# Cold Land Processes Working Group

NASA Land Surface Hydrology Program

## Planning Workshop

June 28-30, 2000

Fort Collins, Colorado

**Includes Post-Workshop Revisions**

**July 13, 2000**

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# Part I: Workshop Details

## Workshop Schedule

**Wednesday, June 28**

| | |
|---|---|
| 8:00 | Vans pick up participants at University Park Holiday Inn, Fort Collins CO |
| 8:30 - 10:30 | Convene workshop at Colorado State University, Fort Collins |
| 8:30 - 8:45 | Opening Remarks and Introductions |
| 8:45 - 9:15 | Overview of Cold Land Processes Mission Planning |
| 9:15 - 9:20 | Election of Working Group Chairman, Vice-Chairman |
| 9:20 - 9:30 | Review Task Plan for CLPM Working Group |
| 9:30 - 10:15 | Overview of Field Experiment Planning |
| 10:15 - 10:30 | Summary and Field Trip Instructions |
| 11:00 | Vans depart Fort Collins to candidate Intensive Study Sites (ISA) |
| 11:00 - 1:00 | Travel to Berthoud Pass, CO |
| 11:30 - 11:40 | Exit 243 (Highway 66): View of Continental Divide flight line planned for Spring, 2001 |
| 1:00 - 1:30 | Tour Q12 site, Berthoud Pass |
| 1:30 - 2:00 | Travel to Fraser Experimental Forest (FEF ISA), near Fraser, CO |
| 2:00 - 2:30 | Cabin Check-in ($15 per person) |
| 2:30 - 5:30 | Tour Fool Creek Watershed, FEF ISA |
| 6:00 - 7:30 | Dinner at restaurant in Fraser |
| 8:00 - 9:00 | Discussion, Main Lodge |

**Thursday, June 29**

| | |
|---|---|
| 7:00 - 7:30 | Continental Breakfast, FEF Dining Hall (provided) |
| 8:00 - 9:15 | Travel to Rand, CO (North Park ISA) |
| 9:00 - 9:10 | Stop 2 mi SE of Rand for brief overview of North Park |
| 9:15 - 11:30 | Travel to Walden, CO (North Park ISA) |
| | Stop: County Road 27/Illinois River<br>Stop: County Road 21/Owl Ridge Overlook<br>Stop: Highway 14/Arapaho National Wildlife Refuge Overlook |
| 11:30 - 12:30 | Lunch at the Elkhorn Café, Walden (“Fresh Homebaked Cook’in”) |
| 12:30 - 1:00 | Travel to Rabbit Ears Pass (Rabbit Ears ISA) |
| 1:00 - 2:00 | Tour USGS, WMO sites |

| | |
|---|---|
| 2:00 - 2:30 | Travel to Steamboat Springs, CO |
| 2:30 - 3:30 | Tour Yampa River Valley below Steamboat Springs and above Hayden, CO (Yampa ISA) |
| 3:30 - 5:30 | Meeting, Steamboat Springs Community Room |
| 5:30 - 6:00 | Check-in, Rabbit Ears Motel, Steamboat Springs ($49/night) |
| 6:00 - | Open |

**Friday, June 30**

| | |
|---|---|
| 7:00 - 7:30 | Continental Breakfast (provided) |
| 8:00 - 11:00 | Meeting, Steamboat Springs Community Room |
| 11:00 - 12:00 | Lunch (Open) |
| 12:00 | Vans depart to Denver International Airport (DIA) |
| 12:00 - 5:00 | Travel to DIA via Kremmling, Silverthorne, I-70 |
| | Stop: Loveland Basin Ski Area Parking Lot |
| 5:00 | Arrive, DIA |
| 5:15 - 6:30 | Vans return to Fort Collins |

## Purpose of the Cold Land Processes Working Group

The Cold Land Processes Working Group (CLPWG) is one of three “Future Hydrologic Mission Working Groups” sponsored by the NASA Land Surface Hydrology Program (LSHP). Together, these groups have the goal of assessing, planning and implementing the required background science, technology, and application infrastructure to support successful land surface hydrology remote sensing missions. As such, these groups should do the following:

1. Bring together a sufficient number of leading researchers in science, technology, and applications on a regular basis in a workshop setting. These workshops should be well advertised to the community and be open to all.

2. Compare potential technologies for each mission, to identify the limitations of existing technologies and to recommend technological research to meet scientific objectives. The science objectives should define the required observations, which in turn should determine the technology requirements. It is important not to allow technological “special interests” to determine the course of mission planning and development.

3. The LSHP Future Hydrologic Working Groups should serve as a community focus for maintaining impetus for their respective mission concepts, marshal the talents and intellectual resources of leading researchers to identify both requirements for these future missions and deficiencies in our current understanding, and to effectively communicate these issues as a means of reaching a community consensus.

4. The most critical requirement of these mission working groups is to provide formally documented, peer-reviewed publications. The first of these publications will be the “EX”

mission planning documents that have already been developed. It is expected that these plans be formally peer-reviewed and published by the working groups (or via a NASA publication mechanism) in the near-term. More targeted reviews of the state of the science and technology should follow.

5. Progress towards developing the required groundwork using existing resources and identifying future needs. Ideally these working groups should position themselves flexibly enough to effectively respond to new research opportunities in support of hydrologic missions as they arise. Planning of coordinated field missions to refine and prove mission concepts should also be a focus of the working groups.

## Purpose of this Workshop

The participants for this workshop were selected to form a core group to act as a steering committee to begin working on the tasks described above.

This workshop will focus on planning for a large-scale field/aircraft experiment to support algorithm and model development associated with the Cold Land Processes Mission. This was identified in the EX-7 Science and Technology Implementation Plan as the most critical research component necessary to prepare for a Cold Land Processes Mission. Preliminary planning for the field experiment has identified a large part of Colorado as a suitable study area, with several candidate intensive study areas (ISA) identified within the state. Also, there are immediate and near-term funding opportunities that can potentially be exploited by the Working Group to support the field experiment. The workshop agenda will focus on familiarization of the proposed study area and some of the ISAs, on strategic planning for obtaining adequate field experiment support, and on planning for future CLPM Working Group activities.

# Part II: Background

## Overview of Cold Land Processes Mission Planning

The planning activities for a space flight mission focusing on hydrological processes in cold land areas originated in 1998 with NASA's preliminary planning for post-2002 Earth science missions. Subsequent planning activities have expanded this focus to include other potential opportunities to achieve the original mission goals. Therefore, the planning activities of the Cold Land Processes Working Group will not be limited to just the NASA post-2002 mission planning process. Today, there are multiple scenarios for reaching cold land process research objectives.

### A Brief History of Post-2002 Mission Planning and EX-7

#### The NASA RFI

To initiate planning of a nominal mission scenario for the 2002-2010 time period, NASA announced a Request for Information (RFI) in April, 1998. One hundred responses were received, which were then reviewed by six NASA interdisciplinary panels. These responses were then integrated into 23 mission concepts in three categories:

1. Earth Observing System Follow-on Missions (EOS), for systematic measurement of critical parameters;
2. Earth Probe Missions (EX), for exploratory research or focused process studies. This category included the Cold Land Processes Mission (EX-7), to focus on observing snow and frozen soil characteristics from space.
3. Operational Prototype Missions (OP), for instrument development.

It is worth mentioning that the RFI process was later formally criticized by the National Academy of Science for the short lead time allowed to respond to the request.

#### Earth Probe Missions

Each EX mission was considered essential for advancement of the respective disciplines. No particular mission priority was intended. The EX missions were intended to follow the model of the Earth System Science Pathfinder (ESSP), where a) baseline mission descriptions allow science, technology, and programmatic planning, and b) missions are selected as late as possible in the implementation process to ensure that the latest science and technology issues are addressed. An important concept with ESSP missions is that missions are not selected until both science and technology are "mission-ready".

#### The Easton Workshop

NASA convened a workshop in Easton, MD in August, 1998 to review and amend the nominal mission scenario developed from the RFI process. The workshop included 150 participants in disciplinary and interdisciplinary panels. The report from this workshop was published in November, 1998. This report endorsed the nominal Cold Land Processes Mission concept, namely, to measure snow water equivalent and frozen ground, using SAR imaging techniques at moderate-high spatial resolution (<= 1km) with a short repeat cycle (<= 3 days).

In total, the Easton Workshop endorsed three hydrology-related missions: 1) EX-7, for snow and frozen ground, 2) EX-4, for soil moisture, 3) EOS-9, a global precipitation mission. The latter was the principal systematic measurement recommendation in the hydrology and water cycle disciplinary domain, but the mission planning falls under the guidance and direction of NASA's Atmospheric Dynamics program.

### The Irvine Workshop

The NASA Land Surface Hydrology Program (LSHP) sponsored a workshop in Irvine, CA in April, 1999 to further refine the two hydrology related missions EX-7 and EX-4, and a third mission concept related to hydrology that involved measurement of lake and river stage using space-based LIDAR (or other techniques, possibly including InSAR). The EX-7 component of this workshop included 15 participants representing both science and technology interests. The EX-7 planning at this workshop refined the nominal mission concept of a SAR system to meet EX-7 goals. It identified key science and technology development and investments needed to become "mission-ready".

A report from this workshop (*Cold Land Processes Mission (EX-7): Science and Technology Implementation Plan*) was released to NASA LSHP investigators in November, 1999. This report was expanded by the NASA LSHP to include passive microwave mission options that were considered unlikely to meet EX-7 objectives at the Irvine workshop. In response to guidance from the NASA LSHP at the time of the Irvine workshop, the report was structured to provide a clear plan of actions necessary to become sufficiently prepared to draft a "mission-ready" proposal for EX-7 by 2003.

Following the Irvine workshop, NASA JPL engineers used existing SAR system cost models to prepare preliminary cost estimates for a dual-frequency, dual-polarization SAR satellite to meet the original mission criteria identified in Irvine. Estimated costs were approximately $350-400 million, well above anticipated ESSP cost caps (~$120 million). This information made it clear that EX-7 would not fly based solely on the ESSP model of low-cost, rapidly developed missions. Similar problems were identified by the group working on planning for the EX-4 (soil moisture) mission.

### The Hydrology Satellite Concept

To explore alternative strategies for meeting EX-4 and, to a lesser extent EX-7 objectives, a meeting was held at NASA JPL in January, 2000. The principal issue at this meeting was to attempt to identify a single "hydrology satellite", which could address mutual objectives at perhaps a lower overall cost, in part by partnering with the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) satellite program. Cost estimates were re-estimated as a result of this meeting, and it was determined that baseline launch vehicle costs alone, for a satellite payload of the order discussed (for either a combined EX-4/SMOS satellite or the nominal EX-7 satellite), exceeded the anticipated ESSP cost cap of $120 million.

## EX-7 Baseline Cost Reduction Considerations

At an estimated cost of $400 million, the baseline EX-7 Mission specifications (dual-frequency, dual-polarization SAR) is likely too costly for NASA to put into its own budget. It is clearly too expensive for current ESSP consideration. There are three obvious mechanisms for reducing the cost of the Mission to NASA: 1) co-funding through international partners, 2) co-funding through the Department of Defense (DOD), and 3) reducing the specifications of the Mission. The first two of these mechanisms have been explored to a limited degree by the NextSAR program (see below).

### International Partnerships

There is a precedent for international collaboration on U.S.-led SAR missions, including SIR-C/X-SAR, SRTM, and the 1998 ECHO-ELSIE ESSP proposal submitted jointly by U.S. partners and CNES. The Italian Space Agency (ASI) has expressed interest in collaboration on NASA's NextSAR mission throgh the potential contribution of an X-band instrument. Other nations, such as Canada, Germany, and Japan are presently planning and developing SAR missions. Mission collaborations with some of these nations were explored for LightSAR, with varying levels of interest. With new sensor specifications beyond LightSAR, collaboration possibilities should again be explored.

**DOD Buy-Down**

Collaborations with DOD were explored for LightSAR, but no serious collaboration interest materialized. Again, with new sensor specifications beyond LightSAR, collaboration possibilities should again be explored.

**Specification Reduction**

The cost of a single-frequency system is approximately one-third to one-half of the cost of a dual-frequency system. Although estimated costs for single-frequency systems still exceed current ESSP cost caps, the deltas are much less, and possibilities for collaborative cost reductions become more palatable.

## NASA's Next SAR: NextSAR(?)

NextSAR's legacy is LightSAR. LightSAR was conceived in 1996 as a single frequency (L-band) SAR. Mission definition studies were completed in 1997, and an Announcement of Opportunity (AO) for an industry partner was released by NASA in 1999. Only one industry proposal was submitted, and no proposal was selected.

This process was informative. Market risks and potential returns on investments do not justify an industry investment in a science-focused (L-band only) mission. If commercial enhancements are added (e.g. dual frequency, high resolution), the market potential increases, but so do costs and market risks and uncertainty. This results in fragile business plans with unacceptable financial risk to the government.

Science advocacy for a SAR satellite has grown beyond LightSAR's original scope. In the NASA post-2002 mission planning process, a dual-frequency, dual-polarization SAR (L-band and X-band) was specified for EX-7, and a SAR can potentially address four of the post-2002 nominal missions. Also, the NSF Earthscope initiative calls for an interferometric SAR in its second phase.

**The OSLTF**

An opportunity emerged for SAR mission collaboration between NASA, the petroleum industry, the U.S. Coast Guard, and the Environmental Protection Agency through the Oil Spill Liability Trust Fund (OSLTF). The OSLTF was established as a result of the Oil Pollution Act of 1990. Under this Act, the owner or operator of a facility from which oil is discharged is liable for the costs associated with the containment or cleanup of the spill and any damages resulting from the spill. When the responsible party is unknown or refuses to pay, funds from the OSLTF can be used to cover removal costs or damages resulting from discharges of oil.

The primary source of revenue for the fund is a five-cents per barrel fee on imported and domestic oil. Collection of this fee ceased on December 31, 1994 due to a "sunset" provision in the law. Other revenue sources for the fund include interest on the fund, cost recovery from parties responsible for oil spills, and any fines or civil penalties collected. The Fund is administered by the U.S. Coast Guard's National Pollution Funds Center.

The fund can provide up to $1 billion for any one oil pollution incident including up to $500 million for the initiation of natural resource damage assessments and claims in connection with any single incident. The main uses of Fund expenditures can include research and development and other specific appropriations.

In September 1999, Texaco initiated discussions with NASA and expressed strong support for a NASA/OSLTF collaboration to develop a SAR mission, under the condition that the petroleum industry participate in the selection of the system parameters, and that they receive priority tasking for oil spill emergency response. A preliminary mission concept has emerged with a dual-frequency, high-resolution, polarimetric, interferometric SAR instrument, that addresses the basic requirements for rapid oil spill response and environmental management, as well as the science objectives for LightSAR, NSF/EarthScope InSAR, and Cold Land Processes Research. The life cycle cost of this mission is estimated to be about $400 million, very close to EX-7 estimates. This new mission concept was presented at the SAR Users Workshop at Houston during January 19-20, 2000; the proposal to use OSLTF funds to co-fund (with NASA) such a mission has apparently been well-received by the oil industry.

However, expenditure of the OSLTF ultimately requires an act of Congress. Congress directed NASA to submit a report by February 1, 2000 describing the actions the agency can take to develop an operational SAR capability in the U.S.. Congressional approval would also be required for the budget increase to NASA necessary for NASA to co-fund the mission. The *SAR Mission Study Report* was submitted to NASA HQ in February, but has remained at NASA Congressional Affairs since that time.

As with EX-7, in the event that Congress does not approve the cost of a dual-frequency, dual-polarization mission, then planning activities for NASA's next SAR mission will likely begin to include other cost-reduction strategies, including specification reduction for more focused science missions.

## Passive Microwave Options

Passive microwave options were introduced to the *EX-7 Science and Technology Implementation Plan* by the LSHP following the Irvine Workshop. At that workshop, passive microwave systems were not considered to be a viable alternative for reaching EX-7 goals, due mainly to the coarse spatial resolution achievable. Although technological development goals include increased spatial resolution over the next several years, near-term target resolutions on the order of 15-20 km were considered to be too coarse for hydrologically meaningful information retrievals (considering median basin sizes on the order of 400 $km^2$). In the longer term, technological development goals include spatial resolutions as small as 5 km, which may be more relevant to hydrological applications. The major concern over spatial resolution at the Irvine Workshop pertained to the need to observe snow water equivalent in mountainous regions, and the reliability of coarse-pixel retrievals over heterogenous snow covers. One objective of the present working group will be to evaluate this issue.

## Summary of Cold Land Processes Mission Planning to Date

The EX-7 Mission was originally conceived as a SAR system through the NASA post-2002 mission planning process. It was later refined, through a NASA-LSHP workshop, into a dual-frequency, dual-polarization SAR sensor, based on theoretical considerations only (demonstrated SWE retrievals are based on three frequencies, considered at Irvine to be far too expensive for serious consideration by NASA). EX-7 Mission objectives were also refined, and focused on providing moderate-to-high resolution snow and freeze/thaw information suitable for input to state-of-the-art hydrological data assimilation models, even in areas of complex topography. The *EX-7 Science and Technology Implementation Plan* resulting from that workshop outlines the work necessary to better prepare for a Cold Land Processes research mission. Not the last word on the matter, research objectives and sensor characteristics described in that report need to be refined further, and supported with objective data. A field experiment was deemed essential to address these issues further.

Substantial uncertainty exists concerning the future course of NASA's post-2002 mission planning. This uncertainty is compounded by the high estimated cost of the nominal EX-7 Mission. Therefore, cost-reduction strategies need to be explored. The trade-offs of single-frequency sensors versus dual-frequency, different spatial and temporal resolution, active versus passive, etc. all need to be explored. Again, a field experiment is necessary to address these issues.

NextSAR is clearly an important opportunity for reaching Cold Land Processes research objectives. The instrument is essentially identical to the baseline instrument initially identified for the EX-7 Mission, and the NextSAR planning process is much further along than the EX-7 planning process. The NextSAR development schedule indicates that is can be launched within four years after project start. In the event of Congressional approval of the mission, it will be incumbent upon the Cold Land Processes Working Group to provide early feedback on system specifications (e.g. C vs. X, resolution requirements, etc.), to participate in mission planning to reach Cold Land Processes research objectives (e.g. ground segment architecture for cold land processes research), and to ensure that at-launch algorithms for snow and freeze/thaw are sufficiently developed. Furthermore, there will be a number of issues regarding data availability from a multi-objective mission involving commercial partners with rapid response requirements. The CLPWG needs to clearly identify and formalize these mission requirements for cold land processes research, and must be prepared to respond rapidly to a decision for NextSAR to proceed.

## Status of the CLPM in NASA's 2000-2010 Draft Strategic Plan

Much of the uncertainty associated with the status of NASA's post-2002 mission planning over the last year or more is likely due to the lack of an overall strategic plan for NASA's Earth Science Enterprise. This problem should be resolved once a strategic plan is finalized and adopted. Progress has been made in this regard with the recent release of a draft plan, "*Understanding Earth System Change, NASA's Earth Science Enterprise Research Strategy 2000-2010*". The draft has been submitted for review by the National Academy of Sciences. The final Research Strategy incorporating the results of that review is expected to be published in Fall, 2000. The following excerpts from the draft plan describe the status of the CLPM within the plan:

**Sec. 2.3: Responses of the Earth System to Natural and Human-Induced Disturbances**

> ...it is essential to understand the global water cycle, both as a central element of atmospheric climate change and a critical environmental factor that influences the other components of the Earth's system. In particular, the availability of soil moisture and the transition of frozen soil to thawed conditions have a controlling influence on the productivity of terrestrial ecosystems....New active and passive remote sensing techniques from space may lead to global observations of soil moisture, snow water equivalent, freeze-thaw transition, the stage of water in rivers and inland water bodies, and river flow, and usher in a new approach for hydrological sciences, emphasizing continental- to global-scale studies.

