Test and Evaluation of an Updated Orographic Precipitation Model for Operational Use

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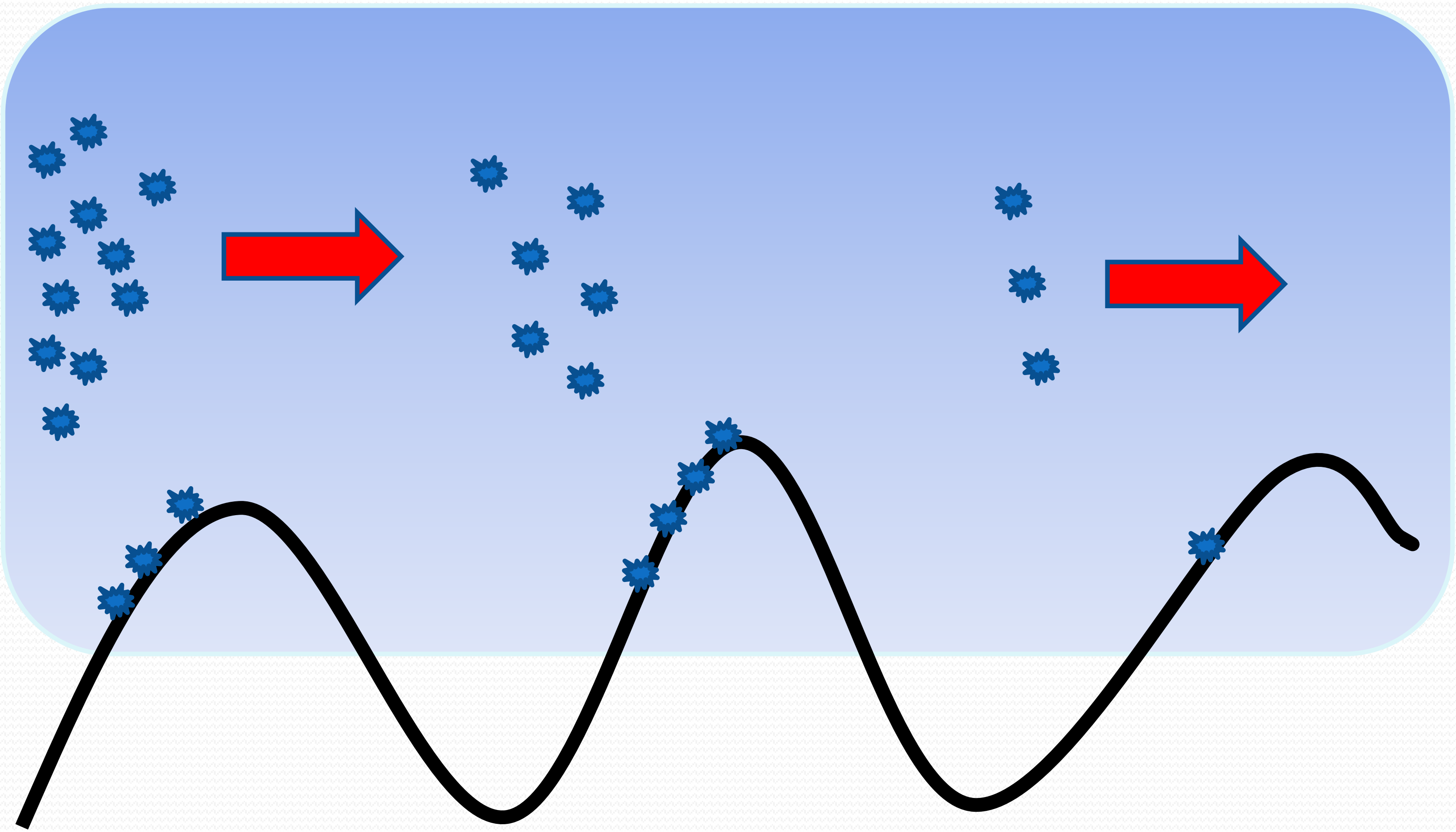
Why an orographic precipitation model is important

- Transportation
- Avalanche
- Snowmelt/water supply
- Flooding
- Recreation
- Nontrivial local forecast problem
- Need for high resolution predictions in digital age
- Ensemble runs?
- Full physics numerical models are improving…



Basic physics of orographic precipitation

Precipitation in mountainous terrain – in general terms

$$R_{total} = R_{gg} + R_{conv} + R_{orog}$$

$$R = \frac{E}{\rho_w g} \int_0^T \int_{p_{LCL}}^{p_{CT}} w \frac{\mathrm{d}q_s}{\mathrm{d}z} \,\mathrm{d}p \,\mathrm{d}t$$

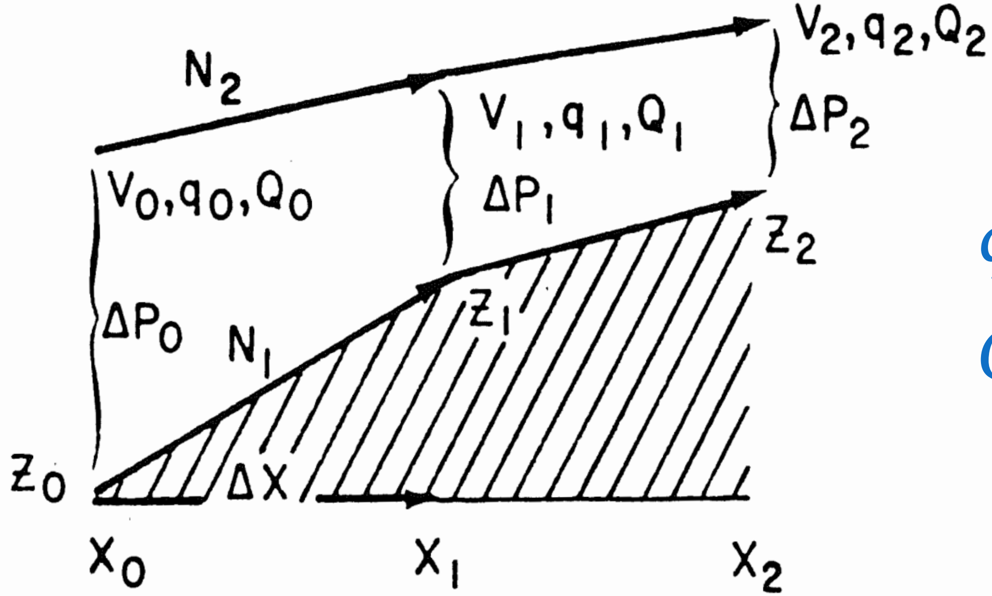
Adaptation of Rhea (1978) model

- Assumes two dimensional flow
- No mountain wave dynamics
- No accounting for blocking
- No microphysics/time delay/hydrometeor drift
- Simple accounting of vertical changes of ascent
- Single profile of temperature/moisture
- Uniform wind
- Fast execution time (~ 20 seconds)
- Historically - performs reasonably well

Atmospheric water balance equation for region between x_0 and x_1

$$\bar{r}_{0,1} = \frac{1}{\rho_w \Delta x}\left[\left((q_0 + Q_0)\frac{\Delta p_0 v_0}{g}\right) - (q_1 + Q_1)\frac{\Delta p_1 v_1}{g}\right]$$

Average precipitation rate between x_o and x_1



q – vapor specific humidity

Q – liquid specific humidity

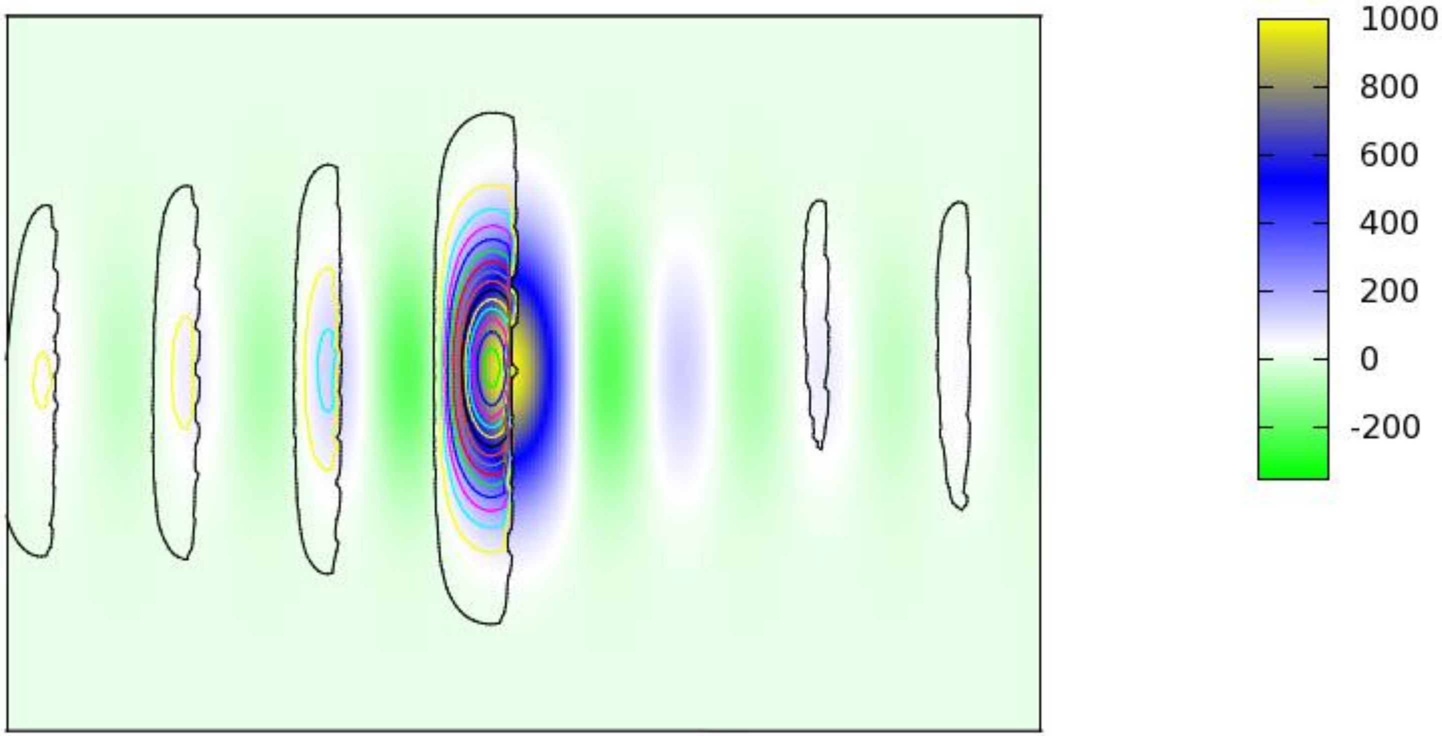
Two dimensional, steady-state, moist adiabatic, hydrostatic flow, constant fraction precipitates

