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I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE CENTRATOM TRIESTE

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MEASUREMENTS TECHNIQUES OF TROPOSPHERE RADIOPROPAGATION PHYSICS

F. BARBALISCIA

Fondazione Ugo Bordoni, Roma, Italy

Fondazione Ugo Bordoni

Francesco Barbaliscia

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Measurement techniques of tropospheric radiopropagation parameters

Francesco Barbaliscia
Fondazione Ugo Bordoni
Viale Europa 190, 00144 Roma
ITALY

ABSTRACT

Terrestrial and satellite radiolinks have shown a dramatic increase in the last decades due to the demand for new services and frequency bands.
The main problems concerning the measuring techniques of the tropospheric parameters affecting the radiopropagation on the e. m. signals in the SHF bands are here presented and discussed.

1. INTRODUCTION

Radiolinks have largely showed particularities and advantages in comparison with cabled systems. Flexibility, cost effectiveness, short implementation times, possibility of covering any area, are some typical characteristics of radio systems, both terrestrial and more recently satellite communication. The latter in particular have stimulated an enormous fast development of new systems and services in the last decades.

The main problem to face with when planning radiocommunication systems concerns the effect of the atmosphere on the radiowaves and therefore the knowledge of the nature and the characteristics of the atmospheric structure and components.

The propagation of radiowaves through the atmosphere have been subject of careful attention and extensive measurements campaigns concerning both the atmosphere components, such as rain, vapour, gases, ice and snow, and its structure: refractive index, temperature, humidity etc.

The continuous growing of services have pushed an increasing demand for new frequencies, up to the SHF and EHF bands particularly for earth-satellite links.

At these frequency the main factor of impairment on radiowaves is represented by the rain, as the wavelenght becomes comparable with the dimensions of the raindrops and, for higher bands, with those of minor costituents, such as cloud droplets and fog. Moreover some atmospheric gases, water vapour and oxygen, present in the SHF and EHF bands noticeable absorption peaks, due to molecular resonance.

In this paper a short review is presented on the problems and the techniques for the measurement of the radiopropagation parameters, with regard to the earth-satellite links at frequencies above 10 GHz.

Earth-station typical set-up is reviewed for the measure of attenuation due to rain and the depolarisating effects induced by the raindrops.

Rain measurements, critical point of this matter, are discussed together with more advanced and sophisticated techniques performed by radar and radiometer.

Finally, in view of the problems arising from the adoption of new techniques, an introduction is presented to the topics to be studied in the near future.

2. MAIN EXPERIMENTS IN RADIOPROPAGATION

In the last decades great attention has been devolved to the radiopropagation problems above 10 GHz.

Extensive programs have been carried on expecially in Europe.

A first Eurocop Cost Project (25/4) was promoted in 1970 on joint research on terrestrial propagation, followed by a second Cost Project (205) focussed on the same topic with regard to satellite links.

Some 14 European countries actively participated to the two projects, both chaired by Italy (Fondazione Ugo Bordoni).

The results of the cooperation were very satisfactory also due to a considerable number of experimental set-up and to the launch of two "ad hoc" satellites: the OTS (ESA) and the SIRIO (Italy), operating successfully for long periods, in the 11, 14 and 18 GHz bands.

More recently new programs have been promoted in view of the launch of two new satellites: the Olympus (ESA) carrying a propagation payload at 12, 20 and 30 Ghz and the ITALSAT (Italy) operating at 18, 40 and 50 GHz. The planned launch dates are June 89 and June 90, respectively.

A large extent of experimental set-up, receiving stations, radars, radiometers are in preparation, mostly in Europe but also in USA and in the tropical regions, expressing the interest of the telecommunication community and the primary role of European countries, ESA members and Italy in particular, in the radiopropagation field.

3. RECEIVING EARTH STATIONS

Receiving earth stations for radiopropagation measurements are characterized by the particular philosophy of detecting , in a certain sense emphasyzing, the effects which should be carefully minimized, as unwanted signals, in the communication stations.

High sensivity and accuracy is a mandatory requirement and sophisticated solutions are performed in order to separate the effects of the observed medium from those occurring due to the limitations and interference of the receiving system itself.

Another main characteristic of propagation station is the need for an aquisition and preprocessing system, able to record, convert, analyze, depurate and process the measured values in the proper way to allow a correct analysis.

3.1 Requirements and Specifications

Specifications for propagation earth station are normally very severe. Costs are generally raised due to the need of components often not easily available on the market.

High accuracy is requested in the measurement of the copolar and crosspolar components, both in amplitude and phase. The possibilty of evaluating phase differences among different bands is a requested element too.

Great care must be paid to the depuration of the systematic errors of both antenna and receiver due to disuniformity of gain and phase.

The accurate pointing is, for antennas larger than some 3 metres, a critical and essential element, as a minimum out-of-axis position can introduce serious impairments in the measured values.

Adequate tracking systems are therefore needed.

Periodical calibration cycles are strictly mandatory as the impurities in the signal introduced by system mismatching are often of the same order of magnitude of the requested accuracies.

Automatic protection facilities against ice and rain films on the antenna feed are requested as well.

3.2 Antenna

The main choice element for the antenna is the optical geometry.

Centred geometry antennas, mostly adopted for small diameters assume good protection from the accumulation of water on of feed in case of rain, or snow also on the disk, avoiding serious errors in the measure, at least for elevation up to 50°.

The off-set geometry antenna is often preferred, due to its mechanical configuration which allows a lower spillover from ground and performs better sidelobes insulation.

The most commonly used type is the parabolic front-fed reflector, with a primary source (feed) and a reflecting parabolic surface (reflector). The feed is positioned in the focus of the paraboloid.

A second type often adopted is the double-reflector Cassegrain antenna, where the feed is positioned near to the main reflector.

In this type of antenna the feeding is simplified and the lateral irradiation improved. The lenght of r. f. waveguide is shortened improving the S/N ratio of the entire system.

The main parameters of the antenna are:

Gain

Represents the directivity characteristics of the antenna. It is measured along the maximum irradiance direction and expressed by:

$$G = \frac{4\pi}{\lambda^2} \eta S_b$$

where:

- λ : wavelenght
- η : efficiency (0.5 ± 0.7)
- S_b : area of the surface

For a paraboloid of diameter D:

$$G = \eta \left(\frac{D\pi}{\lambda}\right)^2$$

Common values of the gain are between 30 and 55 dB.

Effective area

It is the main figure of a receiving antenna:

$$A_e = \frac{\lambda^2}{4\pi} G$$

and represents the area of the equivalent surface, which is adsorbing the incoming e. m. radiation.

Polarisation discrimination

It measures the decoupling capability of the antenna between two e. m. waves incoming from the same direction but polarised along orthogonal planes. A typical figure is higher than 30 dB, along the receiving axis.

Beamwidth

Is given by the beamwidth referred to the angles of half power (3 dB beamwidth) and approximately expressed by:

$$\alpha = \left(\frac{30000}{G}\right)^{1/2} \quad \text{degrees}$$

Auxiliary systems of great importance are the de-icing, obtained by means of electrical heating, controlled by temperature and the rain-blower, able to avoid the water film deposition on the feed in case of rain, controlled by an annexed raingauge.

A critical role is played by the tracking system to maintain the antenna pointed along the receiving axis, which is mandatory for propagation stations with an antenna diameter higher than 3m.

A way to perform the tracking is the step-track system, where a computer controlled procedure searches continuously for the minimum variation of the signal moving from the initial position. This system is simple, cheap but needs a continuous motion of the antenna.

A more sophisticated, and expensive way of antenna pointing is the monopulse, where auxiliary horns or complex odd modes feeds look the phase opposition of the exact pointing.

4. RECEIVERS

The receiver has the critical task of transforming the e. m. field components received in antenna into electrical signals of suitable level and frequency, by means of adequate amplification, frequency conversion and detection of the incoming signals.

The receiver is characterized by the number of chains, depending on the received beacons and polarisations, the number of frequency conversions and the type of detection.

A basic typical scheme is composed by the front-end block, close to the antenna in order to minimize the lenght of r. f. waveguide.

The first step of the receiver is the low-noise amplifier (LNA), which is a r. f. amplifier with a low value of the noise figure F (some 3 - 4 dB for a total 30 dB gain), essential element for the total final gain:

$$F_{TOT} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots$$

when the gain of the first block is high enough it may be written:

$$F_{TOT} \approx F_1$$

The frequency conversion is normally obtained in one or more sequential steps.

The first step is usually from r. f. into high intermediate frequencies (i. e. 20 GHz to 1 GHz) in order to obtain good rejection of the image frequency and to allow an improvement of 3 dB in the signal to noise ratio S/N.

In the coherent detection receivers a Phase Lock Loop (PLL) is utilized to obtain the receiver tracking. The input to the PLL is given by a local oscillator. The PLL mantains the lock on the receiver signal above some 7 + 10 dB of the S/N. This threshold is therefore an input figure to determine the measuring dynamic of the receiver.

The signal is then demodulated extracting the phase and quadrature components (I, Q detection) which are sampled, converted into digital formats and processed to obtain:

$$\text{Amplitude} = (I^2 + Q^2)^{1/2}$$

$$\text{Phase} = \text{arctg}\left[\frac{Q}{I}\right]$$

4.1 Measure Dynamic and Link Budget

The power received by the earth-station is:

$$P_R = P_T \frac{G_T}{4\pi r^2} A_{eR} = P_T G_T G_R \left(\frac{\lambda}{4\pi r}\right)^2$$

where:

P_T	: on-board transmitter power
G_T	: satellite antenna gain
$P_T G_T$	: satellite EIRP
G_R	: earth antenna gain
A_{eR}	: earth antenna effective area = $G_R \frac{\lambda^2}{4\pi}$
λ	: wavelenght = c / f
r	: earth-satellite distance

The S/N ratio in 1 Hz band is:

$$\frac{C}{N_0} = \frac{P_R}{KT_S}$$

where

K	: Boltzmann constant
T_S	: earth station system temperature

$$T_S = T_a + T_0(\alpha - 1) + \alpha T_R$$

where

T_a	: antenna temperature
T_0	: reference temperature (290 K)
α	: waveguide attenuation
T_R	: receiver noise temperature

For a 1 Hz band it can be written:

$$\left(\frac{C}{N_0}\right)_{dB/Hz} = 228.6 + (P_T G_T)_{dBW} + \left(\frac{G_R}{T_S}\right)_{dB} - 20 \log\left(\frac{4\pi r}{\lambda}\right)$$

where the last term is called free-space attenuation.

The link budget calculation is usually referred to the noise figure F:

$$F = \frac{T_R - T_0}{T_0}$$

The fade margin is obtained as:

$$\text{Fade margin (dB)} = \left(\frac{C}{N_0}\right)_{dB/Hz} - 10 \log B_{PLL} - \left(\frac{C}{N}\right)_{TR}$$

where

B_{PLL} :	PLL band (Hz)
$\left(\frac{C}{N}\right)_{TR}$	: minimum C/N for the PLL lock (dB)

Usually a 20 dB fade margin is needed for small stations while 30 dB or over may be requested for higher frequencies in heavy rain regions.

It should be also noted how the coherent detection (PLL), although allowing the tracking of the receiver, introduces a lowering of some 10 dB in the total measure fade margin.

5. ATTENUATION MEASUREMENTS

Attenuation (fading) of the transmitter signal is the major impairment caused by the atmospheric components: rain, clouds, water vapour.

Up to 100 GHz these latters give minor contribution, limited to some lines of resonance: 22.5 GHz for water vapour, 60 GHz for oxygen, which are used for atmospheric soundings.

Ice and snow do not attenuate the signals when in their proper "dry" status, while may give noticeable fading in case of association with the liquid phase: melting ice and wet snow, respectively.

Paramount weight in the fading effect is due to the rain. Rain attenuation increases with the frequency and obviously with the intensity of the rain itself, varying from tenth of dB/Km at 10 GHz and 1 mm/h (light "stratiform" rain), up to some 40 dB/Km at 30 GHz and 150 mm/h (heavy "convective" rain).

When measuring the rain attenuation the typical figure to look for is the value exceeded for a given percentage of the time. According to the CCIR specifications the 0.01% of the year is the availability time for telecommunication services. Therefore the value exceeded for that time interval, about 1 hour per year, represents the limiting threshold to counteract.

When evaluating the attenuation characteristic of a site the yearly cumulative distribution is calculated on the basis of the obtained measurements, giving for each attenuation value the total yearly time during which that value has been exceeded. The fraction of this time with respect to the entire year is extrapolated to a probability level.

When assessing the attenuation CD of a site, careful attention has to be paid to the statistical significance of this information. Attenuation, as effect of strongly and fast variable causes, is a highly and fastly variable both in time and space.

The time variability of the attenuation is noticeable as well, according to various time scales.

A long term variability may be marked among years and many years, up to 10 or even more, are normally necessary for assessing the rain attenuation characteristics of a zone.

Short term variability is also present as the cause, rain, may considerably vary during times of the order of few seconds. This dynamic behaviour of the attenuation must be carefully considered in the measurements, as fundamental implications are involved such as the real time control of the up-link power to counteract the variations on the down-link, the fast control of which is not possible on board.

Moreover phenomena others than rain, such as the fast time variations of the refractive index, may introduce, in "clear sky" conditions, very fast variations of the signal, commonly referred to as "scintillations".

When measuring attenuation levels the critical parameter is the accuracy which should be of some 0.1 ÷ 0.2 dB in view of the sophisticated new systems and the high frequencies envisaged for the near future.

Unfortunately, up to now, the accuracy obtainable with the traditional receivers has been considerably higher: 0.5 dB.

The main sources of error in measuring attenuation are the false events due to equipment malfunctions, the difficulty on establishing a "clear sky" reference level, the presence of water or snow on the feed, and the short term variations caused by satellite movements and thermal cycles on the apparatus.

For the time being with a reasonable errors counteraction and calibration the goal of 0.5 dB is easily obtainable and may be considered acceptable for long-time statistics purposes.

Future systems, adopting new sophisticated techniques, will need considerable improvement of accuracy down to 0.1 ÷ 0.2 dB.

"Ad hoc" earth-stations, with more accurate calibrations, higher stability and fade margin may approach these goals.

Attenuation may also be evaluated through prediction techniques. A first way is that of starting from rain statistics and apply the well known relationship between rain and attenuation, assuming adeguate hypotheses for the spacial structure of rain. The error introduced by these methods is about 25%.

When reliable attenuation data are already available in a site, attenuation statistics may be derived at a certain frequency with a very limited error (10%), scaling from those measured at another one, generally lower.

A particular situation that may be encountered in attenuation measurement is the scatter configuration, which occurs every time that the signal transmitted by an earth-station is reflected by a rain cell into the receiving antenna of another terrestrial or satellite link, operating, within a certain area, at the same frequency.

The probability and behaviour of this interference by hydrometeor scatter are critical for the individuation of the "coordination area" of telecommunication services in high traffic zones and involves particular problems of attenuation measurement.

In this case, infact, the attenuation of the incoherent signal scattered from the rain volume as far as the receiving antenna, is a wanted effect as it attenuates the interfering signal.

Measurements are to be done very accurately on the rain in the scattering volume and along the interference path, in order to assess a rain spacial structure model able to allow the correct calculation of the attenuation itself.

6. DEPOLARISATION MEASUREMENTS

Hydrometeors of various type: raindrops, ice-crystals, snow or hail, or any combinations of them existing simultaneously or at different time and places along the path, may cause depolarisation of radio waves at frequencies above 10 GHz.

All these hydrometeors have the common property of being anisotropic, typically oblate shapes, as the larger raindrops, and of creating different propagation characteristics for the specific attenuation and phase coefficient, along two principal axes.

These effects cause a change in the state of polarisation of a radio wave propagating through the medium, transferring energy from the original polarisation (copolar channel) into the orthogonal one (cross polar channel).

An indication of the level if this transfer may be given by three values:

Cross-polar discrimination:

$$XPD_{ji} = 20 \log_{10} \frac{E_{jj}}{E_{ji}}$$

where:

- i : is the crosspolar channel
- j : is the copolar channel
- E_{jj} : is the signal received in the copolar channel
- E_{ji} : is the signal received in the crosspolar channel when a signal is only transmitted in the copolar channel.

Cross-polar Isolation:

$$XPI_j = 20 \log_{10} \frac{E_{jj}}{E_{ij}}$$

where:

- E_{jj} : is the signal in the copolar channel resulting from a transmission in the copolar channel.
- E_{ij} : is the signal in the copolar channel resulting from a transmission in the crosspolar channel when signals are transmitted in both the channels

Cross-polar level:

- XPL : absolute power in the depolarised component of the signal

The crosspolarisation ratios are in general complex quantities having both a modulus and a phase. The knowledge of the phase, as well as the amplitude, is essential for the evaluation of the system performances

6.1 Accuracy of Measurement

The accuracy with which XPD can be measured depends principally upon the residual XPD of the overall system (satellite antenna, earth-station antenna and receiving equipment) under clear sky conditions.

The satellite antenna system is typically specified to have a XPD equal or greater than 30 dB on the whole coverage area, while on axis it should be noticeably better. The XPD of the earth antenna should be greater than 40 dB on axis. For earth-station with antenna diameter less than 3m, the absence of tracking implies the acceptance of values of some 30 dB.

The range of values which is of interest for system design purposes is about 10 dB to 20 dB.

In order to perform accuracy of ± 1 dB in XPD measurements, the system residual XPD should be at least 20 dB better than the XPD that has to be measured.

The accuracy is very sensitive to this difference and may degrade to ± 3 dB when the residual XPD is only 10 dB better with respect to the measured one.

The source of this uncertainty is the unknown phase difference between the system residual crosspolar vector and the crosspolar vector produced by the depolarising medium.

