A Description of Data Analysis and Numerical Modeling for the Cold Land Processes Experiment (CLPX)

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SUMMARY: The purpose of this project was to generate a research-quality, scientifically-sound, best-as-reasonably possible, three-dimensional meteorological analysis for the entire cold season 2002-2003 for the three CLPX Meteorological Study Areas (MSAs) in northern Colorado (North Park, Fraser and Rabbit Ears) using high-resolution (500 m horizontal grid spacing). This complex terrain meteorological dataset is to be used to complete publishable research from CLPX across the disciplines of atmospheric science, snow science, ecology and forestry. All simulations were completed through the provision of supercomputer time at the National Center for Atmospheric Research and archival/data management has been established at the National Snow Ice Data Center (NSIDC).

1. Grid Configuration

A five-grid telescoping grid system was selected to cover the three areas of interest and to sufficiently displace the exterior model boundary away from these three interior grids (Fig. 1). The map projection is Lambert Conformal with a center point of 40.25°N, 106.25°W and true latitudes of 30°N and 60°N. All interior grids utilized the two-way interactive nesting feature available in MM5.

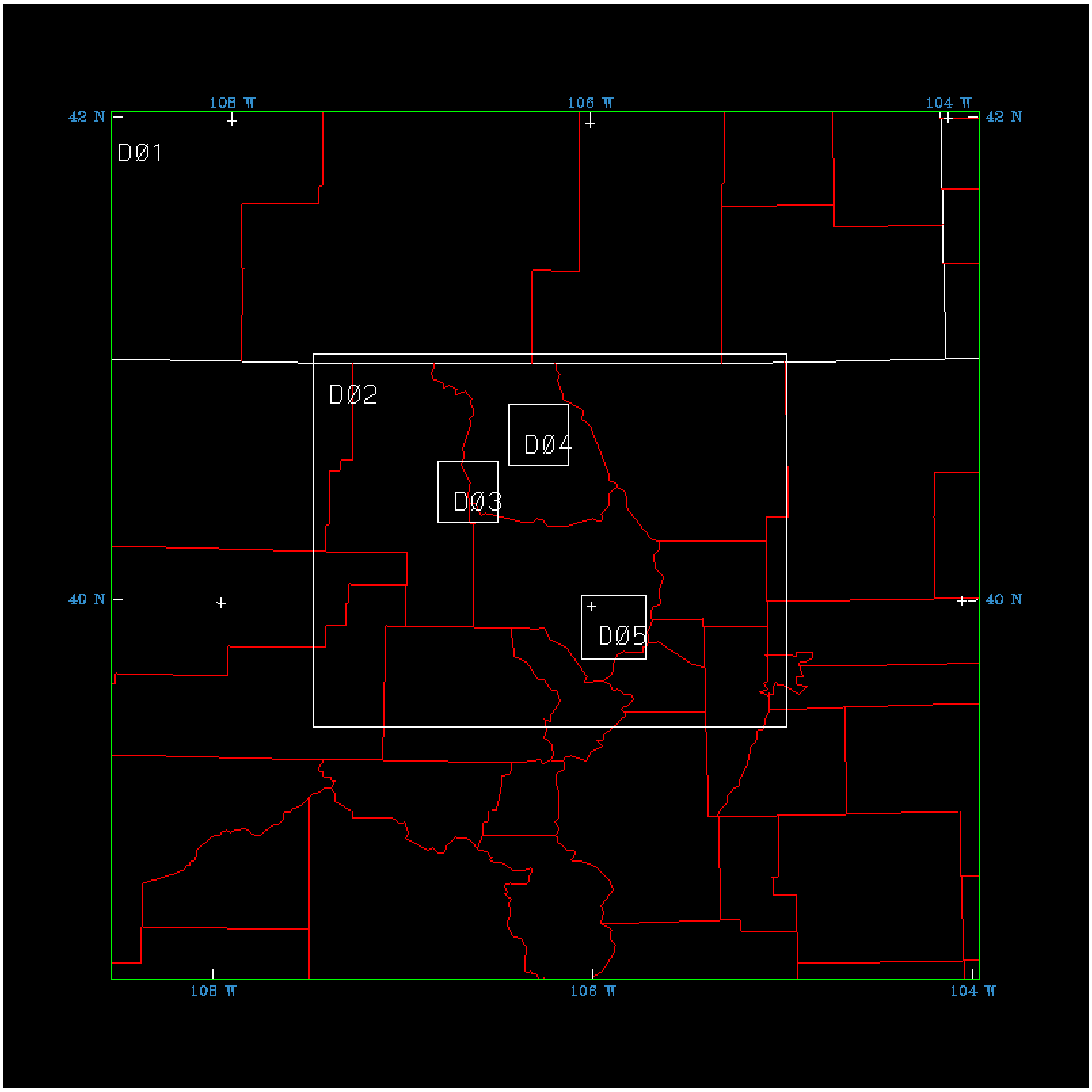

Figure 1: MM5 model grid domains.

Table 1 provides horizontal grid specifics for each domain. In the vertical (Table 2), 50 terrain-following, sigma-pressure levels were employed. A vertical stagger is used such that mass and horizontal wind variables are positioned on half-sigma levels while vertical wind variables are located on full-sigma levels. The lowest half-sigma level is positioned about 10 meters above ground level and the model top is fixed to 100 mb.

Table 1: Horizontal grid specifics for each model domain.

Grid	Dimensions	Grid Spacing
1	87x87	4.5 km
2	142x112	1.5 km
3	55x55	0.5 km
4	55x55	0.5 km
5	58x58	0.5 km

The MM5 TERRAIN program was used to define all static fields including topography, soil and vegetation type, and climatological vegetation cover. USGS 30-second (approximately 1 km) topography data was used to define the terrain for the outer two grids. Since the inner three domains use 500-meter grid spacing, the MM5 TERRAIN code was modified to ingest USGS 3-second topography data for use in defining the inner domains terrain (Fig. 2).

Figure 2:

2. Physics

MM5 Version 3 (release 3-7) was configured with physics options appropriate for the very high-resolution simulations (Table 2). The explicit moisture scheme employed is the Reisner graupel (Reisner 2) technique that uses a mixed-phase approach and is suitable for cloud-resolving models. No cumulus parameterization is utilized. Our experiences with MM5 indicate that the combination of the MRF planetary boundary layer scheme, the RRTM longwave radiation scheme, and the Noah land-surface model provide the best validation for temperature, even though this combination typically exhibits a cool daytime bias and warm nighttime bias.

