IMPROVING THE DATA BASE OF SNOW SCIENCE

BY

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Introduction

The orderly collection of basic data over wide areas and over long periods of time is the fundamental task of the major meteorological and hydrological networks of the world. In the past, major advances in the sciences of meteorology and hydrology have resulted from the inauguration and maintenance of widespread, long term, measurement programmes based on simple instrumentation and standardized observational procedures.

Although remarkable inventions and improvements have been achieved for many types of instrumentation, with associated advances in various research areas, the backbone measuring devices and recording procedures in both the atmospheric and hydrologic sciences are still at a fairly simple level. This paper contends that in the area of snow measurements and observations, considerable advances can still be made at the most basic level. The present concern with gauge catch (Larson and Peck, 1974; Goodison, 1975b) is an example of this. Although notable effort is being directed towards re-designing gauges and shields, more is being put into quantifying the limitations of existing gauges and assessing the effect of windspeed, gauge siting, gauge type, etc. Concern is directed towards increasing the value of existing methods of measurement rather than towards producing a radical change in the instrument operation. After all, one of the basic network needs is for procedures and instrumentation of known validity and reliability for use at the most basic component station. In the long run it is more important (in meteorology-hydrology) to maintain the records of regular, frequent, standardized, albeit simple, measurements and observations than to produce a few highly "accurate" results from special devices, expensive to produce and operate.

We were impressed in this regard with our first view of the Soviet standard snow gauge, the Tretyakov. One has a tendency to ascribe, sometimes rightly, great expertise to the Soviets in snow and ice matters. Their gauge (photo) is in fact a very simple one -- a very straightforward variation on the "bucket theme" which has found wide acceptance in many countries of the world, indeed since the dawn of meteorological history. Yet, given the vast geographical extent of the Soviet Union, how much more sensible it is for them to focus attention on the innovative use of an instrument designed to fit on a cedar post than to develop a complex (expensive) piece of apparatus.

However, once a large organization has made the effort to establish a widespread observational programme, there is often a danger of supporting a long series of measurements without further critical reflection over years and even decades.

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Great effort is expended in inaugurating the programme and great effort is required to maintain it so that little energy (or money!) is left over for further thought about the original purpose of the measurements, about the original reasons for the adoption of a particular procedure or technique, or about the continuing validity and value of accumulating results. The present concern, mentioned above, about the efficiency of gauge catch is healthy for this reason if for no other.

In this paper we would like to focus attention on some current international practices for the measurement and recording of snowfall and snow cover as an example of the importance of reassessing standard practices. These are procedures which are supported by the World Meteorological Organization (WMO) and practised by Member countries, or techniques suggested by other international scientific groups. It is not our intention to deride any work being done or which has been done in the networks but rather to explore opportunities to enrich the information obtained so that the needs of a wider range of "consumers", in particular those with a specialist interest in the subject may be satisfied. Indeed, we believe that the expansion in the number and variety of snow data users has put extreme pressure on existing networks and data banks and that this tendency will continue to increase sharply. We contend, however, that the necessary modifications to existing structures need not be extensive, disruptive or expensive. It is more a question of efficiently using available resources. An example of an "undeveloped resource" is the WMO synoptic (SYNOP) code used in the real time reporting of meteorological conditions by Members of the United Nations.

The WMO Synoptic Code

The Code used at land stations by surface weather observers is the international meteorological code FM 11E, supplemented by certain "National Practices", and by additional code groups, or on occasion by a plain language word(s) approved for use in WMO Region IV (North and Central America). The Synoptic Code is made up of groups of five figures each. The position of the numbers in a given group determines the element of weather which these numbers represent. The format of the Code is shown in Figure 1. Note, for example, that the last two numbers of the fourth group represent the temperature of the air in degrees Celsius.

SYNOP messages are issued four times daily (00, 06, 12, 18 hrs. GMT) by Member countries of the WMO and are transmitted by teletype circuits and other media throughout the world. The Code provides a number of areas for snowfall and snow cover descriptions. There are provisions for supplementary information, particularly in Regional Codes.

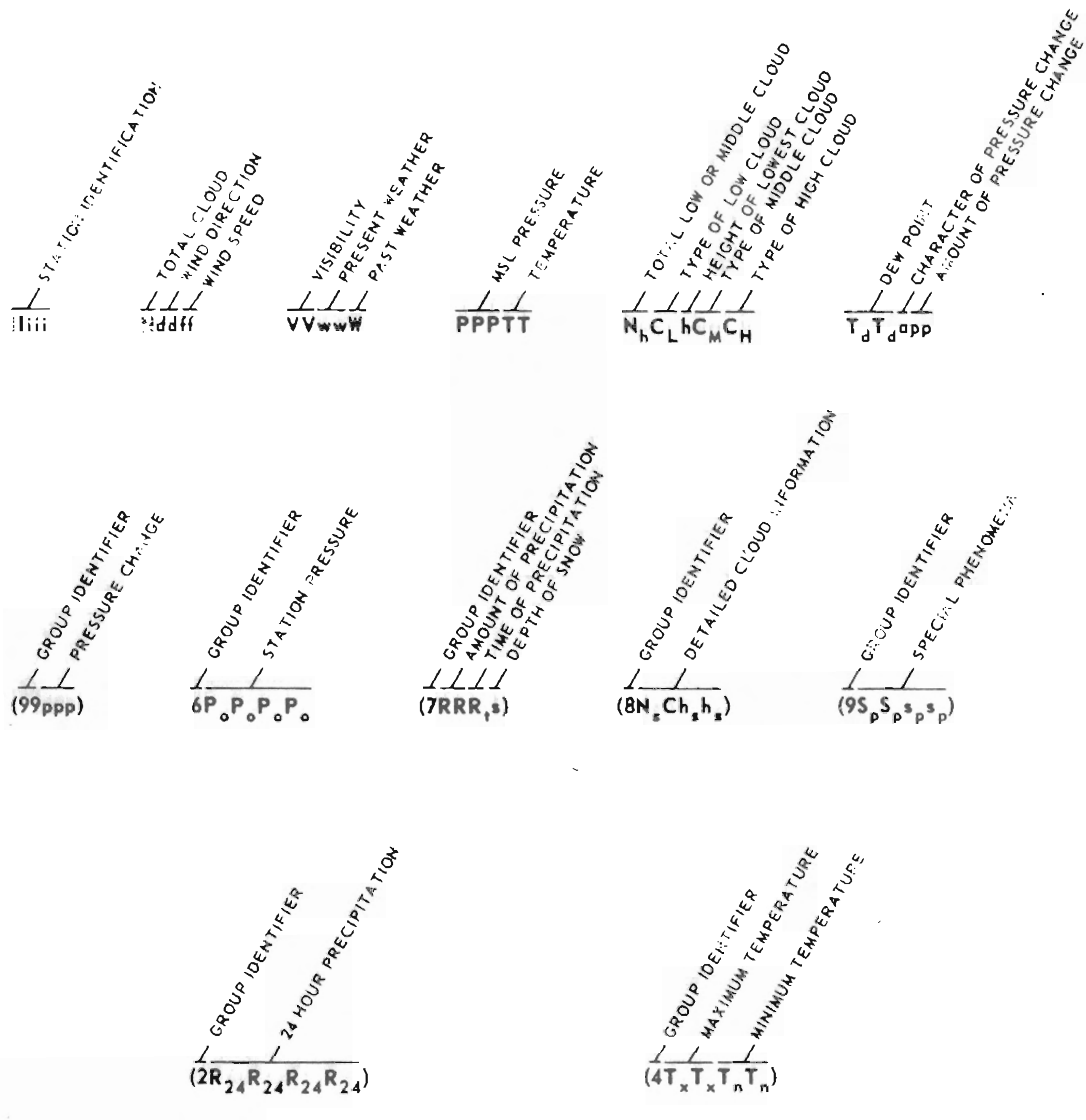
The SYNOP Code As Used To Report Snowfall And Snow Cover

