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PROBLEMS OF SAMPLING AND RADIATION BALANCES - THEIR PROBLEMATICS

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16. Abstract It is shown how the knowledge of the different radiation budgets with their components is largely dependent on the space time sampling of the radiation field of the system Earth-Atmosphere. Whichever instrumental approach is adopted (wide angle view or high resolution) it affects the space time integration of the fluxes measured directly or calculated.

In this last case the necessary knowledge of the reflection patern depends in addition on the angular sampling of the radiances. A series of questions is considered for which the answers are a perequisite to the organisation of a global obervation system.

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1.   INTRODUCTION

Since the beginning of the Space Age, considerable effort
has been expended to measure components of the radiation balance.
Many American satellites carrying wide-field or high-resolution
scanning radiometers, have been put in orbit - often they carried
both at the same time. Nevertheless, our knowledge of the radiation
field of the earth-atmosphere system remains very fragmentary.

The object of this short note is to show the difficulties
encountered and, if possible, to formulate questions whose answers
can be used to set up an optimal observation system. We review
the objectives being sought: they concern knowledge of the distribu-
tion in space and in time of the incoming radiation, of the albedo,
and of the radiation balance at the orbit of the observation plat-
form, at the tropopause, and at the surface of the earth.

The albedo at the selected heights is deduced from knowledge
of the solar flux entering and leaving; the radiation balance of the
energies entering and leaving.

In fact, the stated objective is not an end in itself: it is
also intended to give the boundary conditions needed for evaluating

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*Numbers in the margin indicate pagination in the foreign text

the climatic variations of the earth-atmosphere system, and to put us in a position to tackle the problem of the energy balance of the atmosphere. This latter aspect requires in addition that the distribution of water in its various forms, the temperatures, and the winds be known in the troposhere.
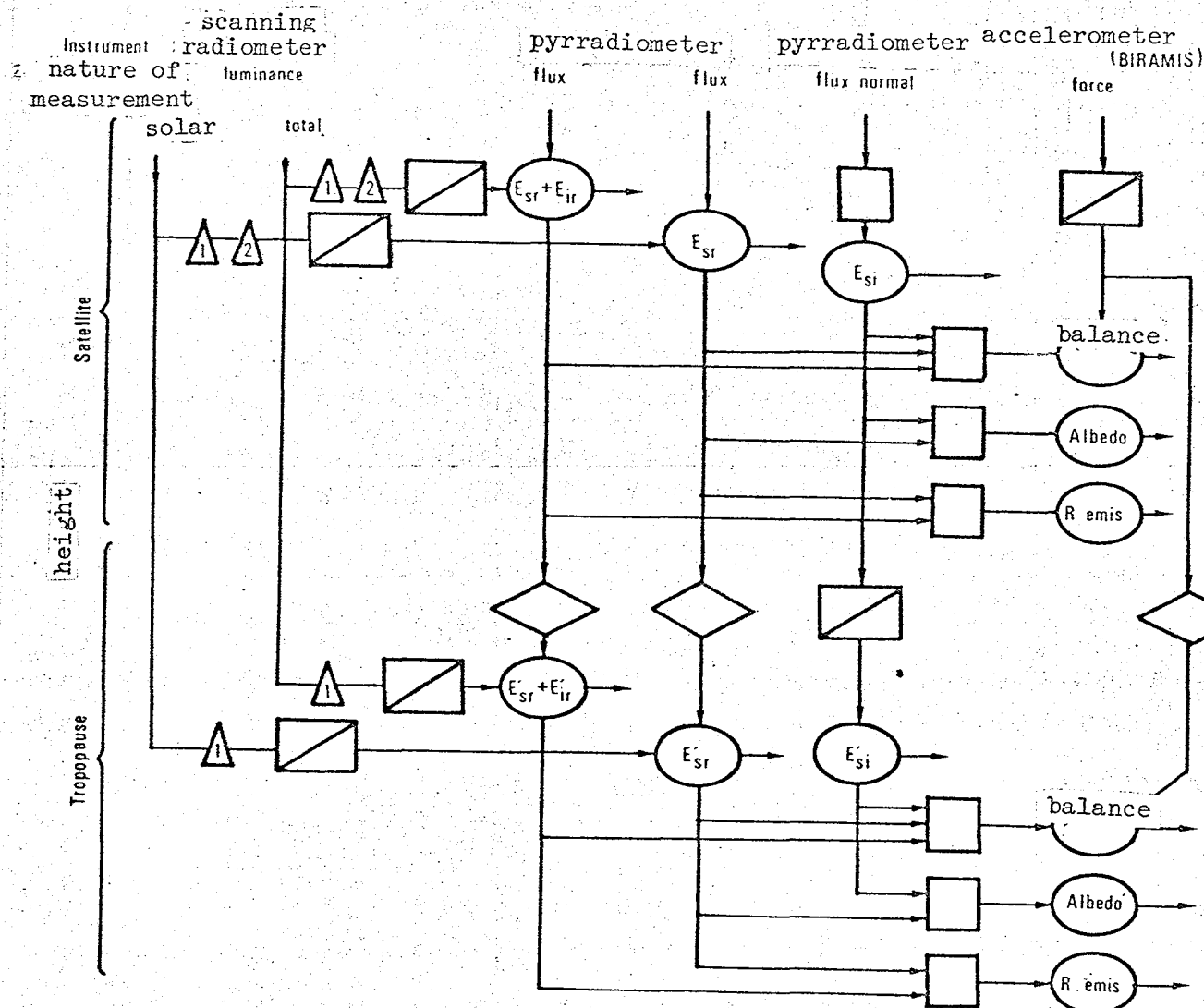
The spatial variability of the radiation field results from:
a. the geographic distribution of the earth's albedo,
b. cloud cover,
c. non-uniform illumination of the earth by the sun.

