METEOROLOGICAL SERVICE

INTERNAL MEMORANDUM 110/86

AN INTRODUCTION TO THE NATURE AND MEASUREMENT OF SOLAR RADIATION

BY

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SOLAR RADIATION

1. Introduction

Energy from the sun in the form of ultra-violet, visible and infra-red electromagnetic radiation is known as solar radiation. It has been measured by the Meteorological Service since 1954 when the first pyranometer was installed at Valentia Observatory. At present, observations of solar radiation are made at seven meteorological stations as well as by some Universities and other research institutes. Data are published in annual volumes and are available on computer tape.

Solar radiation is measured by the Meteorological Service as one of the many elements in its observational programme and is being added to the climatological data base. It is also used in agrometeorology where plant growth, ripening and drying conditions and crop yields are related to the solar energy available. Solar radiation data have been supplied to users interested in studying the correlation between solar radiation and such topics as the growth of plants, algae and planktons; the efficiency of solar energy collectors; solar heating, and research into the measurement and analysis of solar radiation.

These notes are intended to provide background information on the nature of solar radiation, the instruments and methods used to measure it, the Irish station network and the calibration procedures which link each instrument to the world standard reference.

2. Nature of Solar Radiation

Solar radiation is electromagnetic radiation emitted from the surface of the sun and intercepted by the earth. The spectrum is similar to that of a black-body at 5777°K although some estimates range from 4500°K up to 7000°K depending on the part of the spectrum examined. The electromagnetic spectrum ranges from X and Gamma rays at wavelengths shorter than 100nm to microwaves and radiowaves at the longer wavelengths (tens of metres). The wavelengths of solar radiation reaching the earth range from 280nm in the ultra-violet to about 3000nm in the middle infra-red. By comparison, the human eye is only sensitive to radiation with wavelengths between 380nm (violet) and 720nm (red). [Note: 1nm = 10 Angstroms = 10^{-9}m]. Figure 1 shows the solar spectrum and the region covered by longwave infra-red terrestrial radiation. The total solar energy reaching the earth is $1367W/m^2$ on average and this figure is known as the solar constant.

Solar radiation with wavelengths greater than 3000nm, about 2% of the total energy reaching the earth, is absorbed by the atmosphere. Radiation from other sources at still longer wavelengths, such as far infra-red, micro- and radio waves, is transmitted through the "atmospheric window". Water vapour, especially in clouds, and carbon dioxide also absorb some radiation in the infra-red region while ozone absorbs much of the ultra-violet. The eye is sensitive to a region of the spectrum which is not absorbed by the atmosphere.

Radiation is, however, subject to scattering by molecules, water droplets and suspended particles (aerosols) in the atmosphere. The blue skies and red sunsets are a result of the scattering, by air molecules, of the shorter wavelengths by a process known as Rayleigh scattering. This applies particularly to the blue and ultra-violet parts of the spectrum. Radiation is also scattered by aerosols and haze droplets by Mie scattering. Any scattered radiation reaching the Earth's surface is diffuse radiation. Radiation in the direct beam reaching the surface is direct radiation. Global radiation is the sum of the direct beam plus the diffuse radiation incident on a horizontal surface.

The maximum amount of radiation which can reach the surface at any time depends on the elevation angle of the sun. The greatest elevation is at midday and varies from a minimum at the winter solstice to a maximum at the summer solstice. The radiation at the surface, of course, also depends on the extent and thickness of the cloud cover. Usually the mean daily global radiation is a maximum in summer and a minimum in winter although climatic conditions may have an influence at low latitudes. Table 1 shows the mean daily global and diffuse radiation in Ireland for each month in 1984.

The amount of diffuse radiation depends on the degree of scattering of the direct beam by the atmosphere and clouds. The lowest ratios of diffuse to global radiation are usually recorded in bright sunshine when scattering is least, and the highest ratios, never exceeding but often equal to one, occur in overcast conditions.

Radiation near the surface at wavelengths longer than 3000nm is not usually of solar origin but is emitted by much cooler bodies such as the sky or the surface of the earth and is called terrestrial radiation or, more commonly, infra-red or longwave infra-red. The term, infra-red, can be a little confusing as it covers a wide part of the spectrum. The infra-red part of the solar radiation spectrum is in the near and middle infra-red while terrestrial is in the far infra-red. Reference to infra-red on its own usually refers to terrestrial radiation.

Terrestrial radiation is emitted in proportion to the fourth power of the absolute temperature on the Kelvin scale. [0°C = 273.16°K]. The warm earth and low clouds emit more radiation than the cold sky. As a result there is often a net upward flux of terrestrial radiation which at night leads to surface cooling and, sometimes, frosts or fogs. A layer of low or even medium cloud is usually sufficient to prevent this upward flux.

Net radiation is the difference between the incoming and outgoing radiation and includes solar radiation from the sky and that reflected from the ground, as well as terrestrial radiation. It gives a measure of the net flow of energy to or from the surface. The balance is usually net incoming during daylight hours and net outgoing at night although the reverse can occur especially with a covering of snow on the ground when the albedo is very high and the surface temperature is low.

As mentioned earlier, solar radiation is scattered by air molecules, aerosols and water droplets. The amount of radiation scattered by air molecules is dependent only on the mass of air through which the beam passes. Therefore the total scattered radiation and the wavelengths of the scattered radiation depend on the amount of suspended particles or aerosols and haze (very small water droplets). The major source of high concentrations of aerosols is atmospheric pollution. Sunsets are more colourful in polluted areas due to the larger amounts of light scattered from the direct beam. Turbidity is a measure of the amount of scattering in the atmosphere and is usually estimated by measuring the radiation received through various filters.

Summary of radiation terms:

Global	Sum of the direct beam plus the diffuse radiation on a horizontal surface.
Diffuse	Scattered solar radiation on a horizontal surface
Direct	Solar radiation at normal incidence in the direct beam from the sun
Infra-red	Terrestrial infra-red radiation emitted by the sky and the Earth's surface
Net-balance	Combined downward solar and sky infra-red minus upward reflected solar and terrestrial radiation
Turbidity	Measure of the amount of scattering in the atmosphere

3. Measurement of Solar Radiation

Solar radiation, when incident on a surface, is partially absorbed and as a result heats the surface. If the surface is black then almost all of the incident radiation is absorbed. The rise in temperature resulting from the heating of the surface is proportional to the intensity of the incident radiation provided that the surface has a small thermal capacity and responds quickly. Most radiation sensors use this rise in temperature to measure solar radiation although some sensors use other methods such as photo-dissociation as used in photovoltaic cells.

The most frequently used sensor is the pyranometer which consists of a thermopile composed of a number of thermocouples wired in series.

A thermocouple generates a voltage across a junction of dissimilar metals, for example manganin-constantan, in proportion to the temperature. A second similar junction, the cold junction, is kept at constant or ambient temperature and its output is subtracted from that of the first junction. The output from such a pair of junctions is a voltage proportional to the difference in temperature between the two junctions.