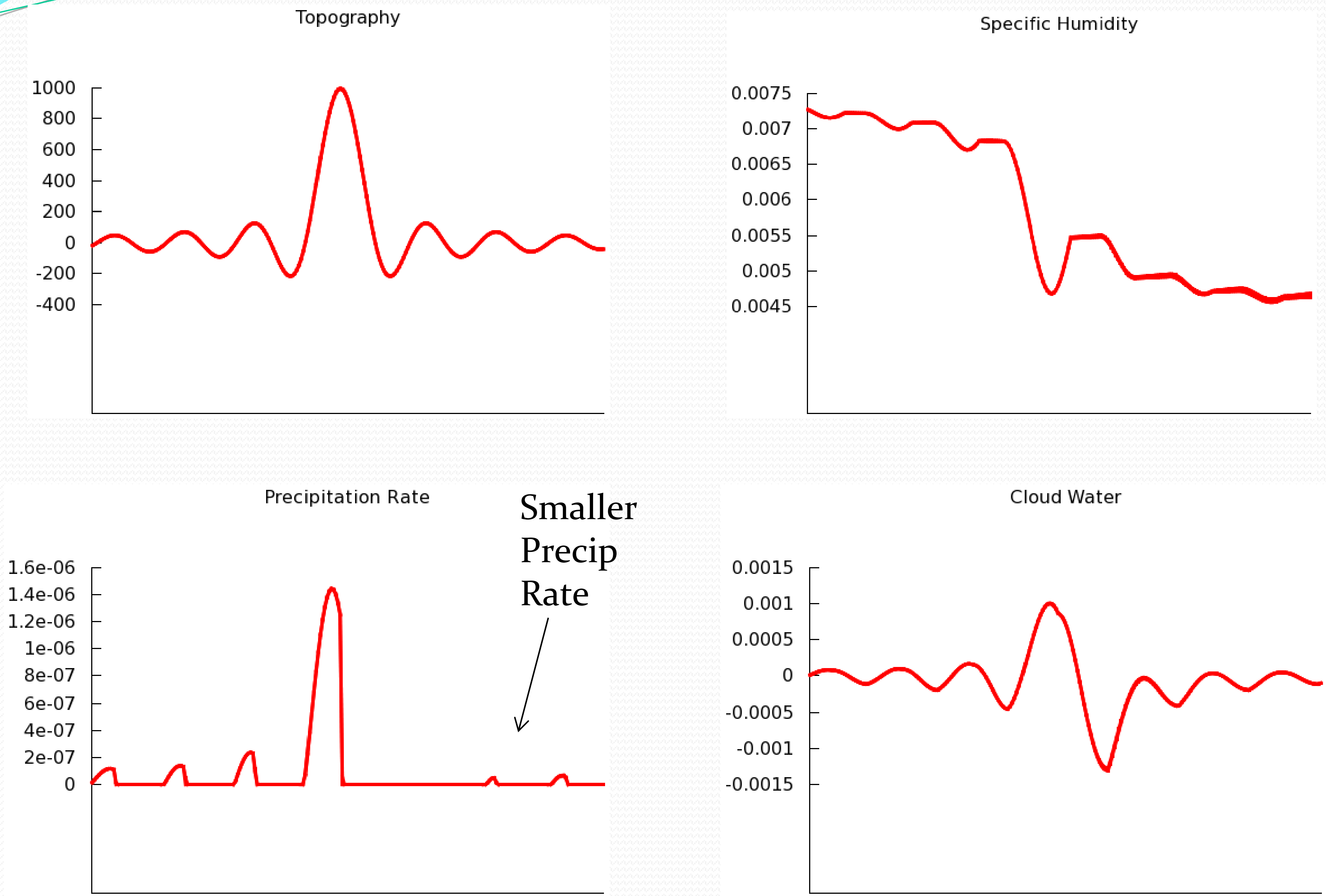
$$\bar{\dot{r}}_{i,i+1} = \frac{E v_0 \Delta p_0}{\rho_w g \Delta x} \left[Q_i - \left(\frac{\mathrm{d}q_s}{\mathrm{d}z} \right)_i (h_{i+1} - h_i) \mu \right] \qquad i = 1, 2, \ldots N$$

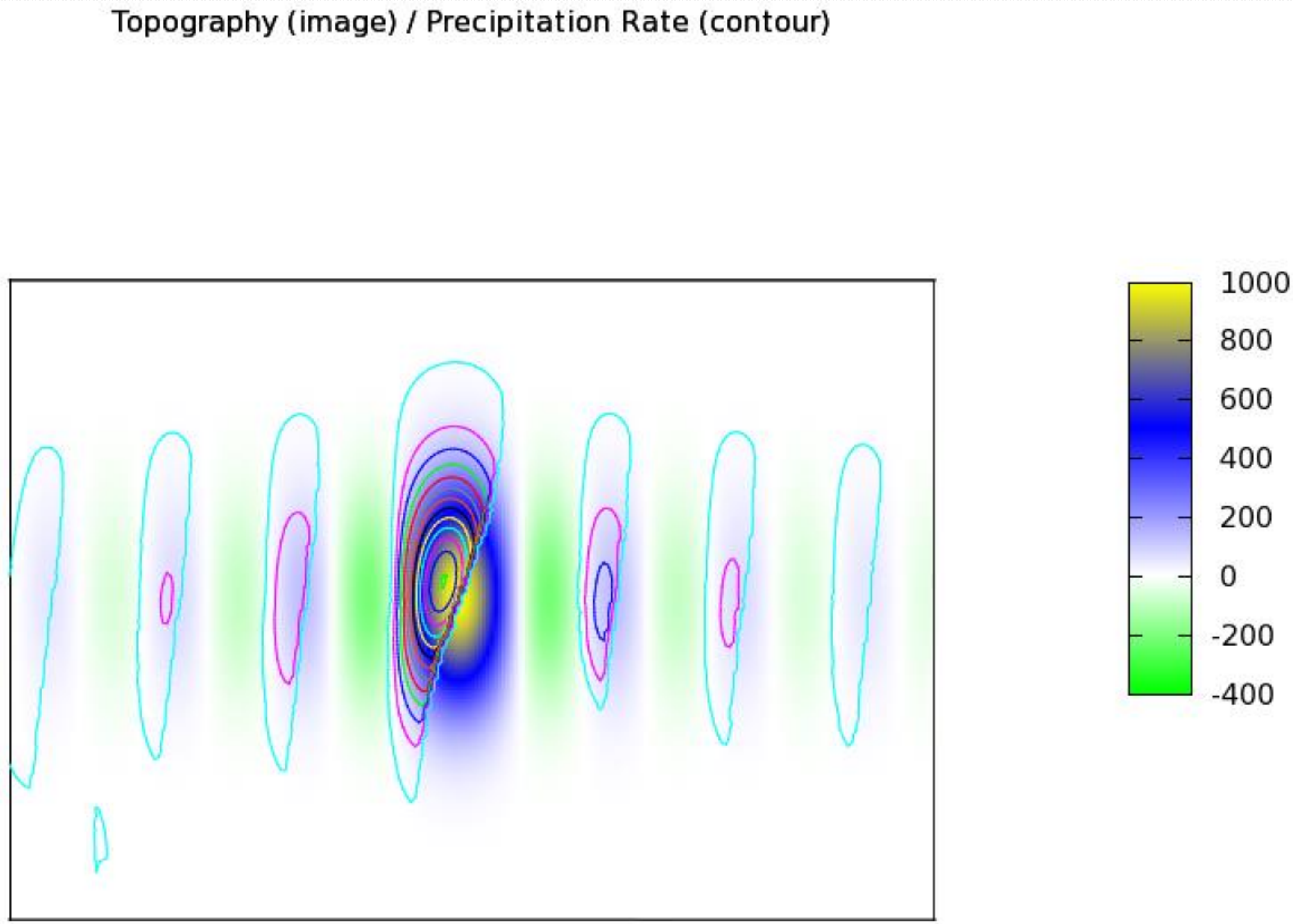
Average precipitation rate due to orographic ascent (Δh) between i^{th} and $(i+1)^{th}$ grid points

Analytic Examples

Topography (image) / Precipitation Rate (contour)




Topography
1000
800
600
400
200
0
-200
-400
Specific Humidity
0.0075
0.007
0.0065
0.006
0.0055
0.005
0.0045
Precipitation Rate
1.6e-06
1.4e-06
1.2e-06
1e-06
8e-07
6e-07
4e-07
2e-07
0
Smaller Precip Rate
Cloud Water
0.0015
0.001
0.0005
0
-0.0005
-0.001
-0.0015


Topography (image) / Precipitation Rate (contour)
1000
800
600
400
200
0
-200
-400

Historical Background

- Rhea (1978) original work
- 1980s to early 1990s

  * Avalanche forecaster adaptation

  * WSFO use (manual → semi-automated)
- Mid 1990s to 2000s

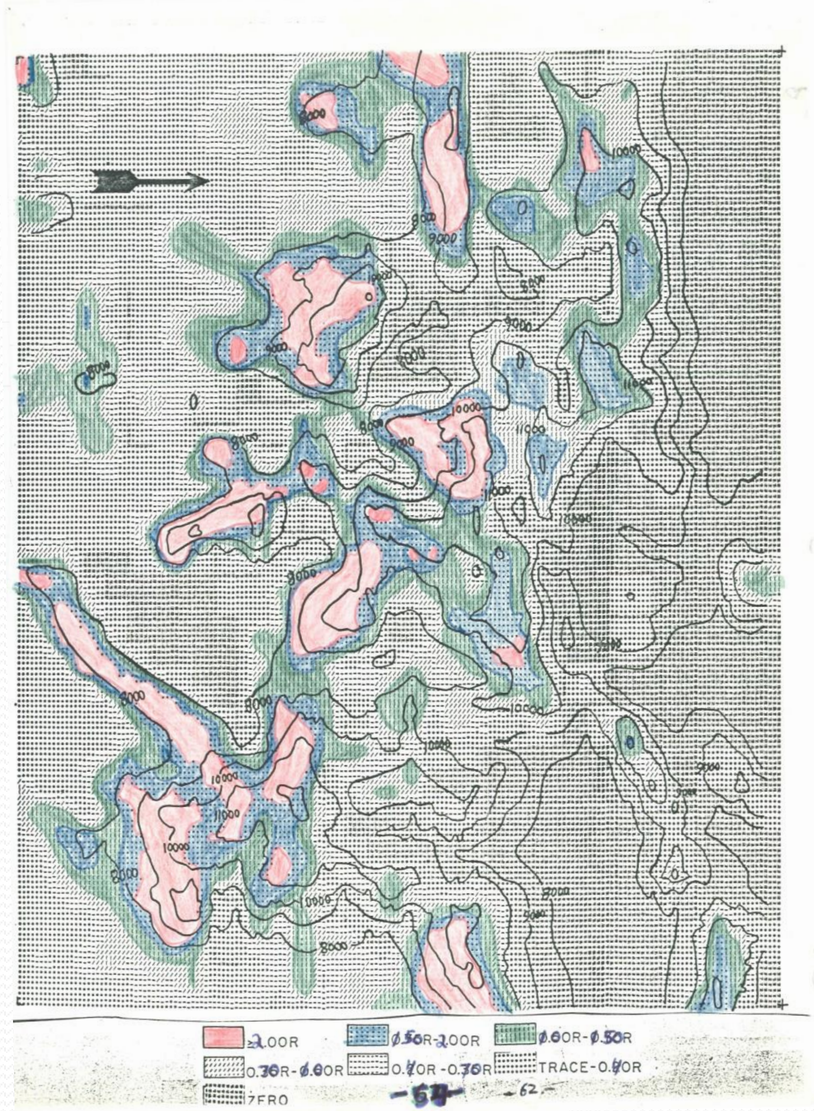
  * Updated to include static stability effects
  (overforecasting in blocked/stable situations)

