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# 1980* FIELD SEASON WORKSHOP REPORT

November 28, 29 & 30, 1978
High Country Inn
Winter Park, CO.

CONVECTIVE STORMS DIVISION

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
BOULDER, COLORADO

*See footnote, page 1.

# Preface

This workshop produced the seven panel reports included here, which discuss various aspects of the work of CSD in considerable detail. They include many thoughtful suggestions which will provide valuable guidance in the development of the Division's program. We are most grateful to the scientists who devoted time and energy to this task, and, as our planning evolves, will keep them informed.

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## 1. Purpose and Structure

The Convective Storms Division (CSD) of NCAR is planning a field program of two to three months' duration*, the purpose of which will be to continue the studies begun in NHRE in which the aim was to gather sufficient data on both the microphysics and dynamics of convective clouds and storms to reveal how their interactions lead to the formation of precipitation, especially hail.

Convective storms are so complex and rapidly changing that an effort to depict even their major features must deploy several aircraft together with ground networks and Doppler and conventional radars in a highly coordinated manner. Operations on this scale offer a valuable opportunity for studies which relate not only to precipitation formation, but also to other aspects of the physics and chemistry of clouds and storms, such as electrical phenomena, the scavenging of particles and trace gases, or storm outflow phenomena. It is hoped that investigators with such interests will see here a useful opportunity for scientific collaboration.

In order to provide an opportunity for scientists at universities and elsewhere to take part from the beginning in formulating the goals, strategies and priorities of the program, a Workshop was held at Winter Park, Colorado on November 28, 29 and 30, 1978. The afternoon and evening of the first day of the Workshop were devoted to a description of earlier programs conducted by NHRE and CSD, and those of other groups with similar or related interests. On the second day, seven panels were formed to discuss various aspects of the program, and in the evening the panel chairmen reported on their deliberations to the whole group for general discussion. On the last day, the panels reconvened to complete their discussions and to finalize a brief report for presentation to the whole group.

Apart from panel chairmen, who had already agreed to serve in this capacity, and CSD staff associated with each panel, participants were free to take part in the discussions of any panel which was of interest to them. On each panel, there was a CSD representative, reponsible to provide or obtain any needed information about CSD capabilities and plans, and a recorder who assisted the chairman by taking notes and in the preparation of his report of the panel's deliberations. Participants are listed in Appendix A.

At the close of the workshop, the CSD Advisory Panel met to review the results and to give guidance for further planning.

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* At the time of the Workshop, the field program was planned for 1980, though the location was not determined, and was in fact a major topic of discussion. In the light of these discussions, CSD has decided that the best course would be to move from its established site at Grover, Colorado, to Miles City, Montana, collocating with HIPLEX in order to economize resources and facilities. The task of relocating facilities is such that it will be necessary to defer the field episode to 1981.

## 2. Proceedings

The proceedings were conducted as indicated in the following agenda, with minor changes of schedule:

Day 1

| | |
|---|---|
| 2:00 p.m. | Welcome and introductory remarks (P. Squires); remarks by NSF representative (R. Dirks). |
| 2:30 | Field programs of CSD - organization and facilities (J. Fankhauser). |
| 2:50 | Some scientific results from NHRE (C. Knight, A. Heymsfield, B. Foote) |
| 4:30 | HIPLEX (B. Silverman and A. Super) |
| 5:30 | Adjourn |
| 7:30 | TRIP (R. Orville)<br>FACE (R. Sax)<br>PACE (P. Hildebrand)<br>SPACE (W. Cotton)<br>SESAME (D. Lilly)<br>AVE (J. Scoggins) |
| 10:30 | Adjourn |

Day 2

| | |
|---|---|
| 8:30 a.m. | Discussion of the draft charge to panels |
| 9:00 | Panel discussions:<br><br>Microphysics and Aerosols (G. Vali)<br>Dynamics (S. Barnes)<br>Atmospheric Electricity (L. Ruhnke)<br>Atmospheric Chemistry (V. Mohnen)<br>Remote Sensing (radar, lidar, satellites) (T. Vonder Haar, R. Serafin)<br>*In situ* Sensing (airborne and surface) (P. Hildebrand)<br>Resources and Strategies (B. Phillips) |
| 12:30 | Adjourn |

Afternoon off

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|---|---|
| 7:30 p.m. | Plenary session - Presentation and discussion of preliminary reports from panel chairmen. |
| 10:30 | Adjourn |

Day 3

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|---|---|
| 9:00 a.m. | Panel discussions to finalize reports |
| 11:00 | Plenary session - final reports of panel chairmen and general discussion |
| 12:00 p.m. | Adjourn workshop |

Summaries of two introductory talks, and the charge to the panels are included in Appendix B.

3. Reports of the Panels

The following reports of the seven panels were prepared by the respective chairmen. The reports discuss the major issues involved in organizing a field program, but recognize that the ultimate decisions will depend on resources and detailed planning.

The panels in general agreed that the possibility of collocating the 1980 CSD field program with that of HIPLEX at Miles City, Montana, would offer significant advantages through the sharing of facilities and data, but pointed out that such a change of locale would cause a considerable disruption of the ongoing research program and might well entail significant additional one-time and recurring costs.

# REPORT OF THE PANEL ON MICROPHYSICS AND AEROSOLS

Chairman: G. Vali

This panel met for a total of about four hours and centered its discussion on some of the important scientific questions which CSD could undertake to investigate within the next three to five years, and how those goals might best be pursued in terms of the organization of field projects and other considerations. This report is a summary of the major points which were raised in the discussions--as the writer understood them. In questions of balance between comprehensiveness and pragmatism we probably erred on the side of what we thought would be practical, both in terms of being tied fairly closely to the past efforts of CSD (NHRE) and in terms of facilities that might be available for planned research.

The point was made during the discussions that it would seem to be appropriate for CSD to emphasize studies of the microphysics of clouds and precipitation in its future activities. This emphasis is justifiable on the basis of the many outstanding problems in that area and on the basis of the past efforts of the Division in that direction. Emphasis on microphysics naturally would not mean an exclusion of other considerations but could be viewed as the general focus of research.

Another general point which was made is that there are valid questions for study related to clouds and cloud systems of all scales, i.e., from small cumulus to severe storms. In fact, it would seem advantageous to continue studying clouds and cloud systems of varying degrees of complexity so that the simpler situations could be taken advantage of for understanding basic phenomena, whereas studies of the more complex systems would demonstrate the important interactions which come into play there. The 1976 field season was a good example of how such different studies complement each other; there seems to be a fairly good case for the next field season to be quite similar to that of 1976.

The general point was made that current studies by other research groups of the microphysics of convective clouds are designed to provide knowledge necessary for purposeful modification of clouds. Hence, studies in these projects may leave underemphasized several basic aspects of cloud microphysics which deserve attention. CSD has the opportunity to address such problems and thus to make significant contributions to the understanding of cloud processes. Some important cases in point are the evolution of cloud droplet spectra, the natural nucleation mechanisms of ice and entrainment processes.

In terms of more detailed scientific questions, it became evident in the discussions that there are still many valid topics for study related to the hail process. Evidence from the NHRE studies is more suggestive than definitive in many regards, and a continued pursuit of these studies would seem to be well justified, both on the basis of scientific progress and on the basis of possible contributions to the development of usable hail suppression technologies. Topics suggested for research included the question of recirculation of hail embryos and the generality of that phenomenon, questions related to the identity and role of the radar "hot spots", the dependence of hail production on the size and tilt of the updraft, and more general questions related to identifying aspects of severe storms which lead to hail production.

The point was made in the discussion that while the study of large hail is interesting because it represents an extreme manifestation of cloud processes, it is perhaps even more important to study processes leading to the formation of small to moderate hail, because of their more general importance and higher frequency of occurrence.

The study of precipitation processes in convective clouds holds many and varied research opportunities. The evidence now on hand concerning the initiation of precipitation via the graupel process in storms of the High Plains is important and deserves further elucidation. In this regard, it is important to isolate the mechanism of nucleation responsible for the initial generation of ice in High Plains clouds. Additionally, there is a need to measure the dependence of the rate of ice generation on such cloud parameters as temperature (in a more precise form than is now known), liquid water content, drop size distributions, updraft velocities, etc. Other topics deserving special attention include the evolution of cloud droplet spectra and the role of mixing, i.e., entrainment, in influencing ice generation. It is also evident that important questions exist with respect to the precipitation processes of clouds in other areas. However, there is a strong argument for continuing research with the clouds of the High Plains, because in these clouds there is a dominant precipitation process, and the study of that process is thereby facilitated. On the other hand, phenomena in the High Plains clouds are not restricted to that single process, and the rare occurrences when other processes (coalesence, ice multiplication) also act provide interesting opportunities for comparisons and contrasts with the more general situation. Studies of these exceptional situations will provide experience for later studies in other geographical areas.