The time-variability of the radiation field has annual and diurnal periodicities of astonomical origin, onto which are super-posed seasonal and meteorological variabilities due to variability of vegetation and cloud cover and to the circulation of the atmosphere, respectively. At the scales which interest us, the spectrum of variations is thus random in neither time nor space. It can be taken that the minimum variation period of the local radiation field due to convective effects on a meso-meteorological scale which has a cascade effect on the temperature and water-vapor distribution fields is of the order of 6 hours. This justifies the climatological practice of observing the meteorological variables every 2 hours.

The upper limit on the spectrum of variations in the spatial distribution of the radiation field (the shortest periods) is determined in practice by the nature of the cloud cover.

It is thus at the surface of the earth that the variability /97 of the radiation fluxes in space and time is greatest. It can be seen qualitatively that to the extent that the surface across which the fluxes are being considered is different from the surface of the earth, the relative amplitude of the flux variations when the detector is displaced decreases rapidly. Consequently, the altitude above the earth's surface for which the flux is determined fixes the spatial and temporal scale of the phenomena which can be studied.

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scanning radiometer

Instrument
nature of
measurement
luminance

pyrradiometer   pyrradiometer   accelerometer
(BIRAMIS)

flux   flux   flux normal   force

solar   total

Satellite

height

Tropopause

$E_{sr} + E_{ir}$

E_{sr}

E_{si}

balance

Albedo

R emis

$E'_{sr} + E'_{ir}$

E'_{sr}

E'_{si}

balance

Albedo

R emis

Operations to be applied to
instantaneous local (illegible)
as a function of altitude

integrated
value

instantaneous integrated value

Legend

Local instantaneous
value sought

Deconvolution, feasibil-
ity to be demonstrated

Elementary operation

Calculation performed
using models

Occurrence of angular
sampling

Occurrence of sampling
of an "image"

Occurrence of spatial
sampling

Occurrence of time image
sampling

Chart of operations to be performed on measurements to obtain radiation
balances, their componets, and integrated values.