**Sec. 4.3: Earth System Responses and Feedback Processes**

> (What are the effects of clouds and surface hydrologic processes on climate change?) Quantitative understanding of hydrologic processes over large areas, commensurate with the scale of climate phenomena, will require a breakthrough in large-scale observation of hydrologic properties and physical climate drivers. Specific observational requirements to address this problem include (in addition to atmospheric properties, precipitation, and surface radiation fluxes) exploratory measurements of soil moisture, snow accumulation, and the transition between frozen and thawed soil conditions.

**Table 4.3: Observational Requirements for Response and Feedback Process Studies**

| Parameter | Implementation Detail | Technical Readiness | Operational Potential | Partnership Potential |
|---|---|---|---|---|
| Snow Cover and Accumulation | Need to assess snow depth or water equivalent quantitatively | Awaiting demonstration | NPOESS commitment for snow cover | Possible |
| Freeze-Thaw Transition | Need to assess in all cloud and vegetation conditions | Awaiting demonstration | Desired; subject to operational viability | Possible |

**Sec. 4.4: Consequences of Global Changes**

The other major impacts of global climate change are regional hydrologic anomalies, floods and droughts, as well as long-term variations in the availability of water resources or the volume of inland water bodies (e.g. the Caspian Sea). The principal challenge in this domain is also the quantitative prediction of precipitation. In addition, exploratory observations of soil moisture, snow accumulation, and freeze/thaw transitions...will provide critical process-level information needed for predicting the hydrologic consequences of regional climate anomalies.

**Sec. 4.5: Global Change Prediction or Assessments**

(To what extent can long-term climatic trends be assessed or predicted?) The long-term prediction of potential changes in global climate is the most daunting challenge of all, because such predictions depend on accurate representation of all relevant “feedback processes” in the atmosphere, ocean, soil and ice, and the biosphere, as well as realistic guesses about future changes in primary forcing factors. Among the most critical problems are...the partitioning of rain and snow among evaporation, storage and runoff...

**Sec. 5: Introduction to NASA’s Earth Science Research Themes**

***3. Global Water and Energy Cycle.*** The principal research objective is to explore the connection between weather processes and climate change and the fast dynamical/physical processes that govern climate responses and feedbacks. Particularly significant is the transformation of water among its three physical states - vapor, liquid, and ice - in the atmosphere and at the surface of the Earth. The condensation of water in cloud and snow control both the albedo and radiation balance of the planet, and the constant renewal of fresh water resources....Another central science objective is exploring the responses of hydrologic regimes to changes in climate (precipitation, evaporation, and surface run-off) and the influence of surface hydrology (soil moisture, snow accumulation and soil freezing) on climate.

# Part III: CLPWG Tasks

## Publication of the Irvine Report

The CLPM working group is expected to publish the report from the Irvine workshop (*Cold Land Processes Mission (EX-7): Science and Technology Implementation Plan*) through NASA or other channels. The contents of the report should be reviewed by the working group, and recommendations for revisions will be discussed during the workshop. The report should then go out to external review; the working group should also consider appropriate reviewers. Once reviewers comments are addressed, the report will be submitted for publication.

## Trade Table Development

One of the most important tasks of the working group is to oversee the development of “official” CLPM trade tables summarizing trade-offs between different sensor characteristics, algorithms, and models. These tables need to reflect our current understanding of the factors affecting retrievals of snow and freeze/thaw information using remote sensing. These tables will necessarily evolve over time, but it is important to maintain a current “best” summary of what can be achieved with particular combinations of sensor characteristics, etc. Ideally, an up-to-date, formal, “blessed” set of trade tables will help provide an unambiguous determination of appropriate requirements for meeting the objectives of the CLPM.

Preliminary trade tables should be developed during the workshop, most likely with several gaps for factors lacking evidence or demonstration. A major objective of the field experiment will then be to fill in those gaps.

## Field Experiment Planning

The principal activity of the workshop is to further develop plans for a comprehensive airborne/field experiment. This task is discussed in detail in Section IV below.

## Strategic Planning and Group Coordination

A successful space flight mission to observe cold land processes is unlikely to occur without significant community support, coordination among working group participants, and strategic planning to take advantage of opportunities as they arise. Research for science and technology development will require significant funding that is not currently identified for this purpose. Rapid response to funding opportunities with short lead times for proposals will require that the research objectives of the working group are well-defined and clearly understood.

During the workshop, the steering committee should discuss ways of fostering strong coordination among the working group, especially as the group grows larger. Methods of coordinating responses to relevant NRAs or other funding opportunities should be discussed. More importantly, methods of coordinating activities of potentially several individual projects needs to be discussed, especially projects concerning to the field experiment.

## Open Workshop Planning

Strategies for opening the CLPM working group activities to a larger constituency need to be explored during this workshop. An open workshop needs to be planned for the not-too-distant future. One objective of this open workshop will likely be to involve a larger, interdisciplinary research community in the field experiment, and to coordinate this involvement. That objective clearly affects the timing of the workshop, and possibly the location. Prior to convening an open workshop, the steering committee should attempt to firm up baseline plans for the field experiment that will ensure that core objectives are reached (see Section IV below).

A Fall AGU special session related to Cold Land Processes is being sponsored by the Hydrology Section, and convened by D. Cline, J. Baker, and K. Kunkel:

> "This session is concerned with the hydrology and land-atmosphere interactions of the terrestrial cryosphere - cold land areas where water is either seasonally or permanently frozen. Contributions are solicited on the following topics: 1) the role of snow, frozen ground, and vegetation freeze/thaw processes in hydrologic, climate and weather prediction, 2) the development, operation, and/or validation of basin or larger scale distributed snow/ice models, 3) advances in the understanding and representation of sub-grid variability in distributed snow/ice models, 4) advances in observing frozen precipitation, and in discriminating between frozen and liquid precipitation in observations or models, 5) advances in understanding of the evolution of snow albedo, the representation of patchy snow/ice cover, sublimation, snowmelt and refreezing, the retention and transport of melt water, the representation of blowing snow, and the interaction between snow/ice processes and soil and vegetation processes, and 6) new methods, techniques, or instruments (especially remote sensing) for measuring and monitoring key components of the terrestrial cryosphere."

This session will provide one opportunity to openly discuss many CLPM issues. The steering committee could consider submitting and soliciting several papers for this session.

## Communication/Advocacy

As planning for the Cold Land Processes Mission proceeds, effective communication within the immediate community, to other disciplinary communities, to NASA headquarters, and to others is essential. The working group is not a lobbying group, but by definition its members share some common interests that should be promoted at appropriate times and venues.

One goal of effective CLPM working group communication should be to build community consensus regarding the objectives and requirements of the mission, deficiencies in our current understanding, and requirements for new research and technological development. A consistent message is important in this regard. With multiple sensor options, political uncertainty, and so forth, the activities of the working group can easily appear confusing. An objective assessment of requirements and objectives by the working group, manifest in group consensus trade tables, should go a long way towards establishing community consensus regarding the mission.

In the near-term, the group should consider providing a list of research requirements relevant to meeting CLPM objectives to NASA program managers, so that 1) they are aware CLPM requirements, and 2) they can effectively judge whether proposals are responsive to CLPM requirements.

# Part IV: Field Experiment Planning

## Field Experiment Objectives

The impetus for the Cold Land Processes Field Experiment is the need to firm up algorithms and sensor characteristics, and to refine models that will either be used in algorithms or will use algorithm products. The overall objective is to demonstrate readiness for a Cold Land Processes Mission.

With this in mind, a distinction can be made between “core” objectives for the experiment - specific requirements to prepare for a space flight mission - and larger, more general science objectives. Both need to be addressed in this field experiment.

### Core Objectives of Field Experiment

#### Minimum Requirements

At the most fundamental level, the experiment must provide data sets that are required to develop, refine, test, and finalize microwave remote sensing retrieval algorithms in preparation of a Cold Land Processes Mission. These data sets will be used to develop tables describing the trade-offs of different sensor characteristics, algorithms, etc. that will be critical for responding rapidly to new cold land processes research opportunities.

To support the specific EX-7 mission planning objectives, the field experiment must, at a minimum:

1. Provide "ground truth" for snow characteristics and freeze/thaw characteristics, necessary to develop, refine, and test remote sensing retrieval algorithms.

2. Provide microwave (active and passive) and optical remote sensing data from various ground, airborne, and satellite platforms.

#### Ground Truth

Ground truth is expected to be comprised of at least three levels of information.

1. There must be an attempt to identify and intensively measure locations that a) have desired characteristics, such as deep snow, shallow snow, boggy soils, dense forests, etc, and b) can be considered a pure pixel and unambiguous from the remote sensing point of view. These sites will serve as Level 1 Ground Truth. These sites will ultimately provide the least ambiguous evaluation of algorithm performance, however there will be relatively few of these sites due to the intensive resources required to measure them.

2. There must be an attempt to characterize surface conditions on a larger scale than "pure pixels". Here, an appropriate sampling scheme is required to observe properties over larger areas, such as complete flight lines. The objectives at this Level 2 Ground Truth scale are to take full advantage of the airborne data, to try to better understand how remote sensing data relates to changing surface conditions, etc. At this scale, distributed modeling will likely be important for inferring surface conditions and diagnosing algorithm performance over complete flight lines.

3. Finally, there must be an attempt to characterize surface conditions over very large areas. This requires spatially distributed modeling, and therefore cannot truly be considered "truth". However, model response will provide insight into physical characteristics affecting remote sensing signals, such as snow wetness, soil temperatures, etc., that simply cannot be measured over sufficiently large areas. This Level 3 Ground Truth is intended more for diagnosis of remote sensing data and signal behavior than for validation purposes.

### Broader Science Objectives of Field Experiment

The experiment should foster a broad spectrum of science investigations both during the experimental period and afterwards. To meet the minimum requirements for mission planning, the Cold Land Processes Field Experiment will generate a unique and rich data set that will be useful for broader scientific objectives that go well beyond the specific objectives for mission planning. For example, the Level 3 modeling component will necessarily involve combining atmospheric models with detailed land surface schemes, and will provide important land surface information during a complex transitional period. There are many potential benefits of the field experiment data sets to atmospheric science, ecological science, water resources, and hydrological science.

The incorporation of broader science objectives in the experiment is critical, and the participation of a broad spectrum of interdisciplinary scientists in the field experiment planning process should be encouraged. However, other objectives must be carefully assessed in order to ensure that they do not detract from the basic mission planning objectives defined above. One approach to ensure that fundamental mission planning objectives are reached is to first define, and fund, a core experiment, then invite additional participants to contribute. Strategies for incorporating broad science participation in the field experiment needs to be discussed by the CLPM working group.

## Proposed Study Area

Selection of an appropriate study site is critical to the success of the field experiment. Four sites were initially suggested at the Irvine Workshop: Alaska, the Sierra Nevada, the Rocky Mountains, and Minnesota. Each suggested site has pros and cons associated with it; no site has everything that might be desired for a field campaign.

After careful consideration, one site is proposed for the Cold Land Processes Field Experiment. The important criteria for site selection were:

- Wide range of physiographic, climatic, hydrologic, and ecosystem conditions, to provide a thorough test bed for remote sensing retrieval algorithms and for establishing performance limits of these algorithms. This was the most important science consideration.
- Existing infrastructure - research facilities, measurement networks, and various support facilities - important both in terms of providing a scientific context for the experiment site, and in terms of reducing costs in the experiment and simplifying logistics during the experiment.
- Efficiency - ease (and cost) of access - the "area size - to - physiographic richness" ratio should be as small as possible to maximize data acquisition and minimize costs;
- Safety - access to shelter, emergency services, etc. - considered critical for a winter campaign involving potentially a large number of personnel, not all of whom may be experienced in outdoor winter work.

The full study area proposed for the EX-7 Field Experiment is located in north central Colorado (Figure


**Figure 1.** The State of Colorado, and the proposed location of EX-7 Field Experiment.

1). The full study area is $3^o$x$5^o$ ($104^o$ - $109^o$W, $38^o$-$41^o$N). At 39.5$^o$N, the full study area is 430 km (267 mi) across. It is 333 km (207 mi) N-S. In considering this area for the EX-7 Field Experiment, several important strengths were recognized:

- Most importantly, it contains a wide range of physiographic characteristics in a relatively small region. As a result, a wide range of snow and freeze/thaw characteristics can be expected, and ground and airborne campaigns can be conducted efficiently.
- A long record of geophysical research on cold-season processes exists in this area, including several current projects. There are several research facilities in the area that offer a unique infrastructure to support the objectives of this experiment.
- The area is centrally located in the west-central U.S., which serves to minimize travel costs to and from the site for the majority of field personnel, and helps lower ferry costs of the NASA DC-8 from California.
- The area contains a substantial infrastructure of transportation and populated areas. Lodging, food, and medical facilities are distributed throughout the area. Numerous airports are located within the area that provide services relevant to the experiment. Primary and secondary road networks are well-maintained during the winter months, allowing access throughout the study area.

Within the full study area are six proposed Intensive Study Areas (ISAs), where intensive ground truth data will be collected:

a. North Park (Vicinity of Walden, CO, 25 miles NE of Steamboat Springs, CO)
b. Rabbit Ears Pass (10 miles SE of Steamboat Springs, CO)
c. Yampa Valley (immediately west of Steamboat Springs, CO)
d. Fraser Experimental Forest (30 miles west of Boulder, CO)
e. Niwot Ridge (20 miles west of Boulder, CO)
f. Grand Mesa (20 miles E of Grand Junction, CO)
g. Upper Gunnison River Basin

Each of these ISAs have unique characteristics that together ensure that a wide range of snow and freeze/thaw characteristics can be sampled, with low risk of weather-related failure (e.g. lack of snow or freeze/thaw transitions).

Opportunistic Study Areas (OSAs) may also be possible. These would be areas that often have snow or frozen conditions, but not reliably enough to devote the level of resources required for an ISA. In the event of favorable conditions, ground teams and aircraft could be directed to a pre-determined OSAs to extend the range of physiographic conditions observed.

## Study Area Characteristics

The study area is most frequently characterized by its rugged mountain topography and deep mountain snow packs, but in fact it contains many different physiographic, climatic, hydrologic, and ecologic characteristics. Steep elevation gradients result in rapid changes in characteristics over short distances. The resulting diversity is beneficial to meeting the objectives of the field experiment, which require a wide range of snow and freeze/thaw conditions to fully evaluate algorithms. Colorado is basically arid; deep seasonal snow packs are primarily limited to the highest elevations. Much of the study area is more likely to have relatively shallow snow packs, on the order of a 1'-2' or less. On the high elevation open parklands, snow packs tend to be relatively shallow and windswept, with enhanced nighttime radiative cooling resulting in significant freezing conditions. For example, Fraser CO is frequently dubbed the "ice box of the nation" for it's extreme cold temperatures (see Table X).

## Land Cover and Hydrography

The study area consists of three major land cover regimes distributed east-west across the area: 1) prairie grasslands and croplands in the eastern fourth of the area, 2) desert and high-altitude plateaus in the western fourth, and 3) a mixture of forested mountains and valleys, and alpine areas in the middle two-fourths of the area (Figure 2). Two large, open parklands lie within the mountainous part of the study area: North Park, surrounding Walden, CO, and South Park, southeast of Leadville, CO. Both areas are broad, open, rolling grasslands at high elevation (North Park lies at ~8000', South Park at ~9000').
The study area contains the headwaters for seven major river systems: 1) North Platte R., 2) South Platte R., 3) Arkansas R., 4) Yampa R., 5) White R., 6) Gunnison R., and 7) Colorado River. The study area is finely dissected by these river systems. The total downstream water yield from these basins is directly proportional to the mountain snow pack.

## Forest Cover

Forest cover types within the study area are predominantly Spruce-Fir, Lodgepole Pine, Ponderosa Pine, Pinyon-Juniper, and Chaparral (Figure 3). About one-third of the study area is unforested. Forest cover density generally increases with elevation to the local tree-line (Figure 4).

## Soils

Surface soils (upper 5 cm) in the study area are predominantly sandy loam or loam (Figure 5). Clay soils are prevalent in the Colorado Piedmont area (i.e. the Denver/Boulder area) and along parts of the Colorado River. Sandy soils are found in the northeast (e.g. South Platte valley) and northwest parts of the study area (e.g. western Yampa valley). The bulk density of surface soils is shown in (Figure 6).

## Precipitation/Climate

Most of this region's annual precipitation occurs as winter snowfall (Figure 7). Pacific frontal systems bring most of the winter moisture to this region. These storm systems can arrive into the region from either the west, northwest, or southwest, and this influences the distribution of precipitation. Westerly tracks are orographically uplifted to some extent by the Wasatch Plateau east of the study area in Utah, and are lifted further by the ranges along the Continental Divide in the central part of the study area. This results in the heaviest precipitation west of the Continental Divide. Northwesterly tracks are lifted by the Wasatch Range and the Uinta Mountains in Utah and by ranges along the divide in the north central part of the study area, resulting in heavier precipitation at these locations. Storm tracks arriving from the southwest don't encounter major orographic effects until they reach the San Juan Mountains in southwestern Colorado, just south of the study area (i.e. south of the Gunnison River in Figure 1). Heavy winter precipitation occurs in this part of the region from these storm tracks. In general precipitation declines markedly throughout areas east of the Continental Divide. However, low pressure systems east of the Divide can bring significant moisture in from the Gulf of Mexico during Spring, resulting in sometimes heavy snow fall in the foothills at lower elevations on the eastern side of the Divide. Lower elevation areas of the Central Rockies receive considerably less precipitation; most of the region's snow pack storage is concentrated in the higher mountains.

The mean date of snow cover formation ranges from October 15 near the Continental Divide to November 15 for most of the rest of the study area. The mean date of snow cover disappearance ranges from early March in the western part of the study area to May 1 in all but the highest elevations near the Continental Divide.

## Snow Measurement Networks

There are three large-scale snow measurement and monitoring networks within the study area (Figure 8): 1) SNOTELs, 2) Snow Courses, and 3) Airborne Gamma surveys.

The National Resource Conservation Service (NRCS) operates over 50 automated SNOw TELemetry sites within the study area. These sites monitor snow water equivalent (SWE) on either an hourly or daily basis using a pressure-sensing pillow. Data are telemeterd using meteor-burst technology to a central processing facility in Portland, OR. Data are generally available a few hours after they are collected. The NRCS has plans to augment SNOTEL sites with soil temperature profile measurements, but has limited resources to do so. It may be possible to collaborate with them to install appropriate sensors within the study area during the summer prior to the field experiment, if desired.

