Aircraft Observations for Improved Physical Parameterization for Seasonal Prediction

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Award # N0001412WX21268

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Award # N0001412WX21322

LONG-TERM GOAL

The long-term goal of this project is to improve the representation of fractional low-level clouds in the medium-range forecast models.

OBJECTIVES

The objectives of the NPS project is to understand the physical processes involved in boundary layers covered by fractional cloudiness and to make extensive measurements specially aimed at quantifying various statistical quantities needed to examine and develop PDF-based cloud and turbulence parameterizations.

The objectives of the NRL project are to obtain measurements of the solar and IR irradiance throughout the cloudy boundary layer in order to characterize the solar and IR radiative energy environment. In particular, to obtain vertical profiles of the solar and IR irradiance throughout the boundary layer to quantify the role of the solar and IR heating/cooling rate profiles on marine stratus.

APPROACH

The NPS work within this project consists of two parts. First, we examined data from previous field programs, in which we first looked into the uncertainties in defining 1-dimensional cloud fraction from limited number of observations using three independent methods. We then explored the cloud and thermodynamic conditions that results in outstanding values of skewness and turbulent fluxes to illustrate the complication of the PDF approach in various boundary layer cloud conditions. This part of the research helps us to identify specific issues that require further observations and to design new measurement strategies. The second part is the new field measurements using the CIRPAS Twin Otter, which occurred in August/September 2012. The new field measurements will be referred to as the Unified Physical Parameterization for Extended Forecast 2012 field project (UPPEF2012).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Aircraft Observations for Improved Physical Parameterization for Seasonal Prediction**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Meteorology Department, Naval Postgraduate School Monterey, CA 93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

For the NRL project, identical pairs of customized pyranometers and pyrgeometers were mounted on the top and bottom of the CIRPAS Twin Otter aircraft to directly measure the down- and up-welling solar and infrared irradiance in the boundary layer. These instruments were commercially available solar and IR radiometers modified for aircraft use.

Qing Wang is responsible for the overall project. A visiting Ph. D student from National Taiwan University, Ms. Erica Kuo, worked on analyses of the previous measurements from ASTEX and DYCOMS-II. Mr. Kurt Nielsen, Mr. Dick Lind, and two NPS MS students participated in UPPEF2012 field measurements.

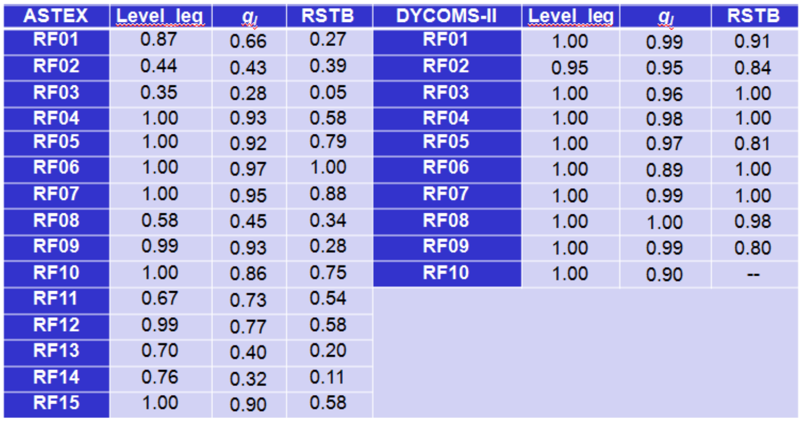
WORK COMPLETED

Our work in FY12 focused on analyses of ASTEX and DYCOMS-II data and UPPEF2012 planning and execution. Specific work done includes:

1. Analyzed all ASTEX and DYCOMS-II measurements on profiles, turbulence statistics, and cloud fraction. Cloud fraction was calculated using different approaches: cloud water measurements from level legs, cloud water measurements from profiles, and downward-look cloud top temperature measurements.
2. Examined uncertainties in determining cloud fraction from aircraft observations.
3. For all cases in ASTEX and DYCOMS-II, examined how mean and turbulent characteristics vary with cloud fraction. In particular, identified the variability vertical velocity skewness in relation with penetrating cumuli in the stratocumulus environment from ASTEX data.
4. Evaluate necessary measurement strategy to sample cloud fraction using satellite cloud imageries.
5. Under the NRL project, the customized solar and IR radiometers were mounted on the CIRPAS Twin Otter aircraft and successfully measured the down- and up-welling solar and infrared irradiance on the numerous flights during UPPEF. The radiometers were calibrated pre-mission at the CIRPAS Radiometer Calibration Lab.
6. Lead the field campaign of UPPEF2012 in August/September 2012.