2. OBSERVATION OF RADIATION FLUXES AT SATELLITE ALTITUDE

2.1 The Problem

Knowledge of the spatial and temporal distribution of the incident solar flux E_{si}, of the outgoing solar flux E_{sr}, and of the outgoing infra-red E_{ir} allows us to determine the planetary radiation balance density at a given instant:

$$\phi_P = \frac{1}{S_p} \int_{S_p} E(t) ds = \int_{S_p} (E_{si} - E_{sr} - E_{ir}) ds \qquad (1)$$

as well as the mean planetary radiation balance for a given interval $\Delta t = t_1 - t_0$

$$\phi_{P,\Delta t} = \frac{1}{S_p \Delta t} \int_{\Delta t} \int_{S_p} E \, ds \, dt \qquad (2)$$

This is meaningful only if the function $E = E(1,g,t,h)$ is known accurately enough from observations made at altitude h. In spherical coordinates, it can be represented in the form of a series of spherical harmonics $Y_{m,n}(1,g)$:

$$E_h(1,g,t) = \Sigma_{m,n} \, A_{m,n}(t) \, Y_{m,n}(1,g) \qquad (3)$$

where the coefficients $A_{m,n}$ depend not only on the distribution to be described, but also on time.

If the distribution is uniform and constant: $E_h(1,g,t) = E_0$ and a single measurement is enough; if it varies only with time: $E_h(1,g,t) = E(t)$ a single point of the surface would have to be observed continually. That is not the way things are, and one must pose the famous sampling problem:

    a) how must the measurements be distributed and how many must be made over a sperical surface at altitude h,

    b) with what periodicity should they be repeated in time;

    c) with what precision do the measurements need to be made,

so that the balance can be known at any place and instant with a given precision?

Answers can be given only if one know the $A_{m,n}(t)$, coefficients of the series which exactly describes the $E_h(1,g,t)$ function, necessary for calculating the difference

$$\Delta E_h(1,g,t) = E_h(1,g,t) - E_h'(1,g,t)$$

$$= \Sigma_{m,n} [A_{m,n}(t) - A_{m,n}'(t)] \, Y_{m,n}(1,g) \qquad (4)$$

where the $A_{m,n}'$ are deduced from the measurements really made by whatever means are available. In addition, they do contain errors.

The errors in the planetary radiation balance density at a given moment and in the mean for a given period are given by:

$$\Delta \Phi_{h,P,t} = \frac{1}{S_p} \int_{S_p} \Delta E_{hs}(1,g,t) \, ds \qquad (5)$$

and

$$\Delta \Phi_{h,P,\Delta t} = \frac{1}{S_p \cdot \Delta t} \int_{\Delta t} \int_{S_p} \Delta E_{hs}(1,g,t) \, ds \, dt \qquad (6)$$

respectively.

Objective knowledge of the $A_{m,n}(t)$ coefficients can come only from measurements made with an ideal observation system which provides over-sampling in space and time, and which gives measurements free of errors. Setting up such an ideal case would be utopian, so $\Delta E_h(1,g,t)$, $\Delta \Phi_{h,P,t}$, and $\Delta \Phi_{h,P,\Delta t}$ have to be evaluated either from a distribution model $E_h(1,g,t)$, which runs the risk of not being realistic enough, or from possible fragmentary observations which do come from luminance measurements.

