NASA-CR-190637

SDSMT/IAS/R-92/08 August 1992

RESEARCH RELATIVE TO WEATHER RADAR MEASUREMENT TECHNIQUES

By: Paul L. Smith, Principal Investigator

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Final Technical Report on Grant No. NAG 5-1477
'od Covered: 15 November 1990 - 14 August 1992

GODDARD
GRANT
IN-47-CR
115105
P.15

Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
501 E. St. Joseph Street
Rapid City, South Dakota 57701-3995

SDSMT/IAS/R-92/08 August 1992

RESEARCH RELATIVE TO WEATHER RADAR MEASUREMENT TECHNIQUES

By: Paul L. Smith, Principal Investigator

Prepared for:

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, MD 20771

Final Technical Report on Grant No. NAG 5-1477
Period Covered: 15 November 1990 - 14 August 1992

Institute of Atmospheric Sciences

South Dakota School of Mines and Technology

501 E. St. Joseph Street

Rapid City, South Dakota 57701-3995

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

This is the final technical report on NASA Grant No. NAG 5-1477, involving research relative to weather radar measurement techniques. This grant provided for some investigations related to measurement techniques applicable to meteorological radar systems in Thailand. Quality data are needed from those systems to support the Tropical Rainfall Measuring Mission (TRMM) and other scientific investigations. A major part of the activity under the grant was devoted to instruction and discussion with Thai radar engineers, technicians, and meteorologists concerning the basic principles of radar meteorology and applications to specific problems, including measurement of rainfall and detection of wind shear/microburst hazards. Weather radar calibration techniques were also considered during this project. Most of the activity took place during two visits to Thailand, in December 1990 and February 1992.

2. SUMMARY OF PROJECT ACTIVITIES

2.1 Details of Visits to Thailand

Each trip was about two weeks in duration, with most of the time being spent at the Thai Meteorological Department (TMD) facilities near the Phuket airport. Visits to TMD headquarters and the facilities of the Royal Rainmaking Research and Development Institute in Bangkok also occurred during the second trip.

For the first visit, the principal investigator departed from Rapid City on 5 December 1990 and arrived in Phuket on 8 December. Visits to the local weather radar site and instruction/discussion sessions occurred over the period 9-15 December. Dr. Daniel Rosenfeld of the Hebrew University of Jerusalem and Mr. Curt Hartzell of the U.S. Bureau of Reclamation also participated in those sessions. Return travel to the U.S. took place on 17-18 December.

For the second visit, the principal investigator departed from Rapid City on 28 January 1992 and arrived in Bangkok in the early morning hours on 31 January. He and Dr. Rosenfeld presented a seminar on operating strategies for meteorological radars to officials of the Thai Meteorological Department on the morning of 3 February. Travel to Phuket occurred on the afternoon of 3 February, and visits to the local radar site and instruction/discussion sessions took place over the period 4-12 February. Mr. Hartzell again participated in the early parts of this visit, and Dr. Rosenfeld was involved over almost the whole period. The return trip to Bangkok, and a visit to the Royal Rainmaking Research and Development Institute, occurred on 13 February, and the return trip to the U.S. took place on 14 February.

2.2 Facilities at Phuket

The weather radar at Phuket is an Enterprise Electronics Corporation (EEC) DWSR-88S S-band Doppler system with the following principal characteristics:

Peak transmitted power	500 kW
Antenna diameter	6.1 m (beamwidth approximately 1.25°)
Pulse duration	2 μs (reflectivity); 0.8 μs (velocity)
Pulse repetition frequencies	250 s^{-1} (reflectivity); 625/935 s^{-1} (velocity)

The antenna and transmitter/receiver units are located on a hilltop a few kilometers away from the Phuket airport. An S-band airport-surveillance-type radar (ASR) with similar power output is located only 50 m away from the weather radar installation. This is a dual frequency/dual feed system which would be expected to cause some interference with the operation of the weather radar system.

The weather radar operator consoles are located in a tower room a few kilometers away, adjacent to the Phuket airport, with the radar data being sent by microwave relay from the antenna location to the operator console. Most of the signal processing takes place at the radar site proper, and only the products are remoted down to the console. Thus one cannot view the actual radar signals themselves at the airport workstation. The data processing there occurs on MicroVAX computers using the EEC-furnished Interactive Radar Information System (IRIS) software.

