REQUEST FOR C-130 and WCR SUPPORT
DYCOMS II *ADDENDUM*
NCAR/ATD - October 2000 OFAP Meeting

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Project Description

Please refer to request by Stevens et al. for description of core project.

At the university of Wyoming, project participants will be Dr. R. D. Kelly as co-PI and David Leon as doctoral candidate.

Dr. Christopher Bretherton of the University of Washington expressed an interest in using the data obtained with the Wyoming Cloud Radar in all of the flights to look for radar features which may be linked to entrainment/turbulence interactions.

Dr. Melanie Wetzel of the Desert Research Institute expressed an interest in using the microphysics data collected during the cloud penetrations in DYCOMS to compare with satellite-derived products.

Abstract/Overview of Proposed Project

The main purpose of this request is to add two more flights to the seven requested for DYCOMS II by Stevens, Lenschow, Bandy and Gerber. The additional flights will be optimized to benefit from the capability of the Wyoming Cloud Radar (WCR) to depict cloud structure and drizzle development. These additional flights will provide necessary auxiliary information to make full use of the radar information from the basic seven flights, and will provide a basis for better understanding of previous daytime studies in coastal clouds. The general goals we wish to pursue with the additional two flights are closely related to the goals of Stevens et al., and these flights will be carried out in the same cloud system.

DYCOMS II offers the opportunity to complement the Oregon coastal work we carried out with the Wyoming King Air in 1995 and 1999, and to make significant advances beyond the results derived from those projects. Significant limitations arose

from the facts that the coastal environment is more complex than regions further off shore, the Oregon flights were all conducted near maximum daily solar radiation and the WCR was equipped with a single antenna. The dual antenna installation proposed for the C-130 will yield dual-Doppler analyses, similar to that obtained in altocumulus by Leon et al. (1999).

We are requesting two flights in order to obtain one daytime and one nighttime data set. In both cases, the flight patters will focus on cloud structure on the scale of tens of kilometers and on the repeated and rapid sampling of even smaller regions of a few kilometers and/or a few stratocumulus elements. The purpose of the daytime flight is to provide a basis for comparison of the DYCOMS data with the Oregon coastal data, while the nighttime flight will extend those results and link to the other DYCOMS flights.

There is evident and strong benefit to all participants from the additional two flights. The seven flights of the basic program will provide a depiction of the larger scale distribution of drizzle and will also yield some data similar to that we intend to collect in the additional flights. In the other direction, data from the added flights will provide a better basis to interpret the limited in-cloud data obtained during the basic seven flights.

Proposal Summary

The principal objectives of our study are to find observational evidence for the factors controlling drizzle development and entrainment in stratus and stratocumulus. We approach these problems with the new perspectives opened by the use of the airborne Wyoming Cloud Radar.

The depiction of stratus and stratocumulus cloud structure, conceptually and in numerical models, consists of a combination of ideas transferred, on the one hand, from cumulus development with its central updraft, and from turbulence in stratified flow on the other. How these two contradictory views combine is mostly left unspecified due to the lack of empirical or theoretical insights. The scales of turbulent motions have been examined in a statistical sense only, as is inherent to turbulence studies. The insufficiency of these descriptions is quite apparent in the modeling of drizzle development and of entrainment.

In studies off the Oregon coast we have demonstrated the ability of the WCR to provide significant new insight into stratus structure (Vali et al., 1998). As may have been expected, the stratus layers were found to contain structure even when they were visually unbroken, and a robust relationship could be shown to exist between vertical velocities and drizzle concentrations. It was also found that the patchiness of radar echoes is not tied to any dominant scale but have exponential size distributions (Vali and Haimov 1998). Entrainment events could be identified in the radar data quite clearly, as narrow, vertically aligned, regions of reduced reflectivity and increased downward velocity. While not definite, some indications were detected for non-isotropy of the radar echoes in horizontal sections; weak wave patterns were resolved, as one would expect in the presence of significant wind shear across the inversion layer. Thus, while the dichotomy of organization and randomness is not resolved by these findings, bases for

more definite formulations of these concepts are emerging.

