Paper G 22

ALTITUDE DETERMINATION AND DESCRIPTIVE ANALYSIS OF CLOUDS ON ERTS-1 MULTISPECTRAL PHOTOGRAPHY

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SUMMARY

A simple method to determine the approximate altitude of clouds is described in this work, with the objetive of refining their classification using only marginal data from the photographs.

The method is based on the application of an approximate equation of the type $a = d . tg\ s$, that relates cloud altitude (a), angle of sun elevation (s), and cloud image to corresponding shadow distance (d) measured directly on the photograph.

A qualitative analysis of the following factors affecting the measurements is presented: Cloud shape and the sun elevation angle, atmospheric refraction, Earth ellipsoid, and topographic relief. The error involved in this method is small, and does not transgresses the range of cloud genetic levels, thus being accurate enough for cloud classification.

The classification of clouds is a part of the descriptive analysis of weather condition of a region. It includes analysis of the form, altitude, structure, density and cloud association characteristics which can be determined on the ERTS-1 multispectral photography.

Clouds and their corresponding shadows commonly found in the photographs, are undesirable for the interpretation of Natural Resources. A cloud analysis however, show features, such as wind direction, sea current direction, long-shore drift, sediments transport and other geomorphic and geologic processes that are useful on Geoenvironmental studies.

Results of the application of this method on photographs of the Goajira Península, Paraguaná Península and the Central Coast of Venezuela are presented. Here, the altitudes computed are used to classify clouds and to identify the genus of others without typical form. Instability of air masses through clouds vertical development, and wind direction as well as other local climatic characteristics such as moisture content, loci of condensation, etc. are determined using repetitive coverage for the time interval of the photography. Applications for the regional and urban planning (including airport location and flights schedule) and Natural Resources evaluation are suggested.

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METHODOLOGY FOR THE ALTITUDE DETERMINATION OF CLOUDS.

Introduction. The space photographs of the earth are taken from satellite ERTS-1 on its orbit at 915 Km of altitude, by an optical-mechanical scanner of a 11.56° visual angle, convering a large área includes in a paralelogram 185 Km on the side (Fig.) Clouds and their correspond ing shadows commonly found in the photographs, are undersirable for the interpretation of Natural Resources. The classication of clouds is a part of the descritive analysis of weather condition of a region. It includes analysis of the form, altitude, structure, density and clouds association, characteristics which can be determined on the ERTS-1 multispectral photography.

Clouds are seen at a scale slightly larger than the terrain scale, and all the features useful for classification can be determined. A cloud analysis however, show features, such as wind direction, sea current direction, longshore drift, sediments transport and other geomorphic and geologic processes that are useful on Geoenvironmental studies.

A simple method to determine the approximate altitude of clouds is described in this work, with the objetive of refining their classification, using only marginal data on the photograph. The error involved in this method is small and does not transgresses the range of cloud genetic levels, thus being accurate enough for cloud classification. Results of the application of this method on photographs of the Paraguaná Península are presented.

Cloud altitude ratio to the cloud-shadow image distance. Sun elevation and solar azimuth (SUN EL 54 AZ 126 of Fig.) are the marginal information provided by the ERTS-1 photograph. These terms are respectively the vertical angle of incidence of the sun rays above the horizon, and the bearing of their path on the horizontal plane, Fig. . The direction of displacement of corresponding points of the clouds and shadows images occur along the solar azimuth.

Clouds located at similar atmospheric level show similar cloud-shadow image distance, but those located at diferent levels show different distances, being larger for the higher clouds.

Fig. show 3 levels of clouds illuminated by solar rays with a constant sun elevations angle (54° as in Fig.). For the demonstration, 3 clouds at different levels are used, with a border coinciding plannimetrically in the photograph. The visual ray from the satellite records the images of the 3 boundaries on the same point of the photograph, but the boundaries of their respective shadows will be recorded at increasingly larger distances, the higher the clouds are located. Thus the cloud-shadow distance for the low level clouds is the short distance d_b; for the intermediate level of clouds is the intermediate distance d_i, and for the high level of clouds is the long distance d_a.

Computation of clouds altitude. For the computation of the clouds altitude, trigonometric relations of the triangles built with the following parameters are used (Fig.).

