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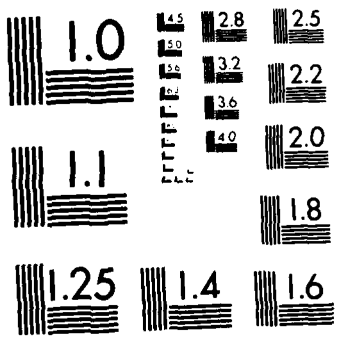

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFOSR-TR- 86-0880	2. GOVT ACCESSION NO	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): MESOSCALE SEVERE WEATHER DEVELOPMENT UNDER OROGRAPHIC INFLUENCES		5. TYPE OF REPORT & PERIOD COVERED: ~~Annual Progress Report~~ Final 1 May 1985 - 30 April 1986
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Elmar R. Reiter, James F. Bresch, Marjorie A. Klitch, Bruce C. Macdonald and John D. Sneaffer		8. CONTRACT OR GRANT NUMBER(s): F49620-85-C-0077 DEF
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Research Institute of Colorado (C/O Colorado State University) Fort Collins, CO 80523 NC		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2310/A1
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Office of Scientific Research Bolling Air Force Base Washington, D.C. 20332		12. REPORT DATE: July 1986
		13. NUMBER OF PAGES: 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Air Force Office of Scientific Research Bolling Air Force Base Washington, D.C. 20332		15. SECURITY CLASS. (of this report): Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Severe weather development; surface energy fluxes, mesoscale numerical modeling, Atmospheric convection, ...

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results from the first year of a three year effort investigating mesoscale severe weather development under orographic influences are described. The overall goals of the project are to 1) examine the role of topography in the development of convective systems and 2) assess the orographic influences on cold season severe weather, such as blizzards, lee cyclogenesis, etc. Four approaches were taken to attain these goals: 1) Implementation of a field measurement program, 2) diagnostic studies of energy fluxes during various seasons, 3) numerical simulation of severe weather development, and 4) evaluation of (continued)

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AFOSR-TR- 86-0880

MESOSCALE SEVERE WEATHER DEVELOPMENT

UNDER OROGRAPHIC INFLUENCES

Annual Progress Report
U.S. Air Force Office of Scientific Research
Contract No. F49620-85-C-0077 DEF

Work Conducted Between 1 May 1985 and
30 April 1986

by

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July 1986

ABSTRACT

Results from the first year of a three year effort investigating mesoscale severe weather development under orographic influences are described. The overall goals of the project are to 1) examine the role of topography in the development of convective systems and 2) assess the orographic influences on cold season severe weather, such as blizzards, lee cyclogenesis, etc. Four approaches were taken to attain these goals: 1) Implementation of a field measurement program, 2) diagnostic studies of energy fluxes during various seasons, 3) numerical simulation of severe weather developments, and 4) evaluation of model sensitivity to various physical processes. As described in the report, progress has been made on all four of these fronts.

1. Introduction.

Our original proposal was submitted through the Research Institute of Colorado whose functions, in the meantime, have been taken over by Colorado State University. The present report covers our research activities during the first of three years of performance and spans the period from May 1, 1985 through April 30, 1986.

The research goals outlined in our original proposal were twofold:

(A) A study of the role of topography in the development of mesoscale convective systems (MCSs) during summer over, and downwind of, the Rocky Mountains and the Tibetan Plateau.

(B) Assessment of orographic effects on rapid, severe weather development during seasons other than summer (such as lee cyclogenesis, heavy precipitation, blizzard conditions, high winds, etc.).

These two goals are to be attained along four simultaneous approaches:

(1) A field measurement program, to be carried out in the Rocky Mountains and in Tibet, to measure surface energy fluxes in complex terrain.

(2) A diagnostic study to evaluate the effects of such energy fluxes on the development of weather systems during different seasons.

(3) Numerical simulation of such weather developments, using a presently existing, high-speed prediction model. This model

will undergo several improvements.

(4) Evaluation of the sensitivity of the model forecast to various dynamic and thermodynamic processes. The trade-offs between model accuracy and model speed for possible battlefield condition simulation will be assessed.

This report summarizes the progress in each of these tasks and approaches. The work effort is briefly described, preliminary results are given, and ongoing and future work is discussed for each task. Considerable progress has been made in each of the first three efforts, and we are looking forward to continuing work on these tasks, as well as initiating work on model sensitivity studies during the upcoming year.

2. Research Progress.

This report contains only a synopsis of past, ongoing, and future work. Detailed results are available in published reports or in more preliminary documents, which are readily available from the research group.