6.2 Cross-polar Cancellation

There are two ways according to which the system residual can be improved and important propagation data recovered from events occurred during periods of poor system residual XPD.

Hardware cancellation is possible by an "ad hoc" circuit where a fraction of the copolar signal, coherent with the crosspolar one, is spilled, adjusted in phase and amplitude and fed into the crosspolar channel, in such a way to cancel the residual crosspolar signal.

When the satellite signal is not stable such a cancellation is no longer useful, since the signal to be cancelled is constantly varying.

Software cancellation may then be adopted by continuously recording the phase of the received crosspolar signal with respect to the copolar.

A linear fit can be made of the crosspolar component during the event, and subtracting the residual vector from the crosspolar measured one. This procedure is followed retrospectively and demands on manpower and computing costs.

7. RADIOMETRIC MEASUREMENTS

Radiometry is a promising technique for sounding the atmosphere components and structure.

For radiopropagation measurement purposes the radiometer is an excellent tool for the determination of the reference clear-sky level, as its sensivity is very good.

From the atmosphere point of view the radiometer may be considered the best compromise between reliability and accuracy for the determination of the water vapour content and profile, the clouds liquid water content and the temperature profile.

Other advantages of this instrument are that it is more economical with respect to the beacon receiver, that it does not require any transmitted beacon and allows complete detail of the hemisphere and long-term statistics.

Main disadvantages of the radiometer are that it is not reliable for high attenuation values (> 10 ÷ 12 dB) and that is a very sensitive instrument, the interpretation and calibration of which is very critical.

The basic principle of the radiometric measurements of attenuation on slant paths is the Kirchhoff law for black body radiation, according to which, for a purely absorbing homogeneous medium of constant temperature, a simple relation exists between attenuation on a path through the medium and the thermal noise generated along that path:

$$T_A = (1 - \alpha)\, T_M + \alpha T_S$$

where:

T_A : noise temperature received by the antenna
T_M : temperature of the medium
α : attenuation coefficient
T_S : sky temperature

In reality, as the medium is neither purely absorbing nor homogeneous and at constant temperature, the definition of an effective T_M should be made for any simultaneous observation of T_S and α.

7.1 Radiometer Calibration

Calibration is the most critical and essential operation to be performed with the radiometer.

A first type of calibration consists on the determination of linearity of the output voltage as a function of input noise power over the measurements range and is generally done by an i. f. calibration in combination with a relative gain measurements.

The most typical calibration is done by determinating the radiometer output for two known values of input noise temperature.

A liquid-nitrogen-cooled reference load is replaced to the antenna and the radiometer output is compared with that of a hot reference load.

An alternative to the cold-load calibration is obtained through the tip-curve calibration, where measurements of sky noise as a function of elevation are carried on in clear-sky conditions or conditions where atmosphere may be assumed to be homogeneously layered.

The main limitations of the radiometer are:

Sensivity

Is inversely proportional to the bandwidth and the integration time.

Medium temperature

The assumed hypothesis are not verified. The medium temperature varies with the height and scattering effect should be taken into account, expecially in the case of rain.

Antenna pattern

Antenna has a limited beam efficiency factor and residual noise is picked up from the ground.

Cold-load calibration

When calibrating with the cold-load procedure the unknown temperature differential along the waveguide introduces errors.

Mismatch errors

These errors are introduced during the operation of the circulator switch, when part of the hot load temperature is reflected into the measuring branch.

Polarisation

Errors may be introduced when measuring rain attenuation by the different polarisation of the beacon and the radiometer.

7.2 Types of Radiometers

Total power radiometer

Is a normal heterodyne receiver where a square-law detector, followed by an integrator, provides an output proportional to the average of the total noise power at the input. This instruments presents the critical disadvantage of having low stability, being very sensitive to the gain variation of the receiving chain.

Dicke-switch radiometer

In order to avoid loss of sensitivity due to rapid gain variations, the Dicke-switch radiometer provides an output which is proportional to the difference between antenna noise and the noise generated by a reference load. As the signal is sampled only for the 50% of the time, this radiometer has a lowered sensivity (3 dB less).

Noise balancing radiometer

This type of radiometer actively controls a reference generator (on-off switched diode) to provide an average noise power equal to the antenna output noise.

Its main advantage consists in the high noise of the reference diode which does not allow the measurement of normal sky noise.

Noise injection radiometer

To obtain balanced measurements, noise is added, via a directional coupler, to the antenna branch of the receiver.

Injected noise is controlled to obtain zero output. Critical points in this scheme are the stability of the noise source and the calibration accuracy of attenuator and couplers.

7.3 Atmospheric Radiometry

For the determination of the two water phases content of the atmosphere a dual-channel radiometer may be employed.

Choosing one frequency on one shoulder (better the inferioR) of the water vapour absorption peak at 22.35 GHz, typically some 21 GHz, and another frequency at 31 or 36 GHz, two different information can be obtained on the contribution of vapour and liquid water as the first line is sensitive to the water vapour, while the second mostly to the liquid water.

The same criterium is applied in the temperature profilers where some (5 - 8) lines are added in the oxygen inferior shoulder from 52 to 58 GHz, where the oxygen concentration and then absorption is a function of temperature.

Appropriate analitical inversion techniques should be applied to allow the individuation of the vertical profiles.

7.4 Radiometer Specifications

Differences exist between the requirements of propagation and atmospheric radiometers.

Antennas should be preferable of the off-set type as it guarantees a better side-lobes insulation (>20 dB).

The beamwidth should be lower in the propagation radiometers (1° + 2° at 3 dB) with respect to that required for water vapour radiometer (4° + 5°).

The same is valid for the receiver bandwidth with values of 100 - 200 MHz and 400 - 600 MHz respectively. The bandwidth should be in principles the larger as the faster are the phenomena to be observed.

The sensivity is requested to be from 0.1 to 1 K, the accuracy of 2 - 3 K or the antenna temperature and up to 5 K for sky noise. The stability should be less than 2 K per hour.

8. RADAR MEASUREMENTS

The weather radar is a powerful tool when used in the framework of radiopropagation measuremenrs.

Its main advantage is the possibility of mapping the two-dimensional structure of the rainy phenomena in conjunction with the vertical layering facilities, which results to be particularly effective when observing the vertical behaviour of the clouds and the melting layer. This upper part is typical of the stratiform light rain and involves serious impairments as it associates to the depolarisating effect of the ice-crystals a noticeable attenuation effect, which is practically absent in the dry ice and snow.

Weather radar presents on the reverse critical problems: first of all a not yet well assessed relationship between the measured reflectivity and the corrispondent attenuation and rain. As far as this latter is concerned the raindrop size distribution represents the most critical element as it varies from one event to the other.

This notwithstanding a well-calibrated weather radar, working with space resolution of some tens of metres over an operative effective range of 50-100 Km, may give a noticeable contribution to the assessment of the rain attenuation spacial structure.

Recently introduced multiparameter radars have moreover improved the possibility of investigating fine details. The dual-polarisation radar, in particular, allows the observation of the ellipticity of the raindrops, given the canting angle, from the differential attenuation on two orthogonally polarised signals.

9. RAIN MEASUREMENTS

Rain is the main cause of attenuation in the frequency interval between some 10 GHz up to 100 GHz. Its contribution increases with the frequency and with the intensity, which may range from very light rain ('drizzle', 1 mm/h), to light-medium rain (5-20 mm/h), up to very intense 'convective' rainstorms (>100 mm/h).

Rain is measured by means of the raingauges, which may be of different types, according to the rain intensity.

The most diffused one is the 'tipping bucket' type, where the falling water,collected through a given area, alternatively moves two small cups of known volume ,the swithing of which generates an electrical pulse (tip) which is recorded together to the time interval within the previous one. This instrument works well from some 10-20 mm/h up to more than 150 mm/h. Above that threshold dynamic phenomena of turbolence may affect the measure, as well as, for intensity lower than 5 mm/h, the integration time is too long, as the tipping-bucket raingauge is sampled on a asyncronous basis by the rain itself.

Other raingauges have been developed in order to face particular problems.

The fast response raingauge is particularly suitable to follow fast variations of the intensity around a certain value. It is composed by a funnel working as the capacitance of an oscillator whose frequency varies as a function of the water level running in the funnel. This raingauge must be carefully calibrated against a parallel tipping-bucket one.

The drop-counter raingauge works particularly well at low levels of rain as it lower considerably the integration time, via hardware detection of single drops. Some instruments are built in such a way to work as a drop-counter raingauge at low intensities and as a normal tipping-bucket one for higher levels.

9.1. Rain Features

Rain is a very difficult variable to be measured as it is highly variable, both in time and space.

The main parameter on rain measurements is the integration time, intended as the time during which water amount (mm) is integrated to express an equivalent rain intensity (mm/h). The longer this time, the higher the risk of ignoring rain intensity variations. Theoretically speaking an absolutely steady rain might be measured regardless of the integration time. For radiopropagation purposes, integration times of tens of seconds, one minute, are ideal, although integration times of 5-10 minutes are still indicative for the lowest levels of rain.

As far as the space structure is concerned, it is well known that the main limitation of the point measurement is the scarce representativity in terms of area. Rain phenomena in fact typically occur in forms of convective cells embedded into a stratiform plafond where they move, are generated and collapse according to criteria which are random to the observer. Usually it may be assumed that convective rains (>50 mm/h) have spacial dimensions rarely larger than one kilometre, while light stratiform rains may interest wide zones up to some one hundred kilometres.

This property of the rain structure is the basis of the small scale site-diversity, where two stations, serving the same area, are positioned 10-20 Km apart each other, being very low the probability of high rain occurrence in the two sites simultaneously. This technique cannot be used at very high frequencies (> 30 GHz), where even light phenomena may cause deep fading and may easily interest very wide areas.

In the future satellite systems the employment of 'common on-board resources' is envisaged, by managing spare resources to be assigned to earth-stations undergoing severe attenuation conditions. As the assisted stations may be very largely spaced, the study of the large scale space correlation of the fading phenomena is involved and the probability of joint events simultaneously occurring in groups of locations is the design figure to be characterized.

The vertical profile of rain is not constant as well. Apart from the possible variations in the cells structure itself, the liquid rain may, strictly speaking be found only below the zero degree level, also if supercooled raindrops are well known in the convective towers of rainstorms. This problem is absolutely critical for the rain attenuation prediction techniques where hypotheses should be made about the lenght of the slant path throughout the liquid rain. Unfortunately upper air measurements are not widely extended nor reliable. For the time being radiosonde data are the most diffuse also if the fast development of atmospheric soundings by multichannels radiometers is well promising for the future.

9.2. Rain Measurements

Rain measurements are normally referred to in form of cumulative distribution as well as for the attenuation, in order to provide an isoprobability correspondence.

Both year-to-year as well as site-to-site variability are normally assessed, with particular regard to the worst month distribution, intended as the tangle of the highest monthly probability for each threshold.

In order to give indications on the rain dynamic phenomena, the cumulative distribution of exceedance durations for given levels is usually calculated too, providing information on the probability of exceeding a rain threshold for a given time.

Reliable statistics of correctly measured rain are very scarce indeed over the world. Estimations are therefore a necessary tool and may be made either by assessing the statistical law of the distributions, if any, and by fitting an empirical relationship between the rain intensity distribution and more widely available data, such as temperature, humidity and longer integrated rain values, i.e. monthly total amount.

10. CLIMATOLOGICAL DATA

Direct measurements and collection of data of climatological variables such as temperature, humidity, air pressure, wind velocity and direction, status of the sky coverage are of interest in radiopropagation study for a double reason.

Climatic data are in fact effects of the same general causes that generate the rain and can be of help when approaching the problem from the model-oriented point of view and ,more simply, in the evaluation of event based single phenomena.

A second important reason consists in the practical impossibility of extending accurate measurements to a wide set of locations for statistically significant periods, unless to renounce completely to the cost-effectiveness. The cheaper way to be followed is therefore that of studyng, for the sites where accurate measurements are taken, the relationship among rain or rain attenuation and those rough climatic parameters data which are normally largely available in the National Services Archives, both in space and time.

According to this way, although introducing also noticeable approximations, design figures may be obtained immediately and economically with high space detail and time significance.

10.1 Clouds Measurements

Clouds are going to play a major role in the future communications systems, as the higher frequencies amplifies the effect of very small liquid hydrometeors. Moreover the adoption of small commercial terminals and the low elevations requested by the wider area coverages makes long time-lasting phenomena such as the clouds coverage essential for the design.

Unfortunately clouds measurements suitable for radiopropagation applications are difficult and not available. The figures of interest in this case are the cloud thickness, the horizontal extension and the liquid water content. This latter is the most difficult one to be assessed and the only possibility comes from radiometric dual-channel investigations which may give information on the height,thickness, liquid water content, temperature and components.

Ground observations, which are available and can be refined by comparison with propagation observations, may furnish rough indications on type and shape of the clouds, the heights of the bottom and top level, the horizontal extent and coverage degree.

Many measurements programs are being developed , mostly in the framework of the next Olympus - Italsat experiments and will be assisted by adequate radiometrical campaigns.

11. NON CONVENTIONAL MEASUREMENTS

Mention should be made of some new, non-traditional measurements which are planned for the next European satellites, in view of the future systems where, due to the transmission techniques and/or to the very sensitive high frequency bands, phenomena neglected till now may arise to a critical importance.

This is the case of the angle of arrival of the wavefront which may vary rapidly as a consequence of the transverse gradient of the refractive index. Spacial disuniformity and the interference between the main and secundary waves, as well as the incoherent radiation are other effects to be carefully studied and investigated by means of 'ad hoc' hardware plants.

The amplitude and phase distortions, already observed during the Sirio experiment must be better detailed as these effects may considerably affect the techniques of the up-link power control and the very high capacity systems envisaged for the next generation satellites.

12. CONCLUSIONS

Radiopropagation measurements are of paramount importance in the design of the telecommunication systems.

Rain attenuation and depolarisation, the effects of minor atmospheric components, such as water vapour and clouds, are the principal topics of study and measurements and the experimental techniques enough well assessed for the design purposes.

As the development of telecommunication is very rapid, new systems are near to be adopted that involve further deep investigations on the matter. Higher frequency bands, small commercial terminals, direct high definition TV broadcasting, very high capacity systems and flexible 'intelligent' satellite will require careful attention to be paid to the 'old' and new propagation characteristics.

Radiopropagation measurements techniques still shows to be the most powerful tool for investigation and are under refinement in order to face the needs for the future.

13. REFERENCES

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ICTP

COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION PHYSICS (TRIESTE, 6 - 24 / 2 /89)

LECTURES ON :

MEASUREMENT TECHNIQUES OF TROPOSPHERE RADIOPROPAGATION PARAMETERS

PROGRAMME

1 - GENERALITIES

2 - RECEIVING EARTH-STATIONS

3 - ATTENUATION MEASUREMENTS

4 - DEPOLARISATION MEASUREMENTS

5 - RADIOMETRIC MEASUREMENTS

6 - RADAR MEASUREMENTS

7 - RAIN MEASUREMENTS

8 - CLIMATOLOGICAL MEASUREMENTS

9 - NON-CONVENTIONAL MEASUREMENTS

10 - LABORATORY ACTIVITY : 20 GHz BEACON RECEIVER

MAIN EXPERIMENTS IN RADIOPROPAGATION

- COST PROJECTS 25 / 4 AND 205

- SIRIO SATELLITE (11 - 18 GHz)

- OTS SATELLITE (11 - 14 GHz)

- OLYMPUS SATELLITE (12 - 20 - 30 GHz)

- ITALSAT SATELLITE (18 - 40 - 50 GHz)

RECEIVING EARTH STATIONS FOR RADIOPROPAGATION MEASUREMENTS

MAIN CHARACTERISTICS

- ' AD HOC ' PHILOSOPHY
- HIGH SENSITIVITY
- HIGH ACCURACY
- SOPHISTICATED SOLUTIONS
- ACQUISITION AND PROCESSING FACILITIES

EARTH STATION

RECEIVING EARTH STATIONS FOR RADIOPROPAGATION EXPERIMENTS

REQUIREMENTS AND SPECIFICATIONS :

- HIGH ACCURACY IN THE MEASUREMENT OF COPOLAR AND CROSSPOLAR COMPONENTS (BOTH AMPLITUDE AND PHASE)
- PHASE MEASUREMENTS AMONG DIFFERENT BANDS
- COHERENCE AMONG RECEIVED SIGNALS
- DEPURATION OF ANTENNA AND RECEIVER SYSTEMATIC ERRORS (DISUNIFORMITY OF GAIN AND PHASE)
- MONOPULSE SYSTEM FOR ANTENNA POINTING
- PERIODICAL CALIBRATION FACILITIES
- DE - ICING AND RAIN PROTECTION SYSTEMS

RECEIVING EARTH STATIONS FOR RADIOPROPAGATION MEASUREMENTS

MAIN SUBSYSTEMS :

1 - ANTENNA

2 - RECEIVER

3 - MEASUREMENT AND CONTROL

4 - DATA ACQUISITION

ANTENNA

TYPES OF ANTENNAS

- PARABOLIC REFLECTOR

- CENTRED GEOMETRY

  PROTECTION FROM RAIN EFFECTS

- OFF - SET

  MINOR NOISE

- DOUBLE - REFLECTOR

  GOOD PERFORMANCES

ANTENNA MAIN PARAMETERS

- DIAMETER

- GAIN : (30 - 55 dB)

$$G = \frac{4\pi}{\lambda^2} \eta S_b$$

η = EFFICIENCY (0.5 - 0.7)