Stress was laid in the panel discussion on the importance of studies of cloud/mesoscale interactions. One of the most important topics is perhaps the interaction of downdrafts with updrafts, and the ways these interactions govern the life cycles of individual clouds and influence where, within a mesoscale system, cloud development occurs. The evolution of raindrop size distributions within rain shafts, and the melting of ice particles in precipitation, have important implications for the generation of downdrafts. The formation of "penetrative downdrafts" high in the clouds, and the connection between these and the downdrafts below cloud base, are areas where much important work remains to be done. The broad question of precipitation efficiency, both at the single cloud scale and at larger scales, is another important research topic.

While the roles of cloud condensation nuclei, large aerosol particles, and ice nuclei in the formation of precipitation are known in theory, there appears to be no evidence that direct observations of these aerosols would provide information about the behavior of hydrometeors that could not be gained from some initial observations of the hydrometeors themselves. Measurements of CCN spectra have substantial predictive value on a regional basis, but the day-to-day variability at a given location generally has a lesser influence than other factors on the cloud droplet spectra. Measurements of large aerosols and of ice nuclei have not contributed yet to operationally important predictions about cloud behavior.

In view of the aforesaid, it appeared that the study of nuclei and of aerosols might well be left as an area for cooperating groups to study in conjunction with future CSD field efforts.

The possible inclusion in future CSD studies of investigations of chemical cycles and chemical tracers within clouds was viewed by the panel as an important and timely factor (cf. report of the Atmospheric Chemistry Panel).

In connection with instrumentation questions, the problems of improved data on cloud droplet size distributions and better measurements of vertical motions within clouds emerged as two points of major concern. In addition, the need was emphasized for continued efforts in the upkeep and calibration of cloud physics instrumentation and for involvement in the CSD field studies of cloud physics aircraft of higher performance than those currently available within the RAF.

Concerning the site and operational mode of the 1980 field experiments, the discussions might be summarized in the following, much abbreviated form: a good case appears to exist for mounting the 1980 field experiments at the Grover site. Completion and extension of the studies previously conducted at that locale hold the promise of valuable contributions, especially if the scale of the effort could be similar to that of the 1976 experiments. Locating the 1980 field experiments at the Miles City headquarters of Project HIPLEX was seen to have the advantages of making available to CSD data from the University of Wyoming King Air aircraft for some periods of joint observations, the possibility of utilizing data from the more extensive joint mesonetworks of both projects, and the contributions that could be made to Project HIPLEX by the availability of CSD facilities there. The similarity of cloud types between the Montana and Colorado sites would ensure that hindrances to building upon past studies of CSD would be relatively minor. Moving the 1980 field studies to areas other than Colorado or Montana was viewed with only partial enthusiasm by panel members due to the need to then face more complicated microphysical cloud situations than those offered by the clouds of the High Plains.

Extensive cooperation between CSD and Project HIPLEX was recognized to be of importance regardless of the location of the 1980 field observations of the CSD. Similarity and complementarity between the broad goals of the two research groups and their experiences in clouds of very similar nature naturally call for close and continued cooperation. There is also a sharing of concern about airborne cloud physics instrumentation and other tools for meso-meteorological research. The economic benefits from the sharing and possible periodic exchange of facilities is also self-evident. To somewhat lesser degrees, the same arguments were seen to be valid with respect to cooperation between CSD and other projects studying convective clouds of midlatitudes. A gradual shift in emphasis toward cooperation with projects not on the High Plains might be foreseen as the studies of the CSD broaden from the graupel-dominated precipitation processes to others.

Panel members, with many fluctuations were: D. Breed, R. Carbone, W. Cooper, R. Egami, W. Hall, A. Heymsfield, J. Hudson, D. Johnson, C. Knight, R. Lavoie, R. List, D. Musil, J. Pflaum, R. Sax, G. Vali and K. Young.

# REPORT OF THE PANEL ON DYNAMICS

Chariman: S. L. Barnes

## I. Conclusions

The Convective Storms Division and its collaborators have developed through its past investigations of Colorado hailstorms a considerable expertise in acquisition, analysis and synthesis of an important data base concerning the dynamical and microphysical processes leading to the formation of precipitation in cumulonimbus convection. The panel concludes that CSD should continue to develop core experiments in these areas in 1980. Expanded collaborations among university researchers and those in similar experimental programs are encouraged to take advantage of the greater observational, technological and scientific resources that are deemed necessary to efficiently advance our understanding of the precipitation process in convective storms. Such precipitation importantly contributes to the climatological rainfall distribution in many parts of the world.

No recommendations are made by this panel as to the specific collaborations that CSD should attempt to develop. However, several are made obvious by the type of observational resource recommended for use in future field programs. The nature of these collaborations we leave to the judgment of CSD and NCAR management, as well as that of their collaborators.

The report identifies both general and specific research objectives that the panel recommends CSD consider pursuing. These objectives include studies of all aspects of dynamical processes leading to the formation of precipitation in convective storms, e.g., understanding the initial vertical transports of heat and moisture from the boundary layers, the formation of cumulus congestus and the organization of convection into mature storms. A reasonable goal of this comprehensive effort is to develop through numerical storm simulations schemes for predicting (3-6 hr) total precipitation amount, and other useful parameters characterizing convective storms that develop in response to explicit (and presumably observable) initial conditions in the environment. We realize that this is an ambitious goal and not one that will be realized as the result of one or perhaps even several field experiments. Also, it will require the innovative and extensive use of both remote and *in situ* observatonal systems, not all of which are currently available within the NCAR facilities.[1]

Concerning the location and frequency of future CSD field experiments, again the panel does not make a specific recommendation. However, the following views are offered for consideration:

A. The geographical location of the field experiment need not be coincident with the climatological maximum of hailstorms provided there exists the opportunity to obtain a more complete data base by combining observational resources in an area somewhat away from the climatological maximum, and provided the frequency of the phenomenon is still sufficiently high to guarantee a reasonable number of opportunities for observation.

[1]In this regard, the panel notes the limitations of currently available rawinsonde systems for mesoscale research. The panel recommends that CSD encourage and support the FOF in the development of a reliable, high accuracy sounding system.

Thus, CSD should consider the benefits that might accrue by a combination of observational facilities at the HIPLEX location in Montana, or in other areas where similar field programs occur (e.g., Illinois, Oklahoma).

B. As a general comment on the frequency of convective storm field experiments around the country, the panel notes that there is a 2-3 year period from data acquisition to analysis and reporting of findings in most meteorological field programs. The panel recommends that CSD should encourage (lead) the meteorological community in adopting a 2-3 year separation between major field experiments at any one location, and should seek the means to develop a mobile, national observational resource and operational team that could be deployed to various experimental locations on a mutually agreeable schedule. (NOTE: One panel member objects to this recommendation as appropriate for CSD--or anyone else--to pursue).

II. General recommendations for studies into the dynamics of convective precipitation with emphasis on High Plains thunderstorms

A. Cumulus congestus studies

CSD should continue their research into the processes which initiate and organize convective storms, including:

1) study of boundary layer processes that lead to convective development;

2) study of the mechanism(s) that organize cumulus congestus into cumulonimbi;

3) study of the evolution of precipitation growth in cumulus congestus;

4) study of the influence of entrainment upon precipitation growth.

B. Dynamics of mature cumulonimbi and relationships to the precipitation process.

1) Determine the internal thermodynamic (i.e., temperature and moisture) and kinematic structures in the evolution of mature cumulonimbi.

2) Develop methods for retrieving buoyancy distribution in cloud from the measurement of reflectivity and three-dimensional air flow using multiple-Doppler radars.

3) Determine the origin and trajectories of hail embryos.

4) Study the entrainment/detrainment processes and their effects upon the precipitation process.

5) Study the distribution of environmental parameters that determine the total area precipitation, the rain/hail volume, and the precipitation efficiency of various types of convective storms.

6) Investigate the utility of aerosols as tracers of air flow through convective storms.

C. Determine the origins of downdraft air, the formation of gust fronts and their structure, evolution and feedback effects upon the parent storm and other storms.

D. Study the near and far cloud environment (1-5 storm diameters) for clues about the influence of environmental conditions upon convective storm entities.

E. Study influences of boundary layer interactions upon the initiation, development and decay of convective storms.

III. General goals for cloud modeling efforts both within CSD and among their collaborators

(with reference to both cloud and mesobeta-scale numerical simulations)

A. Predict (3-6 hour period) the convective characteristics of a given day in a given region ($1 \times 10^4$ to $5 \times 10^4$ $km^2$):

1) rain rates, amounts and distribution;

2) hail sizes, amounts and distribution;

3) degree of cloud electrification predominant discharge type, charge distribution;

4) storm dimensions and intensity including elevation of radar echo tops, maximum reflectivity, cloud bases and tops;

5) dynamical characteristics including maximum vertical draft speeds, tilt, horizontal extent, surface outflow characteristics, storm type (supercell, multicell, etc.), potential for vorticity generation;

6) character and extent of anvil formation;

7) degree of storm steadiness (nature of fine-scale features);

8) organization and interaction of storms within multi-storm systems.