A thermopile consists of a series of thermocouples with the alternate junctions being warm and cold. The thermocouples can be laid out in a rectangular or circular arrangement. The warm junctions are in thermal contact with the absorbing surface which is of low thermal capacity and is usually coated with lamp black or Parson's black lacquer. The cold junctions are in contact with a copper or brass disc, of relatively large thermal capacity, which remains at ambient temperature. Figure 2 shows a schematic diagram of a thermopile and the layout of a Moll type thermopile. In a pyranometer the cold junctions are kept at the temperature of the body of the instrument which is painted white and screened from direct radiation to minimise solar heating. However, many pyranometers are somewhat temperature dependent since the cold junctions follow the air temperature causing an error of around 0.2% per °C for each degree above or below 20°C. Some of the modern pyranometers have special compensation circuits to overcome this problem.

The sensitive surface is protected by a pair of concentric glass domes. Two domes are necessary to prevent condensation on the inner dome which would otherwise occur due to radiative cooling at night. The glass transmits wavelengths of solar radiation between 300nm and 2500nm which corresponds reasonably well with the solar radiation spectrum except at the infra-red end. This loss of some of the infra-red region is not serious as it contains only a small percentage of the total energy.

Pyranometers are not perfect. The black surface may not be uniformly black, particularly as it ages, and it may not be level or smooth. Errors, resulting from sensor faults occur especially at low angles of incidence and are often called cosine errors as they are departures from the normal cosine response expected. Kipp and Zonen CM6 pyranometers, with their rectangular arrangement of the thermopile, are subject to an azimuth error where the magnitude of the error depends on the azimuth angle of the incident radiation. Most pyranometers are temperature dependent as mentioned above. The response time to rapidly changing radiation levels, for example in showery conditions, is slow in some of the older models. Calibration factors can change as the sensor ages and can become unstable and fluctuate widely after 15 to 20 years.

Overall, good pyranometers such as the Eppley PSP and the Kipp and Zonen CM10 which feature a circular thermopile arrangement have small azimuth errors and are accurate to about 2% for hourly values and 1% for daily means. The CM6 and similar pyranometers are accurate to 5% for hourly values and 2% for daily values if regularly calibrated while some of the older models may only be accurate to 10%. Plate 1 shows a Kipp and Zonen CM10 pyranometer, two CM6 pyranometers and an Eppley Infra-Red Pyrgeometer.

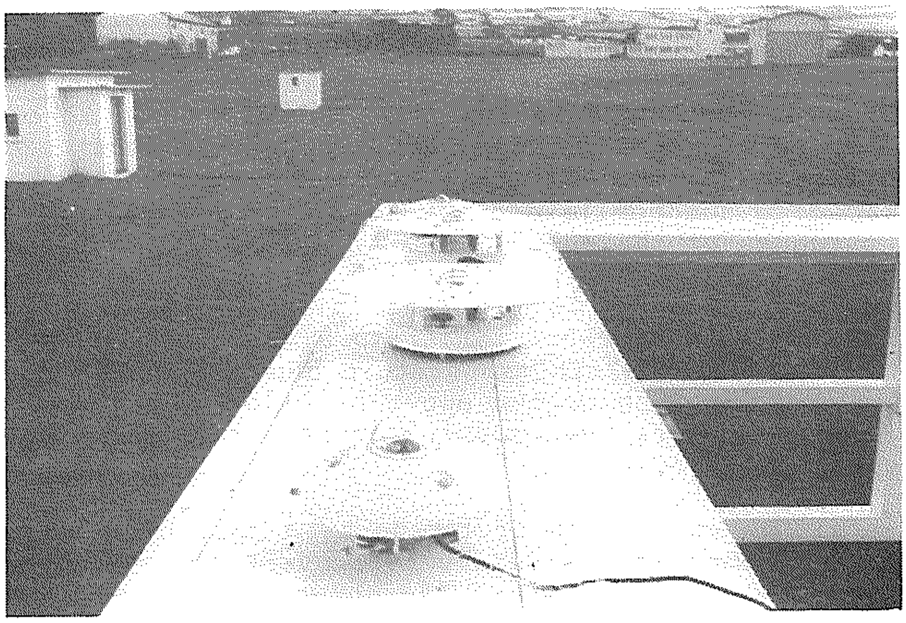

Plate 1. From the front a CM10 Pyranometer, two CM6 Pyranometers (Travelling Standard and Global) and the Infra-red Pyrgeometer.

Global and Diffuse.

A pyranometer mounted with its sensor horizontal measures the vertical component of the total incoming solar radiation. As earlier defined this is global radiation and is the sum of both the direct and diffuse components.

Diffuse radiation on a horizontal surface can be measured in three ways:

1. Measure the global and the direct at normal incidence. Compute the vertical component of the direct and subtract from the global to obtain the diffuse.

2. Measure the diffuse directly by means of a shading or occulting disc to block the direct beam from the sensor.

3. Use a shading ring or band to screen the sun from the sensor and apply the necessary corrections to allow for the portion of the sky obscured by the band (see Plate 2).

Methods 1 and 2 require the use of a motorised mount to point the direct sensor at the sun or to keep the shading disc, which casts a shadow only a little larger than the sensor, between the sun and the sensor. The first is expensive as a pyrheliometer and recording equipment must be used. Both are unreliable as the tracking equipment can fall out of alignment unless closely monitored but are more accurate than the shading ring method.

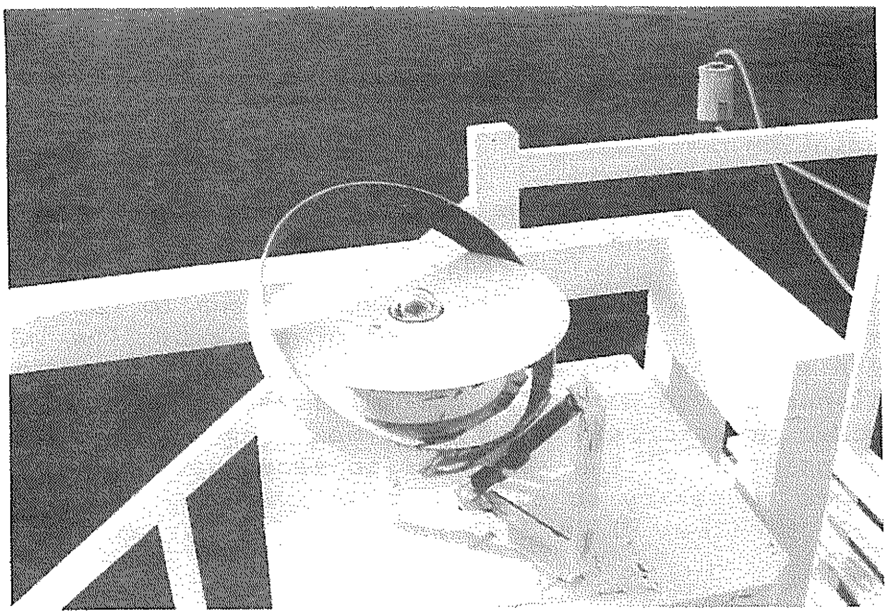

Plate 2. Diffuse Pyranometer with shading ring.

