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GROUND BASED MULTI-SENSOR REMOTE SENSING OF PRECIPITATING CLOUDS

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НАЗЕМНИ МНОГОСЕНЗОРНИ ДИСТАНЦИОННИ ИЗСЛЕДВАНИЯ НА ВАЛЕЖНИ ОБЛАЦИ

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Abstract: *Clouds play a major role in climate and weather on a wide range of spatial and temporal scales, mostly through their ability of changing the radiation budget at the surface and of the atmosphere and through redistribution of heat, moisture, and chemical species vertically and spatially. We present characterization of regional precipitating clouds by ground-based observations in cm and visible spectral ranges. Existing raindrops and cloud top heights are detected by digitized data of meteorological radar measuring at 3 and 10 cm. This information is merged with the ceilometer's data about cloud base height and optical characteristics of precipitating clouds retrieved from the radiance data from ground-based visible images. From the multi sensor measurements we derive cloud physical thickness and consequently, cloud optical thickness which may be indicative of their precipitating potential. The radar and visible images are displayed simultaneously for qualitative evaluation of coincident ground precipitation and cloud macro and microphysical parameters from ground-based observations.*

Ground-based observations of clouds

The continuous ground-based remote sensing observations of clouds are particularly suited to monitor fine scale processes that involve complex interactions between clouds, aerosols, and dynamic radiation processes.

The representation of clouds in models and their impact on the radiation transport in regional and global scale numerical models is only crude. The most challenging aspect is their high temporal and spatial variability available from ground-based observations. Although only about 10% of clouds are precipitating, they contribute significantly to averaged liquid water path values, because they hold nearly ten times much liquid water than non-precipitating clouds. A delay or acceleration in raindrop formation does not automatically lead to a decrease or an increase in the accumulated rain because of strong dynamical feedbacks induced by the changes in the precipitation-forming processes. The evolution of clouds, precipitation formation, and the radiation properties of clouds highly depend on meteorological conditions.

The variations of low-level cloud base height and the radiance of transmitted light, best determined by surface observations, characterize the main cloud radiation properties – the interaction of clouds with both the solar and thermal (terrestrial) radiation fluxes.

The Earth's radiation energy balance and hydrological cycle are fundamentally coupled with the distribution and properties of clouds. The climatologic importance of clouds requires comprehensive observations of their properties at fine space and time scales. The meteorological conditions including the type and amount of aerosols and the motion of air masses determine the formation and evolution, the lifetime and precipitation efficiency of the cloud systems.

The accurate determination of the cloud liquid water content (LWC) profile from one single remote sensing instrument is not possible. The combination of all of the measured properties of the clouds, surface and atmosphere allows for a diagnosis of the effects of cloud variations on the planetary and surface radiation budgets. We present a technique, which allows the merging of measurements from different instruments. A ground based system combining active and passive remote sensing instruments from different spectral ranges is used to investigate cloud formation processes, and cloud physical properties.

Instruments of Observations

Digital camera in visible spectral range, meteorological radars in cm range, ceilometers for precise determination of cloud base height, and a set of instruments for attendant meteorological data - temperature, relative humidity, visibility, wind speed, etc operate simultaneously probing almost the same cloud volume and underneath atmosphere.

In the visible images of clouds obtained by digital camera at earth surface, the brightness of predominantly transmitted light through clouds, which is directly related to the light extinction, and consequently, to the optical thickness of clouds is displayed. The variability of the observed transmittances in series of images taken in short time intervals is an estimate of the rate of changes of cloud optical thickness. Light extinction in clouds is governed mostly by values of the effective radius and liquid water content independently on the particle-size distribution. The number concentration of particles, in addition to size and shape of particles, is of importance for the optical radiation propagation, scattering and extinction in cloudy media [1]. Consequently, the variability of cloud optical thickness is a measure of the rates of microphysical processes in cloud. The formation of cloud droplets results in a large shift of aerosol particle size from the submicron to the super micron size range for those aerosol particles that are activated. The size distribution of the cloud droplets determines how much of the Sun's radiation the cloud reflects back to space. For the same amount of condensed water, many small droplets reflect more sunlight, than fewer and consequently larger droplets. More water also means more reflectivity (lesser transmittance in visible). Clouds with larger particles have ''better'' optical transfer functions (higher values of transmitted radiance) as compared to clouds with very fine droplets, a fact that can be used for cloud microphysical parameters monitoring purposes in visible range. Thus the variability of cloud radiance observed at earth surface is related to the microphysical processes in clouds. Large optical thickness implies higher and thicker clouds, which imply heavier precipitation. Vertically growing clouds are associated with precipitation while decaying clouds are not. The behavior of the cloud base, edges, shape, movement, as displayed in series of visible images, represents the transition processes between cloud and the adjacent air in connection with cloud evolution.