Table 2: MM5 model configuration for CLPX simulations.

Model Category	**Option**
Vertical grid dimension	50
Vertical grid increment	2 hPa stretched to 40 hPa
Model top pressure	100 hPa
Topography	Derived from USGS 30- and 3-sec datasets
Thermodynamics	Nonhydrostatic, Reisner2 explicit moisture scheme
Radiation	Cloud-radiation shortwave / RRTM longwave Includes the effects of cloud water and ice
Cumulus parameterization	None
Top boundary condition	Klemp and Durran
Surface boundary condition	2 m, 4 layer Noah land surface model Predicts soil temp and moisture, canopy moisture, and water-equivalent snow depth

3. Data Assimilation

Complete four-dimensional data assimilation is utilized to incorporate observations; hence, allowing the model equations to ensure dynamical consistency while the observations keep the model simulation close to true conditions. MM5 provides two data assimilation options – analysis nudging and observational station nudging. Both techniques were employed.

a. Analysis Nudging

Two three-dimensional NCEP datasets were available for use by the MM5 analysis nudging. Eta analyses from the Eta Data Assimilation System (EDAS) were available on a 40km Continental United States (CONUS) isobaric grid and Rapid Update Cycle (RUC) analyses were available on a 20km CONUS native-vertical (hybrid-coordinate) grid. While the higher resolution RUC data would have been the desirable dataset to use for analysis nudging, the RUC native hybrid vertical coordinate system was not readily useable by MM5 data conversion utilities. Therefore, a combination of the two datasets was used. RUC surface data was combined with Eta upper-air data to provide the best possible analysis nudging solution. Analyses were processed at 3-hour increments.

b. Observational Station Nudging

All available surface observations within the CLPX domains were used for the MM5 station nudging. Collected CLPX surface meteorological data were provided by Glen Liston at Colorado State University. These data were combined with raw CLPX tower data and operational METAR data from the standard NWS data stream. A total of 61 surface stations had data available for the station nudging; a list of these stations is given in Appendix B. Latitude, longitude, and elevation were converted to an i,j,k point on the MM5 grid, and stations were ordered by time per MM5 requirements. Winds were rotated to the model grid, and the meteorological variables (wind speed and direction, dewpoint) were converted to appropriate MM5 variables (u and v wind components, mixing ratio). Files of surface observations were created for each of the simulation months.

