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GUIDE TO RECOMMENDED PRACTICE OF DAYLIGHT MEASUREMENT

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This Technical Report has been prepared by CIE Technical Committee 3-07 of Division 3 'Interior Environment and Lighting Design' and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory. The latest CIE proceedings or CIE NEWS should be consulted regarding possible subsequent amendments.

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Guide to Recommended Practice of Daylight Measurement

*This guide is dedicated to the late
Prof. Jürgen Krochmann,
a pioneer and leader in daylighting research.*

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TABLE OF CONTENTS

	Page
1. FOREWORD	1
2. PART A: GENERAL CLASS STATIONS	2
2.1 Introduction	2
2.2 The site	2
2.2.1 Selection of site	2
2.2.2 Description of the site	2
2.3 Measurements	3
2.3.1 Basic set	3
2.3.2 Additional set	3
2.3.3 Frequency of measurement	3
2.3.4 Statistical summary of data	3
2.4 Equipment	4
2.4.1 Screening of sensors	4
2.4.2 Calibration and accuracy of photometers	4
2.4.3 Calibration and accuracy of radiometers	5
2.4.4 Sunshine duration	5
3. PART B: RESEARCH CLASS STATIONS	6
3.1 Introduction	6
3.2 The site	6
3.3 Measurements	6
3.3.1 Basic set	6
3.3.2 Additional set	6
3.3.3 Frequency of measurement	6
3.3.4 Statistical summary of data	7
3.4 Equipment	7
3.4.1 Screening of sensors	7
3.4.2 Calibration and accuracy of photometers	8
3.4.3 Calibration and accuracy of radiometers	8
3.4.4 Sunshine duration	8
3.4.5 Cloud cover	9
4. PART C: DATA QUALITY CONTROL, PROCESSING AND DISSEMINATION	11
4.1 Introduction	11
4.2 Data acquisition	11

4.2.1 One-minute measurements	11
4.2.2 Half-hourly measurements	13
4.2.3 Fixed-elevation measurements	13
4.3 Automatic Quality Control (QC)	13
4.3.1 One-minute data	13
4.3.1.1 Test description	14
4.3.1.2 Test implementation	16
4.3.2 Half-hourly measurements: test description on implementation	19
4.3.3 Fixed-elevation measurements	21
4.4 Post-automatic QC processing	21
4.4.1 Diagnostic review - Temporary storage- Reprocessing	21
4.4.2 Manual Quality Control	21
4.4.2.1 Instrumentation inspection	22
4.4.2.2 Data manual inspection	23
4.5 Data formatting - End use processing	23
4.5.1 One-minute frequency distributions	23
4.5.1.1 Description	23
4.5.1.2 Formatting	24
4.5.2 Half-hourly frequency distributions	25
4.5.2.1 Description	25
4.5.2.2 Formatting	25
4.5.3 Half-hourly time series	25
4.5.3.1 Description	25
4.5.3.2 Formatting	26
4.5.4 Fixed altitude time series	28
4.5.4.1 Description	28
4.5.4.2 Formatting	28
4.5.5 Measurements reference and quality control codings	28
4.6 Archiving, dissemination and intercomparability	30
5. REFERENCES	32
6. ACKNOWLEDGEMENTS	33
7. APPENDIX 1: Automatic quality control of daylight measurements Software for IDMP stations	34
7.1 Introduction	34
7.2 The AQC tests	34
7.3 The AQC procedure	36
7.4 Using the AQC.EXE software	38
7.4.1 Input data files	38
7.4.2 Output data files	38
7.4.3 The AQC procedure flags	38
7.4.4 Display of results	38
7.4.5 Availability of the AQC.EXE software	40
7.5 References	40

CIE 108-1994

7.6 Acknowledgements	40
8. APPENDIX 2: Prediction of vertical irradiance/illuminance	41
9. APPENDIX 3: Luminous efficacy models	42
10. APPENDIX 4: IDMP/ASRC time series data file extensions	43
10.1 Textual data	43
10.2 Comment content	44
10.3 Binary files	45
10.4 Comments and binary files	45
11 APPENDIX 5: ISO International two-character country codes	47

GUIDE TO RECOMMENDED PRACTICE OF DAYLIGHT MEASUREMENT**SUMMARY**

The CIE designated the year 1991 "International Daylighting Measurement Year" as the first year of the "International Daylighting Measurement Programme", referred to as the IDMP. The objective of this programme is for participants worldwide to measure daylight availability parameters under a common set of guidelines. There are two categories of IDMP measuring stations: the General Class, in which illuminances and irradiances are the principal quantities measured; and the Research Class, in which the stations also record sky luminance distributions as well as other meteorological quantities.