  * Further automation/incorporated into AWIPS

  * Text-based output

West wind isohyets

Hard-wired to mountainous regions of Colorado



Isohyets based on hypothetical sounding

Text Output

Forecast zone point specific

Scaled isohyets based on actual parameters

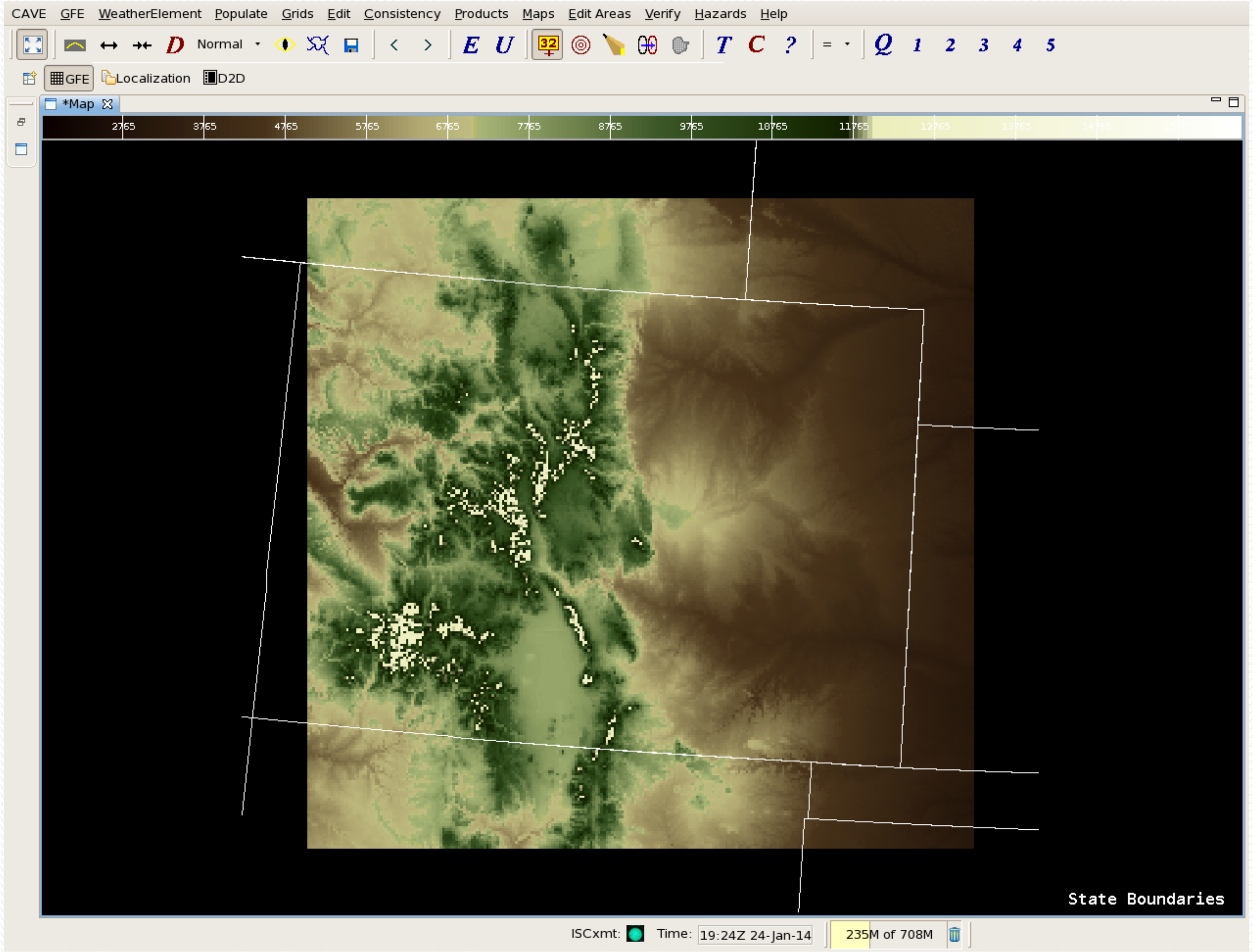
Forecast Orographic Component of Precipitation

For the 24-hour period beginning at 1200 UTC on 01/12/14

INPUT: 700 mb wind : 290 deg at 35 knots   Moisture base/top : 800/450 mb
700 mb temp : -13.0 deg C   Average lapse rate : moist

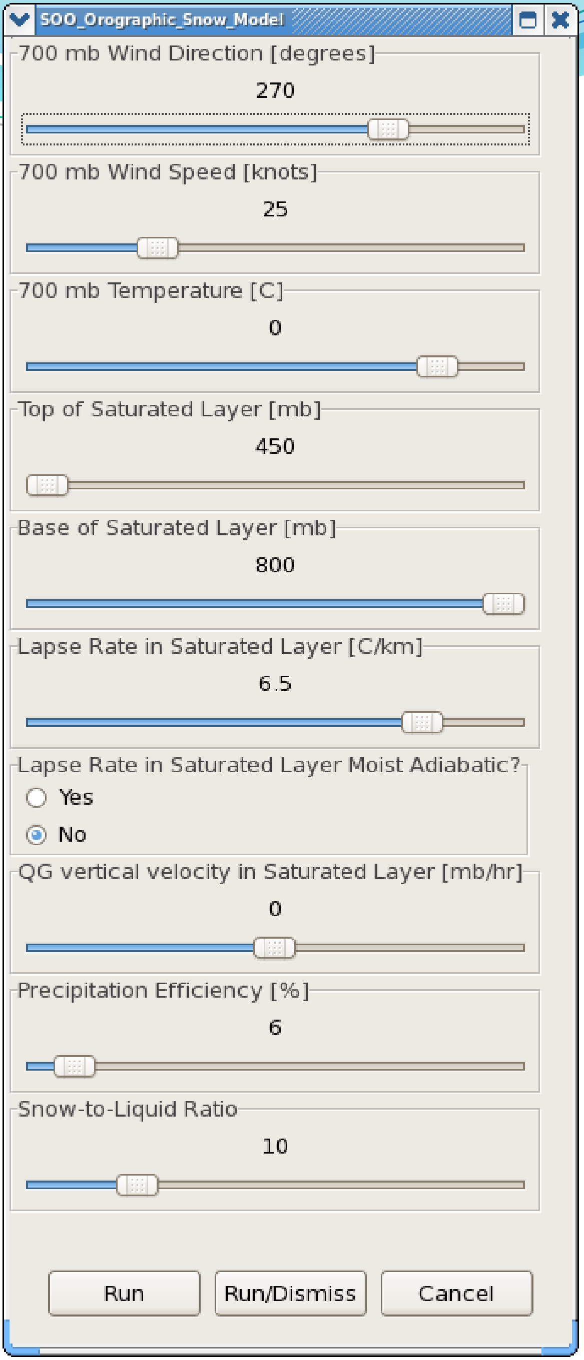
^ = Snotel site		inches water equiv	SNOWFALL ASSUMING THE GIVEN RATIO (DENSITY) 10:1 10.0%	12:1 8.3%	14:1 7.1%	16:1 6.2%	20:1 5.0%	30:1 3.3%
*** ZONE 4 ***								
Dry Lake	^	0.82 - 1.02	8-10	10-12	11-14	13-16	16-20	25-31
Elk River	^	0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Lynx Pass	^	0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Marvine Ranch		0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Rabbit Ears	^	0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Steamboat Mountain		0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Whiskey Park	^	1.03 - 1.23	10-12	12-15	14-17	16-20	21-25	31-37
>>> AVERAGE <<<		0.71 - 0.91	7- 9	8-11	10-13	11-15	14-18	21-27
*** ZONE 30 ***								
Coalmont		0.00 - 0.16	0- 2	0- 2	0- 2	0- 3	0- 3	0- 5
Rand		0.41 - 0.61	4- 6	5- 7	6- 9	7-10	8-12	12-18
Spicer		0.17 - 0.29	2- 3	2- 3	2- 4	3- 5	3- 6	5- 9
Walden		0.00 - 0.16	0- 2	0- 2	0- 2	0- 3	0- 3	0- 5
>>> AVERAGE <<<		0.15 - 0.30	1- 3	2- 4	2- 4	2- 5	3- 6	4- 9
*** ZONE 31 ***								
Buffalo Park	^	0.82 - 1.02	8-10	10-12	11-14	13-16	16-20	25-31
Columbine	^	0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Rabbit Ears Pass		0.62 - 0.82	6- 8	7-10	9-11	10-13	12-16	19-24
Tower	^	0.82 - 1.02	8-10	10-12	11-14	13-16	16-20	25-31
>>> AVERAGE <<<		0.72 - 0.92	7- 9	9-11	10-13	12-15	14-18	22-28
*** ZONE 32 ***								
Fraser		0.29 - 0.41	3- 4	3- 5	4- 6	5- 7	6- 8	9-12
Hot Sulphur Springs		0.17 - 0.29	2- 3	2- 3	2- 4	3- 5	3- 6	5- 9
Kremmling		0.00 - 0.16	0- 2	0- 2	0- 2	0- 3	0- 3	0- 5
Radium		0.00 - 0.16	0- 2	0- 2	0- 2	0- 3	0- 3	0- 5
Stillwater Creek	^	0.29 - 0.41	3- 4	3- 5	4- 6	5- 7	6- 8	9-12
Williams Fork Dam		0.00 - 0.16	0- 2	0- 2	0- 2	0- 3	0- 3	0- 5
>>> AVERAGE <<<		0.12 - 0.27	1- 3	2- 3	2- 4	2- 4	3- 5	4- 8