- Sun elevation angle (s), given in the photograph.
- Clouds-shadow image distance (d), measured in the direction of the solar azimuth directly on the photograph with micrometer. This distance is converted into meters by multiplying it by the photographic scale.
- Cloud altitude (a) measured in meters vertically from the edge of the cloud (n).
- Line (a) drawn from the edge of the cloud (n) on the atmosphere, to its photographic image (i). This line is not vertical, but it approaches closely altitude (a), departing a maximum of 5.78°, that is, half of the optical scanner visual field.
- Angle (n) complementary of angle (s) whose value can varie from 90-s to 84.22°-s. The 90-s value is only a close approximation, valid when the cloud is at the center of the photograph, but its value can varie to a minimum of 84.22°-s when tle cloud is at the edge of the photograph.

From these triangles the following relations are obtained:

$$\frac{\text{sen } s}{a'} = \frac{\text{sen } n}{d}, \quad \text{then:}$$

$$a' = d.\ \frac{\text{sen } s}{\text{sen } n} \qquad (1)$$

Equation (1) provides slightly higher than the true altitude values, when the exact value of angle (n) is used. On the contrary, when aproximate equation (2) is used, slightly lower values are obtained when angle (n) is used as complement of angle (s), on the following relationship:

$$\frac{\text{sen } s}{a''} = \frac{\text{sen } (90-s)}{d}, \quad \text{then}$$

$$a'' = d.\ \frac{\text{sen } s}{\text{sen } (90-s)}, \quad \text{and}$$

$$a'' = d.\ \text{tg } s \qquad (2)$$

The clouds altitude computation is not however exact, because besides the approximate equations used also approximate measurements and data without correction is used. Among these factors are the following:

1. Cloud shape and solar elevation angle
2. Atmospheric refraction
3. Earth ellipsoid
4. Topographic relief.

Cloud shape and solar elevation angle. The cloud and shadow images are formed by the visual and sun rays tangent to the cloud adges (Fig.).

The cloud image tends to resemble the cloud map, as the visual rays from the camera, tangent to the clouds, depart little from the vertical (up to 5.78°), while the shadow image is the tilted section at the angle of the sun elevation, that varies according to latitude and hour. There is more resemblance on their images and therefore better accu racy on the measurement of their distance when the cloud is thin and the angle of sun elevation wider.

When the cloud is thin and the sun elevation angle high (over 45°), the tangents formed by the sun ray and the visual ray from the satellite tend to coincide on the same border of the cloud, and therefore the shadow image resembles much the cloud image.

When the cloud has a medium thickness, the shadow image is produced by a section, til ted steeper than the one producing the cloud image.

When the cloud. has a high vertical development (even with a mushroom or anvil profile on its top), the cloud image may be formed at a lower level, while, the shadow image is formed by a steeper tilted section, including parts of a vertical profile at higher levels, with shapes nor necessarily corresponding with the ones at lower levels. These disimilar shapes of the images are easily detectable and indicate clouds with high vertical development. In both latter cases, the plannimetric difference of location of the edges used for the cloud and shadow projections, is small and even more so considering the usual photographic scales of 1:1.000.000 to 1:500.000. This difference is reduced further with steeper sun elevations angles.

Atmospheric refraction. The refraction of the visual and solar rays on their crossing of the atmosphere to produce the cloud image and its shadow projected on the ground, causes the desplacement of these images located at different altitude and on the ground (Fig.).

The refraction is a direct function of the atmosphere density (p), which depends on its temperature, pressure, etc., data which unfortunately is not easy to obtain. It can be generalized however that objects located in the high atmosphere will be less refracted than the ones close to the ground, where atmospheric density is greater; and during the dry season there will occur less refraction than on the wet season. The greater the thick ness (E) of atmosphere crossed by the rays, the greater refractions they will undergo, thus the images on the ground will be displaced further than the images floatting on the air, as the atmospheric distance crossed by the rays is larger. A cloud image undergoes little refraction due to the less dense (P_2) atmosphere separating it from the satellite. A shadow image on the ground surface undergoes larger refraction due to the greater thickness and denser (P_1) atmosphere separating it from the satellite. The resultant of this differential displacement is the cloud-shadow distance registered in the photograph and the basic data used without correction to compute the clouds altittude.

Earth ellipsoid. A small angularity is formed between the earth ellipsoid and the tangent plane of the photographic projection (Fig.   ). This angularity increases toward the edges of the photograph. The images displacement follows the solar azimuth direction, and it is always toward the sun. The magnitud of the displacement increases toward the photograph adges. This displacement is not notice able toward the center of the photograph, specially at the scales commonly used, not appreciably influencing the computation of the clouds altitude.