- EFFECTIVE AREA

$$A_e = \frac{4\pi}{\lambda^2} G$$

- POLARISATION DISCRIMINATION

DECOUPLING BETWEEN TWO ORTHOGONAL WAVES INCOMING FROM THE SAME DIRECTION ($\geq$ 30 dB)

- APERTURE

ANGLE OF THE HALF POWER BEAM (3 dB)

ANTENNA AUXILIARY SYSTEMS

- DE - ICING

ELECTRICAL HEATING OF THE REFLECTOR
(TEMPERATURE CONTROLLED)

- RAIN BLOWER

AGAINST WATER FILM IN CASE OF RAIN

- POINTING SYSTEM

MONOPULSE

AUXILIARY HORNS OR ODD MODES FEED
NO ANTENNA MOTION
SOPHISTICATED AND EXPENSIVE

STEP - TRACK

MINIMUM GRADIENT AUTOMATIC RESEARCH
ANTENNA FREQUENT MOTION
CHEAPER BUT LESS PRECISE

RECEIVER

INPUT : E.M. FIELD RECEIVED IN ANTENNA

OUTPUT : ELECTRICAL SIGNALS OF GIVEN AMPLITUDE AND FREQUENCY, PROPORTIONAL TO THE ANTENNA RECEIVED SIGNAL

TASKS

AMPLIFICATION

FREQUENCY CONVERSION

DETECTION

CHARACTERISTICS

NUMBER OF CHAINS

NUMBER OF CONVERSIONS

TYPE OF DETECTION

SUBSYSTEMS

- **FRONT END**

  CLOSE TO THE ANTENNA

- **LNA**

  RF AMPLIFIER WITH LOW NOISE FIGURE
  (4 dB FOR 30 dB GAIN)

- **FREQUENCY CONVERSION**

  FIRST STEP : 20 GHz TO 1 GHz
  REJECTION OF THE IMAGE FREQUENCY
  GAIN OF 3 dB IN S/N

  SECOND STEP : 1 GHz TO 70 MHz
  NARROW BAND FILTERING: INCREASE S/N

- **PHASE LOCK LOOP** (PLL)

  LOCKED UNTIL $S/N > 7 \div 10$ dB

- **DEMODULATION**

  PHASE AND QUADRATURE COMPONENTS

- **A / D CONVERSION**

- **ACQUISITION AND PRE - PROCESSING**

RECEIVER

MEASURE DYNAMIC

- RECEIVER POWER

$$P_R = P_T\, G_T\, G_R \left(\frac{\lambda}{4\pi r}\right)^2$$

- S /N RATIO

$$\left(\frac{C}{N_O}\right)_{1Hz} = \frac{P_R}{KT_S}$$

- RECEIVING SYSTEM TEMPERATURES

$$T_S = T_A + T_O(\alpha - 1) + T_R$$

$$T_R = T_O(F - 1)$$

- FADE MARGIN

$$\left(\frac{C}{N_O}\right)_{1Hz} - 10 \log B_{PLL} - \left(\frac{C}{N}\right)_{TR} = 20 \div 30 \text{ dB}$$

EARTH STATION

EARTH STATION LINK - BUDGET (OLYMPUS 12 GHz)

FREQUENCY (GHz)	12.5
EIRP (dBW)	9
FREE SPACE ATTENUATION (dB)	207
ANTENNA GAIN (dB)	45.5
ANTENNA DIAMETER (M)	2
ANTENNA EFFICIENCY (%)	50
SYSTEM TEMPERATURE (K)	780
G / T (dB / K)	16.5
C / N_O (dB / Hz)	47
PLL BAND (dBHz)	17
C /N PLL (dB)	30
C /N THRESHOLD (dB)	10
FADE MARGIN (dB)	20

MAIN CAUSES

- RAIN
- CLOUDS
- ICE
- WATER VAPOUR
- OXYGEN

RAIN ATTENUATION

- INCREASING WITH FREQUENCY
- TIME VARIABILITY
- STATISTICAL STABILITY
- SITE VARIABILITY
- SPACE SIGNIFICANCE
- DYNAMIC CHARACTERISTICS
- SCINTILLATIONS

MEASURE ACCURACY

- SATELLITE EIRP (OTS)	:	18 dBW
- RECEIVED LEVEL	:	-140 dBW
- DYNAMIC RANGE	:	25 dB
- OVERALL RECEIVER GAIN	:	130 dB
- DESIDERABLE ACCURACY	:	0.1 dB
- ACTUAL ACCURACY	:	0.5 dB
- RECENT GOALS	:	0.1-0.2 dB

- CRITICAL STABILITY AND LINEARITY
- SYSTEM CALIBRATION ESSENTIAL

SOURCES OF ERROR

- <u>FALSE EVENTS</u>

  EQUIPMENT MALFUNCTIONS

- <u>REFERENCE LEVEL</u>

  TRANSMITTER DIURNAL VARIATIONS
  OTHER COMPONENTS VARIATIONS
  CLEAR SKY LEVEL ON EVENT SIDES
  RADIOMETER

- <u>WATER AND SNOW ON THE ANTENNA</u>

  FEED WINDOW: SEVERE IMPAIRMENTS
  RAIN BLOWER OR 'AD HOC' GEOMETRIES
  DEPURATION
  MELTING SNOW: DE-ICING HEATER
  MAN-MADE PREPROCESSING

- <u>SHORT TERM VARIATIONS</u>

  SATELLITE MOVEMENTS
  THERMAL CYCLES ON APPARATUS
  DATA FILTERING
  LOWERED TIME RESOLUTION

ACCURACY REQUIREMENTS

- OBTAINABLE ACCURACY : 0.5 dB

  ERRORS COUNTERACTION
  FREQUENT CALIBRATION

- LONG TERM STATISTICS

  SHORT TERM (10 S) AVERAGE ERROR

- DYNAMIC INVESTIGATIONS

  VARIANCE OF ERROR

- MODERN SYSTEMS

  RESOURCE SHARING
  ADAPTIVE TECHNIQUES
  UP-LINK POWER CONTROL
  HIGH ACCURACY REQUESTED : 0.1 - 0.2 dB

SCATTER CONFIGURATIONS

- HYDROMETEORS SCATTER
  ISOFREQUENCIAL CLOSE LINKS
  COORDINATION AREA

- FUCINO BISTATIC LINK
  TELESPAZIO - FUB - SIRIO

- MEASUREMENT OF SCATTERING VOLUME
  PATH ATTENUATION
  RAIN CELL
  RAIN HORIZONTAL STRUCTURE

MAIN CAUSES

- RAIN
- SNOW
  WET SNOW
- ICE
  MELTING ICE
- HAIL
- ANISOTROPY
  OBLATE SHAPE
  ROTATION OF SIGNALS

DEFINITIONS

- **CROSS-POLAR DISCRIMINATION XPD**

  RATIO BETWEEN:
  SIGNAL IN THE COPOLAR CHANNEL
  SIGNAL IN THE CROSS-POLAR CHANNEL
  WHEN A SIGNAL IS ONLY TRANSMITTED IN THE COPOLAR CHANNEL

- **CROSS-POLAR ISOLATION XPI**

  RATIO BETWEEN:
  SIGNAL IN THE COPOLAR CHANNEL
  SIGNAL IN THE COPOLAR CHANNEL
  WHEN SIGNALS ARE TRANSMITTED IN BOTH CHANNELS

- **CROSSPOLAR LEVEL XPL**

  ABSOLUTE POWER IN THE DEPOLARISED COMPONENT OF THE SIGNAL

ACCURACY OF MEASURE

- RESIDUAL XPD IN CLEAR SKY CONDITIONS

  ANTENNAS, RECEIVING EQUIPMENT

- SATELLITE ANTENNA XPD > 30 dB

  HIGHER ON AXIS

- EARTH ANTENNA ON AXIS XPD > 40 dB

- IN ABSENCE OF TRACKING XPD > 30 dB
  (DIAMETER < 3M)

- ACCURACY REQUIREMENT : 1 dB

  THE SYSTEM RESIDUAL XPD SHOULD BE 20 dB BETTER THAN THE XPD TO BE MEASURED AS THE TRUE PATH EFFECTS TYPICALLY 40 dB AND 20 dB RESPECTIVELY

- RESULTING UNCERTAINTY:

  UNKNOWN PHASE DIFFERENCE BETWEEN THE SYSTEM RESIDUAL CROSS-POLAR VECTOR AND THE CROSS-POLAR VECTOR PRODUCED BY THE DEPOLARISING MEDIUM.

CROSS - POLAR CANCELLATION

- HARDWARE CANCELLATION

  COHERENT SIGNALS
  COPOLAR SPILLING INTO CROSS-POLAR BY ADJUSTING PHASE AND AMPLITUDE

- SOFTWARE CANCELLATION

  IN CASE OF SIGNAL INSTABILITY.
  CONTINUOUS RECORDING OF CROSS-POLAR.
  LINEAR FITTING OF PHASE AND AMPLITUDE.
  VECTORIAL SUBTRACTION FROM THE CROSS-POLAR.
  VECTOR MEASURED DURING THE EVENT.

RADIOMETRIC MEASUREMENTS

- <u>PROPAGATION RADIOMETRY</u>

  REFERENCE CLEAR-SKY LEVEL
  LOW FADE EVENTS
  LONG TERM STATISTICS
  LOW AVAILABILITY SYSTEMS

- <u>ATMOSPHERIC RADIOMETRY</u>

  WATER VAPOUR CONTENT / PROFILE
  CLOUDS CONTENT / PROFILE
  TEMPERATURE PROFILE

BASIC PRINCIPLES

- KIRCHHOFF LAW
  FOR BLACK BODY RADIATION
  EMISSION = ATTENUATION

  $T_A = (1 - \alpha)T_M + \alpha T_S$

- RADIOMETER MEASURES THE NOISE TEMPERATURE AT THE OUTPUT FLANGE OF THE ANTENNA

- DEFINITION OF AN EFFECTIVE T_M FOR EACH SIMULTANEOUS OBSERVATION OF T_S AND α (A)

- CALIBRATION : ESSENTIAL AND CRITICAL

-

RADIOMETER CALIBRATION

- **I. F. CALIBRATION**

  DETERMINATION OF LINEARITY
  OF THE OUTPUT VOLTAGE
  VS INPUT NOISE POWER

- **COLD LOAD CALIBRATION**

  DETERMINATION OF RADIOMETER OUTPUT
  FOR TWO KNOWN VALUES OF INPUT
  NOISE TEMPERATURE.
  LIQUID NITROGEN - COOLED LOAD,
  REPLACING THE ANTENNA, COMPARED
  WITH HOT REFERENCE LOAD.

- **TIP - CURVE CALIBRATION**

  ELEVATION SCANNING AVAILABLE.
  ATMOSPHERE HOMOGENEOUSLY LAYERED.
  COMPARISON VS INTEGRATED AIR MASS.

RADIOMETER LIMITATIONS

- **SENSIVITY**

  $$\Delta T = T\sqrt{\frac{1}{Bt}+\left(\frac{\Delta G}{G}\right)^2}$$

  FOR THE DICKE TYPE THE VALUE IS TWICE
  DUE TO THE DUTY CYCLE OF MEASUREMENT

- **MEDIUM TEMPERATURE**

  HEIGHT DEPENDENCE
  SCATTERING EFFECT

- **ANTENNA PATTERN**

  GROUND NOISE

- **COLD LOAD CALIBRATION**

  WAVEGUIDE TEMPERATURE UNKNOWN

- **MISMATCH ERRORS**

  HOT LOAD INTO THE MEASURING BRANCH

- **POLARISATION**

  SHOULD BE THE SAME OF THE BEACON

TYPES OF RADIOMETER

- **TOTAL POWER**

  HETERODYNE RECEIVER
  GAIN VARIATION
  LOW STABILITY

- **DICKE - SWITCH**

  COUNTERACT RAPID GAIN VARIATIONS
  REFERENCE LOAD
  HIGHER STABILITY
  LOWER SENSITIVITY (3dB LESS)

- **NOISE BALANCING**

  REFERENCE GENERATOR (SWITCHED DIODE)
  PROVIDING AVERAGE POWER EQUAL TO THE ANTENNA OUTPUT NOISE.
  NOT SUITABLE FOR LOW NOISE

- **NOISE INJECTION**

  NOISE IS ADDED TO THE ANTENNA BRANCH
  CONTROLLED TO OBTAIN ZERO OUTPUT.
  STABILITY OF NOISE SOURCE IS CRITICAL.
  CALIBRATION OF ATTENUATION AND COUPLERS

ATMOSPHERIC RADIOMETRY

- **LOW ATTENUATION SOURCES**

  WATER - VAPOUR
  CLOUDS

- **DUAL - CHANNEL RADIOMETRY**

  CHOICE OF FREQUENCIES
  WEIGHTING FUNCTIONS
  INVERSION TECHNIQUES
  HUMIDITY PROFILES

- **TEMPERATURE PROFILING**

  OXYGEN LINES

- **EHF BAND RADIOMETRY**

  90 GHz WINDOW

RADIOMETER SPECIFICATIONS

- ANTENNA

CASSEGRAIN : OPTIMIZED GAIN
OFF - SET : SIDE LOBES INSULATION (20 dB)

- BEAMWIDTH

SOME 1° - 2° AT 3dB FOR PROPAGATION
LARGER (4 °- 5°) FOR REMOTE SENSING

- FREQUENCY

SHOULDERS OF THE ABSORPTIONS PEAKS
WEIGHTING FUNCTIONS

- RF BANDWIDTH

± 100 MHz FOR PROPAGATION
LARGER, UP TO 1 GHz, FOR REMOTE SENSING

- SENSIVITY

0.1 K UP TO 1 K

- ACCURACY

2 - 3 K FOR ANTENNA TEMPERATURE
UP TO 5 K FOR SKY NOISE

- STABILITY : ≤ 2 K / HOUR

WEATHER RADAR

- ADVANTAGES

TWO - DIMENSIONAL MAPPING

- DISADVANTAGES

CRITICAL RELATIONSHIP BETWEEN
REFLECTIVITY, ATTENUATION AND RAIN.
RAINDROP SIZE DISTRIBUTION
VARIABLE WITH EVENTS

- RANGE

50 - 100 KM DECREASING WITH RESOLUTION

- SPATIAL RESOLUTION

TENS TO HUNDREDS OF METRES

- MULTIPARAMETERS RADAR

DOPPLER VELOCITY OF TARGETS
DUAL - POLARISATION

RAIN

- MAIN CAUSE OF FADING ABOVE 10 GHz

- ASSESSED LINK WITH ATTENUATION

TYPES OF RAINGAUGES

- TIPPING - BUCKET

- SYPHON RAINGAUGE

- FAST - RESPONSE

- DROP - COUNTER

RAIN FEATURES

- <u>SPACIAL REPRESENTATIVITY</u>

  POINT MEASUREMENTS

- <u>HORIZONTAL STRUCTURE</u>

  SMALL SCALE DIVERSITY
  LARGE SCALE DIVERSITY

- <u>VERTICAL STRUCTURE</u>

  FREEZING HEIGHT

- <u>INTEGRATION TIME</u>

- <u>DYNAMIC CHARACTERISTICS</u>

RAIN MEASUREMENTS

- <u>CUMULATIVE DISTRIBUTION</u>

- <u>WORST MONTH</u>

- <u>YEAR TO YEAR VARIABILITY</u>

- <u>SITE TO SITE VARIABILITY</u>

- <u>DURATION DISTRIBUTION</u>

- <u>PREDICTION TECHNIQUES</u>

CLIMATE DATA

- <u>HUMIDITY</u>
- <u>TEMPERATURE</u>
- <u>PRESSURE</u>
- <u>WIND</u>
- <u>RAIN</u>
- <u>CLOUDS</u>

CLOUDS MEASUREMENTS

- DIRECT OBSERVATIONS
- ARCHIVES DATA
- RADIOSONDE
- RADIOMETER
- RADIATION MEASUREMENTS

NON CONVENTIONAL MEASUREMENTS

- **ANGLE OF ARRIVAL**

  TRANSVERSE GRADIENT OF REFRACTION INDEX
  0.05° FOR ELEVATIONS >30°

- **SPACIAL DISUNIFORMITY**

  INTERFERENCE BETWEEN THE MAIN WAVE
  AND ONE OR FEW SECONDARY WAVES.
  MEASURED AS ABOVE

- **PHASE DISTORTION**

  5°- 10° IN A 500 MHz BAND WITH SIRIO
  UNKNOWN CAUSES.
  MEASURED AT 40 GHz WITH ITALSAT.
  FUTURE VERY HIGH CAPACITY SYSTEMS.

- **AMPLITUDE DISTORSION**

  CAUSED BY RAIN
  UP-LINK POWER CONTROL

- **INCOHERENT RADIATION**

  REFRACTION INDEX SCATTER.
  HYDROMETEORS SCATTER.
  AUTOMATIC POINTING OF ANTENNAS.

NEEDS FOR THE FUTURE

- **HIGHER BANDS**

  40 - 50 - 90 GHZ
  NEW ATMOSPHERIC AGENTS

- **SMALL TERMINALS**

  COMMERCIAL.
  DIRECT BROADCAST HDTV.
  LOW AVAILABILITY SYSTEMS.
  LOW EFFECT AGENTS.

- **HIGH CAPACITY SYSTEMS**

  UP-LINK POWER CONTROL.
  NON-CONVENTIONAL MEASUREMENTS.

- **FLEXIBLE SYSTEMS**

  ON-BOARD MANAGEMENT.
  LARGE SCALE DIVERSITY.