WFO Denver/Boulder Topography

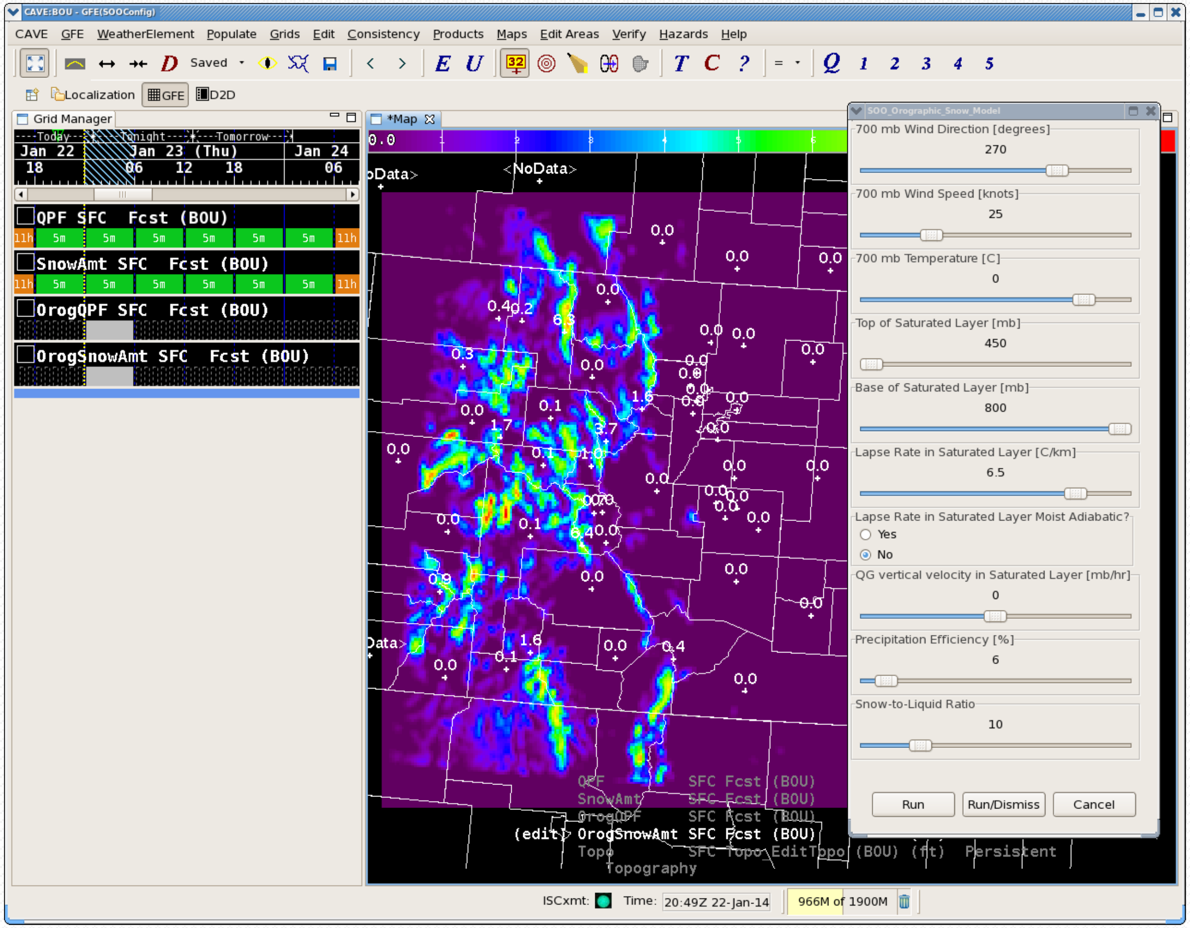


User Interface

- ❖Wind
- ❖Temperature
- ❖Top/Base saturated layer
- ❖Lapse rate
- ❖Large scale vertical motion
- ❖Efficiency
- ❖Snow density



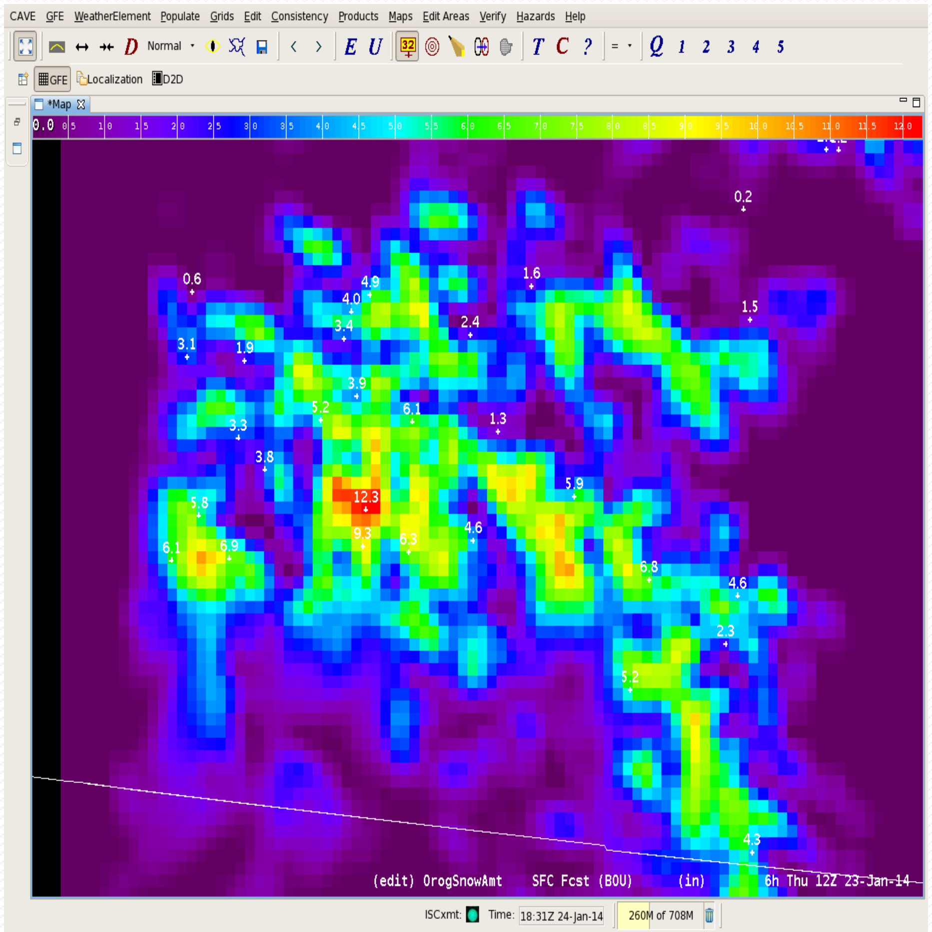
User interface within Graphical Forecast Editor in AWIPS



