EVALUATION OF PILOT ESTIMATED UPDRAFTS USING AIRCRAFT INTEGRATED METEOROLOGICAL MEASUREMENT SYSTEM (AIMMS) MEASUREMENTS

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ABSTRACT. Hygroscopic seeding operations usually acquire cloud base updraft (positive vertical wind) velocities from pilot estimates. Though useful, pilot estimates are subjective and hence potentially inconsistent from case to case and from one project to the next. The Aircraft Integrated Meteorological Measurements System (AIMMS) provides an objective measurement of updrafts. The objective is to use AIMMS measurements to evaluate pilot estimates of updrafts encountered while flying under developing cumulus clouds. The analysis compares the pilot estimated maximum updraft to statistical distribution parameters of 1 Hz AIMMS measurements. Specifically, the five minute distribution mean and 95th percentile values are compared to the range of maximum sustained updrafts that the pilot estimates. Six cases with mean updrafts in the range of 0.6 to 1.4 m s^{-1} (120 to 275 ft min^{-1}) were obtained during the Polarimetric Cloud Analysis and Seeding Test 2012 (POLCAST-2012) field project. Three cases show pilot estimates agreeing with the mean updraft AIMMS velocities; however, the pilot estimates are high for the remaining three cases. For five cases, the pilot estimates are below the 95th percentile range of AIMMS 1.0 Hz measurements. The POLCAST-2012 cases demonstrate the difficulty for pilots to discern the difference between a 1.0 m s^{-1} (200 ft min^{-1}) and a 2.0 m s^{-1} (400 ft min^{-1}) updraft.

1. INTRODUCTION

Updraft (positive vertical wind) velocity is an important parameter for hygroscopic seeding and cloud-physics research (Snider et al. 2003; Gerber and Frick 2012). One method of conducting hygroscopic seeding involves burning wing mounted flares beneath developing cumulus clouds. The burning flares produce particles greater than 1.0 μm in diameter (Bruintjes et al. 2012). Updrafts carry the super-micrometer particles into the clouds where they activate before smaller sized particles to produce larger droplets via condensational growth. The larger sized droplets increase the efficiency of the collision-coalescence process (Cooper et al. 1997). Hence, effective hygroscopic seeding requires burning flares in the updraft regions below the cloud base.

Theory indicates that updrafts of 0.5 m s^{-1} produce maximum supersaturations of approximately 0.3 %, while 2.0 m s^{-1} updrafts produce maximum supersaturations of approximately 0.6 % (Figure 7.4 of Rogers and Yau, 1986). Since there are no reliable methods for *in-situ* supersaturation measurements, the cloud base updraft velocity is typically used to infer maximum supersaturation in cumulus clouds. Without accurate maximum supersaturation values, it is problematic to obtain a high correlation between cloud base cloud condensation nuclei number concentration and cloud droplet number concentration (Delene et al., 2011).

When conducting hygroscopic seeding near the cloud base, updrafts of approximately 2.0 m s^{-1} are desirable to ensure growing clouds are being seeded. Pilot estimates are often the only means of obtaining the updraft velocity. However, pilot estimates are subjective measurements that rely on a pilot's experience and aircraft familiarity. Assessing the accuracy of the pilot estimated updrafts will enable project managers to determine if pilot estimates are sufficiently dependable; or if the expense of deploying instrumentation to measure updrafts is justifiable.

2. OBJECTIVE

The paper's objective is to evaluate the accuracy of updraft estimates made by an experienced weather modification pilot. The evaluation is done by comparing pilot estimates to the Aircraft Integrated Meteorological Measurement System (AIMMS) measurements.

3. METHODOLOGY

On days with a favorable chance of convection, an aircraft is launched from Fargo to locate seeding targets within 100 km of the Grand Forks located, University of North Dakota C-band polarimetric radar (Figure 1). When a potential target is located, the flight crew determines if conditions conform to the established seeding criteria. The Polarimetric Cloud Analysis and Seeding Test 2012 (POLCAST-2012) seeding criteria (National Center for Atmospheric Research et al., 2013) states that target clouds need to have maximum updrafts of at least 500 ft min^{-1} (2.5 m s^{-1}). Therefore, to evaluate potential targets the pilot estimates the maximum sustained updraft, while circling approximately 200-400 ft. beneath the cloud.