Topographic relief. In areas of low relief, the clouds hight is also approximately their altittude, however in mountainous areas, the clouds shadow is projected over the ground, located not at sea level but at an altittude than can be obtained from topographic maps (The Cartografía Nacional maps at a scale of 1:100.000 are enough). Adding the mountain altittude to the computed cloud hight, the cloud altittude above sea level is obtained (Fig.   ).

Applications. Through the usage of equations (1) or (2) approximate altittude of different cloud levels seen on the Paraguaná Península photographs (scale 1:500.000 taken from the ERTS-1 satellite at 10:30 a.m. October 19, 1972, (Fig.   ) can be computed. From the photograph marginal information, a sun elevation angle of 54° and an azimuth of 126° is obtained.

Above the Paraguaná Península a cloud level of cumulus type trend in a ENE-WSW to E-W direction. A sampling of the cloud-shadow distance (d) results in a variable range between 600 to 800 m. Table 1 (Fig.   ). Using equation (2) and multiplying those values of (d) bi the tangent of angle s (tg 54° = 1.376), a cloud altittude range of 826 to 1.101 m. is obtain for this level, verifying in this way the preliminary classification of cumulus.

Other computations are made with Sierra de San Luis Cumulus, with the previously classified as Sierra de Baragua stratu cumulus, and later on reclassified by their altittude as cumulus nimbus. Finally the Golfo de Venezuela (west of the Paraguaná Península) cirrus filamentoso altittude could not be computed by their lack of shadow.

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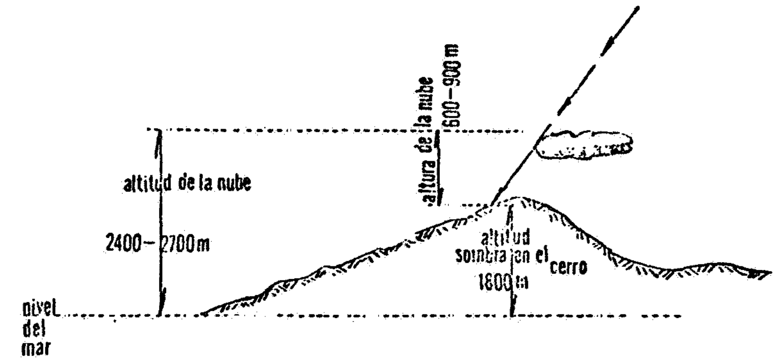
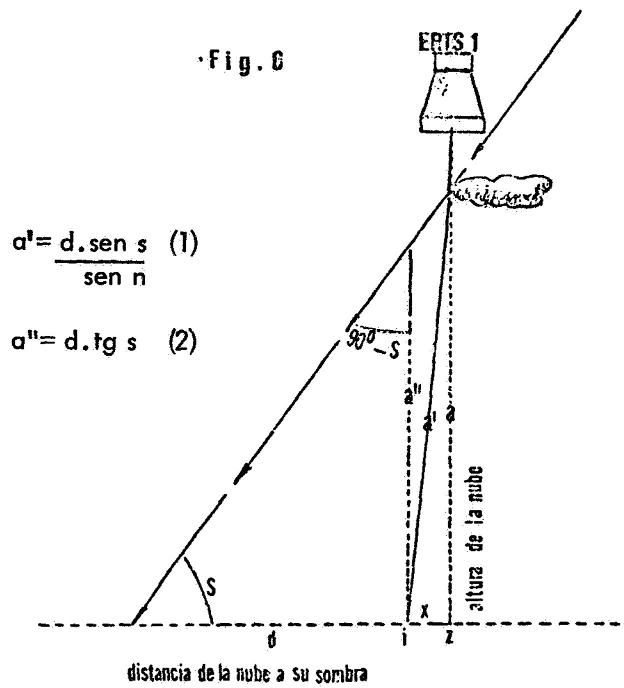
Fig 5


altura de la nube
600–900 m
altitud de la nube
2400–2700m
altitud
sombra en el cerro
1800 m
nivel
del
mar