B. Supply to GCM and other large-scale or regional-scale models useful parameterizations of cloud-scale processes.

C. Assess the importance and strength of interactions between different physical processes within cloud (i.e., dynamical, microphysical and electrical).

D. Develop models for the investigation of physical processes important to both planned and inadvertent weather modification of convective rainfall.

IV. General discriminating measurable parameters that could be useful in the development of cloud simulation models

A. Cloud dimensions and rate of growth.

B. Precipitation evolution (e.g., time to first echo, rain at cloud base, hailfall).

C. Locations, extent and proportions of regions of liquid water, ice and mixtures thereof.

D. Downdraft and updraft locations, tilts and horizontal extents.

E. Nature of gust front and its evolution.

F. Quantitative measures of items in IIIA.

G. Average (net?) vertical velocity over the cloud domain.

H. Thermodynamic structure of the subcloud layer.

I. Three-dimensional reflectivity and air flow and their evolution over the entire cloud domain and in its immediate vicinity.

V. Specific recommendations for the 1980 field experiment

A. First echo measurements

1) Continue experiments internal to growing congestus with sailplane, T-28, King Air and other aircraft as available. Particular emphasis should also be given to the acquisition of redundant data for intercomparison studies between different sensor systems (same parameter--e.g., for temperature, wind).

2) Airborne time-lapse photography should be incorporated to establish cloud dimensions and growth.

3) Turbulence measurements in the cloud and immediate vicinity should be undertaken using the Queen Air and/or Electra.

4) Doppler radar (dual or triple) measurements of air motions in the vicinity of not-yet-precipitating congestus would be helpful in the study of entrainment effects on the organization of the cloud (chaff could be deployed around the cloud and at cloud base using two aircraft, one dropping timed-dispersion packets and the other deploying continuous streamers via a chaff cutter).

5) Additional instrumentation as described in B (below) would augment these studies to be performed over a fixed network area.

B. Measurements to provide initialization data for cloud models.

1) Surface wind, temperature and moisture over at least a 40 x 40 km

domain with station spacing at 5 km. Not all parameters need to be measured at each station. For example, the PAM network could be deployed on a 10-km grid with only wind instruments (on-site recording) interspersed at alternate 5-km grid points. The panel recommends that the observational domain cover 100 x 100 km in order to increase the frequency with which storms will pass through the domain and to observe a sufficient area surrounding a storm of interest so that the model boundary conditions can be determined. The spacing of stations might have to be compromised to cover this domain.

2) Surface heat and moisture flux measurements would be very useful at the fully instrumented ground stations. This could perhaps be accomplished by the addition of a duplicate sensor package at another elevation on the PAM station towers.

3) Nearly continuous monitoring of wind and temperature structure in the clear boundary layer using Doppler radar techniques would aid tremendously in determining the response of convective development to mass, heat and moisture convergence within the boundary layer.

4) Rawinsonde observations at 5 locations (minimum) are necessary to monitor parameters at the lateral boundary of the domain and in the free atmosphere above. One station should be located at each of the four corners of the 100 x 100 km domain with one central station. Observations should be taken at short intervals (perhaps hourly).

5) Boundary layer observations from tethered balloon systems and remote sensing systems would be useful even in limited quantities (i.e., one for each system).

6) At least one (preferably two or more) aircraft instrumented to observe conventional meteorological parameters should be flown along the 100 x 100 km domain boundary to monitor variations between sounding sites. Continuous operation for 6-hour periods is required. Side-mounted cameras to observe cloud development over the domain are required.

7) Estimates of turbulent dissipation ($\varepsilon$) should be made over the 40 x 40 km domain using Doppler spectrum data.

C. Observations during the maturing stage of convective storms.

1) The same resources itemized above (B) would also be used to observe the mature stage of cumulonimbi of opportunity. Measurement emphasis should be similar to that of past CSD programs, except that more emphasis should be placed upon measurements in the near cloud environment.

2) Storms should be circumnavigated at several levels to determine the horizontal fluxes of moisture and momentum into the storm volume. These measurements are imperative in the study of precipitation efficiency as recommended by the panel. Aircraft such as the NOAA P-3, NCAR Electra, Wyoming King Air are examples of the resources required.

3) Multiple-Doppler radars should observe selected storm volumes at short intervals (less than 3 min) to determine the temporal changes in three-dimensional velocity structure for purposes of buoyancy retrieval and air trajectory calculations. This requirement should be weighed against the limitations of the radars and the need for total storm volume observations.

4) The origins of downdraft air and its thermal properties should be observed to determine the seemingly important role this air plays in the boundary layer as a storm regeneration mechanism.

5) Aircraft and sounding data acquired during the occurrence of a mature convective storm over the 100 x 100 km domain will aid in the determination of changes in the mean flow, useful as an indicator of the magnitude of the eddy exchange processes between the storm and environment. These same data will also aid in determining horizontally averaged vertical velocity over the domain, which should indicate the degree to which the storm is coupled to the environmental flow.

6) Make _in situ_ measurements (from penetrating aircraft) of liquid and solid hydrometeor content of selected storms for comparison with similar estimates from radar reflectivity measurements.

D. The panel recommends that expertise in the real-time use of visible and infrared satellite data be incorporated in the field experiment, both on an operational basis and as an augmentation to the quantitative _in situ_ and remote measurements. This expertise should be either acquired through collaboration or developed internally.

E. High-resolution satellite sounding data will be available during 1980 from two polar-orbiting, operational satellites (TIROS-N and NOAA-A). Provisions should be made to incorporate these data into the analyses of the other field data.

The panel realizes that these recommendations are not especially comprehensive, nor have the members considered logistics and funding problems. We believe that the studies emphasized are achievable in 1980, given the cooperation of funding agencies and a large measure of collaboration between CSD, FOF, RAF, and other organizations in control of the required resources.

We take this opportunity to thank the NCAR and CSD management for the opportunity to comment upon this important subject. We hope that the results of our deliberations as well as those of the other panels will help to foster a greater spirit of mutually beneficial cooperation in the effective use of our national resources for future meteorological field experiments.

Participating panel members: C. Anderson, S. Barnes, C. Chappell, T. Clark, W. Cotton, J. Fankhauser, B. Foote, H. Frank, J. Golden, P. Hildebrand, D. Lilly, J. McCarthy, D. Musil, H. Orville, R. Schlesinger, A. Super, E. Zipser.

# REPORT OF THE PANEL ON ATMOSPHERIC ELECTRICITY

Chairman: L. Ruhnke

Some of the fundamental questions of thunderstorm electricity are concerned with the origin and movement of charged particles, the relationship between charge locations and lightning discharges, and the role of electrical forces on precipitation formation. Much of the recent excitement among atmospheric electricians is based on the development of new techniques for probing the insides of storms through the use of Doppler radar and through acoustic and electric means. It appears that significant research progress is possible within a few years. Significant progress toward answering some of the basic questions has already come from the coordinated efforts of many principal investigators applied to the study of stationary storms that develop regularly in preferred locations. More results are expected from this program which has been labeled TRIP (Thunderstorm Research International Program).

It is realized that thunderstorm electricity research must be an integral part of any convective storm program that deals with fundamental research issues. It is possible, perhaps even probable, that electrical forces are important in some aspect of precipitation formation. Embryos needed to start the growth of large hail may be produced by the rain gush mechanism. Electrical forces may significantly modify the motions of cloud particles. This in turn has several implications. In particular, it may introduce errors into Doppler measurements of air motions. Laboratory experiments suggest that strong electric fields as they develop in thunderclouds can modify the crystal habit of ice crystals, accelerate their rate of growth, and cause the formation of large numbers of ice nuclei. It would be useful to differentiate between cloud physical processes involving ice crystals taking place at low- and high-intensity electric fields.

A problem with the High Plains is that the storms do not form preferentially in any specific locations. This limits the types of electrical experiments that can be performed, particularly experiments that attempt to reveal the internal structure of storms. There are, however, unique opportunities for studying thunderstorm electricity in Colorado, Montana, and elsewhere on the High Plains.

It is important to characterize the electrical activity of storms on the High Plains. When in their life cycle do they begin making lightning? What is the frequency of lightning? What percentage of the flashes come to earth? Does electrical activity provide a way to distinguish between different types of storms or between the various phases of a given storm or between a seeded cloud and an unseeded cloud?

Some of the above questions can be approached with relatively simple experiments--time-lapse cameras, television cameras, and lightning location and counting devices. Despite this simplicity results should be quite interesting and useful.

The following is a list of suggested experiments which are scientifically advantageous to conduct in conjunction with the CSD program as well as economically feasible.