The NRCS also operates 60-70 manual snow courses within the study area. These are transects of varying lengths that are generally measured once a month during the winter and spring. Not all of the NRCS snow course sites may be active, and many are co-located with SNOTEL sites. In many cases snow course records go back several decades. It may be possible to arrange for more frequent data collection on some courses than just once a month, if desired.

The National Operational Hydrologic Remote Sensing Center, of the National Weather Service, maintains about 40 airborne gamma survey flight lines within the study area. SWE is determined by measuring the attenuation of terrestrial gamma radiation due to the water content of the snow. Depending on the method of data processing, the SWE measurement is either an average for the flight line area (typically about 3000 m wide by 10 km long), or a series of SWE measurements along the flight line. See http://www.nohrsc.nws.gov/98/html/gamma/gammapage.html for more information. Additional flight lines can be added for the field experiment, but this must be done the previous fall in order to collect background gamma radiation measurements.

## Transportation

Colorado's transportation network is generally very good (Figure 9). Major interstates traverse the study area from east to west (I-70) and from north to south (I-25). There is a relatively dense network of primary and secondary roads that span the study area. These roads are generally well-maintained throughout the winter and spring. Storm conditions or severe blowing snow conditions may temporarily prevent study area access via major roads. Access to areas away from roads shown on the map may require snow machines, skis, or snowshoes. Cooperative ski areas may provide ready access to backcountry areas that otherwise would be difficult or time-consuming to access.

There are numerous airports throughout the study area that provide aircraft maintenance and fuel for light aircraft. Several airports support larger jet aircraft, including Denver, Colorado Springs, Hayden, and Grand Junction. Major air carrier service is available to these locations, facilitating investigator access to the study area. Airports within or near the study area that are capable of handling the NASA DC-8 aircraft (considering runway structure, aircraft gross weight and landing gear, and fire and rescue facilities) are limited to Denver International Airport, Colorado Springs Municipal Airport, and Salt Lake City International Airport.

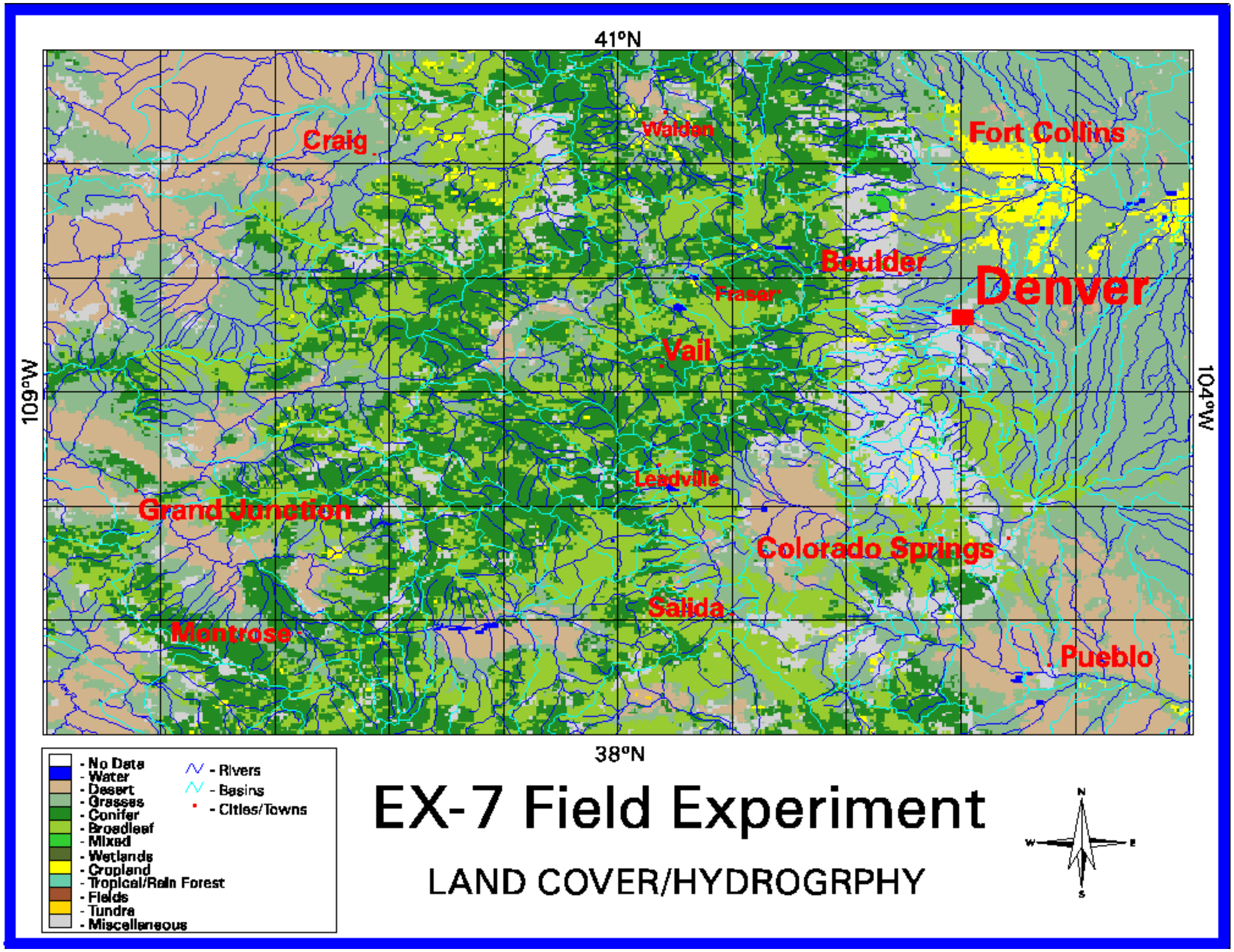


**Figure 2.** Land cover and hydrographic characteristics of the proposed Cold Land Processes Field Experiment study area.