Snowfall data are encoded in the third group (VV ww W). The ww group (present weather) is particularly rich in describing of the nature of falling hydrometeors. Snowfall amounts and depth of snow on the ground are given in the 7 group (7 RRR_tS - a regional variant of 7 RRRjj). Here the total fall of precipitation, the time of beginning or ending of the event, and the snow depth are included.

The present weather (ww) group permits a two-digit specification of conditions from 100 choices. (The total listing is in the WMO code books cited in the bibliography.) Figure 2 illustrates the scope of the ww code. Provision is made for the identification of liquid, freezing, and frozen precipitation forms occurring at the time of observation, their relative intensity, their character (continuous, intermittent, showery), and possible association of events (co-occurrence of fog, thunderstorms, etc.). Precipitation occurring within the past hour, but not at the time of observation is also documented. If the precipitation event

FIGURE 1

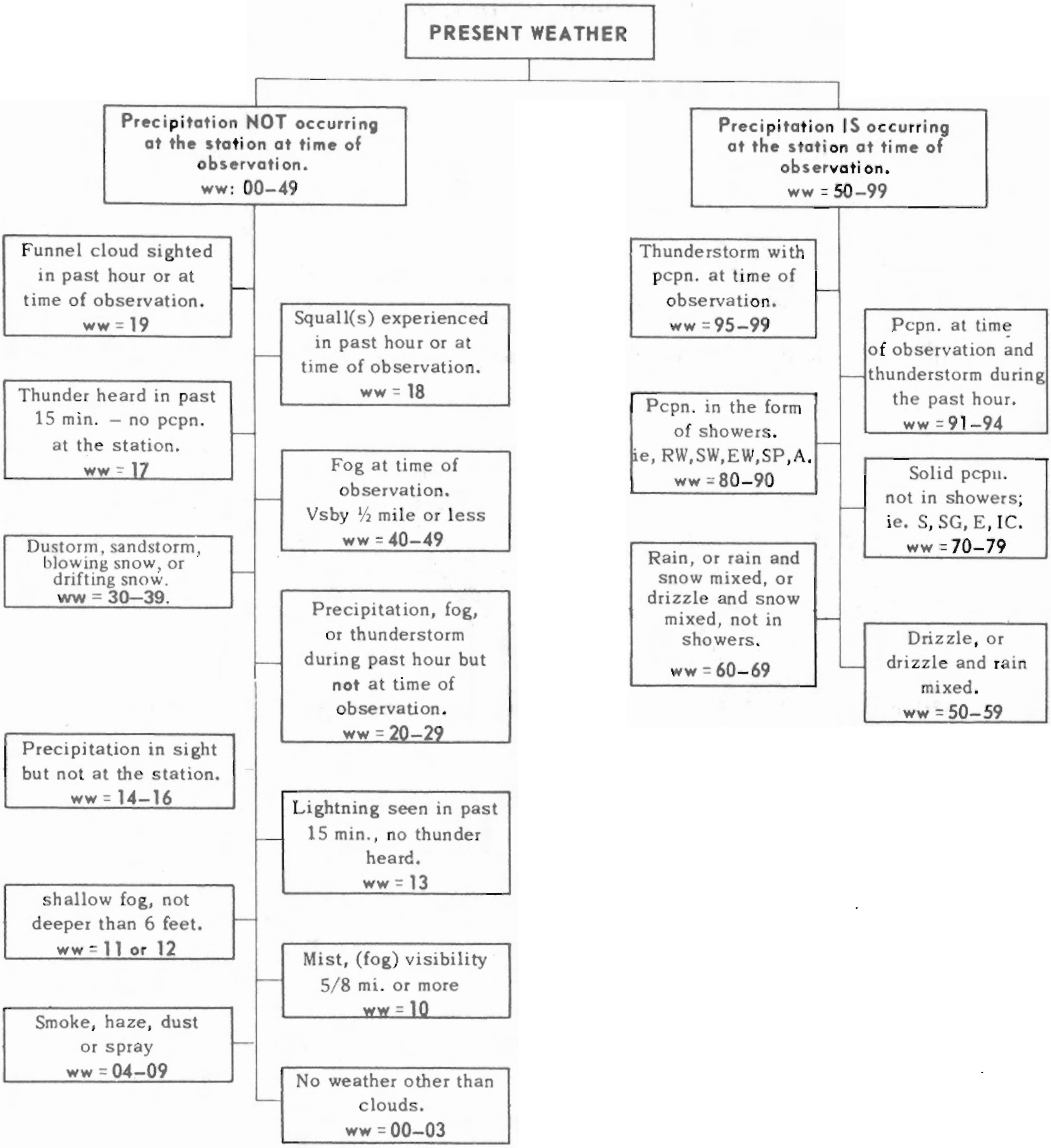
SYMBOLIC FORMS OF THE W.M.O. SYNOPTIC CODE



(after Canada, 1971)

FIGURE 2

CHART FOR ASSISTING IN
THE SELECTION OF THE PRESENT WEATHER CODE



(after Canada 1971)

happens within the five-hour period antedating the first hour prior to observation, it is coded by the W (past weather) code which has one digit only. The association of other important meteorological conditions such as cloud types, air temperature, dew-point, pressure, wind, visibility and precipitation amounts are readily provided by the other groups.