Using these functions, a field showing a space-time variability comparable to that of the field can be constructed, even though some simplifying assumptions must be introduced, which will not change the conclusions being sought in any fundamental way.
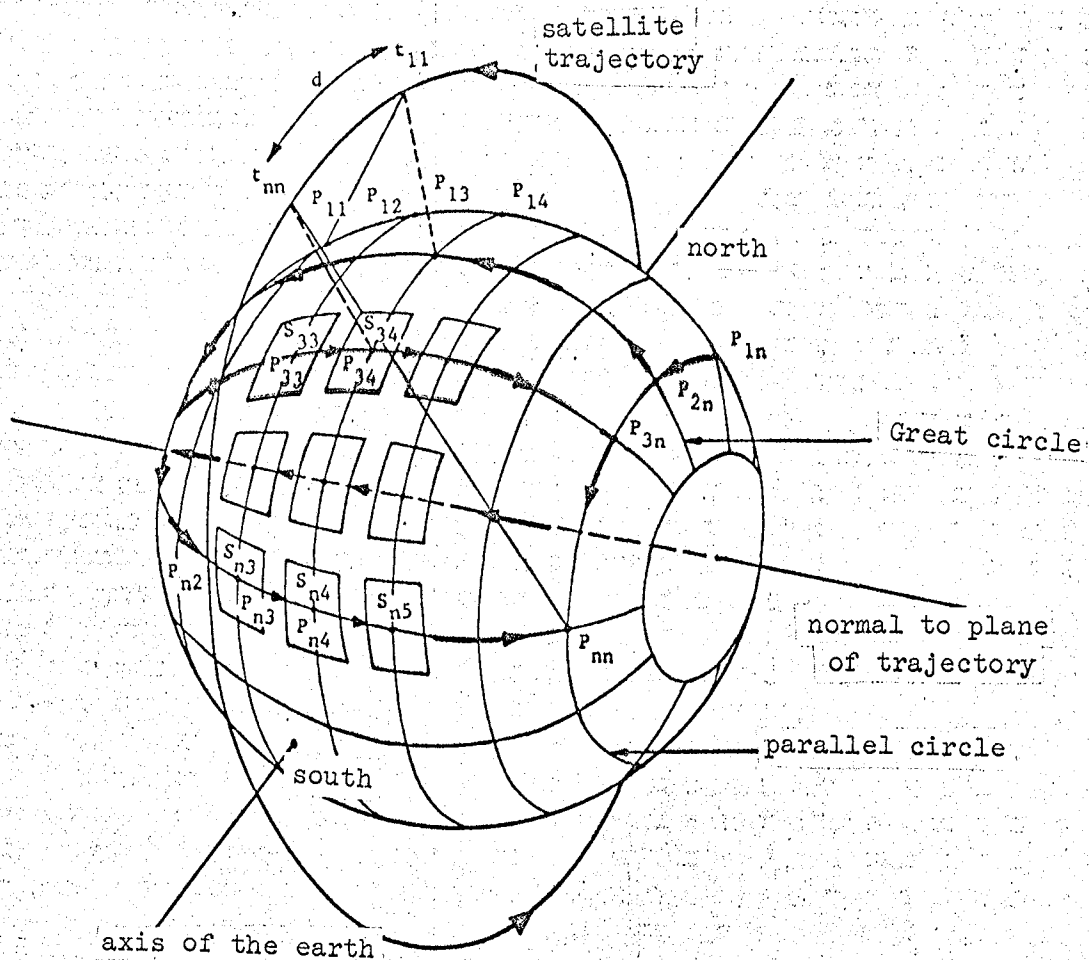
2.2   Elements for an Evaluation

The images obtained from geostationary satellites could make a good basis for evaluation. The spectral luminance observed in the visible is certainly the one which has the highest variability; by making the assumption -- approximate but acceptable for the purpose -- that the radiation is reflected isotropically or according to a model that takes the height of the sun into account, the reflected monochromatic flux distribution can be calculated. The increment length of the net must be taken small enough to prevent any undesirable filtering.

Repeating this calculation for observations made from other geostationary satellites and from one or another suitable polar satellite would give a model of the reflected flux distribution at a selected altitude (tropopause, 500 km, 1000 km) which would represent the most variable component of the field -- that is, the one which determines the spatial and temporal density needed for sampling. Since it is in principle free from any blurring due to the response time of a wide-field instrument, this model will serve as the basis for numerical simulations for reconstitution and for optimizing the configuration of the observation system.

The variables to be considered for a given altitude h are the number of satellites and their orbits.

Studies by J. Schniewind (1978) deal with the sampling capability of a system of satellites; in the one by G. G. Campbell and T. H. Vonder Haar (1978), a model of the field to be sampled was also considered. The conclusions obtained are a first approximation to meeting the problem, but more thorough studes and more precise   /99 and explicit conclusions are needed.