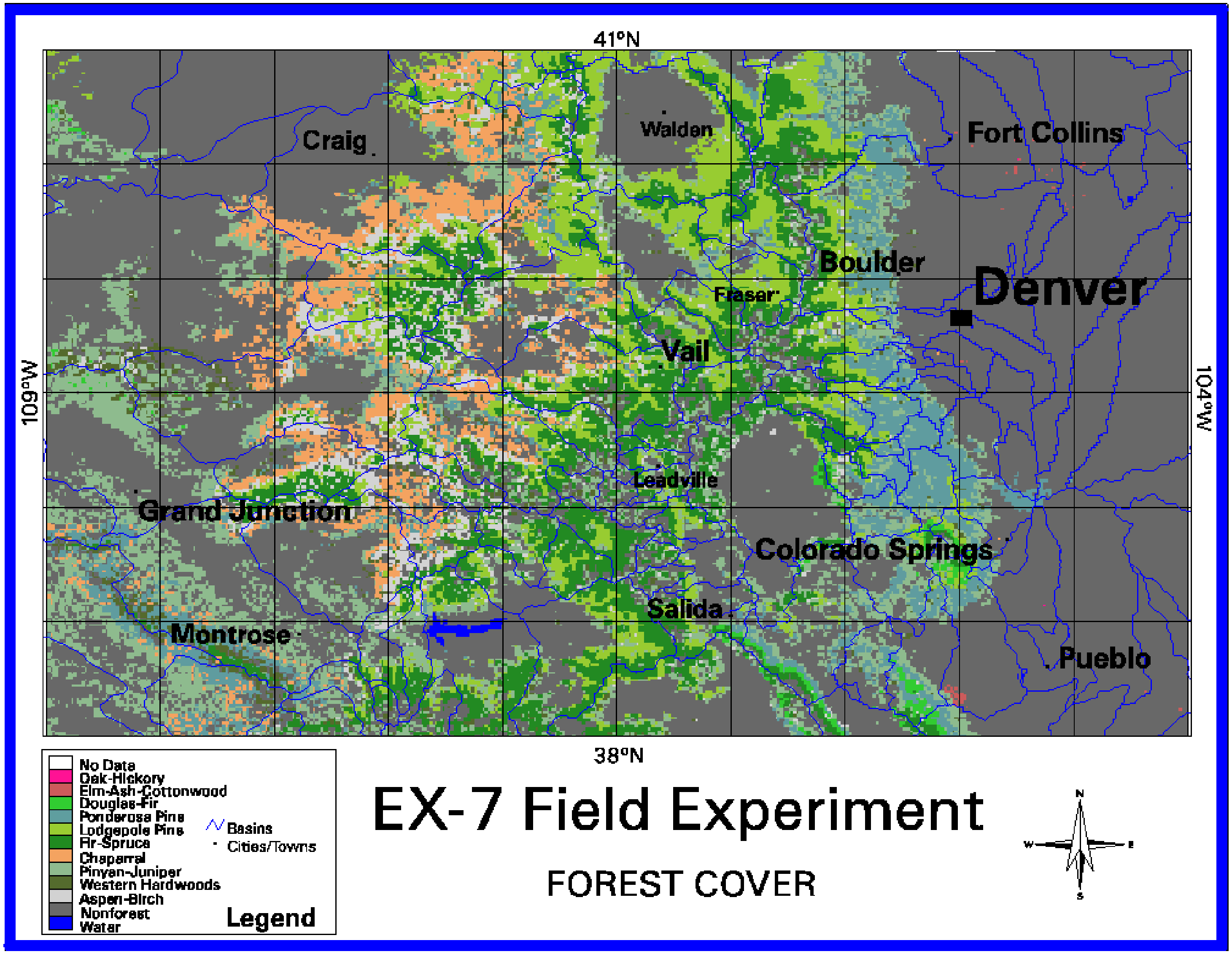


**Figure 3**. Major forest cover types within the proposed CLP Field Experiment study area.

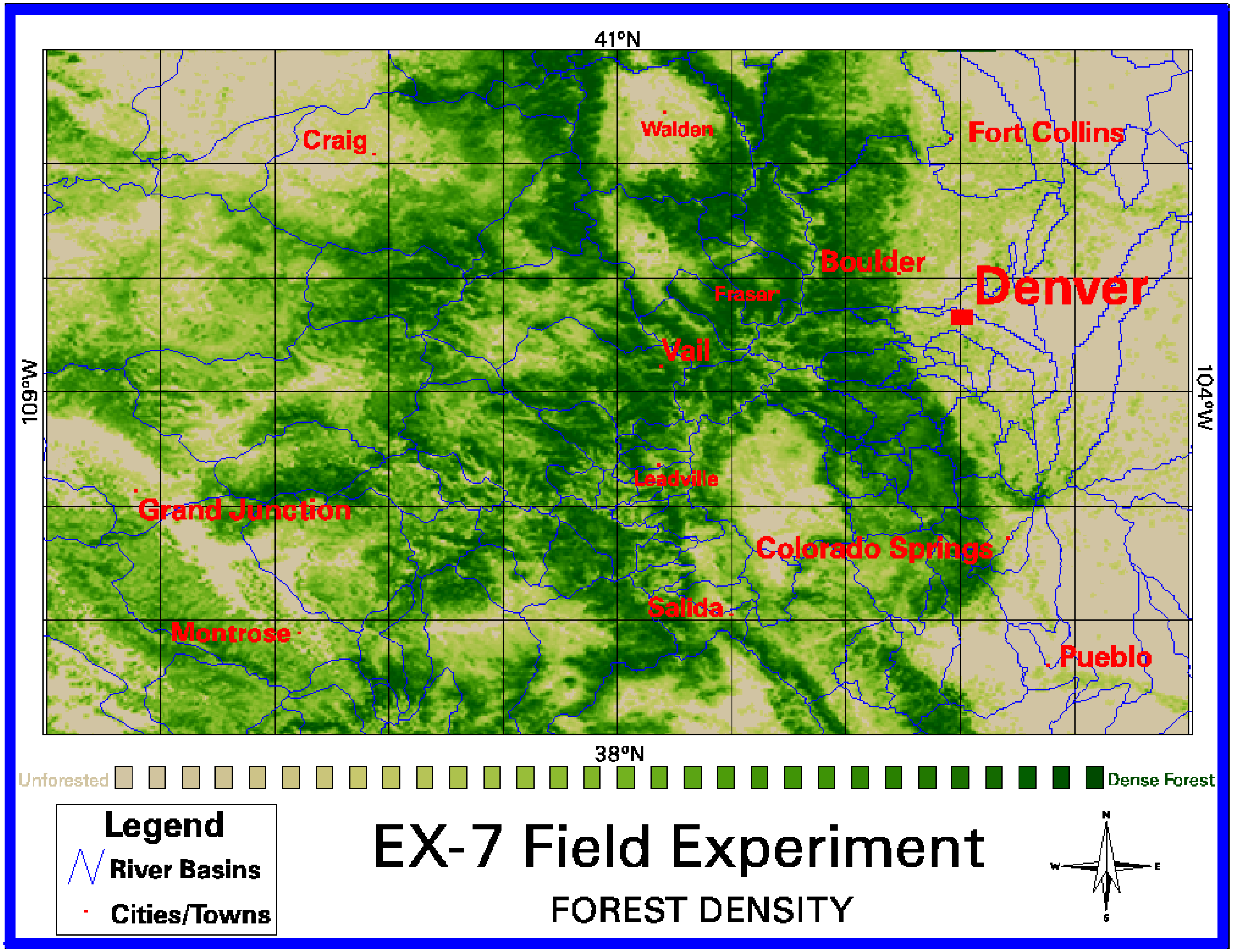


**Figure 4**. Major forest cover density within the proposed CLP Field Experiment study area.

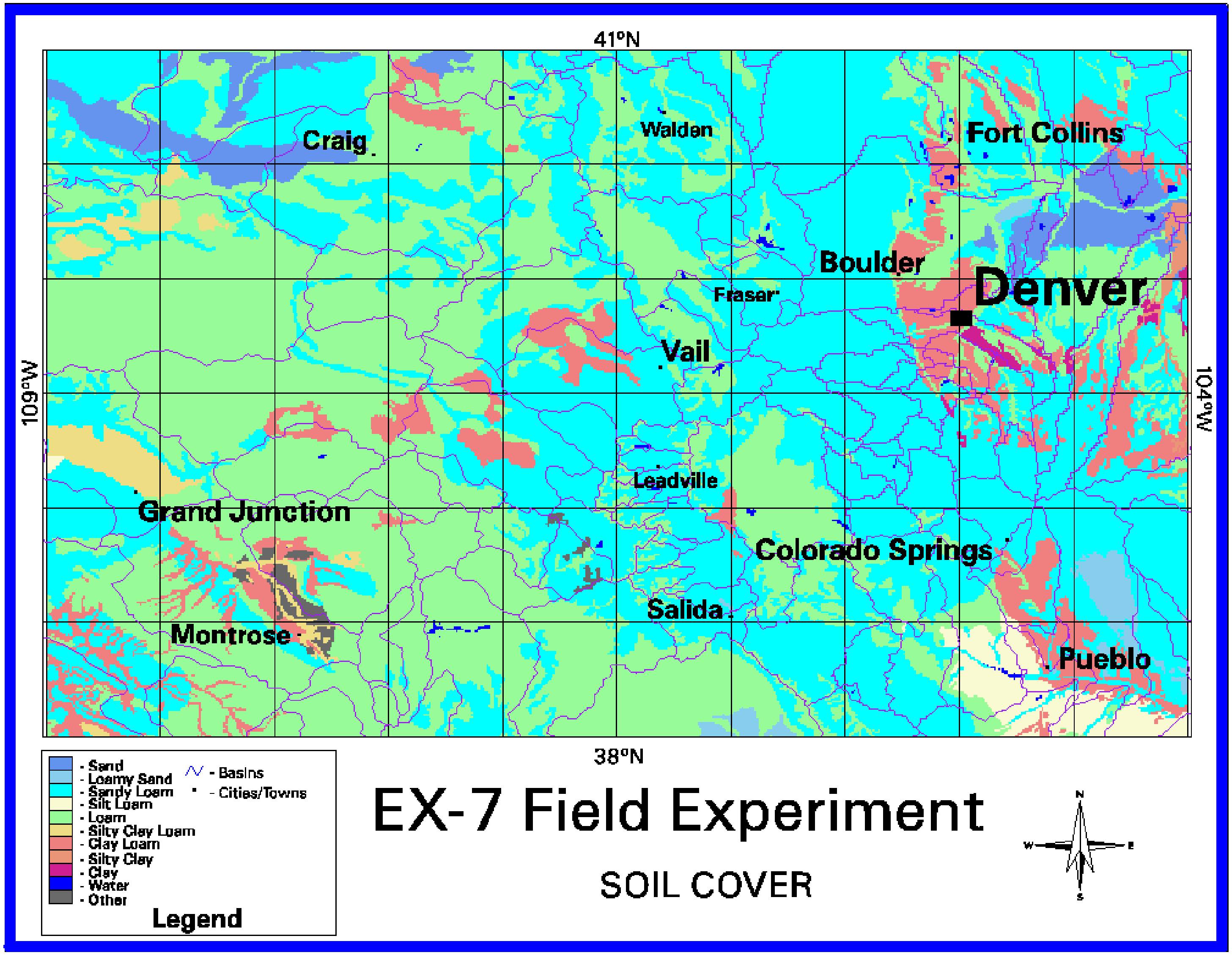


**Figure 5**. Major soil characteristics within the proposed CLP Field Experiment study area.

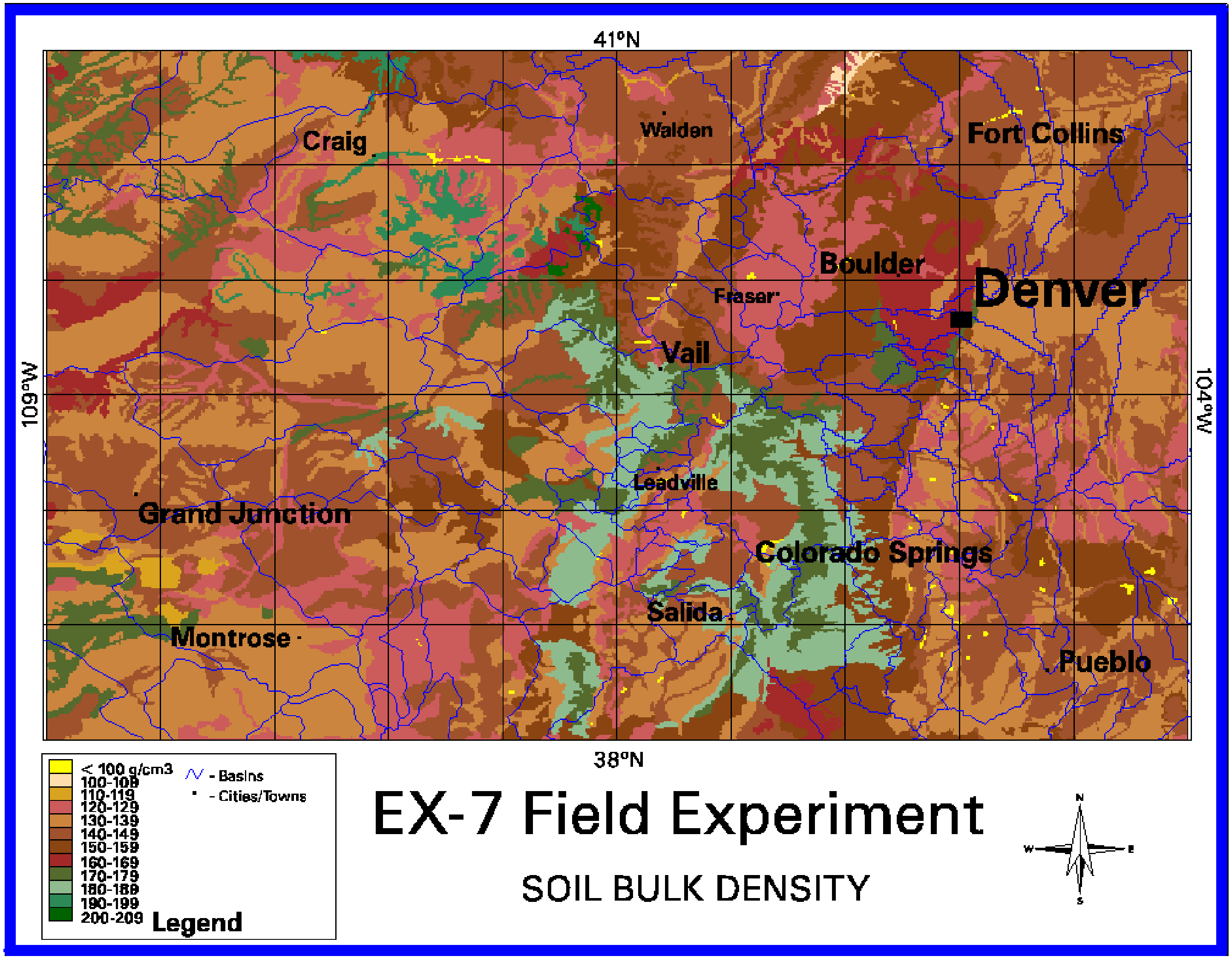


**Figure 6**. Soil bulk density within the proposed CLP Field Experiment study area.

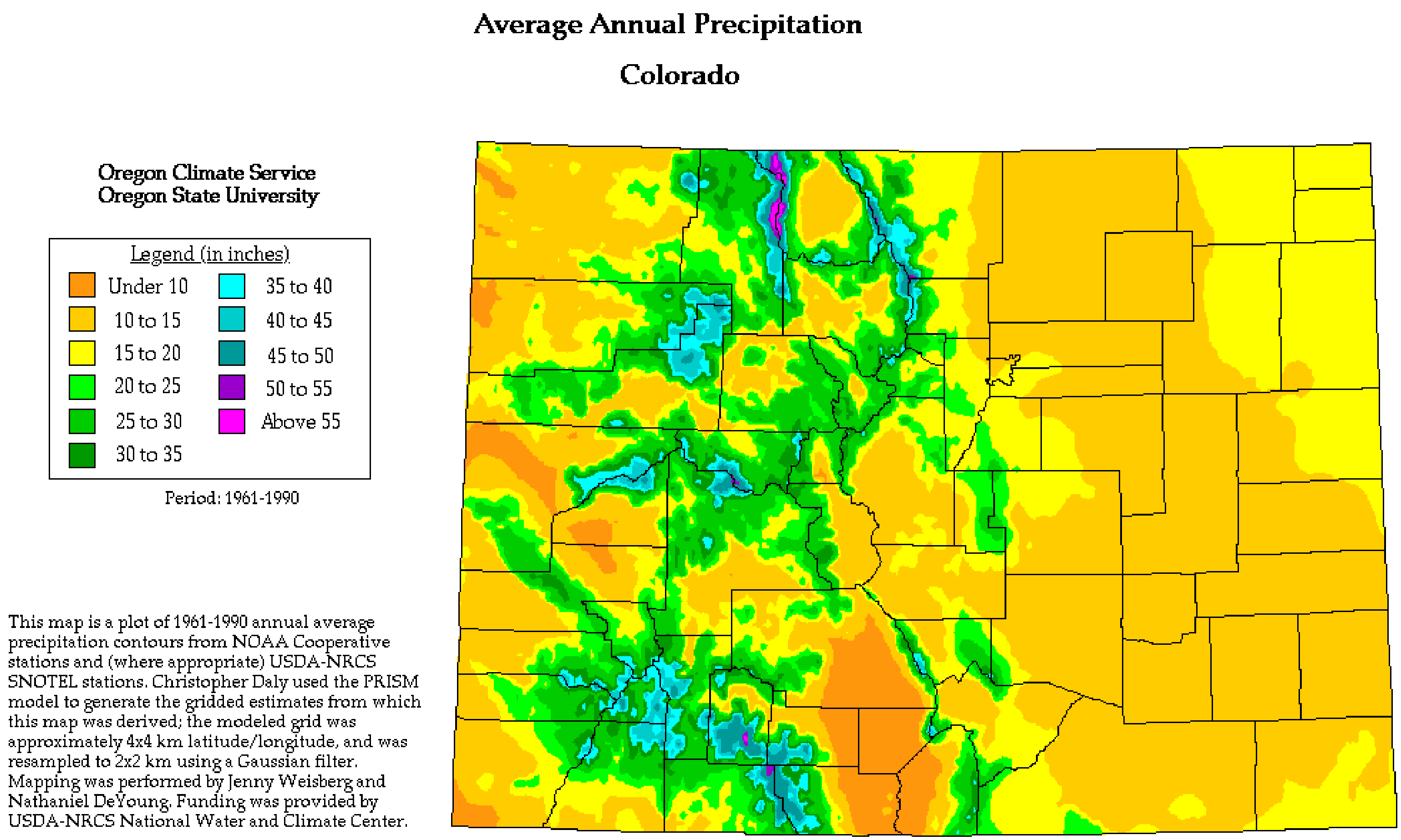


**Figure 7**. Average annual precipitation within the proposed CLP Field Experiment study area.

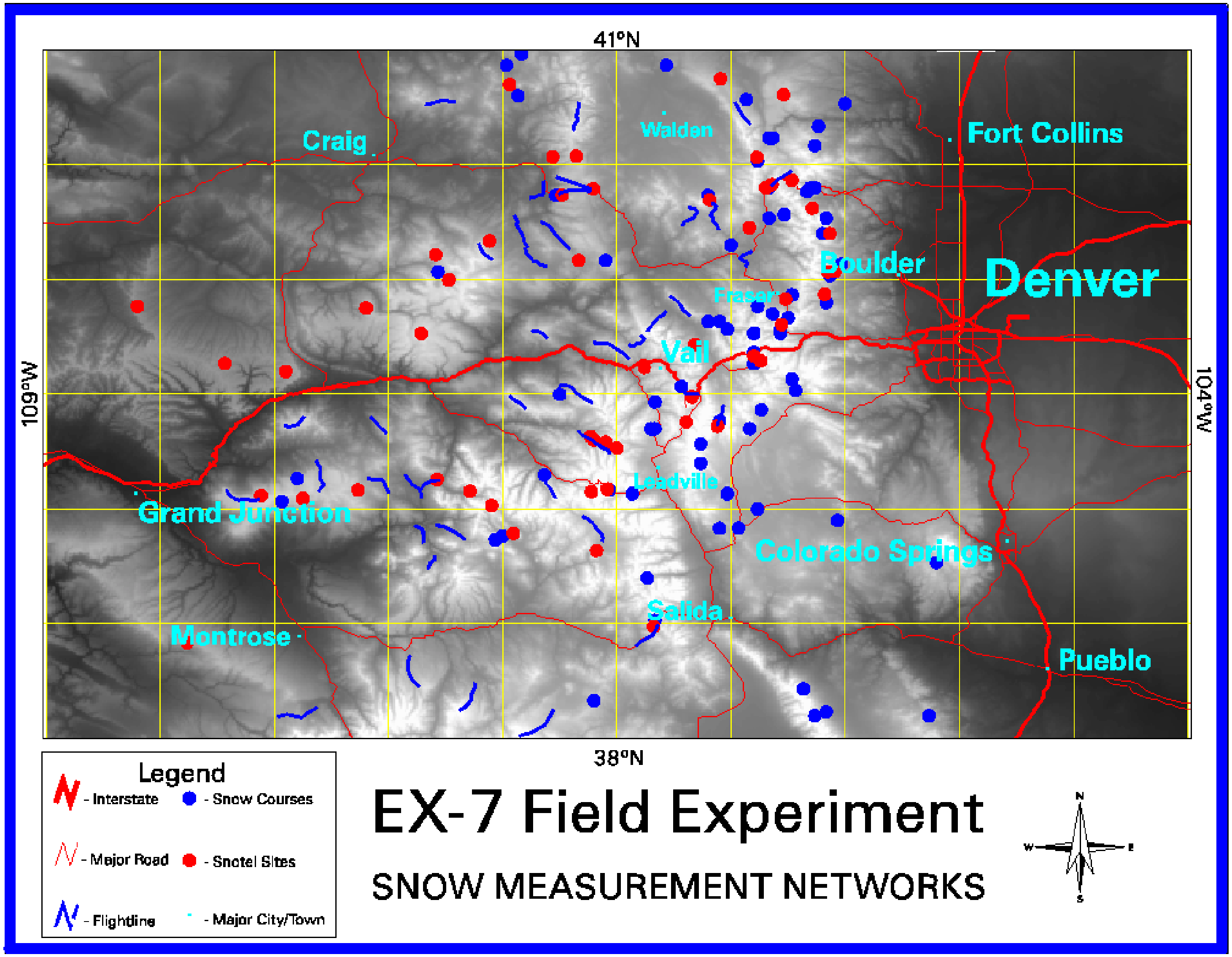


**Figure 8**. Operational snow measurement networks within the proposed CLP Field Experiment study area.

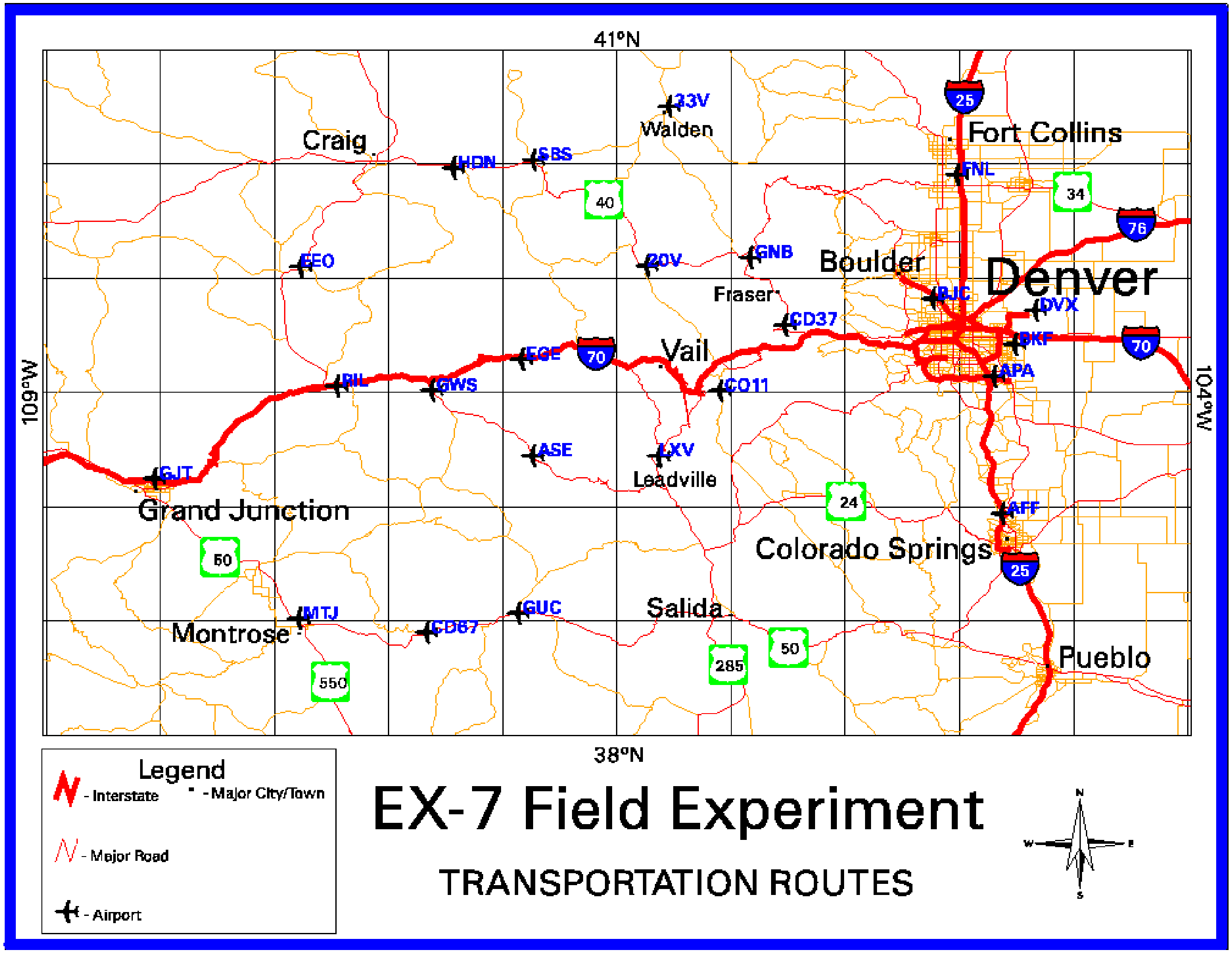


**Figure 9**. Major transportation routes within the proposed CLP Field Experiment study area.

## Candidate Intensive Study Areas

Seven candidate ISAs have been identified. The first six are relatively small areas, each with unique physiographic characteristics. Collectively, these areas provide a broad range of snow and freeze/thaw conditions; intensive ground data collected from some or all of these areas will be used to develop and test remote sensing retrieval algorithms. The seventh ISA is a large basin (~50,000 $km^2$) that itself contains a similarly broad range of conditions. Intensive ground data will be collected from this area also, but withheld from algorithm development, for the purpose of an independent validation of the algorithms that result from the experiment.

a. North Park (Vicinity of Walden, CO, 25 miles NE of Steamboat Springs, CO)
b. Rabbit Ears Pass (10 miles SE of Steamboat Springs, CO)
c. Yampa Valley (immediately west of Steamboat Springs, CO)
d. Fraser Experimental Forest (30 miles west of Boulder, CO)
e. Niwot Ridge (20 miles west of Boulder, CO)
f. Grand Mesa (20 miles E of Grand Junction, CO)
g. Upper Gunnison River Basin

Each of these ISAs have unique characteristics that together ensure that a wide range of snow and freeze/thaw characteristics can be sampled, with low risk of weather-related failure (e.g. lack of snow or freeze/thaw transitions).

### North Park ISA

The North Park ISA (Figure 10) is a broad, high-elevation parkland approximately 25 miles (40 km) in diameter. The town of Walden, CO is located in the center of North Park. The mean elevation of North Park is about 8100' (2470 m) A.S.L. It is an intermountain glacial basin. The area is surrounded by high mountains that develop deep snow packs, but relatively little snow accumulates in North Park itself (Table 1). This area is the headwaters of the North Platte River. Several small rivers drain the surrounding mountains and flow through the relatively flat topography of North Park, where they join the North Platte just north of Walden. Consequently, the area is relatively wet, and includes the 20,000 acre Arapaho National Wildlife Refuge, which includes significant wetland areas. North Park is predominantly unforested. Snow packs tend to be relatively shallow and influenced by wind redistribution. Two secondary highways service Walden, providing easy access through the southern half of North Park, and somewhat more restricted access to the northern half. Several smaller roads traverse the area, but these may not be open reliably during winter.

**Table 1.** Monthly Climate Summary for Walden, CO (058756), for the period 8/1/1948 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 28.8 | 32.3 | 38.9 | 49.5 | 60.6 | 71.0 | 77.9 | 75.7 | 67.9 | 56.1 | 39.7 | 30.9 | 52.4 |
| Average Min. Temperature (F) | 3.8 | 5.8 | 12.8 | 20.5 | 28.3 | 35.9 | 39.6 | 37.3 | 30.0 | 21.6 | 13.0 | 5.8 | 21.2 |
| Average Total Precipitation (in) | 0.59 | 0.51 | 0.66 | 0.87 | 1.32 | 1.09 | 1.28 | 1.17 | 1.14 | 0.83 | 0.72 | 0.62 | 10.81 |
| Average Total Snowfall (in) | 8.6 | 6.6 | 8.1 | 7.3 | 3.7 | 0.5 | 0.0 | 0.0 | 1.4 | 4.1 | 8.9 | 8.9 | 58.0 |
| Average Snow Depth (in) | 6 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 2 |

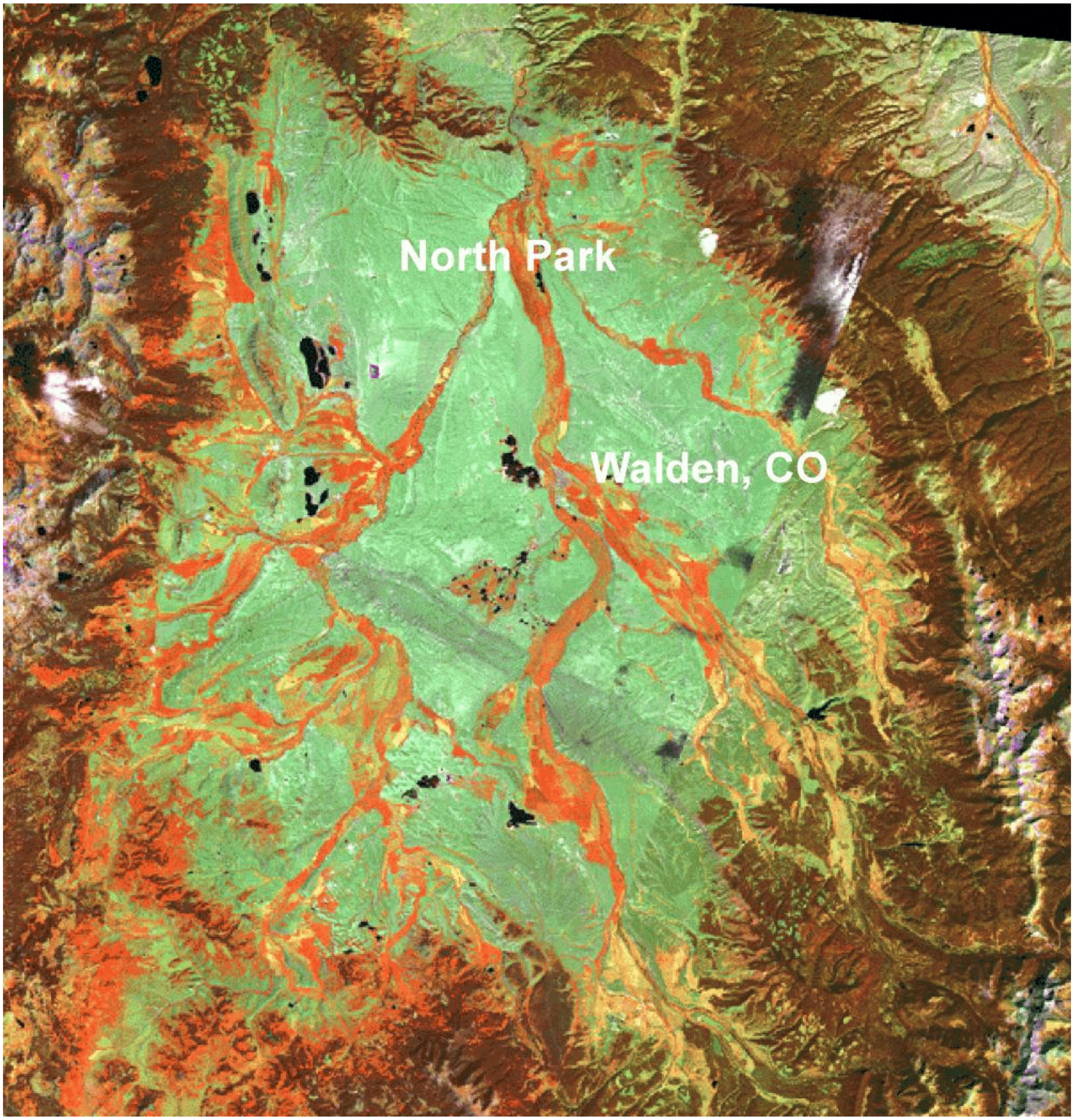


**Figure 10.** Landsat TM composite showing North Park and vicinity.

## Rabbit Ears Pass ISA

The Rabbit Ears Pass area (Figure 11) surrounds a 10-mile long section of Hwy. 40 where it crosses the Continental Divide. Although the area is above 9300' A.S.L., the area has low to moderate, rolling topography, and is predominantly forested. Many open meadows and glades, the relatively gentle topography, and significant winter snow accumulation make this a popular winter recreational area. The area includes a complete micrometeorological station, large lysimeter pans, and a snow course network, supported by the USGS. This was also the site of the WMO intercomparison of winter precipitation gages; the gages are still on the site and are operable. Road access to the area is easy via Hwy. 40, which is well-maintained throughout the winter and spring. Off-road access is also easy, by snow machine or cross-country skiing.