The first questions we want to examine with the DYCOMS data is how well the ideas developed from the Oregon data translate to the clouds further off shore, free from the strong gradients of coastal waters and to nighttime conditions. Each of these factors may have significant effects on the structure and microphysical evolution of the clouds. Some specific features that we will focus on are:

- Vertical profiles of radar reflectivity and Doppler velocity; the statistics of reflectivity and velocity values as a function of altitude.
- The correlation between reflectivity and Doppler velocity as a function of altitude.
- Entrainment signatures (weak reflectivity region with increased downward velocity).
- The relationship between the radar observables and in situ measurements of liquid water content and dropsize distributions.
- Convergence patterns in 2-D from dual-Doppler analyses.
- Qualitative appearance of radar reflectivity fields.
- Changes in echo structure in vertical planes at different orientation with respect to the wind shear.

The observations we propose to make during DYCOMS differ from the 1995 and 1999 Oregon experiments in flight plans due to the difference in radar installation. Instead of upward and side-looking beams, dual down-looking beams will be available. This difference dictated different flight plans. In most other regards the experiments are similar.

References:

Leon, D. C., A. Guyot, P. Laborie. A. Pazmany, J. Pelon, J. Testud, and G. Vali, 1999: Vertical plane velocity fields retrieved from dual-beam airborne Doppler radar data. *Preprints, 29th Intl. Conf. on Radar Meteor., Montreal, Quebec, Canada, 12-16 July 1999.*

Vali, G., and S. Haimov, 1998: On the patchiness of radar echoes in marine stratus. Preprints, AMS Conference on Cloud Physics, Everett, Washington, 314-316

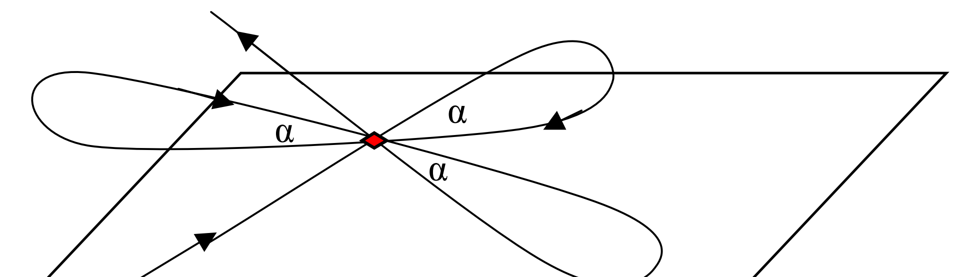
Vali, G., R. D. Kelly, J. French, S. Haimov, D. Leon, A. Pazmany, and R. E. McIntosh, 1998: Finescale structure and microphysics of coastal stratus. *J. Atmos. Sci.*, *55*, 3540-3564.

Proposed flight patterns:

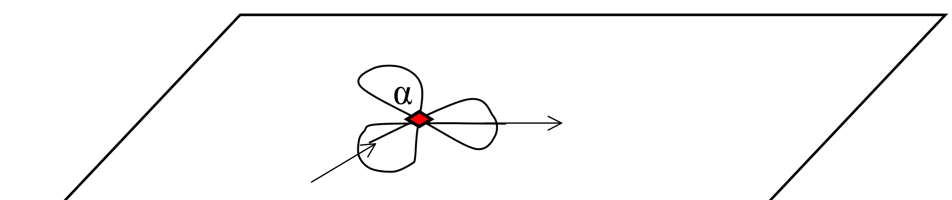
Governing factors in designing the flight patterns are the facts that the WCR will have downward pointing beams, that the dual-Doppler analyses require that the beams be in a vertical plane during sampling, and our desire to repeatedly sample the same cloud volume. The in situ samples are needed from various flight levels within the cloud layer and just above it. Furthermore, since the radar sample is from a vertical plane, the orientation of this plane with respect to the horizontal winds needs to be varied.