The pilot typically makes two to three passes beneath cloud base to determine the maximum updraft (Figure 2). The pilot will reduce the aircraft's power setting (engine thrust) in order to keep the aircraft from rising with large updrafts under the developing cloud. Reduced speed decreases the lift generated by the aircraft wings. In order to make an updraft estimate, the pilot consults the power setting, vertical speed indicator (VSI) and the airspeed indicator (ASI). The VSI indicates the aircraft's rate of climb. The VSI is connected to the static vent and uses a calibrated leak to create a pressure difference that is directly related to vertical speed. Note that VSI displays the vertical speed that occurred six to nine seconds earlier. However, VSI readings are not delayed enough to greatly affect the updraft estimates for normal operations. The airspeed indicator determines the aircraft's airspeed by measuring the difference between ram air and static air pressure.

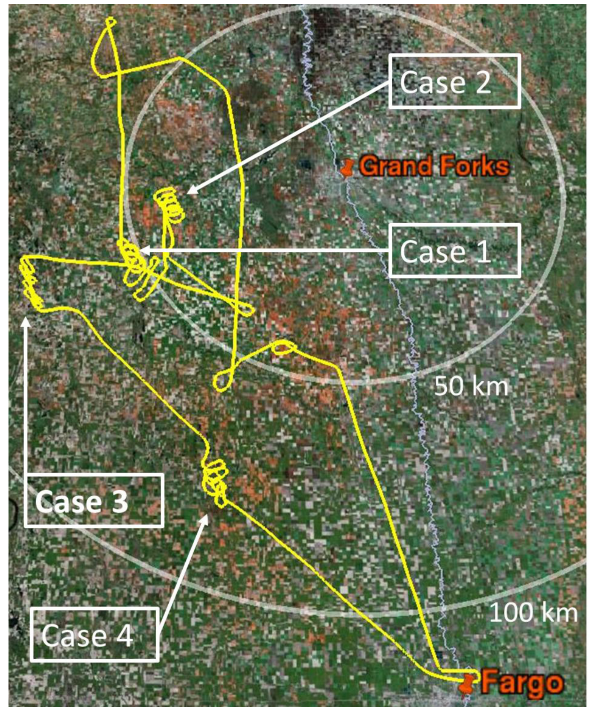

Figure 1: Flight track over a Google Earth image for the first flight conducted on 26 July 2012. Loops in the flight track occur when a target does not meet the seeding criteria, while spirals occur for confirmed target cases (white boxes). The aircraft stays under a target cloud for approximately 12.0 min after confirmation.

There are two methods a pilot can use to estimate the updraft. The first method involves maintaining a constant airspeed setting while adjusting the power to ensure level flight. The pilot infers the updraft by using a combination of the power reductions and the VSI. Power setting values for each aircraft are determined during test runs in still air. The second method involves using the ASI in combination with the VSI. The pilot keeps a constant power setting and constant altitude. The updraft is determined by monitoring increases in the airspeed or rate of climb. An increase in both the airspeed and rate of climb, indicate stronger updrafts.

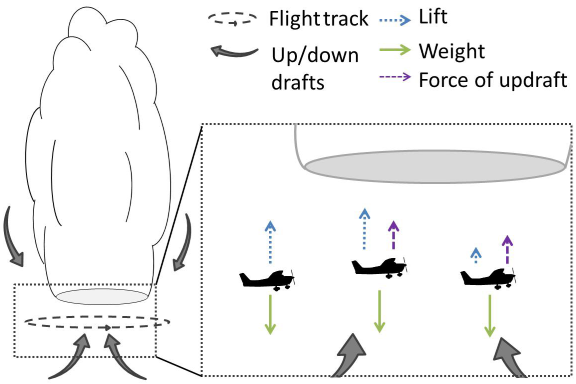

Figure 2: Illustration of an aircraft conducting hygroscopic seeding under a growing cumulus cloud. Boxed image shows the aircraft before encountering an updraft, the aircraft gaining lift as it encounters an updraft and finally returns to level flight following pilot correction.

Because it is harder to quantify updraft values due to changes in airspeed (second method), the first method is used throughout this analysis. Typically, the pilot provides a range of the maximum updrafts encountered. The range and corresponding time interval is written down in the flight scientist's log book.