Other science facilities that are nearby include the Storm Peak Laboratory, an atmospheric science facility at the top of Steamboat Ski Area. The facility is operated by the Desert Research Institute.

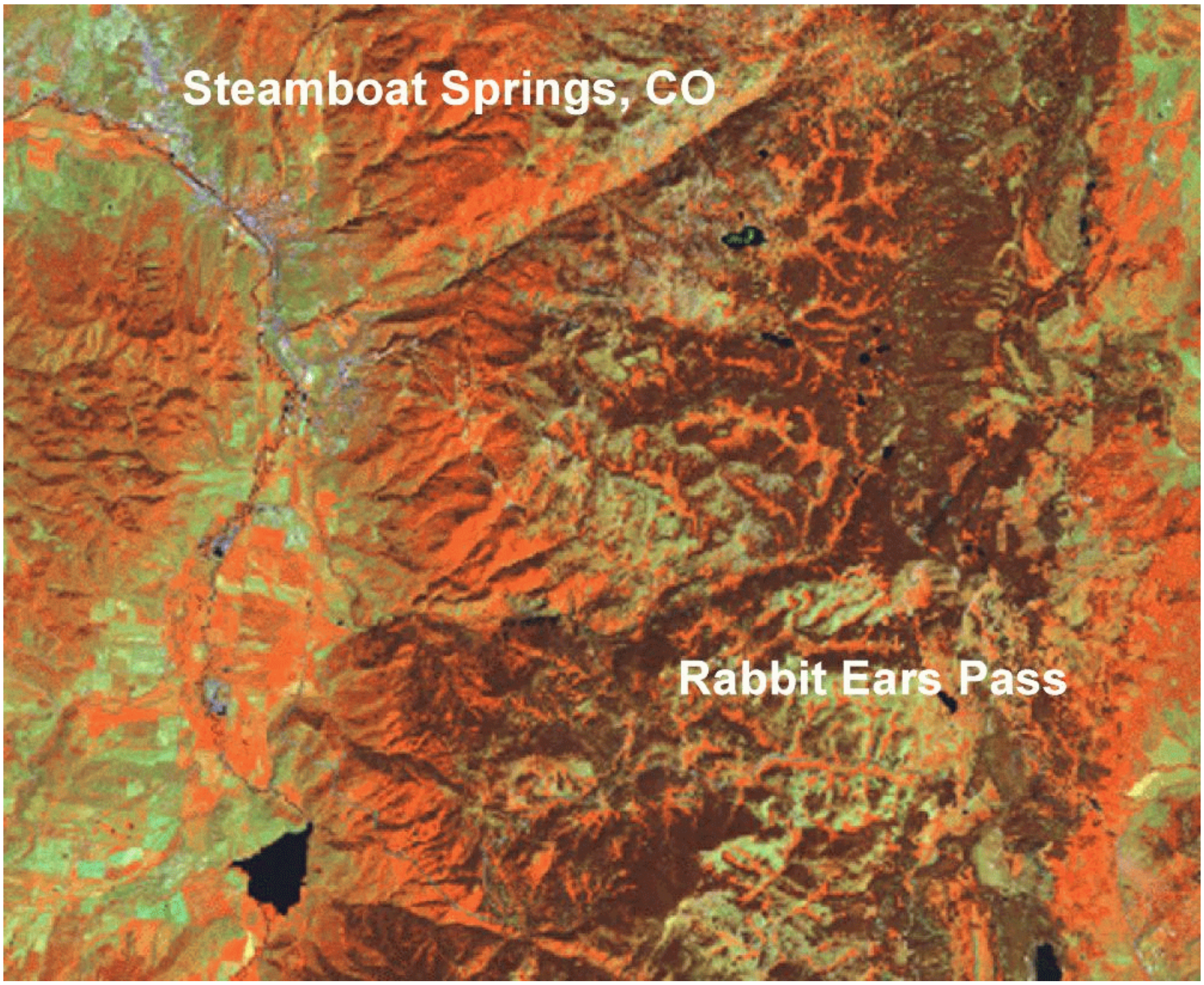


**Figure 11**. Landsat TM image of Rabbit Ears Pass area.

## Yampa Valley ISA

The Yampa Valley above Hayden, CO and below Steamboat, CO (about 25 miles) is a broad valley flanked by low, rounded hills on either side (Figure 12). The valley bottom is primarily irrigated pasture land and is used for grazing, while the surrounding hillsides are primarily deciduous forest. This environment is somewhat different from the other ISAs, and is similar in many respects to mountainous areas of the northeastern U.S..

Substantial east-west precipitation and snow accumulation gradients occur along the main axis of the Yampa Valley (Tables 2 and 3). The average total snowfall at Steamboat Springs, CO is 167.3", over 53" greater than at Hayden, CO, just 25 miles downstream.

**Table 2.** Monthly Climate Summary for Hayden, CO (053867), for the period 1/2/1948 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 30.0 | 34.8 | 43.5 | 56.8 | 68.1 | 78.3 | 84.9 | 82.8 | 74.4 | 62.4 | 44.9 | 32.6 | 57.8 |
| Average Min. Temperature (F) | 5.2 | 8.9 | 17.8 | 27.6 | 35.4 | 41.9 | 47.7 | 46.5 | 38.3 | 28.3 | 18.5 | 8.5 | 27.0 |
| Average Total Precipitation (in) | 1.57 | 1.17 | 1.25 | 1.58 | 1.48 | 1.24 | 1.36 | 1.37 | 1.40 | 1.55 | 1.40 | 1.60 | 16.94 |
| Average Total Snowfall (in) | 27.1 | 18.5 | 14.2 | 7.9 | 0.8 | 0.2 | 0.0 | 0.0 | 0.6 | 4.7 | 15.0 | 25.3 | 114.2 |
| Average Snow Depth (in) | 14 | 16 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 | 4 |

**Table 3.** Monthly Climate Summary for Steamboat Springs, CO (057936), for the period 9/2/1908 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 28.8 | 34.0 | 42.0 | 53.2 | 65.0 | 75.2 | 82.1 | 80.1 | 72.3 | 60.1 | 43.2 | 30.7 | 55.6 |
| Average Min. Temperature (F) | 0.8 | 4.0 | 13.4 | 24.1 | 31.3 | 35.6 | 41.2 | 40.0 | 32.5 | 23.8 | 14.2 | 3.3 | 22.0 |
| Average Total Precipitation (in) | 2.50 | 2.25 | 2.14 | 2.28 | 2.11 | 1.51 | 1.55 | 1.59 | 1.76 | 1.92 | 1.96 | 2.42 | 23.98 |
| Average Total Snowfall (in) | 36.2 | 29.8 | 24.3 | 13.4 | 2.8 | 0.1 | 0.0 | 0.0 | 0.9 | 7.0 | 19.9 | 32.9 | 167.3 |
| Average Snow Depth (in) | 23 | 28 | 20 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 12 | 10 |

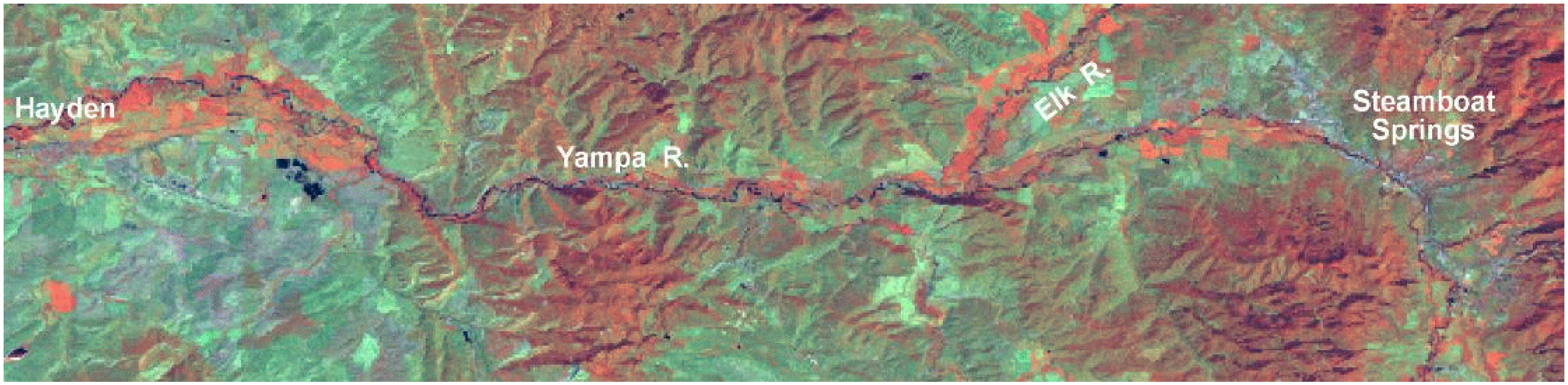


**Figure 12.** Landsat TM image showing Yampa Valley ISA and vicinity.

## Fraser Experimental Forest ISA

The Fraser Experimental Forest (Figure 13) is a USDA Forest Service research facility that includes most of the St. Louis Creek basin above Fraser, CO (about 30 air miles west of Boulder, CO, on the west side of the Continental Divide). The area is about 100 $km^2$ and is a particularly cold area of the state (see Table 4 for nearby Winter Park, CO). The ISA offers a unique opportunity to work on the problem of remote sensing retrievals of snow and freeze/thaw in forested areas. The Fraser Experimental Forest consists of a rich structure of controlled forest characteristics. The forest structure varies from clearcuts (several ha) to patch cuts (< 1 ha) to thinned stands of different age (same species). Chronosequences of lodgepole pine include 50-year (small plots), 75-year (large expanse), and >300-year (large expanse). There are also different structures from cut/leave strips on the Fool Creek watershed, and from different tree densities on north/south slopes. Lexen Creek and Deadhorse watersheds have had stand characteristics extensively mapped and also related to snow course data. Various long-term data sets exist for the site, including extensive weekly snow course information and intensive April 1 surveys since 1964, daily streamflow at 7 sites within the watershed, and a variety of meteorological data.

Facilities at this ISA include on-site housing for up to 28 persons (2 cabins, sleep 3-5 each; lodge, sleeps 6; dormitory, sleeps 12 in individual rooms), cooking facilities, a wet-lab, office, computer space, and a workshop, and 2 snow-cats.

**Table 4.** Monthly Climate Summary for Winter Park, CO (059175), for the period 8/1/1948 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 30.0 | 37.3 | 41.8 | 50.2 | 62.2 | 71.9 | 78.3 | 76.9 | 66.0 | 56.1 | 43.5 | 35.3 | 54.1 |
| Average Min. Temperature (F) | -2.0 | -0.9 | 3.9 | 12.8 | 20.8 | 29.1 | 32.9 | 31.3 | 22.6 | 16.5 | 5.7 | -0.9 | 14.3 |
| Average Total Precipitation (in) | 2.40 | 2.02 | 2.69 | 3.07 | 2.74 | 1.88 | 2.13 | 2.17 | 1.82 | 1.70 | 2.16 | 2.30 | 27.08 |
| Average Total Snowfall (in) | 37.5 | 31.3 | 37.1 | 32.3 | 11.2 | 1.5 | 0.0 | 0.0 | 2.7 | 11.5 | 30.3 | 35.1 | 230.5 |
| Average Snow Depth (in) | 30 | 37 | 39 | 28 | 5 | 0 | 0 | 0 | 0 | 1 | 8 | 19 | 14 |

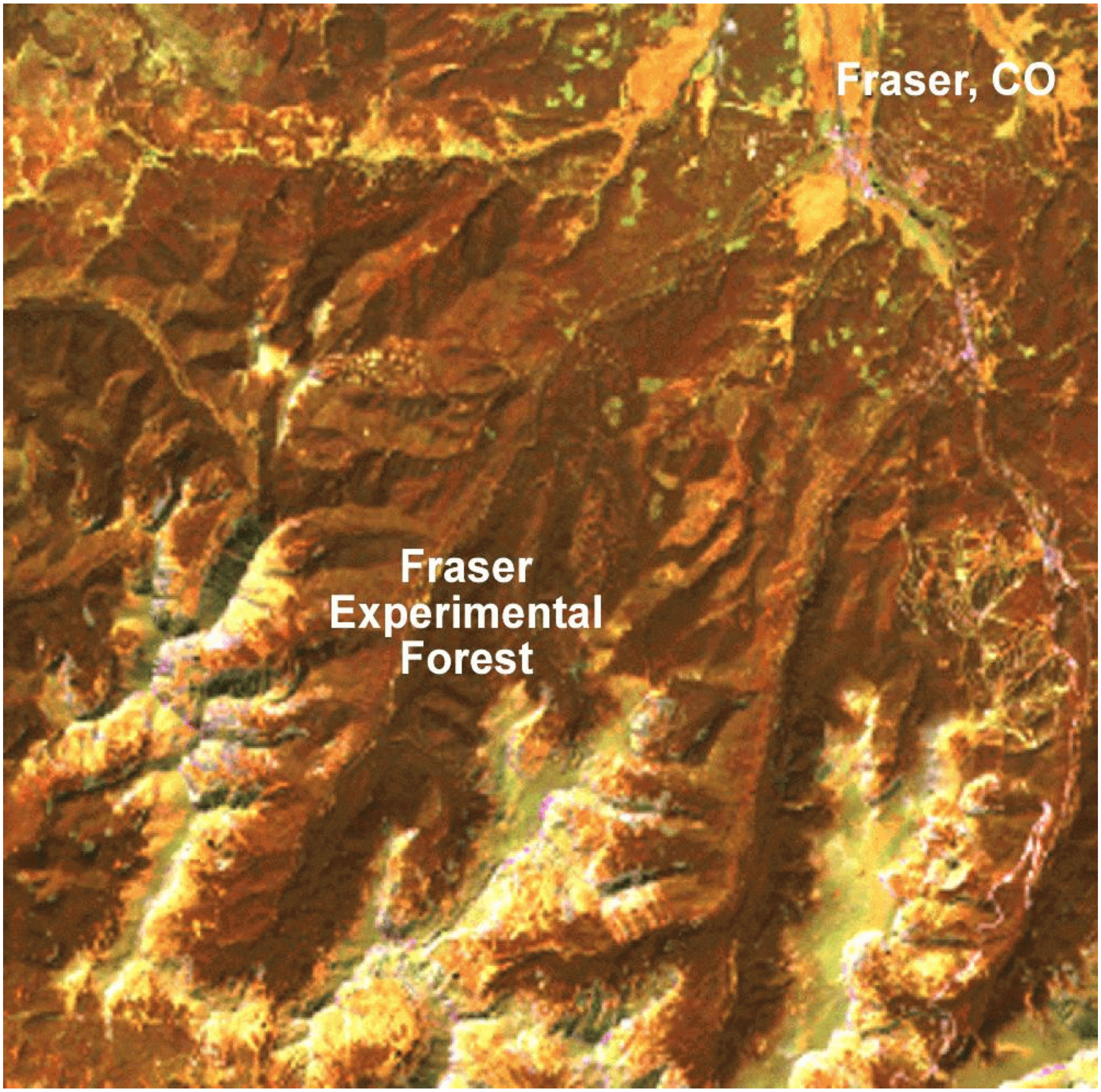


**Figure 13.** Landsat TM image showing Fraser Experimental Forest and vicinity.

## Niwot Ridge ISA

Niwot Ridge is a broad alpine ridge located in the Colorado Front Range, 20 miles west of Boulder, CO. The entire area is above 10,500' A.S.L. The ISA is relatively small, and is predominantly alpine tundra, with areas of patterned ground and permafrost. Topography on the ridge itself is mainly low, rolling hills, although terrain drops off steeply on either side of the ridge (Figure 14, Figure 15).


**Figure 14.** High-altitude aerial photograph of the Niwot Ridge ISA.

**Figure 15.** Niwot Ridge is the broad ridge extending from the lower right corner of the photo towards the photo center.

Snow distribution in this area is controlled by wind and topography; many areas of the ridge remain snow-free throughout the year as a result. Without insulating snow cover, these areas are susceptible to extreme soil freezing.

The alpine research area of Niwot Ridge, 4 km from the Station, was designated in 1975 as an Experimental Ecological Reserve by the Institute of Ecology, and in 1979 as a Biosphere Reserve by UNESCO, the U.S. State Department, and U.S. Forest Service. In 1980 Niwot Ridge was selected by the National Science Foundation as the alpine tundra component of the Long-Term Ecological Research (LTER) program.

Niwot Ridge has also been the site of extensive atmospheric research. The Mountain Climate Program, initiated by John Marr in 1952, continues to collect valuable data at five principal sites spanning a 5000 foot altitudinal gradient. The National Oceanic and Atmospheric Administration has sampled atmospheric gases from Niwot Ridge since 1968. The carbon dioxide record is the third longest in the world, and is the only long-term record from a continental site.

Niwot ridge is probably the most thoroughly studied alpine area in North America, by virtue of over 60 years of research programs. The Mountain Research Station is unique in providing these research opportunities within a 45-minute drive of a major university campus. The site is the focus of the Niwot LTER. Many facilities exist to support research on Niwot Ridge, including an alpine laboratory (Figure 16) with line power and fiber optic telecommunications capabilities, a subnivean laboratory (Figure 17) with complete micrometeorological instrumentation, and a dense network of continuously monitored soil and snow temperature profiles.

**Figure 16.** Alpine laboratory on Niwot Ridge.

**Figure 17**. Micrometeorological site at the Subnivean Laboratory on Niwot Ridge.

The University of Colorado Mountain Research Station (MRS) is an interdisciplinary research facility managed by the University's Institute of Arctic and Alpine Research (INSTAAR), and is located at the base of Niwot Ridge. An unimproved road provides access to the ridge from the MRS. Facilities at the MRS are available to support research activities on Niwot Ridge, including laboratories, lodging, a dining hall, bathhouse and laundry, and meeting rooms. The MRS has two snow cats that can go to Niwot Ridge when snow conditions permit.