The used meteorological radars implement cloud measurements at wavelengths of 3 and 10 cm that characterize the Rayleigh reflectivity from cloud layers, and provide continuous vertical profiles of clouds as they drift over the site. The detailed radar monitoring represents the field of cloudiness at horizontal circular surveys of local signals in radius 100 km, and discreet radial values of 250 m and azimuthally of 10. The discreet of the radar reflectivity (signal amplitude) is 1 dBz. Such monitoring is used for the tracing out moving of the atmospheric fronts, places with heavy rains at the surface, and the transport of aerosol contaminants by clouds. The places with isocontours of 55 dBz localize hailstorm rains, and those of 45 dBz - in most cases – thunderstorm activity.

The quadratic relationship between radar reflectivity and liquid water content of low-level clouds can be applied. Inferred are also cloud top height, the type, and the approximate size of relatively large in size hydrosols, of diameter about 70 microns. Such large particles are usually related to precipitation. Since radar reflectivity is proportional to the 6th power of drop diameter, a very small number of drizzle sized drops produce a detectable back scattering signal. The latter exhibits the general problems with radar reflectivity if drizzle sized droplets are present. On the other hand, the backscattering signal in the visible to near infrared wavelengths, as detected by the ceilometer, increases only with the square of the droplet diameter. This is why the ceilometer does not detect those drizzle sized drops, and is used for more precise determination of cloud base height.

Synergetic Measurements of Precipitating Clouds

The combination of all of the measured properties of the clouds, surface and atmosphere allows for a diagnosis of the effects of cloud variations on the planetary and surface radiation budgets. Combined remote sensing optical and microwave data from space (i.e., the International Satellite Cloud Climatology Project and Special Sensor Microwave/Imager) for estimates of the liquid/ice water path (water content in a vertical cloud column) and rainfall rate of oceanic clouds have already been used [2]. The distribution of cloud properties and their correlated variations is best illustrated either from satellite or from surface measurements by two-dimensional frequency distributions (histograms) of the cloud top pressure (or top height) and visible optical thickness. From ground-based observations cloud top height is determined by meteorological radars and visible optical thickness is inferred from digital photographs. In addition, we add two other cloud properties to these results, cloud particle size which indicates the microphysical behavior of the cloud and precipitation. Also we will add the results of the analysis of cloud vertical structures.

