Numerical Simulations of Snowpack Augmentation for Drought Mitigation Studies in the Colorado Rocky Mountains

Financial Assistance Agreement No. 03-FC-81-0925
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Ross Williams, Applied Weather Associates, was not included in the State of Colorado's proposal to the US Bureau of Reclamation (Reclamation) in response to Solicitation No. 03-FC-81-0890. After the Financial Assistance Agreement 03-FC-81-0925 was awarded to the Colorado Water Conservation Board (CWCB), Joe Busto hired Ross as a consultant to provide GIS support to the project. The CWCB is funding a $4,800 purchase order for Ross' work as additional cost sharing for the project.

Overview of Project Status

The WDMP-Colorado Financial Assistance Agreement was awarded to the CWCB on October 2, 2003. This original assistance agreement had a completion date of September 30, 2004, which did not agree with the proposal. Joe Busto requested a no-cost time extension so that the WDMP assistance agreement would expire on December 31, 2004. In a letter dated December 2, 2003, Reclamation (Randy Jackson, Grants and Cooperative Agreements Officer) clarified that the period of performance would extend through to December 31, 2004. Because of the delay in receiving this clarification from Reclamation, the contract between the CWCB and Colorado State University (CSU) was not signed until December 9, 2003. However, CSU team members were working on the project even before the Project Kickoff Meeting at CSU on October 22, 2003.

The Statement of Work in the CWCB-CSU Contract listed 16 deliverables related to the 6 tasks listed in the project's Research Work Plan. As of the end of January 2004, 6 of these deliverables had been completed by CSU. These 6 deliverables comprise about 43 percent of the CWCB-CSU Contract. These tasks will be summarized in following subsections of this technical progress report.

Denver Water's and the Central Rockies Cloud Seeding Programs:

The Vail/Beaver Creek Seeding Program was originally scheduled to operate through the end of January 2004. However, this Program was extended to operate through February 14, 2004. The Vail/Beaver Creek Program had utilized about 2,860 seeding hours through January 20, 2004 and it is estimated that the Total Seeding Hours will approach about 3,700 hours by February 14, 2004.

The Denver Water Seeding Program in the Blue and Williams Fork Basins is scheduled to end about February 10, 2004. The portion of the Seeding Program affecting the mountains surrounding the Upper South Platte Basin is scheduled to operate through March 31, 2004.

Through the end of December 2004, the Denver Water Program had utilized about 8,130 seeding hours of the 13,602 available seeding hours. As of January 27th, the Program was close to the estimated schedule of utilization of seeding hours (10,700).