## Grand Mesa ISA

The Grand Mesa is an 11'000 flat-topped mountain located 20 miles east of Grand Junction, CO (Figure 18). The area is over 3 million acres. The area is unique for Colorado - the mesa top is relatively flat, and is characterized by forests of Aspen, Engelmann Spruce, and Subalpine Fir, and by nearly 300 lake and

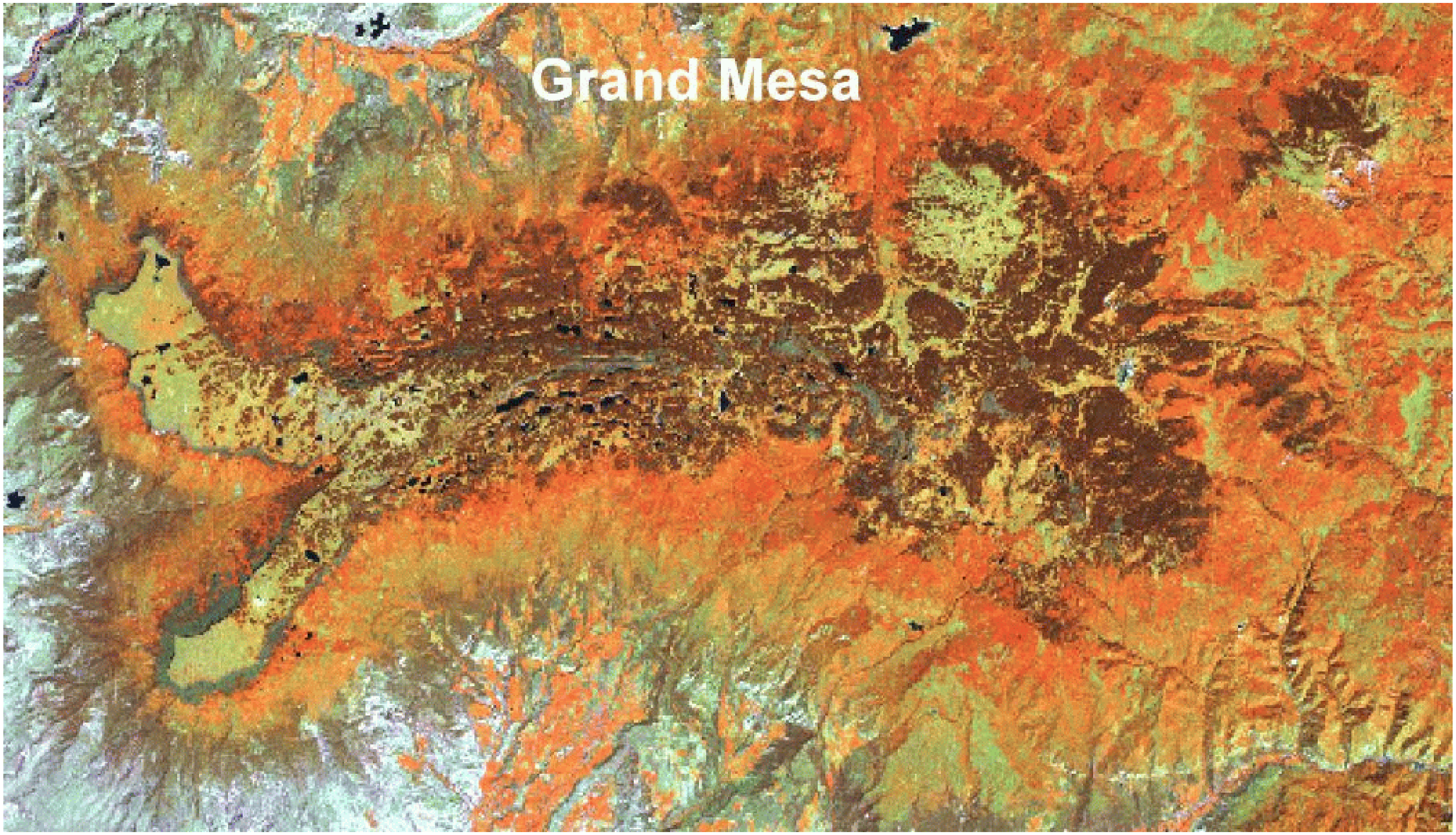


**Figure 18.** Landsat TM image showing Grand Mesa ISA.

reservoirs fed by melting snow. Wetland areas are extensive. Annual snow accumulation on the mesa is 5-10'. The presence of extensive lakes and wetlands in a forested environment provides a useful surrogate for many boreal areas, such as northern Minnesota.

Year-round access to Grand Mesa is provided by Hwy. 65 (the Grand Mesa National Scenic Byway). The Mesa is readily accessible by snow machine or skis. There are few facilities on the Mesa itself, but nearby towns below the Mesa summit provide basic facilities, and Grand Junction is less than an hour away.

## Upper Gunnison River Basin ISA

The Upper Gunnison River Basin (Figure 19) has been the focus of orographic precipitation and distributed hydrologic modeling research for many years, mainly by the USGS Water Resources Division. More recently, this basin has become one of three demonstration basins for the NASA Southwest Regional Earth Science Applications Center (RESAC), with a principal focus on snow cover mapping and snowmelt runoff modeling.

The upper basin is approximately 50,000 km$^2$, and exhibits a broad range of physiographic characteristics. The northern portion of the basin is predominantly montane, while the southern portion is lower elevation and considerably more dry. Snow accumulation and freezing conditions are reliable throughout much of the basin (e.g. Table 5, Table 6).

**Table 5.** Monthly Climate Summary for Gunnison, CO (053662), for the period 1/1/1900 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 25.9 | 31.1 | 41.7 | 55.7 | 66.3 | 76.1 | 80.7 | 78.7 | 72.6 | 61.8 | 45.6 | 30.1 | 55.5 |
| Average Min. Temperature (F) | -7.2 | -1.6 | 11.4 | 22.2 | 29.3 | 35.6 | 42.5 | 40.7 | 32.2 | 21.5 | 10.7 | -2.2 | 19.6 |
| Average Total Precipitation (in) | 0.83 | 0.76 | 0.68 | 0.70 | 0.80 | 0.69 | 1.47 | 1.49 | 0.96 | 0.73 | 0.55 | 0.77 | 10.44 |
| Average Total Snowfall (in) | 12.2 | 10.4 | 7.1 | 3.5 | 0.7 | 0.1 | 0.0 | 0.0 | 0.2 | 1.4 | 5.3 | 10.3 | 51.2 |
| Average Snow Depth (in) | 7 | 8 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |


**Figure 19.** Landsat TM image of Upper Gunnison basin, CO.

**Table 6.** Monthly Climate Summary for Crested Butte, CO (051959), for the period 6/1/1909 to 12/31/1999.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Max. Temperature (F) | 28.1 | 31.9 | 38.2 | 47.1 | 59.1 | 70.2 | 75.8 | 74.0 | 66.8 | 56.5 | 41.1 | 30.7 | 51.6 |
| Average Min. Temperature (F) | -4.1 | -0.9 | 7.1 | 18.0 | 27.7 | 33.2 | 38.3 | 37.5 | 30.1 | 20.5 | 8.5 | -1.9 | 17.8 |
| Average Total Precipitation (in) | 2.71 | 2.35 | 2.38 | 1.80 | 1.48 | 1.34 | 2.01 | 2.11 | 2.00 | 1.51 | 1.69 | 2.23 | 23.60 |
| Average Total Snowfall (in) | 40.0 | 34.4 | 32.4 | 17.6 | 6.4 | 0.7 | 0.0 | 0.0 | 1.3 | 7.9 | 23.6 | 33.2 | 197.5 |
| Average Snow Depth (in) | 26 | 36 | 35 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 14 | 11 |

The Upper Gunnison Basin ISA provides an opportunity to integrate science results from the EX-7 field experiment into on-going hydrological modeling and forecasting investigations. The area is well suited to serve as an intensive validation site for remote sensing retrieval algorithms developed at the other ISAs. Access to the area is primarily via Hwy. 50. Several smaller roads provide year-round access throughout most of the basin.

### Opportunistic Study Areas

In addition to the ISAs described above, there will be opportunities for data collection at other sites. While most of the resources for the experiment will be deployed at the ISAs, an ability to rapidly deploy basic instrumentation and measurement teams at opportunistic sites is desirable. Such sites may include areas such as the high plains in the eastern part of the study area, which do not reliably have snow cover and freezing conditions. If conditions become favorable during the field experiment, deployment to these sites may be considered. Flexibility in the aircraft schedule is a major factor in this regard.

There are many sites within the study area that may contain substantial instrumentation or relevant measurement infrastructure and could be considered opportunistic study areas. For example, the Shortgrass Steppe LTER east of Fort Collins, CO has many attributes conducive to the field experiment, but only occasionally experiences snow cover and substantial freezing conditions.

## Candidate Satellite Sensors

Data from several satellite sensors should be available at low cost (no cost in most cases) for the field experiment. A comprehensive satellite data collection strategy needs to be established, including a) which sensors are most important for meeting core and general objectives of the field experiment, b) selection of a data collection period, c) data acquisition policy, and c) archiving of satellite data sets.

An incomplete list of candidate satellite sensors follows; data from other sensors are likely to be available during the field experiment and should be considered. Acquisition of low-cost data from some of these sensors will require submission of proposals to the managing agencies.

## TERRA Platform

### ASTER

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) provides high spatial resolution (15 - 90 m) imagery in 14 visible, near-infrared, and thermal infrared channels. With a swath width of 60 km, ASTER data will be useful for evaluating the retrieval of the areal extent of snow cover from microwave sensors, particularly within Intensive Study Areas of the field experiment. An ASTER snow mapping algorithm has been developed and compared to high-resolution (2-3m) aerial photography. The field experiment will in turn be useful for further evaluating the accuracy of the ASTER snow mapping algorithm under a variety of viewing and illumination geometries, land cover, atmospheric and terrain conditions.

ASTER data will be requested only on the five selected intensive test sites representing different environments. Each test site is about 60 km by 60 km, within the coverage of a standard ASTER scene. Full-mode day-time ASTER data will be requested four to five times each snow season (October through June) for three years (2001 - 2003).

### MISR

The Multi-Angle Imaging Spectroradiometer (MISR) provides simultaneous imaging of the Earth's surface at nine different angles. One camera points toward nadir, and the others provide forward and aftward view angles, at the Earth's surface, of 26.1°, 45.6°, 60.0°, and 70.5°. As the instrument flies overhead, each region of the Earth's surface is successively imaged by all nine cameras in each of four wavelengths (blue, green, red, and near-infrared). The MISR instrument could be useful for investigating bidirectional reflectance distribution functions (BRDFs) of snow during the field experiment for improving solar radiation forcing for snow models.

### MODIS

The Moderate Resolution Imaging Spectroradiometer (MODIS) provides moderate resolution (250-1000 m) imagery in 36 spectral bands. With a 2330 km swath width, MODIS data will be useful for evaluating the retrieval of the areal extent of snow cover from microwave sensors at substantially larger scales than ASTER. Full-mode day-time MODIS data will be requested several times each snow season (October through June) for three years (2001 - 2003).

## EOS AQUA Platform

The AQUA platform is scheduled for launch in December, 2000.

### AMSR-E

The Advanced Microwave Scanning Radiometer-EOS (AMSR-E) is a 12 channel, 6 frequency passive microwave radiometer providing horizontal and vertically polarized measurements at 7, 11, 19, 24, 37, and 89 Ghz. Gridded snow data products will be available at 25-km resolution. Validation of the AMSR snow data products will be an important element of the Field Experiment.

## ENVISAT-1 Platform (European Space Agency)

The ENVISAT-1 platform is scheduled for launch in June, 2001.

### ASAR

The Advanced Synthetic Aperture Radar (ASAR) will be a C-band, HH and VV radar.

### MERIS

The Medium Resolution Imaging Spectrometer (MERIS) will be a MODIS-like instrument operating with 15 spectral bands in the visible and near-IR, with 300 m ground resolution.

## Other Platforms

### ALOS

The Advanced Land Observation Satellite (ALOS) is a follow-up of the Japanese Earth Resources Satellite-1 (JERS-1) and the Advanced Earth Observing Satellite (ADEOS) and enhanced land observing technology. ALOS will be launched in 2002 and will be used for cartography, regional observation, disaster monitoring, and resource surveying. ALOS has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo mapping (PRISM), the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2), and the Phased Array type L-band Synthetic Aperture Radar (PALSAR). ALOS sensors offer the means for estimating spatially and temporally distributed snow properties.

Pending a successful launch of the ALOS instrument, ALOS data will be requested over three snow years (2003 - 2005) to support field experiment investigations, including:

1. Data from the optical sensor AVNIR-2 will be used to estimate grain size of surface snow layer and the effects of both shallow snow and contamination by absorbing impurities such as dust or soot and thin snow. With these parameters snow albedo throughout the solar spectrum will be estimated.

2. Data from the optical sensor AVNIR-2 and microwave sensor PALSAR will be used to map the areal extent of snow cover and monitor snow extent change, and to identify the spatial distribution of wet snow cover.

3. The feasibility of estimating snow water equivalent using combined PALSAR, ASAR and Radarsat-2 measurements will be investigated.

### RADARSAT-2

This Canadian Space Agency satellite is scheduled for launch in 2002, and is planned to provide spatial resolution from 100 m to 3 m in swaths ranging from 500 km to 20 km. It will be a multi-polarization C-band SAR.

### QuikSCAT

The SeaWinds instrument on the QuikSCAT satellite is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans. SeaWinds uses a rotating dish antenna with two spot beams that sweep in a circular pattern. The antenna radiates microwave pulses at a frequency of 13.4 gigahertz across broad regions on Earth's surface. The instrument will collect data over ocean, land, and ice in a continuous, 1,800-kilometer-wide band, making approximately 400,000 measurements and covering 90% of Earth's surface in one day.

**GOES**

The Geostationary Operational Environmental Satellites (GOES) Imager is a multi-channel optical instrument designed to sense radiant and solar-reflected energy from sampled areas of the Earth. The multi-element spectral channels simultaneously sweep east-west and west-east along a north-to-south path by means of a two-axis mirror scan system. The instrument can produce full-Earth disc images, sector images that contain the edges of the Earth, and various sizes of area scans completely enclosed within the Earth scene using a new flexible scan system. Scan selection permits rapid continuous viewing of local areas for monitoring of mesoscale (regional) phenomena and accurate wind determination.

| CHANNEL | 1 | 2* | 3* | 4 | 5* |
|---|---|---|---|---|---|
| WAVELENGTH (um) | 0.65 | 3.9 | 6.7 | 11 | 12 |

**SSM/I**

The Special Sensor Microwave Imager (SSM/I) is a passive microwave radiometer flown aboard Defense Meteorological Satellite Program (DMSP) satellites: DMSP F-8, DMSP F-10, DMSP F-11, DMSP F-12, and DMSP F-13. The SSM/I is a seven-channel, four-frequency, linearly-polarized, passive microwave radiometric system which measures atmospheric, ocean and terrain microwave brightness temperatures at 19.35, 22.235, 37.0, and 85.5 GHz.

| Frequency (GHz) | Polarization | Integration Period | 3 dB Footprint Size Along-track | 3 dB Footprint Size Cross-track |
|---|---|---|---|---|
| 19.35 | vertical | 7.95 ms | 69 km | 43 km |
| 19.35 | horizontal | 7.95 ms | 69 km | 43 km |
| 22.235 | vertical | 7.95 ms | 50 km | 40 km |
| 37.0 | vertical | 7.95 ms | 37 km | 28 km |
| 37.0 | horizontal | 7.95 ms | 37 km | 29 km |
| 85.5 | vertical | 3.89 ms | 15 km | 13 km |
| 85.5 | horizontal | 3.89 ms | 15 km | 13 km |

# Candidate Airborne Sensors

## AIRSAR

The NASA/JPL airborne SAR (AIRSAR) system operates in the fully polarimetric mode at P-, L-, and C-band simultaneously or in the interferometric mode in both L- and C-band simultaneously. The instrument can be operated in several different modes which must be determined pre-flight. A variety of processors and processing techniques are used to process AIRSAR data to imagery. A real-time correlator is used to produce low-resolution (~25 m) two-look survey imagery. The same equipment is used to generate a slightly higher resolution (~15 m), 16-look image of a smaller area (12 km x 7 km) within 10 minutes of acquisition using the quick-look processor. Final processing of selected portions of the data to high-quality, fully calibrated image products happens in the weeks and months following a flight campaign.

The AIRSAR instrument is flown aboard the NASA DC-8 aircraft at a cost of $3000 per hour to NASA projects. AIRSAR flight requests for 2001 have already been submitted for reconnaissance flights over parts of the proposed field experiment study area (see Spring, 2001 Flight Lines, below).

## Alternative SAR Options

The major limitation of the AIRSAR instrument is that it lacks an X-band sensor, which is fairly critical for the snow algorithms to be tested in the field experiment. A JPL proposal to add an X-band by 2002 was unsuccessful. There are alternative airborne SAR sensors which could be considered for the experiment.

### GEOSAR

The Geographic Synthetic Aperture Radar (GEOSAR) is a dual-frequency sensor with a single-polarization (VV) X-band and a dual-polarization P-band. The sensor will be flown on a Gulfstream II aircraft. GEOSAR is a commercial venture with CALGIS, a GIS company in California that will eventually operate the sensor and the aircraft. The availability of the sensor for the 2002 field experiment depends on its development status. Early validation experiments are planned for California by the California Department of Conservation, with possible expansion to other states as data requests are received. Data costs of the fully commercial system are unknown.

### ERIM Instrument

The Environmental Research Institute of Michigan (ERIM) is purported to have an airborne X-band SAR system, but details are lacking here.

## Polarimetric Scanning Radiometer

The Polarimetric Scanning Radiometer (PSR) is a versatile airborne C-band microwave imaging radiometer operated by the NOAA Environmental Technology Laboratory in Boulder, CO. The PSR consists of a set of five polarimetric radiometers housed within a gimbal-mounted scanhead drum; the drum is rotatable so that the radiometers can view any angle within 70° elevation of nadir at any azimuth angle, as well as external hot and ambient calibration targets. The configuration supports conical, cross-track, along-track, fixed-angle stare, and spotlight scan modes.

The entire assembly has been designed for integration into three NASA aircraft: the DC-8 (nadir-7 port), Orion P-3B (aft end of the P-3 bomb bay), and ER-2 (Q-bay). Integration into the Scaled Composites Proteus aircraft is currently being considered and may be an option by early 2002, with expected flight operation costs of approximately $1500/hour. The PSR can fly on-board the NASA DC-8 with the AIRSAR instrument (the first co-flight with AIRSAR was for CAMEX-3), but this introduces simultaneous ground imaging issues with the nadir PSR view and the side-looking AIRSAR view.

## Gamma

The Gamma Radiation Detection instrument flown aboard the NOAA AC690A Turbo Commander is used for operational snow water equivalent observations by the National Operational Hydrologic Remote Sensing Center (NOHRSC) (Figure 20). Flight operations for this platform are approximately $1000/hour.

