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Preliminary Results Combining Ground-based RAMAN Lidar and NAST-I Airborne Spectrometer to Describe the Evolution of a Cirrus Cloud – EAQUATE, ITALY 2004

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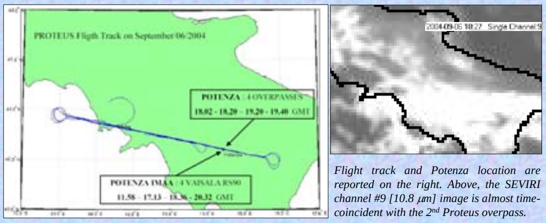
1. INTRODUCTION: ITALIAN EAQUATE CAMPAIGN

The EAQUATE campaign was designed to study the atmosphere using aircraft and ground based instruments, demonstrating the benefit of these measurements in validating hyper-spectral satellite sounding observations. The first phase took place in Italy (5th - 10th September 2004) and the second phase in the UK (13th - 22nd September 2004). The Proteus high altitude aircraft participated in both campaigns, providing measurements from the NAST thermal infrared interferometer and microwave radiometer, the Scanning HIS infrared interferometer, the FIRSC far-IR interferometer, and the micro-MAPS CO sensor. The Italian phase, funded by the Integrated Program Office and by the Province of Benevento, was carried out within an international collaboration between NASA Langley Research Center, University of Wisconsin, the Istituto di Metodologie per l'Analisi Ambientale (IMAA-CNR), the Mediterranean Agency for Remote Sensing (MARS) and the Universities of Basilicata and Napoli. The experiment involved a range of ground based remote sensing instruments (lidars, microwave radiometer, infrared interferometer, ceilometer) as well as an Earth Observing System-Direct Readout Station. A radiosonde system has provided conventional profiles. The aircraft was based at the military side of the Napoli Capodichino airport. Aircraft and crew were hosted by the V GMV of the Italian airforce. Four flights were successfully completed with two different AQUA overpasses. The aircraft flew over the Napoli, Potenza and Tito Scalo ground stations several times allowing the collection of coincident aircraft and in- situ observations [http://metresearch.net/eaquate/Homepage.html].

2. EXPERIMENTAL CONDITIONS: SEPTEMBER 6th 2004



Flight track and Potenza location are reported on the right. Above, the SEVIRI channel #9 [10.8 μm] image is almost time-coincident with the 2nd Proteus overpass.

Data analysed refer to the 6th of September when the Proteus aircraft flew four times over a moderately thick high cirrus cloud in the Potenza region. The evolution of the cloud was monitored by the DIFA Raman lidar ground station in Potenza and four radiosondes were released from the IMAA ground station, thus providing a good description of the atmospheric gaseous and particulate state. The general evolution of the cloud field was monitored using MSG infrared images, available every 15 minutes.

3. GROUND BASE AND AIRBORNE SENSORS:

From left to right: the Proteus carrier [courtesy of NASA], the location of the NAST-I interferometer on the aircraft [courtesy of NASA] and the Raman lidar system located at the DIFA – Potenza .

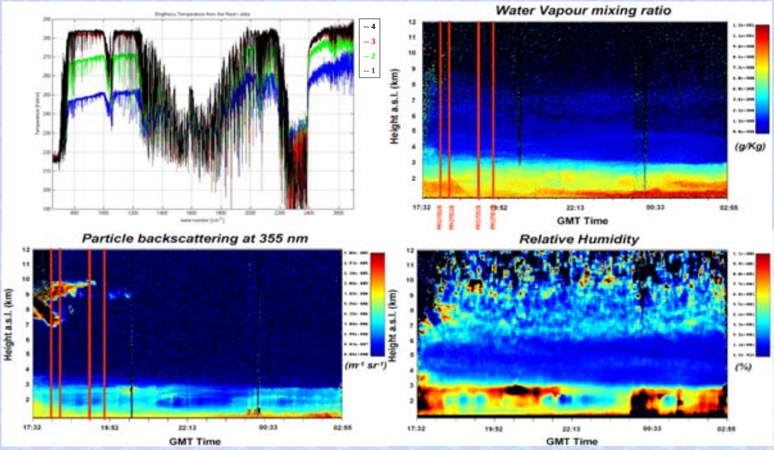
On the same day the Proteus was also carrying the NAST-M mw radiometer and the SHIS interferometer. **NAST-I** is a scanning interferometer [-45, +45°], Δ=7.5° with a spectral coverage covering the band [645, 2700] cm^{-1} and a spectral resolution of $\Delta\nu = 0.24$ cm^{-1}. The DIFA **RAMAN LIDAR** system measures the particle backscatter at 355 and 532 nm, particle extinction at 355 nm, water vapour mixing ratio and atmospheric temperature. Typical precision for day-time water vapour mixing ratio measurement is 10% at 2 km, while 2 % at 2 km and 20% at 6km for night-time operation. Typical precision for day-time particle backscatter measurements is 2 % at 2 km, while 1 % up to 5 km and 5 % at 10 km for night-time operation.