4. DATA

The Polarimetric Cloud Analysis and Seeding Test 2012 (POLCAST-2012) field project was conducted from 27 June – 3 August 2012 in North Dakota. POLCAST-2012 is the fourth study sponsored by the North Dakota Atmospheric Resource Board to evaluate the effectiveness of hygroscopic seeding (Kucera et al., 2006; Delene et al., 2011). The projects have taken place every other summer, since 2006. Mr. Hans Ahlness was the pilot for all flights conducted as part of POLCAST-2012. Mr. Ahlness has 35 years of experience in conducting operational and research flights and has worked full time for Weather Modification Inc. (WMI) since 1985. While working at WMI, Mr. Ahlness has trained numerous pilots to conduct weather modification operations, including how to determine the updraft velocity for determination of valid hygroscopic seeding targets.

Aventech Research Inc. developed the AIMMS instrument mainly for aerial application; however, the instrument is also useful in atmospheric research (Beswick et al. 2008). The AIMMS instrument measures three dimensional winds from an aircraft platform. The system consists of wing top Global Positioning System (GPS) antennas, cabin rack modules and an Air Data Probe (Figure 3). The Air Data Probe is located under the wing as far out from the fuselage as possible (Figure 4). The wing tip location reduces aircraft induced airflow disturbances. The Air Data Probe provides aircraft velocity relative to the surrounding air, while the GPS/IMU provides the aircraft velocity relative to the ground. The 3-dimensional vector difference between air relative velocity and ground relative velocity is the atmospheric wind. The AIMMS data processing uses the full vector equations so that aircraft induced effects are minimized and values in turns are usable.

During the POLCAST-2012 field project, the Cessna 340 flew eleven flights and located seventeen targets. However, certification requirements delayed flying the AIMMS instrument until the last five flights. An AIMMS calibration flight was conducted on 20 July 2012 to obtain parameters that account for aircraft specific aerodynamic distortions. An AIMMS performance flight was conducted on 29 July 2012 to confirm proper probe calibration (Delene et al., 2013). A total of six comparisons were obtained during flights on 25 and 26 July 2012 (Table 1).

A Science Engineering Associates Model 300 Data Acquisition System (M300) recorded the real-time processed data stream from the Central Processing Unit (CPU) module. Additionally, all the raw AIMMS parameters were recorded by the M300 from the data Input/Output (IO) module. Post-processing and analysis was conducted by the open source Airborne Data Processing and Analysis software package (Delene 2011).

The time period for each target's inspection is identified using flight notes and validated by manually reviewing several time series plots. Statistical parameters of the 1.0 Hz AIMMS vertical velocity measurements are calculated for the first