1. The frequency of intracloud and cloud-to-ground flashes.

2. The number of strokes within cloud-to-ground flashes.

3. Current waveshapes of return strokes yielding:

   a. Peak current
   b. Rise times
   c. Charge transferred

4. Location of charge centers within the cloud.

5. Polarity of the charge lowered to ground.

6. Location of lightning ground-strike points.

7. Channel shape within clouds.

8. The conduction current above thunderstorms.

9. Corona current measurements on the ground.

10. Location of intracloud lightning discharge processes.

If a cooperative thunderstorm research program such as NCAR's CSD provides a congenial administrative climate for investigators of atmospheric electricity, exhibiting interest in collaborating and cooperating, then investigators will freely join and participate. It also would be helpful if CSD could acquire an in-house expertise in atmospheric electricity to coordinate and inspire cooperation.

Participating panel members: R. Markson, R. Orville, I. Paluch, L. Ruhnke, W. Taylor, W. Vaughan, B. Vonnegut, and W. Winn.

# REPORT OF PANEL ON ATMOSPHERIC CHEMISTRY

Chairman: V. Mohnen

## I. Opportunities

Almost every geochemical cycle involves cloud and precipitation processes. Clouds act as a chemical reaction reservoir, as source and as sink for a variety of atmospheric trace substances. For example, such major cycles as the sulfur cycle, nitrogen cycle, chlorine cycle, particle cycle, and probably the carbon cycle are believed to be governed to a large extent by physical and chemical processes within clouds or below precipitating clouds.

Both natural and anthropogenic emissions contribute to the geochemical cycles. For proper control strategy, it is vitally important to understand the main atmospheric chemical reaction path(s) governing the residence time, the intermediate and final reaction products of every geochemical cycle, etc. The precipitation composition as a function of geographic region and time of the year reflects the highly interactive processes between cloud and precipitation elements and their gaseous and particulate environment. Examples such as the acid rain issue demonstrate dramatically the need for more information on overall atmospheric chemistry. Clouds control the precipitation quality. Clouds also control the spatial distribution of soluble gases.

## II. Uses of Chemistry

Chemistry of the particulate matter and atmospheric chemistry processes leading to ice nucleation have a direct impact on the cloud formation process. After the initiation of cloud particles, thermodynamic processes are believed to dominate subsequent developments. For ice nucleation it is again the chemical characteristics of particles that determine the efficiency of the various phase transition processes. It must be noted, however, that the chemical characteristics of particulate matter and sorbed gases are invariably altered when processed through the condensed phase. Thus, evaporating clouds may feed back into the initiation of cloud processes and in the appearance of trace gases.

There are chemical measurements which can be made in order to further understand the physical processes taking place in convective storms. These natural tracer experiments are in an embryonic state but appear to offer significant opportunities. Worth mentioning as possible tracers are: ozone, oxides of nitrogen, tritium, deuterium and specific chemical or elemental parameters of the atmospheric aerosol systems (pattern recognition matrix). Some of these natural tracers require collection and subsequent laboratory analysis; others are susceptible to *in situ* measurements with time constants of seconds.

Ozone may be used as a natural tracer of air motions under some circumstances. Preliminary measurements of ozone in clouds indicate that downdrafts with excess ozone, and updrafts with lower ozone concentrations can be observed; however, one should be aware that these circumstances are not always available. Stratospheric ozone intrusions are sometimes observed as laminae of high ozone at mid-altitude, and ground-level photochemical activity can completely reverse the normal ozone profile. Furthermore electrified clouds may produce ozone, and lightning discharges, which generate nitric oxide, certainly will remove ozone.

Oxides of nitrogen themselves may be useful indicators of air parcel identity. In truly rural air the concentrations may be too low (<0.1 ppb) to be usefully measured; however anthropogenically polluted boundary layers often contain 5-50 ppb. This could be observed as it is entrained into the cloud. Again, electrified clouds are a special case in which the measurement of NO formation from well-understood electrical storms is important.

Growth temperatures of hailstones have been inferred from deuterium measurements, and perhaps could be obtained from other chemical measurements such as $CO_2$ or fluorocarbons.

## III. Geographic Area

The atmospheric chemist has a vital interest in all field experiments in cloud physics because of the fundamental role of clouds in geochemical cycles. Depending upon the geographic area, vital information can be extracted on:

1) the chemistry of the unperturbed troposphere;

2) the chemistry of the anthorpogenically perturbed troposphere.

Major societal questions need to be answered by the atmospheric chemistry community related to the impact on the total ecosystem from:

1) energy production and use, with particular emphasis on the increased use of coal;

2) primary energy sources development, again with emphasis on increased coal development (It is projected that the U.S. will entirely depend upon coal in the not-too-distant future.);

3) long-range transport and chemical transformation from major metropolitan complexes.

Any future field experiment should solicit the participation of the atmospheric chemistry community--if for no other reason than to dramatically enhance the project's societal objectives. On the other hand, the information on cloud physics and dynamics is of vital importance to the chemist for the purpose of a) model validation, b) establishment of properly documented background data base, and c) guidance for laboratory measurements, etc.

At this time, the atmospheric chemistry community is interested in any location since the data base on cloud chemistry in particular is virtually nonexistent. However, priorities can be established on the basis of current socio-economic-environmental issues relating to energy development.

The Miles City, Montana area, the general Ohio Valley area, and the continental divide area would fulfill the above cited information need.

## IV. Objectives

Chemical problems in clouds are:

1) Study the chemical composition of western cloud water and air to establish baseline values of "nonpolluted" atmosphere. In particular, $SO_2$, $NO_x$, $NH_3$, $H_2SO_4$, $HNO_3$, $H^+$ and $H_2O_2$ are of great significance.

2) Similar measurements in conjunction with analyses of precipitation at the ground will yield information on the extent to which the soil dust component of atmospheric aerosol neutralizes acidity in falling rain.

3) Measure $H_2SO_4$, $HNO_3$ and $H^+$ in hailstones from which the outer surface is removed in order to get an idea of cloud water composition. Such measurements of hailstones collected over 15 to 20 years would yield an historical record of acidity trends. Since precipitation in remote areas is being found more acidic than theoretically anticipated, such an experiment would help to determine whether the theory is incorrect, or whether there is a global contamination by acids which is undergoing a secular increase.

4) Studies could be made of the distributions of acids in tall cumulonimbus clouds which penetrate the stratosphere, as a function of altitude. Higher acid concentrations at high altitudes would indicate entrainment of stratospheric $HNO_3$ vapor and $H_2SO_4$ aerosol into the cloud. Precipitation from such clouds may be a significant sink for stratospheric trace constituents. To what extent are $O_3$ and $H_2O_2$ transported down from the stratosphere by such storm systems?

5) Measurements of the composition of inflowing air, cloud water, and outflowing air would be useful for understanding chemical conversions in cloud water. Information concerning the regions of inflow and outflow from CSD would make such experiments possible.

   Atmospheric chemists would be extremely interested in performing such experiments in regions where both polluted and clean-air situations would be encountered. Such experiments would also shed light on the extent to which clouds influence the vertical distribution of trace materials. For example, $SO_2$ in the mixed layer may be entrained at the base of the cloud, converted to $H_2SO_4$ by $H_2O_2$ oxidation in cloud droplets, and released by evaporating droplets in the outflow region as sulfuric acid aerosol above the boundary layer.

6) Soot, total C, and organic constituents are important to measure in the cloud water and air for environmental reasons.

7) The formation of oxides of nitrogen by lightning is an important process which can only be studied in a collaborative program involving several disciplines.

The main objective of joint efforts between atmospheric chemists, cloud physicists, and the meteorological community will be the ability to fully assess the chemical evolution of species as they are processed by or through clouds. This understanding is required for several different geographic regions because of the different chemical problems.

The final goal of cooperative efforts of this kind is the ability to realistically model these chemical processes which will then complete our understanding of the geochemical cycles of a number of species. Insofar as the chemical species involved are pollutants with negative impacts, then this information is necessary in order to define a rational control strategy.

## V. Aircraft Platform

If significant participation of the atmospheric chemistry community is desired, the need for a separate, dedicated aircraft is imperative. This aircraft should have the capability of staying aloft for at least three hours and should have sufficient electrical power reserves.

1) All participating aircraft should have a cloud water collector on board capable of collecting a minimum of 10 ml per sample of liquid cloud water. Further specifications for an ideal collector are:

   a) size discrimination capability so that separation and collection of aerosol particles and hydrometeors are possible.

   b) no evaporation or additional condensation as a result of the collection process.

   c) air exiting from cloud collector free of aerosol particles and hydrometeors, so that measurement of trace gases below parts per billion is possible utilizing techniques that are disturbed by liquid water in the inlet system.

   d) material of the cloud collector must be compatible with the chemical species to be measured.

2) Filter packs as used in APEX; impactors for size separation and morphological studies (Acid Precipitation Experiment; for further information contact Dr. Alan Lazrus, NCAR).