As previously mentioned snow on the ground is given in the 7-group, though when the depth exceeds 20 cm or when no precipitation occurs during the synoptic period the special phenomena or the $9\ S_pS_ps_ps_p$ group (WMO Regional Code 483) is employed. This takes the form of 901 nn, where nn is the total depth (in centimetres). Figure 3 shows the entire 9-group as it applies to snow cover, though one notes that only the depth grouping is currently in use.

The advantages of the SYNOP code provisions for snow data are: (a) they provide a real-time data source for comprehensive synoptic meteorological information; (b) a distinction is made as to the hydrometeor type and timing of events; (c) an availability of additional space for new groups exists; (d) new codes may be introduced. At present the provisions of the 9-group are hardly used and, as it is a Regional code, could easily be revised to accommodate new needs. (The 9-group in Region VI (Europe), for example, is entirely different than that in Region IV). Figure 4 is an example of a snow cover code used in mountainous districts of France.

However, there are a number of disadvantages to the SYNOP code as it is used operationally at this time. Teletype traffic is heavy and expensive, and message information must have a real-time requirement in the preparation of weather forecasts. National meteorological services would resist lengthening of the existing code unless very strongly justified. Since almost all the modifications to be suggested in this paper could be transmitted at a lesser frequency and many would be simply encoded for archival purposes to be eventually statistically treated, many of these obstacles could be overcome.

While the comprehensiveness of the code is initially impressive, particularly with respect to the ww selection, a detailed examination reveals important limitations in describing the possible combinations of related synoptic factors to snowfall and snow cover events. The present weather (ww) may not be as important in documenting a snow event as the recent past. The descriptive capabilities of weather conditions within the synoptic period, but not at the time of observation, are relatively sparse, particularly for situations more than one hour before the scheduled observation (W code).

The code does not allow distinction among types of solid hydrometeors beyond gross modifications brought about by melting and refreezing of the particles (snow pellets, grains, ice pellets, etc.). However, crystal types are important in snow studies since they affect visibility, drifting, crust and pack formation, snow gauge catch and a wide variety of snow cover properties.

Some measurement practices for the data reported in the code require serious re-examination. It is well-known that many reporting stations are poorly situated for measuring snowfall and particularly snow on the ground (airports). Other stations are in natural surroundings and the observers take particular care to sample the mean depth. They may even calibrate their instrument site values against snow course information. However, the ultimate user of the data has no idea which stations are good and which are bad without extensive checking of files kept at regional centres or at a national headquarters.

FIGURE 3

W.M.O. REGIONAL CODE 483 (REGION IV) AS IT APPLIES TO SNOW COVER

$S_PS_Ps_ps_p$ —	Special phenomena
$9S_PS_Ps_ps_p$	
00 – 09:	**Ground and miscellaneous phenomena**
900nn	Average depth of deepest snow drifts (in metres)
901nn	Depth of newly fallen snow during past 6 hours (in whole centimetres)
902nn	Water equivalent of snow and/or ice on ground (in millimetres)
903nn	Water equivalent of snow and/or ice on ground (in whole centimetres)
904nn	Total amount of snow and/or ice on ground (in whole centimetres)
9050E	State of the ground
906tt or zz	Frost
907nn	Glaze, average rate of accrual per hour (in millimetres)
9080S	State of sea
$908K_pK_p$	Period of sea swell
909nn	Water temperature in whole degrees Celsius

FIGURE 4

EXAMPLE OF SNOW DEPTH CODE DOCUMENTATION IN FRANCE (DESIGNED FOR AVALANCHE FORECASTS IN MOUNTAINOUS AREAS)

Code Symbol	$7\ H_sH_sH_s\ T_sT_s$
$H_sH_sH_s$	snow cover thickness (whole centimetres)
T_sT_s	snow surface temperature or temperature at 10 cm if surface $\geqslant$ 0°C, 0800 hrs. LST
	$8\ H_pH_pS_nP_sP_s$
H_pH_p	thickness of fallen snow occurring since 0800 hrs. (snow board used) (cm)
S_n	state of snow cover surface

0	fresh or recent snow —	dry
1	" " " " —	moist
3	loose snow not transported	
4	" " transported	
5	old snow, moist, not transported	rotten
6	" " " transported	non-crusted
7	melt crust not transported	
8	" " transported	
9	—	

P_sP_s Ramsonde penetration (1st tube) (cm)

Source: La Météorologie nationale, Centre d'études de la neige (Grenoble, France)

The final disadvantage is that codes by themselves are confusing to persons not directly involved in encoding and decoding. The user may study publications such as MANOBS and the International Cloud Atlas (see bibliography) in order to use the synoptic messages, but this is time consuming. Unfortunately, it is presently necessary since the SYNOP messages are simply archived and not abstracted or published in plain language

Of course in Canada and the United States, snow data from hourly aviation weather reports (METAR substitution) are computer-processed for users.

Data Base Improvements for Falling Snow

The SYNOP message lists useful background information about the incidence of say ice pellets or snow grains, but gives little data regarding common solid precipitation sub-forms, particularly those in the snow group which are differentiated by crystal structure and morphology. Statistics describing physical character, size, shape and other important index characteristics of cover composition useful to transportation operations, wildlife management, hydrology, etc., are not commonly available on even a sub-network basis. Techniques for observing recording and encoding these data are readily available and have been developed for some time, see for example, (Nakaya, 1954; Lliboutry, 1964; Magono and Lee, 1966, LaChappelle, 1969; Mason, 1962; Schaefer, 1951, 1964; Bentley and Humphreys, 1931).

Compare, for example, the ww classes with those of the International Commission on Snow and Ice Classification (Figure 5). The chart here combines the Klein et. al.(1950) format with that of Lliboutry (1964) to provide clearer diagrams and scale.

In this classification we see ten easily differentiated types of solid precipitation with possibilities for the modification of each in terms of degree of completeness, riming, clustering (to produce flakes in the case of snow) and wetness -- all important indicators of atmospheric conditions.

