INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

SMR/406-20

THIRD AUTUMN WORKSHOP ON ATMOSPHERIC RADIATION AND CLOUD PHYSICS
27 November - 15 December 1989

"The Experimental Cloud Lidar Pilot Study (ECLIPS): The 1989 Campaign at Dumont D'Urville"

L. STEFANUTTI
Consiglio Nazionale delle Ricerche
Istituto di Ricerca sulle Onde Elettromagnetiche
Firenze
Italy

Please note: These are preliminary notes intended for internal distribution only.

The Experimental Cloud Lidar Pilot Study (ECLIPS): The 1989 Campaign at Dumont D'Urville

M. Morandi, L. Stefanutti, L. Zuccagnoli, V. M. Sacco
C.N.R. - I.R.O.E. Firenze

Cai Peipei
East China Normal University - Shanghai China

L. Cecconi, P. Guilvard, B. Vroland
Expeditiones Polaires Francaises

ABSTRACT

A depolarization Lidar has been installed at the antarctic French base of Dumont d'Urville (66° 40'S 140° 1'E).

Since January 89 routine cloud measurements are performed in order to collect a set of statistical data.

Two ECLIPS campaigns have been carried out.

Continuous IR downward radiance measurements are performed by a wide field of view standard radiometer, while a T.V. camera and a time lapse video recorder are used in order to monitor cloud cover and to estimate cloud velocity vector.

Ground level and radiosondes data of meteorological parameters, AVHRR and TOVS satellites data are available.

Visible optical properties of clouds have been obtained from Lidar profiles.

Approximate values of cloud IR emissivity have been computed using lidar, radiometric and radiosondes data.

INTRODUCTION

"The Antarctic region has a high negative radiation budget and so acts as one of the Earth's 'refrigerators'. Any changes in the budget will have global consequences on atmospheric and oceanic circulation." (from "The role of Antarctica in Global Change - Scientific Priorities for the International Geosphere - Biosphere

Program (IGPB)" - SCAR)

The studies of the effects of aerosols and clouds on radiative budget and on climate are still an unsolved problem.

Aerosol buildup and cloudiness changes, both in cover and in microphysics structure, can modify both the albedo and the infrared optical properties of the atmosphere, then their effects should be considered as a global feedback mechanism.[1-10]

Cloud optical properties are function of several parameters, like:

- phase (ice/water)
- cloud water path
- drops size distribution
- cloud height.

The global averaged value of one or more of these parameters can be modified by climatic changes like the ones due to modifications in th composition of the atmosphere again on climate

The effects of the increase of "greenhouse" gases are well known in climatic models, but those of aerosols and clouds are still largely unknown:

Pollution can provide additional cloud condensation nuclei (CCN).

In remote regions the dominant source of CCN is the dimethylsulphide released into the atmosphere by marine phytoplankton. Thus, due to increase of CO_2, growth of plankton population and subsequent increase of CCN can be expected [10].

Model calculations and satellite observations indicate that low stratus clouds would be significantly changed by a possible increase of the number of CCN [7]. Moreover increasing temperature, due to the major loading of CO_2, can induce modification in the clouds physical phase with an increase of the water phase versus the ice phase. The precipitation rate of ice clouds is about an order of magnitude greater than that of water clouds. The final effect would be again an increase in cloud cover [5].

CCN buildup induce nucleation in more, but smaller, drops for a given cloud water path. In this way the cloud optical depth increases [8,9,10]. Thus modifications in both "solar" optical properties and IR radiative characteristics may be expected, due to changes in cloud microphysics; variations in precipitation process and in their global distribution may be expected too.

Aerosols effects on radiation budget must be considered for the cloudfree parts of the atmosphere [6].
Little is known on the role of Ice Nuclei and on their possible biologic origin [6].

Several parameter involved in these studies are only roughly known, so at present only qualitative forecasts are possible.