This guide describes the measurement and instrumentation requirements of both classes of stations, providing guidelines and recommendations on data quality control, archiving and dissemination.

The guide was prepared as part of the activities of CIE TC 3-07.

GUIDE PRATIQUE POUR LA MESURE DE LA LUMIERE NATURELLE**RESUME**

La CIE a désigné l'année 1991 comme première année du programme international de mesure de la lumière naturelle: IDMP (International Daylighting Measurement Programme). L'objectif pour les participants à ce programme est de mesurer à l'échelle mondiale la disponibilité de l'éclairage naturel dans un cadre de référence commun. Il y a deux catégories de stations de mesure IDMP: les stations de classe "générale" qui mesurent essentiellement les éclairages lumineux et énergétique, et les stations "de recherche" qui enregistrent aussi la distribution de la luminance de la voûte céleste, ainsi que d'autres données météorologiques.

Ce guide décrit les exigences concernant les mesures et les instruments pour les deux types de stations et donne des références et des recommandations sur le contrôle de qualité, l'archivage et la dissémination des données.

Le guide a été préparé dans le cadre des activités du TC 3-07 de la CIE.

RICHTLINIEN DER EMPFOHLENEN PRAXIS FÜR DIE TAGESLICHTMESSUNG**ZUSAMMENFASSUNG**

Das Jahr 1991 wurde von der CIE zum ersten Jahr des internationalen Tageslichtmessungsprogramms (IDMP) erklärt. Ziel dieses Programmes ist es, weltweit die Tageslichtverfügbarkeit auf einer gemeinsamen Grundlage zu messen. Es existieren zwei Arten von IDMP-Meßstationen: "allgemeine Meßstationen", die im wesentlichen Beleuchtungsstärke und Bestrahlungsstärke messen, und "Forschungsstationen", die auch die Verteilung der Himmelsleuchtdichte und andere meteorologische Parameter messen.

Diese Veröffentlichung beschreibt die an diese beiden Meßstationen gestellten Anforderungen im Hinblick auf Messungen und Instrumente und liefert Richtlinien und Empfehlungen für Qualitätskontrolle, Archivierung und Verbreitung der Daten.

Die Veröffentlichung wurde im Rahmen der Tätigkeit des CIE TC 3-07 erstellt.

1. FOREWORD

Technical Committee 3-07 of the CIE was established to prepare a programme of international collaboration in daylight availability measurements. At present, there are few sites throughout the world for which systematic records of daylight exist: too few, either for accurate long-term prediction of daylight illuminances in buildings or for verification of recent theoretical models of sky brightness. There is a need to establish many more stations for recording daylight availability throughout the world, and there is a need to establish conventions of measurement practice so that data collected in different countries are comparable.

The CIE designated the year 1991 "International Daylighting Measurement Year" as the first year of the "International Daylighting Measurement Programme", referred to as the IDMP, dedicated to the late Prof. Jurgen Krochmann. Under this programme, measuring stations throughout the world participate in a coordinated effort of daylight availability recording. Stations fall in two categories: the General Class, in which illuminances and irradiances are the principal quantities measured; and the Research Class, in which the stations make continuous recordings of sky luminance distributions, as well as of illuminances, irradiances and other meteorological quantities. In addition, it is expected that one or two establishments will act as coordinating centres for the IDMP.

The requirements of General Class Stations and Research Class Stations and the protocol and format of data for international exchange of results are given.