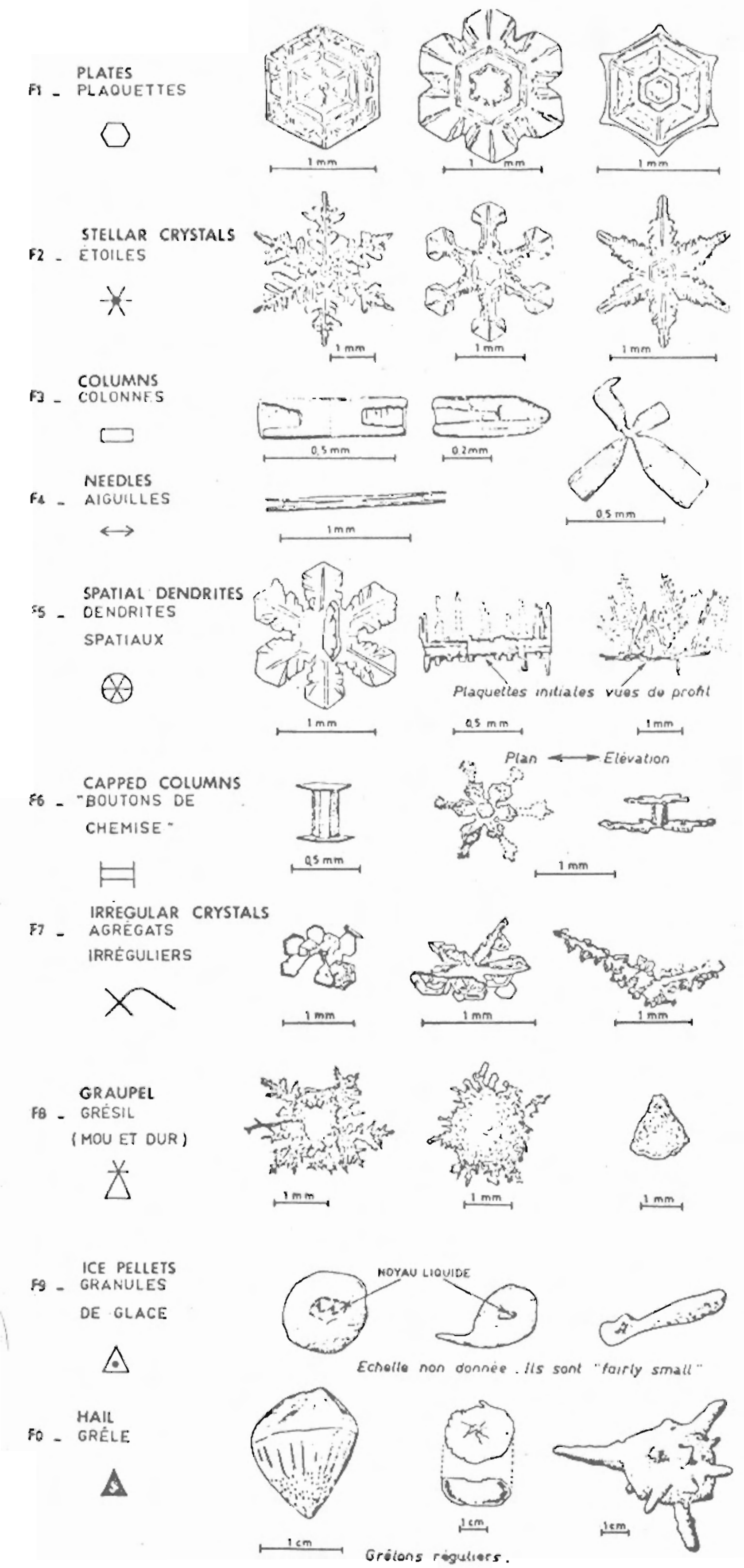
The original publication of this classification (Klein et. al., 1950), included suggested methods of observation, measurement and encoding of snow types. It is important that this be done in a rapid, simple manner as most snow storms include a variety of types of solid precipitation. An example of the application of the recommended procedure, using codes in Figure 5, is "8F4fD2.5+2F8D1.5". Longhand, this describes a sample which contained "eighty per cent needle crystals, in clusters, with a mean length of 2.5 mm. plus twenty per cent graupel with a mean diameter of 1.5 mm".

This is a very meaningful observation of falling snow from the point of view of anyone specifically interested in the properties of snowfall. It is also an extremely useful observation from the general meteorological point of view. Used, for example, in conjunction with nomograms produced by Nakaya (1954) and others (Figure 6), it is possible to generalize humidity, temperature and wind conditions at levels in the atmosphere where the precipitation originated or through which it passed.

This information is also useful from the point of view of general ecology and/or hazards. The nature of falling snow is important in determining its impact on trees and other vegetation, its effect on visibility, the problems it will present for snow removal, or the degree to which it will insulate the ground. Stellar crystals, for example, more commonly form flakes than do unbranched crystal forms, and they also accumulate more readily on trees or roofs and on slopes. Solid crystal forms do not settle readily in vegetation and form a compact, relatively air-free, ground cover with initial densities of 0.2 gm/cm^3 or higher.

FIGURE 5

MODIFIED CLASSIFICATION FOR SOLID PRECIPITATION



MODIFYING FEATURE	SYMBOL SUBSCRIPT
BROKEN CRYSTALS	p
RIME COATED CRYSTALS	r
CLUSTERS	f
WET	w

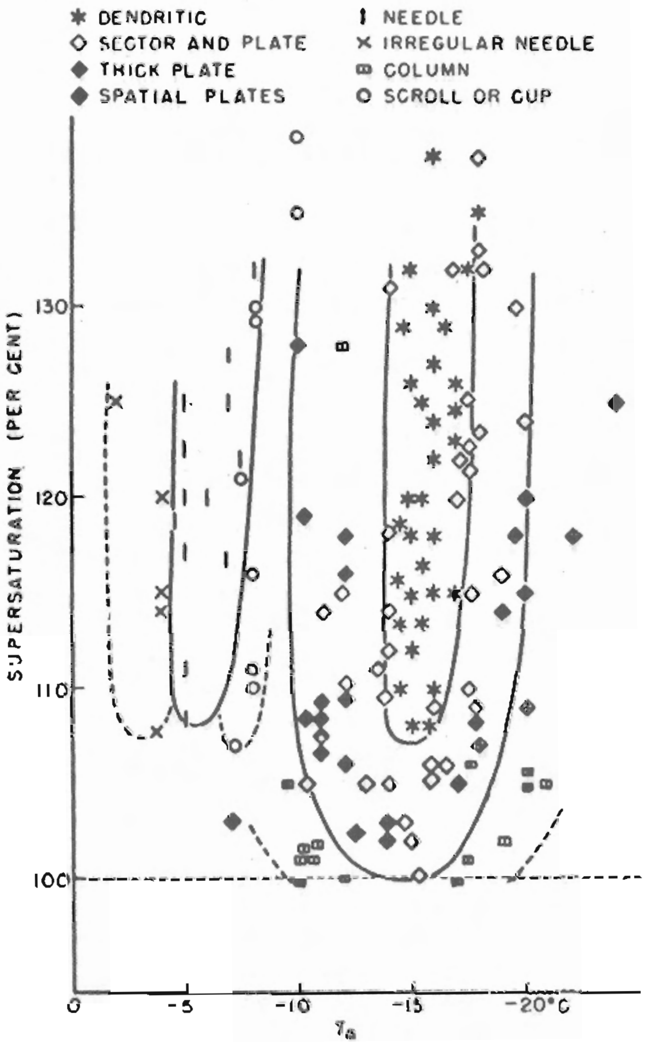
SIZE OF PARTICLE D

MEASURED IN MILLIMETERS

(adapted from Klein *et al.* 1950, and Lliboutry 1964)