Recently J.F.B. Mitchell et al. [5], studied cloud feedback on greenhouse effect. Two different cloud models are considered: a first model based on relative humidity [11], a second one on cloud water content. Starting from a doubled CO_2 atmospheric content, but neglecting changes in amount of CCN, cloud feedback effects were evaluated averaging over five years after reaching equilibrium. The results show rather different quantitative effects for the two different models.

Improvement of knowledge can be obtained only by systematic experimental studies.

Satellite observation have given an important contribution in this kind of research, but still a lot of questions have no answer.

ECLIPS

Under the auspices of the W.M.O. (World Meteorological Organization) the Experimental Cloud LIDAR Pilot Study has been promoted. [12]

The objectives of ECLIPS are:

- To demonstrate the feasibility of obtaining a long term climatology of cloud base height, and cloud optical properties, with groundbased Lidar and to formulate a plan of measurement.

- To improve methods of retrieval of cloud data from satellites by comparison of satellite and lidar data.

- To improve the prediction of the surface energy balance from satellite data.

- To obtain a data set of cloud optical properties which would be complementary to the ISCCP * data set

  * (International Satellite Cloud Climatology Project)

and the requirements are the determination of:

- Cloud types and amount
- Cloud base height with an accuracy of at least ± 50 m
- Cloud depth or "apparent" depth (for dense cloud in which there is not full lidar penetration)
  Cloud extinction coefficient profile
- Depolarization ratio
- Downward infrared longwave flux
- Downward shortwave flux
- Cloud emissivity
- Cloud velocity vector
- Local meteorological measurements and radiosonde data are also requested

Since 1989 coordinated experimental campaigns have been performed.

I.R.O.E. contribution to the ECLIPS program

1989 campaign description

A depolarization Lidar [13], operating at 532 nm, was installed at the French base of Dumont d'Urville, as part of the ECLIPS network of ground based station, and it is the only lidar station involved in ECLIPS operating in a polar region.

Since January 89 routine Lidar measurements of tropospheric clouds and IR radiometric measurements are carried out.

Downward radiance is continually measured by a standard broadband (5-30μm) wide field of view (170^{o}) radiometer (EPPLEY - Mod. PIR)

TV images are acquired by a wide angle camera and a time lapse video recorder.

Radiosounding are daily performed by the Meteorological Service of the base, thus temperature, humidity, pressure and wind profile are available, ground level meteorological parameter are available too.

For routine measurements a ten shots averaged profile is acquired every ten minutes (laser repetition rate 1 shot/minute).

Two ECLIPS campaign were performed in 1989 from 1st to 30th April, and from September 15th to October 31st.

ECLIPS measurements were carried out starting one hour before the overpass time of NOAA 10 or NOAA 11 satellites, twenty minutes during the overpass and one hour after. During this time a six shots averaged profile was acquired every minute. (Laser repetition rate 1 shot/10 second). Overpasses were chosen for low "scan-angle". Two sets of these measurements were daily performed during 1989 ECLIPS campaigns.

Cloud parameter to be evaluated

Cloud geometric and visible parameters are computed from lidar signatures. Directly from the lidar profiles one obtains cloud base and for optically thin clouds, thickness and top. Using either a Klett standard inversion method [14-17] or a step by step numerical procedure , the optical depth, and the profiles of both extinction and backscattering coefficients may be computed in the case of homogeneous clouds (assuming constant the backscattering to extinction ratio) [18]. For very dense clouds only an apparent optical depth can be given, i.e. if there is full lidar pulses extinction in the cloud, true cloud optical depth may be evaluated to be larger than the maximum detectable one.

perpendicular polarization components. Thus information about the phase of cloud water may be obtained. Furthermore, depolarization and backscattering measurements permit the evaluation of sedimentation processes. From the apparent sedimentation rate a estimation of ice particle size is possible [19]. We recall that measurements are carried out on the vertical of a fixed point and the observation in time of a layer at always lower altitude can be interpreted as a sedimentation process. Also transport effects could in certain cases give raise to the same results. If sedimentation rate and ice particle sizes evaluated from such terminal velocities are consistent we may reasonably be in the presence of sedimentation process.