Method 3 is very simple and reliable having no moving parts. The only adjustment needed is to change the position of the ring on pre-set dates to allow for the changing declination of the sun. However, the shade ring, while screening the sensor, also screens a portion of the sky. Therefore a correction, which varies from as little as 4% in winter to as high as 23% in summer, must be applied to the recorded data to allow for this screening. The corrections are based on the amount of the vertical component of the diffuse radiation which is screened and assumes a uniform overcast or isotropic sky. The corrections do not take into account that the sky, especially in bright sunshine, can be far from isotropic with the region near the sun being brightest. Research has taken place to derive a further correction for non-isotropic skies and some methods have been proposed but are not yet applied on a routine basis.

Radiation Balance

The radiation balance meter or net pyrradiometer which measures the net flux of radiation, both solar and terrestrial, consists of two thermopile type sensors. One sensor is facing upwards and measures the total downward radiation. The second is facing the ground and measures the reflected solar radiation and the terrestrial radiation emitted by the ground. The outputs of the sensors are wired in opposition so that only the difference, or net balance, is recorded. Ordinary glass domes cannot be used as glass absorbs the terrestrial infra-red radiation. The domes are, instead, made from lupolen film, a type of polythene, and are kept inflated and in shape by a steady flow of dry air or nitrogen. Condensation on the domes is prevented by using a circular electric heating ring which heats both domes equally. Data are usually recorded on a chart recorder on which the zero is offset to show both the positive and negative swings in the balance.

Direct Radiation

Direct radiation from the sun is measured by a pyrheliometer pointing at the sun. The pyrheliometer consists of a hollow tube about 25cm in length with internal diaphragms which only allow the radiation from a fixed angle around the sun to reach the sensor, a thermopile, at the lower end of the tube. The tube is sealed with a quartz window to provide protection from moisture and turbulence due to wind. The pyrheliometer is mounted on a solar tracker, a motorised equatorial mounting which keeps the instrument pointing at the sun. Occasional adjustments to the alignment are necessary to allow for the changing declination and the equation of time. Plate 3 shows an Eppley Pyrheliometer.

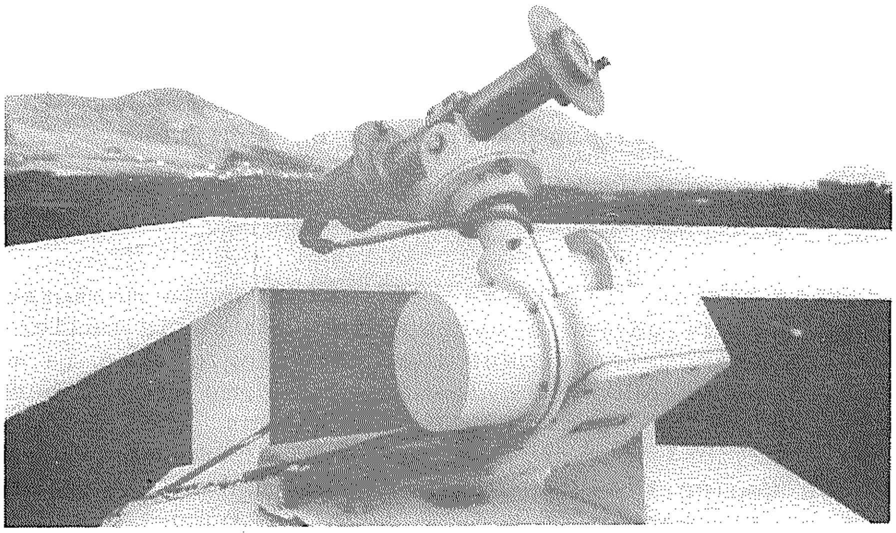

Plate 3. Eppley Normal Incidence Pyrheliometer mounted on an equatorial motor drive solar tracker.

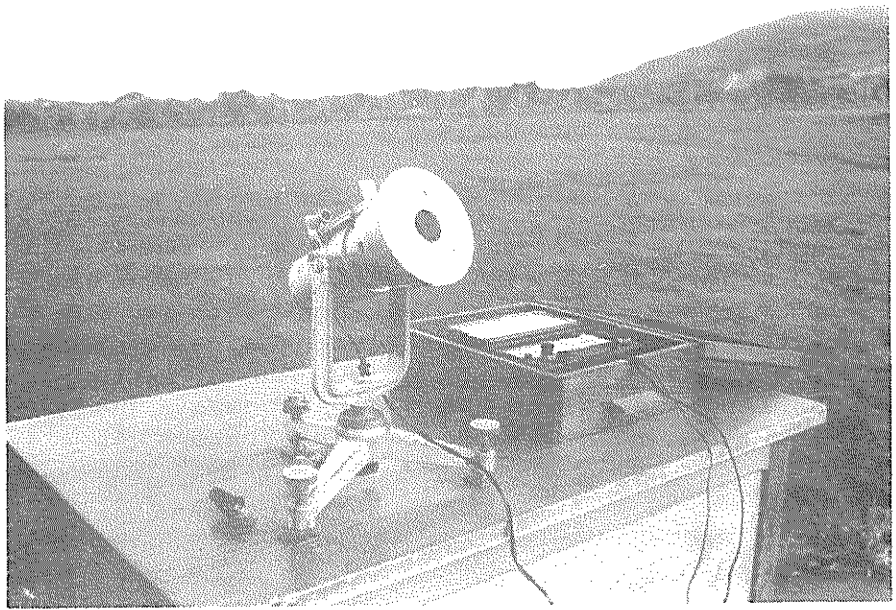

Plate 4. The Linke-Feussner Actinometer.

Instantaneous readings of direct radiation are made with an actinometer (Plate 4). The actinometer is a type of pyrheliometer about 10cm in length, with a thermopile as a sensor. A circular aperture is defined by a series of six internal copper rings which are of large thermal capacity. The instrument features a second thermopile, screened from the sun which is used to partially compensate for changes in ambient temperature and any air currents around the sensor. The aperture is not sealed but provision is made for the addition of filters for use in turbidity observations. Figure 3 shows an outline diagram of an actinometer.

Infra-red

Incoming terrestrial infra-red radiation is measured by a type of radiometer, called a pyrgeometer, which is basically similar to a pyranometer except that the single dome is made of quartz and is silvered on the inside. The dome only transmits terrestrial radiation from the sky and clouds. The sensor, being in thermal equilibrium with the source of the incoming radiation, can often be cooler than the 'cold' junctions which are at ambient temperature resulting in a negative output from the thermopile. A voltage, which includes compensation for changes in the ambient temperature, is added to the output by an internal battery to allow for this effect and keep the cold junctions at a virtual 0°K.

Recording Equipment

The output from most radiation sensors is usually in the 0 to 15mV range and may be recorded on a potentiometric chart recorder such as the Kipp and Zonen BD8 and BD40 recorders or electronically integrated. Charts are scaled by hand. Accurate tabulation, however, can be difficult particularly with records from broken cloudy days.

Electronic integrators, such as the Kipp and Zonen CC1, CC2 and CC11 and the Lintronic and Eppley models, sum the input voltage producing a count when the equivalent of a preset amount of radiation has been received. They provide a convenient and accurate method of recording hourly mean values as most integrators have an hourly printout. At low radiation levels, however, chart recorders are often more accurate due to zero-offset errors and thresholds on some integrators.