Between 1987 and 1993, eight drafts of this document were produced prior to this final one. Each draft was reviewed by the members of TC 3-07. Unfortunately, the committee was not able to finalize this document before the beginning of the IDMP. A positive consequence of this delay is that additional recommendations, based on the experience gathered by IDMP stations' operators since 1991, particularly concerning data quality control and formatting, could be included in this guide in the form of complementary appendices.

2. PART A: GENERAL CLASS STATIONS

2.1 Introduction

Many General Class stations are required to cover the different daylight climates of the world. The resources needed to cooperate in the programme are at a level appropriate for a research project in a district meteorological station, a school of architecture, or a university department which has an interest in daylighting but does not necessarily have specialist staff and equipment. The measurements will be required to be of sufficient accuracy for practical calculations in lighting design; above all, the aim is to collect design data for the countries taking part.

2.2 The site

2.2.1 Selection of site

There are two requirements. The first is that there exists a site from which the sensors have an extensive view of the sky. Continuous obstructions to light, such as adjacent buildings and trees, should not be higher than 0,08 radians (4,6 degrees) above the horizon; a continuous obstruction 0,08 radians high reduces by 10% the illuminance on vertical surfaces from an isotropic sky. In any quarter of the sky (for example between North and East in azimuth) the total solid angle subtended by obstructions should not exceed 0,13 steradians and preferably be significantly less. It is necessary, with most types of equipment, to house the controller and data-recorder in a secure environmentally-controlled room near the sensors. In many places, lightning protection to the sensors is required.

The second requirement of a recording station is that personnel can be made available for maintenance of the equipment and for statistical presentation of the results. The sensors and the data recorder may require attention almost daily during the complete period of daylight measurement. For international exchange of data, stations will be required to reduce the measured values to specified statistics and to present the results in a standard format.

2.2.2 Description of the site

The following information will be required when measured data are presented. A standard data presentation format is described in section 4, Part C of this Guide.

- a) Name of principal investigator, postal address, telephone, telex and facsimile numbers.
- b) Latitude, longitude, elevation, time zone of measuring site.
- c) A concise verbal description of the climate and of any local factors, such as pollution sources, which may affect daylight availability.
- d) Details of local meteorological stations.
- e) A topographic map showing the land within a 5-kilometre radius of the site.
- f) Either mean ground reflectance measured at hemispherical incidence or a description of the ground surface within the 5-kilometre radius.
- g) Photographs of the view from the sensors in the four cardinal directions, and a stereographic drawing of the sky vault showing all obstructions.
- h) A list of the measuring and recording equipment, including manufacturers' names and model numbers, and details of calibration.
- i) A description of any special local factors affecting the daylight measurements or the processing of results.

2.3 Measurements

2.3.1 Basic set

The basic set of measurements made by a station in the General Class should be:

- a) Global horizontal illuminance (E_{vg}),
- b) Diffuse horizontal illuminance (E_{vd}),
- c) Global horizontal irradiance (E_{eg}),
- d) Diffuse horizontal irradiance (E_{ed}),
- e-h) Illuminance by sunlight and skylight on vertical surfaces facing North, East, South and West (E_{vgn} , E_{vge} , E_{vgs} , E_{vgw}),
- i) Sunshine duration (S).

2.3.2 Additional set

If the required resources are available, a General Class station should also record the following quantities:

- a) Direct (normal) solar illuminance (E_{vs}),
- b) Direct (normal) solar irradiance (E_{es}),
- c) Zenith luminance (L_{vz}).

Any other measurements at a General Class station should be as specified for Research Class stations.

2.3.3 Frequency of measurement

Instantaneous values of irradiance, illuminance and luminance at one-minute intervals should be recorded.

2.3.4 Statistical summary of data

The data from each sensor plus the derived global and diffuse luminous efficacies (E_{vg}/E_{eg} and E_{vd}/E_{ed}) should be sorted in three ways:

- a) frequency distributions classified by solar altitude in 6-degree intervals,
- b) frequency distributions classified monthly by half-hourly intervals,
- c) continuous time series of half-hourly mean values.

Sunshine duration (S), should be presented as frequency distributions of the sum of sunshine periods in each half-hour period, classified monthly. The duration should be given in increments of 0,1 hour.

Where resources permit, all raw measured data should be retained.