3) Other desirable instrumentation includes: Aitken particle counter, nephelometer, and instruments for measuring ozone, oxides of nitrogen, and sulfur dioxide.

## VI. Surface Needs

There should be at least one surface station duplicating the aircraft instrumentation. Precipitation collection with standard instrumentation as defined in the MAP III S project with event sample. For further information on MAP III S contact Dr. Michael McCracken at LLL, Berkeley, California.

Collaboration between projects of the atmospheric chemistry community and the Convective Storms Division promises to advance our knowledge to an extent that cannot otherwise be achieved.

Participating panel members: J. Dye, W. Hall, G. Hidy, A. Heymsfield, A. Lazrus, V. Mohnen and D. Stedman.

# REPORT OF THE REMOTE SENSING PANEL

Co-Chairmen: R. Serafin and T. Vonder Haar

## I. Introduction

The Remote Sensing Panel considered the need of CSD for various remote sensing tools in light of two general areas--the prestorm environment and the storms themselves. Potential candidates were further classified as either essential or supplemental. Essential remote sensing tools provide data which are considered fundamental to the apparent needs of CSD. Supplemental tools are those of a lower need but often of a very desirable nature. The panel agreed that CSD should only rely on existing, proven systems but should at the same time encourage the testing of new techniques and systems on an experimental basis.

## II. Prestorm Sensing

Regarding the prestorm environment, the most important measurements would be those which provide information on boundary layer convergence. While there was some disagreement on whether this should be mass convergence or moisture convergence, it was agreed that measurements of moisture flux within the boundary layer were vital. We assumed that a surface network of PAM or equivalent weather stations would be used along with an "adequate" radiosonde network. A second major need is for information on temperature, moisture, and winds as a function of height in the atmosphere.

The only essential remote sensing tool identified for this prestorm study was multiple-Doppler radar. For this use, the radars would depend upon their clear air echo detection capability and should be capable of measuring winds and hence convergence within about 40 km or so. On some exceptional days this range may be considerably farther. Several systems were identified as valuable in a supplemental role. These include:

1) Frequent (three-minute interval) satellite data to give an overview of the larger scale situation and attendant cloud motions.

2) FW-CW radar, acoustic sounders, and/or lidar (vertical or scanning) to provide information on the depth of the boundary layer and the presence of thermals and imbedded waves.

3) Laser triangle wind systems to provide measurements of the net flow into/out from the triangle. While such a network could be implemented by the 1980 field season, the scientific cost-effectiveness of such a system has yet to be determined. The panel felt a seminar for CSD on the laser triangle system would be a useful means of learning more about this system.

4) 8.6 mm scanning radar to provide measurements of cloud formation and early growth. This capability would also tend to fill the gap between clear air measurements and radar measurements at longer wavelengths.

5) VHF Doppler radars to provide wind information throughout the troposphere and lower stratosphere as well as measurements of the height of the tropopause. More than one of these would be desirable.

6) Satellite radiometer measurements combined with radiometer measurements made at the surface to give the vertical structure of the atmosphere for both temperature and moisture.

III. Storm Sensing

Remote sensing instruments are more valuable and, fortunately, available for measurements of the storms themselves. There were five systems considered essential for this part of CSD's research. These were:

1) Multiple-Doppler radars. Obtain as many Doppler radars as can be effectively utilized both operationally and as related to data processing for measurements of the three-dimensional kinematic fields.

2) High-quality radar reflectivity measurements made with a 10-cm wavelength radar. This would continue to be a cornerstone upon which many other studies would build.

3) Surveillance radar with digitized output to maintain a continuous watch of general storm conditions. By doing this the 10-cm radar would be freed to concentrate on specific storms or regions.

4) Frequent (three-minute) satellite data. Again, this would provide a valuable overview but also could provide information on cloud movement and structure.

5) Mobile, vertically-pointing Doppler radar to provide valuable cross checks on the analyses resulting from triple-Doppler radar systems and to provide high-resolution observation of vertical particle motion.

A total of ten systems were identified as valuable supplemental systems. Some of these may not, in fact, be ready by 1980 but are included because they could provide very useful data. These systems include:

1) Dual-polarization data (with a 10-cm radar) to make differential reflectivity measurements for assisting in determining precipitation phase and quantitative rainfall rate.

2) Multiple-wavelength radar systems to aid in distinguishing hail from rain and rainfall measurements from attenuation data. These data would be complementary to the dual-polarization information.

3) Cloud tops and vertical velocities from stereo satellite measurements made by simultaneous pictures from two geosynchronous satellites. This capability, while quite valuable, may not be ready before 1981.

4) Airborne or surface stereo photography to give cloud growth rates and to observe the structure of clouds including overshooting tops.

5) Airborne Doppler radar promises to be a powerful tool for studying convective storms. The great mobility provided by the airborne platform would permit high-resolution observations of important smaller scale storm features such as cyclonic vortices. In the early cloud growth phases the radar, in the up- or down-looking mode, would measure vertical velocities. Finally, in areas removed from ground-based Doppler arrays, airborne Doppler radar may be useful to synthesize a dual-Doppler system, thus providing complete three-dimensional motion within storms. Though a prototype has been built and preliminary tests have been made, its research capability has yet to be determined. The panel urged CSD to strongly support this development and to encourage testing concurrent with the 1980 field season. A major obstacle to utilizing airborne Doppler radar for general research purposes is the current lack of processing software.

6) Airborne Doppler lidar to provide motions in the near environment (clear air). NASA is now developing such a system that is likely to be ready about 1981.

7) Rapid-scan radar to provide very frequent ($\sim$20 sec) complete volume scans of storms within close range.

8) Atmospheric electricity measurements. We assumed that these would be addressed more fully by the Panel on Atmospheric Electricity and hence did not go into any detail here. The panel recommends that some of the simple-to-use systems should be deployed and that some basic remote atmospheric electricity measurements be made for estimating the location of cloud charges, cloud radiation, and lightning. Good time resolution is needed.

9) Microwave radiometer to provide integrated liquid water content and water vapor content from the surface upward. The panel recommends that the potential use of passive radiometric systems be explored and their use is strongly encouraged. CSD should determine quantitatively the extent of the present and future capability of radiometry as means for achieving its scientific goals.

10) FM-CW radar, acoustic sounder and/or lidar to monitor the condition in the boundary layer as well as the effects of the storm on the boundary layer in terms of gust fronts and wave generation.

## IV. Conclusion

The panel recommends that careful consideration be given to data management, quality control checks and processing. The logistical aspects of moving numerous remote sensing systems into the field, especially at a new location, require careful and timely planning. If a move to Miles City is planned, CP-2 and perhaps other systems should be moved as early as possible to insure that all systems are ready before the start of the field season.

The panel also considered various other aspects of a cooperative effort between CSD and HIPLEX. It was agreed that such a move would provide improved facilities for both groups. HIPLEX would also benefit from having access to CSD's scientific team and its established analytical capabilities. The benefits to CSD would be principally the use of HIPLEX's digitized surveillance radar, existing real-time satellite data system, access to the Bureau's data base and its computers, and analysis capability for these systems. The major disadvantages are logistical. We agree with the report of the Resources and Strategies Panel that any move be for a minimum of two seasons. We felt that the decision to join forces with HIPLEX should be based primarily on the "scientific cost effectiveness."

The panel also discussed the benefits of such a move in terms of national facility utilization. It was generally agreed that such collaboration would be of great benefit. Participating scientists should benefit from such collaboration by having funds made available which might otherwise go into development of duplicate facilities. This collaboration would also provide an enlarged and strengthened scientific analysis capability.

Particpating panel members: E. Gossard, I. Harris, G. Heymsfield, A. Jameson, J. Miller, G. Morgan, D. Reynolds, R. Rinehart, R. Serafin and T. Vonder Haar.

# PANEL REPORT ON IN SITU SENSING (SURFACE AND AIRBORNE)

Chairman: P. Hildebrand

## I. Introduction

The meeting opened with a discussion of CSD research goals. It was concluded that the CSD research goal for near future research is the broad study of the cloud physics and dynamics of convective storms, from their genesis through maturity. Consideration of *in situ* sensing needs for 1980 was made in this context. In general, the discussion continually addressed the Grover-Miles City tradeoffs; other possible field locations were not thought to be viable alternatives. Only instruments essential for full investigation of presumed CSD goals were discussed.

## II. Surface Sensing

1) Rainfall measurement - a dense raingage network does not seem necessary for CSD goals. A sparse gage network, with gages at mesonet sites, supplemented by radar, should provide the necessary $\sim$ 10% mean area rainfall accuracy (from gages) plus good measurement of rain from individual cells.