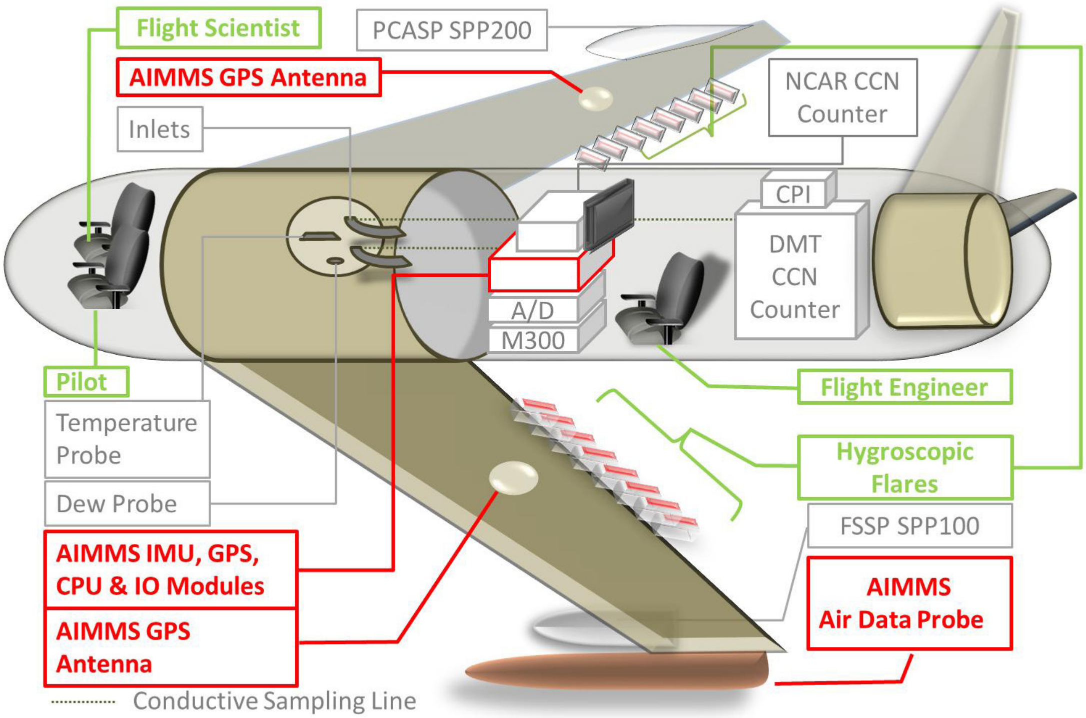

Figure 3: The setup of instruments on the Cessna 340 aircraft during the Polarimetric Cloud Analysis and Seeding Test 2012 (POLCAST-2012) field project. Red components are part of the Aircraft Integrated Meteorological Measurement System (AIMMS). Green denotes the crew and hygroscopic seeding flares. Grey indicates research instruments. The Inertial Measurement Unit (IMU), Global Positioning System (GPS), Central Processing Unit, and Input/Output (IO) modules receive data from the Air Data Probe and GPS antennas, process the data and output the data to the M300 Data Acquisition System.

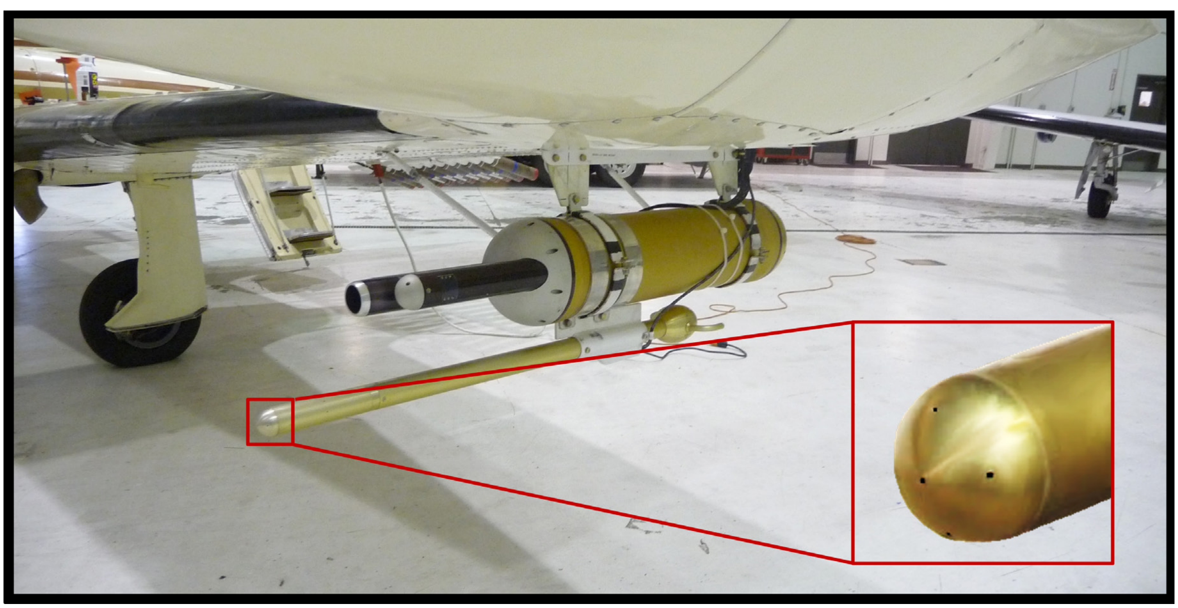

Figure 4: The Aircraft Integrated Meteorological Measurement System (AIMMS) Air Data Probe mounted under the Forward Scattering Spectrometer Probe on the left wing of the Cessna 340 aircraft. The boxed image is a magnified view of the five hole pressure-measurement head.

five minutes of the cloud base inspection. If the inspection is less than five minutes, data under cloud base is still available as the aircraft spends approximately twelve minutes sampling or seeding a confirmed target.