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Typical scanning of the Earth's surface

- points are sampled from P_{11} to P_{nn}

- duration of sampling is $(t_{11} - t_{nn} + t)$, where t is the time to return the viewing direction from P_{nn} to P_{21}

- the image following (P_{11}, P_{nn}) is $(P_{21}, P_{n+1;n})$

- point P_{ij} lies on great circle i and parallel circle j; the surface area associated with P_{ij} is S_{ij}

- from one image to another, points on the same parallel circle are observed at different angles of incidence each time the image sequence sweeps along different great circles

In addition to answers to the questions already asked in Section 2.1., one will have to be able to obtain from them:

    a) the instrument response time for pyrradiometers and pyranometers so that they will not filter out real variations in the field during the measurements;

    b) the required sampling rate along the orbit;

    c) the instrumental precision needed, consistent with the choice of a selected observation system;

    d) the effect of altitude choice on the variability of the radiation fields;

    e) the precision, the resolution in the measurements, and the type of observing system needed to be able to consider deconvolution of observations to the surface of the tropopause; G. G. Campbell and T. H. Vonderhaar suggest it, especially to be able to normalize measurements made at different altitudes to a reference altitude.

It seems to us extremely important that there be a demonstration, based on numerical simulation, that it is possible to deconvolute flux measurements at satellite altitude to the level of the tropopause.

A comparison of results and effort required (number of observations needed, computer time, precision of measurements, etc.) to meet the stated objective from measurements by wide-field radiometers or high-resolution scanning radiometers (Section 3) would be extremely useful in showing the extent to which they are complementary.

3.   LUMINANCE OBSERVATIONS

3.1.   The Problem

Since it is necessary to determine the net radiation fluxes, in particular, at the tropopause, high-resolution scanning radiometers are used to reconstruct the outgoing fluxes and the net flux at the

desired height, starting from measurements, the models, and the assumptions.

The sampling problem developed in Section 2 applies directly to the fluxes which can be obtained by calculations from luminance measurements. This becomes complicated, however, when new questions arise:

- How should the surface of the earth be scanned?
- How should the reflection pattern be determined?
- How can the quality of the measurements be assured?

These problems appear as soon as one gets down to defining the scanning radiometer. They are not generally approached in a logical manner, and the user is often obliged to settle for an instrumental configuation imposed on him.

When he can say what he wants, he runs into technological difficulties, and is generally led to accept trade-offs which are not optimizations based on subsequent processing. Let us try to take a logical look at possible acceptable compromises.

3.2.   Scanning the Earth's Surface

Ideally, the user wants to have a detailed image of the earth's surface -- "like a photo" -- at each point (l,g,t). If the measurements are obtained with a detector which has constant spectral sensitivity over the whole spectrum for the outgoing radiation (reflected plus emitted), and with a detector which has uniform sensitivity from the UV to 3μm and is insensitive beyond that for the reflected radiation, the corresponding fluxes at satellite altitude can be calculated and the results compared to measurements made directly with a pyrradiometer and a pyranometer.

This excessive requirement due to the information density which it involves -- related to the choice of detectors it imposes and to their response times -- can be met with various types of scanning, more or less dense and with various spatial resolutions.

On what principles should the choice be based?

First of all, we note that very high measurement resolution is justifiable only if it can be used: that is, if the mathematical reconstruction of an image from the number of available measuring points in it allows resolution of a spatial variation period of twice the resolution. If this is not the case, the measurements will appear to contain noise which alters them and keeps them from being used.

Consequently, the number of measurement points available in scanning an image determines the optimal spatial resolution, and vice versa. Thus, it will not necessarily be possible to reconstitute the real variability (Section 2) of the field observed, but the real need for doing so will depend solely on the spatial scale aimed at for the particular application.

How must the points observed be distributed?