·Fig. 6


ERTS 1
$a' = \frac{d.\mathrm{sen}\ s}{\mathrm{sen}\ n}$ (1)
$a'' = d.\mathrm{tg}\ s$ (2)
90°–S
a''
a'
a
altura de la nube
S
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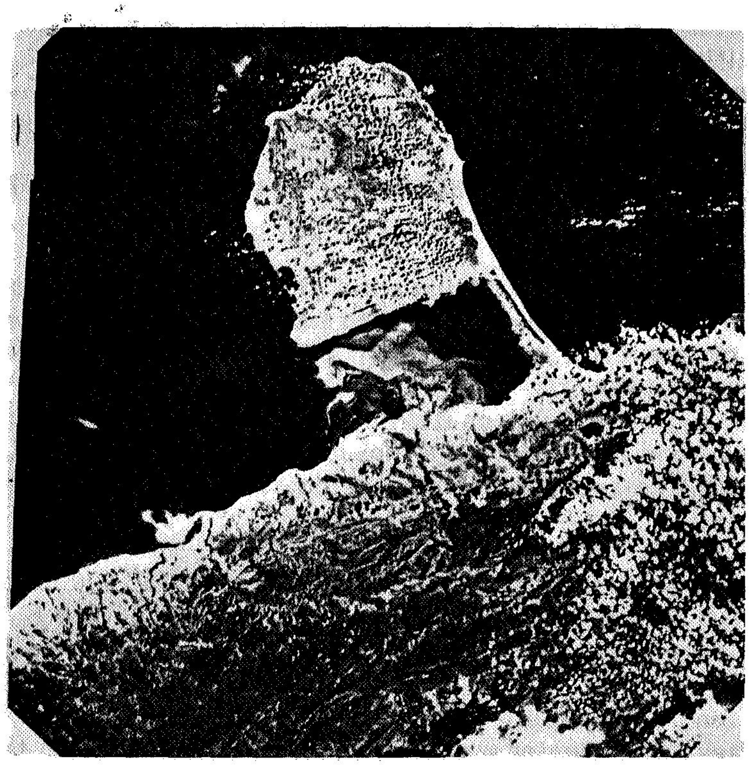
distancia de la nube a su sombra



DESCRIPTIVE ANALYSIS OF CLOUDS IN THE GOAJIRA PENINSULA, PARAGUANA PENINSULA AND THE VENEZUELAN CENTRAL REGION.

Introduction. The clouds study on the satellite photographs is aimed to different facets:

a. Cloudiness determination, or finding the percentage of cloud coverage at the time the photograph was taken, and consequently its degree of usefulness.

b. Cloud altitude determination, useful for their classification.

c. Clouds classification, based mainly on their shape, which in turn depends on the altitude of their condensation process. Temperature, moisture and air movements varies at different leveld over the ground surface, and clouds formed at different altitude differ generally in shape.

d. Determination of air mass instability, in the cloud, which is proportional to the cloud vertical development.

e. Determination of the prevailing wind direction at the time of the take, as indicated by low altitude clouds with low vertical development, over regions of low relief.

f. The areas of greater condensation can be located through a repetitive series of photographs covering a region over a period of time. This analisis is useful in-the selection of airport locations and optimum flight time schedules.

Methodology. Black and white photographs scale 1:500,000 of bands 5 and 7 were used, complemented whith photos scale 1:1,000,000 and band 4. False color photographs were used to differenciate water bodies from cloud shadows.

Shorter wavelengths (bands 4 and 5) allow better discrimination of shadows on water bodies. The greater water penetration renders a light tone for a shallow bottom as a background for the dark cloud shadows. These bands also show better the structure of the less dense clouds, a useful characteristic for their classification. Dense clouds (cumulus type) show better in band 7.

The cloud-shadow distance was carefully measured with parallax bar, thus avoiding additional inaccuracies in the method.

The cloud classification is based on the identification of cloud genus, except for some cases where cloud species were identified.

Analysis. From the cloud altitude computations, the following clouds types were identified:

a. Clouds of low vertical development, less than 600 m thick, located from 700 to 1,600 m of altitude, dense, piled up, with sharp boundaries, identified as cumulus.

b. Other clouds show similar features as the ones above but are located at 2.000 m and above, with this altitude indicating the measurement of the clouds upper level rather than their base; as well as their high vertical development. When these clouds show sharp boundaries and a cauliflower shape, they are named cumulus congestus.