RESULTS

Uncertainties in defining cloud fraction from aircraft observations: Cloud fraction is defined as the fractional cloudiness of the sky. This simple definition becomes difficult to quantify depending on the



ASTEX	Level_leg	q_l	RSTB	DYCOMS-II	Level_leg	q_l	RSTB
RF01	0.87	0.66	0.27	RF01	1.00	0.99	0.91
RF02	0.44	0.43	0.39	RF02	0.95	0.95	0.84
RF03	0.35	0.28	0.05	RF03	1.00	0.96	1.00
RF04	1.00	0.93	0.58	RF04	1.00	0.98	1.00
RF05	1.00	0.92	0.79	RF05	1.00	0.97	0.81
RF06	1.00	0.97	1.00	RF06	1.00	0.89	1.00
RF07	1.00	0.95	0.88	RF07	1.00	0.99	1.00
RF08	0.58	0.45	0.34	RF08	1.00	1.00	0.98
RF09	0.99	0.93	0.28	RF09	1.00	0.99	0.80
RF10	1.00	0.86	0.75	RF10	1.00	0.90	--
RF11	0.67	0.73	0.54				
RF12	0.99	0.77	0.58				
RF13	0.70	0.40	0.20				
RF14	0.76	0.32	0.11				
RF15	1.00	0.90	0.58				

Table 1. Cloud fraction calculated from all methods for ASTEX and DYCOMS-II flights.

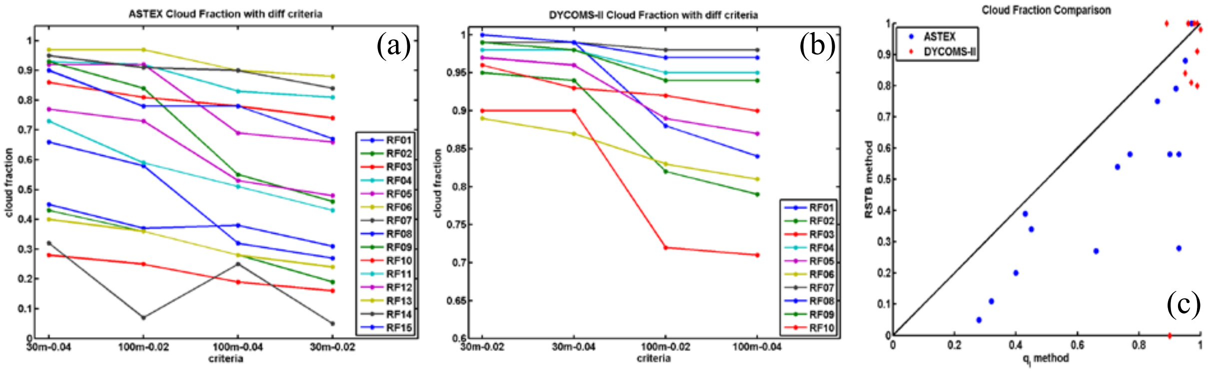


Figure 1. (a and b): Variation of calculated cloud fraction with different Δh and ql (first and second number in horizontal axis, respectively) threshold for ASTEX and DYCOMS-II; (c) Comparison of CF results from methods II and III. In the ql method, the maximum CF from all altitude is listed.

observations and the variables to use as cloud indicators. In this research, we examined cloud fraction defined from three methods: liquid water measured from level legs (method I), liquid water from the entire flight in vertical bins of Δh deep (method II), and downward radiometer measurements of the cloud top temperature (method III). Results from this calculation are shown in Table 1. Table 1 shows that DYCOMS-II flights were made in nearly all solid clouds, and all three methods give very similar results. ASTEX flights, on the other hand, can be very different from one method to another, although in general methods I and II track each other with the right trend. This large difference is due to the insufficient coverage, a severe limitation of calculating 1-Dimensional cloud fraction from flight legs of limited length. The resultant cloud fraction is also affected by the choice of averaging depth and q_l threshold as shown in Fig. 1. These results suggest that we need to design a good measurement strategy to obtain cloud fraction with high confidence in order to proceed with any further quantitative study on cloud fraction related issues.