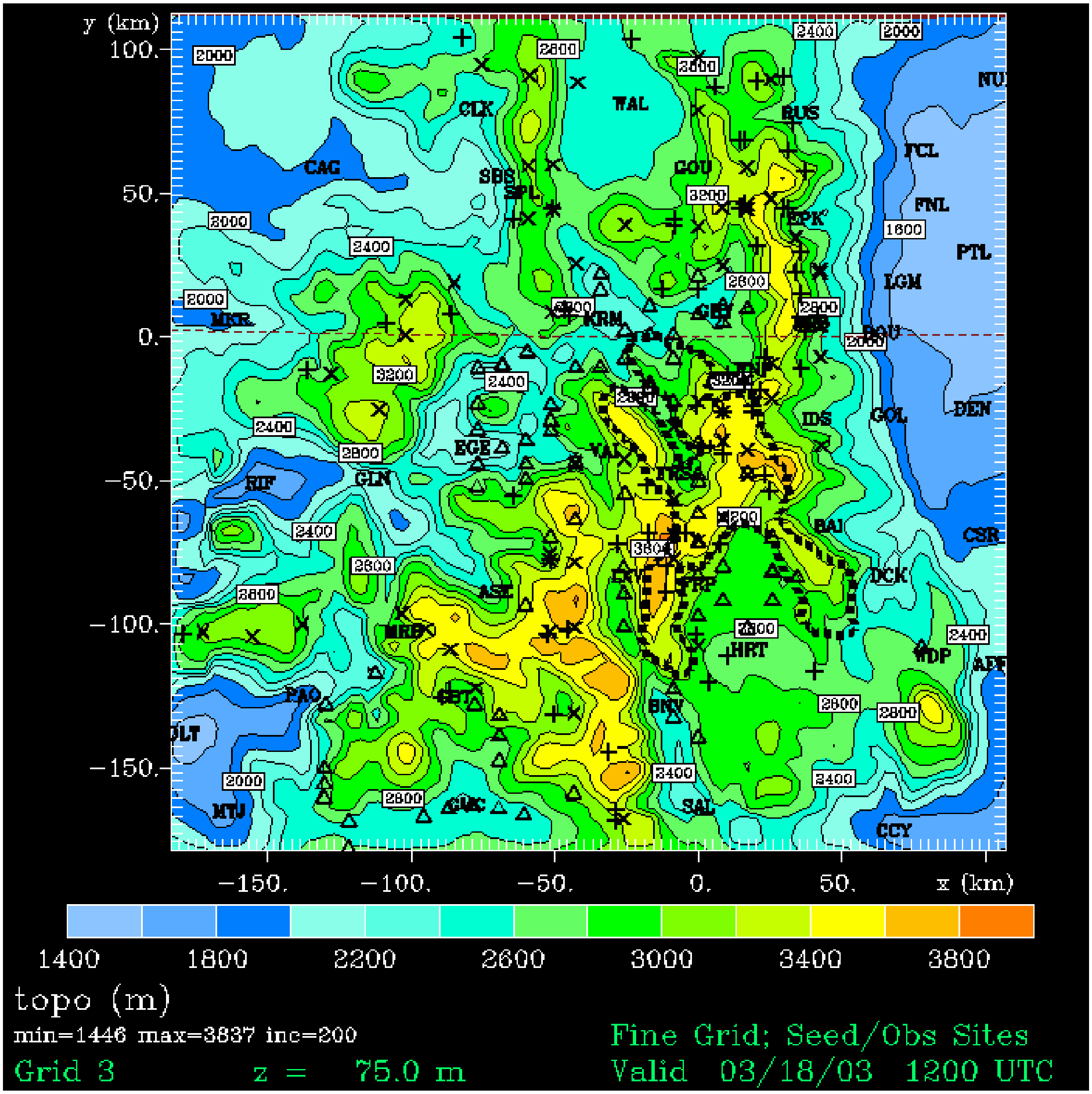
Project Performance and Status by Task

Task 1 – *Set up RAMS over the Denver Water Department operational cloud seeding areas and over the locations of the ground-based generators.*

Deliverable 1 *– Graphic of RAMS grid over cloud seeding area with Snotel/Snowcourse sites, precipitation gages, and WWC ice nuclei generator locations (due December 15, 2003)*

This deliverable was completed and included on CSU's invoice #1 dated December 12, 2003.

Figure 1 shows the RAMS fine grid domain (Grid 3). It consists of 98x98 grid cells, each 3km x 3km, for a total areal coverage of 294km x 294km over the central and northern Colorado Rockies. Grid 3 is nested within a regional grid (Grid 2) covering all of Colorado and portions of surrounding states at 12km grid spacing; Grid 2 is nested within a parent grid (Grid 1) that covers the conterminous U.S. at 48km grid spacing. The dashed line shows the Target Area boundary for Denver Water's seeding program in the east-central portion of Grid 3. Active generator sites for all Colorado seeding programs for the 2003-2004 winter season are shown by triangles. Active observation sites for the 2003-2004 winter season include SNOTEL sites (x), Snowcourse sites (+), and co-located SNOTEL/Snowcourse sites (*). Precipitation observation locations from three additional networks will be added as soon as their site information becomes complete. These include: daily precipitation and/or snowfall observations at nine ski areas in or near the Target Area; NWS climate and cooperative sites; and the volunteer Community Collaborative Rain and Hail Study (CoCoRaHS) network directed by the Colorado Climate Center (http://ccc.atmos.colostate.edu/~hail/).