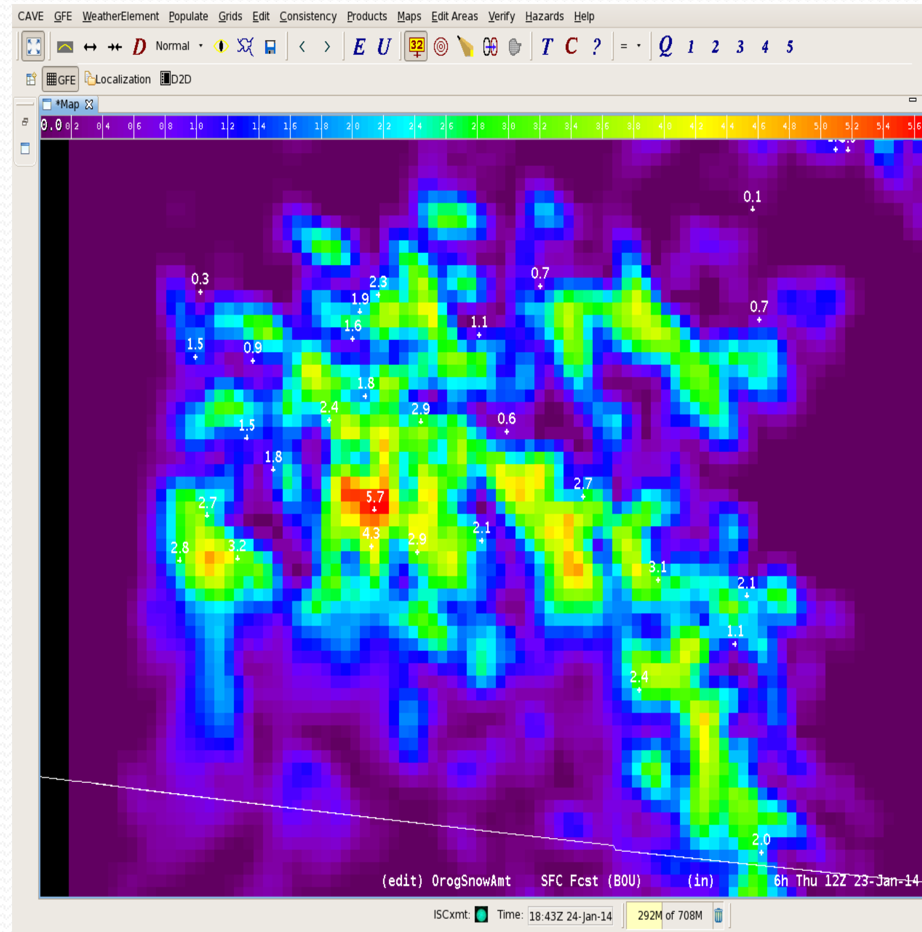
Static Stability Effects

Static Stability Effects

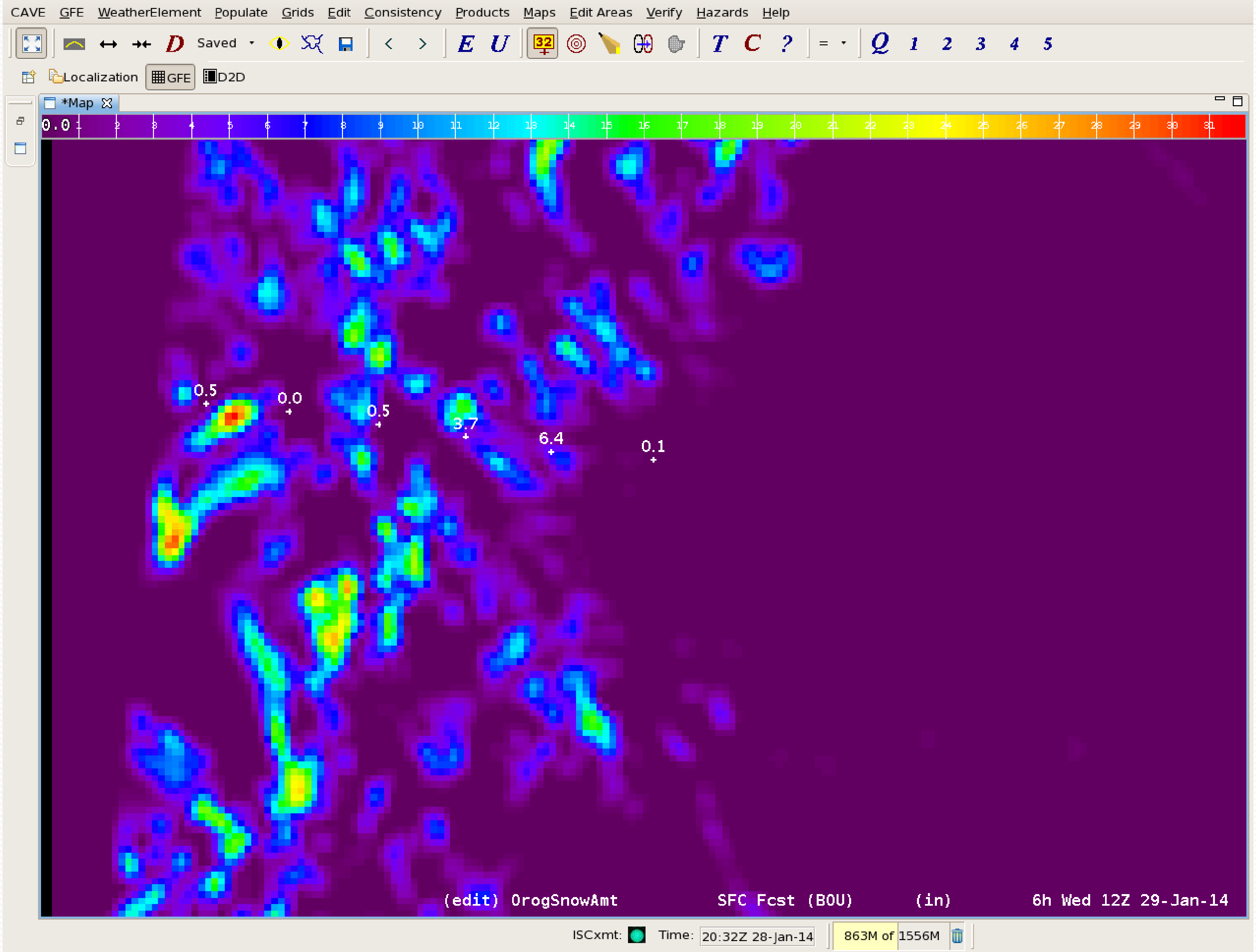
Moist Adiabatic



Stable

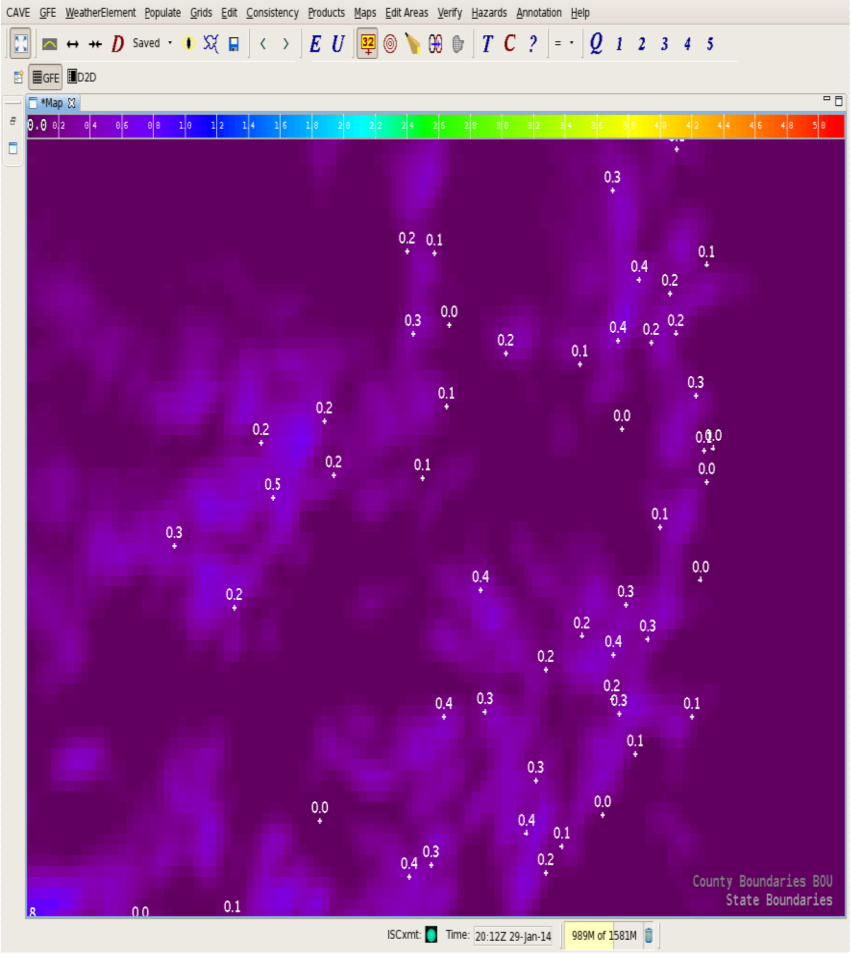


Effects of varying precipitation efficiency (1%, 5%, 15%, 30%)

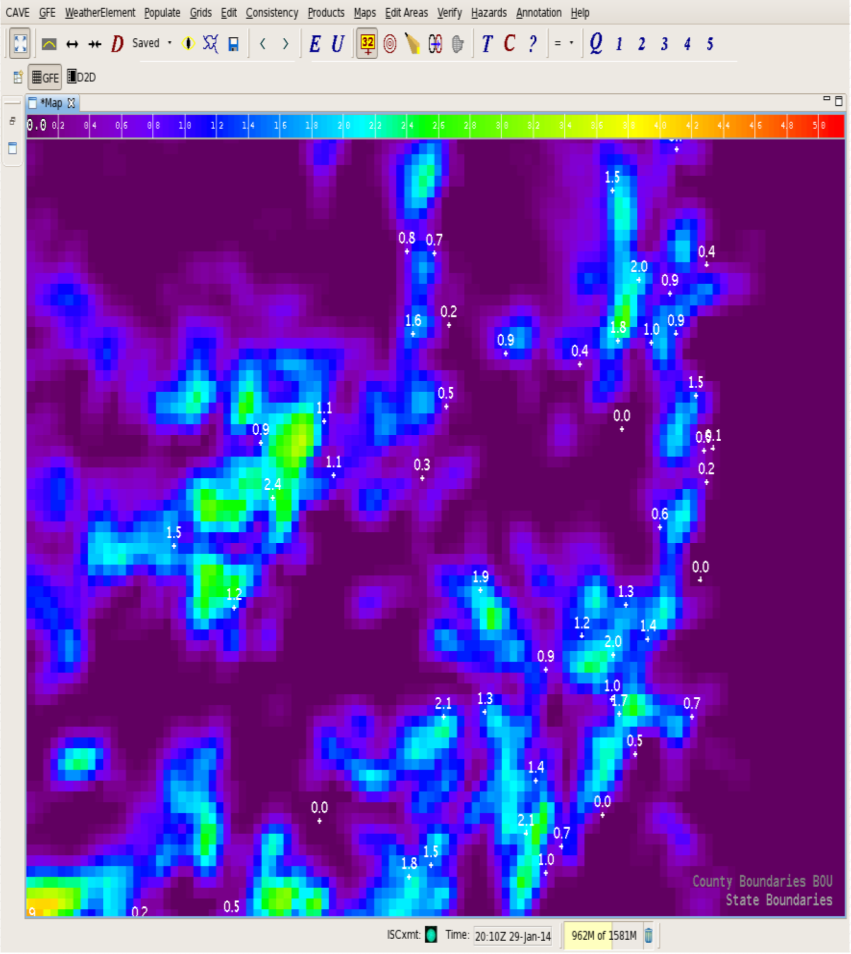

CAVE GFE WeatherElement Populate Grids Edit Consistency Products Maps Edit Areas Verify Hazards Help
Saved
E U T C ? Q 1 2 3 4 5
Localization GFE D2D
*Map
0.0
0.5
0.0
0.5
3.7
6.4
0.1
(edit) OrogSnowAmt SFC Fcst (BOU) (in) 6h Wed 12Z 29-Jan-14
ISCxmt:
Time: 20:32Z 28-Jan-14
863M of 1556M