FIGURE 6

SNOW CRYSTAL TYPE AS A FUNCTION OF RELATIVE HUMIDITY AND TEMPERATURE



(after Nakaya 1954)

In many regions, or for particular periods of time, no snow course data are available, and the information about snow on the ground which is contained in the synoptic reports is the sole source.

The lack of more explicit snow cover information in the basic synoptic record is an interesting point for thought, especially in the light of the point, made above, that a major part of the economic and ecological impact of snow lies in the realm of snow cover rather than snowfall. Today's increasing concern for environmental matters - whether they be meteorological, hydrological or ecological - calls for constant rethinking of why we are collecting data, and whether the information might be modified and be improved for a new group of consumers. In Canada, serious consideration of environmentalists' legitimate data requirements has only recently been recognized.

In the realm of snow cover continued network expansion along with maintenance and improvement of snow courses has been a major step forward in this regard. However, much of the snow course data now on file is of limited value for the assessment of areal and stratigraphic variations in snow cover. The urgent need for the preparation of good site descriptions, which contain accurate vegetational and topographical descriptions, which describe the method of observation and the equipment used, and which provide additional background information, has been demonstrated previously (Ferguson and Goodison, 1974; Goodison, 1975a). At present even when courses do encompass a range of vegetational and topographical environments, their results are not always distinguished from those which do not. Much of the value of good work is then lost.

Limited work has been done on assessing the local areal significance of even well established courses, so that again, their value as an indication of local conditions may be in doubt. Many stations used the bulk method of calculating density and water equivalent, thus providing only mean values of these properties without giving any indication of actual variation or extreme values measured (see Figure 8). In many cases, it is the extremes of snowcover (deepest drift, densest layer, percentage of bare areas, etc.) which may be of greatest interest in terms of economic, ecological or hydrological impact. A single mean snowcourse value is better than a single depth measurement obtained in a meteorological enclosure, but for those interested in other aspects of snow cover, e.g. over-snow trafficability, avalanche prediction, prediction of soil temperatures or the interpretation of satellite imagery, more detail on the stage of the snowpack and its subsequent changes are needed.

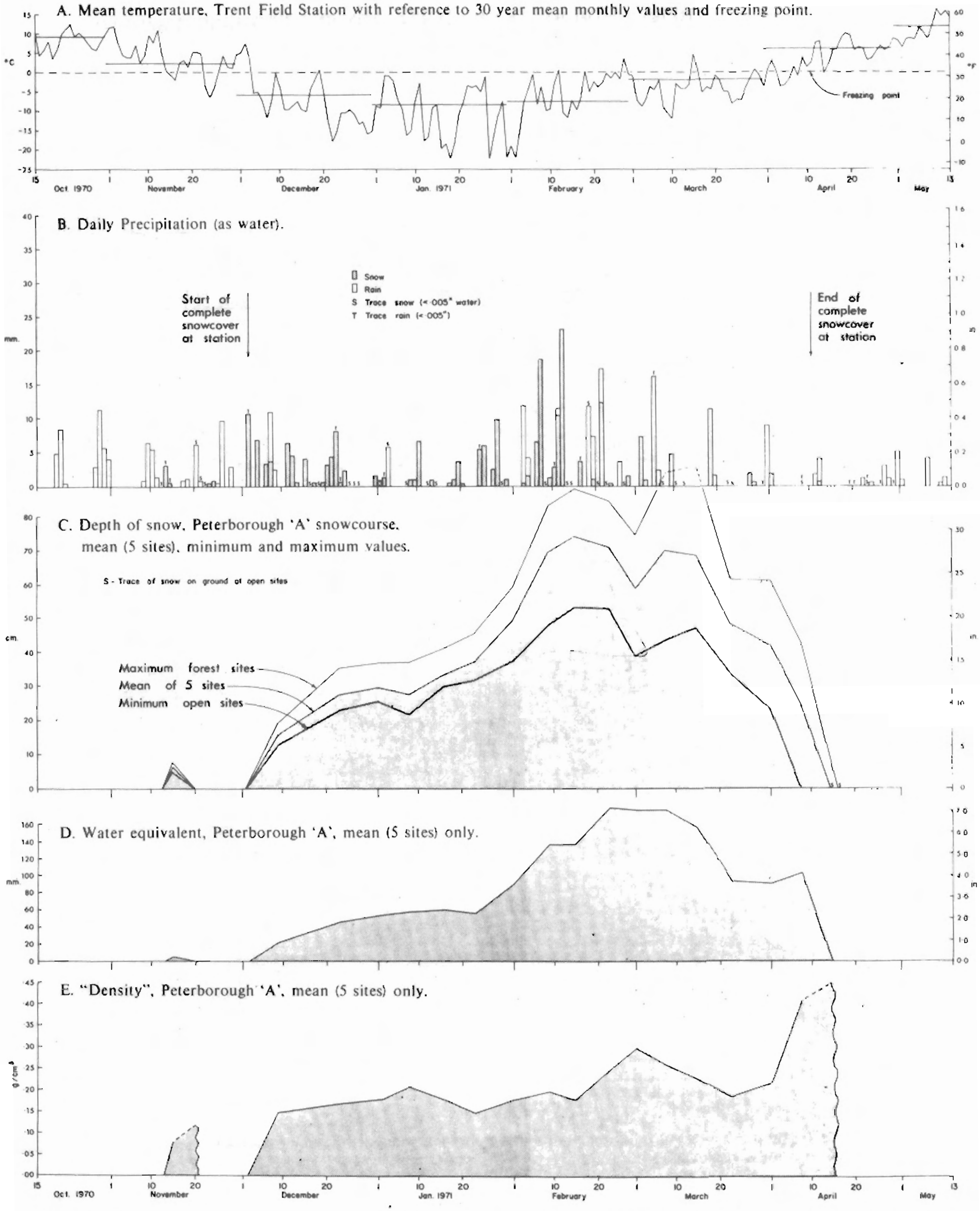
The "good" snowcourse provides a series of points at which depths and water equivalents are measured and from which a mean density value, (i.e. a mean of the densities of all strata involved in the vertical point sample), may be calculated (Figure 9). However the significance of a certain mean density value in determining, for example, the thermal conductivity of the cover may be totally distorted by the distribution of individual strata densities which the mean value encompasses. A snow cover which includes a substantial ice layer and thick layer of very light snow might have the same mean density as one with no ice and a very uniform distribution of density in its vertical profile, yet the two cases could produce very different subnival environments, very different bearing capacities, very different avalanche potentials or very different snow removal problems.