2) Hail measurement - the major need for CSD hail measurement is best satisfied by hail chase teams. Two to four vehicles with radio communication and direction can make the most useful hail measurements, typically providing time-resolved hail samples, size distributions and hail swaths, with concurrent weather observations. Hail samples can be saved for later laboratory analysis. Aircraft support for identification of hail swaths is recommended. These measurements are far more useful to complete hail studies, perhaps in concert with dual-wavelength radar, than are hailpads which suffer from lack of time resolution and weather observations. Hailpads should be considered as an addition based on resource availability. The need for an improved hailpad is stressed. Such a sensor needs hail size and time resolution capabilities.

3) Rawinsondes - rawinsonde support is necessary for CSD research with at least three sites and at least two releases per operational day and several releases during intensive research periods.

4) Mesonet - mesonet stations are considered to include wind, temperature, humidity, and pressure sensors, plus additional optional measurements including rainfall, hail and radiation. The need for digital recording is stressed for the reasons of accuracy and quick access to data. Two basic uses of mesonet data are seen: operational and dynamic analysis support.

   a) Operational - the CSD case studies and model simulation clearly show the need for operational knowledge of gust front location and other storm surface circulations. Such real-time operational knowledge will enable improved direction of aircraft and radar data collection when studying growing convective cells which are likely to merge with the mature storm. The 30-station NCAR PAM network is marginally adequate for this operational surveillance. If spread over 2400 $km^2$

the 30 stations would give 80 $km^2$ per station or a station spacing of 9 km.

b) Dynamic analysis support - a higher station density is needed for good support of storm dynamic analyses, particularly when one considers the resolution of other instruments, and typical storm scales. Scales of $\geq$ 1 km are desired for many in-storm measurements. While such resolution is impossible for large-scale surface instrumentation, reducing the operational 9-10 km PAM station spacing to half that is advisable for analysis work. This would require an additional $\sim$ 100 stations. A nested mesh could also be considered.

The need for work on mesonet data analysis computer programs prior to the 1980 field season is stressed. These programs should consider use of advection of data to increase resolution.

A pair of investigations of surface data are suggested for completion prior to 1980 and for use in designing the field study. Both investigations should be relatively simple.

1) A simulation should be made, using existing data, of the utility of real-time PAM data in directing operations and predicting the location and time at which cloud development might occur.

2) A quick review of necessary scale sizes for surface measurement at the 1980 field site should be undertaken. This will better enable selection of operational and full mesonet station spacing.

The possible move to Miles City - HIPLEX is seen as a distinct advantage for mesonet data due to the additional 50-75 stations, a possible disadvantage for hail measurement due to poor roads, and of no effect for rainfall measurement.

## III. Aircraft Observations

Six types of aircraft are needed for full cloud physical-dynamical studies. Full consideration of the broad CSD goals will require all aircraft types.

1) Subcloud - air motion sensing and inflow subcloud dynamical structure. The NCAR Queen Air aircraft are good for this; use of two is probably required.

2) Cloudbase - cloud physical and dynamical structure. Good cloud physics instrumentation is necessary, as well as sensing of vertical velocity/air motion and thermodynamic parameters. One Queen Air or better aircraft is needed.

3) Midlevel environment - dynamics. One high-performance, perhaps King Air-type aircraft with air motion sensing and dynamical measurement capabilities is needed. Flights out to several cloud diameters are suggested.

4) T-28 - cloud penetration, cloud physics. The T-28 is a unique and valuable instrument and should be maintained and improved with additional and better instruments. Improved vertical velocity or air motion sensing and data gathering capabilities and addition of a humidity sensor are recommended.

5) High level - dynamical and cloud physical measurements. One high altitude aircraft ($\geq$ 30 K ft) is needed to measure high level storm effects including dynamic and thermodynamic structure, and cloud microstructure.

6) Sailplane - early stage cloud physics. The use of the NOAA/NCAR sailplane in early cumulus stage cloud physics is valuable and should be continued. Future replacement of the sailplane with an aircraft of the capabilities of a supercharged Cessna 180 should be considered. Such an aircraft would have many of the soaring capabilities of the sailplane plus additional flight and instrumentation capabilities. Considerably more flexibility in flight plans plus a wider range of instruments would be possible.

The need for improvements in aircraft instrumentation was discussed. CSD should actively address the need for:

1) Quick-look data for all operations. The example of the University of Wyoming is excellent.

2) Improved humidity sensing in low temperature and humidity conditions.

3) Improved cloud physics instrumentation. The most important area is liquid water (drop spectral) measurements. However, the whole spectrum of aircraft cloud physical instrumentation needs careful consideration and some improvement.

4) Accurate flight track information is needed for accurate correlation of aircraft and radar data.

The importance of routine instrument calibration for all instruments including aircraft cannot be overstated. In addition, there is a need for redundant measurement and intercomparison of data between aircraft and other sensors, both in-cloud and out-of-cloud.

The possibility of CSD-HIPLEX collaboration holds some advantages for CSD in regards to aircraft resources. The problem of conflicts between CSD and HIPLEX needs and goals may require division of aircraft time, in part supporting HIPLEX needs, in part supporting CSD needs. Collocation of aircraft and the same operational site and the large available airspace are advantages of collaboration with HIPLEX. These problems need careful consideration, including consideration of advantages of CSD operation alone at Grover in 1980, with consequent reduction in scope of CSD goals for that experiment.

Participating panel members were: C. Biter, J. Dye, J. Fankhauser, P. Hildebrand (Chairman), P. Johnson, N. Knight, P. MacCready, G. Morgan, J. Prodan, P. Smith, and D. Veal.

# REPORT OF PANEL ON RESOURCES AND STRATEGIES

Chairman: B. Phillips

## I. Background and Charge to the Panel

Basically, CSD is asking: Given the available resources, what is the best direction and use for a national scientific team? Where can CSD most effectively commit their scientific resources?

Consideration of these questions was given recognizing the background of a need, on the national scale, for coordinating mesoscale field research efforts because of the limited resources that are available within the atmospheric science community and because of a need to economize rather than proliferate and duplicate costly experimental field programs.

The charge to the Resources and Strategies Panel was recognized as a very difficult one to attack. Since the panel's deliberations rested heavily upon considerations being discussed at other Workshop panels, the initial hour was used to permit our panel members to attend other panel group meetings to try to get the flavor of the considerations in those meetings.

## II. Broad Discussion Areas

Before listing more specific factors considered and recommendations of Resources and Strategies Panel, it is worthwhile to review some general topics which were discussed and about which there existed uniform agreement among panel members. These are as follows:

1) CSD should strive to remain a leader and should continue to work in the scientific areas of convective precipitation and dynamics.

2) The nature of the resource limitations recognized by the panel included scientific manpower, measurement systems and equipment, and dollars.

3) The focus of CSD effort should be directed within the NCAR objectives of attacking problems which are in the national interest and which, because of size and/or continuity of the effort needed for meaningful attack, beyond the normal limits of university research efforts.

4) At the same time CSD has the obligation to provide a focus of research which can directly or indirectly support or encourage university scientific participation and data sharing to the maximum extent possible while not impacting, in a negative sense, the CSD program. For example, the field measurements of university scientists working in thunderstorm electricity could be supported within a CSD field measurement program which would provide the particpating scientists with a much increased total data set.

5) If CSD should choose to engage in cooperative-type field measurement programs, the respective goals, responsibilities, and areas of research should be carefully delineated prior to the program so that there exists no questions between participants regarding the degree of cooperation, responsibility and leadership roles, participant program needs and degree of data sharing, etc.

6) The panel discussed and recognized that, within the overall national atmospheric science program needs, the study of convective elements embedded in cyclonic storms and nighttime convective storms are within the purview of CSD research aims and should be within the present considerations of the panel. In general, a consensus was that these research areas may be of great interest to CSD. However, priorities still favor daytime, more isolated convective systems which are more amenable to study and from which there is still much to learn.

## III. Factors Considered by Panel

Within the broad panel discussions, some ten topics or factors can be identified as significant in the panel's arguments toward arriving at recommendations for future research decisions for the CSD team. These are listed below and are followed by brief paragraphs which are statements of the panel consensus and judgments for each topic/factor.

1) What are the scientific areas of CSD competence, leadership, and interest?

2) What are the existing and expected CSD resources?

3) What are the CSD resource needs?

4) What are the CSD "national" goals?

5) What are the possible impacts to universities which might result from CSD engagement in a cooperative program involvement with other ongoing research programs?

6) Are there primary cloud and weather regime considerations for CSD?

7) What are the costs of relocating CSD field measurements from northeast Colorado (Grover-NHRE)?

8) What are the field research program options facing CSD?

9) Considering cooperative programs with other ongoing research or planned research, what benefits to other programs within the national goals framework would result from CSD participation?

10) Is CSD asking, or should CSD ask, the panel for specific direction of the CSD research?

The panel responses ensuing from the discussions are summarized as follows:

1. Areas of CSD's Competence, Leadership, Interest

   a) Precipitation growth, precipitation growth in relation to cell and storm dynamics and flows in convective storms.

   b) Two convective regimes -

      i. initiation and development phase

      ii. severe storm phase.