Effect of Layer Depth

Thin layer

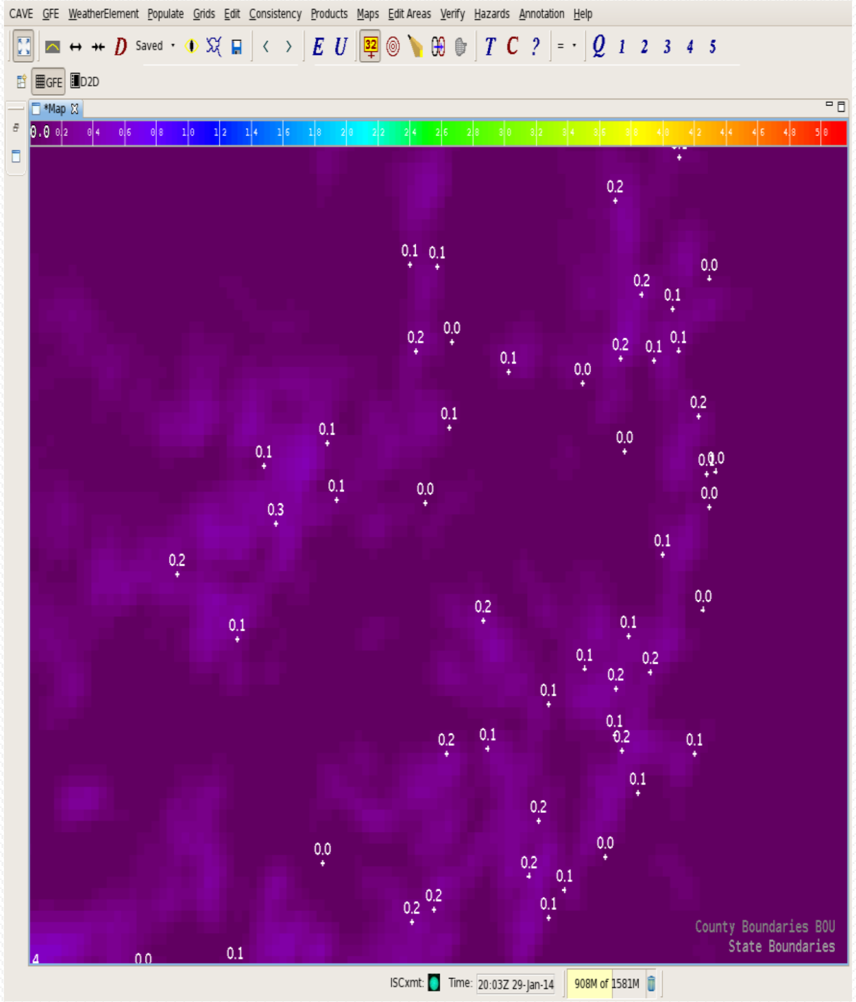


Thick layer

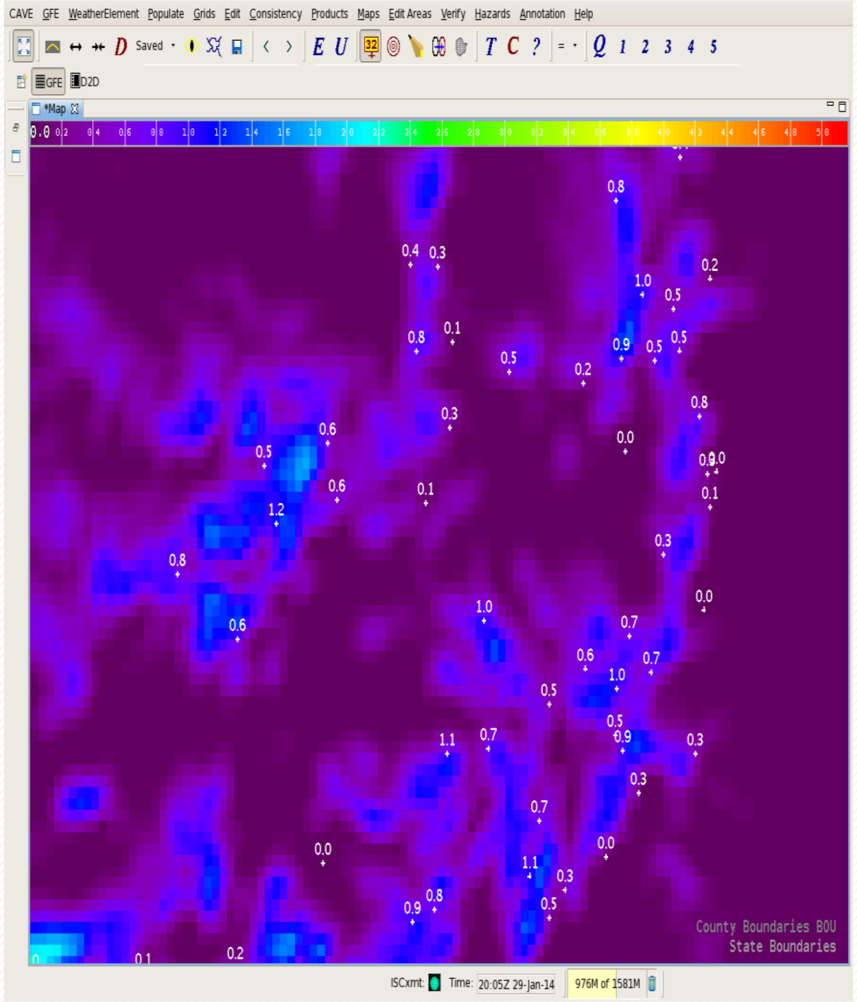


Layer Height Effect

High

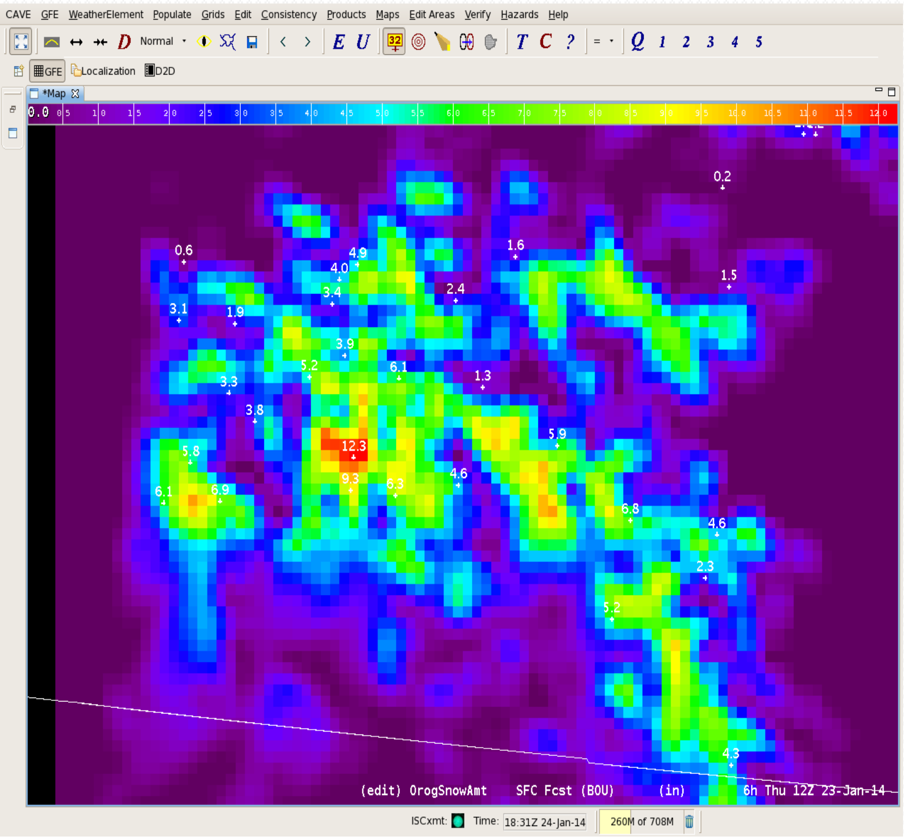


Low

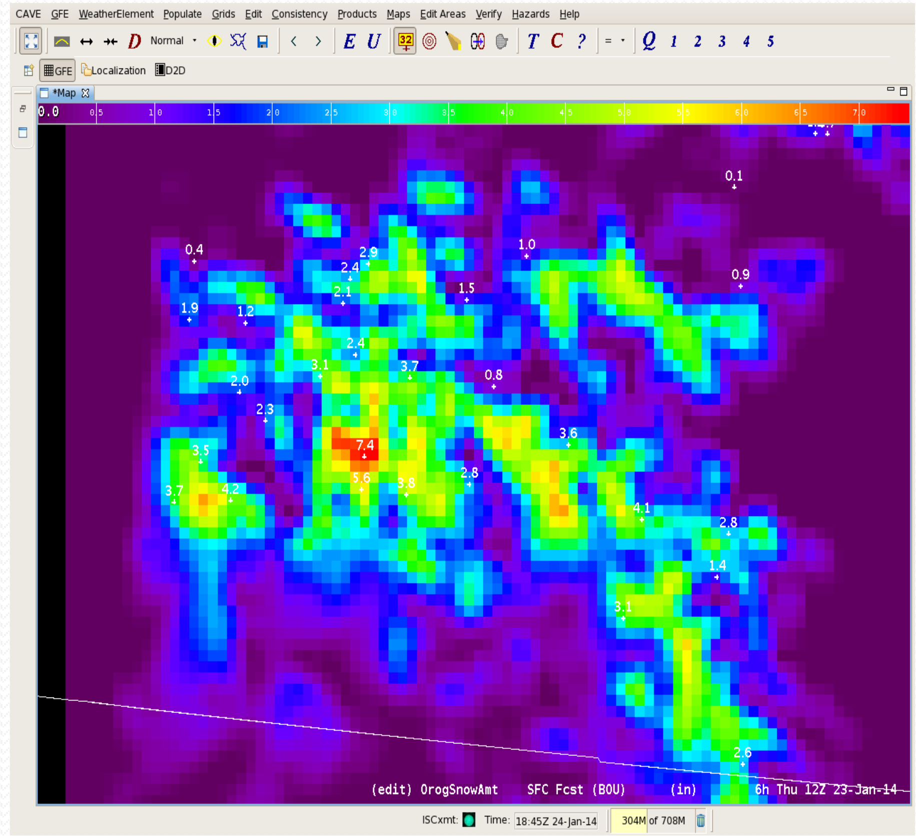


Moist layer depth

Thick

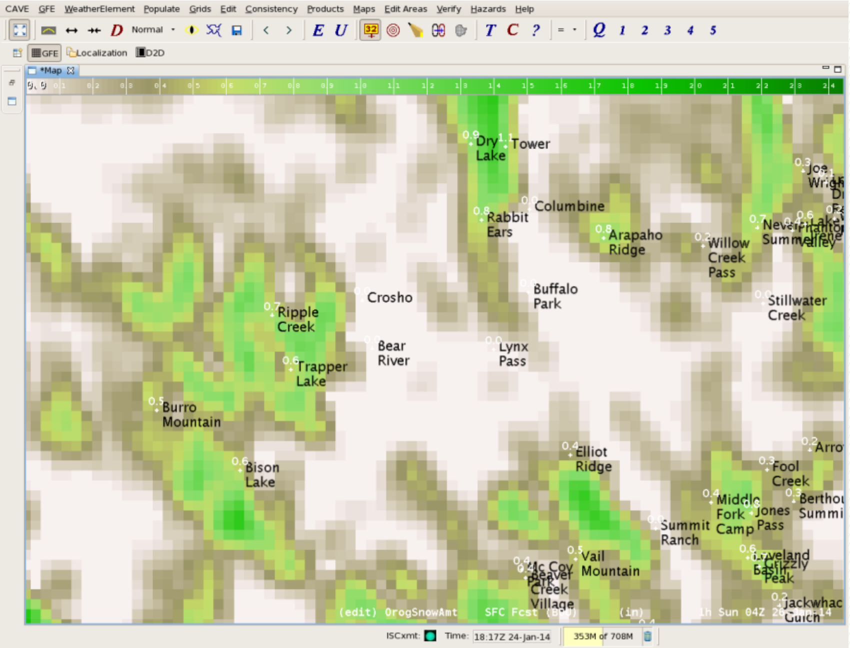


Thin

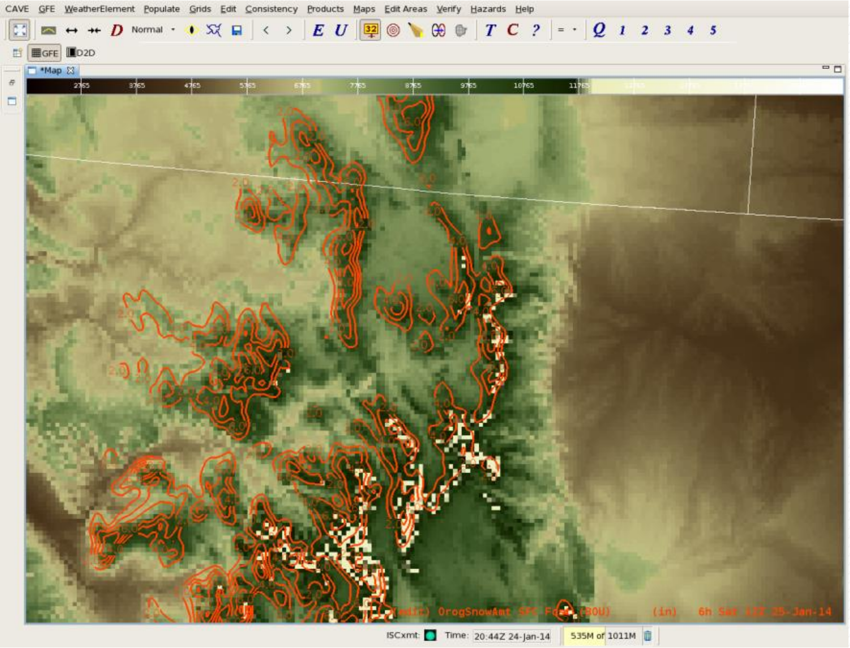


Overlay Capabilities

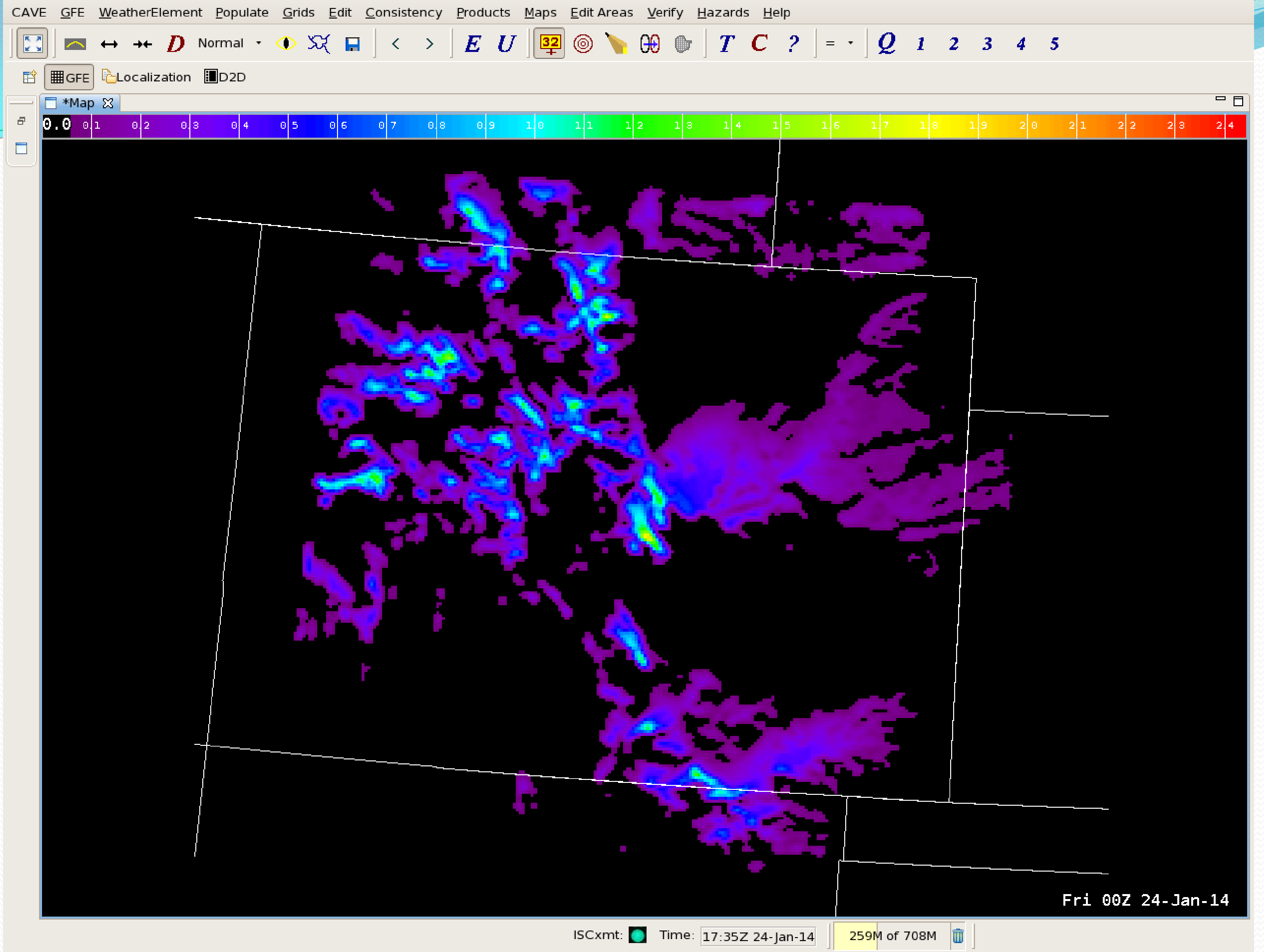
SNOTEL sites



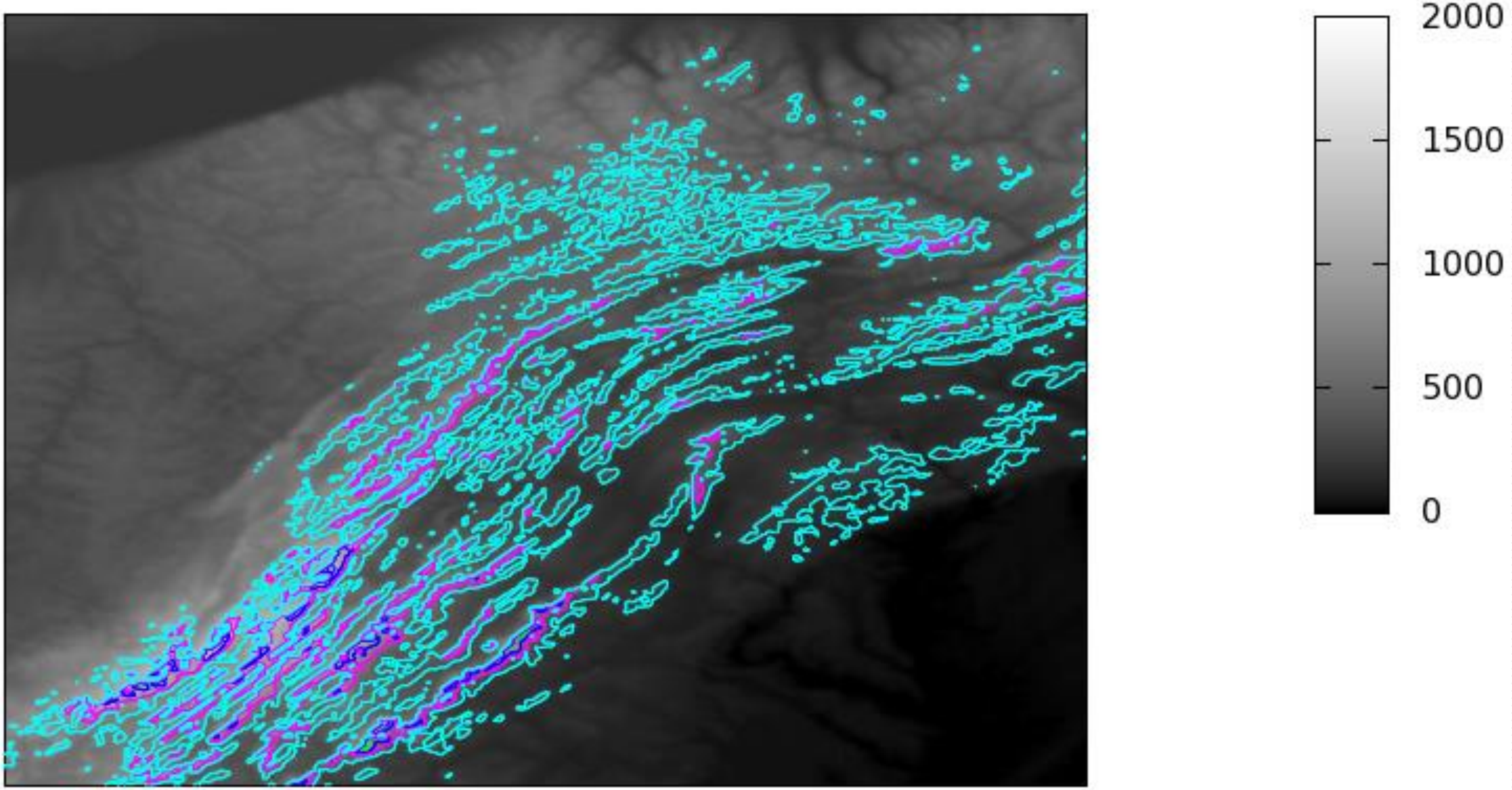