These considerations lead to proposing butterfly flight patterns of two different dimensions (***B1*** and ***B2***) at four flight levels (***a,b,c*** and ***d***), leading to a total set of 8 patterns: ***B1a …. B2d***.   The center of the butterfly pattern is a point allowed to float with the horizontal winds. Thus, the patterns depicted here are to be interpreted as being relative to the 'air', not the ground. In practice, this means flying straight and level segments, making turns to produce the desired change in heading, adjusting the end of the turn so that the heading coincides with the direction required to return to the reference point.

The difference between ***B1*** and ***B2*** will be in the lengths of the straight legs, which will be 20 km for ***B1*** and 5 km for ***B2***.   The number of straight legs per butterfly will be 4 per flight level for ***B1*** and 6 per flight level for ***B2***.



B1:   20 km legs; α = 25º



B2: 5 km legs; α = 75º

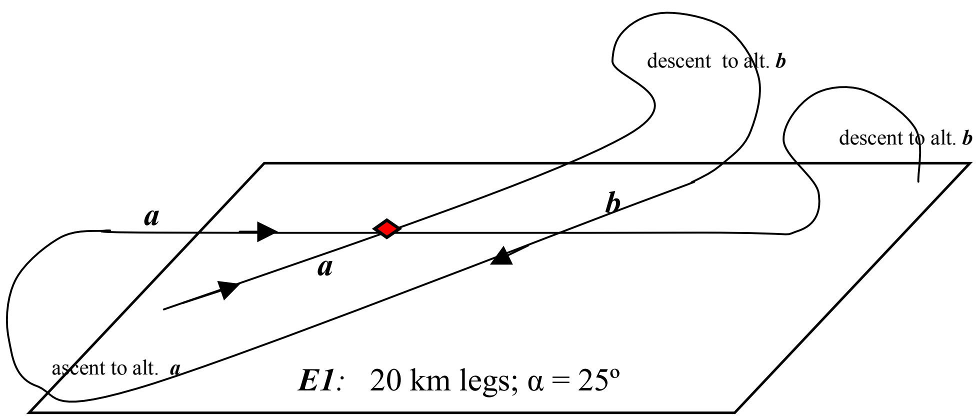
Using, in round numbers, 0.5 km and 1 km for cloud base and cloud top height, the flight levels will be: ***a*** -1.2 km, ***b*** - 0.9 km, *c* - 0.75 and ***d*** - 0.6 km.

The desired full sequence of butterfly flight segments is:

***B1a* → *B1b* →*B1d* →*B1c* →→ *B2a* →*B2b* →*B2d* →*B2c*.**

With 2-min turns, the minimum angles between butterfly legs, so as to intercept preceding legs at their center point, will be 25º for the 20-km legs and 75º for the 5-km legs. These angles will be used in order to minimize the lapse of time between legs. From the pilot's point of view, this means that after completion of a leg turns of 180+25=205º and 180+75=255º turns will be executed. Continuing turns always in the same sense will result in vertical radar cross sections of varying orientation with respect to geographic or wind directions. Each leg, plus the turn at the end, will take 2.5 minutes for ***B2*** and 4.5 minutes for the ***B1***. With 4 legs per level of ***B1*** and 6 legs per level of ***B2***, one full sequence will take approximately 2:15 h.

For the examination of entrainment events it would present a distinct advantage to be able to observe a cloud volume near cloud top with the radar and very soon after penetrate the same volume with the in situ probes. This means flying straight legs above cloud top and then retracing the same line just below cloud top after a 90º-270º turn and descent. The drawback of this pattern is that wind shear will invalidate the assumption that the reference point set at one altitude will also apply at another altitude. Thus, this pattern will be tried on a flight if the initial sounding reveals that wind shear is negligible. Also, since this pattern will be more difficult to execute, it will be tried only with 20-km straight legs. We'll designate this patterns as ***E1***.