Figure 5 shows an example of the 1.0 Hz AIMMS vertical winds measurements while flying below cloud base. Depicted are periods of both updrafts and downdrafts. Changes in vertical wind direction occur over a relatively short time period. The longest continuous updrafts occurred from 67,716 to 67,733 sfm (17 seconds). The average air speed is 66.0 m s^{-1} in this updraft, which gives an updraft width of 1,122 m (0.70 miles).

The direction of positive vertical winds depends on the coordinate system and is not necessarily upward. Therefore, we checked the updraft direction by comparing the vertical wind and aircraft vertical velocity. During takeoff, both measurements remained in phase and the positive wind increased as the aircraft altitude increased. Hence, confirming that values greater than 0.0 m s^{-1} represent updraft winds, while values below 0.0 m s^{-1} represent downdrafts.

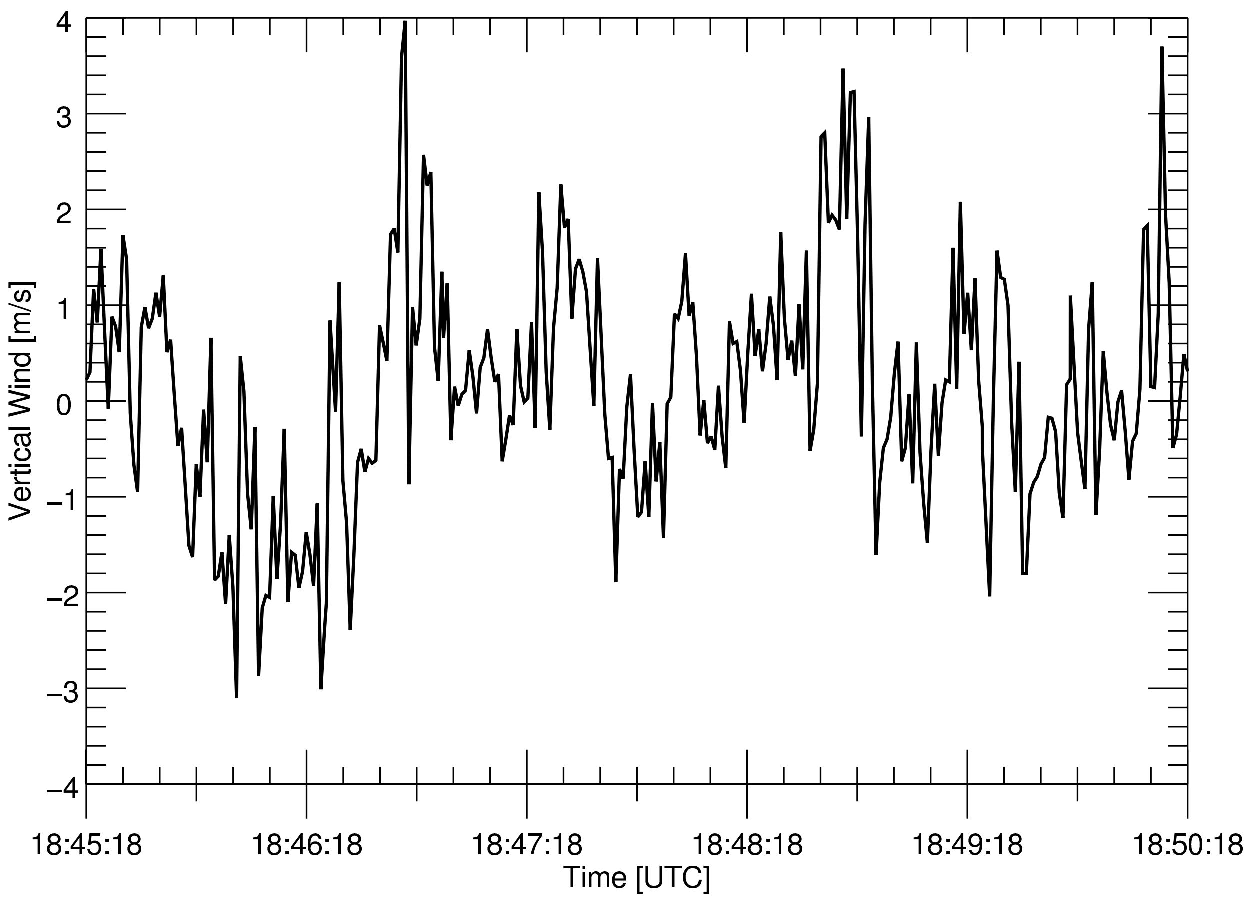

Figure 5: Vertical wind velocity measured at a frequency of 1.0 Hz by the Aircraft Integrated Meteorological Measurement System (AIMMS) during the first flight on 26 July 2012. Time period is the first five minutes (67,518-67,818 seconds from midnight (sfm)) of sampling for target case 1.