Topography/Precip Contours



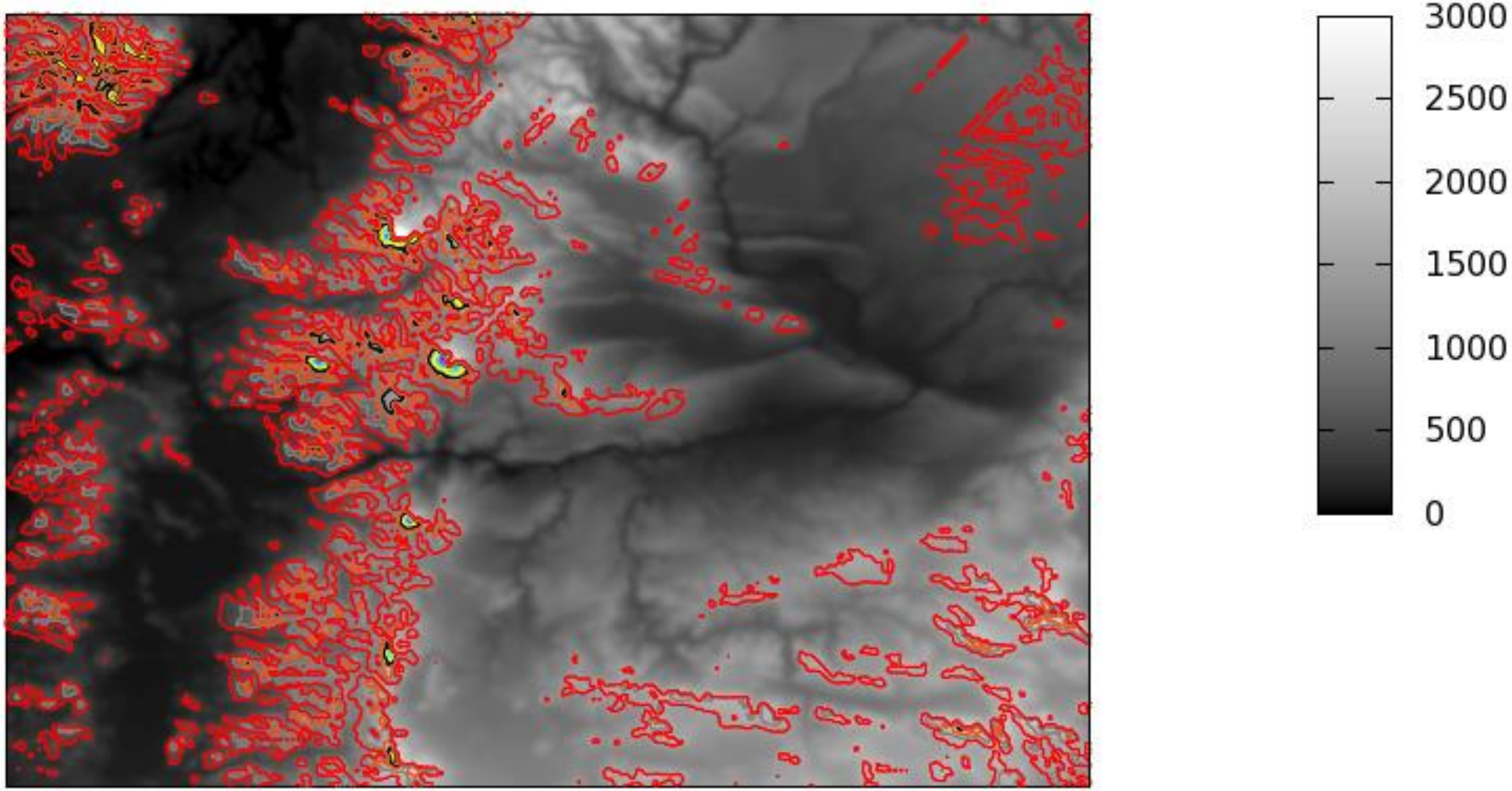
Precipitation as a function of wind direction: Animation from 010^{o} to 360^{o}


CAVE GFE WeatherElement Populate Grids Edit Consistency Products Maps Edit Areas Verify Hazards Help
Normal
E U T C ? Q 1 2 3 4 5
GFE Localization D2D
*Map
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
Fri 00Z 24-Jan-14
ISCxmt:
Time: 17:35Z 24-Jan-14
259M of 708M

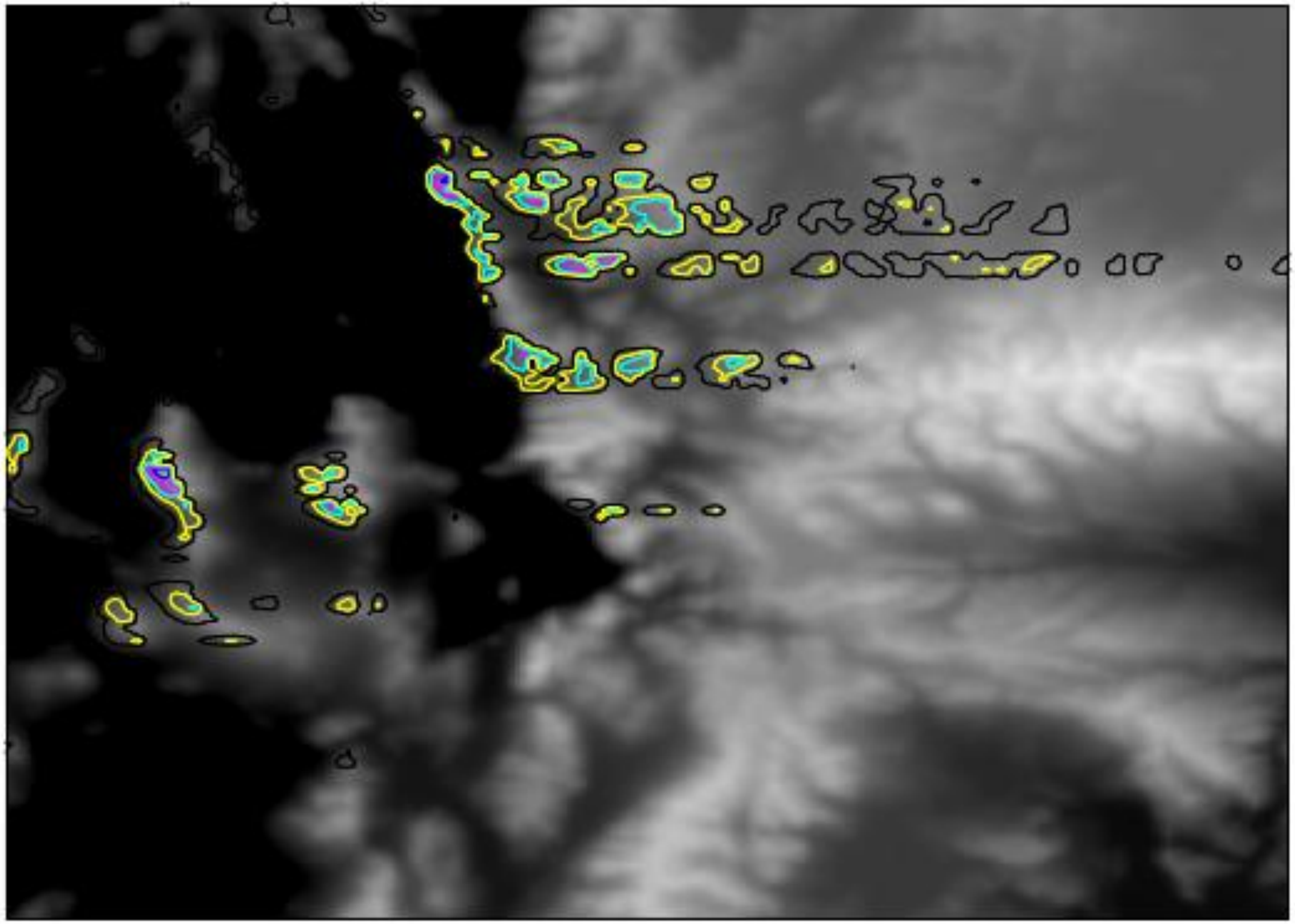
State College – 135°