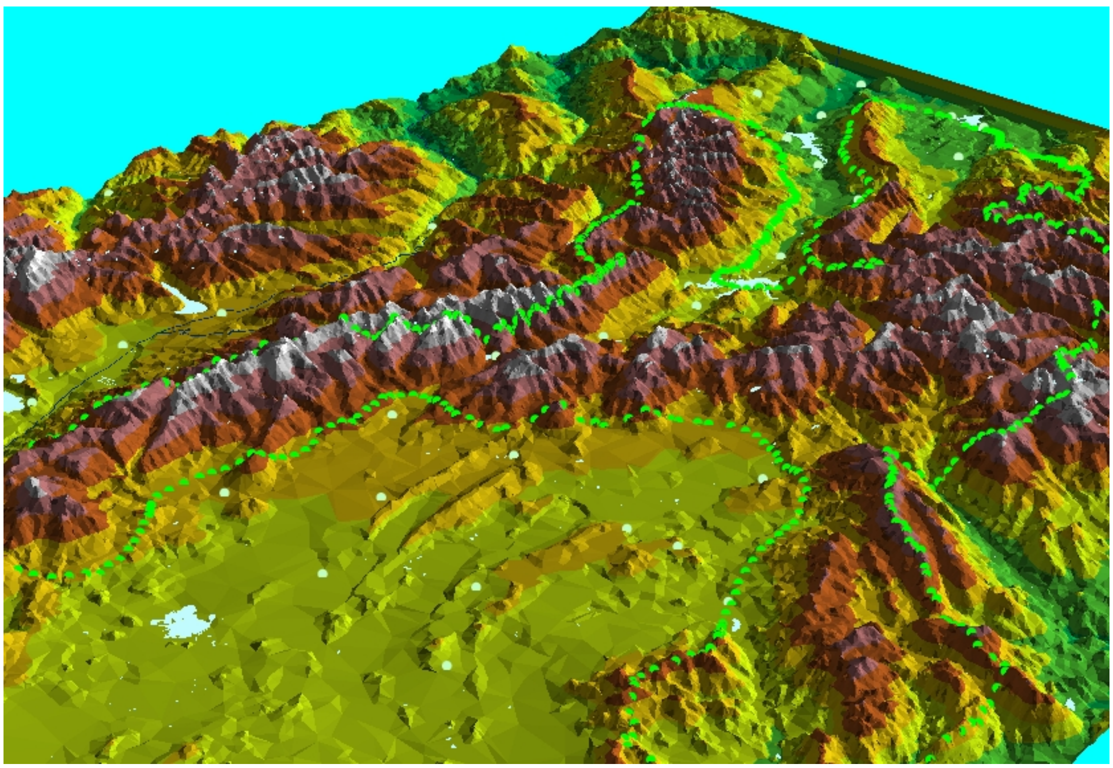
RAMS grid incorporated into GIS – This task was not included in the project's Research Work Plan; however, Joe Busto believed that it would be a significant benefit to the project to add good GIS capability; consequently, the CWCB hired Ross Williams for this purpose. Denver Water (DW) and the research project will use the target-area polygon developed by Ross Williams.

GIS Updates: Regarding the creation and implementation of the GIS for this project, Ross Williams has completed the following:

1) Using proprietary 30-meter DEM data, a terrain model has been built to cover not only the region of study, but also the entire state of Colorado. This high-resolution model will be the base layer for many of the maps created in this study.

2) USGS EROS 90-meter DEM data were utilized to create a lesser resolution terrain model for the area in and surrounding the cloud seeding target area and the RAMS grid. This terrain model is useful for detailed terrain analysis, such as moisture inflow barrier analysis, as well as conversion into a 3-demensional (3D) terrain model.

3) ESRI's ArcView 3D Analyst was used to create a 3D model of the region immediately surrounding and including the cloud seeding target area. There has been some discussion as to the locations of cloud seeding generators in high mountain valleys and the effect of temperature inversions on the effectiveness of those particular stations, so this 3D model may help to display those generators that may not be as effective to the cloud seeding in the target area. Below is a preliminary example of this model. The generator locations and target area boundary are seen as green dots in this example – this has been updated.



4) Although not implemented yet, Ianko Tchoukanski's Profiler Extractor 6.0 can be used to investigate upwind moisture inflow barriers as related to a point in the geographic center of the target area in relation to the locations of cloud seeding generators - in other words, profile lines radiating out from a central point through the generator locations and beyond into the upwind terrain. This method for highly detailed terrain analysis has been used in many site-specific PMP studies throughout the state and in other regions of the US.

5) Recently received were all of the newest information regarding the correct naming and locations of the cloud seeding generators. This work was completed jointly and in a timely manner by Greg Bryant (GIS Specialist – Denver Water Board) and Larry Hjermstad of

Western Weather Consultants. Ross Williams converted and imported these data into the GIS. The data are currently being classified based upon the site clients.