2.1. Field Measurement Programs.

2.1.1. Rocky Mountain Peaks Experiment (ROMPEX-85).

During July/August 1985 we organized an intensive meteorological data collection program, at 20 mountain peak locations between southern Wyoming and northern New Mexico, with emphasis given to the Continental Divide and Western Slope regions of Colorado. Eight of these stations were erected by CSU, using equipment purchased in part from a previous USAFOSR Grant (Grant No. 82-0162). Four of these stations were capable of measuring complete surface heat and energy budgets. In addition, 2 stations were instrumented with equipment made available by the U.S. Forest Service, 5 stations were equipped and serviced by the Los Alamos National Laboratory, 3 stations belonged to the PROFS network, and one station was attached to a separate project at Colorado State University.

The instruments, including the microprocessors which integrated data over 15-minute intervals, worked very well and data recovery was excellent. Most of the data from these 20 stations have been combined into a "level 1" archive by Capt. Richard C. Fleming, USAF. In collaboration with the Los Alamos National Laboratory, we are in the process of constructing a "level 2" archive which will also contain synoptic information from upper-air and valley stations, radar data, satellite data and lightning-strike data for appropriate locations and times.

Preliminary analyses already show that this mountain-peak network is able to resolve mesoscale flow patterns associated with the buildup and collapse of mesoscale convective systems over the Continental Divide region. Since humidity data were also collected at most of our stations, the outflow of cold air from thunderstorm systems can be traced spatially through our network.

Capt. R. Fleming (1986) has given a preliminary description of the experimental layout of ROMPEX. Mr. James Bossert, and Mr. John Sheaffer, together with the P.I., are engaged in further, detailed analysis work which will resume after our return from a field experiment in Tibet in the summer 1986.

2.1.2. Tibetan Plateau Meteorological Experiment (TIPMEX-86).

We have spent considerable time in preparing a field measurement program in Tibet for June and July 1986. Departure of our team (P.I.; Mr. John Sheaffer, CSU; Mr. James Bossert, CSU; Dr. Robert McBeth, NCAR; Dr. Eric Smith, FSU; Dr. Greg Stone, Los Alamos National Laboratory; Dr. Merlin Otteman, M.D., Fort Collins) took place on May 27, 1986.

We will deploy two fully equipped micrometeorological, radiation and energy budget stations in Tibet, one near Lhasa (ca. 3500 m), the other near Nagqu (ca. 4500m in the Transhimalayas). Data from these two stations, and also from two Airsonde stations and from one solar photometer (Univ. of Arizona) will be shared with scientists from the Chinese State Meteorological Administration and will be analyzed jointly.

The expedition is the first of its kind under the Joint Protocol of Agreement for Scientific Collaboration between the U.S. and the P.R.C. Arrangements have been communicated through official channels, including the Department of State.

2.2 Diagnostic Studies.

2.2.1. Energy Budget Studies in Complex Terrain.

Work is underway in analyzing data from three energy budget stations which were operative in 1984. One station was located in a forest clearing at Pingree Park, in the mountainous region west of Ft. Collins; another was on the peak of Mt. Werner near Steamboat Springs, Colorado; and the third, near Zhangye in the

Gobi Desert of western Gansu Province, PRC, at the foot of the northern edge of the Tibetan Plateau.

Analyses of these measurements reveal an interesting and rather basic research problem which will be studied further. The radiometers installed at our energy budget stations enable accurate assessments of the "skin" surface temperature of the ground beneath the radiometers. Using the temperature gradient between the ground surface and the air above, the sensible heat flux can be calculated with a "bulk" equation that contains the drag coefficient. The coefficients which we obtain are much smaller than those reported in the literature (i.e. less than 50%), but agree with recent work done in China. Part of the problem appears to stem from the fact that the drag coefficients derived from micrometeorological tower measurements over homogeneous terrain deal with stratifications not nearly as super-adiabatic as those in the lowest few centimeters above the ground. These extreme conditions, however, are contained in our radiometric measurements of true ground temperature. Relating the classical drag coefficient and its associated heat transport estimates with the newly obtained measurements is an important problem, because remote sensing capabilities from satellites also would indicate a "skin" surface temperature of the ground, thus will encounter similar interpretation problems.

Some of these problems, and also results from our field measurements, are described in a paper by Reiter and Sheaffer (1986). This paper has been submitted to the Journal of

Geophysical Research, has undergone peer review, and has been resubmitted.

2.2.2 Energy Fluxes and Diagnostic Studies During Different Seasons.

At Pingree Park we have available energy and radiation budget data that extend from winter to spring and span the snowmelt season. Mr. Sheaffer and the P.I. have carried out detailed analysis work of sensible and latent heat fluxes during that transition season, addressing the problems of snowmelt, freezing and evaporation. The ultimate goal of this investigation is to gain some ground truth information for possible assessment by satellites of flooding potential during sudden snowmelt periods. Ongoing work will continue the analyses of these data, and we expect to prepare a report of our findings during the upcoming year.