An increasing need for "ground truth" snow cover data has been demonstrated in conjunction with the interpretation of satellite imagery. In the WMO Snow Studies by Satellite project, the following information, particularly related to snow cover, has been recommended as desirable ground truth data: snow depth; water equivalent of the snow pack, surface temperature of the snow, air temperature (dry and wet bulb) somewhere 1-2 m above the snow, character of the snow surface (dry, wet, crusted,

FIGURE 8

TIME MODIFICATION OF SNOW COVER

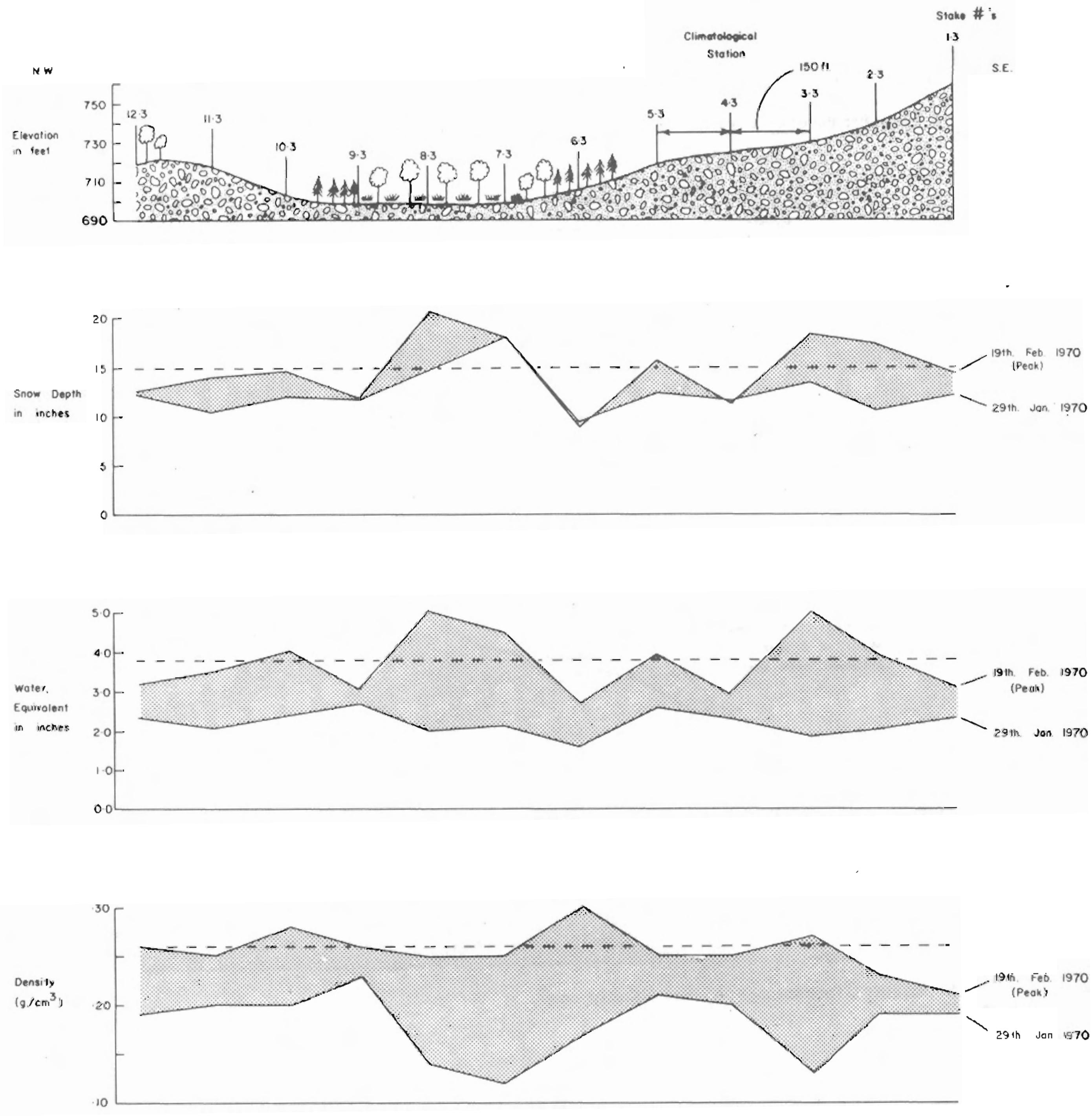
Evolution of snowcover 1970-71 with selected climatological variables.



An example of the use of snow course data as a means of portraying the evolution of cover in a region, in this case Peterborough, Ontario, winter 1970-71. As the bulk density method was used no detail of the areal variations of density and water equivalent can be exhibited. This differentiation of 'forest', 'open', and 'mean' conditions is only possible for depth. Compare similar portrayals, where individual water equivalent measurements were made, in Adams and Barr 1976 (elsewhere in this volume).

FIGURE 9

TRENT UNIVERSITY FIELD STATION SNOWCOURSE, 1969-1970



This illustrates the range of relief, vegetation cover, aspect, snow depth, water equivalent and mean density. (Dashed line represents mean peak values.)

Needle crystals produce a dense layer which readily promotes slab avalanches (La Chapelle, 1969). Also it appears that crystal form, as well as wind speed, is an important factor in determining gauge catch (Goodison, 1975). In addition, crystal forms are a factor in the efficiency with which falling snow scavenges pollutants from the atmosphere.

Thus, it is possible, with a little extra effort, to considerably enhance the value of snow observations from the point of view of both "research" and general use. The simple inclusion of crystal and/or flake size in observations would be an important gain as "snow flakes", for example, can vary in size from much less than a centimetre to five or more centimetres diameter.