6) Also received from Greg Bryant through Joe Busto are the locations of the SNOTEL / Snowcourse sites to be utilized in this study. The data were in good order and will easily be implemented into the GIS.
7) Larry Hjermstad has made available the locations of nine ski areas that will provide data to this project. The locations have been converted into GIS form and added to the GIS.
8) All base layer data, such as roads, highways, streams, lakes, etc., have been created for the study area.

Ray McAnelly and Ross Williams have been in contact with each other regarding the inclusion of the RAMS 3km grid into the GIS. Some data format problems have been encountered that still need resolution. This problem should be resolved soon.

Renaming of Generator Sites – This task was not included in the project's Research Work Plan; however, the CWCB and DW determined that that it was necessary to rename the generator sites not only for the research project, but also for clarity with past and future operational cloud seeding programs. Greg Bryant (Denver Water GIS Coordinator) and Joe Busto worked with Larry Hjermstad (Western Weather Consultants, LLC (WWC) to rename ice nuclei generator sites from initials of the operators to a numbering system. The result was an Excel spreadsheet that contains the site ID, location, elevation, status, and other information for all generator sites. This will be the official site-identification system for DW and their numbers scheme will be built into the research project's GIS and graphics.

During the January 14th conference call there was discussion about adding columns to the Generator Site Excel spreadsheet for WWC seeding reports (e.g. dates, times, and rates by site). Larry suggested using one spreadsheet per storm to reduce confusion. These "storm seeding report" spreadsheets would be combined into a summary spreadsheet at the end of the operational program. Larry could provide these storm spreadsheets to the CWCB, DW, and the project on a monthly basis.

Task 2 – *Implement algorithms simulating cloud seeding generators as sources of IFN at specified ground-based sites.*

Deliverable 2 – *Summary of changes to RAMS source code suitable for inclusion in reports (due December 15, 2003)*

This deliverable was completed and included on CSU's invoice #1 dated December 12, 2003.

The summary of changes to the RAMS source code that was prepared will be included as an appendix to the Final Report.

A two-dimensional model demonstration of the cloud seeding effects was included in the December 12, 2003 invoice from CSU. A ground-based IFN source was located upwind of a two-dimensional mountain. Seeded IFN were produced at a rate typical for seeding operations and were dispersed and advected over the mountain. An appreciable fraction of the seeded IFN became activated in the trajectory over the mountain, with the maximum concentration of activated IFN occurring over the top of the mountain. Compared to a no-seed run in which only natural IFN was modeled, the seeded run produced appreciably larger ice mixing ratios over most of the mountain.

In a preliminary three-dimensional test case from February 4, 2003, an hour was simulated during which the seeding from several generators was included. The test showed that the seeded IFN was introduced at the proper time and locations in the RAMS fine grid, and that some activation occurred as the seeded IFN was carried to higher elevations. This preliminary test was limited, due to incomplete seeding information that we had at the time, and due to the relatively slow single-processing computer used for the test, which limited the simulation duration. However, it did indicate that the seeding algorithms are working properly. We now have complete seeding information for the test case, but our first attempts at running this code on a much faster parallel cluster, which is necessary for a more extensive simulation of this case, were unsuccessful. This parallelization problem is a minor problem and should be solved next week, now that the new project cluster is available. This test case will then be completed before the seeding runs for this season are conducted.

Task 3 - *Perform simulations of Lagrangian transport of seeding materials on selected days covering a range of wind and stability regimes.*

Deliverable 3.1 *– Summary of procedures implemented for the automatic collection of meteorological data needed for decision making, including data type and location, and the establishment of a data archive (due December 15, 2003)*

This deliverable was completed and included on CSU's invoice #1 dated December 12, 2003.

An automated archival system is in place at the CSU Department of Atmospheric Science Weather Laboratory, in which a suite of National Weather Service (NWS) Difax maps are electronically archived (http://vapor.atmos.colostate.edu/archive/). The most pertinent of these products are surface and upper-air analyses, and Eta model analyses and forecasts. From a sounding archive maintained by a University of Wyoming Department of Atmospheric Science website (http://weather.uwyo.edu/upperair/sounding.html), we are acquiring a continuous set of 0000 and 1200 UTC soundings (text data and skew-T plots) for NWS sounding sites in, upwind, and surrounding Colorado (Denver and Grand Junction, CO; Boise, ID; Elko and Las Vegas, NV; Tucson and Flagstaff, AZ; Salt Lake City, UT; Riverton, WY; Albuquerque, NM; Rapid City, SD; North Platte, NE; Dodge City, KS; and Amarillo, TX. These include all soundings in and immediately surrounding the RAMS regional grid (12km grid spacing). Selected geosyncronous infrared satellite images for each day are being electronically obtained from an hourly archive maintained by Unisys Corp. (http://www.weather.unisys.com/archive/sat_ir/).