4. Simulation Details

Simulations were generated one month at a time from October 2002 through June 2003. Each one month simulation was initialized at 0000 UTC on the last day of the previous month to allow for a one day model “spin-up” period with one exception – January 2003. Since the MM5 station nudging is not capable of handling a year change, the January simulation was initiated at 0000 UTC on the first of the month.

Appendix A contains the MM5 namelist (mmlif) used for all simulations. Analysis nudging was applied to wind, temperature, and moisture; and only applied above the boundary layer with the intent to allow the model to generate high-resolution boundary layer features while the above-boundary-layer nudging retains reality within the month long model simulation. Analysis nudging was applied on all five grids. Station nudging was applied to wind and temperature and only applied on the three 0.5 km inner grids as CLPX station data was not available outside these domains.

5. Model Output

Model output was written to standard MM5 fortran binary output files at one-hour intervals. The hourly files were collected into daily files, each containing all five of the CLPX domains. A total of 274 daily files, representing the period 1 October 2002 through 30 June 2003 were sent to the CLPX archive at the National Snow and Ice Data Center. In addition, NSIDC also agreed to store the MM5 history files, which were also stored daily. These files will allow one to initiate an MM5 run at any point within the CLPX study period.

All standard MM5 post-processing software, including the rip image generation package, have the capability to access the provided model output.