4. WORK PLAN AND GOALS:

- To co-locate and jointly process data coming out from a range of **different sensors** (Radiosondes/Raman-lidar/NAST-I interferometer).
- Evaluate the relevance of the **lidar information** in clear and cloudy sky conditions.
- To simulate very high spectral resolution interferometric radiances (at different viewing angles) by using a LbL Multiple Scattering code and investigate the consistency between measured/modelled radiances in presence of ice clouds.
- To arrange a temporal sequence of the cloud **cooling rates**. Evaluate the importance of the combined lidar – spectrometer information in predicting the evolution of a cirrus cloud.
- To put down the basis for a full study of a cirrus cloud evolution accounting for the dynamics and microphysics.

5. DATA

The upper left panel shows the NAST-I brightness temperatures measured during the 4 overpasses when the instrument's FOV intercept the cloud top at about 10 km of altitude above the DIFA site as can be seen from the lidar backscatter data. Ground-based Raman lidar measurements were run almost continuously during the measurement period of the airborne NAST-I interferometer. Lidar provides profile information with exact information of the statistical measurement uncertainty. Large uncertainties of the lidar-measured parameters may be easily identified and imprecise data can be excluded from further interpretations. Measurement were acquired with a maximum temporal and vertical resolution of 1 min and 30 m, respectively. Vertical and temporal resolution can be traded-off to improve measurement precision. Figures aside illustrate the time-height map for particle backscatter at 355, water vapour mixing ratio and relative humidity. Making use of lidar information NAST-I spectral BT were successfully simulated with biases less then 4%.



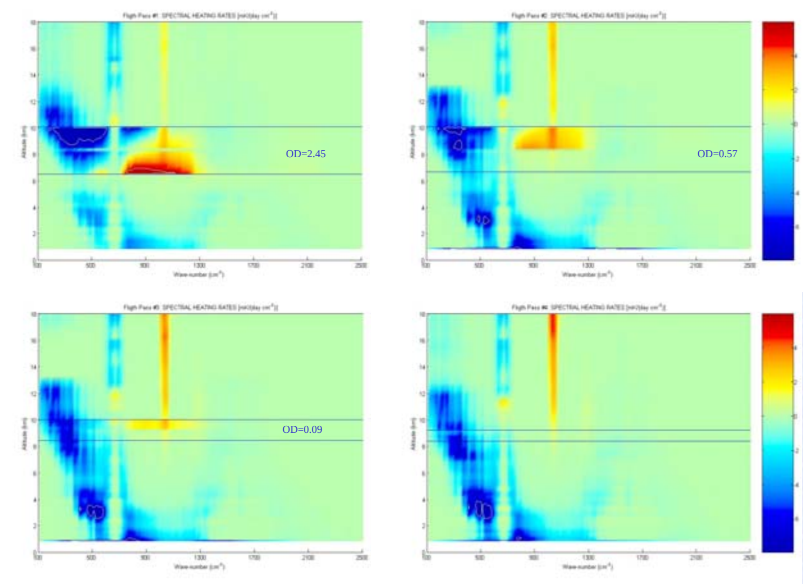
6. METHODOLOGY:

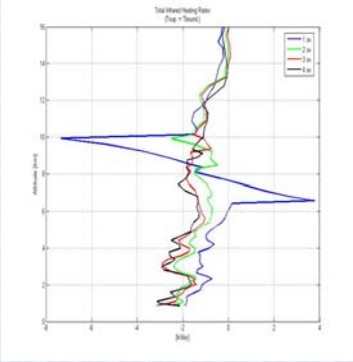
Line-by-line computations are performed to obtain high resolution optical depths for the major gas absorbers. The radiosonde temperature profile is used to characterise the atmosphere below flight level during the 4 overpasses. The water vapour mixing ratio profile is obtained from the lidar measurements when the associated percentage error is less than 50% . The radiosonde mixing ratio profiles are used to fill the lidar blind region (60 m above the lidar) and the lidar data affected by large uncertainties. The rest of the atmospheric column above is described using the US Standard (USS) atmospheric profile. The concentration profiles for the other molecules (CO_2, O_3, N_2O, CO, CH_4, O_2, NO, SO_2, NO_2 ,N_2, CCl_3F, CCl_2F and CCl_4) are also taken from the USS. The number of levels used for the computation is 94.

Line-by-line computations of layers optical depths are performed using **HARTCODE.** Single scattering properties for the cloud layers are generated assuming that ice particles are hexagonal columns. The cloud optical depths, altitudes and geometrical thickness for the 4 overpasses are determined by the lidar measurements of extinction and back-scattering coefficients. The radiative transfer calculations are performed using the **RT3** code, based on adding and doubling method to handle multiple scattering conditions. The code is interfaced with the gaseous and particulate optical depth databases. To simulate accurate interferometric measurements, high spectral resolution radiances are convolved with the appropriate instrumental function. Since the percentage error of the difference between the simulated interferometric radiances and the NAST-I data (in all the 4 overpasses) is amply less than 4% almost all over the spectrum, fluxes and heating rates have been computed at all levels.

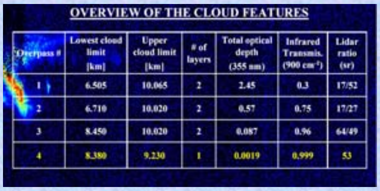
7. RESULTS AND COMMENTS:

Up and downwelling fluxes and cooling rates are computed at all levels and at every 0.05 cm^{-1}, for every NAST-I overpass of the Potenza region. The results are shown in the four panels below on the left. During the first overpass the cloud is made of two very similar optically thick layers. The high optical depth produces heating of the cloud base in the window region. At the far infrared the cloud base is still immersed in a quite opaque region determined by the water vapour rotational band. As a consequence, very low values of heating and cooling are detected there. The maximum cooling is observed from 200 to 600 cm^{-1} and in the upper part of the cloud layer. After 20 minutes the lower cloud layer has almost disappeared and the window heating takes place at the same altitude of the far infrared cooling. The same situation is found during the third overpass, but the heating and cooling are of smaller magnitude because of the smaller optical depth. During the 4th overpass the typical features of the clear sky cooling show up. Interesting feature is the cooling structure at 400-600 cm^{-1} and between 2-4 km of altitude in the rotational band of water vapour, a feature not evident in presence of strong downwelling cloud fluxes during the first overpass. The lidar-derived parameters are fundamental in distributing the IWC inside the cloud depth and thus in determining the cooling rates and layers' energy balance.





The total cooling rates computed for the 4 Proteus overpasses over the DIFA site. The cloud effect is evident both in and out the cloud layers. A sensible gradient between cloud top and bottom is developed only in the first overpass. The total cooling rates show how the radiative forcing seems to be insufficient to explain the complete cloud dissipation.



OVERVIEW OF THE CLOUD FEATURES

Overpass #	Lowest cloud limit [km]	Upper cloud limit [km]	# of layers	Total optical depth (355 nm)	Infrared Transmis. (900 cm^{-1})	Lidar ratio (sr)
1	6.505	10.065	2	2.45	0.3	17/52
2	6.710	10.020	2	0.57	0.75	17/27
3	8.450	10.020	2	0.087	0.96	64/49
4	8.380	9.230	1	0.0019	0.999	53

8. FUTURE:

For the case under study the radiative energy balance does not justify the whole ice cloud sublimation. Microphysics and dynamics need to be accounted for an exhaustive study of a cloud evolution.

More lidar information can be used to constrain the simulation (profile of the extinction coefficient, extinc to backs. ratio, temperature profile) and new cloud particle parameterisations are required to improve consistency between the solar (lidar) and infrared (interferometer) wavelengths.

PARTECIPATING INSTITUTES