As the diagram attempts to illustrate, the sequence will consist of a 20-km straight leg at altitude ***a***, a 90º-270º turn and descent during the turn to altitude ***b***, a 20-km straight leg, a 180º+25º = 105º ascending turn and repetition of the pairs of legs 4 times. This sequence will require approximately 40 minutes after the initial leg has been started (i.e. location selected). If this pattern were to be flown the overall sequence for the flight would be:

B1* →→ *E1* →→ *B2* →→ *E1* →→ *B2.

In addition to the patterns described so far, at the beginning of the flight and at after each series of ***B1a* …. *B2c***, or ***E1*** sequences descent/ascent (***D/A***) maneuvers will be performed to provide soundings through the cloud layer. The initial ***D/A*** will also serve to select the location of the subsequent butterfly patterns. During all of the descent/ascent pairs, the decision will be made whether the location is suitable for the butterfly studies or not. Requirements will be: constant cloud base and cloud top altitude, no important change in the fraction of cloud cover, and unchanged wind field. These conditions are expected to prevail rather than be the exception. The rates of descent and ascent will be 300 m min^{-1}.

A flight consisting of 2 full ***B1a … B2c*** sequences (5 h 20 min), plus 4 ***D/A*** descent/ascent sequences (8-10 min each) would take close to 6 hours. Allowing an additional ½ to ¾ hours for searches and adjustments to cloud conditions thus requires a total on-station time of 6–½ to 6–¾ h. With suitable conditions one of the 20-km ***B1*** sequences might be replaced by 2 ***E1*** patterns, with the 5-km ***B2a .. B2c*** inserted between these, leaving the total flight time about the same.

Instrumentation:

The WCR will be installed on the C-130 with two antennas, one pointing in nadir, one at approximately 45 degrees off nadir. Specific details of the installation and operation of the WCR on the C-130 will be covered in a Letter of Agreement between NCAR/ATD and UWyo.

We are requesting the same instrument configuration as the core DYCOMS II request. The WCR will be operated on all DYCOMS flights. For the flights we request, the radar will be operated in slightly different modes but this has no impact on the rest of the aircraft system.

SABL data would have been specially relevant and helpful to these studies, but it will not be possible to use SABL on the additional flights because of the minimum altitude limitation.

The DMS and ozone measurements will serve the same purpose in all of the DYCOMS flights. In the additional flights there will be good opportunities to analyze entrainment events, similarly to the those described in Vali et al. (1998).

We are not requesting GPS dropsondes.

Previous related research project experience of PI:

G. Vali has been conducting research flights since 1969 with the University of Wyoming Queen Air and King Air research aircraft. He is also a key participant in the instrumentation of the UWyo aircraft, including the Wyoming Cloud Radar. He logged approximately 500 h of research flights, most of them in the right seat as flight director. He is PI on most of the projects that involve analyses of the flight data. While never a direct participant of ATD flight operations, he participated in several research projects in which UWyo and NCAR aircraft were involved in joint flights (NHRE, HIPLEX, SCMS).

Publications to be expected will range from collaborative efforts with other DYCOMS participants and special articles focussing on the issues addressed above. The most likely possibility regarding the latter is a paper submitted to J. Atmos. Sci. in 2003.

Educational benefit of the Project:

David Leon will be using the DYCOMS data as the principal component of his Ph.D. dissertation research.

Funding agency information:

Funding agency	Office of Naval Research - DEPSCoR
Contract officer	Dr. Scott Sandgathe
Contract identification	Pending
Proposal status	To be submitted in August 2000
Approximate amount budgeted	$ 350k over 3 years

Funding agency	National Science Foundation
Contract officer	Dr. Roddy Rogers
Contract identification	Pending
Proposal status	To be submitted in July 2000
Approximate amount budgeted	$ 590k over 3 years

Funding for the UWyo participation in DYCOMS will be in two parts. ONR will be asked to fund the field work as part of a proposal continuing the coastal meteorology work we have been conducting over the past 6 years. NSF will be asked to fund part of analysis effort of the DYCOMS data, as part of the ongoing research using the WCR to study cloud structure and precipitation development.