There is a classroom-type facility (which was still under construction at the time of the first visit) in a building adjacent to the tower housing the radar operator consoles. The lecture/discussion sessions were held in this room. During the first visit, there was no provision for darkening the room to permit showing of 35-mm slides. The physical working arrangements were much improved during the second visit, and we were also granted freer access to the innards of the radar system for calibration measurements.

A printed monograph containing the basic background materials for the presentations and discussions was distributed to all participants. Appendix A contains a copy of the cover page of this document. The copies of the monograph arrived late during the first visit, which complicated the proceedings to some extent. Also, some copies of a supplemental document containing additional material on radar calibration methods and rainfall measurement techniques were distributed during the second visit.

2.3 Specific Activities and Findings

a. Group sessions: During the first visit, five formal sessions with the Thai personnel were conducted on a lecture/discussion basis. About 25 people participated in all or part of these sessions. The topics for the sessions were as follows:

1. Radar Fundamentals
2. Radar Equations
3. Doppler Principles
4. Z-R Relationships and Rainfall Measurements
5. Radar System Calibrations and Echo Pattern Analysis

Dr. Rosenfeld conducted a similar number of sessions dealing with cloud and precipitation physics, storm structure, echo pattern interpretation, and rainfall measurements.

The level of understanding of the discussions among the various Thai personnel seemed to be quite uneven. This was probably due to a combination of factors, including some difficulties with the English language as well as the problem of dealing with a mixture of meteorologists, radar engineers, and technicians in a single group.

During the second visit, six formal half-day sessions with the Thai scientists, engineers, and technicians were again conducted on a lecture/discussion basis. About 33 people, including several who had participated during the earlier visit, were present for much of these sessions. Topics for the sessions were generally the same, but the coverage was broadened, additional details were introduced, and radar system calibration issues were covered in much greater depth. Dr. Rosenfeld again conducted a similar number of sessions on topics including cloud and precipitation physics, storm structure, echo pattern interpretation, and rainfall measurement. As this was the second time through much of this material for several of the participants, the level of understanding appeared to be much enhanced. The presence of three men who had recently completed M.S. programs at U.S. universities was no doubt beneficial in this regard.

b. **Workshop sessions in radar operations room:** It was intended to review some archived radar data as a means of illustrating some of the points under discussion. The radar data display system at Phuket includes a playback capability, but its operation is rather slow. Therefore, it was important to set up in advance some example cases for examination during the workshop sessions. An attempt was made to do this during the first visit, but the limited time available hampered the effectiveness of this approach. Moreover, little locally-recorded data was available for the purpose; fortunately, a good set of evening storms occurred during the visit to provide additional data for discussion. Much of the example data available had been collected by the University of North Dakota radar at Huntsville, Alabama; the recorded data included examples of a microburst and second-trip echoes, which were quite useful. The presence of some anomalous-propagation cases in the examples available for illustration would have been helpful. The radar operations room was small and could only hold about half the group at one time, so repeat sessions had to be held to accommodate everyone.

During the second visit, Dr. Rosenfeld used the data playback capability to recall the recorded radar data from a small squall line which we had observed during the previous visit. The data were still resident in the computer system, and with some effort could be recalled for the purposes of this demonstration. The observations illustrated several of the basic principles of echo pattern interpretation that were discussed in the group sessions.

During the first visit, the solar microwave signal was visible on some of the RHI displays; this was useful because it gave a direct indication of the operation of the range-normalization function. It was also possible to make at least a rough estimate of the antenna beamwidth from looking at the displayed solar signal. In addition, this observation suggested the possibility of using the solar signal for antenna orientation checks, and perhaps even for antenna gain measurement.