5. ANALYSIS AND DISCUSSION

Table 1 shows statistics of unfiltered (total vertical wind) and filtered (positive vertical wind) measurements. The unfiltered vertical winds consistently have pilot estimates that are higher than AIMMS's statistical parameters. All the 75th percentile AIMMS unfiltered measurements have updrafts below 1.0 m s^{-1}, while the pilot estimates range from 1.0 to 2.0 m s^{-1} (Table 1). Unfiltered winds do not realistically represent maximum sustained updrafts since large downdraft regions are also included (e.g. Figure 5). Therefore, calculating statistics using total vertical wind measurements is not a representation of what the pilot is estimating.

A filter excluding all 1.0 Hz downward measurements (values less than 0.0 m s^{-1}) is more representative of the pilot's maximum updraft estimate. Figure 6 shows that three 1.0 m s^{-1} pilot estimates agree with the AIMMS means within measurement uncertainty. However, high pilot estimates (greater than 1.5 m s^{-1}) do not agree with the AIMMS means. Instead the high pilot estimates correspond with AIMMS mean updrafts of only 1.0 m s^{-1} and lower. While uncertainty bars for the pilot updrafts indicate that there are two distinct groups (little overlap), the AIMMS standard deviations overlap for all six cases, indicating no discernible difference. The agreement of low pilot estimates and disparity of higher estimates indicates that the pilot is unable to distinguish the difference between 1.0 m s^{-1} and a 2.0 m s^{-1} updrafts. Figure 6 shows that a single AIMMS measurement around 1.0 m s^{-1} correlates with four pilot estimates ranging from 1.0 to 2.0 m s^{-1} (~200 to 400 ft min^{-1}). Half the time the pilot is able to estimate accurate velocities, while the other half the pilot over estimates the updrafts.

The 75th and 95th percentile AIMMS updraft statistics are more sensitive to peak updrafts than the mean AIMMS updraft. Comparing the 75th percentile AIMMS updraft to the pilot estimate gives a similar pattern as the mean AIMMS distribution (Table 1). AIMMS 75th percentile updraft velocity ranges from 1.0 m s^{-1} to 2.2 m s^{-1}. The

Table 1: Summary of the six cloud base cases obtained during the Polarimetric Cloud Analysis and Seeding Test 2012 (POLCAST4) field project. The flight date and number, the day's seeding target number and the Aircraft Integrated Meteorological Measurement System (AIMMS) analysis start time are given. The start time is in Universal Time as the number of seconds from midnight (sfm) on the day the flight starts. The mid-range of maximum updrafts provided by the pilot are given with the uncertainty encompassing the overall range. AIMMS measurement statistics (mean, standard deviation (STD), and percentile values) are given for each case. AIMMS statistics are based on 5 minutes of 1 Hz measurements. U denotes unfiltered (all measurements) statistics and F denotes filtered measurements where only positive vertical wind measurements are included in the statistics.