Part C of the Guide will describe statistical procedures and the format for storage and transmission of results. It will also list statistical checks to be applied to the data during analysis, and correction factors for illuminance on shaded cells.

2.4 Equipment

2.4.1 Screening of sensors

Sensors measuring diffuse illuminance and irradiance should be screened from direct sunlight by a standard shade ring with a band width, b , between 0,20 and 0,24 of the band radius, r . In presentation of the data the correction factor for an isotropic sky should be applied [1]. To avoid frequent adjustment of shade rings, it is recommended that diffuse illuminance and irradiance be measured with small diameter sensor heads.

Sensors measuring illuminance on vertical surfaces should be screened from ground-reflected light by a matt black screen forming an artificial horizon at the level of the centre of each photocell. The perpendicular distance between the cell and the screen should be at least ten times the diameter of the cell acceptance area. Light reflected upwards within the artificial horizon should be minimized by using matt black louvres or other means.

Sensors measuring normal solar illuminance and irradiance should be mounted on solar tracking devices. The field of view should be defined by an open half-angle of 2,5 degrees with a slope angle of 1 degree [2].

The requirements for luminance sensors are listed in Section 3, Part B of the Guide.

2.4.2 Calibration and accuracy of photometers

The accuracy of daylight measurements depends on the quality of the photometer, on calibration errors, and on the measuring time interval and respective summation period. CIE Publication 69 [4] describes the evaluation of photometers. Photometers are generally calibrated with a luminous intensity standard lamp which was itself calibrated at a National Institute against a Standard Illuminant or with a standard detector. In any report on instrument calibration, the uncertainty of the standard used should be stated.

In addition to uncertainty in the photometric standard, errors can arise during calibration of the photometer in the laboratory. These may be caused by incorrect settings of the electrical parameter of the standard, aging of the standard, incorrect ambient temperature, stray light, or insufficient measuring distance. Errors may be minimized by the use of precision measuring instruments and, if necessary, control measurements at the laboratory responsible for calibrating the photometric standard. It is satisfactory to calibrate photometers by an absolute measurement at one level and obtain calibrations at other levels by relative measurements.

Calibration of photometers should normally be made under the following conditions:

- a) illumination with Standard Illuminant A,
- b) illumination with unpolarised light,
- c) homogeneous illumination of the acceptance area,
- d) normal incidence of light,
- e) ambient temperature 25° C.

Table 2.1 is based on CIE Publication 69 but lists error limits associated with high quality illuminance meters specifically intended for external daylight measurements.

Table 2.1: Error limits of illuminance meters for external daylight measurements

	symbol	error limit %
V(λ)-match	f'	2,5
UV-response	u'	0,2
IR-response	r	0,2
cosine-response	f_2	1,5
fatigue at 10 klx	f_5	0,1
temperature coefficient	a	0,1 %/K
linearity	f_3	0,2
display unit	f_4	0,2
settling time	$t_{\max}$	0,1 s
range change	f_{11}	0,1

In addition, consideration must be given to the following:

- a) aging,
- b) zero setting drift,
- c) mechanical stability,
- d) climatic stability,
- e) recalibration period (normally 1 year).

It is desirable that a check on instrument accuracy be made independently of manufacturer's values.

Illuminance meters should normally be autoranging over $1 \text{ lux} < E < 2 \times 10^5 \text{ lux}$. External photometer heads must be water protected, maintained stable in temperature (normally with thermostatic control between -10° and 40°C), and ventilated to prevent condensation and ice coating. Means of leveling and of orientation of vertical cells should be provided.

2.4.3 Calibration and accuracy of radiometers

The characteristics of equipment for the measurement of irradiance, including both sky irradiance and direct sun irradiance, are described in the World Meteorological Organization Guide to Meteorological Instruments and Methods of Observation [1]. WMO Class 1 instruments should be used.

2.4.4 Sunshine Duration

The periods of sunshine duration should be those that would be recorded as a burnt trace on a standardized card of the WMO International Reference Sunshine Recorder. Alternatively, sunshine duration may be taken as the time during which Normal Solar Irradiance (E_{es}) is at least 120 W/m^2 [3].