These datasets are being built into a project website at CSU that will facilitate examination of each day and the selection of days spanning a range of wind and stability regimes.

Identification of all precipitation observation sites - Ray McAnelly and Larry Hjermstad are collaborating on the development of the list of precipitation observation sites within and around the research project area needed for evaluation studies. Active SNOTEL and Snowcourse site lists are complete and are indicated on Fig. 1. Arrangements have been made to receive daily precipitation observations from nine ski areas, whose locations will also be added to Fig. 1. The SNOTEL, Snowcourse, and ski area sites, being at generally high elevations where the heaviest snowpack accumulates, will provide the most critical precipitation observations for the target area and beyond. Supplementing these observations will be daily precipitation observations from NWS climate and cooperative sites and from the volunteer CoCoRaHS sites in the mountain counties, most of which are located in the more habitable valleys and elevations below the primary high-snowpack regions. The sites for these networks will be added to Fig. 1 soon, when their site lists are complete.

On CSU's project website (http://rams.atmos.colostate.edu/clseeding/), separate maps are being posted for each network (SNOTEL, Snowcourse, ski area, NWS climate and cooperative network, and CoCoRaHS), with unique identifiers for each site that is cross-referenced to a corresponding site list that is posted for that network. For each network, there is a map for the entire Fine Grid shown in Fig. 1, and a portion of the Fine Grid that zooms in on the target area.

Complete data for these networks are being collected from on-line sources and will be posted on CSU's project website. After quality control and evaluation of the data, observations from a subset of the most reliable and representative sites from each network will be used for statistical precipitation analysis.

Deliverable 3.2 *– List of selected meteorological regimes (due March 31, 2004)*

The project team has had some discussion on a couple of possible storms to use in this analysis, but the actual selection of different meteorological regimes and storms has not started as yet.

Deliverable 3.3 *- Preliminary findings from the Langranian case study analyses (due May 31, 2004)*

Langranian Analyses – This task involves selecting meteorological regimes that impact the transport and dispersion of seeding material, and identifying case study days that represent those regimes. The analyses will be for selected days and selected generator sites for various observed wind and stability regimes during operational cloud seeding periods.

Task 4 – *Perform forecasts for seeded and non-seeded days.*

Deliverable 4.1 *– Copy of invoice for the procurement of additional PC processors needed to double the capacity of CSU's existing PC cluster (due December 15, 2003)*

This deliverable was completed and included on CSU's invoice #2 dated January 14, 2004.

CSU could not order the additional PC processors needed to expand the existing PC Cluster until after the CWCB-CSU contract for this project was in place. As stated earlier, this contract was not signed until December 9, 2003. The new PC processors were ordered in late December 2003, received around mid-January 2004, and were installed during the last week of January. During installation, it was found that two out of the eight slave nodes had incompatible network cards (server adapters), and those two nodes could not be booted. The hardware contractor recently shipped compatible replacement cards for the two nodes, and they have been installed. Full testing of the cluster should commence the second week of February, and the real-time forecast runs will be switched to the new cluster by the end of that week. The cluster will then be available for the seeding runs each day between the forecast runs. The cluster will then be available for the seeding runs each day between the forecast runs.

***Deliverable 4.2** – Operational RAMS website containing full suite of products outlined in the WDMP RFP for the proposed research studies, and estimated precipitation accumulations for use in cloud seeding decision making (due December 15, 2003)*

This deliverable was completed and included on CSU's invoice #2 dated January 14, 2004.

The CSU website address is http://rams.atmos.colostate.edu/clseeding/. Observational data from each network will be posted on a link at http://rams.atmos.colostate.edu/clseeding/data. Daily-simulated precipitation maps from the real-time runs will be posted at http://rams.atmos.colostate.edu/clseeding/simprecip. For each day, the 24h simulated precipitation is derived from the 8-32h period of the 48h real-time run (initialized at 00 UTC), or from 08 UTC on the first day of the simulation to 08 UTC on the second day. This period coincides with the 24h precipitation-reporting period that is used uniformly for all SNOTEL sites. The observational data and model precipitation maps will begin being posted to the website during the first week of February 2004, post-dated to the November 1, 2003 start date of the project. The website should be substantially functional by the time of a project meeting scheduled at CSU in mid-February.