The 1951 snow classification does itself have considerable limitations and the much more comprehensive, but still simple, Magono and Lee (1966) classification offers wider possibilities. It, for example, encompasses the miniature 'germ' crystals which surely are the "ICE CRYSTALS (PRISMS)" in the ww classification and it has a range of categories for fragments of crystals so that they can be allocated to their original form. Also, a range of needle types, including sheaths, is explicitly recognized. All of these additions enrich the value of the observations as an indicator of atmospheric conditions as they allow greater precision with regard to conditions at levels where the forms originated and allow a more comprehensive statement on the impact of the snow when it reaches the ground.

Data Base Improvements for Snow on the Ground

As pointed out previously, under the WMO Code 483 there is provision for recording various features of snow on the ground. However, the most common source of data on snowcover used today are the snow course records which are collected and kept by various agencies. In Canada, the Atmospheric Environment Service (1975) publishes annually all snow course data and supplementary information submitted by 18 agencies operating courses throughout the country. An example of the wide variety of information presently available, largely depending on the agency's reason for collecting the data, is given in Figure 7. Some agencies provide auxiliary information to the publishing agency while others provide little or none.

The snow depth information collected by the Fish and Wildlife Research Branch (Ontario) is an interesting example of data collected for non-hydrometeorological consumers. This Branch is interested in the effect of snow cover characteristics on the wildlife population - the data are the average of ten observations made at sixty-foot intervals on a snow course in a pure or nearly pure hardwood stand of moderate to heavy density, with the average height of trees being at least twenty feet. This is the only set of published data which give at least some indication of the physical condition of the snowpack. Unfortunately, there are no water equivalent values, and the geographical sampling is limited.

It must also be acknowledged that there is a distinct time lag in the availability of snow data, (excluding the daily depth measured at synoptic stations) compared to snowfall statistics, unless one makes special arrangements with individual agencies. As well, on a national basis in Canada, the snow cover data are not yet stored in an easily accessible form, although a few individual agencies have a good computerized method of data processing (for example, British Columbia Water Resources Service). Figure 7 illustrates the existing data summary method by the Atmospheric Environment Service. It is hoped this situation will be improved in the near future as a result of efforts towards the standardization of the reporting and publishing of snow cover data being made (Goodison, 1975a).

FIGURE 7

SELECTED CANADIAN SNOW COVER DATA 1973-1974

SNOW COURSE	ELEVATION FEET	LATITUDE ° '	LONGITUDE ° '	YEARS OF RECORD	JANUARY DAY	JANUARY Snow Depth (inches)	JANUARY Snow Depth (inches)	FEBRUARY DAY	FEBRUARY Snow Depth (inches)	FEBRUARY Water Equiv. (inches)	MARCH DAY	MARCH Snow Depth (inches)	MARCH Water Equiv. (inches)	APRIL DAY	APRIL Snow Depth (inches)	APRIL Water Equiv. (inches)	NOTES
WALDEMAR,	1490	4354	8017	14	2	10.0	2.1	15	12.2	3.8	1	12.3	4.8				10x100' R(1)
ONTARIO (11)					15	12.2	3.4				15	0.0	0.0				
ST. JOHN'S A (17)	463	4737	5245	10	Dec 15	0.0	0.0	1	6.8	1.3	1	7.0	2.4				5(2)
NEWFOUNDLAND					23	0.0	0.0	8	8.9	3.9	8	2.4	1.0				
					Jan 1	0.0	0.0	15	8.2	3.3	15	9.5	2.6				
					8	0.0	0.0	23	2.0								
					15	4.4	0.9										
					23	7.0	2.0										
RIVIERE DU SOT (5)				6	16	45.5	10.7	12	45.6	13.7	12	50.0	14.7	2	70.9	20.9	
QUEBEC														19	61.9	20.6	
														May 6	45.8	17.8	
														22	25.6	10.6	
MINDEN,	1180	4455	7844		Dec 17	6.3A		11	18.3B		11	13.5C		15	0.0		
ONTARIO*					31	16.0A		25	20.1B		25	17.8C		29	0.0		
					Jan 14	18.0A											
					28	16.7B											

[1] A ten point course, points spaced at 100 foot intervals; R means the snow course is laid out so as to be representative of the terrain and forest cover in that locality.

[2] A five point course; no information on spacing or whether representative

[5] Ministry of Natural Resources, Quebec Meteorological Service

[11] Ontario Ministry of Natural Resources, Conservation Authorities Branch

[17] Atmospheric Environment Service

* Snow depth only, provided by the Ontario Ministry of Natural Resources, Fish and Wildlife Research Branch: crust conditions described by:
A— no crust, B— light crust, C— crust strong enough to support a man on snowshoes, D— crust strong enough to support a man occasionally without snowshoes.
E— crust strong enough to support a man most of the time without snowshoes.

etc.), and total albedo and/or spectral reflectance from 0.4 - 1.4 μm. We do not regularly collect such data, except for the first two items.

Figure 10 conceptualizes this gap between information provided even by stations with excellent snow courses and the sort of information now being requested by those interested in the winter environment. The techniques involved are simple, and have been developed so that they include simple, rapid means of encoding and recording data.

There is a variety of snow cover information which is potentially available. It is time to make known user's requirements and to attempt a re-assessment of our present field measurements and subsequent data presentation.

Conclusions

Basic snowfall and snow cover data may be improved in a number of ways for a growing and diversified population of users. Some changes require only minor modifications to existing observational and reporting procedures. Protection of present network practices where possible, has been a theme of this paper for the simple reason that most networks and procedures are quite good. Moreover, a conservative approach ensures a continuity to the record, a useful concept when the data are treated statistically. The backbone of operational networks are simple, easy to use, instruments. However, such instruments and observing practices can be more thoroughly understood as to characteristics and possible errors by a fuller documentation of meteorological events, the physical properties of the snow, and good descriptions of site geography.

Initially it is suggested countries or political divisions therein might designate a few snow reporting stations. These may be existing meteorological stations with good natural surroundings for measuring snow. The observers would receive a special short course in snow science and technology. The stations would continue to report ordinary meteorological information, but supplement its snow data by elaborating on the variable forms and size characteristics of the general term "snow" (ww 70-75, 85, 86). Secondly, measurements of depth variability, surface modification, crusts, hardness, ice layers, pack crystal variation, temperature, density, free water content, could be logged according to a modified SYNOP-type code, to be transmitted to a central processing office at regular, though not necessarily real-time intervals.