From TV images amount and type of clouds can be estimated. Moreover, cloud velocity vector can be obtained using both lidar and TV data: cloud height is computed from lidar profile, then speed and direction are obtained correlating successive TV images.

The cloud cover obtained by ground based vertically pointing instrumentation may be compared with visible and IR AVHRR images; it's evident that a ground based system is particularly sensitive to cloud base structure, while satellite borne system to cloud top. By means of inversion algorithms cloud top height and consequently cloud velocity vector are computed. The presence of subvisible clouds and aerosols might cause large errors in these evaluations. When the lidar pulses penetrate through the cloud it's possible to validate both cloud top height and velocity obtained by cloud tracking from satellite images.

Lidar measurements can provide information in multi layer cloud cover that cannot be discriminated from satellite data.

TOVS data, giving temperature and humidity profile, may be compared both with radiosondes data and with the vertical cloud layers obtained by lidar profiles and with the cloud physical phase deduced by depolarization measurements.

New inversion procedures [20] will be tested in order to evaluate if it's possible to obtain, from Lidar data, information about size and distribution of either water drops or ice crystals, at least in homogeneous clouds.

An approximate value of cloud emissivity is computed using together Lidar, radiometer and radiosondes data.

Since next year improvements of our system will be done: a standard Pyranometer (EPPLEY PSP) and a narrow band (8 - 14 μm) narrow field of view (2^{o}) PRT-5 radiometer will be used. The former for downward shortwave solar and sky radiance measurements (since 1990), the latter in order to obtain more precise cloud emissivity evaluation (since 1991).

Using together ground based measurements (Lidar, TV images, Radiometer and Meteorological data), radiosoundes profiles and satellite data a study of the local radiative budget and a characterization of the radiative properties of tropospheric clouds should be possible.

Theory

All aspect of the inversion of lidar data for the calculation of geometric and visible optical parameter have been explained at the 1st Workshop on the Antarctic Atmosphere [18].

<u>Cloud emissivity evaluation</u>

A method for cloud emissivity calculation, combining lidar and radiometric measurements, was proposed by PLATT (21).

These method was revise of our group because of the different technical of radiometric measurement (wide F.O.V. - broad band).

The radiometric data give the total value of downward radiance including sky radiance and the part by ground radiance reflected from clouds.

$$L_{TOT} = \tau \ (L_g + L_c) + L_s \qquad (1)$$

where, L_c, L_s are respectively the cloud and sky radiances, τ is the atmospheric transmittance and L_g is given by

$$L_g = L_G \ \tau \ R_{IR} \qquad (2)$$

where L_G is the ground radiance R_{IR} the cloud IR reflectivity

Cloud emissivity is defined as:

$$\epsilon = L_c/L_t \qquad (3)$$

where L_t is the blackbody radiance for the cloud's temperature T and L_c as the cloud radiance. For a given wavelength, L_t is given by the Plank law

$$L(\lambda) = C'/[\lambda^5 \exp(C''/\lambda T) - 1] \qquad (4)$$

with $C' = 3.74 \ 10^{-16}$ W m^2 and $C'' = 1.44 \ 10^{-2}$ m ^oK

Integrating Eq. 3 between λ_1 and λ_2 one obtains the value of blackbody radiance in the request spectral range. λ_1 and λ_2 are respectively the lower and upper limit of the radiometer bandwidth

$$L_B = \int_{\lambda_2}^{\lambda_1} L(\lambda) \ d\lambda \qquad (5)$$

LOWTRAN 6 computer code, is used in order to compute both theoretical downward sky radiance, and the τ atmospheric transmittance. Radiosondes data of temperature, pressure and humidity are input data.