CONCLUSIONS

- JOINT PROBABILITY VALUES ARE CALCULATED AND AN EMPIRICAL APPROXIMATION FORM IS GIVEN FOR THE EVALUATION

- A MODEL APPROXIMATION EXPRESSION IS GIVEN FOR THE CORRELATION INDEX

- THE BEHAVIOUR OF THE SPACIAL DEPENDENCE OF RAIN IS SHOWN ALONG THREE METEOROLOGICAL SCALES : MESOSCALE (100 KM), SHORT SYNOPTIC SCALE (100 - 700 KM), LARGE SYNOPTIC SCALE (> 700 KM)

- THE INFLUENCE OF THE INTEGRATION TIME IS ANALYSED SHOWING THAT THE DAILY BASIS IS EXAUSTIVE OF THE PHENOMENON BEYOND SOME 300 KM, WHILE FOR SHORTER DISTANCES A RELATIONSHIP IS FOUND WITH SHORTER INTEGRATION TIMES

- A GENERAL APPROACH IS DESCRIBED FOR THE CASE OF A SATELLITE ASSISTING N EARTH STATIONS BY MEANS OF M RESOURCES SYSTEM

FADING CORRELATION STUDY

ANALYSIS OF THE STATISTICAL DEPENDENCE OF RAINY EVENTS IN COUPLES OF SITES

MAIN GOAL

FEASIBILITY, DESIGN AND RELIABILITY OF SATELLITE ON-BOARD COMMON RESOURCES SYSTEMS, TO BE DEVOTED TO STATIONS UNDERGOING SEVERE FADING CONDITIONS

APPROACHES

<u>DESIGN-ORIENTED</u> : JOINT PROBABILITY OF OCCURRENCE OF RAIN/FADING PHENOMENA IN TWO OR MORE SITES

<u>MODEL ORIENTED</u> : SPACIAL CORRELATION OF THE RAIN STRUCTURE ON LARGE SCALE

RADIOMETER

- ZERO LEVEL DETERMINATION
- EVALUATION OF TROPOSPHERIC COMPONENTS OTHER THAN RAIN

ADVANTAGES :

- LESS EXPENSIVE
- NO SATELLITE BEACON NEEDED
- COMPLETE DETAIL OF THE HEMISPHERE
- GOOD RESOLUTION AT LOW LEVELS

DISADVANTAGES :

- DIFFICULT RIGOROUS INTERPRETATION
- UNABLE TO WORK AT HIGH LEVELS

EFFECTS OF CLOUDS

- FREQUENCY

  (0.3 ÷ 1.0 dB / km at 20 ÷ 50 GHz)

- ELEVATION

  (1 ÷ 10 dB at 30 ÷ 10 °)

- SYSTEM AVAILABILITY

  (50 % OF THE TIME)

CLOUDS PARAMETERS

FROM GROUND OBSERVATIONS :

TYPE, SHAPE, HEIGHTS, HORIZONTAL EXTENT, COVERAGE DEGREE

FROM RADIOMETRIC OR BALLOON OBSERVATIONS :

HEIGHT, THICKNESS, LIQUID WATER CONTENT, LIFTING MOTION, TEMPERATURE COMPONENTS

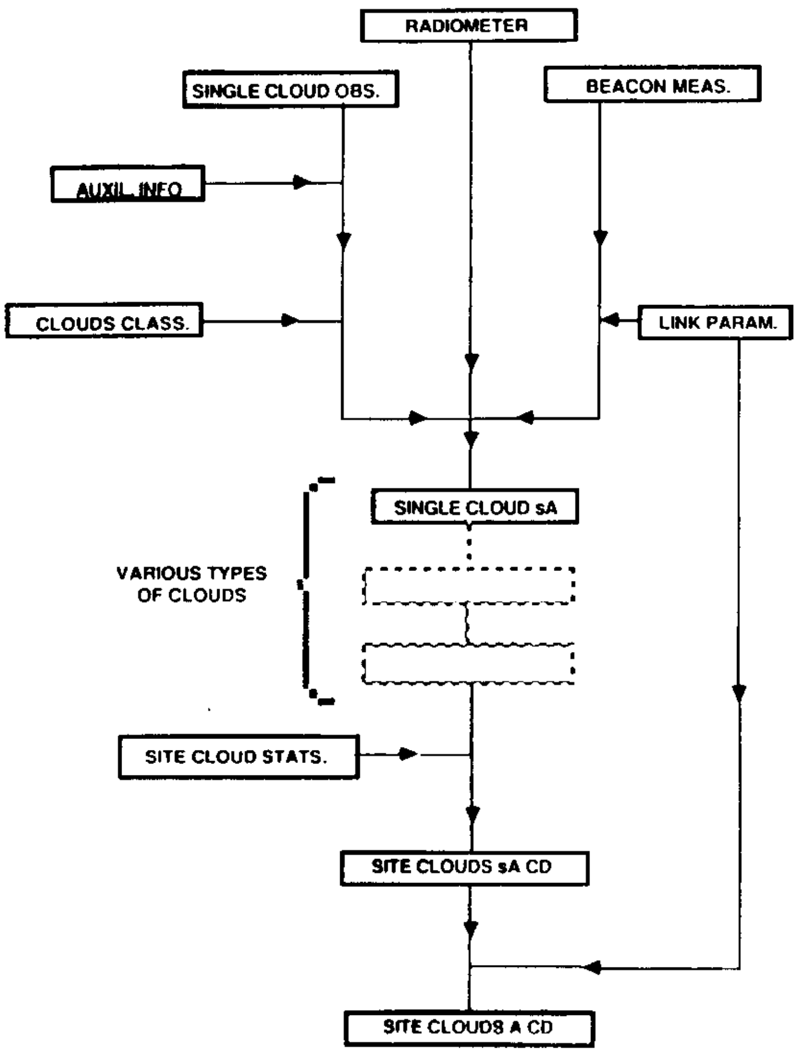
CLOUDS STANDARD DATA

- MONTHLY NUMBER OF DAYS
- THREE - HOURLY VALUES OF CLOUDINESS
- THREE - HOURLY VALUES OF :
  - FRACTION COVERED BY DIFFERENT CLOUDS
  - HEIGHT OF THE BASE OF THE LOWEST
  - DETAILS ON FEATURES

CLOUDS NEEDED INFO

- LIQUID WATER CONTENT
- THICKNESS
- SPATIAL DISTRIBUTION
- TIME BEHAVIOUR

EVALUATION OF CLOUDS ATTENUATION



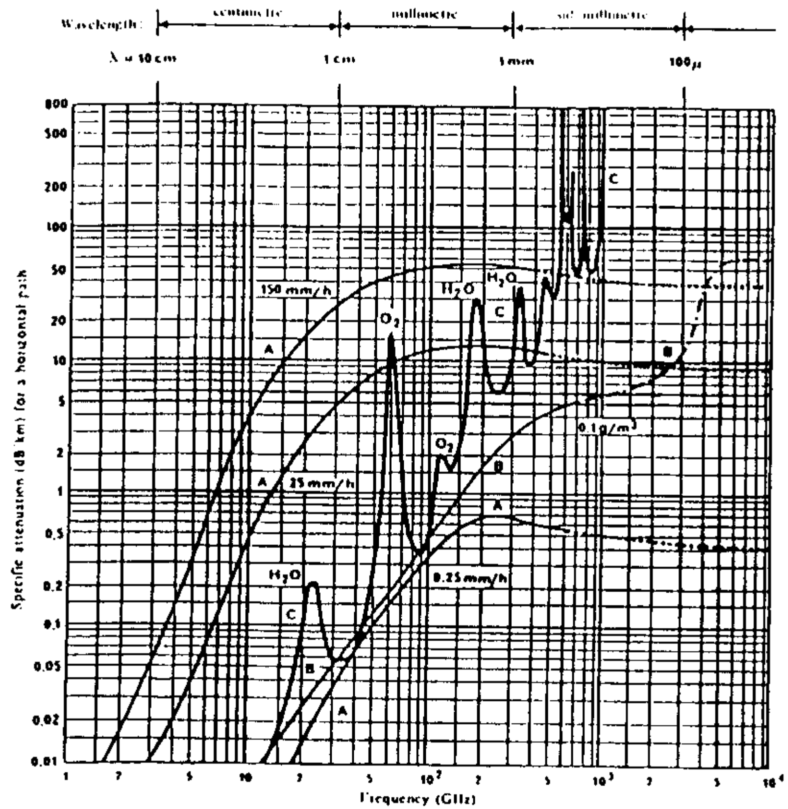
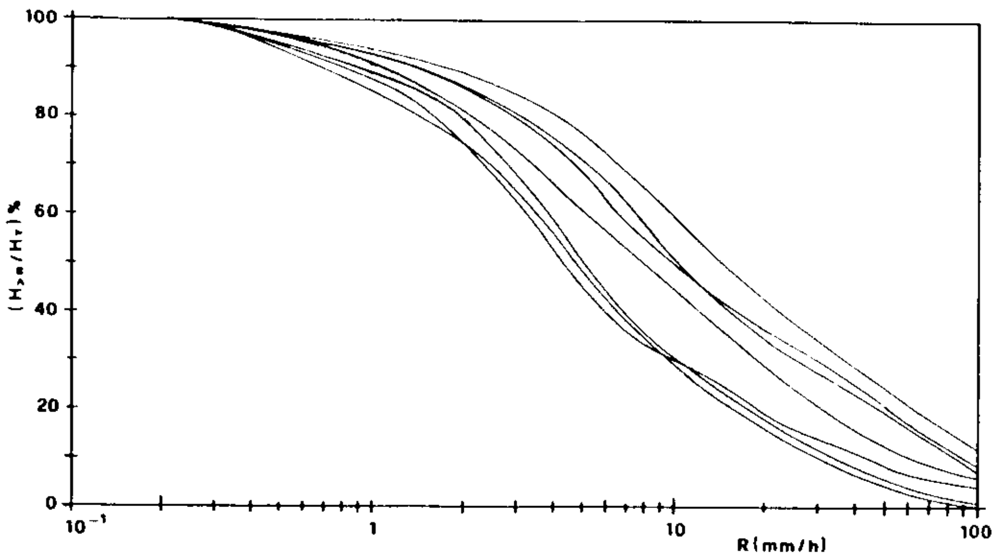


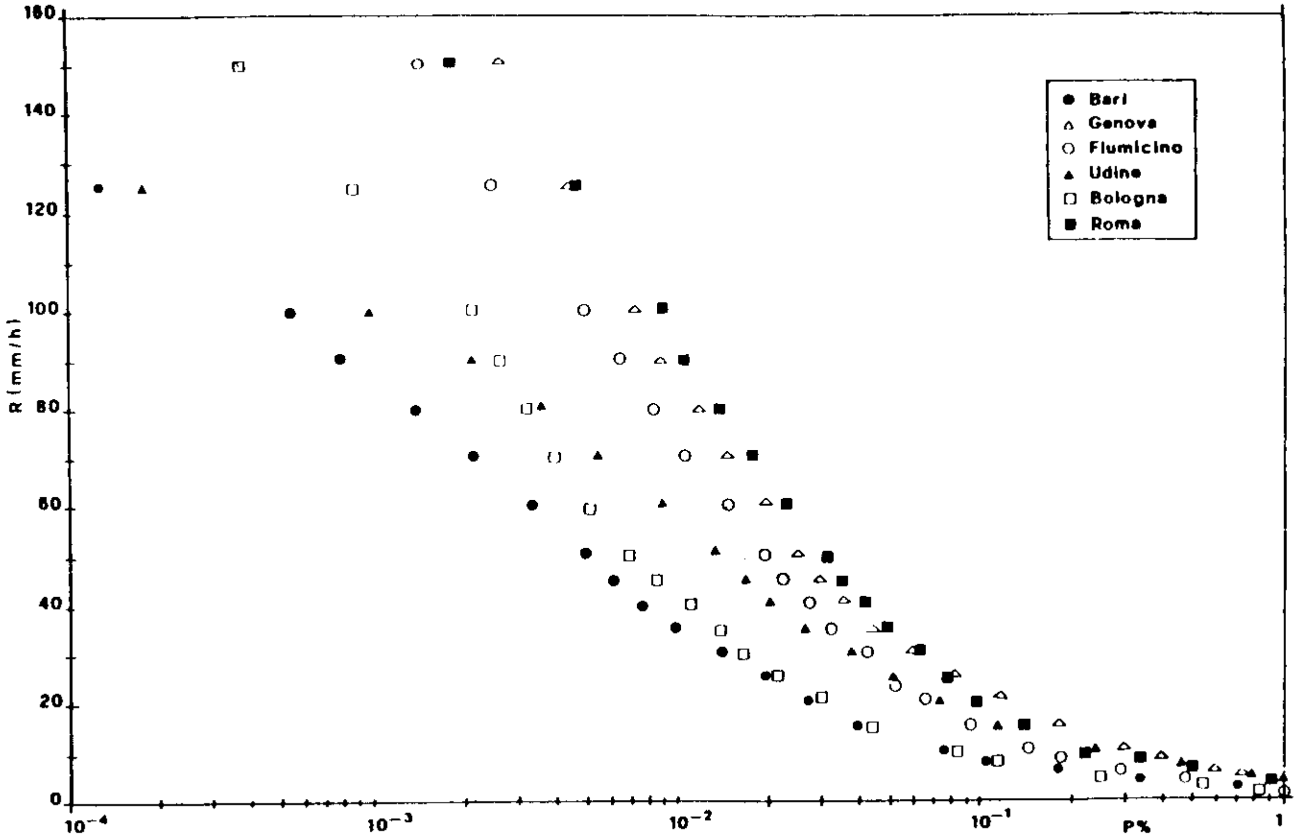
FIGURE 1 - *Attenuation due to gaseous constituents and precipitation for transmissions through the atmosphere*