Turbulence statistics and cloud fraction: One of the important statistical quantities to characterize the PDF is skewness. The skewness of vertical velocity reveals the dynamics of the turbulent field with regard to prominent updraft/downdraft events. Results from DYCOMS-II and ASTEX measurements show distinctive differences (Fig. 2). As expected, w skewness in the cloud falls in the negative range in the stratocumulus clouds in DYCOMS-II, while that from ASTEX is largely scattered, especially in the lower half of the cloud layer.

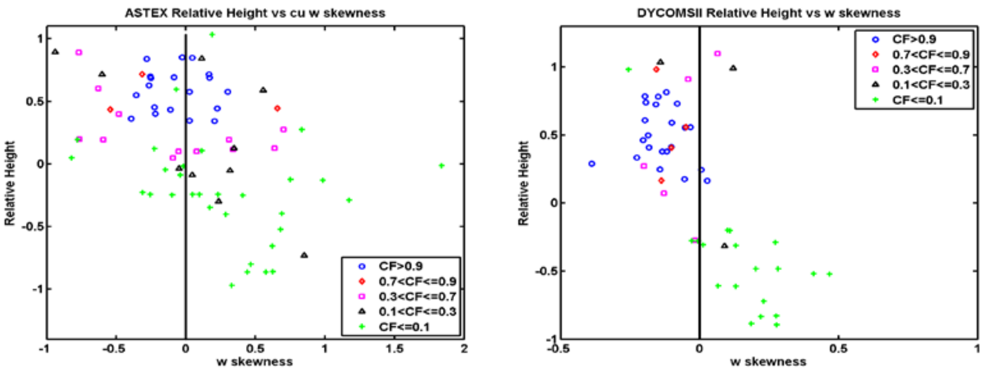


Figure 2. w skewness for all flights of ASTEX and DYCOMS-II. The vertical axis is scaled by the cloud depth with zero at the cloud base.

The w skewness in Fig. 2 are categorized in different ranges of cloud fraction calculated from Method I (level leg q_l) from the corresponding leg. It is seen that the large negative and positive skewness cases are both associated with cloud fractions less than 0.7 in the ASTEX cases. The cases with negative skewness are explored in Fig. 3 below showing the time series of liquid water, specific humidity, potential temperature, and vertical velocity. It is seen that all the 'extreme' skewness cases are associated with partial cloudiness, all seem to involve cumulus penetrating through the stratocumulus deck. The same is true for the extreme positive skewness cases (circled in an orange oval, time series not show). Albrecht (1981) indicated negative skewness in decaying cumulus, which is a possible explanation for the negative skewness. The results then seem to indicate different skewness from cumulus contribution depending on the stage of development of the cumulus convection. We also examined the skewness of specific humidity (not shown). Most cumulus cases show positive skewness throughout the cloud layer in ASTEX, while DYCOMS-II q skewness are largely negative in the upper cloud layer and positive below mid-cloud layer (not shown).

The latent heat and sensible heat fluxes from both experiments show similar magnitudes (Fig. 4). The mostly solid stratocumulus clouds in DYCOMS-II presents a clear increase of both fluxes with the scaled height (less so in sensible heat flux), while the ASTEX cases show much larger variation within a linearly increasing envelop. It is clear in the ASTEX cases that the largest fluxes are found in the solid cloud cover while the fractional cloudiness cases clearly have smaller fluxes (although they contribute to large magnitude in skewness), which is not the case in DYCOMS-II. We examined the cases from ASTEX that yielded the largest sensible heat and latent heat fluxes, most of them are from one flight with strong cumulus imbedded in stratocumulus. This is also the case with nearly the strongest turbulent kinetic energy.