2. CSD Resources

   a) Competence for field program management.

   b) Analysis expertise of the CSD scientific team.

   c) CP-2 10 cm coherent radar.

   d) DADS system.

   e) Multiple aircraft tracking-positioning system.

   f) T-28, South Dakota School of Mines and Technology support team--presently limited by dollars.

   g) Cloud-physics instrumented sailplane.

   h) Grover experimental site with public acceptance, aircraft control space, FAA support.

   i) Approximate $2M annual funding.

   j) Other facilities possibly available to major programs within overall NCAR support: C-Band Doppler radar, research aircraft, PAM 30-station network, 3-station upper air sounding equipment.

3. Probable Needed Resources (implies a defined CSD Field Experiment)

   a) Additional ground network.

   b) Field experiment operational dollars.

   c) Additional instrumented aircraft with scientific and operational support staff.

   d) Additional upper air sounding stations.

e) Ability to keep experimental site active on year-to-year basis.

f) Access to HIPLEX Data Net.

g) Equipment development or access useful--would be a spectrum of remote sensing ground-based equipments and aircraft *in situ* and remote sensing equipments. Included are such systems as cloud Doppler radar, fast-scan radar, remote temperature, humidity, wind soundings, aircraft Doppler radar, microwave radiometers, IR radiometers, etc. These are long-term needs which are mandatory to the research advances in the mid-1980's.

4. National Goals for CSD

a) CSD should maintain leadership in the areas of convective phenomena, precipitation development, and hydrometeor interaction with cell and storm dynamics.

b) CSD should advance understanding in these areas through theoretical studies which are carried forward with field experiments and analysis.

c) A CSD field experiment should provide, to the extent possible, a central focus of research that is attractive and usable the university scientists working in similar or related disciplines (for example, atmospheric chemistry, thunderstorm electrification, etc.).

d) CSD's program should include experimentation in the modification of convective processes.

e) CSD should encourage and assist the development of needed instrumentation and measuring systems.

5. Impact to University Programs of CSD Cooperation with Other Field Experiments

a) Supportive: University programs would gain from the larger available data base which is achieved within the cooperative measurements.

b) Constraints: University programs cannot always be supported by directed measurements to the degree desirable. For example, overall priorities will sometimes preclude directing a Doppler radar sector scan to a specific cloud that may be of immediate interest to a participating atmospheric chemist. Establishment of priorities will be difficult. Most participating university scientists probably would need to be largely independent of operational project direction a major portion of the time.

c) Competitive: Concern was expressed that large cooperative programs would receive preferential funding and facility support or that university proposals would be forced to be in support of the larger programs.

6. Cloud and Weather Regime Considerations

The CSD experience lies in the High Plains convective storm observations and analysis. However, the CSD expertise and resources could be applicable to nearly any area where convective processes are frequent, from the High Plains to Florida. Any area could have advantages and disadvantages given. The continuity of CSD program and scientific understanding would favor continuing field epxeriments in northeast Colorado or in a climatologically and meteorologically similar area for the present. Tracking back to a preceding paragraph, consideration needs to be given to future efforts in convection associated with synoptic storms (imbedded convection), in nighttime convection, and in convection associated with diverse meteorologies and microphysics.

7. CSD Relocation Costs

Estimates of the costs of relocating major components of the CSD equipment resources are in the range of $200K to $400K, considering those components to include CP-2, DADS, network site relocationing, aircraft tracking, etc. The upper limit cost is comparable with the costs of a given summer field program at the existing northeast Colorado site.

8. Field Research Experiment Options

Possible options for CSD field program include:

a) Continue at the northeast Colorado site supported by such other research efforts as are attracted and benefitted by the CSD program.

b) Engage in a cooperative field program with one or more ongoing or planned research programs such as:

i. CSD-HIPLEX - Montana

ii. CSD-NSSL (SESAME?) - Oklahoma

iii. CSD-FACE - Florida

iv. CSD-SPACE-Kansas HIPLEX - Colorado-Kansas

9. Benefits to Other Programs

Benefits to other programs such as listed in the paragraph above seem obvious in each case. Simply put, the types of measurement and analysis which have been demonstrated possible by the CSD group within NHRE are not being done in the other programs (with the partial exception of the Oklahoma program where good Doppler data have been obtained). The discussions on these benefits were not extensive in any case. It was generally accepted that the benefits to the other programs considered above were equal to or greater than the "reciprocal" benefits to the CSD research program.

10. Panel Definition of the CSD Research Program

The panel felt strongly that within the broad guidelines given here, the specific direction of CSD research and the path to achieve that research must be determined by CSD itself. The panel has neither the necessary data nor the scientific prerogative for formulating specific research definition.

## IV. Panel Recommendations for Criteria for CSD Decision

The panel recognizes that key questions to CSD in a practical sense concern whether or not CSD should engage in a cooperative program effort and if so, with which research group and at what site. The recommendations of the panel attempt to define criteria for these judgments as follows.

1. Recommended criteria for CSD decision on cooperation with another program.

a. Decide on what CSD wants to do experimentally in the field in 1980. Set forth clearly the goals and objectives and the desired approach. This may be based on the CSD perception of the critical scientific questions in its area of expertise. Given that, next describe the measurements required to achieve the stated goals. This listing should be first rather complete and alternately somewhat bare-bones.

b. With the projected available budget, think through beforehand what percentage should be set aside for analysis and what could reasonably be allocated to the field effort.

c. With this budget partition, determine to what extent CSD can afford the complete measurements list or even if CSD can afford the bare-bones list.

d. With this information on what can be afforded, examine the question, "How much will the CSD scientific effort deteriorate with the measurements that can be afforded?"

e. Now CSD is ready to make the decision on cooperative work with another group on the basis of scientific payoff, group interest, dislocation problems and costs, scientific community served, etc. For example, by participating with HIPLEX can the desired missing measurements be filled in? Examples may be the King Air, Lear Jet, surface network measurements. Can relocation costs be offset by outside funding or reduced operational costs?

f. If the scientific payoff is substantially greater and the CSD group is interested in the scientific effort set forth as a minimum, then CSD is in a good position to argue that the cooperative aspects offer greater national benefits to CSD as well as to other university investigators, etc.

g. In this fashion CSD will examine cooperation possibilities with all possible programs, not from the point of view of just getting together but from the view of maximizing the scientific output of the group.

From a national resource point of view a cooperative venture may benefit from each party coloring their operational programs slightly differently during cooperative experimental years so as to maximize the total scientific output. This may be required to meet both parties' objectives.

h. Alternately, if CSD determines to remain in northeastern Colorado (Grover), again from a national resource point of view, it may be prudent for other research groups--for example, HIPLEX--to utilize some of the CSD facilities such as the CP-2 radar, rawinsondes, etc., during the non-CSD field operational seasons.

i. In summary, the decision on whether or not to cooperate and on the extent of cooperation must be made on the basis of the scientific productivity of the CSD team within the funds and facilities available. Any cooperative program, of necessity,must be such as to maintain the scientific integrity of the participating organizations. A clear agreement as to participant roles and responsibilities, the degree of data sharing, the provision of resources, etc., must precede any actual selected cooperative program. Finally, a fully comprehensive CSD program with or without cooperation should encourage participation by university scientists of diverse disciplines (such as atmospheric chemists) to the extent possible without impairing CSD scientific output.

Participating panel members: A. Dennis, D. Dirks, C. Downie, J. Hinkelman, W. Hitschfeld, R. Lavoie, R. List, J. McCarthy, B. Phillips , R. Sanborn, J. Scoggins, B. Silverman, P. Squires, W. Vaughan, and D. Veal.

APPENDIX A

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# APPENDIX B


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## Introductory Remarks

by P. Squires (NCAR)

The Convective Storms Division of NCAR is an outgrowth of NHRE. Its mission is to better understand midlatitude convective storms. Our approach is to continue the line of research begun in NHRE, using simultaneous, well-coordinated observations of convective clouds and storms to provide comprehensive data sets delineating those processes which are currently thought to be most important in the formation of precipitation, aiming towards the development of a fully three-dimensionsl cloud model with adequate dynamics and microphysics.

This Workshop is an initial step in the planning of field programs in 1980 and beyond. From our discussions here, the CSD Advisory Panel (nearly all of whom are present) and CSD staff look for both guidance and collaboration. It is our hope that the kind of field program being planned will provide an attractive context for scientists at universities and elsewhere to carry our studies of various storm-related topics, including, for example, thunderstorm electricity, certain aspects of atmospheric chemistry, or downdrafts and outflow phenomena, and it is hoped that those who have such interests will partake fully in these discussions and so help mold the program.

On the basis of the guidance provided by this Workshop, CSD will prepare plans for a program which is commensurate with the resources expected to be available. Scientists who wish to take part in the program may find these plans useful in their own planning; for example, as an appendix to a proposal to NSF or another agency. The first such plan will need to be prepared quite early next year to serve as a basis for a request for NCAR facilities in 1980.