This can be done according to a uniform angular distribution, a uniform distribution over the surface of the earth, or any other profitable distribution (cf. Section 3.3.). This distribution could also be sychronized to the radiometer or to terrestrial coordinates.
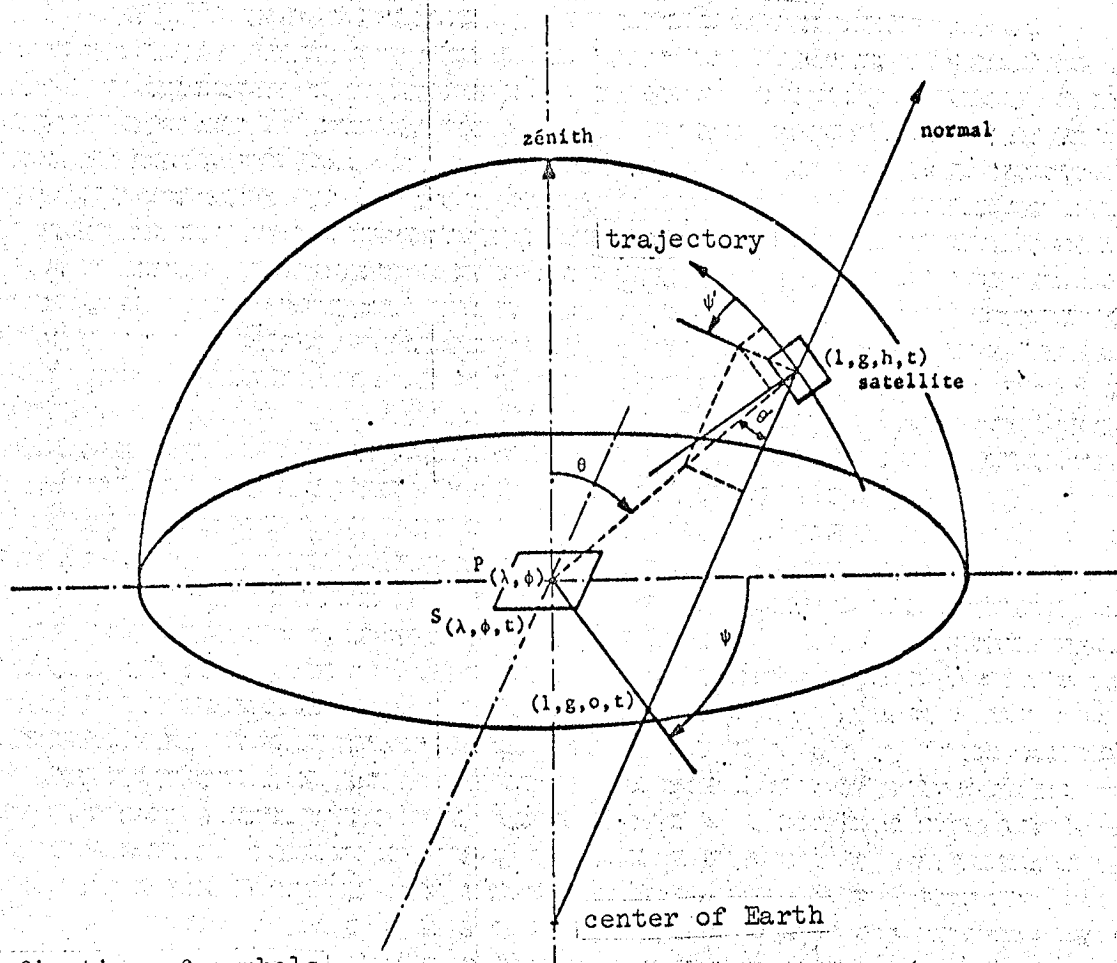
In both cases, the first method is in principle easier for the builder, and the second is more logical, and especially more efficient in terms of the objectives of the user -- particularly for establishing more representative statistics for the luminances measured systematically at various times on a trajectory for points with coordinates fixed from one image to another.

In addition, such an option would be advantageous if it were combined with possible retransmission in real time.

3.3.   Determination of the Reflection Pattern

Since reflection of solar radiation is not isotropic, but

depends on the type of surface and the height of the sun, the actual precision of the result of calculating the flux reflected at a given altitude above the earth's surface depends on the precision /101 with which the angular distribution of the reflected flux is known. Hence, one must ask: how many luminances must be known, with what precision and what angular distribution, so that one can calculate the total flux reflected by a selected surface is not necessarily uniform?