Temperature: 20 °C
Pressure: sea level: 1 atm
Water vapour: 7.5 g/m³

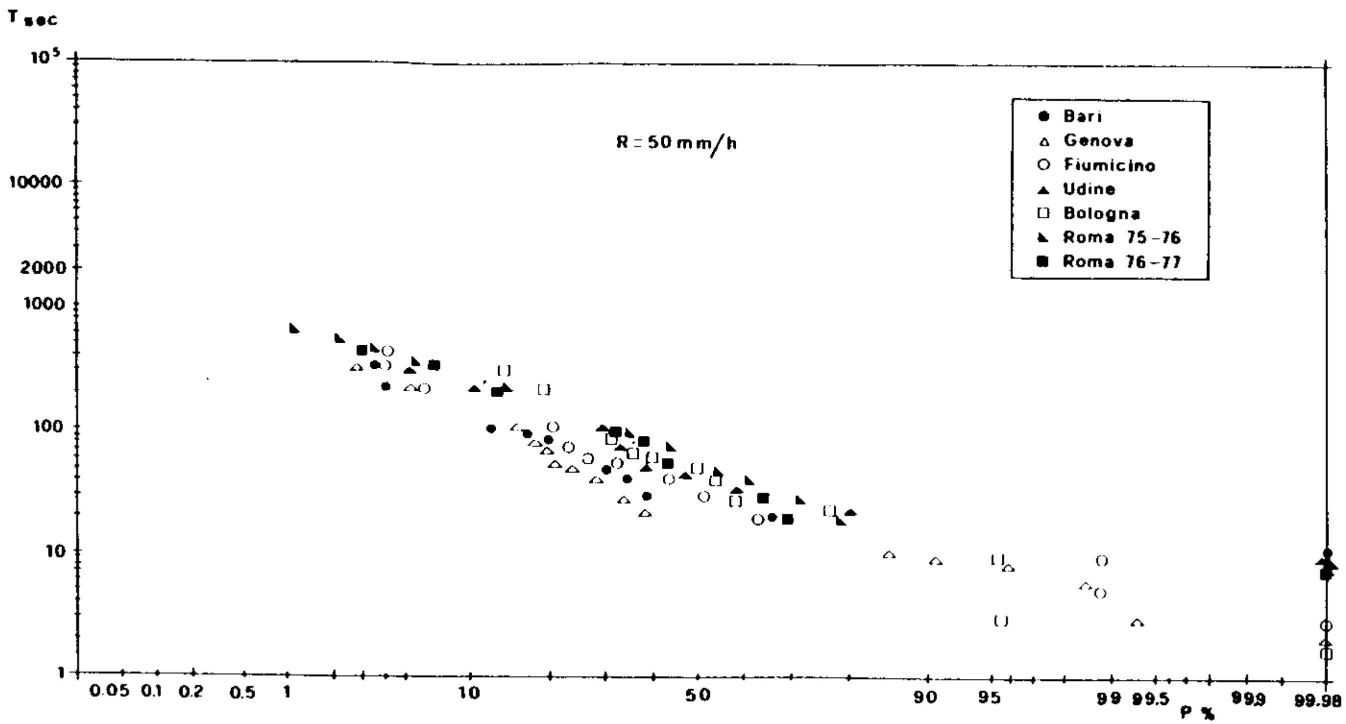
A: rain
B: fog
C: gaseous



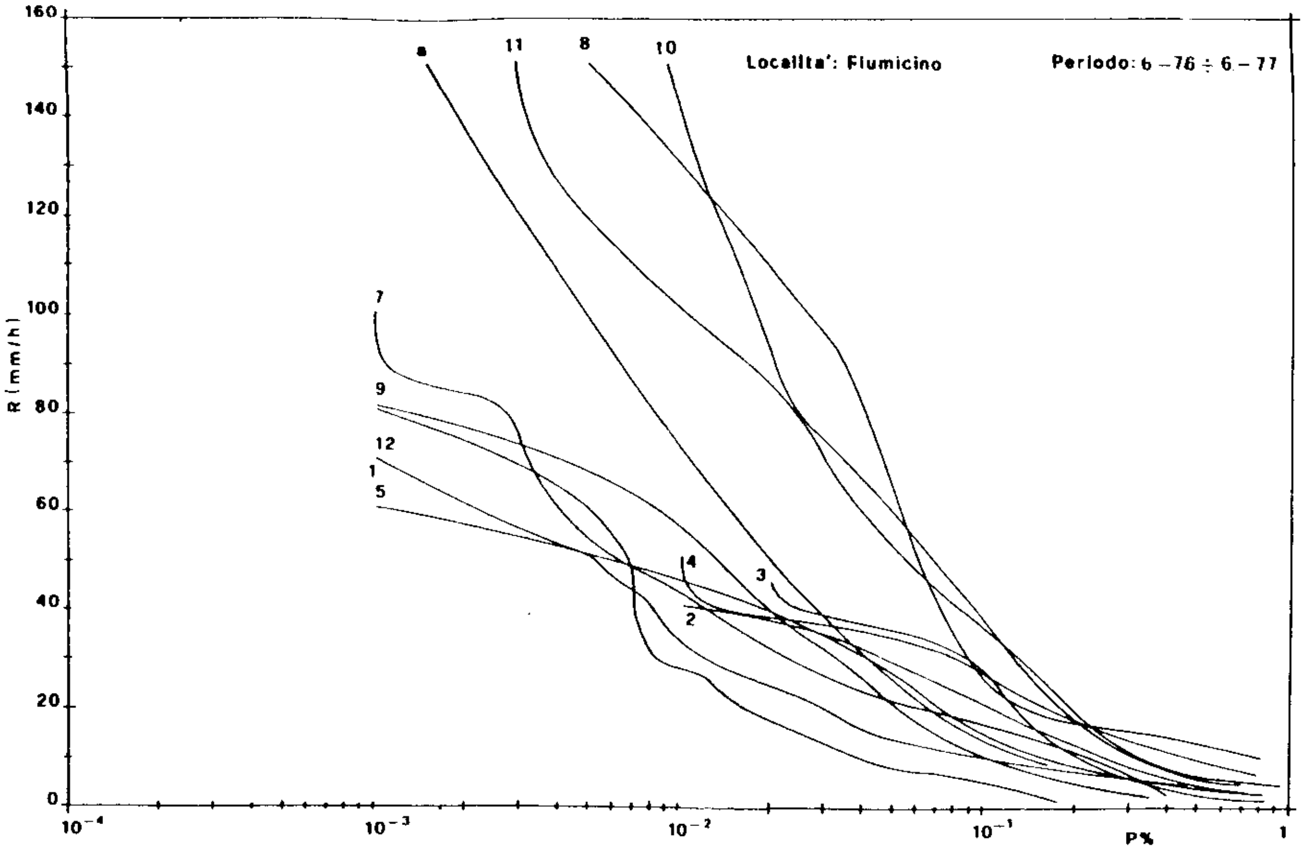
Distribuzione percentuale delle altezze con le intensità.



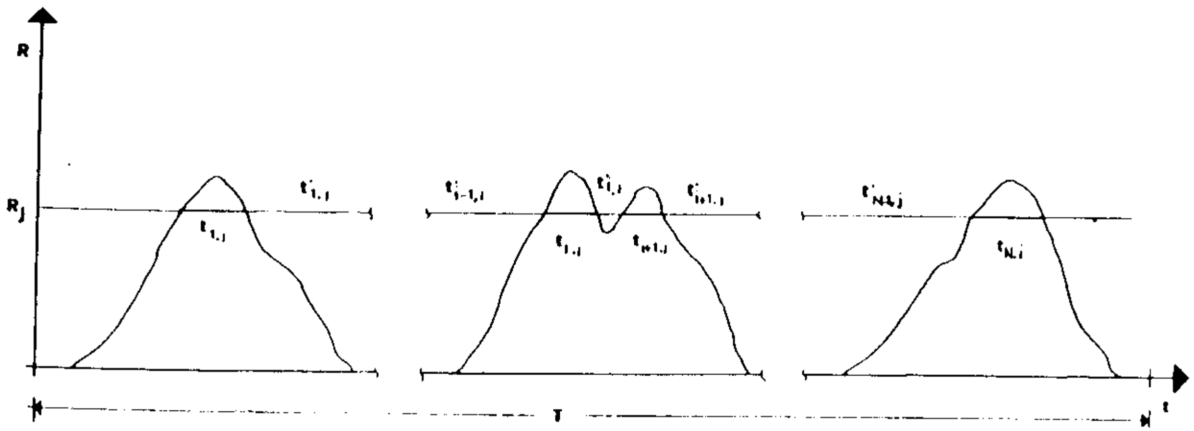
Funzioni di distribuzione delle intensità di precipitazione nelle 6 località.



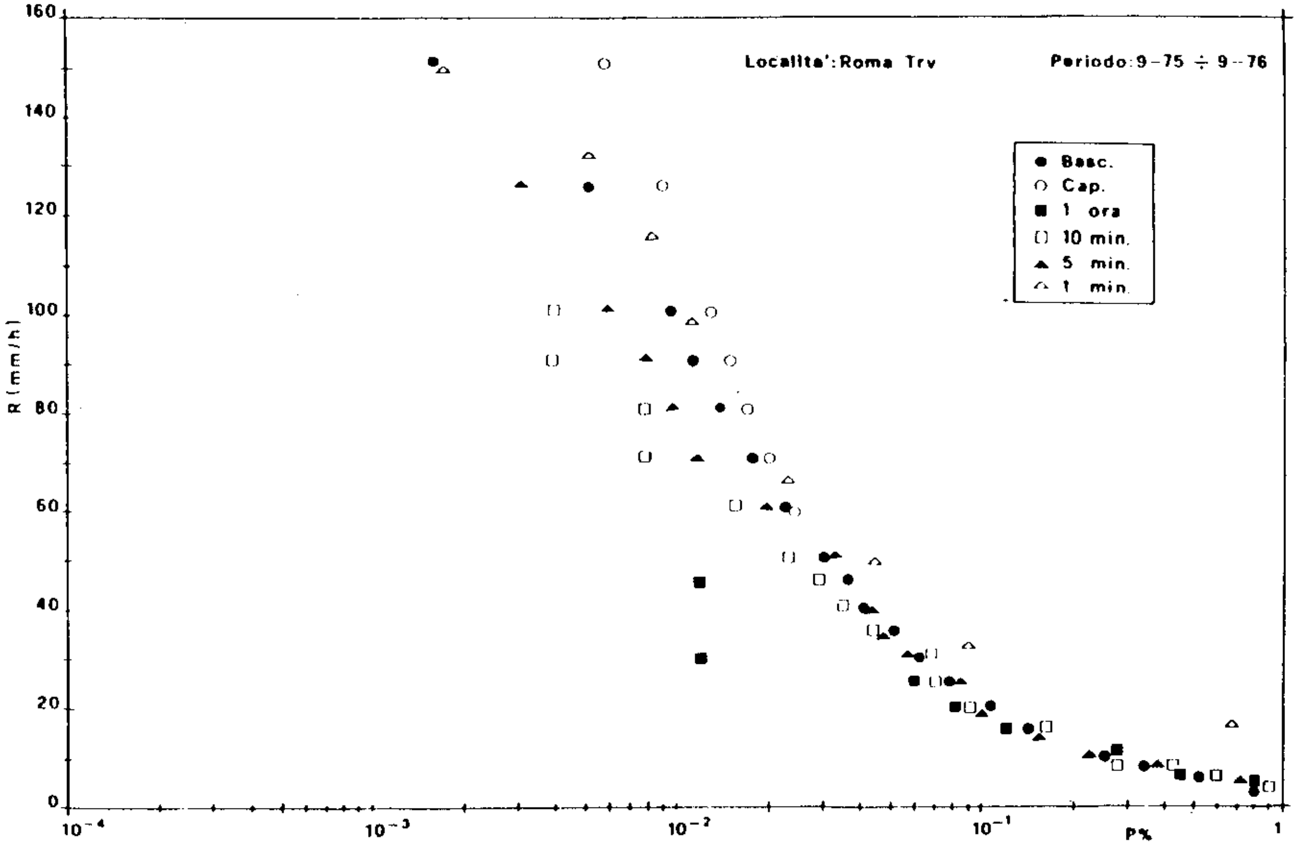
Funzione di distribuzione delle durate di superamento.



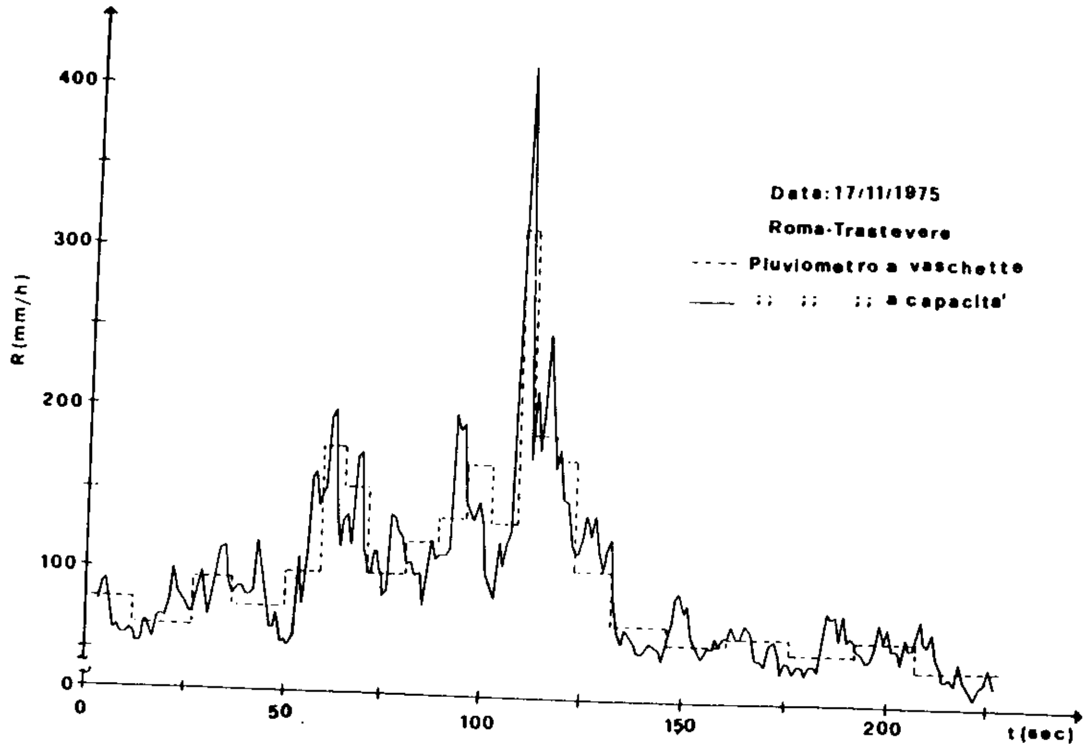
Funzioni di distribuzione mensili, annuale e del mese peggiore.



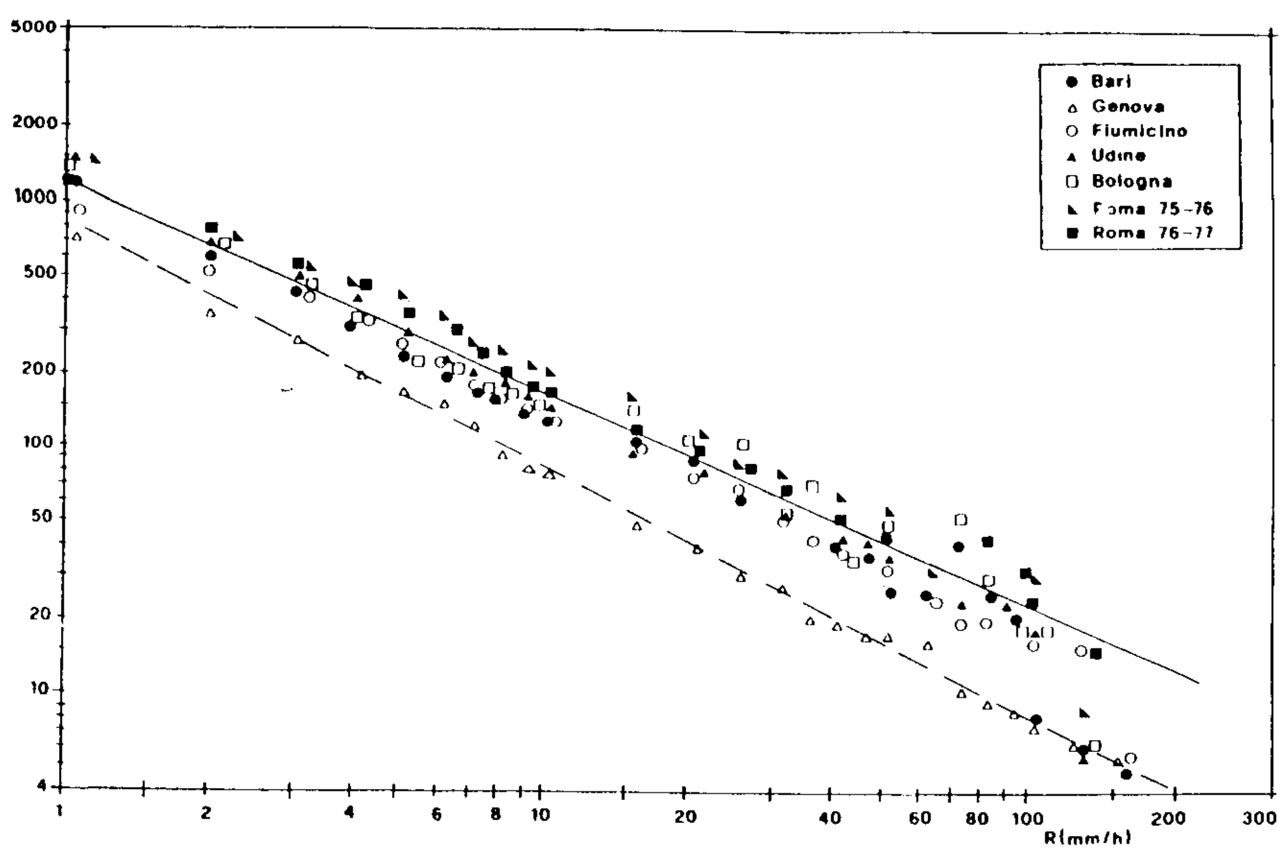
Schematizzazione temporale dei fenomeni piovosi.



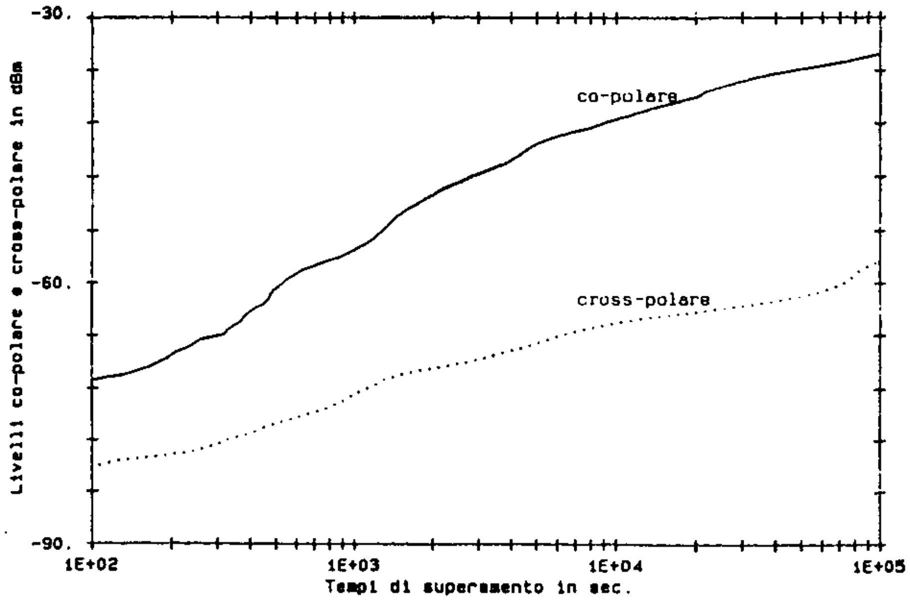
Funzioni di distribuzione della R per diversi tempi di integrazione.