Goajira Peninsula. Cumulus congestus can be seen in the W side of the photograph of October 2, 1972; (Fig.) besides their relatively low moisture content, they imply a strong vertical draft due to a large pressure gradient on the lower strata ot the air mass. In fact, the trade winds from the NE, with some moisture content and less warmer than the ground surface, as they enter the the Goajira, get warmer in contact with the ground and beging their condensation as they rise. The greater their heating, the higher being their vertical development. An intense solar radiation is needed to generate the vertical displacement of the air.

Band 7 shows a high of penetration power through atmospheric water vapor, thus reducing the cloudiness. Band 5 shows entirely the large cirrus covering a great area of Golfo de Venezuela; as opposed to band 7 showing only the denser part of the main cloud with the shape of a fish skeleton, thus identifying it as a fibratus species.

Altocumulus are seen in the SE part of the photograph of February 23, 1973 (Fig.), with a structure of very fine ripples resembling Cirrocumulus, but their computed altitude of 2,553 m. place them in the intermediate level common for Altocumulus.

Clouds of low vertical development at altitudes from 350 to 1,550 m. are observed above the península in the same photograph; their low altitude indicates air wiht low moisture content favorable for saturation at a minimum cooling. These cumulus are aligned parallel, forming the commonly named "Cloud alleys", indicating the prevailing wind direction for that hour, which was blowing from the NNE as confirmed by meteorological record. These cumulus are evidences of the regional good weather conditions prevailing for that date.

Band 5 show a sort of nebulusus without obvious details above Golfo de Venezuela. NW of the Peninsula, filament shaped Cirrus fibratus are identified, resembling the cirrus of the previous photograph but with finer loose elements.

Paraguaná Península. A level of cumulus at an altitud of 800 to 1.100 m. are observed over the Peninsula in the photograph of October 19, 1972 (Fig.). Their low vertical development attained is due to the small extent and lowrelief land on their path. Larger Cumulus development by orographic winds are found in the Sierra de San Luis, with altitudes ranging from 1,600 to 2,200 m. for their upper boundaries. Toward Sierra de Baragua in the southern end of the photograph there is a cloud formation composed of rounded elements with rippen edges, revealing their cumulus origin. This cloud of ligh vertical development, with altitudes ranging from 9,630 to 11,000 m, is identified as a cumulunimbus, posibly originated by the exagerated growth of a cumulus, a common fact ocurring during the warmer months. The clouds albedo on the photograph indicates a day of strong radiation.

Toward the NE of the photograph and over the sea, low density cirrus are observed on band 5; they are absent in band 7.

Lake Valencia. A series of clouds of convective origin are observed in the photograph of October 17, 1972 (Fig.). According to their vertical development the following types are found:

a./ Clouds of medium to high vertical development located at 1.200 to 3.400 m. of altitude, are formed where the relief has forced a steep climb of the air masses. Some of these clouds are found along the crest of the Cordillera de la Costa. Normal to this range are N-S trending clouds, following the wind path through the valleys. Many of these clouds climb the range and continue their trend attaining greater altitude in the opposite flanks.

b./ Cumulus between 700 and 1,600 m of altitude are found in the Galeras del Pao area, on the southern part of the photograph. Some of them show a faint E-W trending alignament, thus pointing the wind direction at the time of the take.

This photograph show a high percentage of cloudiness, a consequence of the convergence of local and tropical air masses, an event foressen at 8 a.m. of the day of the take, by the Weather Bureau.

The photograph of February 2, 1973 (Fig.) shows a better alignament of cumulus trending NE-SW. The altitude of the smaller cumulus ranges from 1.300 to 1.500 m. or an average altitude higher than in the previous photograph. This higher altitude indicates a lower moisture content of the ascending air mass reaching a higher condensation level.

Clouds of medium size show their crests between 1,200 and 1,800 m. of altitude, thus indicating their approximate vertical extent and the air mass instability and moisture content.

A comparison of bands 4 and 7 is used for the clasificationof the large cloud formation over the Cordillera de la Costa. A cloud formation without typical features is seen in the former band, while large bodies of Cumulus-congestus of rounded edges, partially overlain by a faint layer of Altostratus is shown in band 7. This cloud formation is the result of the moisture condensation from the NE winds on their path through the Barlovento coastal plain. In this conex tion a repetitive series of photograph could provide useful data on the loci of recurrent moisture condensation from these winds, where the normal opera tion of airports would be critical from December to March, when the NE wind blows with its greatest intensity.