3. PART B: RESEARCH CLASS STATIONS

3.1 Introduction

In addition to the collection of data which may be used in design, Research Class stations collect data required for basic research in daylight prediction. These stations will be located mainly in research establishments where expert staff are available.

3.2 The site

Same as Part A.

3.3 Measurements

3.3.1 Basic set

The basic set of measurements made by a station in the Research Class should be:

- i. Global horizontal illuminance (E_{vg})
- ii. Diffuse horizontal illuminance (E_{vd})
- iii. Direct (normal) solar illuminance (E_{vs})
- iv.-vii. N,E,S,W vertical illuminance (E_{vgn} , E_{vge} , E_{vgs} , E_{vgw})
- viii. Global horizontal irradiance (E_{eg})
- ix. Diffuse horizontal irradiance (E_{ed})
- x. Direct (normal) solar irradiance (E_{es})
- xi.-xiv. N,E,S,W vertical irradiance (E_{egn} , E_{ege} , E_{egs} , E_{egw})
- xv. Air temperature
- xvi. Dew point temperature
- xvii. Sunshine duration (S)
- xviii. Zenith luminance (L_{vz})
- xix. Total cloud amount
- xx. Sky luminance distribution (L_v)

3.3.2 Additional set

Wind speed and wind direction at 10 metres are recommended as supplemental measurements; these could be obtained from a nearby weather service site. Global horizontal measurements of PAR (photosynthetically active radiation) is a further possibility. As a consequence of the intense interest in ultraviolet radiation changes, 3 to 6 filter measurements between the ultraviolet wavelengths of 280 nm and 380 nm are strongly encouraged (specific wavelengths and instrumentation will be detailed in future publications of the CIE).

3.3.3 Frequency of measurement

Same as Part A with the exception of xix and xx. Luminance distribution measurements should be made every 30 minutes centered at 15 and 45 minutes after the hour. Luminance distribution measurements should also be made whenever the solar elevation angle is divisible by 6 degrees. If the solar elevation angle is within 1 degree of a targeted solar elevation at 15 or 45 minutes after the hour, then only the fixed-time scan shall be made, (high latitude stations may wish to record at 3-degree solar elevation changes).

If possible, cloud cover should be measured at the site at 15 and 45 minutes after the hour; otherwise, cloud cover records from an adjacent meteorological station should be used. If neither full site records nor appropriate meteorological data can be obtained, the daily cloud cover at 6:15 AM and 3:15 PM should be reported (use Local Standard Time or state adjustments made).

3.3.4 *Statistical summary of the data*

All data passing quality-control checks should be permanently archived at the research station. Otherwise, same as Part A except for xix and xx.

Total cloud amount should be reported in octas (eighths). Further, it is suggested that cloud amount within nineteen regions of the sky hemisphere also be reported. The sky dome is to be divided into 8 azimuthal and 3 zenithal regions as illustrated in Figure 3.1 as suggested by [5]. All luminance data for the skylight distribution scans should be reported (see Part C Section 4).

3.4 **Equipment**

3.4.1 *Screening of sensors*

The screening of illuminance and irradiance sensors follows Part A with the exception that normal solar illuminance and irradiance may be measured with a field of view whose open half-angle is less than or equal to 2,85 degrees and whose slope angle is less than or equal to 1,76 degrees. It is imperative to choose the same field of view for the direct illuminance and irradiance measurements.

The sky scanning luminance sensor and the zenith luminance sensor should be tested for their ability to measure luminance in the vicinity of the sun. Scattered light within the instrument can create a false signal. Scattered light from a nearby strong source, such as the sun, can overwhelm the luminance signal that one attempts to measure.

A rigorous method of determining the response of a restricted field-of-view luminance sensor to radiation outside that field of view is to test it in a darkened room, with an electric source illuminating the sensor from some distance, thereby simulating a point source for this test. The sensor is stepped between 0 and 90 degrees, and the sensor response is measured to determine the complete stray light response curve. Actual measurements of direct beam illuminance and sky luminance can subsequently be used in conjunction with the stray light response function to assess the stray light component of any measurement, especially those near the solar direction.