Date Number	Target Number	Time (sfm)	TAS (m s^{-1})	Pilot (m s^{-1})	Type U/F	Mean (m s^{-1})	STD (m s^{-1})	5th (m s^{-1})	25th (m s^{-1})	50th (m s^{-1})	75th (m s^{-1})	95th (m s^{-1})	Max (m s^{-1})
07/25 1	1	72,267	69.3	1.0 ±0.50	U	-0.20	1.74	-3.04	-1.16	-0.37	0.63	2.87	6.30
					F	1.40	1.30	0.11	0.41	1.05	2.17	4.37	
07/25 1	2	74,300	70.7	1.0 ±0.50	U	0.29	1.11	-1.24	-0.43	0.17	0.97	2.31	4.17
					F	1.06	0.83	0.10	0.39	0.86	1.57	2.71	
07/26 1	1	67,518	66.4	1.0 ±0.50	U	0.13	1.21	-1.89	-0.62	0.12	0.86	1.94	3.97
					F	1.00	0.82	0.11	0.38	0.79	1.43	2.67	
07/26 1	3	71,251	63.7	1.8 ±0.50	U	-0.07	1.41	-2.25	-0.73	-0.14	0.88	2.28	4.16
					F	1.18	0.84	0.09	0.53	1.02	1.83	2.66	
07/26 1	4	72,893	64.7	1.8 ±0.50	U	-0.18	0.84	-1.50	-0.73	-0.24	0.24	1.32	2.64
					F	0.66	0.55	0.04	0.18	0.54	1.02	1.62	
07/26 2	5	78,960	61.1	2.0 ±0.50	U	-0.14	1.19	-1.56	-0.87	-0.38	0.26	2.26	5.09
					F	1.09	1.19	0.06	0.26	0.67	1.39	3.78	

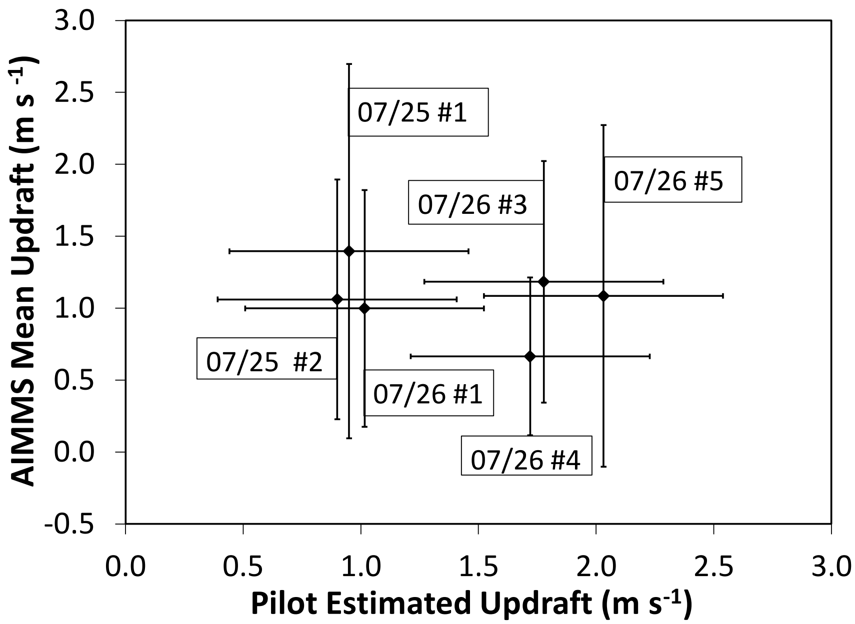

Figure 6: Pilot estimated maximum updrafts versus the mean Aircraft Integrated Meteorological Measurement System (AIMMS) updraft (only positive vertical winds). Horizontal bars denote the ±0.50 m s^{-1} uncertainty in the pilot estimate . Vertical bars indicate one standard deviation for the 1.0 Hz AIMMS measurements. Boxes give the date and corresponding case number of each sample. Three points (07/25 case 1 and 2; and 07/26 case 4) have been offset for visual clarity of the error bars.