L.A.T. and the Equation of Time

All solar radiation recordings, including sunshine, are made in Local Apparent Time (L.A.T.) sometimes called True Solar Time (TST). The sun is due south at midday or 1200LAT. However this does not occur at the same standard (GMT) time every day due to the equation of time. The equation of time gives the difference between local mean time and LAT. This difference is not constant but varies during the year due to the eccentricity of the earth's orbit and the fact that the ecliptic is inclined to the celestial equator (or that the Earth's axis is tilted). Thus the LAT correction at any time is made up of the equation of time, a variation of between +17 and -14 minutes on local mean time, and the difference between GMT and local mean time, at 4 minutes per degree longitude from Greenwich. For example, the difference between GMT and LAT at Valentia varies from 27 minutes in October to 58 minutes in January. Figure 4 shows the variation of the equation of time during the year.

The clocks on all recording equipment must be adjusted occasionally, as often as three times a week at certain times of the year, to allow for the equation of time. This adjustment is carried out automatically on some of the modern microprocessor based integrators such as the Kipp and Zonen CC10/CC11 series.

4.Solar Radiation in Ireland

The Irish Radiation Network

Solar radiation observations by the Meteorological Service commenced in Ireland in 1954 when a Kipp and Zonen Moll-Gorczynski thermopile pyranometer and a recording millivolt meter were installed at Valentia. A second pyranometer, fitted with a shading ring, was installed in 1962 to provide a record of diffuse radiation. Electronic integrators giving hourly printouts were added later.

At present, global and diffuse solar radiation instruments are installed at Birr, Kilkenny, Dublin Airport, Clones and Malin Head. Only global radiation is recorded at Belmullet. At all sites global radiation is recorded on electronic integrators with chart recorders serving as a backup. Figure 5 shows the location of the Meteorological Service radiation stations together with the date of commencement of observations. Figure 6 shows a schematic layout of solar radiation instruments at a station. Solar radiation is also recorded at several other locations by independent users such as Universities and agricultural institutes for research purposes.

Net radiation balance observations, using a Funk type Net Pyrradiometer, commenced at Valentia in 1971 and in Kilkenny in 1982. Data are recorded on chart recorders with the zero offset to allow for the negative swings in the balance. Electronic integrators, which can only measure positive voltages, are unsuitable.

Measurements of direct solar radiation, using an Eppley Normal Incidence Pyrheliometer mounted on a solar tracker, began at Valentia in 1979, as did measurements of terrestrial infra-red using an Eppley Precision Radiometer (Pyrgeometer).

Measurements of total radiation on two south-facing vertical surfaces, one of which is shielded from ground reflected radiation, were introduced at Valentia in 1981 as part of an EEC sponsored research project. In addition, global radiation reflected from the ground was also measured from 1981. The ratio of the reflected to the incident radiation is the albedo of the ground. The albedo of grass is typically around 20% to 25%.

Instantaneous readings of direct radiation are made at Valentia when sky conditions permit. These measurements are made with a Kipp and Zonen Linke-Feussner actinometer fitted with three Schott glass filters - deep red, red and yellow. The filters are used to limit the region of the spectrum reaching the sensor by removing the short wavelengths. The difference between the unfiltered radiation and that measured through a filter gives the amount of short wave radiation in a band determined by the filter, e.g. the yellow filter gives the radiation in the green, blue and violet area while the deep red filter also includes yellow, orange and red radiation. This amount varies with the turbidity as atmospheric scattering tends to remove the shorter wavelengths. The ratio of the radiation measured in the various bands can be used to estimate the Angstrom coefficient of atmospheric turbidity.

Turbidity is also measured by a Volz sun photometer - a hand-held instrument consisting of a photocell, meter and red, green and blue gelatin filters. Measurements are made with light passing through each filter in turn. The photometer gives direct measurements of the radiation in a band unlike the actinometer where the radiation in a band is found by subtraction of two readings. The ratio of the radiation through the filters is used to calculate the turbidity. One of the purposes of turbidity measurement is the monitoring of atmospheric pollution and the movement of air masses.

Data Processing

All solar radiation data processing is done at Valentia. Each month the radiation records from all the stations are sent to Valentia together with the tabulated hourly values of global and diffuse. The data are given a preliminary examination to check for tabulation and instrumental errors and re-tabulated if necessary. Missing data are estimated if possible. Monthly and 10-day totals are extracted from the global records for inclusion in the Agrometeorological Bulletin.

Data are usually processed in six monthly or annual batches. A comparison of the daily totals of global and diffuse data, with the shade ring corrections applied, on days with zero sunshine is used to provide a basis for any adjustments to the diffuse data needed to bring them into line with the global and to check on the consistency of the results. The shade ring corrections, together with any adjustments, are then applied to the diffuse data. Subsequently the corrected diffuse data are compared with the global to ensure that the diffuse do not exceed the global at any time. A check with the sunshine record also serves as a further quality control test. Monthly means are computed when all corrections are completed. Figure 7 shows a schematic summary of data processing.

Direct solar radiation data are first checked against the sunshine record and then against values estimated from differences between the global and diffuse data. Missing direct data can be estimated from the global-diffuse readings for the same hour though accuracy decreases considerably at low solar elevation angles.

Twice yearly the Valentia hourly balance values and the daily totals and monthly means of the global radiation from all stations are sent to the World Radiation Centre in Leningrad, USSR. Daily totals of global, diffuse, direct, terrestrial infra-red and Valentia balance are published in the yearbook. The instantaneous readings taken with the actinometer through the various filters are included in the yearbook as is a description of the layout and instruments used at each station. Hourly values of global, diffuse and balance are transferred to the computer record on the DEC2050 at the Meteorological Service Headquarters in Dublin and undergo a final quality control check. Turbidity measurements, made with the Volz sun photometer are sent to the National Climatic Centre, Asheville in the United States.

Quality Control

Quality control of radiation data starts with the regular maintenance and calibration of the pyranometers and recording equipment. The performance of all equipment is monitored at Valentia and remedial action taken when necessary.

Each day all radiation stations tabulate the global and diffuse records from integrator printouts or chart recordings. As part of this tabulation process the global data are checked against the sunshine record and against the diffuse. In general, the global should be always greater than or equal to the diffuse although the reverse can occur near dawn and dusk due to integrator zero offset errors. In cloudy conditions the diffuse should be approximately 75% of the global in summer and 90% to 95% in the winter. These percentages decrease with increasing sunshine duration. Simple checks as outlined above can eliminate most tabulation errors and some instrumental errors.

At Valentia the records are checked on arrival. They are again checked in detail after the shade ring corrections have been applied to the diffuse and are given a further check when transferred to the computer record.

The Future

In the near future the data processing will probably be done by microcomputer. Looking further ahead, possible developments might include the use of data loggers to record the data on cassette tapes which could be read directly by computer; an expansion of the station network; measurements of balance or infra-red at additional sites and the expansion of the programme to include ultra-violet and daylight illumination (visible light only) measurements.

5.Calibration of sensors and instruments

Most solar radiation sensors, particularly pyranometers, require occasional calibration against an absolute standard or an accurately calibrated secondary standard. Pyrheliometers are usually used as standards as they can be designed to give accurate and stable results.