Defination of symbols

l,g latitude and longitude of satellite
λ,φ latitude and longitude of area observed
h   altitude
t   time

Lacking the required number of measurements, what is the error introduced by the models, how well do they represent reality, and how can the models be made more suitable?

Since the total flux reflected by a non-uniform surface S (solid angle ω) is given by the relation;

$$W = \int_0^{2\pi} \int_0^{\pi/2} [\int_\omega L(1,g,t,\theta',\psi')\cos\theta'\ d\omega] \times \cos\theta\ \sin\theta\ d\theta\ d\psi \quad (7)$$

two basic principles must be followed:

   a) The measurement of the flux reflected in a given direction
      θ, ψ in a solid angle ω from the surface of geometric
      area S and of given shape must be proportional to:

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$$N_S(\lambda,\phi,t,\theta,\psi) = \int_\omega L(1,g,t,\theta',\psi') \cos \theta' \, d\omega \quad (8)$$

b) During each satellite passage when the spot with coordinates λ,ϕ, can be observed, it should be done with the greatest number of angles possible, compatible with the limitations imposed by Section 3.2. It is also necessary that at each angle of incidence (ϕ,ψ) <u>the same surface</u> (λ,ϕ) <u>of known area on the earth -- and only that -- be measured</u>.

This way of working insures that maximum information is acquired in minimum time, while guaranteeing that the conditions of reflection remain constant and that surface S remains well defined from one image to another. It is definitely this latter requirement which is hardest to realize imstrumentally, and which will guide the design in any event.

A scanning radiometer with no moving parts, of the LASS (*) type but meeting the spectral sensitivity conditions given in Section 3.2., with a microprocessor calculating integrals (8) could be the instrumental configuration desired.

The two principles given above and the considerations of Section 3.2. guide the choice of acceptable scanning, as well as the periodicity of image-taking and of their sampling, which must be such that the zenith displacement from one complete image to the next will correspond to the projection onto the earth's surface of the distance travelled by the satellite during the time needed for a complete scan of each image. We have to realize that the instrument which will really satisfy the user must still be developed. It can be hoped, however, that with a reasonable amount of imagination and ability it will come about.

3.4.   Quality and Precision of Measurements

In order that the quality and precision of the measurements

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* Instrument developed by the European Sapce Agency (LASS - Land Application Satellite System).

can be guaranteed, it is necessary that they be well defined, as indicated in Section 3.3. The output signal <u>must be proportional to the total or solar outgoing flux from the observed area of the ground, in solid angle ω centered on the satellite</u>. The effects of the non-uniform distribution of reflecting surfaces and of their particular spectral characteristics are thus directly taken into account in the measurement.

Calibration is usually done on a "black body" whose temperature and emissivity are known accurately. One of the difficulties to be overcome, which has an effect on the geometric configuration used for the scanning radiometer, is the closeness of this source. It could also be a diffusing surface exposed to solar radiation, provided its characteristics are accurately known and stable over time. Another possibility is to use the sun itself as the source.