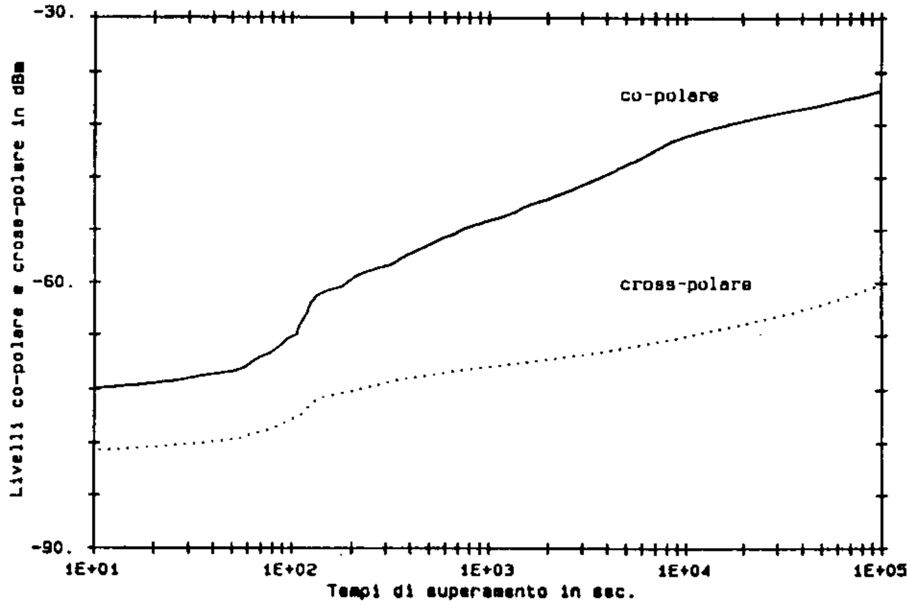


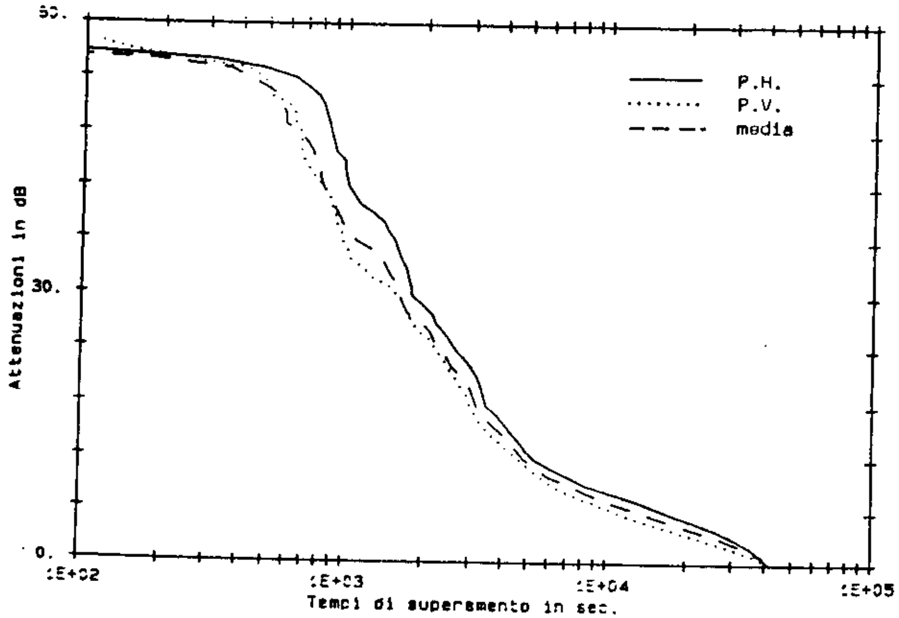
Andamento dell'intensità di precipitazione durante i quattro minuti di maggiore intensità.



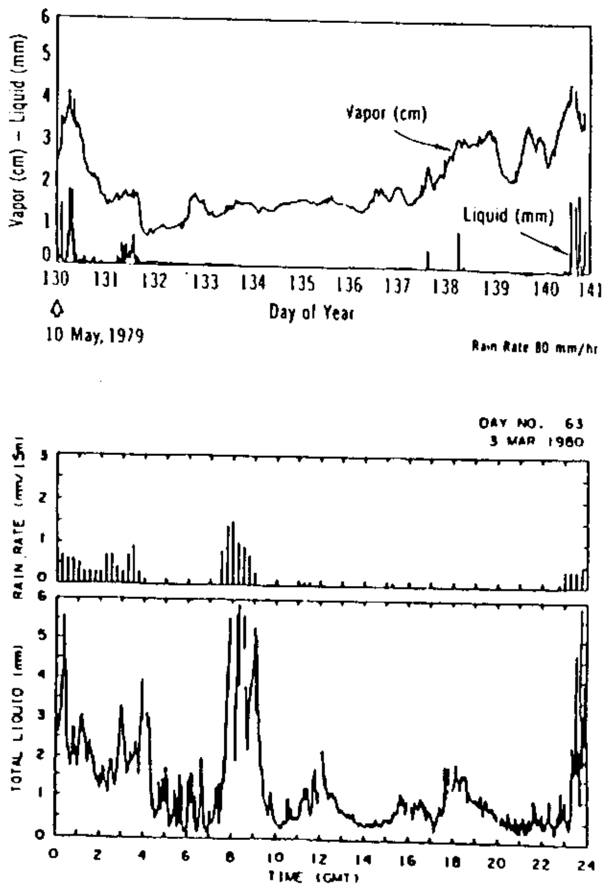
Andamenti del valore mediano delle durate di superamento.


-30.
-60.
-90.
co-polare
cross-polare
1E+02
1E+03
1E+04
1E+05
Livelli co-polare e cross-polare in dBm
Tempi di superamento in sec.

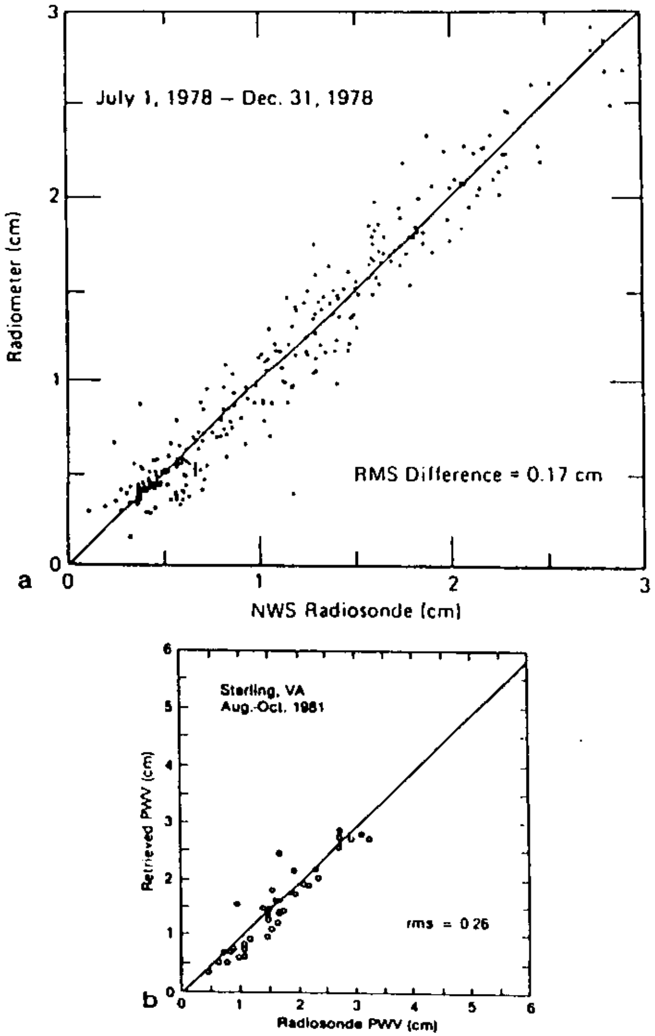

-30.
-60.
-90.
co-polare
cross-polare
1E+01
1E+02
1E+03
1E+04
1E+05
Livelli co-polare e cross-polare in dBm
Tempi di superamento in sec.



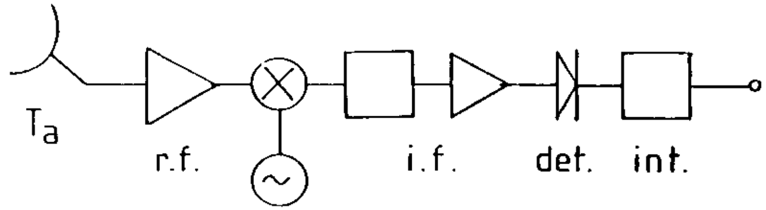
Distribuzione dell'attenuazione



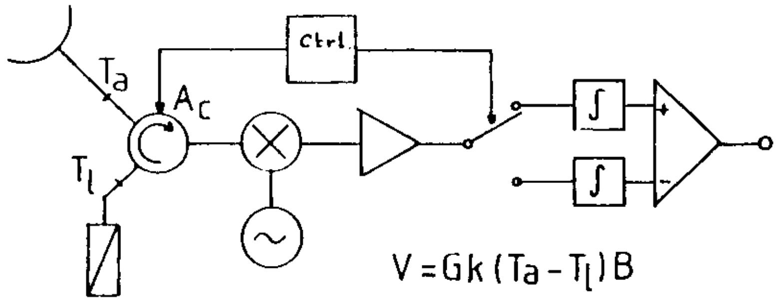
Esempi di serie temporali di contenuto integrato di vapor d'acqua e di acqua liquida, con indicazione dell'eventuale precipitazione.



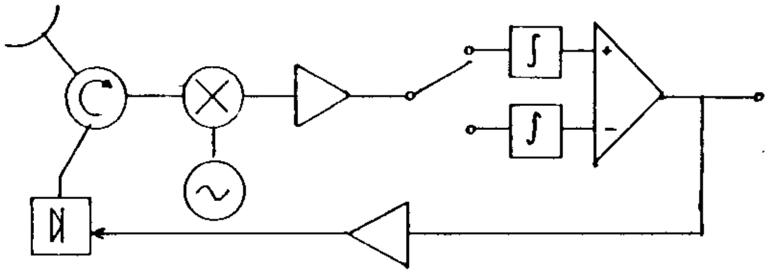
Confronto tra contenuto totale di vapore dedotto da misure radiometriche e quello ottenuto dai radiosondaggi in località con climatologie diverse.



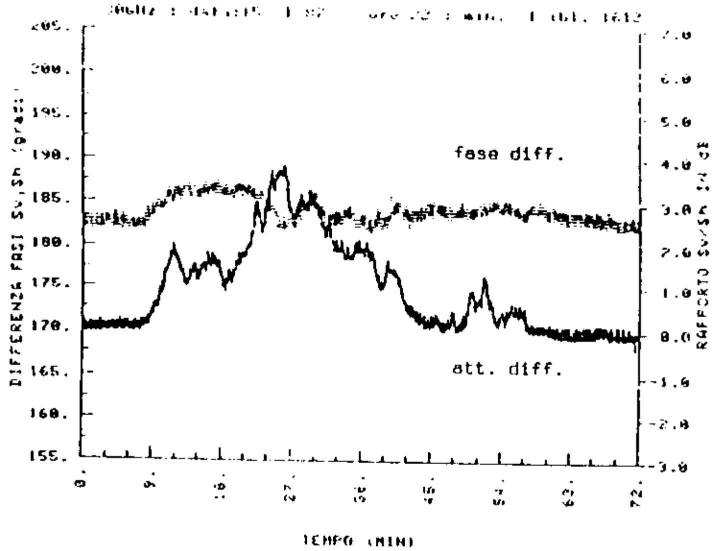
Total-power radiometer

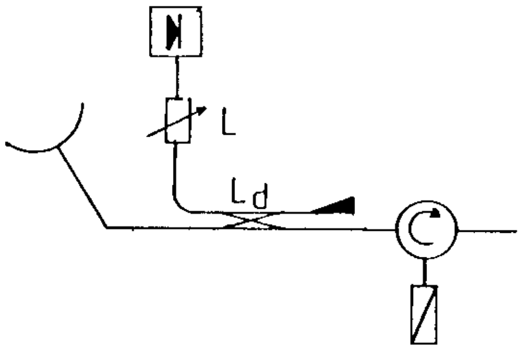


Dicke switch

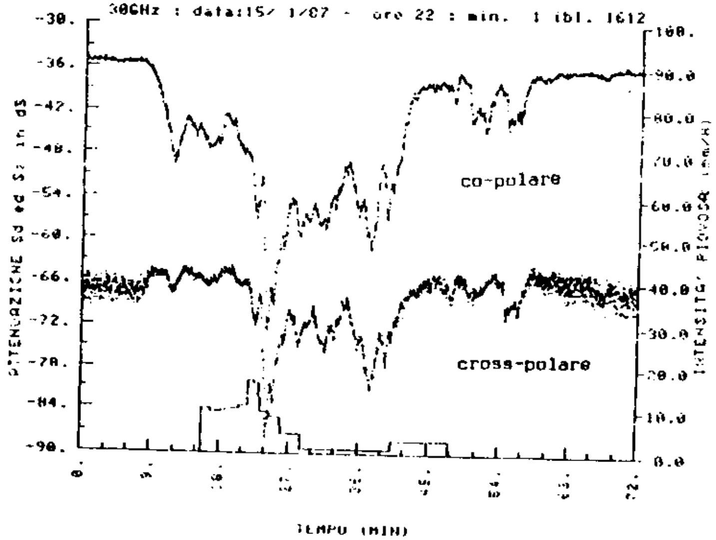


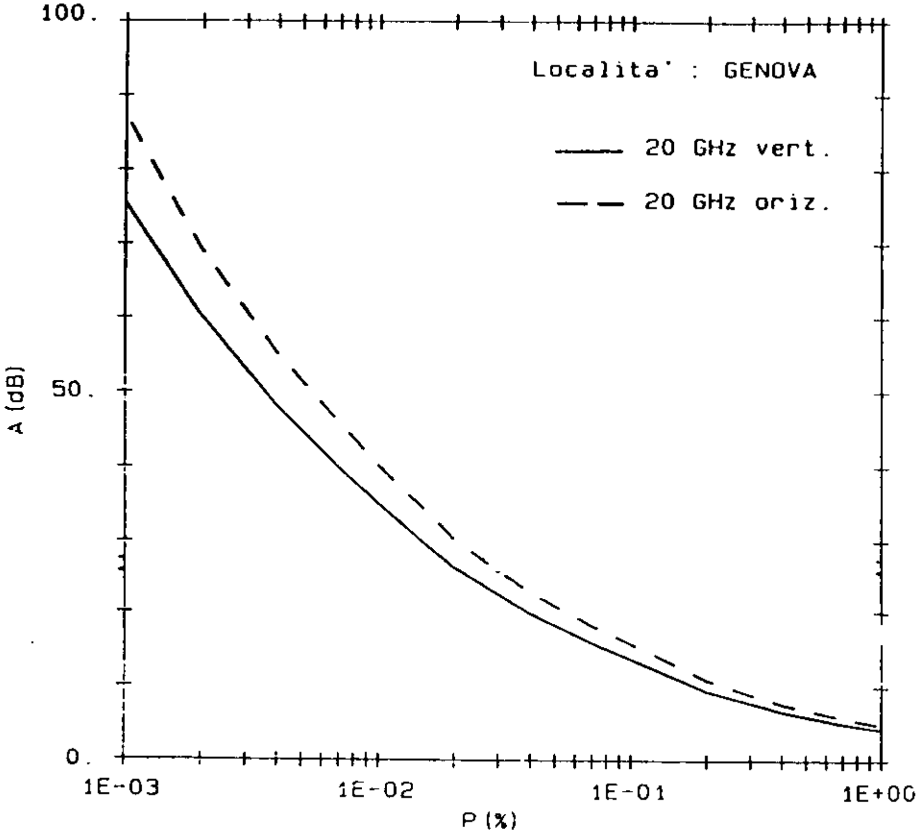
Noise balance



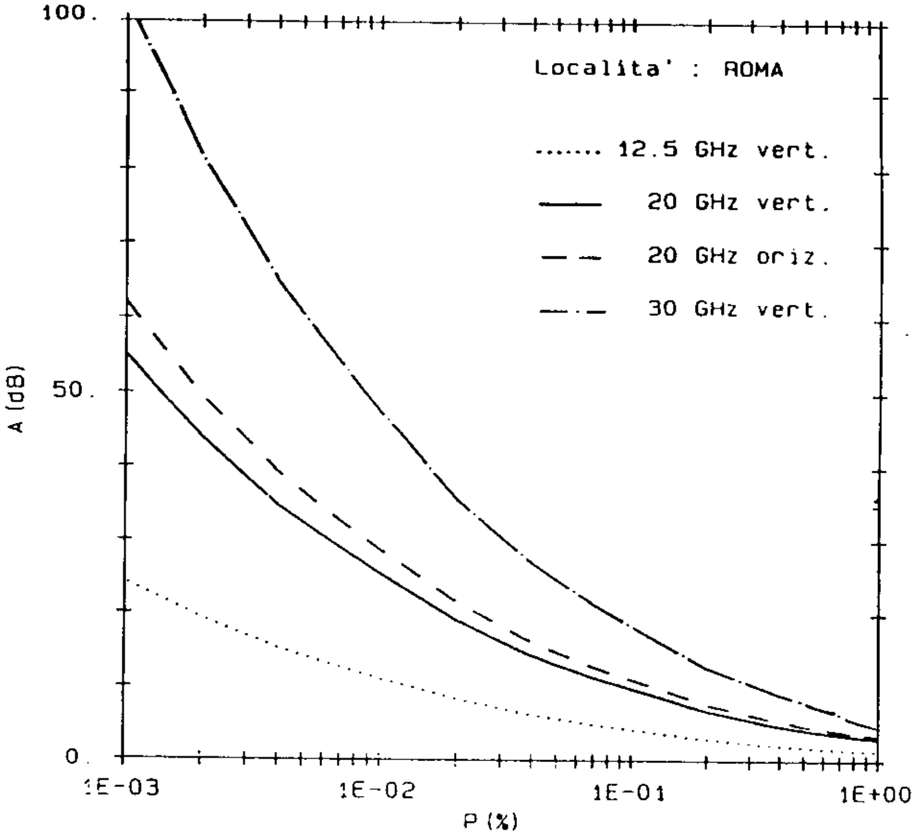


Noise injection

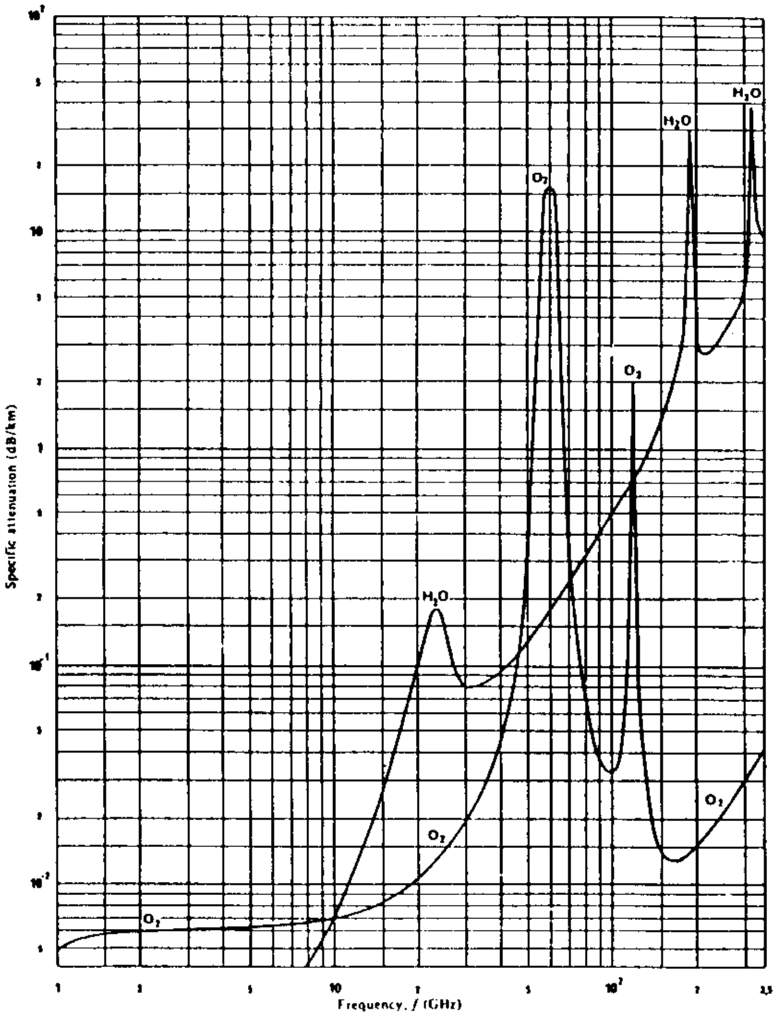




Distribuzione dell'attenuazione da pioggia nella zona di Genova.