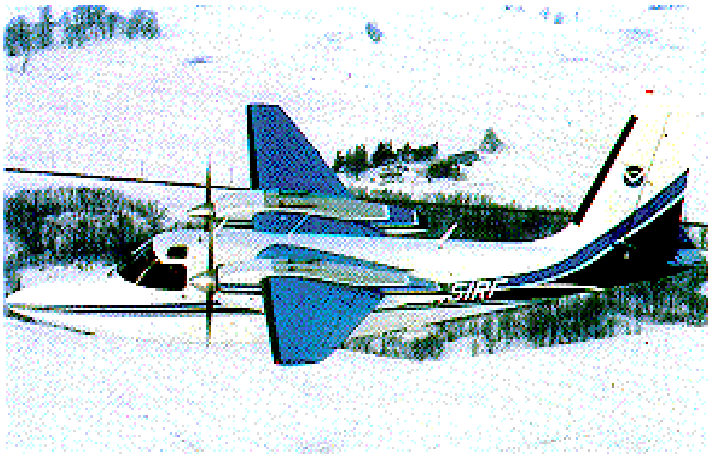

**Figure 20**. The NOAA AC690A aircraft.

The ability to make reliable airborne gamma radiation SWE measurements is based on the fact that natural terrestrial gamma radiation is emitted from the potassium, uranium, and thorium radioisotopes in the upper 8 inches of soil. The radiation is sensed from a low-flying aircraft flying 500 feet above the ground. Water mass in the snow cover attenuates, or blocks, the terrestrial radiation signal. Consequently, the difference between airborne radiation measurements made over bare ground and snow-covered ground can be used to calculate a mean areal SWE value with a root mean square error of less than one-half inch. The technique measures the attenuation of the radiation signal due solely to the intervening water mass.

The airborne detector package consists of five downward-looking 10.2 x 10.2 x 40.6 cm NaI(Tl) scintillation detectors; two 10.2 x 10.2 x 20.3 cm, upward-looking detectors (used to isolate the effects of the random gas contribution); a pulse height analyzer (PHA); a Hewlett-Packard 9825 minicomputer used to reduce and record the output data onto magnetic tape; temperature, pressure, and radar altitude sensors; and a remote control unit used by the system operator or navigator to control and monitor the data collection.

## NOAA LongEZ Platform

The N3R LongEZ is a personally owned aircraft with exceptional performance and aerodynamic characteristics. Instrumentation aboard the N3R includes a variety of instruments for measuring air-surface exchange parameters, including a Best Aircraft Turbulence (BAT) probe for measuring mean and turbulent wind parameters, humidity, temperature, and radiation, etc. It is capable of flying very low (e.g. at 10 m above the surface) and very slow with great agility, and is rated for +9, -6 Gs and for aerobatics should the need arise. The N3R aircraft has a low operational cost (~$150/hour); typical program costs run from $40K to $150K depending on complexity.

### FMCW Radar

A L-band frequency-modulated continuous wave (FMCW) radar operated by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) should be available for the field experiment. The radar can be flown on low-flying aircraft; the hovering capability provided by a helicopter may make this the most useful platform.

## Ground Observations

### Candidate Ground-based Remote Sensing Instruments

TBD

### SNOTELs

The National Resources Conservation Service SNOw TELemetry (SNOTEL) network in Colorado (see Figure 8) provides a valuable source of SWE and other meteorological data for the field experiment. The SNOTEL instruments are snow pillows that provide essentially a point measurement. The SNOTEL locations are selected for statistical runoff and water supply forecasting procedures, rather than for providing a spatially representative sample of SWE. Locations tend to be in small forest clearings at similar elevations for a given region of the state. This complicates the appropriate use of SNOTEL data for estimating mean SWE over larger areas.

SNOTEL sites provide automated data collection in near-real time. Many SNOTEL sites provide hourly data, while some may only provide daily observations. All snow pillow data are subject to various measurement problems, such as ice bridging and collapse, wayward elk, etc. Data are routinely quality controlled by the NRCS, which necessarily delays the availability of data by a day or two to as much as a week. There may be opportunities to augment the SNOTEL instrumentation at selected sites if necessary.

### Snow Courses

Manual snow courses are conducted principally by the National Resources Conservation Service (see Figure 8), and to a lesser extent by other federal, state, and local agencies. SWE is measured along defined transects, generally once or twice each month during the winter and spring. Snow course locations are selected for more or less the same reasons as for SNOTELs, although in most cases the snow course records are much older and the intended use of specific snow course data may have been different at the time a site was selected. In general, snow courses may provide a more representative measurement of SWE than SNOTELs, since they transect a variety of terrain.

### Intensive Ground Observations

Intensive ground measurement of SWE are not routinely collected, and will have to be planned as part of the field experiment. Options for intensive ground sampling include the excavation of snow pits for detailed observation of SWE and other snow pack characteristics, the use of various coring devices (e.g. Federal samplers, Adirondack tubes, etc.) to measure SWE without excavation, and depth probing.

Spatially intensive snow surveys require significant planning and resources (warm bodies) to conduct. A variety of sampling strategies may be appropriate, depending on terrain and expected snow characteristics. Often, a stepped measurement approach works well, where a large number of systematic depth probe measurements are collected relatively rapidly, a lesser number snow density measurements are collected through coring (slower than depth probing), and a relatively small number of full snow pits are excavated to determine internal snow pack characteristics. Depending on measurement objectives, it may not be necessary to excavate snow pits all the way to the ground. For example, if snow wetness or grain size of the upper few centimeters is all that is required, then pits may be very shallow.

All intensive ground measurements should include precise geolocation information using handheld GPS. With selective availability now turned off, adequate accuracy for most purposes is easily and quickly obtainable. Aerial photographs can be useful during intensive ground surveys to note relationship to landmarks, etc.

Ground measurement protocols need to be established and then followed by all ground observers during the field campaign. Some skill is required to properly use depth probes, coring devices, snow cutters and other snow pit tools, and GPS equipment. Coordinated training for all anticipated field personnel prior to the field experiment should be considered. This may be difficult to achieve given relatively ad hoc funding, as different groups may plan to participate in the field experiment in different ways. One approach to consider would be to form field observation teams, with at least one experienced backcountry snow surveyor to lead each team. This approach has important benefits for field safety as well (see below).

# Field Safety

The importance of field safety considerations for this field experiment cannot be overstated.

The field experiment will be conducted in remote, high mountain environments during late winter and early spring (which is still effectively winter in this environment). The measurement objective involves snow, which is a) cold, and b) often wet, which tends to make observers cold and wet if they are ill-prepared. Mountain storms can strike rapidly with little or no warning, changing conditions from fair and warm to white-out in a matter of minutes. Snow avalanches kill experienced backcountry travelers every year. Under clear, sunny skies, observers working on high-albedo snow fields can develop acute sunburn very quickly, in places they may not have previously considered eligible.

## Traumatic Disorders

Traumatic disorders - injuries produced by physical forces such as falls or falling objects - are the most common in short mountaineering trips. Observers traveling skis or snowshoes may take an unusually hard fall sufficient to require medical attention, or sustain other common injuries. Observers traveling by snowmobile are prone to a larger variety of injuries which can result from being thrown from the sled, overturning, collisions, etc. Snowmobile accidents involving low unseen tree branches, or more severely, barbed-wire fences, are not uncommon. Helmets are an obvious requirement for all snowmobile users during the field campaign.

## Avalanches

Snow avalanches are extremely common in many parts of the study area. Most avalanche victims die from traumatic injuries sustained from large blocks of snow or ice, or impact with rocks or trees. A smaller number suffocating under loose snow. The two requirements for avalanches - snow and gravity - exist throughout the study area and can pose a significant hazard even in seemingly unlikely areas. Many avalanche accidents occur on obvious, reoccurring avalanche paths, but many also occur on modest slopes. Physiographic characteristics and snow characteristics conducive to avalanches must both be readily recognized by field observers to avoid accidents. General backcountry avalanche warnings should be heeded, and the provision of special avalanche warnings for the field campaign should be considered. At least one member of each field party should be well-trained in avalanche safety, and all field observers should receive basic training on avalanche safety, what to do if caught in an avalanche, and avalanche rescue operations.

## Cold Injuries

The most common major injuries produced by cold are hypothermia and frostbite. Field observers working in winter, mountain conditions are especially susceptible to these injuries without adequate preparations and safeguards.

### Hypothermia

Hypothermia is a decrease in the core temperature of entire body which becomes significant when muscular and cerebral functions are impaired. Prevention of hypothermia is of utmost importance, and requires adequate amounts of water, food, and clothing. Hypothermia can advance rapidly, and can become life-threatening if not treated quickly. Every field observer should be trained to recognize signs of hypothermia. Mild hypothermia is most often accompanied by a feeling of chilliness. As the condition advances, the victim begins to lose muscular coordination; first fine hand movement is lost, then stumbling may occur. Shivering usually appears when body temperature has dropped two to four degrees. The intellect is also impaired as hypothermia develops. A common early sign is refusal to admit that anything is wrong. Subsequently the victim becomes apathetic and is unconcerned about his deteriorating condition. Mental sluggishness may be manifested by slow thought and speech. Signs of severe hypothermia usually occur when body temperature has fallen to about 90° F. An easily recognizable indicator of severe hypothermia is the gradual disappearance of shivering. Muscular incoordination is severe, and intellectual impairment is greater. A common and important sign of severe hypothermia is neglect or carelessness about protection from the cold. Eventually confusion and irrationality progress to incoherence and semiconsciousness. Finally, the victim loses consciousness entirely and become totally comatose.

Recognition of mild hypothermia is the most critical aspect of its treatment. Treatment of mild cases involves decreasing heat loss and increasing heat production, through a variety of means. Treatment of severe hypothermia is a much more complex problem that is largely unresponsive to treatments for milder cases. Rapid rewarming is hazardous and requires great care. Medical facilities are equipped to perform such treatment safely, but safely rewarming severely hypothermic cases in the field is difficult, and most often is hopeless without evacuation. Seemingly insignificant bumps and jolts caused by the evacuation itself can lead to fibrillation, further complicating the problem. The key is to avoid hypothermia in the first place.

### Frostbite

Frostbite is an injury, usually localized, characterized by freezing of the tissues. The hands and feet, which are furthest from the heart and have a more tenuous blood supply, and the face and ears, which are often exposed, are most commonly affected. To conserve heat for the central portions of the body, blood vessels in the extremities constrict. Constriction can be so severe that circulation to those areas almost ceases. Cold also damages the capillaries in the affected areas, causing plasma to leak through their walls. As the circulation becomes so severely impaired, the skin and superficial tissues exposed to severe cold begin to freeze. With continued cooling, the frozen area enlarges and extends to deeper levels. Ice crystals form within and between the cells and grow by extracting water from the cells. The cells are injured physically by the ice crystals, as well as by dehydration and the resulting disruption of osmotic and chemical balance.

The typical early signs of frostbite are sensations of cold or pain and pallor of the affected skin. However, some victims may suffer little pain, and pain typically disappears as tissues begin to freeze. As freezing progresses, the tissues usually become even whiter in appearance and all sensation is lost. Severe frostbite can affect an entire hand or foot and lower leg. Frostbite of the face, tip of nose, or ears can be recognized by pain and pallor of the affected tissues. With minor frostbite the tissues may only be red for a few days after thawing. With more severe injuries, blisters commonly develop after rewarming and may cover entire fingers or toes. The most severe frostbite injuries are not followed by blisters; they are followed by spontaneous separation of the dead tissue.

Frostbite is best prevented by avoiding the conditions by which it is produced. Proper clothing, and correctly fitting boots are important for avoiding frostbite. Field observers need to have a good understanding of proper clothing for winter field work. The preferred treatment for frostbite is rapid rewarming in a relatively large water bath, preferably administered in a hospital. Rewarming in the field should only be attempted when evacuation is not possible.

## High-Altitude Sickness

Medical problems associated with high altitude include a number of uncomfortable symptoms and some life threatening conditions. All are primarily the result of a decreased oxygen concentration in the blood caused by the lower atmospheric pressure at high altitude. The field experiment will be conducted at altitudes ranging from 8,000 to 14,000 feet. Eight thousand feet is a rough threshold above which altitude illness occurs.

Acute mountain sickness refers to a group of unpleasant symptoms related to high altitude, including headache, dizziness, fatigue, shortness of breath, loss of appetite, nausea and vomiting, disturbed sleep, and a general feeling of unwell, comparable to “flu” or a hangover. Drowsiness is common. After rapid ascents from sea level to between 8,000 and 10,000 feet occasional individuals have symptoms, and in some cases can be severe. High altitude pulmonary edema is the most dangerous of the common types of altitude illness. This disorder results in a drop in the concentration of oxygen in the blood, eventually causing cyanosis, impaired cerebral function, and finally death by suffocation. The chances of developing symptomatic high altitude pulmonary edema after a rapid ascent to 12,000 feet are about one in two hundred. Symptoms include an undue shortness of breath, a sense of “tightness in the chest”, or a feeling of impending suffocation at night, weakness, and marked fatigue. Relief from acute mountain sickness can usually be achieved by descent to lower altitude, although in minor cases this is not usually necessary. Recognition of symptoms of acute mountain sickness, and an understanding of basic treatment, are important skills that must be possessed by all field observers.

Physical performance decreases at high altitude, so observation schedules must plan accordingly.

## Safety Training

Many participants in the field experiment will likely have substantial winter backcountry experience, but many likely will not. Formal winter backcountry safety training should be considered for all field personnel. The NRCS provides a winter safety course each year at low cost to reduce risk to snow surveyors; this course could be suggested or required of personnel participating in the field experiment.

Other safety courses are also available, including specialized courses on avalanche awareness and safety.

### Medical Facilities

Emergent and non-emergent care facilities are available in most larger towns throughout the study area, although ground transport from remote field sites to such facilities can require several hours. Helicopter evacuation is possible from the largest medical facilities in the area. Planning considerations should include ensuring that each field team is equipped with cell phones and/or radios to contact help in the event of an emergency, as well as to assist in general communication during the experiment.

## Spring, 2001 Reconnaissance Experiment

To prepare for the large-scale 2002 Colorado field experiment, a smaller reconnaissance experiment is planned for the spring of 2001. The primary objectives of the recon experiment are 1) to become familiar with the region, expected snow conditions, accessibility, etc., 2) to establish ground data collection requirements and determine what new data collection infrastructure is required, 3) to gain a head-start on algorithm development activities, and 4) to begin developing the coordination infrastructure required for a large-scale experiment. It is, in essence, a warm-up experiment.

AIRSAR flights have been requested for four flight lines within the Colorado study area for two date windows in the spring of 2001. The first window is March 7 plus or minus two weeks. The second window is April 23 plus or minus two weeks. The lines were originally requested by J.C. Shi for an investigation of snow properties using InSAR; Shi has agreed to perform the investigation in Colorado to provide an opportunity to collect reconnaissance flight line data in advance of the field experiment.

Approximately $35K from various sources has been identified to conduct the recon experiment, which will be used entirely to fund the four flight lines. At this time, all other work associated with the recon experiment, such as ground data collection or remotely sensed data processing, will have to be performed at no cost.

### Planning Groups

During the workshop, the steering committee formed three groups to address near-term planning of the 2001 recon experiment, and longer term planning of the 2002 field experiment: 1) Modeling, 2) Algorithms, and 3) Observations. Members of the steering committee committed to performing various tasks identified for each group, discussed below.

**Modeling Group** (Cline, Davis, Elder, Granberg, Houser, Kimball, Leavesley, Liston)

Two categories of tasks were identified:

1. Ensuring that meteorological forcing data sets are available for the field experiment period, including BFM, MM5, FSL LAPS, RAMS, and RESAC forcing data.
    a. The point of contact (POC) for this task is Liston, with assistance from Leavesley and Davis.

2. Various modeling development efforts that will occur as a result of the experiment, including:
    a. Tree, snow, and soil (POC Davis)

b. SWE Distribution (POC Elder)
c. XYZ (POC Leavesley)
d. NOHRSC Snow Data Assimilation System (SNODAS) (POC Cline)
e. Blowing Snow (POC Liston)
f. LDAS (POC Houser)
g. GSFC Snow Data Assimilation (POC Houser)
h. PRMS (POC Leavesley)

**Algorithms Group** (Foster, Li, McDonald, Shi, Tsang)

Tasks for this group were divided into three categories:

1. SWE retrievals from SAR data (POC Shi), including:
    a. Interferometry without GEOSAR to retrieve SWE
    b. Polarimetry without GEOSAR to retrieve snow density, bare surface properties
    c. Polarimetry with GEOSAR to retreive SWE

2. Freeze/thaw retrievals (POC McDonald)
    a. QuikSCAT (with weather info) freeze/thaw planning data set
    b. Opportunistic second data take (diurnal?)

3. Other snow retreivals (POC Foster)
    a. AMSR validation (with airborne GAMMA data collection)

**Observations Group** (Cline, Davis, Elder, Foster, Granberg, Houser, Kimball, Li, Leavesley, Liston, McDonald, Shi, Tsang)

This group was divided into two subgroups, with Cline as the overall Observations Group POC:

1. Airborne/Satellite Observations Subgroup (Cline, Davis, Foster, Li, McDonald, Shi, Tsang)
    a. Airborne Data Collection (POC Cline)
        i. AIRSAR
        ii. GEOSAR
        iii. GAMMA
    b. Satellite Data Collection
        i. RadarSAT, QuikSCAT (POC McDonald)
        ii. AVHRR, Landsat (POC Davis)
        iii. MODIS (POC Li)
        iv. ASTER, MISR (POC Shi)
        v. AMSR, SSM/I (POC Foster)
        vi. IKONOS (POC Houser/Leavesley)

2. Ground Data Collection Subgroup (Cline, Davis, Elder, Foster, Granberg, Houser, Kimball, Leavesley, Liston, McDonald, Tsang)

    a. Ground Meteorological Data Collection (POC Houser (north), Leavesley (south)
    b. Snow, Freeze/Thaw Data Collection (POC Elder, assisted by Granberg)
        i. Manual SWE
        ii. Snow depth
        iii. Snow density
        iv. Snow wetness
        v. Grain size
        vi. Other

c. GIS/DEM Data Sets (POC Davis, assisted by Cline)

## Flight Lines for Reconnaissance Experiment

The four selected lines provide a cross-section of environments within the study area. Swath corners for the four lines are listed in Table 7.

**Rabbit Ears Pass/North Park Flight Line**
The first line is 90 km long, located over the Rabbit Ears and North Park ISAs (Figure 21). It passes directly over Walden, CO, and is accessible by Highways 14, 40, and 125. It will provide a preview of SAR imaging both of deep snow packs (Rabbit Ears Pass typically receives some of the deepest snow packs in Colorado), and of grassland and wetland environments in this area.

**Fraser Flight Line**
The second line is 80 km long, located over the Fraser ISA (Figure 21). It passes over low, relatively flat grasslands in the North, Fraser Experimental Forest in the center, and Loveland Pass in the South, and will provide a preview of SAR imaging over a wide landscape gradient including several different forest characteristics and high alpine areas.