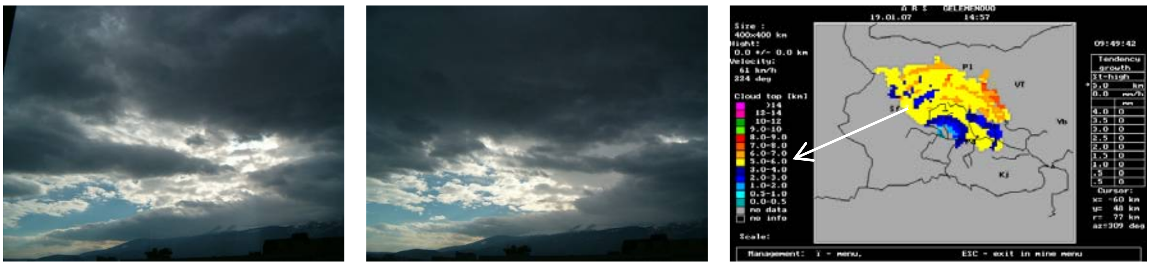
Light extinction in clouds is governed mostly by values of effective particle radius and liquid water content. Dark clouds in visible images taken at earth surface are more likely to precipitate, but not all dark clouds in visible precipitate - stratus clouds are dark but do not rain as much, or as often, as Cumulonimbus clouds. Many small droplets make the likelihood for formation of drizzle that more of the condensed water gets to stay in the cloud, rather than fall out as precipitation. Changes in aerosol number can lead to changes in drop number during cloud formation. The overall impact of increasing anthropogenic aerosols on low clouds such as stratocumulus may be great, and generally resulting in smaller, more numerous drops and leading to darker, longer-lived clouds. Together with dynamical meteorological processes, this determines the life cycle of the clouds. The average diameter of droplets in no raining water clouds is usually around 20 μm. Particles with a large diameter cannot reside in atmosphere for a long time due to the gravitation force. The threshold of the occurrence of drizzle is around d =30 μm, liquid water content ~1.6 g/m3.

High tops in radar images imply large physical thickness of clouds and greater probability of rain, however Cirrus clouds are cold, but do not produce as much precipitation as some warmer clouds. Consequently, precipitating clouds can be distinguished from all others on the basis of brightness characteristics in visible images OR top heights from radar images. The best approach involves at least bi-sensor combinations of data. The visible theory relies on the relationship between cloud optical thickness and precipitation rate, while the microwave theory depends on the direct relationship between ice and water content in clouds and precipitation. By combining both theories into one algorithm, the future of ground and space based precipitation estimation appears promising. Rain is most certain in clouds that are both dark in visible and have high tops in radar images taken at earth surface.

The radar and visible images are considered for the same geographic projection format and displayed simultaneously for qualitative evaluation.

Examples and results

In Fig.1 (19.01.07) fast forming clouds at the deep cyclone front during the lowering of the pressure P from 1019 to 1005 hPa (at sea level) for less than three hours are shown. The skies are mostly cloudy. Visible images indicate the high rate of the growing optical thickness – the linear average of the brightness decreases by 49% in only 4 minutes, while still no data about radar reflectance. At this stage of cloud formation, the size of hydrosols is too small to give detectable radar reflectance. Nevertheless, radar measurements indicate relatively high top height of clouds – about 6000 m, and ceilometer determined base height is ~1800 m above ground level that makes over 4000 m physical thickness of cloud layer. About two hours later it began to rain, and in the course of six hours the amount of precipitation was 6 litre/m^2.



a b c

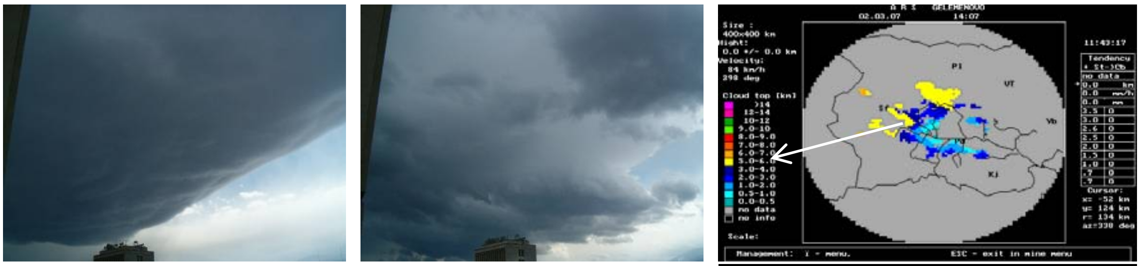
Fig.1. Visible images (a) and (b) taken in time interval of 4 minutes; The optical thickness grows very fast by 49%. Meteorological and radar (c) data: Base height ~1800 m, Top ~6000 m, Thickness >4000 m, T=15^o C, RH=45%, P=1005 hPa (<<norm)