Some of the questions concerning which guidance is needed are listed in the "Draft Charge to the Panels." Special attention is drawn there to the question of choosing a field location. The field programs of NCAR-CSD cannot be considered in isolation, but should be planned in the context of other research. A simple example of this was that when plans were announced for SESAME 1979, we deferred our plans to go into the field for a year to avoid facility conflicts, and also so that some of our staff could take part in SESAME at the NSSL site in Oklahoma, and hopefully that some NSSL staff might be able to collaborate in our field program. The problem of making the best use of limited resources has many complex ramifications; the next speaker (Dr. Dirks of NSF) will report on a recent workshop which discussed the future planning of mesoscale research, and we have arranged the agenda to devote this afternoon and evening to briefly reviewing not only our past work, but also that carried out in other large programs in midlatitude mesoscale meteorology which center on convective processes.

CSD staff has given some thought to the question of a field site. Because the primary (though not exclusive) orientation of our work has been towards understanding precipitation processes in an existing storm, rather than towards understanding the initiation of storms, we have been inclined to think that there are significant advantages in choosing as our initial target storms such as those of the High Plains, in which, on most occasions, precipitation seems to form by the Wegener-Bergeron-Findeisen mechanism, and neither droplet coalescence nor ice multiplication (as we currently think this happens) appear to be important. The evidence available suggests that such storms can be found over a wide area--for example, at the HIPLEX site in Montana. Because of the close similarity of our scientific objectives and those of HIPLEX, it would appear that one possible choice for CSD would be to collocate with HIPLEX at Miles City, Montana, and some exploratory conversations have been held with the Bureau of Reclamation staff on this topic. Later this afternoon there will be a presentation on HIPLEX, and some climatological data and maps for several research sites, including Miles City, are on display.

## Report on NSF Mesoscale Planning Conference

by R. A. Dirks (NSF)

The NSF asked UCAR to convene a small two-day Mesoscale Planning Conference in early November 1978 to consider the problems and opportunities in midlatitude mesoscale field research and to initiate what the NSF hopes will be ongoing discussions and planning for a more coordinated national program in this area. The discussions were also to provide advice to the NSF for its programs in this area. Conference participants represented major NSF-related field programs, major facility operations and Federal agencies.

The conference was motivated by several factors:

1. A current proliferation of field projects with at least an apparent lack of coordination and limited interaction.

2. Limited funding; the near-term growth rate in NSF funding may be less than inflation unless we develop a convincing strategy that a thrust in mesoscale meteorology of midlatitudes is an important national interest.

3. Limited facilities; use of available facilities is in competition with atmospheric chemists and tropical meteorologists and there is already an over-subscription of all NCAR facilities.

Conference participants were divided into three subgroups:

1. Studies of storm precipitation processes (e.g., CSD/NHRE).

2. Environment of convective storms (e.g., SESAME).

3. Mesoscale convective and precipitation processes associated with synoptic systems (e.g., CYCLES).

Lists of scientific questions, technical needs and operational and policy problems were identified. In addition, the following general recommendations were given:

1. Increased group interaction in field programs with more cooperative efforts between programs in the same geographic region.

2. Careful balance between large and small programs to provide opportunity for resources and facilities to small programs which emphasize individual and small group creativity.

3. Large cooperative programs must have a focal group (maybe two) with a stable funding base.

4. Intermittent rather than annual field operations can be achieved and cost effective in certain circumstances.

5. There should be a national approach to major facilities both at NCAR and at universities.

6. Both the scientific and societal values of mesoscale projects should be more specifically defined.

We see the present workshop as providing a forum for expanding on a part of the planning conference.

We strongly endorse a highly cooperative university-NCAR field program on convective storm research. NSF is willing to support a number of university collaborators in such a cooperative program.

# DRAFT CHARGE TO PANELS

The following Draft Charge to Panels was adopted by the Workshop:

UCAR has defined two missions for NCAR: providing facilities and providing a focus for attacks on large problems, in collaboration with scientists at universities and elsewhere. The task of CSD is to continue the thrust of the research carried out in NHRE, in which comprehensive and coordinated observations on storms were used to study the interactions between storm dynamics and microphysical processes, leading to the formation of precipitation.

In discussing "goals and strategies" for the 1980 field program of CSD, the Workshop will necessarily consider this effort in the setting of mesoscale research across the nation, and in particular of that segment of such research which is primarily concerned with convective precipitation processes. At a meeting to discuss midlatitude mesoscale research at NCAR on November 7 and 8, the whole topic was subdivided into three parts, each of which was considered by a working group, as follows:

1. Storm precipitation processes (Changnon).

2. The initiation and environment of storms (Simpson).

3. Mesoscale convective and precipitation processes in synoptic systems (Braham).

A summary of the reports of the three groups will be presented at the Workshop; this should help orient discussion of this important aspect.

In panel discussions, as in the whole workshop, it would appear that the questions addressed should include the following:

1. What scientific topics and opportunities should be emphasized?

2. What factors should be taken into account in the choice of a field site?

3. At what intervals should CSD mount major field programs?

4. In what scientific areas will other scientists wish to collaborate? Who?

5. What scientifically productive interactions can be expected to occur between the various collaborating groups?

6. What arrangements (logistical, data exchange, etc.) will be needed to maximize useful interactions?

7. What NCAR facilities should be requested for 1980?

Many of these questions are highly interactive and complex. Question 2 is especially basic; the criterion which states that phenomena should be studied where they occur in their simplest and purest form is susceptible of various interpretations, and the merits of concentration of effort in one location may be argued against those of geographical diversification.

Panel chairmen are asked to prepare notes for a few-page report of their discussions for presentation and discussion at the evening session on Wednesday, the 29th, and to have the report ready in draft form by 10:00 a.m. on Thursday, the 30th.

## Some Suggested Topics for Panel Discussions

In view of the complexity of the issues, and the short time available, CSD staff put together some suggested topics which the various panels might wish to include in their discussions:

### Microphysics and Aerosols

Is the thesis valid that High Plains storms are microphysically simpler than those, say, of Florida?

Are hailstone embryos (frozen drops versus graupel) a reliable indicator of the microphysical nature of the cloud?

What are the relative merits of studying the earliest stages of precipitation formation versus mature storms?

In trying to understand the formation of precipitation, would it be sufficient to start with observed cloud particle properties, or is it necessary to study the aerosol?

What can be done to accelerate the development of more reliable microphysical instrumentation?

### Dynamics

What basic dynamic processes can we observe?

What are the realistic goals of cloud modeling?

What are some discriminating parameters which could be used to make comparisons of models with observation? Can they be measured?

### Atmospheric Electricity

Opportunities: the influence of cloud microphysics and dynamics on cloud electricity.

Potential utility of atmospheric electricity measurements in exploring cloud physical problems.

Geographic area and cloud size as factors determining potential for collaboration on atmospheric electricity problems.

Possible realistic objectives for collaboration.

Aircraft platform flight plans and instrumentation needs as related to the above realistic objectives.

Surface and other instrument or data needs.

Chemistry Panel

Opportunities: problems of cloud influences on atmospheric chemistry.

Uses of chemistry to explore cloud physical problems.

Geographic area and cloud size as factors determining potential for collaboration on chemical problems.

Possible realistic objectives for collaboration.

Aircraft platform, flight plans and instrumentation needs as related to the above realistic objectives.

Surface and other instrument or data needs.

Possible (doubtful) topic: artificial tracer studies.

Remote Sensing Panel

Keeping in mind the emphasis on air motions and physical characteristics within convective clouds, the following would seem to be questions the panel may wish to discuss:

What is the potential role for satellite-derived information?

What radar system or sets of systems can be best employed?

Is there a role for lidar systems?

Is there a role for other remote sensing techniques, such as acoustic soundings?

Based on above:

What existing systems should be requested from NCAR?

Can some collaborating groups bring systems into the field? If so, who will analyze collected data?

Should new systems be acquired or developed, and if so, by whom?

In Situ Sensing

In view of the emphasis on the internal physics of clouds, how important are the surface network measurements of pressure, temperature, humidity, wind, and precipitation? How large an effort should be put into the measurement of hail?

How seriously does local topography (and other factors such as roads) affect the logistics of monitoring surface networks, the utility of the data, and radio communications?

What level of effort should be put into the intercomparison and validation of aircraft instrumentation? What instruments should receive priority attention in this regard?

Resources and Strategies

Does the probable microphysical simplicity of High Plains storms make them a more attractive initial target than, say, those of Florida, where the forcing mechanisms may be simpler?

If CSD were to collocate its field program with another existing project, what kind of guidelines could be defined concerning operational management in the field and the subsequent sharing of data?

Is it desirable to consider a site which includes a large urban area in order to include in the objectives a consideration of inadvertent effects?