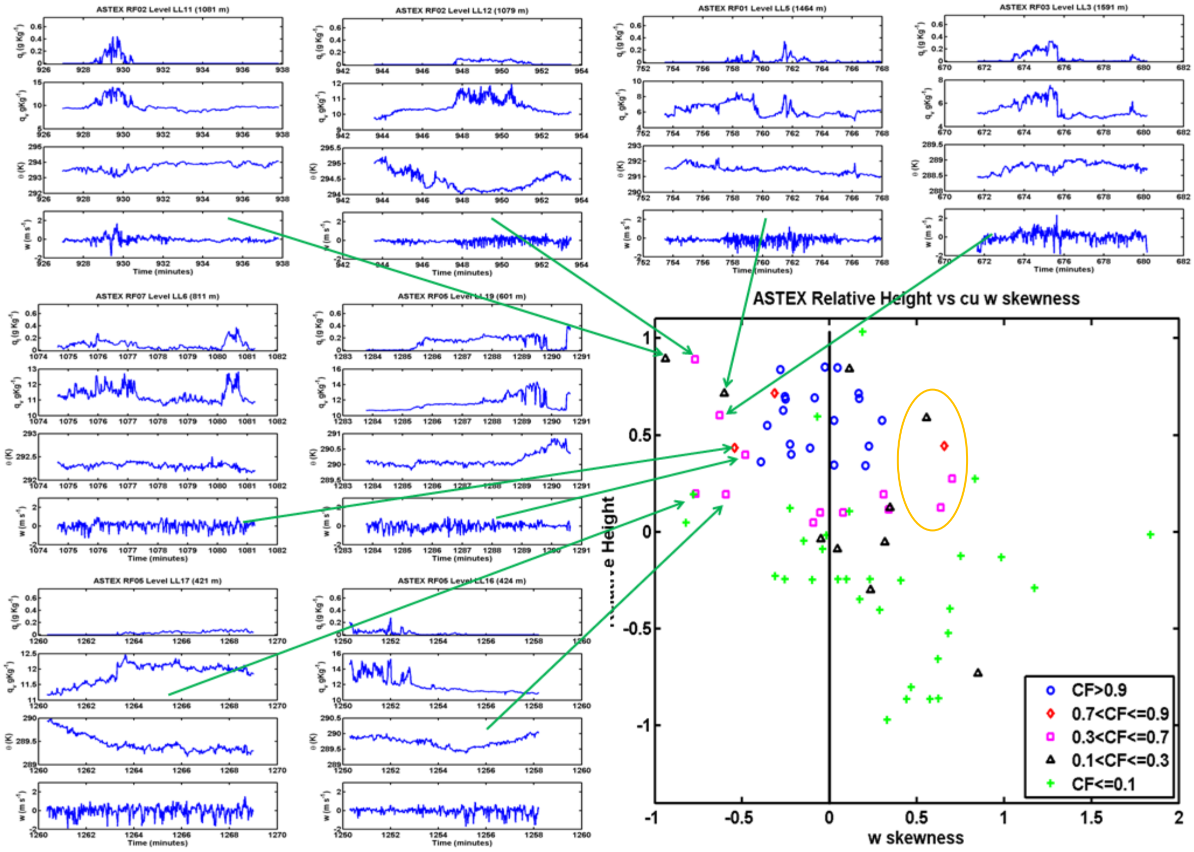


Figure 3. Effects of cumulus clouds on vertical velocity skewness.

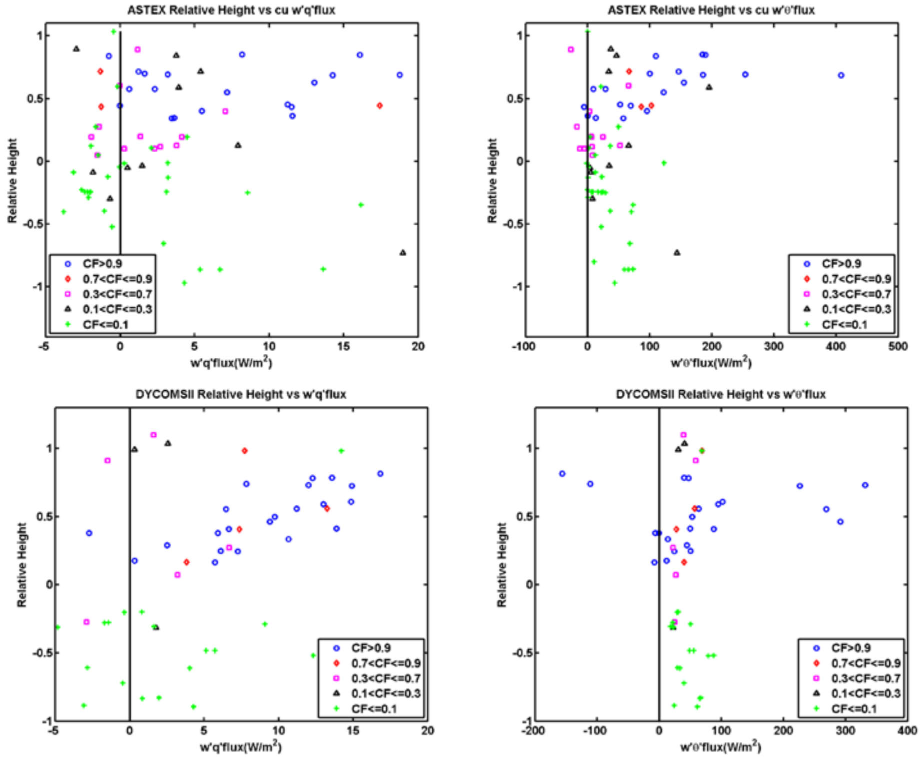


Figure 4. Sensible heat and latent heat fluxes from ASTEX (top) and DYCOMS-II (bottom)