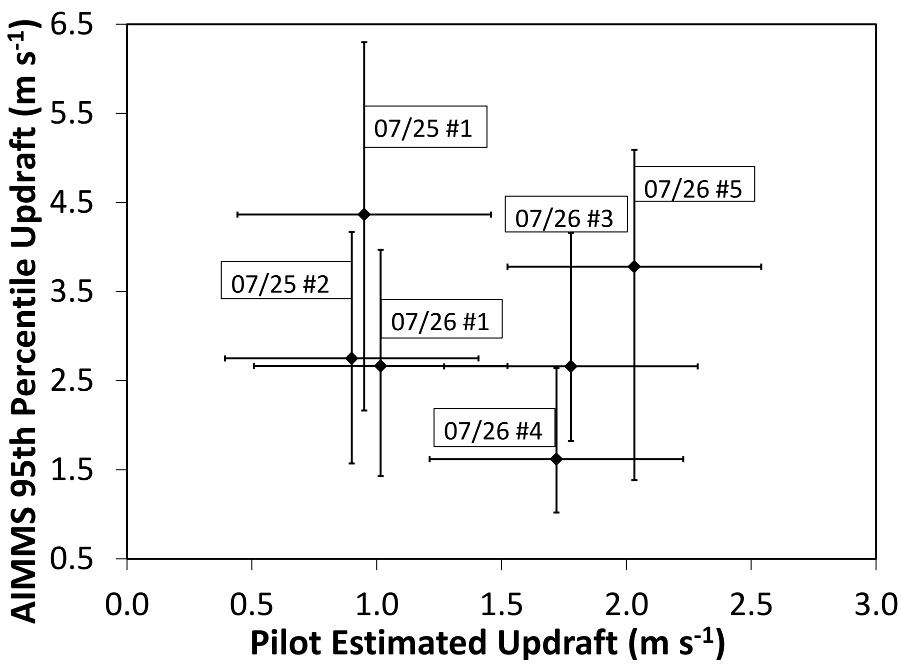

Figure 7: Pilot estimated updraft versus the 95th percentile Aircraft Integrated Meteorological Measurement System (AIMMS) updraft. Horizontal bars denote the ±0.50 m s^{-1} uncertainty in the pilot estimate . The top of the vertical bars denote the maximum value, while the bottom denotes the 75th percentile for the 1.0 Hz AIMMS measurements. Boxes give the date and corresponding case number of each sample. Three points (07/25 case 1 and 2; and 07/26 case 4) have been offset for visual clarity of the error bars.

corresponding pilot updrafts range from 1.0 m s^{-1} to 2.0 m s^{-1} (200-400 ft min^{-1}). Again the pilot updrafts are in two groupings (3 closer to 1.0 m s^{-1} and the remaining closer to 2.0 m s^{-1}). Table 1 shows the first three pilot estimates comparing low against the AIMMS measurements. The fourth case shows agreement, however the final two are higher than the AIMMS values.

The 95th percentile AIMMS statistics (Figure 7) shows even less agreement with pilot estimates than the 75th percentile AIMMS updraft. The 95th percentile comparisons show low pilot estimates with only one pilot estimate in the range of the AIMMS 95th percentile updraft. The lack of agreement with the 95th percentile updraft indicates the pilot is unable to identify the stronger gusts detected by the AIMMS.

The pilot's difficulty in gauging marginal differences of updrafts and detecting peak gusts may be due to the high level of activity during target assessments. While estimating updrafts the pilot is making tight turns to remain under the area of the cloud. The pilot must also correct for level flight due to updrafts. While conducting different maneuvers the pilot will divide his gaze between the flight instruments and outside the cockpit. The aircraft also encounters vertical winds that affect the level flight of the aircraft. The pilot must correct for deviations caused by up and downdrafts.

6. CONCLUSION AND FUTURE WORK

The evaluation of the six cases obtained during POLCAST-2012 shows that the pilot estimate agrees with the mean AIMMS updrafts (positive vertical winds only) of approximately 1.0 m s^{-1} for three cases; however, the pilot estimates are high for the remaining three cases. Comparison of the AIMMS 75th and 95th percentiles updrafts to the pilot estimates show that the pilot estimates are low. For five cases, the pilot estimates are below the 95th percentile value.

The POLCAST-2012 cases demonstrate the difficulty pilots have in knowing the difference between a 1.0 and 2.0 m s^{-1} maximum updraft. To be able to discern this important difference, cloud seeding projects would need to use an instrument similar to the AIMMS. Data acquisition systems are able to calculate five minute running means and 95th percentile values in real time; hence, AIMMS measurements can be used during flights to access the potential target's maximum updraft. Using an instrument based system would also remove the subjectivity out of the process. The pilot may subconsciously want to find targets matching the seeding criteria and hence increase some of their assessments.

Obtaining more cases during future project's would strengthen these conclusions. Additionally, it would be interesting to extend the analysis to cases where potential targets were not selected as target cases because of weak updrafts. To make use of all these targets, the AIMMS averaging time would have to be reduced since typically it does not require five minutes to determine that there are no strong updrafts present. Possibly a dynamically adjusted time interval should be used. For example, a running mean updraft could be computed for all time periods with continuous updrafts longer than 5.0 seconds. The five strongest updrafts, along with their period, over the last 3 minutes could be displayed in real time and used as an objective seeding candidate evaluation criteria.

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