Over the sea a degeneration into patches of a layer of Altostratus, could be mis identified by patches of dense Cirrus, their considerable horizontal extent however, their gray tone and altitude of 3,500 m. allows their identification as Altostratus.

Barlovento Area. An homogeneous type of clouds are shown on the photograph of March 27, 1973 (Fig.). Cumulus with heights from 0 m. (Sticked to the crest of Serranía del Litoral) to 1370 m. are found over the land. Their low altitude and the similarity of the cloud and shadow images indicate a low to moderate vertical development.

The low cloud base is another important fact to point out, this implies a high moisture content of the air masses on the area, a fact partly explained by the vecinity to the sea and of moisted surfaces such as the dense vegetative formations of the Guatopo jungle and Barlovento Coastal plain, made of deltaic deposits.

The display, somehow disordered of the clouds reveal a dominante wind direc tion, however the small cumulus show a SE-NW trending coastal plain of Barlovento.

The rasing of air along the flanks of the Serranía del Litoral explains the exis tance of clouds along its crest. The absence of clouds in the coastal belt implies a dominant southern wind; the previously mentioned NW-SE aligned Cumulus confirms a prevailing wind direction from the SE.

Cirrus uncimus (of hook shape) are found over the sea, they are commonly formed on clear air with few component in suspension. Band 5 shows them move obviously. North of these an extensive Altocumulus generated by verti cal displacement of air located on the atmospheric layers is observed.

In summary of the photographs studied, clouds with vertical development (cu mulus type) are found generally along the coast and inland, thus confirming their thermal convection and differential gradient origin. On the contrary over the sea surface the constant movement of water favors a continuous heat transfer toward greater depths, with the air above mantaining a greater density and moving toward the coast, the void being filled with air from the upper layers, thus causing subsidance and consequently fine weather. This fact is observed at the time of the take, when wind blows from the sea.

In conclusion the coastal belt of northern Venezuela show a characteristic homogeneity of cloud types, wich belonged mostly to the Cumulus genus; except for some examples of Cirrus, Altostratus y Altocumulus generally found over the sea.

The clouds altitude plus their shape and structure obtained through the comparative study of the different photographic bands, become the necessary tools for their identification. Their classification provides information on the physical processes developed in the atmosphere as well as certain regional climatic characteristic, such as moisture content, wind direction, etc.

Fig. 1 Tabla de alturas de nubes (Table of clouds altitude)

Nubes	Distancia (d)	tg	Altura m.	Orientación
Península de la Goajira 2-10-72		tg 56°		
Cumulus	600-1012 m.	1,4825	889-1500	NE-SO
" congestus	944-1281	"	1400-1900	
23-2-73				
Cumulus	300-1400 m.	1,1106	333-1554	NE-SO
Altos Cumulus	2300	"	2553	
Península de Paraguaná 19-10-72		tg 54°		
Cumulus de poco desarrollo vertical. Paraguaná	600- 800 m.	1,376	826-1101	ENE-OSO
Cumulus de mediano desarrollo vertical S. San Luis	1200-1600	"	1652-2202	SSE-NNO
Cumulunimbus. S. Baragua	7000-8000	"	9635-11011	
Cirrus filamentoso Golfo de Vla.	sin sombra		no determinada	
Lago de Valencia 17-10-72		tg 55°		
Cumulus de poco desarrollo vertical. Galeras del Pao	500-1100 m.	1,428	714-1570	E-O
Cumulus en el Litoral	850-1200	"	1213-1713	N-S
Cumulus de mediano desarrollo vertical	1200-1400	"	1713-1999	
Cumulus congestus	1800-2380	"	2570-3398	
E. del Lago de Valencia				
2.2.73		tg 45°		
Cumulus. Galeras del Pao	1300-1500 m.	1	1300-1500	NE-SO
Cumulus de mediano desarrollo	1200-1800	1	1200-1800	
Nubes adosadas a la Cordillera de la Costa	600-1000	"	600-1000	
Altostratus sobre el mar	3500	"	3500	
Cabo Codera 27-3-73		tg 55°		
Cumulus. Cresta Serranía del Litoral	0-450	1,428	0-643	E-O
Cumulus. Llanura costera Barloventeña	400- 850	"	571-1214	SE-NO
Cumulus. Serranía Interior	800-960	"	1142-1371	
Cumulus. Altos llanos Centrales	690-950	"	985-1356	

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