**Grand Mesa/North Gunnison Flight Line**
The third line is 160 km long, located over Grand Mesa ISA and extending over the northern part of the Gunnison ISA to just east of Independence Pass (Figure 22). This line will provide a preview of SAR imaging over a boreal-like environment as well as rugged topography with varying snow conditions.

**East Gunnison Flight Line**
The fourth line is 144 km long, located over the eastern part of the Gunnison ISA (Figure 22). This line intersects the Grand Mesa/North Gunnison line over Independence Pass, and will provide a cross-section of many different snow, freeze/thaw, and landscape environments.

**Table 7.** AIRSAR flight line distances, headings, and swath corners for Spring, 2001 Colorado reconnaissance experiment.

| Flight Line | Dist (km) | Heading | 1st Corner (Degrees) | 2nd Corner (Degrees) | 3rd Corner (Degrees) | 4th Corner (Degrees) |
|---|---|---|---|---|---|---|
| Rabbit Ears/ North Park | 90 | NE | -106.79,40.35 | -106.73,40.27 | -106.00,40.85 | -106.06,40.94 |
| Fraser | 80 | S | -105.96,40.24 | -105.96,39.50 | -105.85,39.50 | -105.85,40.24 |
| Grand Mesa/ North Gunn. | 160 | E | -108.28,39.11 | -106.42,39.11 | -106.42,39.02 | -108.28,39.02 |
| East Gunnison | 144 | S | -106.65,39.38 | -106.53,39.38 | -106.53,38.08 | -106.65,38.08 |

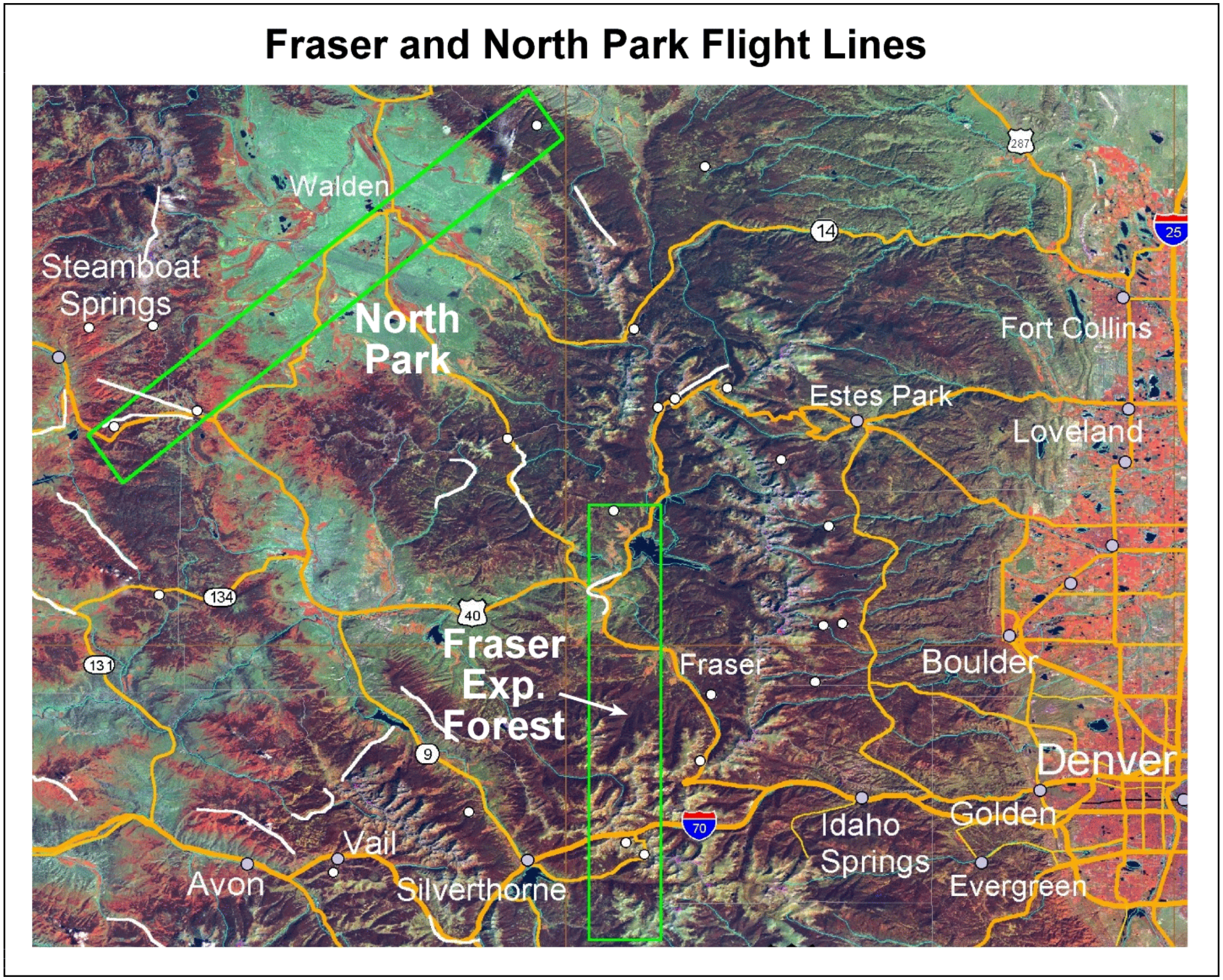


**Figure 21.** Rabbit Ears Pass/North Park flight line (upper left), and Fraser flight line (lower center). White lines are existing NOHRSC airborne gamma flight lines, and white circles are NRCS SNOTEL sites.

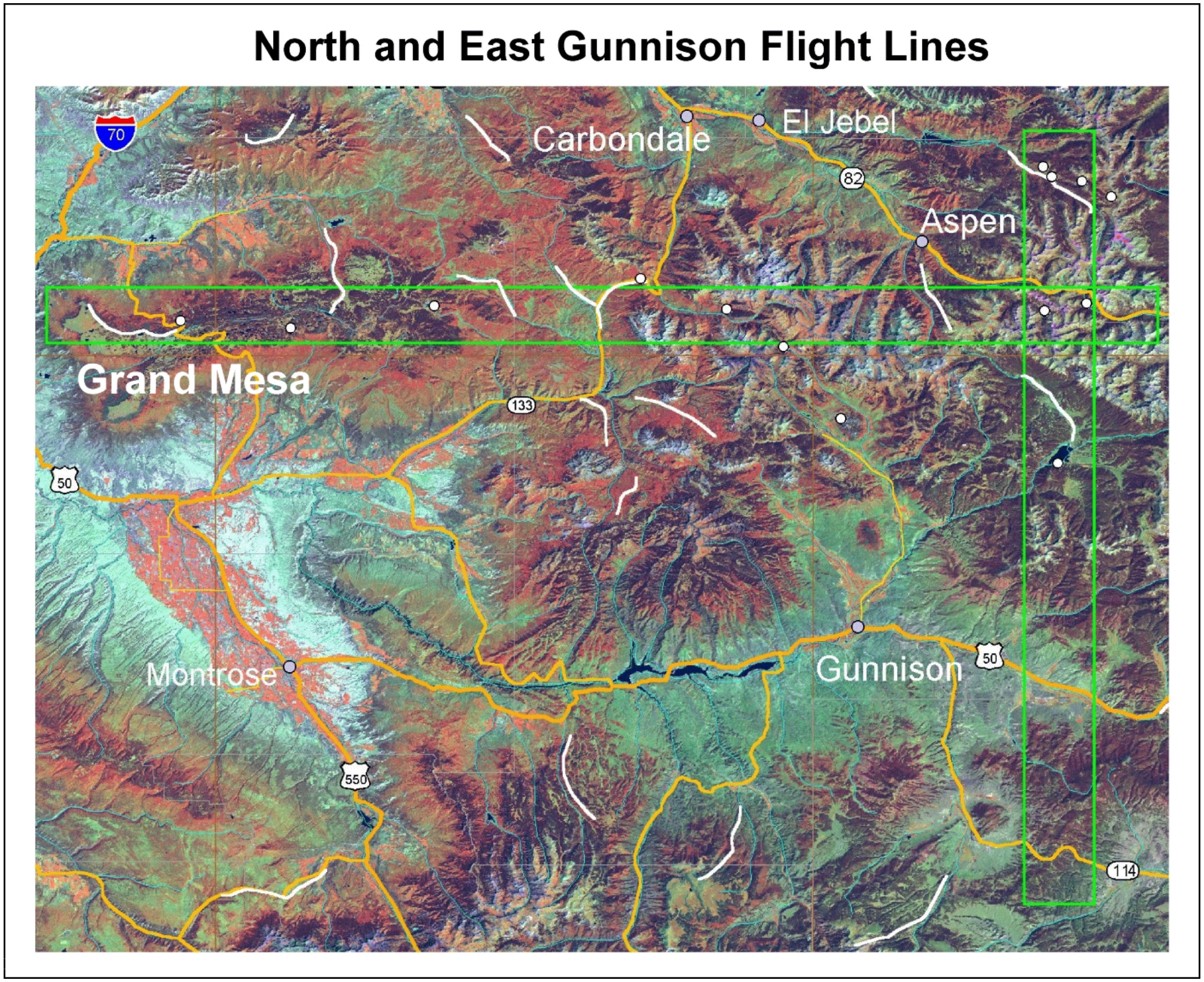


**Figure 22.** Grand Mesa/Gunnison North flight line (upper center), and East Gunnison flight line (far right). White lines are existing NOHRSC airborne gamma flight lines, and white circles are NRCS SNOTEL sites.

## ArcView Digital Atlas for the CLPM Field Experiment

A CD-ROM containing an ArcView Digital Atlas for the field experiment has been prepared to assist in planning experiment activities. The atlas is a compilation of data sets for the proposed study area in Colorado. An ArcView project is the primary method for viewing the geographic data. The Spatial Analysts extension for ArcView is required to view the atlas.

Maps in the atlas include:

3. **National.** The continental US is used as the source of reference for the EX-7 study area defined as 38-41 degrees North and 104-109 degrees West, an area in north central Colorado.

4. **Intensive Study Areas.** The map offers a general layout of the study area. Major highways, cities, and the six intensive study areas (ISAs) are provided against an outline of the study area. The roads theme is from the USGS.

5. **Transportation.** The map offers a slightly more detailed look at the roads of Colorado. The map is helpful for general navigation across the study area.

6. **Digital Elevation Model.** With county boundaries and a 1 degree graticule to use for reference, the DEM is 3-arc-seconds resampled to 30-arc-seconds.

7. **Forest Cover Density.** Again using county boundaries and a 1 degree reference graticule, the forest cover theme comes from the USDA. Grid resolution of this data set is 30 arc-seconds.

8. **Forest Cover Type.** Again using county boundaries and a 1 degree reference graticule, the forest cover type theme comes from the USDA. Grid resolution of this data set is 30 arc-seconds.

9. **Land Use/Land Cover.** The land-use/land-cover theme is a polygon theme prepared by the EPA and the USGS.

10. **PRISM Precipitation.** This theme depicts mean monthly precipitation using data from the National Resource Conservation Service (NRCS).

11. **Hospitals.** The hospitals theme comes from the Colorado Department of Public Health and the Environment. Those hospitals designated as level I-IV trauma centers are color coded. Hospitals in the Denver metropolitan area have been thinned for practical and visual reasons.

12. **Intensive Study Areas.** 1:24,000 DEMs are used in these views of the six ISAs. Hillshading is used as a brightness theme for the DEM. River reaches from the National Hydrography Dataset are used at this resolution and scale. The Yampa ISA is not included here.

13. **Soils - Dominant Texture Class.** This is from the CONUS-soils database, which is derived from the USDA-NRCS State Soil Geographic Database (STATSGO), this map shows the dominant soil texture class for each of 11 standard layers. Grid resolution of this data set is 30 arc-seconds.

14. **Soils - Bulk Density.** This is from the CONUS-soils database, which is derived from the USDA-NRCS State Soil Geographic Database (STATSGO), this map shows the bulk density for each of 11 standard layers. Grid resolution of this data set is 30 arc-seconds.

15. **Soils - Porosity.** This is from the CONUS-soils database, which is derived from the USDA-NRCS State Soil Geographic Database (STATSGO), this map shows the porosity for each of 11 standard layers. Grid resolution of this data set is 30 arc-seconds.

16. **Soils - Sand, Silt, Clay Fractions.** This is from the CONUS-soils database, which is derived from the USDA-NRCS State Soil Geographic Database (STATSGO), this map shows the fraction of sand, silt, and clay for each of 11 standard layers. Grid resolution of this data set is 30 arc-seconds.

17. **Flight Lines.** The National Operational Hydrologic Remote Sensing Center (NOHRSC) has established 41 gamma snow and soil moisture survey flight lines within the study area. These flight lines are shown, as well as airports.

18. **Snow Data Sites.** Against a backdrop of the DEM, NRCS SNOTELs and snow courses are displayed.

19. **Landsat**. A multiband Landsat TM composite is displayed. The data set is at 30-m resolution, providing a useful depiction of the landscape.

20. **Hydrography.** The USGS RF-3 hydrography data set is displayed.

21. **Snow Maps.** A collection of NOHRSC maps showing the areal extent of snow cover is displayed. Relatively cloud-free maps were selected on a monthly basis with maps from the beginning of the month given preference. These maps are low resolution (30 arc-seconds), but offer a general idea of the usual extent of the snow pack from January through June.

The data sets used to generate these maps are georegistered and can be used for modeling or related activities. All data sets and associated metadata are included on the CD-ROM.

## Field Experiment Funding Opportunities

There are at least three current or pending NRAs to be aware of that may provide resources for supporting field experiment activities.

### NRA: AMSR Validation

This NRA has already been announced (NRA-00-OES-03 - AQUA), and is for validation studies for data products from the Earth Observing System AQUA (PM) platform and EOS-related spectroscopic activities. Letters of intent to propose were due June 5, 2000. A letter of intent was submitted in behalf of the CLPM working group, entitled “Validation of AMSR-E Standard Snow Products in Mountainous Terrain”. Volunteers to write this proposal would be welcome.

### NRA: Joint LSHP et al.

Not yet released at the time of this writing, a joint NRA between the NASA LSHP and other programs is expected soon. This NRA may be particularly relevant to field experiment support. The working group needs to be prepared to respond effectively to this NRA.

### NRA: GEWEX America Prediction Project (GAPP)

A third NRA related to NASA-related GAPP (formerly GCIP) activities may be announced later this year. This NRA is expected to address remote sensing issues related to new satellite missions and their relevance to global water and energy cycles.

# Other Actions and Action Items from Workshop

## Working Group Officers

Cline was elected CLPWG Chairman, and Davis was elected CLPWG Vice-Chairman.

## General Points of Discussion

**Need for High Degree of Coordination in Field Experiment**
It was agreed that a high degree of coordination between experiment participants will be essential to the success of the experiments. Safety issues, and ensuring that data sets are generated and used consistently across elements of the investigation, were deemed the major reasons for this requirement.

The need for a core funded experimental effort was discussed in detail as the most viable means of ensuring a high degree of coordination. Organization of the SGP experiments was discussed as an example of how this has worked well previously. The NASA LSHP was identified as the most likely source of core experiment funding, with a possibility of NASA IDS providing similar funding.

**Trade Table Development**
Several trade tables relevant to EX-7 planning were discussed by the group. Trade tables will generally consist of 2 axes: a) the measurement that can be achieved, and b) the various methods of measurement, conditions of measurement, or characteristics of the feature being measured. It was resolved that tables describing various trade-offs between the following should be developed through the course of the field experiment(s).

1. Sensor Class/Type
    a. Active vs. passive microwave (each including various frequencies combinations)
2. Temporal Resolution
    a. Ranging from diurnal, to a few days, to several days
3. Spatial Resolution
    a. Ranging from a few meters to 10s of kilometers
4. Vegetation
    a. Various types of vegetation most important
    b. Various vegetation characteristics, such as height, cover, LAI, reflectance also may be useful
5. Topographic Characteristics
    a. Various criteria possible
    b. SAR baseline characteristics should be considered
6. Snow Characteristics
    a. Snow extent, depth, density, and wetness are the major considerations
    b. Snow grain size, albedo, and stratigraphy are less important
7. Freeze/Thaw Characteristics
    a. Vegetation, snow, and soil discrimination are the major criteria
8. Land Cover/Land Use
    a. Various criteria possible

9. Soil Properties
    a. Capability stratified by various soil properties important
        i. Thermal properties
        ii. Moisture properties
        iii. Roughness properties

It was resolved that a set of preliminary, largely subjective trade tables addressing these criteria should be developed to the extent possible, in conjunction with a position paper (see below).

## Next Workshops and Meetings

**Field Experiment Workshop**
It was resolved to convene a second workshop in early Fall, 2000, to firm up planning for the 2001 reconnaissance experiment. This workshop will be opened to a larger, but limited group of interested researchers. It will be important for new participants to understand that the 2001 experiment is very low-budget, and that we will be soliciting "free" help.

Late October was suggested as a convenient time to hold the workshop.

A suggested agenda for the fall workshop is:
1. Information meeting for 2002 Field Experiment (1st day)
2. Solicit limited help for 2001 reconnaissance experiment in advance of workshop, then devote 1 day to planning (2nd day)

**Open Cold Land Processes Working Group Meeting**
It was resolved to convene an open CLPWG informational meeting during the Fall AGU Meeting in December, to provide a forum for discussion regarding any aspects of the Cold Land Processes Mission. This meeting will be well advertised in advance, and open to anyone interested.

**2000 Fall AGU Special Session**
It was resolved to participate in the Fall AGU Special Session on Cold Land Processes, convened by Cline, Baker, and Kunkel. At a minimum, Cline plans to present an overview of EX-7 planning, and Davis will present an overview of the 2001 Experiment Plan (see below). Others presenters will be solicited from the CLPWG to discuss various science aspects of the Mission planning.

There is also a special session scheduled on Snow Hydrology, which should be a useful forum for EX-7 presentations.

## Publications

Three publications were identified at the workshop, with resolutions to begin publication efforts immediately.

**EX-7 Position Statement**
It was determined that the Irvine Workshop Report was already out of date, and in many specific instances no longer relevant. Therefore it was resolved to draft an EX-7 Position Statement, based on currently relevant parts of the Irvine report. Preliminary trade tables should be developed and included in the statement. Details of current field experiment planning should not be included in this Statement. The time frame for completion of this statement is as soon as possible.

A draft of the Position Statement will be circulated to the CLPWG Steering Committee as soon as possible, with a solicitation for internal comments and suggestions for revisions. The Statement will be discussed at the next CLPWG workshop, then finalized and submitted for publication shortly thereafter.

***Eos***
It was resolved to submit the Executive Summary of the EX-7 Position Statement for publication in *Eos*, *Transactions of the AGU* in the fall of 2000.

**Field Experiment Plan White Paper**
It was resolved to formalize EX-7 field experiment plans in a white paper format. Davis agreed to generate a draft report describing the 2001 reconnaissance experiment planning, with the expectation that this report will later be embedded in a larger document describing the 2002 Field Experiment Plan.

## Required Reading

All participants should familiarize themselves with the *Cold Land Processes Mission (EX-7) Science and Technology Implementation Plan*, which is available on the web at:

http://www.nohrsc.nws.gov/cline/ex7_web/ex7_home.html

## Contact Information

**Working Group Coordinator**
(any questions or issues with the workshop, schedule, etc.)

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