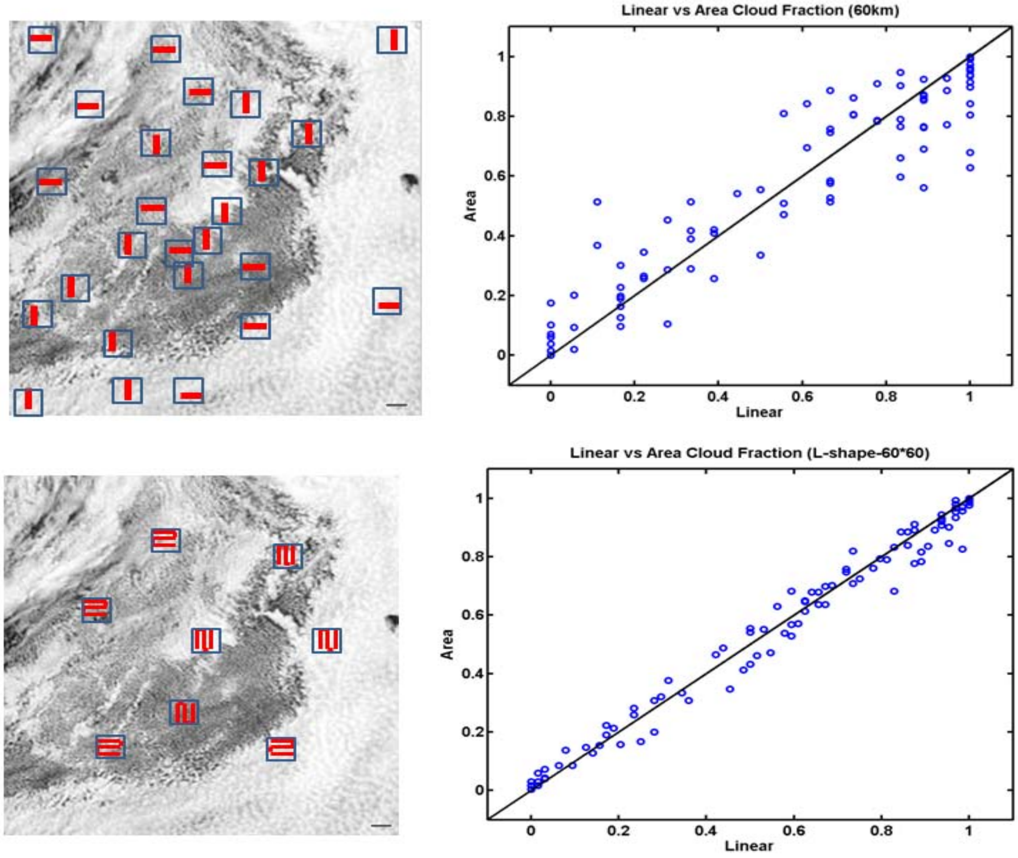


Figure 5. Illustration of linear and lawn-mowing sampling of cloud fraction (left panels) and the resultant cloud fraction calculation in comparison with cloud fraction sampled over an area of 60 km ×60 km.

Evaluating sampling strategy for improved cloud fraction measurements: Satellite cloud imageries are used to examine the appropriate sampling strategy for quantifying cloud fraction. For this purpose, we take random linear samples from the imageries and define cloud fraction based on grayscale threshold to identify clouds. Similarly, cloud fractions defined from sampling with a lawn-mowing pattern are also calculated. Figure 5 below shows illustrations of the linear and lawn-mowing samples and the resultant cloud fractions compared to cloud fractions obtained from the gray square area covering the linear or lawn-mowing sample tracks. The results of cloud fractions correspond to the cloud image showing in Fig. 5. The natural variability of the cloud fraction in this image covers the entire range of 0-1 using 60 km boxes, which is one reason of the large variability seen from previous observations. On the other hand, increasing the sampling size from linear to the lawn-mowing pattern greatly reduced the scattering as seen in Fig. 5. It is therefore essential to have long or multiple measurement legs to appropriately quantify cloud fraction, a strategy that was adopted in the measurements of UPPEF2012.