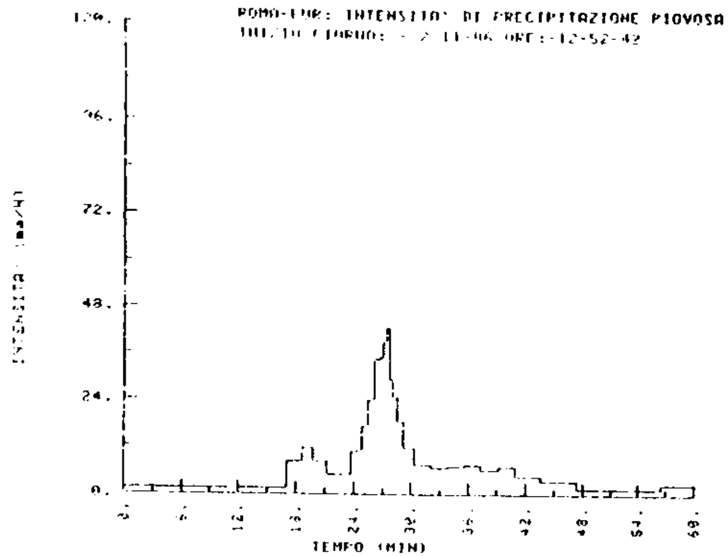


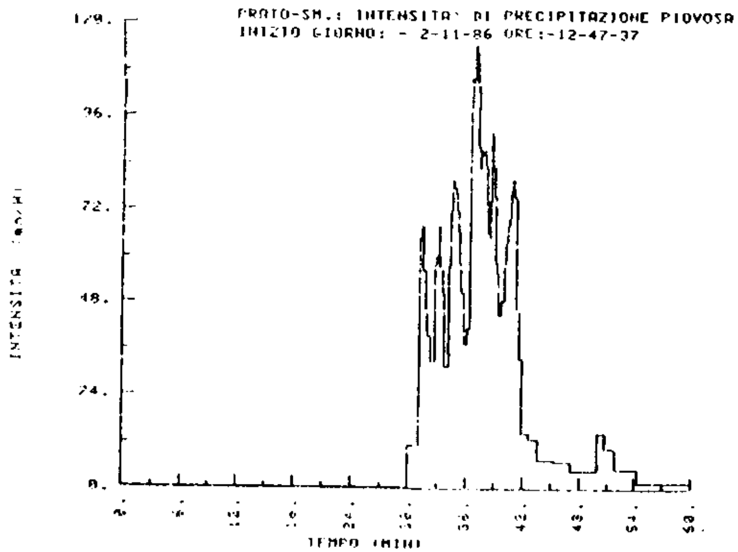
Distribuzione dell'attenuazione da pioggia nella zona di Roma

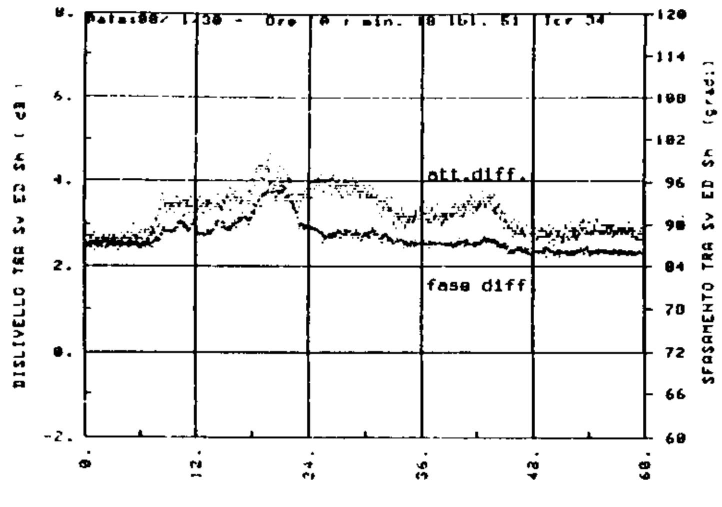


Specific attenuation due to atmospheric gases

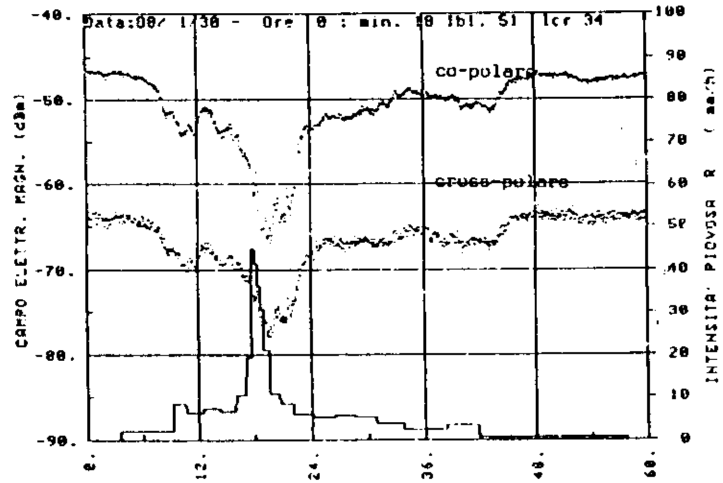
Pressure: 1013 mb
Temperature: 15 °C
Water vapour: 7.5 g/m³



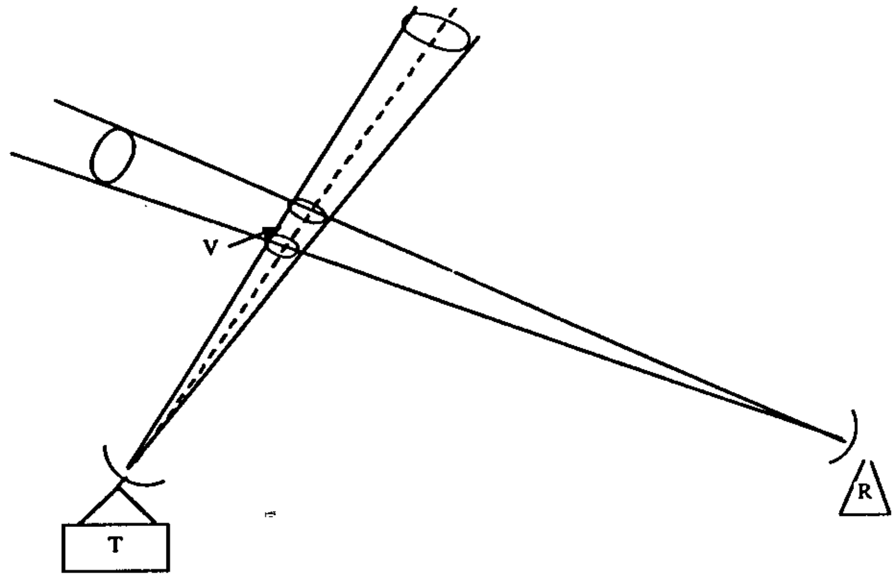




POLARIZZ. C2. - (tempo di misura in minuti)



POLARIZZ. C2. - (tempo di misura in minuti)



Collegamento in Troposcatter

T : Stazione trasmittente
V : Volume comune
R : Antenna ricevente

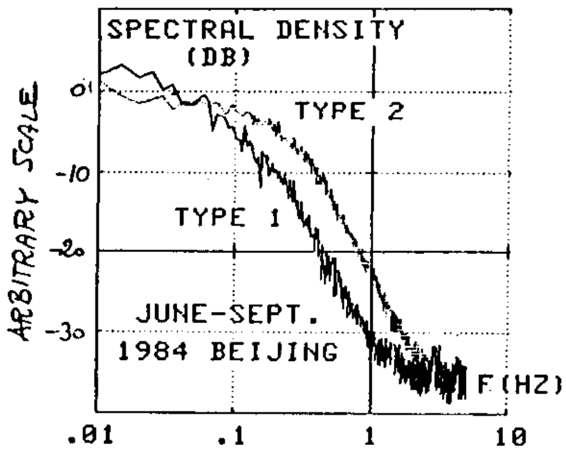
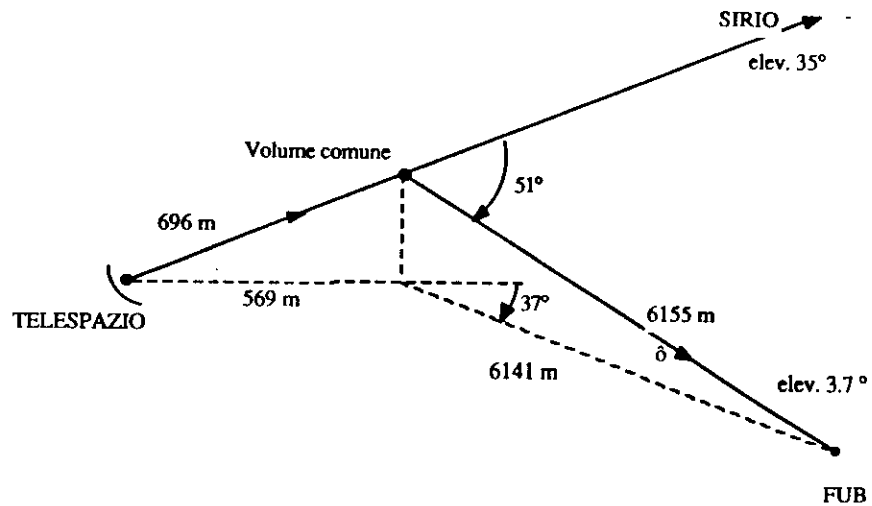
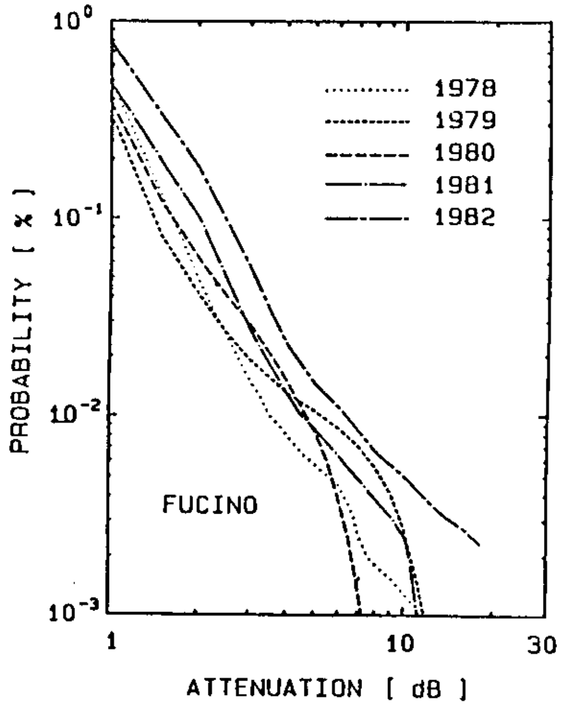


FIG.6: scintillations

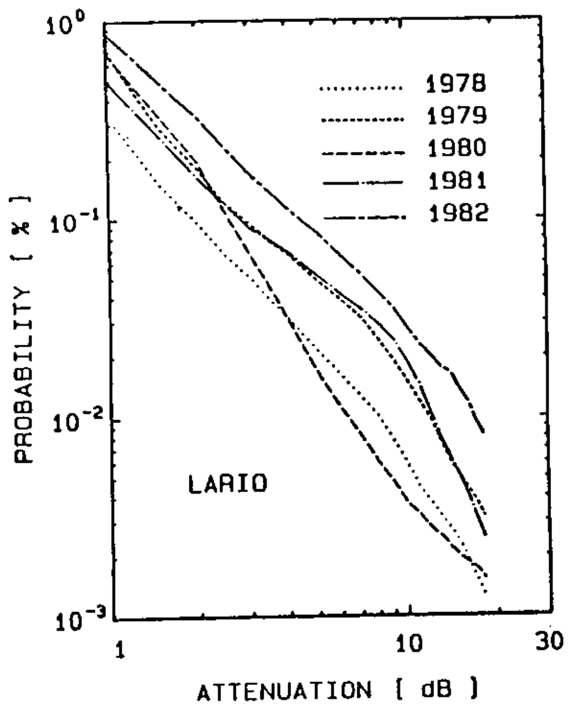
TYPE 1: with rain
TYPE 2: without rain



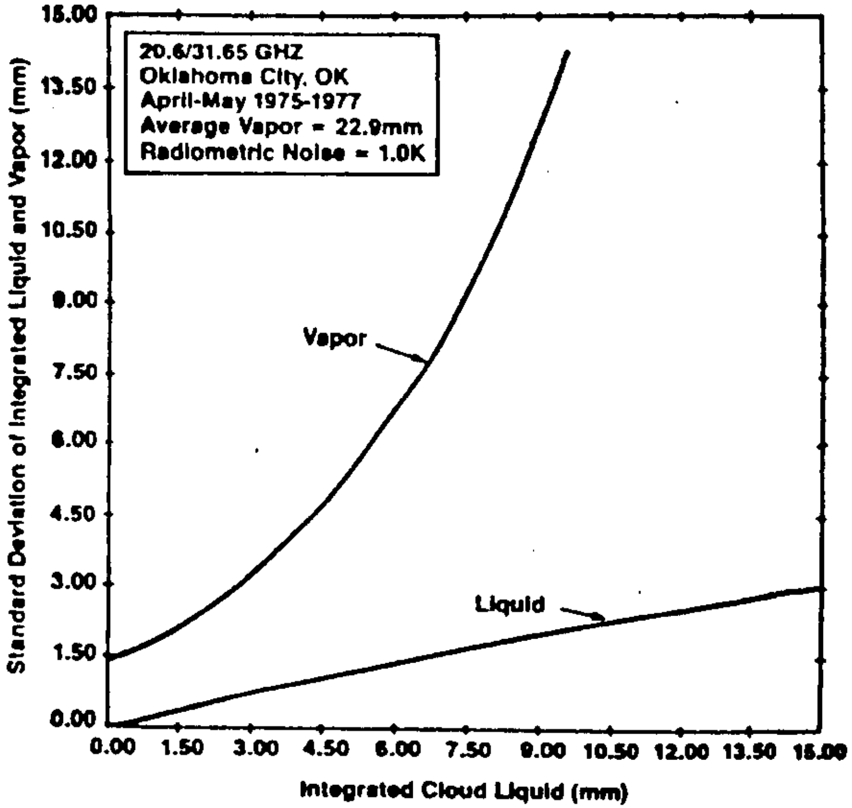
Geometria del collegamento bistatico del Fucino



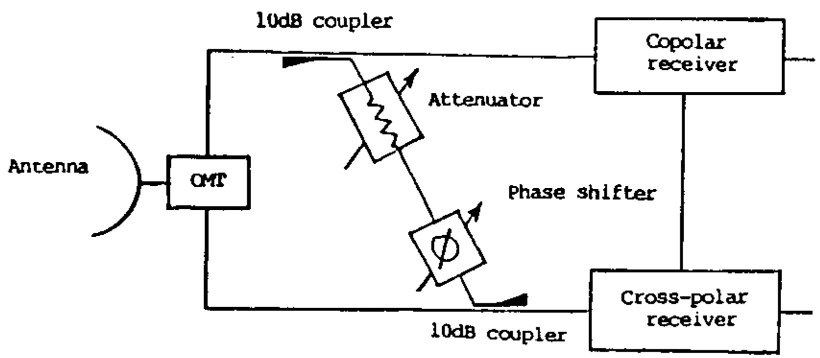
1978
1979
1980
1981
1982
FUCINO
PROBABILITY [%]
ATTENUATION [dB]
10^0
10^{-1}
10^{-2}
10^{-3}
1
10
30