***Deliverable 4.3** – Report on manually updated archive on RAMS website containing data from first and second model runs (due February 29, 2004)*

Because the hardware for expanding the CSU PC cluster could not be ordered until after the CWCB-CSU contract was signed, the installation of the new PC processors was not completed until late January 2004, and testing of the new cluster could not commence until the first week of February. The new cluster is expected to be fully tested and operational by the end of that week, at which time the real-time forecast runs will be switched to the new cluster, with no interruption in the daily real-time forecast cycle. The runtimes are expected to be at least as fast as the current runs, so there will be no detrimental impacts as far as providing real-time forecast support for the seeding operations. The new PC cluster will also then be used for the seeding runs, as soon as the operational seeding information becomes available.

***Deliverable 4.4** – Quality controlled final archive on RAMS website containing lists of seeding operations and data from first and second model runs (due April 30, 2004)*

Real-time model runs – At the time the WDMP Colorado Finical Assistance Agreement was awarded (October 2003), it was expected that the existing PC Cluster would be available for daily model non-seeded operational runs until the new PC processors were procured and the cluster expanded. However, due to circumstances stated earlier in the **Overview of Project Status** section, CSU was not able to purchase the new PC processors on the schedule they had anticipated. Consequently, starting the evening of December 1, 2003, CSU switched the real-time 00Z forecast cycle from the faster cluster to a slower one. This was due to impending deadlines of two other research projects where the use of the faster cluster was critical; i.e., they required the greater memory and processing speed of the faster cluster. The forecast products still got to the CSU website (but at a 3x slower rate than usual) and the model output was still archived as usual – it was expected that there would be no interruption of the daily real time/no-seed/control runs in whatever period remains before the new cluster was ready.

How did the change to a slower system effect Western Weather's operational decision making? Larry Hjermstad stated, "When I need data in the evening following the input of the new 00Z information, I can't get any meaningful data until the next morning, which doesn't help for the night's operations. I usually am forced to use the NOAA Eta Model data when RAMS isn't available or current." The main thing that was lost during the slower runs was the detail that RAMS provided, especially on nighttime operations when there was concern for adequate dispersion conditions for seeding material along with the detailed vertical velocity fields in the vicinity of the mountains in the target areas. The fact that there is only one update of the RAMS data per 24 hours at 00Z each day, the evening data have the most value both for accuracy and application to operations for that night.

The other two CSU projects that required the faster system ended in early January 2004, and the RAMS 00Z real-time forecast runs were subsequently switched back to the faster cluster effective the evening of January 10, 2004. So beginning January 10, 2004, through the upcoming transition to the new cluster, and on through the end of the seasonal seeding operations, the real-time runs have been and will continue to be run on a fast cluster that provides good support for the seeding operations.

An operational problem that arose with the slower real-time runs also applies, but to a lesser extent, with the faster runs. When a new forecast cycle began, the existing procedure had been that the old products from the previous cycle were deleted from the CSU real-time forecast website. This was to avoid confusion by users, who otherwise might not realize (unless they carefully looked at the initialization and valid time labels on the plots) that when they were examining a time sequence of products, the valid time might cross over discontinuously from the new forecast cycle to the old cycle. However, particularly with the slow runs, the deletion of the old cycle products resulted in no high-resolution forecast guidance for the first day or so of the new cycle, until the new cycle reached that far.

It was thus decided to keep the old forecast cycle's products until they were superceded and over-written by each two-hourly increment of the new cycle. In this way, the products valid at 36h in the old cycle (or 12 UTC on Day 2), for instance, are retained to provide guidance at 12 UTC on Day 1 of the new cycle, until the new cycle's products are produced. To help the user avoid the possible confusion of not realizing the discontinuity, prominent labels are updated and displayed on each menu that give the initialization time of the current cycle and how far out in the 48h cycle it has reached. Thus, any products beyond that point are more easily recognized as being from the older cycle, but are still available for high-resolution guidance. This change was made beginning with the January 19, 2004 forecast cycle.