UPPEF 2012 measurements: UPPEF2012 measurements was conducted between Aug. 31-Sept 30, 2012 off the coast of Monterey California. The measurements emphasized mesoscale variability and fractional cloudiness in the region. A total of ten research flights were made for the cloud mission under this funding support, each having a duration of 3.5 to 5.3 hours. The last two flights on Sept 30 are part of Dave Emmitt's effort to study boundary layer rolls in clear condition. Table 2 below summaries all flight information.

Flight #	Date	Takeoff-Landing Time (PDT)	Flight Duration	Major Flight Pattern	Comments
RF01	8/31/2012	1207-1705	5	L-pattern	Sampled at the clear/cloud boundary, ~20-30 kts wind. No CTV.
RF02	9/4/2012	1210-1720	5.2	S-pattern	Mesoscale variability in solid cloud cover at the beginning. Broken cloud later. Multiple soundings were made. ~10 kts wind. No CTV.
RF03	9/6/2012	1228-1717	4.8	S-pattern	Thin solid/broken cloud cover; Weak wind; high SST. Had a hard time staying in cloud because the cloud layer was very thin. NO CTV.
RF04	9/7/2012	0941-1500	5.3	U-pattern	Gradual increase of cloud fraction from the coast to the west side of the U-pattern. cloud survey and turbulence from U-pattern at 100'. More clearing later in the flight. No CTV.
RF05	9/11/2012	0953-1310	5.3	U/box-pattern	Solid cloud with visible roll structure. Large clearing to the north. Some strong wind to the west in the along-wind leg. Variable surface waves and swell. No CTV still.

RF06	9/13/2012	1137-1507	3.5	long linear transect	1-hour long straight leg to the west to capture mesoscale features and broken clouds further offshore. First mission of UPPEF with CTV.
RF07	9/17/2012	1022-1537	5.3	U-pattern	Persistent solid cloud with clear mesoscale features. Cross-wind leg of U pattern is 90 km to capture mesoscale features. No CTV.
RF08	9/19/2012	1102-1617	5.3	long linear transect	Long linear transect going through cloud (near coast) to clear transition. Roll structure. CTV was functional.
RF09	9/20/2012	0910-1430	5.3	U-Pattern	Thin cloud, dissipated later on. Most of the measurements were made in clear with some thin puffy clouds. With CTV.
RF10	9/26/2010	1006-1342	3.6	Linear	UPPEF cloud mission with CTV and with TODWL installed. Maximum flight duration is 3.6 hour in this configuration. Solid to broken cloud transition from coast to further west.
RF11/RF12*	9/30/2012	0920-1636	5.8	Varied	Two flights on this day after several days of waiting for clear condition. These flights are not part of UPPEF2012 cloud missions, but are part of Dave Emmitt's research for EDMF study. Both with CTV. Wind lidar data not available for most part of the second flight due to high cabin temperature.

Table 2. Summary of UPPEF2012 flights. The last two flights (denoted with a *) are part of Dave Emmitt's project to quantify roll structure near the coast in clear air.

We are currently working on completing the flight summaries for each flight, although a draft summary for most flights were available during the measurement phase. The NPS FY13 efforts will focus on data analyses of this dataset. The NRL effort in FY13 is to calibrate the radiometers in post-mission and work on the quality-control of the radiometer dataset and the further analysis to generate measured heating/cooling rate profiles.

IMPACT/APPLICATIONS

Analyses of previous datasets provided a basis for defining uncertainties in calculating cloud fraction to assist in improved sampling strategy for new measurements to be made under this DRI. The new measurements by the CIRPAS Twin Otter under this project will be a valuable dataset to further our understanding of physical processes affecting fractional clouds and therefore for obtaining improved parameterization in fractional cloud condition in forecast models.

The radiometer measurements (NRL effort) are important to this study because the solar radiative heating and IR radiative cooling are two of the primary drivers of turbulent processes in marine stratus and in the evolution and persistence of these clouds.

RELATED PROJECTS

Related project is the ONR DRI on Unified Physical Parameterization for Extended Forecast.