2.2.3. Precipitation Variability with Elevation.

In support of our numerical modeling work, we have been involved in an investigation of precipitation variability with elevation and various other location parameters. This problem assumed some importance with the development of a mesoscale numerical prediction model which performed very well in simulating two flash-flood disasters of relatively recent history (see Section 2.3.3). Since practically all rain gauges are located at valley stations, there exists the problem of model verification. Our model takes into account rather detailed terrain features, hence is sensitive to precipitation dependence on terrain.

To determine when factors are best for categorizing stations for regression analysis, average monthly precipitation for 4 years has been correlated with station elevation considering three characteristics:

a) Geography - location and elevation,

b) Surface roughness - local and large scale, and

c) Exposure angle - local and large scale.

Regional differences in the degree of correlation of precipitation with elevation did not emerge, but all areas indicated precipitation was more highly correlated with elevation in summer. Stratification by terrain roughness demonstrated that the rougher the terrain, the higher the correlation of precipitation with elevation; this fact is encouraging because the areas with the roughest terrain are where a "valley bias" correction is most desired. At both local and large scales, different exposures showed wide variation in the degrees of correlation of precipitation with elevation. Inclusion of concurrent low-level winds in analyzing the hourly precipitation will aid in the interpretation of these results.

Ongoing and future work will examine the seasonal effect and attempt to isolate the effects of terrain characteristics on the relationship (see Bryson and Mitchell, 1984; and Kuo and Cox, 1975). The factors of geography, roughness and exposure angle will also be incorporated for both the local and large scale.

2.2.4. "Explosive" Lee Cyclogenesis.

. Mr. Qi Hu, M.S. candidate from Lanzhou, Gansu Province, P.R.C., is currently conducting a detailed diagnostic analysis of a case of very rapid lee cyclogenesis in the region east of the Rocky Mountains. The study results are being compiled into a thesis which should be ready for publication by the end of the summer.

Analysis results, so far, indicate that the very rapid development of deep cyclones hinges upon the superposition of an upper-level short wave which is well pronounced at jet stream level and is characterized by a well-marked, narrow intrusion of stratospheric air into the troposphere. This intrusion is elongated meridionally, indicating the short-wave nature of the rapidly migrating trough. Furthermore, there seems to be a preexisting low-level jet streak with winds from the southwest and a pronounced vorticity pattern which would favor convergence in the region where the cyclone is about to develop. As the upper-level short wave becomes superimposed upon this low-level jet, surface pressure falls rapidly and strong frontogenesis and cyclogenesis occur. Subsidence appears to prevail in the core of this cyclone during the rapid intensification stage. Also, a level of nondivergence, which is normally encountered near 500 mb during less severe developments, appears to be absent or at least rather poorly defined during explosive cyclogenesis.

We intend to pursue these studies further, because they will be important in understanding high wind and blizzard conditions associated with sudden cyclone development. Further work will involve testing the sensitivity or relative importance of these features in additional selected cases.

2.3. Numerical Studies

2.3.1. Lee Cyclogenesis East of the Rocky Mountains.

A case of lee cyclogenesis over Colorado has been studied, using an improved version of the model described by Shen et al. (1986a). Even the older version of this model has been highly successful in simulating the development and life cycle of vortices over, and to the east of, the Plateau of Tibet (Shen et al., 1986b; Shen et al., 1986c). The lee cyclogenesis case, described in more detail in Bresch et al., (1986), could also be classified as "explosive" cyclone development. Our model, which runs on an HP-9000/500 computer was more successful in correctly locating the cyclone and predicting the central pressure, than was the LFM forecast issued at that time.

2.3.2. Vortex Development over Eastern China.

Mr. Zhengshan Song, Visiting Scholar from the P.R.C., is currently finishing a study of vortex and precipitation development over eastern China to the lee of the Tibetan Plateau, using the model described by Shen et al. (1986a). Again, the computational simulation was able to predict the development and placement of a rather weak vortex and its attendant precipitation pattern with reasonable accuracy. Apparently these weak vortex developments which, nevertheless, can give rise to excessive rainfalls, are difficult to predict in China. For this reason, our model experiments appear to be highly encouraging.

2.3.3. Modeling of Orographically Controlled Severe Weather.

Research work by Ms. Donna Tucker (to be published this year as part of her Ph.D. dissertation) addresses the important problem of enhancement of convective systems by topographic features. Two flash-flood cases of recent history are presented: the 1976 Big Thompson Flood which claimed over 130 lives, and the August 1985 Cheyenne Food which killed 12 people. In both cases the model performed excellently in placing the high-precipitation area over the location of the actual flood. The model predicted the precipitation amounts which were slightly more than observed. However, it is difficult to ascertain actual areal rainfall from a widely scattered rain gauge network, especially in such convective situations.

The model employed in these studies is a nested grid model with a resolution of 24 km in the fine-grid domain. The approach taken by us is rather innovative, because it does not carry the whole model physics on the fine-mesh grid, only the modification of the low-level wind field and moisture flux convergence caused by topographic details. Such a procedure reaps large savings in computer time, making this model a candidate for operational use in flash-flood forecasting.

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