In any event, calibration is a difficult operation, which can profitably be checked by comparison of the flux reproduced by calculation with the flux measured directly by pyrradiometer and pyranometer.
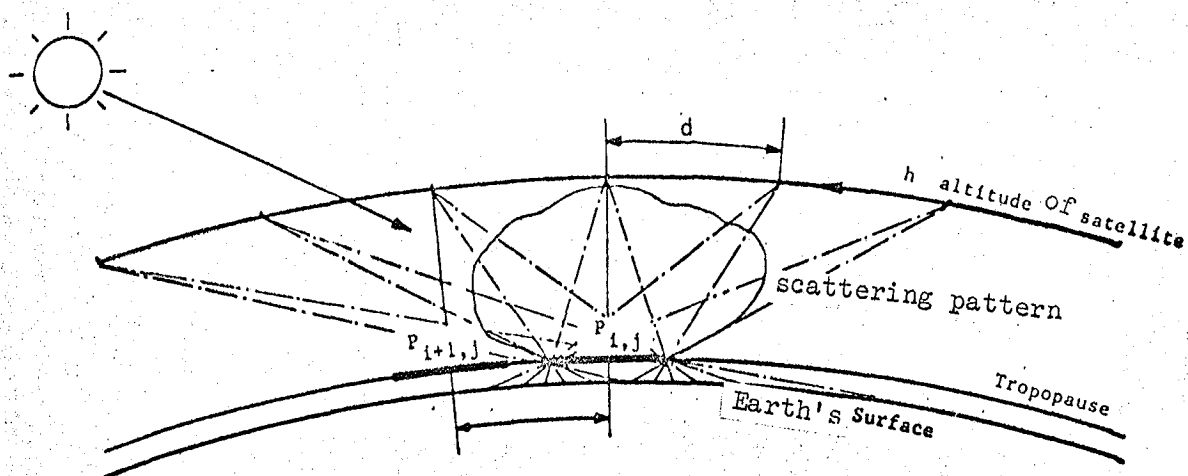
4.   CONCLUSIONS

Determination of the radiation balances and their components depends heavily on sampling in space-time and on the fluxes both when they are measured directly and when they are reconstructed from luminance measurements combined with models and assumptions. Another sampling problem comes into play, one which bears on the validity of the reflection pattern models used.
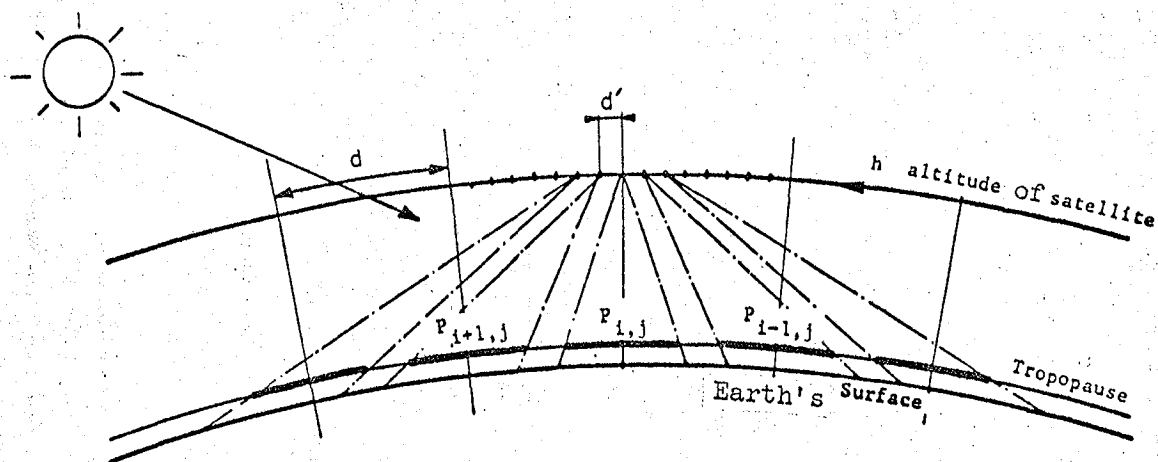
Before one can set up an observation system logically designed to measure the terms of the radiation balance, it is thus imperative to find answers to the various questions which have been raised, using numerical simulation. It is to be expected that only an overall view combined with a pragmatic approach will allow; 1) a proper statement of the problem, and 2) development of the appropriate instruments, defined as a function of the scientific and metrological

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necessities, which are also designed to be integrated into a coherent, uniform observation system.

The absolute international cooperation required for its organization and implementation would have to submit to some inevitable to inevitable standardization required by the strategy to be followed in order to reach the objective. The two instrumental techniques, wide-field and high-resolation, supplement each other to fill in gaps each has. They are complementary.

b) Sampling of reflection pattern (d is distance travelled by satellite from one image to the next)

a) Sampling of Earth's surface during one image (d' is distance travelled to go from one great circle to another

Sampling for scanning radiometer