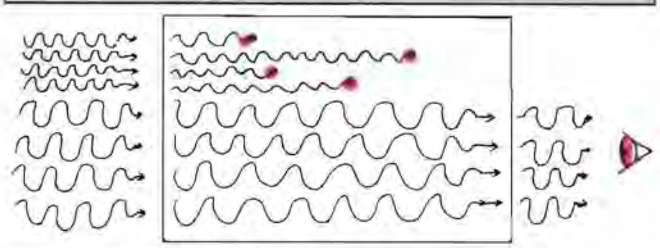


Figure 4 DIFFERENTIAL ABSORPTION.
Radiation passing through a medium that selectively absorbs short wavelengths. The observer sees a beam depleted of the radiation that is selectively absorbed.

MULTIPLE MEDIA

Until now, we have not considered the transmission of radiation through multiple media. The manipulation of radiation at a discontinuity between media can be very striking.

Refraction of radiation is the redirection of the radiation due to a change in the density of the propagating medium. If the density gradient is gradual, continuous refraction results. If the discontinuity is abrupt, like that at an air/water interface, then classical refraction results. Most important of all to note is that refraction is dispersive, meaning that the degree of refraction is wavelength dependent. Thus refraction can affect intensity and colour as well as the apparent position of objects that are viewed.

Reflection is a process whereby a discontinuity between two media returns a portion of the incident radiation back into the medium through which the radiation approaches. An idealized white body reflects all of the incident radiation while a black body reflects none.

Since energy must be conserved, reflection of radiation at a discontinuity must be balanced by transmission across the boundary. This balance is determined by the types of media, radiation wavelength and the angle of incidence of the radiation.

> Important points from the preceding background information:
> 1 Refraction is dispersive and thus reduces the intensity of the light.
> 2 Refraction displaces the image of a surface.
> 3 Reflection dominates transmission at an air/water interface if the angles of incidence/viewing are greater than 80 degrees.

In the next issue of *Chinook*, I will develop some interpretation guidelines and apply these to a realistic painting.

Philip Chadwick is a meteorologist with the Maritimes Weather Centre in Bedford, Nova Scotia. He is also a very successful artist.

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GUIDELINES FOR CONTRIBUTORS OF ARTICLES TO *CHINOOK*

1. Content, Language and Readership
Articles on topics of general interest in meteorology and oceanography, written in either English or French and suitable for a high school readership, are invited.

2. Length and Format
The suggested article length is in the range of 1500 to 3000 words with two to four figures (and captions). Clear illustrations and photographs are particularly encouraged. Contributors are also asked to provide a 100-200 word summary, preferably but not necessarily in the other language. Summaries will be translated (if necessary) and published in the other language only.

3. References
Literature citations within the text are discouraged. Instead, it is suggested that credit for results and ideas be given by naming the authors or their institutions in the text, and including references at the end of the text in the form of a short "Suggested Reading" list. A reference to a journal article should include the authors' names and initials, year of publication, full title of article, and journal name, volume number and page numbers. A reference to a book should include the authors' names and initials, year of publication, title of book, and the publisher's name and address. All references should be listed in the alphabetical order of the first authors' surnames.

4. Procedure for Submission
Two double-spaced typewritten copies of the manuscript should be sent to: *Chinook* Editor, c/o Canadian Meteorological and Oceanographic Society, 151 Slater Street, Suite 805, Ottawa, Ontario, Canada K1P 5H3. Finished line drawings and good quality black-and-white photographs (one original and two photocopies of each) should be included. Colour illustrations or photographs are welcome as candidates for the front cover of each issue. Contributors are also asked to provide a short description (about 50 words) of their professional affiliation (if any) and their meteorological and oceanographic interests, and to indicate whether their contribution has been or will be published elsewhere.

5. Editorial Policy
The suitability of articles for publication will be decided by the Editor upon consultation with at least one other member of the Editorial Board. Particular attention will be given to the readability of articles by a lay readership.

6. Reprints
Reprints of articles will not be made available. Four copies of the issue in which an article appears will be provided to the principal author. Additional copies will be supplied at the author's cost, provided the request is received before printing.