During the second visit, we found the ANTENNA and A-SCOPE utilities in the IRIS system to function quite satisfactorily for conducting solar scans to check the orientation of the weather radar antenna. Such scans were carried out on the afternoon of 7 February and the morning of 11 February. Mr. Hartzell supplied a computer program for determining the true solar azimuth and elevation angles. Results of an analysis of the solar observations showed that the antenna angle indications coming from the Phuket weather radar were in error by about +10° in azimuth and +1° in elevation. The table in Appendix B provides a synopsis of the observations leading to this conclusion. We were not successful in obtaining permission to take the necessary steps to remove the errors from the indicated angles, but hopefully this was later taken care of by local personnel.

Usually a PPI Doppler velocity display tends to show weaker echoes than are visible on the corresponding reflectivity display, because velocity patterns can often be recognized even in "clear-air" situations when the echoes are otherwise too weak to be identified. This occurs largely because of the increase in sensitivity associated with the Doppler processing of the echoes (Smith, 1986). In the Phuket radar, there seemed to be some threshold limit in effect that screened out most of this "clear-air-type" echo so that it did not show up on the velocity display. This is probably an adjustable threshold in the radar system or in the software, but we did not succeed in pinpointing the source of this threshold or modifying the system to get rid of it during the visits. It is also possible that some kind of radar system coherence problem may be contributing to this difficulty.

c. **Radar site activities:** During the first trip, the visit to the radar site itself was interesting but somewhat nonproductive. Access to even a simple A-scope display could not be obtained at the site because of the Thais' reluctance to do anything in the face of the perceived warranty limitations in effect. Thus it was not practical to review the radar calibration procedures in any detail.

During the second trip, visits to the radar site were much more productive. We were allowed to conduct several basic radar calibration exercises, being limited mainly by the test equipment available. Table 1 lists the equipment needed for a reasonably complete set of calibration measurements; however, not all of the equipment listed turned out to be available in the field at Phuket. Also, work inside the radome at Phuket is not possible unless the neighboring ASR can be shut down for the time period required. We could not arrange to have the ASR turned off to permit such work inside the radome. Communications from the radar site to the operator console were quite good.

Smith (1977) contains an overview of most of the necessary calibration procedures. Some difficulties arose in trying to adapt those procedures to the radar in Thailand. For example, the IRIS system had to be incorporated into the methodology; this turned out to be fairly successful. The hilltop location presents a difficult challenge to use of the standard-gain-horn or calibration-sphere methods for measuring antenna gain, and the solar alternative would appear to be most promising. However, the suitability of the DWSR-88S system configuration for solar antenna gain measurements is uncertain.

We were able to conduct measurements of the transmitted power, and noticed that the peak power output appeared to be somewhat below the nominal value (but not enough to be of concern). The lack of a Type N barrel adapter made it impossible to check the test cables to be sure that the loss values were correct. No frequency meter was available for determining the transmitted frequency. For the linear receiver, the signal-generator test indicated about a 30 dB dynamic range, which is quite reasonable. The ZAUTO utility worked quite well for calibration of the logarithmic receiver, although the system configuration was such that we could not drive it all the way to the saturation point. Apparently, this was the first time that such a calibration had been made on the system at Phuket; the operators in charge were willing to incorporate the new calibration data into their operational routine. A check of the VSWR on the antenna showed that to be satisfactory. No test equipment was available for determining the antenna gain, or for examining the duration and shape of the transmitted pulse.

During the first visit, there was some discussion of a receiver problem which was leading to periodic dropouts of the Doppler velocity data. The problem was evidently related to the gating of samples of the transmitted pulse for the purpose of locking the STALO. It may be that the locking

TABLE 1

Test Equipment Needed for Radar System Calibration

---

a. Instruments

1) Microwave power meter with power sensor
2) Frequency meter or counter
3) Microwave signal generator
4) Oscilloscope
5) Coaxial attenuator set (3/6/10/20 dB)
6) Crystal detector
7) Multimeter

b. Cables and Connectors

1) RF cable (RG-214, RG-9 or equivalent) about 1.5 - 2 m long with Type N (M) connectors each end
2) Type N barrel adapter (F/F)
3) Several IF cables 1.5 - 2 m long, with BNC M connectors each end. Cable impedance should match the radar system video output impedance
4) Miscellaneous BNC connectors (T's, F/F adapter, etc.)
5) BNC termination matched to the video output impedance