In Fig. 2 (29.01.07), the visible images show the early formation of cloud (a) with bright veil behind that means accelerated convection and occasional thunderstorm, and the development (b) of the cloud for a little more than two hours - the cloud get larger and darker in view of the prolonged exposition of the second picture. In the radar image (c) lesser top height and thickness of clouds as compared with the previous example is indicated. However, the mixed phase ice-water hydrosols are large enough to be detected by radar - reflectance R =10 -15. Two hours later a drizzle occur, and then one more an hour later on precipitation accompanied by thunder began. The relatively small thickness of the variable cloudiness is an indication of relatively poor precipitation potential – 1 litre/m^2.

a b c

Fig. 2. Visible images: (a) – early formation of cloud; (b) –development for two hours. Meteorological and radar data (c): Base height ~1500 m, Top ~4000 m, Thickness ~2500 m, T=4^o C, RH=56%, P=1010 hPa (< norm), Reflectance: 10-15, Precipitation -1litre/m^2

In Fig. 3 (02/03/07) the appearance of precipitating cloud before and during first raindrops reaching the ground is shown. The well defined cloud base and edges (a) is quite typical visible feature for most nimbostratus cumuli. The rarefying of the observed cloud (b) leads to increasing of the relative humidity and to formation of new low clouds that in turn go up. Later light rain showers for nine hours give insignificant amount of precipitation.



a b c

Fig. 3. Visible images: (a) - 13:45 h, still no rainfall; (b) - 14:20 h, passing light drizzle. Meteorological and radar data (c): Base height ~1500 m, top ~6000 m, temperature 16^o C, thickness ~4500 m at the beginning of the rainfall.

The last example in Fig. 4 (07.05.07) shows the fast formation of dark convective clouds surrounded by bright aerosol veil that is a sign of probable thunderstorms. Visible images (a) and (b) are taken in only two minutes. The larger radar reflectance (R=20-25) and thickness than in the previous examples are related to the higher liquid water path of these warm clouds. Two hours later began thunderstorm and rainfall of amount 3 litre/m^2.

a b c

Fig. 4. Visible images (a) and (b) present the quick darkening of clouds in only two minutes. Meteorological and radar data (c): Base height ~1300 m, Top ~8000 m, Thickness >6500 m, T=21^o C, RH=56%, P=1008 hPa (<norm), Reflectance: 20-25.

Our observations are in accordance with some other results, for example in [3] that a decrease in precipitation efficiency of single cumulus clouds arising in microphysical continental air is attributable to a greater loss of the precipitating mass due to a greater sublimation of ice and evaporation of drops while they are falling from higher levels through a deep layer of dry air below the cloud.

Precipitating clouds are characterized by much higher thickness above 2500-3000 m than that for ordinary stratocumulus clouds, which is usually in the range 500–1000 m.

Geometrical thickness of clouds varies, depending on the cloud type and temperature – warmer precipitating clouds are thicker than colder clouds. The warm clouds precipitate at thickness around 4500 m, while colder clouds could precipitate at lesser – about 2500 m.

The amount of precipitation is directly related to the accumulated liquid water path, which is determined by cloud water content and cloud geometrical thickness.

The rain delay depends on the rate of cloud formation and thickening that is well displayed in visible images. Fast convective clouds over polluted urban areas (the city of Sofia) often produce thunderstorms.

Multi-sensor synergetic measurement of clouds in different (visible/IR and cm) spectral ranges of electromagnetic spectrum give a good basis for cloud exploration and estimation of the precipitation efficiency of meteorologically significant clouds from ground-based data.

References:

1. K o k h a n o v s k y A. Optical properties of terrestrial clouds. Earth-Science Reviews 64, 189–241, 2004
2. L i n B. *Observations of Cloud Water Path and Precipitation over Oceans Using ISCCP and SSM/I data*. Ph.D. Thesis. Columbia University, 1995.
3. K h a i n A., D. R o s e n f e l d and A. P o k r o v s k y. Aerosol impact on the dynamics and microphysics of deep convective clouds. Q. J. R. Meteorol. Soc., 131, pp. 2639–2663, 2005; doi: 10.1256/qj.04.62