Appendix A

MM5 namelist (mmlif)

```
&OPARAM
 TIMAX = 46080,
 TISTEP = 13.5,
 IFREST = .FALSE.,
 IXTIMR = 720,
 IFSAVE = .FALSE.,
 SVLAST = .FALSE.,
 SAVFRQ = 360.,
 IFTAPE = 1,
 TAPFRQ = 60.,
 BUFFRQ = 60.,
 INCTAP = 1,1,1,1,1,1,1,1,1,1,
 IFSKIP = .FALSE.,
 CDATEST = '1993-03-13_00:00:00',
 IFPRT = 0,
 PRTFRQ = 46080,
 MASCHK = 99999,
 IFTSOUT = .FALSE.,
 TSLAT = 0.0,0.0,0.0,0.0,0.0,
 TSLON = 0.0,0.0,0.0,0.0,0.0,
 MPP_IO_NODE = 1,
/

&LPARAM
 RADFRQ = 30.,
 IMVDIF = 1,
 IVQADV = 1,
 IVTADV = 1,
 ITHADV = 1,
 ITPDIF = 1,
 ICOR3D = 1,
 IFUPR = 1,
 IBOUDY = 3, 2, 2, 2, 2, 2, 2, 2, 2, 2,
 IFDRY = 0,
 ISSTVAR = 0,
 IMOIAV = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
 IZ0TOPT = 0,
 IFSNOW = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
 ISFFLX = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
 ITGFLG = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
 ISFPAR = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
```

```
 ICLOUD = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
 IEVAP = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
 ISMRD = 0,
 IFRAD = 2,
 ICUPA = 1,1,1,1,1,1,1,1,1,1,
 IMPHYS = 7,7,7,7,7,7,7,7,7,7,
 IBLTYP = 5,5,5,5,5,5,5,5,5,5,
 ISHALLO = 0,0,0,0,0,0,0,0,0,0,
 ISOIL = 1,
 ISTLYR = 10,40,100,200,
 ISMLYR = 10,40,100,200,
/

&NPARAM
 LEVIDN = 0,1,2,2,2,1,1,1,1,1,
 NUMNC  = 1,1,2,2,2,1,1,1,1,1,
 NESTIX =   87,  112,   55,   55,   58,
 NESTJX =   87,  142,   55,   55,   58,
 NESTI  =    1,   26,   62,   79,   21,
 NESTJ  =    1,   21,   38,   59,   81,
 XSTNES =    0,    0,    0,    0,    0,
 XENNES =46080,46080,46080,46080,46080,
 IOVERW =    1,    1,    1,    1,    1,
 IACTIV =    1,    1,    1,    1,    1,
 IMOVE  = 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
 IMOVCO = 1,   1,   1,   1,   1,   1,   1,   1,   1,   1,
 IMOVEI = 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
 IMOVEJ = 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
 IMOVET = 0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
           0,   0,   0,   0,   0,   0,   0,   0,   0,   0,
 IFEED = 4,
/

&PPARAM
 ZZLND = 0.1,
 ZZWTR = 0.0001,
```

```
 ALBLND = 0.15,
 THINLD = 0.04,
 XMAVA = 0.3,
 CONF = 1.0,
/

&FPARAM
 FDASTA = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
 FDAEND =46080,46080,46080,46080,46080, 0, 0, 0, 0, 0,
 I4D = 1, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0,
 DIFTIM = 360, 360, 360, 360, 360, 0, 0, 0, 0, 0, 360.,
360., 360., 360., 360., 0., 0., 0., 0., 0.,
 IWIND = 1,1,1,1,1,0,0,0,0,0,
       0,0,0,0,0,0,0,0,0,0,
 GV = 2.5E-4,2.5E-4,2.5E-4,2.5E-4,2.5E-4,0.,0.,0.,0.,0.,
    2.5E-4,2.5E-4,2.5E-4,2.5E-4,2.5E-4,0.,0.,0.,0.,0.,
 ITEMP = 1,1,1,1,1,0,0,0,0,0,
       0,0,0,0,0,0,0,0,0,0,
 GT = 2.5E-4,2.5E-4,2.5E-4,2.5E-4,2.5E-4,0.,0.,0.,0.,0.,
    2.5E-4,2.5E-4,2.5E-4,2.5E-4,2.5E-4,0.,0.,0.,0.,0.,
 IMOIS = 1,1,1,1,1,0,0,0,0,0,
       0,0,0,0,0,0,0,0,0,0,
 GQ = 1.E-5,1.E-5,1.E-5,1.E-5,1.E-5,0.,0.,0.,0.,0.,
    1.E-5,1.E-5,1.E-5,1.E-5,1.E-5,0.,0.,0.,0.,0.,
 IROT = 0,0,0,0,0,0,0,0,0,0,
 GR = 5.E6,5.E6,0.,0.,0.,0.,0.,0.,0.,0.,
 INONBL = 1,1,1,1,1,0,0,0,0,0,
         1,1,1,1,1,0,0,0,0,0,
         1,1,1,1,1,0,0,0,0,0,
         1,1,1,1,1,0,0,0,0,0,
 RINBLW = 250.,
 NPFG = 267,
 I4DI = 0,0,1,1,1,0,0,0,0,0,
 ISWIND = 0,0,1,1,1,0,0,0,0,0,
 GIV = 4.E-4,4.E-4,2.78E-4,2.78E-4,2.78E-4,0.,0.,0.,0.,0.,
 ISTEMP = 0,0,1,1,1,0,0,0,0,0,
 GIT = 4.E-4,4.E-4,2.78E-4,2.78E-4,2.78E-4,0.,0.,0.,0.,0.,
 ISMOIS = 0,0,0,0,0,0,0,0,0,0,
 GIQ = 4.E-4,4.E-4,0.,0.,0.,0.,0.,0.,0.,0.,
 RINXY = 40.,
 RINSIG = 0.001,
 TWINDO = 120.0,
 NPFI = 267,
 IONF = 1,
 IDYNIN = 0,
 DTRAMP = 60.,
```

/

Appendix B

Surface observations used in the MM5 station nudging.