c. Other Items

a) A small compass
b) A plumb line that can be hung over the antenna
c) A gunner's quadrant, or equivalent clinometer which can be clamped onto the antenna support structure
d) A computer program to give sun position in horizon coordinates (azimuth, elevation)
e) A digital clock or watch that can be set to UTC (via WWV radio receiver, or whatever)

d. Also Desirable

a) An S-band standard-gain horn with waveguide-to-coax adapter
b) A small spirit level
c) Portable radios of some kind for two-way communication over distances of a few kilometers

pulse, which is only available for the 0.8 μs of the transmitted pulse in the Doppler mode, is not adequate for discriminator operation. The problem could also be related to difficulties with the AGC applied to the linear receiver for the Doppler processing of the echoes. Without suitable test equipment and extensive time to troubleshoot the problem, it could not be definitely resolved. However, it does point to the possibility of a general coherency problem.

d. Other comments: The presence of the ASR radar so near the weather radar site raises concerns, because at those power levels the filter/limiter arrangement in the weather radar is not likely to provide adequate receiver system protection. Synchronization of the transmitted pulses might be possible, but the radar PRF's are not well matched (the ASR has a nominal 880 s^{-1} PRF, which does not match any of the standard weather radar PRF's noted above). However, no conspicuous indications of a significant problem were present in the products displayed at the operator's consoles.

Sea clutter in some of the recorded data had managed to pass through the clutter filter because of the fact that it had non-zero Doppler.

REFERENCES

Smith, P. L., Jr., 1977: *Evaluation of Miles City SWR-75 Weather Radar.* Report 77-1, Institute of Atmospheric Sciences, S.D. School of Mines and Technology, Rapid City, SD. 55 pp.

Smith, P. L., 1986: On the sensitivity of weather radars. *J. Atmos. Oceanic Tech.*, 3, 704-713.

APPENDIX A

NASA

National Aeronautics and
Space Administration

Fundamentals of Weather Radar

Part I and II

Paul L. Smith
South Dakota School of Mines and Technology

APPENDIX B

STATION Phuket | LATITUDE 8° 8' 4" N | LONGITUDE 98° 19'46" E | DATE 7 Feb 92/11 Feb

LOCAL TIME A	GUNNER'S QUADRANT B (Mils)	GUNNER'S QUADRANT C (Deg)	SOLAR ELEV D	BORESIGHT ERROR E = C-D	ELEV DIAL F	EL DIAL ERROR G = F-D	AZ IND H	SOLAR AZ I	AZ OFFSET J = H-I
16:59:08	(7 Feb)		21.94		22.9	0.96	259.9	249.76	10.14
17:06:38			20.20		21.2	1.00	260.2	250.27	9.93
17:09:55			19.43		20.6	1.17	260.2	250.51	9.69
17:11:25			19.08		20.2	1.12	260.2	250.58	9.62
:13:50			18.52		19.6	1.08	260.7	250.73	9.97
:15:35			18.11		19.2	1.09	260.7	250.84	9.86
18:30			17.43		18.6	1.17	261.0	251.02	9.98
19:35			17.17		18.5	1.33	261.0	251.09	9.91
21:30			16.72		17.8	1.08	261.3	251.20	10.10
22:40			16.45		17.7	1.25	261.3	251.37	9.93
07:14:59	(11 Feb)		6.07		7.21	1.14	115.58	105.34	10.24
16:20			6.39		7.65	1.26	115.58	105.40	10.18
17:37			6.69		7.82	1.13	115.75	105.46	10.29
18:40			6.94		8.00	1.06	115.75	105.50	10.25
19:37			7.17		8.17	1.00	116.02	105.54	10.48
53:51			15.30		16.26	1.04	117.60	107.22	10.38
55:18			15.72		16.60	0.88	117.77	107.32	10.45
56:42			15.98		17.06	1.08	117.77	107.38	10.39
57:50			16.24		17.23	0.99	117.95	107.45	10.50
	PLUMB G.Q.			SUM AVG S.D.		SUM (West) AVG 1.125 S.D. 0.11	(East) 1.064 0.11		SUM (West)\(East) AVG 9.91 10.33 S.D. 0.16 0.11