Considering the cloud as an isotropic source, and in the case of homogeneous cover of whole sky, a theoretical value L_o of the total radiance for unit of solid angle is obtained for a given ϵ . A cloud model may be considered and cloud IR reflectivity may be evaluated using a Montecarlo method. In our preliminary results the ground contribution was neglected.

The total downward radiance is obtained integrating the theoretical value L_o over the field of view of our radiometer:

$$L^* = 2\pi \int L_o \sin\theta \cos\theta \, d\theta \qquad (6)$$

varying the emissivity in our cloud model up to obtain an agreement between L^* and L_{TOT} (computed and measured values of total downward radiance) a value ϵ^* for the cloud emissivity is obtained.

A second approach, suggested by Platt [21], can be followed. In the visible region the following equation holds, relating the backscattering coefficient $\beta_C(\pi,z)$ to the extinction coefficient $\sigma_C(z)$

$$\beta_C(\pi,z) = K\,\sigma_C\,(z) \qquad (7)$$

and the optical thickness is defined as

$$\delta_C(h) = \int_{z_o}^{z_T} \sigma_C\,(z)\, dz \qquad (8)$$

where $h = z_T - z_o$; z_o and z_T are respectively the cloud base and top height.

The extinction coefficient in the visible region and the IR extinction coefficient may be related

$$\alpha = (\sigma_S + \sigma_A)_{VIS} / (\sigma_S + \sigma_A)_{IR} \qquad (9)$$

and neglecting the scattering (σ_S) and the absorption (σ_A) respectively in the IR and visible regions one obtains

$$\sigma_C(z) = \alpha\,\sigma_A(z) \qquad (10)$$

$$\delta_A(h) = \int_{z_o}^{z_T} \sigma_A(z)\, dz = \alpha \int_{z_o}^{z_T} \sigma_C(z)\, dz \qquad (11)$$

The emissivity ϵ can be also defined as

$$\epsilon = 1 - \exp [- \delta_A(h)] \qquad (12)$$

Calling $J'(\pi)$ the integrated lidar backscattering we can write

$$J'(\pi) = \int_{z_0}^{z_T} \beta_C (\pi,z) \exp [-2 \int_{z_0}^{z} \sigma_C (z') dz'] dz \qquad (13)$$

Using together the equations 7, 8, 10 and 11 Eq.13 becomes:

$$J'(\pi) = K/2 [1 - \exp (-2\alpha \ln 1/1-\epsilon)] \qquad (14)$$

$J'(\pi)$ may be obtained integrating the lidar data; for a first step ϵ was assumed to be equal the computed value ϵ^*, while the K constant may be computed by inverting lidar signatures [18].
Thus in the case of a fairly homogeneous cloud cover a reasonable value of the constant α may be obtained from Eq. 14, solved for α, using a set of lidar data.

The z_0, z_T, and the visible optical depth $\delta_C(h)$ are computed from lidar data, then $\delta_A(h)$ may be obtained by Eq. 11. Then a more precise value of ϵ is obtained by the equation 12 [21].

Experimental Results

The lidar data of the 1987-88 antarctic campaign at Terra Nova Bay have been processed in order to obtain a statistical data set. The time series of this first campaign was limited, so this statistic is not significant, but permits to test both the measurement method and the inversion procedure .

Fig. 1 and Fig. 2 show the temporal evolution respectively of February 2nd and February 3th 1988 at Terra Nova Bay. In the case of Fig. 1 a phenomenon of sedimentation is evident.

Fig. 3 shows a one hour temporal evolution of both backscattering (Fig. 4a) and depolarization (Fig. 4b) ratios.

At present only a few lidar data of the 1989 campaign are available, while AVHRR and TOVS satellite data are no yet available.

Lidar and radiometric data of January and February 89 have been used to test the above method for the evaluation of cloud emissivity .