Absolute pyrheliometers, which require no calibration, are expensive and, sometimes, elaborate instruments. The World Radiometric Reference is the mean reading of a set of absolute pyrheliometers kept at the World Radiation Centre at Davos in Switzerland. An absolute pyrheliometer is not in use in Ireland. However, a good quality secondary standard, the Angstrom Compensation Pyrheliometer made by the Swedish Meteorological and Hydrological Institute in Stockholm, is used as a National standard. This instrument is calibrated, usually every five years, against absolute pyrheliometers at WMO Region VI comparisons held at the Regional Radiation Centre at Carpentras in the south of France. Valentia is the National Radiation Centre for Ireland.

The Angstrom pyrheliometer consists of two manganin foil strips, blackened with candle soot, one of which may be exposed to the sun via a rectangular aperture while the other is shaded and heated by an electric current passing through the strip. A pair of thermocouple junctions are in thermal contact with the strips and the output is proportional to the difference in temperature between the two strips. The current is adjusted until the temperatures are within 0.01°C. The process is repeated but with the first strip shaded and heated electrically and the second exposed to the sun. An observation consists of a series of 11 readings of the heating current at approximately 90 second intervals. The instrument is accurate to about 0.5% and retains its calibration over several years without appreciable loss of accuracy.

The operation of the Angstrom pyrheliometer is too complicated for use in routine observations or the calibration of pyranometers. Instead the Linke-Feussner actinometer is calibrated against the Angstrom and used as a secondary standard. The actinometer is a direct reading instrument and can be read very accurately when used with a good quality meter. It is also used for the measurement of turbidity. The standard pyranometers, the Valentia global and the travelling standard are calibrated using the actinometer as a reference. The travelling standard can then be used to calibrate any other pyranometer at an outstation by taking simultaneous measurements over several days.

The actual pyranometer calibrations at Valentia are performed in clear sky conditions when both the direct and the diffuse radiation are steady. The output of the pyranometer being calibrated is compared against the combined readings of the vertical component of the direct (as computed from the actinometer readings) and the diffuse (as measured by a second pyranometer with its sensor screened from the sun by a 60mm diameter disc 1 metre away). The area of the sky shaded by the disc corresponds with the area seen by the actinometer. The second, shaded, pyranometer does not need to be accurately calibrated as the diffuse component is only 10% to 20% of the total.

The diffuse pyranometers at outstations may be calibrated directly against the travelling standard when it is at the station by removing the shade ring so that no part of the sky is obscured. The test can also be performed more frequently at a station by comparing the global and diffuse on either totally overcast or completely clear days; for such days it is possible to estimate the missing diffuse record lost due to dropping the shade ring. As a further comparison the corrected diffuse values on cloudy days can be compared with the global at the processing stage.

The Eppley pyrheliometer which measures the direct radiation is calibrated by comparison with the actinometer and Angstrom pyrheliometer readings, if available. The three pyrheliometers are not totally comparable due to their different aperture angles. The Angstrom's aperture is rectangular, viewing angle 2° by 8°, while the actinometer's and the Eppley's apertures are circular with angles of 10° and 6° respectively. As a result the turbidity can have an effect on the readings as the wider aperture instruments include more of the circumsolar radiation which varies with the turbidity. Usually this is only a problem if turbidities are high at international comparisons where 0.5% accuracy is necessary but, nevertheless, comparisons are usually avoided on occasions of high turbidity.

The infra-red pyrgeometer may be calibrated by placing the radiometer inside a hemispherical dome heated by a surrounding water jacket. The radiation emitted by the dome can be calculated from the measured water temperature using the Stefan-Boltzmann law and compared with the output of the radiometer.

The calibration of any pyranometer or pyrheliometer can be traced to the world reference at Davos via the travelling standard pyranometer; the actinometer; the Angstrom pyrheliometer and the absolute standards at Carpentras. By this means pyranometers and pyrheliometers in any country are linked to a common standard.

The electronic recording equipment is occasionally calibrated. Electronic integrators, in particular, need to be checked for linearity (which is usually very good); calibration drift; zero offsets and thresholds, any of which can lead to errors. A precision voltage reference is used to input a voltage to the integrator and a stopwatch is used to measure the count rate. Measurements of the count rate are made over a range of voltages from 0.05mV to 10mV, a range typically covering 2J/cm^2 to 360J/cm^2 per hour. The modern integrators have good linearity with small zero offset errors. Some of the older models, which are being gradually phased out, have substantial zero offset errors, as large as 3-4J/cm^2 per hour. These can be allowed for during processing but, nevertheless, degrade the quality of the data.

Chart recorders can also be checked with the precision voltage reference. Most recorders only require occasional adjustment to their calibrations but more frequently need repairs or replacement of parts, particularly gearboxes in the BD8s.

Table 1

Mean daily totals of Global Solar Radiation in 1984
(Joules/cm^2)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Valentia	209	452	822	1477	1926	1656	2028	1393	899	561	342	176
Kilkenny	272	399	763	1458	1888	1720	2023	1407	1005	671	304	200
Birr	231	382	659	1263	1628	1361	1688	1159	847	563	261	167
Dublin A.	245	375	707	1425	1841	1773	1965	1435	959	606	270	175
Clones	220	348	779	1359	(1770)	1703	1840	1352	908	548	272	139
Belmullet	203	415	993	1457	1960	1369	1734	1348	937	514	292	149
Malin Head	158	379	787	1433	2019	1531	1649	1369	897	536	231	129

Mean daily totals of Diffuse Solar Radiation in 1984
(Joules/cm^2)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Valentia	152	288	521	639	879	1003	1043	807	618	352	200	143
Kilkenny	167	286	510	703	996	1053	959	902	583	348	172	123
Birr	160	276	493	706	944	954	961	836	567	331	152	119
Dublin A.	145	258	476	671	892	1066	919	850	556	319	169	110
Clones	155	268	529	733	(938)	1052	1087	920	610	343	187	108
Belmullet	--	--	--	--	--	--	--	--	--	--	--	--
Malin Head	124	268	476	677	907	1064	1058	822	573	292	144	93