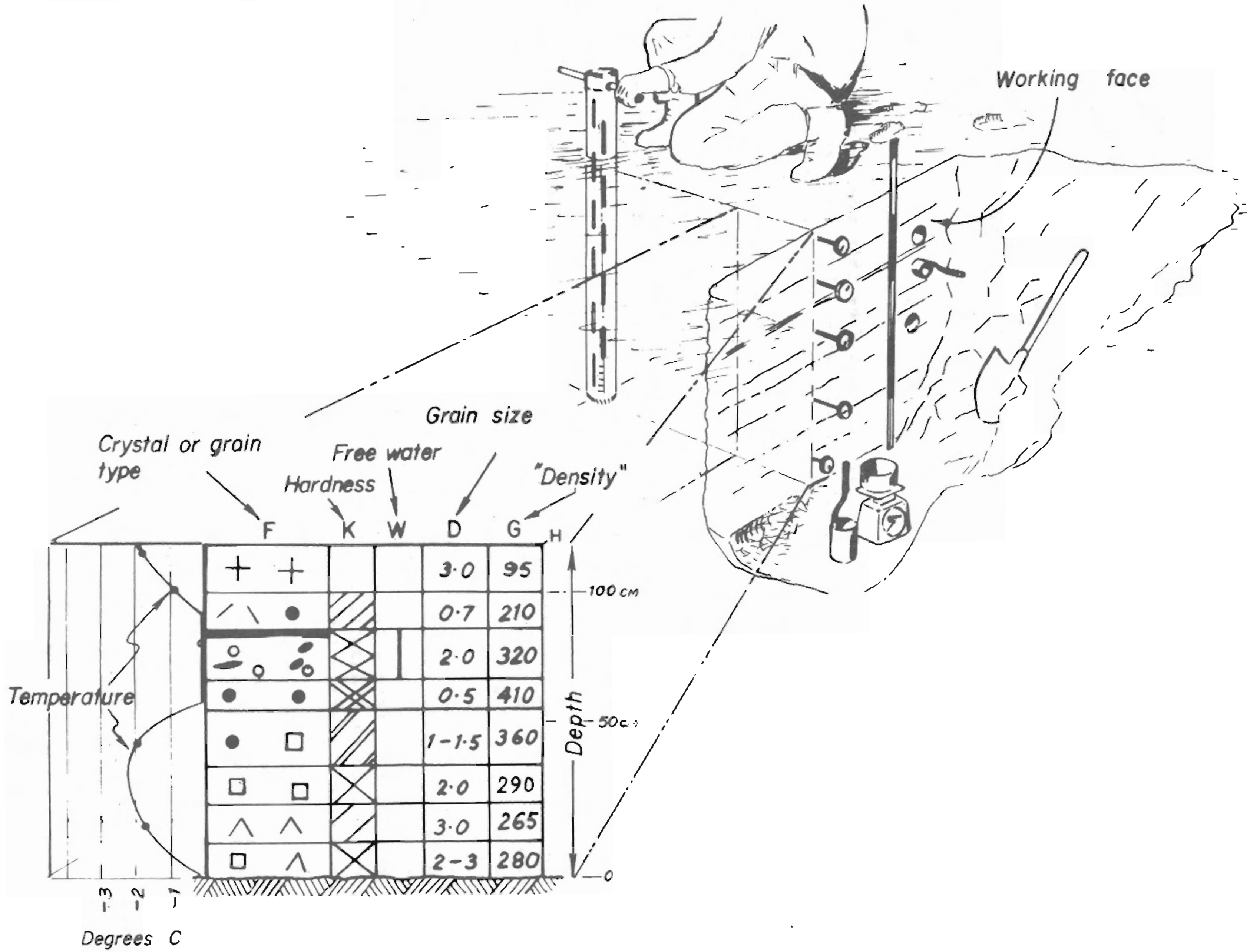
The regular observing stations require documentation as to site characteristics and observing practices. They could be compared ultimately with the regional snow stations which would serve as a standard.

The snow course overcomes the sampling problem in area of very variable snow cover. Snow courses on a national basis (and often regional) are poorly documented regarding site characteristics, and are non-standardized respecting observing and reporting procedures. While this is natural, inasmuch as each agency has its own objectives, users working with data from more than one agency have considerable difficulty making inter-comparisons.

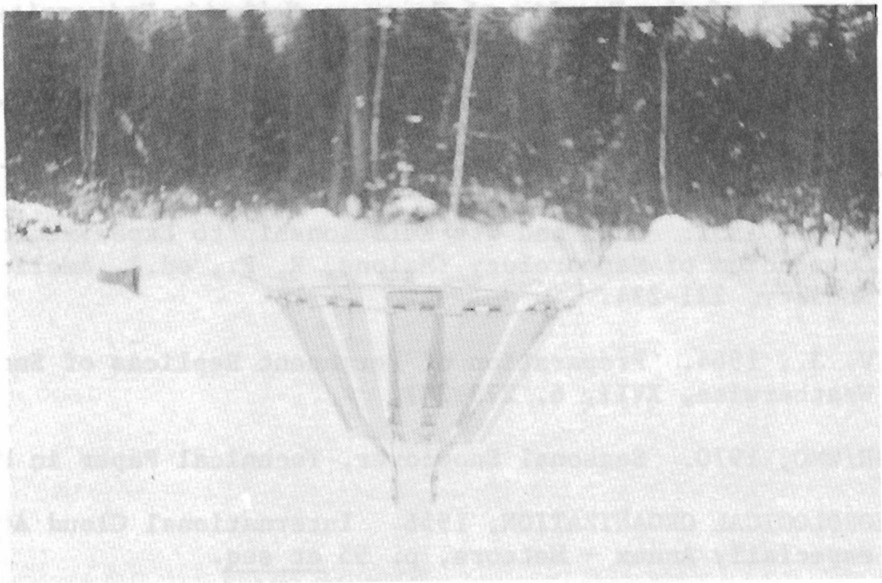
Finally and, our most general point is that existing programmes of measurement and of data accumulation should be constantly reassessed. Often a little thought at the right time is the difference between the accumulation of extremely valuable or totally useless data. After the expenditure of some effort on the 'little thought', the effort and expense of running the programme concerned is the same in both cases.

FIGURE 10

ILLUSTRATION OF A COMPREHENSIVE METHOD FOR DESCRIBING THE STRATIGRAPHIC PROPERTIES OF A SNOW COVER



These data are required in order to estimate snow trafficability, avalanches and snow clearance the symbols are standard (see UNESCO 1970, and Adams and Barr 1974).



The Tretyakov Snow Gauge

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