Fig. 5 shows an example of these results for measurements performed on February 8th 1989. During the measurements time interval the cloud cover was fairly homogeneous, but same snowstorm occurred. $J'(\pi)$ is plotted as a function of ϵ (continuous line), for the computed value of α, experimental data are plotted too. In order to understand their quiet large dispersion is useful to look also at the depolarization ratio of each profile.

Fig. 6 shows the temporal evolution of the depolarization ratio; its strong variability should indicate a phase change in the clouds, occurring during the warmest hours of the day.

The data indicated in Fig. 5 with a dot are referred to a snowfall phenomena that took place during these measurements. Moreover, due probable to "anomalous" backscattering, unusual values of K were found for the two higher data.

Fig.7 shows an other example of comparison between theoretical and measured cloud emissivity. These measurements have been performed on February 2nd 89. In this case, due to a more quite weather, a good agreement was found between the two emissivities ϵ^* and ϵ. Only two experimental data are significantly lower than the ones of ϵ^*.

For the first low value of ϵ (at about 3 pm), for which a normal value of K was found. This might be due to a short time, but strong, variation in the cloud optical depth above the measurement point; such an event influences lidar measurements but not radiometric data, because of the wide field of view. The value of δ_c changes from .35 (right before and after this measurement) to .13 for this lidar signature. The second low experimental value (at about 5 pm) might be explained again by "anomalous" backscattering phenomenon, in fact for this lidar profile the value of K increases quickly from about .1 to .3 then decrease again.

At present, due to the wide field of view of the radiometer, this method can be only used for homogeneous cloud cover and gives only indicative results.

When a narrow band - narrow field of view radiometer (PRT-5) will be available (1991) lidar and radiometric measurements will be referred to the same cloud volume, this way more accurate emissivity measurements will be possible [21,22].

REFERENCE

1) Schneider S.H. J. Atmos. Sciences 29, p.1413 (1972)

2) Cess R.D. J. Atmos. Sciences 33, p.1831 (1976)

3) Platt C.M.R. J. Atmos. Sciences 44, p.729 (1987)

4) Wetherald R.T. et al. J. Atmos. Sciences 45, p.1397 (1988)

5) Mitchell J.F.B. et al. Nature 341, p.132 (1989)

6) "International Global Aerosol Program:A Plain Outline",1989
IACP 89-2 prepared for IAMAP, IGPB, WMO

7) GRASSL Abstract of " European Aerosol Conference " - Vienna
18,23 .LM .30"
Sept. 1989"

8) Slingo A. IAMAP 1989, Abstract AC.R5

9) Cakley J.A. et al. Science 237, p.1020 (1987)

10) Chalson R.J. et al. Nature 326, p.655 (1987)

11) Mitchell J.F.B. et al. Nature 330, p.238 (1987)

12) ECLIPS - Report WCRP/CSIRO Workshop, WMO/TD-n.251 (1988)

13) Sacco V.M. et al. Opt. and Quantum Electr. 21, p.215 (1989)

14) Klett J.D. Appl. Opt. 20, p.213 (1981)

15) Klett J.D. Appl. Opt. 22, p.514 (1983)

16) Klett J.D. Appl. Opt. 24, p.1638 (1985)

17) Klett J.D. Appl. Opt. 25, p.2462 (1986)

18 Morandi et all: SIF Conference Proc. 20 p. 111 (1989)
(1989)

19) HEYENSFIELD A.J.: Atmosp. Sciences 9 1348 (1972).

20) Flesia C. "A stochastic methode for the Lidar inversion equation application for cloud size distribution measurements" same issue

21) Platt C.M.R. J. Appl. Meteor. 18, p.1130 (1979)

22) Flamant P. et al. Annales Geophysicae 7, (1), p.1 (1989)

23) Stefanutti L. et al. "NEW LIDAR SYSTEMS: THE DIAL AND THE AUTOMATIC DIODE PUMPED ND-YAG SYSTEM" Same Issue

24) Ferrario A. et al "Sorgenti laser complementate a stato solido per stazioni lidar automatiche" same issue