Underlined Values: Means based on 29 or 30 days

Bracketed Values: Means based on 25 days or less

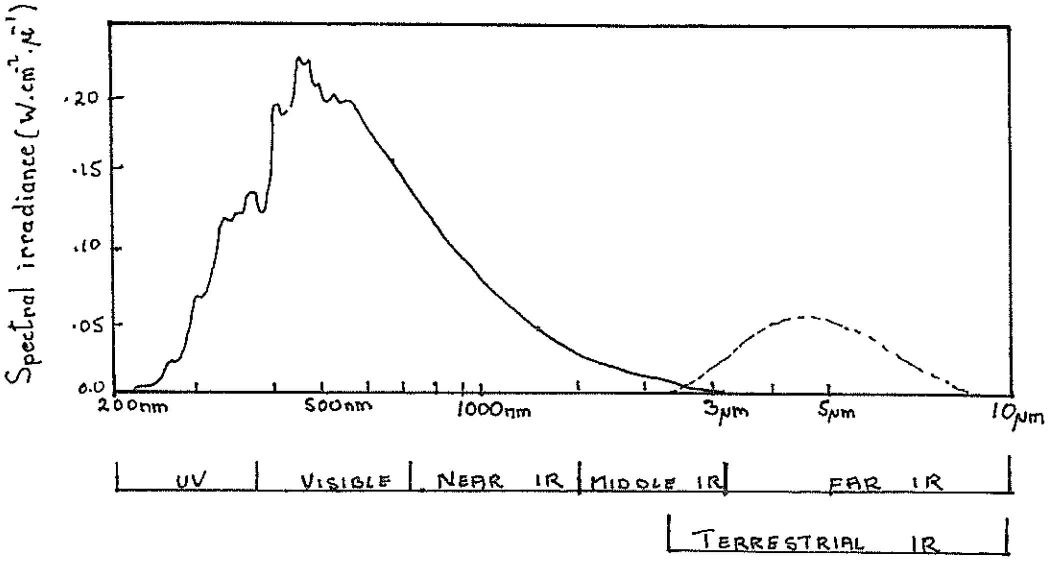

Figure 1 Spectral irradiance outside the atmosphere and the Terrestrial Infra-red spectrum