A reasonably easy, although less rigorous, test of stray light for the scanning sensor is to perform three sky scans in rapid succession on a clear day near solar noon. The first and third scans are performed normally, but the middle scan is performed with the direct radiation on the entrance aperture blocked by a shading device at a distance that precludes the contamination of all but the near sun sample. Comparison of the samples in the sun's vicinity should indicate whether further baffling is needed. Samples centered 22 degrees from the sun centre should not have a scattered component >10% of the measured signal.

Concentric baffles within the sensor housing are typically used to decrease the scattered light that reaches the sensor. An alternate approach to increased baffling is to perform all measurements with the direct solar radiation blocked by a tracking sun shade for the entrance aperture.

The field of view for the zenith luminance sensor should be defined by an open half-angle of 5,5 degrees. Zenith luminance should not be recorded when stray light from outside the geometric field of view exceeds 10% of the total signal received.

The recommendations for the sky-scanning luminance meter (luminance mapper) are given by limits rather than precise specifications because several well characterized scanners now exist and for physical reasons that are explained in what follows.

Tregenza [6] suggested a measurement pattern that is recommended here for researchers who will design and build a scanning luminance meter for this campaign.

Table 3.1: Position of sky scan samples

elevation of band centre	# samples	azimuth increment
6 deg	30	12 deg
18	30	12
30	24	15
42	24	15
54	18	20
66	12	30
78	6	60
90	1	-

For the sake of intercomparability, it will be a requirement to report measurements for these sky directions, even though taken at other directions or more directions (as with sky imaging). The method of interpolating from the actual measured sky directions to the reported directions shall be stated by the researcher and in no case shall the nearest adjacent measured direction depart from the reported direction by more than 10 degrees. The first sample of each elevation scan should be taken centered at the solar azimuth. The sequence should start at the lowest elevation proceeding in a westward direction. A field of view of 11 degrees is suggested. Although this field of view should be the goal, smaller fields of view are acceptable because it is unlikely that the mean luminance within an 11 degrees cone will differ appreciably from the mean luminance within a smaller cone, especially in a statistical sense, and because well characterized scanners with smaller fields of view currently exist.

The duration of the complete sky scan should be as short as possible. One minute scans are recommended as a goal for instrument designers. However, a time limit on the scan is rather arbitrary, and slower scans should be acceptable because well characterized scanners with longer scans currently exist and for the following physical reasons: clear skies and heavily overcast skies change their luminance distribution rather slowly. It is the partially obscured sky that is of most concern when trying to set a time limitation. However, it is important to note that no partly cloudy sky luminance distribution will ever be reproduced, therefore, it may not be crucial to impose a time limitation on a scan. Since the scan will be composed of instantaneous luminances, the goal to sample realistic skies is accomplished, even if not simultaneously for the complete sky. Based on these considerations, an upper limit of 2,5 minutes for scan completion is recommended.

3.4.2 Calibration and accuracy of photometers

Same as Part A. The instruments should have the accuracy published in CIE documents or be correctable to the indicated levels. Calibration should be repeated every six months. Participants and others interested in the IDMP will be advised of amendments or new publications regarding these requirements.

3.4.3 Calibration and accuracy of radiometers

Same as Part A. The instruments should have the accuracy published in WMO documents or be correctable to the indicated levels. Calibration should be repeated every six months. Participants and others interested in the IDMP will be advised of amendments or new publications regarding these requirements.

3.4.4 Sunshine duration

Same as Part A.

3.4.5 Cloud cover

Total and directional amount should be assessed. One of the following should be used: all-sky photographs or video-based images in two filters (blue-red) are preferred; on-site observations will be required, otherwise.