The Use of the RAMS Model Output to Refine Forecasts for Operational Cloud Seeding Conditions in the Central Colorado Rocky Mountains - by Larry Hjermstad

Western Weather Consultants, LLC (WWC) is using the CSU/RAMS Model outputs in conjunction with other meteorological services provided on the internet to define favorable seeding conditions within cloud systems over Seeding Target Areas in the Central Colorado Rocky Mountains. The precipitation or snowfall in the watersheds or ski slopes in the Target Areas have great economic value to the Seeding Program Sponsors. A reasonable increase in snowfall/precipitation in these target areas will return a multiple paybacks to the sponsors for the cost they have invested in the Seeding Program. Consequently, it is important to consistently select portions of weather systems that have reasonable potential for precipitation augmentation. The more accurately you can select and treat the best cloud conditions for seeding, the greater the likelihood of consistent and significant responses to the cloud seeding treatment.

The procedure that WWC uses to refine the opportunity recognition of favorable cloud conditions using the CSU/RAMS Model output is as follows:

1) Using the scale –3 surface map, we determine the most likely timing of the start and ending of the precipitation event using the 2-hourly precipitation presentation. This presentation also gives a fine detail of surface wind direction and speed. This information helps to confirm the best network of generators to use and also the favorable continuity of the wind transport of the seeding material on 2-hourly presentations. This is very important if there is any concern for the development of possible surface inversions.
2) Next, I would look at the total precipitable condensate regions and the vertical velocity fields on the 700MB level presentations throughout the duration of the weather event. This information along with the fine detail wind field gives a good representation of precipitation regions expected in the target areas and confirms the most targetable areas for seeding from the existing meteorological conditions and available generators. The negative vertical velocity fields in association with light or drainage wind fields can signal possible developing inversions which would disrupt the favorable dispersion of seeding material.
3) Along with the above information, I would next look at various vertical profiles across the target region to evaluate the likely location of the cloud base and its change with time throughout the target area. I would also look at the quantity and location of the cloud development relative to the barrier to interpret its seedability given the current dispersion conditions. I would also check to see if the model sees any significant concentration of ice particles in the lower region of the cloud system when the cloud-base temperatures begin to turn cold (colder than –10 degrees C).

As Larry becomes more familiar with the data presentations from the model outputs, he plans to expand the use of these data further. So far the model outputs have been very helpful in identifying favorable areas of precipitation initiation in portions of the target area that currently has no visual observations to support WWC operational decisions (the South Park Region and the Upper Arkansas Basin).

Problems identified in RAMS Real-time Forecast Model - In January 2004, it became evident that unrealistic meteorological features were developing in the real-time forecasts on a recurrent basis. These included too much low-level warming over high topography, unrealistic convergent flow into the elevated terrain on Grid 3 that developed in response to the warming, and over-predicted precipitation over the mountains that developed in response to the warming and convergent flow. During the second half of January and early February, the CSU team ran a series of tests to isolate the reasons behind the inaccurate forecast simulations, and determined three different factors that acted separately and in concert to produce the inaccuracies.

The first factor involves the terrain-following coordinate system and the particular horizontal and vertical diffusion schemes that are selected for a given run. In the previous winter season, it was found that the schemes normally used sometimes resulted in numerically unstable surface cooling tendencies at certain locations near very steep topography, which led to the model crashing. Such crashes usually occurred on very cold, clear winter scenarios when nocturnal radiational cooling would trigger the numerically unstable cooling tendencies. An alternate horizontal diffusion scheme was developed years ago to circumvent this numerical instability, and it prevents the runaway cooling problem. Thus, this alternate horizontal diffusion scheme was adopted for operational use in order to avoid the model crashes and allow complete forecast cycles. However, this scheme came with the caveat that it was not strictly mass conserving. While generally producing satisfactory simulations, the use of this scheme tended to over-predict precipitation, especially with more heavily precipitating dynamic synoptic systems. This is likely due to unrealistic convergence into the mountains that is able to develop because of the non-conservation of mass, especially in concert with the following two factors. We found a suitable fix to this problem, i.e., a mass-conserving scheme that avoids the runaway cooling problem, by reverting back to the standard horizontal diffusion scheme, combined with an alternate scheme for vertical diffusion.