Metadata for each location are given as:

station id:station name:latitude(deg):longitude(deg):elevation(m).

```
KAFF:CO-USAF Academy      38.9667:-104.8167:2003
KAPA:CO-Denver/Arapahoe   39.5667:-104.8500:1775
KARL:WY-Arlington         41.7000:-106.2167:2179
KASE:CO-Aspen             39.2333:-106.8667:2354
KBIT:WY-Bittercreek       41.6500:-108.5833:2160
KBJC:CO-Broomfield        39.9167:-105.1167:1724
KBKF:CO-Denver/Buckley    39.7167:-104.7500:1726
KBRX:WY-Bordeaux          41.9333:-104.9500:1422
KCAG:CO-Craig             40.5000:-107.5167:1887
KCCU:CO-Red Cliff Pass    39.4667:-106.1500:3680
KCOS:CO-Colorado Springs  38.8167:-104.7167:1856
KCTD:WY-Continental Div   41.7167:-107.7833:2146
KCYS:WY-Cheyenne          41.1500:-104.8167:1868
KDEN:CO-Denver            39.8333:-104.6500:1640
KEEO:CO-Meeker            40.0500:-107.8833:1930
KEGE:CO-Eagle County      39.6333:-106.9167:1993
KFCS:CO-Fort Carson       38.6667:-104.7667:1789
KFNL:CO-Ft Collins        40.4500:-105.0167:1529
KGUC:CO-Gunnison          38.5167:-106.9167:2339
KGUN:WY-Gunbarrel         41.4333:-104.3500:1695
KGXY:CO-Greeley           40.4167:-104.6167:1420
KHDN:CO-Hayden            40.4667:-107.2167:2012
KLAR:WY-Laramie           41.3167:-105.6667:2216
KLXV:CO-Leadville         39.2333:-106.3167:3028
KMNH:CO-Monument          39.2167:-104.6333:2152
KPUM:WY-Pumpkin Vine      41.0500:-105.4667:2420
KRIL:CO-Rifle             39.5333:-107.7333:1678
KRWL:WY-Rawlins           41.7833:-107.2000:2077
KSKL:WY-Skyline           41.1167:-106.5667:2451
KVDW:WY-Vedauwoo          41.1500:-105.4000:2542
KWTR:WY-Whitaker          41.4167:-104.8667:1882
  FA:FA-Alpine            39.8480:-105.8610:3598
  FF:FF-Fool Creek        39.8810:-105.8679:3101
 FHQ:FHQ-Fraiser HQ       39.9048:-105.8840:2767
  FS:FS-St Louis Creek    39.9263:-105.8692:2725
 105:Sublimation-lower    39.8917:-105.9075:2974
 106:Sublimation-upper    39.8897:-105.9339:3222
 107:Bottle Ridge         39.8950:-105.9397:3371
```

```
 108:SSFP-clearcut        39.8958:-105.8939:2853
 109:SSFP-forest          39.8969:-105.8933:2860
 110:42-Arrow             39.9170:-105.7500:2950
 111:47-Berthod Summit    39.8000:-105.7670:3450
 112:111-Jones Pass       39.7670:-105.9000:3170
 113:112-Middle Fork Camp 39.8000:-106.0330:2743
  NI:NI-Illinois River    40.6955:-106.2546:2472
  NM:NM-Michigan River    40.6451:-106.1810:2596
  NP:NP-Potter Creek      40.6678:-106.3232:2478
 204:87-Roach             40.7670:-106.1330:3002
 205:34m Flux Tower       40.6589:-106.3239:2477
  RB:RB-Buffalo Pass      40.5342:-106.6780:3233
  RS:RS-Spring Creek      40.5291:-106.7577:2804
  RW:RW-Walton Creek      40.3999:-106.6458:2950
 304:50-Columbine         40.4000:-106.6170:2794
 305:58-Dry Lake Snotel   40.5330:-106.7830:2515
 306:85-Rabbit Ears       40.3670:-106.7330:2911
 307:97-Tower             40.5330:-106.6670:3219
 308:202-Dry Lake RAWS    40.5330:-106.7830:2515
 309:203-Storm Peak Lab   40.4500:-106.7400:3210
F168:UM Micromet N-0168   39.9066:-105.8829:2767
O170:Openpine met N-0170  39.9038:-105.8830:2767
D170:Densepine met N-0170 39.9032:-105.8830:2767
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