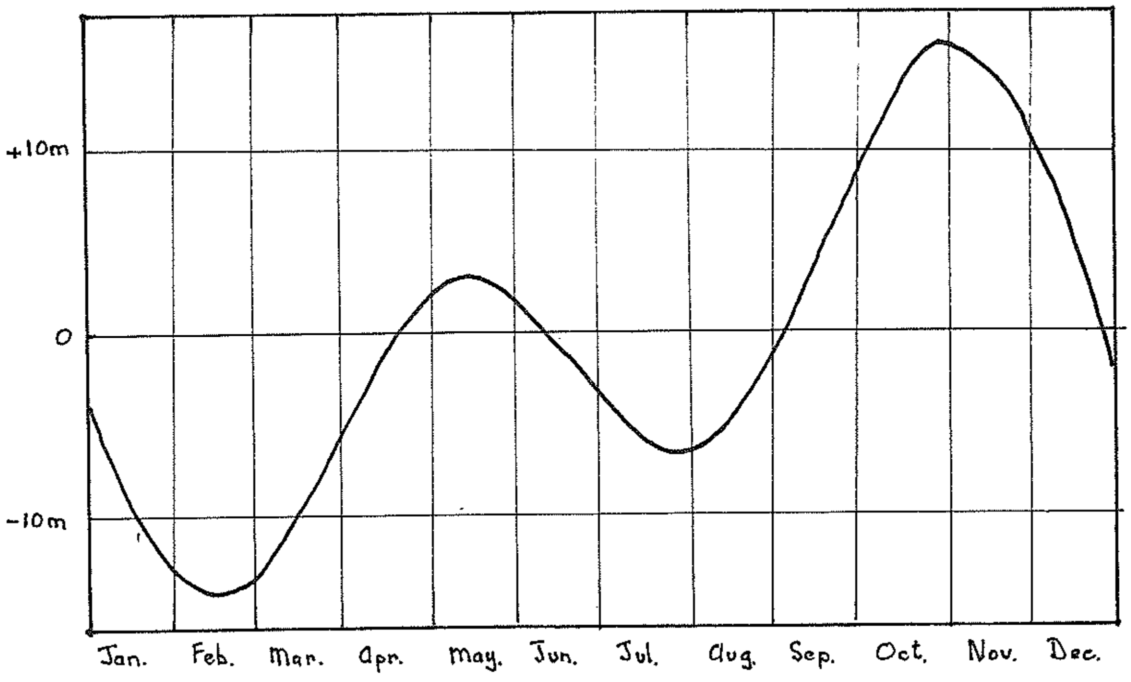

Figure 4 The Equation of Time

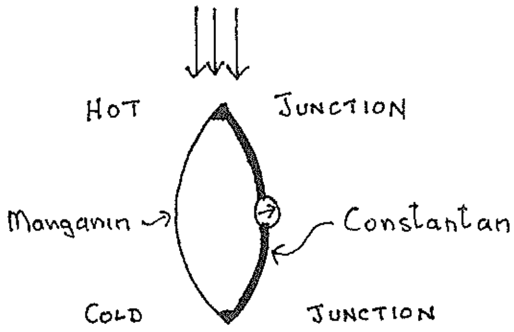

Figure 2a Thermocouple

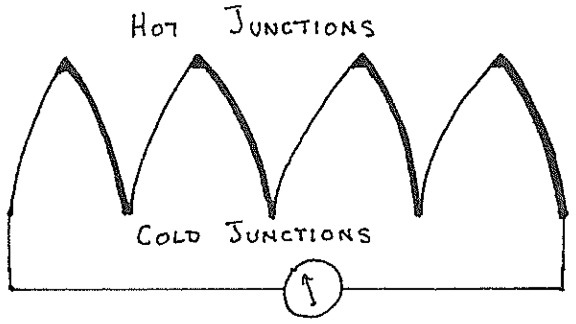

Figure 2b Thermopile

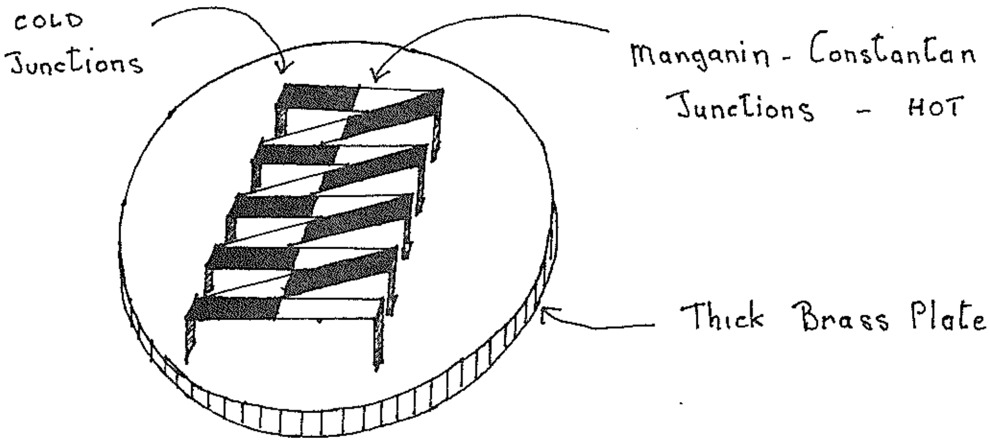

Figure 2c Moll Thermopile

Figure 2 Schematic Diagram of a Thermocouple, Thermopile and a Moll Thermopile