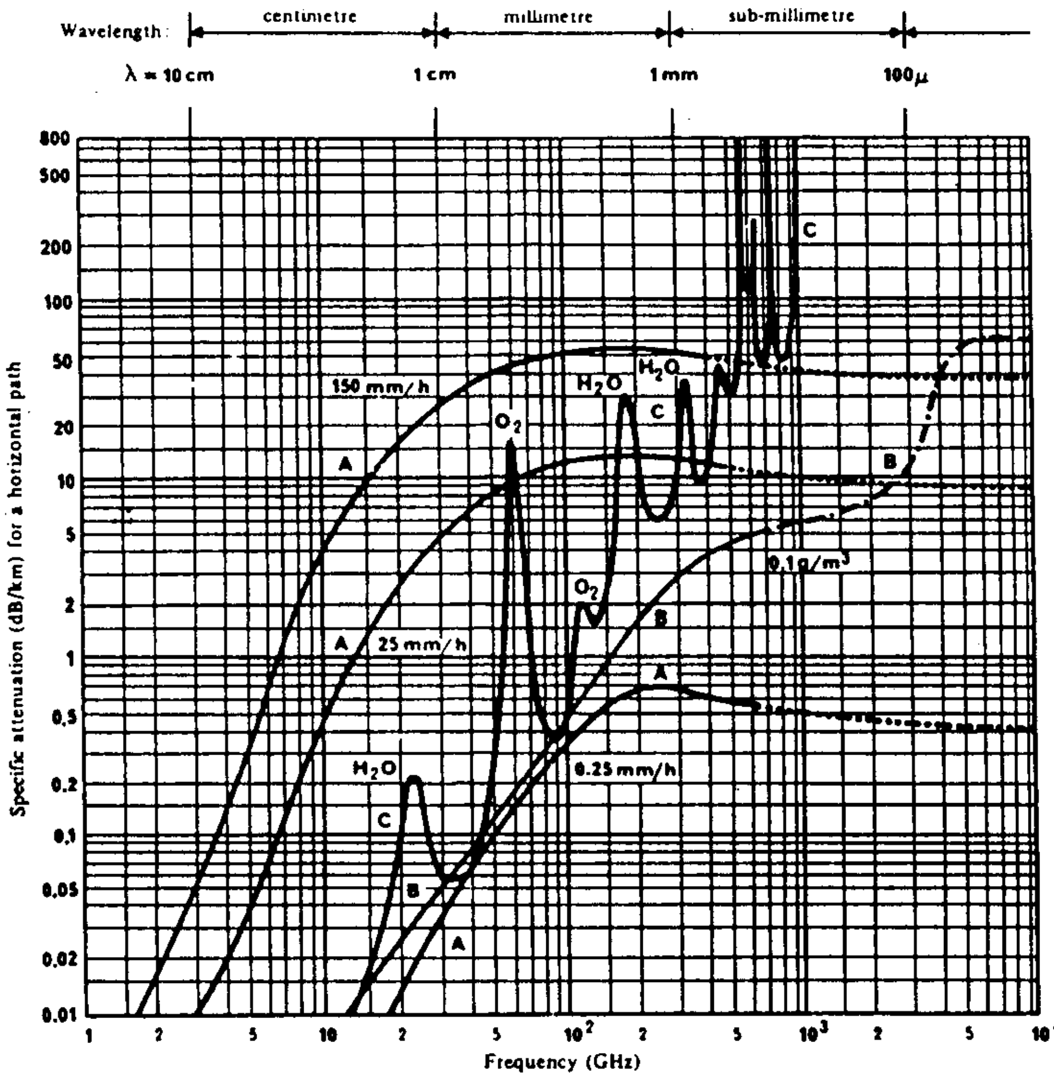
1978
1979
1980
1981
1982
LARIO
PROBABILITY [%]
ATTENUATION [dB]
10^0
10^{-1}
10^{-2}
10^{-3}
1
10
30



Errors in retrievals



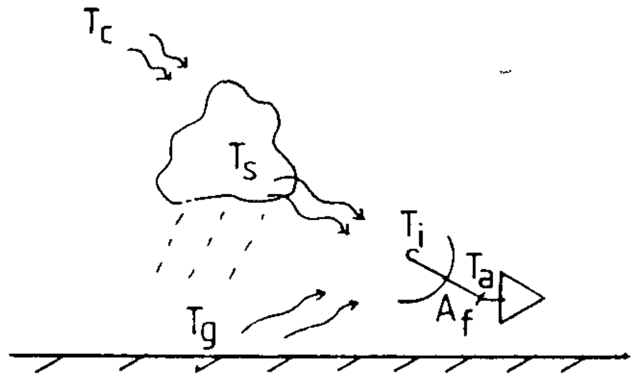
OMT = Orthomode transducer



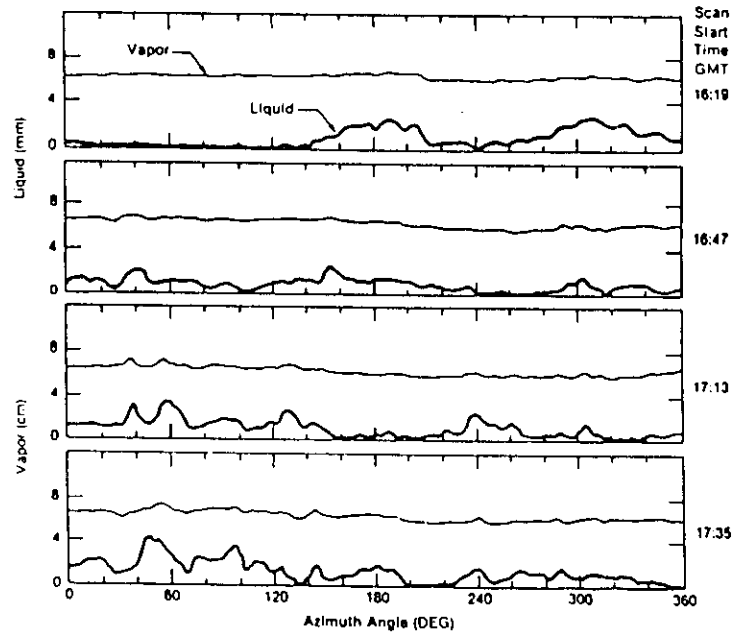
Attenuation due to gaseous constituents and precipitation for transmissions through the atmosphere

Temperature: 20 °C
Pressure: sea level: 1 atm
Water vapour: 7.5 g/m³

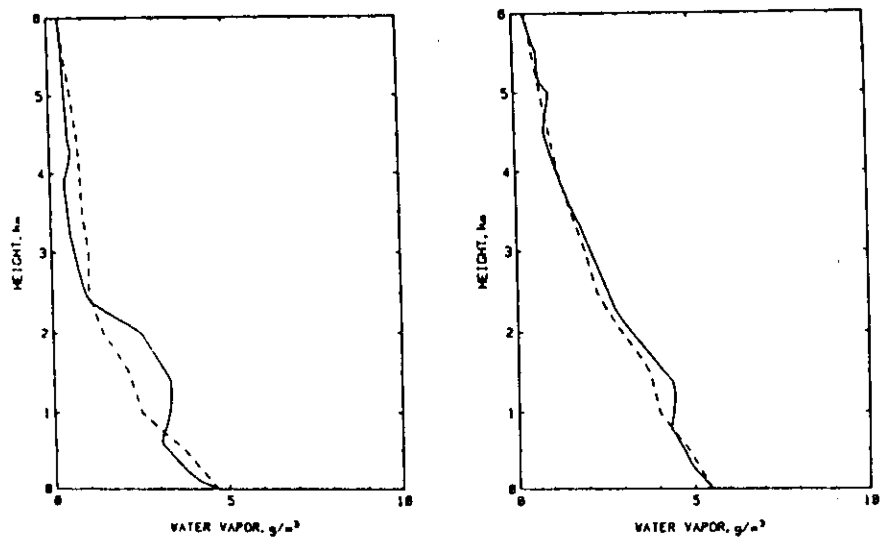
A: rain
B: fog
C: gaseous



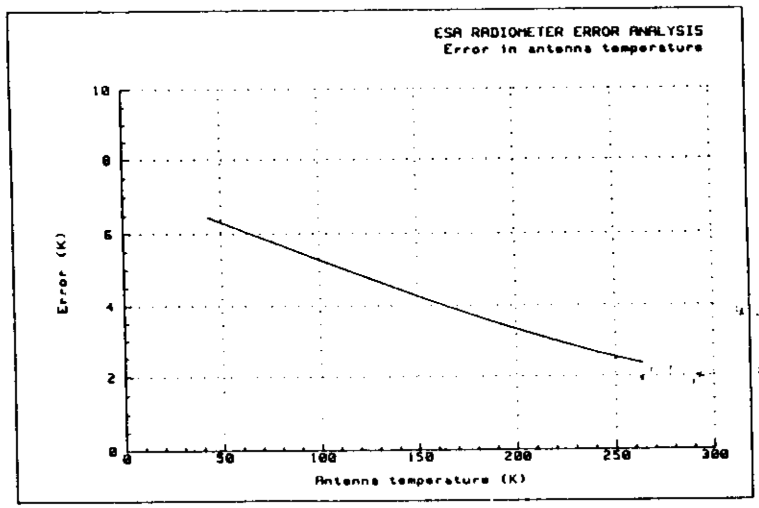
Input noise temperatures



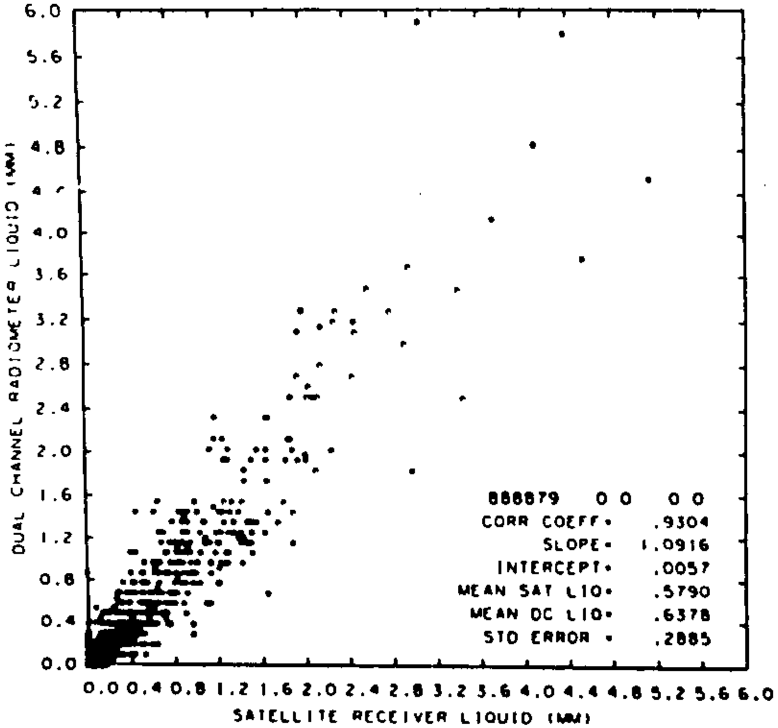
Andamenti del contenuto integrato di vapore e di acqua liquida in funzione dell'azimut per un angolo di elevazione dell'antenna radiometrica di 12.5 gradi misurati a distanza di una ventina di minuti.



Profili di vapor d'acqua ottenuti da misure radiometriche (curve tratteggiate) e da radiosonda (curva continua).



Error in antenna temperature.



Confronto tra il contenuto di acqua liquida dedotto da dati radiometrici e quello ottenuto da misure di propagazione.

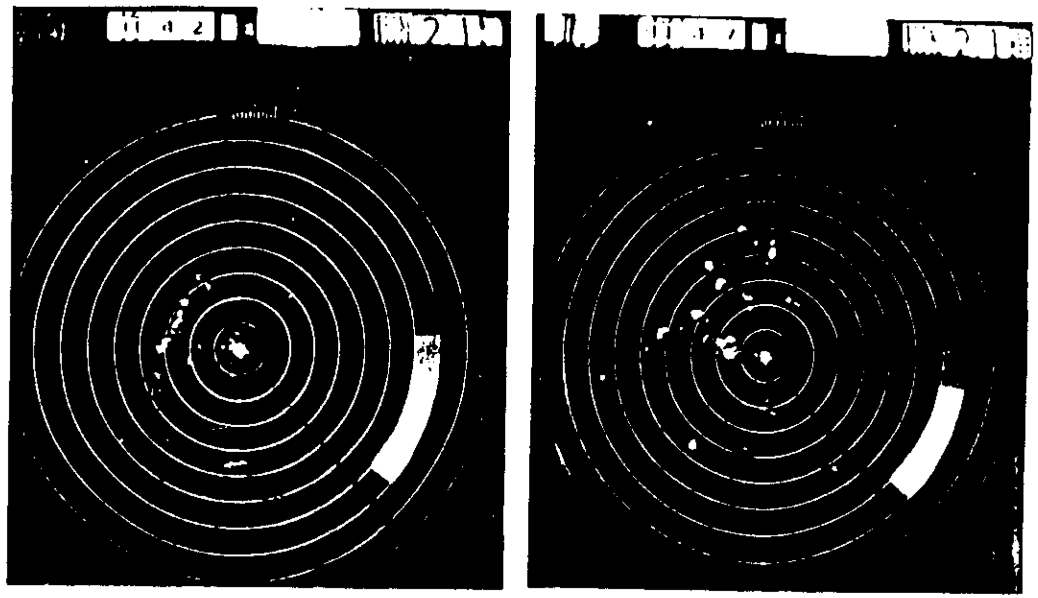


FIG. 11.6. Two examples of radar records of showers. In the picture on the left some echoes are organized in a line: the echoes in the right picture are located randomly. Range rings at 10-mi intervals. Grey scale thresholds in 10-dB steps, with calibration pattern at 70 mi to the east. (From Alberta Hail Studies Laboratory.)

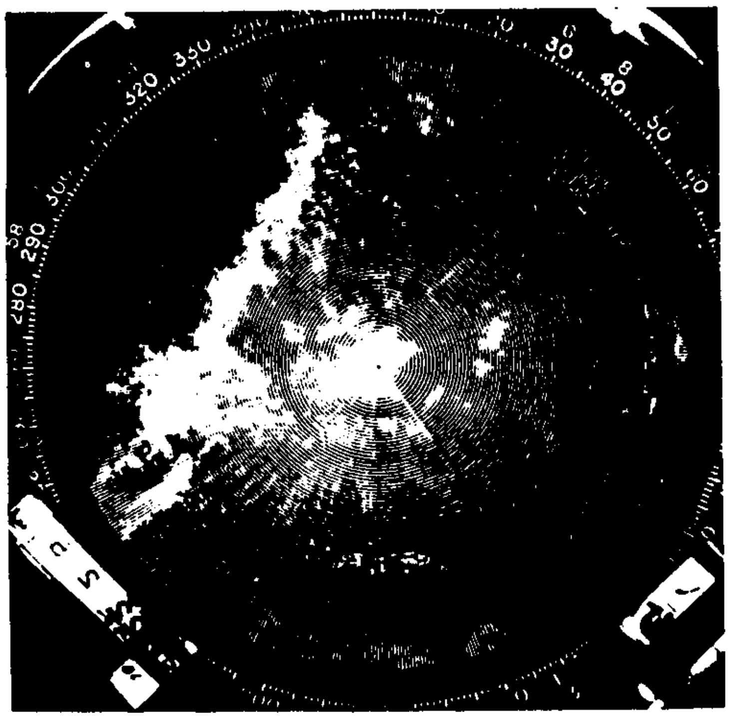


FIG. 11.1. Radar PPI map of rain mainly stratiform in structure. Maximum range 40 miles. Display consists of an array of discrete dots whose brightness and size are proportional to the reflectivity factor, in steps of 10 dB. (From McGill Radar Weather Observatory.)

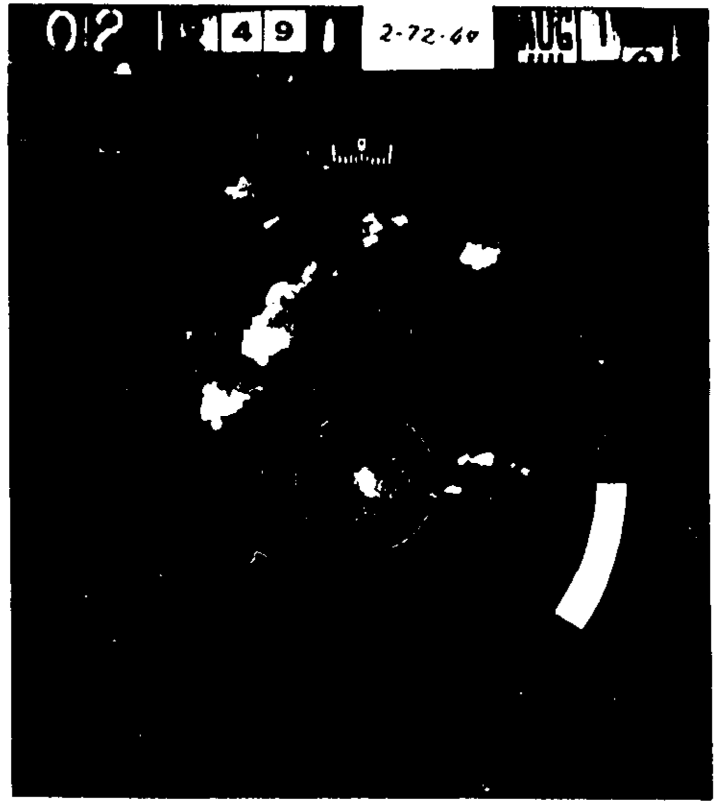


FIG. 12.3. Alberta hailstorms observed by radar at elevation angles of 2, 4, and 6 deg. Range rings at intervals of 10 miles; grey shades at 10-dB intervals. The two echoes to the northwest at about 50 miles range are similar to Browning's supercell.