The second factor involves the initialization of soil temperature. As the 2003-2004 winter season progressed well into its coldest phase, it became obvious that too much surface sensible heat flux was occurring in the model. This was due, in part, to the way in which LEAF-2, the module in RAMS that models the exchanges of heat and moisture between the soil, vegetation canopy, and atmosphere, indirectly formulates soil temperature. It is formulated through a thermal energy content equation, with a default assumption that all soil moisture is liquid. Because of the large heat capacity of liquid water relative to ice, and because the thermal energy of liquid water includes the latent heat of fusion, the temperature of what is intended to be frozen moist soil under these assumptions is held to 0C. Thus on very cold winter days when the air is much colder than 0C, especially at high elevations, there is an unrealistic heat flux from soil that is near 0C to the colder surface layer of air. A solution for this problem is to assume during initialization that the soil moisture in frozen soil is partly or totally frozen. This results in an initially lower thermal energy content, a corresponding temperature that is below zero as intended, and greatly reduced sensible heat fluxes.

Finally, a third problem, also affecting soil temperature in the LEAF-2 module, was discovered even after fixing the problem with soil moisture in frozen soil. This also occurred in very cold regimes, and resulted from a coding error associated with the formation of frost on the top soil layer or the initial fallout of frozen precipitation to the surface. The coding error gave a many orders of magnitude larger than intended increase in the soil's thermal energy content when this frozen water was initially added, and resulted in a very rapid increase in substantially sub-zero soil temperatures to near 0C. Like the second problem, this resulted in an unrealistically large sensible heat flux. We enlisted the help of a graduate student in another group at CSU who is very familiar with the LEAF-2 code, and he uncovered the coding error and fixed it. While this coding error had not affected his modeling applications, the fix should be very beneficial to many users of the code in very cold simulation scenarios.

It is worth noting that these three problems were reinforcing in their adverse effects and only became a serious collective problem deep into the winter after actual ground temperatures at higher elevations cooled down considerably below freezing. In previous winters, the adverse effects of these problems did not manifest as strongly because the fine grid was smaller, was located in northern Colorado where the mean elevation was lower, and generally did not contain the topographic peculiarities that trigger the runaway cooling. After the extensive testing, the collective fix to all three problems was implemented operationally in the real-time forecast simulations beginning with the 00 UTC February 7, 2004 forecast cycle. CSU is planning on rerunning all the 00z forecasts to replace the current set of real-time runs with a more realistic set of no-seed control runs.

Task 5 – *Perform evaluations of model predictions of precipitation using MRBP.*

Deliverable 5.1 *– Copy of updated MRBP analysis code with documentation for users and selection of the month from the 2003-2004 operational winter season to be used in analysis (due March 31, 2004)*

At the Project Kickoff Meeting on October 22, 2003, this deliverable was clarified as follows: The updated MRBP analysis code with documentation should be provided on a CD. Also, the "selection of the month" represents 30 days with precipitation events that do not have to be consecutive.

During February and March 2004, Gustavo, Ray, Paul, and others will collaborate on the selection of precipitation observation sites; the comprehensive list needs to be narrowed down to specific sites for use in this study. This selection process will proceed after the ongoing accumulation of observational precipitation and snowpack data from the various networks and the quality control and evaluation discussed above under Task 3, Deliverable 3.1, "Identification of all precipitation observation sites." It should be noted that Snowcourse measurements will not commence until February 2004; their use will be primarily as a quality control measure for nearby SNOTEL sites.

This deliverable includes the updating of the MRBP analysis code with documentation for users, and the selection of about 30 days from the 2003-04 operational winter season to be used in this study. Work with the code will commence in February 2004, and the selection process will follow the quality control and evaluation of observational data toward the end of February.

Deliverable 5.2 *– Preliminary results form the MRBP analysis (due May 31, 2004)*

Task 6 – *Research study supervision and reports.*

Deliverable 6.1 *– Draft technical progress report - First Quarter (due January 31, 2004)*

This deliverable was completed and should be included on CSU's invoice #3 in February 2004.

Deliverable 6.2 *– Draft technical progress report - Second Quarter (due April 30, 2004)*

***Deliverable 6.3** – Draft technical progress report – Third Quarter (due July 31, 2004)*

***Deliverable 6.4** – Draft Final Report (due October 31, 2004)*

***Deliverable 6.5** – Final Report submitted to US Bureau of Reclamation (due December 31, 2004)*