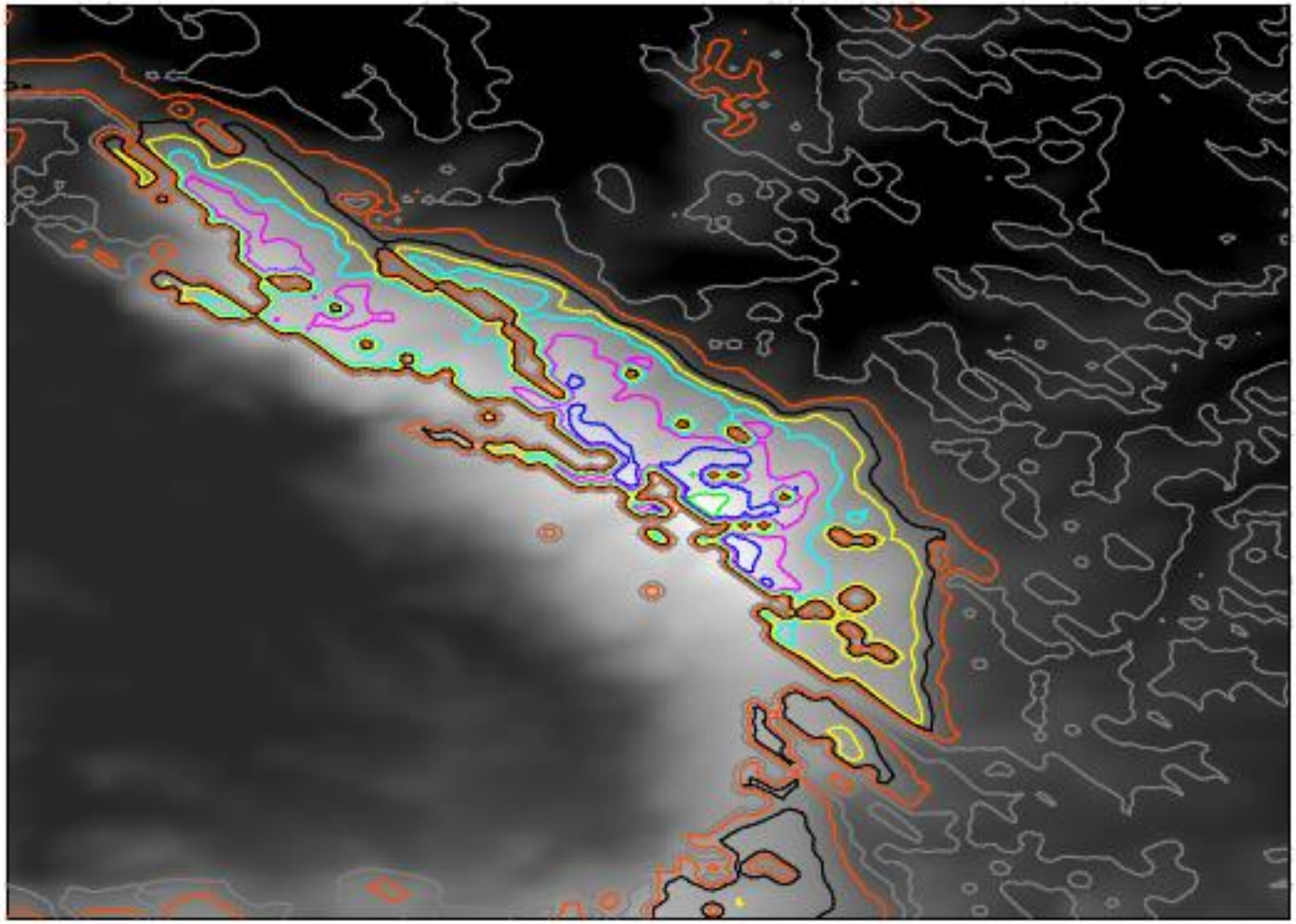
Spokane – 225°



Salt Lake City – 270º



Big Horn Mountains (Northern Wyoming) – 045^{o}



Conclusions/Future Plans

- Make available to other NWS offices
- More formal verification
- Increase resolution
- Improved microphysics (cloud/hydrometeor drift)
- Inclusion of wave dynamics/multiple layers
- Fully three dimensional flow
- More complete vertical profiles of temperature/moisture
- Real/model sounding input (less manual intervention)