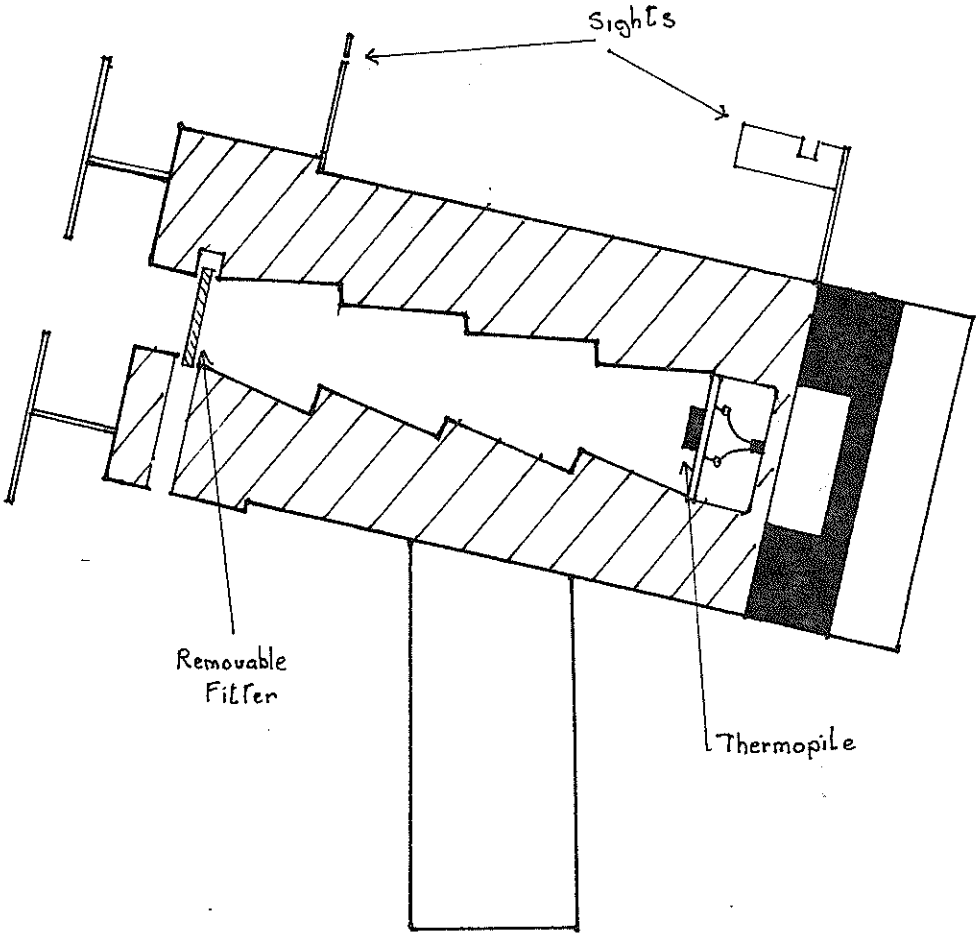

Figure 3 Linke-Feussner Actinometer

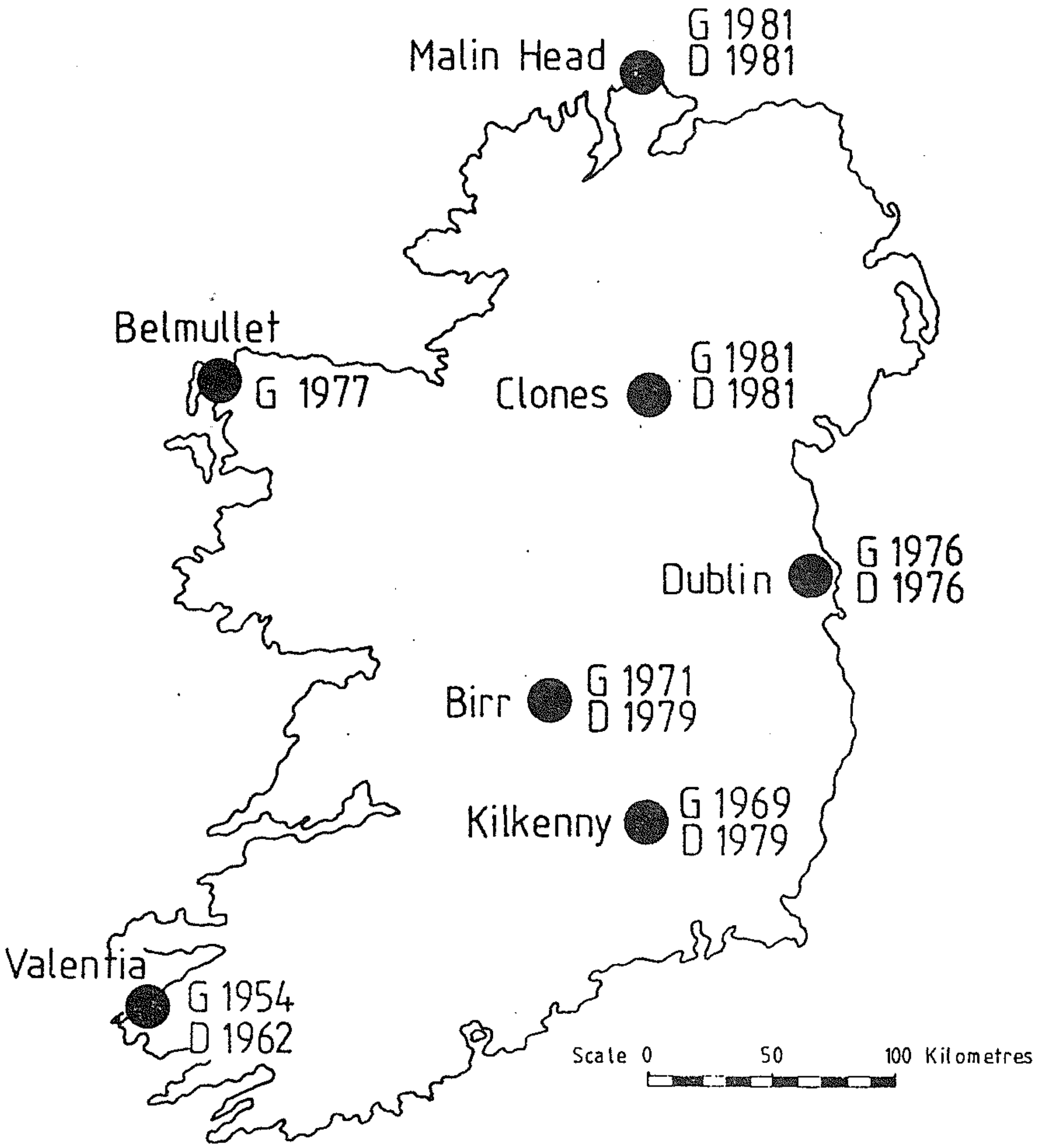

Figure 5 The Irish Solar Radiation Network

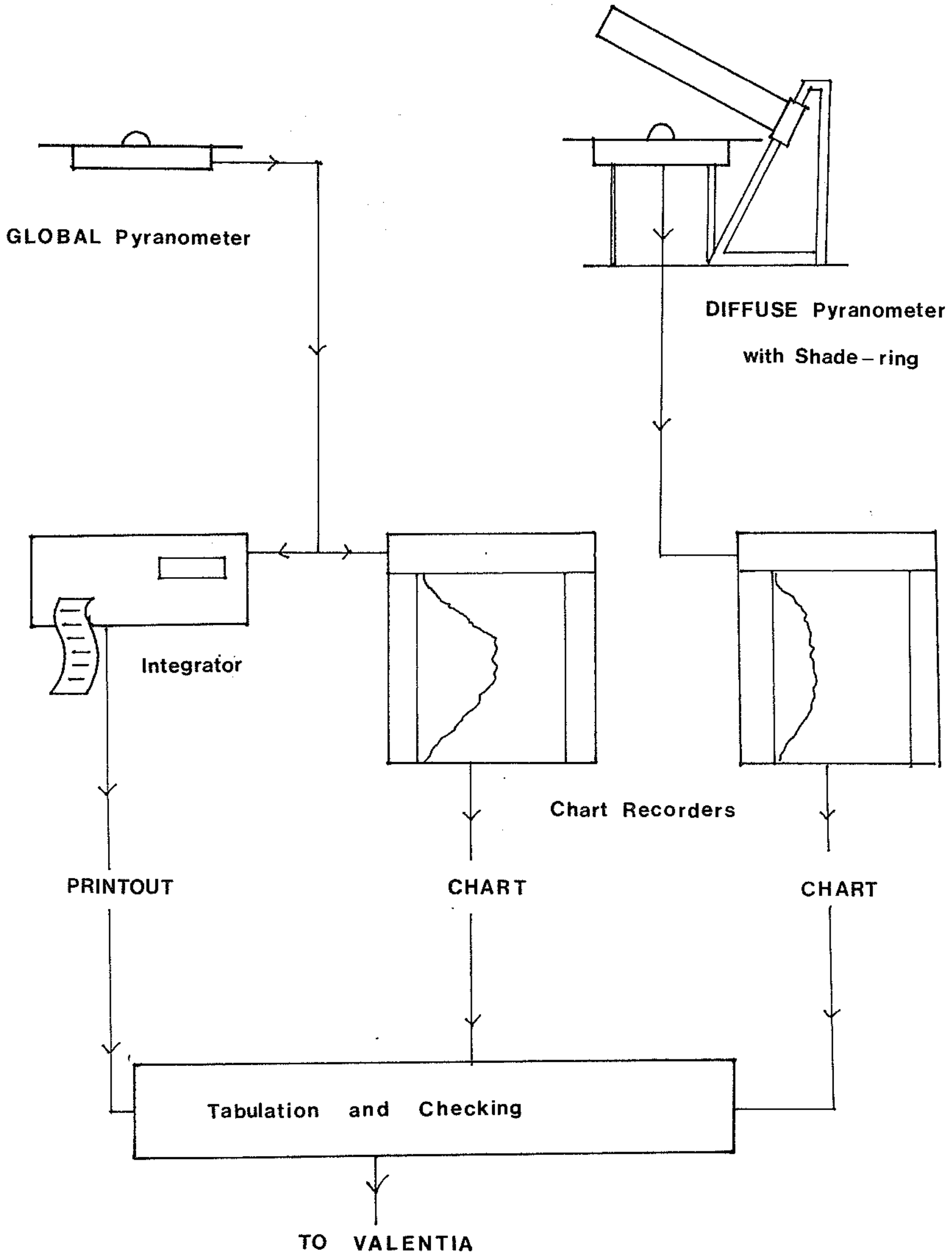

Figure 6 Schematic Layout of Radiation Instruments

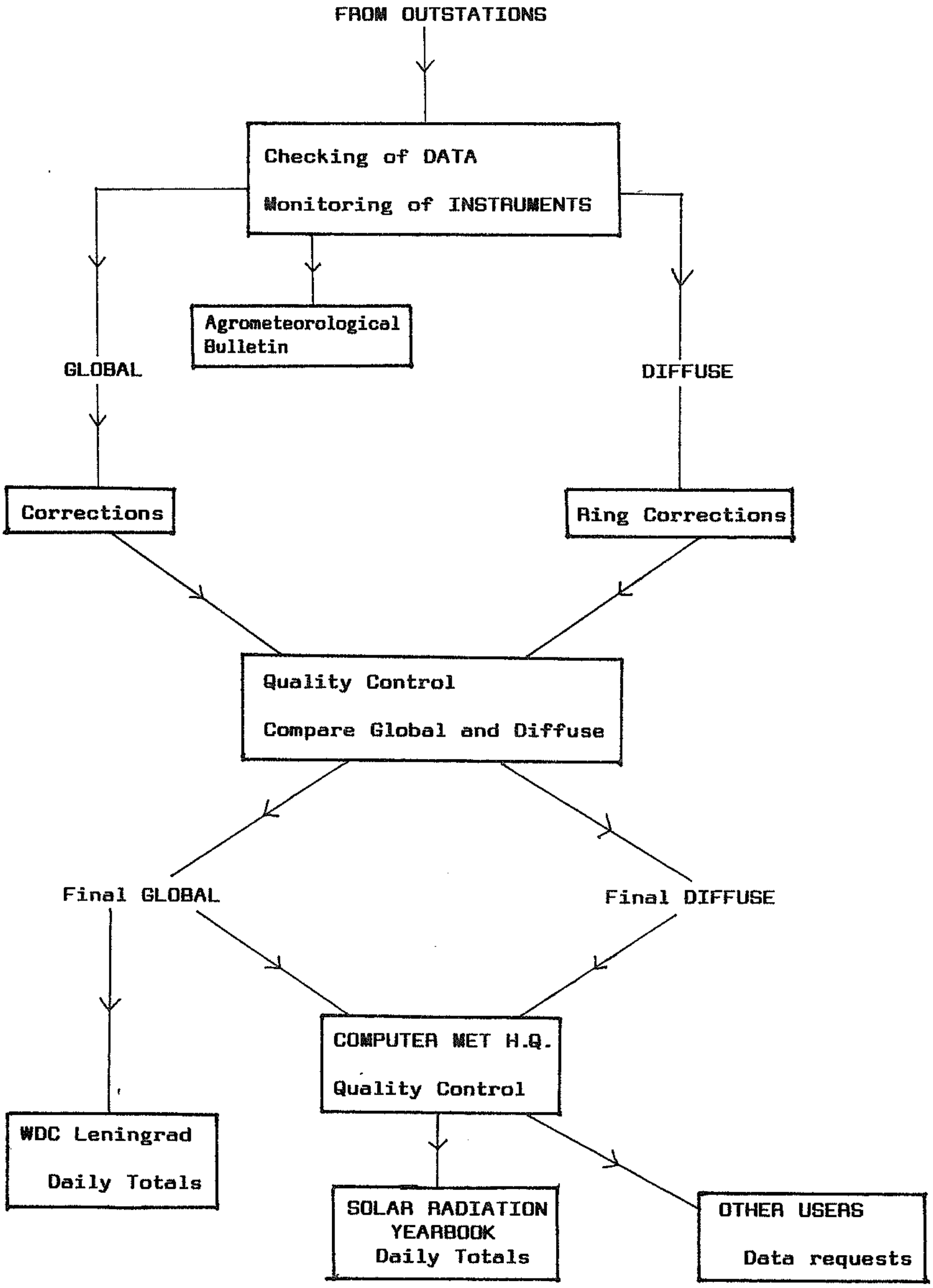

Figure 7 Data Processing of Solar Radiation Data