This should be based on a subdivision of the sky into the nineteen zones shown on Figure 3.1:

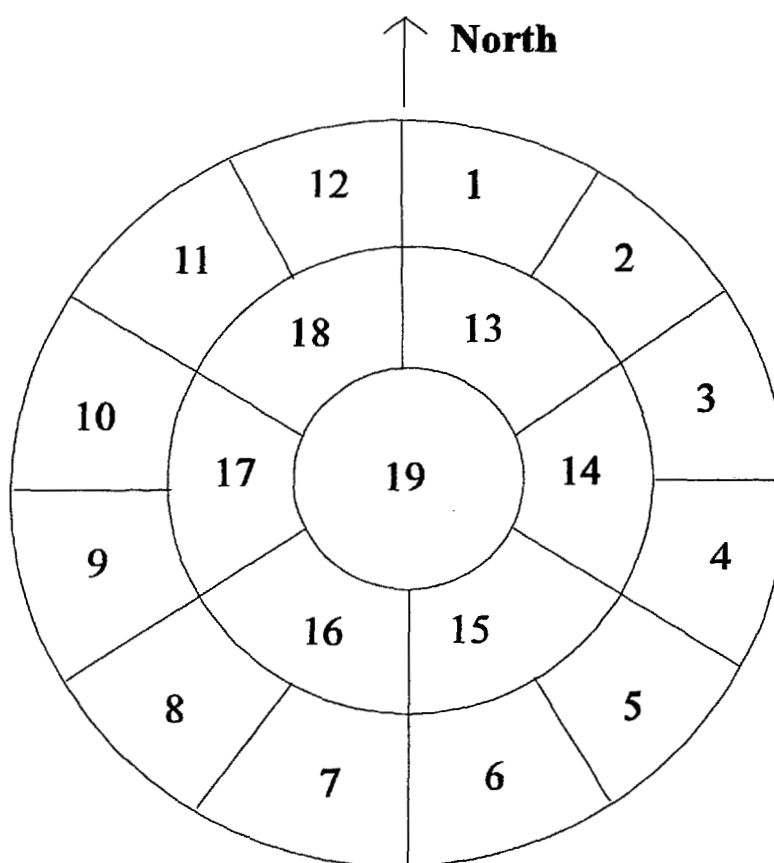


Figure 3.1: Subdivision of the sky for cloud assessment (stereographic projection).
 Angular size on zones:
 lowest band (1-12) 0° to 30° elevation; size: 0,31 steradians
 central band (13-18) 30° to 60° elevation; size: 0,38 steradians
 zenith zone (19) 60° to 90° elevation; 0,31 steradians.

CIE 108-1994

The following should be recorded:

- i. Total cloud cover in octas, based on an average of all zones.

Then, for each zone, if a detailed analysis is possible:

- ii. The fraction of the zone covered by cloud, in octas. It should be coded as follows:

0	no cloud
1-7	one-eighth to seven eighths of zone covered by cloud
8	zone completely covered
9	zone obscured, or cloud cover cannot be estimated.

- iii. The principal cloud type in the zone (the cloud type covering the greatest area of sky). It should be coded as follows, using WMO classification of cloud type:

0	no cloud present
1	cirrus
2	cirrocumulus
3	cirrostratus
4	altocumulus
5	altostratus
6	nimbostratus
7	stratocumulus
8	stratus
9	cumulus
10	cumulonimbus
11	cloud type cannot be assessed.

Cloud cover and type might be assessed in one of the following ways:

- a. Subjective observations of the sky. It should be noted that, even with trained observers, considerable inaccuracies can occur, and this method should be employed only when other means are unavailable.
- b. Analysis of full sky photographs, the photographic image of the sky should be overlaid with a grid or a dot pattern to assess the proportion of sky covered in various zones. Subjective estimates should not be made from unstructured photographs. Care should be taken in assessing cloud near the horizon, and in the vicinity of the sun, where overexposure of the image may mask cloudiness. If there is doubt, categories ii.9 and iii.11 (above) should be used.
- c. Automatic analysis of cloud quantity from video camera image made through filters.
- d. Analysis of satellite images. This may be done visually as for full-sky photographs, from standard weather satellite recordings, or automatically, using computer techniques. It should be noted that the distribution of clouds seen from space differs from that seen from a point on the ground, due to the three-dimensional forms of clouds. The cloud assessed should be that lying within a ten-kilometre radius of the recording station. It is essential to ensure that the time of the satellite image corresponds with the appropriate recording time of the ground station.

The method of cloud assessment should be listed in the standard site description.